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Report of Time Department
Programme of Work and Budget for 2016-2019

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Introduction

The Work Programme of the Time Department for the period 2016-2019 has been included in the Work Programme of the BIPM (PoW) that has been presented to the 25th General Conference to Weights and Measures (CGPM) in November 2014 as a support to the dotation for the same period.

The International Committee for Weights and Measures (CIPM) has approved in its session of March 2015 this Programme of Work.

The proposal for the time metrology activities at the BIPM is consistent with the Strategy Document adopted by the CCTF.

With the aim of presenting the CCTF all elements discussed and included in the Programme of Work, the document here below is an excerpt of the complete BIPM PoW containing the sections relevant to the Time Department activities.

24/08/2015

Work Programme

of the International Bureau of Weights and Measures

for the four years 2016-2019

Comité international des poids et mesures

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SECTION I: INTRODUCTION

Executive Summary

The Work Programme

This document describes the BIPM work programme, adopted by the 25th General Conference on Weights and Measures (2014), for the years 2016 to 2019. It was developed following the consolidated planning process carried out by the BIPM and the CIPM and builds on the interactions with NMI Directors and Member State Representatives, and has been the subject of specific consultation with the Member States.

It includes several new features:

- A thematic approach for the formulation of projects in chemical and ionizing radiation metrology
- A single physical metrology theme for mass and electricity projects to increase the flexibility of staff deployment and give a single focus for the watt balance project
- International coordination work combined into a single theme across departments
- Greater clarity between the work done by the Time Department in support of UTC and timescales, and that done as the wider support to the scientific community.

Highlights

The programme includes projects in physical metrology and time metrology that include the following new activities:

- The coordination of a comparison of primary realizations of the kilogram (ahead of the new definition) followed by bilateral key comparisons thereafter.
- Provision of travelling AC Josephson voltage standards for comparisons.
- Realization of the quantum Hall effect in graphene to replace GaAs as the basis of a new travelling standard
- Coordination of a key comparison of capacitance.
- Contributing to the comparison of optical standards with the highest accuracy over all distances, in view of their future use for the improvement of TAI and as a basis for consideration of a redefinition of the SI second.

In the thematic programme, which addresses grand challenges for metrology, new high-priority measurands are proposed in comparisons of:

- ozone standards for surface ozone monitoring,
- selected standards for air quality monitoring,
- priority gas standards for climate change assessment,
- organic primary calibrators for clinical chemistry and laboratory medicine, food analysis, environmental analysis, forensics and pharma.
- X-ray radiation quantities widely used in radiotherapy and radiodiagnostics.

- γ-ray and electron beams widely used at radiotherapy and/or radioprotection levels, and serving as reference for the calorimetric measurements in high-energy photon beams (medical accelerators).
- reference air kerma for High Dose Rate (HDR) sources used worldwide in brachytherapy applications.
- γ, β and α emitters widely used in nuclear medicine or appearing in the nuclear cycle or environmental monitoring.
- short-lived γ-emitting radionuclides of interest in nuclear medicine and positron emission tomography (PET).

The level of participation in the proposed work programme is given in the table below:

	Projected numbers of NMI and DI participations in comparisons coordinated by the BIPM	
	2013-2015	2016-2019
Mass	16	9
Electricity	21	45
Time*	73	80
Ionizing Radiation	45	59
Chemistry	115	176
Total	270	369

* the participants indicated for the Time Department are those that participate in the monthly determination of UTC.

Basis for costing

Each project is presented together with the indicative resources necessary to deliver it expressed in terms of person months (of BIPM staff and visiting staff), the operating costs and the estimated investment costs. The programme also includes a number of additional projects that will only be executed if additional funding resources beyond the Dotation can be secured.

THE MISSION AND ROLE OF THE BIPM

The BIPM is an intergovernmental organization established by the Metre Convention, through which Member States act together on matters related to measurement science and measurement standards.

The mission of the BIPM is to ensure and promote the global comparability of measurements, including providing a coherent international system of units for:

- Scientific discovery and innovation,
- Industrial manufacturing and international trade,
- Sustaining the quality of life and the global environment.

The unique role of the BIPM is based on its international and impartial character enabling it:

- To coordinate the realization and improvement of the world-wide measurement system to ensure it delivers accurate and comparable measurement results.
- To undertake selected scientific and technical activities that are more efficiently carried out in its own laboratories on behalf of Member States.
- To promote the importance of metrology to science, industry and society, in particular through collaboration with other intergovernmental organizations and international bodies and in international forums.

The unique role of the BIPM enables it to achieve its mission by developing the technical and organizational infrastructure of the International System of Units (SI) as the basis for the world-wide traceability of measurement results. This is achieved both through technical activities in its laboratories and through international coordination.

The objectives of the BIPM

- To establish and maintain appropriate reference standards for use as the basis of a limited number of key international comparisons at the highest level.
- To coordinate international comparisons of national measurement standards through the Consultative Committees of the CIPM; taking the role of coordinating laboratory for selected comparisons of the highest priority and undertaking the scientific work necessary to enable this to be done.
- To provide selected calibrations for Member States.
- To coordinate activities between the National Metrology Institutes (NMIs) of Member States, such as through the CIPM MRA[1], and to provide technical services to support them.
- To liaise as required with relevant intergovernmental organizations[2] and other international bodies[3] both directly and through joint committees[4].
- To organize scientific meetings to identify future developments in the world-wide measurement system required to meet existing and future measurement needs in industry, science and society.
- To inform, through publications and meetings, the science community, the wider scientific public and decision makers on matters related to metrology and its benefits.

[1] The CIPM Mutual Recognition Arrangement (CIPM MRA) is coordinated jointly by the BIPM and the Regional Metrology Organizations.
[2] Examples of intergovernmental organizations in liaison with the BIPM are: OIML, IAEA, WMO and WHO.
[3] Examples of other international bodies in liaison with the BIPM are: ILAC and ISO.
[4] Examples of joint committees are the Joint Committee on Guides on Metrology and the Joint Committee on Traceability in Laboratory Medicine.

IMPACT OF THE WORK PROGRAMME AND THE BENEFITS FOR MEMBER STATES

Impact of the global metrology system

The global metrology system is the technical and administrative infrastructure maintained by the National Metrology Institutes (NMIs) in collaboration through the Regional Metrology Organizations (RMOs) and the BIPM that enables a comparable basis for measurements around the world. It benefits Member States because it creates an internationally agreed framework within which the equivalence of measurements made in different states can be demonstrated. Additionally, involvement in the system provides a benchmark for the performance of NMIs and supports national agendas in:

- Scientific discovery and innovation,
- Industrial manufacturing and international trade,
- Sustaining the quality of life and the global environment.

Numerous studies have been carried out by Governments to quantify these benefits and examples from many Member States are accessible through the BIPM website:

http://www.bipm.org/en/practical_info/useful_links/impact.html

Two of the examples given are:

- the economic benefits from public investment in measurement at the national level identified in a UK study showed benefits of 5 000 million pounds for an investment of 40 million pounds. http://www.berr.gov.uk/files/file32855.pdf.
- the benefits of the CIPM MRA have been estimated as savings to the NMIs of 85 million euros (http://www.bipm.org/en/cipm-mra/economic.html) and a potential impact on reducing technical barriers to international trade of 4 billion euros annually.

Coordination role of the BIPM

The CIPM Mutual Recognition Arrangement (CIPM MRA) has been in operation since 1999 and has a recognised role in reducing technical barriers to trade as well as driving up standards and performance in NMIs worldwide. NMI Directors from around one hundred states and economies have signed the CIPM MRA, as have four international organizations with a number of other states working towards participation. There are now more than 1 200 comparisons of measurement standards underpinning the CIPM MRA and some 25 000 peer-reviewed entries listing the capabilities of the NMIs (and Designated Institutes) in the publically available database operated by the BIPM. A recent survey of visitors to the database shows that nearly 25% of all “visitors” to the data on comparisons, and nearly 35% of all “visitors” to the data on capabilities are from outside the NMI community. This confirms that the CIPM MRA has growing visibility amongst its wider community of users.

Today, the CIPM MRA forms the foundation of rapidly accessible international recognition of the national measurement standards and of the calibration and measurement certificates issued by national metrology institutes and other designated institutes. It is an important resource for industry and thousands of calibration and testing laboratories worldwide. The CIPM MRA has recently been adopted as the formal basis for international recognition of measurement traceability by the International Laboratory Accreditation Cooperation. The instances of regulators demanding traceability to the SI through their national laboratory is reducing as regulators increasingly accept the CIPM MRA as the basis for international recognition of calibration and measurement certificates issued by NMIs. The BIPM Work Programme for 2016 to 2019 will support the implementation of the CIPM MRA following an in-depth review to be conducted in 2015 that will optimize the efficiency and effectiveness with which it is implemented.

In the field of *in-vitro* devices (IVD) the work of the Joint Committee for Traceability in Laboratory Medicine (JCTLM), operated by the BIPM in conjunction with the IFCC and ILAC, enables manufacturers to demonstrate compliance with the EU regulations for traceability.

The unique system of Consultative Committees managed by the BIPM brings together the world's experts from many NMIs and a number of intergovernmental organizations. It provides the forum in which decisions about the SI are made. It facilitates knowledge and technology transfer between the NMIs as well as enabling the coordination of the work of the NMIs thereby facilitating cost and time saving.

Laboratory work carried out by the BIPM

The scientific work carried out at the BIPM focuses on the coordination of international comparisons of national measurement standards of the highest priority and undertaking the scientific work necessary to enable this to be done. In this way, the BIPM maintains the specialized equipment and expertise needed to do this on a cost-shared basis. In some cases, this requires it to establish and maintain appropriate reference standards. As a result of this work, the BIPM often has the capability to provide selected calibrations for Member States.

Examples of the benefit of this work are that all Member States can:

- Be provided with calibrations of platinum-iridium mass prototypes free of charge. The BIPM is also the unique provider of platinum-iridium mass prototypes, which are a key element in the highest level dissemination of the kilogram.
- Contribute data to the generation of the world time scale, UTC, thus obtaining traceability to the SI second. They then benefit from having national time scales that are consistent with the world time scale.
- Receive direct on-site comparisons of high-energy photon beams used in clinical accelerators. Hence, Member States can benefit from sharing the cost for SI traceable radiotherapy, radio-diagnostics and radioprotection dosimetry.
- Receive direct on-site comparisons of short-lived radionuclides for nuclear medicine in therapy and diagnosis, as well as for nuclear safety and environmental monitoring.
- Participate in comparisons with the unique traveling electrical standards operated by the BIPM which are the only way of comparing national quantum-based standards of voltage and resistance at the highest level. Additionally, Member States without Josephson Junction voltage or quantum Hall resistance standards benefit from calibrations using the BIPM's standards;
- Underpin NMI capabilities for pure organic calibrators, covering organic compounds (of mass from 100 Da to 10 kDa) thereby establishing the traceability of measurement results in clinical, environmental, food, forensic and pharma application areas. This is possible through the BIPM’s coordination of international comparisons in organic chemical analysis.

- Ensure the performance of National Standards at a level required for: long-term monitoring of carbon dioxide and methane in air (the two major greenhouse gases) as well as monitoring of ozone and nitrogen oxide species (two major air pollutants and the focus of air quality objectives for the protection of human health). This is possible through the BIPM's coordination of international comparisons of standard gas mixtures.

In summary, all Member States of the BIPM have access to the facilities, services and the know-how of an internationally recognized, fully neutral and independent top level metrology laboratory.

International liaison work of the BIPM

Many intergovernmental bodies and international organizations depend on sound measurements to execute their mission. Some, such as OIML, ILAC and ISO, along with the BIPM and the wider international metrology, form part of the integrated quality infrastructure community and close institutional cooperation is clearly essential. Other bodies rely to a greater or lesser extent on the metrology infrastructure to execute their missions effectively.

In total the BIPM interacts at institutional or technical level (or both) with some 30 international or intergovernmental bodies, spreading measurement best practice and promoting the use and benefits of the worldwide metrology infrastructure.

The BIPM has established a long-term strategy for its international liaison work in which the liaisons are classified into long-term institutional liaisons (typically at a level where individual NMIs do not have access) and 'door opening' liaisons (where NMI experts could be present, but are not, usually because of a lack of awareness of the value of SI traceability). In this second case the role of the BIPM is one of providing specific technical expertise to demonstrate credibility, whilst convincing the liaison organization of the value of engagement with the international metrology community. When this has been achieved, and the NMI community and infrastructure is appropriately engaged, the BIPM is able to reduce its involvement.

A prime example of this strategy being implemented is with the World Meteorological Organization. In the early 2000's, recognizing the need for standardized, accurate and reliable data in the fields of meteorology, hydrology and other related geophysical sciences the BIPM and the WMO agreed to work together. The agreed aim is to ensure that data coming from the programmes organized under the auspices of the WMO are properly based on measurement units traceable to the SI. Cooperation was accelerated by a joint workshop in 2010 leading to a series of joint recommendations, during which the WMO signed the CIPM MRA. The WMO and its stakeholders now interact directly with the wider NMI community. This example demonstrates the leverage available to the BIPM as an intergovernmental body and its strategic role in advocating the global comparability of measurements amongst international organizations.

RATIONALE FOR THE BIPM LABORATORY PROGRAMME

Why does the BIPM have technical capability/laboratories in one area and not another?

During the strategic planning exercise that underpinned development of the BIPM work programme it was recognized that it would be useful to better articulate the rationale for the BIPM to maintain laboratory capabilities in certain areas (Mass, Electricity, Time, Ionizing Radiation and Chemistry) but not others (Acoustics, Length, Photometry and Radiometry, Thermometry). The Mission, Role and Objectives of the BIPM provide the underpinning decision basis.

Acoustics, Ultrasound and Vibration	Electricity and Magnetism	Length	Mass and related quantities
Application of metrology - in new areas well suited to being addressed in the research programmes of the NMIs. **No BIPM laboratory programme**	Fundamental area of modern physical metrology, core to many other fields of metrology (e.g. all other measuring systems produce/use electrical signals, watt balances are based on electrical quantum standards, highest accuracy thermometry depends on resistance measurements). Comparisons of quantum devices require specialized and dedicated travelling equipment e.g. travelling Josephson and quantum Hall standards; comparing quantum standards requires special expertise. Experience with transportable standards does not exist at the NMIs. Realization of capacitance is difficult. Calculable capacitor supports new SI though R_K determination subsequently strengthens on-going comparison and calibrations for capacitance. **BIPM laboratory programme**	Whilst dimensional metrology is core to many fields, the measurement methods are mature. Traceability to SI realization generates negligible uncertainties in most applications. Realizing the metre and piloting comparisons in the field of dimensional metrology are activities that are relatively mature, comparability largely demonstrated Comparison of frequency combs may, however, be needed in the future to ensure traceability to absolute wavelength measurements. **No BIPM laboratory programme**	**<u>Mass:</u>** The international prototype of the kilogram (IPK) providing requires a central and neutral laboratory for long-term maintenance and global dissemination in order to provide global traceability. *After redefinition:* traceability to the SI unit of mass will be based on multiple primary realizations obtained with complex experimental facilities including the BIPM watt balance, which will require comparisons to maintain world-wide mass uniformity. In addition their potential small number requires an international and central programme to guarantee continuous access to primary realizations (via BIPM ensemble of reference mass standards and watt balance). **BIPM laboratory programme** -------------------------------- **<u>Related quantities:</u>** Largely applied activities more suited to NMIs. **No BIPM laboratory programme**

Photometry and Radiometry	Metrology in Chemistry	Ionizing Radiation	Thermometry	Time and Frequency
The field is relatively stable, and the methods mostly mature. Fundamental comparability is achieved at the required levels by NMIs using their cryogenic radiometers. Focus in the field is to make their uncertainty available in a convenient and cost effective way for applications. (Noting recent new lighting sources such as solid state lighting face difficulties in their evaluation). **No BIPM laboratory programme**	Relatively new area with a short traceability chain. Accurate chemical measurements critically important particularly for Quality of Life, metrology not mature yet and guidance to NMIs invaluable, especially for countries where capabilities are expanding rapidly. Expertise in chemical measurement is essential for effective collaboration with particularly IFCC, WMO, WHO, Codex Alimentarius, etc. The programme has the strong support of all the major NMIs and many developed and developing countries that already have adequate physical metrology infrastructure are expanding their chemical metrology infrastructure. Specialized expertise in gas and organic purity comparison has driven down uncertainties. **BIPM laboratory programme**	High impact on health (radiotherapy, radiodiagnostics, and nuclear medicine) environment radioactive monitoring (soils, water and atmosphere). Comparisons are difficult (handling radionuclides, short half-lives, radiation beams) and mainly require world-wide unique reference systems (SIR, well established radiation beams and primary standards and dedicated travelling equipment e.g. graphite calorimeter, SIR transfer instrument) Uncertainties directly impact the user community Maintaining a laboratory programme ensures leverage when engaging with stakeholders, particularly IAEA, WHO, IOMP, ICRU, ICRM, ICRP and IRPA. **BIPM laboratory programme**	Realizing the kelvin and piloting comparisons are mature (noting however that the forthcoming definition of the kelvin makes part of the realization of the unit less mature). Comparability is largely demonstrated. ITS 90 realized comprehensively by many NMIs. **No BIPM laboratory programme**	Single, unique and independent reference system world-wide. Wide impact (Satellite navigation, telecoms, national timekeeping, earth & space science, time stamping services). Experienced scientists have substantial leverage when representing the NMIs and supporting the SI when engaging with particularly ITU, IAU, IUGG, ICG, IGS, IERS, GNSS (GPS Civil) and URSI. **BIPM coordination programme** (with some laboratory work)

CRITERIA AND FOCUS USED TO FORMULATE POTENTIAL SCIENTIFIC/TECHNICAL WORK AT THE BIPM.

After establishing those areas that are priorities for a BIPM laboratory capability, the BIPM and CCs reflected on which, of the many competing possibilities, to propose to the CIPM for consideration to include in the BIPM work programme.

An established set of criteria were used to check whether any proposed project is suitable for consideration, in effect establishing a baseline. Proposals for projects failing to meet the criteria are not considered further.

A scientific project at the BIPM must fulfil one or more of the following criteria by:

a) Contributing to the establishment, development and evolution of the SI

The project will lead either to the improvement of the realization of the SI units, or to the development and comparison of reference measurement systems, enabling the realization of SI traceable measurements.

b) Providing international reference facilities

The project will enable the BIPM to provide long-term availability of international reference facilities for use by all Member States.

c) Implementing "mandated" activities

The project will incorporate activities that are conferred to the BIPM through the Metre Convention or specific Resolutions of the CGPM. These are currently:

- the responsibility of the BIPM to "conserve the kilogram… and carry out comparisons necessary to assure the uniformity of measures throughout the world" and
- the BIPM's role in computing TAI (and UTC).

d) Supporting the international comparison programmes of Consultative Committees

The Metre Convention makes provision for the BIPM to organize and pilot international comparisons. Comparisons piloted by the BIPM will support the Consultative Committee programmes in pilot studies and key comparisons required under the CIPM MRA.

e) Developing improved or next generation measurement standards and comparison capabilities

Projects will allow the BIPM to interact in research activities which are aimed at improving current facilities and capabilities, both at the BIPM and in the NMIs of Member States. Such projects will enable the BIPM to improve or develop new services, new international reference facilities and to lead comparisons in new areas of activity, and generally be foci for secondments to or from, or collaborations with NMIs in Member States.

f) Providing calibration services requested by Member States

The Metre Convention makes provision for the BIPM to provide calibrations to Member States, NMIs and other bodies. The BIPM's financial or other resources clearly do not allow it to offer calibrations in all areas, even if it has a laboratory activity which meets one or more of the other criteria set out in this paper. A calibration service developed or maintained by the BIPM (other than mandated services) shall meet the following criteria:

- fulfils the needs of Member States not holding primary standards or maintaining primary measurement methods;
- is based on a BIPM facility that is a spin-off from a project that meets other criteria;
- is used or is expected to be used on a regular basis;
- does not utilize BIPM resources required for higher priority projects, especially when similar services are available from NMIs in Member States.

Sub-projects may provide internal calibrations where this enables other equipment in the BIPM laboratories to be calibrated directly and cost-effectively at the required uncertainties.

g) Developing higher order measurement standards and methods in support of key sectors

To lead to the development of higher order metrological standards and measurement methods for identified key sectors and of a high priority for NMIs in the Consultative Committees.

h) Providing 'shared cost' capability when requested by Member States

In some instances it is beneficial for a single capability to be developed or maintained on behalf of the international metrology community on a shared cost basis.

When establishing the work programme for the BIPM, the CIPM considered the individual "per project" criteria detailed above. However, consideration is given to the wider perspective. Some projects are only viable if other capabilities exist (for example the watt balance project requires the availability of a variety of other capabilities at the BIPM). The expertise at the BIPM must be sufficiently deep and broad to effectively engage with the key international and intergovernmental bodies that depend significantly on the metrology infrastructure. Additionally, as previously stated, the CIPM must consider the expertise and capabilities already available at the BIPM; it is not practical nor a wise use of Member State's resources to try to change entirely the orientation and capability every four years to pursue the latest "hot topic".

The CIPM considered whether the BIPM is uniquely placed to undertake the work and whether projects are complementary to the activities of the NMIs. The key principle is "Added Value" - there must be a specific reason for the work to be commissioned at the BIPM rather than undertaken by the NMIs. The CIPM also considered whether it is cost effective for the work to be undertaken by the BIPM and if the BIPM will have the necessary resources. Clearly all work proposed must have the support of Member States.

Some aspects of the BIPM's work are truly unique, for example the conservation of the international prototype of the kilogram, and the calculation of UTC. In other cases the BIPM operates comparison capabilities that are specialist, for example the BIPM travelling standards for Josephson and quantum Hall, the graphite calorimeter and the transportable transfer instrument, SIRTI, for short-lived radionuclides. There is a benefit to Member States because the costs of the BIPM capabilities are shared, and the BIPM is able to develop specialist skills in conducting comparisons which benefit participating NMIs. In all cases affordability and value for money tests also apply.

SECTION II: BIPM WORK PROGRAMME FOR 2016-2019

TIME METROLOGY

The role of the BIPM in calculating and disseminating TAI/UTC is unique, and the interactions with the wider global community are of a specialist nature with a well-defined community in the field of timing, satellite navigation, geophysics and astronomy. The mission of the BIPM in the field of time is the realization and dissemination of the international time scale, International Atomic Time (TAI). As the uniform time scale it is kept as close as possible to the SI second. Coordinated Universal Time (UTC) is a time scale derived from TAI to provide a reference scale which takes into account the irregular rotation of the earth.

Key activities in Time

New activities are indicated in italics

- **Creating UTC, improving the accuracy and stability of international time references, increasing dissemination and improving accessibility through:**
  - **developing the analysis of data provided by new methods for time and frequency transfer.**
  - **optimizing the algorithms for clock data characterization.**
  - **reducing the delay in the publication of UTC, maintaining adequate extrapolations.**
- ***Contributing to the comparison of optical standards with the highest accuracy over all distances, in view of their future use for the improvement of TAI and as a basis for consideration of a redefinition of the SI second. (New)***
- **Contributing to the provision of a coherent set of space-time references and models for application in space and earth sciences.**

Strategy for time projects

- To calculate, disseminate and improve the world reference time scale through integrating data from atomic clocks and frequency standards maintained and operated at the NMIs (and other participating laboratories),
- To contribute to the investigation of the benefits of a future re-definition of the second and of time-keeping based on optical clocks,
- To promote the importance and benefits to the international telecommunications, astronomy and earth science communities of:
  - UTC
  - frequency measurements traceable to the SI and
  - common space-time references.

Priority activities in the field of Time metrology

The mission of the BIPM in the field of time is the realization and dissemination of the international time scale, International Atomic Time (TAI). As the uniform time scale it is kept as close as possible to the SI second. Coordinated Universal Time (UTC) is a time scale derived from TAI, to provide a reference scale which takes into account the irregular rotation of the earth.

The time scales TAI and UTC are disseminated monthly through BIPM *Circular T*. The *BIPM Annual Report on Time Activities* provides all relevant information, data and results for the year previous to its publication. Reports on time-transfer techniques are also issued regularly.

Other activities related to the time scales are developed in the Department; these contribute to improving the calculation algorithms and increasing knowledge about time transfer techniques.

T-A1 Frequency stability and accuracy of TAI/UTC

Project Code	Name	Deliverables	Resources in: a) Person months b) Operating costs c) Capital investment
T-A1.1	Time transfer for TAI/UTC Provides the differences between two realizations of UTC in contributing laboratories that input data to the key comparison on time CCTF-K001.UTC (monthly BIPM *Circular T*), and to the weekly computation of the rapid UTC (UTCr). *Time/frequency transfer and algorithms are the two key points in the elaboration of a time scale* *Participating laboratories: 73 (2013)*	1) New and refined methods for clock comparison for application on new techniques as implemented in NMIs necessary for the full exploitation of GNSS systems with the calculation of multi-system time links. In parallel, in combination with TWSTFT, this will contribute to the improvement of the uncertainty. Benefits - redundancy of data, impacting on: (a) the reliability of the time links system; (b) the statistical uncertainty of the links; (c) the characterization of clocks; (d) since the time link uncertainty is the major component of the uncertainty of [UTC-UTC(*k*)], enhanced time transfer will impact on the traceability of local realization UTC(*k*) to the SI second; (e) the ultimate impact is on the stability of the time scales. 2) Application of novel methods (beyond GNSS and TWSTFT) of time transfer using optical fibres as they are implemented between contributing laboratories. As in 2013 only one of these links is operational between two UTC laboratories, and we should expect a substantial increase in the mid-term. Deliverable is enhanced time links for TAI, Particularly: (a) increasing the reliability of the time link system by the use of an independent technique; (b) improving the statistical uncertainty of time links to the picosecond; (c) improving the Type B uncertainty (calibration, related to T-A2); (d) since the time link uncertainty is the major component of the uncertainty of [UTC-UTC(*k*)], enhanced time transfer will impact on the traceability of local realization UTC(*k*) to the SI second; (e) the ultimate impact is on the stability of the time scales. 3) Methods based on optical fibre and space techniques for time and frequency transfer with 10^{-18} targeted relative uncertainty for allowing optical clock comparisons. Benefits: when optical clocks are operated over appropriate time intervals, they could be linked keeping their precision to the UTC system and contribute to the	a) 92 pers months + 12 secondee b) 39 k€ c) 32 k€

		accuracy of the time scales. 4) Distribution of data, results, comparisons to UTC participants and other relevant users. 5) CCTF-K001.UTC, *Circular T* (*70 participants in 2013, 10 % increase expected*).	
T-A1.2	**Algorithms** Development of new algorithms and upgrading of the algorithms already in use for the provision of time scales at the BIPM (TAI/UTC as in CCTF-K001.UTC - monthly BIPM *Circular T*, in weekly UTCr, in the annual TT(BIPM) and its monthly predictions). *Time/frequency transfer and algorithms are the two key points in the elaboration of a time scale* *Participating laboratories: 73 (2013)*	1) Improved stability by adequate clock frequency prediction and clock weighting. Target is improving the present 3×10^{-16} frequency stability with a target of improving stability by a factor of two. 2) Improved accuracy by use of primary and secondary frequency standard measurements and procedure for frequency steering. The target is improving the present frequency accuracy (few parts in 10^{-16}) with a target of improving accuracy by a factor of two. 3) Distribution of data, results, comparisons to UTC participants and other relevant users (data distributed – some 200 data/results per day by ftp plus large numbers of web consultations). 4) Generation of TT(BIPM): a coordinated time calculated at the BIPM for scientific applications requiring long-term stability. TT(BIPM) has applications in some fields of astronomy (pulsar timing for the construction of a dynamic time scale), in space research, etc. Its algorithm is similar to that for TAI, but with a major role for the primary frequency standards. The introduction of secondary standards (optical clocks) will demand changes in the algorithm, with impact on the long-term stability and accuracy. TT(BIPM) is published in January every year for (year-1), with monthly extrapolations for the current year.	a) 48 pers months + 12 secondee b) 34 k€ c) 12 k€
T-A1.3	**Rapid UTC** *Participating laboratories: 40 (2013)*	1) Publication of UTCr, rapid UTC providing weekly access to a UTC Rapid solution for better synchronization of local realizations of UTC(*k*) in contributing laboratories, particularly enabling NMIs to improve the UTC(*k*) serving as a reference for GNSS time steering (*40 participants in 2013, 100 % increase expected over the programme*).	a) 36 pers months b) 6 k€ c) 22 k€

T-A2 Characterization of delays in GNSS equipment operated in TAI/UTC contributing laboratories

All laboratories that contribute to UTC are equipped with GNSS time receivers to provide data for the comparison of their clocks (T-A1). The comparison between the local clock and the clock in the satellite is carried out within the receiver located in the laboratory, whilst the signal from the satellite arrives at the antenna and has a path delay until it reaches the comparison point. As a consequence, the measurement of the delay is essential to the stability and accuracy of the UTC time links system. The BIPM has centralized the characterization of GNSS equipment delays in contributing laboratories since it is part of the actions necessary for the provision of UTC. The activity is mostly referred to as "*calibration of GNSS receiver equipment in laboratories*".

The result of a "*calibration*" is part of the data used for the calculation of time links for TAI/UTC (T-A1).

Project Code	**Name**	**Deliverables**	**Resources in:** **a) Person months** **b) Operating costs** **c) Capital investment**
T-A2.1	**Maintenance of BIPM travelling receivers and procedures for calibration** The equipment in the BIPM Time laboratory is principally used for maintaining the BIPM travelling standard receivers. The ensemble of receivers consists of equipment similar to that installed in the contributing laboratories. Some of the equipment is used for travelling, whilst other equipment remains in the laboratory to act as the reference during a campaign. An atomic clock providing the local time reference is necessary. In parallel, the Time Department develops strategies for delay characterization based on different geometries, data acquisition processes and statistical treatment of measurements.	1) Characterization of equipment compatible with those operated in NMIs. 2) Reliable/redundant travelling and fixed-reference standards. 3) Guidance documents and support for contributing NMIs. 4) Technical protocols for calibration. 5) Methods of calibration aimed at improving the time link uncertainty, which remains the largest component of the uncertainty of *UTC-UTC*(*k*). The target is improving the present 5 ns value of the Type B uncertainty by a factor of at least 2.	a) 20 pers months b) 0 k€ c) 170 k€

T-A2.2	**Realization of delay measurement campaigns for pivot laboratories (G1 labs)** The BIPM organizes and realizes travelling standard visits among the contributing laboratories for measuring the (relative) delays in GNSS equipment. The measurements are analysed and processed at the BIPM and the result forms part of the data used for the time links calculation. Absolute determination of delays is made using the BIPM/CNES calibrator.	Typically two characterization campaigns (requiring the sending of BIPM travelling system without staff) to each of approximately 15 contributing laboratories (G1 labs) during the programme: 1) Regular assessment of the values of the Type B uncertainty of time links via periodic calibration of GNSS equipment in a selected group of NMIs (potential “pivot” laboratories, laboratories in regions where RMOs are not active or organized). 2) Evolving Protocols for calibration. 3) Improved link accuracy from 5 ns to 2 ns. 4) Input data for time links used in CCTF-K001.UTC, BIPM *Circular T* and rapid UTC.	a) 18 pers months + 12 secondee b) 30 k€ c) 0 k€
T-A2.3	**Coordinating with the RMOs for campaigns of G2 laboratories (labs which are not pivot labs) and linking results to the BIPM G1 reference** RMOs organize regional calibration campaigns with their own travelling equipment supporting the BIPM in the maintenance of time link system stability. The BIPM provides guidance to RMOs, establishes priorities and interacts with them for the coordination of the campaigns. The BIPM validates the results of the RMOs’ calibrations, makes the link to the BIPM system and decides on the results to be used for TAI/UTC.	1) Provision of Guidelines for the calibrations, including technical instructions for RMOs and protocols for linking their calibrations to the BIPM time link system. 2) Regular assessment of the values of the Type B uncertainty of time links via periodical calibration of GNSS equipment in a set of laboratories as defined by the BIPM for approximately 60 contributing laboratories. 3) Improved link accuracy from 5 ns to 2 ns 4) Generating Input data for time links used in CCTF-K001.UTC, BIPM *Circular T* and rapid UTC.	a) 10 pers months b) 0 k€ c) 0 k€

T-A3 Use of very accurate frequency standards - Secondary representations of the second

This activity should be considered of common interest to time and length metrology. The application of frequency combs, traditionally related to the length comparisons, is now expanding into the field of time metrology.

Project Code	Name	Deliverables	Resources in: **a) Person months** **b) Operating costs** **c) Capital investment**
T-A3.1	**Time and frequency transfer techniques for highly accurate optical standards** Study and implementation of techniques. Cooperation with different sectors is planned (French space agency, NMIs)	1) Comparison of optical standards with $\sim 10^{-18}$ relative uncertainty over short and long baselines. This includes continental links via optical fibres and intercontinental comparisons using enhanced TW links and one-way space techniques. 2) Contributing to the discussion on the redefinition of the second (2018 onwards).	a) 30 pers months +12 secondee b) 30 k€ c) 0 k€
T-A3.2	**Maintenance of equipment** The equipment will serve (a) to study the physics related to the transfer techniques; (b) to develop competency for the statistical treatment of measures for application in time scale construction; (c) to characterize their uncertainties, including calibration. Equipment consists of: Frequency combs and terminals for advanced time transfer using microwave links; H-maser for providing the frequency reference.	1) Evaluation of the use of microwave links as a possible candidate for future high level optical clock comparisons based on a comparison of Space-Earth and Earth-Earth Comparison of atomic clocks, within the ACES. Activities will be in cooperation with the French Space Agency (CNES). 2) Comparison of optical standards with $\sim 10^{-18}$ fractional uncertainty over short and long baselines. 3) Improved time link accuracy. 4) Contributing to the discussion on the redefinition of the second (2018 onwards).	a) 18 pers months b) 0 k€ c) 350 k€

Additional activities in the field of Time Metrology - not covered by the adopted budget

T-A3.3	**Frequency comb validation** Assuring the correct validation of the increasing number of frequency combs in NMIs at accuracy levels aiming to meet both time and length requirements, taking particular note of the emergence of optical clocks	Organising a comparison of NMI frequency combs based on the existing BIPM frequency comb (estimated for maximum of 5 node NMIs for length, and up to 10 NMIs for frequency) Target is parts in 10^{18} (driven by frequency needs), - 10^{16} sufficient for length	a) 12 pers months b) 20 k€ c) 10 k€

International Liaison and Coordination

Key activities in international liaison and coordination

New activities are indicated in italics

- ***Support implementation of selected improvements to the CIPM MRA.***
- ***Refine and implement the strategy for international liaison at the BIPM and set priorities for the allocation of resources used on key stakeholders and sectoral organizations (new)***
- **Provide Executive Secretaries for the ten CCs and the JCGM.**
- **Develop and operate a new version of the KCDB and JCRB CMC review website and provide the JCRB Executive Secretariat.**
- **Operate the JCTLM database and provide the secretariat**
- **Liaise and represent the BIPM/CIPM with key stakeholders e.g. the RMOs, OIML, ILAC, ISO**
- **Liaise and represent the BIPM/CIPM with selected organizations of sectoral importance including: - e.g. IAEA, WMO, ITU + more than 30 others.**
- **Facilitate and inform candidate Member States and candidate Associate States.**
- **Facilitate the transition from Associate to Member State status**

Strategy for coordination and liaison

To foster cooperation with international organizations and to promote the world-wide comparability of measurement

- communicating effectively (with Member States, potential new Member States and other key stakeholders) about the Metre Convention, the SI and the new SI
- providing scientific liaison through participation in selected Stakeholder committees and working groups
- improving and promoting the mutual recognition of national measurement standards and of calibration and measurement certificates issued by NMIs (the CIPM MRA), particularly by operation of the KCDB and supporting the JCRB.
- promoting the importance of the global comparability of measurements with international organizations of strategic importance to the BIPM mission including: OIML, ILAC, ISO, WTO.
- developing and implementing best practice in the support of the Consultative Committees and Joint Committees through the provision of Executive Secretaries and the implementation of best practices

A major task carried out by the BIPM is the coordination of international metrological activities and liaison with other intergovernmental/international organizations that are relevant to or which have an interest in metrology. Coordination activities are particularly concerned with the activities of the Consultative Committees created by the CIPM where the world's leading metrology experts from Member State NMIs come together. The BIPM provides the Executive Secretaries for these CCs, chosen among the senior scientists of the BIPM. The BIPM prepares, convenes and hosts CC meetings at the BIPM and provides scientific expert advice to the CCs and most of their working groups. The CCs themselves coordinate the NMI research activities to improve the realization and dissemination of the SI and coordinate the key comparison activities of the CIPM MRA. They also discuss the scientific in the field in general and more specifically the work of the BIPM.

The CIPM MRA and its key comparison database (KCDB) provide recognition of the national measurement standards and the calibration and measurement capabilities (CMCs) of the NMIs of Member States and the Associates of the CGPM. The BIPM Director chairs the Joint Committee of the Regional Metrology Organizations. The BIPM is supported by a seconded JCRB Executive Secretary. The CIPM has tasked the JCRB with the coordination of activities with the RMOs. The CIPM MRA is expected to be formally reviewed in late 2015. The outcome will lead to revised and renewed work practices and IT tools including for the KCDB.

The liaison activities between the BIPM and other intergovernmental organizations and international bodies are of growing importance. This is especially true for the cooperation with the International OIML, ILAC and ISO. The cooperation with ILAC is particularly important to ensure that calibrations performed by accredited laboratories are traceable through the NMIs to primary realizations of the SI. The core element of demonstrating traceability is the KCDB.

Other organizations with whom the BIPM has major and on-going interactions include the IAEA, WHO, WMO, ITU and WTO. Liaisons at an institutional and/or technical level related to specific committees or working groups and particular topics extend to more than 30 such organizations.

Another type of liaison and coordination is that within joint committees. The Joint Committee for Guides in Metrology (JCGM) maintains and promotes the use of the Guide to the Expression of Uncertainty in Measurement (known as the GUM) and the International Vocabulary of Basic and General Terms in Metrology (known as the VIM). Currently chaired by the BIPM, which provides the Executive Secretary and participate in the working groups, the other member organizations are: IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML.

The BIPM is a member and provides the Secretariat and operates the database for the he Joint Committee on Traceability in Laboratory Medicine (JCTLM), with the IFCC and ILAC. The JCTLM provides a worldwide platform to promote and give guidance on internationally recognized and accepted equivalence of measurements in laboratory medicine and traceability to appropriate measurement standards.

The BIPM also participates in the DCMAS Network, the network on Metrology, Accreditation and Standardization for Developing Countries which allows a variety of organizations to exchange information and where possible collaborate in supporting the development of technical infrastructures to support sustainable development and trade in developing countries and countries in transition. In addition to the BIPM the network participants are: IAF, IEC, ILAC, ISO, ITC-ITU, OIML, UNIDO and UNECE.

The BIPM actively encourages those countries which do not yet participate in the activities of the BIPM to become either Associates of the CGPM or full Members. In addition, the BIPM promotes international metrology through activities such as the posters and promotional materials for “World Metrology Day” which is celebrated annually on 20 May, the anniversary of the signing of the Metre Convention in 1875. The World Metrology Day initiative, run jointly by the BIPM and the OIML, has become a major opportunity for NMIs to raise awareness of the importance of metrology among the public and their key stakeholders. Many NMIs display the poster and hold national events and the BIPM and OIML operate a dedicated web area devoted to the initiative.

Executive Secretaries and other international liaisons in science departments

Project Code	Name	Deliverables	Resources in: a) Person months b) Operating costs c) Capital investment
CT-A1.1	**Coordination and promotion of SI time activities for the advancement in the development of time scales** Activities within the scope of/linking to/cooperating with: - ITU - IGS - ICG - Space agencies operating GNSS - NMIs	1) TAI/UTC/TT(BIPM)/ maintenance 2) GNSS time transfer 3) GNSS coordination 4) Support to GNSS system times 5) Time and frequency transfer methods.	a) 24 pers months b) 120 k€ c) 0 k€

CT-A1.2	**Coordination and promotion of SI time activities for scientific applications** Activities within the scope of/linking to/cooperating with: - IERS - IAU - IUGG/IAG - URSI	1) Space-time references, IERS Conventions 2) Timescales for astronomy/TT(BIPM)/Pulsar timescales 3) Time references for geodetic and geophysical applications Geodetic references.	a) 16 pers months b) 50 k€ c) 0 k€
CT-A1.3	**Coordination and Support to the CCTF** (Time and Frequency)	Provision of the CCTF Executive Secretary, general support to the CC and WGs plus specifically support for: 1) Coordination between NMIs for the maintenance of UTC 2) Monitoring and validation of the BIPM Time Department activities and plans 3) Development of strategic plans 4) Key comparisons in time and frequency 5) Recommendation of standard frequencies as secondary representations of the second 6) Secretariat of CCTF and WGs 7) Participation in WGs.	a) 16 pers months b) 25 k€ c) 0 k€

International liaison activities delivered at corporate level by the ILC Department

Project Code	Name	Deliverables	Resources in: a) Person months b) Operating costs c) Capital investment
ILC-1.1	**Corporate Liaison and Coordination**	Support for and representation to: RMOs - (AFRIMETS, APMP, COOMET, EURAMERT, SIM and *GULFMET*). International/intergovernmental: OIML, ILAC, ISO, WMO, WTO, IUPAC, IUPAP, IEC, IFCC, CODATA TGFC.	a) 44 pers months b) 134 k€ c) 28 k€
ILC-1.2	**CIPM MRA**	JCRB Executive Secretary and CMC review website. KCDB Office and databases entry/nomination review process. Maintenance and upgrade of the KCDB.	a) 52 pers months + 48 pers months secondment b) 20 k€ c) 200k€ (new KCDB and CMC review website)
ILC-1.3	**Support to BIPM Director, CIPM and promotion of the Metre Convention**	Support to the BIPM Director, CIPM, Member States and Associates. Promotion of the Metre Convention and support to potential Member States and Associates.	a) 44 pers months b) 40 k€ c) 0 k€
ILC-1.4	**Support to the CCU** (units)	Provision of the CCU Executive Secretary, general support to the CCU. Participation in the elaboration of the 9th edition of the SI Brochure.	a) 12 pers months b) 0 k€ c) 0 k€
ILC-1.5	**Coordination of JCGM**	Provision of JCGM (one annual meeting) and JCGM WG2 (two annual meetings) Executive Secretary and *rapporteur*, general support to JCGM, representation in JCGM WG2, maintainace of JCGM products on the BIPM website.	a) 8 pers months b) 0 k€ c) 0 k€
ILC-2.1	**Publications**	Drafting/Minuting reports, including editing, translation into French, typesetting and publication of CIPM and BIPM reports, publications and posters.	a) 128 pers months b) 245 k€ c) 0 k€
ILC-2.2	***Metrologia***	Editor and publication of *Metrologia.*	a) 24 pers months b) 46 k€ IoPP, (note 400k income for BIPM) c) 0 k€
ILC3.0	**Library services**	Journal subscriptions (on-line or hard copy) buy-per-view scientific articles and books for BIPM staff)	a) 4 pers months b) 398 k€ c) 14 k€
ILC4.0	**BIPM Website**	Provision of BIPM internet and intranet	a) 36 pers months b) 37 k€ c) 25 k€
ILC5.0	**Workshops on key topics identified by the CIPM and support to a combined metrology school**	"X Grand challenge CIPM workshops plus Metrology school delivered collaboratively with Verona"	a) 0 pers months b) 140 k€ c) 0 k€

In addition around 600 k€ is required over the programme life for routine meetings of CCs, CC Working Groups, the CIPM, NMI Directors and Member State Representatives hosted by the BIPM, plus one General Conference on Weights and Measures. Meetings involve around 1500 participants per year.

Acronyms used in the present volume

AFRIMETS	Inter-Africa Metrology System
APMP	Asia/Pacific Metrology Programme
BIPM	International Bureau of Weights and Measures
CC	Consultative Committee of the CIPM
CCAUV	Consultative Committee for Acoustics, Ultrasound and Vibration
CCEM	Consultative Committee for Electricity and Magnetism
CCL	Consultative Committee for Length
CCM	Consultative Committee for Mass and Related Quantities
CCPR	Consultative Committee for Photometry and Radiometry
CCQM	Consultative Committee for Amount of Substance: Metrology in Chemistry/
CCRI	Consultative Committee for Ionizing Radiation
CCRI(I)	CCRI Section I: x- and gamma rays, charged particles
CCRI(II)	CCRI Section II: Measurement of radionuclides
CCRI(III)	CCRI Section III : Neutron measurements
CCT	Consultative Committee for Thermometry
CCTF	Consultative Committee for Time and Frequency
CCU	Consultative Committee for Units
CIPM	International Committee for Weights and Measures
CIPM MRA	CIPM Mutual Recognition Arrangement
CNES	*Centre National d'Études Spatiales* (France)
Codex Alimentarius:	Commission under the Joint FAO/WHO Food Standards Programme
COOMET	Euro-Asian Cooperation of National Metrology Institutions
DCMAS Network	Network on Metrology, Accreditation and Standardization for Developing Countries
ERMS	BIPM Ensemble of Reference Mass Standards
EURAMET	European Association of National Metrology Institutes
FAO	Food and Agriculture Organization of the United Nations
GaAs	Gallium arsenide
GNSS	Global Navigation Satellite System
GULFMET	Gulf Association for Metrology
GUM	Guide to the Expression of Uncertainty in Measurement
HDR	High dose rate
HR	Human Resources
IAEA	International Atomic Energy Agency
IAF	International Accreditation Forum
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICG	Internal Committee on Global Navigation Satellite Systems
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IERS	International Earth Rotation and Reference Systems Service

IFCC	International Federation of Clinical Chemistry and Laboratory Medicine
IGS	International GPS Service
ILAC	International Laboratory Accreditation Cooperation
IOMP	International Organization for Medical Physics
IPK	International prototype of the kilogram
ISO	International Organization for Standardization
ITS 90	International Time Scale of 1990
ITU	International Telecommunication Union
IUGG	International Union of Geodesy and Geophysics
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
JCGM	Joint Committee for Guides in Metrology
JCRB	Joint Committee of the Regional Metrology Organizations and the BIPM
JCTLM	Joint Committee for Traceability in Laboratory Medicine
JVS	Josephson voltage standards
KCDB	BIPM key comparison database
KCRV	Key Comparison Reference Value
LDR	Low dose rate
LSC	Liquid scintillation counting
MMM	Measurements Method Matrix
NMI	National Metrology Institute
OIML	International Organization for Legal Metrology
PET	Positron Emission Tomography
QHR	quantum Hall resistance
RMO	Regional Metrology Organization
SI	International System of Units
SIM	Inter-American Metrology System
SIR	International Reference System for gamma-ray emitting radionuclides
SIRTI	Transfer Instrument of the SIR
SSDL	IAEA Secondary Standards Dosimetry Laboratory
TAI	International Atomic Time
TDCR	Triple-to-Double Coincidence Ratio Technique
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UNECE	United Nations European Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization
URSI	International Union of Radio Science
UTC	Coordinated Universal Time
UTCr	rapid UTC
VIM	International Vocabulary of Basic and General Terms in Metrology
WADA	World Anti-Doping Agency
WHO	World Health Organization
WMO	World Meteorological Organization
WTO	World Trade Organization.