
Bureau International
des Poids et Mesures

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

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Intergovernmental Organization
of the Convention of the Metre

Note on the use of the English text

To make its work more widely accessible, the Comité International des Poids et Mesures has decided to publish an English version of its reports.

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

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Foreword

In October 1995 the 20th Conférence Générale des Poids et Mesures (CGPM) requested the Comité International des Poids et Mesures (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.

The requested study has now been completed and the CIPM is pleased to submit this report to the Governments of the Member States of the Convention of the Metre.

During the study and preparation of the report there has been wide consultation with interested parties and consideration has been given to comments received on several drafts of the report. There have been discussions with the Directors and other senior personnel of many National Metrology Institutes, and in February 1997 a draft of the report was considered at a meeting of the Directors in Sèvres. Drafts of the report have also been discussed with senior representatives of many other relevant organizations and cooperating groups, including:

Global Organizations

- Organisation Internationale de Métrologie Légale (OIML),
- International Organization for Standardization (ISO),
- International Electrotechnical Commission (IEC),
- International Laboratory Accreditation Cooperation (ILAC),

Regional Organizations in Metrology

- Asia/Pacific Metrology Programme (APMP),
- European Metrology Collaboration (EUROMET),
- North American Metrology Cooperation (NORAMET),

Regional Cooperations in Laboratory Accreditation

- Asia Pacific Laboratory Accreditation Cooperation (APLAC),
- European Cooperation for Accreditation (EA).

On behalf of the CIPM we express our gratitude to all who have given their time and expertise to assist in the preparation of this report.

J. Kovalevsky
President of the CIPM

W. R. Blevin
Secretary of the CIPM

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Executive summary

Numerous issues of concern to national governments are increasing 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 must be 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 BIPM is improving communication at the most senior level with its principal clients, the National Metrology Institutes of the Member States, by arranging periodic meetings of the Directors of these institutes with members of the CIPM and senior BIPM staff. These meetings provide a unique forum within which to discuss major issues in international metrology.

There is general agreement that the programmes undertaken with the authority of the Metre Convention have been of considerable value and 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. A procedure which ensures this objective has been developed and is currently being put into practice. This calls for the periodic execution of a wide range of "key" measurement comparisons, and their coordination with a series of similar comparisons arranged by

regional metrology organizations. By publishing the results of these comparisons and their analysis by appropriate Consultative Committees, the CIPM will provide the wider measurement community with direct access to the accumulation of data which demonstrate the degree of equivalence of the national standards. Moreover, an agreement for the mutual recognition of national measurement standards and calibration certificates issued by National Metrology Institutes is nearing completion and is scheduled for presentation to the 21st Conférence Générale des Poids et Mesures. The agreement will be implemented and maintained by the CIPM on behalf of the Member States: its signatories will be the National Metrology Institutes of the Member States.

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 Measurement Institutes is important for the establishment of international equivalence between standards. Possible extensions to cover the fields of acoustics, ultrasound, vibration, hardness and flow are currently being investigated 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 initiate appropriate international cooperation.

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, the Organisation Internationale de Métrologie Légale, the International Organization for Standardization and the International Electrotechnical Commission; at the regional level it will collaborate with the Regional Metrology Organizations. An initiative already taken by the CIPM is the creation of a Joint Committee of Regional Metrology Organizations and the BIPM, 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 and the Regional Metrology Organizations.

In this report, the CIPM lays out the role to be undertaken by the BIPM in the early decades of the 21st century, 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. An early change to the laboratory activities of the BIPM is the initiation of a small programme on metrology in chemistry. This programme and the introduction of the key comparisons together require the establishment of several new staff positions at the BIPM but, by internal redeployment and the use of existing and foreseen vacancies, this will be done without raising the staff total above that which existed in 1991.

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 appropriate level of future funding for the BIPM has been considered in the light of these and other factors, not least the present economic constraints encountered by the Member States and the increasing cost of the BIPM pension fund. The CIPM anticipates that it will recommend to the 21st CGPM that the BIPM annual dotation be held constant in real terms at the level set by the 20th CGPM for the year 2000, at least for the first quadrennium of the next century, 2001-2004. Present financial estimates indicate, however, that by 2006 it will no longer be possible for the BIPM to continue all its programmes without a real increase in dotation. The 22nd CGPM in 2003 will therefore be faced with a difficult decision: whether to continue to hold the dotation constant for 2005-2008 and succeeding quadrennia, which would necessitate a significant reduction in the BIPM scientific programme, or to increase the dotation.

In addition to the annual payment of the dotation to the BIPM, a range of other costs are encountered by each Member State that participates in the work carried out under the Convention of the Metre. Some of the CIPM's recent decisions, among them the introduction of key comparisons 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 which there is universal agreement that they must be done, 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, the only alternative to additional expenditure being a severe re-assessment of the traditional priorities.

1 Introduction

The process of measurement is of considerable importance in almost every field of human activity, and it has been estimated that in industrialized countries measurement and related operations account for 4 % to 6 % of the Gross National Product. This amounts to several hundred billion US dollars for the European Union alone. To be meaningful, measurements must be underpinned by metrology, the science of measurement. Accordingly, the total worldwide effort put into metrology is itself huge. This effort is shared by the public (government) and private (industry) sectors of national economies.

In practice, measurements are never perfectly accurate. Associated with any measurement are potential sources of error that combine to give a degree of uncertainty to the result. If this uncertainty is too great for the purpose of a particular measurement, the result of the measurement may be almost worthless. The degree of uncertainty that can be tolerated varies enormously between different applications of measurement. For example, measurements in the manufacture and operation of high-technology devices usually require much lower uncertainties (i.e. much higher accuracies) than retail measurements in the supermarket. The accuracy of measurements needs to be appropriate for the purpose.

Most national governments have long accepted that one of their responsibilities is to ensure that the basic elements of a national measurement system are developed and maintained in order to support trade and other measurement-related activities by increasing the reliability of measurements. These elements include:

- the adoption of a system of units of measurement for use throughout the nation;
- the operation of a National Metrology Institute (NMI) to develop, maintain and disseminate national measurement standards appropriate to the national needs, and to develop and transfer to users new measurement technology;
- the operation of a National Legal Metrology Organization to assist government with the enactment and implementation of legislation and regulations relating to measurements in trade and some other areas;
- the recognition of a National Laboratory Accreditation Organization for the accreditation of measurement and testing laboratories that satisfy appropriate criteria.

In several countries the NMI and National Legal Metrology Organization belong to a common organization.

Internationally, there has been increasing evidence for over one hundred years of the benefits that flow from international uniformity of measurement systems. Non-uniformity in measurement, testing and product certification has become recognized as one of the major technical barriers to trade. As a consequence, trade agreements between nations and regions now specifically require all signatories to accept the results of measurements and tests performed by any other party. This policy is supported by the World Trade Organization (WTO). The increased emphasis on the equivalence of measurement and testing services for trade will have far-reaching effects on national and international measurement systems.

Ideally, all national measurement systems would use a common system of units, their national measurement standards would be equivalent, and laws and regulations relating to metrology would be internationally harmonized. In practice, however, there are two primary impediments to achieving this ideal. First, for reasons of domestic concerns or perceived short-term economic advantage, some nations continue to maintain unique arrangements and seek to justify them. Second, even when nations attempt to achieve uniformity, there are always some measurement uncertainties involved in comparing their measurement standards and the best that can be done is to confirm their equivalence within specified small limits.

An early and major step towards international uniformity in measurement was the signing of the Convention of the Metre in 1875. This Convention founded the Bureau International des Poids et Mesures (BIPM), which serves as an international laboratory and secretariat, and facilitates metrological collaboration among its member nations (forty-eight in January 1998). The activities of the BIPM were at first rather narrowly focused on the measurement of length and mass, but an enabling clause in the Convention has allowed the BIPM's charter to be broadened progressively to include a very much greater range of responsibilities. A summary prepared in 1984 of the BIPM's modern role is given in Appendix A, and a more detailed account of its work can be found in the 1995 BIPM publication *Le BIPM et la Convention du Mètre* (reprinted in 1997). The BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM) which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM). The CGPM brings together periodically, at present once every four years, representatives of the governments of the Member States; it elects the members of the CIPM and decides the level of funding to be sought from the Member States to support the BIPM.

The present document is the response of the CIPM to a request made by the 20th CGPM in October 1995, in its Resolution 11, for a 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”. Appendix B gives the full text of this Resolution and of the associated Resolutions 1, 2 and 3.

In order to study the long-term role of the BIPM, it is necessary to place the BIPM’s activities in context with those aspects of metrology that are currently catered for by other (global) international organizations. Of these, the organizations with the broadest relevance are the following:

- International Laboratory Accreditation Cooperation (ILAC): accreditation of calibration and testing laboratories;
- International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC): documentary standards.
- Organisation Internationale de Métrologie Légale (OIML): legal metrology;

There are, however, numerous other global organizations active in specific areas of metrology, of which the following are merely examples:

- International Astronomical Union (IAU): metrology in astronomy;
- International Commission on Illumination (CIE): photometry and colorimetry;
- International Commission on Radiation Units and Measurements (ICRU): ionizing radiation metrology;
- International Federation of Clinical Chemistry (IFCC): metrology in clinical chemistry;
- International Measurement Confederation (IMEKO): international exchange of information on measurement science and technology;
- International Union of Pure and Applied Chemistry (IUPAC): metrology in chemistry;
- International Union of Pure and Applied Physics (IUPAP): units and fundamental constants.

For convenience, the acronym BIPM is used in this document not only to refer to the Bureau International des Poids et Mesures as an institution, but on some occasions in a broader sense to refer to the totality of activities under the Convention of the Metre. Each usage is clear from the context. The BIPM is an intergovernmental organization, but for simplicity in this document no distinction is made in general between “intergovernmental organizations” and “international organizations”.

2 Users of metrology

In order to establish the future needs for metrology it is essential to consider what continuing and new services will be required by the users. Metrologists themselves are essentially service providers rather than users. As noted in the Introduction, almost all fields of human activity rely significantly on measurement and metrology; the following is a far-from-complete list of some of the larger and more important fields of use:

- manufacturing and other industries;
- trade and commerce;
- health and safety;
- environmental protection;
- science;
- communications and transportation;
- enforcement of government regulations;
- generation and distribution of energy;
- surveying and navigation;
- military services.

In the past the number of fields of measurement in which users have pressed for improved accuracy and compatibility has grown steadily. When the Convention of the Metre was originally signed in 1875 the emphasis was on length, mass and related quantities, because these were the principal requirements of trade and commerce at that time. Other fields of metrology subsequently grew to be of great importance to users. For example, electrical measurements came to the forefront at the beginning of this century, ionizing radiation after the Second World War, and metrology in chemistry much more recently. Today, the movement of our society to higher technology is accelerating and brings with it the need for a wide range of new and complex measurements. Examples are the measurement requirements in information technology, in microengineering and nanotechnology, in the characterization of new materials, and in high-speed dynamic processes. Similarly, the increasing use of complex measurements in fields such as medi-

ciné, biotechnology, food and drug evaluation, and environmental protection is bringing urgent requirements for more reliable metrology in chemistry and biology as well as in the more traditional fields of physics and engineering. National and international metrology is far from satisfying the needs of these new fields and, in order to catch up, many new developments must be undertaken in the coming decade.

Moreover, many users have in the past paid too little attention to the use of sound metrological practices to underpin their measurements, with consequent adverse effects on the quality of the goods and services they provide and on productivity. There is now, however, an increasing awareness of the need for metrological underpinning. This has been brought about by several factors including the recent emphasis on quality management systems and the requirement by governments and trading partners that measurement and testing facilities be accredited.

For a large fraction of measurements undertaken, though not all, it is highly important to the user that the same results would be obtained within acceptable uncertainty limits if corresponding measurements were made in other locations, by other parties, or at different times or epochs. It is also important to users of metrology that their measurement results can readily be communicated to, and be accepted as valid by, other interested parties.

These needs of users directly indicate some basic requirements for metrology that will apply indefinitely into the future, at both national and international levels.

- Universal adoption of a common system of units of measurement, firmly linked to fundamental physics, is highly desirable. The establishment of the International System of Units (SI) by the CGPM in 1960 has led to great progress towards achieving this. In science and technology, the SI is now almost universally used and, for most international trade and for the manufacture of high-technology products, it has largely replaced older systems of units.
- Measurements by all users need to be based on equivalent physical realizations of the units. This can be achieved by ensuring that the measurements are traceable either to a unique measurement standard that is maintained internationally, or to national measurement standards that are known to be equivalent to each other within acceptable limits of uncertainty. In order to be traceable, each measurement must be related to the appropriate standards by an unbroken chain of comparisons, all having stated uncertainties. Such a traceability chain traditionally takes the form of a series of calibrations, each of which is performed against a higher level, more accurate, reference standard. In analytical chemistry, considerable use is made of certified reference materials for this purpose.

These points were highlighted in Resolutions 1, 2 and 3 of the 20th General Conference, entitled “The need to use SI units in studies of Earth resources, the environment, human well-being and related issues”, “World-wide traceability of measurement standards” and “The need for long-term metrological research”. Copies of these important Resolutions are given in Appendix B of this Report.

3 National needs relating to metrology

Governments are becoming increasingly aware of the economic and social advantages of having an effective national measurement system and, in particular, of the importance of such a system as a tool of industrial competitiveness. There seems little doubt therefore that national measurement systems will continue indefinitely to serve as the basic building blocks of the world system, and it is important to consider them in their own right. This is so despite it being somewhat artificial to consider national and international needs for metrology separately, since few international needs are not direct reflections of national needs. The interests and requirements of many users of metrology are not limited to the domestic scene of their own nation but are indeed international, as is immediately apparent from consideration of the users listed above. Many companies are engaged in international trade, international co-manufacture of products has become commonplace, military defence arrangements often involve groups of nations, environmental pollution problems often extend beyond national boundaries, and so on.

Figure 1 gives a broad representation of the principal metrological activities required at national level. It illustrates how the benefits arising from a national system of units and measurement standards, maintained in an NMI, flow to users through several channels, including: *a*) directly from the NMI, *b*) indirectly via accredited calibration laboratories and *c*) through organizations responsible for legal regulations, voluntary standards specifications, etc. It is expected that in the foreseeable future there will be a continuing need for all of these activities at the national level, but with increasing emphasis on global harmonization.

A comprehensive national measurement system includes several facets, or areas of responsibility: units of measurement and national measurement standards, laboratory accreditation, legal metrology, documentary standards, etc. In some countries each facet is the responsibility of a separate organization, whereas in others, several facets are grouped under a common parent organization. Either system can operate satisfactorily provided that provision is made to coordinate the work of all the facets. For some facets the responsibility is often shared between several organizations, an example being legal metrology for which responsibilities are frequently shared between national, state or provincial organizations. However, it is highly desirable, and almost essential, that within each facet a

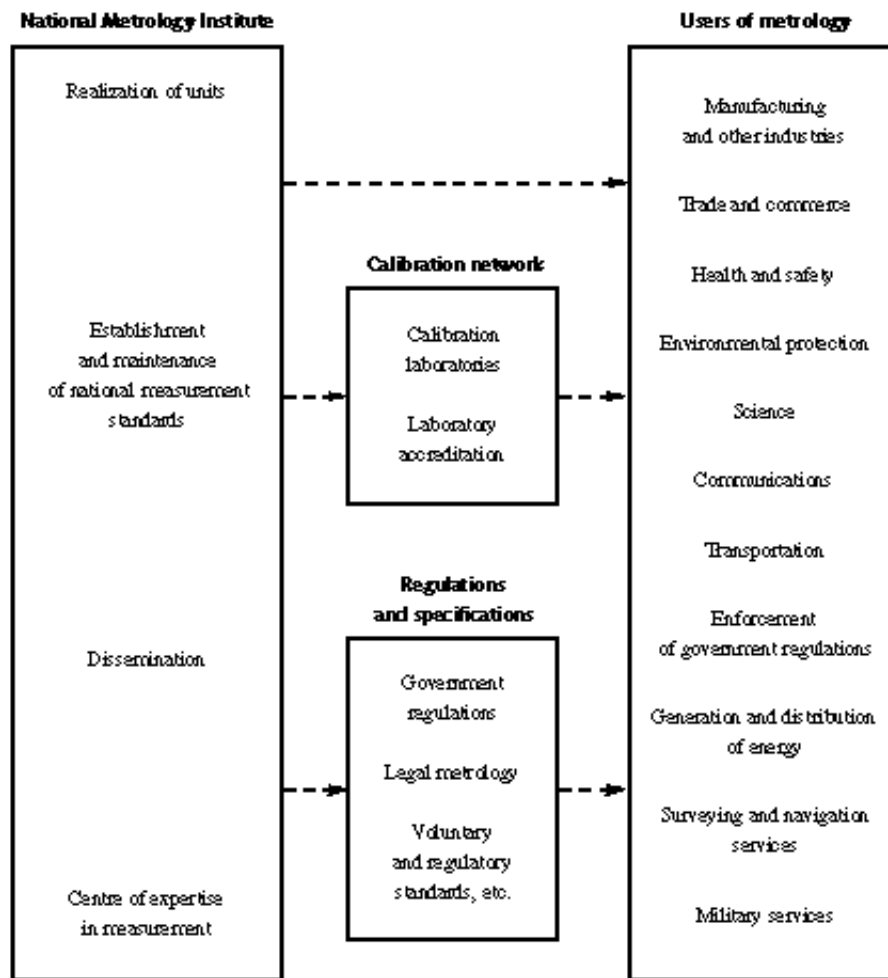


Figure 1 Schematic illustration of how, in a well-established national measurement system, technical benefits flow from the National Metrology Institute to diverse users of metrology, both directly and through other organizations.

single organization be empowered to represent the national interest in international discussions and in negotiations on international agreements.

3.1 Units of measurement

The first requirement of a national measurement system is the adoption of a national system of units and the enactment of legislation that only the units within this system will be recognized in law. It is highly desirable that the SI be adopted as the national system, because *a*) the SI is a coherent, practical and widely understood system and *b*) much progress has already been made towards universal use of the SI. As science and technology advance and users' requirements evolve, the SI will continue to be kept up-to-date by the BIPM, and there seems no reason to doubt that its use will continue to grow.

3.2 National measurement standards

The practice of establishing National Metrology Institutes, with responsibility for maintaining national measurement standards and ensuring that national measurement needs are met, began late in the 19th century in the more technically developed countries. It has continued up to the present day and within the last few decades many developing countries have given high priority to establishing their own NMIs at a level of competence appropriate to their needs. Suggestions are sometimes made that the establishment of regional metrology institutes would avoid the need for all nations to have their own NMI. These suggestions overlook the fact that modern NMIs are much more than repositories of measurement standards. They serve as national centres of excellence in measurement and as vital components of the national technical infrastructure, able to give a wide range of technical advice and assistance to government, industry and the wider community on measurement-related matters. The effectiveness of NMIs is certainly being enhanced by the increasing emphasis on regional collaborations, but it will be the norm into the foreseeable future for each nation to support its own NMI to which the government, industry and other users can have direct access.

As illustrated in Figure 2, each NMI has a choice of procedures available for its task of establishing national measurement standards.

1. The first of these procedures involves the NMI in the physical realization of the unit from its definition, so establishing a primary standard that will serve as the national standard. This is the most fundamental approach and is of great importance because physical realizations provide a firm connection between the unit's definition and its physical embodiment as a standard. Usually, however, it is the most difficult and costly approach.
2. The second procedure is available for only a limited number of physical quantities. It also involves establishing a primary standard to serve as the national standard, but in this case, not by realizing the unit from its definition, but by setting up a highly reproducible standard whose value has been agreed to through the BIPM by international convention. This procedure is referred to as "reproduction" of the unit rather than "realization". Examples are the use of recommended frequency-stabilized lasers to establish a standard for the metre, of the Josephson effect for the volt, and of the quantum Hall effect for the ohm. Because of their great reproducibility, reproduction standards are normally preferred as national standards even by those NMIs that have themselves realized the units concerned and thus contributed to the assignment of the conventional values.
3. The third procedure is to use a secondary standard as the national standard, its value being determined by a periodic comparison with a primary standard maintained for the same quantity by the BIPM or by another NMI. This is the

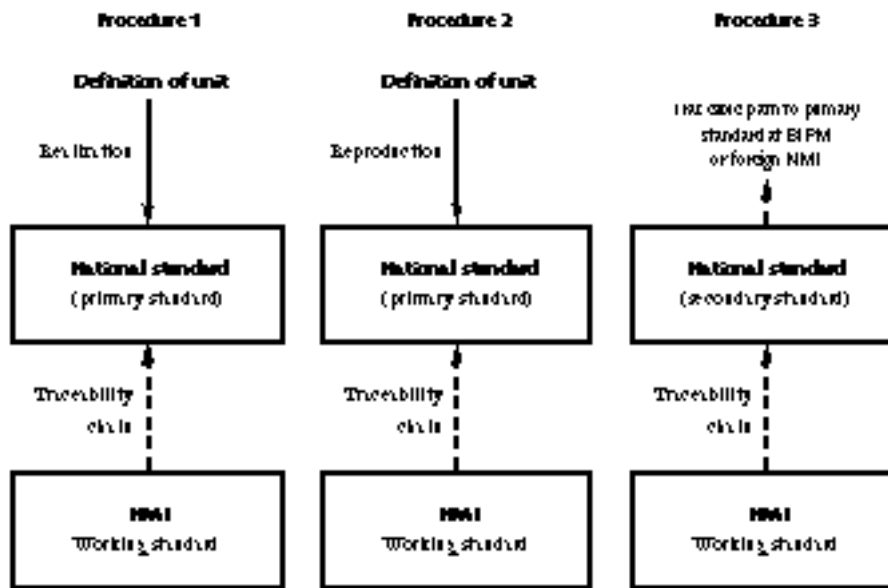


Figure 2

Illustration of the three alternative procedures available to a National Metrology Institute (NMI) for establishing its national measurement standards. Calibration services provided by the NMI utilize working standards that are traceable to the national standards.

procedure used by all NMIs in the case of the mass, since by definition the only primary standard of mass is the International Prototype of the Kilogram maintained at the BIPM.

The relative extent to which these different procedures are used to establish national standards varies considerably from one NMI to another, and probably this will always be the case. In the most expert NMIs it is usual for almost all national standards to be primary standards, there being little call for external calibration of secondary standards other than for the kilogram. At the other end of the spectrum many small NMIs, with less stringent accuracy requirements, base their national standards almost exclusively on secondary standards. For the less-used physical quantities they may choose not to maintain standards at all, but instead refer their clients to foreign NMIs. The best accuracies obtained by these smaller NMIs, while usually lower than those of the most expert laboratories, may nevertheless be adequate for many applications and the actual needs of the country. There should not be peer pressure on them to strive to attain unnecessarily high levels of performance, nor to establish primary standards.

There is scope for error in all three of the above procedures for establishing national measurement standards and such errors cannot always be identified by in-house assessment. If the standards are to gain international credibility, it is essential to compare them with the national standards of other NMIs or with

standards maintained by the BIPM. Such comparisons serve as a check both on the quality of the standards and on the ability of the NMI to operate them.

A basic objective of NMIs is to provide the means by which users can make measurements in terms of the SI at an accuracy appropriate to each application. Whether traceability to one particular NMI can be regarded by users as equivalent to traceability to a more expert NMI depends on the specific measurement application and on its accuracy requirements. Such decisions should be based on an analysis of those requirements and after reference to published accounts of the performance of the NMIs in periodic international comparisons for the relevant physical quantities. This matter is further discussed below.

3.3 Calibration networks and laboratory accreditation

Since NMIs typically undertake only a small fraction of the total national demand for calibration of secondary and reference standards, supplementary arrangements are required to ensure the accuracy of the many other standards used throughout the nation. Users of such arrangements need to have confidence that the values ascribed to their reference and working standards agree, within quantified and acceptable limits of uncertainty, with the values that would have resulted from direct comparison with the national standards. The traditional arrangement is to establish a hierarchical network of calibration laboratories, with the NMI at the peak of the hierarchy. While a number of variants on this arrangement are possible, all must satisfy some basic requirements.

In some fields of measurement, particularly in chemistry, the distribution of certified reference materials is frequently used as the method to improve measurement accuracy and uniformity. The methods used to measure and characterize such reference materials have not always been conducive to rigorous evaluation of the associated uncertainties of measurement in terms of the SI units. Greater emphasis will be required in the future on identifying and adopting methods that can be completely described and understood, and for which a complete uncertainty statement can be written down.

Reliability of the traceability chain from national standards to the working standards at the point of application is of critical importance to the national measurement system. All laboratories in each chain, and therefore all in the national network of calibration laboratories, should be able to demonstrate their competence. To assist in achieving this goal, the practice of laboratory accreditation has developed whereby each laboratory is assessed by an external organization with appropriate expertise. A single national laboratory accreditation organization has become the norm in most countries, and in the case of calibration laboratories is almost universal. Such organizations are often responsible for the accreditation not only of calibration laboratories but also of a wide range of testing laboratories. Very close collaboration between the NMI and the national laboratory accreditation organization will continue to be of major importance. The work of an NMI can be fully effective only if supported by a calibration network of demonstrated competence, and conversely the accreditation organization requires

access to the measurement expertise of its NMI in the planning and implementation of its accreditation programme.

National laboratory accreditation organizations further enhance confidence in the national calibration network by conducting measurement comparisons “horizontally” between the accredited laboratories in order to test their equivalence. They frequently refer to this process as proficiency testing. Inclusion of the NMI in such comparisons can be useful as it provides a check on the “vertical” traceability chain to national standards.

3.4 Legal metrology

Governments have over the years enacted a considerable number of laws and regulations that require reliable measurements for their fair and effective implementation. The term “legal metrology” is used to cover this field of interaction between regulations and measurement. Legal metrology originated from the need to ensure fair trade and provide consumer protection, and it continues to place its greatest emphasis on this area. In recent decades, however, the need to protect society in other areas such as health, safety and the environment has led to new laws and regulations, and a broadening of legal metrology activities.

As already noted in the introduction to this paper, most national governments have established a national legal metrology organization, but much of the responsibility for legal metrology is delegated not infrequently to sub-national states or provinces. The responsibilities of some of these organizations are limited to trade, while in other cases they are much wider. Many government departments are at least potentially involved with legal metrology in areas such as consumer affairs, health, the environment, commerce, communications and agriculture. The national legal metrology organization is usually located in one specific department and, unless the government gives it responsibility for all areas of legal metrology, its influence on other departments may be limited to advice and coordination.

Complete harmony between the NMI and the national legal metrology organization is essential on issues such as units, national measurement standards, calibration networks and laboratory accreditation. As legal metrology expands it is likely to involve fields of measurement that are new to national legal metrology organizations but for which substantial expertise already exists in the NMIs. A recent example of this is the need for microwave measurement capability in testing measuring instruments for electromagnetic interference and compatibility. Close collaboration will be required to avoid unnecessary duplication of facilities and to attain nationally optimum solutions. Similarly, national legal metrology organizations can assist NMIs in identifying and solving any legal issues affecting the promotion of uniform measurement.

The demand for legal metrology services is clearly linked to governmental policies and will vary over time. While in some nations considerable deregulation is

taking place at present, in others regulation is expanding to include measurements in non-traditional fields such as environmental protection and health care.

3.5 Documentary standards

Documentary standards fulfil two important national needs relating to metrology.

First, they systematize and represent a consensus on a considerable fraction of the measurements that are made in industry and the wider community, and a consensus also on the accuracy required.

Second, they provide an efficient means of disseminating throughout a nation basic information about its national measurement system. This information includes terminology, quantities and units, measurement and testing methods, evaluation of measurement uncertainties, and so on.

In addition, participation in the committees that draft national documentary standards provides a valuable mechanism for the provider of metrological services to learn about the needs of users. This supplements the information that each provider gains through its own direct contacts with users. These are: the National Metrology Institute with the extensive users of its calibration and measurement advisory services, the national laboratory accreditation organization with the proprietors of calibration and testing laboratories seeking accreditation, and the national legal metrology organization with government regulators and with representatives of trade, measurement and other relevant industries.

It is not uncommon to find in the same country a number of organizations engaged in writing documentary standards, but with one of them recognized as the peak or national organization and referred to here as the national documentary standards institute. It is desirable that the metrology service providers collaborate with these organizations, and with those of the standards drafting committees for which measurement and metrology are particularly relevant.

3.6 Training in metrology

In many countries there appears to be inadequate provision for training in metrology at every level of the educational system: schools, technical colleges and universities. Metrology often has to be “learned on the job”, which makes the development of a uniform national measurement system much more difficult. This need for better training is an important issue that will, for the most part, have to be addressed nationally. However, the nations that are most advanced in metrology provide significant training to those that are less advanced, and the continuation of this activity is to be encouraged.

4 International needs relating to metrology, and appropriate international collaborations

Although the desirability of international uniformity in measurement was recognized prior to the establishment of the BIPM in 1875, the need has continuously increased ever since and particularly over the past few decades. Reasons for this 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 increased concern with health, safety and environmental issues. This trend, expected to continue, is strengthening a mutual desire between nations for greater confidence in each other's measurements, tests and product-conformance assessments.

Experience shows that the most efficient and effective path to measurement uniformity is through multilateral collaboration between relevant national organizations, both at the global and the regional level.

At present, five international organizations serve as the principal centres for multi-lateral collaboration in measurement and metrology at the global level (see Table 1). Each has the responsibility of harmonizing internationally one or more of the facets of metrology that have been identified above as national needs.

The BIPM, as already outlined in the Introduction, is responsible for the International System of Units (SI) and for developing international agreements on measurement standards. It serves as the principal focus for collaboration between the NMIs. Of particular relevance here are the meetings and programmes of the Consultative Committees (CCs) set up by the CIPM. These advise the CIPM and coordinate international work in their respective fields of metrology. The titles and acronyms for the nine CCs which now exist are listed in Table 2. Each comprises a Chairman (normally a member of the CIPM), delegates from the member NMIs and other specialized institutes that are most expert in the field, as well as some individual experts and representatives of the BIPM. The criteria for membership of CCs have recently been reviewed by the CIPM and are given in Appendix C. It is appropriate, as an aid to communication with the regional organizations cooperating in metrology, that each CC include at least one NMI from each region where sufficient expertise is available to satisfy the criteria. The names and acronyms of some of the CCs were changed by the CIPM in 1997 to reflect the wider responsibilities they have been given (see Section 4.3 below). The new names are given in Table 2.

Table 1. Principal organizations for multilateral international collaborations in metrology

Field of Collaboration	Global Organizations/ Institutions	Regional Organizations / Cooperations
International System of Units and International measurement standards	BIPM	–
Collaboration between NMIs (including comparisons of national measurement standards)	BIPM	ANDIMET (South America) * APMP(Asia & Pacific) CAMET (Central America) * CARIMET (Caribbean) * COOMET (Central & Eastern Europe) EUROMET (Europe) NORAMET (North America) * SADCMET (Southern Africa) SURAMET (South America) *
Laboratory accreditation	ILAC	APLAC (Asia & Pacific) EA(Europe) IAAC (The Americas) NACC (North America) SARAC (Southern Africa)
Legal metrology	OIML	APLMF (Asia & Pacific) COOMET (Central & Eastern Europe) SALMEC (Southern Africa) WELMEC (Europe)
Documentary standards	ISO / IEC	AIDMO (Arab Region) ACCSQ (Far East) ARSO (African Region) CEN/CENELEC (Europe) COPANT (The Americas) PASC (Pacific Region) SADCSTAN (Southern Africa)
* The five cooperations in the Americas are linked by the Inter-American Metrology System (SIM).		

Table 2. The Consultative Committees of the CIPM on 1 January 1998

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1. Consultative Committee for Electricity and Magnetism (CCEM)
 2. Consultative Committee for Photometry and Radiometry (CCPR)
 3. Consultative Committee for Thermometry (CCT)
 4. Consultative Committee for Length (CCL)
 5. Consultative Committee for Time and Frequency (CCTF)
 6. Consultative Committee for Ionizing Radiation (CCRI)
 7. Consultative Committee for Units (CCU)
 8. Consultative Committee for Mass and Related Quantities (CCM)
 9. Consultative Committee for Amount of Substance (CCQM)
-

A feature of CC meetings has been the open and frank discussion of all items on the agenda, including the standards programmes in the participating NMIs. This has been of enormous value to the development of metrology and the accomplishment of the BIPM's mission, and has frequently stimulated the research programmes in the NMIs themselves. There is concern that the requirements that have been placed on a number of NMIs in recent years to be more commercial and competitive may endanger the traditional openness of CC meetings and curtail the presentation and discussion of some aspects of standards research. Any such development would be extremely detrimental to the work of the CCs. Although it may be regarded as a natural consequence of the growing globalization of trade and liberalization of international markets, the CIPM must work to find common ground within a competitive environment so that the NMIs can continue to cooperate openly and make metrological progress. This, indeed, is a topic of ongoing discussion by the CIPM.

An initiative has been taken to improve communication at the most senior level between the BIPM and its principal clients, the NMIs of the Member States. Periodic meetings of the Directors of the NMIs with members of the CIPM and senior BIPM staff are now being convened by the BIPM to discuss major issues in international metrology. These meetings give all NMIs an opportunity to influence BIPM policies and practices, whether or not they have staff members on the CIPM and the CCs. The first meeting took place in February 1997 and a second in February 1998.

The International Laboratory Accreditation Conference (ILAC) was established in 1977 as a forum to foster international harmonization in the field of laboratory accreditation with a view to developing a worldwide network of mutual recognition and acceptance of measurement and test reports. In September 1996 representatives of more than forty national accreditation bodies signed a Memorandum of Understanding replacing the original ILAC by a more formal and structured organization having the same acronym but entitled the International Laboratory Accreditation Cooperation. ILAC now has a general assembly that meets annually, an executive committee and four specialist committees that address accreditation policies, technical issues, public affairs and laboratory liaison. It proposes to establish a small permanent secretariat in the near future.

The Organisation Internationale de Métrologie Légale (OIML), like the BIPM, is an intergovernmental organization established by the signing of an international convention. Set up in 1955, by May 1995 it had fifty-four Member States as signatories to the Convention and forty-one others as corresponding members. It has a permanent secretariat entitled the Bureau International de Métrologie Légale (BIML), located in Paris, France, but its mission does not require a laboratory. In its mission to achieve international harmonization in legal metrology, the OIML conducts *inter alia* four-yearly conferences of the member nations and annual meetings of its steering committee, known as the Comité International de Métrologie Légale (CIML). It operates some eighteen technical committees for the drafting and revision of international recommendations and documents.

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) form the world system for international voluntary documentary standards, IEC being responsible for the field of electrical and electronic engineering and ISO for all other fields. Based in Geneva (Switzerland), their primary aim is to facilitate international trade and the exchange of goods and services by eliminating technical barriers to trade. This is achieved by developing and publishing international standards which can be adopted worldwide by their national members. As with the national organizations for documentary standards, the ISO and IEC make valuable contributions to metrology both by systematizing a wide range of measurement requirements that need metrological underpinning and by publishing and disseminating the core conventions of metrology that have been agreed to internationally.

In addition to these global institutions, a number of regional organizations or cooperations of relevance to metrology have been established, and are listed in Table 1. Of most direct relevance to the work of the BIPM are the regional metrology organizations (RMOs), each of which has the objective of developing collaborations among the NMIs in its region in order to meet regional requirements for uniformity of measurement. The RMOs are of rather recent origin, the oldest of them dating back only to the mid-1970s, and their regions do not yet cover the entire globe. The RMOs are not interposed between the NMIs and the BIPM and in no way lessen the opportunity for NMIs to have direct contact with the BIPM. They provide a supplementary means for the NMIs in each region to collaborate, including the NMIs of nations that are not signatories to the Convention of the Metre. An important point is that the RMOs are not inter-governmental with assured financial backing and permanent secretariats, but are voluntary cooperations between the participating NMIs.

4.1 The International System of Units (SI)

Although it is desirable to have as stable as possible a system of units as the foundation of metrology, the SI will continue to require periodic amendments into the indefinite future as science and technology progress and new needs arise. The matter is kept under continual review by the BIPM, the CIPM and its Consultative Committee for Units (CCU). The latter includes representatives of

major relevant international organizations, among them the IEC, ISO, IUPAC, IUPAP and OIML. Amendments to the SI are necessarily a compromise between changes that are scientifically desirable and the understandable reluctance of users to accept changes that are not essential.

In the past the BIPM played a prominent part in encouraging countries to adopt the SI as their national system of units. The countries that have not yet done so are well aware of the advantages that would flow from universal adoption. Their delay in changing to the SI is mainly due to internal political and social issues, so the BIPM now devotes little of its activity toward speeding up the process.

A number of close relationships exist between the units and standards of measurement, and the fundamental constants of physics. Examples are the relationships between the Planck constant h and the quantum-based electrical standards, and between the Avogadro constant N_A and the proposed new mass standard based on silicon atoms. Studies of such relationships and more accurate determinations of the fundamental constants continue to make important contributions both to metrology and to science generally. The BIPM should maintain an association with this field of research and from time to time, when it has special expertise or facilities to do so, contribute to the ongoing international effort.

The BIPM should continue to play a key role in standardizing the terminology of metrology and the methodology for determining and expressing the uncertainty of measurement results. The documents *International Vocabulary of Basic and General Terms in Metrology* and *Guide to the Expression of Uncertainty in Measurement*, prepared jointly with the IEC, IFCC, ISO, IUPAC, IUPAP and OIML, should be kept up-to-date and the need for further basic documents of this type kept under review. The second of these, on the expression of uncertainty in measurement, is a document of great importance. The principles in this document are now used over the whole field of metrology, and increasingly so at the practical and industrial level.

4.2 International collaboration in developing measurement standards

The BIPM is strongly involved with the NMIs, principally through the activities of the Consultative Committees, in the coordination of worldwide research into the development of improved primary standards of measurement. It also undertakes the establishment, maintenance and dissemination of certain of these standards in its own laboratories.

- The kilogram is the only unit whose primary standard continues to be a unique physical artefact, namely the International Prototype of the Kilogram, conserved at the BIPM. Considerable effort, mainly in the NMIs, is being put into developing alternative approaches to the definition of the kilogram, based on atomic masses or electromagnetic forces. Significant obstacles remain to be overcome, however, and success may well be some decades away. Meanwhile, the BIPM's ongoing task of conserving and disseminating the unit of mass continues.

- In relation to the unit of time, the second, the BIPM has the specific task of establishing and disseminating International Atomic Time (TAI) and, in collaboration with the appropriate astronomical organizations, Coordinated Universal Time (UTC). There are user requirements for still greater accuracy in this already highly accurate field of metrology, and a leap forward based on the technologies of cold atoms and trapped ions is expected shortly. The BIPM and CCTF are expected to continue to have a busy programme in the future.
- As already noted in Section 3.2 there are a number of units for which technology is available to establish extremely reproducible primary standards based on conventional values chosen to give as close as possible conformity with the definitions of the units. Examples are the establishment by reproduction of primary standards: for the metre, based on conventional values of frequency for certain frequency-stabilized laser radiations; for the volt, based on a conventional value for the Josephson constant; and for the ohm, based on a conventional value for the von Klitzing constant. Rather similarly, the international temperature scale ITS-90 uses conventional values for its fixed points. The BIPM coordinates the extensive work required to develop these techniques of reproduction and to determine the values to be adopted by convention, and collaborates with the NMIs in performing this work. It is expected that scientific advances as yet unforeseen will provide new opportunities for establishing standards by reproduction.
- For some units, e.g. the candela, adequately reproducible standards have yet to be discovered. Consequently it is necessary to make more frequent realizations of them from their definitions. In such cases the BIPM works with the NMIs in the search for more stable standards and for more accurate and convenient methods of realization.
- For measurements of quantity of matter, i.e. for metrology in chemistry, measurements consistent with the definition of the SI unit (the mole) cannot in practice be achieved through the comparison of physical artefacts because the number of substances that would have to be compared individually is very large. Instead, the Consultative Committee for Amount of Substance (CCQM), set up by the CIPM in 1993, is identifying a range of primary methods of measurement. A primary method of measurement is a method having the highest metrological qualities, whose operation can be completely described and understood, for which a complete uncertainty statement can be written down in terms of SI units, and whose results are therefore accepted without reference to a standard of the quantity being measured. Greater accuracy and uniformity in chemical measurement is an urgent need of major economic and environmental importance, requiring leadership from the BIPM itself as well as from the CCQM. It is recommended therefore that the BIPM establish a small laboratory group in this field to contribute to the resolution of some of the key problems.

Research carried out at the BIPM has made many major contributions to the improvement of methods for physically realizing the SI units and to the develop-

ment of new measurement standards. Certain projects are particularly suited to the international environment of the BIPM, to the expertise of its staff and to the ensemble of scientific equipment that it has available. It is important that the future funding of the BIPM be sufficient to allow such contributions to continue.

The BIPM has only a small laboratory staff of some 40 scientists and technicians, and inevitably will continue to be involved in a considerably narrower range of experimental standards activities than many of the NMIs. Fortunately, however, experience has shown that CCs can operate effectively in some fields even when the BIPM is itself inactive. An example is the field of temperature measurement, where the Consultative Committee for Thermometry (CCT) has been effective notwithstanding a minimal programme in thermometry in the BIPM itself. There is a caveat, however, that the overall amount of experimental work and research undertaken at the BIPM must be above the threshold required to attract and retain a viable team of first-class scientists with the capability of working with senior NMI scientists as respected peers or leaders.

There is a continuing need for the BIPM to assist the NMIs of the Member States of the Convention of the Metre to establish and maintain national standards that are closely equivalent to, or reliably traceable to, well-recognized primary standards. For this, the tools at its disposal include technology transfer and, particularly for those NMIs choosing to use externally calibrated secondary standards as their national standards, a range of calibrations in terms of the standards maintained at the BIPM. In the case of mass, such a service will be obligatory for so long as the kilogram continues to be defined by an international prototype; in the case of time the BIPM will likewise be obliged to continue its unique function with respect to TAI and UTC. It is recommended that, apart from these, the BIPM should offer calibrations only for physical quantities where it has the capacity resulting from the development of the necessary standards through other aspects of its charter. These would be through development of primary standards in collaboration with the CCs or through participation in international comparisons. It is inevitable that BIPM's range of standards and calibrations will always be less extensive than those of the larger NMIs.

4.3 The Consultative Committees: an expanded role

The CIPM strategy for the future now recognizes more fully that the CCs have evolved to become the principal meeting-grounds of the NMIs expert in their respective areas of metrology. The number of CCs and the areas covered by them have steadily grown since the first, the Consultative Committee for Electricity (CCE), was set up in 1927, but there has hitherto been no systematic attempt to broaden the scope of the CCs to cover all areas of metrology. There remain some important gaps, such as the fields of magnetism, vibration, acoustics and ultrasound. In order to cover the full gamut of metrology considered by the NMIs to require significant international collaboration, the CIPM is now broadening the terms of reference of its CCs and encouraging them to make greater use of working groups in specific areas. If necessary it will also establish one or two

additional CCs. This is not intended to imply that the BIPM itself should necessarily become active in many of the additional fields. Moreover, particular care should be taken by the CCs not to move into areas where there are already adequate opportunities for collaboration in metrology through other bodies, e.g. CIGRE, for high-voltage metrology, and CIE for colorimetry. The CCs should keep under review all the fields allocated to them, but be active only in those where the need is judged to be greatest.

In September 1996, in a significant step towards broadening the scope of the CCs, the CIPM established an *ad hoc* working group to advise it on the needs for a programme under the Convention of the Metre on acoustics, ultrasound and vibration standards. Such a programme might be undertaken either by a new CC or by a new working group within an existing CC. Although within Europe there seems to be reasonable collaboration between the NMIs active in these fields, on the global scale there are few avenues for contacts except through personal networks and ISO/IEC technical committees concerned with documentary standards. The need seems most acute in ultrasound where the metrological requirements of three areas need to be addressed: medical diagnostic ultrasound, medical therapeutic ultrasound and industrial ultrasound. But this is just one example. In September 1997 the CIPM initiated studies to see whether it is timely to bring standards of hardness and fluid flow under the umbrella of the Convention of the Metre. One might also consider other rheological properties of matter such as viscosity, plasticity and strain; thermophysical properties of materials such as thermal conductivity, thermal capacitance and emissivity; measurement and standardization problems in granulometry, etc. Measurements of these quantities have a direct industrial impact: they already engage the attention of the NMIs and eventually there will be pressure on the BIPM to ensure the worldwide equivalence of measurements in many of these fields.

The traditional titles of a few of the existing CCs have not adequately reflected the breadth of their work and have 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) does not reflect the present much broader activities of that Committee in length measurement and dimensional metrology. Consequently the CIPM, in September 1997, amended the titles (and acronyms) of four of the CCs. 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 (CEM), 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.

4.4 Equivalence of national measurement standards

The enormous and ever-increasing need for worldwide uniformity of measurement, and the reasons for it, have already been described. Since national measurement systems continue to serve as the basic building blocks of the global system, worldwide uniformity is achievable only if the national measurement standards maintained in different countries are equivalent. As a consequence there is today a strong demand by users of metrology for more explicit and transparent evidence of the degree of equivalence (or of non-equivalence) of the national standards maintained by the NMIs. The incompleteness of the existing evidence, and the lack of ready access to it, are of particular concern to laboratory accreditation organizations, which require detailed knowledge of international equivalence. Such knowledge is required, for example, when a calibration laboratory seeking accreditation has some of its measurement standards traceable to a foreign NMI, rather than to its local NMI: this occurs particularly when newly calibrated standards have recently been imported by the laboratory and immediate recalibration by the local NMI seems unnecessary. A second and important example is when two or more national laboratory accreditation organizations wish to develop a mutual recognition agreement.

In order to evaluate whether, for a given physical quantity, the measurement standards of two or more NMIs are equivalent within certain specified limits, an assessment is required of:

- the origin and background of the national standard maintained by each NMI, and the uncertainty claimed for it;
- the quality of the environment and associated equipment in each NMI, and the experience and competence of the staff;
- the performance over a period of each NMI in international comparisons of measurements involving the standards in question.

For completely comprehensive and infallible conclusions to be reached on the equivalence of all the standards and measurements of participating NMIs, the international comparisons would need to be made on a regular basis for every physical quantity and at every level at which measurements are required. This would lead to an impossible workload. Instead, a judicious selection has to be made of the comparisons needed to give a reasonable level of confidence, taking into account not only the scientific needs but also the requirements of metrology users.

The BIPM has conducted international comparisons of a significant number of national standards for about one hundred years, either directly or through the CCs. Typically, however, only some ten or twenty NMIs participate in each comparison, these being mainly, but not exclusively, the most expert member laboratories of the CCs. It would not be practicable to include in these comparisons all Member States of the Convention, let alone all nations worldwide. Other solutions are required.

The growth of regional collaborations between NMIs over the past twenty years, through the newly formed Regional Metrology Organizations, is already quite effectively supplementing the global collaborations through the BIPM and the CCs. Regional comparisons of measurement standards are being conducted that include NMIs from countries, both inside and outside the Convention of the Metre, that rarely participate in the BIPM comparisons. Mutual exchange of information, training, and advice on measurement standards and calibration facilities are also improving uniformity.

Over the past ten to twenty years a number of NMIs have exchanged bilateral statements formally recognizing the equivalence of their national measurement standards within specified limits. The evidence of equivalence has largely been drawn from earlier multilateral comparisons, but not infrequently has required some additional bilateral comparisons and extensive discussions. Although these bilateral recognitions of equivalence have proven beneficial in a number of ways, and may always have a place between pairs of countries having a special need for them, experience has shown that the workload involved would make it impractical to base a comprehensive worldwide system on a network of bilateral agreements.

The need for more to be done to demonstrate the degree of equivalence of national measurement standards was recognized by the 20th CGPM in 1995. Its Resolution 2 recommends:

- that national metrology laboratories, in collaboration with the BIPM, ensure that the necessary comparisons between national standards be carried out in sufficient number to demonstrate equivalence of international traceability of measurement standards,
- that adequate connections be maintained between the comparisons carried out under the auspices of the BIPM and those carried out by the regional groups,
- that the results of comparisons carried out by the regional groups be communicated to the BIPM in appropriate form for them to be published by the BIPM and thereby be given wide international recognition.

In the same year, the CIPM initiated an investigation of the best way forward. The investigation is being led by the Director of the BIPM and undertaken in close communication with the Directors of the NMIs, the RMOs and ILAC. Its outcomes are being implemented progressively as consensus is reached among the relevant parties for each issue.

One consensus already reached is that the technical basis for equivalence assessments will be a series of carefully selected measurement comparisons, to be known as “BIPM key comparisons”, which will be repeated at appropriate intervals of time. A document giving guidelines for these comparisons is being prepared by the Director of the BIPM for the approval of the CIPM. Identification of the key comparisons and their periodicity is being undertaken by each CC for its particular field of metrology, bearing in mind the need to cover the principal

quantities and techniques in that field. This process is nearing completion and to date some seventy key comparisons have been identified. Each comparison will be organized by the relevant CC, with the collaboration of the BIPM, and participation will be open to those NMIs having high technical competence and experience in the field, and also to the BIPM when appropriate. The results of each comparison will be analysed by the CC and used to identify an appropriately weighted mean or median, to be known as the key comparison reference value, and to determine its uncertainty. This will be followed by an evaluation of the deviation of each participant's declared result from the reference value and of the uncertainty in that deviation. The ensemble of values obtained for the deviations and their uncertainties will serve as indicators of the degree of metrological equivalence of the national measurement standards involved in the key comparison.

A few of the key comparisons will be executed directly by the BIPM. In recent years the BIPM has also adopted a policy of establishing portable state-of-the-art standards wherever this is feasible with the appropriate reproducibility, examples being standards for the metre, volt and ohm. These standards are then carried to different regions where the standards of several NMIs can be compared with them. As well as making a valuable contribution to the quest for uniformity, this procedure results in beneficial technology transfer and has further potential for the future.

In order that NMIs not participating in the BIPM key comparisons can relate their national standards to key comparison reference values, the RMOs are being invited to organize regional key comparisons corresponding to the BIPM key comparisons (see Figure 3). An important part of a key comparison is the writing of a protocol for its implementation and it is essential that the regional and BIPM comparisons use the same or very similar procedures. It is intended that each regional comparison will include at least two, and preferably more, of the NMIs participating in the corresponding BIPM comparison in order to provide robust links between the data. It will then be possible for the CCs to relate the results of each NMI participating in the regional comparisons to the key comparison reference values established in the BIPM comparisons, and to calculate the corresponding deviations.

It is of great importance for the worldwide growth of measurement uniformity that the BIPM continue to take part in RMO activities as an additional avenue of collaboration with the NMIs. It should take responsibility for coordinating the BIPM and regional key comparisons and invite the RMOs to contribute to the choice of key comparisons. In order to establish an effective mechanism for this collaboration, the agreement of the coordinators of the well-established RMOs has been obtained for the creation of a Joint Committee of Regional Metrology Organizations and the BIPM, to be chaired by the Director of the BIPM. The BIPM should also encourage countries not yet involved in regional cooperation in metrology either to join existing RMOs or, where appropriate, to form new ones.

The results of appropriately performed bilateral key comparisons can also be used by the CCs to relate the national standards of an individual NMI to key comparison reference values. It will be essential of course for one of the laboratories to have been a participant in the corresponding BIPM key comparison or in a linked regional comparison.

The BIPM will continue its present policy of publishing in *Metrologia* summaries of the results, as they become available, of all multilateral and bilateral measurement comparisons involving NMIs or the BIPM, including the key comparisons organized by the BIPM, the CCs, the RMOs and other parties. The CCs are to review the results of all such comparisons and consider their implications. As a service to the NMIs of Member States of the Convention of the Metre, the BIPM will publish electronically an accumulating record of: the individual results in the key and related comparisons, the key comparison reference values, the deviations of the

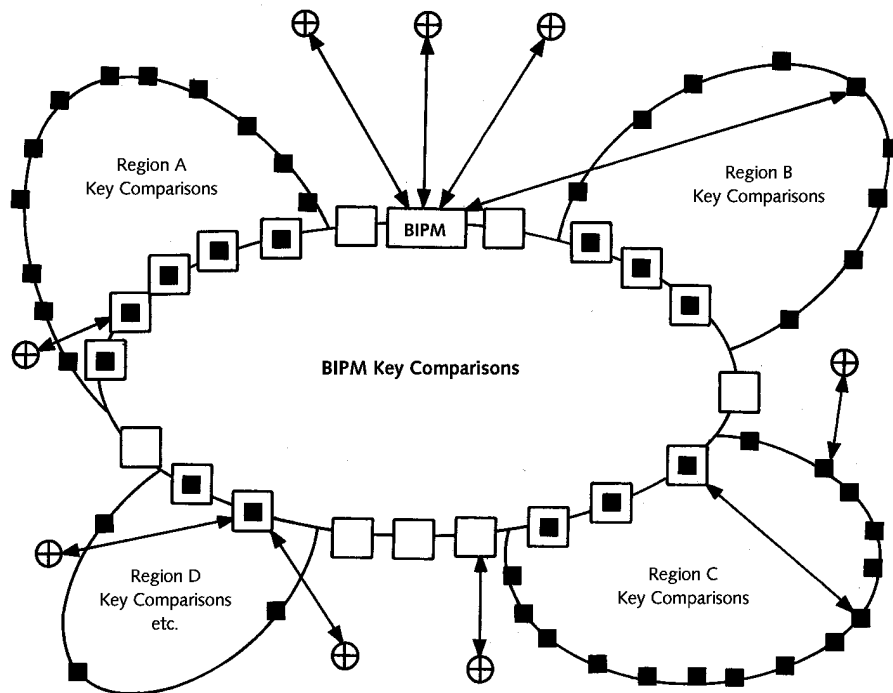


Figure 3

Schematic illustration of how BIPM key comparisons of national measurement standards, linked with corresponding regional key comparisons and bilateral comparisons, can efficiently provide a technical basis for assessing the degree of equivalence of the national standards of many countries.

- National Metrology Institute (NMI) participating in the BIPM key comparison.
- NMI participating in regional key comparisons.
- ◼ NMI participating in both BIPM and regional key comparisons.
- ⊕ Other NMI.
- ↔ Bilateral key comparison.

participants' results from these reference values, and the associated uncertainties. This record will be accessible worldwide on the Internet and is expected to serve as the main data bank for accreditation bodies and others to assess the degree to which international equivalence of national measurement standards has been demonstrated. In this publication activity an important responsibility for the BIPM is to ensure, by appropriate refereeing, the validity of the comparisons whose results are to be used.

The above procedures should be particularly beneficial to those NMIs that have little or no direct participation in the measurement comparisons conducted by the CCs and the BIPM. They provide an opportunity for their measurement expertise to be demonstrated against international benchmarks and to become more widely recognized.

Reports being prepared for the CIPM by the Director of the BIPM describe in more detail the methodology to be used for the key comparisons and for the analysis of the results, including the determination of the key comparison reference values and the deviations from them. Moreover, in collaboration with the Directors of the NMIs and the RMOs, an agreement based on the key comparisons is being implemented for the mutual recognition of national measurement standards and of calibration certificates issued by NMIs. The NMIs are to be invited to become signatories to this agreement, which will be maintained by the BIPM on behalf of the Member States.

The greater responsibilities being placed on the CCs, particularly concerning key comparisons and their interpretation, is increasing the need for the CCs to remain quite active and to make decisions between meetings. In order to assist in this, the BIPM is now allocating to each CC a senior member of staff to serve as its executive secretary and is proposing to provide additional secretariat support.

4.5 International collaboration in laboratory accreditation

The national laboratory accreditation organizations and their international cooperation, ILAC, have played a key role in assisting governments to overcome trade barriers relating to testing. The practical success of the world's measurement infrastructure, including the work of the BIPM and the NMIs, depends critically on the success of these agencies in ensuring effective measurement traceability to national and international measurement standards.

The ILAC and the corresponding regional laboratory accreditation cooperations have the important task of ensuring the international equivalence of measurement at levels below that of the NMIs. Figure 4 illustrates the measurement hierarchies of two hypothetical nations in a given region of the world: in each case the measurement standards used in the workplace are linked to the accredited calibration network, from that network to the working standards used for the NMI's calibration services, and finally to the NMI's national measurement standards. The complementary roles of the BIPM and the RMOs in ensuring equivalence between the national and working standards in the NMIs are discussed in Section 4.4. In order

to check the continuity of the vertical traceability paths, there is a need for the regional laboratory accreditation cooperations to organize intra-regional horizontal comparisons and proficiency tests as shown in Figure 4, and for ILAC to organize corresponding inter-regional checks.

It is important that the BIPM establish a close relationship with ILAC in order to complement the relationships at the national level between the NMIs and national laboratory accreditation organizations. A number of broad issues are of common interest to these two bodies. One of these is the equivalence of the national measurement standards. Another is the development of an agreed policy on the requirements for acceptable measurement traceability, from international and national measurement standards down to the workplace. As noted above, ILAC is soon to establish a small permanent secretariat. It would be to the mutual advantage of the BIPM and the ILAC if this were located at or near the BIPM. It is understood that the full cost of an ILAC secretariat at the BIPM would be supported by ILAC.

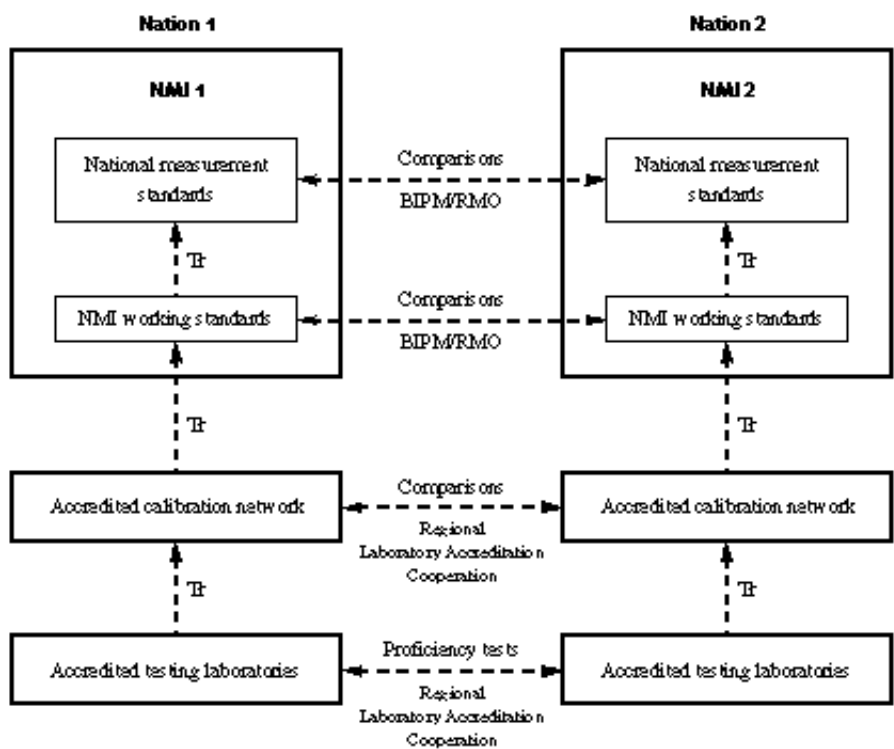


Figure 4

An illustration, for one hypothetical world region, of the complementary roles of the BIPM, the Regional Metrology Organization and the Regional Laboratory Accreditation Cooperation in providing horizontal checks of the equivalence of measurements at various levels of the national calibration hierarchies.

NMI denotes National Metrology Institute.

RMO denotes Regional Metrology Organization.

Tr denotes traceability chain.

4.6 International collaboration in legal metrology

Since its establishment in 1955 the OIML has had considerable success in harmonizing internationally the national regulations and procedures relating to legal metrology, particularly in the area of trade measurement. It has published guidelines covering general aspects of legal metrology, including the adoption of SI units as legal units of measurement, and has developed a wide range of international recommendations intended for adoption as national regulations to ensure the proper design, verification and use of measuring instruments that are subject to legal requirements. In 1991 the OIML certificate system for measuring instruments was introduced to facilitate administrative procedures and lower costs associated with the international trade of measuring instruments subject to legal requirements. Recently, the OIML has extended its work beyond trade measurement into fields where human welfare is affected by regulations requiring measuring instruments for their implementation (for example: safety, health and the environment). The need for such work is expected to grow, although the willingness of governments to adopt internationally uniform regulations and regulatory policies is sometimes difficult to predict.

The BIPM and the Bureau International de Métrologie Légale (BIML) have always enjoyed a cordial working relationship and have jointly contributed to the drafting of some basic metrological documents, but they have perhaps collaborated less than might be expected given that they are the only two global metrology organizations funded by national governments. As legal metrology moves further beyond its trade measurement origins, the mutual need for collaboration will grow. A joint working party of the CIPM and the Comité International de Métrologie Légale (CIML) is currently seeking 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.

4.7 International documentary standards

In order to achieve worldwide uniformity of measurements, there is a clear and continuing need to have available a range of international documents covering the basic aspects of metrology. The ISO and IEC (and, to a lesser extent, the OIML) play an important role in this respect, and their documents in this field are frequently adopted by national organizations. Examples of the most basic of these international documents are:

- ISO 31 (Parts 0 to 13), *Quantities and units*;
- ISO Guides 30-35, *Reference materials*;
- ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*;
- IEC Publication 27 (Parts 1 to 4), *Letter symbols to be used in electrical technology*;

- IEC Publication 50, *International Electrotechnical Vocabulary*;
- OIML D2, *Legal units of measurement*.

Two particularly relevant documents have been published by the ISO on behalf of the BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML. These are:

- *International vocabulary of basic and general terms in metrology*;
- *Guide to the expression of uncertainty in measurement*.

Of particular relevance to calibration laboratories and their accreditation are the jointly published ISO/IEC Guides for product and company certification and conformity assessment, in particular:

- ISO/IEC Guide 25, *General requirements for the competence of calibration and testing laboratories*;
- ISO/IEC Guide 58, *Calibration and testing laboratory accreditation systems – General requirements for operation and recognition*.

The ISO 9000 series of standards on quality management and quality assurance has had a beneficial impact on world metrology by alerting many organizations seeking quality certification to their need for reliable metrology and measurement traceability. In some cases, unfortunately, confusion has arisen between the roles of quality certification and laboratory accreditation.

The work of the ISO Committee on Reference Materials (REMCO) shares a number of common objectives with the work of the BIPM and the Consultative Committee for Amount of Substance (CCQM) on metrology in chemistry. Communication between these groups has recently been improved by the admission of REMCO to membership in the CCQM.

It is recommended that the BIPM, ILAC and OIML engage periodically in joint discussions with the ISO and IEC about the need for additional international documentation relating to basic aspects of metrology and uniformity of measurement. The drafting of appropriate international guidelines might well play a useful role in achieving equivalence and mutual recognition of the national measurement standards maintained by the NMIs, and in developing more uniform criteria for measurement traceability. In this connection, it should be noted that the ISO, IEC and OIML are already represented on the Consultative Committee for Units.

ISO/IEC documentary standards constitute an excellent source of information on the measurements required for different industries, products and services. These can be of great value to the providers of the metrology services required to underpin the measurements. An example is the IEC 1000 series of standards on electromagnetic compatibility. It is recommended that the BIPM and OIML make as much use as possible of the ISO and IEC in the preparation of documentary standards relating to specific fields of applied or “practical” measurement. There are many such fields and it is unrealistic to expect the costs involved to be met from

the funds provided by governments to the BIPM and the OIML for the more general and core aspects of metrology and legal metrology.

4.8 The needs of developing countries

The CIPM recognizes that the BIPM needs to find new ways to assist developing countries in strengthening their national measurement systems. In part this can be achieved by collaboration with the OIML, which already has in place a Development Council to address the needs of developing countries. To this end the BIPM is currently collaborating with the OIML and IMEKO in supporting a seminar in June 1998 on *The Role of Metrology in Economic and Social Development*, being organized and hosted by the Physikalisch-Technische Bundesanstalt in Braunschweig, Germany.

Several of the initiatives announced in this report will increase the opportunities for developing countries to become associated with the work of the BIPM, particularly those countries that are Member States of the Convention of the Metre. For example, the periodic meetings of the Directors of NMIs with the CIPM and senior BIPM staff are open to developing countries as well as to those with well-developed measurement systems, provided they are members of the Metre Convention. The decision to admit observers to meetings of the Consultative Committees will increase the interaction between BIPM and less advanced NMIs. Very importantly, as already stated in Section 4.4, the coordination of the BIPM key comparisons with the regional key comparisons provides an ongoing opportunity for developing countries to demonstrate their growing measurement expertise against international benchmarks and so to gain wider recognition of their capabilities.

Another initiative for the BIPM to undertake is to establish relationships at a high level with international funding agencies, such as the World Bank and the Regional Development Banks, to advise them on the effective channelling of funds into the metrological structures of developing countries. An important aim is to raise the profile of metrological activity as a component in economic development.

5 Role of the BIPM in the early decades of the 21st century

The Convention of the Metre provides the formal basis for worldwide agreement on measurements for industry, trade and commerce, science and engineering, communications, medicine and essentially all the activities of a modern state, including human health and safety. The Convention originated late in the nineteenth century, at a time of rapidly increasing trade in manufactured products, because of a wide recognition of the need for international agreement on units of measurement. It is now an essential part of the technical infrastructure of the modern world. The BIPM is the main tool of the Convention for achieving its mission and, since in the Member States the range of activities that require accurate and uniform measurements is increasing rather than decreasing, a considerable expansion of the role and scope of the BIPM could be foreseen. The fact must be faced, however, that economic restraints in Member States and a widespread policy of not increasing spending militate against such an expansion. The CIPM has therefore undertaken a serious review of several scenarios for the future of the BIPM. These include, on the one hand, the possibility of an increase in its scope and funding to meet increasing demands, and on the other, the consequences of reductions in various parts of the programme and even reductions in overall budget. It is important to note that in carrying out this review the CIPM was conscious of the fact that the point at issue is not whether the work of the BIPM needs to be done – there is universal agreement that it does – but whether it can be done more efficiently, either at the BIPM or elsewhere, and how it can be done in the most cost-effective way.

The BIPM's current work falls into two broad categories.

- It serves as an administrative and scientific secretariat for coordinating international collaborations under the Convention of the Metre.
- It operates as an active scientific institute that performs a mix of service work and scientific research associated with metrology.

To the best knowledge of the CIPM, there is universal agreement that the role of the BIPM as an administrative and scientific secretariat is essential. It is the view of the CIPM that the BIPM could not fulfil this role effectively if it were not also to maintain laboratories and pursue an active programme of scientific work. This has always been the view of the CIPM and has been supported by Member States

at successive CGPMs, and it is not called into question here. It is, however, worth restating some of the principal arguments that support this position:

- Many governments regard it as a matter of strategic importance to maintain the independence of the technological and metrological infrastructure of their country and, when international traceability is required, prefer to relate to an independent international laboratory and not to be obliged to depend on foreign NMIs. In particular, cessation of laboratory work at the BIPM would require one or more NMIs to be designated by the Member States to maintain and disseminate the world's standard of mass, the world's time scale, the International Reference System for radioactivity measurements, and so on. All those NMIs that at present rely on the BIPM for calibrations to establish the traceability of their national standards would have to rely instead on foreign NMIs. Similarly, the considerable amount of technology transfer and technical advice related to primary measurement standards, at present provided to NMIs by BIPM scientific staff in the course of international comparisons, would have to be obtained from another NMI. Confidence that international comparisons of national standards are conducted and analysed objectively and fairly would inevitably decline if involvement by competent and independent BIPM scientists were to cease.
- If worldwide uniformity of measurement is to be achieved economically, much of the international collaboration required, including comparisons of national standards, needs to be multilateral rather than bilateral. Coordination of multilateral collaborations is one of the strengths of the BIPM, but continued success in this role depends critically on the BIPM having competent and expert scientific staff. About one hundred organizations and institutes from around the world participate in the work of the nine Consultative Committees and, in 1997 alone, some one hundred and seventy experts from national institutes came to the BIPM for meetings of six of the Committees. If the BIPM were to lose its competence to coordinate these multilateral activities, collaboration between these 100 institutes would have to be either bilateral or regional, with inter-regional linkages. Both alternatives would be much less efficient and more costly than the present system based on the BIPM. It is also unlikely that individual NMIs would be prepared to take over the BIPM's present scientific programmes and responsibilities without corresponding financial recompense from the other Member States, especially in view of the pressures on many of them to be more commercial.

The BIPM must therefore maintain a scientific staff and continue to function as an active scientific laboratory.

The CIPM, having decided that cessation of laboratory work at the BIPM is not a viable option, went on to examine various scenarios for maintaining both the secretariat and laboratory functions of the BIPM in the face of economic restraints and the changing needs of the ensemble of NMIs. It reviewed the statement it adopted in 1984 summarizing the role of the BIPM, reproduced here in Appendix A, and amended it to read:

Role of the BIPM in the early decades of the 21st century

The mission of the BIPM is to ensure worldwide uniformity of measurement.

The BIPM will achieve this mission both by providing the necessary physical basis for such uniformity and by collaborating with other institutions and organizations that have related missions. Its principal tasks are therefore:

- to keep up-to-date and disseminate the International System of Units (SI);
- to conserve and disseminate the primary standard of mass, the International Prototype of the Kilogram;
- to establish and disseminate International Atomic Time and, in collaboration with the appropriate astronomical organizations, Coordinated Universal Time;
- to provide a centre for the international comparison of physical realizations of other base and derived units of the SI, as may be necessary to meet the needs of the ensemble of National Metrology Institutes, and to make its own realizations in those cases where specific advantages are foreseen; and to participate in the development of primary methods of measurement in chemistry;
- to collaborate with the Consultative Committees and Regional Metrology Organizations in identifying key international comparisons required in order to evaluate the degree of equivalence of national measurement standards, and in arranging for these comparisons to be carried out;
- to publish summaries of the available results of all multilateral and bilateral measurement comparisons involving the National Metrology Institutes or the BIPM, and to publish evaluations of the extent to which these demonstrate the equivalence of the national measurement standards;
- to implement and maintain on behalf of the Member States an agreement for the mutual recognition of national measurement standards and calibration certificates issued by National Metrology Institutes;
- to strengthen the traceability of the national measurement standards of Member States by providing calibrations sought by their National Metrology Institutes, wherever this is feasible;
- to undertake scientific research related to measurement units and standards, including appropriate fundamental research and the determination of physical constants;
- to collaborate with international bodies having related missions, among them the Regional Metrology Organizations, the International Laboratory Accreditation Cooperation, the Organisation Internationale de Métrologie Légale, the International Organization for Standardization and the International Electrotechnical Commission, to ensure with them that basic documents needed for uniformity of measurements, such as those on vocabulary in metrology and on the expression of uncertainty in measurement, are kept up-to-date and widely disseminated;

- to provide the scientific and administrative Secretariat for the Conférence Générale des Poids et Mesures and for the Comité International des Poids et Mesures and its Consultative Committees.

In addition to this summary statement the CIPM made twenty-one specific decisions affecting the role of the BIPM. These are listed in the next section of this report.

6 Decisions by the CIPM

As a consequence to its deliberations in the preparation of this report the CIPM made the following decisions about the future roles of the BIPM and the Consultative Committees. Some of these decisions are essentially affirmations of previous policy, while others contain substantial elements of new policy.

World leadership in metrology

1. The BIPM will continue to provide world leadership in ensuring worldwide uniformity of measurements, in improving and promoting the use of the International System of Units (SI) and foreseeing new needs, in developing improved measurement standards, and in establishing a readily accessible data bank on the degree to which the national measurement standards of different countries are equivalent.
2. The BIPM will facilitate improved communication at the most senior level with its principal clients, the National Measurement Institutes of the Member States, by arranging periodic meetings of the Directors of those Institutes with members of the CIPM and senior BIPM staff to discuss major issues in international metrology.

Laboratory activities at the BIPM

3. The BIPM will undertake a variety of research related to units and standards in order to provide the vibrant research environment necessary to attract and retain first-class scientists capable of working with senior NMI scientists as respected peers or leaders, this being essential for the effective accomplishment of its mission. Some associated fundamental research and determinations of physical constants may be included. The total laboratory effort at the BIPM will be maintained at least at its present level, a level barely above the threshold necessary to maintain a viable team.
4. Because the BIPM has unique responsibilities for the International Prototype of the Kilogram, and for TAI and UTC, active laboratory programmes will be maintained in the fields of mass, time and frequency.
5. The International Reference System developed by the BIPM over many years for activity measurements of radionuclides provides the worldwide basis for

ensuring the equivalence of national standards of activity. It will continue to be supported.

6. The other current laboratory activities at the BIPM – mainly in length, electricity, ionizing radiation, and radiometry and photometry – continue to make important contributions to measurement uniformity and to the corresponding standards programmes in the NMIs. However, since the BIPM is too small to participate in all branches of metrology, its fields of laboratory activity must change from time to time to reflect the evolving needs of the ensemble of NMIs.
7. The BIPM will commence a small laboratory programme with a staff of about four, on one or more carefully selected aspects of metrology in chemistry. In particular, this programme will support the work of the Consultative Committee for Amount of Substance in providing leadership to the chemical community in strengthening the traceability of chemical measurements to the units of the SI.
8. The BIPM will continue to assist the NMIs of Member States to strengthen the traceability of their national measurement standards, by providing calibrations wherever it has the capacity to do so.

Equivalence of national measurement standards

9. The BIPM will collaborate with the CCs to identify in each field of metrology those international comparisons of measurements, to be known as BIPM key comparisons, that are required to evaluate the degree of equivalence of national measurement standards. It will assist the CCs in organizing periodic key comparisons between NMIs expert in the field, ensuring that wherever possible at least two and preferably more NMIs are included from each RMO.
10. The building of strong links between the BIPM and the RMOs will be reinforced and the agreement of the coordinators of the well-established RMOs will be sought for the creation of a Joint Committee of Regional Metrology Organizations, chaired by the Director of the BIPM. The BIPM will encourage the RMOs to conduct regional key comparisons, synchronized with the BIPM key comparisons, so that global links can be made to the greater possible number of national standards. It will also encourage countries not yet a member of an RMO to become involved in regional cooperation in metrology, either by joining an existing RMO or where necessary by forming a new one.
11. The BIPM will continue its policy of publishing in *Metrologia* refereed summaries of the results of all measurement comparisons involving NMIs or the BIPM, particularly those of the BIPM and regional key comparisons.
12. From the results of each BIPM key comparison the CCs will determine a key comparison reference value. For each participant in BIPM, regional and bilateral key comparisons, the deviation of its declared value from the reference value will be evaluated, together with the associated uncertainty. As a service

to the NMIs of Member States the BIPM will maintain electronically an accumulating record of their individual results in the key comparisons and of their deviations from the key comparison reference values. This record is to be made readily accessible worldwide on the Internet.

13. In collaboration with the Directors of the NMIs and the coordinators of the RMOs, the BIPM will implement and maintain an agreement for the mutual recognition of national measurement standards and of calibration certificates issued by NMIs. The Directors of the participating NMIs will be invited to sign this agreement.

Consultative Committees of the CIPM

14. The criteria for membership of the CCs have been revised by the CIPM (see Appendix C). The terms of reference of the CCs will be broadened and, if necessary, one or two additional CCs will be established, so as to cover the principal fields of metrology in which international equivalence of standards and collaboration between the NMIs are important.
15. Appendix D proposes model terms of reference for a typical CC, although the terms of reference will vary considerably from one CC to another. Greater emphasis is now placed on planning key comparisons, reviewing and analysing the results, and evaluating the degree of equivalence of the national measurement standards.
16. The titles of four of the existing CCs have been amended so as to give a clearer indication of their activities (see Table 2). Consideration is being given to the establishment of a CC for acoustics, ultrasound and vibration.
17. Coordination of the standards research in the NMIs will remain an important CC activity, and opportunities will be given at CC meetings to consider sharing some of the more expensive facilities.
18. In view of their increased responsibilities the CCs will conduct a continuing programme of work between meetings, with the BIPM providing the support of a central secretariat for each CC and allocating a particular member of staff to serve as its executive secretary.

Collaborations with related international organizations

19. As the world's senior international organization for metrology, the BIPM will arrange periodic meetings at a senior level between representatives of the BIPM, BIML, ISO, IEC and ILAC. The objectives of these meetings include the following:
 - to ensure that the missions of the five organizations dealing with measurement and metrology are complementary and, when taken together, sufficiently comprehensive to ensure global unification of standards;

- to plan strategies for making national governments and relevant international organizations aware of the ongoing importance of measurement and metrology;
 - to review existing international documentary standards, guides and other documents that serve to advance international uniformity in metrology, to identify needs for additional documents and the most appropriate body to take responsibility for them;
 - to consider joint initiatives to assist developing countries in metrology, including strengthening relationships with leading international funding agencies such as the World Bank and Regional Development Banks.
20. The BIPM will take steps to develop a close and continuing liaison with the ILAC and collaborate with it on broad issues such as the equivalence of national measurement standards and the criteria which determine measurement traceability. It should encourage the proposal to locate the new ILAC secretariat at the BIPM.
21. The BIPM will seek to work in closer collaboration with the BIML, taking particular note of the recommendations arising from the joint working party of the CIPM and CIML.

7 Financial commitments required from the Member States of the Convention of the Metre

This Report now turns to the financial commitments that will be required from the Member States of the Convention of the Metre in the coming decades so that the strategies and decisions given above may be implemented effectively and efficiently. These commitments fall into three categories.

- The first category is the annual dotation that each Member State undertakes to pay to the BIPM, this representing a direct financial commitment. The total dotation for each year is determined in advance by the CGPM after considering the BIPM's proposed work programme, and is distributed among the Member States by means of a procedure approved by the CGPM and based on the scale of assessments of the United Nations Organization for the apportionment of contributions.
- The second category comprises the additional costs to each Member State of collaborating with the CIPM, BIPM and CCs in their programmes of work. Most, but not all, of this collaboration is undertaken by the NMIs, particularly through participation in international comparisons of measurement and in other work of the CCs.
- The third category is the increased expenditure that Member States are expected to face within their own countries in order to respond to the increased demand for reliable metrology that is anticipated in a number of new fields.

Future requirements are now discussed for each of these categories in turn.

7.1 Annual dotation of the BIPM

Before discussing the appropriate magnitude of the dotation for the next few decades, data for the period 1980-1996 are briefly analysed in order to indicate recent trends. During this period the total dotation determined by the CGPM increased from 7 475 000 gold francs to 25 918 000 gold francs. If the index for French inflation is taken into account and both amounts are expressed in 1996 gold francs, the increase was from 15 548 000 gold francs to 25 918 000 gold francs, which represents an increase over the period of approximately 66.7 % in real terms. The percentage of the dotation actually received each year by the BIPM ranged over the period from 85.95 % to 116.10 % and averaged 99.31 %. It is relevant to note that the number of permanent pensionable BIPM staff grew

from 50 in 1980 to 68 in 1991, an increase of 36 %, although by 1996 the staff had been temporarily reduced to 65 in order to accommodate a transient financial crisis associated with the dissolution of the USSR. In part the increase resulted from the BIPM taking over responsibility for TAI in 1985. Moreover, the level of the staff qualifications became significantly higher over the period, there being for example 9 staff with doctoral degrees in 1980 and 21 in 1996. In addition, the laboratory equipment increased considerably in complexity, with innovations including the laser laboratory, cryogenic radiometry, the Josephson effect and the quantized Hall resistance facilities, and the time laboratory.

In 1995 the 20th CGPM decided that the dotation of the BIPM for the years 1997-2000 would be:

27 144 000 gold francs in 1997,
28 365 000 gold francs in 1998,
29 642 000 gold francs in 1999,
30 976 000 gold francs in 2000.

These amounts correspond to an increase of 4.5 % per year and were decided after taking into account increased contributions to the BIPM pension fund, maintenance and updating of the BIPM buildings, expected price inflation in France, and additional costs caused by the increasing complexity of metrology.

Turning now to the dotations foreseen for the early decades of the 21st century, particular emphasis is placed on the quadrennia 2001-2004 and 2005-2008, for which the annual dotations will be determined by the 21st CGPM in 1999 and the 22nd CGPM in 2003, respectively.

The CIPM decisions listed in Section 6 of this report foreshadow a number of new activities for the BIPM that will involve significant expenditure. Principal among these are:

- the decision to start a laboratory programme on metrology in chemistry with a staff of about four, all of whom will probably need to be recruited externally,
- the decisions concerning the equivalence of national measurement standards and the key comparisons, which will significantly increase the administrative workload of the senior BIPM scientists who serve as executive secretaries of the CCs and will require additional administrative support of up to two people.

The costs associated with these two new activities can be summarized as follows. The laboratory programme in metrology in chemistry will increase the number of scientific sections in the BIPM from six to seven. The proposed programme is about the same size as those of some of the existing sections; with three professional and one technical staff it is the minimum viable. Its direct permanent operating cost will be about 8 % of the annual budget. The cost of refurbishing laboratory space to set up the programme is estimated to be about 1.5 million gold francs and the capital value of the equipment required initially to be about 3 million gold francs. It is envisaged that much of the equipment will become available

through donations from national laboratories and commercial companies. Other start-up costs will be met from the reserves. The cost of additional administrative support, up to two staff, for the key comparison programme will involve a cost of about 3 %; the combined ongoing operating cost of the two new activities will, therefore, be 10 % to 11 % of the budget.

It is the view of the CIPM that this increase in operating cost can, with tight management, be offset by corresponding budgetary savings of 10 % to 11 %. One significant reduction in BIPM expenditure in coming decades will result from the completion by 2000 of the long-term building programme, which has absorbed on average about 4 % of the BIPM annual budget since the programme was formulated by the CIPM early in the 1980s. Included in that programme were a new laboratory building for laser activities, a new administration building with a library and offices, and a new workshop to replace the existing unsuitable accommodation. The laser and administration buildings are complete and have been in use for a considerable time, and construction of the new workshops, which is now in progress, will complete the programme. No need is foreseen for further new buildings within the next few decades. Significant renovation and refitting of some existing accommodation will be required, but the cost of such work and of general building maintenance is routinely allowed for in the BIPM budget. The further savings required, of 6 % to 7 %, can be brought about only by increased efficiency and by terminating or curtailing selected areas of current work. It must be remembered that significant cuts in overall costs can be made only by staff reductions since some 40 % of the budget is consumed by direct salary costs and a further 20 % by pension costs, expatriation and family allowances, and medical and other insurance. The Director has already implemented some staff reductions and efficiency savings, but more will be required in order to achieve the savings target. It is believed that this target can be achieved by general reductions without actually terminating any existing programme, but that there will be little, if any, scope left for future across-the-board savings of this type.

Another major budgetary concern for the future is the increasing annual allocation to the BIPM pension fund to provide for an anticipated doubling of the number of BIPM pensioners over the period 1994-2010. In 1994, in response to an actuarial report on the fund, the CIPM decided *inter alia* to increase the allocation progressively every year from 1996 to 2008 by an amount equivalent to 2% of the salaries (at that time equivalent to about 1% of the total annual budget of the BIPM). This was allowed for by the 20th CGPM in deciding the dotations for 1997-2000. If the CGPMs of 1999 and 2003 do not make a similar allowance, the result will be a progressive reduction in the BIPM budget for other purposes after the year 2000.

Against the above background the CIPM, with the Director of the BIPM, has considered several hypothetical scenarios regarding the level of annual dotation for the decade 2001-2010.

- The first scenario considered is that of a constant dotation in real terms throughout the decade, equivalent to that already determined for the year 2000.

With the efficiency savings and curtailments discussed above, this would enable the existing and the new BIPM activities to continue for a few years. From the year 2006, however, cuts in expenditure of at least 5 % would be required in order to balance the budget. In view of the effort already made, cuts of this magnitude would require a significant reduction in the scientific programme. One of the options to be considered would be closure of one of the scientific sections.

- The second scenario is again that of a constant dotation, but at a level in real terms 5 % above that for the year 2000. This would enable the existing and the new activities to continue through the decade. The efficiency savings and programme curtailments discussed above would still be necessary, but they would be less severe and would not have to be implemented with as much urgency as in the first scenario.
- The consequences of real decreases in the dotation have also been considered. A cut of 10 % in real terms from the year 2001 would require an immediate staff reduction of six or seven persons by closure of one or more of the scientific sections. By 2005 another scientific section would probably have to go. Cuts of 20 % or 30 % would respectively double and triple the magnitudes of the staff reductions that would be required immediately. With a 30 % cut, the staff reduction would be equivalent to about half the existing scientific programme and it might well prove impossible for the BIPM to remain viable as an active scientific institute. It would be difficult to recruit high-quality scientists to an institute having such a restricted programme and too few scientific staff to achieve critical intellectual mass. The CIPM emphasizes that, while some NMIs have been subject to funding cuts comparable with those just mentioned, the BIPM is already a very small institution operating at the lower limit of viability in terms of intellectual and financial resources; comparable cuts would therefore have disproportionate effects on the efficiency of its operation.

In the light of the analysis summarized above, the CIPM anticipates that it will recommend to the 21st CGPM in 1999 that the BIPM annual dotation be held constant in real terms during the quadrennium 2001-2004, at the level already determined by the 20th CGPM for the year 2000. While recognizing the present economic constraints in Member States, this would allow both the existing and the new BIPM programmes to proceed, albeit with tight budgeting. For the 22nd CGPM in 2003, the CIPM will have to make the difficult decision whether to recommend continuation of a constant dotation during 2005-2008, and consequent reduction of the BIPM's scientific programme, or to recommend an increase of dotation of about 5 % in real terms. This decision is best deferred until closer to the time, when the prevailing economic situation is clearer and more up-to-date BIPM budgeting details are available for this period. The possibility should not be excluded that by 2003 the pressure from Member States to undertake new programmes of work programmes may be such that the CIPM will propose a larger increase of dotation.

Predictions for the following decades are more difficult. Payments to the pension fund are not expected to increase after the year 2008, but the fund will be the subject of a further actuarial study meanwhile. There is little doubt that the BIPM will continue to initiate new programmes that will require new staff; possible examples are programmes related to the anticipated redefinition of the kilogram or to a quantum-based realization of the ampere, but such developments cannot be foreseen in detail. What is important is that the BIPM should be able to adapt its programmes to take advantage of new developments. Although it might well prove possible, by curtailing other programmes and redeploying staff, to undertake such new programmes while continuing to keep the dotation constant in real terms, it is too early to reach any final decision on this.

7.2 Other costs under the Convention of the Metre

In addition to the payment of the annual dotation to the BIPM, a range of other costs are encountered by each Member State that participates in the work carried out under the Convention of the Metre. Examples of activities that lead to such additional costs are:

- participation in meetings of the CGPM, CIPM and CCs;
- participation in international measurement comparisons and other collaborative laboratory programmes, mainly organized by the CCs and their Working Groups;
- occasional donations of major items of equipment to the BIPM, such as the modern diamond-turning lathe recently donated by Japan and the precision balance donated earlier by the USA;
- occasional support of visiting scientists at the BIPM.

The emergence of the RMOs over the past few decades is also drawing upon the resources of the NMIs that participate in their measurement comparisons and other activities.

The introduction of the BIPM and regional key comparisons will significantly increase the number of comparisons undertaken by many NMIs. While the associated financial burden for each NMI is best evaluated by the NMI itself, it seems clear that there is no more cost-effective way to determine the degree of equivalence of national measurement standards worldwide. There is a potential for the broadening of the fields of metrology covered by the CCs to have cost implications for the participating NMIs, although it is expected that new programmes will be undertaken only when adequate benefits for the Member States are foreseen.

It is emphasised that each Member State, through its NMI, should identify with care the committees, measurement comparisons and other activities under the Convention of the Metre in which it wishes to be involved. This should allow priority to be given to those activities judged to be most relevant to that Member

State's national interest and at the same time enable the costs additional to the dotation to be held within acceptable limits.

7.3 Impact on the Member States of new fields in metrology

Sections 7.1 and 7.2 discuss the anticipated future costs to Member States of being a signatory to the Convention of the Metre and participating in BIPM activities.

As far as internal national programmes on metrology are concerned, each Member State will of course make its own decisions about its future level of funding. It is appropriate however that this report give warning that there will be significant cost implications for the Member States associated with the increased demand for reliable metrology that is anticipated in a number of new fields. As pointed out earlier, these fields are expected to extend far beyond the traditional areas of physics and engineering and to include metrology in chemistry, biology, medicine, health and safety, environmental protection, and so on. Member States are bound to experience pressure to expand their activities in these fields for the benefit of their industry and trade, and out of concern for human welfare. This will inevitably lead to higher expenditure on metrology programmes by the Member States, or to a diversion of funds by a considerable and perhaps drastic reduction of their traditional programmes.

As far as its limited budget permits, the BIPM will serve as a focal point for the international coordination of the programmes of the Member States and their NMIs in these new fields. If the BIPM is held to a constant budget, however, its contribution will be severely limited and responsibility for international coordination will have to lie mainly with the NMIs themselves, and particularly the larger and better-equipped ones, a duty that will induce a significant increase of their financial load.

Appendix A. 1984 Statement of the role of the BIPM

At its 1984 meeting (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1984, **52**, 7) the CIPM discussed the role of the BIPM in the 1980s and its conclusions were made known in the Convocation to the 18th Conférence Générale (*BIPM Comptes Rendus 18^e Conf. Gén. Poids et Mesures*, 1987, 23) in the following terms:

The purpose of the BIPM is to provide the physical basis necessary to ensure worldwide uniformity of measurements. Therefore, its principal tasks are:

- to conserve and disseminate the unit of mass;
- to establish and disseminate the International Atomic Time and, in collaboration with the appropriate astronomical organizations, Coordinated Universal Time;
- to provide a centre for the international comparison of the realizations of other base or derived units and for further dissemination of these units, as may be necessary to meet the needs of the ensemble of national metrological laboratories. This requires, among other things, that in some areas the BIPM maintain its own realizations of certain base or derived units;
- to determine, when it may be appropriate, physical constants closely related to the definition, realization or dissemination of base or derived units;
- to provide the scientific and administrative Secretariat for the Conférence Générale des Poids et Mesures, the Comité International des Poids et Mesures and its Consultative Committees;
- to furnish whatever help is possible in the organization of those international comparisons which, although not carried out at the BIPM, are carried out under the auspices of a Consultative Committee;
- to ensure that the results of international comparisons are properly documented and, if not published elsewhere, are published directly by the BIPM.

In order to carry out these tasks efficiently and at the level required of it, the BIPM must have appropriate scientific, technical and administrative staff together with up-to-date equipment, laboratories, library, workshop and other facilities.

Appendix B. Resolutions 1, 2, 3 and 11 of the 20th CGPM, October 1995

■ 20th CGPM, 1995, Resolution 1: The need to use SI units in studies of Earth resources, the environment, human well-being and related issues

The 20th 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, and the consequences for human health and well-being, are the subject of major studies world-wide,
- 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,

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 world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention of the Metre.

■ **20th CGPM, 1995, Resolution 2: World-wide traceability of measurement standards**

The 20th Conférence Générale des Poids et Mesures,

considering

- the increasingly stringent requirements of science, technology and international trade for traceability in measurement at many levels of accuracy,
- the existence of groups of cooperating national metrology laboratories in different regions of the world,
- the need to demonstrate world-wide equivalence or traceability of measurement standards among national laboratories and regional groups of cooperating national laboratories,
- the calibration services of the Bureau International des Poids et Mesures (BIPM) for the national laboratories,
- the role of the BIPM in carrying out and coordinating world-wide comparisons of standards at the highest level among the national laboratories,
- the necessary participation of national laboratories in international comparisons,

welcomes the trend towards regional grouping of national metrology laboratories as an efficient way of promoting cooperation and regular comparisons of national standards among laboratories, some of which do not participate in comparisons carried out by the BIPM or the Comités Consultatifs,

recognizes the global advantages of interconnections between the comparisons carried out under the auspices of the BIPM and those of the regional groups of metrology laboratories,

recommends

- that national metrology laboratories, in collaboration with the BIPM, ensure that the necessary comparisons between national standards be carried out in sufficient number to demonstrate international traceability of measurement standards,
- that adequate interconnections be maintained between the comparisons carried out under the auspices of the BIPM and those carried out by the regional groups,
- and that the results of comparisons carried out by the regional groups be communicated to the BIPM in appropriate form for them to be published by the BIPM and thereby given wide international recognition.

■ 20th CGPM, 1995, Resolution 3: The need for long-term metrological research

The 20th Conférence Générale des Poids et Mesures,

considering

- the continual increase in demand for accurate and efficient measurement in science, technology and international trade,
- that the development of improved measurements standards and techniques needs to be carried out well in advance of their application in science and industry,
- that these developments can only take place on the basis of a solid foundation of long-term metrological research closely linked to advances in science,

recommends that national laboratories

- continue to undertake long-term metrological research as well as meet the more immediate requirements of measurement services and
- keep the Bureau International des Poids et Mesures informed as to the results of the work related to fundamental metrology.

■ 20th CGPM, 1995, Resolution 11: Metrology, long-term needs

The 20th Conférence Générale des Poids et Mesures,

referring to Resolution 1: The need to use SI units in studies of Earth resources, the environment, human well-being and related issues, Resolution 2: World-wide traceability of measurement standards, and Resolution 3: The need for long-term metrological research,

considering

- the particular impact of metrology on the economic growth and international trade of Member States,
- the contribution to these of the Bureau International des Poids et Mesures (BIPM) and the national metrological laboratories,

requests the Comité International des Poids et Mesures 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.

Appendix C. Criteria for membership of the Consultative Committees of the CIPM

At its 85th meeting in 1996, the CIPM adopted new criteria for membership of the Consultative Committees (*BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1996, **64**, 123-124) in the following terms:

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 (CC) should be 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 CC, the BIPM or a regional metrology organization.

In addition to laboratory members, CCs may include as members:

- named individuals whose knowledge and competence in the field are such that they can provide valuable assistance to the CC 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 CC.

The Presidents of CCs 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 might expect to be a member or an observer of at least one CC.

Appendix D. Model terms of reference for a typical Consultative Committee of the CIPM (CC for X)

The CC for X is responsible to the CIPM and is given the following responsibilities by the CIPM:

1. to serve as the CIPM's principal source of advice on the following fields of metrology: X1, X2, X3 . . . , particularly on matters concerning the units, the standards of measurement best able to meet the world's needs, and the attainment of worldwide uniformity;
2. to provide a forum for an open exchange of information on recent scientific and technical advances in the CC's fields of metrology and on new and anticipated requirements by users;
3. to decide in which of its fields the CC needs to have an active work programme and in which only a watching brief is required, e.g. areas considered to be of low priority or where another organization already covers the field adequately;
4. to establish working groups to assist with specific aspects of the CC's programme;
5. to coordinate where appropriate the work of the NMIs, allowing for adequate but not excessive duplication of effort, to arrange joint projects, and to hold preliminary discussions on the possibility of sharing the use and cost of the more expensive facilities;
6. to identify in each of its fields a small number of key international comparisons that need to be carried out periodically in order to ascertain the degree of equivalence of the national measurement standards maintained by the NMIs, and to decide their periodicity;
7. to organize these comparisons among the NMIs that are expert in the field, including where possible at least two and preferably more NMIs from each RMO, and from an analysis of the results of each comparison to determine a key comparison reference value;
8. to determine from analyses of the results of the BIPM key comparisons, and those of linked regional and bilateral key comparisons, the deviation of each participant's result from the key comparison reference value and the associated uncertainty;

9. to assist the BIPM to choose and establish its scientific programmes, to review the programmes periodically and report to the Director of the BIPM the full spectrum of opinions on their appropriateness and quality, and to keep the CIPM advised of any requirements for which a new laboratory programme at the BIPM is considered to be *a)* essential or *b)* highly desirable.

Acronyms and abbreviations used in this report

Abbreviations used for generic organizations

CC	Consultative Committee of the CIPM (see Table 2 for specific CCs)
NMI	National Metrology Institute
RMO	Regional Metrology Organization

Other acronyms

ACCSQ	ASEAN Consultative Committee on Standards and Quality
AIDMO	Arab Industrial Development and Mining Organization
ANDIMET	Northern South American Metrology Cooperation (Bolivia, Colombia, Ecuador, Peru and Venezuela)
APLAC	Asia Pacific Laboratory Accreditation Cooperation
APLMF	Asia-Pacific Legal Metrology Forum
APMP	Asia/Pacific Metrology Programme
ARSO	African Regional Standards Organization
BIML	Bureau International de Métrologie Légale
BIPM	Bureau International des Poids et Mesures
CAMET	Central American Metrology Cooperation (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama)
CARIMET	Caribbean Island Metrology Cooperation (Antigua & Barbuda, Barbados, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, St Kitts & Nevis, St Lucia, St Vincent & the Grenadines, Suriname, The Bahamas, and Trinidad & Tobago)
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CGPM	Conférence Générale des Poids et Mesures
CIE	International Commission on Illumination
CIGRE	Conférence Internationale des Grands Réseaux Électriques à haute tension
CIML	Comité International de Métrologie Légale
CIPM	Comité International des Poids et Mesures

COOMET	Cooperation in Metrology among the Central European Countries
COPANT	Panamerican Standards Commission
EA	European Cooperation for Accreditation
EUROMET	European Metrology Collaboration
IAAC	Inter-American Accreditation Cooperation
IAU	International Astronomical Union
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IFCC	International Federation of Clinical Chemistry
ILAC	International Laboratory Accreditation Cooperation
IMEKO	International Measurement Confederation
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
NACC	North American Calibration Cooperation
NORAMET	North American Metrology Cooperation
OIML	Organisation Internationale de Métrologie Légale
PASC	Pacific Area Standards Congress
SADCMET	Southern African Development Community Cooperation in Measurement Traceability
SADCSTAN	Southern African Development Community Standardization Cooperation
SALMEC	Southern African Legal Metrology Cooperation
SARAC	Southern African Regional Accreditation Cooperation
SI	International System of Units
SIM	Inter-American Metrology System
SURAMET	Southern South American Metrology Cooperation (Argentina, Brazil, Chile, Paraguay and Uruguay)
TAI	International Atomic Time
UTC	Coordinated Universal Time
WELMEC	West European Legal Metrology Cooperation

STEDI

1, BOULEVARD NEY, 75018 PARIS

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