





The BIPM

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

THE VISION AND MISSION OF THE BIPM

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 uptake and impact.
- To be a centre for scientific and technical collaboration between Member States, providing capabilities for international measurement comparisons on a shared-cost basis.
- To be the coordinator of the world-wide measurement system, ensuring it gives comparable and internationally accepted measurement results.

Fulfilling the BIPM mission and objectives is complemented by its work in:

- Capacity building, which aims to achieve a global balance between the metrology capabilities in Member States,
- Knowledge transfer, which ensures that the work of the BIPM has the greatest impact.

Contents

The BIPM	2	CBKT	11
Director's introduction	3	CIPM MRA	12
Physical Metrology	4	Launch of the revised SI	13
Time	6	Financial summary	14
Ionizing Radiation	7	Comparisons and calibrations	16
Chemistry	8	Organizational structure	17
Liaison and Communication	10	Publications	18

Director's introduction

I am delighted to report here the highlights of the work of the BIPM laboratories and secretariat during 2019. The greatest of these has been our continued work to promote the changes to the SI system which were focused around the celebration of World Metrology Day on 20th May, and our piloting of the first key comparison subject to the new definition.

Our performance in 2019 was also marked by another year of sound financial performance. We provide summary financial information in this report. The Financial Report is available on-line[†].

The preparation of this report took place during a period when activities on the BIPM site were limited because of the confinement measures imposed in France in response to the global COVID crisis. I am very pleased to report that most BIPM staff have been able to continue to work on site or remotely through this period and we have been able to sustain all of our services. We will be able to report in more detail on this at the end of the year.

Martin Milton
BIPM Director

Highlights of 2019

- The revised SI was launched on 20 May 2019 along with the publication of the 9th edition of the SI Brochure. World Metrology Day was one of the most successful ever held involving events registered in 43 countries and the poster being translated into more than 15 different languages.
- The new version of the BIPM key comparison database (KCDB 2.0) has been launched. It implements many of the changes agreed in the review of the CIPM MRA, including support for the complete CMC process from draft to publication, and a numerical search capability.
- Crucial steps towards the completion of the BIPM Kibble balance for realizing the new kilogram definition were achieved in 2019; the relative standard uncertainty has been reduced to 5×10^{-8} , which has allowed the BIPM to participate in the first CCM key comparison of kilogram realizations.
- A new instrument (the 'ESIR') has been developed for comparisons of standards of pure beta-emitting radionuclides. Accurate measurements of such radionuclides are needed for applications in nuclear medicine and environmental protection.
- The accuracy of the global atmospheric composition measurement scale has been demonstrated by measurements in the BIPM laboratories of standards of CO₂ in air from 14 institutes world-wide. Among the standards are those used within the WMO-GAW monitoring network on which all global background observations of CO₂ and long-term trends are based.
- Different algorithms have been tested for the incorporation of time data from new GNSS systems (including the Chinese BeiDou system and the European Galileo system) into UTC which will lead to greater robustness of the system and reduced uncertainty.

[†]This report includes summaries of the BIPM financial performance, and complements the Financial Report <https://www.bipm.org/en/committees/cipm/publications-cipm.html#ra> and the Proceedings of the CIPM <https://www.bipm.org/en/committees/cipm/publications-cipm.html> (both of which are available in French and English).

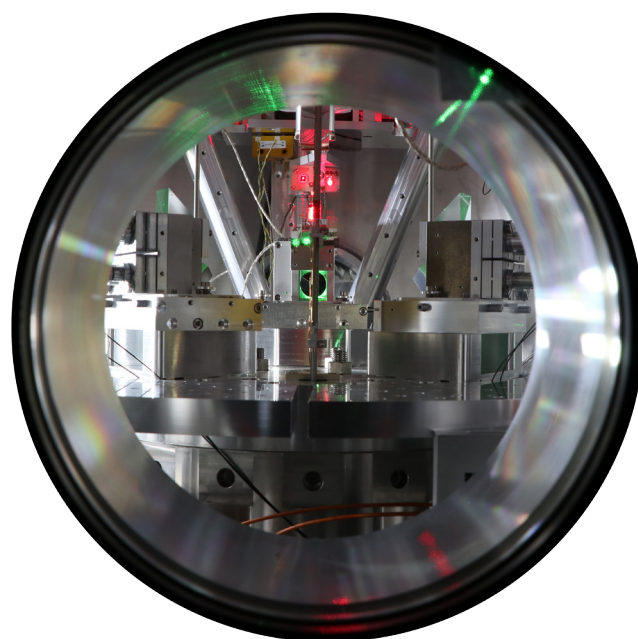
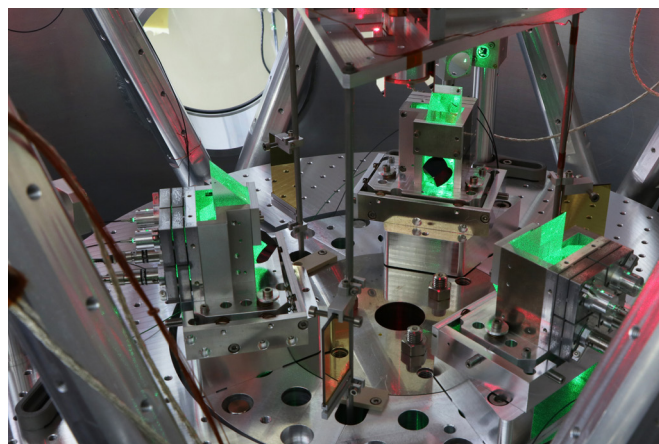
Physical Metrology

Calibration of mass standards

Following the official launch of the revised SI, the BIPM will continue to provide calibrations of mass standards for NMIs of Member States. At present, traceability to the new definition is achieved via the known relationship between the mass of the IPK and the Planck constant^[1]. During 2019, eight calibration certificates were issued for Pt-Ir prototypes and eighteen for stainless steel standards belonging to 13 NMIs. A new 1 kg Pt-Ir mass prototype, n° 112, was delivered to the Republic of Indonesia.

BIPM Kibble balance

Crucial steps towards the completion of the BIPM Kibble balance for realizing the new kilogram definition were achieved in 2019. The type B uncertainty due to misalignment was significantly reduced after the integration of a new interferometer which is firmly mounted on the magnetic circuit. The electrical grounding of the whole apparatus has been improved, the measurement sequence optimized, and the apparatus control and data processing software refined. As a consequence, the relative standard uncertainty has been reduced to about 5×10^{-8} . This will allow the BIPM to participate in the first key comparison of kilogram realizations. A large number of measurements in vacuum of a 1 kg Pt-Ir mass standard were carried out during three one-month periods. During these periods, the apparatus was re-aligned in air several times. The average masses deduced from each period were in good agreement, demonstrating the effective repeatability and reproducibility of the apparatus. The next step will be to develop a new mechanical system for generating the vertical coil displacement and to perform force measurement with the objective of achieving a target uncertainty of 2×10^{-8} .



Official launch of the revised SI

A major event in the field of mass metrology was the official launch of the revised SI on 20 May 2019. The definition of the kilogram is now based on the fixed numerical value of the Planck constant, and no longer relies on the mass of the International Prototype of the Kilogram (IPK)^[2]. The BIPM has issued a note^[3] explaining the impact of this change on mass calibration uncertainties that were stated on BIPM calibration certificates issued before 20 May 2019. The dissemination process after the redefinition is described in a note issued by the Consultative Committee for Mass and Related Quantities (CCM)^[4]. Initially the dissemination will be internationally coordinated to guarantee world-wide uniformity. Later, NMIs operating a method to realize the definition of the kilogram will be allowed to disseminate directly from their own realizations.

The BIPM is the pilot laboratory for the first key comparison of realizations of the kilogram, CCM.M-K8.2019. Seven institutes, including the BIPM, will participate with realizations based on Kibble balances, while two institutes will use the X-ray-crystal-density-technique. The first travelling standards arrived at the BIPM in October 2019 and weighings under vacuum started in November 2019. A Draft A report for this comparison is expected in 2020. The outcome of this comparison will become the basis for the calculation of the “consensus value”, which in turn will become the basis for the temporary international coordination of the dissemination of the kilogram.

On-site QHR resistance standard comparisons

In the field of electricity, the BIPM series of on-site comparisons of quantum Hall resistance standards (BIPM.EM-K12) continued with visits to the NMC, A*STAR (Singapore), NIM (China) and KRISS (Republic of Korea). Altogether, nine comparisons have been performed since this programme resumed in 2013. This series of on-site comparisons allows NMIs to validate their implementation of the quantum Hall effect for dc resistance traceability. Each comparison consists of an on-site comparison of the BIPM quantum Hall resistance (QHR) to that of the visited NMI by measuring a 100 Ω transfer standard, supplemented by the measurement of two resistance ratios. This allows the comparison of the ratio bridges used to scale the 100 Ω up to 10 k Ω and down to 1 Ω . During the comparisons carried out in 2019, a new set of temperature-controlled resistors built at the BIPM, and specifically designed for this task were used.

Four terminal-pair ac-resistance bridge

The characterization of the renovated four terminal-pair ac-resistance bridge, which was started in 2018 by a secondee to the BIPM from NMIJ (Japan), has been finalized. This work led, in particular, to a complete frequency characterization of the ac-resistors used in the quadrature bridge for linking the BIPM 10 pF capacitance reference to the dc quantized Hall resistance^[5]. The BIPM built two Haddad type resistors for the LNE (France) of nominal value 1000 Ω and 1290.6 Ω during 2019. An additional 1290.6 Ω Haddad resistor was fabricated for the BIPM. Its negligible frequency dependence was verified using the renewed four terminal pair ac-resistance bridge.

Implementation of the ac-QHR

The study for the implementation of the ac-QHR at the BIPM started in 2019. Following fruitful exchanges between the PTB (Germany) and the BIPM in 2018, it was decided to implement the double-shielding approach developed at the PTB. The GaAs quantum Hall device will be of type LEP 513 or LEP 514 (the device usually used at the BIPM) and its holder will be very similar to that developed during Euromet project 540. The cryo-probe has been assembled and the first measurements are planned to start in early 2020. The final aim is to build a new quadrature bridge incorporating two ac-QHRs.

Josephson voltage standards

In the field of voltage, an on-site comparison of dc Josephson voltage standards has been carried out with MIKES (Finland). The BIPM is making progress with the development of a new protocol to extend its on-site comparison of Josephson standards from dc to ac voltages for frequencies below 1 kHz. A pilot study was carried out at the PTB in collaboration with the KRISS (Republic of Korea), the NMIA (Australia) and the VNIIM (Russian Federation). The aim was to gain experience of the differential sampling technique for ac voltages and to understand the impact of critical parameters that could affect the final result and its uncertainty. The influence of filters (developed at the NMIA) at the output of the ac voltage sources, used as transfer standards, was investigated. In order to monitor the drift of the transfer standard output voltage, dedicated software (developed at the VNIIM) provided a continuous rms value, based on a full sampling technique, from a DVM connected in parallel to the output of the source. The result of these measurements was compared to the result given by the differential sampling technique, which computes the rms value from a reconstruction of the sinewave. Finally, the influence of the type of samplers and the arrangement of the measurement setup were investigated. Further investigations of these parameters are needed to derive a comparison protocol that offers the best benefit for the NMIs.

In addition to the two on-site comparison programmes, a number of bilateral comparisons using travelling standards were carried out in 2019^[6-8]: for resistance (BIPM.EM-K13) with NMC, A*STAR and NIM and for voltage (BIPM.EM-K11) with BIM (Bulgaria). A capacitance comparison (BIPM.EM-K14) with SASO (Saudi Arabia) is under way. A total of 76 calibrations have been provided by the electricity laboratories to NMIs in the fields of resistance, capacitance and voltage.

Time

Robustness of the UTC algorithm

The robustness of the Coordinated Universal Time (UTC) algorithm was tested in collaboration with NMIs that realize their national time scale with the support of primary frequency standards. The aim is to study long-term instabilities induced by the frequency steering in UTC and in the local realizations UTC(k)^[9].

Time transfer using BeiDou and Galileo

The activity on time transfer techniques based on the Global Navigation Satellite Systems (GNSS) focused mainly on testing the new Chinese BeiDou and European Galileo systems within the current algorithm for the computation of UTC. Results show that the time transfer obtained by Galileo observations is as good as that achieved from GPS^[10]; the BeiDou system is still under test, particularly its latest generation, BDT3.

Calibration of GNSS equipment

The department continued with its work on the absolute and differential calibration of GNSS equipment in 2019. A BIPM receiver has been absolutely calibrated for all the available GNSSs in collaboration with the European Space Agency (ESA). In addition, in collaboration with the Royal Observatory of Belgium an overall evaluation of all the available differential and absolute calibration data has been carried out with the aim of fixing the reference values for the GNSS measures in the computation of UTC and also for the publication of GNSS time dissemination services in BIPM *Circular T*.

GNSS calibration campaigns

The GNSS calibration campaigns, in coordination with the RMOs, are progressing as expected, with the aim of visiting the G1 laboratories in each RMO every two years. The third complete voyage of the BIPM travelling apparatus was concluded with a visit to the SIM G1 laboratories. A final calibration report was published and the results are available on the BIPM website. This latest campaign included Galileo observations for the first time.

Calibration travelling box

The Time Department, in collaboration with the OP SYRTE (France), has developed a new “calibration travelling box”, which is currently under test. The apparatus includes a carefully designed measurement chain, which is aimed at calibrating GNSS and Two Way Satellite Time and Frequency Transfer (TWSTFT) equipment when the TWSTFT mobile calibrating station is not available or is not suitable.

IPPP research

The BIPM is collaborating with the CNRS (France) on research into the use of Integer Precise Point Positioning (IPPP) as an improved treatment of the GNSS carrier phase measures to avoid cycle slips that degrade the stability of the time transfer solution^[11, 12]. Dedicated software has been developed and used to validate other time transfer techniques such as optical fibres or Very-long-baseline interferometry (VLBI), in collaboration with the laboratories involved. Plans to use IPPP in the computation of UTC are under development.

Ensuring the accuracy of UTC

To ensure the accuracy of UTC, the role of primary and secondary frequency standards is fundamental. The department is following the development in the NMIs and supporting the introduction of frequency measurements in UTC, particularly the newly developed optical frequency standards.

CBKT training course

The Time Department, in collaboration with a secondee from NICT (Japan), has prepared a training course on “Time scale and algorithms”, within the framework of the BIPM CBKT programme. The course will be given at the BIPM or within the RMOs.

Atomic Clock Ensemble in Space

The BIPM has started working with the Working Group for the exploitation of the Atomic Clock Ensemble in Space (ACES) experiment on the International Space Station (ISS) with the aim of studying a high-accuracy microwave link for possible future use in UTC, and related effects of relativity on clocks^[13, 14, 15].

BIPM frequency comb successfully installed by INTI

Following its dismantling, a number of pieces of equipment from the former BIPM Length Section's laser laboratory were identified as being worth offering to NMIs for use in their work programmes. In particular, there were two frequency combs, which had been built by the BIPM and which are used in comparing microwave to optical frequency radiations. Information about the frequency combs was circulated among the NMIs and INTI (Argentina) offered to acquire one of the combs.

It took more than nine months to receive the custom clearance, and on 16 October 2019 the comb left the BIPM. It arrived at INTI a few days later and has been successfully installed in its length laboratory.

Ionizing Radiation

Launch of the ESIR

A new comparator (the 'ESIR') was launched in 2019 for standards of pure beta-emitting radionuclides; such radionuclides have applications in nuclear medicine for cancer therapy or pain palliation, and are also common in the nuclear industry. The instrument is based on liquid scintillation counting using the Triple-to-Double Coincidence Ratio (TDCR) method^[16]. A problem encountered has been that measurements can be sensitive to small changes in electronic components such as the phototubes. After detailed validation studies, a method that reduces the impact of the changes to an acceptable level has been found. The first comparison based on the technique will take place early in 2020. The work was supported by experts from the POLATOM (Poland), LNHB-LNE (France), NPL (UK), PTB (Germany) and NIM (China).



The ESIR

Ongoing work with the SIR

The high-precision comparator for long-lived gamma-emitting radionuclides (the 'SIR') has continued to be well used, with seven institutes submitting standards of seven different radionuclides for measurement on the instrument. A project to replace the reference sources of ^{226}Ra , on which the measurements depend, is ongoing (this project is necessary as ^{226}Ra sources are no longer available). An alternative radionuclide has been identified ($^{166\text{m}}\text{Ho}$), however the raw material available on the market has been found to contain impurities. The IRA (Switzerland) is arranging purification at a specialist facility and replacement sources are expected to be available mid-2020. In 2019 comparisons were completed for: ^{139}Ce and ^{133}Ba NMISA (South Africa); ^{152}Eu NMIJ (Japan); ^{133}Ba NIST (USA); ^{88}Y BEV (Austria); ^{225}Ac PTB (Germany); and ^{60}Co VNIIM (Russian Federation).

Extension of the SIRTl

The transportable version of the SIR (the 'SIRTl') was launched in 2009 for comparing standards of short-lived radionuclides, particularly those used in medical imaging such as ^{18}F for positron emission tomography. The focus in 2019 has been on characterizing the SIRTl for two radionuclides that have not previously been measured (^{153}Sm and ^{123}I); the measurements were completed successfully with the support of a

seconded from the LNMRI/IRD (Brazil). The studies have increased the number of radionuclides covered by the SIRTl, so that a metrology institute can compare a wide range of standards during a single on-site measurement campaign. In addition, the results of the first comparison of ^{11}C standards were presented at the 22nd International Conference on Radionuclide Metrology, held in Salamanca (Spain) in May 2019^[17]. In 2019, studies were completed for ^{123}I and ^{153}Sm with the help of a seconded from LNMRI (Brazil) and missions will restart in 2020.

High demand for radiation dosimetry services

BIPM services for radiation dosimetry continue to be in high demand. National metrology institutes participated in five comparisons and twenty calibration exercises; each exercise can be time-consuming, involving measurements of one to three instruments in up to five radiation beams.

Traceability of LINACs

A detailed study was carried out to investigate a possible issue in the traceability of measurements of radiation dose for cancer therapy using linear accelerators (LINACs). Unlike the old technology based on ^{60}Co sources, the radiation field from a LINAC could have different characteristics depending on the make and model even if set to the same nominal energy; a calibration using one model of LINAC might therefore not be applicable at the stated uncertainty to measurements on another model. The hypothesis was tested out using measurements on LINACs at DOSEO (France), the LNE-LNHB (France) and the DTU (Denmark), supplemented by Monte Carlo simulations. The results indicate that the differences are within the measurement uncertainties, confirming that the existing traceability scheme is valid, and a report is in preparation. This work was carried out with the support of the NRC (Canada).

X-ray studies

Other studies completed during 2019 included back-scatter correction factors for x-ray dosimetry (these data are needed for an update of the IAEA publication TRS-398 and were carried out in collaboration with experts from the IAEA). Improvements were also made to characterization of measurements in low-energy x-ray and mammography beams, reducing the uncertainties and expanding the options for comparison services. This work was carried out by an expert from the VNIIM (Russian Federation).

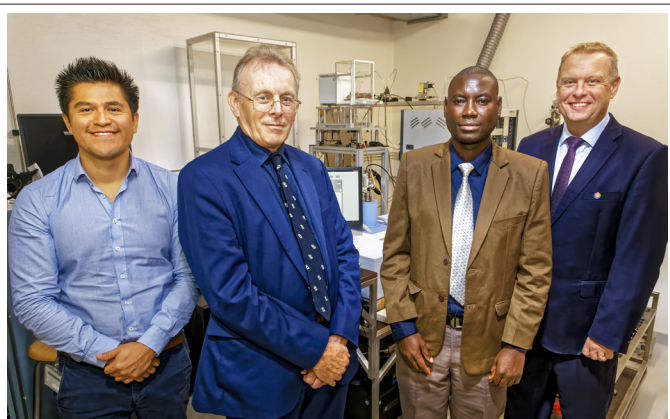
Chemistry

Comparison on CO₂ isotope ratio standards

Preparation for a comparison on CO₂ isotope ratio standards (CCQM-P204), coordinated jointly by the BIPM and the IAEA continued, with the protocol prepared and distributed and twenty institutes expressing interest in participation. Development of isotope ratio measurement and gas preparation facilities continued with support from visiting scientists from VNIIM (Russian Federation) and NPL (UK). A paper describing the optimized optical measurement facility has been submitted for publication. Preparations for the comparison of nitrous oxide in air at background levels coordinated by the BIPM together with KRISS (CCQM-K68.2019) continued, with comparative measurements performed at the BIPM at the end of 2019 and completed into the first quarter of 2020.

FTIR Measurements on Gas Standards course

Two visiting scientists from the KEBS (Kenya) and KazInMetr (Kazakhstan) undertook the Metrology for Clean Air course on FTIR Measurements on Gas Standards in the BIPM laboratories. They received training in the use of B-FOS software for use with FTIR in gas metrology applications.



Left to right: E. Flores (BIPM), R. Gunn, NPL (UK), C. Solo, KEBS (Kenya) undertaking a six month training programme at the BIPM on FTIR for Gas Standards and P. Thompson, NPL (UK). The NPL sponsored visiting scientists to participate in the Metrology For Clean Air CBKT programme at the BIPM

Air quality measurement standards

The BIPM comparison programme in support of air quality measurement standards continued, focusing on ozone, nitrogen oxides and formaldehyde. The BIPM continued to contribute to the CCQM GAWG Ozone Cross Section Task Group, including the publication of a paper summarizing the recommended best value and uncertainty for the ozone cross-section to be used in the key comparison BIPM.QM-K1^[18]. Organization of a workshop on the implementation of the new cross-section value with stakeholder communities in September 2020 at the BIPM has started. Seven NMIs: ISCI (Spain), KRISS (Republic of Korea), NIST (USA), JRC (EC), EEA (Austria), UBA (Germany) and

SE Ukrmetrteststandard (Ukraine) sent their ozone standards to the BIPM and participated in BIPM.QM K1, as well as a comparison for NSW (Australia). The Final report of CCQM-K137 (NO in N₂ at 30 µmol/mol and 70 µmol/mol) was completed and published in the BIPM key comparison database^[19]. Measurements at the BIPM for the comparison of NO₂ in N₂ standards at 10 µmol/mol (CCQM-K74.2018) were completed. Additional measurements for the pilot study of HNO₃ measurements in such standards (CCQM-P172) have been performed on a new set of standards. The work that was carried out on the stability of formaldehyde standards as part of the preparation for CCQM-K90 has been published^[20].

International comparison demonstrates accuracy of the global atmospheric CO₂ measurement scale

The results of the CCQM comparisons on CO₂ in air standards (CCQM-K120 and CCQM-P188) were presented at the 20th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques (GGMT-2019), held in Jeju (Republic of Korea) from 2-5 September 2019. This coincided with the presentation of an updated CO₂ scale (WMO-CO₂-X2019), the primary reference for the WMO-GAW monitoring network on which all global background observations of CO₂ are based.

The scale will be used by the WMO Global Atmosphere Watch programme in its global monitoring network for tracking trends in the background CO₂ amount fraction in the atmosphere. The accuracy of the scale was demonstrated in the key comparison (CCQM-K120), organized by the CCQM Working Group on Gas Analysis (CCQM-GAWG) with comparative measurements performed at the BIPM. The comparison involved the analysis of the composition of 46 gas reference materials from 13 NMIs and The National Oceanic and Atmospheric Administration (NOAA), the institute designated by the WMO.

Progress in reducing uncertainties in SI traceable standards has led to a key comparison reference value for CO₂ in air concentrations with state-of-the-art uncertainties of parts in 10⁴. This has enabled benchmarking of international comparability and provided support for an update to the global scale.

The developments to the global scale recognize the substantial collaborative progress made between the metrology and atmospheric monitoring communities since the WMO signed the CIPM MRA in 2010.

Organic and protein primary calibrators

In the area of organic and protein primary calibrators, the BIPM programme of comparisons for ensuring global equivalence of standards for small organic molecule and protein calibrators continued. The final report of CCQM-K78.a, a comparison on multi-component amino acid calibration solutions, was completed and published^[21]. Measurements for the CCQM-K148.a comparison (bisphenol A calibrator purity) were completed, and results presented to the meeting of the CCQM Working Group on Organic Analysis (CCQM-OAWG).

Internal Standards for qNMR

Support for laboratories using Quantitative NMR to value assign primary reference materials was provided through the development of four reference data documents on 'Internal Standards for qNMR' for Dimethyl Terephthalate, 3,5-Bis(trifluoromethyl) benzoic Acid, 1,4-Bis(trimethylsilyl)benzene and 4,4-Dimethyl-4-silapentane-1-sulfonic acid-d₆. These documents were published on the BIPM website as BIPM Rapports 2019/01^[22], 2019/02^[23], 2019/03^[24] and 2019/04^[25]. A paper^[26] describing the universal calibrator programme for qNMR at the BIPM, an activity initiated together with the NMJJ, and supported by visiting scientists was published, together with a review article on the applications of qNMR^[27]. A visiting scientist from BAM (Germany) was seconded to the BIPM to further develop qNMR techniques for ¹⁹F NMR.

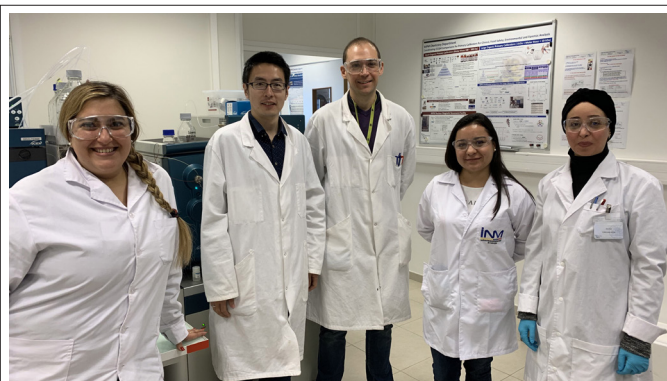
Peptide calibrator materials

Measurements for the comparison on oxytocin (peptide calibrator material) coordinated by the BIPM (CCQM-K155.b) were completed, and the results and Draft A report were presented at a meeting of the CCQM Working Group on Protein Analysis (CCQM PAWG). Samples for comparisons on hexapeptide calibrators for HbA1c glycated hexapeptide (GE), for CCQM-K115.c, and non-glycated hexapeptide (VE), for CCQM-K115.2019, were distributed by the BIPM to participating NMIs. A review article on purity assessment of peptide calibrators was published^[28]. Visiting scientists from NIMT (Thailand), LNE (France) and NPL (UK) were seconded to the BIPM to develop methods for the characterization of candidate peptides for comparisons, and notably hexapeptides for HbA1c and HbA0, parathyroid hormone with ion mobility mass spectrometry, and triskelion peptides.

Metrology for Safe Food and Feed

In April 2019, the fourth meeting for the CBKT programme on "Metrology for Safe Food and Feed" was held at the BIPM, focusing on mycotoxin metrology and standards. The BIPM laboratory programme on mycotoxin standards was supported by a visiting

scientist from NIM (China) working on aflatoxin B₁, deoxynivalenol and patulin materials. Three visiting scientists from LATU (Uruguay), INM (Columbia) and INRAP (Tunisia) undertook three-month training secondments on mycotoxin calibration solution and characterization, focusing on Aflatoxin B₁ calibrants. Stock solutions of AFB₁ have been provided to the ten NMIs that have participated in the programme to date (KEBS, INTI, NMISA, NIMT, INMETRO, UME, LATU, INM, INRAP, NIM), in preparation for the second key comparison (CCQM-K154.b) on mycotoxin calibration solutions. Measurements for the key comparison on Zearalenone calibration solutions (CCQM-K154.a) were completed at the BIPM, and the Draft A report was presented at the meeting of the CCQM Working Group on Organic Analysis (CCQM-OAWG). A paper and guidelines describing the characterization of AFB₁ calibrants was published^[29,30], as well as guidelines on the evaluation of purity of ZEN primary reference materials^[31]. An agreement with NRC (Canada) to extend and provide materials for a comparison on Ochratoxin A calibrants, which is foreseen for 2023, was concluded. A three-day workshop held from 4-6 November 2019 in Riyadh (Saudi Arabia) on "Metrology for Safe Food and Feed - Organic Analysis and Standards" was organized for GULFMET as part of the BIPM 'Metrology for Safe Food and Feed Programme' Capacity Building and Knowledge Transfer programme.



Visiting scientists L. Casas, LATU (Uruguay), L. Morales Erazo, INM (Columbia) and R. Torkhani, INRAP (Tunisia) undertaking three-month training secondments on mycotoxin calibration solution production and characterization, focusing on Aflatoxin B₁ calibrants, together with Xianjiang Li, NIM (China) and G. Martos (BIPM)

25th anniversary of the CCQM

A CCQM Workshop on "Advances in Metrology in Chemistry and Biology", marking the 25th anniversary of the CCQM, was organized at the BIPM in April 2019, and resulted in twenty publications in the related *Metrologia* special issue, including a paper on Amount of substance and the mole in the SI^[32].

International Liaison and Communication

The BIPM and the Organisation for Economic Co-operation and Development (OECD) cooperate to use the “Partnership of international organisations for effective international rulemaking” (IO Partnership) for effective dissemination of information on the importance of the quality infrastructure and particularly metrology as a key component in the wide-ranging activities of the IO Partnership. The OECD established the IO Partnership as a voluntary platform of IOs, academics and OECD Regulatory Policy Committee delegates, to exchange good practices and promote greater quality, effectiveness, and impact in international rulemaking.

The BIPM cooperates with the OECD within the IO Partnership to promote the value of a sound approach to metrology and the contribution of the national metrology infrastructures.

The OECD study *‘The Case of the International Bureau of Weights and Measures’* was published within the IO Partnership on 6 February 2020. (see page 13)

The BIPM has also contributed to the analytical work within the IO Partnership which resulted in the publication of the brochure *‘The Contribution of International Organisations to a Rule-Based International System: Key Results from the partnership of international organisations for effective rulemaking’* in April 2019.

The BIPM will continue contributing to the next-phase (2019-2021) work of the IO Partnership by involvement in the work of its working groups for implementation and evaluation of international instruments as well as in the capacity of the co-focal point for its working group for coordination among international organizations.

The theme for World Metrology Day 2019 was “The International System of Units: Fundamentally better”. This theme was chosen to coincide with the launch of the revised SI on 20 May 2019. The 2019 World Metrology Day poster was translated into more than 15 languages and 43 countries shared information about their national celebratory events.

The BIPM and the World Trade Organization (WTO) cooperate to ensure effective dissemination of information on the importance of the quality infrastructure and particularly metrology as one of its key components among trade regulators and international / intergovernmental organizations that hold *ad hoc* observer status at the WTO Committee on Technical Barriers to Trade (WTO TBT Committee). BIPM staff attended and delivered reports to the WTO TBT Committee in 2019. In November 2019 Mr Henson, Director of the International Liaison and Communication Department delivered a presentation at the thematic session of the WTO TBT Committee

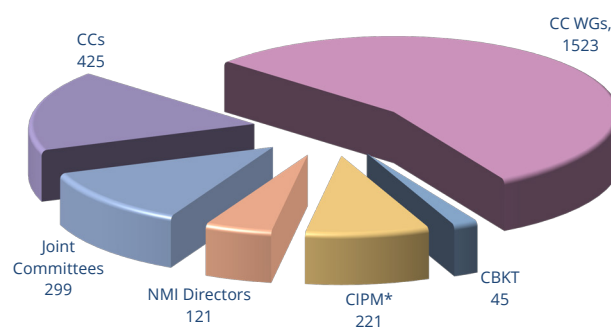
dedicated to NQI and attended the ‘Metrology session’ of the four-day TBT Advanced Short Course, as an expert speaker on the role of scientific and legal metrology (together with the OIML) as one of the QI key pillars. The BIPM also liaises with the WTO through the International Network on Quality Infrastructure (INetQI).

The BIPM and the United Nations Educational, Scientific and Cultural Organization (UNESCO) cooperate to ensure effective dissemination of information on the importance of the quality infrastructure and particularly metrology in the scientific and wider context. The BIPM and UNESCO have reinvigorated their relationship dating back to 1949 and they are re-establishing a new programme of joint activities. A number of ideas for collaboration were explored in 2019, and will be progressed in 2020. The BIPM also attended the sessions of the UNESCO Executive Board and General Conference in 2019.

The BIPM and the International Union of Pure and Applied Chemistry (IUPAC) have formalized their long-standing cooperation through the signature on 17 October 2019 of a Memorandum of Understanding.

The BIPM-IFCC-ILAC Declaration of Cooperation establishing the Joint Committee for Traceability in Laboratory Medicine (JCTLM) was revised in 2019, to facilitate expansion of the JCTLM Executive Committee to include additional organizations in its membership from further branches of laboratory medicine, and was re-signed in December 2019. The International Council for Standardization in Haematology (ICSH) was welcomed as a new Executive Committee Member, effective December 2019. This important collaboration brings expertise in clinical laboratory haematology to the JCTLM and provides the opportunity to align the standardization and harmonization of haematology laboratory methods with the reference measurement system of the JCTLM, further enhancing the aim of ‘accurate results for patient care’.

Meeting attendance at the BIPM in 2019



*Includes CIPM WGs, SCs, bipartite and quadripartite meetings

Capacity Building & Knowledge Transfer

During 2019, CBKT activities continued to expand. In total, 17 NMI staff received sponsorship to take part in Capacity-Building placements in 2019. A further 27 participated in workshops held at the BIPM and 125 took part in workshops held jointly by the BIPM in the regions.

Optimizing the CIPM MRA - the KCDB 2.0

4-8 November 2019 at the BIPM

The one-week course, organized by the BIPM and sponsored by NIST, was attended by 27 CIPM MRA experts. It was designed to equip RMO TC/WG Chairs and TC/WG members (who actually coordinate the review and act as reviewers) with the necessary knowledge to use the 'optimized' CIPM MRA and the KCDB 2.0.

Metrology for Safe Food and Feed - Organic Analysis and Standards

4-6 November 2019 in Riyadh (Saudi Arabia)

Thirty participants from six members of the GULFMET RMO took part in the three day workshop, which was organized as part of the BIPM 'Metrology for Safe Food and Feed Programme' Capacity Building and Knowledge Transfer project. The workshop was sponsored by the GCC Standardization Organization (GSO).



Participants and lecturers at the "Metrology for Safe Food and Feed - Organic Analysis and Standards" workshop, which was held from 4-6 November 2019 in Riyadh (Saudi Arabia).

The KCDB CBKT training platform

An offline version of the KCDB 2.0 database has been developed to support the KCDB user community at training events. It simulates all aspects of the CMC review and comparison registration processes. The CMC Writers and Reviewers are able to create 'offline' their user accounts; to develop their CMCs and to submit their CMCs for intra- and inter-regional review; to act as Reviewers; to submit comparisons as a Pilot; and finally to manage the process as a TC Chair.

BIPM - TÜBİTAK UME project placements completed with great success

The joint BIPM-TÜBİTAK UME initiative "TÜBİTAK UME project placements" has proven to be a great success. The BIPM collaborated with TÜBİTAK UME, the NMI of Turkey, to support young metrologists from 14 countries to gain in-depth knowledge and experience on a subject of scientific interest.

Over two cycles, organized in 2018 and 2019, the BIPM and TÜBİTAK UME initiative sponsored 20 participants from AFRIMETS, APMP, COOMET and GULFMET. All participants were from NMIs that have recently become a signatory to the CIPM MRA, or were inexperienced in the CIPM MRA processes. The placements, of between 1 and 3 months, hosted in the TÜBİTAK UME laboratories, allowed participants to focus on specific metrological projects, to learn the theory and to test it in practical situations in order to maximize the transfer of knowledge. In addition, participants were able to gain a better understanding of the international aspects of metrology during the seminars organized under the joint initiative and delivered by BIPM and TÜBİTAK UME staff. The TÜBİTAK UME project has been extended to 2020 and 2021 following the success of the 2018 and 2019 cycles.

Other CBKT activities in 2019

- **Important transitions in the CIPM MRA infrastructure.**
29-30 November in Sydney (Australia)
- **EURAMET-BIPM Training Course "Organisation and Piloting of Intercomparisons in Ionizing Radiation".**
9-11 October in Teddington (UK)
- **Varenna Metrology School**
Organized jointly with the Italian Physical Society
4-12 July in Varenna (Italy)
- **BIPM-GULFMET "CMCs and QMS Review" Workshop.**
23 April in Muscat (Sultanate of Oman)
- **BIPM-COOMET "CIPM MRA review outcomes" Workshop.**
2 April in Dresden (Germany)

The CIPM MRA



Following a recommendation by the CIPM Working Group on the Implementation and Operation of the CIPM MRA, the BIPM key comparison database (the KCDB) has been revised and the new version (the KCDB 2.0) was launched on 29 October 2019, offering a collaborative web platform for editing and reviewing Calibration and Measurement Capabilities (CMCs) as well as extended search facilities. The comprehensive support and guidance for comparisons, that was

offered to users, was well used by the end of 2019. The new CMC platform was introduced and made accessible to users and a training site was launched.

The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which NMIs demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the Arrangement are the internationally recognized (peer-reviewed and approved) CMCs of the participating institutes. Approved CMCs and supporting technical data are publicly available from the KCDB.

Key and supplementary comparisons

In December 2019, the key and supplementary comparisons database included 1 047 key comparisons and 588 supplementary comparisons. This represents an increase of 32 key comparisons on the previous year, while supplementary comparisons increased by 28. Around 60 comparisons were completed and published during 2019. Today, almost 90 % of the 96 ongoing BIPM key comparisons and around 70 % of all registered comparisons of the Consultative Committees and RMOs have results published in the KCDB. Almost all Associates participating in the CIPM MRA had at least one of their metrology institutes listed as a participant in a key or a supplementary comparison.

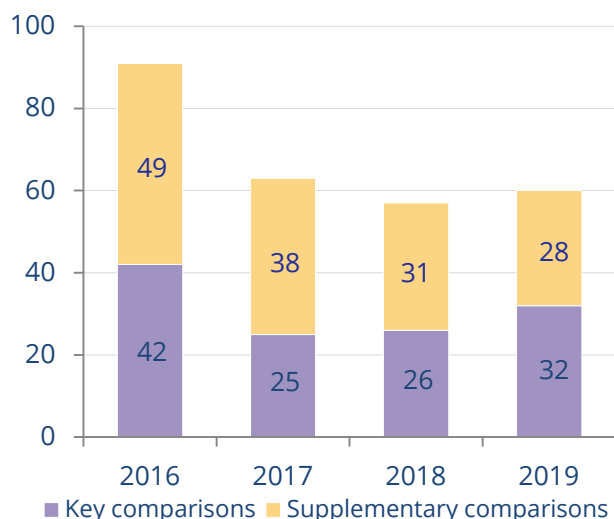
The KCDB currently includes a dozen examples where more than seven key comparisons are linked together.

Calibration and Measurement Capabilities

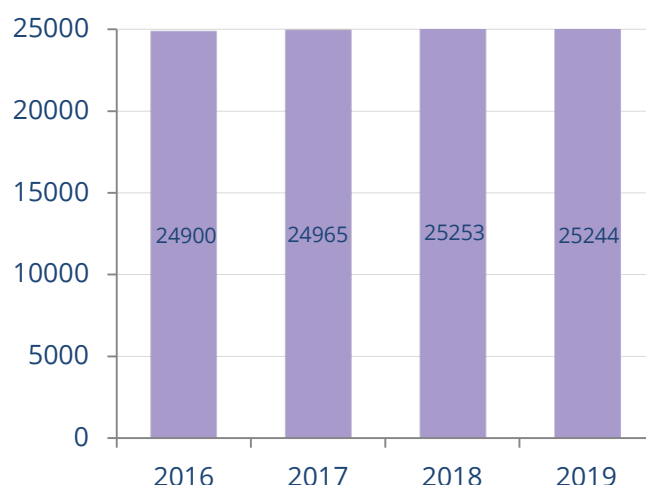
On 31 December 2019, there were 25 244 CMCs registered in the KCDB. Of these, 14 978 were in the field of general physics, 3 856 in ionizing radiation, and 6 410 in chemistry. The total number of CMCs was quasi-stable during 2019. Twenty-four of the 42 Associates that participate in the CIPM MRA had CMCs published in the KCDB at the end of 2019.

It is possible to temporarily withdraw CMCs from the database by “greying out”. At the end of 2019, 481 CMCs were “greyed out”, an increase of 17 %, mainly linked to postponements of activities. Thirty-one CMCs that had already been greyed out were definitively deleted. This is a negligible number when compared to the total number of registered CMCs.

Number of new comparisons registered in the KCDB



Total number of CMCs registered at 31st December

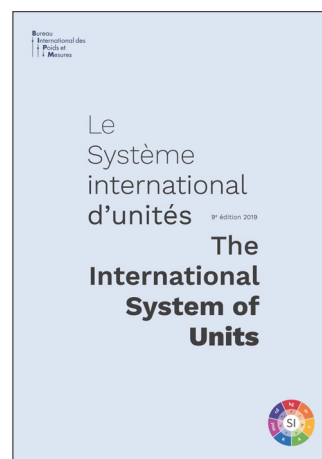


Launch of the revised SI

The 26th meeting of the General Conference on Weights and Measures (CGPM) adopted a set of far-reaching changes to the International System of Units (SI) in November 2018. The meeting introduced a new approach to articulating the definitions of the units in general, and of the seven SI base units in particular, by fixing the numerical values of seven “defining” constants. Among them are fundamental constants of nature such as the Planck constant and the speed of light, so that the definitions are based on and represent our present understanding of the laws of physics. For the first time, a complete set of definitions is available that does not make reference to any artefact standards, material properties or measurement descriptions. These changes enable the realization of all units with an accuracy that is ultimately limited only by the quantum structure of nature and our technical abilities but not by the definitions themselves. Any valid equation of physics relating the defining constants to a unit can be used to realize the unit, thus creating opportunities for innovation and realization everywhere with increasing accuracy as technology proceeds.

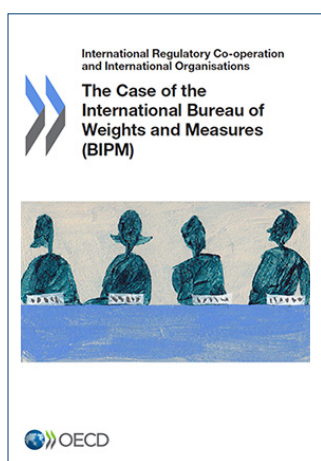
The implementation of the revised SI took place on 20 May 2019, a date chosen because it is World

Metrology Day, the day when the signing of the Metre Convention in 1875 is commemorated. Whilst the future impact of the changes will be far reaching, considerable attention has been paid to ensure that these definitions are consistent with those in place at the time the change was implemented.



To coincide with the implementation of the revised SI, the 9th edition of the SI Brochure (2019), which defines and presents the SI, was published. The SI Brochure can be downloaded from the BIPM website.

OECD study



The OECD study ‘*The Case of the International Bureau of Weights and Measures*’ was published within their International Organization Partnership on 6 February 2020 (see page 10). This study complements a series of the OECD studies of rule-making practices of selected IOs developed during 2014–2016 for the FAO, IMO, ISO, OECD, OIML, UNECE, WHO and in 2019 for the WTO and in 2020 for the OIE†.

†Food and Agriculture Organization (FAO), International Maritime Organization (IMO), International Organization for Standardisation (ISO), Organisation for Economic Co-operation and Development (OECD), International Organization of Legal Metrology (OIML), United Nations Economic Commission for Europe (UNECE), World Health Organization (WHO), World Trade Organization (WTO) and World Organisation for Animal Health (OIE).

IMRR

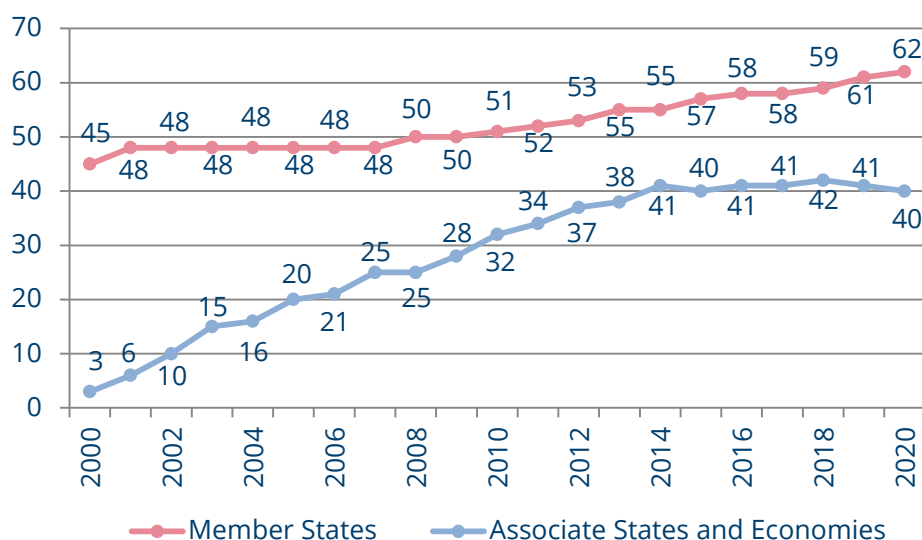
The International Metrology Resource Registry (IMRR), developed by NIST and hosted by the BIPM, is a web-based service that allows National Metrology Institutes and Designated Institutes to publish information about their data holdings, data services, standards documents, metrology-related software, websites, and about their organizations themselves.



The goal of the IMRR is two-fold: expose the services and capabilities of the NMIs to a broad community of researchers, industrial partners, and government agencies, and allow the NMIs to better coordinate their research and development efforts through increased visibility of each other’s activities.

Financial Summary

Growth in Member States and Associate States and Economies from 2000 to 2020



New Member States in 2019

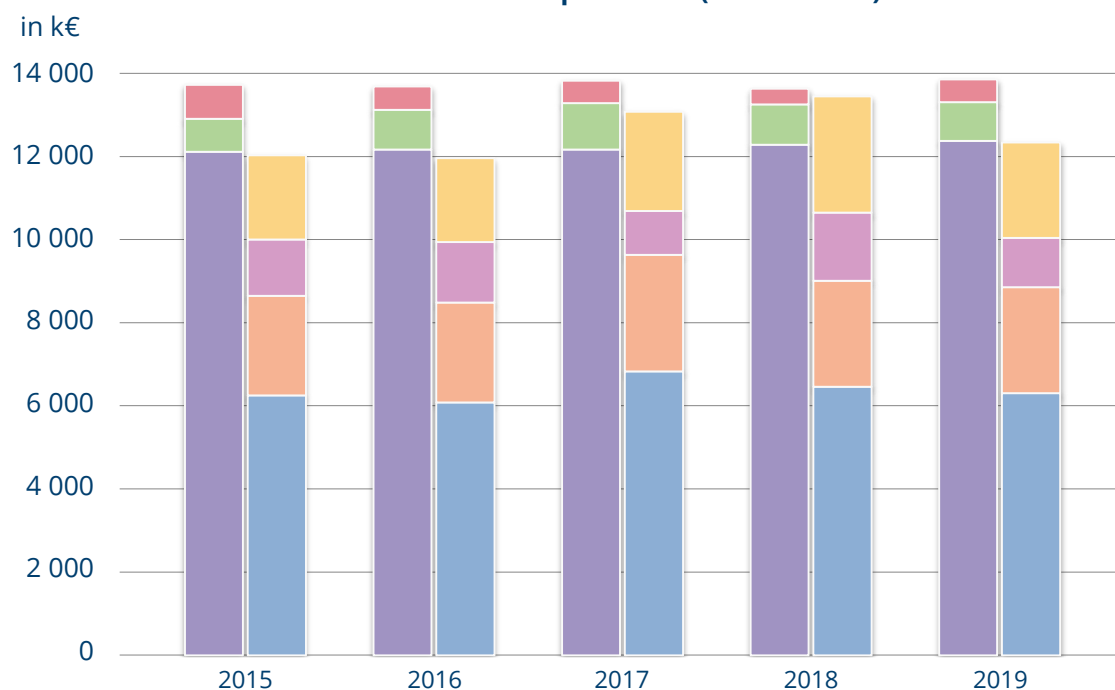
- **Ecuador** on 6 August 2019 (formerly an Associate since 2000)
- **Kingdom of Morocco** on 24 May 2019

Key financial points

- Income received from Member States and Associate States and Economies closely followed the forecast. At the time of writing of this report only one Member State has arrears outstanding from 2018.
- Total staff costs were reduced by 2.5 % from the 2018 level largely due to a reduction in the costs of seconded staff. Staff salary costs continue to be below the level in 2012. The combined costs of staff including also pensions and healthcare were 64 % of total income.
- Total operating costs returned to the level of 2017 following the extra costs incurred in 2018 for the 26th meeting of the CGPM. Investment decreased according to plan reflecting this having been the last year of the 4-year programme cycle.
- The “earnings” (i.e. the difference between income and spend corrected for changes in asset/liability values) were 2 852 k€, which exceeded the cost of depreciation (1 391 k€).

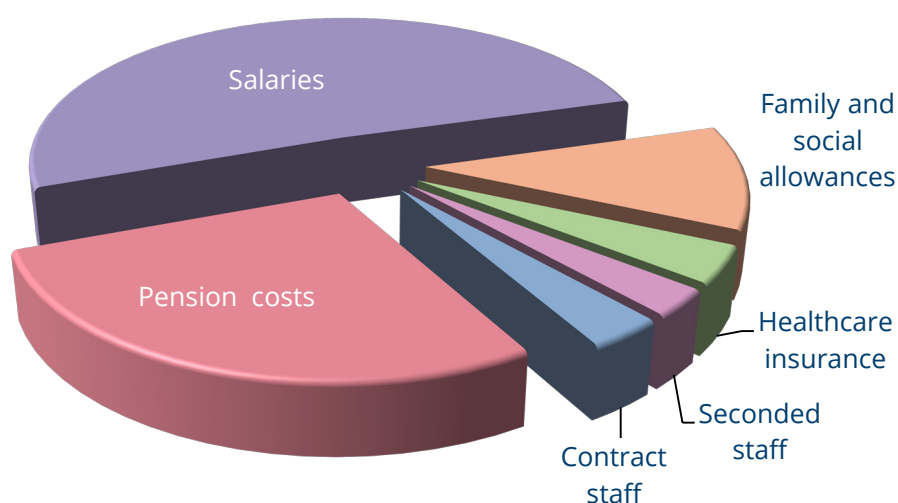
Financial Summary

Revenue and expenditure (2015 to 2019)



in k€	2015	2016	2017	2018	2019
Operating, laboratory and building expenditure	2 027	2 020	2 383	2 794	2 302
Capital spend	1 353	1 458	1 061	1 641	1 184
Contribution to the pension fund	2 400	2 400	2 800	2 550	2 550
Current staff cost	6 256	6 091	6 836	6 468	6 310
Other income	823	561	539	379	547
Subscriptions	790	955	1 116	967	935
Contributions	12 121	12 178	12 178	12 290	12 379

Staff and pension costs

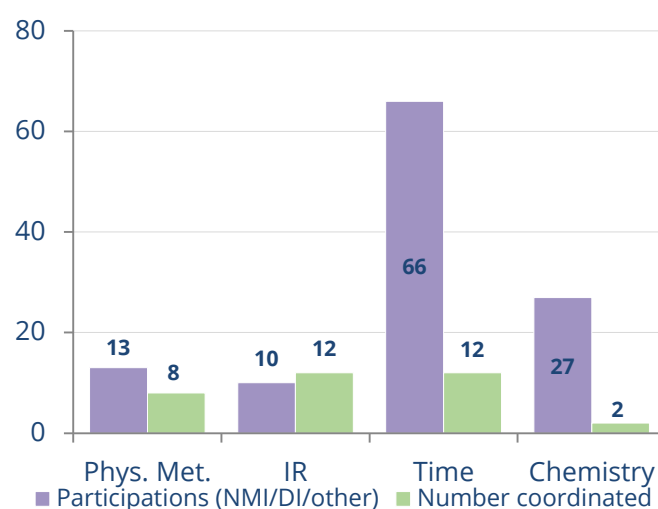
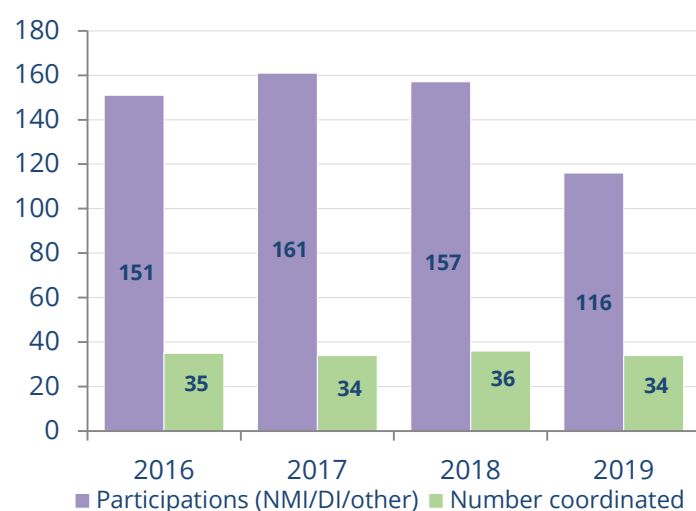


Full details of the financial and administrative situation of the BIPM are available in the *"Financial Report 2019"*

Comparisons and Calibrations

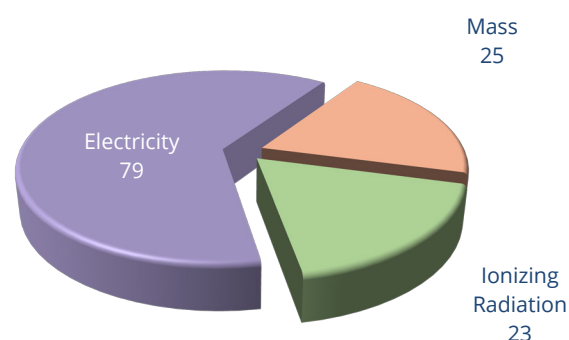
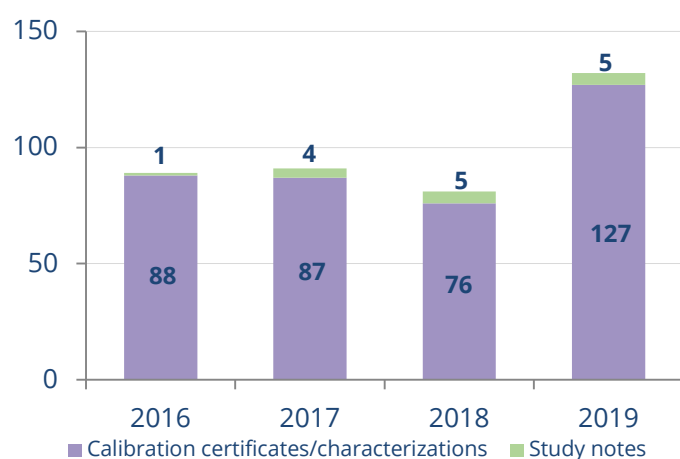
Comparisons coordinated by the BIPM laboratories

2019 – Breakdown by Department



Calibrations and Study Notes from the BIPM laboratories

2019 – Calibrations by metrology area



BIPM organizational structure

The CIPM

President

Dr W. Louw (South Africa)

Secretary

Dr T. Usuda (Japan)

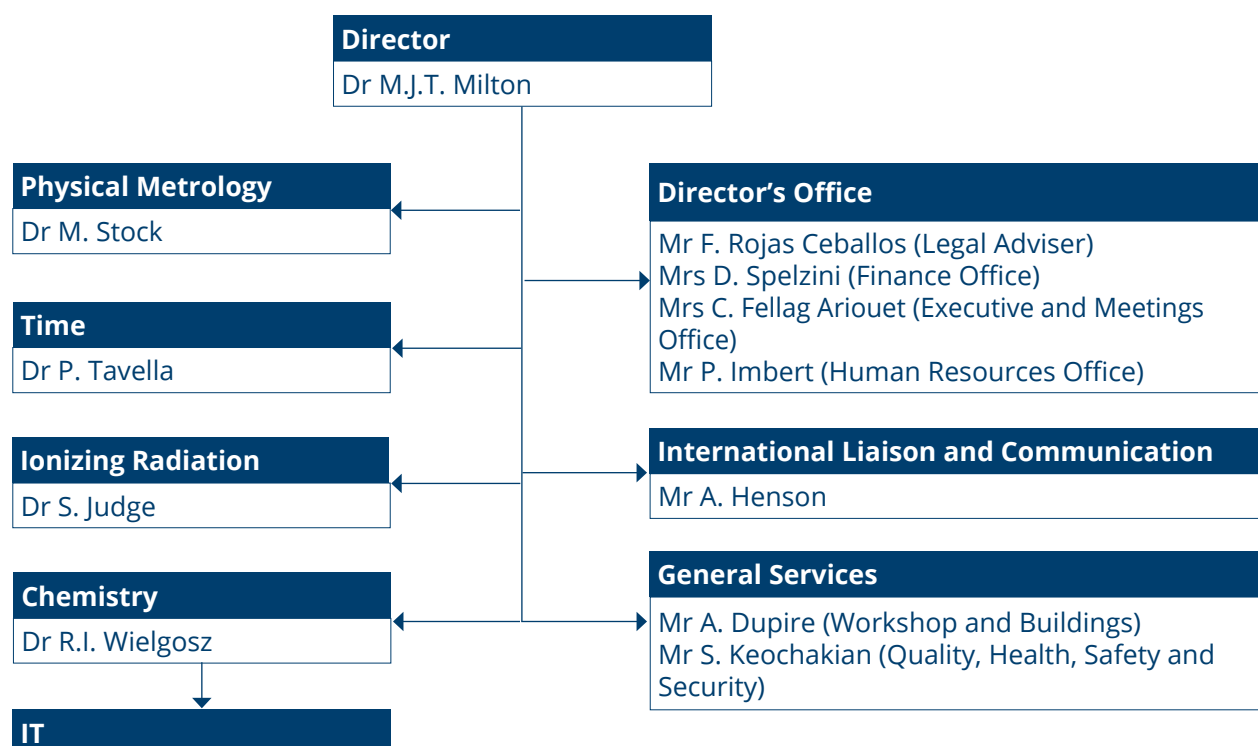
Vice-Presidents

Dr J. Olthoff (United States of America)
Prof. J. Ullrich (Germany)

Other CIPM members

Dr F. Bulygin (Russian Federation)
Dr I. Castelazo (Mexico)
Dr D. del Campo Maldonado (Spain)
Dr Y. Duan (People's Republic of China)
Dr N. Dimarcq (France)
Dr H. Laiz (Argentina)
Dr T. Liew (Singapore)
Prof. P. Neyezhnikov (Ukraine)
Dr S.-R. Park (Republic of Korea)
Dr M.L. Rastello (Italy)
Dr P. Richard (Switzerland)
Dr G. Rietveld (Netherlands)
Dr M. Sené (United Kingdom)
Dr A. Steele (Canada)

The BIPM staff



Publications

1. **Data and analysis for the CODATA 2017 special fundamental constants adjustment**
Metrologia, 2018, **55**(1), 125-146
 Mohr P.J., Newell D.B., Taylor B.N., Tiesinga E.
2. **The revision of the SI – the result of three decades of progress in metrology**
Metrologia, 2019, **56**(2), 022001
 Stock M., Davis R., de Mirandés E., Milton M.
3. **Note on the impact of the redefinition of the kilogram on BIPM mass calibration uncertainties**
https://www.bipm.org/utis/common/pdf/CC/CCM/BIPM_Note-on-kilogram-redefinition.pdf
4. **CCM detailed note on the dissemination process after the redefinition of the kilogram**
https://www.bipm.org/utis/common/pdf/CC/CCM/CCM_Note-on-dissemination-after-redefinition.pdf
5. **Capacitance metrology at the BIPM to support National Metrology Institutes**
Proc. 19th International Congress of Metrology, (2019), 14001
 Moreno J.A., Gournay P.
6. **Bilateral comparison of 10 pF and 100 pF standards (ongoing BIPM key comparisons BIPM.EM-K14.a and 14.b) between the NIMT (Thailand) and the BIPM**
Metrologia, 2019, **56**, Tech. Suppl., 01005
 Gournay P., Homklintian M.
7. **Bilateral comparison of 10 pF and 100 pF standards (ongoing BIPM key comparisons BIPM.EM-K14.a and 14.b) between the SMD (Belgium) and the BIPM**
Metrologia, 2019, **56**, Tech. Suppl., 01012
 Moreno J.A., Gournay P., Vlad D.
8. **Bilateral comparison of 1 Ω and 10 k Ω standards (ongoing BIPM key comparisons BIPM.EM-K13.a and 13.b) between the NIM (The People's Republic of China) and the BIPM**
Metrologia, 2019, **56**, Tech. Suppl., 01011
 Rolland B., Stock M., Yunfeng L., Jianting Z., Qing H.
9. **The analysis of long-term instability of UTC: a case study**
Proc. IEEE IFCS and EFTF Joint meeting. Orlando, Florida, April 2019
 Panfilo G., Harmegnies A., Tavella P., Abgrall M., Rovera D., Bauch A.
10. **Tests of Galileo and BeiDou Links for UTC**
Proc. IEEE IFCS and EFTF Joint Meeting. Orlando, Florida, April 2019
 Petit G., Harmegnies A.
11. **Latest Developments on IPPP Time and Frequency Transfer**
Proc. IEEE IFCS and EFTF Joint Meeting. Orlando, Florida, April 2019
 Leute J., Petit G.
12. **Advanced satellite-based frequency transfer at the 10^{-16} level**
IEEE Trans. UFFC, 2018, 973–978
 Fujieda M., Yang S.-H., Gotoh T., Hwang S.-W., Petit G. et al.
13. **A new test of gravitational redshift using Galileo satellites: The GREAT experiment**
Comptes Rendus Physique, 2019, **20**(3), 176-182
 Delva P., Meynadier F. et al.
14. **New test of Lorentz Invariance Using the Microscope Space Mission**
Phys. Rev. Lett., 2019, 123 231102
 Pihan-le Bars H., Meynadier F. et al.
15. **Gravitational redshift test with the future ACES mission**
Class. Quantum Grav., 2019, **36**(24), 245004
 Savalle E., Meynadier F. et al.
16. **The international reference system for pure β -particle emitting radionuclides: an investigation of the reproducibility of the results**
Metrologia, 2020, **57**(3), 035009
 Coulon R.M., Broda R., Cassette P., Courte S., Jerome S., Judge S., Kossert K., Liu H., Michotte C., Nonis M.
17. **The first official measurement of ^{11}C in the SIRTI**
Appl. Radiat. Isotop., 2019, 154, 108834
 Galea R., Michotte C., Nonis M., Moore K., El Gamal I., Keightley J., Fenwick A.

- 18. Recommendation of a consensus value of the ozone absorption cross-section at 253.65 nm based on a literature review**
Metrologia, 2019, **56**(3), 034001
 Hodges J.T., Viallon J., Brewer P.J., Drouin B.J., Gorshelev V., Janssen C., Lee S., Possolo A., et al.
- 19. CCQM-K137 Final Report** <https://www.bipm.org/kcdb/comparison?id=1511>
- 20. Stability of gaseous volatile organic compounds contained in gas cylinders with different internal wall treatments**
Elem. Sci. Anth., 2019, **7**(1), 28
 Rhoderick G.C., Cecelski C.E., Miller W.R., Worton D.R., Moreno S., Brewer P.J., Viallon J., et al.
- 21. Mass fraction assignment of Amino Acids in acidic aqueous solution (CCQM-K78.a)**
Metrologia, 2019, **56**, Tech. Suppl., 08010
 Westwood S., Josephs R., Choteau T., Daireaux A., Wielgosz R., Melanson J., Thibeault M.-P., et al.
- 22. qNMR Internal Standard Reference Data (ISRD) Dimethyl Terephthalate [ISRD-04]**
Rapport BIPM-2019/01, 24 pp
 Westwood S., Stoppacher N., Martos G., Garrido B., Huang T., Saito T., Ün I., Yamazaki T., Zhang W.
- 23. qNMR Internal Standard Reference Data (ISRD) 3,5-Bis(trifluoromethyl)benzoic Acid [ISRD-05]**
Rapport BIPM-2019/02, 23 pp
 Westwood S., Stoppacher N., Martos G., Garrido B., Huang T., Saito T., Ün I., Yamazaki T., Zhang W.
- 24. qNMR Internal Standard Reference Data (ISRD) 1,4-Bis(trimethylsilyl)benzene [ISRD-06]**
Rapport BIPM-2019/03, 22 pp
 Westwood S., Stoppacher N., Martos G., Garrido B., Huang T., Saito T., Ün I., Yamazaki T., Zhang W.
- 25. qNMR Internal Standard Reference Data (ISRD) 4,4-Dimethyl-4-silapentane-1-sulfonic acid-d6 [ISRD-07]**
Rapport BIPM-2019/04, 23 pp
 Westwood S., Stoppacher N., Martos G., Garrido B., Huang T., Saito T., Ün I., Yamazaki T., Zhang W.
- 26. Development and cross validation of a suite of standards for the purity assignment of organic compounds by quantitative NMR spectroscopy**
Metrologia, 2019, **56**(6), 064001
 Westwood S., Yamazaki T., Huang T., Garrido B., Ün I., Zhang W., Martos G., et al.
- 27. Advanced approaches and applications of qNMR**
Metrologia, 2019, **57**(1), 014004
 Huang T., Li H., Zhang W., Numata M., Mackay L., Warren J., Jiao H., Westwood S., Song D.
- 28. Establishment of measurement traceability for peptide and protein quantification through rigorous purity assessment, a review**
Metrologia, 2019, **56**(4), 044006
 Josephs R.D., Martos G., Li M., Wu L., Melanson J.E., Quaglia M., Beltrão P.J., et al.
- 29. The BIPM Mycotoxin Metrology Capacity Building and Knowledge Transfer Program: Accurate Characterization of a Pure Aflatoxin B1 Material to Avoid Calibration Errors**
J. AOAC Int., 2019, **102**(6), 1740-1748
 Josephs R.D., Li Xiaomin, Li Xiuqin, Guo Z., Garrido B., Ün I., Daireaux A., et al.
- 30. Calibrant Assessment Guideline: Aflatoxin B1**
Rapport BIPM-2019/07, 30 pp
 Martos G., Westwood S., Josephs R., Li X., Guo Z., Wielgosz R.
- 31. Purity Evaluation Guideline: Zearalenone**
Rapport BIPM-2019/06, 36 pp
 Westwood S., Josephs R., Choteau T., Li X., Garrido B., Ün I., Yamazaki T.
- 32. Amount of substance and the mole in the SI**
Metrologia, 2019, **56**(4), 044002
 Güttler B., Bettin H., Brown R.J.C., Davis R.S., Mester Z., Milton M.J.T., Pramann A., Rienitz O., Vocke R.D., Wielgosz R.I.



Pavillon de Breteuil
F-92312 Sèvres Cedex
France
<https://www.bipm.org>



ISBN 978-92-822-2279-9
ISSN 1606-3740