Bureau International des Poids et Mesures

General Conference on Weights and Measures

21st Meeting (October 1999)

Contents

Proceedings
of the 21st General Conference
on Weights and Measures
11-15 October 1999

Agenda

The provisional agenda of the 21st General Conference (see page 341) is adopted as the final agenda.

1 Opening of the Conference

Prof. Guy Ourisson, President of the French Academy of Sciences of the Institut de France, opened the 21st General Conference on Weights and Measures (CGPM) with the following address:

"General Secretary,

Ladies and Gentlemen, Dear Colleagues,

It is a great pleasure to have the privilege of welcoming you to the General Conference. I owe this privilege exclusively to the fact that at the time of your meeting I find myself President of the French Academy of Sciences. It has nothing to do with my scientific competence in your field. I am only a chemist and, as I shall illustrate in a few moments, chemists nowadays are often rather mediocre metrologists.

First of all, I should like to congratulate you on the success of your extraordinary propaganda efforts just prior to the Conference, with reports that the Mars exploration satellite crashed as the result of an error of metrication. Even if the reason for the crash is later found to be different, it is a major publicity coup to have been able to write in all the papers that, had the International System of Units (SI) been used, this expensive accident would have been avoided.

I would also like to thank you for having given me the opportunity to visit Dr Quinn in his small kingdom at the Pavillon de Breteuil. In primary school we of course learnt that such a place existed, but we could not have imagined that it was such an interesting or beautiful working place. Metrologists need to work in a quiet environment, and they have it there. We can be proud to have been able to offer this location to the international community. The Republic sometimes knows how to be cleverly generous with its monarchic heritage.

As a chemist trained in the old school, I believe I understand some of your interests. At an elementary level of course, I learnt to calibrate a weakly damped laboratory balance, to measure optical absorption spectra with a galvanometer, to use a micrometer to measure the position of spectral rays on a photographic plate, to measure optical rotations with an optical polarimeter, to avoid parallax errors by successive approximations when reading a barometer, before measuring a boiling point, to measure melting points with correction for the emergent column, and so on. I note that all these operations are now replaced by simply reading a numerical value from a diode or liquid crystal display. Even if the balance is dirty or badly zeroed, the electronics are faulty, and the working conditions disastrous, a result is always displayed and it can be read and noted, if it can't simply be saved,

and inserted in the text of an article, with as many decimal places as are given on the display. As the Editor of primary chemical journals, I am constantly having to fight against the publication of ridiculous results, for example when otherwise excellent chemists report optical rotations with two or three decimal places, for solutions so dilute that even the first digit is probably meaningless. Far removed from your discussions and decisions during the next few days, even in fields where measurements are essential, often they are of dismal quality. The use of non-metric units, such as psi for pressure, also continues simply because industrial manometers are often US-made. You should not only concern yourselves with definitions, but also give us the arguments for the rational use of measurements, despite the fact that practical improvements have made them so much simpler to realize in everyday laboratory practice.

I hope that the surroundings of the Collège de France will help you to achieve your important programme during your brief stay in Paris, and I wish your Conference much success."

Prof. Kovalevsky, President of the International Committee for Weights and Measures (CIPM), added his thanks to the Administrator of the Collège de France for having put his facilities at the service of the CIPM and the General Conference. He also thanked the French Ministry of Foreign Affairs and the Italian Embassy at Paris for the receptions they were going to host, and the French Ministry of Foreign Affairs for providing simultaneous translation during the Conference. He then took the opportunity to thank the Canadian, Italian, and British Embassies for their communications with the French Ministry of Foreign Affairs concerning plans for construction of a new building on the site of the International Bureau of Weights and Measures (BIPM), and the French Ministry of Foreign Affairs for their help in obtaining approval of the plans.

Prof. Ourisson then informed delegates that, due to other commitments, he was obliged to leave the Conference, but that Prof. Christian Bordé, physicist, scientific advisor to the Bureau National de Métrologie and Member of the French Academy of Sciences, would replace him for the remainder of the conference.

2 Presentation of credentials by delegates

The Convocation requested that details of the composition of each delegation be sent to the BIPM at least two weeks before the opening of the Conference. On arrival, delegates were required to present their credentials from their Government.

3 Nomination of the Secretary of the Conference

Prof. Bordé, the new President of the Conference, proposed Dr W.R. Blevin, Secretary of the CIPM, as Secretary of the Conference; this proposal was adopted.

4 Establishment of the list of delegates entitled to vote

The Secretary, having examined the credentials of the delegates, proceeded to the establishment of a list, by Member State, of those delegates eligible to vote on behalf of their Governments. The list, in alphabetical order, was as follows:

Argentina	J. Valdés
Australia	B. Inglis
Austria	R. Dittler
Belgium	M. Vorhoof
Brazil	M.A. Albuquerque de Araújo Lima
Bulgaria	T. Štrashimirov

Canada	J. Lusztyk
Chile	R. Nuñez-Brantes
China	Gao Jie
Czech Republic	A. Šafařik-Pštrosz
Denmark	K. Carneiro
Finland	U. Lähteenmäki
France	A. Keller
Germany	E.O. Göbel
Hungary	P. Pataki
India	A.K. Raychaudhuri
Italy	P. Soardo
Japan	H. Imai
Korea (Republic of)	Myung Sai Chung
Mexico	H. Nava-Jaimes
Netherlands (the)	T.M. Plantenga
New Zealand	C.M. Sutton
Norway	H. Kildal
Poland	K.A. Mordziński
Portugal	E.M. de Almeida Farinha
Romania	P. Darvariu
Russian Federation	L.K. Issaev
Singapore	Lam Kong Hong
Slovakia	P. Kneppo
South Africa	T. Demana
Spain	Á. García San Román
Sweden	H. Andersson
Switzerland	W. Schwitz
Thailand	P. Shiowattana
Turkey	I. Çelik
United Kingdom	S.I. Charik
United States	K.H. Brown
Uruguay	A. Navarro

Of the forty-eight Member States of the Metre Convention, thirty-eight were represented.

5 Approval of the agenda

The agenda printed in the Convocation (see page 341) was approved. Dr Blevin announced that discussion of Draft Resolution N on the katal would take place after the report by Dr Kaarls, President of the Consultative Committee for Amount of Substance (CCQM), and that a working group on the BIPM dotation would be established after Item 7 of the agenda to consider Draft Resolution M.

The President then asked Prof. Kovalevsky to present his report.

6 Report of the President of the CIPM on the work accomplished since the 20th General Conference (October 1995 – September 1999)

Professor Kovalevsky, President of the CIPM, presented the following report:

"In conformity with Articles 7 and 19 of the Rules annexed to the Metre Convention, it is my pleasure as President of the CIPM to report on the work accomplished since the 20th General Conference held in October 1995.

It is now nearly one hundred and twenty-five years since the Metre Convention was signed in Paris by the delegates of seventeen nations. It is now adhered to by forty-eight nations, including all the industrialized nations of the world. In his report to the 20th General Conference, my predecessor, Professor Dieter Kind, traced the development of international metrology from 1875 to 1995. He showed how the need for international metrology has expanded and drew attention to the corresponding developments in the activities carried out under the Metre Convention. These concern not only the BIPM and its programme of work but also the national metrology institutes (NMIs) which provide the main foundation for accurate and reliable measurement worldwide. The 20th General Conference then went on to discuss and adopt eleven Resolutions, three of which have provided the stimulus for important work carried out by the CIPM and BIPM since 1995 and are directly the subject of items on the agenda of the present Conference.

These are Resolution 2 (1995) on worldwide traceability of measurement standards, Resolution 7 (1995) on metrology in chemistry and Resolution 11 (1995) on long-term needs for metrology. In addition, Resolution 10 (1995) required the President of the CIPM to report at this Conference on discussions with the President of the Organisation Internationale de Métrologie Légale (OIML).

In Resolution 11 (1995), the 20th General Conference asked the CIPM:

> "to study and report on the long-term national and international needs relating to metrology, the appropriate international collaborations and the unique role of the BIPM to meet these needs, and the financial and other commitments that will be required from the Member States in the coming decades."

In response to this Resolution, the CIPM asked one of its members, Dr W.R. Blevin, to draw up a draft report. Following extensive consultations, a first draft was presented to the CIPM in September 1996 and a further draft was presented in September 1997. The final text adopted by the CIPM at the end of 1997 was published by the BIPM and sent to Member States in August 1998. The full title is *National and international needs relating to metrology: International collaborations and the role of the BIPM. A report prepared by the CIPM for the governments of the Member States of the Convention of the Metre*.

It is the most far-reaching review of international activities in metrology that has ever been carried out and is of immense importance for the future of the Metre Convention. It will be presented and commented upon by the Secretary of the CIPM under Item 7 of the agenda. Many of its conclusions have already resulted in decisions and action by the CIPM or the BIPM, and others are embodied in the Draft Resolutions presented to this General Conference.

One of the conclusions of this report is that the CIPM should have much closer contacts with the national metrology institutes and with the regional metrology organizations. This has led the CIPM to hold meetings with the directors of the national metrology institutes of the Member States of the Metre Convention. Two such meetings have been organized by the BIPM and taken place in Sèvres: the first in February 1997 and the second in February 1998. The third will take place on Thursday during this Conference. The success of these meetings has clearly shown the need for a forum for the directors to meet outside the formality of a General Conference, where they can discuss matters of common interest amongst themselves and with the CIPM as well as with senior BIPM staff. Such meetings will continue to be held in the future. It was at these two meetings of directors that successive drafts were discussed of an agreement on "Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes", which I refer to here as the MRA.

In 1996 it became clear that there was a rapidly growing need for some sort of worldwide agreement on recognition of national measurement standards. This was implied but not explicitly foreseen in Resolution 2 (1995) of the 20th CGPM on the worldwide traceability of measurement standards. The need for a mutual recognition arrangement in metrology stems from the need to provide a firm metrological foundation for the increasing number of mutual recognition agreements related to calibration, testing and accreditation. Discussions had taken place at meetings of the regional metrology organizations (RMOs) on the possibility of regional agreements with a view to linking these regional agreements at some time in the future. A proposal was made at the 1997 meeting of directors that a more efficient and cost-effective solution would be a worldwide agreement under the auspices of the CIPM. This was approved in principle by the directors and intense discussions took place during the year that followed. The draft MRA that resulted from the 1998 meeting was initialled by the directors of the NMIs of thirty-nine Member States of the Metre Convention and forms the basis of the text to be offered for signature on Thursday 14 October 1999. For legal reasons related to the formal status of international agreements, we have now called our document an "arrangement" rather than "agreement" to make it clear that it is not a legally binding document. The technical basis for the MRA is a programme of key comparisons of national measurement standards now being carried out by the Consultative Committees, the RMOs and the BIPM. More than seventy key comparisons are now in progress and the full list, including details of quantity, range, starting and finishing dates, pilot institutes and participants, is available on the BIPM website (www.bipm.org). At the six Consultative Committee meetings that have taken place this year, the progress of the key comparisons, the calculation of the key comparison reference values and degrees of equivalence have provided much of the subject for discussion. Considerable effort went into the preparation of a document entitled *Guidelines for CIPM Key Comparisons*. This is now used in all of the CIPM key comparisons and similar documents, closely following the *Guidelines*, are being adopted by the RMOs for their own key comparisons. The importance of consistent estimates of the uncertainty of a measurement has been highlighted by the need for the results of key comparisons carried out by the Consultative Committees and those carried out by the RMOs to be linked in a quantitative manner. The importance of proper estimates of uncertainty is emphasized in the *Guidelines*. It is stated that a result will not be included in a comparison unless it is accompanied by an uncertainty supported by a full uncertainty budget. Perhaps one of the most significant consequences of the key comparison programme is that NMIs are now required to be much more rigorous in their evaluation and reporting of uncertainties. This is a wholly positive effect!

In February 1999 a discussion meeting on the key comparisons took place in Sèvres, attended by some eighty representatives of NMIs on Consultative

Committees. The aim of the meeting, which was successfully achieved, was to examine in detail the application of the *Guidelines* within the context of the MRA.

The final presentation of the results of key comparisons and the calibration and measurement capabilities of NMIs will be through a database, known as the BIPM Key Comparison Database (KCDB), which will in due course be maintained at the BIPM. The development of the database is being carried out by the NIST in collaboration with the BIPM and is expected to be ready by November 1999.

For each participant, the result of the comparisons is expressed as a "degree of equivalence", giving the difference from the reference value, and the associated uncertainty. It is listed in Appendix B of the MRA.

While the key comparisons are executed by the Consultative Committees, the RMOs and the BIPM, an important task is the drawing up and analysis of the calibration and measurement capabilities of the NMIs to go into Appendix C of the MRA. This is coordinated by a new Committee set up by the CIPM in the context of the MRA and known as the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). The JCRB has met three times, most recently in July 1999, and has a key role in the operation of the MRA. The responsibilities foreseen in the MRA for the RMOs have led each of them to set up structures within their own organizations to deal with the execution of key comparisons and the evaluation of the measurement and calibration capabilities of their member institutes to be included in Appendix C of the MRA. The RMOs have responded to this and indeed we have seen the formation of a new RMO, the Middle East Metrology Organization (MENAMET), and much increased activity in the Inter-American Metrology System (SIM) and in the Southern African Development Community Cooperation in Measurement Traceability (SADCMET). The requirement in the MRA for quality systems to be established in NMIs led to considerable discussion and reflects a significant change in the attitudes that up to now have existed in many NMIs as regards their independence and prerogatives. It is no longer possible, for example, for an NMI to maintain that its measurements are by definition correct by virtue of its position as the national standards institute. The implementation of quality systems in so many industrial and government organizations has forced most national metrology institutes to follow suit. The experience of those that have already done so is that, although the initial cost of setting up such a system can be high, the benefits in terms of confidence in the subsequent operation of the institute are evident. Overall, it is clear that the MRA is having a major effect on the NMIs and that it will be of considerable importance for international metrology. It will provide a firm metrological foundation for many wider agreements related to trade and regulatory affairs and will demonstrate that NMIs are fulfilling the role set for them by

governments. It will also show in a clear and public way that the ensemble of NMIs is a cost-effective way of ensuring reliable measurements worldwide.

The development of the MRA has highlighted the need to find a way of linking to the SI the metrological activities of a much larger number of States than are at present Member States of the Metre Convention. We cannot be unaware that world trade demands traceability of measurements to the SI in all trading nations of the world. We have to accept, however, that there are many smaller or less affluent States that would find it difficult to pay even the minimum annual subscription necessary to be a Member State of the Metre Convention (0.5 % of the BIPM dotation). The CIPM takes the view that the General Conference should take responsibility for providing a mechanism of establishing links to the SI from the measurement systems of all States and Economies, including those that are not Member States of the Metre Convention. Participation in the MRA through the RMOs appears to be a way of doing this. Some formal link to the BIPM is, however, necessary and some financial contribution must be made to cover the costs. The Metre Convention has no provision for a category of Associate but, inspired by the OIML Convention, the CIPM proposes that the 21st General Conference create a category of Associates of the General Conference. Associate States and Economies would be eligible to participate in the MRA in a specified way. This proposal, which is supported by the French Government as depository of the Metre Convention, is embodied in Draft Resolution C which will be presented for discussion under Item 9 of the agenda.

In Resolution 10 (1995), the 20th General Conference invited the President of the CIPM, together with the President of the OIML, to identify ways of achieving increased cooperation and effectiveness in the achievement of their objectives and the use of their resources. A joint working group met several times and was later joined by representatives of the International Laboratory Accreditation Cooperation (ILAC). A report on this activity will be presented under Item 10 of the agenda.

6.1 The Consultative Committees

Another of the recommendations of the report on long-term needs related to metrology was that the range of matters covered by the Consultative Committees should be increased to cover all areas where there is a need for international coordination and where this need is not already met by another body. The CIPM has identified three new fields where such a need exists: the first comprises acoustics, ultrasound and vibration; the second is hardness; and the third is fluid flow, including viscosity. The need for international coordination of measurement standards in the first of these has been shown to be sufficiently urgent and important that the CIPM has created a new Consultative Committee for this field: the Consultative Committee for

Acoustics, Ultrasound and Vibration (CCAUV). For hardness, fluid flow and viscosity, the CIPM has created working groups within an existing Consultative Committee, the Consultative Committee for Mass and Related Quantities (CCM). One of the decisions of the CIPM resulting from the study on long-term needs for metrology was that the traditional titles of a few of the existing Consultative Committees did not adequately reflect the breadth of their work. This tended to strengthen the dangerous misconception existing in some quarters that the work of the BIPM is narrow and purely scientific, with little relationship to the practical needs of metrology. For example, the traditional title Consultative Committee for the Definition of the Metre (CCDM) did not reflect the much broader activities of that Committee in length measurements and dimensional metrology. In consequence, the CIPM, in September 1997, amended the titles (and acronyms) of four of the Consultative Committees. In addition to the CCDM, which became the Consultative Committee for Length (CCL), the Consultative Committee for Electricity (CCE) became the Consultative Committee for Electricity and Magnetism (CCEM), the Consultative Committee for the Definition of the Second (CCDS) became the Consultative Committee for Time and Frequency (CCTF), and the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) became the Consultative Committee for Ionizing Radiation (CCRI).

The membership of the Consultative Committees was examined by the CIPM at its meetings in 1996 and 1997. In 1996 the International Committee drew up the following statement on the criteria for membership of Consultative Committees:

> "Membership of Consultative Committees is decided by the CIPM in consultation with the Presidents of the Consultative Committees and the Director of the BIPM. Laboratories invited to be members of a Consultative Committee are those already recognized internationally as most expert in the field. This normally requires that they:
>
> - be national laboratories charged with establishing national standards in the field;
> - be active in research and have a record of publications in research journals of international repute;
> - have demonstrated competence by a record of participation in international comparisons organized either by the Consultative Committee, the BIPM or a regional metrology organization.
>
> In addition to laboratory members, Consultative Committees may include as members:
>
> - named individuals whose knowledge and competence in the field are such that they can provide valuable assistance to the Consultative Committee even though they do not come from a laboratory meeting the requirements for membership;

- international unions or other international organizations whose advice or expertise would be helpful to the Consultative Committee.

The Presidents of Consultative Committees may from time to time invite observers to meetings, including representatives of appropriate laboratories that are not yet members.
In general, the national metrology institute of each Member State of the Convention of the Metre wishing to participate can expect to be a member or an observer of a least one Consultative Committee."

Experience since 1996 has shown that the key comparisons and the prospect of the MRA have increased very significantly the interest in the activities of the Consultative Committees and that more and more NMIs are applying for full membership or observer status. The CIPM welcomes this development since it broadens the base of the activities carried out under the Metre Convention. The creation of the category of observer member has been particularly welcomed by the NMIs of the smaller Member States.

Since 1995 there have been nineteen meetings of Consultative Committees, which is almost double the number of meetings held in the previous four-year period. This reflects the increase in activity of the Consultative Committees driven in large part by the key comparisons. There has also been a feeling among members that the Committees should, in any case, meet more frequently to match the increased need for international activity in metrology that is itself the driving force behind the MRA.

I now come to brief summaries of the work of each Consultative Committee, summaries that will be described in more detail later in the agenda by the President of each Committee.

The CCDM, subsequently renamed the CCL, met in 1997 and proposed a revision of the practical realization of the definition of the metre. The proposal was approved by the CIPM and is the subject of Draft Resolution E (see page 355). The importance of dimensional metrology for high-technology manufacturing industry has stimulated the CCL to embark on a much wider programme in this area than in the past. The CCL Working Group on Dimensional Metrology is now very active and a number of key comparisons are in progress. Draft Resolution F (see page 356) refers to dimensional metrology.

The CCM met in 1996 and again in 1999. The CCM, with its working groups in the fields of mass, force, and pressure, covers a very wide range of metrology almost all of which is close to industrial applications. A particularly successful activity carried out by the pressure working groups is the regular organization of an international conference on pressure metrology that takes place close to the meeting of the CCM. The CCM Working Group on Force has for many years carried out what are essentially key comparisons, as a result of which the transition to the new key comparison regime has been particularly easy. In addition to these permanent working

groups, a CCM Working Group on the Avogadro Constant has been created at the request of a number of NMIs collaborating in a worldwide project to redetermine the Avogadro constant using a method based on the properties of single-crystal silicon. The objective of this work is to provide a possible new definition of the kilogram and is the subject of Draft Resolution G (see page 357). In order to extend the worldwide unification and coordination of measurements in areas that are not yet in the domain of activities of the BIPM, in 1998 the CIPM created two new working groups under the auspices of the CCM. One is the *ad hoc* Working Group on Hardness whose members include the International Measurement Collaboration (IMEKO), the International Organization for Standardization (ISO) and the OIML, the objective being to unify the hardness scales currently in use. The other working group is concerned with flow and viscosity, and its first meeting in July this year gathered many representatives of NMIs already engaged in these fields.

The CCDS, now the CCTF, met in 1996 and 1999. The work of the CCTF, and indeed the work of the BIPM in this field, is strongly driven by the rapid advances in physics, particularly in atomic spectroscopy. Recent advances in our ability to examine cold atoms and trapped ions is leading to new primary frequency standards having an accuracy of at least one, or perhaps two, orders of magnitude better than the classical caesium standards. Draft Resolution H (see page 358) addresses this point. While these are not yet operational standards, it is clear that before too long there will be a number of these new standards in operation around the world. Until this year, it was believed that the regular time comparisons providing the BIPM with data for the calculation of International Atomic Time (TAI) were sufficient to provide adequate comparison material, and that no key comparisons were needed. But in 1999 the CCTF decided that the advent of these very accurate new standards necessitates direct comparisons and proposed the initiation of key comparisons of frequency standards. This poses the challenge of finding adequate means for their comparison and also of improving the regular multi-way time links that provide the data for the calculation of TAI. The demand for ever-increasing accuracy in time measurement reflects the large commercial investment that already exists in global navigation systems. In addition to the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS), a number of new so-called overlay systems are in preparation that will lead to the complete adoption of satellite navigation systems for civil aviation. All of these will require atomic time scales of the highest accuracy and reliability. At the 1999 meeting of the CCTF a letter was drafted and sent by the Director of the BIPM to the major satellite navigation organizations, drawing their attention to the importance of using TAI as the time scale for all these new systems. In 1998, a joint project was begun with the International GPS Service (IGS) on the use of GPS for precise time comparisons using the techniques developed for geodesy relying on GPS phase and code data. This is an important initiative

and brings in many members of the CCTF. In 1997, a joint project was also begun with the International Astronomical Union (IAU) on the application of general relativity to space-time reference systems. This project originated from the CCDS Working Group on the Application of General Relativity to Metrology, which completed its work in 1997.

The CCE, now the CCEM, met in 1997 and is due to meet again in 2000. The field of electricity is one that underwent radical change through the introduction of the quantum-based standards for the volt and the ohm in 1990. Since then, the BIPM has carried out many direct comparisons of national representations of Josephson standards and, more recently, of quantum-Hall-effect resistance standards. These comparisons have been made by carrying the BIPM standards to NMIs. In addition, the CCE identified a set of key comparisons that were initiated at the 1997 meeting and which are due to be completed in time for the meeting of the CCEM in 2000. The breadth of the field of electrical standards, including dc, low-frequency ac and high-frequency ac, is one that has always required a relatively large number of international comparisons, a fact reflected in the choice of about a dozen dc and low-frequency key comparisons and rather more high-frequency comparisons. The latter are organized by the CCEM Working Group on Radiofrequency Quantities (GT-RF), which has been in existence since 1963. The field of electricity and magnetism is one of great industrial and commercial importance and the work of the CCEM in maintaining an accurate and reliable international network of links between NMIs will continue to be its primary aim. The Committee has established a working group on key comparisons that met in July 1999 in preparation for the meeting of the CCEM in 2000. Let us note that the determination of the Avogadro constant is not the only avenue to a new definition of the kilogram. The CCEM has a working group on electrical methods to monitor the stability of the kilogram, in particular the watt balance which compares an electromagnetic force with a weight.

The Consultative Committee for Thermometry (CCT) met in 1996 and is due to meet again in 2000. At its meeting in 1996, the Committee designated six key comparisons with a view to their completion in time for the next meeting, then foreseen for 1999. In fact, the 1999 meeting has been postponed until 2000 because the key comparisons were not yet ready to be discussed by the CCT in full session. In looking at past comparisons that could be used as the basis for provisional equivalence, it was found that very few comparisons have been made since the mid-1980s when a large amount of work was done in preparation for the adoption of the International Temperature Scale of 1990 (ITS-90). This accounts for the relatively heavy load of comparisons now under way. The CCT is also working on an extension to lower temperatures of the ITS-90. It is planned to extend the present lower limit of 0.6 K to a few millikelvins using the melting pressure of helium as thermometric parameter. Draft Resolution I (see page 360) refers to this. A joint working group of the CCT and the Consultative

Committee for Photometry and Radiometry (CCPR) is comparing methods of determining high temperatures based on the alternative techniques of radiation thermometry as defined in the ITS-90 and of absolute spectral radiometry based on recently developed radiometric methods using a cryogenic radiometer as reference. Also under the auspices of the CCT, a working group on humidity standards was created in 1994 and has begun to carry out some pilot comparisons in preparation for designating key comparisons in this important field.

The CCPR met in 1997 and 1999. At the 1997 meeting a set of six key comparisons was chosen and initiated. At the 1999 meeting three of these were presented as completed and the results approved by the Committee. These are now ready to be included in Appendix B of the MRA and in the KCDB. The analysis of the results of most of the CCPR key comparisons is particularly complex, as most of the measurements resulting from these comparisons are spectral data that cover a wide range of wavelengths. Since it is not easy to find a simple way to express the degrees of equivalence, the Committee has chosen to include the data individually for each wavelength. It is for the user to choose the wavelength or range of wavelengths that are of importance for a particular application. The almost universal adoption of the cryogenic radiometer by NMIs as their reference has led to a significant improvement in accuracy and consistency of national radiometric scales. One area that still needs improvement, however, is the ultraviolet (UV) region where comparisons show much larger differences between national scales than elsewhere. In view of the importance of UV measurements for human health and safety and for certain environmental measurements, the CCPR has identified the UV as a priority area for future work.

The CCEMRI, now the CCRI, met in 1996, 1997 and 1999. The CCRI continues to work through its three Sections: Section I on photon dosimetry, Section II on radionuclides and Section III on neutron dosimetry. International comparisons have always played a large part in the activities of the CCRI and continue to do so now as key comparisons. A notable development in recent years has been the extension of the need for dosimetry comparisons to higher energies as hospitals increasingly use accelerators to provide therapeutic photon beams. To meet this need without equipping the BIPM with an accelerator, which is not a feasible proposition, the CCRI has devised a method using a set of ionization chambers that operate at both low and high energies. Comparisons using the first of these new chambers are now under way. The CCRI decided that international equivalence in radionuclide measurements can be demonstrated through the results of the International Reference System for radionuclides (SIR), which has been operated by the BIPM since 1975. The SIR has recently been extended to include β-emitters using the method of liquid scintillation counting.

The Consultative Committee for Amount of Substance (CCQM) has met annually since it was created in 1993 and has very rapidly made an impact on

the vast subject of metrology in chemistry. There is now no doubt that the community of analytical chemistry, at one time wholly unconcerned by the need to link measurements to the SI, is now fully aware of the problem and is beginning to take note of the work of the CCQM and of other international initiatives linked to it. The range of work now being carried out under the auspices of the CCQM is increasing at a rapid rate. At its 1999 meeting the Committee identified some sixteen potential key comparisons, of which nine are in progress. The results of three key comparisons presented and approved by the Committee at its 1999 meeting should very soon be ready to be entered into Appendix B of the MRA and the KCDB. I draw your attention to Draft Resolution J (see page 362) which deals with metrology in chemistry. As an extension to the work on analytical chemistry, it is now clear that metrology in the closely related field of biotechnology will soon become important and this is addressed in Draft Resolution K (see page 363).

The new CCAUV met for the first time in 1999, following a preparatory meeting of an *ad hoc* group in 1998. In 1998 the CIPM decided to create this new Consultative Committee after considering the report of its *ad hoc* working group and the requests from a number of NMIs that concerted international action was needed in the field of acoustics, ultrasound and vibration. The working group itself identified a number of international comparisons, provisionally identified as key comparisons, and initiated some of them. The new Consultative Committee includes experts not only from NMIs but also from the ISO and International Electrotechnical Commission (IEC), two organizations that have in the past been active in promoting international coordination in these fields and both of which supported the creation of a Consultative Committee. This extension of the range of work under the auspices of the Consultative Committees follows the recommendation that this should happen in the report on long-term needs referred to earlier in my report.

The Consultative Committee for Units (CCU) met twice since the last Conference, in 1996 and 1998, and approved a 7th edition of the SI Brochure, which was published in 1998. Two Draft Resolutions stemming from the work of the CCU are presented, namely Resolution L, on the neper and the bel (see page 364), and Resolution N on a special name for the derived SI unit mole per second, the katal (see page 366). The latter is in response to a request from the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC). The work of the CCU is of critical importance for the SI. Although the main development of the SI took place in the 1960s and 1970s, there remains from time to time the need to modify or update parts of it. The two Draft Resolutions presented to this Conference are examples. The discussions that precede any proposal to change the SI are often complex and subtle. It is becoming increasingly difficult to find highly experienced scientists who are qualified and interested in taking part in these discussions. There is no longer the attraction for younger physicists that was present when the system was being developed, but without younger scientists

taking an interest there is a danger that changes to the SI will lack the secure foundation that only experience and deep understanding can give. This will remain a problem for the future and I ask directors of NMIs to encourage some of their brightest young scientists to develop an interest in the subject of units. They should be reminded that a deep understanding of units and physical quantities is an essential guide to clear thinking in physics.

6.2 The CIPM

I come now to the composition of the CIPM. At the meeting of the CIPM that took place at the close of the last Conference in October 1995, a new bureau was elected that included Luigi Crovini as Deputy Secretary. It was understood by all that he would soon take the important post of Secretary of the CIPM. Sadly it was not to be, for a few weeks after the 20th Conference he died at the early age of fifty-eight and the CIPM lost one of its most highly respected members. At the time of his death Luigi Crovini was Director of the Istituto di Metrologia G. Colonnetti (IMGC) in Turin. He was also President of the CCT, in which Committee he had played an important role in the development of the text of the ITS-90. In his memory, his colleagues in the thermometry community put together a special issue of *Metrologia* devoted to thermometry (*Metrologia*, 1996, **33**, No. 4).

In October 1996, on the announcement of the resignation of Dieter Kind, who had been President since 1984 and member of the CIPM since 1976, I was elected President, Dr Bill Blevin, Secretary and Dr Katharine Gebbie and Dr Kozo Iizuka, Vice-Presidents. Josef Skákala had resigned as Vice-President in 1995 and from the CIPM in 1996. Both Dieter Kind and Josef Skákala were elected Honorary members of the CIPM. Other resignations from the CIPM since the last General Conference are those of Kai Siegbahn, Jacques Vanier, Yuri Tarbeev, Rafael Steinberg and Peter Clapham. Kai Siegbahn was elected an Honorary member of the CIPM.

To fill these eight vacancies new provisional members were elected by the CIPM, under Article 14 (1875) of the Rules annexed to the Metre Convention, are Prof.-Dr Ernst Göbel, President of the Physikalisch-Technische Bundesanstalt (PTB, Braunschweig, Germany), Prof. Sigfrido Leschiutta, President of the Istituto Elettrotecnico Nazionale Gallileo Ferraris (IEN, Turin, Italy), Dr Roy VanKoughnett, Director General of the Institute for National Measurement Standards (INMS) of the National Research Council of Canada (NRC, Ottawa, Canada), Dr Lev Issaev, Gosstandart (Moscow, Russian Federation), Dr Hüseyin Ugur, Director of the Ulusal Metroloji Enstitüsü (UME, Gebze-Kocaeli, Turkey), Dr Andrew Wallard, Deputy Director of the National Physical Laboratory (NPL, Teddington, United Kingdom), Dr Chung Myung Sai, Director of the Korea Research Institute of Standards and Science (KRISS, Taejon, Republic of Korea) and

Dr Joaquín Valdés from the Instituto Nacional de Metrología Industrial (INTI, Buenos Aires, Argentina). According to Articles 7 (1875) and 8 (1921) of the Rules annexed to the Metre Convention these provisional elections must be presented to the next General Conference for confirmation, along with another name drawn by ballot to bring the total number of members of the CIPM for election or re-election to nine. These elections will take place under Item 15 of the agenda (see page 316).

The CIPM at its meeting in 1997 considered the criteria for election to the CIPM. The rules in the Metre Convention relating to membership of the CIPM are as follows: membership of the CIPM is treated in Article 8 (1921) of the Rules annexed to the Metre Convention, election to the CIPM in Article 14 (1875) of the Rules, and election of the officers of the CIPM in Article 9 (1921) of the Rules. The role of the General Conference in confirming elections to the CIPM is treated in Article 7 (1875) of the Rules. Rules of procedure for the CIPM are laid out in Articles 11 (1921), 12 (1921) and 13 (1875) of the Rules annexed to the Convention.

In summary, as regards membership, the Convention simply requires that each of the eighteen members be of a different nationality and that on the death or resignation of a member the vacancy be filled by an election carried out by correspondence among the remaining members and confirmed by a vote at the next General Conference.

In 1983 the 17th CGPM accepted the report of the working group established by the 16th CGPM in 1979 to examine proposals for changing the Metre Convention. One of these proposals was to increase the number of seats on the CIPM to equal that of the number of Member States of the Convention, and for members to be the delegates of their governments. The CGPM working group recommended that no change should be made in the constitution of the CIPM either in respect of the number of seats or in the independence of the members, who remain individual members and not delegates of their governments. It did recommend, however, that at the time of election the CIPM take steps to ensure that the candidate, if elected, would be acceptable to his or her government. A copy of the report of the CGPM working group is available at the BIPM. It was never published in full, but copies were sent to all member governments at the time.

In 1981 the CIPM decided that the curricula vitae of all candidates proposed for election must be presented and discussed at a meeting of the CIPM before any particular candidate is proposed for election. In the past, such discussions occasionally took place by correspondence.

The principles currently followed by the bureau and the CIPM in making elections are the following:

- Persons proposed for election are always of a high standing in their country and have experience qualifying them to take part in the work of the CIPM.

- One member of the CIPM is always of French nationality. This recognizes the role of France as the originator of the metric system and depository of the Metre Convention.
- One member comes from each State paying the maximum contribution.
- One member is generally expected to come from each State paying a contribution of 2 % or above.
- Efforts are made to maintain a reasonable balance between regions and also to ensure the presence of a small number of members from those States paying the minimum contribution.
- Candidates from Member States three or more years in arrears with their payments to the BIPM are not considered for election.

The CIPM expressed the view that the present composition of the CIPM is in accord with the principles laid out above. These principles are publicly available on the BIPM website and the CIPM encourages potential candidates to make themselves known to one of the CIPM members whose addresses are available on the same site.

Since 1980, there has been a rapid change in membership. None of the present members was on the CIPM in 1980, two (the President and Secretary) were members in 1985, three (including K. Iizuka, Vice-President) were members in 1990, four were members in 1992, seven in 1993 and, as we have seen, ten in 1995 at the time of the last General Conference. Thus nearly half of the membership has changed since 1995 and practically all since 1990. It is the opinion of the CIPM that the length of time individual members remain on the CIPM is becoming too short and it will soon become difficult to find Presidents of Consultative Committees who are present for more than two meetings of their Committee, a state of affairs that is not desirable for the efficient running of the Consultative Committees. If this tendency for short-term membership continues it will become difficult to find members who can serve on the bureau of the CIPM for long enough to develop a consistent policy, a situation that could lead to serious difficulties.

Before coming to the activities of the BIPM, I must mention an important event that will occur four years from now. As the present Director, Dr T.J. Quinn, will then reach his retirement age, the CIPM decided to initiate a call for candidates and defined a selection procedure in such a way that the selected candidate could get acquainted with the work during at least one year, preferably two, before taking over as Director. The vacancy notice was finalized by the CIPM and is being distributed during this meeting of the General Conference.

6.3 The BIPM

At each General Conference, Member States are required to examine the work of the BIPM and proposals for the programme to be carried out in the next four-year period, then to approve a corresponding budget. These are Items 12 and 13 of the agenda. A very full discussion on the work and prospects for development of the BIPM is given in the report on long-term needs already referred to frequently in my report. Here I give a brief summary of the work carried out in the laboratories of the BIPM since the last General Conference, i.e. covering the period October 1995 to September 1999. I remind you that each year the Director prepares for the CIPM a report on the progress achieved which is published in the report of the meeting of the CIPM and sent to Member States. In addition, a formal annual report is sent to the governments of Member States in the March of each year, giving full details of the financial and administrative operation of the BIPM for the previous year. The financial accounts of the BIPM are audited and the report of the auditor is presented to the annual meeting of the CIPM. According to Article 3 (1875) of the Metre Convention, the BIPM operates exclusively under the direction and supervision of the CIPM which is itself under the authority of the General Conference made up of delegates of Governments of the Member States. The CIPM takes great care that Member States are fully informed of all of its decisions related to the BIPM and of all the work performed by the BIPM.

Since 1995, the work of the BIPM has been strongly influenced by the implementation of the key comparisons identified by the Consultative Committees. This has included direct participation in some of them, acting as pilot institute in others, and for those within which it is not directly engaged, the BIPM provides a central secretariat as required. Each of the Consultative Committees has an Executive Secretary, the head of one of the scientific sections of the BIPM. I draw your attention once again to the BIPM website (www.bipm.org), which includes a full description of the activities carried out under the Metre Convention including the CGPM, the CIPM, the Consultative Committees and the BIPM as well as the complete text of the SI Brochure and access to the recent issues of *Metrologia*. An easy way is provided of purchasing by credit card all of the BIPM publications and a selected set of publications of the ISO and the International Union of Pure and Applied Chemistry (IUPAC) concerned with quantities and units. In addition to the formal publications of the BIPM, since 1998 occasional newsletters containing up-to-date information on the work of each of the scientific sections and a general newsletter on the activities of the BIPM and the CIPM have been prepared. Examples of the BIPM publications are available for delegates at this Conference and I encourage you to take copies.

Publications of wide general importance to which the BIPM has in the past made significant contributions are the *Guide to the Expression of Uncertainty in Measurement* (GUM) and the *International Vocabulary of*

Basic and General Terms in Metrology (VIM). Both of these were published by the ISO on behalf of the seven international organizations responsible for the text, namely the BIPM, IEC, IFCC, ISO, IUPAC, the International Union of Pure and Applied Physics (IUPAP) and the OIML. At the time, the work was carried out by the ISO/TAG 4. By common agreement among the seven organizations it was decided that an independent common working group formed by the seven organizations would provide a better forum for future revisions of both of these documents and, if necessary, for the preparation of others. In 1997, therefore, a new Joint Committee for Guides in Metrology (JCGM) was created. At the first meeting of the JCGM two working groups were set up: one for the revision of the GUM and the other for the revision of the VIM. Work is now under way in these two working groups. The first chairman of the JCGM is the Director of the BIPM. Another important activity of the BIPM is that of editing and publishing *Metrologia*, the international journal on scientific metrology. During the years 1995-1998, 4 volumes (about 2500 pages) were published, including refereed papers and results of international comparisons.

The scientific work of the BIPM falls into three categories, each one essential. These are: (a) calibrations for NMIs of Member States; (b) international comparisons, now key comparisons; and (c) research that maintains the professional scientific competence without which (a) and (b) would not be possible. It is of course these scientific activities that make the staff of the BIPM competent also to carry out their scientific secretarial activities for the Consultative Committees of the CIPM. The challenge for the Director and senior scientific staff of the BIPM is to identify those areas of research that can be carried out with the limited resources available. It is notable that over the past twenty years the type of research necessary for activities (a) and (b) has changed significantly. Metrology is now much closer to the frontiers of science than it used to be. This means that research in metrology is itself at the leading edge of science and therefore requires an appropriately qualified staff. In 1978, 17 % of the staff had a Ph.D. or equivalent, whereas in 1999 this proportion has risen to 34 %. The total number of permanent staff at the BIPM has fallen from 65 on 1 January 1995 to 62 on 1 January 1999. I refer you to the document "Programme of work and budget of the BIPM for the four years 2001 to 2004*"* (Appendix B, see pages 371-393) for more details of staff numbers and their evolution over the years. The present reduction has been made to face up to the need to develop the BIPM's scientific work while maintaining an essentially constant budget in real terms. Small changes in emphasis have therefore been made and advantage has been taken of the relatively large number of retirements that have taken place in the past few years. Since 1 January 1996 there have been fifteen retirements (nearly a quarter of the total staff), of which eight took place in 1998. This has allowed a considerable renewal of the staff and excellent young candidates have been found. Among the twenty-nine professional scientific staff there are eleven different nationalities from all

over the world. The programme presented under Item 12 is thus a balanced one that takes account of the needs expressed by the NMIs, the staff expertise, and the institute facilities and financial resources available. In 1998, the CIPM, following another of the recommendations in its report on long-term needs, decided to establish a small programme of work at the BIPM in metrology in chemistry. After discussions at meetings of the CCQM and wide consultations among expert laboratories, the Director proposed a programme of metrology in the analysis of gas mixtures. The programme of metrology in chemistry will require the recruitment of up to four specialized staff, which will bring the total number of permanent staff back to what it was in 1995. It is planned to begin this programme in 2000 after the refurbishment of part of the ionizing radiation building which will be made available by the removal of parts of the mechanical workshop to a new building that is now under construction.

In 1983 the CIPM proposed to the General Conference a long-term plan for the provision of new buildings at the BIPM. Included were a laboratory building for the laser work, completed in 1984, a building for a library and offices, completed in 1988 and, finally, a building for the mechanical workshop. This final stage of the programme is now under way and will house some offices and meeting rooms as well as the mechanical workshop. It is due to be completed in the year 2001 and will at last give the BIPM up-to-date facilities for the workshop. Until now workshop facilities have been a continuing source of worry to the CIPM because of their inadequacy and failure to meet modern standards of safety. It has also been possible to plan for the installation of a small laboratory for measurements in chemistry in space to be made available by the move of the workshop to the new building. On this occasion, I want to thank publicly the Embassies of several Member States, and the French Ministry of Foreign Affairs for the help they have given the BIPM in finalizing the project and arriving at a design satisfactory to all parties concerned.

Work of the BIPM

My next and final item is the report on the activities carried out in the laboratories of the BIPM during the four years from October 1995 to September 1999, a very active and successful period.

Length

1995/1996: Two stabilized argon lasers, one using the frequency-modulated-sideband and the other the third-harmonic technique, were compared. The measured frequency difference was less than the measurement uncertainty. This was an important result since it indicated that no frequency changes are introduced when the laser stabilization technique is changed. The first tests

on radiation from a frequency-modulated doubled Nd:YAG laser at $\lambda \approx 532$ nm confirmed its potential as a future recommended radiation, justifying the priority put on its development this year. The modulation transfer technique has been tried with success on He-Ne lasers at $\lambda \approx 543$ nm; these lasers will also be compared with others at $\lambda \approx 543$ nm stabilized using the usual third-harmonic technique. Collaboration continued with the École Normale Supérieure (ENS), the Institut National de Métrologie of the Bureau National de Métrologie (BNM-INM) and the Laboratoire Primaire du Temps et des Fréquences of the BNM (BNM-LPTF), France: an absolute frequency determination of the 5S–5D two-photon transition in rubidium at $\lambda \approx 778$ nm was carried out in January 1996 with a combined uncertainty of 2 kHz (5 parts in 10^{12}). The priority given to the frequency-doubled YAG lasers has led the BIPM to reduce its activity on CO_2 lasers at $\lambda \approx 10.6$ μm. Using the BIPM FG5 absolute gravimeter, measurements were made at the various stations used during international comparisons of absolute gravimeters and the results were more consistent than those obtained using relative gravimeters at the time of the last international comparison.

1996/1997: Two important grouped laser comparisons at $\lambda \approx 633$ nm were completed. One with the laboratories of the North American Metrology Cooperation (NORAMET) took place at the Centro Nacional de Metrología (CENAM) in Mexico and involved lasers from the CENAM (Mexico), the National Institute of Standards and Technology (NIST), the Joint Institute of Laboratory Astrophysics (JILA, United States) and the NRC (Canada). The other took place at the National Institute of Metrology (NIM, China) and involved the KRISS (Rep. of Korea), the NIM, the National Research Laboratory of Metrology (NRLM, Japan) and the Standards and Calibration Laboratory (SCL, Hong Kong). These two comparisons completed a series extending over the past four years that links some forty laboratories from all the regional metrology organizations active in this field: the Asia-Pacific Metrology Programme (APMP), the Cooperation in Metrology among the Central European Countries (COOMET), the European Collaboration in Measurement Standards (EUROMET), and the NORAMET. All of these comparisons were made by reference to the BIPM lasers and most of them by taking our lasers to national laboratories where grouped comparisons took place. Development of new laser systems continued, particular effort being given in this year to the frequency-doubled Nd:YAG laser at $\lambda \approx 532$ nm.

1997/1998: Increased effort was devoted to the development of the frequency-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 continued 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 remained high, no large-scale comparisons were carried out in 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-cavity diode lasers at $\lambda \approx 633$ nm, an international comparison of such lasers from five national laboratories was planned towards the beginning of 1999. As a result of the decision to transfer the scientist engaged in this work to the Electricity section, the programme on diode lasers was much reduced by the end of 1998. The research on infrared lasers at wavelength $\lambda \approx 3.39$ μm continued following the purchase and delivery in July 1998 of a laser from the Lebedev Institute (Russian Federation), with preparations in hand for comparisons of frequency chains of the PTB (Germany) and the JILA (United States). The small activity in nanometrology continued with the development of a laser interferometer diffractometer using a three-wavelength method. This interferometer was 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 was started.

1998/1999: International comparisons mainly concerned lasers working at the recommended wavelengths of $\lambda \approx 3.39$ μm and $\lambda \approx 633$ nm. The 3.39 μm BIPM laser built by the Lebedev Institute was compared at the JILA with another laser from the Lebedev Institute. With this laser the BIPM took part in a series of comparisons whose goals were the absolute frequency calibration of (He-Ne)/CH_4 transportable systems, mainly lasers built by the Lebedev Institute, and the comparison of the PTB and BNM-LPTF frequency chains. The first comparison of iodine-stabilized extended diode lasers at $\lambda \approx 633$ nm, announced the previous year, was carried out in January 1999; eight national laboratories took part, and the frequency stability was found to be better than that usually obtained with He-Ne lasers stabilized on very strong iodine transitions. Beat-frequency measurements between our two commercial infrared YAG lasers yielded a frequency stability, expressed as an Allan standard deviation, of 2×10^{-13} for a 100 ms sampling time, although some concern was caused by the detection of low-frequency instabilities in the IR lasers themselves. Work at this wavelength was held up because the two YAG lasers developed faults that the manufacturer was unable to resolve. In the field of nanometrology, a preliminary international comparison of fine line scales was started between the Office Fédéral de Métrologie (OFMET, Switzerland), the PTB and the BIPM. Following the cessation of work at the BIPM in the field of line scales and end gauges, we were pleased to donate the two principal instruments used for many years, namely, the photoelectric and interference SIP comparator and the Tsugami interferometer, to the CENAM (Mexico) and the National Institute of Standards (NIS, Egypt), respectively. A great deal of time was spent in the final preparation for publication of the 1997 *mise en pratique* of the definition of the metre. This work was carried out in collaboration with the CCL working group set up just for this purpose. The

final text including appendices has appeared in the CCDM report (1997) and in *Metrologia* (1999, **36**, 211-244).

Mass

1995/1996: The international comparison of 1 kg stainless-steel standards initiated by the CCM continued, the BIPM acting as pilot laboratory. Fifteen laboratories took part in the comparison. The stability of the transfer standards appeared to have been adequate during the first year of the comparison. In parallel with this work, the Mass section continued an extensive search for possible biases due to the balance used. The continuing studies of anelasticity in metals were focused on torsion strips. A special property of torsion strips that may prove exploitable in measurements of the gravitational constant was rediscovered. This property is absent from torsion fibres, conventionnally used to measure this constant. A prototype apparatus to test the applicability of this property was constructed and showed promising results.

1996/1997: The international comparisons of 1 kg standards in stainless steel were almost completed. The new flexure-strip balance underwent commissioning tests; although sub-microgram repeatability had already been achieved, a few simple modifications were expected to improve this performance. The expertise developed in the study of Cu-Be strips under tension was exploited in the construction of a novel torsion balance to determine the Newtonian gravitational constant, G. A new hydrostatic apparatus for measuring densities was designed and its construction begun.

1997/1998: The final round of the international comparison of 1 kg standards in stainless steel was completed. A draft report was sent to participants. The 1 kg prototype standards of the BIPM were 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 was fully commissioned. The mean standard deviation of one day's measurements was about 0.03 µg. The observed day-to-day variations in mass between two standards was about 0.1 µg. It was not clear whether these variations, which are extremely small, represented variations in the masses themselves or imperfections of the balance. The prototype torsion balance designed to measure G was servo-controlled, as a result of which noise sources could be explored in a more detailed way. Based on this work, an improved model was designed and its construction started.

1998/1999: The Draft B report of the key comparisons of 1 kg standards in stainless steel was approved by the participants and a summary was presented to the CCM in May of 1999. The CCM called for preparations to begin for a repeat comparison, again piloted by the BIPM. A new 1 kg balance was acquired for use in maintenance and dissemination of the unit of

mass. Our research balance, FB-2, continues to function well and is used for studies of air density and the stability of silicon artefacts. Measurements of *G* improved steadily. In order to cope with a growing workload in the area of basic services in mass and density, the Mass section was strengthened in April 1999 by the transfer of Dr L.F. Vitushkin from the Length section, although a substantial part of his time will continue to be devoted to maintaining the BIPM competence in gravimetry. In addition, a new assistant was recruited and joined the BIPM Mass section in September 1999.

Time

1995/1996: The reference time scales TAI and Coordinated Universal Time (UTC) were computed regularly and published in the monthly *Circular T*. Since January 1996, following a decision of the CCDS, TAI and UTC were calculated at intervals of five days, instead of the ten days previously used, to allow more efficient prediction of TAI and UTC for real-time needs. The receipt of data from primary frequency standards of significantly increased accuracy reinforced the need to improve all aspects of the calculation of TAI, from the comparison of clocks to the detailed treatment of the data at the BIPM.

1996/1997: The medium-term stability of TAI, expressed in terms of an Allan standard deviation, was estimated to be 1.3×10^{-15} for averaging times of about forty days and this improvement was largely due to increasing use by national laboratories of the new and much improved HP 5071A caesium clocks. From October 1996 to September 1997, our estimation of TAI accuracy was mainly based on results from two primary frequency standards, PTB CS2 and NIST-7, the primary standard PTB CS3 not yet having proved its reliability. No data were received from the BNM-LPTF caesium fountain after May 1996. An important part of our research activity dealt with time comparison studies using common views of GPS and GLONASS satellites observed with multi-channel receivers.

1997/1998: The medium-term stability of TAI, expressed in terms of an Allan deviation, continued to improve. It was estimated to be 1.0×10^{-15} for averaging times of about forty days. From October 1997, the estimation of TAI accuracy continued to be based mainly on results from seven primary frequency standards: the classic PTB standards CS1, CS2 and CS3, the ultra-accurate caesium fountain LPTF-FO1, and the optically pumped standards CRL-01, NIST-7, and NRLM-4. An important part of the BIPM activity dealt 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 was dedicated to the search for new pulsars and to the extension of the relativistic framework for the realization of coordinate times.

1998/1999: The medium-term stability of TAI, expressed in terms of an Allan deviation, was estimated to be about 0.6×10^{-15} for averaging times of twenty to forty days. The accuracy of TAI is based on six primary frequency standards: the three classic PTB standards CS1, CS2 and CS3, operating continuously, and three optically pumped standards CRL01, NIST-7 and NRLM-4. As a consequence of the increase in the number of primary standards and their improved stability, the scale unit of TAI is estimated to match the SI second to within 5 parts in 10^{15} since early 1998. An important part of our research activity deals with studies of time and frequency comparisons using navigation satellite systems such as GPS and GLONASS, with particular emphasis on multi-channel multi-system techniques, and on the use of GPS carrier-phase measurements. Additional research work has been dedicated to space-time reference systems, particularly to the relativistic framework for defining and realizing coordinate times. Other research subjects are pulsars, future clocks in space, and atom interferometry. Following the transfer of Dr C. Thomas in November 1998 to the new post of coordinator of the KCDB, a new head of the Time section, Dr E.F. Arias, has been recruited and is due to take up the post in November 1999.

Electricity

1995/1996: Two comparisons of 1 V Josephson voltage standards using the BIPM transportable apparatus took place, at the NIM (China) and the Statens Provningsanstalt (SP, Sweden). The transportable quantum Hall effect (QHE) resistance standard apparatus, including cryostat, magnet and resistance bridge, was taken to the PTB (Germany) where the third on-site comparison of QHE standards was carried out. The results demonstrated agreement between measurements made with the two systems to within a few parts in 10^9 with a combined relative standard uncertainty of about the same value. The transportable Josephson effect and the transportable QHE apparatus were both capable of providing traceability between laboratories with uncertainties reduced by one order of magnitude or more compared with those obtained using conventional travelling standards. An important development was in the programme of bilateral comparisons of electrical standards. For this purpose, an order was placed for 1 Ω travelling standards made by the National Measurement Laboratory (CSIRO-NML, Australia), and Zener-diode voltage standards, to be sent from the BIPM to participating laboratories for bilateral comparisons. Considerable progress was made in the assembly of an impedance bridge to link the quantized Hall resistance (QHR) to the impedance of the capacitors that will act as the BIPM's reference standards.

1996/1997: An important piece of work this year was the completion of the impedance bridge to link the quantized-Hall resistance to the impedance of standard capacitors. This was tested by comparing the results of accurate PTB determinations of a capacitance ratio, nominally of 10:1, with the

results of measurements made here using the new impedance bridge. This comparison was not completed this year but preliminary results indicated agreement to within a few parts in 10^8, a very satisfactory outcome. Also this year, we took our equipment to the IEN (Italy) for a comparison of 1 V Josephson standards. Excellent results were obtained, comparable with those obtained in the previous direct comparisons of Josephson standards.

1997/1998: Highlights of this year's activities included a new comparison of 1.018 V Josephson standards at the Centro Español de Metrología (CEM, Spain) and a novel three-way comparison of 10 V Josephson standards at the PTB with the participation also of the SP. A comparison of QHR standards took place at the NPL (United Kingdom). A calibration chain was successfully established between the QHR and a bank of standard capacitors, allowing calibration of 10 pF and 100 pF capacitors with respect to $R_{K\text{-}90}$ with a total relative standard uncertainty of about 4 parts in 10^8. Studies of the temperature and pressure dependence of Zener-diode-based voltage standards meant that it became 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 was in full operation for bilateral comparisons. Similarly, five 10 kΩ standards and two 1 Ω standards belonging to the BIPM became available for such comparisons. Following initial studies of six new 1 Ω resistors obtained from the CSIRO in February 1998, they too became available for bilateral comparisons.

1998/1999: The work this year has been marked by a considerable increase in comparison activity. At the highest level of accuracy, the fifth on-site comparison of QHR standards, carried out with the NIST (United States), was very successful. A preliminary analysis of the data indicates agreement in the measurement of the resistance of a 100 Ω standard with respect to the QHR of 1.2 parts in 10^9 with a combined standard uncertainly of 2.0 parts in 10^9. The twenty-second BIPM on-site comparison of Josephson standards was carried out with the Slovenský Metrologický Ústav (SMU, Slovakia) in May 1999. This has been a particularly active year for our programme of bilateral comparisons using Zener-diode travelling standards; a half-dozen of these were carried out, most using BIPM Zeners. Through these comparisons over the past two years we established solid links for dc voltage standards to four regional metrology organizations: the APMP, COOMET, EUROMET and the SIM/NORAMET. Our studies of the QHR at kHz frequencies have confirmed the existence of a small linear frequency dependence, although very recent work carried out here with Dr B. Kibble (invited researcher) indicates that this can be suppressed. Firm progress has been made towards reducing the heating effect that limits the amplitude of ac current in QHR measurements of metrological quality. Studies of the noise and stability of Zener-diode voltage standards and of nanovoltmeters has revealed the presence of correlations as a result of which we have begun to use the Allan variance to describe the measurement scatter. We have applied a number of different methods of time-series analysis to detect and quantify correlations

in a series of measurement results. These methods can be used in a wide range of metrology applications.

Radiometry, photometry, thermometry and pressure

1995/1996: Following the decisions of the 1994 meeting of the CCPR, the BIPM was the pilot laboratory for two international comparisons in the fields of radiometry and photometry. One concerned cryogenic radiometers, the other the luminous responsivity of photometers. For the comparison of cryogenic radiometers, which is an indirect comparison, fourteen so-called tunnel trap detectors were constructed at the BIPM. In conjunction with the existing reflection traps, these acted as transfer instruments for the comparison. The BIPM cryogenic radiometer was taken, for the first time, to another laboratory, the PTB (Germany), where a satisfactory comparison was carried out with a cryogenic radiometer from another manufacturer. Work began on a radiometric realization of the candela based on the cryogenic radiometer. In the field of thermometry, the international comparison of water triple-point cells was completed; results were presented to the CCT in September 1996. Although most laboratories appeared to agree to within their standard uncertainties, generally about 0.1 mK, some larger differences were observed and the stability of the cells was not as good as expected. Following a decision of the CCM to begin an international comparison of pressure standards in the atmospheric pressure range, in which the BIPM will participate, the BIPM purchased a ceramic-piston pressure balance for use in the comparison.

1996/1997: Most of the work this year was devoted to the international comparisons approved by the CCPR in 1994. For the BIPM this meant piloting two comparisons, one on the responsivity of cryogenic radiometers by means of trap detectors, scheduled for completion in 1998, and the other on the luminous responsivity of photometers, completed in the summer of 1997. The first direct realization of the candela was achieved at the BIPM: four commercial photometers, modified by fitting them with calibrated apertures purchased from the NPL (United Kingdom), were calibrated as illuminance meters so providing a direct radiometric realization of the candela. Previous representations of photometric units maintained at the BIPM were based on a group of lamps for which the average output was linked to past international comparisons. When the result of the new realization was compared with those obtained during the international comparison of photometers and with the candela maintained on lamps since 1985, the agreement was excellent. This new realization, and future similar ones based on the BIPM cryogenic radiometer, will improve the stability of the candela maintained at the BIPM.

1997/1998: Work continued on the international comparisons initiated by the CCPR for which the BIPM was the pilot laboratory: the comparison of

cryogenic radiometers was completed, and the comparison of the luminous responsivity of photometers neared completion. This year much more effort than in recent years was 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 Dr Y. Ohno, a guest worker from the NIST, an independent realization of the lumen was conducted at the BIPM using an integrating sphere. Results indicated that the reflectance of the surface coating of the integrating sphere was rather low and had a large temperature coefficient. The pressure balance purchased for a key comparison of pressure standards organized by the CCM was submitted to a preliminary characterization using the BIPM primary manobarometer, in collaboration with the NPL. In the area of thermometry the BIPM participated, at the gallium point only, in a key comparison of temperature standards organized by the CCT and piloted by the NIST.

1998/1999: Work has again been focused upon international comparisons, with the completion of a comparison of cryogenic radiometers and two key comparisons in photometry; reference values for the latter were adopted by the CCPR. The BIPM is the pilot laboratory for the key comparison of spectral responsivity in the visible region, preparations for which are under way. A new measurement facility using black-body radiation has been set up and is being characterized along with a system for the measurement of aperture areas. The BIPM also took part in the CCT key comparison of long-stem standard platinum resistance thermometers (SPRTs) and the CCM comparison of medium pressure measurements.

Ionizing radiation

1995/1996: The section's work continued to be dominated by international comparisons in x-ray dosimetry, γ-ray dosimetry and radioactivity, and by the need to calibrate secondary standards for countries having no primary standards. In dosimetry, supporting research work was carried out to improve the determination of the correction factor for electron loss and photon scatter in free-air chambers, and so to determine ion recombination coefficients for various ionization chambers. Six comparisons of air kerma were made: one in the soft x-ray beam, two in the ^{137}Cs beam and three using the ^{60}Co source. Final measurements were made in Japan for the international comparison of neutron fluence measurements which use Bonner spheres as transfer instruments. This comparison was due to be finished by the end of 1997. In the field of radioactivity measurements, the trial comparison, involving six laboratories, of measurements of ^{204}Tl was completed and the full-scale comparison planned to begin before the end of 1996. The results of a trial

comparison of measurements of the activity of ^{192}Ir were analysed. The BIPM participated in an EUROMET comparison of measurements of the activities of ^{63}Ni and ^{55}Fe. During the year, nine laboratories sent ampoules for standardization by the SIR. A new study was begun to identify and quantify radionuclides that may contaminate the ampoules used in international comparisons of the activity of radionuclides. With the retirement of J.W. Müller, the long series of studies at the BIPM on counting statistics come to an end with a short note on the determination of prime numbers.

1996/1997: Recent meetings of the three Sections of the CCEMRI emphasized a continuing need to improve the traceability of measurements in ionizing radiation. In the field of x- and γ-ray dosimetry new comparisons, carried out by the BIPM with a number of other laboratories, showed results in close agreement with comparisons made up to fifteen years previously. International comparisons of activity measurements once again showed themselves to be useful in revealing unsuspected problems in the standardization of nuclides for which measurements are relatively easy. The extension of the SIR to β-emitters is expected to be fully operational after completion of the very promising comparison of activity measurements of ^{90}Sr solutions, under way this year.

1997/1998: The national laboratories showed 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 in new measurements of equivalent activity using the SIR. Several studies were 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, led to an accurate determination of the impurity level in ampoules and a consequent increase of coherence in the SIR data.

1998/1999: This has been a busy year for photon dosimetry comparisons. One of the consequences of the forthcoming MRA is that all the NMIs participating in Section I of the CCRI requested a BIPM bilateral comparison. This year eleven comparisons have been completed in air kerma and two in absorbed dose. In addition, twenty-six calibrations have been made for secondary standards laboratories. In the field of photon dosimetry, Monte-Carlo calculations have been carried out for electron-loss and photon-scatter correction factors for free-air chambers operating in the range from 10 kV to 300 kV. Much of the equipment for dosimetry is old and a programme of renewal has begun; in particular a new series of graphite ionization chamber standards has been acquired. We are still awaiting the delivery of a new ^{60}Co source and the long delay in obtaining approval from the French authorities for the transport of the source to the BIPM has been a considerable inconvenience. In the radionuclide field, the international comparison of activity measurements of ^{204}Tl has been completed and the

results were presented to the meeting of CCRI Section II in June 1999. The pilot international comparison of activity measurements of ^{152}Eu has started and the ampoules were measured in the SIR before they were dispatched to participants. A significant number of new results have been entered into the SIR this year and a monograph containing the entire set of data registered since the creation of the SIR in 1976 is in the final stages of preparation. These data will be used to provide information on equivalence of national standards in this field for the MRA. Various studies are under way or completed on aspects of the operation of the SIR and its extension to β emitters using liquid-scintillation counting. Among these are the detection of radioactive impurities in ampoules submitted for the SIR and the implementation of the triple-to-double coincidence ratio counting method.

Calibrations

In addition to the extensive range of international comparisons and supporting research work outlined above, calibrations are carried out for many of the national metrology institutes of the Member States of the Metre Convention. In 1995/1996 fifty-six Certificates and two Study Notes were issued by the BIPM, followed in 1996/1997 by fifty-seven Certificates and eight Study Notes, in 1997/1998 by fifty-five Certificates and three Study Notes and in 1998/1999 by fifty-seven Certificates and one Study Note.

Publications

Since October 1995 the following have been published:

20th Conférence Générale des Poids et Mesures (1995), Proceedings, 230 pp.

Comité International des Poids et Mesures, Reports of meetings, T. **63 (**84th meeting, 1995), 220 pp.; T. **64** (85th meeting, 1996), 219 pp.; T. **65** (86th meeting, 1997), 354 pp.; T. **66** (87th meeting, 1998), 279 pp.

Annual Report of the BIPM Time Section, Vol. **8** (1995), 156 pp.; Vol. **9** (1996), 162 pp.; Vol. **10** (1997), 143 pp.; Vol. **11** (1998), 141 pp.

Consultative Committee for Electricity, 20th meeting (1995), 76 pp.; 21st meeting (1997), 135 pp.

Consultative Committee for Photometry and Radiometry, 14th meeting (1997), 80 pp.

Consultative Committee for Thermometry, 19th meeting (1996), 104 pp.

Consultative Committee for Units, 12th meeting (1996), 68 pp.; 13th meeting (1998), 59 pp.

Consultative Committee for the Definition of the Second, 13th meeting (1996), 81 pp.

Consultative Committee for the Definition of the Metre, 9th meeting (1997), 163 pp.

Consultative Committee for Mass and Related Quantities, 6th meeting (1996), 47 pp.

Consultative Committee for Amount of Substance, 2nd meeting (1996), 38 pp.; 3rd meeting (1997), 47 pp.; 4th meeting (1998), 87 pp.; 5th meeting (1999), 95 pp.

Consultative Committee for Standards of Ionizing Radiation, 14th meeting (1996), 140 pp.; 15th meeting (1997), 227 pp.

Circular T (monthly), 6 pp.

Le BIPM et la Convention du Mètre, reprint, 1998, 63 pp.

Le Pavillon de Breteuil : bref historique de 1672 à nos jours, reprint, 1998, 19 pp.

The International System of Units (SI), 7th edition, 1998, 152 pp.

National and international needs relating to metrology: International collaborations and the role of the BIPM, 1998, 132 pp.

To these publications must be added 50 BIPM reports and about 180 articles in scientific journals or conference proceedings, and *Metrologia* volumes **33**, **34**, **35** and **36**."

On completion of Prof. Kovalevsky's report, the President of the Conference invited questions and comments from delegates.

Dr Plantenga (the Netherlands) noted that the names of several Consultative Committees had been changed to reflect their broadening areas of work, and expressed concern that increasing pressure was being placed on the Consultative Committees and the BIPM.

Prof. Kovalevsky replied that the problem was recognized and should be borne in mind when restrictions of the BIPM budget were being considered.

Dr Quinn, Director of the BIPM, remarked that the increased activity of the Consultative Committees represented an additional burden on the national metrology institutes, and the greater number of Consultative Committee meetings of course added to the workload of the BIPM. He reported that this year more Consultative Committee meetings than ever before had been held, noting that since January 1999 over five hundred delegates had attended meetings at the BIPM. He reassured Dr Plantenga that he did not foresee a major problem for the BIPM in the future, but said that he would return to this issue during his presentation of the programme of future work of the BIPM (Item 12 of the agenda).

7 Report of the CIPM on national and international needs relating to metrology

Dr W.R. Blevin presented the report *National and international needs relating to metrology: International collaborations and the role of the BIPM. A report prepared by the CIPM for the governments of the Member States of the Convention of the Metre*, introduced by Prof. Kovalevsky under Item 6 (see page 224).

This important document has been widely distributed and is available on the BIPM website (www.bipm.org); it is included with this report.

Dr Blevin summarized the broad content as follows.

Numerous issues of concern to national governments continue to increase the demand for international uniformity of measurement and are raising the importance of accreditation and international recognition of measurement and testing services. These issues include: the strong trend towards globalization of world trade; the move to international co-manufacture of goods; the greater technical complexity of most products and services; and the increased concern for health, safety and environmental matters. Recent trade agreements between nations and regions specifically require all signatories to accept the results of measurements and tests performed by any other party. This increased emphasis on the importance to trade of the equivalence of measurement and testing services will have far-reaching effects on national and international measurement systems. This is the background against which future national needs relating to metrology and those for international collaboration are assessed. Aspects of metrology that call for continued, often strengthened, international collaboration include: agreements on the definition and realization of the units of measurement, establishment of national measurement standards of demonstrable international equivalence, laboratory accreditation, legal metrology and documentary standards. It is essential that there be multilateral collaboration in these fields at both global and regional levels.

The report stresses that the programmes undertaken with the authority of the Metre Convention have been of considerable value and concludes that most current programmes need to be continued. There is, however, a widely held view that the BIPM and the Consultative Committees of the CIPM must now do more to help the national metrology institutes of the Member States demonstrate the degree of equivalence of their national measurement standards. This has already been taken up by the CIPM and the BIPM by the introduction of CIPM key comparisons of measurement standards, the

coordination of these with similar comparisons arranged by regional metrology organizations, and the development of the MRA.

The role of the Consultative Committees is to be strengthened considerably, with more active work programmes between meetings. The criteria for membership of the Committees have been reviewed and clarified, and observers will be admitted to meetings so that a larger number of Member States may participate. More specific terms of reference are to be prepared for each Committee, and a member of the BIPM scientific staff has been assigned to each Committee to serve as its Executive Secretary. The areas of metrology covered by some Committees are to be broadened, with the formation of one or more additional Committees, so that collectively they cover the principal fields of metrology in which collaboration between the national metrology institutes is important for the establishment of international equivalence between standards. Extensions to cover the fields of acoustics, ultrasound, vibration, hardness, fluid flow and viscosity have been proposed and have already been taken up by the CIPM, but there are many other fields in which, sooner or later, it will be necessary to establish worldwide equivalence of standards and measurements. The BIPM is uniquely placed to identify such emerging needs and to initiate appropriate international collaboration.

Dr Blevin added that it was vital that the areas of work of the Consultative Committees continue to evolve, and that as some fields were added, others would be given lower priority.

Many global and regional bodies are now concerned with basic or applied aspects of metrology. At the global level, the BIPM has undertaken to collaborate more actively with the ILAC, ISO, OIML, and the IEC: at the regional level it will collaborate with the regional metrology organizations. An initiative already taken by the CIPM is the creation of the JCRB, chaired by the Director of the BIPM.

Strategies have recently been adopted which allow the BIPM to provide some assistance to developing countries with a view to strengthening their national measurement systems, most particularly by raising the profile of measurement as a significant component in economic development. Some of these strategies involve close collaboration with the OIML, the RMOs and the IMEKO.

In its report, the CIPM lays out the role to be undertaken by the BIPM in the early decades of the 21st century. This is accompanied by a list of twenty-one specific decisions concerning the future activities of the BIPM and the Consultative Committees. There is an ongoing need for the BIPM to undertake new programmes from time to time, either in response to new requirements set by the Member States or to take advantage of progress in science and technology. The impact of such new programmes on the BIPM budget depends largely on the balance between the need for new staff and the

resource savings that can be achieved by terminating or curtailing selected current activities, or by improving efficiency. The long-term building programme developed for the BIPM in the early 1980s is nearing completion and no need is foreseen for the construction of new buildings within the next few decades.

The report ends with an examination of the financial commitments required from the Member States of the Metre Convention, including future needs for funding of the BIPM in the light of foreseeable developments in its activities and taking account of economic restraints now imposed by most Member States. This part of the report is taken up under Item 12 of the agenda.

Dr Blevin concluded by saying that the 88th meeting of the CIPM (October 1999) had agreed that the study of long-term needs was important and should continue, and that the present report would be updated in the future.

Questions were then invited from delegates.

Dr Kildal (Norway) opened the discussion by asking whether there had been any developments regarding the proposal to house the ILAC secretariat at the BIPM. Dr Blevin replied that discussions had been held with senior ILAC officers, who had agreed that a close relationship between the BIPM and the ILAC would be beneficial. The ILAC was not yet ready, however, to make a decision concerning the eventual location of its secretariat. Dr Quinn added that discussions had been held with the French Ministry of Foreign Affairs regarding the statutory conditions concerning possible housing of the ILAC secretariat at the BIPM. The CIPM is now awaiting the ILAC's response.

Prof. Bordé suggested that for the time and frequency work it might be interesting for the BIPM to establish relations with space agencies. Prof. Kovalevsky replied that indeed the CIPM was becoming involved with aspects of space science, and drew attention to Recommendation 1 (CI-1999) adopted at the 88th meeting of the CIPM, concerning future global navigation satellite systems and the UTC and TAI time scales. He thanked Prof. Bordé for his comment and promised that the CIPM would study the issue.

Dr Quinn also mentioned his involvement with the Satellite Test of the Equivalence Principle (STEP) project, a proposed investigation in space for a test of the equivalence principle. For some years the BIPM has been studying the fabrication of Pt-Ir masses and the variations in density across them. The present proposal is that masses for the STEP project would probably be fabricated at the PTB (Germany).

On behalf of the CIPM, Dr Blevin then read Draft Resolution A (see page 347) concerning long-term needs relating to metrology. Dr Sutton (New Zealand) expressed concern that "degree of equivalence" was not adequately

defined and suggested that the emphasis should be purely on the establishment of a mutual recognition arrangement. Prof. Kovalevsky said that the bureau of the CIPM would consider modifying the wording, but it was decided that the Resolution did not imply any particular definition of "degree of equivalence". In fact, after further consideration the bureau of the CIPM decided against proposing any changes and Draft Resolution A was subsequently adopted as Resolution 1 (see page 325) with one abstention (New Zealand).

Dr Blevin then proposed a list of twelve Member States to form a working group on the BIPM dotation, whose task would be to meet during the morning of 13 October in order to consider Draft Resolution M (see page 369) and make a recommendation to the Conference. This list was accepted with the addition of Denmark whose delegation indicated that it would also like to participate. The list of members of the working group and a report of their discussions are presented under Item 13.1 (see page 313).

Dr Inglis (Australia) expressed his strong support for the BIPM's proposed programme of work, noting that he considered the proposed level of funding absolutely essential.

8 Worldwide traceability of measurement standards

On the invitation of the President, Dr Quinn then proceeded to discuss the traceability of national measurement standards and to present Draft Resolutions B and D (see pages 349 and 354, respectively).

Resolution 2 of the 20th General Conference laid the foundation for an important initiative concerning the worldwide mutual recognition of the national measurement standards maintained by national metrology institutes and the calibration and measurement certificates issued by them. The requirement for worldwide traceability of measurement standards is now universally accepted. The problem faced by NMIs was how to achieve this while avoiding an unmanageable number of bilateral agreements on equivalence of measurement standards. It was clear that within regional groups of cooperating national metrology institutes, multilateral agreements could be envisaged. It was thought that a worldwide scheme could then be set in place through bilateral agreements between regional groups.

At the first meeting of directors of NMIs in February 1997, a proposal was made by the Director of the BIPM that an attempt be made to move directly towards a worldwide agreement rather than a network of regional agreements. This generated much discussion and through subsequent correspondence a broad consensus was reached that such a worldwide agreement should be attempted. After extensive consultation with directors of NMIs and discussion at the meeting of the CIPM in September 1997, a draft agreement was presented to directors at their second meeting in February 1998. Following some further amendments a draft text was initialled by the directors or senior representatives of the NMIs of thirty-nine Member States, with a view to reaching agreement on a final text for signature at a meeting of directors to be held at the time of the 21st General Conference. The draft text initialled by directors was sent to Member States' diplomatic representatives in Paris in May 1998 in order to inform Member Governments officially of this proposal. It was later amended, but only in detail, after further consultation with directors before a final text was prepared in August 1999 for signature in October 1999.

Reference was made in the draft text to the JCRB. The CIPM created this Joint Committee in September 1997 and it held its first meeting in February 1998 under the chairmanship of the Director of the BIPM.

Dr Quinn then presented Draft Resolution B (see page 349), updating the text to include the new word "arrangement" wherever appropriate. Dr Göbel (Germany) expressed his support for the MRA and thanked the Director for his efforts. Dr Sutton (New Zealand) added his thanks, and congratulated the Director on the speed with which the arrangement was being put into place.

There then followed a discussion in which it was made clear by Dr Quinn that the MRA is not a binding agreement and was never intended to be one. He ended by saying that various minor revisions to the text of the MRA had been made over the past year to make this clear. It was then proposed by Dr Sutton that the Draft Resolution be modified to encourage all States, not just the signatories of the MRA, to use the MRA as a means of establishing traceability of their own national measurement standards.

After a minor adjustment of the wording to take account of the New Zealand comments, Draft Resolution B was approved unanimously as Resolution 2 (see page 326).

The MRA was signed in Paris on 14 October 1999 at a meeting of directors of the national metrology institutes of Member States of the Metre Convention. The directors of the national metrology institutes of thirty-eight Member States of the Convention and representatives of two international organizations signed the document. The text of the MRA is included in this volume. The text and list of signatories of the MRA are also available on the BIPM website (www.bipm.org).

Dr Lam (Singapore) suggested that the BIPM should draft a press release on the MRA and urge Member States to follow suit. Dr Quinn replied that such action should be taken by the NMIs rather than by the BIPM.

Dr Quinn also presented Draft Resolution D (see page 354), concerning the need to use SI units. This resolution was adopted unanimously, without changes, as Resolution 4 (see page 328).

9 Admission of Associates of the General Conference

Prof. Kovalevsky then turned to the proposal to admit Associates of the General Conference. He reported that the development of the MRA had highlighted the need to find a way to link to the SI the metrological activities of a much larger number of States than are at present Member States of the Metre Convention. World trade increasingly demands that measurements in all trading nations of the world be traceable to the SI, but there are many smaller or less affluent States that would find it difficult to pay even the minimum annual subscription necessary to be a Member State of the Metre Convention (0.5 % of the BIPM dotation). Since the exclusion of countries could be considered to constitute a technical barrier to trade, the CIPM holds the view that the General Conference should take responsibility for providing a mechanism to establish links to the SI from the measurement systems of all States and Economies, including those that are not Member States of the Metre Convention. Participation in the MRA through the RMOs appears to be a way of doing this. Some formal link to the BIPM is, however, necessary and some financial contribution must be made to cover the costs. The Metre Convention has no provision for a category of "Associate" but, inspired by the OIML Convention, the CIPM proposes that the 21st General Conference create a category of Associates of the General Conference, aimed particularly at smaller states who might be unable to pay a full contribution to the Metre Convention. This proposal, which is supported by the French Government as depository of the Metre Convention, is embodied in Draft Resolution C (see page 351).

Prof. Kovalevsky reminded delegates that the aim of the MRA was to establish international equivalence of measurements and traceability of measurements to the SI, indications of which will be demonstrated to the world via the KCDB. Access to the database will be unrestricted, but as

things stand now only signatories of the Metre Convention will have the right to take part in the key comparisons and have their calibration and measurement capabilities included therein.

Associate status would give States and Economies the right to take part in the General Conference as non-voting observers, to participate in the MRA, and to have their results included in the KCDB. They would not, however, benefit from the other advantages of membership of the Metre Convention. For example, Associates of the General Conference and their national metrology institutes would not benefit from:

- provision by the BIPM of standards, including Pt-Ir kilograms;
- free calibrations by the BIPM of a range of national measurement standards;
- participation in CIPM and BIPM comparisons;
- active participation in Consultative Committees and at General Conferences;
- the possibility for a national to be elected to the CIPM;
- attendance at meetings of directors of national metrology institutes.

He added that at its 88th meeting (1999) the CIPM had decided that Member States in arrears with their contributions must repay their debts to their fellow Member States before they can apply for Associate status.

Prof. Kovalevsky then presented Draft Resolution C (see page 351) for discussion. He accepted the suggestion by Dr Carneiro (Denmark) that "worldwide measurement system" should be replaced by "worldwide measurement infrastructure".

Dr Castelazo (Mexico) raised the issue of a Member State in arrears with its contributions and unable to repay its debts immediately. Would such a State be excluded from General Conferences? Prof. Kovalevsky affirmed this was the case and added that the CIPM had carefully considered this issue and concluded that the debts, which are debts to all Member States, could not simply be written off by the CIPM. Instead, as agreed by the CIPM in 1998, arrangements were being sought with the debtor States to repay the debts in instalments, over a number of years. The decision to exclude a Member State from a General Conference must be presented to the State in question at least six months before the Conference.

Dr Sutton (New Zealand) queried the proposal to include international scientific unions and other international organizations as Associate organizations. Prof. Kovalevsky explained that this would put technical cooperations with other international organizations on an official footing, thus helping to improve the efficiency of contacts. Dr Quinn stressed the importance of close contacts, particularly with organizations such as the IFCC and IUPAC although he recognized the difficulties that might arise in selecting appropriate international organizations. Dr Brown (United States) asked whether there were any restrictions concerning which international organizations and unions could become Associates. Prof. Kovalevsky replied

that the bureau of the CIPM will reconsider the inclusion of international organizations in the light of this discussion.

Mr Érard (France) noted that the Institute for Reference Materials and Measurements (IRMM) undertakes calibrations and asked whether, if it wishes to participate in the MRA, it should also sign the agreement. Prof. Kovalevsky replied that the IRMM was already a member of a Consultative Committee, and Dr Quinn stressed the distinction between Associates of the General Conference and signatories of the MRA. Associates of the General Conference will be able to sign the MRA. The IRMM and the International Agency for Atomic Energy (IAEA) have been invited to sign the MRA as international organizations.

Mr Faber expressed his congratulations to the CIPM on behalf of all Member States of the OIML. Prof. Kovalevsky replied that in the next item of the agenda he would be discussing the special relation between the CIPM and the OIML, and said that Mr Faber's presence at the meeting demonstrates that the OIML is already invited to the General Conference!

After minor rewording to remove the possibility of international organizations becoming Associates, Draft Resolution C was adopted as Resolution 3 (see page 327), with one abstention (Spain).

10 Relations with the Organisation Internationale de Métrologie Légale

Prof. Kovalevsky made the following declaration.

"I remind you that Resolution 10 (1995) of the 20th General Conference invited the President of the CIPM together with the President of the Comité International de Métrologie Légale (CIML) to appoint a joint working group to identify ways of achieving increased cooperation and effectiveness in the achievement of their objectives and the use of their resources, including, but not limited to, the possibility of merging the two organizations. The same Resolution also invited the CIPM, having received the report of its President, to advise Member States of the Metre Convention of the outcome of the discussions and of its opinion as to whether further action should be taken.

Three meetings were accordingly organized between the bureaus of the CIML and the CIPM, in 1996, 1997 and 1998. At the first meeting, it was

decided that the ILAC would be invited to participate, in as much as traceability problems are at the core of the relationships between the Metre Convention and the OIML, so that a close cooperation between these three organizations would be profitable for society as a whole.

Before presenting the results and the present status of the relationship between these two organizations, it seems appropriate to outline how both parties have moved towards a closer relationship, in accordance with the wishes of the General Conference.

First of all there was a communication from the French Ministry of Foreign Affairs informing Dr Quinn and myself "that the French Government would be favourably disposed to a modification of the Metre Convention to allow incorporation of those activities currently covered by the OIML". In the same document we find the following sentence: "The position taken by the French Ministry of Foreign Affairs is that the question is worth posing and that, after having considered the situation, the Ministry would back up what would in effect be the taking over of the OIML by the Metre Convention".

Bearing in mind this proposal, the CIPM concluded that in principle there were three routes to a single intergovernmental metrology organization: (1) create a new intergovernmental convention; (2) maintain, but modify, one of the two conventions; (3) maintain, unmodified, one of the two conventions.

The CIPM, after deliberation, concluded that only the last two options were viable, because of the huge political difficulties which would be involved in the creation and signature of a new convention. It agreed on the third one but did not completely rule out the second one. Moreover, should one of these two solutions be adopted, the CIPM proposed to create under its auspices a Committee for Legal Metrology, comprising the representatives of the States or institutions now full members of the OIML or members of the Metre Convention. This Committee would be responsible to the CIPM.

Having been informed of this response of the CIPM, the Ministry of Foreign Affairs at the 20th General Conference gave a more qualified statement than it had at first: "The French Government would view favourably a closer relationship between both organizations created by these conventions in view of a possible merging according to means yet to be fixed".

I remind delegates that, in French, "éventuel" does not mean, as it does in English, a final well-defined objective, but instead "possible, contingent, liable to happen".

One can see that the idea of bringing together both organizations had evolved since the original proposal, and it is in this light that the 20th General Conference voted for Resolution 10 (1995) as mentioned above. At its 30th meeting, the CIML adopted a similar resolution.

The OIML's point of view differed from that of the CIPM, however, in that it did not consider it possible to merge both organizations without modifying the Metre Convention. Meanwhile the CIPM, on further consideration, moved away from the above-mentioned second solution owing to increasing fears about diplomatic difficulties and time-consuming delays relating to signature of even a modification of the Convention, with the additional risk that diplomats would modify what the metrologists would like to see included; the CIPM further noted that the expected increase in efficiency or reduction in cost would not justify the effort involved. This all being contradictory to the position of the OIML, the idea of a merger was at least provisionally abandoned.

It is nevertheless true that the third proposal of the CIPM, that of the creation of a Committee for Legal Metrology within the Metre Convention, remains valid, and we remain ready to discuss the specifics. It is indeed a difficult problem because Member States of the OIML do not necessarily want to assume the cost of membership of the Metre Convention if they do not think the related advantages are useful to them. One can think of solutions, however, made possible by the flexibility of the Metre Convention and the scope left to the CIPM to interpret it. As with the creation of Associates of the General Conference, for example, we could also envisage Associates to the Committee for Legal Metrology, which would not involve many countries: seventeen members of the OIML are not members of the Metre Convention and nine members of the Metre Convention are not members of the OIML. The invitation to install the Committee for Legal Metrology at the BIPM remains valid. The door is thus not closed forever and the file could be reopened in a few years' time.

These discrepancies have not prevented the OIML and the CIPM from moving closer together by means of common actions. The OIML and the Metre Convention worked together with other institutions to write the VIM prepared jointly with the GUM. The JCGM, mentioned in the report of the President, is currently revising these works in a combined effort led by the OIML and the BIPM. Another very successful joint effort concerns our relations with developing countries. In collaboration also with IMEKO, a major symposium on the role of metrology in economic and social development was organized in Braunschweig in June 1998. Seventy-nine countries and seventeen international or regional organizations attended. On this occasion Cameroon, a Member State of the Metre Convention that ceased many years ago to participate in our activities, resumed contact with the BIPM and reintegrated itself into the Metre Convention.

Returning to the subject of cooperation with the OIML, a number of points have been evoked but not yet followed up. I feel that the perspectives resulting from the extension of the domains covered by the CIPM as well as the implementation of the MRA open new areas where collaboration between the OIML and the CIPM would be fruitful. Through its TC10/SC5

group the OIML participates in the CCM Working Group on Hardness. The growing interest of the CIPM in the measurement of gas and liquid flow should be of considerable interest to the OIML, because of the importance in the legal field of trade in fluids (petrol, domestic gas, etc.). There will be other examples, even though the CIPM policy is not to take the initiative in fields already covered adequately by other bodies.

As regards the MRA, which will ensure the equivalence of standards and measurement certificates of the signatory institutes, the consequences for export and import controls are obvious, as are they also for the technical coherence of national rules.

In conclusion, in reply to Resolution 10 (1995) of the 20th General Conference, the CIPM informs Member States of the Metre Convention that it has launched actions with a view to improving collaborations with the OIML, that the prospects are good for the future, but that for the time being there is no reason to pursue further the possible merging of the two bodies."

Following the declaration of Prof. Kovalevsky, Mr Faber stated that he hoped the CIPM and the OIML would continue to investigate possible future joint actions. Dr Imai (Japan) added that the APMP welcomed the discussions between the OIML, the ILAC and the CIPM.

11 Reports of Presidents of Consultative Committees

11.1 The Consultative Committee for Length

Dr Chung Myung Sai, President of the Consultative Committee for Length (the Comité Consultatif des Longueurs, CCL), previously the CCDM (the Comité Consultatif pour la Définition du Mètre), presented his report on the work of the Committee, together with Draft Resolutions E, on the revised *mise en pratique* of the definition of the metre (see page 355), and F, on requirements for dimensional metrology (see page 356).

The CCL held its 9th meeting at the BIPM on 16, 17 and 18 September 1997.

Although the BIPM and the NMIs have held various comparisons to maintain traceability, world trade and accreditation agreements now demand a much larger scope of formal, documented evidence of equivalence of national measurement standards, and in particular, the equivalence of routine

calibration services. The CCL recognized such new demands to establish key comparisons that will provide the technical basis for the MRA. The key comparisons, which test a laboratory's ability in length measurements, should not just be a test of a primary standard, but should also test the work in general to support mutual recognition of calibration certificates. For the optimal selection and execution of the comparisons the following criteria have been established by the CCL Working Group on Dimensional Metrology (WGDM):

(1) A key comparison should challenge a key technique in that area, be important to the community of NMIs, provide an optimal link to regional comparisons, satisfy accreditation needs, and be repeated at selected intervals.

(2) Artefacts used in a key comparison should exhibit availability (and be replaceable if damaged), good performance in previous comparisons, industrial relevance, demonstrated stability, and be a challenge to measure.

(3) Participating laboratories should provide this measurement (now or in the future) as a calibration service, have measurement uncertainties below a certain level, not get their traceability elsewhere for components of the measurement which make a major contribution to the uncertainty of the measurement, and be willing to participate in the regional comparison.

Applying these criteria, the WGDM has identified six key comparisons in dimensional metrology, which are planned to start before or in 2000. The key comparisons, pilot laboratories and proposed start dates are the following:

- CCL-K1: gauge blocks, OFMET (Switzerland), March 1998;
- CCL-K2: long gauge blocks, NPL (United Kingdom), September 1999;
- CCL-K3: optical polygons, Council for Scientific and Industrial Research (CSIR, South Africa), July 1998;
- CCL-K4: cylindrical diameter standards, NIST (United States), September 1998;
- CCL-K5: CMM step gauge and ball bar, PTB (Germany) and NIST, March 1998;
- CCL-K6: CMM 2D ball plate, CENAM (Mexico), January 2000.

The WGDM met in San Diego in July 1998 and again at the BIPM in September 1999.

In addition to the key comparisons in dimensional metrology, the CCL endorsed the ongoing BIPM laser comparison at the wavelength of 633 nm using He-Ne iodine-stabilized lasers as a key comparison, provisionally designated BIPM.L-K1. Since the last General Conference, NMIs of some thirty Member States have participated in these comparisons.

The CCL discussed the basis for modifications to the 1992 *mise en pratique* (the practical realization) of the definition of the metre, including proposals for new recommended radiations. The following are some of the important comments in the discussion: new improved measurements of the iodine-stabilized frequency-doubled Nd:YAG 532 nm radiation will soon reduce its relative uncertainty below the current level of 7×10^{-11}, and the high signal-to-noise of this laser's control signal has made it popular with many laboratories involved in developing systems. Two laboratories reported preliminary measurements of the laser-cooled trapped strontium ion transition at $\lambda \approx 674$ nm, which demonstrated the potential of trapped ions for future high-accuracy references. The two-photon transition in rubidium ($\lambda \approx 778$ nm) is an attractive laser system because it is based on laser diodes and can be made portable. The 1S–2S two-photon transition in hydrogen provides the most accurate reference for short wavelengths ($\lambda \approx 243$ nm). The CO_2 laser system based on osmium tetroxide ($\lambda \approx 10$ μm) plays a pivotal role in frequency chains as it links the infrared and visible spectral regions.

A working party formed to compile the revised list of recommended radiations presented a draft to the CCL meeting. The list of radiations is divided into two parts. It was agreed that they all have equal status for the realization of the metre. The reason for the division is to separate older standards from new ones. The older standards are clearly declining in use, so it is inadvisable to build new equipment based on these standards.

The CCL supported the proposed changes to the *mise en pratique*: (1) to include the definition of the metre and the three methods for realizing the metre in the introduction; (2) to revise the existing calcium frequency; (3) to include five new radiations in the list of recommended radiations. One of the other changes is the publication of recommended values for spectral lamp radiations that are still currently in use. Following approval by the CIPM, the revised *mise en pratiq*ue was published in *Metrologia* (1999, **36**, 211-244).

Based on the favourable replies received in response to a questionnaire distributed by the BIPM, a new working group on the *mise en pratique* has been formed. This working group will be asked to consider the contents of the *mise en pratique* and propose future changes, make proposals for key comparisons, and look into the preparation of a database of stabilized-laser frequencies.

The CCL discussed the work at the BIPM. Regarding the issue of a replacement for the iodine-stabilized He-Ne laser at $\lambda \approx 633$ nm, a general discussion concluded that the 633 nm laser will remain useful while commercial laser interferometers and low-cost secondary standards are based on this wavelength. Rival laser systems are the frequency-doubled Nd:YAG at $\lambda \approx 532$ nm and the diode laser stabilized on the two-photon transition in rubidium at $\lambda \approx 778$ nm. Another possible area of work is in frequency synthesis through collaboration with the other laboratories in Paris. Dimensional metrology is too large a field for the BIPM to become involved

in. It was suggested that the BIPM should continue to concentrate on transportable standards for disseminating the metre, but an activity in nanometrology would be appropriate.

It was agreed that the next CCL meeting would take place in the year 2001.

Prof. Bordé thanked Dr Chung for his report and commented on how rapidly the field was evolving, mentioning also its close link with the work of the time and frequency community. He highlighted the recent advances made towards infrared and ultraviolet measurements, using CO_2 and H_2 lasers, respectively. However, he expressed concern that, although the H_2 standard was included in the revised *mise en pratique*, such measurements are very difficult and currently only one laboratory in the world can realize a standard at this frequency. He suggested that Prof. Klepner, Massachusetts Institute of Technology (MIT, United States), who has achieved Bose-Einstein condensation on H_2, could also be asked to realize a standard at this wavelength. He then mentioned recent measurements of the $^1S–^2S$ transition in hydrogen, made with the French Cs standard, and called for further investigations in this area.

Dr Chung thanked Prof. Bordé, following which Dr Quinn responded that the CCL Working Group for the *Mise en Pratique* had considered very carefully all transitions included in the guidelines for the practical realization of the definition of the metre. Only well-established wavelengths could be included. The inclusion of a number of wavelengths now at the frontier of progress, however, acts as encouragement for future work (on fundamental constants).

Draft Resolution E was approved unanimously as Resolution 5 (see page 329).

Prof. L.K. Issaev (Russian Federation) proposed the inclusion of "including nanometrology" in the last sentence of the recommendation of Draft Resolution F. Dr Chung agreed that there was much interest in nanometrology, but said that the definition of nanometrology was not yet ready. He was continuing discussions with Dr Quinn and Mr Chartier (BIPM) and a working group would soon be established.

The opinions of other delegates on whether or not to include "nanometrology" explicitly were divided, and the discussion continued when Draft Resolution F was put to the vote. Dr Sutton (New Zealand) felt that, since nanometrology was already mentioned explicitly in the third point of "considering", it was not necessary to include it explicitly under "recommends". Dr Valdés (Argentina) argued that, since many countries develop standards in response to the CGPM's resolutions, nanometrology should be mentioned explicitly. Dr Carneiro (Denmark) agreed that inclusion of nanometrology would underline the importance of support for

nanometrology. Dr Molinar (Italy) emphasized that nanometrology was a large technical area and development of instrumentation required much effort. Dr Schwitz (Switzerland) expressed concern that mention of one specific field might imply exclusion of others. Dr Brown (United States) suggested that, rather than changing the "recommends", the word "inclusively" could be added to the third point of "considering". This proposal was supported by Mr Charik (United Kingdom).

Dr Blevin rounded off the discussion by reminding delegates that it was for the NMIs to interpret the CGPM resolutions. He then called for a vote on the two suggested rewordings: the explicit mention of nanometrology under "recommends", and the addition of "inclusively" under "considering". The latter was carried and the former rejected. The modified form of Draft Resolution F was adopted as Resolution 6 (see page 330) with one abstention (Spain).

11.2 The Consultative Committee for Mass and Related Quantities

Dr K. Iizuka, President of the Consultative Committee for Mass and Related Quantities (the Comité Consultatif pour la Masse et les grandeurs apparentées, CCM), presented his report on the work of the Committee and Draft Resolution G on the definition of the kilogram (see page 357).

Since the 20th General Conference, the CCM has held two regular meetings separated by an interval of three years; the 6th meeting occurred in May 1996 and the 7th meeting in May 1999. Since its creation in 1981, the CCM has dealt with problems encountered in the improvement of the standards of mass, density, force and pressure. As the technologies concerned with these standards are very different from each other, the actual scientific activities of the CCM have been promoted by the working groups organized for respective quantities (mass, density, force, high pressures, medium pressures and low pressures). As a result, the role of the CCM is to review the work of the working groups and to investigate new problems which are not covered by the existing working groups. Responding to proposals made by member countries, the CCM has created two more working groups since 1995. The first is the Working Group on the Avogadro Constant, the formation of which was already reported in the last General Conference. The second is the *ad hoc* Working Group on Hardness, which started its activities in 1998. In the following, the activities of each working group since the last General Conference are summarized together with some supplementary remarks on the decisions made by the CCM itself.

Mass

Following the third periodic verification of national prototypes of the kilogram by the BIPM completed in 1992, the Working Group on Mass

Standards organized an international comparison of 1 kg secondary standards of stainless steel prepared by the BIPM as the pilot laboratory. The round-robin comparison of two stainless steel standards among fourteen national laboratories was finished and the report is now under preparation according to the *Guidelines for CIPM Key Comparisons*. At the same time, the group discussed the necessary comparisons to ensure the mutual agreement of mass standards over a wider range and chose as such six levels, at 100 mg, 2 g, 20 g, 500 g, 1 kg and 10 kg, for the key comparisons. As the comparison of 1 kg standards had already been started, the comparison of the other five levels of mass was organized by the PTB (Germany) as the pilot laboratory and is now in the final stages. At the 7th CCM meeting in 1999, it was decided to add a 50 kg standard as another key comparison. In addition to the above-mentioned key comparisons, the results of regional comparisons are now being compiled.

Apart from the key comparisons, the Working Group on Mass Standards is continuing various studies, including the effects of the cleaning method, the stability of Pt-Ir prototypes and stainless steel standards, the determination of the density of ambient air, and the evaluation of the magnetic properties of weights.

The informal Balance Club has been organized on the occasion of each CCM meeting to exchange information on current activities of metrology laboratories on the development of new balances. At the last meeting, the topics were the flexure-strip prototype balance developed by the BIPM, the watt balance under development at the OFMET (Switzerland), and a number of developments in other laboratories.

Density

The main task of the Working Group on Density has been the formulation of the new density table of pure water. After lengthy investigations on the absolute determination of the density and thermal expansion of pure water, the group has finalized the new table for the temperature range from 0 °C to 40 °C. Other topics were the regional comparison of density measurements of air, hydrostatic measurements of the volume of solid artefacts, and the determination of the absolute density of mercury. Regarding the key comparison for density standards, it was agreed to organize a round-robin comparison of silicon artefacts and the protocol is being prepared by a group of three laboratories.

Force

The Working Group on Force has undertaken numerous international comparisons in the past and has decided to enter the results of comparisons made since 1986 into the KCDB for the MRA. As for CIPM key

comparisons, the group decided to organize new comparisons in the force ranges up to 10 kN, 100 kN, 1 MN and 4 MN, according to the capacity of standard machines of the participating laboratories. These comparisons will be organized in two groups, each group calibrating two transducers using the specified procedure but with the first group calibrating at two levels and the second group at only one level. It is hoped that the number of participating laboratories will be less than ten. The whole comparison should be completed in 2003.

As well as the comparisons, the group will discuss the method of evaluation of uncertainties in the calibration and especially those of the standard realized by the build-up system.

Low pressures

Since this working group was formed by merging the working groups on low pressures and very low pressures in 1991, it has prepared comparisons in the ranges from 10^{-7} Pa to 10^{-3} Pa and from 1 Pa to 1 kPa, both of which were identified as key comparisons at the 6th meeting of the CCM in 1996. The former comparison was started in January 1999 by circulating three Bayard-Alpert ionization gauges and two spinning rotor gauges among six laboratories and is scheduled to be completed in September 2000. The latter comparison is organized in two groups, one for European laboratories and the other for Asian ones; two capacitance diaphragm gauges and two micromachined resonant silicon diaphragm gauges are being used in either absolute or differential mode. This comparison was scheduled to be completed by September 1999. In fact, the working group had previously made comparisons in the ranges from 10^{-7} Pa to 10^{-3} Pa and 10^{-4} Pa to 1 Pa and already published these results. However, the group recognizes only the latter in the KCDB.

Medium pressures

In this pressure range, a number of laboratories participated in comparisons in the range from 10 kPa to 140 kPa which took place between 1983 and 1995. The results have been confirmed by each laboratory for use in the KCDB. The group is also considering linking the results of regional comparisons made by the APMP and EUROMET with the above CIPM key comparisons. In the meantime, a new key comparison in the range from 10 kPa to 120 kPa in both absolute and gauge modes is in progress by circulating a gas-operated piston gauge. The measurements are expected to be completed by July 2000.

High pressures

This working group has also made a series of comparisons since its creation. Recent activity has been focused on the following two comparisons: (1) a comparison of calculated effective areas determined by diameter measurements of two piston-cylinder units and a gas- and gauge-mode pressure comparison with the same units in the range from 50 kPa to 1 Mpa; (2) a gas- and gauge-mode pressure comparison in the range from 80 kPa to 7 MPa. The final report of the first comparison is almost completed, whereas that of the second will be presented early in 2000. The working group also evaluated the past CIPM and regional comparisons and concluded that the comparison of liquid pressure up to 100 MPa, which was reported in *Metrologia* (1991, **28**, 419-424), could be entered in the KCDB and that the regional comparisons of liquid pressure from 0.5 GPa to 1 GPa could also be included if connected together. The group also confirmed that it should focus its activity on a new key comparison of liquid pressure at 100 MPa.

Combined activity of the working groups on pressure

The three working groups on pressure jointly organized the third conference on pressure in Turin in May 1999 (CCM Third International Conference: Pressure Metrology from Ultra-High Vacuum to Very High Pressures). They also held combined meetings on the occasion of the CCM meetings and discussed the plan of future key comparisons of pressure standards. As a result, a conclusion was reached to retain the previously selected six key comparisons for the moment and to add comparisons of gauge-mode gas pressure from 10 kPa to 120 kPa and of gauge-mode oil pressure between 10 MPa and 100 MPa, both having been accepted by the CCM.

Apart from the key comparisons, the CCM adopted the declaration to issue warnings on the use of overprecise conversion factors for pressure units, in view of the uncertainties of the densities of liquids being used for manometers and the value of the gravitational acceleration.

The Avogadro constant and the future redefinition of the kilogram

The determination of the Avogadro constant is needed to improve the accuracy of the table of fundamental constants. It is also expected to lead to the realization of a new definition of the kilogram instead of relying on the prototype kilogram in the future. The working group, created as an *ad hoc* group in 1994, now meets once every year as a standing working group under the CCM.

Since the last General Conference, the group has made great efforts to sort out the problems to be solved in order to reduce the relative uncertainty to the order of 10^{-8}. It has been confirmed that the relative uncertainties of

measurements of the density and lattice spacing of silicon single crystals are now coming down to the order of 10^{-8} and the major remaining problem could be the difference in the molar mass of different silicon crystals, although this is still not confirmed. The uncertainty due to this factor and other problems involved in the redetermination of the constant will be investigated at the working group meeting in September 1999.

Besides the determination of the Avogadro constant, there are a few other potential ways for monitoring the stability of the international prototype of the kilogram which are being investigated by a working group under the CCEM. As the progress made in the development of such methods is of great interest to the CCM, it has decided to propose Draft Resolution G (see page 357) to the General Conference in order to encourage the national laboratories to make efforts to refine their experiments linking the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram.

Hardness

The hardness of a material is defined in a practical way by referring to specified testing methods. In this sense, the value of the hardness is expressed as a conventional number, which is not necessarily based on a strictly physical law although it has a well-understood physical meaning. However, in the field of engineering, hardness is of great importance in quality control and the traceability of hardness standards has been established in each country. As there are strong requirements for the establishment of international traceability and since hardness standards are maintained in many national measurement laboratories, the CIPM has decided to undertake an international comparison of hardness standards with the collaboration of the specialized working groups of other international organizations, particularly the IMEKO/TC 5, ISO/TC 164/SC 3 and OIML/TC 10/SC 5. It therefore created an *ad hoc* Working Group on Hardness in 1998 with members including representatives from the above organizations.

In response to a questionnaire produced by the group, many NMIs expressed their interest in an international comparison of Rockwell, Vickers and Brinell hardness standards. It has therefore been decided to organize round-robin comparisons of these hardness standards. As some work has already been done on Rockwell cone hardness by the ISO/TC 164/SC 3, the working group will investigate the availability of the data for the KCDB. At the same time, it is preparing for the comparison of the evaluation of Rockwell cone indenters and the comparison of Vickers hardness standards.

Prof. Bordé thanked Dr Iizuka for his presentation and invited discussion on the best directions for future work, and the consequences for the BIPM in the

light of new possibilities. He initiated the discussion by considering determinations of the Avogadro constant, N_A, and asking if it was feasible to produce spherical Si crystals without defects. Dr Iizuka replied that the results of recent determinations of N_A by the Si sphere method differ by 3 parts in 10^6. The quality of the crystal sample used affects the measurement of both the molar mass and the molar density. The CCM Working Group on the Avogadro Constant initially suspected that the origin of the difference between the molar mass values determined by the IRMM and a Beijing institute lay in the crystal quality. However, both laboratories measured the same crystal, so the difference must instead be caused by their measurement methods. Crystal quality is also an important issue, however, and the working group has decided to repeat a series of measurements with a common set of crystals. Dr Iizuka hopes that the method will yield a more accurate value of the Avogadro constant.

Prof. Bordé then asked about methods of measuring atomic mass, mentioning the free-fall experiment at Stanford and the watt balance experiments at the NIST, the NPL and the OFMET. Dr Iizuka replied that recent progress in the development of moving-coil watt balances had led to a proposal by Taylor and Morr (NIST) to redefine the kilogram in terms of atomic mass, and that watt balances promise to provide a stable method of control. Dr Quinn agreed that the watt balance appeared to be more promising than the Si sphere method for a future redefinition of the kilogram, commenting that the BIPM might also be interested in beginning activity in this area. The watt balance method involves the simple equilibration of gravitational and electromagnetic forces, based on the Kibble method, and should, in principle, yield a relative uncertainty of the order of 10^{-9}. In contrast the Si method appears to have several difficulties that rapidly become intractable as uncertainties at the level of a few parts in 10^8 are approached: it requires measurement of molar mass (currently achievable only at the IRMM, although the Chinese institute can measure relative molar mass), molar density (complicated by the Si oxide layer), crystal defects and the lattice constant, as well as extremely accurate manufacture and dimensional metrology.

Prof. Göbel (Germany) said that he agreed that the watt balance method was the most promising, but added that he was not pessimistic about the Si method. He noted that the Si oxide layer could be prepared with a known thickness, and mentioned an alternative approach being developed for measuring molar mass, based on prompt neutron emission.

Dr Schwitz (Switzerland) reported on the watt balance being set up at the OFMET, saying that they hoped to obtain results with an uncertainty of 1 part in 10^8 in 2000 or 2001. Dr Blevin responded that the Swiss programme was extremely important. A definition of the kilogram based on the watt balance method could not rival the existing kilogram artefact if the method was too complicated or the equipment existed only at one or two

laboratories. Such a situation was too precarious, and the method could be lost completely by a change in management strategy in the institutes concerned.

When put to the vote, Draft Resolution G was approved unanimously as Resolution 7 (see page 331).

11.3 The Consultative Committee for Time and Frequency

Prof. S. Leschiutta, President of the Consultative Committee for Time and Frequency (the Comité Consultatif du Temps et des Fréquences, CCTF), previously the CCDS (the Comité Consultatif pour la Définition de la Seconde), presented his report and Draft Resolution H on operational primary frequency standards (see page 358).

This report reflects the major activities of the BIPM Time section as well as the CCTF and its member laboratories in the period 1995-1999. Since time and frequency devices or methods play some new or unexpected roles in today's society, this report also mentions these aspects.

The report covers the following points: the second and TAI, primary frequency standards, time-scale formation and the establishment of TAI, the future of UTC, comparisons between remote clocks, time scales used in technology, new uses of time references and some events pertaining to time and frequency metrology.

The second and International Atomic Time

The primary frequency standards operating in the NMIs and in other timing institutions strive to create a time interval as close as possible to the SI second, but this "second" must be disseminated and information about the "date" has to be provided. These last two features are achieved by constructing a time scale that is materialized by clocks and driven by frequency standards. The task of the NMIs is to obtain via physical experiments the "best" realization of the SI second and to construct a local time scale.

The task of the BIPM is to create a reference time scale, called TAI, based on the readings of the clocks of the NMIs. The goal of the BIPM, via its Time section, is to construct TAI in order to obtain both the accuracy of the time interval and the best possible long-term stability, at the same time making TAI widely available.

The recognized success in reaching these goals is largely due to Dr Claudine Thomas who led the BIPM Time section for eight years. Since the 13th CCDS meeting, Dr Thomas has been in charge of the KCDB, the

central component of the new system of mutual recognition arrangements between the NMIs.

Dr Elisa Felicitas Arias, currently Director of the Naval Observatory in Buenos Aires and Professor of Astronomy at the University of La Plata, will take over the position of Head of the Time section in November 1999. Dr Gérard Petit, of the BIPM staff, is acting as interim Head of the Time section.

Primary frequency standards

A matter of concern, expressed and reiterated in the past by the CCDS/CCTF and the CIPM, has been the small number of primary frequency standards of laboratory type operating and evaluated in the NMIs. For about ten years, until 1995, the accuracy of TAI was based on two primary clocks developed at the PTB (Germany). The situation was improved at the time of the previous General Conference when an optically pumped primary standard went into operation at the NIST (United States) with an accuracy of 1 part in 10^{14}, similar to the two standards operating at the PTB. Other "classical" caesium standards, i.e. with a thermal beam of atoms, were in various stages of development but with an accuracy of about 1 part in 10^{13}.

Moreover, the CCDS had always recommended tests of alternative configurations in order to overcome the limitations of the classical design and to detect systematic effects. A breakthrough occurred at the ENS and at the BNM-LPTF (France), both in Paris: an old idea – to observe the atoms in free fall – was rejuvenated using a "fountain" of cold Cs atoms. A relative uncertainty of 1.4×10^{-15} was reported at the last CCTF meeting, with a large potential for improvement.

By 1999, the situation has definitely improved, at least in terms of the amount of research performed in the NMIs on different caesium devices, as can be seen by inspection of the following table listing the number of activities now in progress in fourteen laboratories.

Primary Cs frequency standards					
Thermal beam, magnetic preparation and detection	Thermal beam, optical pumping	Fountain of cold atoms	Beam of slow atoms	High field	Maser
4	3	15	3	1	1

Several laboratories are studying frequency standards based on other atom transitions (calcium, magnesium, mercury, ytterbium) and dual caesium-rubidium cold atom fountains are now being tested.

It is planned to evaluate some of the caesium fountains in the next few years. It is worthwhile recalling that a primary frequency standard is indeed a very complex device, that the expertise needed is not commonly available, and that a learning period must be planned. Experience dictates that the construction of a primary and state-of-the-art standard requires the activity of skilled and dedicated researchers and that the completion period is near to ten years.

While the progress in developing primary standards is very satisfactory, one should not forget that the ultimate objective is to use them to maintain and improve the accuracy of TAI. This implies that the primary frequency standards must be maintained over many years as operational facilities. This means that considerable resources should be devoted by the NMIs to this task. The objective of Draft Resolution H (see page 358) presented at this Conference is to request that such efforts be implemented.

Nevertheless, the availability of devices with an accuracy better than 10^{-14} and possibly 10^{-16}, has raised at least four other problems: black-body effects, general relativity, the expression of the uncertainties in primary frequency standards and**,** in the more distant future, a possible new definition of the SI second.

Concerning the black-body effects, in response to Recommendation S 2 (1996) of the 13th CCDS meeting, two laboratories, the PTB and BNM-LPTF, have devoted experiments to this study. At the PTB a shift in relative frequency of -17.9×10^{-15} with a standard uncertainty of 1.6×10^{-15} was measured for black-body radiation at 300 K, in close agreement with the theoretical prediction of -16.9×10^{-15}. Similar results were obtained at the BNM-LPTF.

Concerning general relativity, a Joint Committee on General Relativity for Space-Time Reference Systems and Metrology, promoted by the BIPM and the IAU, was created in 1997 to study problems related to the application of general relativity to space-time reference systems and metrology at large. A report of the studies hitherto performed and in progress was presented by its Chairman, Dr G. Petit of the BIPM, during the CCTF 14th meeting in 1999; a summary of this report is included in the associated proceedings. The CCTF asked Dr Petit to remain abreast of the activities of the IAU, the International Union of Geodesy and Geophysics (IUGG) and other related bodies on these matters and to keep the CCTF informed.

A discussion on the expression of uncertainties in primary frequency standards will be covered in the next section.

With regard to a possible new definition of the SI second, participants at the the 14th CCTF meeting agreed in recognizing the vitality of the present simple definition that has allowed forty years of progress from a relative accuracy of 10^{-9} with the Essen device in 1955 to the 10^{-16} that now seems

within reach, at least under conditions in space (there are plans to put a cold caesium beam standard on the International Space Station).

The CCTF also decided to propose Recommendation S 1 (1999), on the *mise en pratique* of the definition of the second, to the CIPM to enhance further the clarity of the definition for those designing and operating primary realizations of the second. This Recommendation states that the measurements should be corrected for the velocity of atoms with respect to the clock reference frame, for magnetic and electric fields including ambient background black-body radiation, for spin-exchange effects and for other possible perturbations.

Expression of the uncertainties in primary frequency standards

During the 1996 meeting of the CCDS, discussion was engaged on how the GUM should be applied to measurements involving frequency standards. A working group led by Dr R. Douglas carefully considered the question and decided to concentrate its activity on the problem of expressing the uncertainty in comparisons using primary frequency standards which are the top end of a traceable chain for frequency. During the 1999 CCTF meeting further discussions led to Recommendations S 2 (1999) on stating uncertainty in comparisons involving primary frequency standards and S 3 (1999) on the comparison of primary frequency standards.

The spirit of these two Recommendations is that the GUM should be followed, but only where appropriate, and that sufficient detail of how the total uncertainty was arrived at should be published in order that it can be fully understood by all users and also, if necessary, revised *post factum* by an end user on the basis of new information and understanding.

Time-scale formation, establishment of TAI

As pointed out previously, the construction of TAI is the principal task of the BIPM Time section. A number of refinements have been introduced over the past few years, such as a shorter interval of calculation (one-month instead of two-month blocks of data), more frequent access to TAI (every five days instead of ten days), and a change in the weighting method in order to allow better discrimination between the performances of the best participating clocks.

As a consequence of these measures, the average relative frequency stability of TAI was reduced from a value of 2.6×10^{-15} over 1995 (averaging time of forty days) to 6×10^{-16} over 1998-1999 (averaging time twenty to forty days). At the beginning of 1999 the estimated relative accuracy of TAI was $(-0.4 \pm 0.4) \times 10^{-14}$.

The choice and implementation of an algorithm for the construction of a time scale is a more complicated process than one might imagine and is strongly dependent on the desired feature of the time scale, the characteristics of the clocks forming the local time scales, and the time-transfer methods. The last mentioned problems are addressed by the CCTF Working Group on TAI led by Prof. Pâquet.

As several laboratories have developed their own algorithms for computing national time scales, and thus the expertise is available, the CCTF considered it appropriate to establish within the Working Group on TAI a sub-group devoted to time-scale formation. The terms of reference were adopted and the BIPM will participate in these activities.

Coordinated Universal Time UTC

About thirty years ago, the present form of UTC was proposed and introduced by the International Telecommunication Union (ITU), via its Commission 7 (Standard Frequency and Time Signal Services) of the International Radio Consultative Committee (CCIR).

The main characteristic of UTC is its lack of uniformity due to the presence of leap seconds, introduced whenever necessary, usually one every one to two years, in order to take into account the slowing of the Earth's rotation. By this means, a compromise was reached between two classes of users: the first comprises physicists, engineers and some astronomers, who need a uniform time scale and consequently base their activity on TAI; for the second class of users (including some astronomers, and some navigation and geodesy users) the time signals should also preserve information about the angular position of the Earth.

The compromise reached is the following: a leap second is introduced so that the difference between UTC and UT1 (a rotational astronomical scale that represents closely the angular position of the Earth) will not exceed 0.9 s. In the period 1972-1999, 22 leap seconds were introduced.

The formal adoption of UTC at that time was made after consultation with the Bureau International de l'Heure (BIH)*, the IAU, the IUGG, the International Union of Radio Science (URSI), the International Association of Lighthouse Authorities (IALA), the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and other bodies concerned.

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* The responsibilities of the former BIH were transferred in part to the Time section of BIPM for international time-scale formation and in part to the International Earth Rotation Service (IERS) for the topics pertaining to the rotation of the Earth; for instance, the IERS is responsible for the amount and date of the leap second introduction.

The situation has been altered profoundly with the introduction of satellite navigation systems based on atomic clocks, so that nowadays the continuation of UTC and especially of the leap second is in question. This problem was discussed during the April 1999 meeting of the CCTF and a number of options were identified; the BIPM Director was asked to raise the problem in a letter to all the parties concerned, at the same time recommending the use of TAI where a time scale without discontinuity is needed.

Comparison and dissemination of time scales

The dissemination of local time scales is performed directly by the NMIs by various methods and with different levels of performance. Comparisons with the utmost accuracy and precision are performed at the BIPM and NMIs to study frequency standards and to use time-transfer measurements for the construction of TAI.

No suitable method is currently available for comparing primary frequency standards kept in remote laboratories that takes into account their individual performances. Indeed, such comparisons would only be based on the data from commercial clocks with which these are compared locally.

Time comparisons play a fundamental role in the activities of the BIPM and it is essential that the staff of the Time section maintain a sound knowledge and practical experience of known and newly proposed methods and techniques used to compare clocks, because this is the only way to detect the systematic errors that implicitly affect each method or technique.

In the four-year period covered by this report, three items were considered: the consolidation of the well-known use of time codes based on atomic clocks on board navigation satellites, the recognition of the timing capabilities of a two-way microwave method using communication satellites and the introduction of an approach using the carriers emitted by navigation satellites.

Time codes emitted by GPS and GLONASS satellites

Time comparisons using the time codes emitted by the GPS are still the backbone behind the formation of TAI, with some fifty time services observing satellites in accordance with programmes regularly established by the BIPM for the different geographical areas. The comparisons use the so-called “common-view” technique, in which the same satellite is observed at the same time by several laboratories. In this manner several sources of error are eliminated or partly compensated, including the intentional degradation in accuracy introduced for reasons of military security.

The regular and widespread practice of these comparisons has allowed the identification of some additional causes of error, such as thermal effects on cables and antennae, or unexpected vagaries of the delay introduced by each receiver. The BIPM itself has performed studies on the thermal effects and is circulating a receiver to monitor the variations in delay in the receivers used by the various NMIs.

While the use of GLONASS satellites presents some potential advantages, in that no intentional degradation in performance is included, there are also some problems to be solved, one of which is the paucity of receivers able to track GLONASS or both GPS and GLONASS.

The CCDS established a sub-group on GPS-GLONASS time-transfer standards and the findings and recommendations of this working party can be found in the report of the 14th meeting of the CCTF (1999).

In summary, under the best experimental conditions, even with calibrations of the time delays within the receivers, operational time comparisons yield a level of uncertainty somewhere between 1 ns and 3 ns and this can be 2-3 times poorer when no calibrations are performed.

At any rate, the problems encountered with some equipment still in use in the laboratories could be alleviated by the introduction of new multichannel and multi-code (GPS-GLONASS) receivers. Based on these findings, the CCTF at its last meeting decided to submit to the CIPM Recommendation S 4 (1999) in which it is proposed that necessary studies be undertaken to allow the use of multi-channel and multi-code GPS and GLONASS time receivers, with steps also for the formation of TAI.

Time transfer using a two-way method via communication satellites

Two-way satellite time and frequency transfer (TWSTFT) via communication satellites presents some interesting features. Adopting the two-way approach, some components in the total uncertainty budget are eliminated or reduced; for instance, with some assumptions, the position of the satellite is not needed. The equipment is not unduly expensive and can be collocated with the clocks to be compared. Finally, the method offers a remarkable potential in precision (not accuracy) since, under operational conditions, the comparison errors are about 1/100 of the period of the code. In well-controlled links, such as that between the Technical University Graz (TUG, Austria) and the NMi Van Swinden Laboratorium (NMi-VSL, the Netherlands), a standard deviation of 200 ps was observed over averaging times of 1 hour and a peak-to-peak variation of approximately 1 ns detected over two years.

In 1993, the CCDS established a working group on TWSTFT that met four times during the period 1996-1999, addressing a number of topics and organizing research and experiments. The findings and recommendations of

this working party can be found in the report of the 14th meeting of the CCTF (1999).

To summarize, TWSTFT is a mature technique; it has demonstrated full operational capability for three years, finds widespread use in about twenty timing laboratories, and can provide a time transfer comparable with GPS with the additional advantage of being fully independent of the common-view technique which is currently the sole means of time transfer contributing to the formation of TAI.

For these reasons the CCTF at its last meeting decided to submit to the CIPM Recommendation S 7 (1999) which proposes that necessary studies be undertaken to allow the incorporation of TWSTFT data into the construction of TAI.

Techniques using the carriers emitted by navigation satellites for time transfer

The new idea is to compare the satellite and station clocks using the phase of the carriers instead of the codes. The comparison precision is astonishing, since it is in the region of 10 ps; the problem is to transform the precision of the phase measurements to a corresponding accuracy in the time comparisons. However, it should allow the realization of frequency comparisons with unprecedented accuracy.

Under the initiative of the International GPS Service (IGS) a joint IGS/BIPM Pilot Project was established in 1997; following a period of intense activity, its conclusions were presented at the 14th meeting of the CCTF in April 1999. About twenty-five research groups are presently involved in the Pilot Project, more than half being timing laboratories. From the treatment of the data a great deal of useful information is derived such as precise satellite orbits, satellite clock data, receiver clock data, receiver coordinates and ionospheric corrections.

The potential of this technique is relevant and should be fully investigated for time and frequency applications; consequently the CCTF at its last meeting decided to submit to the CIPM Recommendation S 5 (1999) in which the action of the joint IGS/BIPM Pilot Project is supported and a number of actions recommended.

Other time scales used in technology

Currently some satellite systems are in development with the objective of enlarging the use of existing systems such as GPS or GLONASS (for instance in the civil aviation services) and designing different navigation systems. Common features for all these developments are the use of atomic clocks (some hundreds are planned) and the construction of dedicated time

scales. Similar developments on a smaller scale are under way in the field of telecommunications.

A diffusion of time-ordered systems is in principle welcome because any global navigation satellite system is potentially a source of time information, but it must be designed carefully because a non-controlled or non-organized proliferation could lead to ambiguities.

The former CCDS with its Recommendation S 4 (1996) listed some guidelines that are followed by both the GPS and GLONASS systems. The CCTF at its last meeting decided to reiterate this concern, in accordance with the CIPM Recommendation S 6 (1999) in which some guidelines are proposed, and asked the Director of the BIPM to approach the bodies that are promoting the above-mentioned developments.

New uses of time references

The diffusion of new national and international communication networks in which personal computers have access to other computers or services has raised a number of problems that to some extent are in the realm of legal metrology, but are also of relevance for the NMIs and indirectly for the BIPM.

This type of problem stems from the increasing use of so-called "electronic commerce" or investments on the stock-exchange markets via personal home computers. The problem to be solved is called "time-tagging" or "time-stamping", i.e. to insert the "date" of the transaction; usually an uncertainty of one second is considered to be sufficient. Consequently the problem is not a scientific or technical one, but legal and commercial. In some countries, commercial organizations provide this kind of service with a sort of "selective availability" plus cryptographic protection; they require traceability from the national timing laboratory or use the navigation satellite system GPS directly as a reference.

Some events pertaining to time and frequency metrology

The implementation of the MRA being signed at this General Conference will involve the selection and the organization of a large number of key comparisons. The results of a key comparison will have to be approved by the appropriate Consultative Committee before they can be included in the KCDB. This topic was discussed during the last CCTF meeting in April 1999.

In 1996, the CCDS deemed that the actual construction and dissemination of the existing TAI/UTC meet the general needs for time comparisons and are globally in accordance with most of the *Guidelines for Key Comparisons*. Therefore, no key comparison was proposed. However, this decision

overlooked the problem of frequency comparisons and it was decided at the last CCTF meeting that some key comparisons should be selected in the domain of frequencies. Nevertheless, some problems remain open, such as the choice of key comparisons. Moreover, no generally agreed protocol is available for expressing uncertainties in a calibration certificate in the time and frequency area. To study these kinds of problems the CCTF decided to form an *ad hoc* group, led by Dr G. de Jong, charged to study the consequences for the CCTF of the MRA key comparisons system and to recommend appropriate actions.

Prof. Leschiutta then read Recommendation 1 (CI-1999) on future global navigation satellite systems:

The Comité International des Poids et Mesures,

considering that

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

recommends that

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

Prof. Kovalevsky stipulated that this recommendation was distributed for information only; it had been adopted by the CIPM at their 88th meeting the previous week and a vote for its adoption could not be taken at this General Conference. All Draft Resolutions proposed for vote must be distributed six months before the General Conference.

Prof. Bordé thanked Prof. Leschiutta for his presentation and invited questions. Dr Schwitz (Switzerland) asked how many new-generation clocks are in operation and how many contribute to TAI. Prof. Leschiutta replied

that twenty-seven new-generation clocks are under construction but that none of them are yet operational. He hoped that between two and four would be functional as frequency standards, not clocks, before the end of 1999. He anticipates an initial relative uncertainty of the order of 10^{-14}, which with continued effort should possibly reach 10^{-15}, and perhaps even 10^{-16}. Such continued research was very important.

Prof. Bordé noted that the BNM-LPTF (France) had developed a transportable clock with a relative uncertainty of 10^{-15}. This offers for the first time the possibility of transporting such a highly accurate clock for direct comparison with another, and he suggested that this experiment should be considered the prototype for a key comparison of frequency standards at the level of a part in 10^{15} or better. He then turned attention to PHARAO (a space frequency standard using cold atoms) as a means of comparing clocks around the planet, suggesting that their use could reduce the relative uncertainty of TAI from 10^{-15} to 10^{-16}. He remarked that it was also essential to have good local oscillators. The development of cryogenic clocks of the highest possible spectral purity was very important.

Prof. Leschiutta agreed that the development of clocks of the highest possible spectral purity was important, since their high short-term stability would permit investigations of the stability of the fundamental constants. He said that a great deal of effort was being made in the development of different clocks.

Draft Resolution H was approved unanimously and adopted as Resolution 8 (see page 332).

11.4 The Consultative Committee for Electricity and Magnetism

Prof. E.O. Göbel, President of the Consultative Committee for Electricity and Magnetism (the Comité Consultatif d'Électricité et Magnétisme, CCEM), formerly the CCE (the Comité Consultatif d'Électricité), presented his report.

Since the last General Conference the CCEM met once, in June 1997. It discussed matters related to the fundamental constants and the SI, including the work on electrical methods to monitor the stability of the international prototype of the kilogram and the status of the least-squares adjustment of the fundamental constants. Of particular interest to the CCEM is the work involving improvements in the knowledge of K_J and R_K, the Josephson and von Klitzing constants. The metrological use of single-electron tunneling devices (SET) was another topic of discussion. The prospect of carrying out accurate measurements of the quantized Hall resistance at frequencies in the kHz range is of great current interest as evidenced by the creation of the CCEM Working Group on ac Measurements of the QHR. The important problem of the present and future sources of arrays of Josephson junctions

and quantum Hall samples was discussed. The importance of key comparisons in electricity and magnetism was already evidenced in 1995 when the CCE Working Group on Key Comparisons was formed. Key comparisons were, of course, a main subject of discussion at the meeting and the CCEM drew up a list of key comparisons in electricity. In the domain of high-frequency electrical quantities, the GT-RF carries out a vigorous campaign of key comparisons and a report on their work was presented to the CCEM. Finally, the CCEM reviewed the activities of the Electricity section of the BIPM.

The report of the CCEM Working Group on Electrical Monitoring of the Stability of the Kilogram by Electrical Means summarized the status of the different measurements and the relative uncertainties. To judge the progress toward this goal, it should be borne in mind that, to monitor the stability of the kilogram, the relative uncertainty in the independent determination of its mass should be about 1 part in 10^8 or less.

The relative uncertainty of the mass levitation experiment is presently about 2 parts in 10^6 and it is hoped that future improvements can reduce this to the level of 1 part in 10^7. The experiment to measure the Avogadro constant using a silicon artefact was recently reviewed by the CCM Working Group on the Avogadro Constant. The experimental values of the Avogadro constant determined from different silicon single crystals agree within a relative uncertainty better than 10^{-7}. For the absolute determination with the same or improved uncertainty more accurate absolute values of the lattice spacing, volume of the crystal, and in particular molar mass are still needed. The PTB (Germany) is conducting an experiment using a mass spectrometer to accumulate an accurately measurable mass of gold deposited by a current of the order of 0.1 mA. The current will have to be increased by at least a factor of ten to achieve a relative uncertainty below 1 part in 10^6. Concerning watt balance experiments, the NIST (United States) moving coil watt measurement has achieved a relative uncertainty of 9×10^{-8} and the results are consistent with those obtained in 1988 by the NPL (United Kingdom). Several new experiments include the OFMET (Switzerland) watt balance which uses a considerably different approach: the moving and weighing parts of the experiment are separated from each other and the permanent magnet is suspended from the balance, which is a modified commercial instrument.

At that time the Committee on Data for Science and Technology (CODATA) least-squares adjustment of the values of the fundamental constants was nearing completion. Combining values of K_J from determinations of various constants available in 1988 with some more recent ones, and taking into account the recent recalculation of the fine structure constant together with new determinations of the Avogadro constant and the gyromagnetic ratio of the proton, a value of K_J was obtained that is in excellent agreement with the adopted value of $K_{J\text{-}90}$ and the uncertainty assigned to the difference between $K_{J\text{-}90}$ and K_J.

Concerning R_K, new data include the revised value of the fine structure constant; new determinations of R_K via calculable capacitors and a new determination of the low-field gyromagnetic ratio of the proton were combined with other fundamental constants to estimate its value. The adopted value of $R_{K\text{-}90}$ was still in excellent agreement with the experimental data. Today, the new CODATA adjustment is finished. It shows that $R_{K\text{-}90}$ is within a few parts in 10^8 of the 1999 estimate of R_K. This result will probably lead the CCEM to consider reducing the uncertainty assigned to the difference between $R_{K\text{-}90}$ and R_K. The uncertainty of $K_{J\text{-}90}$ with respect to K_J should also be examined, although at the present time the case for reducing this uncertainty may be less apparent.

Studies of the reproducibility of the QHR as a function of device material, the QHR plateau number and the sample geometry show it to be independent of these parameters within a relative uncertainty of 4×10^{-10}. Concerning possibly anomalous QHR values observed on some Si-MOSFET devices, the CCEM concluded that these probably arise from imperfections in the quantization of the Hall resistance that can be detected by applying the CCEM guidelines for QHR measurements. The CCEM concluded that the guidelines are still applicable at the highest levels of accuracy.

Recent progress on the metrological use of SET has been made using an SET pump scheme to measure accurately the charge on cryogenic capacitors. Another promising experiment is the achievement of a one-thousandfold increase in current by transporting single electrons across a device by surface acoustic waves operating at 2 GHz.

A major activity in electrical metrology today is to link accurately the QHR to capacitance. Two approaches have been used. The first involves dc measurements of the QHR and linking resistance to capacitance via a chain that includes a resistor having sufficiently well-known reactive impedance component so that the difference between its resistance measured at dc and that measured at ac is accurately known. The second approach is to measure the QHR directly at a frequency in the kilohertz range. Today, several laboratories have achieved relative uncertainties of a few parts in 10^8 in capacitance values linked to the QHR via the first approach. The second approach has encountered a problem. When measured at kilohertz frequencies, the QHR appears to differ from the dc value by one part in 10^7 or more. Furthermore, the Hall resistance plateaus appear to narrow and develop undesirable structure as the frequency increases. Given these problems, the newly created CCEM Working Group on ac Measurements of the QHR aims to foster cooperation among researchers in order to resolve these problems and to develop eventually a set of guidelines for the accurate measurement of the QHR at ac.

The CCEM is aware of the dangers of a shortage in the supply of metrological-quality QHR samples and of arrays of Josephson junctions. Several NMIs are successfully making small quantities of QHR samples. On

a larger scale, in 1995 the Laboratoire Central des Industries Électriques (BNM-LCIE, France) organized a EUROMET project to arrange for the fabrication of suitable QHR samples by the French industrial laboratory that had produced 350 samples in a BIPM/EUROMET project in 1990. In July 1998, 440 GaAs/AlGaAs heterostructures were delivered. Nineteen metrology laboratories have now received samples and test results indicate that the yield of good samples is above 60 %.

As for arrays of Josephson junctions, several NMIs are producing them with success in small quantities. Others have successfully transferred or are presently transferring the fabrication technology to industrial firms. (Remark: as far as I know, so far only the NIST has successfully transferred to the firm Hypres. At the PTB we are in the process of implementing the technology transfer but I would not state that it has been successfully completed yet. I recall that Dr Endo from the Electrotechnical Laboratory (ETL, Japan) mentioned the transfer of technology for making 1 V arrays to a small Japanese industrial firm. They had supplied one of these to the BIPM but as far as I know no other laboratories used them. The firm did not produce 10 V arrays.)

Since its creation in 1927 as the first Consultative Committee of the CIPM, the CCE/CCEM has maintained a keen interest in international comparisons and so when the concept of key comparisons was introduced it moved quickly to establish a list. At the meeting in 1997, the CCE agreed to reconfirm the key comparison list as a basis for establishing the equivalence of national electrical standards and measurements. It also agreed that the key comparisons and their periodicity might not be sufficient to fulfil the requirement of traceability and that from time to time supplementary comparisons might be necessary.

Finally, in 1995 the CCE agreed to begin two new dc and low-frequency comparisons.

The CCEM Working Group on Key Comparisons met at the 1998 Conference on Precision Electromagnetic Measurements (CPEM'98) to refine the list of key comparisons and to work towards establishing a list of interim key comparison results based on international comparisons carried out by the CCEM or by the BIPM before the key comparison scheme was put into place. It met again on 6-7 July 1999 to establish the list of comparisons to recommend to the CCEM for consideration as interim key comparisons and for inclusion in the KCDB. It recommended as interim key comparisons three dc and low-frequency comparisons, as well as six comparisons of the GT-RF. It also recommended seven BIPM key comparisons that are carried out on a continuous basis for inclusion in the KCDB.

From the perspective of the MRA and the *Guidelines for Key Comparisons*, the Working Group discussed in detail Draft B of the recently completed

10 pF capacitance comparison and decided to request some modifications to the report. This was followed by a discussion of possible new comparisons in resistance and capacitance at values different from those under way or completed. It approved a proposal to organize a CCEM meeting of experts in magnetic metrology to discuss the organization of comparisons in this area. The meeting concluded with a discussion of the organization of the CCEM and its working groups.

The GT-RF met in June 1997 to discuss the list of key comparisons in its area. It considered the recommendations of its sub-group on key comparisons that met in Braunschweig (Germany) at the CPEM'96. At that time, four comparisons had been completed since the last General Conference, three were nearly finished, seven were in progress, three new comparisons were approved and possible topics for future comparisons were discussed.

The GT-RF met again on 7 July 1998 in Washington DC (United States) at the CPEM'98. Two more comparisons were completed. The progress of the ongoing comparisons was discussed as well as topics for future comparisons. One new comparison was approved at that meeting.

The GT-RF last met on 30 June 1999. It recommended to the CCEM six previously completed comparisons as interim key comparisons. After reviewing two completed comparisons and the progress of the twelve comparisons not yet completed, it decided to carry out two new comparisons. Finally the GT-RF identified five topics for consideration as possible future key comparisons.

Key comparisons are clearly an important activity of the CCEM; some forty key comparisons are either finished or under way. The BIPM key comparisons in electricity are carried out on a continuous basis and represent a considerable amount of work; since the last General Conference seven on-site comparisons of Josephson standards, three on-site comparisons of QHR standards and twenty bilateral comparisons of resistance and voltage standards via conventional travelling standards have been completed.

Prof. Bordé thanked Prof. Göbel for his presentation and invited questions from the floor. Dr Carneiro (Denmark) drew attention to the fact that, although the quantum Hall effect can be measured with a relative uncertainty of about 10^{-9} in NMIs, the uncertainty passed on to the end user is very much greater. He asked if the CCEM had considered what might be done to improve the efficiency of the dissemination of electrical units. Prof. Göbel replied that the larger uncertainty transferred to the end user did not yet pose a problem. The CCEM's priority has been to reduce the uncertainty of the measurements at the highest level, and the next step will be to improve the transfer standards and thus dissemination to the end user.

Dr Witt (BIPM) commented that significant progress has already been made at the BIPM in the accuracy of voltage transfer standards. By correcting for the pressure coefficient, temperature coefficient and $1/f$ noise curve of a BIPM travelling Zener standard, the results obtained have been improved by one order of magnitude.

Prof. Bordé asked whether it was possible to verify Ohm's law on a quantum-mechanical basis. Prof. Göbel responded that this was a key question. The Josephson constant and the von Klitzing constant are macroscopic quantum effects, but to verify Ohm's law it is also necessary to develop a quantum-based current constant. He hopes that this will be achieved by means of SET devices, and lent his support to continuing studies.

11.5 The Consultative Committee for Thermometry

Dr K.B. Gebbie, President of the Consultative Committee for Thermometry (the Comité Consultatif de Thermométrie, CCT), presented her report and Draft Resolution I on the extension of the International Temperature Scale below 0.65 K (see page 360).

The CCT has met once since the last General Conference. In addition to the reports of the working groups, discussions concerning the ITS-90 focused on non-uniqueness, on the reproducibility of the fixed points, on questions relating to the interpolating instruments, on new information on $(T - T_{90})$, and on the uncertainty of the realization of ITS-90. A further discussion on temperature scales below 1 K and the possible extension of the ITS-90 below 0.65 K resulted in a recommendation of the CCT to the CIPM concerning the increasing importance of these measurements. A second recommendation focused on the importance of temperature measurements above 2500 K.

A second meeting of the CCT, scheduled for June 1999, was postponed until the spring of 2000. After discussion with the Chairmen of the CCT working groups, Terry Quinn and the President of the CCT decided that it would be better to hold the meeting when the results of the key comparisons were ready for discussion and approval by the CCT.

Defining fixed points and interpolating instruments

The effort here focuses on improving techniques for realizing the fixed points of the ITS-90 and for interpolating instruments, on studying non-uniqueness and on updating *Supplementary Information for the International Temperature Scale of 1990.*

Two papers on the ITS-90 have appeared in *Metrologia*. The first paper discusses the purpose of an international temperature scale and presents some concepts that are basic to the ITS-90, including those of non-

uniqueness and temperature fixed points underlying the scale. The second paper recommends techniques for comparisons, at the highest levels of accuracy, of fixed-point cells that are used for contact thermometry. An additional paper discusses the influence of impurities on fixed-point temperatures.

Investigations continue on the stability of high-temperature standard platinum resistance thermometers, on non-uniqueness, on the fixed points and their realizations, and interpolation methods for the ITS-90.

A revised version of *Supplementary Information for the International Temperature Scale of 1990* is in preparation.

Secondary fixed points and techniques of approximation to the ITS-90

Two main tasks related to this activity have been completed: publication of a new list of secondary fixed points and a revision of thermocouple and industrial platinum thermometer reference tables. The chief remaining task is the revision of the monograph *Techniques for Approximating the International Temperature of 1990*.

International equivalence of temperature measurements

The tasks here focus on collecting information on regional and bilateral comparisons, organizing suitable comparisons between regional groups at the highest level of accuracy, and establishing procedures for estimation of uncertainties.

A meeting of some members of Working Group 3 and members of the laboratories piloting temperature key comparisons was held in Bratislava at the SMU (Slovakia) in April 1999, and a subsequent meeting was held in June 1999 at the Nederlands Meetinstituut (NMi, the Netherlands).

Most of the key comparisons are still in progress. None of the results are ready yet for approval by the CCT. Discussions revealed that there is not yet a clear consensus on (1) what calibration services should be included in Appendix C of the MRA, (2) how these services are to be determined to be "consistent" with results in Appendix B, and (3) what additional comparisons, if any, are necessary to support Appendix C declarations on industrial thermometers such as thermocouples.

A meeting of Working Group 3 together with representatives of pilot laboratories of the CCT key comparisons will take place at the NIST (United States) on 17 and 18 January 2000.

Thermodynamic temperature determinations and extension of the ITS-90 to lower temperatures

Activities here are in three areas:

1) Study of determinations of thermodynamic temperature T and differences $(T - T_{90})$

Few new determinations have been published since 1996, but a notable paper on acoustic thermometry in the range 217 K to 303 K by Moldover and colleagues at the NIST (*J. Res. Natl. Inst. Stand. Technol.*, 1999, **104**, 11-46) shows departures of up to 4.6 mK from the ITS-90, with significant implications for the accuracy of the scale at higher and lower temperatures.

Several experiments are planned in a number of laboratories including, for example, a continuation of the NIST work up to 800 K, noise thermometry at the Measurement Standards Laboratory (MSL, New Zealand) up to 693 K and at the PTB (Germany) up to 1830 K, spectral or total radiation thermometry at the NPL (United Kingdom), PTB and elsewhere, and gas thermometry in various ranges below 300 K, by constant volume, dielectric constant and Rayleigh scattering means, at the NMi, PTB and NPL, respectively.

Such experiments are long-term, and a clearer picture of the accuracy of the ITS-90 will be slow to emerge. Meanwhile a theoretical analysis of the resistivity of platinum is being refined at the MSL to test the consistency of the experimental results obtained.

2) Study of the ^{3}He vapour pressure scale below 3 K

Experiments in ^{3}He vapour pressure thermometry have been carried out at the NIST and the NMi, and are in progress at the PTB. The difficulties and differences increase as the temperature falls, but it is important to establish the accuracy of the ITS-90 at its current lower limit, and to obtain an accurate correlation between ^{3}He vapour pressures and melting pressures, which are needed for the extension of the scale.

3) Study of temperature scales below 0.65 K

The objective of this activity is to make a recommendation to the CCT regarding the extension of the ITS-90 down to 1 mK. Progress in developing a ^{3}He melting pressure relation was reviewed at a workshop held in Leiden (the Netherlands) in September 1998. The differences between the scales developed at the PTB and at the NIST and the University of Florida are considerable at the lowest temperatures, and have since been extensively analysed using thermodynamic calculations. No firm conclusions have yet been reached, and it is not clear whether agreement on a provisional melting pressure equation will be achieved before the meeting of the CCT in April 2000.

A meeting of the Working Group 4 is planned for 20 and 21 January 2000 at the NIST.

Thermodynamic temperature determinations for high-temperature black bodies

An *ad hoc* joint CCT/CCPR working group is exploring the relative merits of using the ITS-90 or absolute radiometry for the measurement of the thermodynamic temperature of a high-temperature black body. The ITS-90 recommends that such measurements be made by monochromatic radiation thermometry and reference to any one of the silver, gold or copper freezing points. A number of radiometrists, however, prefer to use alternative methods such as absolute measurement of the radiant flux in a well-characterized spectral band using a cryogenic radiometer, or measurement of the ratio of radiant fluxes in two or more spectral bands at a single temperature.

In its preliminary report for the 1996 CCT meeting, the working group concluded that for routine applications the ITS-90 methods are currently a little more accurate and easier to use than those of absolute radiometry, but that for an expert in both fields, absolute radiometry can be marginally more accurate. Both methods are ultimately expected to yield the same accuracy.

Small-scale international comparisons of filter radiometers and of black bodies are now under way, with the NPL and the NIST acting as pilot laboratories.

Humidity measurements

In response to the increasing demands from industry for humidity standards and the growing importance of such measurements and standards in national laboratories, a working group on humidity measurements was established in 1994. Since then the group has focused its effort on the first of its four tasks, namely the organization of an international comparison of humidity generators (dew-point standards), which is now well under way. Regional comparisons in the APMP, the EUROMET and the SIM will be followed by one in which the RMOs are fully linked to the CIPM comparisons.

In EUROMET, two NPL dew-point transfer standard hygrometers, which together cover the range from –75 °C to 80 °C, have been circulated among eight national laboratories: the Centre Technique des Industries Aérauliques et Thermiques (CETIAT, France), the IMGC (Italy), the Instituto Nacional de Técnica Aeroespacial (INTA, Spain), the Mittatekniikan Keskus (MIKES, Finland), the NMi (the Netherlands), the NPL (United Kingdom), the OFMET (Switzerland) and the PTB (Germany). Results of the comparison have been reported at the International Symposium on Humidity and Moisture held at the NPL in April 1998.

As part of the current phase of the international comparison, comparisons using an INTA precision dew-point transfer standard have been conducted among the national laboratories at the INTA, NIST, NPL and the PTB. Results of a bilateral comparison between the INTA and the NIST standard generators in the range from −70 °C to 20 °C were also reported at the International Symposium.

In the SIM, the NIST will provide a precision dew-point hygrometer for use as a transfer standard for comparison among three national laboratories: the CENAM (Mexico), the Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial (INMETRO, Brazil) and the NIST (United States).

In the APMP, a comparison is being conducted among the national laboratories at the Centre for Measurement Standards (CMS, Taiwan), the KRISS (Rep. of Korea), the NML (Australia), the National Research Center for Certified Reference Materials (NRCCRM, China), the NRLM (Japan), Singapore Productivity and Standards Board (SISIR, Singapore) and the Standards and Industrial Research Institute (SIRIM, Malaysia). An NRLM precision dew-point hygrometer is being used as a transfer standard.

Dr Gebbie then paid homage to Prof. Luigi Crovini, who died suddenly on 21 October 1995 at the age of 58. Luigi participated in all CCT meetings since its 9th meeting in 1971 until the 18th in 1993, at which he was President for the first time. At the time of his death, he was Director of the IMGC, a Director of the Consiglio Nazionale delle Ricerche (CNR), and Secretary Designate of the CIPM. His scientific interests were wide and his many publications in refereed journals include articles not only on temperature measurement and temperature scales, but also on the thermal properties of materials, noise measurement, humidity measurement and various aspects of the theory of measurement. Throughout the 1980s Prof. Crovini played a key role in the development of the ITS-90, and in the short time he was President of the CCT he initiated studies on the implementation of the ITS-90 and its extension to lower temperatures. A special issue of *Metrologia* (1996, **33**, No. 4) has been dedicated to his memory.

Draft Resolution I on the extension of the ITS-90 to lower temperatures was then approved unanimously as Resolution 9 (see page 332).

11.6 The Consultative Committee for Photometry and Radiometry

Dr A.J. Wallard, President of the Consultative Committee for Photometry and Radiometry (the Comité Consultatif de Photométrie et Radiométrie, CCPR), presented his report.

Since the 20th General Conference the CCPR has met twice, holding its 14th meeting at the BIPM on 10-11 June 1997 and its 15th meeting, also at the BIPM, on 24-26 March 1999. The main issues of concern to the Committee during its formal meetings were the selection of key comparisons to be carried out in support of the MRA and maintaining the momentum of its working sub-groups.

Key comparisons

At its 14th meeting the CCPR identified six key comparisons, based on the recommendations of a working group led by Dr A.C. Parr (NIST, United States). These are:

Spectral irradiance (CCPR-K1) between 250 nm and 2500 nm. The pilot laboratory is the NPL (United Kingdom) with the work expected to be carried out between April 1999 and May 2000. One interesting aspect of this comparison is that it will enable the CCPR to evaluate the performance of FEL and type II Polaron lamps as well as to assess the effects, if any, on these two types of lamps which result from hand-carrying or from conventional transportation. These aspects of this comparison will help advance a closely argued discussion on the relative merits of the two types of source.

Spectral responsivity (CCPR-K2). This is a comparison of detector performance split into three wavelength ranges:

- near infrared (900 nm-1600 nm): the NIST is the pilot laboratory for this comparison, scheduled to finish by August 2000;
- visible (300 nm-1000 nm): the BIPM pilots this comparison which is due to start in January 2000 and be completed by June 2001;
- ultraviolet (200 nm-400 nm): starting in July 2000, this comparison is led by the PTB (Germany) and will finish in 2001.

The comparison repeats a similar spectral responsivity comparison reported to the last General Conference but it is timely as many laboratories now use cryogenic radiometers. Also, in the last comparison only the wavelength range from 250 nm to 1000 nm was used.

Luminous intensity/responsivity (CCPR-K3.a and CCPR-K3.b). Two related comparisons of luminous intensity and responsivity are based on comparisons launched in 1994 by the CCPR at its 13th meeting. One is a lamp-based comparison of luminous intensity and the other a detector-based photometric comparison led respectively by the PTB and the BIPM. These comparisons were both completed in 1999. The results will be discussed later in this report.

Luminous flux (CCPR-K4). Linked closely to the luminous intensity comparison, the PTB, as pilot laboratory, has now completed the comparison. The results will be discussed later.

Spectral diffuse reflectance (CCPR-K5). The NIST is the pilot laboratory for this comparison which will be confined to the visible region, where careful specification of the measurement conditions is required. The comparison will begin early in 2000. In preparing for this comparison, the CCPR noted that several laboratories are using goniophotometers rather than the older integrating-sphere-based approach to diffuse reflectance and that anomalous results had been found. A small sub-group of laboratories has agreed to investigate this.

Spectral regular transmittance (CCPR-K6). This comparison was chosen because of the subject's increasing importance in, for example, the pharmaceutical, glass, plastics and drinks industries. The comparison will be piloted by the BNM-INM (France). The filters to be used have been selected and the timing will be coordinated with that of CCPR-K5.

Other CCPR comparisons

The CCPR has launched three supplementary comparisons, which are:

Spectral radiance (CCPR-S1). This comparison, piloted by the All-Russian Research Institute for Optophysical Measurements (VNIIOFI, Russian Federation), is expected to be completed by November 1999. It covers the range 220 nm to 2200 nm and will exploit new, high-performance, black-body references as well as a range of lamps.

Aperture area (CCPR-S2). This is an important comparison which will test laboratories' capabilities and techniques for the measurement of apertures themselves, often a critical factor in many other measurements. The comparison was initially delayed because of the relocation of facilities at the pilot laboratory, the NIST.

Cryogenic radiometers (CCPR-S3). In this comparison which finished in 1999, seventeen cryogenic radiometers have been compared successfully indirectly by using transfer detectors.

Analysis of key comparisons

At its 14th meeting, the CCPR decided to establish a small working group, under the chairmanship of the President, to oversee the receipt and analysis of CIPM key comparison reports, as well as reports of key comparisons or supplementary comparisons from RMOs. Its initial meetings were timed to coincide with major related events such as NEWRAD and CORM conferences. In these meetings there was considerable debate over how best to tackle the analysis of results in photometry and radiometry, especially the

issues of "outliers" and the options for evaluating a reference value when a quantity has a high spectral dependence.

These meetings, with the help of considerable e-mail and other correspondence, enabled a meeting of the CCPR Key Comparison Working Group to be held on the day before the 15th meeting of the CCPR. This preparatory discussion allowed the group to reach the following consensus: on the assumption that the laboratories in key comparisons had agreed on robust uncertainty budgets for each participant, a mean derived from individual results weighted by the square of the inverse uncertainty would be statistically robust. The CCPR aims to achieve this ideal arrangement in due course, but acknowledged that some comparisons already under way had not always had full uncertainty budget analyses. For the completed comparisons, the CCPR accepted the working group's recommendation to set by consensus a state-of-the-art cut-off uncertainty where individual participants had claimed very low uncertainties.

This approach was adopted for the photometric key comparisons (i.e. not those with a spectral dependence) so that the final results could be calculated for reports in preparation for publication, and data could be prepared for inclusion in the KCDB.

The working group recognizes that it must tackle the difficult issue of spectrally dependent data in time to give guidance to pilot laboratories and participants in these comparisons.

In the meantime and for all future comparisons the CCPR will, however, insist on full uncertainty budgets with appropriate careful analysis, critical assessment and discussion between comparison participants.

The future work of the working group will cover RMO comparison data where the comparisons have been carried out in accordance with the procedures approved in the MRA.

Air-UV Radiometry Working Group

The work of this increasingly important group continues. New source and detector techniques, as well as new requirements are emerging and the CCPR is keen to encourage the exploitation of detectors such as cryogenic radiometers at synchrotrons or electron storage rings which, in the short-wavelength UV region, can provide an interesting alternative to the use of x-ray dosimetry sources for calibrations.

Since the last General Conference the working group has continued its comparisons of spectral radiance between 200 nm and 400 nm. These measurements show close agreement in the wavelength region around 200 nm, where the results of the NIST, the PTB and the NPL all agree within one standard deviation. Despite clear evidence for ageing effects, it also revealed that deuterium lamps could be used for comparisons and for

maintenance of a relative spectral power distribution rather than as an absolute scale. Spectral radiance measurements proved more satisfactory than those of spectral irradiance, where results were somewhat worse than those reported in the 1992 comparison.

In this area as in others, detector-based methods have continued to improve and advance, as evidenced in the several special meetings and workshops that have been held, notably at the PTB and around the NEWRAD meetings. Pt-Si photodiodes show improved stability and can now be regarded as providing acceptable transfer standards, especially in the range from 200 nm to 400 nm, while filtered radiometers can achieve relative uncertainties of less than 5×10^{-3}. The group has been asked to continue its studies and will be presenting a proposal for a new work plan to the 16th meeting of the CCPR.

CCT/CCPR Working Group

The CCT/CCPR Working Group had planned comparisons of temperature measurements using filter radiometers with special reference to the gold point temperature. The work has been delayed as a result of the heavy load already placed on NMIs by the key comparison programme.

Concluding remarks

The CCPR continues to note that there are special needs in laboratories using laser sources for power measurements in relation to applications in, for example, the fabrication of high-resolution microcircuits, and new requirements in optical computing employing fibre optics and opto-electronics. In identifying these requirements, the CCPR comes close to the interests of other Consultative Committees, especially the CCEM. The Presidents of the CCPR and CCEM had briefly reviewed the potential for a common interest after the 14th CCPR meeting but did not identify a pressing need that was not then covered or, as was the case for optical power meters, being handled at the RMO level. At its 15th meeting, however, the CCPR accepted the NIST's offer to review the field and to report back.

The Committee's interests continue to be stimulated by the increasing numbers of cryogenic radiometers in the world's national metrology institutes and we note that accuracies better than a few parts in 10^4 are regularly achieved. These therefore are now dominating the techniques in the visible and infrared. New high-temperature black bodies are also offering new capabilities and detector-based transfer standards are challenging existing source-based scales. The field is vibrant in technology and promises to provide challenges to national metrology institutes for the foreseeable future.

Finally, and as President only since 1996, I wish to pay tribute to my predecessor, Dr William Blevin. As an acknowledged world expert, he not only made substantial personal contributions to the field but steered the CCPR over fourteen years during which there were many notable advances, including a redefinition of the candela as a direct result of his proposal.

The CCPR will hold its 16th meeting in 2001.

Prof. Bordé thanked Dr Wallard and brought up the difficulty of comparing the intensities of coherent and incoherent light. Dr Wallard agreed that this was an important issue. He said that many laboratories now use coherent (laser) sources over a wide wavelength range. One problem with non-coherent sources is that the intensity of the beam varies across the surface of the detector.

11.7 The Consultative Committee for Ionizing Radiation

Prof. G. Moscati, President of the Consultative Committee for Ionizing Radiation (the Comité Consultatif des Rayonnements Ionisants, CCRI), formerly the CCEMRI (the Comité Consultatif pour les Étalons de Mesure des Rayonnements Ionisants), presented his report.

Ionizing radiation plays an important role in many fields of science and technology. The accurate measurement of ionizing radiation is most important in radiotherapy applications, but other medical and industrial applications make heavy demands on metrological services and measuring levels of activity in the environment is becoming increasingly important for many governments. High levels of activity (from TBq to PBq) are used in radiotherapy, for gamma radiography, food preservation, medical instrument sterilization and in the nuclear industry, together with high dose levels (from Gy to MGy) both from radionuclide sources and from linear accelerators; medium levels of activity are used in radiopharmaceuticals and for brachytherapy sources (from MBq at diagnostic levels to GBq at therapy levels) with corresponding medium dose levels (from mGy to Gy), the lower values also being delivered from diagnostic x-ray equipment; low levels of activity (from Bq to kBq) and of dose (μGy to mGy) are needed for example for evaluating contamination in the environment and for personal dosimetry. Taken together, these applications call for measurements covering a wide range of radiation types, energies and doses.

While the measurement uncertainty required by the users in these fields is modest in relation to other fields of metrology (from 1 % for radiotherapy to 10 % for the environment), the need to achieve the defined accuracy is crucial, as failure can be life-threatening. In the national metrology institutes, the uncertainties must be of at least an order of magnitude better than those for calibration laboratories which themselves need to be better than the end

user requirement. No single measurement method covers all the types, energies, activities and doses of radiation which are of interest, so a broad range of techniques must be maintained to link the measurements to SI units. As well-characterized ionizing radiation is difficult to produce and many parameters must be measured, ionizing radiation metrology is an important and heavy load on the NMIs. The CCRI fulfils a key role in bringing together representatives of the world's ionizing radiation metrology institutes. The work initiated by the CCRI, both at the BIPM and elsewhere, provides a secure and permanent link between ionizing radiation measurements and the SI.

Since the 20th General Conference, the CCRI has met three times and each of its three Sections has met twice. Section I (X- and γ-rays, electrons) met from 14 to 16 April 1997 and 26 to 28 May 1999; Section II (Radionuclide measurements) from 23 to 25 April 1997 and 31 May to 2 June 1999 and Section III (Neutron measurements) from 21 to 22 April 1997 and 31 May to 1 June 1999. The then designated CCEMRI met on 27 and 28 June 1996, 7 and 8 July 1997 and the CCRI met on 3 June 1999. Since its meeting in 1997, the CCRI has been reduced in size to include just its President and the Chairmen of the three Sections, together with the Director of the BIPM and the Executive Secretary. The meeting now lasts less than a day and the new format seems to work well.

In the report which follows, the work of the CCRI, which is closely linked to the corresponding activity of the BIPM, is described in Section order.

X- and γ-rays, electrons

The measurements made at the BIPM in the field of dosimetry are of two complementary types: international comparisons approved by the CCRI and calibrations based on established and maintained standards. To support this work there is a continual programme of research and development of measurement standards and techniques.

The ongoing activity in comparisons and calibrations against the BIPM standards for air kerma and absorbed dose to water is considered a priority by the CCRI. Since 1995, over thirty comparisons of primary standards involving more than twelve countries have been carried out. This major increase in interest by the NMIs stems from the MRA developed during this period. Section I decided on the comparisons that should be included in the KCDB and agreed that primary standards should be compared with the BIPM at least every ten years. It was also agreed that the values determined by the BIPM standards will be used as the key comparison reference values for all dosimetry comparisons.

For national laboratories which maintain secondary standards, calibrations are made periodically and this work has involved over forty ionization chambers from twelve countries. The International Atomic Energy Agency

(IAEA) in cooperation with the World Health Organization (WHO) coordinates a network of Secondary Standards Dosimetry Laboratories (SSDLs) established in seventy-two countries which significantly extends the traceability of radiotherapy and indeed other dosimetry ranges. The IAEA's dosimetry references are traceable to BIPM standards, periodic calibrations of its reference instruments (ionization chambers, thermoluminescent dosimeters) being carried out in the BIPM radiation beams.

Primary standards for radiotherapy and radiation protection are maintained using x-ray beams and sources of ^{60}Co and ^{137}Cs γ-rays. The ^{60}Co source used for radiotherapy-level standards is due to be replaced this year, having decayed to an unacceptably low level. With the proposed increase in activity from 40 TBq to 170 TBq, a new radiation safety and monitoring system has been designed and installed. A planned replacement programme for the measuring equipment and the x-ray installations has also started and should be completed within four years.

Various parameters linked to primary standards and to comparisons and calibrations have been investigated, among them the calculation (using Monte Carlo codes) of electron-loss and photon-scatter correction factors for free-air ionization chambers of various designs used as national standards, the relationship between air kerma and absorbed dose to water for various secondary standards, and the influence of irradiation conditions on the calibration of ionization chambers in terms of absorbed dose to water.

High-energy beams of photons and electrons from linear accelerators are increasingly used in radiotherapy and indeed in industry. A transportable transfer system for comparisons between the NMIs has been developed based on ionization chambers. Six institutes have expressed an immediate interest. For absolute dosimetry, a graphite calorimeter has been donated by the Institut Universitaire de Radiophysique Appliquée (IRA-OFMET, Switzerland) and a modern data acquisition system is being developed to measure absorbed dose in high-energy x-ray beams (up to 20 MeV).

Radionuclide measurements

The activity measurements performed at the BIPM in collaboration with Section II include both absolute and relative measurements. Absolute measurements concern international comparisons in which aliquots of a radioactive solution are distributed among the participants; relative measurements concern the SIR to which samples of any γ-emitting radionuclide within a given range of activity, are submitted by national standards laboratories for comparison against the ^{226}Ra reference sources at the BIPM.

During the period covered by this report, Section II undertook international comparisons of the quasi-pure beta-particle emitters ^{90}Sr and ^{204}Tl. The results of the ^{90}Sr comparison are satisfactory. A detailed analysis of the ^{204}Tl results showed significant discrepancies in the results and a working group

has been formed to review the standardization methods used and any influencing factors. Problems concerning the standardization of ^{192}Ir were also highlighted and it was agreed to investigate these before continuing with the full international comparison. A comparison of ^{152}Eu activity measurements is under way and new comparisons of ^{89}Sr and ^{238}Pu are planned for the year 2000. The results approved by Section II for absolute activity comparisons will be included in the KCDB. Some comparisons are more than ten years old but it was felt important to maintain these results.

The SIR plays a role of increasing importance in efforts to improve worldwide quality assurance through the international equivalence of national activity measurements. A total of 762 ampoules had now been measured which has produced 535 independent results for 59 gamma-ray emitters including some radioactive gases. The extension of the SIR to pure beta emitters measured at the BIPM using the liquid scintillation technique developed by the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT, Spain) and the NIST (United States) has been successful but a system to maintain reproducibility over extended periods will be necessary. The measurement of short-lived radionuclides is under consideration. Section II agreed that the results of the SIR which are directly traceable to primary standards methods will be used to produce the key comparison reference values for the MRA. The SIR continues to serve as a calibration system for laboratories that use secondary or derived methods for radionuclide standardization. A monograph describing the entire SIR is in preparation for publication.

The SIR ionization chamber efficiency curve has been re-evaluated and the results are being published. A gamma spectroscopy system, based on a Ge(Li) detector, has been developed at the BIPM and has already proved its usefulness in identifying possible impurities and measuring their activities in ampoules submitted to the SIR. A hyperpure Ge detector has been purchased and a system with better resolution is consequently being realized. A triple-to-double coincidence ratio method for absolute activity measurements is being developed and should provide a useful addition to the absolute measurement methods available at the BIPM.

A stable and reproducible standard ionization chamber, realizable by any NMI at any time, is under development at the NPL (United Kingdom) as a project of Section II. The incorporation of such a chamber into the SIR would provide initially a back-up instrument and, once proved, could eventually replace the SIR ionization chambers. Having identical chambers at each NMI should ultimately facilitate comparisons of gamma emitters, particularly of short-lived radionuclides, and enable many more comparisons to be conducted.

Neutron measurements

The main activity of Section III has been an international comparison between six national institutes of measurements of 24.5 keV neutron fluence. Such neutrons may be generated by filtered reactor beams, Sb-Be (γ,n) radioactive sources, and reaction of proton beams on Sc targets. The comparison involved the circulation of a set of three Bonner spheres with a common ^{3}He proportional counter detector. The BIPM was involved in the stability checks of the transfer instrument between each institute's measurement. Once the measurement uncertainties have been fully evaluated, the weighted mean will be used as the key comparison reference value. The results will be published in *Metrologia.*

Comparisons of neutron measurements have now been made from 24.5 keV to 14.7 MeV over several selected energies. Section III decided that as neutron comparisons take many years to complete, all its past comparisons, dating back to the 1960s, should be indicated in the KCDB but no degrees of equivalence will be determined until each comparison is repeated. Plans are under way for new key comparisons: of thermal neutron fluence rates by circulating a set of ^{10}B ionization chambers as transfer instruments; of monoenergetic fast neutron fluence rates with each participant taking its standard to the PTB so that all the measurements can be made within a short time frame; and of radionuclide neutron source emission rates using an ^{241}Am-Be (α,n) source circulated to the participants.

Since the neutron work at the BIPM ceased in August 1995 the equipment and reference standards have been returned to the original owners or given to laboratories with a particular interest in the field; for example, the Bonner spheres and the ^{3}He proportional counters have been returned to the NPL and the Mn bath is now installed at the Instituto de Radioproteção e Dosimetria (IRD) in Brazil.

Prof. Bordé thanked Prof. Moscati for his presentation and invited questions. Dr Wallard asked why only provisional results were available for CCRI key comparisons. Dr Allisy-Roberts (BIPM) explained that the description "provisional" indicated only that the results had not yet been published. Dr Ugur said that he was pleased to see that the ^{60}Co comparisons covered 65 % of the world population, but asked what the policy of the CCRI is regarding non-member countries. Prof. Moscati replied that the CCRI supports the Member States of the Metre Convention, and that RMOs extend the coverage to other countries. With the introduction of Associate States, this will be extended. In response to a question from Dr Leitner (Austria), Dr Allisy-Roberts said that at the last meeting of CCRI Section I it had been decided not to include dosimetry measurements in the list of CCRI key comparisons but they would instead be included as a supplementary comparison.

11.8 The Consultative Committee for Amount of Substance

Dr R. Kaarls, President of the Consultative Committee for Amount of Substance (the Comité Consultatif pour la Quantité de Matière, CCQM), presented his report and Draft Resolutions J and K, on metrology in chemistry and biotechnology (see pages 362 and 363).

The mole and metrology in chemistry

Since the 20th General Conference, the CCQM has met every year (14-15 February 1996, 20-21 February 1997, 19-20 February 1998 and 8-12 February 1999). The interest shown by the NMIs and their associate institutes in the field of metrology in chemistry has increased very much over the last five years.

In many countries the NMIs have started or intensified activities in this field. As investments in appropriate equipment, in particular that needed to carry out primary measurements, can be considerable and specialized knowledge in chemistry is needed, the NMIs in several countries have established close cooperation with other leading laboratories in their respective countries.

The rapidly increased interest in metrology in chemistry is certainly triggered by the requirements of trade and industry for reliable and traceable measurement data. Also the requirements of society with respect to such areas as health, safety and the protection of the environment have necessitated more accurate and traceable measurements in chemistry. Trade agreements as concluded under the World Trade Organization (WTO) and agreements between accreditation bodies have to be underpinned by reliable and traceable measurements. Technical barriers to trade have to be avoided.

In the field of chemical measurements an enormous amount of work still has to be done in order to arrive at a more satisfactory situation. Therefore the interest to join in the work of the CCQM and its working groups is great and has led to many requests for at least observer status in the CCQM. Parallel to this development one can observe increased activities in this field by the RMOs.

The CCQM has established good cooperation with regional and global organizations active in the field of metrology in chemistry like the Cooperation on International Traceability in Analytical Chemistry (CITAC), the IUPAC, IFCC and the ISO-REMCO.

At the 20th General Conference in 1995 a report was presented on the first actions and results by the CCQM and its predecessor, the CIPM Working Group on Metrology in Chemistry which was created in 1992. Since then considerable progress has been achieved, a strategy has been developed, priorities set and a framework of studies and key comparisons agreed and implemented.

Results of studies and comparisons

The CCQM has continued its considerations and discussions on what are the primary methods to apply, what are primary reference materials and more generally about the role of certified reference materials.

A liaison has been established with the JCGM Working Group on the VIM in order to discuss some definitions of terms which fulfil the needs of the chemical society and which can be understood by this society.

Documents and protocols have been finalized and published which describe the primary methods of isotope dilution mass spectrometry, coulometry, gravimetry, titrimetry and determination of freezing point depression (differential scanning calorimetry).

In the meantime some other potentially primary methods, such as nuclear magnetic resonance (NMR) spectroscopy, are under study.

The following comparisons have been carried out:

- Lead in water sample: pilot laboratory the NIST (United States)

  This comparison is partly a repetition of the study carried out during the starting period of the CCQM. A better guidance document has been written and more detailed preparations were carried out before the real comparison took place. Now the results are very satisfactory, demonstrating that all eleven participants were able to demonstrate comparability to within ± 1 %.
- Gas mixtures CO, CO_2, NO, SO_2 in nitrogen, and three compositions of natural gas: pilot laboratory the NMi (the Netherlands)

  This large series of comparisons has been completed. The results have demonstrated that satisfactory comparability between the participating NMIs and traceability to the SI can be well achieved to within ± 1%, in many cases even an order of magnitude better.
- pp'-DDE in iso-octane by isotope dilution mass spectrometry (IDMS)

  The results at higher mass fractions (4.74 µg/g) showed satisfactory agreement (within ± 1 % of the reference value) between all the ten participating institutes. However, at lower mass fractions (0.072 µg/g), a wider spread in the results of the participating institutes has been observed; six of the ten participating institutes agreed to within ± 1 % of the reference value.

In all cases it became clear that more harmonization in the statement of measurement uncertainty has to be obtained.

Organization of the work of the CCQM

In order to organize the work to be carried out by and under the CCQM in an efficient and effective way and taking into account the consequences of the MRA, the CCQM has created five working groups, being:

- Working Group on Key Comparisons, chaired by the NIST;
- Working Group on Organic Analysis, chaired by the NIST;
- Working Group on Inorganic Analysis, chaired by the Laboratory of the Government Chemist (LGC, United Kingdom);
- Working Group on Gas Analysis, chaired by the NMi;
- Working Group on pH, chaired by the PTB.

Working Group on Key Comparisons

The CCQM distinguishes between its work in studies and key comparisons.

Studies do not only include relevant research and development projects but also trial comparisons as a first exercise for potential new key comparisons.

Since the area of metrology in chemistry is very extensive, the CCQM has concluded that it has to set priorities. Thus, only those key comparisons will be defined and carried out which are central for a certain chemical area, are interesting from the point of view of metrology, and have a great impact for trade, industry or society.

Also, the CCQM has started to define a more lengthy programme of studies and key comparisons. The framework adopted by the CCQM covers the following areas:

- *Health*: clinical diagnostic markers
- *Food*: pesticide residues, toxins in food, drinking water
- *Environment*: water, air, global warming gases, point-source emissions, contaminants in soils/sediments/incinerator ash, metals in biological tissues, toxic metals in recycled plastics
- *Advanced materials*: semiconductors, metal alloys, polymers and plastics, catalysts
- *Commodities*
- *Forensics*
- *Pharmaceuticals*
- *Biotechnology*
- *General analytical applications*: purity of materials, calibration solutions, isotopic standards

So far, nine key comparisons are ongoing or have been planned and twenty studies have been carried out or have been planned.

The list of comparisons and studies submitted to the CCQM is published in the report of the 5th meeting of the CCQM (1999) in Table 1 (pp. 86-89), and the list of key comparisons (K) and pilot studies (P) of the CCQM, completed, ongoing or planned, is given in Table 2 (pp. 42-43).

Working Group on Organic Analysis

Over the course of the past year the work to be carried out by this working group became well structured.

At the last CCQM meeting, results of studies and comparisons were presented and progress was reported on the following issues:

- NMR spectroscopy of mixtures, which potentially may be a primary method to be applied in the area of organic compounds in liquid mixtures. The results were promising and the study will be continued.
- pp'-DDE in corn oil comparisons demonstrated promising comparability between the participating institutes, especially at higher concentration levels. Key comparisons of this type in cod liver oil have been planned again for the next period.
- Studies on the characterization of pure organic substances by a variety of purity assessment techniques. These studies have been very useful in identifying the issues which need to be resolved in future studies of this type.
- Cholesterol in human serum comparisons demonstrated satisfactory results for clinical analysis but not directly as an exercise to demonstrate equivalence among the NMIs. Further comparisons will be organized.

Working Group on Inorganic Analysis

Projects in this field also became much more structured over the last year.

Results of studies and comparisons were presented and progress reported on the following issues at the last CCQM meeting:

- Characterization of pure inorganic substances like NaCl, KCl and $K_2Cr_2O_7$ by different methods led to the conclusion that there is a need to formulate much more precisely the analytical procedures and procedures of handling the samples (for example the drying procedure).

  Also there is a need to define much more precisely which methods are usable for which compounds and which ranges, taking into account the intended use of the compound under examination.
- Isotope dilution mass spectrometry of Cd and Pb in natural fresh water samples demonstrated good progress in establishing traceability and comparability between the participating NMIs. Moreover, since this key comparison was connected to comparisons organized by the IRMM including a large number of analytical laboratories in different countries,

it also demonstrated a good way of establishing traceability directly for field laboratories. The results of these field laboratories, however, are in many cases disappointing and made clear that much more training and education at the level of secondary reference laboratories and field laboratories is highly needed.

Working Group on Gas Analysis

This working group has been very active since the beginning and has demonstrated that in the area of gas analysis very good results can be achieved in establishing worldwide traceability. The following progress was reported:

- The results of the major exercise starting in 1993, involving analysis of six important groups of gas mixtures (CO in nitrogen, CO_2 in nitrogen, NO in nitrogen, SO_2 in nitrogen and three types of natural gas) demonstrated good comparability.
- Comparisons of CO, CO_2 and C_3H_8 (automotive gases) in nitrogen were recently completed.
- A comparison of ethanol in air has just begun, and comparisons of benzene, toluene and xylene in N_2 or air are planned.
- Studies and comparisons on global warming gases and air quality are in preparation.

Working Group on pH

This working group has not yet carried out any comparisons or studies pending on a discussion on pH scales by the IUPAC. The IUPAC working group on this issue has now reached a consensus, so that the CCQM Working Group on pH will now start a key comparison involving pH determinations in two phosphate buffer solutions.

This working group will also consider comparisons in the field of electrical conductivity of solutions.

General issues

Over the last four years the CCQM has discussed several issues of general importance.

- *Terminology*: One of the difficulties faced by the CCQM is the difference in terminology and understanding between the physical and chemical communities. The CCQM is actively trying to bridge this gap, to redefine, to "translate" or to explain certain concepts like primary standard, primary method and primary reference material.

- *Measurement uncertainty*: In all cases of (key) comparisons carried out so far the calculation and statement of measurement uncertainty appeared to be a difficult and unclear issue. As a consequence it is still difficult to come to conclusions with respect to the equivalence between the participating NMIs. Therefore the CCQM will organize a special workshop for its members and participants in the comparisons by the end of 1999 at Sèvres.

  More generally it can be concluded that the concept of measurement uncertainty is not yet fully explained and accepted by the chemical community. In this respect the work done by the Eurachem and CITAC by creating guidance documents for the calculation of measurement uncertainty in quantitative chemical analysis is very useful.
- *Reference value of a key comparison*: The meaning and role of the reference value of a key comparison and the possibility of transferring this value to regional comparisons have been discussed. The CCQM concluded that in many cases the transfer cannot be done directly. This means that, apart from the results of key comparisons, further measures need to be implemented to assure and demonstrate the competence of NMIs to disseminate traceability. The implementation of quality systems and introduction of peer review visits are useful tools for building up confidence in the capabilities and competence of the NMIs.
- *Certified reference materials*: The role of certified reference materials has been discussed. It was generally agreed that primary or certified reference materials can be used as national measurement standards, but that finally measurement technologies and capabilities, like primary methods, have to be developed much further and more fundamentally in order to establish worldwide traceability to stable anchor points like the SI and to be able to satisfy the rapidly growing needs of trade, industry and society in the field of measurements in chemistry.
- *BIPM programme of metrology in chemistry*: The CCQM concluded that it is essential that the BIPM build up its own fundamental knowledge in the field of metrology in chemistry in order for it to become a competent partner in the international community of chemists and to assist clearly in the establishment of a worldwide system of traceability and comparability in the field of measurements in chemistry. Therefore the CCQM has advised the CIPM to establish a chemical metrology activity at the BIPM, which will make it possible to develop the necessary knowledge and skills to contribute to the basic principles of traceability in the field, to be practical and of added value to the NMIs by being able to deliver services underpinning traceability and to be seen and recognized by the chemical community as a key player in this respect. The installation of a laboratory in the field of gas analysis has been welcomed by the CCQM and is seen as a good starting point for some future possible fundamental developments.

- *Qualitative analysis and identification*: One of the great difficulties in analytical chemistry is the identification of what one is really measuring and the certainty with which one can state that the measurement result is really the defined measurand. In many cases also the measurand is not well and completely enough defined. This issue will be on the agenda of the CCQM in the next few years.
- *Viscosimetry*: Several NMIs have also suggested the organization of studies and comparisons concerning viscosimetry. In September 1999 a meeting was organized at the BIPM in Sèvres to investigate the problems, needs and possibilities for further activities in the area.

The katal and the SI

The CCQM endorsed the proposal of the CCU to adopt as a derived unit in the SI the unit "katal" (abbreviation "kat") to denote mol/s when expressing enzyme activity.

The original proposal was submitted to the CCU by the IFCC and the CCQM added a recommendation that when the katal is used the measurand must be specified by reference to the measurement procedure, which must identify the indicator reaction.

Draft Resolution N (see page 366) is presented by the CCU on behalf of both Consultative Committees.

Draft CGPM resolutions on metrology in chemistry and metrology in biotechnology

Over the past several years much more awareness with respect to traceability of measurements in chemistry has been perceived by those directly or indirectly concerned in the results of measurements in chemistry. Several regional and international organizations now have this issue on their agenda and have published or will publish papers and guidance documents with respect to traceability, comparability, measurement uncertainty, and the quality and role of certified reference materials.

Among these organizations one can mention the CITAC, Eurachem, IAEA, ISO-REMCO, and IUPAC, while others, such as the Association of Official Analytical Chemists (AOAC), are considering the issue.

The need to eliminate measurement-related technical barriers to trade in general as part of trade agreements under the WTO requires much more attention from the NMIs. In particular the areas of food science, pharmaceuticals, environment and advanced materials require a better, more accurate and traceable base of measurement standards in chemistry. Also the

quality of life and the costs of environmental and health decisions require more careful and accurate control. A long-term stable and sufficiently accurate measurement system, delivering worldwide traceability and comparability, is an essential requirement for realizing the goals set by society, trade and industry.

This requires the full, efficient and coordinated support of the NMIs. Since time and money should not be wasted it is recommended that the NMIs cooperate where feasible with other analytical chemical laboratories having key responsibilities in certain areas like health, food, the environment, and forensic or general chemical analysis.

The same considerations apply to the area of biotechnology. Society becomes more and more aware about the importance of accurate (fit for purpose) and internationally traceable measurements in chemistry and the enormous burden of costs involved in false measurement results. Regulations on in-vitro measurements now have a traceability requirement (for example in Europe). The fast-growing importance of bioscience and technology in human health, food production, forensic medicine and the protection of the environment make it clear that an adequate metrological infrastructure is highly needed in order to realize reliable measurement results based on the SI. National and international cooperation with all parties concerned is necessary. Draft Resolutions J and K were prepared in this light (see pages 362 and 363).

Prof. Bordé thanked Dr Kaarls for his presentation and invited questions from the floor. Mr Faber (OIML) remarked that chemical metrology was a new discipline in many national metrology laboratories, warning that the CCQM should be wary of beginning activities in too many fields, because new activities required a large investment. He suggested that the work of the CCQM would be better spread over a number of different laboratories in order to lighten the load on the NMIs. Dr Kaarls responded that the distribution of work was a matter for the national governments, but agreed that the involvement of other key laboratories (other than the NMIs) was essential. He added that it was important that the RMOs also take this into account.

Prof. Bordé asked if Dr Kaarls had a list of top priorities to which Dr Kaarls replied that he had many. The highest priority was to launch the key comparisons listed in his report. The CCQM had chosen areas with a direct impact on society and in which it was likely that results could be achieved.

Draft Resolution J was approved unanimously as Resolution 10 and Draft Resolution K approved with one abstention (South Africa) as Resolution 11 (see pages 333 and 334 respectively).

11.9 The Consultative Committee for Acoustics, Ultrasound and Vibration

Dr A.J. Wallard, acting President of the Consultative Committee for Acoustics, Ultrasound and Vibration (the Comité Consultatif de l'Acoustique, des Ultrasons et des Vibrations, CCAUV), presented his report.

At its 87th meeting in September 1998, the CIPM agreed to establish a new Consultative Committee to cover the fields of acoustics, ultrasound and vibration. This resulted from recommendations of a working group of the CIPM chaired by Dr Andrew Wallard.

The working group concluded that:

- There is a growing industrial, scientific and medical activity in these areas worldwide.
- Consultations with interested parties in the NMIs and from the ISO and the IEC reveal strong support for a coordinated activity by the BIPM.
- NMIs are keen to coordinate their research.
- Five key comparisons should be initiated.
- A new Consultative Committee would have strong support from NMIs.
- A special issue of *Metrologia* devoted to acoustics, ultrasound and vibration would be welcomed.

The CIPM accepted these findings and agreed to the formation of the CCAUV. The Committee held its first meeting in July 1999 under Dr Wallard's presidency and with Dr Allisy-Roberts (BIPM) as Executive Secretary. The participants presented their interests in the various fields and discussed the criteria for membership. The Director of the BIPM was asked to write to the NMIs asking them to declare an interest in full or observer status for the CIPM to consider in drawing up a list of members of the new Consultative Committee.

The five key comparisons proposed by the CIPM working group were endorsed and one more was planned:

- CCAUV.A-K1: comparison of sound pressure in air measurements from 63 Hz to 8 kHz;
- CCAUV.A-K2: comparison of sound pressure in air measurements at specific power-line frequencies (20 Hz, 50 Hz, 63 Hz);
- CCAUV.W-K1: comparison of sound pressure in water measured using hydrophones, from 1 kHz to 500 kHz;
- CCAUV.U-K1: comparison of ultrasonic power at various levels;
- CCAUV.U-K2: comparison of ultrasonic pressure measured using membrane hydrophones from 1 MHz to 15 MHz;

- CCAUV.V-K1: comparison of piezoelectric accelerometers from 40 Hz to 5 kHz.

The field is, therefore, well covered and there is good regional participation either from NMIs or, particularly in the case of underwater acoustics, nominated laboratories which hold the national standards.

There was agreement on how the RMOs could extend the CIPM key comparisons. The members present were also able to identify relevant RMO comparisons that could be prepared for analysis by the CCAUV and subsequent inclusion in the KCDB where appropriate.

Strong links with the IEC and ISO were established through the common membership of nominated individuals who were invited to act as liaison persons between the CCAUV and the appropriate IEC and ISO Technical Committees.

The CCAUV has agreed to meet in 2001 but a working group to deal with the analysis of key comparisons could meet earlier if there are completed comparisons for it to consider.

There were no questions from the floor.

11.10 The Consultative Committee for Units

Prof. I. M. Mills, President of the Consultative Committee for Units (the Comité Consultatif des Unités, CCU), presented his report and Draft Resolutions L, on the neper, and N, on the katal (see pages 364 and 366, respectively).

During the last four years the CCU has met three times, in February 1995, April 1996, and in September 1998. The most notable event for the CCU in this period was the preparation and publication of the 7th edition of the SI Brochure, which is the definitive publication from the BIPM on the SI. The 7th edition was published in June 1998, and representatives at the General Conference will have received a copy. The revision of the SI Brochure at intervals of six or seven years is a major responsibility of the CCU, and the 7th edition replaces the 6th edition which was published in 1992.

The meetings in February 1995 and April 1996 were mainly concerned with the preparation of the new edition of the SI Brochure. As with the previous two editions, the text is presented in both French and English. The new edition includes all decisions of the General Conference and the CIPM made since 1991, and also some further amendments made by the CCU.

Some changes of style have been introduced with the intention of making the Brochure more user-friendly to our international readership. The historical introduction and the discussion of the context of the SI have been expanded, including a note on SI units in the framework of general relativity. A section on units for dimensionless quantities has been introduced. The chapter on

units outside the SI has been significantly revised: after emphasizing the advantages of using SI units, the brochure now presents factual information on non-SI units without necessarily deprecating their use. Tables are provided classifying non-SI units into those that are accepted for use with the SI [Table 6] (such as the minute and the hour as units of time), those accepted for use whose values are obtained experimentally [Table 7] (such as the electronvolt), those currently accepted for use to satisfy the needs of special interests [Table 8] (such as the nautical mile, the ångström, and the barn), and those of more historical interest whose use is now discouraged [Tables 9 and 10]. For the first time a decimal point is used as the decimal marker in the English text, and a decimal comma in the French text. An entirely new chapter is introduced (Chapter 5) describing how to write the names and symbols for quantities and units, mainly taken from the recommendations of ISO/TC 12 in the ISO Standard 31, *Quantities and Units*.

At the meeting in September 1998 a number of new issues were discussed concerning further changes to the SI that have been proposed to the CCU by various bodies. Two of these have been recommended for further action by the CCU, approved by the CIPM, and now appear before the General Conference for your approval as Resolutions L and N. They concern recommendations for two new special names for coherent derived SI units, namely the neper (a dimensionless unit equal to one, used to express values of logarithmic decrement or attenuation) and the katal (equal to a mole per second, used to express values of catalytic activity). The neper is recommended because it is illogical not to include it when the radian is accepted as an SI unit, and the katal (which has already been in use for many years) because it is already widely used in clinical chemistry and to exclude it from the list of SI units may represent a danger to human health, as in the case of the becquerel, the gray and the sievert.

Other issues discussed at the 1998 meeting, but on which either the CCU or the CIPM decided to take no further action at the present time, were the following:

- We considered the possible extension of the SI prefixes from their present range of 10^{24} to 10^{-24}, to encompass 10^{48} to 10^{-48}. However, the CCU decided that such an extended range would be rarely used, and the advantages were outweighed by the possible confusion that it would introduce.
- We considered the possibility of changing the symbols for the prefixes for kilo, hecto and deca from k, h, and da to K, H and D.
- We considered the possibility of a name and symbol for the unit one (perhaps the uno, symbol U) to allow the use of prefixes on the unit for dimensionless quantities (such as microuno, μU, rather than the widely used ppm).

- We considered the possibility of revising the wording of the definitions of the base units of the SI, in order to achieve a standard form for all the seven definitions in line with modern thinking, in place of the historical wording which is different for each of the base units.
- We eventually reached the decision not to make any of these changes for the time being, however, although we shall keep all possibilities under review. The reason is that the CCU feels that changes to the SI should be kept to a minimum, and should only be made when there are very strong reasons for change. The SI is of worldwide importance, and to make many small changes at frequent intervals may lead to confusion amongst our many different users.

Draft Resolution N was presented on behalf of the CCU and the CCQM. Prof. Mills said that the CCU received many proposals for special names for derived units. They had been persuaded to recommend adoption of the katal because this unit is widely used in medical applications and prohibition of its use could cause difficulties for medical technicians, creating a possible danger to human health. Moreover, its adoption will serve as encouragement to the medical community to use the SI (see also Draft Resolution K, page 363).

Dr Plantenga (the Netherlands) stated that he considered the katal to be a useful addition to the SI, but questioned why the recommendation restricted its use to the fields of biochemistry and medicine. Prof. Mills agreed that the katal could be used in other applications, notably chemical kinetics, but reiterated the advice of the CCQM and CCU that its use should be restricted to medical applications. Dr Quinn added that, in general, use of the base units of the SI is preferred – in this case mol s^{-1} – rather than katal. Dr Blevin drew a parallel with other special names adopted within the SI for derived quantities related to ionizing radiation, and Dr Carneiro (Denmark) added that he supported the use of special names under special circumstances, in which case the purpose should be identified when the units are presented.

After minor rewording of the section "decides" to take into account the view that the use of the katal should not be restricted exclusively to medicine, Draft Resolution N was adopted as Resolution 12 (see page 334). Italy and Poland abstained.

Prof. Mills then presented Draft Resolution L on the neper and the bel (see page 364). He explained that in expressions such as that for a decaying harmonic oscillator,

$$f(t) = \exp(-\gamma t)\cos(\omega t) = \mathrm{Re}\,[\exp(-\gamma t + \mathrm{i}\omega t)],$$

the quantities γt and ωt are dimensionless. In expressing values for these quantities, however, it is customary to give them the unit "neper" and "radian" respectively, although since the quantities are dimensionless both the neper and the radian are actually equal to one. Thus the neper is used for expressing the value of logarithmic decrement of field quantities using

natural logarithms, and the radian is used for expressing the value of the angle appearing as the argument of trigonometric quantities. The neper has, of course, been used for many years, although it has not seen frequent use. The more commonly used unit of logarithmic decay is the bel, or its submultiple the decibel, based on logarithms to the base ten, and generally used for power quantities.

Prof. Mills explained that the CCU believes that it is not logical to include the radian as an SI unit, but to exclude the neper, when both occur in a similar way in the argument of the exponential function in equations such as that above. The CCU also believes that the neper and not the bel is the coherent SI unit for expressing the value of logarithmic decay, just as the radian and not the degree is the coherent SI unit for expressing the value of angles. This Draft Resolution was approved by the CIPM at its meeting in 1998.

This Draft Resolution was then discussed by the General Conference. Doubts were expressed about some aspects of the resolution. Prof. Giacomo, Emeritus Director of the BIPM, pointed out that neither the neper nor the bel are derived SI units in the usual sense, since they cannot be defined as algebraic combinations of SI base units in the normal manner, unlike the radian and steradian. Prof. Giacomo also observed that in practice the names neper and bel, which are both used to express the value of a number, are actually used to convey information on the nature of the quantity concerned, because the names used for the quantities in practice never mention either the fact that a logarithm is used or the base of this logarithm. Units should not be used in this way. He also suggested that although the use of the base "e" is more natural in relation to the exponential function used to describe physical phenomena, the use of the base ten might be regarded as more natural in relation to expressing the values of numbers.

The President of the Conference, Prof. Bordé, also expressed some doubts about the resolution, noting that in the spectroscopic application of the decaying harmonic oscillator, the quantity ω appears as the angular frequency and γ as the half linewidth of the corresponding spectral line, suggesting that the unit used for expressing the values of ω and γ should actually be the same rather than being radian per second and neper per second respectively as suggested by this resolution.

In view of the doubts expressed in the discussion, Prof. Mills suggested that it would be better to withdraw the resolution on this occasion, and await further consideration. He emphasized that he still believed, as did the CCU, that the neper should eventually be adopted as an SI unit, but he did not wish to press the resolution at this time while a number of members of the General Conference expressed such reservations about it.

The Conference accepted this course of action and Draft Resolution L was withdrawn.

12 Programme of future work at the BIPM

Dr T.J. Quinn, Director of the BIPM, presented a detailed programme of the work to be carried out at the BIPM during the years 2001 to 2004.

The text of the programme proposed by the International Committee is reproduced in Appendix B (see pages 371-393).

13 Annual dotation of the BIPM

13.1 Report of the meeting of the Working Group on the Dotation

Dr Blevin reported that the Working Group on the Dotation met during the morning of Wednesday 13 October. It comprised the delegations from Argentina, Canada, China, Czech Republic, Denmark, France, Germany, Italy, Japan, the Russian Federation, Singapore, the United Kingdom, and the United States.

13.2 Draft Resolution M

The Working Group on the Dotation held a lengthy discussion about the BIPM's financial situation, its work programmes and its plans for the future. Careful consideration was given to Draft Resolution M (see page 369), which concerns the BIPM dotation for the years 2001-2004. The CIPM's proposition was to maintain the dotation in real terms at the level agreed by the 20th General Conference for the year 2000. The Draft Resolution included an increase of 2 % per year in monetary terms to allow for expected inflation.

Although each Member State on the working group reported that it would not vote against the levels of dotation in Draft Resolution M if these were put to the General Conference, the working group nevertheless considered that the 2 % allowed for inflation was a little too high according to the latest economic predictions, and that 1.5 % would be a more appropriate

increment. The working group therefore recommended to the General Conference a modified form of Draft Resolution M, based on 1.5 % instead of 2 % increments. The working group supported a changeover from the gold franc to the euro. In the modified draft the recommended dotations are expressed in euros as well as in gold francs, as recommended by the working group.

13.3 Secondment of staff from NMIs to the BIPM

The working group suggested that some NMIs, particularly the larger ones, might be willing to augment the BIPM's scientific staff by sending appropriate staff on secondment to the BIPM as guest workers, chiefly at the expense of the NMIs.

13.4 Draft Resolution C

The working group agreed unanimously with the CIPM that any Member State or past Member State of the Metre Convention in arrears with its subscription should be able to become an Associate State or Economy of the General Conference only after full payment of its arrears.

13.5 Voting on Draft Resolution M

Draft Resolution M was passed as Resolution 13 (see page 335) with no votes against and two abstentions (Germany and the United States).

Prof. Göbel reported on behalf of the German delegation that they were very pleased and satisfied with the work done at the BIPM since the last General Conference and with the future work programme presented by the Director of the BIPM. However, the German Government had decided that its contribution to all international and intergovernmental organizations would be held constant nominally, and the German delegation was therefore obliged to abstain from voting for Draft Resolution M. Prof. Göbel confirmed that the German Government continues, however, to support the work of the BIPM.

Similarly Dr K. Brown explained that present legislation requires the United States Government to follow a policy of zero nominal growth in the assessments of international organizations. This policy applies to all international organizations across the board, even to specialized technical and scientific agencies like the BIPM. Despite their abstention in the vote on Draft Resolution M, the United States delegation conveyed their Government's continued support of the BIPM's work programme.

14 Proposals by delegates

Prof. Kovalevsky reminded participants that the Convocation requested that Member States inform the CIPM at least six months before the General Conference of their wishes or any proposals that they would like to submit for consideration. This is in order that the CIPM can abide by the decision of the 9th General Conference (Resolution 10, 1948), that "(1) the wishes or proposals thus deposited will be distributed by the bureau of the CIPM to all Member States of the Convention at least four months before the opening of the Conference so that delegates may receive the necessary instruction and authority; (2) all other wishes and proposals will be presented to the Conference only if the CIPM has had time to study them and has approved them".

Prof. Kovalevsky reported that no formal proposals had been received from Member States, but that he would like to submit three items for discussion.

14.1 Celebration of the 125th anniversary of the Metre Convention

May 2000 sees the 125th anniversary of the Metre Convention and the CIPM wishes to mark the occasion by organizing a day of colloquia presented by Nobel Prize winners who have contributed to developments in metrology. The French Academy of Sciences has offered to host this event jointly with the CIPM. In order to facilitate arrangements, the CIPM suggests that the celebrations should be scheduled to coincide with the next CIPM meeting, and that a meeting of directors of the national metrology institutes of the Member States of the Metre Convention should be held at the same time. The dates will be fixed to be during the week of 16-20 October 2000. The French Ministry of Foreign Affairs will host an evening reception for participants at the colloquium.

14.2 Establishment of an International Metrology Day

The CIPM has decided that 20 May should be celebrated internationally as Metrology Day, to be listed in the register of worldwide days. Prof. Kovalevsky encourages NMIs to make the most of this day to promote their metrological activities.

14.3 Search for candidates to replace Dr T.J. Quinn as Director of the BIPM, on his retirement at the end of 2003

Prof. Kovalevsky reminded delegates that, in accordance with the Metre Convention, the Director of the BIPM is appointed by the CIPM. He explained how the CIPM intends to approach the recruitment of a new director to replace Dr Quinn when he retires at the end of 2003. He called on delegates to circulate widely the prepared job announcement, calling for applications before 15 April 2000. A jury comprising the bureau of the CIPM will consider the candidates and report to the CIPM at their next meeting (in October 2000), when the appointment will be decided by the CIPM.

15 Renewal of half of the International Committee

In conformity with Articles 7 (1875) and 8 (1921) of the Rules annexed to the Metre Convention, half of the membership of the International Committee must be proposed for renewal by secret ballot at the General Conference. Incoming provisional members (those who in the case of vacancies have been provisionally elected since the last Conference) are first; others must be selected by lot from among the remaining members of the International Committee.

Before proceeding to the vote, Dr Quinn made a few remarks on the rules relating to membership and elections to the CIPM and the practice followed by the Committee in selecting candidates for membership. He began by describing the rules laid out in the Convention.

15.1 Rules in the Metre Convention relating to membership of the CIPM

Dr Quinn essentially reiterated the remarks made by Prof. Kovalevsky in his report concerning the rules in the Metre Convention pertaining to criteria for membership of the CIPM: each of the eighteen members must be of a different nationality and on the death or resignation of a member the vacancy should be filled by an election carried out by correspondence among the remaining members to be confirmed by a vote at the next General Conference.

15.2 The present situation

The present distribution of members of the CIPM is shown in the following table. The information given in each column is the following:

A. RMOs;

B. Number of Member States in each of the regions covered by the RMOs;

C. Total dotation from the Member States in each region, as a percentage of the total;

D. Number of members of the CIPM from each region and in parentheses what this number represents as a percentage of the total membership;

E. Dotation from those Member States having a member on the CIPM, as a percentage of the total dotation.

Not included in this table are Cameroon, the Dominican Republic, the Democratic People's Republic of Korea and Iran. Under the heading SIM are also given the sub-regions of NORAMET and SURAMET which together include all the Member States in the Americas. It may be that the numbers of States shown for one or two RMOs are no longer up to date, but this does not alter significantly the overall picture presented by this table.

As mentioned by the President in his report (see 6.2), nearly half of the membership has changed since 1995 and almost all since 1990.

Table relating to membership of the CIPM

A RMO	B No. of Member States	C Dotation (% of total)	D No. of CIPM members/and (% of total)	E Dotation/CIPM Member States (% of total)
EUROMET	19	54	7 (39)	40
COOMET	3	3.2	1 (6)	2.2
SIM	8	20	4 (22)	18
NORAMET	3	15	2 (11)	14
SURAMET	5	5	2 (11)	4
APMP	10	18	5 (28)	15
SADCMET	1	0.6	0	0
MENAMET	3	1.7	1 (6)	0.66

In summarizing his presentation, Dr Quinn drew two main conclusions: first, that the membership of the CIPM fairly represents the Member States in terms of geographical distribution and financial contribution; and second, that the length of time individual members remain on the CIPM is becoming too short. He reiterated the concerns expressed by Prof. Kovalevsky over

short-term membership of the CIPM and the difficulties that could lie ahead for efficient operation of the CIPM and its Consultative Committees.

The following members (the eight new members since the 20th General Conference and a ninth name drawn by lot during the 88th meeting of the CIPM, October 1999) were proposed for election or re-election by the 21st General Conference: E.O. Göbel, L.K. Issaev, S. Leschiutta, O. Lounasmaa, Myung Sai Chung, H. Ugur, J. Valdés, R. VanKoughnett and A.J. Wallard.

Mrs Serre (France) and Mr Castelazo (Mexico) acted as scrutineers of the ballot. All nine proposed members were elected with a large majority. A total of seven votes were cast for other candidates: Prof. Boháček (Czech Republic), 1 vote; Dr de Almeida Farinha (Portugal), 1 vote; Dr Carneiro (Denmark), 4 votes; and Dr García San Román (Spain), 1 vote.

16 Votes on all Resolutions

Draft Resolution A was adopted as Resolution 1 with 1 abstention (New Zealand).

Draft Resolution B was adopted as Resolution 2 unanimously.

Draft Resolution C was adopted as Resolution 3 with 1 abstention (Spain).

Draft Resolution D was adopted as Resolution 4 unanimously.

Draft Resolution E was adopted as Resolution 5 unanimously.

Draft Resolution F was adopted as Resolution 6 with 1 abstention (Spain).

Draft Resolution G was adopted as Resolution 7 unanimously.

Draft Resolution H was adopted as Resolution 8 unanimously.

Draft Resolution I was adopted as Resolution 9 unanimously.

Draft Resolution J was adopted as Resolution 10 unanimously.

Draft Resolution K was adopted as Resolution 11 with 1 abstention (South Africa).

Draft Resolution L was withdrawn.

Draft Resolution M was adopted as Resolution 13 with 2 abstentions (Germany and the United States).

Draft Resolution N was adopted as Resolution 12 with 2 abstentions (Italy and Poland).

The final texts of the Resolutions are presented on pages 323-336.

17 Other business

Dr Castelazo (Mexico) asked a question concerning the recommended decimal separator in English texts: the decimal point or decimal comma? He noted that the CIPM had decided in 1997 to use the decimal point in English language texts published by the BIPM. He remarked that the WTO had ruled that international standards should be used wherever possible, and that ISO 31 specifies that only the comma should be used. This discrepancy is causing much confusion and he suggested that perhaps both the point and the comma should be considered acceptable as was the case in the past, as long as no punctuation (other than a fine space) was inserted between groups of three digits. Dr Quinn replied that discussions on this issue were under way within the ISO TC12.

In response to a question from the Swiss delegate, Dr Schwitz, Dr Blevin confirmed that the non-SI units bel and decibel were unaffected by the Conference's decision to withdraw Draft Resolution L on the neper, and were still accepted for use with the International System (as detailed in Table 6 of the SI brochure).

Finally Dr Quinn reported that, following the meeting of directors of national metrology institutes held in February 1998, the BIPM had copyrighted the two BIPM logos.

17.1 Visit to the BIPM

Delegates to the General Conference were invited to visit the laboratories of the BIPM on Wednesday 13 October 1999. They had the opportunity to visit the laboratories, examine the projects and facilities, and talk to the physicists, who presented their work.

17.2 Visit of the depository of the metric prototypes: Record

On 13 October 1999, at 16:00, in the presence of the President of the CIPM, the Director of the 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 BIPM, 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 CIPM.

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:	22.25 ºC
maximum temperature:	23.5 ºC
minimum temperature:	20.5 ºC
relative humidity:	60 %

The safe as well as the doors of the vault were then locked.

The Director	*For the Curator*	*The President*
of the BIPM,	*of the Archives Nationales,*	*of the CIPM,*
T.J. Quinn	Mrs M.P. Arnauld	J. Kovalevsky

17.3 The Mutual Recognition Arrangement

The Mutual Recognition Arrangement was signed on 14 October 1999 by the directors of the NMIs of the Member States of the Metre Convention.

18 Closure of the Conference

The President of the Conference closed the meeting by thanking the Administrator of the Collège de France for having made his facilities available for the Conference. He also expressed his thanks to Dr W.R. Blevin, for having acted as Secretary of the Conference, and all the members of the bureau of the CIPM; Dr T.J. Quinn and the ensemble of the BIPM personnel, particularly Mrs F. Joly and the BIPM secretariat; the French Minister of Foreign Affairs and Mrs Serre; all the speakers, particularly the presidents of the Consultative Committees for their presentations; and the translators. He said that it had been a great pleasure to be present at the Conference, and that many important decisions had been taken. He reminded delegates that the next General Conference would take place in four years' time, in October 2003.

On behalf of all present, Prof. Kovalevsky in turn thanked the Conference President, Prof. Bordé, for having chaired the meeting in such an excellent manner.

Resolutions adopted by the 21st General Conference on Weights and Measures

Long-term needs relating to metrology

Resolution 1

The 21st Conférence Générale des Poids et Mesures,

considering

- Resolution 11 of the 20th General Conference, which requested the International Committee to study and report on the long-term needs relating to metrology,
- the study which was completed in 1997 after extensive international consultations,
- the resultant report, entitled *National and international needs relating to metrology: International collaborations and the role of the BIPM*, which was sent by the International Committee in 1998 to the governments of the Member States,

welcomes the many decisions made by the International Committee as a consequence of the study and, in particular

- the progressive broadening of the terms of reference of the Consultative Committees to cover the principal fields of metrology where collaboration between the national metrology institutes is important, not only in physics and engineering but also in other disciplines such as chemistry and biotechnology,
- the strengthening of the role of the Consultative Committees and the admission of observers to their meetings to enable more Member States to participate,
- the emphasis on evaluating and publishing the degree of equivalence of national measurement standards of the Member States and on the establishment of an associated mutual recognition arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes,
- the introduction of periodic meetings with the directors of the national metrology institutes of the Member States,
- the statement by the International Committee of the role of the Bureau International des Poids et Mesures (BIPM) in the early decades of the 21st century,
- the increased collaboration of the BIPM with related international organizations, especially the regional metrology organizations, the International Laboratory Accreditation Cooperation and the Organisation Internationale de Métrologie Légale,
- the considerable progress already made by the International Committee in implementing its decisions,

notes the discussion in the report of the International Committee of the long-term financial commitments required from the Member States,

thanks the many organizations and individuals who have contributed to the study and the report of the International Committee.

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

Resolution 2

The 21st Conférence Générale des Poids et Mesures,

considering

- Resolution 2 of the 20th General Conference concerning worldwide traceability of measurements,
- the rapidly increasing emphasis on the need to demonstrate international equivalence of measurements and test results related to trade,
- the increasing number of mutual recognition arrangements and agreements being negotiated internationally concerning calibration and testing services,
- that the calibration and testing services in each nation depend on a national metrology institute both for their measurement standards and for traceability to the International System of Units (SI),

recognizes that mutual recognition of the national measurement standards and the calibration services of the national metrology institutes is necessary in order to provide the basis for mutual recognition of calibration and test services generally,

welcomes

- the initiative taken by the International Committee in drawing up a mutual recognition arrangement related to national measurement standards and to calibration and measurement certificates issued by national metrology institutes,
- the decisions of those Member States that have already given authority to the director of the designated national metrology institute in their country to sign the arrangement,

invites

- all other Member States of the Metre Convention to participate in the arrangement by giving authority to the director of the designated national metrology institute in their country to sign the arrangement,

- all Member States to make every effort to implement the arrangement and to encourage other authorities in their country to recognize the equivalence of national measurement standards and calibration and measurement certificates thereby demonstrated,
- all States to use this arrangement as the basis for recognizing the national measurement standards and calibration and measurement certificates of signatory national metrology institutes.

Associates of the Conférence Générale des Poids et Mesures

Resolution 3

The 21st Conférence Générale des Poids et Mesures,

considering that

- the worldwide measurement infrastructure, based on the International System of Units (SI) used in almost every aspect of modern society, rests on the universal application of the decisions of the General Conference,
- all States, not only those that are Member States of the Metre Convention, engage in measurements which are related to trade and need to be traceable to the SI,
- States which are not Member States of the Metre Convention are at present excluded from the activities of the Convention,
- Member States of the Metre Convention support the world's measurement system by devoting considerable financial resources to the Bureau International des Poids et Mesures (BIPM) and to their own national measurement systems,
- many smaller States would have difficulty in allocating funds sufficient to meet the cost of membership of the Metre Convention,

decides

- to assume a responsibility for providing those States and Economies not yet members of the Metre Convention with the means to establish links to the world's measurement system so as to provide recognition of the traceability of their measurements to the SI,
- that an important link can be through participation in the mutual recognition arrangement related to national measurement standards now operated by the International Committee,

- that participation in the arrangement for such a State or Economy should be by the association of their national metrology institutes with a regional metrology organization that is a member of the Joint Committee of the Regional Metrology Organizations and the BIPM,

and consequently **decides**

- to invite such States and Economies to take part in the General Conference as Associates, thereby establishing the connection with the Member States of the Metre Convention necessary for them to participate in the mutual recognition arrangement,
- that Associate States and Economies of the General Conference participate in the Conference through the appointment of non-voting observers,
- that Associate States and Economies shall pay an annual subscription to the BIPM to meet the cost of providing the services that the International Committee may make available to them; the annual subscription of each Associate State or Economy will be determined from its UN contribution, as for Member States but with a minimum equal to 0.05 % of the annual dotation of the BIPM,
- that a State or Economy wishing to become an Associate may do so by application to the Director of the BIPM, either directly or through its Embassy in Paris, and by the payment of the first annual subscription,
- that an Associate State or Economy three years in arrears with its subscription cease to be an Associate; it may be reinstated on payment of these arrears.

The need to use SI units in studies of Earth resources, the environment, human well-being and related issues

Resolution 4

The 21st Conférence Générale des Poids et Mesures,

considering that

- the effects on the geosphere and biosphere of industrial and commercial activities and of many other human pursuits, as well as natural phenomena, and the consequences for human health and well-being are the subject of major studies worldwide,
- governments are increasingly faced with decisions of great economic and political significance concerning the regulation of these activities,
- the policies of governments are influenced by studies depending critically on accurate and mutually compatible measurements often requiring very large economic investments,

- much of the important scientific evidence required for decisions by governments comes from measurements of small changes in certain key parameters, measurements sometimes extending over several decades,
- certain critical measurements have traditionally been made in *ad hoc* units, based upon special instrumentation or procedures, and not in the well-characterized and internationally agreed SI units,
- experience over many years has shown that measurements not directly linked to the International System of Units (SI) cannot be relied upon in the long term, cannot be compared with similar measurements made elsewhere and do not adequately bring out possible relationships with measurements made in other scientific disciplines,
- increasing demands for reliability in measurements made for medical and therapeutic purposes are leading to more demanding regulation in these areas,

recommends that those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterized SI units so that they are reliable in the long term, are comparable worldwide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Metre Convention.

Revision of the *mise en pratique* of the definition of the metre

Resolution 5

The 21st Conférence Générale des Poids et Mesures,

recalling that

- in 1983 the 17th General Conference adopted a new definition of the metre,
- in the same year the General Conference invited the International Committee
  - to draw up instructions for the practical realization of the metre (the *mise en pratique*),
  - to choose radiations which can be recommended as standards of wavelength for the interferometric measurement of length and draw up instructions for their use,
  - to pursue studies to improve these standards and, in due course, to extend or revise these instructions,

- in response to this invitation the International Committee made recommendations in 1983 and again in 1992 concerning the practical realization of the metre,

considering that

- science and technology continue to demand improved accuracy in the realization of the metre,
- since 1992 work in national laboratories, the Bureau International des Poids et Mesures and elsewhere has substantially improved the reproducibility of radiations which are suitable for the practical realization of the metre,
- such work has also substantially reduced the uncertainty in the determined values of the frequencies and vacuum wavelengths of some of these radiations,
- a revision of the list of recommended radiations is desirable for many applications, which include not only the direct realization of the metre by means of optical interferometry for practical length measurement, but also spectroscopy, atomic and molecular physics and the determination of fundamental constants,
- the accuracy already achieved and advances now foreseeable in certain space-time measurements require the practical realization of the definition of the metre to be considered in the context of the theory of general relativity,

welcomes the adoption by the International Committee in 1997 of a revised *mise en pratique* of the definition of the metre,

and **recommends** that national laboratories pursue experimental and theoretical research on optical wavelength and frequency standards, including the development of new techniques for the comparison of different standards over a wide range of wavelength and frequency to improve yet further the experimental basis of the International System of Units.

▮ Requirements for dimensional metrology

Resolution 6

The 21st Conférence Générale des Poids et Mesures,

considering that

- requirements for advanced dimensional metrology continue to increase,
- tolerances in high-technology manufacturing continue to fall and that in some areas they are already at the limit of what is possible today,

- the range over which such requirements exist extends inclusively from the domain of nanotechnology to the domain of geophysics,
- many different areas of metrology call upon realizations of SI derived units that themselves include the metre,
- the most demanding requirements in dimensional metrology often call for the realization of the metre by the simplest and the most direct way possible using stabilized lasers,
- to provide for the future and to ensure that the world's metrological system is capable of meeting future demand, continued basic research is essential,

recommends that national laboratories maintain a wide research base in length metrology that includes the maintenance and development of techniques to meet the diverse and growing demands in the field of dimensional metrology.

The definition of the kilogram

Resolution 7

The 21st Conférence Générale des Poids et Mesures,

considering

- the need to assure the long-term stability of the International System of Units (SI),
- the intrinsic uncertainty in the long-term stability of the artefact defining the unit of mass, one of the base units of the SI,
- the consequent uncertainty in the long-term stability of the other three base units of the SI that depend on the kilogram, namely, the ampere, the mole and the candela,
- the progress already made in a number of different experiments designed to link the unit of mass to fundamental or atomic constants,
- the desirability of having more than one method of making such a link,

recommends that national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future redefinition of the kilogram.

Operational primary frequency standards

Resolution 8

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance of maintaining an adequate number of primary frequency standards to assure the accuracy and long-term stability of International Atomic Time (TAI),
- that new primary standards are being developed using new technology,
- that these new standards are significantly more accurate than the traditional primary standards upon which TAI and Coordinated Universal Time (UTC) have been based in the past,
- that in consequence, the accuracy of TAI and UTC will rapidly become dependent on these new standards,
- that considerable resources are required to maintain primary frequency standards as operational facilities to assure the accuracy of TAI,

requests national metrology institutes and other laboratories developing new primary standards, to make every effort to provide the human and other resources necessary to maintain as operational facilities these new standards upon which the accuracy of TAI and UTC will be based.

Extension of the International Temperature Scale below 0.65 K

Resolution 9

The 21st Conférence Générale des Poids et Mesures,

considering that

- many important research activities are in progress at temperatures below 0.65 K,
- these researches require an accepted temperature scale which closely represents thermodynamic temperatures,
- the direct measurement of thermodynamic temperature is often difficult and time-consuming at temperatures below 0.65 K down to a few millikelvins, but at temperatures much lower than this direct measurements once again become feasible,
- considerable work has already been accomplished towards the development of a temperature scale for the range from 0.65 K down to 1 mK based on the melting pressure of ^{3}He,

invites the International Committee to prepare a ^{3}He melting pressure equation as a function of thermodynamic temperature to serve as the basis for an extension of the International Temperature Scale of 1990 (ITS-90) below its present lower limit of 0.65 K.

Metrology in chemistry

Resolution 10

The 21st Conférence Générale des Poids et Mesures,

recalling Resolution 7 of the 20th Conférence Générale des Poids et Mesures on metrology in chemistry,

considering

- the worldwide development of trade agreements under the World Trade Organization,
- the need to eliminate metrology-related technical barriers to trade particularly in the areas of food science and pharmaceuticals,
- that many environmental and public health decisions are based on measurements in chemistry,
- that the development of worldwide traceability is still far from complete for measurements in chemistry,

recommends that national metrology institutes

- continue to initiate and coordinate national activities in the field of metrology in chemistry, in close cooperation with other relevant bodies,
- in collaboration with the International Committee, work to define the areas of priority and essential international comparisons which are key to the traceability of measurements in chemistry, both worldwide and within regions.

Metrology in biotechnology

Resolution 11

The 21st Conférence Générale des Poids et Mesures,

considering

- the growing importance of biotechnology in human health, food production, forensic medicine and the protection of the environment,
- the need to make accurate measurements traceable to the International System of Units (SI) in these fields,
- the lack of an adequate metrological infrastructure to ensure such traceability,

recommends national laboratories

- to consider developing programmes related to the measurement of quantities important in biotechnology,
- to collaborate with the international scientific unions and the international organizations concerned in the establishment of an adequate international measurement infrastructure to ensure traceability to the SI in measurements in biotechnology.

Special name for the SI derived unit mole per second, the katal, for the expression of catalytic activity

Resolution 12

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance for human health and safety of facilitating the use of SI units in the fields of medicine and biochemistry,
- that a non-SI unit called "unit", symbol U, equal to $1\ \mu\text{mol} \cdot \text{min}^{-1}$, which is not coherent with the International System of Units (SI), has been in widespread use in medicine and biochemistry since 1964 for expressing catalytic activity,
- that the absence of a special name for the SI coherent derived unit mole per second has led to results of clinical measurements being given in various local units,
- that the use of SI units in medicine and clinical chemistry is strongly recommended by the international unions in these fields,

- that the International Federation of Clinical Chemistry and Laboratory Medicine has asked the Consultative Committee for Units to recommend the special name katal, symbol kat, for the SI unit mole per second,
- that while the proliferation of special names represents a danger for the SI, exceptions are made in matters related to human health and safety (15th General Conference, 1975, Resolutions 8 and 9, 16th General Conference, 1979, Resolution 5),

noting that the name katal, symbol kat, has been used for the SI unit mole per second for over thirty years to express catalytic activity,

decides to adopt the special name katal, symbol kat, for the SI unit mole per second to express catalytic activity, especially in the fields of medicine and biochemistry,

and **recommends** that when the katal is used, the measurand be specified by reference to the measurement procedure; the measurement procedure must identify the indicator reaction.

▮ Dotation of the BIPM

Resolution 13

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance of the work carried out by the Bureau International des Poids et Mesures (BIPM) and the services it renders to Member States of the Metre Convention,
- the considerable efforts made by the BIPM to enhance the efficiency of its operation, and its commitment to continue these efforts,
- the conclusions of the report *National and international needs relating to metrology: International collaborations and the role of the BIPM*,
- the decision of the International Committee, based on this report, to broaden the responsibilities of the BIPM,
- the recommendation in the report that, in recognition of the difficult economic situation now existing in many Member States of the Metre Convention, the BIPM annual dotation be held constant in real terms during the quadrennium 2001-2004 at the level determined by the 20th General Conference for the year 2000,

noting that

- on 1 January 1999, the new currency, the euro, came into operation in most States of the European Union and the rates of exchange between the euro and their currencies were definitively fixed,
- on 1 January 2002, most of today's European currencies, including the French franc, and thus the gold franc, will disappear,

decides that

- henceforth the currency to be used in voting the annual dotation for the BIPM will be the euro,
- the fixed part of the annual dotation of the BIPM will be increased in a way such that the sum of the fixed part and the complementary part (defined by Article 6, 1921) of the Rules annexed to the Metre Convention (1875) shall, for those States members of the Metre Convention at the time of the 21st General Conference, be

  8 697 000 euros in 2001 (31 440 039 gold francs)

  8 828 000 euros in 2002 (31 913 610 gold francs)

  8 960 000 euros in 2003 (32 390 796 gold francs)

  9 094 000 euros in 2004 (32 875 212 gold francs).

Appendix A

Convocation of the 21st General Conference on Weights and Measures

Note: The text of the present Convocation was sent to Member Governments in December 1998. A Draft Resolution on the katal was added in April 1999. At the General Conference many of the Draft Resolutions were modified and the final adopted versions are given on pages 323-336. Throughout the Convocation the document on the mutual recognition of national measurement standards is refered to as an "agreement", in fact it was decided to call it an "arrangement" and this is reflected in the final text of the Resolutions.

Convocation of the of the 21st General Conference

The 21st *Conférence Générale des Poids et Mesures* is hereby convoked for

Monday the 11th of October 1999 at 10:00

at the Centre de Conférences Internationales*, 19 Avenue Kléber, Paris 16e.

Constitution of the 21st General Conference

Convention du Mètre (1875): Article 3**

> "The operation of the Bureau International shall be under the exclusive direction and supervision of a *Comité International des Poids et Mesures**** which latter shall be under the control of a *Conférence Générale des Poids et Mesures***** to be composed of the delegates of all the contracting Governments."

Rules annexed to the Metre Convention (1875): Article 7

> "The General Conference, mentioned in Article 3 of the Convention, will meet in Paris on the convocation of the International Committee at least once every six years.
>
> Its task is to discuss and to initiate measures necessary for the propagation and improvement of the metric system, and to sanction new fundamental metrological determinations which may have been made between its meetings. It will receive a report of the International Committee on the work accomplished and will proceed, by secret ballot, to the renewal of half of the International Committee.
>
> Votes at the General Conference take place by States: each State has the right to one vote.
>
> The members of the International Committee have the right to take part in the meetings of the Conference. They may at the same time be delegates of their Governments."

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* The Centre de Conférences Internationales being closed for refurbishment, the President of the French Academy of Sciences had used his good offices to allow the 21st CGPM to take place exceptionally at the Collège de France.

** BIPM translation.

*** Often referred to in this document as CIPM or International Committee.

**** Often referred to in this document as CGPM or General Conference.

Place and dates of sessions of the 21st General Conference

All the sessions will take place at the

Centre de Conférences Internationales*

19, avenue Kléber, Paris 16e

in a room offered by the Ministère des Affaires Étrangères de France with simultaneous translation in French and English.

First session,	Monday	11 October 1999	at	10:00
Second session,	Monday	11 October 1999	at	15:00
Third session,	Tuesday	12 October 1999	at	09:30
Fourth session,	Tuesday	12 October 1999	at	15:00
Fifth session,	Friday	15 October 1999	at	09:30
Sixth session,	Friday	15 October 1999	at	15:00

A visit to the Bureau International followed by a reception at the Pavillon de Breteuil will take place on Wednesday 13 October at 15:00. It is foreseen that the General Conference Working Group on the Dotation of the BIPM will meet at 09:30 on Wednesday 13 October and that a meeting of directors of national metrology institutes of the Member States will take place on Thursday 14 October starting at 09:30 and lasting all day. The meetings of the Working Group on the Dotation and of directors will take place at the Centre de Conférences Internationales. The meeting of directors is not, formally, a part of the General Conference and will be chaired by the President of the International Committee.

It is expected that most of the main points of the agenda up to and including Item 11 will be dealt with in sessions one to four and that sessions five and six will mainly be concerned with the programme and budget of the BIPM and voting on all the Resolutions.

* As was said before, the CGPM finally met at the Collège de France.

Provisional agenda of the 21st General Conference

1 Opening of the Conference
2 Presentation of credentials by delegates
3 Nomination of Secretary of the Conference
4 Establishment of the list of delegates entitled to vote
5 Approval of the agenda
6 Report of the President of the International Committee on work accomplished since the 20th General Conference
7 Report of the CIPM on national and international needs relating to metrology
8 Worldwide traceability of measurement standards
9 Admission of Associates of the General Conference
10 Relations with the Organisation Internationale de Métrologie Légale
11 Reports of Presidents of Consultative Committees
12 Programme of future work at the BIPM
13 Annual dotation of the BIPM
14 Proposals by delegates
15 Renewal of half of the International Committee
16 Votes on all Resolutions
17 Other business
18 Closure of the Conference

Notes on the principal points of the agenda

Note on Draft Resolutions: *the place in the Convocation at which the Draft Resolutions are presented does not necessarily reflect the position in the agenda at which they will be discussed or voted upon. In all cases, votes on the Resolutions are taken on the last day of the Conference after all discussion has been completed.*

1 Opening of the Conference

The 21st General Conference is taking place four years after the preceding Conference. The practice of having quadrennial General Conferences is now well established, since such a periodicity provides sufficient opportunity for Member States to review the important activities carried out under the Convention while not being so frequent that the administrative and other costs of running a General Conference are prohibitive.

2 Presentation of credentials by delegates

To help in the efficient organization of the Conference, it is desirable that the BIPM be informed of the composition of each delegation at least two weeks before the opening of the Conference.

Delegates entitled to vote at the Conference are required, on arrival, to present credentials from an appropriate authority of their Government.

6 Report of the President of the International Committee on work accomplished since the 20th General Conference

Article 19 of the Rules annexed to the Metre Convention stipulates that "The President of the International Committee will give the General Conference an account of the work carried out since the time of the last meeting".

In his report the President will introduce the important developments that have taken place in the affairs of the Metre Convention since the 20th General Conference. Many of these were initiated at the 20th General Conference: the report on the long-term needs for metrology (Resolution 11), the proposed mutual recognition agreement on measurement standards (linked to Resolution 2) and discussions on relations with the Organisation Internationale de Métrologie Légale (Resolution 10). Each of these features

has an agenda item at the present Conference and almost all of the important matters for discussion and decision at the 21st General Conference are related to or stem from one or other of these items. The period since the 20th General Conference has been one of unprecedented activity in the affairs of the Metre Convention.

The report on national and international needs relating to metrology was transmitted to Member States in August 1998. It is the most far-reaching review of international activities in metrology that has ever been carried out and is of immense importance for the future of the Metre Convention. It will be presented and commented upon by the Secretary of the CIPM under Item 7 of the agenda. Many of its conclusions have already resulted in decisions and action by the CIPM or the BIPM, and others are embodied in the Draft Resolutions before this General Conference.

One of the conclusions of this report is that the CIPM should have much closer contacts with the national metrology institutes and with the regional metrology organizations. This led the CIPM to hold meetings with the directors of the national metrology institutes of the Member States of the Metre Convention. Two such meetings have been organized by the BIPM and taken place in Sèvres, the first in February 1997 and the second in February 1998. The third will take place in Paris on Thursday 14 October 1999 during the week of the 21st General Conference. The success of these meetings has clearly shown the need for a forum for the directors to meet outside the formality of a General Conference, and to discuss matters of common interest amongst themselves and with the CIPM and senior BIPM staff. Such meetings will continue to be held in the future.

In addition, the CIPM decided to create a Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). This Joint Committee met for the first time in February 1998.

In consultation with the directors of the national metrology institutes, the CIPM took the initiative in the development of a mutual recognition agreement concerning national measurement standards and calibration certificates issued by national metrology institutes. Resolution 2 of the 20th CGPM laid the formal basis for this agreement. It has been initialled by the directors of the national metrology institutes of thirty-nine Member States of the Metre Convention. The CIPM invites the 21st General Conference to recognize this agreement, which is the subject of Item 8 of the agenda.

To restrict participation in this agreement to States that are members of the Metre Convention may be interpreted as a technical or political barrier to trade. The CIPM is aware of the fact that for many countries the annual contribution to the BIPM is a financial burden even though significant benefits accrue. It is, therefore, proposing to the Conference under Item 9 in the agenda, the creation of a category of Associates of the Conference. One of the aims of creating such a category of Associates is so that a formal link can be made with those States that do not yet wish or are unable to join the

Metre Convention so that they can take part in the mutual recognition agreement and thereby extend traceability of measurements to the SI.

The CIPM report on national and international needs relating to metrology, in considering the role of Consultative Committees of the CIPM, concluded that the range of metrology covered by Consultative Committees should be increased to cover all areas where there is a need for international co-ordination and where this need is not already met by another body. The CIPM has identified three new fields where such a need exists: acoustics, ultrasound and vibration comprise the first, hardness is the second and fluid flow including viscosity, is the third. The need for international co-ordination of measurement standards in the first of these has been shown to be sufficiently urgent and important that the CIPM has created a new Consultative Committee for this field, the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV). For hardness, fluid flow and viscosity, the CIPM has created working groups within an existing Consultative Committee, the Consultative Committee for Mass and Related Quantities. One of the decisions of the CIPM resulting from the study on long-term needs for metrology was that the traditional titles of a few of the existing Consultative Committees had not adequately reflected the breadth of their work. This had tended to strengthen the dangerous misconception existing in some quarters, that the work of the BIPM is narrow and purely scientific, with little relationship to the practical needs of metrology. For example, the traditional title Consultative Committee for the Definition of the Metre (CCDM) had not reflected the much broader activities of that Committee in length measurement and dimensional metrology. In consequence, the CIPM, in September 1997, amended the titles (and acronyms) of four of the Consultative Committees. In addition to the CCDM, which became the Consultative Committee for Length (CCL), the Consultative Committee for Electricity (CCE) became the Consultative Committee for Electricity and Magnetism (CCEM), the Consultative Committee for the Definition of the Second (CCDS) became the Consultative Committee for Time and Frequency (CCTF), and the Consultative Committee for Standards of Ionizing Radiation (CCEMRI) became the Consultative Committee for Ionizing Radiation (CCRI). The acronyms in English continue to follow the names in French.

In 1983 the CIPM proposed to the General Conference a long-term plan for the provision of new buildings at the BIPM. Included were a laboratory building for the laser work, completed in 1984, a building for a library and offices, completed in 1988 and, finally, a building for the mechanical workshop. This final stage of the programme is now under way and will house some offices and meeting rooms as well as the mechanical workshop. It is due to be completed in the year 2001 and will at last give the BIPM up-to-date facilities for the workshop. Until now workshop facilities have been a continuing source of worry to the CIPM because of their inadequacy and failure to meet modern standards of safety. It has also been possible to plan

for the installation of a small laboratory for measurements in chemistry in space to be made available by the move of the workshop to the new building.

Finally, the President will report on the work of the BIPM since the 20th General Conference.

7 Report of the CIPM on national and international needs relating to metrology

Resolution 11 of the 20th General Conference asked the CIPM:

> "to study and report on the long-term national and international needs relating to metrology, the appropriate international collaborations and the unique role of the BIPM to meet these needs, and the financial and other commitments that will be required from the Member States in the coming decades."

In response to this Resolution, the CIPM asked one of its members, Dr W.R. Blevin, to draw up a draft report. Following extensive consultations, a first draft was presented to the CIPM in September 1996 and a further draft was presented in September 1997. The final text adopted by the CIPM at the end of 1997 was published by the BIPM and sent to Member States in August 1998. The full title is *National and international needs relating to metrology: International collaborations and the role of the BIPM. A report prepared by the CIPM for the governments of the Member States of the Convention of the Metre*. Copies are available from the BIPM. This most important document has been widely distributed and is available on the BIPM home page on the world wide web (www.bipm.org). The report and its conclusions are presented to Member States for discussion. The broad content of the report can be summarized as follows:

Numerous issues of concern to national governments continue to increase the demand for international uniformity of measurement and are raising the importance of accreditation and international recognition of measurement and testing services. These issues include: the strong trend towards globalization of world trade; the move to international co-manufacture of goods; the greater technical complexity of most products and services; and the increased concern for health, safety and environmental matters. Recent trade agreements between nations and regions specifically require all signatories to accept the results of measurements and tests performed by any other party. This increased emphasis on the importance to trade of the equivalence of measurement and testing services will have far-reaching effects on national and international measurement systems. This is the background against which future national needs relating to metrology and future needs for international collaboration are assessed. Aspects of metrology which call for continued, often strengthened, international collaboration include: agreements on the definition and realization of the

units of measurement, establishment of national measurement standards of demonstrable international equivalence, laboratory accreditation, legal metrology and documentary standards. It is essential that there be multilateral collaboration in these fields at both global and regional levels.

The report stresses that the programmes undertaken with the authority of the Metre Convention have been of considerable value and concludes that most current programmes need to be continued. There is, however, a widely held view that the BIPM and the Consultative Committees of the CIPM must now do more to help the national metrology institutes of the Member States demonstrate the degree of equivalence of their national measurement standards. This has already been taken up by the CIPM and the BIPM by the introduction of BIPM key comparisons of measurement standards, the co-ordination with these of similar comparisons arranged by regional metrology organizations, and the development of the mutual recognition agreement (see Draft Resolution A).

The role of the Consultative Committees is to be strengthened considerably, with more active work programmes between meetings. The criteria for membership of the Committees have been reviewed and clarified, and observers will be admitted to meetings so that a larger number of Member States may participate. More specific terms of reference are to be prepared for each Committee, and a member of the BIPM scientific staff has been assigned to each Committee to serve as its Executive Secretary. The areas of metrology covered by some Committees are to be broadened, and one or more additional Committees may be established, so that collectively they cover the principal fields of metrology in which collaboration between the national metrology institutes is important for the establishment of international equivalence between standards. Extensions to cover the fields of acoustics, ultrasound, vibration, hardness, fluid flow and viscosity were proposed and have already been taken up by the CIPM, but there are many other fields in which, sooner or later, it will be necessary to establish worldwide equivalence of standards and measurements: the BIPM is uniquely placed to identify such emerging needs, and to initiate appropriate international collaboration.

Many global and regional bodies are now concerned with basic or applied aspects of metrology. At the global level, the BIPM has undertaken to collaborate more actively with the International Laboratory Accreditation Cooperation (ILAC), the Organisation Internationale de Métrologie Légale (OIML), the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC): at the regional level it will collaborate with the regional metrology organizations. An initiative already taken by the CIPM is the creation of the JCRB, chaired by the Director of the BIPM.

Strategies have recently been adopted which allow the BIPM to provide some assistance to developing countries with a view to strengthening their national measurement systems, most particularly by raising the profile of

measurement as a significant component in economic development. Some of these strategies involve close collaboration with the Organisation Internationale de Métrologie Légale, the regional metrology organizations and the International Measurement Confederation (IMEKO).

In this report, the CIPM lays out the role to be undertaken by the BIPM in the early decades of the twenty-first century. This is accompanied by a list of twenty-one specific decisions concerning the future activities of the BIPM and the Consultative Committees. There is an ongoing need for the BIPM to undertake new programmes from time to time, either in response to new requirements set by the Member States or to take advantage of progress in science and technology. The impact of such new programmes on the BIPM budget depends largely on the balance between the need for new staff and the resource savings that can be achieved by terminating or curtailing selected current activities, or by improving efficiency. The long-term building programme developed for the BIPM in the early 1980s is nearing completion and no need is foreseen for the construction of new buildings within the next few decades.

The report ends with an examination of the financial commitments required from the Member States of the Metre Convention, including future needs for funding of the BIPM in the light of foreseeable developments in its activities and taking account of economic restraints now imposed by most Member States. This part of the report is taken up under Item 12 of the Draft agenda. The CIPM proposes the following Draft Resolution A concerning the report:

▮ Long-term needs relating to metrology

Draft Resolution A

The 21st Conférence Générale des Poids et Mesures,

considering

- Resolution 11 of the 20th General Conference, which requested the International Committee to study and report on the long-term needs relating to metrology,
- the study which was completed in 1997 after extensive international consultations,
- the resultant report, entitled *National and international needs relating to metrology: International collaborations and the role of the BIPM*, which was sent by the International Committee in 1998 to the governments of the Member States,

welcomes the many decisions made by the International Committee as a consequence of the study and, in particular

- the progressive broadening of the terms of reference of the Consultative Committees to cover the principal fields of metrology where collaboration

between the national metrology institutes is important, not only in physics and engineering but also in other disciplines such as chemistry and biotechnology,

- the strengthening of the role of the Consultative Committees and the admission of observers to their meetings to enable more Member States to participate,
- the emphasis placed on evaluating and publishing the degree of equivalence of national measurement standards of the Member States and on the establishment of an associated mutual recognition agreement related to national measurement standards and calibration certificates issued by national metrology institutes,
- the introduction of periodic meetings with the directors of the national metrology institutes of the Member States,
- the statement by the International Committee of the role of the BIPM in the early decades of the 21st century,
- the increased collaboration by the BIPM with related international organizations, especially the regional metrology organizations, the International Laboratory Accreditation Cooperation and the Organisation Internationale de Métrologie Légale,
- the considerable progress already made by the International Committee in implementing its decisions,

notes the discussion in the report of the International Committee of the long-term financial commitments required from the Member States,

thanks the many organizations and individuals who have contributed to the study and the report of the International Committee.

8 Worldwide traceability of measurement standards

Resolution 2 of the 20th General Conference laid the foundation for an important initiative which has resulted in a draft worldwide mutual recognition agreement of national measurement standards maintained by national metrology institutes and calibration certificates issued by them. The requirement for worldwide traceability of measurement standards is now universally accepted. The problem faced by national metrology institutes was how to achieve this while avoiding an unmanageable number of bilateral agreements on equivalence of measurement standards. It was clear that within regional groups of co-operating national metrology institutes, multilateral agreements could be envisaged. It was then thought that a worldwide scheme could be set in place through bilateral agreements between regional groups.

At the first meeting of directors in February 1997, a proposal was made by the Director of the BIPM that an attempt should be made to move directly towards a worldwide agreement rather than a network of regional

agreements. This generated much discussion and through subsequent correspondence a broad consensus was reached that such a worldwide agreement should be attempted. After extensive consultation with directors of national metrology institutes and discussion at the meeting of the CIPM in September 1997, a draft agreement was presented to directors at their second meeting in February 1998. After some further amendment a draft text was initialled by the directors or senior representatives of the national metrology institutes of thirty-nine Member States, with a view to reaching agreement on a final text to be signed at a meeting of directors to be held at the time of the 21st General Conference. The draft text initialled by directors was sent to Member States diplomatic representatives in Paris in May 1998 in order to inform Member Governments officially of this proposal.

Reference is made in the draft agreement to the JCRB. The CIPM created this Joint Committee in September 1997 and it held its first meeting in February 1998 under the chairmanship of the Director of the BIPM.

The President of the CIPM will report to the Conference on the latest situation regarding the mutual recognition agreement and will propose that the General Conference adopt the following Draft Resolution B:

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

Draft Resolution B

The 21st Conférence Générale des Poids et Mesures,

considering

- Resolution 2 of the 20th General Conference concerning worldwide traceability of measurements,
- the rapidly increasing emphasis on the need to demonstrate international equivalence of measurements and test results related to trade,
- the increasing number of mutual recognition agreements being negotiated internationally concerning calibration and testing services,
- that the calibration and testing services in each nation depend on a national metrology institute both for their measurement standards and for traceability to the SI,

recognizes that mutual recognition of the national measurement standards and the calibration services of the national metrology institutes is necessary in order to provide the basis for mutual recognition of national calibration and test services generally,

welcomes

- the initiative taken by the International Committee in drawing up a mutual recognition agreement related to national measurement standards and calibration certificates issued by national metrology institutes,

- the decisions of those Member States that have already given authority to the director of the designated national metrology institute in their country to sign the agreement,

invites

- all other Member States of the Metre Convention to participate in the agreement by giving authority to the director of the designated national metrology institute in their country to sign the agreement,
- all Member States to make every effort to implement the agreement and to ensure that all authorities in their country recognize the equivalence of national measurement standards and calibration certificates thereby demonstrated.

9 Admission of Associates of the General Conference

The development of the mutual recognition agreement, treated in Item 8 of the agenda of this Conference and the subject of Draft Resolution B, has highlighted the need to find a way to link to the SI the metrological activities of a much larger number of States than are at present Member States of the Metre Convention. We cannot ignore that world trade increasingly demands traceability of measurements to the SI in all trading nations of the world. We have to accept, however, that there are many smaller or less affluent States that would find it difficult to pay even the minimum annual subscription necessary to be a Member State of the Metre Convention (0.5 % of the BIPM dotation). The CIPM takes the view that the General Conference should take a responsibility for providing a mechanism to establish links to the SI of the measurement systems of all States and Economies including those that are not Member States of the Metre Convention. Participation in the mutual recognition agreement through the regional metrology organizations appears to be a way of doing this. Some formal link to the BIPM is, however, necessary and some financial contribution must be made to cover the costs. The Metre Convention has no provision for a category of "Associate" but, inspired by the OIML Convention, the CIPM proposes that the 21st General Conference create a category of Associates of the General Conference. Associate States and Economies would be eligible to participate in the mutual recognition agreement in a specified way. This proposal, which is supported by the French Government as depository of the Metre Convention, is embodied in the following Draft Resolution C:

▮ Associates of the Conférence Générale des Poids et Mesures

Draft Resolution C

The 21st Conférence Générale des Poids et Mesures,

considering that

- the worldwide measurement system, based on the International System of Units (SI) used in almost every aspect of modern society, rests on the universal application of the decisions of the General Conference,
- all States, not only those that are Member States of the Metre Convention, engage in measurements which are related to trade and need to be traceable to the SI,
- States which are not Member States of the Metre Convention are at present excluded from the activities of the Convention,
- Member States of the Metre Convention support the world's measurement system by devoting considerable financial resources to the BIPM and to their own national measurement systems,
- many smaller States would have difficulty in allocating funds sufficient to meet the cost of membership of the Metre Convention,

and further **considering** the need to maintain close relations with the international scientific unions and other international organizations whose work is related to metrology,

decides

- to assume a responsibility for providing those States and Economies not yet members of the Metre Convention with the means to establish links to the world's measurement system so as to provide recognition of the traceability of their measurements to the SI,
- that an important link can be through participation in the mutual recognition agreement related to national measurement standards now operated by the International Committee,
- that participation in the agreement for such a State or Economy should be by the association of their national metrology institutes with a regional metrology organization that is a member of the Joint Committee of the Regional Metrology Organizations and the BIPM,

and consequently **decides**

- to invite such States and Economies to take part in the General Conference as Associates, thereby establishing the connection with the Member States of the Metre Convention necessary for them to participate in the mutual recognition agreement,
- to invite international scientific unions and other international organizations pursuing activities related to those of the Metre Convention also to take part in the General Conference as Associate Organizations,

- that Associate States, Economies and Associate Organizations of the General Conference participate in the Conference through the appointment of non-voting observers,
- that Associate States and Economies shall pay an annual subscription to the BIPM to meet the cost of providing the services that the International Committee may make available to them; the annual subscription of each Associate State or economy will be determined from its UN contribution, as for Member States but with a minimum equal to 0.05 % of the annual dotation of the BIPM,
- that a State or Economy wishing to become an Associate may do so by application to the Director of the BIPM, either directly or through its embassy in Paris, and by the payment of the first annual subscription,
- that an Associate State or Economy three years in arrears with its subscription cease to be an Associate; it may be reinstated on payment of these arrears.

10 Relations with the Organisation Internationale de Métrologie Légale

Resolution 10 of the 20th General Conference invited the President of the CIPM together with the President of the CIML to appoint a joint working group to identify ways of achieving increased co-operation and effectiveness in the achievement of their objectives and the use of their resources, including, but not limited to, the possibility of merging the two organizations. The same Resolution also invited the CIPM, having received the report of its President, to advise Member States of the Metre Convention of the outcome of the discussions and of its opinion as to whether further action should be taken.

As requested by the 20th General Conference, the President of the CIPM and the President of the CIML established a working group which has met three times, in February 1996, February 1997 and February 1998 with a further meeting planned for February 1999. Since 1998, representatives of ILAC have been invited to meetings of the working groups.

Early in the discussion within the working group, it became apparent to the CIPM representatives that a fusion of the two organizations would offer very little scope for improved efficiency in their operations or effectiveness in carrying out their tasks which could not already be attained by co-operation between the separate organizations. A number of ways were identified, therefore, for the two organizations to co-operate more closely and carry out certain actions together and these are already being implemented. The CIPM was informed of this conclusion in 1996.

An important action carried out by the BIPM, IMEKO and the OIML, and organized by the Physikalisch-Technische Bundesanstalt (PTB, Braun-

schweig), was a meeting on the metrological needs of developing countries and countries in transition which took place at the PTB in June 1998.

Another joint action of the BIPM and the BIML concerns responsibility for the *International Vocabulary of Basic and General Terms in Metrology* and the *Guide to the Expression of Uncertainty in Measurement*. The responsibility for these two documents has, by common agreement among the seven international organizations concerned, namely ISO, BIPM, IEC, IFCC, OIML, IUPAC, and IUPAP, been transferred from the former ISO TAG-4 to a new Joint Committee for Guides on Metrology (JCGM). The new JCGM comprises the same seven international organizations plus ILAC, is independent of ISO and not, therefore, subject to certain constraints that might have hampered future development of these documents. The secretariat of the JCGM is operated jointly by the BIPM and the BIML. The first chairman of the JCGM is the Director of the BIPM.

The President of the CIPM will give a report on the latest results of the discussions within the Metre Convention/OIML working group.

In response to Resolution 10 of the 20th General Conference, the International Committee advises Member States of the Metre Convention that the International Committee has taken action to improve the co-operation with the OIML but that no further action need be taken by them at present in respect of the suggested fusion of the two organizations.

11 Reports of Presidents of Consultative Committees

Reports will be presented by the Presidents of the ten Consultative Committees of the CIPM on work accomplished since the 20th General Conference. Written versions of the reports will be available to delegates at the Conference. The published reports of the meetings of the Consultative Committees cited by the Presidents in their reports are available on the BIPM home page on the world wide web (www.bipm.org).

The following Draft Resolution D, which applies to all areas of metrology, recalls Resolution 1 of the 20th General Conference and once again draws the attention of governments of Member States to the need for critical measurements to be made in SI units:

▮ The need to use SI units in studies of Earth resources, the environment, human well-being and related issues

Draft Resolution D

The 21st Conférence Générale des Poids et Mesures,

considering that

- the effects on the geosphere and biosphere of industrial and commercial activities and of many other human pursuits, as well as natural phenomena, and the consequences for human health and well-being are the subject of major studies worldwide,
- governments are increasingly faced with decisions of great economic and political significance concerning the regulation of these activities,
- the policies of governments are influenced by studies depending critically on accurate and mutually compatible measurements often requiring very large economic investments,
- much of the important scientific evidence required for decisions by governments comes from measurements of small changes in certain key parameters, measurements sometimes extending over several decades,
- certain critical measurements have traditionally been made in *ad hoc* units, based upon special instrumentation or procedures, and not in the well-characterized and internationally agreed SI units,
- experience over many years has shown that measurements not directly linked to the SI cannot be relied upon in the long term, cannot be compared with similar measurements made elsewhere and do not adequately bring out possible relationships with measurements made in other scientific disciplines,
- that increasing demands for reliability in measurements made for medical and therapeutic purposes are leading to more demanding regulation in these areas,

recommends that those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterized SI units so that they are reliable in the long term, are comparable worldwide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Metre Convention.

11.1 The Consultative Committee for Length

The 9th meeting of the Consultative Committee for the Definition of the Metre (re-named the Consultative Committee for Length, CCL) took place in September 1997. Three important matters were treated by the Committee: the first was a revision of the 1992 *mise en pratique* of the definition of the metre; the second concerned the enlargement of the scope of the Committee to take in dimensional metrology; the third dealt with the selection of key

comparisons in the field of length to demonstrate international equivalence of national measurement standards.

The revision of the *mise en pratique* adopted by the CCL, and subsequently approved by the CIPM, reduces the uncertainties given for the wavelengths and frequencies of some of the recommended radiations, includes five new recommended radiations and deletes two radiations that are no longer used. A note was added on the interpretation of the *mise en pratique* of the definition of the metre in the context of general relativity. Draft Resolution E refers to the new *mise en pratique*:

▮ Revision of the *mise en pratique* of the definition of the metre

Draft Resolution E

The 21st Conférence Générale des Poids et Mesures,

recalling that

- in 1983 the 17th General Conference adopted a new definition of the metre,
- in the same year the General Conference invited the International Committee
  - to draw up instructions for the practical realization of the metre (the *mise en pratique*),
  - to choose radiations which can be recommended as standards of wavelength for the interferometric measurement of length and draw up instructions for their use,
  - to pursue studies to improve these standards and, in due course, to extend or revise these instructions,
- in response to this invitation the International Committee made recommendations in 1983 and again in 1992 concerning the practical realization of the metre,

considering that

- science and technology continue to demand improved accuracy in the realization of the metre,
- since 1992 work in national laboratories, the Bureau International des Poids et Mesures and elsewhere has substantially improved the reproducibility of radiations which are suitable for the practical realization of the metre,
- such work has also substantially reduced the uncertainty in the determined values of the frequencies and vacuum wavelengths of some of these radiations,
- a revision of the list of recommended radiations is desirable for many applications, which include not only the direct realization of the metre by means of optical interferometry for practical length measurement, but also spectroscopy, atomic and molecular physics and the determination of fundamental constants,

- the accuracy already achieved and advances now foreseeable in certain space-time measurements require the practical realization of the definition of the metre to be considered in the context of the theory of general relativity,

welcomes the adoption by the International Committee in 1997 of a revised *mise en pratique* of the definition of the metre,

and **recommends** that national laboratories pursue experimental and theoretical research on optical wavelength and frequency standards, including the development of new techniques for the comparison of different standards over a wide range of wavelength and frequency to improve yet further the experimental basis of the International System of Units.

The extension of the range of activities of the CCL to include dimensional metrology is in response to the need to choose and execute key comparisons in this field. The CCL chose a number of artefacts used as dimensional metrology standards to test the principal techniques in each field. Key comparisons were initiated for gauge blocks, optical polygon angle standards, diameter and form standards, and step-gauges and ball plates for testing coordinate measuring machines. In view of the importance of length metrology for science and high-technology industry, the CIPM proposes the following Draft Resolution to the General Conference:

▮ Requirements for dimensional metrology

Draft Resolution F

The 21st Conférence Générale des Poids et Mesures,

considering that

- requirements for advanced dimensional metrology continue to increase,
- tolerances in high technology manufacturing continue to fall and that in some areas they are already at the limit of what is possible today,
- the range over which such requirements exist extends from the domain of nanotechnology to the domain of geophysics,
- many different areas of metrology call upon realizations of SI derived units that themselves include the metre,
- the most demanding requirements in dimensional metrology often call for the realization of the metre by the simplest and the most direct way possible using stabilized lasers,
- to provide for the future and to ensure that the world's metrological system is capable of meeting future demand, continued basic research is essential,

recommends that national laboratories maintain a wide research base in length metrology that includes the maintenance and development of techniques to meet the diverse and growing demands in the field of dimensional metrology.

11.2 The Consultative Committee for Mass and Related Quantities

The Consultative Committee for Mass and Related Quantities (CCM) met in May 1996. The CCM continues to operate through its specialized working groups of which there are seven including a working group on the Avogadro constant. Much of the work of the CCM at this meeting and since has been devoted to key comparisons. The Committee chose a number of key comparisons to cover the fields of mass and pressure metrology and the first round of most of these should be completed in time for the next meeting of the CCM due to take place in May 1999. The areas of metrology covered by the CCM have a wide scientific and industrial importance and all of the national metrology institutes of the Member States of the Convention work in these areas. Regular international conferences are held, devoted to the metrology of pressure and force, which are organized by national metrology institutes in co-operation with the corresponding working groups of the CCM or IMEKO. The Working Group on the Avogadro Constant was created at the request of national metrology institutes to co-ordinate the worldwide effort now being made to determine this constant to high accuracy as a way of providing an alternative definition of the kilogram based on atomic masses. The project is still some way from realization but important progress has been made and problems related to the structure and composition of single crystal silicon have been uncovered.

▮ The definition of the kilogram

Draft Resolution G

The 21st Conférence Générale des Poids et Mesures,

considering

- the need to assure the long-term stability of the SI,
- the intrinsic uncertainty in the long-term stability of the artefact defining the unit of mass, one of the base units of the SI,
- the consequent uncertainty in the long-term stability of the other three base units of the SI that depend on the kilogram, namely, the ampere, the mole and the candela,
- the progress already made in a number of different experiments designed to link the unit of mass to fundamental or atomic constants,
- the desirability of having more than one method of making such a link,

recommends that national laboratories continue their efforts to refine experiments that link the unit of mass to fundamental or atomic constants with a view to a future re-definition of the kilogram.

11.3 The Consultative Committee for Time and Frequency

The Consultative Committee for the Definition of the Second (now the Consultative Committee for Time and Frequency, CCTF) met in May 1996. Unlike most of the other Consultative Committees which have been busy choosing and executing new key comparisons, the CCTF has been for many years demonstrating the degree of equivalence of national measurement standards through its responsibility for International Atomic Time (TAI). Time and frequency are perhaps the two quantities for which there is the most obvious need for international equivalence at the highest level of accuracy. They are also the quantities for which international comparisons can be made to the highest levels of accuracy. Much of the work of the CCTF continues to be devoted to studies of improvements in TAI, its calculation and diffusion as Coordinated Universal Time (UTC), and theoretical work related to these tasks. Improvements in primary clocks and in the means of comparing time and frequency by satellite have increased the stability and reduced the uncertainties in TAI and UTC by nearly a factor of ten since the last General Conference. The fact that the requirements for precise timing in many applications of navigation and communications are so close to the present limits of what is possible, means that there is a powerful driving force from users for improved accuracy in metrology in this field. It is thus important that new developments in primary frequency standards should result as soon as possible in fully operational standards contributing to TAI and UTC. The following Draft Resolution addresses this point:

▮ Operational primary frequency standards

Draft Resolution H

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance of maintaining operational an adequate number of primary frequency standards to assure the accuracy and long-term stability of TAI,
- that new primary standards are being developed using new technology,
- that these new standards are significantly more accurate than the traditional primary standards upon which TAI and UTC have been based in the past,
- that in consequence, the accuracy of TAI and UTC will rapidly become dependent on these new standards,
- that considerable resources are required to maintain primary frequency standards as operational facilities to assure the accuracy of TAI,

requests national metrology institutes and other laboratories developing new primary standards to make every effort to provide the human and other resources necessary to maintain as operational facilities these new standards upon which the accuracy of TAI and UTC is based.

The accuracy of the comparisons of national time scales by means of satellites is continuously improving and some of the parameters used in this work are becoming more and more critical. There is a need to co-ordinate as far as possible the various studies of these parameters and this has been addressed by the CCTF.

11.4 The Consultative Committee for Electricity and Magnetism

The Consultative Committee for Electricity (now the Consultative Committee for Electricity and Magnetism, CCEM) met in June 1997. Electrical metrology has a broad impact not only on industrial and commercial affairs but also in fundamental physics where the macroscopic quantum effects, namely the Josephson and quantum-Hall effects, have made possible many new measurements directly related to fundamental and atomic constants. The CCEM continues to take a close interest in such experiments and an important part of the discussion at the meetings of the CCEM concerns matters related to fundamental constants and the SI. The CCEM Working Group on Electrical Methods to Monitor the Kilogram was established to advise the CCEM and hence the CIPM on this important matter. So far, the experiments in question have not reached a level of reproducibility that warrant any direct measurements related to the international prototype of the kilogram but expectations are that, in due course, they will. The CCEM also monitors closely direct experiments for the realization of the SI electrical units and receives reports on the progress being made in the development of single-electron tunnelling devices as well as recent work aimed at a better understanding of the quantum-Hall effect. Much effort is now devoted by the members of the CCEM to the execution of the key comparisons in the electrical area. A working group on key comparisons first identified a set of comparisons and is now charged with the responsibility of ensuring that they are carried out and evaluated according to the "Guidelines for CIPM Key Comparisons" drawn up by the BIPM. The same working group is charged with examining past comparisons to identify those completed comparisons that can be used provisionally to demonstrate equivalence of national measurement standards. The CCEM also received a report on the activities carried out by its Working Group on Radiofrequency Quantities.

11.5 The Consultative Committee for Thermometry

The Consultative Committee for Thermometry (CCT) met in September 1996. The principal activities of the CCT continue to be those related to the International Temperature Scale, the ITS-90, and determinations of thermodynamic temperature using primary methods. This was the first meeting since 1989 when the text of the ITS-90 was adopted. It was, sadly, overshadowed by the death of its much loved and highly respected President,

Luigi Crovini, which had occurred in October 1995 shortly after the 20th General Conference.

The CCT examined closely the experience gained by national laboratories since 1990 in the realization of the ITS-90, an experience that has fully justified the immense amount of work that went into the development of the new scale in the 1980s. Further studies need to be undertaken, however, and these are being co-ordinated by the five working groups of the CCT. Included are the organization of the key comparisons in thermometry and the evaluation of past comparisons, studies of the defining fixed points and interpolating instruments, determinations of thermodynamic temperature and the extension of the ITS-90 to temperatures below its present lower limit of 0.65 K, and work on thermodynamic temperature determination for black bodies above 2500 K. The last of these topics is a joint project with the Consultative Committee for Photometry and Radiometry. The CIPM proposes the following Draft Resolution concerning the extension of the ITS-90 to lower temperatures:

▮ Extension of the International Temperature Scale below 0.65 K

Draft Resolution I

The 21st Conférence Générale des Poids et Mesures,

considering that

- many important research activities are in progress at temperatures below 0.65 K,
- these researches require an accepted temperature scale which closely represents thermodynamic temperatures,
- the direct measurement of thermodynamic temperature is often difficult and time consuming at temperatures below 0.65 K down to a few millikelvin, but at temperatures much lower than this direct measurements once again become feasible,
- considerable work has already been accomplished towards the development of a temperature scale for the range from 0.65 K down to 1 mK based on the melting pressure of ^{3}He,

invites the International Committee to prepare a ^{3}He melting pressure equation to serve as the basis for an extension of the ITS-90 below its present lower limit of 0.65 K.

The CCT also has a working group on humidity measurements, a working group originally created by the CCM. The creation of this working group was a result of the growing industrial importance of accurate measurements of relative humidity and moisture, often at extremes of high and low humidities and moisture levels.

11.6 The Consultative Committee for Photometry and Radiometry

The Consultative Committee for Photometry and Radiometry (CCPR) met in June 1997. The main items on the agenda concerned the choice and initiation of the key comparisons in photometry and radiometry. Detailed discussions took place on the procedures for carrying out such comparisons and on how the results should be evaluated and presented. Although much of the effort in national laboratories in recent years has been devoted to improvements in spectral radiometry based upon the wide application of cryogenic radiometers, the important industrial needs for accurate photometric standards were reflected in the choice of key comparisons. These include both radiometric and photometric comparisons. Particular attention is being paid to ultra-violet metrology. The CCPR maintains its liaison with the International Commission on Illumination (CIE), which deals with international co-ordination in, among other things, matters related to colour. Since 1985, members of the CCPR have been at the forefront in organizing a series of conferences with the general title NEWRAD which bring together representatives of the metrology, Earth resources, solar physics and space communities. The success of these conferences has led to the formation of a permanent NEWRAD committee which, although not formally linked to the CCPR, will continue to strive to ensure that the increasingly important radiometric measurements related to Earth resources and solar physics are metrologically soundly based. This has not always been true in the past. Resolution 1 of the 20th General Conference addressed this issue but it has proved difficult to persuade those responsible for such measurements that if their results are to be reliable, traceability to the SI is essential. For this reason the CIPM once again draws attention to this problem in Draft Resolution D.

11.7 The Consultative Committee for Ionizing Radiation

The Consultative Committee for Standards of Ionizing Radiation (now the Consultative Committee for Ionizing Radiation, CCRI) met in June 1996 and in July 1997. Accurate measurement standards and traceability to the SI in measurements of ionizing radiation are essential to safeguard human health. The correct dose of ionizing radiation used in radiotherapy for the treatment of cancer can only be assured by accurate measurements traceable to the SI. Adequate protection from ionizing radiation resulting from industrial or scientific use of ionizing radiation also requires accurate traceable measurements. It is the task of the CCRI to assure worldwide traceability of such measurements and hence their reliability. The CCRI operates through three groups known as Section I (radiation dosimetry for x-rays, γ-rays and electrons), Section II (radionuclide measurements), and Section III (neutron measurements). The main tasks of the three Sections are to organize and carry out international comparisons of standards, some of which have already been identified as BIPM key comparisons, and ensure that the primary

standards for the various quantities defined in this field are accurately maintained.

11.8 The Consultative Committee for Amount of Substance

The Consultative Committee for Amount of Substance (CCQM) met in the February of 1996, 1997 and 1998. As a new Consultative Committee, which met for the first time in 1995, the CCQM has tried to establish its visibility as quickly as possible in the worldwide community of analytical chemistry. This it has done with considerable success but not without much effort. It is now clear that the decision of the CIPM to create the CCQM was made at just the right time. The very rapid development in regulations related to international trade has shown that international comparability in analytical measurements is at a level far below what is required. The concept of traceability to the SI is almost unknown in most areas of analytical chemistry and there exists a deep-seated reluctance to change long-standing practices. Even though the CCQM is not alone in working towards the introduction of valid metrology in analytical chemistry, and it is not the group most closely associated with the working chemist, it has now established its own particular role. Among all the organizations working in this field the CCQM is now recognized as the body dealing with the establishment of primary methods of measurement and the co-ordination of metrological work among the national metrology institutes charged with national measurements in chemistry. The CCQM at its most recent meeting chose the first two key comparisons and envisages at least eight others for the near future. The CCQM includes members or observers from Eurachem, the European co-operation in metrology in chemistry, CITAC, a worldwide co-operation in analytical chemistry, and ISO-REMCO as well as IUPAC. It is recognized by all that establishing a sound metrological basis for analytical chemistry comparable with that which exists for most physical measurements will take many years. The CIPM proposes the following Draft Resolutions J and K which draw attention to this important matter:

▮ Metrology in chemistry

Draft Resolution J

The 21st Conférence Générale des Poids et Mesures,

recalling Resolution 7 of the 20th Conférence Générale des Poids et Mesures on metrology in chemistry,

considering

- the worldwide development of trade agreements under the World Trade Organization,

- the need to eliminate metrology-related technical barriers to trade particularly in the areas of food science and pharmaceuticals,
- that many environmental and public health decisions are based on measurements in chemistry,
- that the development of worldwide traceability is still far from complete for measurements in chemistry,

recommends that national metrology institutes

- continue to initiate and co-ordinate national activities in the field of metrology in chemistry, in close co-operation with other relevant bodies,
- in collaboration with the International Committee, work to define the areas of priority and essential international comparisons which are key to the traceability of measurements in chemistry, both worldwide and within regions.

▮ Metrology in biotechnology

Draft Resolution K

The 21st Conférence Générale des Poids et Mesures,

considering

- the growing importance of biotechnology in human health, food production, forensic medicine and the protection of the environment,
- the need to make accurate measurements traceable to the SI in these fields,
- the lack of an adequate metrological infrastructure to ensure such traceability,

recommends national laboratories

- to consider developing programmes related to the measurement of quantities important in biotechnology
- to collaborate with the international scientific unions and the international organizations concerned, in the establishment of an adequate international measurement infrastructure to ensure traceability to the SI in measurements in biotechnology.

11.9 The Consultative Committee for Acoustics, Ultrasound and Vibration

In response to requests from a number of national metrology institutes, the International Committee organized a meeting of experts in March 1998 to examine the need for concerted international action in the metrology of acoustics, ultrasound and vibration. As a result of this meeting, which included experts from the international standardizing bodies ISO and IEC as well as representatives of the national laboratories, the following recommendations were made: (a) that action be taken under the auspices of the Inter-

national Committee for the organization of international comparisons of national measurement standards in these fields and; (b) a Consultative Committee be created.

The CIPM at its meeting in September 1998 considered these recommendations and decided to create a Consultative Committee for Acoustics, Ultrasound and Vibration. The first session of the new Consultative Committee will take place in 1999 and its President will report to the General Conference.

11.10 The Consultative Committee for Units

The Consultative Committee for Units (CCU) met in April 1996 and in September 1998. One of the important tasks of the CCU is to propose to the CIPM the text of the SI Brochure in its successive editions. At its meeting in 1996, the CCU examined a draft of the 7th edition, which incorporated the decision of the 20th General Conference to abolish the class of supplementary units in the SI. The CCU decided to review the text completely and made many small modifications intended to clarify the meaning and render the Brochure more accessible. The 7th edition of the SI Brochure was published in June 1998.

The CCU, at its 13th meeting in September 1998 proposed to the CIPM that the neper be formally accepted as the special name for the dimensionless derived unit "one" for expressing values of logarithmic quantities. The CIPM endorsed this proposal and presents the following Draft Resolution L:

▮ The neper and the bel

Draft Resolution L

The 21st Conférence Générale des Poids et Mesures,

considering that

- the natural logarithm is used to define logarithmic decrement, field level and power level in the system of quantities on which the SI is based,
- quantities and quantity equations on which the SI is based become simplified when the natural logarithm is used,
- in particular, for complex quantities the only useful logarithm is the natural logarithm,
- with the use of the natural logarithm, the radian and neper become coupled and thus should be given a comparable status in the SI,
- the 20th General Conference (1995, Resolution 8) decided to interpret the then supplementary units in the SI, namely the radian and steradian, as dimensionless derived units and consequently to eliminate the class of supplementary units as a separate class in the SI,

- the International Committee through the SI brochure, 7th edition (1998), has accepted the neper, symbol Np, as a special name for the coherent SI unit "one", for expressing the values of logarithmic quantities, when using natural logarithms, and also the bel, symbol B, for expressing the values of such quantities, when using logarithms to the base ten, and has emphasized the importance of stating the reference level,
- there is a need to complete the SI in a consistent way by formally adopting the special name and symbol for the coherent SI unit "one", unit for expressing the values of logarithmic quantities in areas such as acoustics and electrotechnology,

confirms the decision of the International Committee to accept for use with the International System the name bel, symbol B, and its commonly used submultiple the decibel, symbol dB, when using logarithms to the base ten, and

decides to adopt the special name neper, symbol Np, for the SI dimensionless derived unit one, for expressing the values of logarithmic quantities such as logarithmic decrement, field level, or power level, when using natural logarithms.

Note: The Comité International des Poids et Mesures proposed in April 1999 to the 21st General Conference an additional Draft Resolution, Draft Resolution N, related to a new special name, katal, for the coherent SI derived unit mole per second to be used for the expression of catalytic activity.

In making this proposal to the General Conference, the CIPM is acting on the advice of its Consultative Committee for Units (CCU) and Consultative Committee for Amount of Substance (CCQM), both of which have considered the matter and recommended that such a proposal be made.

At its meeting in 1998, the CCU examined a proposal made to it by the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) requesting that for reasons of human health and safety and to facilitate the use of SI units in clinical chemistry, the name katal be formally adopted by the General Conference as a special name for the SI derived unit mole per second for the expression of catalytic activity. The CCU accepted the arguments of the IFCC and made the appropriate recommendation to the CIPM which in turn examined the proposal at its meeting in September 1998. The CIPM, while accepting the arguments of the CCU, decided to consult its CCQM before making a decision. The CCQM at its meeting in February 1999 recommended that the CCU proposal be accepted. In consequence, the CIPM now makes the following proposal to the 21st General Conference.

▮ Special name for the SI derived unit mole per second, the katal, for the expression of catalytic activity

Draft Resolution N

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance for human health and safety of facilitating the use of SI units in the fields of medicine and biochemistry,
- that a non-SI unit called "unit", symbolized U, equal to 1 μmol · min^{-1}, which is not coherent with the SI, has been in widespread use in medicine and biochemistry since 1964 for expressing catalytic activity,
- that the absence of a special name for the SI coherent derived unit mole per second has led to results of clinical measurements being given in various local units,
- that the use of SI units in medicine and clinical chemistry is strongly recommended by the international unions in these fields,
- that the International Federation of Clinical Chemistry and Laboratory Medicine has asked the Consultative Committee for Units to recommend the special name katal, symbol kat, for the SI unit mole per second,
- that while the proliferation of special names represents a danger for the SI, exceptions are made in matters related to human health and safety (15th General Conference, 1975, Resolutions 8 and 9, 16th General Conference, 1979, Resolution 5),

noting that the name katal, symbol kat, has been used for the SI unit mole per second for over thirty years to express catalytic activity,

decides to adopt the special name katal, symbol kat, for the SI unit mole per second for use in the fields of medicine and biochemistry for the expression of catalytic activity,

and **recommends** that when the katal is used, the measurand be specified by reference to the measurement procedure; the measurement procedure must identify the indicator reaction.

12 Programme of future work at the BIPM

A detailed programme of the work to be carried out at the BIPM during the years 2001 to 2004 has been proposed by the International Committee in a document entitled *Programme of future work and budget of the Bureau International des Poids et Mesures for the years 2001 to 2004* which appears in Appendix B (see pages 371-393).

13 Annual dotation of the BIPM

The 20th General Conference decided to increase the annual dotation of the BIPM by 4.5 % per annum from 1997 to 2000. Price increases in France during 1997 and 1998 have been lower than the 2.5 % foreseen at the time of the 20th General Conference and this has helped the BIPM to implement certain of the recommendations made in the report on national and international needs relating to metrology. Of great assistance also has been the fact that in recent years the annual contributions received from Member States have been, on average, close to the dotation voted by successive General Conferences. For example, in the period 1990 to 1997, some 99.4 % of the total dotation voted for this period by the General Conference has been received although yearly fluctuations have been large, in one case exceeding 30 %. Parallel efforts made at the BIPM to improve efficiency by cutting costs where possible and maintaining the same programme but with a smaller number of staff have also borne fruit. The financial situation of the BIPM in 1998 is healthy and in a good position to face up to the future. By careful budgeting, it has been found possible to embark on the construction of the third and final stage of the long-term plan for building, first set out at the 1983 General Conference and referred to in the report of the President of the CIPM. It has also been possible to plan for the installation of a small laboratory for measurements in chemistry in space to be made available by the move of the workshop to the new building. The level of reserves foreseen for the year 2000 is still some 65 % of the annual budget and the increased resources needed by the BIPM pension fund are being provided by the annual budget. All of this is very positive, and the CIPM is pleased to report to governments of Member States that the considerable financial resources given to the BIPM have been well used.

In making proposals to the 21st General Conference for the future funding of the BIPM, however, the International Committee finds itself in a difficult dilemma. It is clear that demands on the services of the BIPM will increase: there will be an increased number of international comparisons; the role of the BIPM Executive Secretaries of the Consultative Committees will increase their work load; the JCRB will require servicing; finally, metrology in chemistry is a rapidly increasing field in which the BIPM must be involved to say nothing of the broad and general increase in international metrology activity driven by the globalization of international trade. The overall impact on the BIPM of the implementation of the mutual recognition agreement is still unclear, although it is bound to be significant. All of this means more laboratory and administrative work, as well as more international conferences and visits so as to develop a deeper understanding and familiarity with the work, needs, and capabilities of national metrology institutes. It is also clear that the majority of governments of Member States are imposing economic restraints on spending such that over the next four-

year period it seems inappropriate to call for an increase in real terms in their contributions to the BIPM.

The CIPM, in its report on long-term needs for metrology, examined the financial situation of the BIPM and made projections of costs extending beyond the next two four-year periods, namely, the periods 2001 to 2004 and 2005 to 2008 for which the dotations will be decided by the 21st and 22nd General Conferences in 1999 and 2003, respectively. After considering several hypothetical scenarios regarding the appropriate level of annual dotation during the decade 2001 to 2010, the CIPM decided to recommend to the 21st General Conference that the annual dotation be held constant in real terms during the quadrennium 2001 to 2004, at the level already determined by the 20th General Conference for the year 2000. It reached this decision in the expectation that, with further careful budgeting, combined with a continuing search for economies and improvements in efficiency, this funding would be sufficient to enable the BIPM to implement the expanded programme for the quadrennium.

In considering the future funding of the BIPM, the CIPM also took into account the other costs to Member States in relation to their participation in the Metre Convention and in the regional metrology organizations. These costs are in addition to the annual payment of the dotation to the BIPM. Some of the CIPM's recent decisions, among them the introduction of key comparisons, the mutual recognition agreement and the broadening of the fields of metrology covered by the Consultative Committees, have the potential to increase these costs somewhat. For tasks such as these, however, which are worldwide in scope and for whose implementation there is general agreement, there is no more cost-effective way of carrying them out than by worldwide collaborative effort. Each Member State is encouraged to contain these additional costs by identifying those technical activities that are most relevant to its national interest and by giving priority to its participation in these. It must be borne in mind, however, that metrology is evolving and expanding in terms of both the number and complexity of its applications, so national programmes in metrology may require progressive extension and modification, the only alternative to additional expenditure being a severe re-assessment of the traditional priorities.

The CIPM at its meeting in September 1998 confirmed the conclusion reached in its report on long-term needs for metrology and decided that the dotation requested from governments of Member States at the 21st General Conference for the four years 2001 to 2004 should be constant in real terms and be at the level of the dotation voted by the 20th General Conference for the year 2000.

A careful analysis of predictions for inflation in France has led the International Committee to the conclusion that a constant level of funding in real terms for the period 2001 to 2004 will require an annual increase of the dotation in monetary terms of 2 % starting from the level fixed by the

20th General Conference for the year 2000. This is embodied in Draft Resolution M which follows:

▮ Dotation of the BIPM

Draft Resolution M

The 21st Conférence Générale des Poids et Mesures,

considering

- the importance of the work carried out by the Bureau International des Poids et Mesures (BIPM) and the services it renders to Member States of the Metre Convention,
- the considerable efforts made by the BIPM to enhance the efficiency of its operation, and its commitment to continue these efforts,
- the conclusions of the report *National and international needs relating to metrology: International collaborations and the role of the BIPM*,
- the decision of the International Committee, based on this report, to broaden the responsibilities of the BIPM,
- the recommendation in the report that, in recognition of the difficult economic situation now existing in many Member States of the Metre Convention, the BIPM annual dotation be held constant in real terms during the quadrennium 2001 to 2004 at the level determined by the 20th General Conference for the year 2000,

noting that

- on 1 January 1999, the new currency, the euro, comes into operation in most States of the European Union and the rates of exchange between the euro and these currencies will be definitively fixed,
- on 1 January 2002, most of today's European currencies, including the French franc, and thus the gold franc, will disappear,

decides

- that the fixed part of the annual dotation of the Bureau International des Poids et Mesures will be increased in a way such that the sum of the fixed part and the complementary part (defined by Article 6, 1921) of the Rules annexed to the Metre Convention (1875) shall, for those States members of the Metre Convention at the time of the 21st General Conference, be the equivalent in euros of

31 596 000 gold francs in 2001
32 228 000 gold francs in 2002
32 873 000 gold francs in 2003
33 530 000 gold francs in 2004

- henceforth the currency to be used in voting the annual dotation for the BIPM will be the euro.

14 Proposals from delegates

Delegates from Member States are requested to let the International Committee know of their wishes or any proposals they would like to submit to the General Conference as soon as possible, but in any case at least six months before the General Conference, so that, in accordance with the decision of the 9th General Conference (1948), "the wishes or proposals thus deposited will be distributed by the bureau of the Comité to all Member States of the Convention at least four months before the opening of the Conference so that delegates may receive the necessary instructions and authority; all other wishes and proposals being presented to the Conference only if the International Committee has time to study them and has approved them".

15 Renewal of half of the International Committee

In conformity with Articles 7 (1875) and 8 (1921) of the Rules annexed to the Metre Convention, the Conference will proceed by secret ballot to the renewal of half of the membership of the International Committee. Outgoing members are first, those who in the case of vacancies have been provisionally elected since the last Conference, and second, those selected by ballot from among the remaining members of the International Committee. Outgoing members are eligible for re-election.

December 1998
revised April 1999

For the Comité International des Poids et Mesures
Pavillon de Breteuil, F-92312 Sèvres Cedex

The Secretary, — W.R. Blevin

The President, — J. Kovalevsky

Appendix B

Programme of work and budget of the BIPM for the four years 2001 to 2004

Note: Throughout the Convocation and the Programme of work and budget of the BIPM for the four years 2001 to 2004 the document on the mutual recognition of national measurement standards is refered to as an "agreement", in fact it was decided to call it an "arrangement" and this is reflected in the final text of the Resolutions.

Introduction

This document provides information on Items 12 and 13 of the provisional agenda of the 21st General Conference (see Convocation of the General Conference, Appendix A, pp. 337-370). Agenda Item 12 concerns the programme of future work at the BIPM and agenda Item 13 concerns the annual dotation, total income and budgeted expenditure, for each of the four years 2001 to 2004.

In its report entitled "National and international needs relating to metrology" sent to Governments of Member States in August 1998, the International Committee (CIPM) laid out the role of the BIPM in the early decades of the 21st century. The Report, included with this volume of the General Conference, lists twenty-one specific decisions made by the CIPM, which directly affect the role of the BIPM. The programme of work which follows should be viewed in the context of these decisions.

The programme of work at the BIPM, Item 12 of the draft agenda of the 21st General Conference, is treated here under the following headings:

1 Length
2 Mass
3 Time
4 Electricity
5 Radiometry and photometry
6 Ionizing radiation
7 Metrology in chemistry
8 General laboratory and scientific services
9 General administrative services
10 Buildings and grounds
11 Staff
12 Contribution to the pension fund

1 Length

1.1 International comparisons

The main activity of the Length section continues to be the international comparisons of laser frequencies selected by the CIPM as the reference frequencies for the *mise en pratique* of the definition of the metre. The long series of comparisons at a wavelength of 633 nm using helium-neon lasers stabilized on absorption lines of iodine, an ongoing project since 1972, was selected by the Consultative Committee for Length (CCL) (the former CCDM) at its meeting in 1997 as one of the key comparisons in length metrology. This series will continue since 633 nm remains the wavelength most commonly used by national laboratories in their realization of the definition of the metre. Increasingly, comparisons are made by transporting the BIPM standards to a national metrology institute (NMI) chosen to allow a number of other national laboratories in the region to bring their standards at the same time to the same institute to make a multilateral comparison. International comparisons also take place at other wavelengths, for example $\lambda \approx 3.39$ μm related to new determinations of the Rydberg constant, or during realizations of the frequency chain from the caesium clock to the visible. In these cases the BIPM will continue to act as a reference laboratory holding stable standards that can be used to link measurements in different laboratories made at different times.

1.2 Recommended radiations for the *mise en pratique* of the definition of the metre

Work will continue on the improvement of the stability and reproducibility of transportable laser frequency standards to support the programme of international comparisons mentioned above. It is not possible to work on all of the radiations specified by the CIPM in 1997 for the realization of the metre. However, by careful examination of the needs of national laboratories and by taking account of advances in physics, it is possible to make a reasonable choice of the most advantageous radiation and laser upon which we should concentrate our efforts. At present, and probably for the next four years, it seems likely that the frequency-doubled radiation of the Nd:YAG laser at a wavelength of $\lambda \approx 532$ nm will be an important area of work. Similarly, considerable progress is being made in the development of diode lasers as frequency standards stabilized on iodine at $\lambda \approx 633$ nm and rubidium-stabilized diode lasers at $\lambda \approx 778$ nm. As part of this work, the manufacture of iodine cells for iodine-stabilized lasers manufactured outside will continue and as time permits we shall continue the study of the factors that limit the reproducibility of such cells, in particular the effects and identification of gaseous impurities.

1.3 Gravimetry

The accurate measurement of the acceleration due to gravity, *g*, continues to be required by the geophysics community. The maintenance of the worldwide gravity network, whose reference point A is at the BIPM, requires periodic international comparisons of absolute gravimeters. These are organized by the BIPM in collaboration with the International Union of Geodesy and Geophysics and the International Association of Geodesy. The next such comparison is due to take place at the BIPM in 2001. Improvements of our gravity stations are planned before this comparison. The measurement of *g* at the BIPM is now made using a commercial absolute gravimeter and, although little research is now carried out here on the development of such instruments, maintenance and operation requires a modest effort that will be continued.

1.4 Dimensional metrology: nanometrology

A small effort will continue in the field of dimensional metrology at the nanometrology level in the development of optical methods of measuring the spacing of line scales.

2 Mass

2.1 Manufacture and calibration of mass standards

The BIPM will continue to supply NMIs of Member States of the Metre Convention with 1 kg platinum-iridium standards made to match the mass of the international prototype within 1 mg. These new prototypes are currently calibrated with an uncertainty of 4 μg and subsequently take part in the periodic calibrations organized by the BIPM. The new diamond-machining lathe presented to the BIPM in 1998 by a Japanese non-profit foundation (Japan Society for the Promotion of Machine Industry), and now in course of commissioning at the BIPM, will be used for the manufacture and adjustment of all these new standards.

Although the principal task of the BIPM with respect to calibrations of mass standards concerns 1 kg Pt-Ir prototypes, calibrations are also made of 1 kg stainless steel standards. These are carried out both for NMIs whose national standards are of stainless steel and for institutes that rely on stainless steel artefacts as secondary standards. The balances and other equipment necessary not only to provide these calibrations but also to provide the calibrations and density measurements of Pt-Ir prototypes must always be maintained at the highest level with the ability to introduce latest technology as soon as it is available. Some of these developments we make ourselves but others are brought in from outside. Linked to the calibration service is the

need to monitor the density of air. New equipment using novel methods as well as classic measurements of pressure, humidity and carbon dioxide content will be required during the period 2001 to 2004. The development will continue of improved methods of measuring the density of materials used in mass standards.

2.2 Balance development

In 1998, the BIPM commissioned its new flexure-strip balance, the FB-2, which is based on flexure strip technology developed at the BIPM during the past fifteen years. Up to eight 1 kg standards can be compared automatically. Optimization of the system for automatic mass exchange has been as important as the flexure design in achieving overall success. The FB-2 balance is operational in both air and vacuum. It has a type A standard uncertainty in the comparison of two 1 kg masses of less than 0.1 μg.

Since it has become clear that the FB-2 is uniquely suited to vacuum weighing and related research, a new commercial balance has been bought for future calibration work. This new balance, made by Metrotec to our specifications, complements the Mettler-Toledo HK 1000MC acquired some years ago to replace the NBS-2 in use since 1970.

2.3 Stability of Pt-Ir and other mass standards

The long-term stability of Pt-Ir mass standards is not well understood but is being addressed in experiments designed to monitor the stability of the kilogram. Several promising experiments are under way to do this in terms of fundamental constants of physics. These are all complicated and costly research projects. For the moment, the BIPM has no similar effort. Nevertheless, we take a keen interest in these experiments and participate wherever our expertise can be useful. During the period 2001 to 2004, the FB-2 will be one of the main tools used for research aimed at a better understanding of the surface effects that limit the stability of mass standards in air and also in vacuum.

One feature of all the kilogram experiments is that they are carried out in vacuum. Therefore they all will employ some mass artefact capable of making the transfer between vacuum and atmospheric conditions with low uncertainty. Questions of air buoyancy and surface stability will be of major importance. We expect to study these with the FB-2 balance. At the same time we also recognize the fact that other methods can be used. For instance, we are acquiring a refractometer, recently developed at the BNM-INM, optimized for monitoring changes in air density.

The short-term stability of Pt-Ir mass standards depends in large part on their recent history of cleaning and storage. The Physikalisch-Technische

Bundesanstalt (PTB) has applied ellipsometry to the study of the effects of cleaning and the subsequent growth of surface films. This technique seems particularly useful since it is non-destructive and potentially absolute. We are acquiring equipment to embark upon studies in this area. The techniques will also be applied to surfaces of stainless steel and single-crystal silicon.

2.4 Studies of anelasticity and gravitational experiments

The programme of research on the anelastic properties of materials used in balance suspensions, carried on at the BIPM since the 1980's, will continue. It is hoped that time will be found to pursue work on suspensions made from single crystal-silicon, a topic that was started in 1988 but not continued due to lack of time. The measurement of the Newtonian constant of gravitation at present under way is likely to extend into the early part of the period 2001 to 2004.

3 Time

3.1 Computation and diffusion of TAI and UTC

Since the 20th General Conference in 1995, the quality of the timing data used for TAI computation has further improved. Around 75 % of the clocks are either commercial caesium clocks of the new type or active, auto-tuned hydrogen masers, and they contribute 89 % of the total weight of TAI. The TAI algorithm has been modified twice: since 1 January 1996 TAI and UTC are calculated for all modified Julian dates ending in 4 and 9 (one point every five days); as of 1 January 1998 the weighting method has been changed to adopt a relative maximum weight of a clock, with the calculation interval of TAI reduced from two months to one. The efficiency and reliability of the data collection, calculation and diffusion of TAI and UTC are continuously kept under review. Further automation is planned of the processes involved, taking advantage of recent developments in electronic communication and data treatment facilities at the BIPM.

As it is now possible to obtain clock comparison data from distant clocks in near real time, the question of the production and diffusion of time scales available in real time that predict UTC as precisely as possible will become very important. We shall have to consider these new applications, whilst maintaining the current status of the reference time scales TAI and UTC.

The introduction of new, more accurate, primary frequency standards has also improved the accuracy of TAI. Most of these are “classical” caesium beam standards, some of them using optical techniques for the excitation and detection of the atoms. The first results of a primary standard using cold atoms in a fountain geometry were submitted in 1995. This is a first step

towards a larger number and greater diversity of frequency standards, as recommended on several occasions in the past by the Consultative Committee for Time and Frequency (CCTF) (then the Consultative Committee for the Definition of the Second, CCDS). In the future we hope to receive data from a larger number of primary frequency standards using cold atoms. As these standards operate only intermittently and over limited periods in time, specialized frequency comparison techniques are needed to compare them with each other and to transmit their accuracy to TAI. More generally, the reduced uncertainties of such standards and their increasing number will require a more detailed understanding of their operation in order to optimize their use in TAI.

3.2 Clock comparisons

Clock comparisons are now carried out employing GPS for all links used for TAI. However, the GPS C/A-code single-channel common view method is now barely precise enough, owing to the improvement in the quality of the clocks and the reduction of the interval between the dates of calculation from ten days to five days. In future it will be necessary to use all GPS or GPS+GLONASS satellites in view and to consider techniques that use the carrier phase or the precise code (P code). Such developments go hand in hand with the now generalized use of precise ephemerides and a better determination of ionospheric and tropospheric corrections. We shall also have to consider the use of two-way techniques in all cases where they will improve the precision; their effective introduction in the calculation of TAI is already imminent. The improved accuracy and stability of new clocks and primary standards (e.g. fountain clocks) will lead to new demands for accuracy in time transfer. In consequence, improved clock comparison techniques must be developed to ensure that their progress matches at least that of the clocks.

3.3 Space-time reference systems

In 1997, the BIPM and the International Astronomical Union (IAU) created a Joint Committee on General Relativity for Space-time Reference Systems and Metrology. The committee aims to present its first resolutions to the CIPM and the IAU in 2000. The improvement of the clocks and the prospect of their operation in space, as well as the refinement in clock comparisons and the link between these techniques and those of space geodesy, open new fields of study calling for collaboration in the areas of fundamental physics and reference systems.

3.4 Dynamical time scales

Timing of millisecond pulsars is one of the experiments that requires reference time scales of utmost long-term stability. On the other hand, it is possible that the stability of pulsar rotation periods will provide information on the very long-term stability of atomic time scales. We shall maintain an interest in this and any other technique that can give rise to dynamical time scales (binary pulsars, solar system ephemerides, etc.)

3.5 Time laboratory

The time laboratory has considerably increased its number and range of both GPS and GLONASS receivers to meet the increasing importance of receiver calibrations for TAI. Maintenance of the equipment at a high level of quality and reliability is necessary in order to meet the increase in calibration requirements. At the same time it is imperative that we gain competence in any new clock comparison technique accessible to the resources of the BIPM.

4 Electricity

4.1 Maintenance of a representation of the volt, international comparisons and calibrations

The basic reference standards of the BIPM for international comparisons and calibration of voltage standards are 1 V and 10 V Josephson array standards. The ongoing programme of comparisons of national representations of the volt made by transporting BIPM Josephson systems will continue. To date, some twenty such comparisons have been made and these are designated as one of the key comparisons by the Consultative Committee for Electricity and Magnetism (CCEM). For all NMIs including those that do not yet have Josephson arrays as their reference standards, the series of bilateral comparisons using BIPM Zener standards will continue. A small group of BIPM Zener standards is at the disposal of NMIs wishing to participate in bilateral comparisons. Much of the work of the BIPM in this field is aimed at improving the stability, reliability and ease of use of its Josephson standards and understanding more completely the behaviour of its Zener travelling standards. This will continue as will the calibration service for Zener standards sent to the BIPM by NMIs. Very few Weston cells are now sent to the BIPM for calibration.

4.2 Maintenance of a representation of the ohm, international comparisons and calibrations

The basic reference standards of the BIPM for international comparisons and calibration of resistance standards are its quantum-Hall resistance standards. The programme of on-site comparisons of quantum-Hall standards will continue but is likely to be less extensive than that for the Josephson standards since travelling wire-wound resistors are relatively much more stable than the comparable voltage standards. The programme of bilateral comparisons of resistance standards using the BIPM travelling standards allows the comparison of laboratories' standards with an uncertainty of about 5 parts in 10^8. The calibration of resistance standards for NMIs is an important part of our activity and will continue. During the period 2001 to 2004, improvements will be made to the quantum-Hall systems as understanding of the physics of these devices progresses.

4.3 Capacitance standards derived from the quantized-Hall resistance

Since 1998 the BIPM has maintained capacitance standards derived from the quantized-Hall resistance through a chain of impedance bridges. International comparisons of capacitance standards, part of the key comparison series, and calibrations are now part of the BIPM programme. This work requires the measurement of the quantum-Hall resistance at a frequency of 1.6 kHz and in consequence that we participate in the study of the behaviour of quantum-Hall devices at these frequencies.

4.4 Studies of the stability of electrical standards and detectors

We are continuing our use of low-frequency spectral analysis techniques, below 10 Hz, to examine the stability and noise characteristics of nanovoltmeters, detectors, standard cells and Zener-diode standards. The results of a preliminary study carried out in 1998 indicate that this is a powerful method of analyzing many types of measurement data that up to now have not been examined in this way. This work will continue.

5 Radiometry and photometry

5.1 Radiometry

The reference standard for all BIPM measurements in radiometry and photometry is the cryogenic radiometer. The development and characterization of stable transfer detectors continue with plans for extension to the infrared and ultraviolet regions of the spectrum.

The sodium heat pipe black-body source operating at a temperature near 1000 °C, due to be installed during 1999, will be used to establish a spectral responsivity scale in the near infrared. Filter radiometers characterized at wavelengths in the visible will be calibrated against the cryogenic radiometer and used to determine the temperature of the black body. From this information and the Planck formula the spectral radiance of the black body can be calculated. This will then be used to calibrate other filter radiometers in the near infrared. Filter radiometers calibrated in such a way at about equally spaced wavelengths allow calibrations to be made at other wavelengths by interpolation. This work will be extended to allow measurements of spectral irradiance referred to the black-body source and hence to the cryogenic radiometer.

Using the diamond-turning lathe at the BIPM, work will begin in 1999, extending through the period beyond 2001, aimed at the accurate manufacture of apertures required in radiometry and photometry, together with the measurement of their cross-sectional areas using novel techniques.

The BIPM will continue to participate, from time to time as the pilot laboratory in some of the key comparisons in radiometry chosen by the Consultative Committee for Photometry and Radiometry (CCPR).

5.2 Photometry

After a transitional period beginning in 1999, the photometric standards of the BIPM will be fully based on the newly-developed detector methods linked to the cryogenic radiometer. In this method, photometers fitted with precision apertures are calibrated spectrally against the cryogenic radiometer to determine their luminous responsivity. Luminous intensity measurements can then be made by placing these photometers at a known distance from a source. These calibrated photometers are also used to determine the luminous flux introduced from an external source into the BIPM integrating sphere. This known flux is then used to calibrate lamps of unknown luminous flux which are placed inside the sphere. The traditional reference standards based on a group of lamps will then cease to be used. It is expected that this will result in a much improved stability and reliability of the luminous flux and the luminous intensity standards at the BIPM. One of the advantages of the new method is that it can be reproduced at any time with little effort. The development and commissioning of this new method will extend into the period 2001 to 2004. The BIPM will continue to provide calibration services of lamps for photometric quantities to NMIs that request them.

The BIPM has been the pilot laboratory for the key comparison of luminous responsivity and will continue to be ready to repeat this and other key comparisons based on lamps, luminous flux and luminous intensity, whenever the CCPR decides that they are necessary.

6 Ionizing radiation

6.1 Dosimetry

A large number of dosimetry comparisons are taking place in the current four-year period as NMIs are updating their dosimetry comparisons, particularly those related to ^{60}Co, ready for the key comparison database. This trend is likely to continue with comparisons in the x-ray ranges as many of these earlier comparisons are more than ten years old. Periodic calibrations will continue of transfer instruments used as secondary standards by NMIs which have no primary standards. The BIPM also participates in comparisons using passive dosimeters, particularly for the Secondary Standards Dosimetry Laboratories (SSDL) of the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO). The IAEA standard is traceable to the BIPM.

The ionometric standard of absorbed dose to water for ^{60}Co developed at the BIPM and its comparison with the standards of a number of national laboratories based on other methods will be supplemented by the development of a graphite calorimetric standard during the next four years. This will enhance the robustness of the key comparison results for absorbed dose to water. An international comparison has been organized by the BIPM for NMIs operating high-dose (kGy) facilities. It is likely that this will result in further such comparisons.

The BIPM has developed a transfer system for the comparison of high-energy x-ray beams based on ionometric measurements. A calorimetric standard for high energies is being developed which will ultimately replace the transfer system at these energies. It is anticipated that high-energy comparisons using the BIPM transfer system will be much in demand. Investigations will be undertaken to consider the implications for the BIPM of extending its comparisons to high-energy electron beams.

6.3 Radionuclides

The International Reference System (SIR) continues to expand its database and provide the key comparison reference values particularly for gamma-emitting radionuclides. Pure beta emitters are being sent to the BIPM for analysis and reference values will be available for these in the future. Radionuclides with more complex disintegration schemes require further work before they too can be included. The work on the SIR will continue.

The periodic organization and analysis of comparisons with a specific radionuclide continue to be major tasks for the BIPM. These comparisons are selected by Section II of the Consultative Committee for Ionizing Radiation (CCRI) to satisfy the requirements of the NMIs. Each comparison is linked

through the BIPM to the SIR so that the NMI comparison values can be added to the SIR database.

Research will continue on developing new methods of activity determination such as the triple-to-double coincidence ratio method (TDCR) and on the identification of, and correction for, impurities in radionuclide solutions using hyperpure germanium spectroscopy.

7 Metrology in chemistry

The programme of metrology in chemistry approved by the CIPM in 1998 will begin with the refurbishment of laboratory space during the second half of 1999. It is planned to recruit one of the four new staff planned for this work during 2000, and the remaining three during 2001. The detailed plan of activities will be decided in consultation with experts from the Consultative Committee for Amount of Substance (CCQM) during 1999 and 2000 but will be in the field of gas analysis. It is too soon here to give details but the programme will most probably include the preparation of reference gas mixtures by weighing and the analysis of gas mixtures, initially by gas chromatography and in due course by mass spectrometry, with plans for participation in key comparisons as soon as possible.

8 General laboratory and scientific services

8.1 Mechanical workshop

The transfer of the workshop into the new building (see the notes on Agenda Item 6 in the Convocation, Appendix A) should take place during the year 2001 and thus most of the financial commitment will be engaged before the beginning of the period 2001 to 2004. The new building, which will at last provide facilities for the workshop that meet modern standards of safety and efficiency, should considerably enhance the productivity of the service ; at present the workshop is distributed in three different buildings. The use of computer-aided design and numerically controlled machines will continue to be central to the operation of the mechanical workshop. In the new building provision is made for temperature-controlled space for metrology and will house the form and dimension measuring machines now operating in less than ideal conditions. The new diamond-machining lathe presented to the BIPM in 1998 by a Japanese non-profit foundation (Japan Society for the Promotion of Machine Industry) will be used for the manufacture of platinum-iridium prototype kilogram mass standards and other applications where extreme precision in manufacture is required. Insofar as it is possible within the budgetary constraints, the mechanical workshop will continue to be equipped with the most up-to-date and efficient machine tools and

measuring instruments that allow the demanding requirements of a metrology laboratory to be met.

8.2 Temperature and pressure measurements

The capabilities for routine calibrations in thermometry for the room-temperature region and in pressure for the atmospheric pressure range will be maintained for the internal use of other sections at the BIPM.

8.3 Information technology

Within the BIPM there is an increasing need to have an efficient and up-to-date information technology infrastructure. This is required not only for the scientific work but also for internal secretarial and editing functions, for external communication and for the BIPM key comparison database (see below). An important part of the work in the Time section relies on data sent to the BIPM on a regular basis by some sixty laboratories and observatories around the world. It is essential that this data be received in a reliable and efficient way.

We shall continue to provide an up-to-date BIPM web page containing useful information about the BIPM, the Metre Convention, the various Committees of the CIPM and their publications. Useful links to the web pages of NMIs are included. The BIPM web page includes a "mirror" site of the list of CODATA fundamental constants held by the NIST.

8.4 The BIPM key comparison database

The mutual recognition agreement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes called for the creation of a single worldwide database that would contain the results of key comparisons. Key comparisons are the technical basis of the agreement. The database is being constructed at the NIST and is in the process of being transferred to the BIPM. It will progressively be updated with the results of key comparisons as they are approved by the Consultative Committees. The key comparisons will be those carried out by the Consultative Committees, by the regional metrology organizations and by the BIPM. It is expected that the database will grow in importance and that developments in its structure and range are to be foreseen. Included in the database will be the calibration measurement capabilities of the participating NMIs.

9 General administrative services

9.1 Finance, personnel and general administration

Finance, personnel and general administration are under the responsibility of one professional helped by three part-time assistants whose combined time is equivalent to a total of 1.7 assistants. The consequent total number of administrative staff today is not significantly larger than it was some thirty years ago and is the absolute minimum required to run these services.

9.2 Secretariat

The secretariat of the BIPM consists of two professionals and two secretaries, the former comprising the secretary-cum-personal assistant to the Director and a librarian who also assists in BIPM publications and translations. New technology is used for all typing and editing work and the internal computer network is, of course, linked to the secretariat. The total number of staff in the secretariat has fallen from five to four over the past five years with the retirement of a third professional who was not replaced. No increase in secretarial staff is foreseen.

9.3 Publications

The publications of the BIPM are an essential part of its activities and all modern means of communication are actively employed. The reports of the meetings of the General Conference, of the CIPM and of the Consultative Committees, and the successive editions of the SI brochure are the main formal publications of the BIPM. Produced in French and English, these are distributed to all Member States, to NMIs and also widely among the metrology community. These documents are on sale from the BIPM electronic bookshop and are available in this form free of charge from the BIPM website. The other main publication of the BIPM is the journal *Metrologia*, now in its thirty-fifth year of publication. Since 1997 *Metrologia* has also been published on-line. The electronic version is available free of charge to subscribers to the hard copy. Work is under way to extend the electronic access to earlier volumes, to create a powerful, fully searchable, electronic reference tool. A database containing titles and authors' names from Volume 1 onwards is already available. *Metrologia* now publishes six issues per year, normally four issues for contributed articles covering a wide range of metrological matters, including international reports that contain summaries of the results of key comparisons, one special issue made up of commissioned review articles covering a special topic and one Conference issue comprising papers from a Conference of metrological interest. On average, *Metrologia* contains about 600 pages per annual volume although

recent conference proceedings have burgeoned to the extent of almost doubling this figure. The staff responsible for publications is headed by the editor of *Metrologia* and includes the assistant editor of *Metrologia*, part of the time of the librarian and one part-time secretary.

In addition to contributing to BIPM publications, the scientific staff publish the results of their work in refereed journals, including but not exclusively *Metrologia*, and present the results of their work at scientific conferences. In recent years some twenty to thirty publications in refereed journals and a dozen publications in proceedings of conferences are published annually by the BIPM staff.

9.4 Library

The library of the BIPM continues to be a part of the infrastructure of the laboratory essential to the efficient pursuit of the scientific work. The number of journal subscriptions remains essentially constant, but as interest and work evolve the individual journals taken are subject to change. The creation of a new section for metrology in chemistry will require an expansion of the library into this new area, but in order to keep the costs under control this will have to be at the expense of some of the less commonly used journals in the traditional areas of work at the BIPM. Unfortunately, experience has shown that the cost of subscriptions to scientific journals increases at a rate above that of inflation. As a result, the more expensive journals, unless they are considered part of the BIPM core collection, are abandoned. Subscription to Contents journals is an efficient and cost-effective way of keeping abreast of publications not held in the library.

9.5 Travel and transport of equipment

In recent years the cost of travel and transport of equipment has increased from 1.8 % of annual budget in 1990 to about 3.4 % in 1998. This increase arises in large part from the additional costs incurred by the much extended programme of international comparisons made by transporting BIPM reference standards to national laboratories. The costs of transporting iodine-stabilized lasers, Josephson voltage standards and quantum-Hall standards account for most of this increase. The benefits to national laboratories do, however, far outweigh this small increase in cost to the BIPM, so that these and other similar programmes will continue. Administrative costs related to customs formalities can sometimes be heavy but this is part of a wider problem that appears to have no general solution, related to the customs formalities encountered during international exchange of measurement standards. Travel by the scientific staff and the Director to national laboratories, conferences and meetings related to metrology are an essential

part of the activities of the BIPM and will continue. The main cost of such travel is not the direct financial one but the time taken. The number of invitations to take part in meetings and conferences as well to visit national laboratories continues to increase and many must be refused simply for lack of time.

10 Buildings and grounds

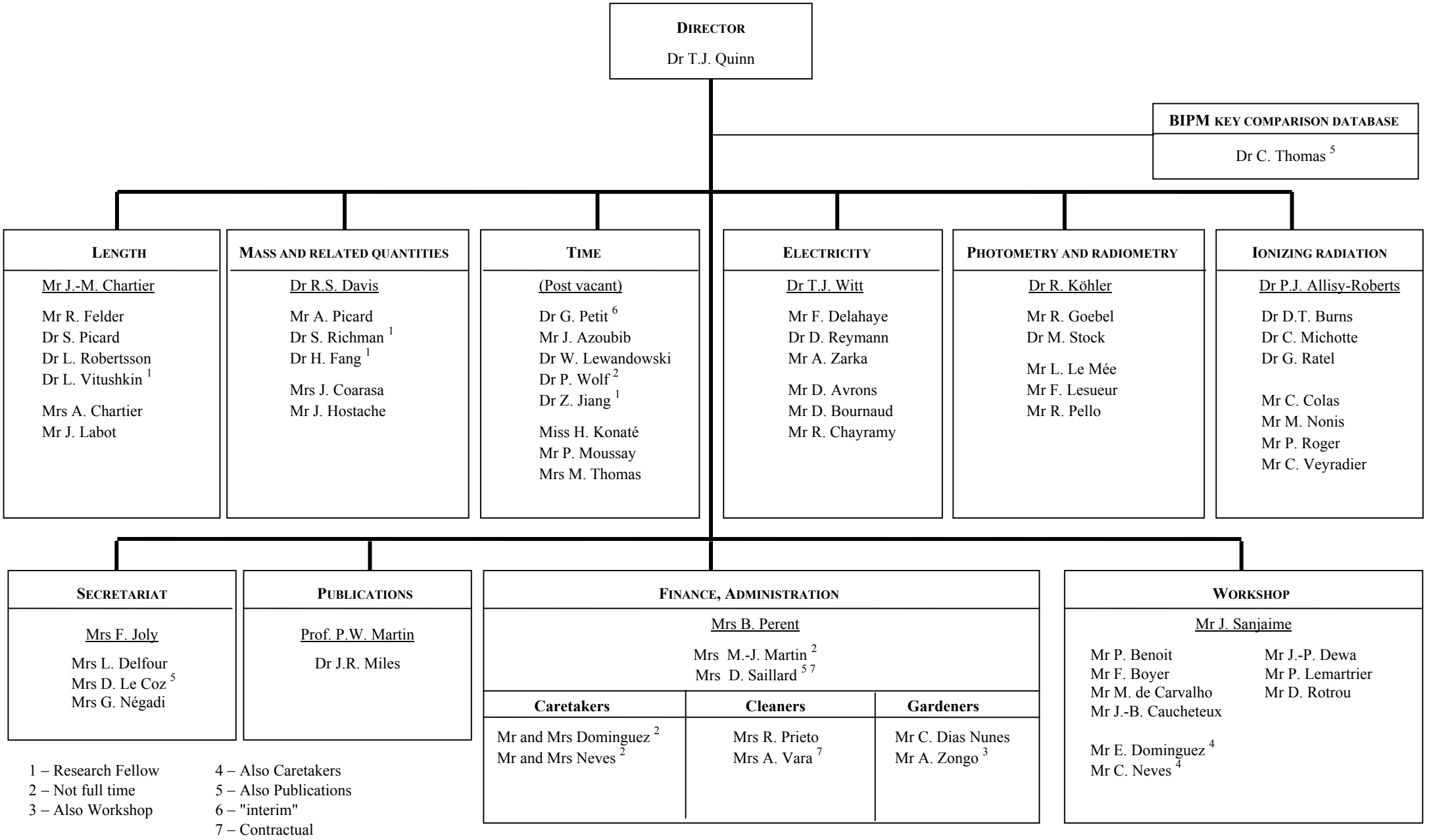
The Pavillon de Breteuil is an historic site and both the Pavillon itself and the grounds must be maintained to a high standard. The maintenance of buildings ranging in date from the time of Louis XIV (the Pavillon de Breteuil) to the present day is not only expensive but requires a wide range of skills and techniques. The maintenance of adequate air conditioning in the laboratories is a major task that requires continual surveillance and updating of equipment but it is one of the essential requirements for today's metrology. The construction of the new building for the workshop, offices and additional meeting rooms, completes the long-term plan for building presented to the 17th General Conference in 1983 and mentioned at every succeeding Conference. There are no future plans for extensions to or construction of buildings at the BIPM. Major renovations of the buildings will, however, continue to be required from time to time either to take account of new requirements resulting from changes in programme, such as the refurbishment of part of the Ionizing radiation building for metrology in chemistry, or simply the updating of old installations.

11 Staff

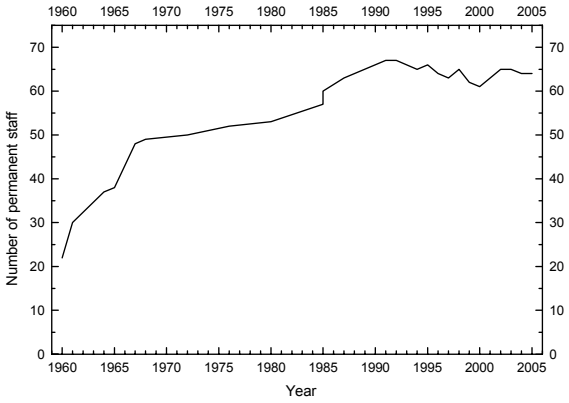
The total number of full-time equivalent permanent staff employed at the BIPM on 1 January 1999 was 62 (cf. 66 on 1 January 1995). These staff are distributed among the various sections as shown in the organization chart on the following page. The organization chart includes Research Fellows employed for fixed periods, normally two years, and it indicates which staff are part-time and on contract. The evolution in the number of staff since 1960 and its predicted numbers up to the year 2004 are shown in the Figure below. The average age of all staff on 1 January 1999 was 47 years and that of the scientific staff 46 years (cf. 47 on 1 January 1995).

ORGANIZATION OF THE BUREAU INTERNATIONAL DES POIDS ET MESURES

1st March 1999



1 – Research Fellow
2 – Not full time
3 – Also Workshop
4 – Also Caretakers
5 – Also Publications
6 – "interim"
7 – Contractual



12 Contribution to the pension fund

An actuarial study made in 1994 indicated that the number of BIPM pensioners would double by the year 2010. To prepare for this, the CIPM decided in 1994 to increase the annual allocation to the pension fund each year from 1996 to 2008 by an amount equivalent to 2 % of the salaries.

13 Annual dotation of the BIPM

The Comité International des Poids et Mesures, in the Convocation to the 21st General Conference, asked the Conference to adopt the equivalent in euros of the following dotations for the years 2001 to 2004.

2001: 31 596 000 gold francs

2002: 32 228 000 gold francs

2003: 32 873 000 gold francs

2004: 33 530 000 gold francs.

The justification for these figures is given in detail in the Convocation to the 21st General Conference and need not be repeated here.

In what follows, the projected overall costs are given for the programme of work laid out in this document. The cost headings (operating expenses, laboratories expenditure, staff expenses, etc.) are those used in the financial part of the document entitled “Rapport annuel aux Gouvernements des Hautes Parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures” distributed each year to Member

Governments of the Metre Convention. All figures are given in thousands of gold francs*.

In sections 13.1 to 13.8 that follow laboratory expenditures are listed for the projects outlined in sections 1 to 8 of this document. These are followed by expenses for general services, including publications and travel, section 9, by building maintenance and renovation, section 10, by staff costs, section 11, then finally by pension fund, section 12. In these sections the costs are presented in aggregated form for the four years 2001 to 2004.

Annual budgets for the years 2001 to 2004 are presented in section 13.13. The corresponding breakdown of costs by category is shown graphically in section 13.14. In establishing the budget proposals for each year, additional sums of about 5 % of the total have been included over and above the dotation. These additional sums represent projected income from interest on capital and other minor revenues from calibrations, sale of Pt-Ir prototypes, etc. (see "Rapport annuel aux Gouvernements des Hautes Parties contractantes sur la situation administrative et financière du Bureau International des Poids et Mesures" for recent years).

	Estimated costs (1000's of gold francs)	
13.1 Length		**2 885**
International comparisons	580	
Recommended radiations for the *mise en pratique* of the definition of the metre	1 585	
Gravimetry	430	
Dimensional metrology: nanometrology	290	
13.2 Mass		**2 472**
Manufacture and calibration of mass standards	620	
Balance development	620	
Stability of Pt-Ir mass standards	395	
Studies of anelasticity and gravitational experiments	837	
13.3 Time		**1 648**
Computation and diffusion of TAI and UTC	660	
Clock comparisons	346	
Space-time reference systems	35	
Dynamical time scales	35	
Time laboratory	572	

* 1 gold franc = 1.814 52 French francs.
1 euro = 6.55 957 French francs.

	Estimated costs (1000's of gold francs)	
13.4 Electricity		**3 709**
Maintenance of a representation of the volt, international comparisons and calibrations	930	
Maintenance of a representation of the ohm, international comparisons and calibrations	1 110	
Capacitance standards derived from the quantized-Hall resistance	1 300	
Studies of the stability of electrical standards and detectors	369	
13.5 Radiometry and photometry		**2 885**
Radiometry	2020	
Photometry	865	
13.6 Ionizing radiation		**2 472**
Dosimetry	1 122	
Radionuclides	1 350	
13.7 Metrology in chemistry		**2 472**
13.8 General laboratory and scientific services		**5 227**
Mechanical workshop	1 648	
Temperature and pressure measurements	600	
Information technology	1 879	
The BIPM key comparison database	1 100	
13.9 General services		**14 871**
General services	5 673	
Secretariat	2 413	
Publications	1 198	
Library	1 697	
Travel and transport of equipment	3 890	
13.10 Buildings and grounds		**3 232**
13.11 Staff		**74 222**
Salaries	57 225	
Family and social allowances	11 445	
Social benefit contributions	5 552	
13.12 Pension fund		**18 921**

13.13 Budgets for each of the years 2001-2004

Recapitulation of main headings (in 1000's gold francs)

	2001	2002	2003	2004	4 years
A. Staff (13.11)	17 703	18 446	18 907	19 166	**74 222**
B. Contribution to the pension fund (13.12)	4 093	4 557	4 953	5 318	**18 921**
C. General services (13.9)	3 543	3 623	3 847	3 858	**14 871**
D. Laboratory expenditure (13.1 to 13.8)	5 767	5 883	6 000	6 120	**23 770**
E. Buildings (13.10)	1 277	1 055	500	400	**3 232**
F. Miscellaneous and contingent	946	404	412	421	**2 183**
Total	33 329	33 968	34 619	35 283	**137 199**

13.13.1 General services (in 1000's gold francs) (details of 13.9)

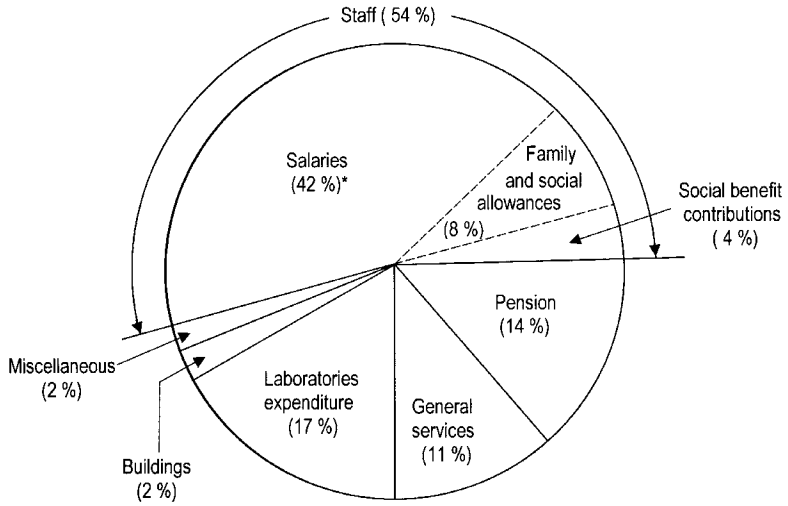
	2001	2002	2003	2004	4 years
Heating, water, electricity	510	525	541	557	**2 133**
Insurance	110	116	121	127	**474**
Publications	284	290	296	328	**1 198**
Office expenses	581	593	622	617	**2 413**
Travel, transport of equipment	938	957	1 040	955	**3 890**
General maintenance	643	656	732	769	**2 800**
Library	412	420	428	437	**1 697**
Bureau of the Comité	65	66	67	68	**266**
Total	3 543	3 623	3 847	3 858	**14 871**

13.13.2 Laboratories expenditure (in 1000's gold francs) (details of 13.1 to 13.8)

	2001	2002	2003	2004	4 years
Length	700	714	728	743	**2 885**
Mass	600	612	624	636	**2 472**
Time	400	408	416	424	**1 648**
Electricity	900	918	936	955	**3 709**
Radiometry and photometry	700	714	728	743	**2 885**
Ionizing radiation	600	612	624	636	**2 472**
Metrologie in chemistry	600	612	624	636	**2 472**
Workshop	400	408	416	424	**1 648**
General laboratory and scientific services	867	885	904	923	**3 579**
Total	5 767	5 883	6 000	6 120	**23 770**

13.14 Graphical representations of projected expenditure for the years 2001-2004

Recapitulation of main headings, including breakdown of staff costs 13.13)



* percentage of total 4 year budget (rounded)

Liste des sigles utilisés dans le présent volume
List of acronyms used in the present volume

1 Sigles des laboratoires, commissions et conférences
Acronyms for laboratories, committees and conferences

AIEA/IAEA	Agence internationale de l'énergie atomique/International Atomic Energy Agency
AIG/IAG	Association internationale de géodésie/International Association of Geodesy
AISM/IALA	Association internationale de signalisation maritime/ International Association of Lighthouse Authorities
AIST	Agency of Industrial Science and Technology, Tokyo et Tsukuba (Japon)
AOAC	Association of Official Analytical Chemists
APMP	Asia-Pacific Metrology Programme
BIH	Bureau international de l'heure
BIML	Bureau international de métrologie légale
BIPM	Bureau international des poids et mesures/International Bureau of Weights and Measures
BMwA	Bundesministerium für wirtschaftliche Angelegenheiten, Vienne (Autriche)
BNM	Bureau national de métrologie, 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-LPTF	Bureau national de métrologie, Laboratoire primaire du temps et des fréquences, Paris (France)
BRML	Bureau roumain de la métrologie légale, Bucarest (Roumanie)
CC	Comité consultatif du CIPM/Consultative Committee of the CIPM
CCAUV	Comité consultatif de l'acoustique, des ultrasons et des vibrations/Consultative Committee for Acoustics, Ultrasound and Vibration
CCDM*	Comité consultatif pour la définition du mètre/Consultative Committee for the Definition of the Metre, *voir* CCL

* Les laboratoires ou organisations marqués d'un astérisque soit n'existent plus soit figurent sous un autre sigle.
Orgnizations marked with an asterisk either no longer exist or operate under a different acronym

CCDS*	Comité consultatif pour la définition de la seconde/ Consultative Committee for the Definition of the Second, *voir* CCTF
CCE*	Comité consultatif d'électricité/Consultative Committee for Electricity, *voir* CCEM
CCEM	(ex CCE) Comité consultatif d'électricité et magnétisme/ Consultative Committee for Electricity and Magnetism
CCEMRI*	Comité consultatif pour les étalons de mesure des rayonnements ionisants/Consultative Committee for Standards of Ionizing Radiation, *voir* CCRI
CCIR	Comité consultatif international des radiocommunications/International Radio Consultative Committee
CCL	(ex CCDM) Comité consultatif des longueurs/Consultative Committee for Length
CCM	Comité consultatif pour la masse et les grandeurs apparentées/Consultative Committee for Mass and Related Quantities
CCPR	Comité consultatif de photométrie et radiométrie/ Consultative Committee for Photometry and Radiometry
CCQM	Comité consultatif pour la quantité de matière/Consultative Committee for Amount of Substance
CCRI	(ex CCEMRI) Comité consultatif des rayonnements ionisants/Consultative Committee for Ionizing Radiation
CCT	Comité consultatif de thermométrie/Consultative Committee for Thermometry
CCTF	(ex CCDS) Comité consultatif du temps et des fréquences/Consultative Committee for Time and Frequency
CCU	Comité consultatif des unités/Consultative Committee for Units
CEI/IEC	Commission électrotechnique internationale/International Electrotecnical Commission
CEM	Centro Español de Metrología, Madrid (Espagne)
CENAM	Centro Nacional de Metrología, Mexico (Mexique)
CETIAT	Centre Technique des Industries Aérauliques et Thermiques, Villeurbanne (France)
CGPM	Conférence générale des poids et mesures/General Conference on Weights and Measures
CIE	Commission internationale de l'éclairage/International Commission on Illumination
CIEMAT	Centro de Investigaciones Energéticas, Medio-ambientales y Tecnológicas, Madrid (Espagne)
CIML	Comité international de métrologie légale
CIPM	Comité international des poids et mesures/International Committee for Weights and Measures

CITAC	Cooperation on International Traceability in Analytical Chemistry
CMA/MIKES	Mittatekniikan Keskus/Centre for Metrology and Accreditation, Helsinki (Finlande)
CMI	Český Metrologický Institut/Czech Metrological Institute, Prague et Brno (Rép. tchèque)
CMS/ITRI	Centre for Measurement Standards of the Industrial Technology Research Institute, Hsinchu (Taiwan)
CNR	Consiglio Nazionale delle Ricerche, Turin (Italie)
CODATA	Committee on Data for Science and Technology
COOMET	Coopération métrologique entre les États d'Europe centrale/Cooperation in Metrology among the Central European Countries
CORM	Council for Optical Radiation Measurements (États-Unis)
CPEM	Conference on Precision Electromagnetic Measurements
CRL	Communications Research Laboratory, Tokyo (Japon)
CSIR-NML	Council for Scientific and Industrial Research, National Metrology Laboratory, Pretoria (Afrique du Sud)
CSIRO-NML	Commonwealth Scientific and Industrial Research Organization, National Measurement Laboratory, Lindfield (Australie)
DFM	Danish Institute of Fundamental Metrology, Lyngby (Danemark)
ENEA	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Rome (Italie)
ENS	École normale supérieure, Paris (France)
ETL	Electrotechnical Laboratory, Tsukuba (Japon)
EUROMET	European Collaboration in Measurement Standards
GT-RF	Groupe de travail pour les grandeurs aux radiofréquences du CCEM/CCEM Working Group on Radiofrequency Quantities
GUM	Glówny Urzad Miar/Central Office of Measures, Varsovie (Pologne)
HUT	Helsinki University of Technology, Helsinki (Finlande)
IAEA*	*voir* AIEA
IAG*	*voir* AIG
IALA*	*voir* AISM
IAU*	*voir* UAI
ICAO*	*voir* OACI
IEC*	*voir* CEI
IEN	Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin (Italie)
IERS	Service international de la rotation terrestre/International Earth Rotation Service

IFCC	Fédération internationale de chimie clinique/International Federation of Clinical Chemistry
IGS	International GPS Service for Geodynamics
ILAC	International Laboratory Accreditation Conference
IMEKO	International Measurement Confederation
IMGC	Istituto di Metrologia G. Colonnetti, Turin (Italie)
IMO*	*voir* OMI
INM*	*voir* BNM-INM
INMETRO	Instituto Nacional de Metrologia, Normalizaçao e Qualidade Industrial, Rio de Janeiro (Brésil)
INN	Instituto Nacional de Normalización, Santiago (Chili)
INTA	Instituto Nacional de Técnica Aeroespacial, Madrid (Espagne)
INTI	Instituto Nacional de Tecnología Industrial, Buenos Aires (Argentine)
IPQ	Instituto Português da Qualidade, Lisbonne (Portugal)
IRA	Institut universitaire de radiophysique appliquée, Lausanne (Suisse)
IRD*	*voir* LNMRI
IRMM	Institut des matériaux et mesures de référence, Commission européenne/Institute for Reference Materials and Measurements, European Commission
ISO	Organisation internationale de normalisation/International Organization for Standardization
ISO-REMCO	Organisation internationale de normalisation, Comité pour les matériaux de référence/International Organization for Standardization, Committee on Reference Materials
ITU*	*voir* UIT
IUGG*	*voir* UGGI
IUPAC*	*voir* UICPA
IUPAP*	*voir* UIPPA
JCGM	Comité commun pour les guides en métrologie/Joint Committee for Guides in Metrology
JCRB	Comité mixte des organisations régionales de métrologie et du BIPM/Joint Committee of the Regional Metrology Organizations and the BIPM
JILA	Joint Institute for Laboratory Astrophysics, Boulder CO (États-Unis)
JV	Justervesenet, Oslo (Norvège)
KRISS	Korea Research Institute of Standards and Science, Taejon (Rép. de Corée)
LCIE*	*voir* BNM-LCIE
LGC	Laboratory of the Government Chemist, Teddington (Royaume-Uni)
LNM/NMI	Laboratoire national de métrologie/National Metrology Institute

LNMRI	Laboratório Nacional de Metrologia das Radiaçoes Ionizantes, Rio de Janeiro (Brésil)
LPTF*	*voir* BNM-LPTF
MENAMET	Middle East Metrology Organization
Metas	(ex OFMET) Office fédéral de métrologie et d'accréditation, Wabern (Suisse)
MIKES	*voir* CMA
MIT	Massachusetts Institute of Technology, Cambridge MA (États-Unis)
MRA	Arrangement de reconnaissance mutuelle/Mutual Recognition Arrangement
MSL-IRL	Measurement Standards Laboratory of New Zealand, Lower Hutt (Nouvelle-Zélande)
NEWRAD	New Developments and Applications in Optical Radiometry Conference
NIM	National Institute of Metrology, Beijing (Chine)
NIMT	National Institute of Metrology of Thailand, Bangkok (Thaïlande)
NIMTT	National Institute of Measurement and Testing Technology, Sichuan (Chine)
NIS	National Institute for Standards, Le Caire (Égypte)
NIST	National Institute of Standards and Technology, Gaithersburg (États-Unis)
NMI	*voir* LNM
NMi-VSL	Nederlands Meetinstituut, Van Swinden Laboratorium, Delft (Pays-Bas)
NML	*voir* CSIR
NML	*voir* CSIRO
NORAMET	North American Metrology Cooperation
NPL	National Physical Laboratory, Teddington (Royaume-Uni)
NRC-CNRC*	*voir* NRC
NRC-INMS	Conseil national de recherches du Canada, Institut des étalons nationaux de mesure/National Research Council of Canada, Institute for National Measurement Standards, Ottawa (Canada)
NRCCRM	National Research Centre for Certified Reference Materials, Beijing (Chine)
NRLM	National Research Laboratory of Metrology, Tsukuba (Japon)
OACI/ICAO	Organisation de l'aviation civile internationale/ International Civil Aviation Organization
OFMET*	Office fédéral de métrologie/Eidgenössisches Amt für Messwesen, Wabern (Suisse), *voir* Metas
OIML	Organisation internationale de métrologie légale

OMC/WTO	Organisation mondiale du Commerce/World Trade Organization
OMH	Országos Mérésügyi Hivatal, Budapest (Hongrie)
OMI/IMO	Organisation maritime internationale/International Maritime Organization
OMS/WHO	Organisation mondiale de la santé/World Health Organization
PSB	(ex SISIR) Singapore Productivity and Standards Board (Singapour)
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig et Berlin (Allemagne)
RMO	*voir* ORM
SADCMET	Southern African Development Community Cooperation in Measurement Traceability
SCL	Standards and Calibration Laboratory (Hong Kong)
SIM	Système interaméricain de métrologie/Sistema Interamericano de Metrologia
SIP	Société genevoise d'instruments de physique, Genève (Suisse)
SISIR*	Singapore Institute of Standards and Industrial Research (Singapour), *voir* PSB
SIRIM	Standards and Industrial Research Institute, Shah Alam (Malaisie)
SMU	Slovenský Metrologický Ústav/Slovak Institute of Metrology, Bratislava (Slovaquie)
SP	(ex Statens Provningstanstalt) SP Sveriges Provnings- och Forskningsinstitut/Swedish National Testing and Research Institute, Borås (Suède)
SSDL	Secondary Standards Dosimetry Laboratories
STEP	Satellite Test of the Equivalence Principle Meeting
SURAMET	Coopération métrologique sud-américaine (Argentine, Brésil, Chili, Paraguay et Uruguay)
TUG	Technical University, Graz (Autriche)
UAI/IAU	Union astronomique internationale/International Astronomical Union
UGGI/IUGG	Union géodésique et géophysique internationale/ International Union of Geodesy and Geophysics
UICPA/IUPAC	Union internationale de chimie pure et appliquée/ International Union of Pure and Applied Chemistry
UIPPA/IUPAP	Union internationale de physique pure et appliquée/ International Union of Pure and Applied Physics
UIT/ITU	Union internationale des radiocommunications/ International Telecommunication Union
UME	Ulusal Metroloji Enstitüsü/National Metrology Institute, Marmara Research Centre, Gebze-Kocaeli (Turquie)

UN	Nations unies/United Nations
URSI	Union radioscientifique internationale/International Union of Radio Science
VNIIM	Institut de métrologie D.I. Mendéléev/D.I. Mendeleev Institute for Metrology, Saint-Pétersbourg (Féd. de Russie)
VNIIMS	Russian Research Institute for Metrological Service of Gosstandart of Russia, Moscou (Féd. de Russie)
VNIIOFI	Institut des mesures en optique physique, Gosstandart, Moscou (Féd. de Russie)
VSL*	Van Swinden Laboratorium, Delft (Pays-Bas), *voir* NMi
WGDM	Groupe de travail du CCL sur la métrologie dimensionnelle/CCL Working Group on Dimensional Metrology
WHO*	*voir* OMS
WTO*	*voir* OMC

2 Sigles des termes scientifiques
Acronyms for scientific terms

EIT-90/ITS-90	Échelle internationale de température de 1990/International Temperature Scale of 1990
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GUM	Guide pour l'expression de l'incertitude de mesure/Guide to the Expression of Uncertainty in Measurement
IDMS	Spectrométrie de masse avec dilution isotopique/Isotope Dilution Mass Spectrometry
ITRF	Système de référence terrestre spécifié par le Service international de la rotation terrestre/Terrestrial Reference Frame maintained by the International Earth Rotation Service
ITS-90	*voir* EIT-90
KCDB	Base de données du BIPM sur les comparaisons clés/BIPM Key Comparison Database
LPTF-FO1	Fontaine à césium n° 1 du Laboratoire primaire du temps et des fréquences
NMR	Résonance magnétique nucléaire/Nuclear Magnetic Resonance
PHARAO	Projet d'horloge atomique à refroissement d'atomes en orbite
QHE	Effet Hall quantique/Quantum Hall Effect
QHR	Résistance de Hall quantifiée/Quantum Hall Resistance
SET	Effet tunnel monoélectronique/Single Electron Tunnelling
SI	Système international d'unités/International System of Units
SIR	Système international de référence/International Reference System

SPRT	Thermomètre à résistance de platine étalon/Standard Platinum Resistance Thermometer
TAI	Temps atomique international/International Atomic Time
TDCR	Rapport des coincidences triples aux coincidences doubles/ Triple-to-double Coincidence Ratio Method
TWSTFT	Comparaison de temps et de fréquence par aller et retour sur satellite/Two-way Satellite Time and Frequency Transfer
UTC	Temps universel coordonné/Coordinated Universal Time
UV	Ultraviolet
VIM	Vocabulaire international des termes fondamentaux et généraux de métrologie/International Vocabulary of Basic and General Terms in Metrology