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Work Programme

of the International Bureau of Weights and Measures

for the four years 2020-2023

Near final version

for presentation/discussion

at the

26th meeting of the CGPM

November 2018

The draft of this work programme has been subject to two rounds of consultation with NMIs and representatives of Member States, and has been reviewed by the CIPM.

Contents

EXECUTIVE SUMMARY

This document provides the proposed BIPM work programme for the years 2020 to 2023 that addresses the objectives agreed by the CIPM in the BIPM Strategic Plan (2018).

A first draft was opened for comment through the BIPM website for April and May 2018, prior to being reviewed by the CIPM in June 2018, with the refined version available for a second round of consultation until October 2018. Fine tuning to ensure the proposed projects matched the requested budget has been undertaken. This 'near final' version is made available for presentation/discussion at the 26th meeting of the CGPM in November 2018.

The proposed activities are ambitious and depend on the work of visiting scientists and specialists working alongside BIPM staff for their delivery. The increasing participation of visiting scientists reduces cost, brings in specific expertise when it is needed, injects new ideas, and provides greater flexibility in staffing. Estimates of the resources needed for each task are given. The proposals also include capacity building and knowledge transfer activities, some of which depend on the BIPM securing sponsorship from NMIs, Member States and RMOs, or other bodies.

The programme includes projects in four technical areas that will:

Physical Metrology

- Coordinate the comparison of primary realizations of the kilogram according to the new definition and maintain the consensus value on the BIPM working standards and the BIPM ensemble of mass standards.
- Disseminate the unit of mass by establishing metrological traceability from the BIPM Kibble balance based on the new definition of the kilogram.
- Organize a new comparison of AC voltage standards based on the Josephson effect.
- Develop a new approach to providing traceability for capacitance standards based on the AC quantum Hall effect.

Time Metrology

- Introduce high-accuracy frequency data from optical clocks into the UTC calculation to prepare the way for the re-definition of the second.
- Implement a new optical fibre-based method for time transfer to validate inter-laboratory GNSS receiver calibration.
- Automate data handling protocols in order to optimise the monthly calculation of UTC and to pave the way towards more frequent dissemination of UTC.
- Increase the number of laboratories participating each week in Rapid-UTC by 10 %.

Chemical Metrology

- Coordinate the implementation of new values for ultra-violet absorption cross-sections for ozone amongst 25 NMIs world-wide that are centrally involved in providing the basis for world surface ozone measurements.

- Triple the number of nuclei covered by the BIPM's qNMR Internal Standard Reference Data, allowing wider application of qNMR techniques at NMIs for chemical standard characterization.
- Apply unique absolute carbon dioxide measurement methods and isotope ratio comparisons to underpin NMI, WMO and IAEA standards for atmospheric monitoring.
- Provide comparisons for the 20 NMIs world-wide most involved in delivering organic calibrants for the detection of food contamination.

Ionizing Radiation Metrology

- Double the number of NMIs taking part in key comparisons and calibrations of the primary standards that underpin radiotherapy dosimetry for 11 000 clinical accelerators world-wide by making greater use of the off-site DOSEO facility.
- Provide comparisons and calibrations using an off-site ^{137}Cs facility for radiation protection dosimetry, to support traceability of the calibration of dosimeters used by the 22 million people world-wide exposed to ionizing radiation in the workplace.
- Launch the next-generation International Reference System (SIR) for comparing standards of gamma-emitting radionuclides, for applications in nuclear medicine and environmental monitoring. Exploit new low current measurement technologies that may have spin-off advantages for their use at NMIs and DIs.
- Introduce new comparisons for long-lived radionuclides, to underpin standards used when decommissioning nuclear plants and for the measurement of naturally-occurring radioactive materials (NORM).

Note:

Following a detailed project costing exercise it was established that two activities could not be supported with the proposed budget and they have been removed from the work programme. These are: the development of a new transportable QHR standard based on graphene (activity removed from project PMD-E2 E2.1) and the development of facilities and methods for calibration of CH_4 optical isotope ratio measurements, and associated comparison (activity removed from project Chem-G3). These cut projects are shown in Appendix 2.

Liaison, Coordination, Communication and Promotion

This work programme also describes liaison, coordination and communication activities that will address objectives agreed in the strategy and will thereby respond effectively and in a timely way to opportunities (and threats) arising from the evolving environment.

Highlights amongst the liaison activities will include increased interactions with the most relevant international bodies, in order to promote the benefits of the world-wide metrology infrastructure delivered through the international quality infrastructure. The liaison activities are broad, and the BIPM must remain agile in terms of its activities as liaison partners respond to their changing needs. However, what can be assured is the importance of seamlessly linking scientific and legal metrology, and thus the continued close collaboration with the OIML as both organizations strive to present 'one voice' for metrology to the outside world. Additionally, the BIPM will continue to work closely with the other 'Quality Infrastructure' partners, most notably ISO and ILAC, aided by the agreement through the INetQI – International Network of a common definition for Quality Infrastructure.

Capacity Building and Knowledge Transfer (CBKT)

During the 2016-2019 work programme, the BIPM launched a series of new activities supported by sponsorship from NMIs in the areas of capacity building and knowledge transfer. In the programme presented here selected activities carried out during 2016-2019 on a sponsorship basis have been identified as being core to the BIPM's mission and will be supported by the BIPM's dotation. These include capacity building at each of the key stages of involvement in the international metrology system that will:

- Support the next generation of technical leaders (in Consultative Committees, Technical Committees and comparison piloting) to facilitate sharing the leadership burden and enable them to be more effective.
- Integrate staff from new Member States and Associates into the international metrology system and enable them to engage effectively in the CIPM MRA.
- Provide candidate Member States and Associates with the information and understanding needed when considering participation in the activities of the Metre Convention.

These core CBKT activities will be strategically planned with the RMOs and performed at the BIPM, and where appropriate, in the regions. At least 60 NMI/DI staff are expected to attend courses and workshops held at the BIPM, with a further 360 NMI/DI staff expected to benefit through the participation of BIPM staff in joint activities organized with the RMOs.

Additionally, sponsorship will be sought from NMIs, Member States, other interested bodies and RMOs to expand the topic based capacity-building activities (workshop and laboratory). Subject to achieving such sponsorship, the following highlights are planned:

- Launch a new technical capacity-building activity on protein and peptide analysis to support NMIs developing capability in "Metrology for accurate patient care".
- Continue the "Safe food and feed" and "Metrology for clean air" capacity building projects, expanding the activities to include additional regions of the world.
- Develop new capacity-building opportunities in the BIPM Time laboratory by the establishment of a "UTC simulator".
- Provide capacity building opportunities related to techniques necessary for the comparison of electrical quantum standards and for the dissemination of mass standards.
- Engage with NMIs and DIs working in radiation dosimetry and radionuclide metrology, through joint projects and workshops.
- Implement new activities proposed and funded by stakeholders advancing the work of the wider metrology community and being consistent with the objectives of the BIPM.

It is estimated that around 40 laboratory placements totalling around 170 person months will be offered, with a further 100 participations in laboratory-based workshops organized at the BIPM.

SECTION I: INTRODUCTION

The Work Programme addresses the objectives agreed by the CIPM in the BIPM Strategic Plan (2018). We repeat here the Vision, Mission and Objectives:

THE VISION AND MISSION 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.

Its vision is to be universally recognized as the world focus for the international system of measurement.

Its mission is to work with the NMIs of its Member States, the RMOs and strategic partners world-wide and to use its international and impartial status to promote and advance the global comparability of measurements for:

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

THE OBJECTIVES OF THE BIPM

- **To represent the world-wide measurement community - aiming to maximize its impact.**
  - We liaise with relevant intergovernmental organizations and other international bodies in order to develop opportunities for the application of metrology to global challenges.
- **To be a centre for scientific and technical collaboration between Member States providing capabilities for international measurement comparisons on a shared-cost basis.**
  - We coordinate international comparisons of national measurement standards agreed to be of the highest priority.
  - We establish and maintain appropriate reference standards for use as the basis of key international comparisons at the highest level and provide selected calibrations from them.
- **To be the coordinator of the world-wide measurement system ensuring it gives comparable, fit-for-purpose and internationally accepted measurement results.**
  - We coordinate activities between the NMIs of Member States and the RMOs, including the provision of technical services to support the CIPM MRA and the infrastructure for the development and promotion of the SI.

Fulfilling our mission and objectives is underpinned by our work in:

- **capacity building**, which aims to achieve a global balance between the metrology capabilities in Member States.
- **knowledge transfer**, which ensures that our work has the greatest impact.

PRIORITIES IDENTIFIED FOR THE WORK PROGRAMME

The development of the BIPM Strategic Plan (2018) established the challenges facing the BIPM in preparing this Work Programme:

1. **To identify the highest-value activities required by the Member States by**
   - operating a Consolidated Planning Process that assembles views from the NMIs, the CIPM and the CC strategies.
   - developing a work programme that recognizes the distinctive nature of the BIPM's role.
   - recognizing the differing requirements of different NMIs.
   - describing activities in sufficient detail to facilitate planning and monitoring of the outcomes of projects.

2. **To review the technical work needed at the BIPM in physical metrology following the expected decision to redefine the base units of the SI at the 26th CGPM (2018), noting**
   - that the dissemination of mass calibrations will continue to be required by NMIs that will not have access to a primary realization.
   - the continuing need to support the dissemination of standards for electrical quantities.

3. **To balance the resources committed to the three strategic objectives (liaison, technical collaboration and coordination) with the capacity building and knowledge transfer activities, whilst taking account of**
   - the need for greater flexibility in the BIPM funding model in order to take advantage of donor-funded projects.
   - opportunities to outsource access to facilities where feasible and beneficial.
   - the need for all departments at the BIPM to be involved in knowledge transfer and capacity-building activities.

4. **To develop a sustainable long-term financial plan for the operation of the BIPM enabling it to fulfil its mission to 2025 by**
   - providing plausible scenarios for decision at the 26th CGPM (2018) that avoid or minimize additional financial obligations that would need to be considered at subsequent meetings of the CGPM.
   - planning for improved financial controls, using independent expert actuarial and financial advice.
   - anticipating the need to recruit and retain staff and exploit existing infrastructure.
   - agreeing a mechanism for dialogue with Member States regarding the long-term financial sustainability of the BIPM beyond 2025.

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,
- Improving the quality of life and sustaining the global environment.

The global metrology system plays a crucial and underpinning role in the wider quality Infrastructure. The INetQI Network of international organisations (plus the World Bank) defines the QI as:

"The system comprising the organizations (public and private) together with the policies, relevant legal and regulatory framework, and practices needed to support and enhance the quality, safety and environmental soundness of goods, services and processes." And go on to state: "The quality infrastructure is required for the effective operation of domestic markets, and its international recognition is important to enable access to foreign markets. It is a critical element in promoting and sustaining economic development, as well as environmental and social wellbeing. It relies on: metrology, standardization, accreditation, conformity assessment, and market surveillance."

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

https://www.bipm.org/en/bipm/int/impact-studies.html

Coordination role of the BIPM

The CIPM Mutual Recognition Arrangement (CIPM MRA) has been in operation since 1999 and is coordinated by the BIPM under the authority of the CIPM. It has a recognised role in reducing technical barriers to trade as well as driving up standards and performance in NMIs world-wide. NMI Directors from around one hundred states and economies have signed the CIPM MRA, as have four international organizations. There are now more than 1 500 comparisons of measurement standards underpinning the CIPM MRA and some 25 000 peer-reviewed entries listing the capabilities of the NMIs (and Designated Institutes - DIs) in the publicly available database operated by the BIPM. This confirms that the CIPM MRA has growing visibility among 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 NMIs and other DIs. It is an important resource for industry and thousands of calibration and testing laboratories world-wide. The CIPM MRA has been adopted as the formal basis for

international recognition of measurement traceability by the International Laboratory Accreditation Cooperation (ILAC), and is referenced in the 2017 revision of ISO/IEC 17025, the standard used by more than 50 000 calibration and testing laboratories world-wide. The instances of regulators demanding traceability to the SI through their national laboratory have reduced significantly in recent years as they increasingly accept the CIPM MRA as the basis for international recognition of calibration and measurement certificates issued by NMIs. The BIPM Work Programme for 2020 to 2023 will support the implementation of the CIPM MRA following its current in-depth review, which is optimizing 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 International Federation of Clinical Chemistry and Laboratory Medicine (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 at 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, BIPM staff maintain the specialized equipment and expertise needed to do this on a cost-shared basis. In some cases, this requires them to establish, maintain and develop appropriate reference standards. As a result of this work, the BIPM laboratories have the capability to provide selected calibrations for Member States.

The projected numbers of NMI and DI participations in comparisons coordinated by BIPM staff and calibrations delivered by BIPM staff:

BIPM Scientific Department	2016-2019	2020-2023
Physical Metrology	134	137
Time*	80	83
Chemistry	176	199
Ionizing Radiation	136	193
Total	**526**	**612**

**the participations indicated for the Time Department correspond to the monthly determination of UTC.*

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

BIPM liaison work

Many intergovernmental bodies and international organizations depend on sound measurements to execute their mission. In total BIPM staff interact at an 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 world-wide metrology infrastructure. One liaison partner can be considered as a special case. The International Organization of Legal Metrology (OIML), the other intergovernmental body in the field of metrology, offers recommendations for governments to adopt in their legislative and regulatory framework to facilitate trade, establish mutual confidence and harmonize the level of consumer protection worldwide. As such the OIML can be considered as a sister organization to the BIPM. The BIPM staff and the BIML (the bureau of the OIML) have worked increasingly closely in recent years. This trend continues. Whilst the missions of the two organizations are complementary, both now present an integrated description of the worldwide metrology infrastructure, and its benefits.

The interaction with liaisons aims:

- to present of coherent and cohesive single voice for metrology by working closely with OIML.
- to promote good measurement practice including use of the International System of Units, the SI.
- to update the international community about BIPM activities and effectively disseminate information about metrology in the quality infrastructure context.
- to advocate on behalf of the NMI community such that the members of other International Organisations can gain the best benefit at national level from the available national metrology resource for their missions.
- to exchange knowledge in the use of measurement standards, development measurement techniques and methods, and agree on strategies for achieving common goals.
- to mutually contribute to capacity building activities through lecturing or developing training material, etc.

The BIPM's liaison work is overseen by the CIPM. Increasingly for key liaison initiatives formal guidance on the specific objectives is defined in position papers adopted by the CIPM.

The BIPM works with its liaisons through a wide range of forums, including the quadripartite arrangement with the International Organization for Standardization (ISO), International Laboratory Accreditation Cooperation (ILAC) and the OIML and, in the working groups (WGs) of the Joint Committee for Guides in Metrology (JCGM). These international organizations along with the BIPM and the wider international metrology community, 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.

The BIPM is an intergovernmental body and it has a strategic role in advocating the global comparability of measurements among international organizations. A long-term strategy has been established for liaison work in which 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, BIPM staff are able to reduce their involvement.

BASIS FOR COSTINGS AND THE INVOLVEMENT OF SECONDED STAFF

Each project is presented here together with the estimated 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 includes a number of projects that are significantly dependent on seconded staff for their success. These will only be completed if these additional resources can be secured.

Seconded staff contributing to delivery of the Work Programme

The total staff resources required for programme delivery (including visiting scientists and other specialists) are:

BIPM Department	**BIPM staff** *(person months)*		**Staff seconded from NMIs/DIs for programme delivery** *(person months)*
	Programme delivery	*Dep. management*	
Physical Metrology	598	15	44
Time	314	15	108
Chemistry	489	15	174
Ionizing Radiation	385	15	48
International Liaison and Communication	326	15	88
Total	**2112**	**75**	**462**

Notes:

The estimated involvement of seconded staff is more than twice that projected for the 2016-2019 BIPM Work Programme.

Seconded staff benefitting from the CBKT activities are not included above.

SECTION II: BIPM WORK PROGRAMME FOR 2020-2023

LABORATORY WORK CARRIED OUT BY THE BIPM

The strategy for scientific and technical collaboration work to be carried out in the BIPM laboratories is:

To be a centre for scientific and technical collaboration between Member States providing capabilities for international measurement comparisons on a shared-cost basis.

- We coordinate international comparisons of national measurement standards agreed to be of the highest priority.
- We establish and maintain appropriate reference standards for use as the basis of key international comparisons at the highest level and provide selected calibrations from them.

In considering whether a proposed project meets objective of the BIPM as listed above and its suitability to be carried out in the BIPM laboratories, criteria are considered in four areas:

- **The importance of the measurand/quantity**
  - The measurand/quantity that will be addressed by the comparison (or reference facility) must have a wide impact in its field as identified in the Consultative Committee strategy and be recognised to be of importance globally.
- **The extent of planned participation and future use**
  - Participation over the project cycle should generally be at least at the level of 15 NMIs/DIs and the project should be of enduring value as evidenced by a projected future requirement for at least the next 10 years (from the start of the project). It should be necessary to retain the facilities and expertise developed for repeated future use.
  - The NMIs and DIs can benefit by conducting comparisons and calibrations in an efficient and timely manner (for example, through reducing the burden of shipping sensitive instruments or hazardous materials for multi-centre comparisons).
- **Uniqueness**
  - Projects should provide access for NMIs/DIs to facilities and expertise that are not available openly to them elsewhere in the world.
- **Wider applications of the facilities used**
  - When applicable, the project should be organized to involve participation of scientists visiting from NMIs/DIs and the facilities may be of use for capacity building activities.
  - When applicable, the benefit of facilities and expertise developed for the project may be disseminated by providing traceability through calibrations (to NMIs/DIs)

PHYSICAL METROLOGY

Strategy for physical metrology

- To provide a long-term primary realization of the kilogram.
- To coordinate comparisons of primary realizations held by NMIs to support the *mise en pratique* for the kilogram.
- To support the dissemination of the unit of mass by providing calibrations of mass standards on request to NMIs.
- To develop and provide on-site comparisons using travelling quantum electrical standards.
- To support the *mise en pratique* of the electrical units.
- To exploit facilities at the BIPM by providing the highest-priority calibrations for electrical quantities requested by NMIs.

Activities in the field of electrical metrology

The mission of the BIPM to advance the global comparability of measurements takes in the field of electrical metrology in the form of ensuring that NMIs have continued access to means of comparing or calibrating their national primary standards, with the lowest possible uncertainty, for the most fundamental electrical quantities – voltage, resistance and capacitance. From these quantities most other electrical quantities can be derived. For these purposes the Physical Metrology Department maintains and develops international reference facilities: transportable Josephson voltage standard, transportable quantum Hall resistance standard, calculable capacitor, and the associated measurement systems. The comparison programme of the BIPM electricity laboratories is an integral part of the CCEM comparison programme. The importance of the quantum electrical standards, based on the Josephson and quantum Hall effect, is expected to increase even more in the future as they will become realization methods for electrical units as a consequence of the revision of the SI in 2018. A second important task is the continued support of the Kibble balance and other BIPM departments in the field of electrical measurements.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
International reference standard for voltage			
1.	PMD-E1	**E1.1: On-site comparisons of Josephson voltage standards (JVSs)** Direct comparison of JVSs at dc and/or ac using the BIPM transportable JVSs to obtain lowest possible uncertainty *NMI Participations: 8*	
		1) Bilateral on-site comparisons at dc as part of **BIPM.EM-K10.a/b** and/or ac (**new comparison**) with relative uncertainty of 1×10^{-10} (dc) and below 10^{-6} (ac) 2) Maintenance of the transportable Josephson voltage standards, supporting also bilateral comparisons of Zener voltage standards (E1.2) and calibrations of Zener voltage standards for NMIs (E1.3)	a) 60 pm + 6 pm for visiting scientist b) 92 k€ c) 160 k€
		E1.2: Bilateral voltage comparisons using Zener diode transfer standards For NMIs not possessing JVSs, and as a first step before an on-site comparison of JVSs (E1.1) *NMI Participations: 4*	

		a) Bilateral comparisons of Zener voltage standards as part of **BIPM.EM-K11.a/b** with relative uncertainty of 5×10^{-8} b) Participation in related RMO comparisons to link them to BIPM.EM-K11 c) Maintenance of the BIPM secondary dc voltage standards (Zeners), also supporting the calibration of Zener voltage standards for NMIs (E1.3)	a) 10 pm b) 10 k€ c) 0 k€
		E1.3: Calibrations of Zener diode secondary standards For NMIs not possessing a primary voltage standard, as most of the new Member States, using measurement systems already in place for comparison activities. *Calibration for: 10 NMIs (12 Certificates)*	
		Calibration of Zener diode secondary standards for NMIs without primary realization and for internal customers (Ionizing Radiation and Kibble balance)	a) 5 pm b) 10 k€ c) 0 k€
International reference standard for resistance			
2.	PMD-E2	**E2.1: On-site comparisons of quantum Hall resistance (QHR) standards** Direct comparison of QHR standards using the BIPM transportable standard, to obtain lowest possible uncertainty *NMI Participations: 6-8*	
		1) Bilateral on-site comparisons of quantum Hall standards (including new graphene samples) as part of **BIPM.EM-K12** with relative uncertainty 1×10^{-9} 2) Providing the basis for the realization of the capacitance unit farad 3) Maintenance of the transportable standard and related measurement chain, also supporting bilateral resistance comparisons using resistance transfer standards (E2.2) and calibrations of secondary standards for NMIs (E2.3)	a) 58 pm + 12 pm for visiting scientist b) 71 k€ c) 40 k€
		E2.2: Bilateral resistance comparisons using resistance transfer standards As a first step before an on-site comparison and for NMIs not possessing a QHR standard *NMI Participations: 4-6*	
		1) Bilateral comparisons of resistance transfer standards as part of **BIPM.EM-K13.a/b** with relative uncertainty of 5×10^{-8} 2) Participation in related RMO comparisons to link them to BIPM.EM-K13 3) Maintenance of BIPM secondary resistance standards and related measurement chain, also for the calibration of resistance secondary standards for NMIs (E2.3)	a) 13 pm b) 10 k€ c) 0 k€
		E 2.3: Calibrations of resistance secondary standards For NMIs not possessing a primary resistance standard, as most of the new Member States, using measurement systems already in place for comparisons *Calibration for: 25 NMIs (150 Certificates)*	
		Calibration of resistance secondary standards for NMIs without primary realizations and for internal customers (Mass, Ionizing Radiation, Kibble balance)	a) 20 pm b) 0 k€ c) 0 k€
International reference standard for capacitance			
3.	PMD-E3	**E3.1: Bilateral capacitance comparisons using capacitance transfer standards** For NMIs wishing to demonstrate their capabilities in capacitance calibrations *NMI Participations: 4-6*	
		1) Bilateral comparisons of capacitance transfer standards as part of **BIPM.EM-K14.a/b** with relative uncertainty of 5×10^{-8} 2) Maintenance of the measurement systems to derive the capacitance unit from the quantum Hall effect and/or the calculable capacitor, also supporting the calibrations of capacitance secondary standards (E3.2)	a) 15 pm b) 42 k€ c) 20 k€

		E3.2: Calibrations of capacitance secondary standards For NMIs not possessing a primary capacitance standard, as most of the new Member States. *Calibration for: 20 NMIs (110 Certificates)*	
		Calibrations of capacitance secondary standards for NMIs without primary realizations	a) 18 pm b) 0 k€ c) 0 k€
		E3.3: ac quantum Hall effect To develop a primary method to realize ac impedances according to the revised SI	
		1) Development of the ac quantum Hall effect into an operational primary standard of impedance, to reduce the uncertainty of the realization of the capacitance unit 2) Direct comparison of the ac quantum Hall effect and the calculable capacitor, for verification of the validity of the equation for the von Klitzing constant at the 10^{-9} level, supporting the *mise en pratique* for the electrical units	a) 43 pm + 12 pm for visiting scientist b) 65 k€ c) 170 k€

Activities in the field of mass metrology

The role of the BIPM in the field of mass metrology will evolve after the redefinition of the kilogram, which is expected to be approved in 2018 and implemented on 20 May 2019. The existence of independent realizations of the kilogram at several NMIs using Kibble balances or isotopically enriched ^{28}Si spheres will be a fundamentally new situation for mass metrology. The BIPM will play an important role in ensuring the world-wide uniformity of dissemination of the kilogram by organizing comparisons of the NMIs' kilogram realizations. During a transition period the consensus value determined by these comparisons will serve as the basis for dissemination from the participating NMIs and the BIPM to ensure world-wide uniformity. The BIPM will provide a stable mass reference for these comparisons. The Department will implement the most accurate and efficient means of realizing the kilogram, to support a robust international system for the realization and dissemination of the kilogram. The BIPM will continue to provide mass calibrations for NMIs which do not realize the mass unit.

N	**Project Code**	**Deliverables and Activities**	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
Mass dissemination			
4.	PMD-M1	**M1.1: Calibration of 1 kg national prototypes and mass standards** *Calibration for: 25 NMIs (50 Certificates)*	
		1) Calibration of existing 1 kg national Pt-Ir prototypes in air or under vacuum. 2) Calibration of 1 kg stainless steel national mass standards, including volume and centre-of-gravity determination, if requested. 3) Monitoring of the mass evolution of the BIPM working standards. 4) Calibration of pressure gauges, as an internal service necessary to support mass calibrations at the required uncertainty, and for other BIPM departments.	a) 73 pm b) 30 k€ c) 80 k€
		M1.2: Provision of 1 kg Pt-Ir prototypes *Fabrication for: 3 NMIs*	
		1) Fabrication of 1 kg Pt-Ir prototypes for Member States. 2) Calibration of new 1 kg Pt-Ir prototypes including volume determination.	a) 5 pm b) 0 k€ c) 0 k€

Comparisons of realizations of the new kilogram definition			
5.	PMD-M2	**M2.1: Organization of a key comparison of kilogram realizations** To guarantee uniform mass realization and dissemination at the highest level *NMI Participations: 10*	
		1) Organization of a periodic CCM key comparison of all available kilogram realizations and participation in the determination of the consensus value, which during the first years after the redefinition will serve as the basis for dissemination for all participants to ensure world-wide uniformity of mass measurements. 2) Ongoing bilateral key comparison of kilogram realizations, linked to (1) 3) Update of the mass values attributed to the ensemble of reference mass standards (ERMS) and the Pt-Ir working standards, traceable to the reference value of the comparison of kilogram realizations.	a) 12 pm b) 0 k€ c) 0 k€
		M2.2: Organization of a comparison of calibrations of stainless steel mass standards To test the uniformity of the mass unit at the level of dissemination *NMI Participations: 15*	
		1) Organization of a new comparison of stainless steel 1 kg mass standards 2) Participation in related RMO comparisons.	a) 12 pm b) 0 k€ c) 0 k€
		M2.3: Maintaining the ERMS (ensemble of reference mass standards) The ERMS will be used for mass dissemination and as a flywheel for comparisons. The masses of the standards need to be as stable as possible; therefore some monitoring is necessary, while protecting the standards against wear.	
		1) Link of the ERMS masses with values from realization experiments. 2) Mass comparison of standards within the ERMS. 3) Modeling of mass changes in-between calibrations against realization experiments. 4) Using a previously-characterized high-quality Si sphere for quasi-realization of the kg, based on surface characterization (in collaboration with an NMI), at the parts in 10^8 level.	a) 37 pm b) 80k€ c) 45 k€
Kibble Balance			
Developing and maintaining the Kibble balance International reference facility for realization of the new definition of the kilogram on a long-term cost-shared basis			
6.	PMD-M3	**M3.1:** Achieving a target uncertainty of 2 parts in 10^8 (corresponding to 20 µg at 1 kg) by further improvements of the apparatus and the development of a detailed uncertainty budget.	a) 59 pm + 12 pm for visiting scientists b) 30 k€ c) 90 k€
		M3.2: Reengineering of critical mechanical subsystems to enable semi-routine operation.	a) 59 pm b) 30 k€ c) 90 k€
		M3.3: Developing software and control system for full operation in vacuum.	a) 25 pm b) 30 k€ c) 90 k€
		M3.4: Develop a capability, in conjunction with NMIs that have a transportable gravimeter, for the determination of gravitational acceleration at the uncertainty level of a few parts in 10^9. This will require absolute gravimeter(s) to be brought to the BIPM from NMIs that have successfully participated in the most recent ICAG, accompanied by the NMI experts, for measurements in the BIPM Kibble balance laboratory.	a) 3 pm + 1 pm for visiting scientists b) 5 k€ c) 0 k€
		M3.5: Participate in the ongoing comparison of realizations of the kilogram (PMD-M2).	a) 6 pm b) 0 k€ c) 0 k€
		M3.6: Carry out a design study for a Kibble balance, taking advantage of the re-definition of the kilogram to realize directly masses below 1 kg, with smaller uncertainties than at present.	a) 24 pm b) 0 k€ c) 30 k€

Laboratory support for capacity building and knowledge transfer activities

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
7.	PMD-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in the field of electricity and mass metrology *(estimates are based on delivery of the CBKT topics presented on page 38, sponsorship will be required for delivery)*	a) 4 pm b) 0 k€ c) 0 k€

TIME METROLOGY

Activities in the field of time metrology

The main mission of the BIPM in the field of time is the realization and dissemination of the international time scale, International Atomic Time (TAI), and of the Coordinated Universal Time (UTC), derived from TAI, to provide a reference scale which ensures approximate agreement with the time derived from the irregular rotation of the earth.

To realise TAI, UTC, and a rapid approximation called UTCr at the best level of accuracy and stability, whilst taking advantage of the clocks and time transfer techniques developed by NMIs and RMOs, continuous improvements are necessary. Therefore, research activities are carried out in the Time Department, including the maintenance of a time laboratory which is able to provide reference GNSS receivers for the measurement of the NMI receiver delays.

The ultimate world reference time scale can maintain its highest level of accuracy and stability only if it is ready to incorporate and harmonise the developments achieved by NMIs and if it is capable of facing scientific and technological challenges. In the next decade, research shall focus on support towards the development and optimal use of the optical frequency standard measures and their high accuracy comparison at distance. This will lead to a significant improvement in TAI and UTC as well as to a possible redefinition of the SI second which, in turn, will require an improved knowledge of the Earth gravitational potential.

Moreover, the Time Department promotes the use of a unique time scale reference by all countries, all GNSS providers, and in different applications (for example time stamping regulations). In addition, it evaluates the needs of the emerging user communities through a proactive contribution to the Liaison programme.

Strategy for time metrology

- To calculate, disseminate and improve the world reference time scale through the integration of data from atomic clocks at the NMIs (including tests and inclusion of new type of standards and their comparison at long distance).
- To investigate the scope for a 100-fold improvement in frequency accuracy through a future redefinition 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.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Generation of TAI/UTC, stable and accurate international reference			
1.	Time-U1	**U1.1: Computation of UTC and KC for Time and Frequency transfer** *Participating laboratories: 80 (2017)*	
		Monthly provision of the international reference time scales TAI, UTC, and the terrestrial Time (TT), continuously improving their metrological quality. This is obtained by computing the differences between UTC/UTCr and the local real time realizations UTC(*k*) of the contributing laboratories. Results are published in the monthly BIPM *Circular T*, the weekly bulletin of the UTCr, and providing data to the KCDB for the key comparison CCTF-K001.UTC. The process to obtain UTC and its validation is part of the BIPM Quality System. The Department also issues an annual report with a summary of the results.	a) 58.4 pm b) 5 k€ c) 8 k€
		U1.2: Development and optimization of the UTC computation	
		The continuous improvement of UTC and related products is based on the development of appropriate SW tools and HW reliability. The goals of this WP are mostly based on: – Automatization of the computation system augmenting the automatic checks on input and output data to improve the reliability of the results. – Use of a redundant and secure ensemble of servers based on virtualization technology. – Use of data base structure for the time transfer and calibration data to provide user-friendly access to the results to the contributing NMIs.	a) 50 pm b) 5 k€ c) 30 k€
2.	Time-U2	**Improved algorithms for time scale and time transfer data processing**	
		The algorithms developed, maintained, and continuously improved by the Time Department are devoted to: – the ensemble time scale formation, – the corrected processing of the time transfer measures, – the steering by the use of primary and secondary frequency standards. The goals are an algorithm for outlier and faults detection, monitoring of the data flow and link comparison, redundant links, multi-constellation GNSS time transfer, as well as algorithms treating each clock with adapted and modern statistical tools. The contribution of a secondee would be fundamental to ensure the necessary progress of these activities. The use of a GIT* laboratory capability within the frame of the TWSTFT WG so that software for software defined receiver (SDR) measurement technique can be developed through a collaborative effort with leading NMIs. This shared configuration will then be validated by a joint BIPM/NMI team and be made available for download as a service to NMIs (and other UTC time laboratories). Opportunities to use the capability for training and equipment monitoring will also be explored. *GIT is a free and open source distributed version control system	a) 62 pm + 12 pm for visiting scientists b) 5 k€ c) 4 k€
3.	Time-U3	**Calculation and dissemination of Rapid UTC** *Participating laboratories: 57 (2018), 2023 target is to grow by 10 %*	
		To meet the requirements of the NMI time labs and of other UTC users, a rapid approximation of UTC, called rapid UTC, is available weekly based on a subset of data. The automatization of the process and a reliable anomaly detection are in this case still more important and will be pursued in this WP, evaluating the possibility for a more frequent evaluation of the time scale.	a) 26 pm + 14 pm for visiting scientists b) 10 k€ c) 5 k€

		To be in pace with emerging user communities, as for example the GNSS navigation and timing systems, the Time Department will investigate the impact of reducing the delay in the publication of UTC and UTCr.	
Characterization of delays in time transfer equipment operated in TAI/UTC contributing laboratories			
4.	Time-D1	**D1.1: Maintenance of BIPM GNSS travelling receivers and procedures for calibration** The BIPM Time laboratory maintains and operates the travelling standard receivers, the reference ones not travelling, and the atomic clock providing the local time reference	
		1) Characterization, study, and experimental tests 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).* 6) Maintaining a time lab supporting test and calibration of high accuracy microwave link. 7) Provision of a frequency reference to the other BIPM labs. The dissemination of this frequency signal and the related internal calibrations are part of the BIPM Quality System.	a) 19 pm + 5 pm for visiting scientists b) 10 k€ c) 197 k€
		D1.2: Realization of delay measurement campaigns for pivot laboratories (G1 labs)	
		This project ensures the calibration trips by GNSS receiver to the labs belonging to GNSS Group 1 or to other networks of labs. The different steps are: – To organize the GNSS measurement campaigns (requiring the shipping of the BIPM travelling system without staff) to each of approximately ten contributing laboratories (G1 labs), a number that should expand with new RMOs. The whole process involves several circulating trips and is repeated every other year. – to calibrate the TWSTFT networks by travelling GNSS receivers and by setting up additional dedicated travelling equipment with the aim to reach the best possible achievable uncertainty. – to check the receiver conditions and measure internal delays before and after the circulation. – to carry out the data analysis and issue the calibration report.	a) 10 pm + 5 pm for visiting scientists b) 5 k€ c) 1 k€
		D1.3: Coordinating with the RMOs for GNSS campaigns of G2 laboratories (labs which are not pivot labs) and linking results to the BIPM G1 reference	
		1) Provision of Guidelines. 2) Regular assessment of the values of the Type B uncertainty. 3) Validation of the G2 calibration reports and maintenance of the database. 4) Realization of differential calibration at the BIPM for G2 labs outside RMOs.	a) 5 pm b) 0 k€ c) 0 k€
Use of very accurate optical frequency standards - Secondary representations of the second			
5.	Time-O1	**O1.1: New time and frequency transfer techniques in TAI/UTC. Possible redefinition of the SI second and TT**	
		1) Develop an operational algorithm for the analysis and comparison of optical frequency standard measures to estimate the relative frequency values. 2) Study, develop, and make operational new algorithms for the processing of new and innovative time and frequency measures (optical fibres, 3-way by satellite). 3) Collaborate with NMIs and the CCTF for standardization of measurement process, data format; data treatment. 4) Promote the refinement of the Earth gravity potential as necessary for the	a) 25 pm b) 8 k€ c) 4 k€

		comparison of optical frequency standards. 5) Contribute to the discussion on the redefinition of the second.	
		O1.2: Optimal use of optical standard measurements in TAI/UTC	
		New optical standards as well as new time and frequency comparison in the optical domain call for an update of the TAI/UTC data processing to optimize the contribution of these new measures. To this aim, the Time Department need: (a) to develop the correct statistical treatment of measures that may have peculiarities (dead time, long period of missing data, only frequency comparison…); (b) to adapt the TAI algorithm for the optimal introduction of the optical frequency standard measurements; (c) to study new optical transfer techniques and their technical constraints with the aim to appropriately estimate the uncertainty; (d) to set up calibration techniques and guidelines. The feasibility for the BIPM time lab to be connected to the network of optical fibres under construction by the NMIs will be explored. This would provide the possibility to: (a) validate the usual GNSS calibrations by independent and more accurate technique, (b) be connected to several of the new optical standards under development and to different UTC(*k*) time scales (c) provide training on the technologies of the future and explore the possibility for providing a hub for international PSFS comparison for NMIs. These additional activities require additional effort that the BIPM staff could ensure only at a very basic level. To face the new challenges with appropriate resources and optimizing the use in TAI/UTC, the support of a full time secondee is necessary both in the data treatment, and in the set-up of the experimental fibre connection. In case this should not be available, only a minimal, un-optimized, and incomplete activity can be ensured.	a) 6 pm+ 72 pm for visiting scientists b) 36 k€ c) 32 k€

Laboratory support for capacity building and knowledge transfer activities

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
6.	Time-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in the field of time metrology *(estimates are based on delivery of the CBKT topics presented on page 38, sponsorship will be required for delivery)*	a) 6 pm b) 0 k€ c) 0 k€

CHEMICAL METROLOGY

Activities in the field of Chemistry

The BIPM chemistry laboratory activity focuses on gas standards for air quality and global atmospheric monitoring, and primary calibrators for clinical chemistry and laboratory medicine, food analysis, environmental analysis, forensics and pharma. The BIPM coordinates key comparisons and pilot studies prioritized by the CCQM, in response to NMI needs, for:

- greenhouse and air quality gases including their isotope ratios, for which the uncertainty of standards is critical, to ensure the accurate long-term, global monitoring of these species, including the BIPM key comparison BIPM.QM-K1 for surface ozone and BIPM.QM-K2 for atmospheric carbon dioxide;
- the purity assessment of organic calibrators (source of traceability for measurements of the amount of organic species in a wide range of clinical, environmental, food, forensic and drugs in sport applications) and reference data for their value assignment. Coordination of an on-going series of CCQM key comparisons covering all small-organic-molecule-based CMCs, with an extended model of comparisons for large organic molecules.

Strategy for chemical metrology

- To provide and coordinate comparisons of national measurement standards for:
  - **greenhouse gases**, demonstrating consistency at levels required to support national energy and environmental priorities;
  - **major air quality gases**, demonstrating consistency at levels required to support national health and environmental priorities.
- To provide the basis for metrological traceability for organic and biochemical measurements by coordinating comparisons of primary reference materials for:
  - **small organic molecules**, demonstrating consistency at levels required to support reference measurement systems for laboratory medicine, food safety, forensics, environmental analysis and pharma.
  - **peptides and large organic molecules**, demonstrating consistency at levels required to support reference measurement systems for laboratory medicine and health care sectors.
- To promote and develop the use of SI traceable standards and measurements (available from the NMIs) with intergovernmental stakeholders.

International equivalence of gas standards for air quality and global atmospheric monitoring

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Surface ozone and air quality gas standard comparisons			
Coordination of comparisons to determine and improve the international equivalence of gas standards for air quality monitoring *NMI Participations: 30*			
1.	Chem-G1	**G1.1:** 20 ozone standards bilateral comparisons as part of **BIPM.QM-K1 coordination** (2020-2023), based on the unique triad of standards at the BIPM, which will maintain consistency of calibration services for surface ozone measurements for local, regional, national and global air quality monitoring networks. *NMI participations: 20*	a) 12 pm b) 20 k€ c) 35 k€
		G1.2: Updates of SRP electronics systems for **National Ozone Standards**, developed and validated at the BIPM, in collaboration with the NIST, enabling NMIs to extend the lifetime of their ozone standards (Note, costs included relate to upgrade and maintenance of the BIPM systems only, any provision of systems to NMIs is at cost) *NMI participations: 10*	a) 12 pm b) 20 k€ c) 30 k€
		G1.3: Coordination of reactive gas/air quality comparisons **(NO_2, HNO_3 and HCHO impurity comparison and spectroscopy studies**), based on state of the art dynamic standard reference facilities at the BIPM, enabling NMIs to demonstrate equivalence of their standards for air quality and vehicle emission verification measurements. *NMI participations: 15 (Measurements started in 2016-2019 BIPM Work Programme)*	a) 16 pm b) 20 k€ c) 0 k€
International reference facility for comparison of standards and scales for clean air			
Coordination of comparisons to determine and improve the international equivalence of radiative forcing gases *NMI Participations: 47*			
2.	Chem-G2	**G2.1:** Coordination of **BIPM.QM-K2** on Carbon dioxide in air **(2020-2023),** based on a unique manometric reference comparison facility maintained at the BIPM, providing an independent absolute analytical reference method for on-demand comparisons of gravimetrically prepared NMI standards for greenhouse gas and emissions measurement calibrations. *NMI participations: 20*	a) 28 pm + 12 pm for visiting scientists b) 35 k€ c) 35 k€
		G2.2: Completed homogeneity and stability studies on blended mixtures and coordination of **CCQM-Pxx (2020)** on isotope ratios in carbon dioxide, and method development for reduced uncertainties, based on BIPM's high accuracy flow and cryogenic trapping system and optically based IRIS facility in collaboration with IAEA, demonstrating the state of the art in equivalence of CO_2 isotope ratio standards for atmospheric and point of origin measurement applications. *NMI participations: 15*	a) 20 pm +24 pm for visiting scientists b) 35 k€ c) 20 k€
		G2.3: Developed facility and methods for isotope ratio value assignment of CO_2 in air standards and coordination of **CCQM-Kxx (2023)** on isotope ratios in carbon dioxide, based on lowest uncertainty mass spectrometric and optically based measurements techniques at the BIPM, demonstrating equivalence of scale based isotope ratio measurements and standards and relationship to SI traceable values. *NMI participations: 12*	a) 32 pm + 36 pm for visiting scientists b) 65 k€ c) 385 k€

International reference facility for comparison of standards and scales for radiative forcing gases			
Coordination of comparisons to determine and improve the international equivalence of gas standards for radiative forcing gases. *NMI Participations: 20*			
3.	Chem-G3	**G3.1:** Completion of key comparison on nitrous oxide and coordination of methane in air standards comparison **(CCQM-K82.2023**), based on dedicated greenhouse gas standard comparison facilities at the BIPM with minimized analytical uncertainty to provide demonstration of continued improvement in the accuracy of radiative forcing gas standards world-wide for atmospheric monitoring. *NMI participations: 20 + 16 (Measurements started in 2016-2019 BIPM Work Programme)*	a) 14 pm b) 40 k€ c) 25 k€
		G3.2: Developed methods with reduced uncertainties for Greenhouse Gas comparisons, based on the improvement of cryogenic separation facilities for greenhouse gases and their quantitative operation in sample preparation for greenhouse gas mole fraction and isotope ratio measurements.	a) 20 pm +15 pm for visiting scientists b) 40 k€ c) 20 k€

International equivalence of organic primary calibrators for Clinical Chemistry and Laboratory Medicine, Food Analysis, Environmental analysis, Forensics and Pharma

Small Molecule Organic Primary Reference Comparisons (Pure Materials)			
Coordination of comparisons to determine and improve the international equivalence of organic primary calibrators for clinical chemistry and laboratory medicine, food analysis, environmental analysis, forensics and pharma. *NMI Participations: 50*			
4.	Chem-O1	**O1.1:** Completion of bisphenol A purity comparison **CCQM-K148.a (non-polar organic (< 500 Da)**, with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis, providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for small molecule low polarity organic analytes. *NMI participations: 25(Measurements started in 2016-2019 BIPM Work Programme)*	a) 12 pm b) 63 k€ c) 33 k€
		O1.2: Coordination of **CCQM-K148.b (polar organic (< 500 Da)** with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for polar small molecule organic analytes. *NMI participations: 25*	a) 24 pm b) 63 k€ c) 15 k€
		O1.3: Coordination of CCQM-K148.c organic purity (500 Da to 1000 Da) and method development, with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis, providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for larger small molecule analytes, together with the extension in methods for their characterization. *NMI participations: 25*	a) 24 pm b) 55 k€ c) 0 k€

Small Molecule Organic Primary Reference Comparisons (Calibration Solutions)			
Coordination of comparisons standards and methods for organic calibrants. *NMI Participations: 30*			
5.	Chem-O2	**O2.1:** Coordination of the calibration of solution comparison **CCQM-K78.b** (Multi-component non-polar), based on BIPM gravimetrically prepared calibration solutions with multi component non-polar analytes, with the mass fractions of primary reference materials quantified within the BIPM purity measurement facilities, providing a core comparison for non-polar organic calibration solutions for NMIs. *NMI participations: 25*	a) 24 pm b) 61 k€ c) 0 k€
		O2.2: Developed and published reference data for qNMR internal standards (three internal standards), based on BIPM's dedicated qNMR facility and in collaboration with NMIJ providing published reference data on qNMR internal standards, enabling the extension of the use of qNMR to accurate measurements with ^{19}F, ^{31}P and ^{13}C nuclei, and extending the scope of applicability of qNMR for SI traceable measurements on organic analytes, and support for NMI measurement services and their comparisons.	a) 33 pm +24 pm for visiting scientists b) 68 k€ c) 30 k€
Large Molecule Organic Primary Reference Method Development and Comparisons			
Coordination of comparisons to determine and improve the international equivalence of organic primary calibrators for Clinical Chemistry and Laboratory Medicine, Forensics and Pharma *NMI Participations: 30*			
6.	Chem-O3	**O3.1:** Developed and published methods for the characterization of large molecule primary calibrators, based on high resolution mass spectrometry facilities at the BIPM, extending the application of mass spectrometric methods for the identification and quantification of structurally related impurities in peptide calibrators that are future candidates for comparisons to underpin NMI measurement capabilities.	a) 12 pm + 12 pm for visiting scientists b) 80 k€ c) 20 k€
		O3.2: Completion of purity key comparison **CCQM-K115.c C-HbA1c hexapeptide purity and CCQM-K115 repeat on HbA0 hexapeptide purity**, based on mass-balance and protein impurity corrected amino acid analysis characterization performed at the BIPM, providing a core comparison of capabilities for value assignment of primary reference material straight chain peptides with molecular weights smaller than 5 kDa at NMIs, and underpinning reference measurements systems for glycated hemoglobin and their development for diabetes diagnosis and patient monitoring. *NMI participations: 15*	a) 14 pm +9 pm for visiting scientists b) 80 k€ c) 15 k€
		O3.3: Coordination of CCQM-K155.d Primary peptide calibrator (5 kDa to 10 kDa) large organic molecule primary calibrator comparison**,** based on mass-balance and protein impurity corrected amino acid analysis characterization performed at the BIPM, providing a core comparison of capabilities for value assignment of primary reference material peptides with molecular weights greater than 5 kDa, cross-links and post-translational modifications for NMIs, and underpinning reference measurements systems for protein diagnostics. *NMI participations: 15*	a) 24 pm + 24 pm for visiting scientists b) 80 k€ c) 0 k€

Laboratory support for capacity building and knowledge transfer activities

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
7.	Chem-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in the field of chemical metrology *(estimates are based on delivery of the CBKT topics presented on page 38, sponsorship will be required for delivery).*	a) 90 pm + 18 pm for visiting scientists b) 175 k€ c) 0 k€

IONIZING RADIATION METROLOGY

Activities in the field of ionizing radiation metrology

The external drivers for ionizing radiation metrology continue to evolve and expand. Nuclear medicine is expanding rapidly, driven by the need for early diagnosis and the demand for better cancer therapies; the world-wide market for nuclear medicine is predicted to grow from 9 billion USD in 2020 to 13 billion USD in 2024. The first-generation nuclear power reactors are being decommissioned (166 power reactors have already shut down and a further 183 reactors are scheduled for decommissioning in the 2020s), leading to increased demand for radionuclide metrology to ensure the safe disposal of the wastes arising. Perhaps the most demanding field (in terms of measurement accuracy) is the new science of nuclear forensics - the examination of radioactive material in the context of nuclear security.

The rising incidence of cancer (the World Health Organization estimates that the number of new cases of cancer per year will increase by 70 % over the next 20 years) is also driving expansion in the use of external beam radiotherapy and brachytherapy. The Director General of the IAEA has stated that there is a shortfall of 5000 radiotherapy machines in the developing world. The IAEA also has noted that developments in imaging technology are fundamentally changing radiation therapy. Proton therapy is also predicted to expand, with the global market reaching 3 billion USD by 2025.

These societal challenges are placing increasing demands on the ionizing radiation metrology community for accurate primary standards and for their dissemination to hospitals, the nuclear industry and security services. The demands are international, with clinical trials of new radiopharmaceuticals being carried out in several countries, and the safe disposal of radioactive waste being of global concern (radioactive waste knows no borders). The need to demonstrate equivalence of primary standards has never been more pressing but NMIs/DIs that volunteer to pilot comparison exercises face a unique problem: the regulatory, logistical and practical burden of shipping hazardous materials or delicate primary standards instruments.

The vision of the Ionizing Radiation Department is to reduce the burden of piloting comparisons, to build on the successful and established traceability schemes, to be the focal point to reduce the need for large scale comparison exercises and to work closely with strategic partners to increase the geographical reach of the work. The focus for this work programme is therefore moving to the next generation of techniques for comparing standards and realizing primary standards, working with stakeholders to optimise use of expensive facilities, adopting new technology to future-proof the methods used by the department and providing an efficient service for NMIs and DIs.

Strategy for ionizing radiation metrology	
– To rationalize the provision of the international measurement system, taking into account options to use external facilities.	Following consultation with the NMIs, DIs and the IAEA, develop a new model for the provision of comparison and calibration services for the quantities identified as bringing the most significant benefits from sharing resources. Ensure regulatory compliance when using BIPM or other facilities.
– To demonstrate the equivalence of national standards for radiation dosimetry of x-rays, gamma-rays and high-energy photons in support of radiotherapy, medical imaging and radioprotection.	Maintain and improve the BIPM standards for x-ray and photon dosimetry, including use of the DOSEO facility. Following consultation with the NMIs and DIs, develop a standard to establish the KCRV for a priority field (for example, brachytherapy, electron beam dosimetry, proton therapy).
– To demonstrate the equivalence of national standards of radioactivity, in support of nuclear medicine, the nuclear industry, nuclear physics, environmental protection, radioprotection and nuclear forensics.	Maintain and improve the BIPM comparators for photon emitters (SIR and SIRTI) and beta-emitters (ESIR). Develop the next generation SIR, using new technologies to reduce the need for sealed sources as reference radiations and minimizing quantities of radioactivity held. Following consultation with the NMIs and DIs, develop a method to enable comparisons of standards needed for nuclear decommissioning.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Radiation Dosimetry			
1.	IR-D1	**International reference system for x-ray dosimetry** Underpinning the international equivalence of national standards for radiotherapy, diagnostic x-rays, mammography and radiation protection, through the provision of comparisons and calibrations. *NMI Participations: 36*	
		D1.1: Bilateral comparisons (BIPM.RI(I)-K2, -K3, -K7) using high-stability (0.02 %) reference x-ray beams and high accuracy and stability primary standards (0.2 % for air kerma). *NMI participation: 16* **D1.2:** Characterization and calibration of national standards, on request. *Calibration for: 20 NMIs* **D1.3:** Quality assurance of the BIPM primary standards for air kerma and absorbed dose to water, to confirm the long-term stability. **D1.4:** Quality assurance and continual improvement of the BIPM international reference x-ray beam facilities.	a) 42 pm b) 22 k€ c) 90 k€
2.	IR-D2	**International reference system for gamma-ray dosimetry** Underpinning the international equivalence of national standards for radiotherapy and radio-sterilization, through the provision of comparisons and calibrations. *NMI Participations: 37*	

		D2.1: Bilateral comparisons (BIPM.RI(I)-K1, -K4, -K5) using the BIPM ^{60}Co reference beam facility and high accuracy and stability primary standards (0.4 % for absorbed dose and 0.2 % for air kerma). *NMI participation: 12* **D2.2:** Calibration and characterization of national standards, on request. *Calibration for: 25 NMIs* **D2.3:** Quality assurance of the BIPM primary standards for air kerma and absorbed dose to water, to confirm the long-term stability. **D2.4:** Quality assurance and continual improvement of the BIPM international reference gamma-ray beam facility.	a) 45 pm b) 30 k€ c) 20 k€
3.	IR-D3	**International reference system for high energy photons** Underpinning the international equivalence of national standards for high energy photons to meet the expanding need from the use of clinical linear accelerators for radiotherapy, through the provision of comparisons and calibrations. *NMI Participations: 26*	
		D3.1: Bilateral comparisons (BIPM.RI(I)-K6) using the BIPM off-site facility at DOSEO, with the BIPM absorbed dose standard and high-stability beam monitoring system. *NMI participation: 14* **D3.2:** Characterization and calibration of national standards, on request. *Calibration for: 12 NMIs* **D3.3:** Quality assurance of the BIPM absorbed dose standard (graphite calorimeter and transfer instruments) to confirm their long-term stability. **D3.4:** Quality assurance and continual improvement of the measurement systems used at the DOSEO/BIPM high-energy photon beam facility.	a) 54 pm +6 pm for visiting scientists b) 500 k€ c) 20 k€
4.	IR-D4	**Towards a new reference standard for state-of-the-art radiotherapy modalities** Preparations for the development of a new primary standard to meet future requirements for radiation dosimetry (for example, hadron beam dosimetry at an out-sourced facility, electron calorimetry, x-ray brachytherapy).	
		D4.1: Report on an investigation into future requirements for radiation dosimetry, identifying the priorities for the long term, taking into account feedback from NMIs and potential growth areas. **D4.2:** Specification, detailed design and modelling of a new reference standard for the priority identified.	a) 10 pm +12 pm for visiting scientists b) 5 k€ c) 0 k€
5.	IR-D5	**International reference system for radiation protection dosimetry (^{137}Cs)** Underpinning the international equivalence of national standards for radiation protection dosimetry using an off-site ^{137}Cs facility, through the provision of comparisons and calibrations. *NMI Participations: 36*	
		D5.1: Bilateral comparisons (BIPM.RI(I)-K5) using a BIPM-characterized and operated facility (established in the previous programme) and high accuracy and stability primary standards (0.3 %). *NMI participation: 16* **D5.2:** Characterization and calibration of national standards, on request. *Calibration for: 20 NMIs* **D5.3:** Quality assurance and continual improvement of the BIPM primary standards, and the associated ancillary equipment.	a) 12 pm b) 5 k€ c) 50 k€
Radionuclide Metrology			
6.	IR-R1	**International reference system for gamma-emitting radionuclides (SIR / SIRTI)** Provision of on-demand capability for bilateral comparisons of gamma-emitting radionuclides for applications in nuclear medicine, the nuclear industry, nuclear physics, environmental protection, radiation protection and nuclear forensics. *NMI Participations: 33*	

		R1.1: Bilateral comparisons (BIPM.RI(II)-K1) of national standards of long lived gamma emitting radionuclides using the high precision, high stability, SIR ionization chambers (reproducibility better than 0.02 %). *Participating NMIs: 25* **R1.2:** On-site bilateral comparisons (BIPM.RI(II)-K4) of national standards of short lived gamma emitting radionuclides (SIRTI), using the high precision, high stability SIRTI scintillation counter (reproducibility better than 0.05 %). *Participating NMIs: minimum of two per year, six radionuclides per site visit* **R1.3:** Technical support for the SIR and SIRTI comparators (quality control checks and continual improvement including software updates). **R1.4:** Quality assurance and continual improvement of the high resolution gamma spectrometer for impurity checks and applications in health physics. **R1.5:** Tasks to ensure compliance with regulations, including radiation protection monitoring, safety testing of irradiators (for Dosimetry), arranging disposal of radioactive waste, and associated health and safety requirements.	a) 60 pm b) 100 k€ c) 30 k€
7.	IR-R2	**Development of the next generation international reference system (SIR 2.0)** The installation and validation of a new SIR based on state-of-the-art instrumentation for measuring low currents and reducing the dependence on sealed radioactive sources, drawing on the studies completed in the previous programme.	
		R2.1: Installation of a new ionization chamber and current measurement system, data collection and analysis software, using new technology for electrical current measurement and reducing the dependence on sealed radioactive sources as reference points. **R2.2:** Validation of the new system including determining the long term stability and precision of the system and confirmation of the linearity of the response (current versus activity). **R2.3:** Bilateral comparisons of national standards of gamma-emitting radionuclides (in parallel with measurements on the SIR under BIPM.RI(II)-K1, to establish new key comparison reference values in terms of current versus activity).	a) 20 pm +12 pm for visiting scientists b) 5 k€ c) 30 k€
8.	IR-R3	**International comparison systems for alpha- and beta-emitting radionuclides (ESIR)** Provision and extension of the on-demand capability for bilateral comparisons of alpha- and beta-emitting radionuclides for applications in nuclear medicine, environmental protection, radiation protection and nuclear forensics, based on the ESIR established in the previous programme. *NMI Participations: 25*	
		R3.1: Bilateral comparisons (BIPM.RI(II)-Kx) of national standards of long lived pure alpha- and beta-emitting radionuclides, using the new ESIR comparator established in the previous programme with a reproducibility of better than 0.1%. *Participating NMIs: 25* **R3.2:** Technical support and continual improvement of the new ESIR comparator including the development of additional software and hardware (such as extending the capability to cover additional radionuclides and the use of digital pulse processing systems).	a) 70 pm +12 pm for visiting scientists b) 10 k€ c) 15 k€
9.	IR-R4	**Development of a reference system for the nuclear decommissioning and NORM industries** Development of a new comparator for priority measurements of standards for the complex decay chains of naturally-occurring radionuclides or key radionuclides for nuclear decommissioning	
		R4.1: Report on requirements for a new comparator, taking into account use of the MMM. **R4.2:** Specification, design and modelling of new comparator for the priority identified. **R4.3:** Construction and implementation of comparator. **R4.4:** Report on outcomes from validation studies.	a) 22 pm +6 pm for visiting scientists b) 10 k€ c) 30 k€

Laboratory support for capacity building and knowledge transfer activities

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
10.	IR-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in ionizing radiation *(estimates are based on delivery of the CBKT topics presented on page 38, sponsorship will be required for delivery).*	a) 13 pm b) 0 k€ c) 0 k€

Costs shared across all laboratories

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
Workshop and Scientific gas supplies			
1.	**Lab-1**	**Lab-1.1:** Workshop: raw materials, consumables, special subcomponents and other operating costs	Operating costs: 180 k€
		Lab-1.2: Scientific gas and cryogen supplies	Operating costs: 52 k€

INTERNATIONAL LIAISON

Liaison work - to foster cooperation with international organizations and to promote the world-wide comparability of measurement. The BIPM liaison activities are broad, encompassing more than 30 international organizations. In a fast changing world, the BIPM must remain agile in terms of its activities to be able to take advantage of new opportunities as liaison partners respond to their changing needs. Consequently, the BIPM maintains and updates individual strategic aims for its interactions with liaison organisations. Greater focus is expected to be given to OECD, WTO, World Bank, UNIDO as well as the Quality Infrastructure partners, and very specifically, the OIML.

Strategy for international liaison work

- To increase participation by International Organizations (IOs) in technical coordination activities at the BIPM, including CCs and their working groups, and to achieve greater recognition by IOs of the value of SI traceable measurements.
- To promote the importance of the global comparability of measurements with international organizations of strategic importance to the BIPM mission (including the OIML, ILAC, ISO, WTO-TBT) and to work with them and others through Joint Committees.
- To increase opportunities for Member States with emerging measurement systems, encouraging "prospective Member States" to make the transition from Associate to Member State.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Liaison with Member States, Associates, the CIPM and RMOs			
1.	ILC-L1	1) Support to Member States and Associates, CIPM and the BIPM Director; 2) Promotion of the Metre Convention and support to potential Member States and Associates; 3) Support for and representation to RMOs (AFRIMETS, APMP, COOMET, EURAMET, SIM and GULFMET).	a) 36 pm b) 0 k€ c) 0 k€
Liaison with strategic partners			
2.	ILC-L2	Institutional liaison with International/intergovernmental/Quality Infrastructure: – OIML, UNIDO, ILAC, ISO, OECD, WTO, World Bank; – Institutional liaison with other international organizations as required (BIPM liaises with around 30 international organizations).	a) 36 pm + 18 pm for visiting scientists b) 0 k€ c) 0 k€
3.	PMD-L1	1) Representation of the BIPM in the CODATA Task Group on Fundamental Constants (4 meetings); 2) Representation of the BIPM in the Executive Committee of the CPEM (Conference on Precision Electromagnetic Measurements) (4 meetings).	a) 3 pm b) 0 k€ c) 0 k€
4.	Time-L1	Coordination and promotion of time activities for the advancement in the development of time scales and their applications. 1) Dissemination of TAI/UTC/TT(BIPM) 2) GNSS time transfer 3) GNSS coordination 4) GNSS system time definition and realisation 5) GNSS dissemination of UTC 6) Need in Time and frequency transfer methods.	a) 14 pm b) 0 k€ c) 0 k€

5.	Time-L2	Coordination and promotion of time activities for scientific applications. TF metrological support to: 1) Space-time references, IERS Conventions 2) Timescales for astronomy/TT(BIPM)/Pulsar timescales 3) Geodetic and geophysical applications of TF metrology e.g. geodetic references, Earth gravity potential.	a) 7 pm b) 0 k€ c) 0 k€
6.	Chem-L1	1) Liaison activities with: IUPAC; ISO TC 212, IFCC, WMO, WHO, WADA, Codex, ISO TC 146.	a) 20 pm b) 0 k€ c) 0 k€
		2) Liaisons activities related to revision of Ozone standard reference method and global implementation.	a) 6 pm b) 0 k€ c) 0 k€
7.	IR-L1	1) International Commission on Radiation Units (ICRU) (Commissioner and sponsor of Report Committees) 2) International Atomic Energy Agency (IAEA) (SSDL Scientific Committee) 3) International Committee for Radionuclide Metrology (ICRM) 4) ISO (SC2 and working group meetings)	a) 12 pm b) 0 k€ c) 0 k€

Department support for capacity building and knowledge transfer activities

N	**Project Code**	**Deliverables and Activities**	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
8.	ILC-CBKT	1) Delivery of, and lecturing on, sponsor supported topic based CBKT activities on courses (topics of interest chosen with the NMI/DI community and sponsors): – at the BIPM and – within the RMO Framework (i.e. at courses arranged in the regions by the RMOs), and aligned with NMI laboratory placements	a) 8 pm b) 0 k€ c) 0 k€

COORDINATION

Coordination - to be the coordinator of the world-wide measurement system ensuring it gives comparable, fit-for-purpose and internationally-accepted measurement results.

Strategy for coordination

- To develop a role for the BIPM as the gateway to data and data-related services held by the international metrology community.
- To improve and promote 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 and expanding the opportunities presented by the International Metrology Resource Registry (IMRR), which is hosted by the BIPM.
- To support *in vitro* diagnostic measurements world-wide by providing a database of available higher-order reference materials, methods and services that can be used to establish metrological traceability.
- To liaise with the NMIs of Member States and the Regional Metrology Organizations (RMOs).

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
CIPM MRA			
1.	ILC-C1	1) Coordination of the CIPM MRA mechanisms through the JCRB 2) Provision of the KCDB database (Including Exec Sec of the JCRB). 3) Advising the CIPM MRA participants and mining the data for stakeholders	a) 52 pm + 44 pm secondment b) 78 k€ [1] c) 48 k€
JCGM			
2.	ILC-C2	Provision of JCGM Executive Secretary and rapporteur for WG2 (JCGM- one annual meeting, JCGM WG2 - two annual meetings), general support to JCGM, representation in JCGM WG2.	a) 6 pm b) 0 k€ c) 0 k€
3.	IR-C1	Provision of the Scientific Secretary for JCGM WG1 and support including: *1) Rapporteur* 2) Two annual meetings.	a) 5 pm b) 0 k€ c) 0 k€
JCTLM			
4.	Chem-C3	Support for: 1) JCTLM Executive and WGs (eight meetings) 2) JCTLM Database entry/nomination review process 3) Maintenance of: JCTLM Database	a) 32 pm b) 40 k€ c) 2 k€
NMI Directors and RMO Chairs meeting			
5.	ILC-C3	1) To work with the panel of NMI Directors to organize an annual meeting at the BIPM 2) Organization of the CC Presidents meetings 3) Access to and understanding of best practice in the operation of RMOs	a) 2 pm b) 0 k€ c) 0 k€

[1] *ILC-C1 - the KCDB operating costs accounted for in the 'Site Expenses' under 'IT platform' in the BIPM accounts.*

		a) Development of a global perspective on key issues; *b) Optimal support for states with emerging metrology systems* *c) Facilitated by the BIPM convening annual meetings of the RMO Chairs*	
IMRR			
6.	ILC-C4	Support for: 1) Hosting of the database 2) Further development 3) Hosting meetings	a) 4 pm b) 0 k€ c) 0 k€
Support of CCs (including provision of Executive Secretaries)			
7.	PMD-C1	Provision of CCEM (Electricity and Magnetism) Executive Secretary in order to support: 1) Two CCEM meetings 2) Annual working group meetings 3) Pro-active interaction on strategy and communication 4) Coordination of CCEM processes 5) Related liaison with RMO technical committees (4 meetings)	a) 14 pm b) 0 k€ c) 0 k€
8.	PMD-C2	Provision of CCM (Mass and Related Quantities) Executive Secretary in order to support: 1) Two CCM meetings 2) Annual working group meetings 3) Pro-active interaction on strategy and communication 4) Coordination of CCM processes 5) Related liaison with RMO technical committees (4 meetings)	a) 14 pm b) 0 k€ c) 0 k€
9.	PMD-C3	Provision of CCU (Units) Executive Secretary in order to support: 1) Two CCU meetings 2) Pro-active interaction on strategy and communication 3) Coordination of CCU processes	a) 6 pm b) 0 k€ c) 0 k€
10.	Time-C1	Provision of CCTF (Time and Frequency) Executive Secretary in order to support: 1) Organizing the CCTF bi/triennial meetings 2) Providing secretariat of CCTF and WGs 3) Pro-active interaction on strategy and communication 4) Coordinate CC processes including comparison and other MRA reports. 5) Key comparisons in time and frequency 6) Recommendation of standard frequencies as secondary representations of the second	a) 14 pm b) 0 k€ c) 0 k€
11.	Time-C2	Provision of CCL (Length) Executive Secretary in order to support: 1) CCL meetings 2) Participation in WGs 3) Pro-active interaction on strategy and communication 4) Coordination between NMIs for length related activities. Key comparisons in length, support to comparisons of stabilized lasers piloted by NMIs 5) Recommendation of standard frequencies for the practical realization of the metre	a) 6 pm b) 0 k€ c) 0 k€
12.	Time-C3	Provision of CCAUV (Acoustics, ultrasound and vibration) Executive Secretary in order to support: 1) Biennial CCAUV meetings and three WG meetings 2) Pro-active interaction on strategy and communication 3) Development of strategic plans 4) Coordinate review of CC and RMO comparison reports before publication 5) Related liaisons with RMOs.	a) 6 pm b) 0 k€ c) 0 k€

13.	Chem-C1	Provision of CCQM (Amount of Substance) Executive Secretary in order to support: 1) CCQM meetings (four plenary meetings) and eleven WG meetings (44 meetings in total) 2) Pro-active interaction on strategy and communication 3) Coordination of review of CC and RMO comparison reports before publication 4) Development and review of CCQM documents and guidelines 5) Organization and coordination of CCQM workshops	a) 14 pm b) 0 k€ c) 0 k€
14.	Chem-C2	Provision of CCPR (Photometry and Radiometry) Executive Secretary in order to support: 1) Two CCPR plenary meetings and associated WG meetings 2) Pro-active interaction on strategy and communication 3) Coordination of review of CC and RMO comparison reports before publication 4) Development and review of CCPR documents and guidelines	a) 6 pm b) 0 k€ c) 0 k€
15.	IR-C2	Provision of CCRI (Ionizing Radiation) Executive Secretary in order to support: 1) Biennial CCRI and sections I, II and III meetings 2) Regular meetings of seven working groups 3) Development of strategic plans 4) Co-ordination engagement with RMOs	a) 14 pm b) 0 k€ c) 0 k€
16.	IR-C3	Provision of CCT (Thermometry) Executive Secretary in order to support: 1) Biennial CCT meetings and twelve WG meetings 2) Pro-active interaction on strategy and communication 3) Coordinate review of CC and RMO comparison reports before publication 4) Related liaisons with RMOs	a) 6 pm b) 0 k€ c) 0 k€

CAPACITY BUILDING AND KNOWLEDGE TRANSFER

The BIPM Capacity Building and Knowledge Transfer Programme (CBKT) aims to increase the effectiveness within the world-wide metrology community and particularly of those Member State and Associates with emerging metrology systems. The CBKT Programme is described in three activities: core funded CBKT is to support effective operation and participation in the CIPM MRA; sponsor supported topic based workshops/courses and laboratory placements; and the knowledge transfer activities from visiting scientists/specialists seconded to the BIPM who contribute to delivery of this work programme.

Strategy for capacity building and knowledge transfer

- To reinforce the international metrology system and to "balance the load" amongst the NMIs and promote efficient operation of the system.
- To aid NMIs from Countries and Economies with Emerging Metrology Systems (CEEMS) to engage appropriately and effectively with the international measurement system.
- To sustain a programme for visiting/seconded scientists to (and from) the BIPM.

- **Core funded CBKT Programme activities**

(These activities are dependent on increase of the BIPM dotation. If this increase is not forthcoming sponsorship will be sought and the activities will be supported on a best effort basis)

The management of the CBKT Programme and those activities that are considered core to the effective implementation and operation of the CIPM MRA are included in the base case funding envelope of this work programme.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Planning and coordination of BIPM CBKT Programme activities			
1.	ILC-CBKT1	1) Planning, coordination and operation of core CBKT activities supporting the CIPM MRA and sponsor supported topic based CBKT activities, including scheduling, course design, call and selection processes (liaising with RMOs on prioritization of candidates), identification of speakers, funding of participants' costs where appropriate, provision of BIPM lecturers and sourcing of external RMO/NMI lectures together with all associated logistics. 2) Developing and managing of the BIPM RMO framework ensuring coordinated delivery of CBKT activities by BIPM and the RMOs – Liaison with RMOs to ensure coordinated CBKT delivery	a) 24 pm b) 0 k€ c) 0 k€
Delivery of, and lecturing on core BIPM CBKT activities			
2.	ILC-CBKT2	1) Delivery of, and lecturing on, core CBKT activities supporting the CIPM MRA: – Future leaders (aimed at new and potential RMO TC/WG Chairs) – Sound beginning (aimed at new participants in the CIPM MRA) – Orientation for new RMO TC/WG Chairs – Participation in the activities of the Metre Convention (including orientation for new NMI/DI Directors)	a) 12 pm b) 228 k€* c) 0 k€

3.	ILC-CBKT3	Delivery of joint Varenna metrology school for world class young scientists/metrologists - with the Italian Physical Society.	a) 2 pm + 2 pm secondment b) 60 k€ c) 0 k€

***Note*:**

**This activity is dependent on increase of the BIPM dotation, as requested in the Convocation. If this increase is not forthcoming sponsorship will be sought and the activity will be supported on a best effort basis.*

Summary of the core funded CBKT Programme activities

We estimate that the opportunities for NMI/DI staff to benefit from CBKT workshops and courses delivered at the BIPM: (These CBKT activities are funded through this Work Programme)

CBKT activities	**CBKT beneficiaries** *(Number of recipients)*	
	Delivered at the BIPM	*Delivered in the regions as part of the integrated framework with RMOs/NMIs*
Core funded CBKT activities	60	360

• Sponsor supported CBKT Programme activities

Wider topic-based BIPM CBKT activities, including workshops, courses and laboratory placements will depend on securing external sponsorship, expanding the practice that has been successfully implemented since early 2016. The resources necessary for the BIPM to engage with and manage sponsor-supported CBKT opportunities are also included in the work programme costings.

N	**Project Code**	**Deliverables and Activities**	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
CBKT BIPM Laboratory based placements and workshops			
Activities are identified by stakeholders advancing the objectives of the BIPM and wider metrology community. Provisionally the following activates are identified as the priority topics to be addressed during the programme period: • **Metrology for Clean Air** *(laboratory placements)* • **Metrology for Safe Food and Feed** *(laboratory placements)* • **Metrology for Accurate Patient Care** *(laboratory placements)* • **Workshop/training on Realization and dissemination of the kilogram** • **Workshop on 'Use of quantum electrical standards to realize the electrical units in the revised SI'** • **Workshops and capacity building activities in Time Metrology, including training on UTC simulator** • **Workshops and capacity building activities in Ionizing Radiation**		

Summary of projected sponsor supported CBKT Programme activities

We estimate that the opportunities for NMI/DI staff to benefit from CBKT activities in the BIPM laboratories are as follows: (The success of these projects depends on securing sponsorship)

BIPM Department	**Seconded staff – CBKT beneficiaries**		
	Typical length of placement *(months)*	Number of recipients	Total *(person months)*
Physical Metrology	-	80	-
Time	-	20	-
Chemistry	5	30	150
Ionizing Radiation	2	9	18
Total	-	**139**	**168**

Notes:

For laboratory placements in the Chemistry and Ionization Radiation Departments the typical length of placements and total person months are shown in the table above, whilst for laboratory workshops in the Physical Metrology and Time Departments only the numbers of recipients are shown.

To ensure best use of opportunities arising and optimal impact, a degree of flexibility is necessary for sponsor based CBKT activities.

- **Knowledge transfer activities from visiting scientists/specialists seconded to the BIPM**

As indicated in the laboratory work programme of the BIPM, a significant number of projects depend on seconded staff for their success. Visiting scientists/specialists seconded to the BIPM contribute to the delivery of the programme projects; benefit from the work at the BIPM laboratories and also help to knowledge transfer to the CBKT beneficiaries.

The total visiting scientists/specialists required to contribute to delivery of the Work Programme is:

BIPM Department	**Staff seconded from NMIs/DIs for programme delivery** *(person months)*
Physical Metrology	44
Time	108
Chemistry	174
Ionizing Radiation	48
International Liaison and Communication	88
Total	**462**

Notes:

The estimated involvement of seconded staff is more than twice that projected for the 2016-2019 BIPM Work Programme.

To ensure best use of opportunities arising and optimal impact a degree of flexibility is necessary for visiting scientist placements.

COMMUNICATION AND PROMOTION

Strategy for communication and promotion

- To communicate effectively (with Member States, potential new Member States and other key stakeholders) about the Metre Convention, the SI and its revision.
- To inform the science community, the wider scientific public and decision makers on matters related to metrology and its benefits through publications and meetings.
- To aim for the BIPM website to be the portal of choice for all stakeholders seeking information on world-wide metrology.

N	Project Code	Deliverables and Activities	Resources in: **a)** Person months **b)** Operating costs **c)** Capital investment
Reporting, Publications and the BIPM website			
1.	ILC- CP1	1. Provision of BIPM internet. 2. Website update - to adapt effectively to the rapidly changing world of electronic media to ensure that the website continues to deliver services effectively and portrays an up-to-date image of the BIPM.	a) 54 pm b) 212 k€[2] c) 48 k€
2.	ILC-CP2	Generating BIPM reports including drafting/minuting, editing, translation into French, typesetting and publication of CIPM and BIPM reports, publications and posters.	a) 52 pm b) 70 k€[3] c) 0 k€
3.	ILC-CP3	Editing and publication of *Metrologia* 1. To ensure the success of *Metrologia* as the key scientific publication for high level metrology with an increase in impact factor. 2. To increase the number of annual issues of *Metrologia* from 6 to 10 3. Maintain a viable journal taking account of the trend towards "open access" for journals.	a) 32 pm b) 40 k€[4] c) 0 k€
4.	ILC- CP4	Journal subscriptions (on-line or hard copy) buy-per-view scientific articles and books for BIPM staff)	a) 0 pm b) 138 k€[5] c) 14 k€
World Metrology Day			
5.	ILC- CP5	To build on the success of World Metrology Day, doubling participation through all media by 2022 (Project run jointly with OIML) with participation by at least 50 states. Provision of: 1. Website content, 2. Poster (in consultation RMOs and with selected NMI), 3. Directors messages, 4. Events listings for all participating countries 5. Press release 6. Participation in at least 4 national events in countries with emerging metrology systems	a) 2 pm b) 0 k€ c) 0 k€

[2] *ILC-CP1 - Website operating costs accounted for in 'Site Expenses' under 'IT platform' in the BIPM accounts.*
[3] *ILC-CP2 - Publications operating costs accounted for in 'Coordination and Communication' under 'Publications' in the BIPM accounts.*
[4] *ILC-CP3 - Metrologia annual operating costs accounted for in 'Site Expenses' in the BIPM accounts.*
[5] *ILC-CP4 - Journal subscriptions and other library costs accounted for as operating costs under Site expenses in the BIPM accounts.*

Impact study			
6.	ILC- CP6	Authoritative independent study highlighting the impact arising from metrology in the Quality Infrastructure	a) 0 pm + 12 pm secondment b) 60 k€
Mining the captured NMI knowledge and the quality assured KCDB data			
7.	ILC- CP7	A strategically plan to enhance the visibility and availability of metrological best practice, for example through the availability of Best Practice Guides, with at least 3 examples.	a) 2 pm + 12 pm secondment b) 0 k€ c) 0 k€
Workshops on key topics			
8.	ILC- CP8	To identify (with the CIPM and NMIs) topics of importance to the metrology community (such as 'big data') to be addressed at BIPM Workshops.	a) 2 pm b) 0 k€ c) 0 k€

CORPORATE SUPPORT

Strategy for corporate support services

- To provide a highest level of corporate support and governance.
- To follow "best practice" in staff training and development.
- To increase the skill mix and experience available at the BIPM.
- To develop and implement best practice in the support of the Consultative Committees and Joint Committees through the provision of Executive Secretaries.

Director

The BIPM Director's time together with Director's PA (2 full time equivalent).

Directors Office: Financial, Legal and HR

The Finance team (3 full time equivalent) addresses the BIPM's annual accounts and financial statements, medium- and long-term plans, annual budget and a range of financial management functions to meet corporate needs as well as those of the scientific departments and includes cash management, purchasing and pay role.

The BIPM Legal Office (1 full time equivalent) addresses all legal issues including those related to the Regulations, Rules and Instructions applicable to staff members and the Regulations and Rules of the BIPM Pension and Provident Fund, agreements such as Memoranda of Understanding and complex purchase contracts and agreements, international institutional law and international law.

The Human Resources Office (2 full time equivalent) carries out all of the processes needed to provide the staff benefits specified in the BIPM Regulations, Rules and Instructions. They manage the staff reporting processes, and provide all of the liaison necessary with National French authorities relating to staff employment. They also support the recruitment and installation of all staff and secondees.

TECHNICAL SERVICES

Strategy for technical services

- To develop the laboratory environment to sustain the BIPM Work Programme.
- To ensure that the BIPM meeting facilities which support the CCs and WGs continue to be "best in class".
- To develop the BIPM IT infrastructure to support its mission.
- To maintain the heritage buildings and estate at a level consistent with the mission of the BIPM.

Meetings, Reception and Housekeeping

The Meetings Office (2 full time equivalent) supports the Director and, among other responsibilities, the growing workload related to the administrative coordination of the Consultative Committees. This includes issuing invitations and support related to meetings organized by the BIPM, supporting the scientific Executive Secretaries as well as visiting delegates. Housekeeping services (3 full time equivalent) ensure the BIPM is cleaned, reception manned, and meeting services, including meals, provided. Reception services are contracted.

Quality, Health and Safety

The quality and occupational health and safety system is administrated by a Quality, Health and Safety Manager (1 full time equivalent).

The BIPM maintains a self-declared quality system based on ISO/IEC 17025:2017 "General requirements for the competence of testing and calibration laboratories" for its calibrations and measurements, and extends the principles of the standard to all laboratory comparison activities. The relevant parts of ISO 17034:2016 "General requirements for the competence of reference materials producers" are implemented within the Chemistry Department. The quality system is routinely audited both internally and also externally by experts from leading NMIs and the system is periodically presented to a group of regional quality experts from the Regional Metrology Organization (on a rotating basis).

The BIPM maintains an Occupational Health and Safety management system that is consistent with BS OHSAS 18001:2007 – "Occupational health and safety management systems – Requirements". Occupational health and safety is audited internally and subject to a variety of external technical controls (following French law) related to key risk aspects such as electrical, pressure, ionizing radiation, lightning protection and fire hazards.

Grounds and Security

The BIPM is located in the *Domaine national de Saint-Cloud*, a historic site granted by the French Government. The Pavillon de Breteuil and the six other buildings erected since the creation of the BIPM and the grounds must be maintained to a high standard. The maintenance of buildings, ranging in date from the seventeenth century (the Pavillon de Breteuil and the Petit Pavillon) to the present day, requires a wide range of skills and techniques (2 full time equivalent). The BIPM operates a "site guardian" service (1 full time equivalent) supplemented by external contractors.

Workshop and Site Maintenance

A mechanical workshop (3 full time equivalent) is essential for the efficient operation of a scientific laboratory such as the BIPM. The workshop not only designs and manufactures specific components for research instrumentation at the BIPM, such as the Kibble balance and the calculable capacitor, but also provides the special parts needed to adapt NMI standards to the BIPM reference facilities. It also repairs damaged equipment on the spot allowing comparisons and calibrations to run without major delays. The operation of such a mechanical workshop is an indispensable prerequisite for the efficient running of the BIPM. The mechanical workshop also produces platinum/iridium copies of the kilogram prototype against reimbursement of cost. This is a unique service that is only available to Member States. In addition workshop staff assist with general building maintenance tasks (3 full time equivalent).

IT Services

Like any other scientific institution, the BIPM relies heavily on a fully operational IT support service (2 full time equivalent). In particular the KCDB and JCTLM databases need to be accessible to the outside world on a permanent basis. The need to establish International Atomic Time (TAI) and Coordinated Universal Time (UTC) is dependent on the reliability and security of the BIPM's IT services. In addition to these tasks the typical spectrum of hardware and software for scientific, financial and administrative computing, and computerized instrument operation as well as electronic communication needs to be covered by the IT services.

ACRONYMS USED IN THE PRESENT VOLUME

AA	Amino acid
AC	Alternating current
AFRIMETS	Inter-Africa Metrology System
APMP	Asia/Pacific Metrology Programme
BIML	International Bureau of Legal Metrology
BIPM	International Bureau of Weights and Measures
CBKT	Capacity Building and Knowledge Transfer
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 and Biology
CCRI	Consultative Committee for Ionizing Radiation
CCT	Consultative Committee for Thermometry
CCTF	Consultative Committee for Time and Frequency
CCU	Consultative Committee for Units
CEEMS	Countries and Economies with Emerging Metrology Systems
CGPM	General Conference on Weights and Measures
CIPM	International Committee for Weights and Measures
CIPM MRA	CIPM Mutual Recognition Arrangement
CMC	Calibration and Measurement Capability
Codex Alimentarius:	Commission under the Joint FAO/WHO Food Standards Programme
COOMET	Euro-Asian Cooperation of National Metrology Institutions
DI	Designated Institute
DOSEO	Doseo technology platform CEA SACLAY
DON	Deoxynivalenol
ERMS	BIPM Ensemble of Reference Mass Standards
ESIR	Extended SIR
EURAMET	European Association of National Metrology Institutes
FTIR	Fourier-transform infrared
GNSS	Global Navigation Satellite System
GULFMET	Gulf Association for Metrology
GUM	Guide to the Expression of Uncertainty in Measurement
IAEA	International Atomic Energy Agency
IAU	International Astronomical Union
ICAG	International Comparison of Absolute Gravimeters
ICG	International Committee on Global Navigation Satellite Systems
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Units and Measurements
IDMS	Isotope dilution mass spectrometry
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
IMRR	International Metrology Resource Registry
INetQI	International Network for Quality Infrastructure
IPK	International Prototype of the Kilogram
ISO	International Organization for Standardization
ITS-90	International Temperature Scale of 1990
ITU	International Telecommunication Union
IUGG	International Union of Geodesy and Geophysics
IUPAC	International Union of Pure and Applied Chemistry
IVD	*in vitro* diagnostics
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
LSC	Liquid scintillation counting
MMM	Measurements Method Matrix
NIST	National Institute of Standards and Technology (United States of America)
NMI	National Metrology Institute
NMIJ	National Metrology Institute of Japan (Japan)
NORM	Naturally Occurring Radioactive Materials
OECD	Organisation for Economic Co-operation and Development
OIML	International Organization for Legal Metrology
OTA	Ochratoxin A
PAT	Patulin
PICAA	Peptide Impurity Corrected Amino Acid Analysis
QHR	quantum Hall resistance
qNMR	quantitative Nuclear Magnetic Resonance
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
TAI	International Atomic Time
TT	Terrestrial Time
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

Appendix 1

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 Vision, 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.	Fundamental area of modern physical metrology, core to many other fields of metrology (e.g. all other measuring systems produce/use electrical signals, Kibble 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.	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.	**<u>Mass:</u>** Providing traceability to the international prototype of the kilogram (IPK) requires a central and neutral laboratory for long-term maintenance and global dissemination. *After redefinition:* traceability to the SI unit of mass will be based on multiple primary realizations obtained with complex experimental facilities including the BIPM Kibble 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 Kibble balance). **BIPM laboratory programme** **----------** **<u>Related quantities:</u>** Largely applied activities more suited to NMIs.
No BIPM laboratory programme	**BIPM laboratory programme**	**No BIPM laboratory programme**	**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).	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.	Supports a mature and well-established equivalence and global traceability scheme in a field with high impact on healthcare (radiotherapy, radiodiagnostics and nuclear medicine), environmental protection (radioactivity in the foodchain) the nuclear industry and nuclear forensics. Unique, very high precision, instruments and radiation fields for use in comparisons. A single focus for comparisons and calibrations reduces the need for NMIs / DIs to deal with burdensome regulations when shipping radioactive sources or sensitive instruments for large-scale comparisons. Maintaining a laboratory programme ensures leverage when engaging with stakeholders, particularly IAEA, WHO, ISO, ICRU, ICRM, ICRP and IRPA.	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	Single, unique and independent reference system world-wide. Wide impact (Satellite navigation, telecoms, national timekeeping, earth and 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.
No BIPM laboratory programme	**BIPM laboratory programme**	**BIPM laboratory programme**	**No BIPM laboratory programme**	**BIPM coordination programme** (with some laboratory work)

Appendix 2

ACTIVITIES THAT COULD NOT BE SUPPORTED BY THE REQUESTED BUDGET

As a result, capital expenditure for the following two activities that had been included in the earlier consultation versions of the work programme has been cut from their respective projects, the amounts cut are shown below.

N	Project Code	Deliverables and Activities	**Resources in:** **a)** Person months **b)** Operating costs **c)** Capital investment
International reference standard for resistance			
1.	PMD-E2	**E2.1: On-site comparisons of quantum Hall resistance (QHR) standards** Direct comparison of QHR standards using the BIPM transportable standard, to obtain lowest possible uncertainty *NMI Participations: 6-8*	
		Development of a new transportable QHR standard based on graphene, for simplified operation and cost reduction	a) 0 pm b) 0 k€ c) 175 k€
International reference facility for comparison of standards and scales for radiative forcing gases			
2.	Chem-G3	**Coordination of comparisons to determine and improve the international equivalence of gas standards for radiative forcing gases.**	
		G3.3: Developed facilities and methods for calibration of CH_4 optical isotope ratio measurements and coordination of **CCQM-Pxx (2023) CH_4 isotope ratios**, based on a dedicated optical isotope analyser, to demonstrate the level of comparability of methane isotope ratio standards from NMIs, supporting calibrations for emission source and inventory verification measurement networks. *NMI participations: 12*	a) 0 pm b) 0 k€ c) 90 k€