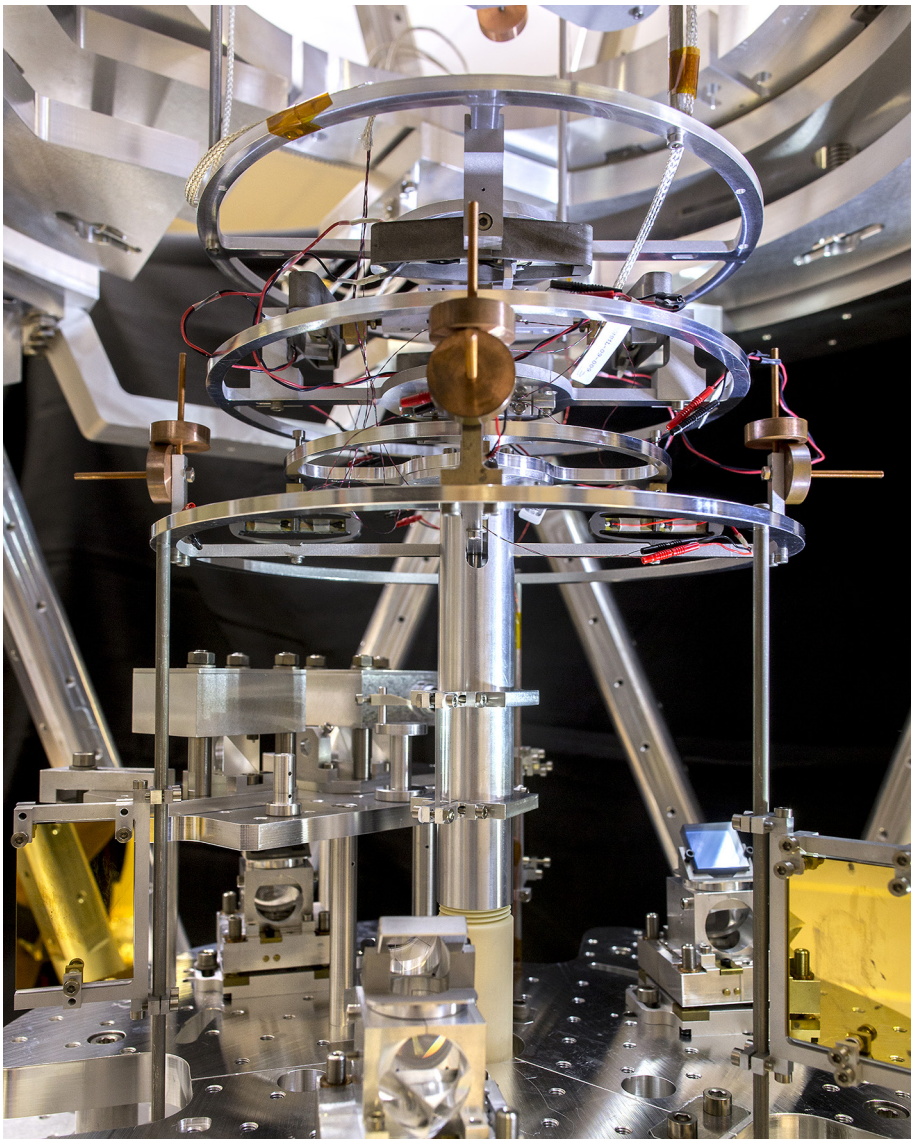
Bureau
International des
Poids et
Mesures



Annual Review 2015

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 Metre Convention was signed in Paris on 20 May 1875. It is the formal intergovernmental agreement through which Member States act together on matters related to measurement science and measurement standards.

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

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

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

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

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

www.bipm.org/en/worldwide-metrology/metre-convention/

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Front cover: the BIPM watt balance

Director's introduction

Dr Barry Inglis, President of the CIPM, (left) with Dr Martin Milton, Director of the BIPM (right).

I am pleased to bring you this new format Annual Review which summarizes developments at the BIPM during 2015.

One of the major new developments at BIPM during 2015 was the start of our activities under the BIPM Capacity Building & Knowledge Transfer Programme. The proposal that BIPM should be active in the area of capacity building was strongly supported in discussions at the CGPM in 2014 but was not funded at that time by an increase in the BIPM dotation. Hence, the programme has been launched on a voluntary funding model. Its aims are to increase the effectiveness within the world-wide metrology community of those Member States and Associates with emerging metrology systems. The first projects include training courses aimed at improving the operation of the CIPM MRA as well as a project that will allow NMIs to work together to strengthen their metrology infrastructure.

Another important new initiative during the year has been the review of the effectiveness and efficiency of the CIPM MRA which was launched at a dedicated workshop in October. A working group has been formed that will report back during the second and third quarters of 2016.

This report also includes summaries of the BIPM financial performance which are available in full in the *Rapport Financier*. Again, we report a small reduction in operating costs and a small increase in revenue.

In closing, you will have noticed the new format for our annual reporting. This short "Annual review" is complemented by extended reports of the achievements of each of the BIPM Departments which are available from our website.

Each year we will continue to provide full audited financial information in our *Rapport Financier* and the annual proceedings for the CIPM in both French and English. All of these documents can be downloaded from our website.

Highlights of 2015

- The BIPM Capacity Building and Knowledge Transfer Programme has started.
- The awareness campaign for the proposed revision of the SI is under way.
- The review of the effectiveness and efficiency of the CIPM MRA began, with a dedicated workshop held in October.
- The Mass and Electricity Departments were merged into a single Physical Metrology Department in October.
- The measurement campaign of calibrations against the International Prototype of the Kilogram was completed, in anticipation of the redefinition of the kilogram.
- A paper was published on the use of the technique of integer ambiguity resolution to achieve frequency transfers via GPS satellites to 1×10^{-16} accuracy.
- Following completion of testing, the qNMR facility was used for the first time to assign a purity value to the CCQM-K55.d comparison material, folic acid.

Physical Metrology

The BIPM Physical Metrology Department was created in October 2015 by merging the staff and activities of the Electricity and Mass Departments.

The measurement campaign of calibrations against the International Prototype of the Kilogram (IPK) in anticipation of the planned redefinition of the kilogram (Extraordinary Calibrations) was completed in 2015. The mass standards of NMIs involved in determinations of the Planck constant have been calibrated in Phase 2. As a result, all recent determinations of the Planck constant have an improved uncertainty traceable to the IPK. During Phase 1 it had been observed that the BIPM as-maintained mass unit had developed an offset of 35 µg with respect to the IPK[1]. The results of the analysis of the temporal evolution of this offset have been used to provide amendments for all mass calibration certificates issued between 2003 and early 2014. The correlation coefficient between the determinations of the Avogadro constant in 2011 and 2015 has been calculated, to determine how far both results can be seen as independent[2].

The BIPM is the pilot laboratory for a comparison of primary realizations of the mass unit, as outlined in the '*Joint CCM and CCU roadmap towards the redefinition of the SI in 2018*' and a technical protocol has been developed. The objectives are to investigate the coherence of realizations of the mass unit based on different primary realization experiments and continuity with the present definition of the kilogram.

A new strategy for the use of the working standards has been developed that features three hierarchical levels of working standards, which will be used at different periodicities, and the organization of the calibrations for NMIs during two dedicated periods of the year. In 2015, mass standards from 25 Member States were calibrated following the new scheme. In addition, three new Pt-Ir prototypes were delivered during 2015.

The hydrostatic weighing apparatus for the determination of density and volume of new Pt-Ir prototypes and stainless steel standards is being upgraded. In the future silicon cylinders will serve as the reference for density, instead of water, which should simplify the operation.

A new vacuum transfer system for the M_one mass comparator will allow mass standards to be brought into the comparator under vacuum or inert gases, an important capability for the BIPM's future work with the Ensemble of Reference Mass Standards (ERMS). Work on the storage network for the ERMS is almost complete and it is planned that the mass standards will be placed in their containers in early 2016. All mass standards are now available, following the arrival of the silicon spheres and the silicon stack. The BIPM workshop is fabricating a new series of improved containers to allow storage under vacuum. The mass evolution of stainless steel and Pt-Ir mass standards in air continues to be monitored.

Assembly of the new watt balance apparatus is nearly complete. The new, open support structure allows convenient access to the apparatus for alignment. A novel technique for aligning the magnetic circuit has allowed alignment to be achieved to within 30 µrad[3]. The new interferometer, which is based on a space-separated heterodyning technique, is being integrated into the watt balance. First measurements with the new apparatus are planned for early 2016.

The BIPM watt balance

Dr Richard Davis has presented a simple experiment to determine the value of the Planck constant to better than 1 % by measuring the mass of a 20 g aluminium cube[4].

The BIPM's measurement services in electricity were used extensively in 2015. Two on-site Josephson voltage comparisons and one on-site quantum Hall resistance (QHR) comparison were carried out. Previous work on this new series of QHR comparisons had led to interesting observations on the behaviour of 1 Ω resistors[5]. Seven comparisons were carried out in 2015 using BIPM transfer standards: Zener voltage standards (2), resistors (4) and capacitors (1).

The BIPM is the pilot laboratory for the future CCEM-K4 capacitance comparison and the comparison protocol is being developed. The Department participated in the second round of EURAMET.EM-S31, a comparison of capacitance calibrations to come to an understanding of the observed and unexpected differences between participants. The Department provided 45 calibration certificates for resistors, 35 for capacitors and three for Zener voltage standards during 2015.

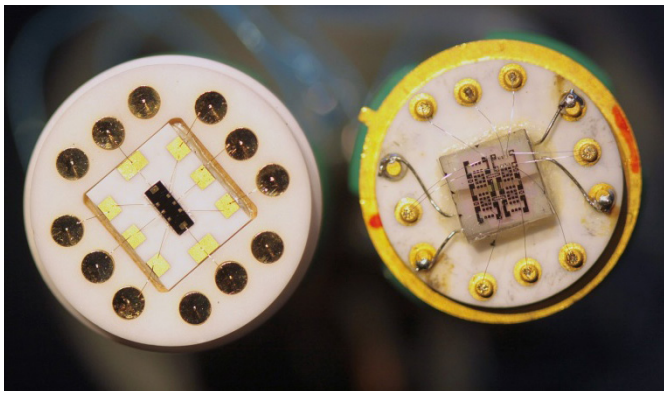
A precision alignment probe for the calculable capacitor has been developed and fabricated and the laser for the interferometer has been redesigned for easier and more reliable use. The calculable capacitor will be moved to and realigned in a new dedicated laboratory that is less subject to environmental disturbances, in particular ground vibrations. The capacitor will be reinstalled together with the complete quadrature measuring chain including the quantum Hall resistance. Measurement of R_K will then resume in the new laboratory.

Work on the Josephson voltage standard (JVS) for the measurement of the induced voltage in the watt balance has progressed, with the first generation of a stepwise voltage ramp. The a.c. JVS system, provided to the BIPM by the NIST, was used for the first time during an on-site comparison at the NMIJ (Japan) in December 2015.

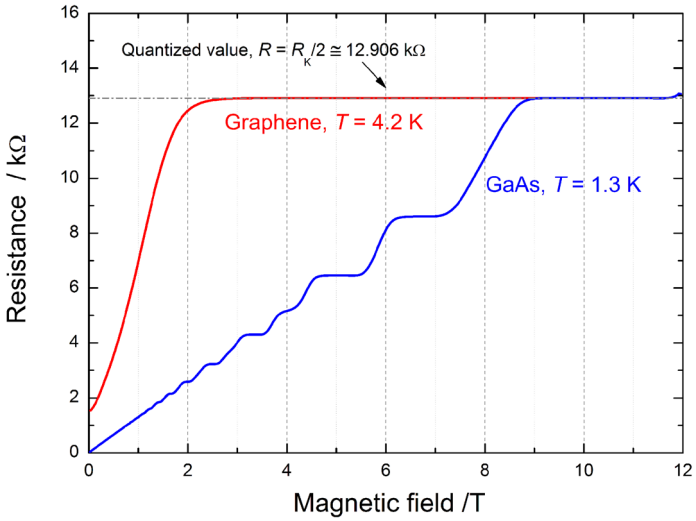
Graphene-based QHE measurements

Graphene offers the possibility to greatly simplify the quantum Hall effect (QHE) standard used for electrical resistance calibrations – offering the same reference based on the von Klitzing constant ($R_K = h/e^2$) as at present, but allowing easier implementation at lower magnetic fields and higher temperatures. The sample fabrication technique that looks most promising for precision metrology applications uses graphene grown on SiC wafers, and over the last couple of years there have been several advances in this technique.

The BIPM was involved in some of the first precision measurements that demonstrated the equivalence between graphene and the existing GaAs references, and is now investigating samples that are close to delivering on the promise of simplified experimental conditions for routine use. The first commercially available devices were tested during 2015. Equivalence at a few parts in 10^9 was found with the BIPM's traditional GaAs reference, although measurements are not yet possible with low field, high temperature and high current simultaneously. Further sample improvements are expected in the near future and we envisage being able to implement a much simplified transportable system for on-site QHE comparisons (operating at a temperature of 4 K and field of 5 T).



A SiC wafer graphene QHE sample (right) next to a traditional GaAs device (left), mounted on the BIPM measurement probe, ready for insertion into the cryostat.



Time

Major achievements in the Time Department in 2015 included a reduction of the uncertainty of time transfer by a factor of about 2.5. This followed the implementation of calibrations of equipment in coordination with the Regional Metrology Organizations (RMOs) using the procedures described in the 'BIPM Guidelines for GNSS calibrations'. This procedure involves repeated calibrations at intervals of about two years, allowing an improvement in the monitoring of the stability of the equipment and consequently a reduction of the uncertainty. The BIPM has concluded the first measurement campaign at nine selected institutes from APMP, COOMET, EURAMET and SIM. The results of this campaign have been implemented in the computation of Coordinated Universal Time (UTC) since September 2015. The second campaign will begin in the first trimester of 2016. After completion of equipment calibration in other laboratories by the RMOs, all time links for UTC will be calibrated, with a positive impact on the uncertainty of the degrees of equivalence [*UTC* – *UTC*(*k*)] in the key comparison CCTF-K001. UTC. In parallel, work started on the algorithm for the evaluation of the uncertainties of [*UTC* – *UTC*(*k*)] to correct two drawbacks of the present algorithm: the absence of correlations and the non-optimal utilization of all available clock comparison data. An optimal solution using redundant links is being investigated, where the matrix of correlations will provide the uncertainties of [*UTC* – *UTC*(*k*)].

Studies continued on the implementation of a Kalman filter routine for the computation of UTC. Kalman filtering is a powerful mathematical tool for dealing with the white phase noise that affects time transfer data. It is often applied for the computation of real-time time scales. This study is the first application to a clock ensemble for producing a post-processed time scale of the UTC-type. When implemented on a sub-set of the UTC contributing clocks, results show a significant improvement of the time scale frequency stability in the short- and mid-terms. This study was carried out in collaboration with the University of Turin (Italy).

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 74 participants that together contributed data from about 470 atomic clocks at the end of 2015.

Regular publication of rapid UTC (UTCr) continued in 2015, providing a weekly solution based on data collected over four weeks, and which represents about 70 % of the clocks in UTC. Consequently, the frequency instability is of the same order of UTC. This rapid solution supports the quality of the representations of UTC in national laboratories and the steering of the Global Navigation Satellite Systems' times to local representations of UTC.

UTC will retain leap seconds until at least 2023

Members of the International Telecommunication Union (ITU) met at the World Radiocommunication Conference (WRC-15) in Geneva in November 2015 and decided to maintain UTC with leap second insertions until 2023, when another WRC will consider the issue again after wider consultation. The BIPM, as a member of the ITU Radiocommunication Sector, participated in WRC-15 as an observer, and contributed to the work of the committee that handles the choice of a method for achieving a continuous reference time scale.

A resolution was passed by the WRC-15 to clarify roles and responsibilities. It calls for reinforcing the links between the ITU and the BIPM, and confirms that the BIPM is responsible for establishing and maintaining the SI second and its dissemination through the reference time scale. Coordinated actions of the two, including decisions of the CIPM and the CGPM, together with other relevant organizations such as the International Astronomical Union (IAU), International Earth Rotation and Reference Systems Service (IERS) and the International Union of Radio Science (URSI) are expected in the coming years, involving studies on the impact and application of a future reference time scale.

IPPP: a new technique to improve clock frequency comparisons

A new technique known as IPPP (precise point positioning (PPP) with integer ambiguity resolution), which has the potential to revolutionize clock frequency comparisons using GPS signals, has been developed by the BIPM Time Department in collaboration with colleagues from the Centre National d'Études Spatiales (CNES) and the Collecte Localisation Satellites (CLS). A joint publication in *Metrologia* describes the work[6]. The CNES and CLS teams constitute an analysis centre of the International GNSS Service (IGS), and they are developing specific IGS products needed for IPPP.

The most significant result compares IPPP to a 420 km optical-fibre time link in Poland[7], which is in continuous operation and which reports to the BIPM. As a result of the fibre link's better accuracy, it was possible to demonstrate that, in comparing the frequency of two clocks, the IPPP technique reaches a performance of 1×10^{-16} in about 5 days and that the achieved accuracy continues to improve with longer averaging times. This represents a significant improvement over classical PPP (Fig. 1 compares the IPPP in blue with the classical PPP in red) and is the best published performance for a GPS frequency comparison.

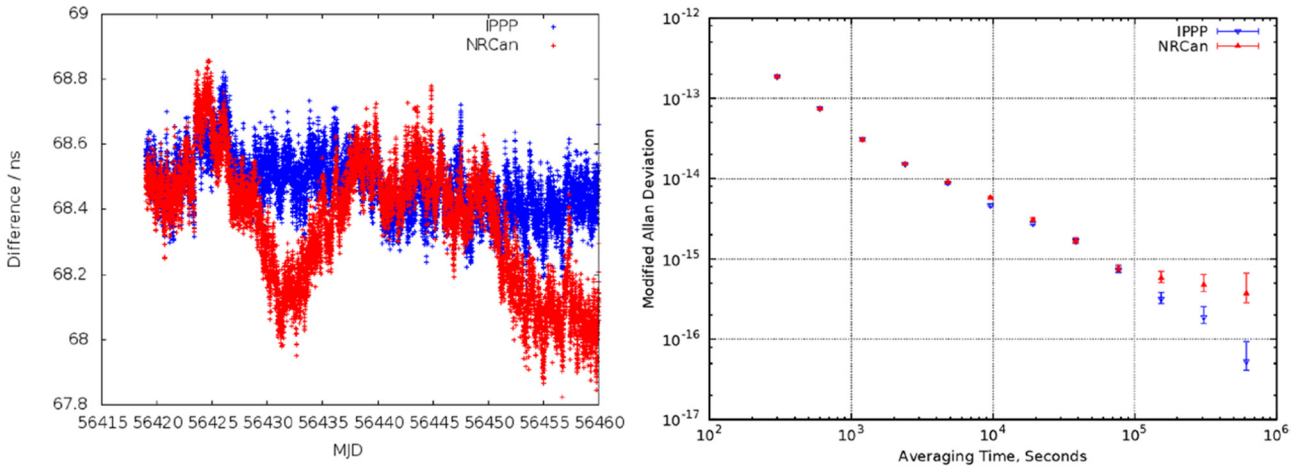


Fig. 1. Comparison between the optical fibre link between AOS and GUM and the results obtained with IPPP (blue) and PPP (red) over 41 days. Left: Plot of the time differences with arbitrary offset; right: stability analysis.

The Global Positioning System (GPS) has been used to compare clocks at a distance for decades. The present technique of choice is Precise Point Positioning (PPP), which provides the majority of the links used for UTC. Its performance for frequency comparisons is of the order a few parts in 10^{16} in 10 days, which is adequate for all commercial clocks, but insufficient to compare the best Cs or Rb fountains which claim an uncertainty below 2×10^{-16}, as well as the forthcoming ion clocks or atom lattice clocks.

One way to overcome the current limitations of GPS for clock comparisons is to base the results only on the phase of the transmitted signals and to explicitly account for the integer-cycle nature of the phase ambiguities that need to be resolved between the different arcs and satellites that are successively observed during the comparison.

As IPPP can compare two clocks wherever they are located on the Earth and can be operated immediately using existing equipment, it will be a significant step towards the comparison of ultra-accurate clocks. Optical fibre links will progressively build up into networks that cover continental areas, however this will take time. For world-wide frequency comparisons at the sub-10^{-16} level, no other operational techniques are on the horizon except during the Atomic Clock Ensemble in Space (ACES) mission, which is expected to operate onboard the International Space Station in 2016-2018.

Chemistry

A paper that demonstrates equivalence between methane standards made in whole and synthetic air measured by cavity ring-down spectroscopy (CRDS) and gas chromatography – flame ionization detection (GC-FID) for atmospheric monitoring applications was published in 2015[8]. This completed the Department's activities related to the CCQM-K82 comparison (methane in air).

Validation work continued on the CCQM-K120 comparison (carbon dioxide in air), with validation of Fourier transform infrared spectroscopy and isotope ratio infrared spectrometer measurement systems with a set of 23 standards produced by NIST, NPL and NOAA (the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) Central Calibration Laboratory (CCL) for CO_2). The standards were produced using five different sources of CO_2 that resulted in a diversity of $\delta^{13}C$ and $\delta^{18}O$ values for the standards. Their isotopic composition was value assigned on the VPDB scale with traceability to the JRAS06 standards of the Max Planck Institute for Biogeochemistry in Jena (Germany). In parallel, the assembly of a manometric system for CO_2 measurements has progressed, supported by the secondment of Dr Stephen Maxwell from the NIST. The all-glass apparatus was installed in

The manometric system for CO_2 measurements

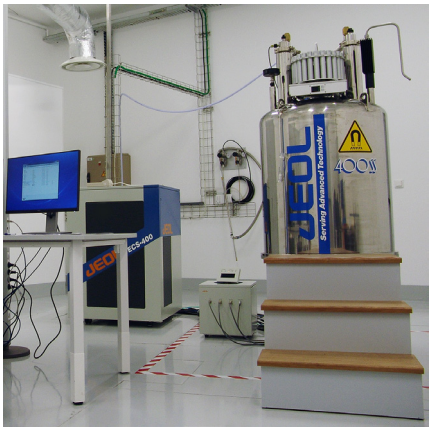
a temperature-controlled oven and the connections to a cryostat and Residual Gas Analyser were tested, allowing the cryogenic separation of CO_2 from air. Full automation and validation of the system is anticipated in 2016. The importance of these comparisons for the monitoring of essential climate variables (ECVs) was presented and discussed at the BIPM Workshop on Global to Urban Scale Carbon Measurements, which was held on 30 June to 1 July 2015. Discussions on oceanic ECVs have resulted in a set of review papers in *Metrologia* on 'Metrological challenges for measurements of key climatological observables: oceanic salinity and pH, and atmospheric humidity'[9].

In the area of air quality, four laboratories brought their national ozone standards to the BIPM in 2015 for comparison with the BIPM-SRP27 reference standard. Gas phase titration measurements of ozone with nitrogen monoxide have been completed, confirming the agreement of these measurements with those made by UV absorption in 2014.

The CCQM-K90 comparison on formaldehyde standards continued. Following completion of measurements at the BIPM, eight cylinders were selected and sent to participants. Six cylinders remain at the BIPM and have been measured regularly to monitor their stability. Participants performed their own measurements between June and October 2015. Cylinders are being returned to the BIPM for final measurements and the results will be presented to the CCQM Working Group on Gas Analysis (GAWG) in April 2016.

A key comparison (CCQM-K137) on nitrogen monoxide (NO) at 30 µmol/mol to 70 µmol/mol in nitrogen is scheduled for late 2016. Validation measurements have been carried out on the BIPM's comparison facilities and 20 laboratories have expressed an interest in participating.

The BIPM's organic small-molecule purity programme continued with the transfer of ownership of a 400 MHz nuclear magnetic resonance (NMR) spectrometer to the BIPM. Successful qualification and acceptance testing was completed at the beginning of 2015. A visit to the BIPM by Dr Takeshi Saito, NMIJ (Japan), in February 2015, marked the start of the BIPM-NMIJ collaborative projects in this area. Secondments to the BIPM during 2015 helped to develop and validate methods for performing high accuracy quantitative NMR (qNMR) measurements in various deuterated solvents. This work



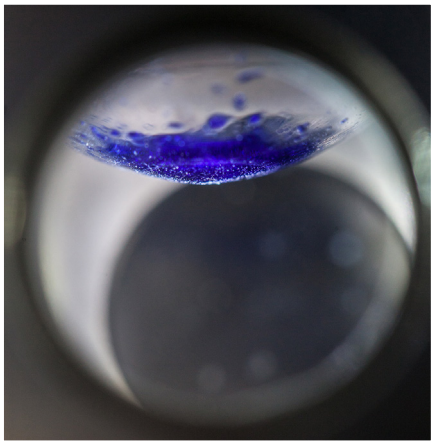
The BIPM qNMR facility

allowed the qNMR facility to be used for the first time to assign a purity value to the CCQM-K55.d comparison material, folic acid, in addition to mass balance methods. The comparison samples were distributed to participants in September 2015 and results are expected in January 2016.

Validation studies of methods for the assignment of the mass fraction content of amino acids in solution using liquid chromatography-UV (LC-UV), liquid chromatography-charge aerosol detector (LC-CAD), liquid chromatography-tandem mass spectrometry(LC-MS/MS) and ion chromatography (IC) in preparation for the CCQM-K78 comparison were completed in 2015. A candidate material consisting of a batch of 200 ampoules of a multi-component amino acid solution has been prepared and will be evaluated as a suitable candidate for the CCQM-K78 comparison material. The BIPM continued to coordinate the drafting of technical guidelines on 'Methods for the SI Value Assignment of the Purity of Organic Compounds for use as Primary Reference Materials and Calibrators' as an International Union of Pure and Applied Chemistry (IUPAC) project. The final Technical Report will be produced in 2016.

Measurements on the first CCQM key comparison on peptide purity (CCQM-K115/P55.2), coordinated by the BIPM in collaboration with NIM (China), were completed and presented at the inaugural meeting of the CCQM Working Group on Protein Analysis (PAWG) in October 2015. High-resolution mass spectrometry methods for related structure impurities were developed by a secondee from NIM. Method development for future comparisons has continued, with a secondment from the LNE (France), to work on high resolution mass spectrometry coupled to liquid chromatography (LC-hrMS) for the purity determination of hepcidin. Hepcidin is a key regulator of iron homeostasis and a promising clinical biomarker for iron deposition in the brain, a possible causal agent of Alzheimer's disease. High-purity oxytocin and calcitonin, both synthetic therapeutic peptides, have been produced in collaboration with NIM to serve as future candidate key comparison materials for small peptides with disulphide bonds. A paper describing the development and comparison of mass spectrometric methods for the quantification of angiotensin (ANG I) has been published[10].

Publication of new ozone cross-section measurements for the accurate monitoring of air quality



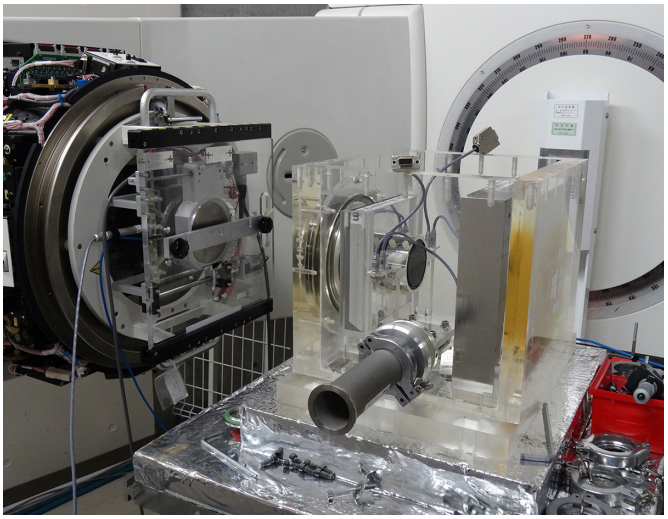
Pure liquid ozone trapped in the temperature-controlled cryostat

Ozone is a major air pollutant affecting human health and agriculture, with many national and regional regulations defining maximum exposure limits and requiring continual air-quality monitoring for the protection of their populations. Measurements of ozone concentrations at ground level are based on the absorption of UV light at 254 nm, with the traceability and consistency of measurements assured through national ozone reference photometers, notably the NIST Standard Reference Photometer, and their comparisons coordinated by the BIPM (BIPM.QM-K1).

New measurements of the ozone cross section carried out in the BIPM laboratories, together with visiting scientists from KRISS (Republic of Korea) and GUM (Poland), have been published. These measurements report a value 1.8 % lower than the conventionally used value. A description of the experimental design and measurement results was published in *Atmospheric Measurement Techniques*[11]. The CCQM GAWG has discussed the potential impact of this result on ozone-monitoring networks.

Ionizing Radiation

The BIPM dosimetry programme supports eight ongoing comparisons, BIPM.RI(I)-K1 to BIPM.RI(I)-K8, and a project to develop an absorbed-dose standard for medium-energy x-rays is nearing completion. A pilot comparison with the PTB (Germany) using this primary standard was conducted in November 2015 and should result in a new comparison series beginning in 2016. Minor problems with instabilities in the transfer instruments remain under investigation and a fourth transfer chamber is being characterized. The ninth comparison in the series BIPM. RI(I)-K6 for absorbed dose to water in high-energy photon beams was carried out on-site at the NMIJ/AIST (Japan), using their 6 MV, 10 MV and 15 MV beams.



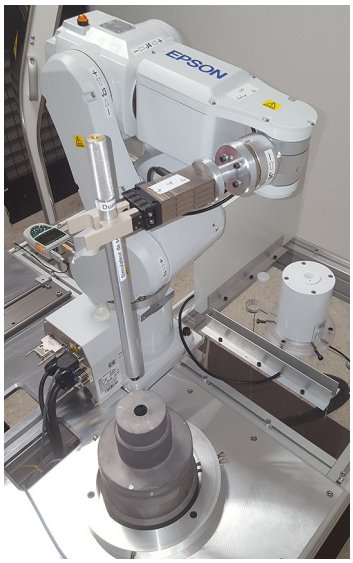
The BIPM primary standard calorimeter in position in the NMIJ/AIST high-energy photon beam as part of the BIPM.RI(I)-K6 comparison

A comparison (BIPM.RI(I)-K8) for the reference air kerma rate for HDR ^{192}Ir brachytherapy sources was also carried out on-site at the NMIJ. The results and reports of two previous comparisons were published. The design study to establish a new laboratory for this activity is complete and is being implemented.

Ten dosimetry comparisons and 18 dosimetry characterizations of national secondary standards were carried out in 2015, which are underpinned by a significant effort in equipment calibration and maintenance. In addition, 15 comparison reports were approved and published in *Metrologia's Technical Supplement*.

In the radionuclide measurements programme, the International Reference System (SIR) received eight ampoules of five different radionuclides from seven laboratories. Five ampoules were oriented to generate equivalence values in the ongoing BIPM.RI(II)-K1 comparison. Three ampoules of ^{68}Ge from three laboratories were received during 2015 and will serve to evaluate the key comparison reference value (KCRV) for this radionuclide and to provide a link for the Consultative Committee for Ionizing Radiation (CCRI) key comparison CCRI(II)-K2.Ge-68. ^{223}Ra ($T_{1/2}$ = 11.43 d, u_c = 0.03 d) is a promising radionuclide for the therapy of some cancers, for which two ampoules from two laboratories were evaluated in 2015, constituting a new SIR entry. An earlier submission of ^{111}Ag has been evaluated and the final report published in the *Technical Supplement*.

SIR Transfer Instrument (SIRTI) comparisons (BIPM.RI(II)-K4) of ^{99m}Tc and ^{18}F took place at the NMISA (South Africa). In addition, the first calibration measurements of the SIRTI against the SIR were carried out for ^{64}Cu by measuring a solution from the CNRS-Orléans (France) in both systems.



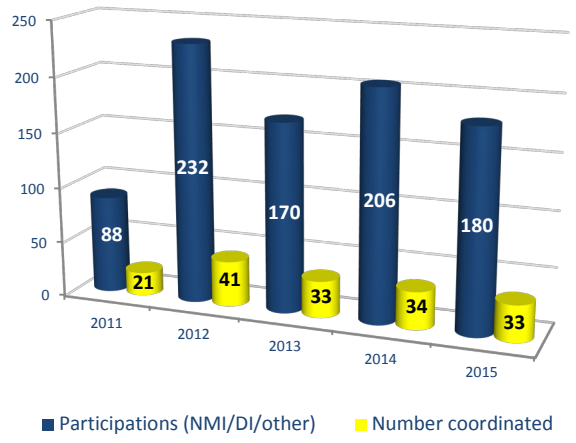
The new BIPM facility for the BIPM.RI(I)-K8 comparison. The image shows manipulation of a radioactive source using a robotic arm to study the stability of the brachytherapy standard

In total, 12 radionuclide activity comparisons were undertaken and five updated reports of BIPM RI(II)-K1 comparisons were approved and published in the *Metrologia Technical Supplement* covering ^{56}Mn, ^{65}Zn, ^{85}Sr, ^{207}Bi and ^{166m}Ho, including the link from the CCRI(II)-K2. Zn-65 comparison. In addition, the first three results in the BIPM.RI(II)-K4.F-18 comparison were presented at the ICRM-2015 conference in Vienna (Austria) on 8-11 June 2015 and submitted for publication in *Applied Radiation and Isotopes*. The radioactivity group contributed to three papers in the *Metrologia* special issue on 'Uncertainties in Radionuclide Metrology' as well as to the guest editors' team[12,13,14,15].

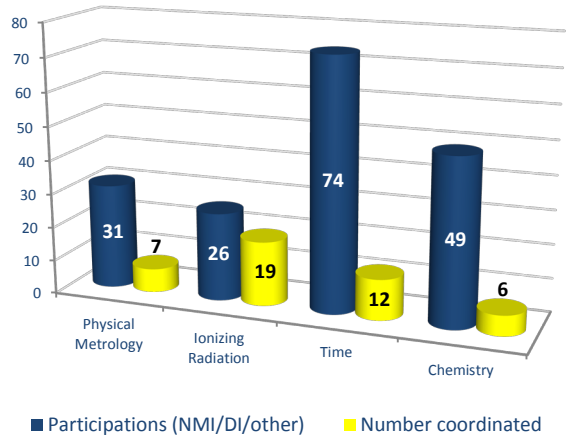
Comparisons and Calibrations

Comparisons coordinated by the BIPM

2011-2015



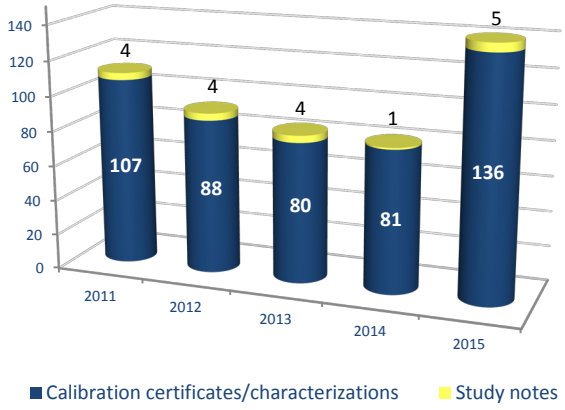
2015 - Breakdown by Department



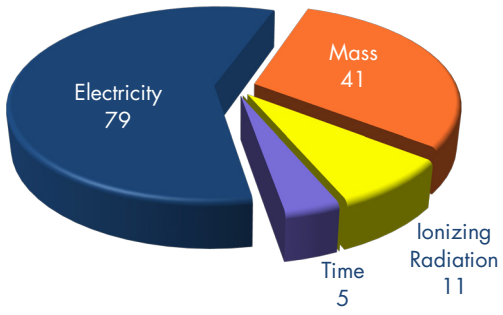
Full details of the BIPM's comparison programme can be found at:
www.bipm.org/en/bipm-services/comparisons/

BIPM Calibrations and Study Notes

2011-2015



2015 - 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/

International Liaison and Communication

The BIPM International Liaison and Communication Department has the role of promoting metrology to the scientific community, industry and the public. The BIPM has an ongoing relationship and interacts with around thirty international organizations and provides or shares information with these bodies relating to the SI and the international comparability of measurements. Collaborations are both institutional and technical and in 2015, a typical year, BIPM staff undertook more than 100 missions to countries and economies to provide their expertise to such organizations and to the NMIs.

Key liaison activities are with intergovernmental organizations such as the World Trade Organization (WTO), the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), the World Meteorological Organization (WMO), the International Organization of Legal Metrology (OIML) and international bodies such as the International Organization for Standardization (ISO) and the International Laboratory Accreditation Cooperation (ILAC). Interaction varies from high-level discussions to participation in dedicated working groups but the objective remains the same: to promote the importance of measurement, the SI and the comparability of measurement and to ensure the appropriate use of metrology and the international infrastructure.

The BIPM contributes to activities supporting developing countries' technical infrastructure by participating in the DCMAS Network, which it is currently chairing and through the new BIPM Capacity Building and Knowledge Transfer Programme (CB&KT).

As of 31 December 2015 there were 57 Member States and 40 Associates of the CGPM.

The BIPM welcomed the following new Member States in 2015:

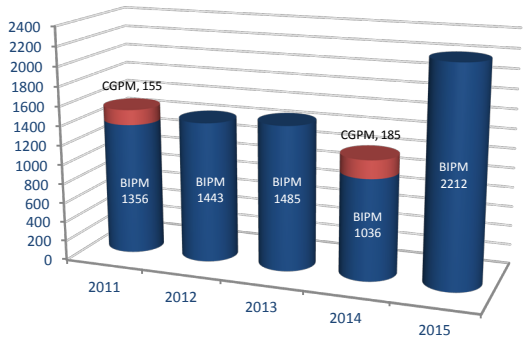
- **The United Arab Emirates** on 27 April
- **The Republic of Lithuania**, which had been an Associate since 2001, on 16 April

And the following new Associate of the CGPM:

- **The Republic of Azerbaijan** on 1 January

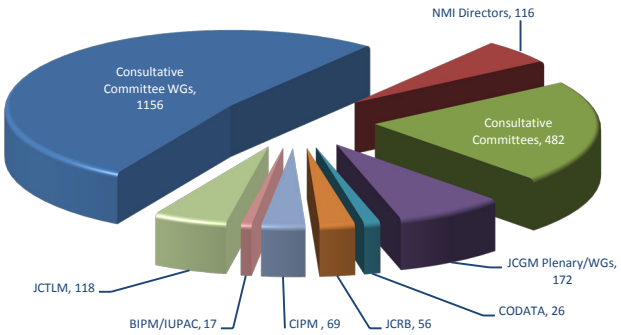
An up-to-date list of the BIPM's Member States and the Associates of the CGPM can be found at:
www.bipm.org/en/about-us/member-states/

Attendance at meetings hosted at the BIPM



Attendance at meetings hosted at the BIPM was unusually high in 2015 largely due to an exceptionally large number of Consultative Committee and Working Group meetings.

Meeting attendance 2015



The BIPM Capacity Building and Knowledge Transfer (CB&KT) Programme

The BIPM Capacity Building and Knowledge Transfer (CB&KT) Programme has been established to increase the effectiveness and engagement within the world-wide metrology community of Member States and Associates that have emerging metrology systems.

The BIPM donor-funded CB&KT Programme has been established to:

- assist individual NMI staff, NMIs and RMOs to increase their understanding and capability with regard to engagement in the world metrology system, with the aim of strengthening the capacity of the international metrology community to operate the world-wide measurement system on an equitable cost-shared basis.
- embed metrology more effectively in wider quality infrastructure development initiatives.

Sponsors have been secured for the first BIPM CBKT projects and planning is well under way. These projects include: METAS sponsored opportunities combining attendance at the joint BIPM and Italian Physical Society Metrology School "Metrology: from physics fundamentals to quality of life" in Varenna, during the summer of 2016 with time at METAS in Switzerland; NIST sponsored training for "Leaders of Tomorrow" for November 2016 aimed at enhancing participation in the CIPM MRA; and a laboratory based knowledge transfer project "Metrology for Safe Food and Feed in Developing Economies" supported by a variety of sponsors. Other projects are under development and new sponsors are encouraged to contact the BIPM with their ideas.

Full details of the BIPM Capacity Building and Knowledge Transfer Programme can be found at:
www.bipm.org/en/cbkt/

Awareness campaign for the proposed revision of the International System of Units

It is expected that the CGPM will adopt a substantial redefinition of the International System of Units (SI) in 2018. This will be an important event for the world-wide metrology community. It will require us all to communicate the technical consequences of the proposed changes to the way that traceability will be disseminated to users. It will also provide a special opportunity to promote metrology and to educate the general public about the importance of accurate measurement in daily life. In preparation, the CIPM has established the 'Task Group for the Promotion of the New SI' to engage with the world-wide stakeholder community and to develop a world-wide awareness campaign concerning the revision of the SI.

In the 'New SI' four of the SI base units – namely the kilogram, the ampere, the kelvin and the mole – are expected to be redefined in terms of constants, with the new definitions based on fixed numerical values of the Planck constant (h), the elementary charge (e), the Boltzmann constant (k_B), and the Avogadro constant (N_A), respectively. Furthermore, the definitions of all seven base units of the SI will be uniformly expressed using the explicit-constant formulation, and specific *mises en pratique* will be drawn up to explain the realization of the definitions of each of the base units in a practical way.

The Task Group will identify and develop key tools to support promotion of the new SI among a wide range of different audiences. The Group will share communication tools and messages through a web page **www.bipm.org/en/committees/cc/wg/cipm-tgsi.html**. The messages and tools will be available for all to use as they find appropriate.

The Task Group meets annually, with a PR Expert Group undertaking activities between meetings.

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 a decade and a half of successful operation, the CIPM MRA is being reviewed to ensure its sustainability for the future. A dedicated CIPM MRA Review workshop was held in October 2015, where it was agreed to establish a Working Group on the Implementation and Operation of the CIPM MRA.

The **State Committee for Standardization, Metrology and Patent of the Republic of Azerbaijan (AZSTAND)**, Azerbaijan, signed the CIPM MRA on 28 January 2015.

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 2015, the KCDB included 922 key comparisons and 442 supplementary comparisons. The number of key and supplementary comparisons increased by 38 and 32 respectively. Meanwhile, around 100 comparisons were completed and published during 2015. 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.

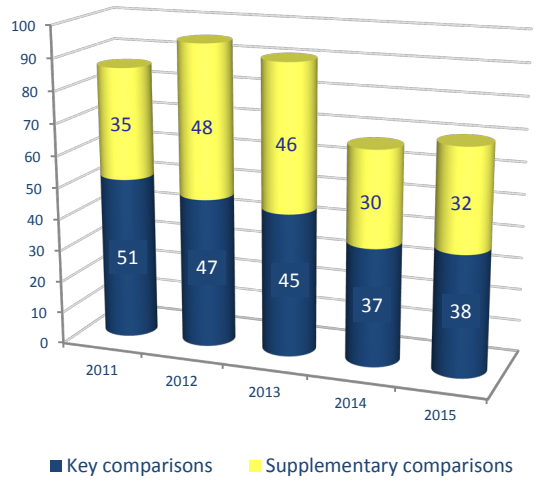
The KCDB currently includes a dozen examples where more than seven key comparisons are linked together. Graphs of participation in key and supplementary comparisons are available on the KCDB web page (**kcdb.bipm.org**).

Calibration and Measurement Capabilities

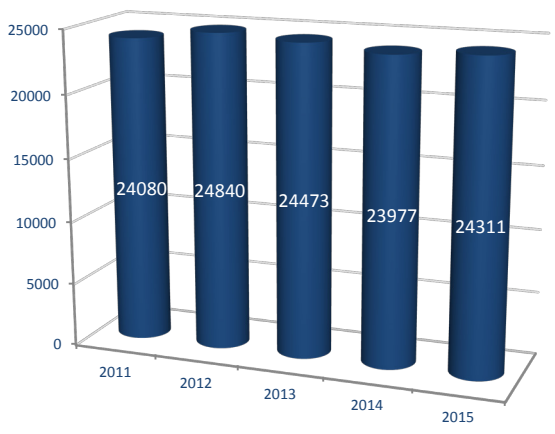
On 31 December 2015 there were 24 311 CMCs registered in the KCDB. Of these, 14 368 were in the field of General Physics, 4 040 in Ionizing Radiation, and 5 903 in Chemistry. The total number of CMCs increased by 350 in 2015. The first sets of CMCs were declared by Montenegro (in thermometry and mass) and published at the end of the year.

At the end of 2015, 260 CMCs were temporarily removed from the KCDB ("greyed out"). Another 16 were definitively deleted from the KCDB in 2015, either on request from the corresponding NMI, or due to the lack of a QMS. Both these numbers are negligible compared to the total number of registered CMCs.

Number of new comparisons registered in the KCDB

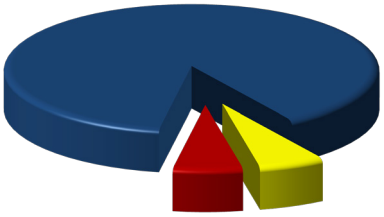


Total number of CMCs registered at 31st December



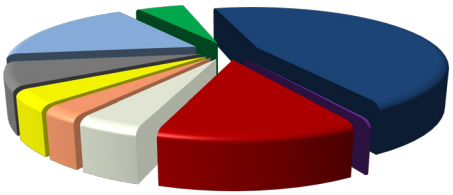
Financial Summary

2015 Revenue



- Contributions
- Subscriptions
- Other revenue

2015 Expenses



- Staff
- Change in healthcare and retirement indemnity provision
- Contribution to the BIPM Pension and Provident Fund
- General services
- Laboratory operating expenses
- Building maintenance
- Other operating expenses
- Depreciation, amortization and loss on disposal and impairment of assets
- Financial expenses

Key financial data

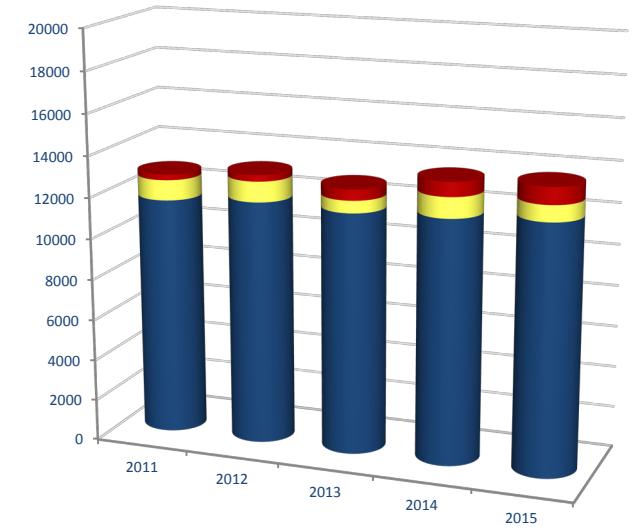
(in k€)	**2014**	**2015**
Revenue	13 596	13 734
Expenses	19 473	12 958
Net result	(5 877)	776
Corrected EBITDA	**2 795**	**3 203**

A breakdown of revenue and expenses from 2011-2015 can be found on page 16

Financial Summary

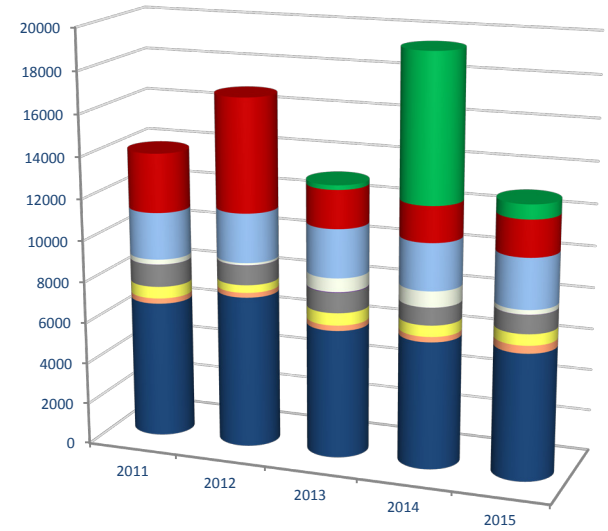
Revenue

in k€



Expenses

in k€



in k€	2011	2012	2013	2014	2015
Contributions*	11 590	11 875	11 744	11 885	12 121
Subscriptions**	271	320	530	702	790
Other income	986	998	598	1 009	823
Total	**12 847**	**13 193**	**12 872**	**13 596**	**13 734**

*Contributions from Member States

**Subscriptions from Associates of the CGPM

in k€	2011	2012	2013	2014	2015
Staff	6 611	7 358	6 208	6 145	6 104
Building maintenance	260	235	261	258	373
Laboratory operating expenses	574	372	595	540	539
General Services	1 092	958	987	844	899
Financial expenses	8	8	24	3	8
Other operating expenses	240	103	653	763	216
Contribution to the BIPM Pension and Provident Fund	2 270	2 369	2 329	2 251	2 400
Depreciation, amortization and loss on disposal and impairment of assets	2 851	5 444	1 833	1 708	1 737
Change in healthcare and retirement indemnity provision	0	0	(213)	6 961	682
Total	**13 906**	**16 847**	**12 677**	**19 473**	**12 958**

Full details of the financial and administrative situation of the BIPM are available in the "*Rapport Financier 2015*":
www.bipm.org/en/committees/cipm/publications-cipm.html#ra

Publications

Scientific papers referenced in this report

1. **Calibration campaign against the international prototype of the kilogram in anticipation of the redefinition of the kilogram part I: comparison of the international prototype with its official copies**
   Metrologia, 2015, **52**(2), 310-316
   Stock M., Barat P., Davis R.S., Picard A. and Milton M.J.T.
2. **Improved measurement results for the Avogadro constant using a ^{28}Si-enriched crystal**
   Metrologia, 2015, **52**(2), 360-375
   Barat P., and Stock M. (with NMIJ, Japan; PTB, Germany; INRIM, Italy; and NIST, USA)
3. **Alignment of the magnetic circuit of the BIPM watt balance**
   Metrologia, 2015, **52**(6), 775-782
   Bielsa F., Lu Y.F., Lavergne T., Kiss A., Fang H. and Stock M.
4. **What is a kilogram in the revised International System of Units (SI)?**
   J. Chem. Ed., 2015, **92**(10), 1604-1609
   Davis R.S.
5. **Behavior of 1 Ω resistors at frequencies below 1 Hz and the problem of assigning a dc value**
   Metrologia, 2015, **52**(4), 509-513
   Fletcher N., and Rolland B. (with PTB, Germany)
6. **1×10^{-16} frequency transfer by GPS PPP with integer ambiguity resolution**
   Metrologia, 2015, **52**(2), 301-309.
   Petit G., Kanj A., Loyer S., Delporte J., Mercier F., and Perosanz F.
7. **Comparing a GPS time link calibration with an optical fibre self-calibration with 200 ps accuracy**
   Metrologia, 2015, **52**(2), 384-391
   Jiang Z., Lewandowski W., and Arias E.F. (with GUM, Poland, and AOS: Time and Frequency Department, Astrogeodynamic Observatory of Space Research Center, Poland)
8. **Methane standards made in whole and synthetic air compared by CRDS and GC-FID for atmospheric monitoring applications**
   Analytical Chemistry, 2015, **87**(6), 3272-3279
   Flores E., Viallon J., Moussay P., Choteau T., and Wielgosz R.I (with NIST, USA)
9. **Metrological challenges for measurements of key climatological observables: oceanic salinity and pH, and atmospheric humidity. Part 1: overview**
   Metrologia, 2016, **53**(1), R1-R11
   Feistel R., and Wielgosz R.I. *et al.*
10. **Accurate quantification of impurities in pure peptide material – angiotensin I: Comparison of calibration requirements and method performance characteristics of liquid chromatography coupled to hybrid tandem mass spectrometry and linear ion trap-high resolution mass spectrometry**
    Rapid Comm. Mass Spectrom., 2015, 29, 1651-1660
    Stoppacher N., Josephs R.D., Daireaux A., Choteau T., Westwood S.W., and Wielgosz R.I.
11. **Accurate measurements of ozone absorption cross-sections in the Hartley band**
    Atmos. Meas. Tech., 2015, 8, 1245-1257
    Viallon J., Lee S., Moussay P., Tworek K., Petersen M., and Wielgosz R.I.
12. **Practical implementation of uncertainty analysis in radionuclide metrology**
    Metrologia, 2015, **52**(3), S1-S2
    Los Arcos J.M. (with NIST, USA, and NPL, UK)
13. **Uncertainty of combined activity estimations**
    Metrologia, 2015, **52**(3), S30-S41
    Ratel G., Michotte C. and Bochud F.O.
14. **Uncertainty evaluation in activity measurements using ionization chambers**
    Metrologia, 2015, **52**(3), S108-S122
    Michotte C., and Ratel G., (with CEA, LIST, Laboratoire National Henri Becquerel, France; NIST, USA; Institute of Radiation Physics, Switzerland; and NPL, UK)
15. **Uncertainty determination for activity measurements by means of the TDCR method and the CIEMAT/NIST efficiency tracing technique**
    Metrologia, 2015, **52**(3), S172-S190
    Ratel G. (with PTB, Germany; National Centre for Nuclear Research, Radioisotope Centre POLATOM, Poland; Laboratoire National Henri Becquerel, CEA-LNHB, France; and NIST, USA)

A complete list and further details of publications can be found at: **www.bipm.org/en/publications/open-literature**

Organizational structure of the BIPM

The CIPM

President

Dr B. Inglis (Australia)

Secretary

Dr J. McLaren (Canada)

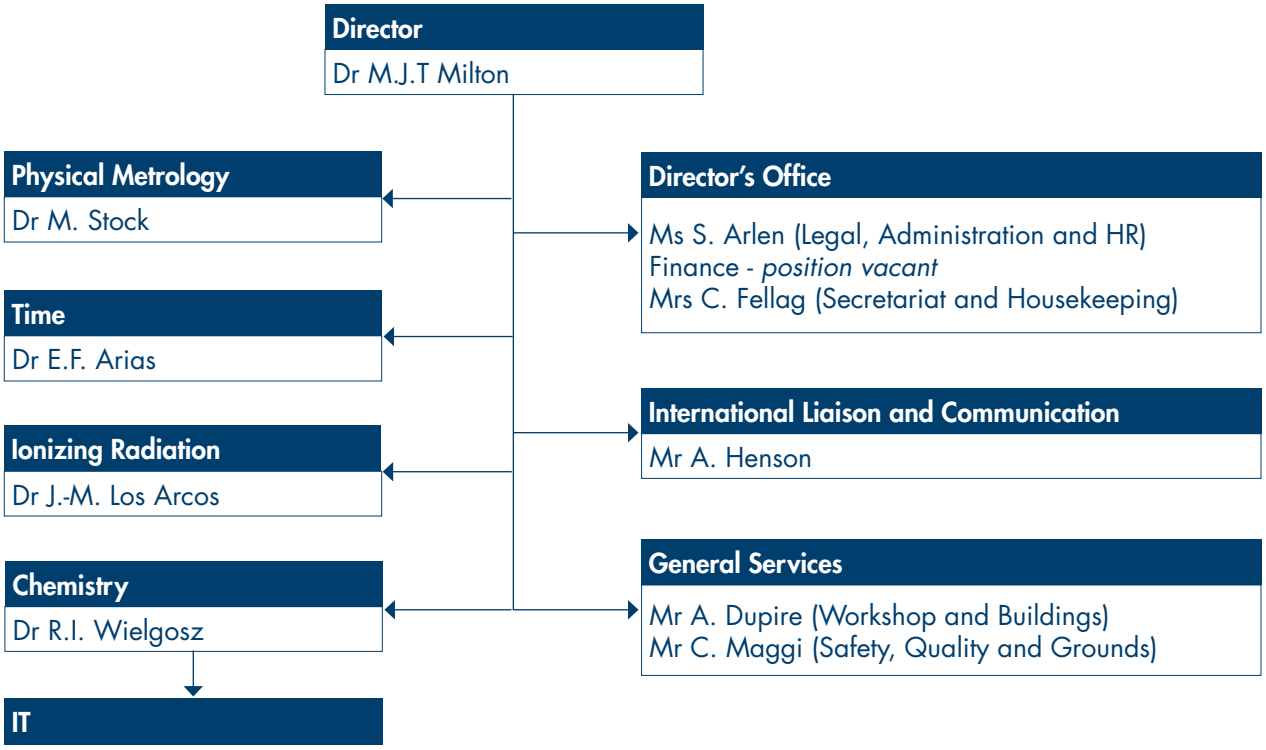
Vice-Presidents

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

Other CIPM members

Dr B. Bowsher (United Kingdom)
Prof. H. Brandi (Brazil)
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)
Prof. M. Inguscio (Italy)
Dr D.-I. Kang (Republic of Korea)
Dr T. Liew (Singapore)
Dr W. Louw (South Africa)
Dr P. Richard (Switzerland)
Dr G. Rietveld (Netherlands)
Dr T. Usuda (Japan)

The BIPM



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 world's increasingly demanding requirements for measurement. Currently much work is under way related to the intended future revision of the SI.

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

Other useful links

The CIPM MRA: **www.bipm.org/en/cipm-mra/**
BIPM liaison work: **www.bipm.org/en/worldwide-metrology/liaisons/**
World Metrology Day: **www.worldmetrologyday.org/**

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