



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.

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Director's introduction

The global effort towards the historic revision of the International System of Units (the SI) gathered pace in 2017. Formal approval to go ahead was granted by the CIPM, which agreed at its meeting on 20 October 2017 to recommend to the General Conference on Weights and Measures (CGPM) that it proceed in 2018 with the expected redefinition of four base units of the SI. The redefinition of these SI base units brings the vision of an International System of Units based on invariant constants a step closer to realization.

The BIPM's activities in the area of capacity building went from strength to strength during 2017, with four courses being sponsored by NMIs during the year. These courses included training and workshops organized jointly with the regions (EURAMET and APMP), which are described on page 11 of this report. In addition, the technical activities under the "Metrology for Safe Food and Feed" and "Metrology for Clean Air" projects, coordinated by the BIPM Chemistry Department, continued to grow with voluntary financial support provided by a number of NMIs.



The BIPM Director, Dr Martin Milton (centre) with the Directors of the BIPM Departments. Left to right: Mr Andy Henson (International Liaison and Communication), Dr Patrizia Tavella (Time), Dr Michael Stock (Physical Metrology), Dr Robert Wielgosz (Chemistry) and Dr Steven Judge (Ionizing Radiation).

Amongst the highlights in the technical work carried out in the BIPM laboratories were: improvements to the experimental set-up for the Kibble balance; the ensemble of reference mass standards becoming fully operational; successful completion of two onsite comparisons of quantum Hall resistance standards; further improvements to TWSTFT and the uncertainty of [UTC-UTC(k)]; upgrading of the algorithm for rapid UTC; extension of the SIR methodology to cover beta-emitting radionuclides; publication of the first Internal Standard Reference Document for qNMR; and validation of the method for measuring isotopic abundances in CO₂ with optically-based instruments.

A total of twenty six visiting scientists participated in the work of the BIPM in 2017. This is a record number and the mutual benefits in terms of knowledge transfer will enrich the work of both the BIPM and the NMIs in the years to come.

A further example of our partnership approach to delivering our work programme is the agreement signed with the CEA-LIST to allow access to the DOSEO platform during 2017. This significant agreement has allowed us to establish a new comparison service for primary standards for high-energy photon radiotherapy, in response to the growing use of accelerators for cancer therapy.

This report includes summaries of the BIPM financial performance, and complements the Rapport Financier and the annual proceedings of the CIPM (both of which are available in French and English). All of these documents can be downloaded from our website together with extended reports of the achievements of each of the BIPM Departments.

Highlights of 2017

- The CIPM agreed at its meeting on 20 October 2017 to recommend to the CGPM that it proceed in 2018 with the expected redefinition of four base units of the SI.
- The 50th anniversary of the adoption of the atomic definition of the second was celebrated by the CCTF.
- A paper has been published which describes how the kilogram will be maintained and disseminated following its redefinition.
- Four Capacity Building and Knowledge Transfer courses were held during 2017.
- The first reference data document on 'Internal Standards for qNMR' was completed for maleic acid, and has been published.
- The BIPM signed an agreement with CEA-LIST for access to the DOSEO platform.

Physical Metrology

The Physical Metrology Department was heavily involved in activities towards a new definition of the kilogram during 2017. The BIPM served as the pilot laboratory for the Consultative Committee for Mass and Related Quantities' (CCM) Pilot Study of future realizations of the kilogram. The first objective of this study was to test the consistency of future realizations of the kilogram based on different Kibble balances and x-ray crystal density (XRCD) experiments. The second objective was to test the continuity between traceability to the present definition (the mass of the International Prototype of the Kilogram, IPK) and to the proposed future definition (the numerical value of the Planck constant). Participants were the LNE (France), the NIST (USA), the NRC (Canada), which used Kibble balances, and the NMIJ (Japan) and the PTB (Germany), which used ^{28}Si spheres from the International Avogadro Coordination. They calibrated 1 kg mass standards using their realization experiments and sent them to the BIPM for comparison. All measurements were carried out during 2016, the final report was published in June 2017 and a paper has been published in the *Metrologia* Focus Issue on the redefinition of the kilogram^[1]. The results of four of the participants agreed within the standard uncertainties and one result agreed within the expanded uncertainty. The weighted mean of the five results has an uncertainty of 10 μg and is in good agreement with the calibration result traceable to the IPK.

The BIPM is participating in a comparison of calibrations of 1 kg stainless steel mass standards (EURAMET.M.M-K4) to link it to the comparison CCM.M-K4, which was organized from 2011 to 2012 by the BIPM. The measurements were carried out at the BIPM during November 2017, and the results are expected in the second half of 2018.

A new 1 kg Pt-Ir prototype has been delivered to the KRISS (Republic of Korea). Four national standards of Pt-Ir and eleven of stainless steel have been calibrated. After the redefinition of the kilogram, the BIPM will continue to provide mass calibrations, which will then be traceable to the reference value obtained through comparisons of primary realizations. The maintenance and dissemination of the kilogram following its redefinition is described in ^[2].

Kibble balance progress

A new experimental set-up for the Kibble balance has been designed and assembled. It includes a more stable suspension, which facilitates coil alignment, and a stiffer mass loading and exchanger system, which will allow a mass of up to 1 kg to be used. The refined experiment is operational in both air and vacuum. It now works with a 1 kg mass and a velocity of 1 mm/s, both of which contribute to improving the signal-to-noise ratio. Two programmable Josephson voltage standards were successfully completed and are now routinely used to calibrate the DVMs. Preliminary measurements show a day-to-day repeatability of several parts in 10^7 . The type B uncertainty of a few parts in 10^7 is still limited by the alignment and the voltage measurement. A detailed study was carried out to evaluate the effect of the coil-current on the magnetic field^[3]. It has been demonstrated that this effect has to be taken into account at the present level of uncertainty exhibited by Kibble balances. Other papers have been published in *Metrologia* on gravitational self-attraction mapping and the permanent magnet system^[4,5].

Ensemble of reference mass standards (ERMS)

The ensemble of reference mass standards (ERMS) is now fully operational, with all mass standards stored in their specific environments: air, nitrogen, argon and vacuum. During the CCM Pilot Study, the mass standards were calibrated against the primary mass standards of the five participating National Metrology Institutes (NMIs).

Maintaining and disseminating the kilogram following its redefinition

The expected adoption of a new definition of the kilogram by the 26th General Conference on Weights and Measures (CGPM) in November 2018 will bring to an end the period during which the kilogram was defined as the mass of a material artefact, the International Prototype of the Kilogram. In the future the kilogram will be defined in terms of the Planck constant, guaranteeing long-term stability of the SI mass unit. The new definition opens the possibility for NMIs to develop their own realization experiments: a Kibble balance or an x-ray crystal density (XRCD) experiment.

To ensure a smooth transition from the present dissemination scheme from one single institute (the BIPM) to the future dissemination scheme from multiple realization experiments, it is planned that dissemination will be internationally coordinated by a task group of the Consultative Committee for Mass and Related Quantities (CCM). This will come into effect after the adoption of the redefinition and during a transition period, which will continue until the robustness of the new approach has been demonstrated. The BIPM, together with co-authors from the CCM, has published a paper^[2] which describes the maintenance and the dissemination of the kilogram following its redefinition.

On-site comparisons of QHR standards

An important achievement in the field of electrical metrology was the organization of two successful on-site comparisons of quantum Hall resistance (QHR) standards, with the CMI (Czech Republic) and the METAS (Switzerland). For these comparisons, the BIPM QHR equipment, including the cryostat with the magnet and the quantum Hall sample, a resistance comparison bridge and thermo-regulated resistors of 1 Ω , 100 Ω and 10 k Ω are transported to the participating institute. The measurands are the value of the 100 Ω resistor, measured using the BIPM's and the NMI's QHR standards and bridges, and the 1:100 ratios between the resistors, measured with the BIPM's and NMI's bridges. The comparison between the BIPM and the CMI showed a very good agreement with relative differences at the level of 1 part in 10^9 and standard uncertainties of 2 to 3 parts in $10^{9[6]}$. The results obtained with METAS remain to be fully analyzed but it is expected that they will show the same level of agreement.

'Star scheme' used in a CCEM comparison for first time

The BIPM is the pilot laboratory for a comparison of 10 pF and 100 pF capacitance calibrations, CCEM-K4.2017. This is the first time a Consultative Committee for Electricity and Magnetism (CCEM) comparison has been organized using the 'star scheme': the seven participating NMIs calibrated a set of four of their own capacitors, sent them to the BIPM for comparison and verified the stability after the return of the standards. This scheme will allow the comparison to be completed much faster and

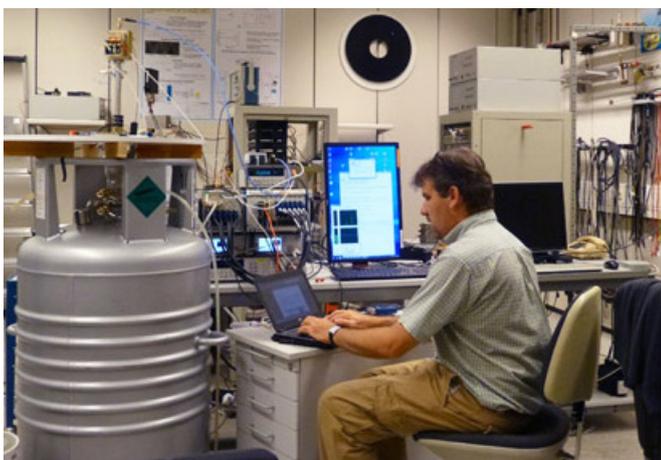
it is more robust against potential transport problems. The comparison measurements at the BIPM are complete and results from all return measurements from the participants have been received.

GULFMET: first comparisons in the field of electricity

The BIPM is supporting one of the first comparisons by GULFMET in the field of electricity; a comparison of Zener voltage standards, GULFMET.EM.BIPM-K11. The BIPM participates in the measurements to link this comparison to the BIPM series of comparisons BIPM.EM-K11, and determines the temperature and pressure correction coefficients of the travelling standards. Before the start of this comparison, the organizer, Dr Steven Yang from the SCL (Hong Kong (China)) was seconded to the BIPM for two months to share experience on the calibration of Zener standards using Josephson voltage standards. To underpin the uncertainties of the department's Zener voltage comparisons and calibrations the temperature and pressure coefficients of the BIPM standards have been re-evaluated for the first time in 15 years. It is believed that this is the only long-term study of the evolution of these important correction coefficients. Changes of some of the temperature coefficients have been observed, whereas the pressure coefficients have remained stable.

In addition to its comparison programme for electrical quantities, the department provided about 70 calibrations to NMIs in the field of resistance, capacitance and voltage.

BIPM develops AC Josephson voltage standards



Stéphane Solve (BIPM) operating the BIPM AC travelling quantum voltage standard in the PTB laboratories (Braunschweig).

Over the last decade, considerable research on AC quantum voltage references has been carried out by NMIs to meet growing demand for applied AC measurements in industry and scientific research.

The BIPM is contributing to these objectives by using its own transportable AC Josephson Voltage Standard (JVS), supplied by the NIST, to develop a comparison protocol for a future series of BIPM on-site comparisons. Over a two-week period in August 2017, the BIPM collaborated with the PTB (Germany), in an on-site measurement campaign. The BIPM transportable quantum voltage standard (QVS) was compared to the PTB AC QVS using an AC signal generator as a transfer standard.



Time

Improvements in TWSTFT

The department's work on two-way time and frequency transfer (TWSTFT) has opened the possibility of incorporating software defined radio (SDR) receivers at most of the earth stations operated by 13 UTC contributing laboratories in North America, Europe and Asia. This is the result of the BIPM's coordination work within the Consultative Committee for Time and Frequency (CCTF) Working Group on Two-Way Satellite Time and Frequency Transfer (WGTWSTFT). The Time Department developed the strategy for the exploitation of the new data, and led a pilot experiment, which ran throughout the year and concluded with the validation of the technique and the implementation of two links in UTC since November 2017. It was demonstrated that additional noise, with a diurnal signature, increasing the typical small noise of TW links can be significantly reduced by using the SDR.

Validation of BeiDou time transfer for UTC

Work is under way to validate the use of BeiDou time transfer in UTC as part of a cooperative agreement between the BIPM and the NIM (China). The experiment involved the BIPM and seven institutes distributed throughout the world. It included studies over multiple-length baselines and the absolute calibration of BeiDou receivers. The knowledge gained from the pilot experiments will be used to develop calibration capacities at the BIPM and NIM. The pilot work is an important first step towards implementing multi-system time comparisons in UTC. A 30-day GPS-BeiDou comparison over the NIM-BIPM baseline found that time differences computed with BeiDou are consistent with those from GPS.

Improving the uncertainty of [UTC-UTC(k)]

Further improvements in the uncertainty of [UTC-UTC(k)] will require optimization of the underlying algorithm. The current uncertainty values, as published in *Circular T*, strongly depend on the time link uncertainties. Each time link connects a contributing laboratory to the PTB, which acts as the pivot. At present, no correlations are accounted for in the uncertainty propagation algorithm. The algorithm for the calculation of the uncertainties of [UTC-UTC(k)] has been refined to take the correlations in uncertainty propagation into account. The algorithm was validated by the CCTF in June 2017 and the first stage of its implementation is scheduled for early 2018.

BIPM Circular T

BIPM *Circular T* continues to be published monthly, giving traceability to the SI second via UTC to its local realizations in national laboratories. It is the most frequent key comparison, with one evaluation of the key comparison reference value UTC and the degrees of equivalence [UTC - UTC(k)] every five days for the 77 participants that together contributed data from about 500 atomic clocks in 2017.

Upgraded algorithm for rapid UTC

The algorithm for the computation of rapid UTC (UTC_r) has been upgraded and made fully consistent with that of UTC. This upgrade contributed to making UTC_r a more reliable tool to help institutes check the steering of their local UTC realizations as well as the steering of the Global Navigation Satellite Systems' times to local representations of UTC. Regular publication of rapid UTC (UTC_r) continued in 2017.

50th anniversary of the adoption of the atomic definition of the second^[7]

13 October 2017 marked the 50th anniversary of the adoption of the atomic definition of the second by the CGPM in 1967. The CGPM adopted a definition of the SI second in terms of the measured period of a specified transition of the caesium 133 atom as the precision and stability of caesium frequency standards had been proven to be superior to what was available from astronomical observations. The atomic definition replaced the Ephemeris second, which had been adopted by the CGPM in 1960.

The CCTF celebrated the anniversary by inviting Dr Dennis McCarthy to its 2017 meeting to give a lecture on the history of the second. Dr McCarthy is a former Director of the Directorate of Time at the United States Naval Observatory (USNO) and former President of the International Astronomical Union (IAU) commissions on Rotation of the Earth and Time.

Time Department CBKT initiative

The Time Department organized a training course within the framework of the BIPM CBKT programme on "Effective participation in UTC". The course was supported by METAS and took place in February 2018. About twenty institutes participated and the course was open to RMO technical chairpersons in the time and frequency field. The aim of the course was to transfer knowledge on how to work effectively with receivers and equipment during a calibration campaign.

Ionizing Radiation

The BIPM has established a new comparison service for primary standards for high-energy photon radiotherapy, in response to the growing use of accelerators for cancer therapy. The service has been set up at the DOSEO facility, a specialist radiotherapy and medical imaging research centre at Gif-sur-Yvette, France. The beam has been characterized in terms of absorbed dose rate to water using the BIPM primary standard and NMI standards for absorbed dose to water can now be compared with the BIPM standard at this facility (BIPM.RI(1)-K6). The first such comparison took place with the KRISS in November 2017 and the results are expected to be published in 2018.



Susanne Picard and Philippe Roger in the DOSEO laboratory

High-energy photon beams are used to treat cancers deep in the body; lower energy x-rays (100 kV to 250 kV) are used to treat tumours located in the first few cm of tissue. A number of NMIs use water calorimeter standards to determine absorbed dose to water in this lower energy range and there is a growing need for comparisons of these standards. The BIPM has therefore developed an ionometric primary standard to provide a robust and stable long-term reference for x-rays. The standard will be used to make indirect comparisons of NMI standards through the calibration of waterproof transfer chambers in a water phantom; the standard is based on the free-air chamber standard for air kerma and the method uses transfer ionization chambers and detailed Monte Carlo simulations to convert from air kerma to absorbed dose to water. A calibration service for national secondary standards is also provided. By using this method rather than existing protocols, the uncertainty of the reference absorbed dose rate in the clinic is reduced from around 3 % to 0.7 %.

Thirteen dosimetry comparisons were undertaken by the Ionizing Radiation Department during 2017 and thirty six calibrations of national secondary dosimetry standards were carried out for nine NMIs and the International Atomic Energy Agency (IAEA). In addition, Dr David Burns co-authored a text book to replace one of the major texts in the field of ionizing radiation dosimetry^[8].

The BIPM's agreement with CEA-LIST for access to the DOSEO platform

The agreement between the BIPM and the *Commissariat à l'énergie atomique et aux énergies alternatives* (CEA LIST Institute), will allow the BIPM to operate the ongoing BIPM.RI(1)-K6 comparison for high-energy photon beams at the DOSEO platform for research and development in radiotherapy and imaging technologies.

The DOSEO platform is located at the Paris-Saclay CEA site, and the BIPM has been granted access to use the accelerator facilities for up to 8 weeks per year. This agreement enables the BIPM to use the same stationary reference accelerator beam to define and determine their own conditions for reference dosimetry for any NMI that participates in high-energy photon dosimetry comparisons. The agreement has the added advantage that it will allow national secondary standards to obtain direct D_w (absorbed dose to water) traceability to the BIPM in this field.

Radionuclide metrology

The cornerstone of the BIPM's work in radionuclide metrology is high-stability ionization chambers - the '*Système International de Référence* (SIR)', which now covers 70 radionuclides. Samples of eleven different radionuclides were received for measurement during 2017 and updates to Key Comparison Reference Values for eight radionuclides were agreed by the Consultative Committee for Ionizing Radiation (CCRI). A transportable version of the SIR (SIRTI) was used for comparisons of short-lived radionuclides: ^{99m}Tc , ^{18}F , ^{64}Cu and ^{11}C at the NRC and ^{99m}Tc , ^{18}F and ^{64}Cu at ANSTO (Australia). The comparison of ^{11}C was the first time that this radionuclide had been measured on the SIRTI.

The use of beta- and alpha-emitting radionuclides is expanding in radio-immunotherapy. Work has therefore continued on extending the SIR methodology to cover beta-emitting radionuclides; extensive validation studies were carried out on a possible technique, in collaboration with NIST and NIM (China). This work will continue in 2018, with the establishment of a similar system for alpha-emitters to follow.

Chemistry

The Chemistry Department ran four comparisons in 2017, involving ninety three participations in these studies by NMIs. Seven comparison reports were published as well as five papers in peer reviewed journals. A total of twenty visiting scientists from NMIs (on secondment to the BIPM from between three to eighteen months) participated in the Chemistry Department Programme in 2017, of which twelve undertook Capacity Building and Knowledge Transfer (CBKT) programme secondments either in "Metrology for Clean Air" or "Safe Food and Feed" projects, spending between 3 months and 1 year at the BIPM.

Small organic primary calibrator comparison programme

The final report of the CCQM-K55.d comparison on folic acid purity was approved by the CCQM Working Group on Organic Analysis (OAWG). Measurements for the CCQM-K78.a comparison on multi-component amino acid calibration solutions were completed, and the results presented to the working group, with the Draft A report in preparation. The BIPM submitted results to the CCQM-P150.b comparison on qNMR, as well as completing characterization of samples and their homogeneity and stability for the CCQM-K148.a comparison (bisphenol A calibrator purity).

First Internal Standard Reference Document for qNMR published

The first reference data document on 'Internal Standards

for qNMR' was completed for maleic acid, and has been published on the BIPM website^[9]. This was an output of the universal calibrator programme for qNMR at the BIPM; an activity initiated together with the NMIJ (Japan), and supported in 2017 by secondees from the NMIJ, and INMETRO (Brazil), with characterization of the performance of four standards in three different solvents undertaken in 2017.

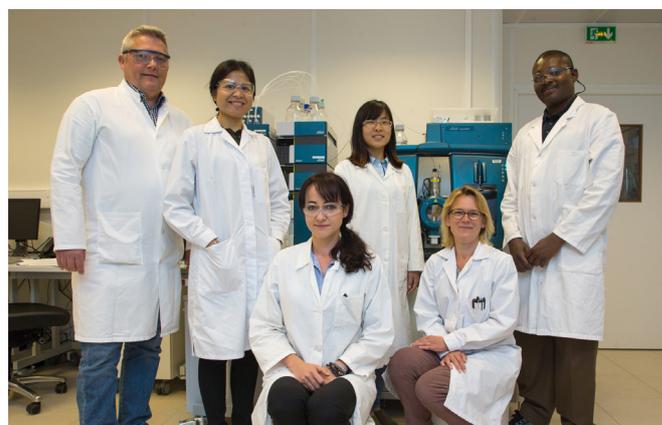
Comparability of primary standards for peptide and protein analysis

The final reports of the key comparison and associated pilot study on C-peptide purity (CCQM-K115/P55.2) were published in *Metrologia* and the BIPM KCDB. A paper on the evolving calibration hierarchies for C-peptide measurements was published in *Clinical Chemistry*^[10]. Preparative work for the next comparison of peptide calibrant value assignment facilities, focusing on oxytocin (CCQM-K155.b) in collaboration with NIM (China) has continued with the secondment of a visiting scientist from NIM. Methods for pure peptide characterization to be used in future comparisons have been studied during secondments by visiting scientists from the LGC (UK), studying BNP calibrators, and from the NIBSC (UK) studying short-peptide tryptic digest calibrators. The methods used to characterize pure peptide calibrators were published in *Analytical and Bioanalytical Chemistry*^[11], *Journal of Chemical Metrology*^[12] and *Trends in Analytical Chemistry*^[13].

Metrology for "Safe Food and Feed" Knowledge Transfer secondments at the BIPM

The BIPM Chemistry Department hosted five secondees during 2017 who took part in a series of three-month-long "Knowledge Transfer" secondments for scientists from NMIs wishing to develop mycotoxin metrology capabilities. The secondees from INMETRO, INTI (Argentina), KEBS (Kenya), NIMT (Thailand) and NMISA (South Africa) received training on the production of mycotoxin calibration solutions, characterization and value assignment. The training programme was performed on the mycotoxin zearalenone (ZEN). Pure materials for aflatoxin B1 and have also been characterized, and are available for future training programmes and comparisons. The secondments were part of the Mycotoxin Metrology CBKT project. The PTB (Germany) provided financial support for the secondments from INTI, INMETRO, KEBS and NIMT.

The laboratory programme on Mycotoxin Standards was supported by three visiting scientist from the NIM (for related structure impurity analysis and calibration solution characterization) and from UME (Turkey) and INMETRO in the area of qNMR analysis of pure mycotoxin materials.



Left to right: Ralf Josephs (BIPM), Sornkrit Marbumrung (NIMT), Desiree Prevo (NMISA), Xiaomin Li (NIM), Adeline Daireaux (BIPM) and Isaac Mugenya (KEBS) in the mass spectroscopy laboratory.

Air quality measurement standard comparisons

The BIPM continued to contribute to the CCQM GAWG Ozone Cross Section Task Group, organizing the review of input data by the group and drafting of the first version of the paper summarizing the recommended best value and uncertainty for the ozone cross-section to be used in the key comparison BIPM.QM-K1. Six NMIs: VSL (the Netherlands), NPL, ISCII (Spain), INE (Mexico), NIST and CHMI (Czech Republic) sent their ozone standards to the BIPM and participated in BIPM.QM-K1, with four reports of the comparison published in *Metrologia* and the BIPM KCDB. Collaboration with the NIST on the upgrade of the electronic module for the ozone SRP continued, with a prototype electronics module successfully constructed and tested at the BIPM, and the components and design for the final version agreed. The final report of the CCQM-K90 comparison on formaldehyde in nitrogen standards at 2 $\mu\text{mol/mol}$ was completed and published in *Metrologia* and the BIPM KCDB. Measurements on 24 standards from NMIs submitted to the BIPM as part of CCQM-K137 (NO in N_2 at 30 $\mu\text{mol/mol}$ and 70 $\mu\text{mol/mol}$) were completed, with standards returned to participating NMIs for stability assessment. The protocols for the comparison of NO_2 in N_2 standards at 10 $\mu\text{mol/mol}$ (CCQM-K74.2018) and the pilot study of HNO_3 measurements in such standards (CCQM-P172) were agreed with the CCQM Working Group on Gas Analysis (GAWG), with 14 NMIs electing to participate in the comparisons.

Greenhouse gas standard comparisons

Measurements on 46 standards of CO_2 in air submitted for the CCQM K120 comparison were completed at the BIPM, including Fourier transform infrared spectroscopy (FTIR), isotope ratio infrared spectrometer (IRIS) and gas chromatography with a flame ionization detector (GC FID) methods for mole fraction and isotope ratio value assignment. The Draft A report of the comparison has been prepared. The method developed for measuring isotopic abundances in CO_2 with optically-based instruments was published in *Analytical Chemistry*^[14], and presented to the WMO-IAEA GGMT experts meeting in Switzerland in September 2017. This demonstrated the measurement standards and methods that could be used for such instruments in the future. Development and validation of a manometric system for CO_2 measurements, in support of a future planned ongoing comparison of CO_2 standards (BIPM.QM-K2), has progressed with a second secondment from the NIST. The first all-glass prototype was replaced with a coated stainless steel version, with much improved mechanical stability. The measurement protocol was optimized, including the identification and elimination of biases caused by trace gases within the system: new results are expected in early 2018. Preparation for a comparison on CO_2 isotope ratio standards, coordinated jointly by the BIPM and the IAEA continued, with an IRIS

Metrology for Clean Air CBKT project

Three visiting scientists have now taken part in the Metrology for Clean Air Course on FTIR Measurements on Gas Standards (NO_2 , HCHO , HNO_3 , CO_2) in the BIPM laboratories. They were trained on the use of B-FOS software for use with Fourier Transform Infrared spectroscopy (FTIR) in gas metrology applications, with the software being made available for use within the participating NMIs.

The National Physical Laboratory (NPL), UK, has provided additional sponsorship for the programme, enabling three visiting scientists to undertake six-month knowledge transfer secondments at the BIPM during 2017-2019 as well as providing sets of primary reference gas mixtures for each institute involved in the programme.

The project is designed to allow NMIs to strengthen their gas standard capabilities and further develop their national metrology infrastructure in support of their air quality and emissions measurement communities. Within the project the BIPM provides knowledge transfer on the establishment and operation of FTIR capabilities for the value assignment and comparison of gas standards for air quality and emissions monitoring.



Edgar Flores (BIPM), R.S. Radha (NPL) and Michael Ward (NPL) setting up the FTIR for accurate measurements of NO_x gases

system for isotope ratio measurements integrated into the SIRM-GEN facility and the first blending experiments for CO_2 gases have been carried out. Validation work on optical tuneable diode laser spectroscopy (TDLs) and gas chromatography with electron capture detection (GC-ECD) systems, in preparation for CCQM-K68.2019 (N_2O in air, ambient level), were undertaken during a three month secondment by a visiting scientist from KRISS, with linearity and measurement uncertainty of the optical instrument being verified.

International Liaison and Communication

The strategic aims of the BIPM’s recently agreed liaison with the Organisation for Economic Cooperation and Development (OECD) are to have the world metrology system activities and structures recognized as a critical part of the quality infrastructure (QI), and to have that QI recognized as vital to the OECD mission. The liaison offers the opportunity to work within the OECD “Partnership for effective international rule-making” which assembles 45 participating international organizations, plus an additional eight observer organizations, to effectively disseminate information about metrology in the QI context. The BIPM is now listed among the organizations used to underpin the OECD’s regulatory initiative and staff from the BIPM International Liaison and Communication (ILC) Department participate in Working Groups of the Partnership.

BIPM staff continue to work within the DCMAS Network, which brings together specialized organizations that operate at an international level and are active in promoting and implementing activities on metrology, accreditation, standardization and conformity assessment as tools for sustainable economic development. The network (BIPM, IAF, ILAC, IEC, ISO, ITC, ITU, OIML, UNECE and UNIDO¹), together with the World Bank, agreed a common definition for the term ‘Quality Infrastructure’, which was formally adopted in June 2017. This seemingly simple step required significant discussion and debate. Having a common definition greatly enhances the ability of BIPM staff to play an advocacy role for metrology, for example through the OECD initiatives described above. The DCMAS Network is considering a possible change of name to better reflect the agreed QI definition.

Following a three-year revision by ISO CASCO Working Group 44, the third edition of the international standard

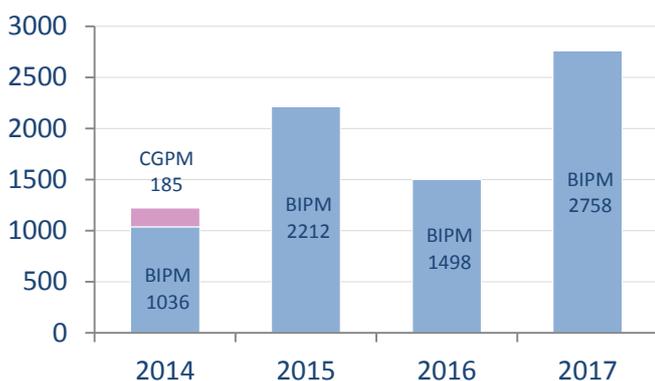
ISO/IEC 17025:2017, “General requirements for the competence of testing and calibration laboratories” was published in November 2017. The ILC Department Director participated in WG 44 and the WG core drafting team on the revision and the BIPM has welcomed the publication. A transition plan is in place to ensure the revised standard is understood by the BIPM staff and is effectively implemented.

A brochure “The role of metrology in the context of the 2030 Sustainable Development Goals” was published in 2017 as a result of a strategic partnership between the staff of UNIDO, BIPM and OIML. The brochure, which was largely written by the BIPM, highlights the contribution of metrology to the implementation of the 2030 Agenda for Sustainable Development. The brochure is one of a series published by UNIDO covering the key QI elements of metrology, documentary standards and laboratory accreditation. The partnership enables these international organizations to cooperate in mutually supportive areas of operation, in order to enhance the impact of industrial development on economic growth.

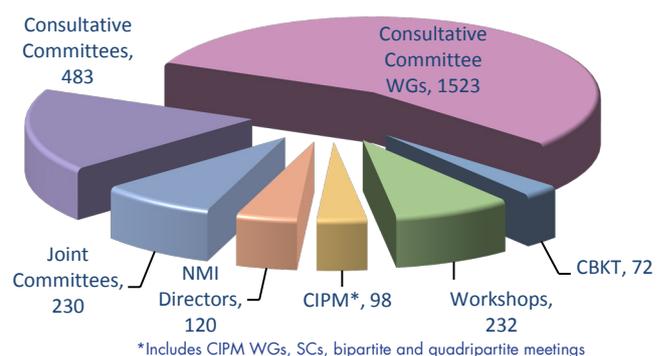
The BIPM was fully engaged with the World Trade Organization (WTO) during 2017, with a member of the ILC staff participating in all three formal meetings of the Technical Barriers to Trade (TBT) Committee. In addition, ILC staff presented at the WTO Round Table on National Quality Infrastructure for the Chinese trade delegation (alongside other QI IOs) and shared the BIPM’s experience in capacity building with trade negotiators, regulators, national enquiry points and representatives from the various ministries of foreign affairs as well as the many WTO member state representatives in the Technical Assistance session of the Advanced Thematic course on the TBT Agreement.

Meetings

Attendance at meetings hosted at the BIPM



Meeting attendance at the BIPM 2017



¹International Accreditation Forum (IAF), International Laboratory Accreditation Cooperation (ILAC), International Electrotechnical Commission (IEC), International Organisation for Standardisation (ISO), International Trade Centre (ITC), International Telecommunications Union (ITU), International Organization of Legal Metrology (OIML), United Nations Economic Commission for Europe (UNECE) and United Nations International Development Organisation (UNIDO).

Capacity Building and Knowledge Transfer

The BIPM Capacity Building and Knowledge Transfer (CBKT) programme continues to go from strength to strength. In addition to the initiatives outlined in the departmental sections, a range of courses were run at the BIPM and in association with the RMOs throughout 2017. As a measure of the popularity and success of the CBKT programme, all of the courses organized so far have been heavily oversubscribed.

BIPM-EURAMET "TC Leadership" course

7 to 10 February 2017 at the BIPM

Eighteen participants from 12 member countries of the European Association of National Metrology Institutes (EURAMET) successfully completed the joint course. The training will enable them to become involved more effectively in the CIPM MRA. It will also allow them to make valuable personal contributions in their prospective future roles as Technical Committee (TC) Chairs or in support of existing Chairs in CIPM MRA related matters.

"This was the first joint training course organized by BIPM and EURAMET, and I am convinced that it is very beneficial for both organizations and the participants. I think we achieved our aim to prepare possible future TC leaders for their responsibilities within the CIPM MRA, giving them a sound understanding of its structure and mechanisms which is the basis to do the job effectively."

Wolfgang Schmid, EURAMET's Member Service Manager

EURAMET-BIPM Training on review of quality management systems 7 to 8 November 2017 at INTI (Spain)

Twenty three participants from 12 countries took part in the course, with guests from COOMET and GULFMET also attending. The joint training focused on the processes related to evaluation of quality systems and peer-review of NMI/DI technical capabilities within the framework of the CIPM MRA. Participants reviewed quality management systems in the scope of the CIPM MRA, with additional focus on EURAMET specifics of the peer review process and requirements for reviewers.

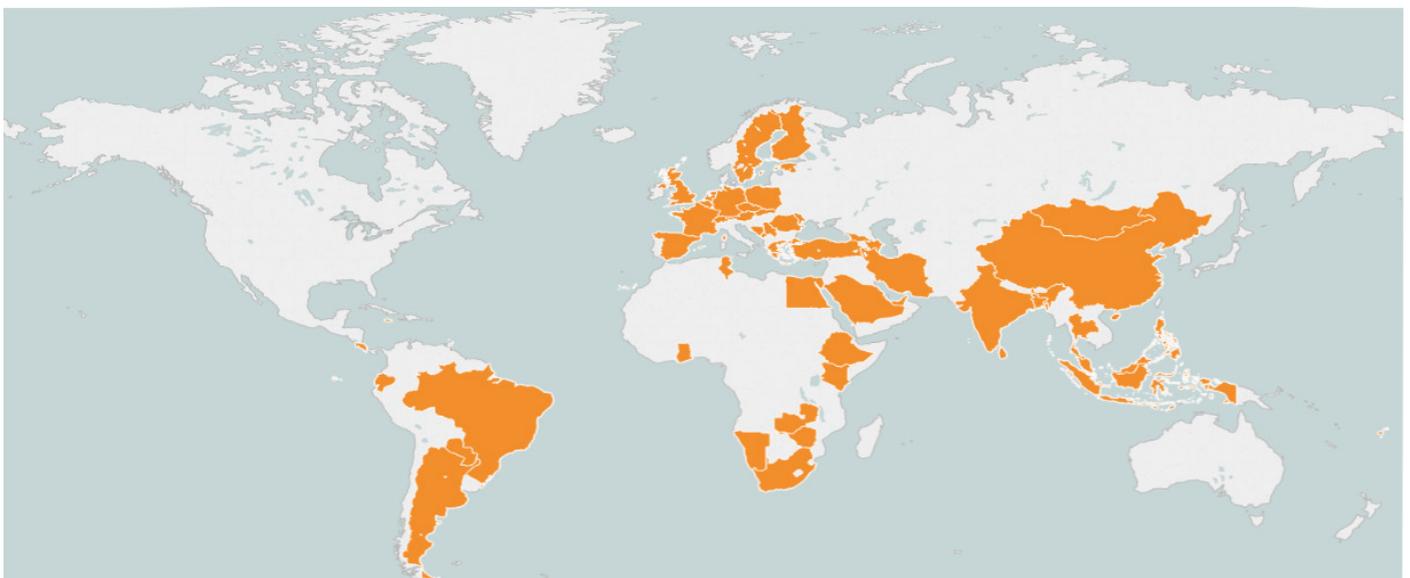
Sound beginnings in the CIPM MRA 13 to 24 November 2017 at the BIPM

Twenty four participants from 20 countries took part in the two-week capacity building course, which was organized by the BIPM and sponsored by NIST (USA). The lecturers were drawn from leading NMIs and the BIPM. Candidates were selected from NMIs that are new to, or inexperienced in, the CIPM MRA processes and the knowledge that they gained will accelerate the international recognition of their NMI's CMCs, making the task of reviewing CMCs more equitable.

APMP-DEC Leadership Training 4 to 8 December 2017 at the NIMT (Thailand)

The Asia Pacific Metrology Programme (APMP) organized a joint initiative with the BIPM in support of the APMP Developing Economies' Committee (APMP-DEC) and Metrology-Enabling Developing Economies in Asia (MEDEA) project. The course was designed to meet the specific needs of APMP's developing NMIs and provided participants with a better understanding of the global quality infrastructure, particularly the role of international organizations.

Countries that benefited from CBKT courses in 2017



The CIPM MRA

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) Calibration and Measurement Capabilities (CMCs) of the participating institutes. Approved CMCs and supporting technical data are publicly available from the BIPM key comparison database (the KCDB). After almost two decades of successful operation, the CIPM MRA is being reviewed to ensure its sustainability for the future. The Working Group on the Implementation and Operation of the CIPM MRA recommended that the KCDB be revised and the specifications for this revision were drafted in 2017. Development of the revised KCDB is in progress: a collaborative web platform for editing and reviewing CMCs as well as extended search facilities are planned.

An up-to-date list of CIPM MRA participants can be found at:
www.bipm.org/en/cipm-mra/participation/signatories.html

Key and supplementary comparisons

In December 2017, the key and supplementary comparisons database included 989 key comparisons and 529 supplementary comparisons. This represents an increase of 25 key comparisons, while supplementary comparisons increased by 38. Around 100 comparisons were completed and published during 2017. Today, almost 90 % of the 89 ongoing BIPM key comparisons and around 70 % of all registered comparisons of the Consultative Committees and RMOs have published results 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.

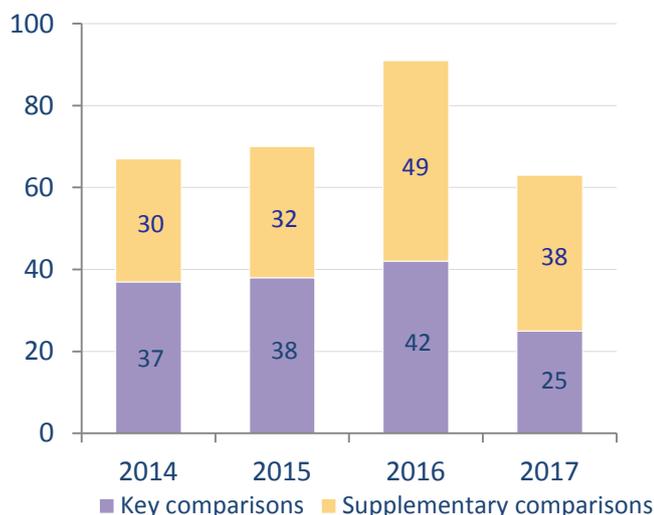
The KCDB currently includes a dozen examples where more than seven key comparisons are linked together.

Calibration and Measurement Capabilities

On 31 December 2017, there were 24965 CMCs registered in the KCDB. Of these, 14662 were in the field of general physics, 4101 in ionizing radiation, and 6202 in chemistry. The total number of CMCs increased by 65 during 2017. Hence the number of CMCs appears to have flattened out since two years ago. Only 22 of the 42 Associates that participate in the CIPM MRA had CMCs published in the KCDB at the end of 2017.

It is possible to temporarily withdraw CMCs from the database – “greying out”. At the end of 2017, 248 CMCs were “greyed out”, a slight increase from 2016. Only 12 were definitively deleted from the KCDB in 2017, either on request from the corresponding NMI, or due to the lack of a QMS. Both these numbers are negligible 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



Revision of the SI



Momentum is building towards the historic revision of the International System of Units (the SI), which is expected to be approved at the 26th General Conference on Weights and Measures (CGPM) in Versailles in November 2018. The revision will mark the culmination of many years of work by the international metrology community. Formal approval to go ahead was granted by the CIPM, which agreed at its meeting on 20 October 2017 to recommend to the CGPM that it proceed in 2018 with the expected redefinition of four base units of the SI.

In January 2018, the CIPM Task Group for Promotion of the SI met at the BIPM to continue its work to identify and develop key tools to support all Member States to promote the revised SI among a wide range of audiences. The messages and tools that the Task Group develops will be made available for Member States to use and will be shared through its dedicated web page.

The changes to the SI will base it on a set of definitions each linked to the laws of physics, thus eliminating the final link between the SI and definitions based on physical artefacts. Following the revisions, the kilogram will be linked to the exact value of the Planck constant rather than the International Prototype of the Kilogram, as sanctioned by the 1st CGPM in 1889. The values of the constants that will be used to redefine the SI have been published in *Metrologia*. Many important results were submitted to *Metrologia* ahead of the 1 July 2017 deadline set by the CIPM for new experimental results to be received

and accepted for publication. This was in order for them to be considered in the special 2017 adjustment of the fundamental constants. The CODATA Task Group on Fundamental Constants carried out the special least-squares adjustment requested by the 24th CGPM (2011), and the results were published on schedule. (See: Decision CIPM/2017-10 and The CODATA 2017 values of h , e , k , and N_A for the revision of the SI^[15]).

"The decision by the CIPM to propose a resolution to the 26th CGPM on the redefinition of the base units in the SI brings the vision of an International System of Units based on invariant constants of nature one step closer to realization. In taking this decision, the CIPM acknowledges the outstanding contributions by many metrologists and the commitments of their institutes to undertake the long-term experiments necessary to make this decision possible."

Dr Barry Inglis, President of the CIPM

The BIPM organized a scientific symposium *"The fundamental constants of physics: what are they and what is their role in redefining the SI"* on 7 September 2017, under the auspices of the Consultative Committee for Units (CCU). The symposium celebrated the work accomplished towards the proposed revision of the SI and included a distinguished line-up of invited speakers who gave the following lectures:

- Dr Gilles Cohen-Tannoudji
Lambda, the fifth fundamental constant considered by Einstein.
- Prof. Klaus von Klitzing (Nobel laureate)
The quantum Hall effect and the new SI.
- Prof. Jean Marc Lévy-Leblond
Variations on the Planck constant.
- Dr Terry Quinn (Emeritus Director, BIPM)
From Artefacts to Atoms – at last!
- Dr Jean-Philippe Uzan
Fundamental constants, gravitation and cosmology.
- Prof. Gabriele Veneziano
Fundamental strings and fundamental constants.

Keep up to date with the revision of the SI...

The SI is not static but evolves to match the increasingly demanding requirements for measurements globally. The latest information about the revision of the SI can be found on the BIPM website:

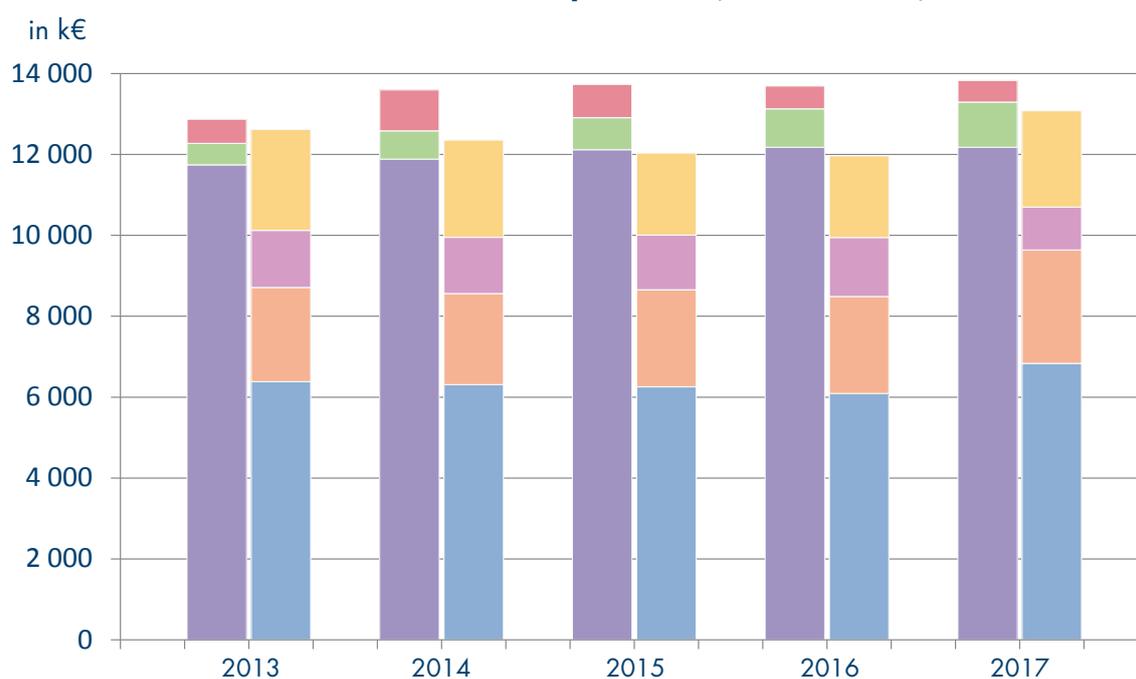
www.bipm.org/en/measurement-units/new-si/

Financial Summary

Key financial points

- Income followed forecast with no change in Member States or Associate States during 2017. Sponsorship from NMLs for activities in the CBKT programme increased to 230 k€ (160 k€ in 2016).
- Staff costs remained constant on a like-for-like basis. The cost of secondments increased as a result of the strategy of encouraging greater external participation in BIPM's laboratory programme. A one-off lump sum payment of 400 k€ was made to the Pension Fund.
- Other operating costs increased by 363 k€ due to increased numbers of participants in meetings at the BIPM, the fee for use of the DOSEO facility and an increase in the cost of electricity.
- Investment activity remains constant although spend was behind the plan for 2017 because of the late delivery of a specialized mass spectrometer. Two large software/website renewal projects are underway for completion in 2018 and 2019.

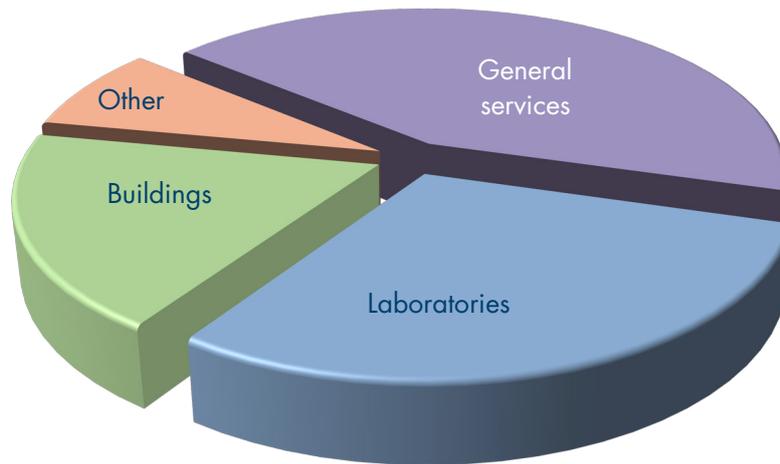
Revenue and expenditure (2013 to 2017)



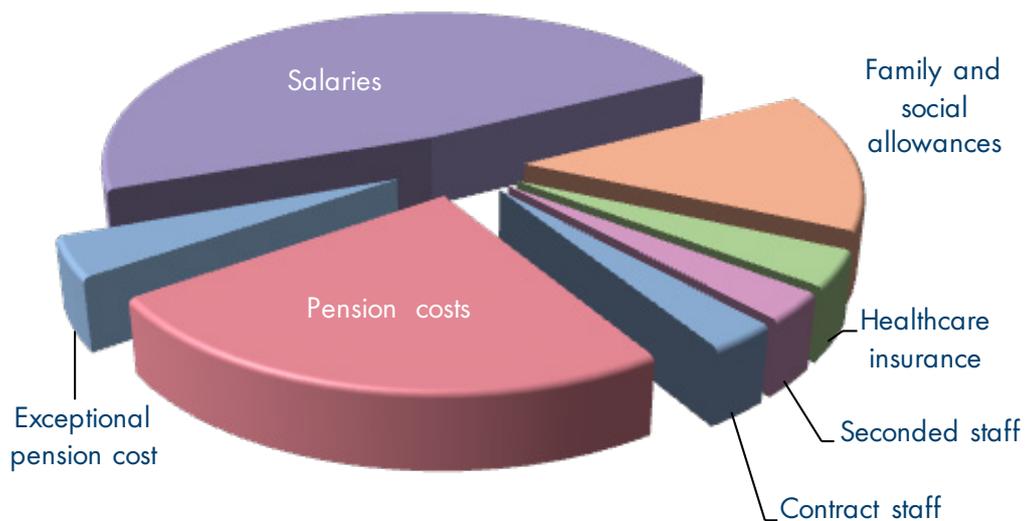
in k€	2013	2014	2015	2016	2017
Operating, laboratory and building expenditure	2 496	2 405	2 027	2 020	2 383
Capital spend	1 411	1 394	1 353	1 458	1 061
Contribution to the pension fund	2 329	2 251	2 400	2 400	2 800
Current staff cost	6 382	6 309	6 256	6 091	6 836
Other income	598	1 009	823	561	539
Subscriptions	530	702	790	955	1 116
Contributions	11 744	11 885	12 121	12 178	12 178

Financial Summary

Operating expenses



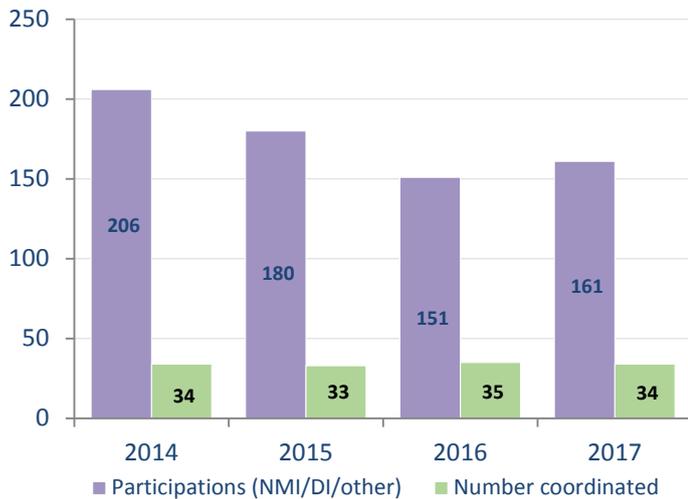
Staff costs



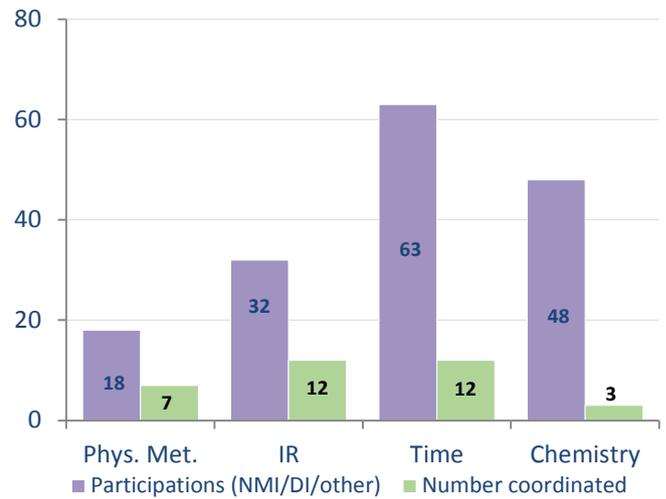
Comparisons and Calibrations

Comparisons coordinated by the BIPM

2014 – 2017



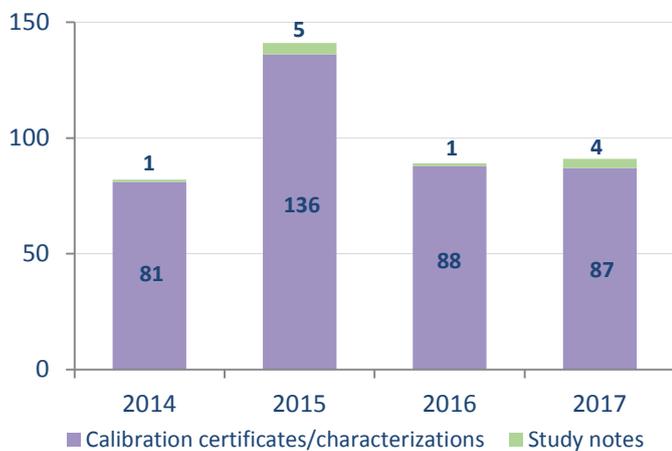
2017 – Breakdown by Department



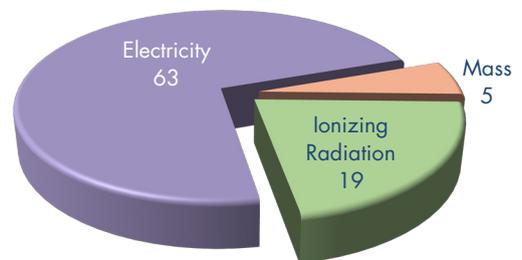
Full details of the BIPM's comparison programme can be found at:
www.bipm.org/en/bipm-services/comparisons/

BIPM Calibrations and Study Notes

2014 – 2017



2017 – Calibrations by metrology area



Full details of the BIPM's calibration and measurement services can be found at:
www.bipm.org/en/bipm-services/calibrations/

Organizational structure of the BIPM

The CIPM

President

Dr B. Inglis (Australia)

Secretary

Dr J. McLaren (Canada)

Vice-Presidents

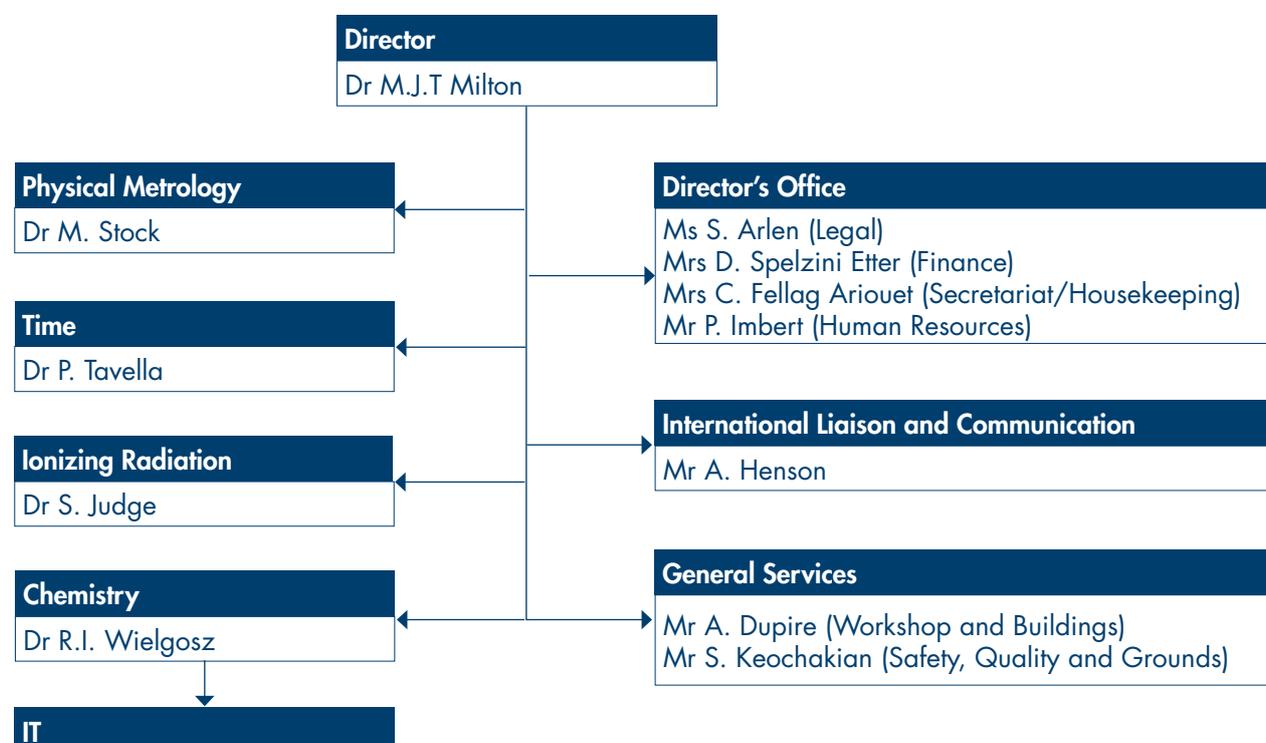
Dr W.E. May (United States of America)
Prof. J. Ullrich (Germany)

Other CIPM members

Dr F. Bulygin (Russian Federation)
Dr M. Buzoianu (Romania)
Dr I. Castelazo (Mexico)
Dr Y. Duan (People's Republic of China)
Mr L. Érard (France)
Dr D.-I. Kang (Republic of Korea)
Dr H. Laiz (Argentina)*
Dr T. Liew (Singapore)
Dr W. Louw (South Africa)
Dr M.L. Rastello (Italy)*
Dr P. Richard (Switzerland)
Dr G. Rietveld (Netherlands)
Dr M. Sené (United Kingdom)*
Dr T. Usuda (Japan)

*Provisionally elected to the CIPM on 7 December 2016

The BIPM staff



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3. **Coil-current effect in Kibble balances: analysis, measurement, and optimization**
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4. **Self-attraction mapping and an update on local gravitational acceleration measurement in the BIPM Kibble balance**
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Little R.R., Wielgosz R.I., Josephs R., Kinumi T., Takatsu A., Li H., Stein D., Burns C.
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Bros P., Josephs R.D., Stoppacher N., Cazals G., Lehmann S., Hirtz C., Wielgosz R.I., Delatour V.
12. **Concept paper on SI value assignment of purity - model for the classification of peptide/protein purity determinations**
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Josephs R.D., Stoppacher N., Westwood S., Wielgosz R.I., Li M., Quaglia M., Melanson J., Martos G., Prevoo D., Wu L., Scapin S., Öztug Senal M., Wong L., Jeong J.-S., Chan K.W.Y., Arsene C.G., Park S.-R.
13. **State-of-the-art and trends for the SI traceable value assignment of the purity of peptides using the model compound angiotensin**
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Josephs R.D., Stoppacher N., Daireaux A., Choteau T., Lippa K.A., Phinney K.W., Westwood S., Wielgosz R.I.
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Newell D.B. *et al.*



Useful links

BIPM Work Programme

The BIPM has the mandate to provide the basis for a single, coherent system of measurements throughout the world, traceable to the International System of Units (SI). This task takes many forms, from direct dissemination of units (as in the case of mass and time) to coordination through international comparisons of national measurement standards (as in electricity and ionizing radiation).

View full details of the BIPM Work Programme at: www.bipm.org/en/bipm/

Committee structure

CGPM: www.bipm.org/en/worldwide-metrology/cgpm/

CIPM: www.bipm.org/en/committees/cipm/

The CIPM has established a number of Consultative Committees, which bring together the world's experts in their specified fields as advisers on scientific and technical matters.

Consultative Committees: www.bipm.org/en/committees/cc/

In addition the BIPM participates in the work of a number of Joint Committees which have been created in collaboration with other international entities to undertake particular tasks of common interest.

Joint Committees: www.bipm.org/en/committees/jc/

Measurement units: the SI

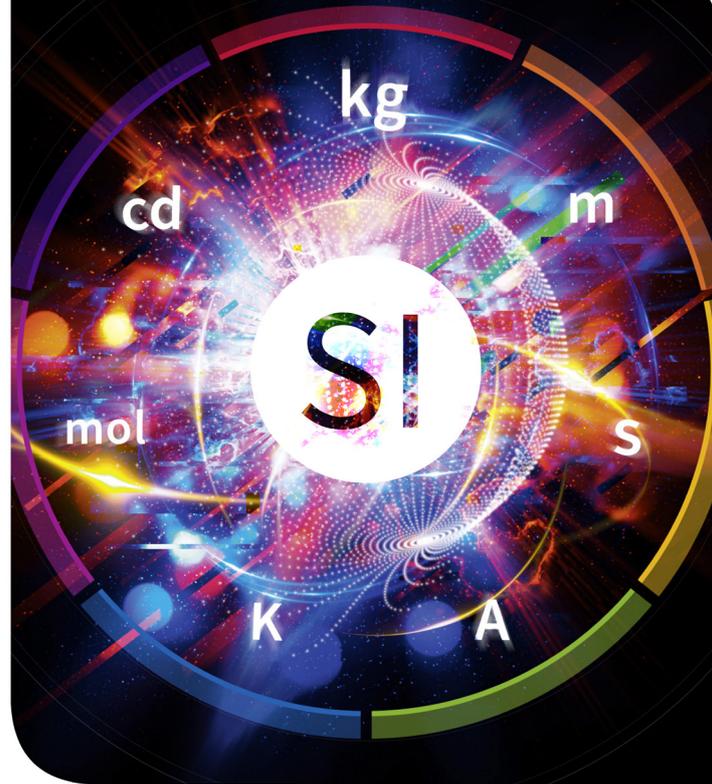
The recommended practical system of units of measurement is the International System of Units (Système International d'Unités, with the international abbreviation SI). The SI is not static but evolves to match the increasingly demanding requirements for measurements globally. Currently, much work is under way related to the proposed revision of the SI.

The SI: www.bipm.org/en/measurement-units/

Revision of the SI: www.bipm.org/en/measurement-units/new-si/

World Metrology Day

www.worldmetrologyday.org



Bureau
International des
Poids et
Mesures



Constant evolution

The International System of Units
20 May 2018

Pavillon de Breteuil
F-92312 Sèvres Cedex
France



ISBN 978-92-822-2270-6

ISSN 1606-3740