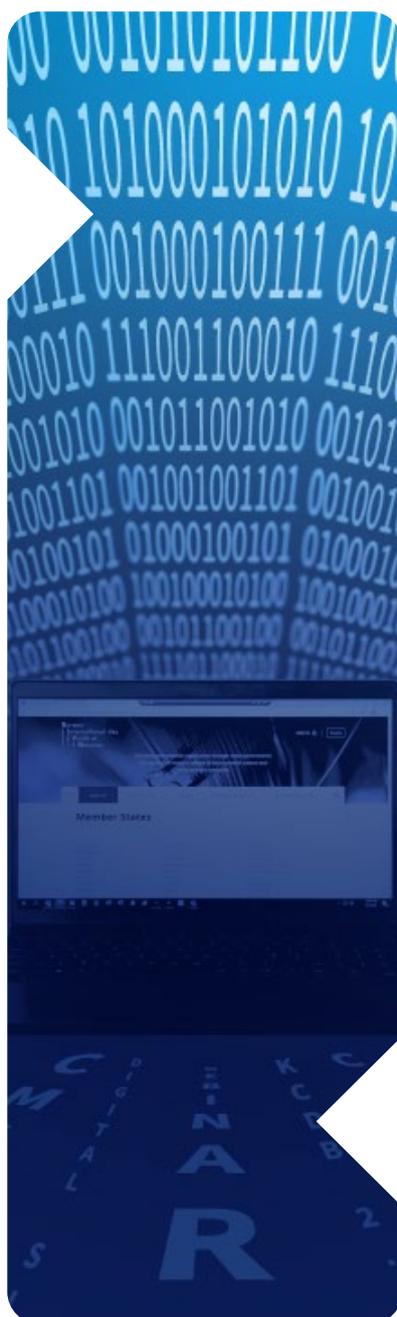


Annual Review 2020/2021





The BIPM

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

THE VISION AND MISSION OF THE BIPM

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

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

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

THE OBJECTIVES OF THE BIPM

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

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

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

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Director's introduction

We report here the highlights of the BIPM laboratory, liaison and coordination work during 2020. These were all achieved during a period when we adapted our activities to be carried out with most staff working remotely because of the confinement measures imposed in France in response to the global COVID crisis.

We have adapted quickly to the new style of working and have made changes to our programme so that we can best serve the metrology community worldwide at this time. We reviewed the content of our capacity building projects to adapt them to deliver remotely. We worked closely with the Consultative Committees of the CIPM to support them in organizing their meetings on-line and in offering on-line webinars to increase the participation in their work. We also responded to a request from the CIPM President to host an on-line repository so that NMIs could share information about their efforts to respond to the pandemic.

Our performance in 2020 was also marked by another year of sound financial performance. We provide summary financial information in this report. The Financial Report is available on line[†].

Finally, we would like to thank all Member States and Associate States/Economies for their support in a time of growing financial uncertainty by paying all contributions and subscriptions on time. As a result, the total amount of contributions and subscriptions received during the 2020 was very close to the amount forecast.

Martin Milton
BIPM Director

Highlights of 2020

- Projects to facilitate machine-readability of data were launched including for the KCDB.
- The first CCM key comparison of realizations of the kilogram, CCM.M-K8.2019, was completed.
- Work continued on new techniques that allow frequency comparison of distant optical clocks.
- The Chemistry Department/CCQM-GAWG joint virtual workshop on '*Accurate Monitoring of Surface Ozone*' included a communication on the intention to implement a change in the globally used value of the ozone cross section and its uncertainty.
- NMIs demonstrated a high accuracy reference measurement system for SARS-CoV-2 testing in a comparison study organized by the CCQM Working Group on Nucleic Acid Analysis.
- A symposium was held to celebrate the centenary of the award of the Nobel Prize in Physics to Charles-Édouard Guillaume.

[†]This report includes summaries of the BIPM financial performance, and complements the Financial Report and the Proceedings of the CIPM, which are available in French and English.

Physical Metrology

Mass

CCM key comparison of realizations of the kilogram

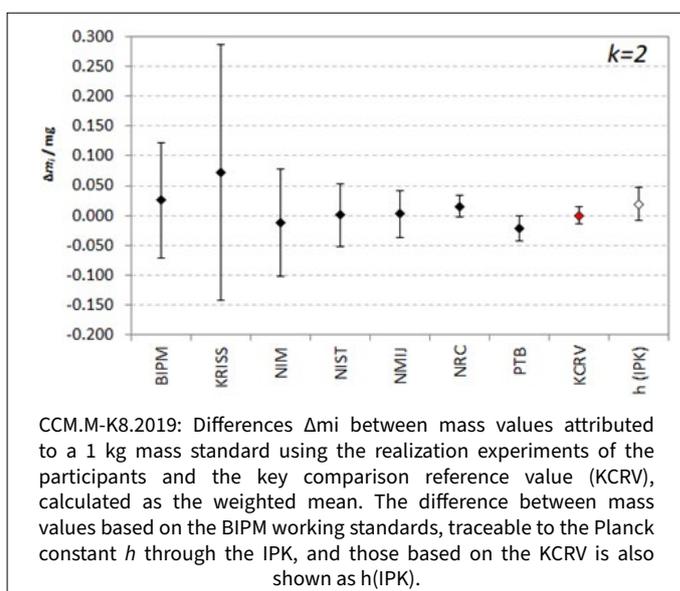
In the field of mass metrology the most important activity in 2020 was the continuation and completion of the first Consultative Committee for Mass and Related Quantities (CCM) key comparison of realizations of the kilogram, CCM.M-K8.2019^[1], which was started soon after the new definition of the kilogram came into force. The objectives of this comparison were to determine the level of agreement between kilogram realizations from different NMIs and to provide information for the calculation of the first CCM ‘consensus value’, which will be the basis for the internationally coordinated dissemination of the kilogram for the coming years. Seven institutes, including the BIPM, participated with realizations based on Kibble balances, a joule balance and the X-ray-crystal-density technique. Each of the participants determined the mass of one or two 1 kg standards under vacuum using their realization method. The BIPM compared all mass standards in a vacuum mass comparator against a reference standard. These weighings, together with the mass values determined by the participants, allowed the comparison of the consistency of the individual realizations. The chi-squared test for consistency using the 95 % cut-off criterion was passed, although the two results with the smallest uncertainty were not in agreement with each other. The weighted mean of the participants’ results for a 1 kg mass standard deviates by -0.019 mg from the value based on the BIPM as-maintained mass unit, which is traceable to the Planck constant through the International Prototype of the Kilogram (IPK).

Consensus value for the mass of the kilogram

The CCM Task Group on the Phases of the Dissemination of the kilogram has calculated the consensus value as the arithmetic mean of the results of the calibration campaign using the IPK in 2014, the CCM pilot comparison of kilogram realizations in 2016 and the key comparison reference value of CCM.M-K8.2019. The consensus value for the mass of the IPK thus determined is $1 \text{ kg} - 0.002 \text{ mg}$. The standard uncertainty is 0.020 mg . Traceability for the SI unit of mass will be taken from the consensus value of the kilogram commencing 1 February 2021. Since the change between mass values based on the current traceability to the Planck constant, h , through its known relationship with the IPK, and the new values, based on the consensus value, is small in relation to the uncertainties, no adjustment to the international mass scale needs to be made. However, NMIs with CMCs below or close to 0.020 mg at the level of 1 kg will need to increase their calibration uncertainty

The BIPM participated using its Kibble balance in the key comparison of kilogram realizations with a relative uncertainty of 4.9×10^{-8} . A paper describing the apparatus, measurement results and the uncertainty budget was published^[2]. The operation of the apparatus has been

continuously improved and automated. In particular, the frequency servo-control of the laser source for the interferometer was upgraded^[3]. Investigations have been pursued to refine the electrical measurements to reduce the second largest uncertainty contribution due to current leakage during voltage measurement. Work has started towards the ‘Mark II’ version of the BIPM Kibble balance. As a first step, new middle and lower suspensions were designed and fabricated. A new bifilar coil with more turns was wound. The ensemble has been adapted and integrated into the present apparatus. The next step will be to change the upper suspension and to replace the commercial force sensor with a home-made sensor to reduce the largest uncertainty due to misalignment.



Calibrations of 1 kg mass standards

The BIPM continues to provide calibrations of 1 kg mass standards for the NMIs of its Member States. During 2020, traceability to the new definition was achieved via the known relationship between the mass of the IPK and the Planck constant. This changed on 1 February 2021, when the CCM consensus value was implemented.

Electricity

quantum Hall resistance standards

During 2020 no on-site comparisons of quantum Hall resistance standards (BIPM.EM-K12) were carried out, but the reports of the recent comparisons with KRISS (Republic of Korea)^[4], NIM (China)^[5] and NMIJ (Japan)^[6] were finalized and published. The interest in such comparisons is high as demonstrated by a survey carried out among NMIs. Nine NMIs have expressed interest in participating in the BIPM.EM-K12 programme by 2024. The frequency and power coefficients of the set of resistance standards (1 Ω , 100 Ω and 10 k Ω) used for these comparisons were remeasured to complete the historical data sets. These coefficients must be known with the best possible uncertainty in order to reduce the overall uncertainty of the on-site QHR comparisons. Resistance metrology has moved into a new laboratory, which is equipped with a new Faraday cage which offers more space and significantly better electromagnetic screening than the previous laboratory.

A new cryogenic sample probe was fabricated for QHR measurements. This probe has been designed for specific commercial graphene QHR devices. The investigation into this application started at the end of 2020. It is anticipated that this study will demonstrate that these devices are sufficiently reliable for use in resistance metrology at the BIPM. Replacing GaAs QHR devices with graphene devices would simplify the implementation of this primary standard and reduce utilization costs. This would be particularly interesting for the on-site QHR comparison programme.

Traceability of the BIPM 10 pF and 100 pF reference capacitors is realized from the QHR through a multifrequency quadrature bridge. These references were calibrated twice in 2020 and their frequency dependence was re-determined^[7]. Traceability of the 1 pF reference capacitors was re-established in view of their future use in the measuring chain that will link the calculable capacitor to the reference group of 10 pF capacitors.

Voltage metrology

In the field of voltage metrology, the global coronavirus pandemic prompted a modification of the scheduled activities: an on-site comparison of dc Josephson voltage standards with BIM (Bulgaria) was cancelled but a number of requests for calibrations of secondary voltage standards were addressed and completed.

Within the framework of a collaboration with the PTB (Germany), the KRISS (Republic of Korea), the NMIA (Australia) and the VNIIM (Russian Federation) to develop a protocol for a future BIPM comparison of ac quantum voltages, a pilot study with the PTB on the differential sampling technique in the BIPM laboratory had to be interrupted because of the coronavirus lockdown. This collaboration will resume when travel restrictions due to the pandemic are relaxed. In the meantime, work in the laboratory continued with the implementation of a second calibrator to serve as a secondary standard for ac voltage using the differential sampling technique. As part of the collaboration with the KRISS^[8], a new sampler was delivered to the laboratory and is expected to be implemented in the near future. Two computer-controlled low thermal electromotive force switches were developed in collaboration with the PTB. They will be used in the future ac voltage differential sampling comparison to switch the 10 MHz reference signal and the output ac voltage of the transfer standard between the setups of the BIPM and the participant.

Calibrations

In 2020, a total of 69 calibrations were provided by the electricity laboratories to NMIs: 26 for resistance, 38 for capacitance and five for voltage. In addition, a BIPM.EM-K13 resistance comparison with the EMI (United Arab Emirates) and a BIPM.EM-K14 capacitance comparison with the SASO (Saudi Arabia)^[9] were carried out. Two other BIPM.EM-K13 comparisons with INMETRO (Brazil) and NSAI NML (Ireland) and a BIPM.EM-K11 voltage comparison with the NSAI are under way.



Time

Throughout 2020, the Time Department devoted considerable effort to maintaining the regular production of Coordinated Universal Time (UTC), rapid UTC (UTCr), and the contribution to the key comparison CCTF-K001.UTC during the disruption caused by the coronavirus pandemic. The quality of the department's work was maintained despite the necessity by almost all of the time laboratories around the world to work remotely. A considerable collaborative effort among the national laboratories that supply data allowed the BIPM to maintain regular publication of its products and allowed their continued use by the time laboratories. Of particular importance was the almost normal operation of primary and secondary frequency standards with two new caesium fountains providing data from NRC (Canada) and NPL (UK), as well as a new ytterbium standard from NMIJ (Japan). The contribution of primary and secondary frequency standards (PSFS) is illustrated in a plot maintained at the BIPM and updated every month. The reporting of the PSFS measurement uncertainty was updated in *Circular T* by improving the contribution of the laboratory uncertainty.

A statistical analysis of the behaviour of H-masers has allowed an understanding of possible changes in the UTC algorithm parameters to improve long-term stability. Tests that were aimed at improving the robustness of UTCr have been implemented, in particular to improve the data transfer procedure from UTC to UTCr after the calculation of *Circular T*. A paper describing a revised algorithm for the evaluation of uncertainties on [UTC - UTC(k)] as reported in *Circular T* was published^[10].

The two-way satellite time and frequency transfer (TWSTFT) Software Defined Radio receiver (SDR) on the LNE-Syrté - Observatoire de Paris and the PTB (OP-PTB) link was calibrated, approved and entered use as an official link in UTC calculation in March 2020. Research into improving the TWSTFT technique is progressing, with tests of a new SRS modem, initiated by NICT (Japan), being conducted within the CCTF Working Group on Two-Way Satellite Time and Frequency Transfer (CCTF-WGTWSTFT).

A study has been carried out to set a reference value for the calibration of the GPS and Galileo receivers of the UTC time laboratories, by using all the known sources of absolute calibrations, in collaboration with ORB (Belgium). A new mobile calibration box (B4TS) has been built around two multi-GNSS receivers; one of these has since undergone absolute calibration by CNES. The expected performance matches that of current SATRE modem specifications and the intention is to use the B4TS for TWSTFT calibration trips. Despite logistical problems due to the Covid-19 pandemic, calibration exercises for GNSS equipment for UTC links were carried out; the 2020 BIPM Group 1 trip within the Asia-Pacific region is under way and 15 Group 2 results have been provided by UTC laboratories. A project to centralize and standardize the software routines for monitoring automatic UTC data collection has started. The GNSS calibration database has been updated to include

the calibration of Galileo signals, which have become available since the last calibration campaigns.

A collaborative study on the time interoperability of GNSS, using UTC as a pivot time scale to estimate the offset between two different GNSS time scales, was submitted^[11], and an invited paper on the mutual benefit of GNSS and timekeeping was published^[12]. The Time Department's support to the ACES-PHARAO mission continues with the aim of understanding the feasibility of a high accuracy microwave link for possible future use in UTC^[13,14].

A Memorandum of Understanding was signed between the BIPM and the International Telecommunication Union (ITU) in June 2020.

New radio techniques allow frequency comparison of distant optical clocks

Optical clocks have reached a proven accuracy of the order of 10^{-18} in relative frequency, surpassing the present Cs fountains by two orders of magnitude and driving the CCTF to initiate work towards a redefinition of the second. However, comparing these clocks with a similar uncertainty is only possible using optical fibres and is presently limited to a few links at distances not exceeding 1000 km. Radio techniques have world-wide coverage and are currently regularly used in UTC with GNSS-based techniques and Two-way time transfer using geostationary satellites, but they have limited accuracy.

An international collaboration between the NICT (Japan), INRIM (Italy), INAF (Italy) and BIPM has compared the Yb lattice clock at INRIM and the Sr lattice clock at NICT using two new and independent radio techniques. One is Very Long Baseline Interferometry (VLBI), a technique used in astronomy for observing extra-galactic objects, and which has been used for the first time for accurate frequency transfer thanks to the development of mobile antennas and *ad hoc* hardware and processing facilities. The second technique is Integer ambiguity Precise Point Positioning (IPPP) using GNSS signals, the development of which has been driven by the BIPM over the past few years.

The results obtained with the two techniques agree within the uncertainty of the frequency comparisons, below 3×10^{-16} in relative frequency for each technique^[15,16] and both VLBI and IPPP have the potential to yield further improvements in accuracy.

Ionizing Radiation

The year 2020 marked the 60th anniversary of the decision taken during the 11th meeting of the General Conference on Weights and Measures (CGPM) to establish an Ionizing Radiation department at the BIPM. The rationale for the department has not changed – helping to ensure safe and effective use of ionizing radiation in healthcare and industry by providing comparison services for radiation dosimetry and radioactivity, as well as associated calibration services for dosimetry. Applications continue to evolve, the development of radiopharmaceuticals for cancer therapy being just one example (a new Consultative Committee for Ionizing Radiation (CCRI) Working Group has been set up to address the needs of this growing field).

Machine readable SIR data

Comparisons of national standards of gamma-emitting radionuclides rely on the International Reference System (the SIR). Development of the SIR in 2020 focused on making the results from comparisons accessible and machine readable. A comprehensive database of measurements was developed and populated, with more than 1000 detailed entries on measurements from 1976 to the present day. New software has been written to automate the generation of comparison reports and to calculate key comparison reference values, reducing significantly the time needed to prepare reports. Software has also been developed to convert the database into machine-readable formats (XML and JSON) to enable studies of the accuracy of primary standards.

The SIR (a re-entrant ionization chamber) relies on the accurate measurement of low electrical current. Recent developments in electrical metrology have included an Ultra-stable Low Current Amplifier (the ULCA, see ref.^[17]), which could offer a high-precision, high-linearity technique to reduce the dependence on sealed radioactive sources. The results from initial measurements have shown promise and investigations to reduce electronic noise are under way.

Many radionuclides used for medical imaging have short half lives; the time needed for shipping sources to the BIPM means that the SIR is not always suitable for these radionuclides. The transportable version of the SIR (the SIRTl) enables comparisons of radionuclides with short half lives to take place on site at a metrology institute, thus avoiding shipping delays. The SIRTl is operated by BIPM staff but, to make the service easier to access, the SIRTl is being adapted so that the instrument can be used by staff from metrology institutes with remote oversight by departmental staff. The first ‘remote’ SIRTl comparison is planned for 2021. In the meantime, the SIRTl has been characterized for two radionuclides (¹²³I and ¹⁵³Sm) to increase the number of radionuclides covered by the instrument.

The SIR and SIRTl can only be used if the radionuclide emits gamma rays; a new instrument (the ESIR) has been developed to offer a similar service for comparing standards of pure beta-emitting radionuclides (needed for applications such as life sciences and environmental monitoring). The ESIR is based on a liquid-scintillation counting technique (the Triple-to-Double Coincidence Ratio (TDCR) method). A detailed study has been carried out to test the optimum parameter to use to compare standards^[18] and a pilot international comparison is under way. A paper on the estimation of measurement uncertainties has been published^[19].

Radiation dosimetry comparisons

Comparisons for radiation dosimetry have continued. A total of eleven comparisons were carried out, for Australia (3 comparisons), Austria (2), Canada (2), Poland (3) and the Russian Federation (1). Sixteen calibrations were made, for Argentina (4 calibrations), Denmark (4), Spain (2), South Africa (4) and the IAEA (2). Comparisons and calibrations using the LINAC at the DOSEO platform also continued (one comparison with Canada and three calibrations for the IAEA).

Medium-energy x-ray generator

After nearly two decades of reliable operation, the medium-energy x-ray generator had to be replaced. A new generator has been commissioned and validated and is now in routine use. A new x-ray tube has been purchased and a support system including beam collimation and filtration has been designed and is under construction. The main advantage of this new arrangement is remote changing of the beam filtration with a consequent improvement in beam stability. The new x-ray tube is the first part of the project to renew the existing facility, to be followed by a new measurement bench and a new primary standard instrument.

Knowledge transfer

Staff from the department have continued involvement in knowledge transfer activities using remote-conferencing technologies. A series of technical webinars has started; a presentation on traceability was given at a seminar organized by the Kenya Bureau of Standards and staff participated in the EURAMET and APMP technical committees. A series of recorded presentations have been developed with guidance on submitting CMC claims, on behalf of the CCRI RMO Working Group on IR CMCs (CCRI-RMOWG). These will be made available on the BIPM e-learning platform.

Chemistry

The Chemistry Department progressed 15 interlaboratory comparisons in 2020, including preparatory work with NMIs to launch a study (CCQM-P216) on the Quantification of SARS-CoV-2 antibodies, in September 2020. Fifteen comparison reports and BIPM rapports; and two papers in peer reviewed journals were published. Three visiting scientists from NMIs participated in the department's activities benefiting from the "Metrology for Clean Air" and "Safe Food and Feed" programmes, as well as contributing to the comparison programme on therapeutic and diagnostic peptide standards. The department hosted 76 online meetings, for eleven working groups of the Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM) and the Joint Committee for Traceability in Laboratory Medicine (JCTLM) in 2020. Two webinars on the 'Reliability of measurements in response to the Covid-19 pandemic', and an online workshop on a globally coordinated implementation of a more accurate ozone cross section value for atmospheric ozone measurements took place. A special issue of the JCTLM Database Newsletter discussed testing for Covid-19. The department co-organized the 'Therapeutics and Diagnostics, Measurement, Standards, Quality and Safety' symposium (TD-MDQS 2020) in Nanjing (China) on 10-12 November 2020. It was held as a hybrid meeting.

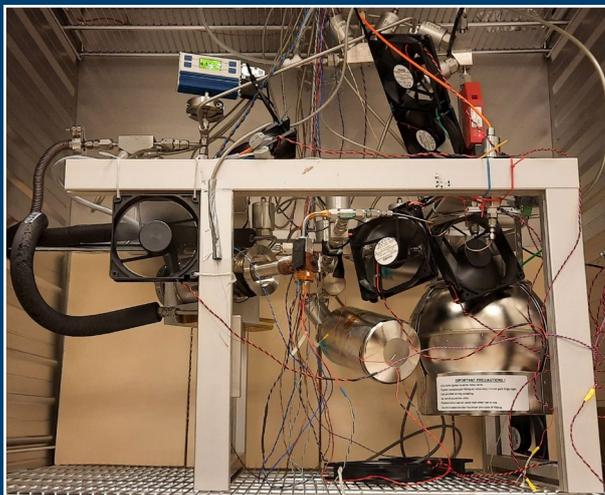
Metrology for the Environment

In its programmes related to Metrology for the Environment, the Chemistry Department continued its programme of comparisons to ensure global equivalence of standards for major greenhouse gases and air quality pollutants. Validation of the BIPM's primary manometric system for CO₂ measurements, in support of a planned ongoing comparison of CO₂ standards (BIPM.QM-K2), demonstrated standard deviations of 0.05 µmol/mol for the measurement of CO₂ in air standards in the range 380 µmol/mol to 800 µmol/mol. A facility was established to verify the stability of the manometric system.

Comparison of CO₂ isotope ratio standards

The comparison of CO₂ isotope ratio standards (CCQM-P204) for pure CO₂ samples, coordinated jointly by the BIPM and the International Atomic Energy Agency (IAEA), continued with 60 of 76 cylinders having been received from the 16 participating laboratories. Validation of the sample preparation system at the BIPM is complete, with confirmatory mass spectrometry measurements having been performed at the IAEA. The performance of the optically based measurement system at the BIPM has been demonstrated and published^[20]. An isotope ratio mass spectrometry (IRMS) system has been installed at the BIPM; its operation has been validated and measurement methods have been developed with the support of an external expert, Dr Colin Allison.

BIPM Manometric reference facility for the comparison of CO₂ in air standards



The facility was developed at the BIPM in collaboration with visiting scientists from the NIST (USA) and RISE (Sweden). It operates through the principal of cryogenic separation of CO₂ from air samples, with measurement of pressure, temperature and volume of both samples. Initially validated in the CCQM-P188 and CCQM-K120 comparisons, the facility will provide reference values for the future on-going BIPM.QM-K2 comparison of CO₂ in air standards. It will allow on-demand comparisons of NMI/DI standards in the range of 380 µmol/mol to 800 µmol/mol and will support measurement services for atmospheric greenhouse gas monitoring and authentication of CO₂ emission levels.

Nitrous oxide in air standard comparison

Measurements for the nitrous oxide (N₂O) in the air standard comparison (CCQM-K68.2019) have been completed at the BIPM. Eighteen standards have been compared using gas chromatography with electron capture detection (GC-ECD) and laser spectroscopy methods.

Air quality measurement standards

Projects in support of air quality measurement standards focused on ozone and nitrogen oxides during 2020. The department hosted and organized, together with the CCQM Working Group on Gas Analysis (CCQM-GAWG), a virtual workshop from 5 to 9 October 2020 on 'Accurate Monitoring of Surface Ozone'. Its recommendations, which were published before the end of 2020, included a communication on the intention to implement a change in the globally used value of the ozone cross section and its uncertainty, with the change process estimated to take between three to five years to complete.

Comparison of ozone standards

Two laboratories, ECCC (Canada) and METAS (Switzerland), sent their ozone standards to the BIPM for comparison with BIPM held standards and to participate in BIPM.QM-K1. Ten comparison reports were published^[21-30]. Draft A reports for the comparison of NO₂ in N₂ standards at 10 µmol/mol (CCQM-K74.2018) were prepared by the BIPM and discussed in three online meetings with participants. Agreement was reached on calculation of the key comparison reference value that takes into account decay in concentration as a function of time and knowledge of the decay profile at the time of the comparison. Measurements on the related pilot study of HNO₃ (CCQM-P172) were completed, and the draft report prepared. A visiting scientist from KEBS (Kenya) completed the Metrology for Clean Air Course on FTIR Measurements on Gas Standards in the BIPM laboratories, which will enable FTIR facilities in gas metrology to be set up at KEBS.

Metrology for Health

The department's programmes related to Metrology for Health published comparison reports on oxytocin (a peptide calibrator material) coordinated by the BIPM (CCQM-K155.b^[31] and -P55.2.b^[32]). A CITAC 2019 best paper award was given to scientists from the BIPM and NMIs for a publication on traceability for peptide and protein quantification^[33]. Measurements on samples for comparisons on hexapeptide calibrators for the HbA1c glycated hexapeptide (GE) (CCQM-K115.c and CCQM-P55.2.c), and the non-glycated hexapeptide (VE), (CCQM-K115.2018 and CCQM-P55.2.2018), were completed by participating NMIs. The results were submitted to the BIPM for presentation at an online meeting of the CCQM Working Group on Protein Analysis (CCQM-PAWG). Accurately characterized hexapeptides to provide an alternative calibration hierarchy, is being developed at several NMIs, for the measurement of glycated haemoglobin, an important biomarker in diabetes care and treatment. Characterization of triskelion peptides, as candidates for future comparisons, was completed by a visiting scientist from NPL (UK). The BIPM established a comparison pilot group with NMIs in the CCQM-PAWG to support NIM (China) in developing the protocol for a CCQM pilot study on SARS-CoV-2 antibody quantification. The protocol was finalized and approved by the CCQM as CCQM P216, and coordinated by NIM, NRC (Canada) and the BIPM.

JCTLM

The Chemistry Department continued to support the JCTLM, by providing the secretariat for the committee and hosting the JCTLM Database of Reference Materials, Methods and Services. The secretariat's work in 2020 included: preparation of 80 nominations for JCTLM database entry review; publication of 30 new entries in the JCTLM database from 2019 nominations; processing the appointment of 70 JCTLM Review Team members for 12 review teams; ensuring resources for the JCTLM process for the next

5-years; developing technical specifications for a new JCTLM database on supported software platforms and introducing the possibility of machine readability; organizing and publishing newsletters on JCTLM activities over the last year; and publishing a special issue of the JCTLM Database Newsletter related to testing for Covid-19. The department organized and hosted two CCQM webinars on the reliability of measurements in response to the Covid-19 pandemic; the first focused on molecular and antibody testing, and the second on antigen and mass spectrometric measurement systems.

Metrology for Safe Food and Feed

In its programmes related to Metrology for Safe Food and Feed, the department published the first comparison report (CCQM-K154.a and a.1)^[34]. The supplementary comparison on Mycotoxin Calibration Standards was completed in the first quarter of 2020 at the BIPM. Preparation of pesticide comparison materials, trifluralin and methoxychlor multicomponent solution (270 units), were completed for CCQM-K78.b, (multi-component non-polar compounds). A review paper for the International Union of Pure and Applied Chemistry (IUPAC) on organic purity was submitted for publication. The reference value for the CCQM-K148.a comparison (bisphenol A calibrator purity) was agreed with the CCQM Working Group on Organic Analysis (CCQM-OAWG), and the final report prepared. The fifth meeting of the CBKT programme on "Metrology for Safe Food and Feed", coordinated by the department, was organized as an online meeting discussing mycotoxin, veterinary drug residues and pesticide standards.

Mycotoxin standards

The laboratory programme on mycotoxin standards was supported by a visiting scientist from NIM (China) who worked on patulin materials and preparations for the CCQM-K154.d comparison. The comparison protocol for aflatoxin B1 calibration solutions (CCQM-K154.b) was approved by the CCQM-OAWG; samples were received at the BIPM from NMISA (South Africa) and NIM (China) for measurement in 2020. The remaining laboratories will submit samples during 2021. The guideline for calibrant solution assessment for zearalenone was published^[35]. The collaborative project on an ochratoxin A calibrant material comparison with NRC (Canada) continued, with progress in the preparation of bulk material at NRC. The collaborative project on veterinary drugs continued with the first series of measurements on four tetracycline materials completed at UME (Turkey). Quantitative NMR (qNMR) and liquid chromatography/ultraviolet spectroscopy (LC-UV) measurements were performed on oxytetracycline at the BIPM, which is the proposed material for the CCQM-K148.b comparison.

International Liaison and Communication

Each year on 20 May, the global metrology community celebrates the day the Metre Convention was signed in 1875. The project is run jointly by the BIPM and the International Organization of Legal Metrology (OIML). The theme chosen for 2020 was “Measurements for global trade” to raise awareness of the importance of measurement in facilitating fair global trade by ensuring products meet standards and regulations and satisfy customer quality expectations. The 2020 poster was designed in collaboration with the AFRIMETS RMO, specifically with AA&W Legal Metrology Egypt, and translated into more than 20 languages. The 2020 World Metrology Day Resource Website <https://www.worldmetrologyday.org> listed a further 23 national celebratory events.

The BIPM and OIML undertook a significant review of document OIML D 1 “Considerations for a Law on Metrology”, edition dated 2012, with their stakeholders. The document was broadened in scope and published with a new title “National metrology systems – Developing the institutional and legislative framework” as a joint BIPM/OIML publication. It is available on the websites of both organizations.

A Joint Task Group was established between the BIPM (representing the States Parties to the Metre Convention) and the OIML to foster enhanced cooperation between the two organizations.

The BIPM interacted with the International Laboratory Accreditation Cooperation (ILAC) on the following documents during the reporting period: ILAC P10:07/2020 “ILAC Policy on Metrological Traceability of Measurement Results”; ILAC P14:09/2020 “ILAC Policy for Measurement Uncertainty in Calibration” and G18:04/2010 “Guideline for the Formulation of Scopes of Accreditation for Laboratories”. The scope of BIPM input to these documents is governed by the CIPM.

The BIPM and the World Trade Organization (WTO) cooperate to ensure effective dissemination of information on the importance of the quality infrastructure. A particular focus of this cooperation is metrology as one of the key components among trade regulators and international/intergovernmental organizations that hold *ad hoc* observer status at the WTO Committee on Technical Barriers to Trade (WTO TBT Committee). BIPM staff submitted the BIPM statements and attended the virtual meeting of the WTO TBT Committee in October 2020.

The Organisation for Economic Co-operation and Development (OECD) established the *Partnership of international organisations for effective international rulemaking* (IO Partnership) as a voluntary platform of international organizations (IOs), academics and OECD Regulatory Policy Committee delegates. Its aim is to exchange good practices and promote greater quality, effectiveness, and impact in international rulemaking. The IO Partnership is currently working on a Compendium, which will use examples from the BIPM and many other IOs to highlight how IOs work better together and how they can learn from

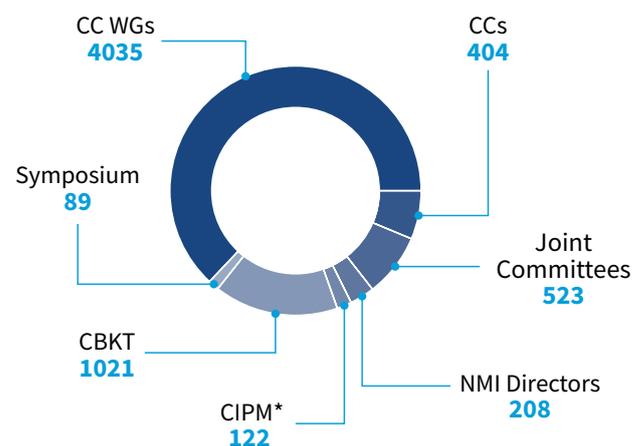
each other about best practices. The BIPM cooperates with the OECD within the IO Partnership to promote the value of a sound approach to metrology, the contribution made by the national metrology infrastructures, and their importance in underpinning effective international rulemaking. The BIPM has a shared role as focal point within WG5 on coordination among IOs to better tailor the specific needs of IOs and to address in-depth IO coordination issues that arise. The BIPM continues to contribute to the work of the working groups for implementation and evaluation of international instruments.

Dr Martin Milton, Director of the BIPM, together with the heads of other IOs, participated as a panellist in the OECD high-level webinar: “International Organisations and their Members Facing the Global Crisis Together”. The virtual meeting was held on 3 September 2020 as part of the 7th Annual IO Meeting within the context of the IO Partnership. Following this webinar, a second webinar: “The IO Partnership in Action: Towards a Compendium of IO Practices and Beyond - Self-reflection, Peer-Learning and Adapting to a Changing World” was held. During this webinar, the BIPM reported on the outcomes of the ‘WG5 on Coordination among IOs’ breakout session, which was held on 31 August 2020.

The BIPM and the United Nations Educational, Scientific and Cultural Organization (UNESCO) cooperate to ensure effective dissemination of information on the importance of the quality infrastructure and particularly metrology in the scientific and wider context. BIPM staff attended the Sixth Special virtual session the Executive Board of UNESCO in June 2020.

The BIPM formalized its long-standing cooperation agreements with the International Telecommunication Union (ITU) and the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) in June and September 2020 respectively, through the electronic signature of two Memoranda of Understanding.

Meeting attendance in 2020



*Includes CIPM, WGs, SCs, bipartite and quadripartite meetings

Capacity Building & Knowledge Transfer

The CBKT programme responded rapidly to the challenges created by the coronavirus pandemic during 2020. A dynamic approach was adopted and its activities shifted to meet the demands for online participation. Physical meetings were supplemented by online workshops and webinars, with 1071 people participating in CBKT activities during the year. The development of remote learning capabilities accelerated and continues in 2021.

BIPM-EURAMET Workshop: “the KCDB 2.0”

17-19 February 2020 at the BIPM

The two and half day workshop was designed for EURAMET experts involved in CIPM MRA processes. Its aim was to equip TC Chairs and TC Members (CMC reviewers) with the skills to use the KCDB 2.0 effectively and efficiently.

This was the last workshop held physically at the BIPM before the coronavirus pandemic. There were 29 participants.

Following the lockdowns resulting from the Covid-19 outbreak it quickly became apparent that organizing physical meetings would be challenging for the foreseeable future. The “KCDB 2.0” workshop was rapidly reconfigured and offered as an online workshop.



Participants at the BIPM-EURAMET Workshop held at the BIPM in February 2020

Mycotoxin Metrology Capacity Building and Knowledge Transfer programme (MM-CBKT)

27 November 2020 - online

This project is designed to allow NMIs to work together to strengthen the mycotoxin metrology infrastructure; provide knowledge transfer to scientists developing capabilities in this area; and enable NMIs to provide mycotoxin calibrant and matrix reference materials and proficiency test materials to support mycotoxin testing laboratories within their countries.

BIPM CBKT Programme extended to include remote-learning

In response to the Coronavirus pandemic, the BIPM CBKT Programme accelerated the development of its online presence and added a “remote-learning” capability in 2020. It provides online assistance to NMI/DI staff from Member States and Associates involved in the CIPM MRA.

The remote learning support has two elements aimed to optimize use of the KCDB tools:

KCDB 2.0 - Online short course

This webinar course aims to improve the skills of users of the KCDB tools for the creation of CMCs, operation of the review process, and piloting of comparisons. The courses are expected to be delivered in consultation with a particular RMO, with dedicated content tailored to the RMO’s requirements. The first online short course was:

- **BIPM-COOMET Workshop: “the KCDB 2.0”**

25-27 May 2020 - 100 participants

KCDB 2.0 - Online technical exchanges

These one-hour online technical exchanges focus on particular topics related to the KCDB and typically require participants to prepare by watching a selection of short video clips and/or presentations. The sessions are based on a ‘questions and answers’ format with experts from the BIPM team.

The technical exchanges have been organized to deal specifically with how to use the KCDB 2.0 facilities for different groups, such as creating CMCs in the KCDB or managing the review process. During the reporting period ten individual online sessions were held.



Participants in the online BIPM-COOMET Workshop: “the KCDB 2.0” in May 2020

The CIPM MRA

A new version (the KCDB 2.0) was launched on 29 October 2019, offering a collaborative web platform for editing and reviewing Calibration and Measurement Capabilities (CMCs) as well as extended search facilities. An API was added in 2020, allowing the generation of customized statistics depending on regional body, country or metrology area (see below). The CMC platform and web support for comparisons have been extensively employed by users during 2020. Support in the form of written instructions and videos have also been developed.

The API KCDB

The BIPM has recently developed an Application Programming Interface (API) for CMCs published in the KCDB (API KCDB). Direct coded queries for CMCs in the KCDB may be addressed via the API, independently of the KCDB web site, providing machine access to the publicly available data. The API KCDB has been beta-tested in collaboration with several NIMs. Some adjustments to the vocabulary are presently being made before making the API openly available.

This development presents several advantages. It may be integrated in languages other than English. The KCDB web offers the possibility to generate statistics tailored to the RMO, metrology area or state economy profile. The API KCDB gives the opportunity to widen the statistical projections and can contribute to big data evaluations. It is also pertinent for the provision of data for digital calibration certificates, a topic which is presently under study.

Key and supplementary comparisons

On 31 December 2020, the key and supplementary comparisons database included 1 087 key comparisons and 634 supplementary comparisons. This represents an increase of 40 key comparisons on the previous year, while supplementary comparisons increased by 46. Around 101 comparisons were completed and published during 2020. Today, almost 90% of the 97 ongoing BIPM key comparisons and around 70% of all registered comparisons of the Consultative Committees and RMOs have results published in the KCDB. Almost all Associates participating in the CIPM MRA had at least one of their metrology institutes listed as a participant in a key or a supplementary comparison.

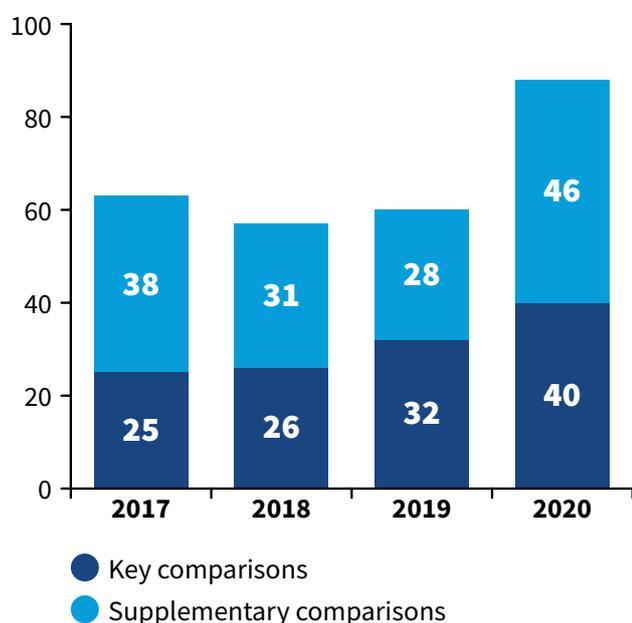
The KCDB currently includes a dozen examples where more than seven key comparisons are linked together.

Calibration and Measurement Capabilities

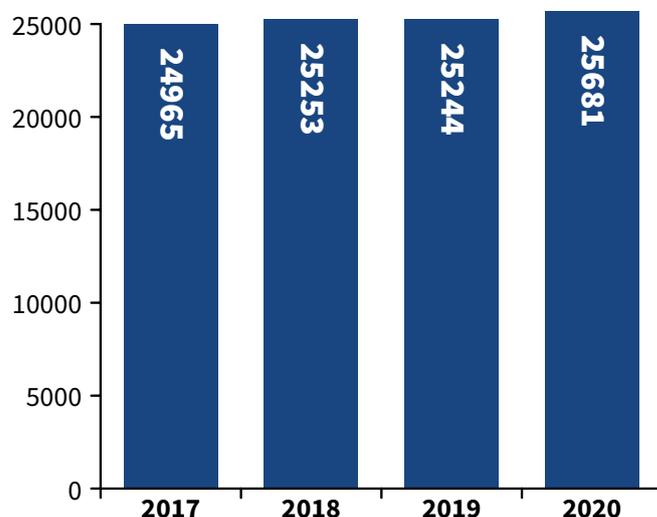
On 31 December 2020, there were 25681 CMCs registered in the KCDB. Of these, 15482 were in the field of general physics, 3853 in ionizing radiation, and 6346 in chemistry. The total number of CMCs increased by 437 in 2020. Twenty-three of the 40 Associates that participate in the CIPM MRA had CMCs published in the KCDB at the end of 2020.

It is possible to temporarily withdraw CMCs from the database by “greying out”. At the end of 2019, 511 CMCs were “greyed out”, an increase of 6% since the previous year, mainly linked to obsolete quality management proof and postponed activities.

Number of new comparisons registered in the KCDB



Total number of CMCs registered at 31st December



BIPM and the coronavirus pandemic

Highlights of the BIPM's response to the Covid-19 pandemic include:

Response to COVID-19 repository

The CIPM President asked NMIs to share examples of how their work is supporting the fight against the pandemic – for example by applying expertise in measurement science to assist with the development of personal protection equipment, medical devices, certified reference materials or have joined efforts to find a vaccine.

The responses received from the NMIs are listed in a dedicated 'Metrology in the fight against COVID-19' repository, which is available on the BIPM website.

JCTLM Newsletter on reliability of measurements in COVID-19 diagnostics

A special edition JCTLM Newsletter focusing on reliability of measurements in COVID-19 diagnostics was published in July 2020.

The newsletter focused on "reliability of measurements in COVID-19 diagnostics", to facilitate knowledge transfer on ongoing activities in the JCTLM community. The primary purpose was to inform readers of new developments that focus on the "reliability of measurements in COVID-19 diagnostics", including reference materials, reference measurement methods, interlaboratory comparisons and relevant research, publications and seminars.

CCQM Webinars on 'Ensuring the reliability of measurements in response to the COVID-19 pandemic'

The first two in a series of CCQM webinars on activities ensuring the reliability of measurements were held on 7 July and 10 December 2020.

Presentations included:

- Review of diagnostic modalities involved in the response to the COVID-19 pandemic, J. Moran-Gilad
- International proficiency testing scheme results with molecular diagnostics for SARS-CoV-2, Heinz Zeichhardt
- SARS-CoV-2 Antibody testing and what we can learn from interlaboratory studies, M. Neumaier
- The Development and Assessment of COVID-19 Serological Platforms, M.A. Drebot
- Molecular testing for SARS-CoV-2, standardization, challenges and needs, M. Zambon
- Validation and implementation of rapid antigen testing for detecting SARS-CoV-2 infection, C. Geurts van Kessel
- Experiences from projects for MS-based SARS-CoV-2 detection, H. Vissers

The webinars can be viewed on the BIPM YouTube channel.

NMIs demonstrate high accuracy reference measurement system for SARS-CoV-2 testing

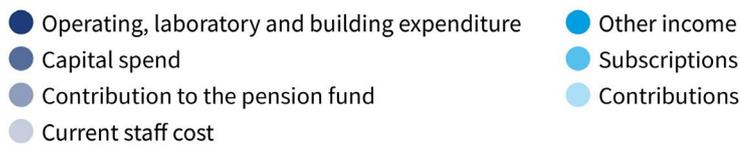
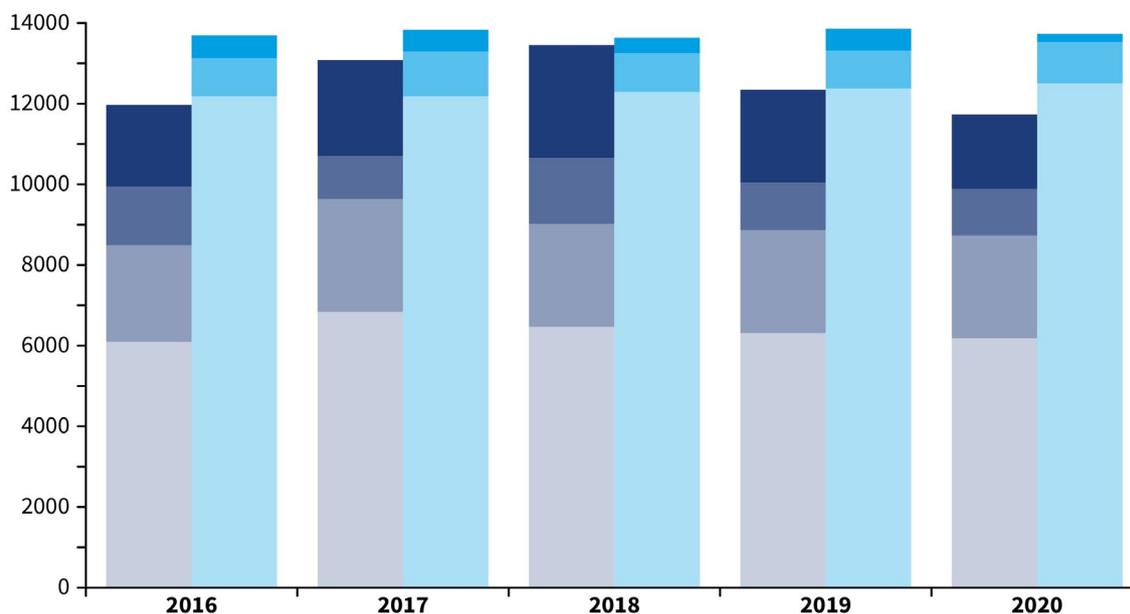
Twenty-one National Metrology Institutes and expert laboratories from sixteen countries demonstrated that highly accurate measurements of the amount of the SARS-CoV-2 viral RNA can be achieved world-wide using reverse transcription-digital PCR (RT-dPCR). The ability to accurately measure the amount of the viral cause of COVID-19 with global equivalence will considerably improve testing confidence and support countries in effectively tackling the pandemic.

The comparison study (CCQM-P199.b), organized by the CCQM Working Group on Nucleic Acid Analysis (CCQM-NAWG), and coordinated by the National Measurement Laboratory at LGC (UK), NIM (China), NIBSC (UK) and NIST (US), required quantification of the same viral genetic sequences targeted by many of the diagnostic tests. The RT-dPCR results were found to agree very well with each other and different SI-traceable non-molecular orthogonal methods; most values were within +/-40% of the mean. The reproducibility of the method is unprecedented for absolute molecular measurements, where orders of magnitude of spread in reported copy numbers can be found using conventional molecular diagnostic methods. This work, made possible by over a decade of CCQM led collaborative efforts within the bio-metrology community, represents the most comprehensive example of highly reproducible and sensitive measurement of RNA and opens the possibility for SI-traceable quantification of viral genes. The methods and results are already being used by NMIs to value assign reference materials that underpin the quality of SARS-CoV-2 diagnostic tests. The comparison was conducted under an accelerated timeline, with the world-wide comparison completed in under six months.



Financial Summary

Revenue and expenditure (2016 to 2020)



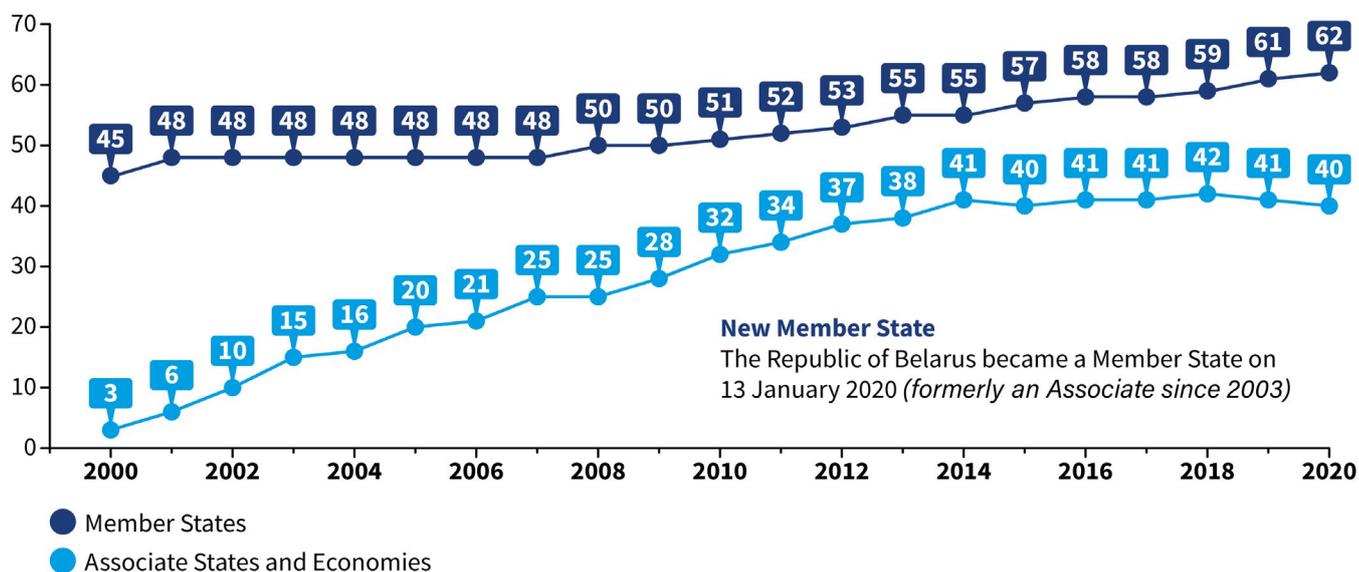
in k€		2016	2017	2018	2019	2020
	Operating, laboratory and building expenditure	2020	2383	2794	2302	1848
	Capital spend	1458	1061	1641	1184	1153
	Contribution to the pension fund	2400	2800	2550	2550	2550
	Current staff cost	6091	6836	6468	6310	6180
	Other income	561	539	379	547	209
	Subscriptions	955	1116	967	935	1022
	Contributions	12178	12178	12290	12379	12503

Key financial points

Revenue	Income followed forecast despite a small reduction in grant income due to a reduction in meeting activities on site.
Operating expenditure	Staff costs were reduced as a result of a reduction in the number of secondees from ten projected to four. Operating costs on site were reduced due to the absence of meetings. There was a large reduction in travel and transport costs.
Capital investment	The CIPM agreed to an increase in investment in laboratories since 2020 was the first year of a 4-year programme. A large investment to replace all of the windows in the Marie Curie building was not feasible and was postponed to 2021.

Financial Summary

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



Full details of the financial and administrative situation of the BIPM are available in the “*Financial Report 2020*”

Symposium celebrating the life and work of Charles-Édouard Guillaume

The BIPM hosted its first “hybrid meeting” on 17 October 2020 with a symposium celebrating the life and work of Charles-Édouard Guillaume, Director of the BIPM from 1915-1936.

The year 2020 marked the centenary of his award of the Nobel Prize in Physics “*in recognition of the service he has rendered to precision measurements in physics by his discovery of anomalies in nickel steel alloys*”. Charles-Édouard Guillaume dedicated more than half a century to precision metrology. His major study of the properties of nickel-iron alloys spanned more than twenty-five years and not only revolutionized geodesy measurements but also chronometry and precision horology.

The hybrid symposium was attended by a hundred people: both online around the world or at the BIPM, where members of the Guillaume family and colleagues from the Paris area heard presentations given from the BIPM and Switzerland.

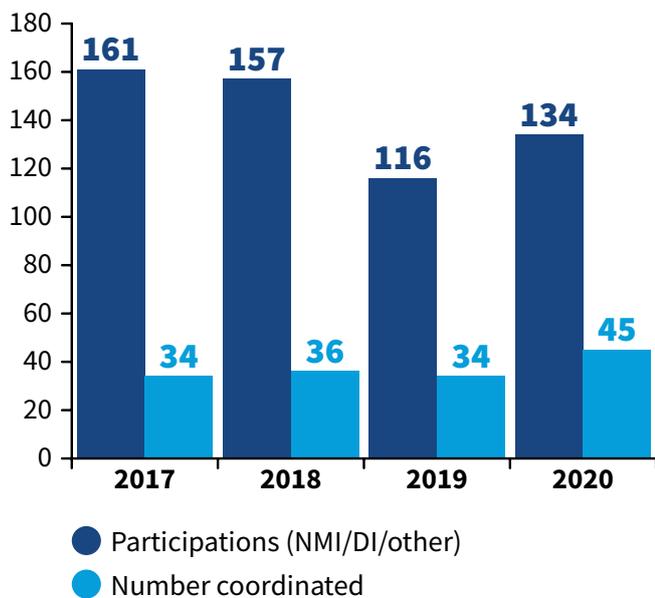


The Charles-Édouard Guillaume symposium.

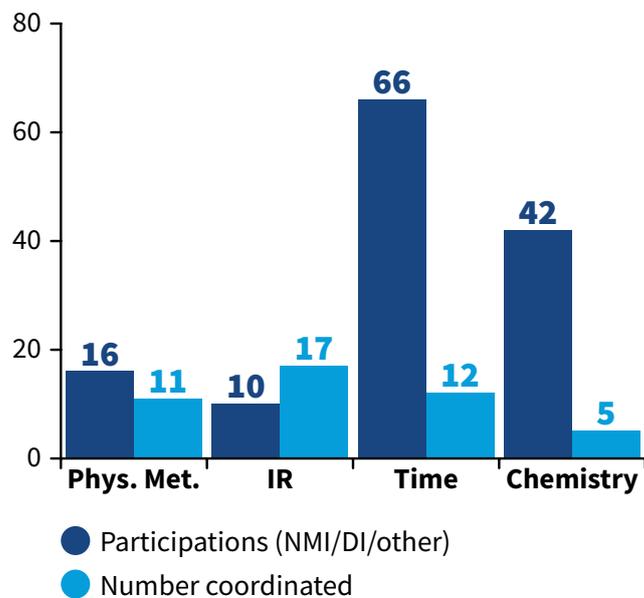
Comparisons and Calibrations

Comparisons

Comparisons coordinated by the BIPM laboratories

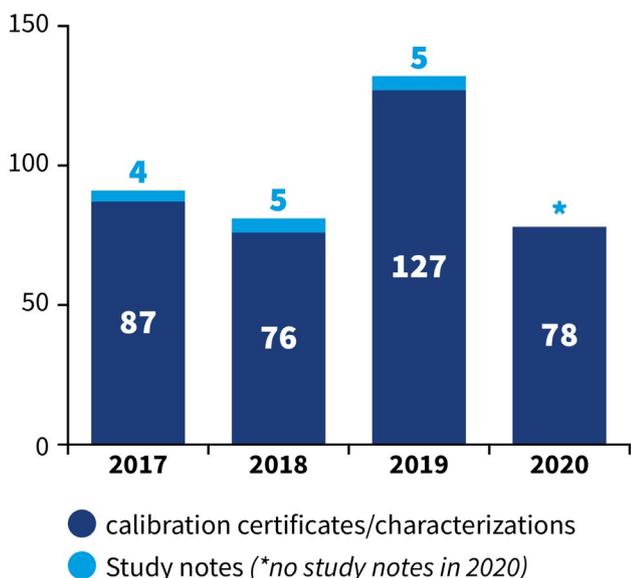


2020 Breakdown by Department

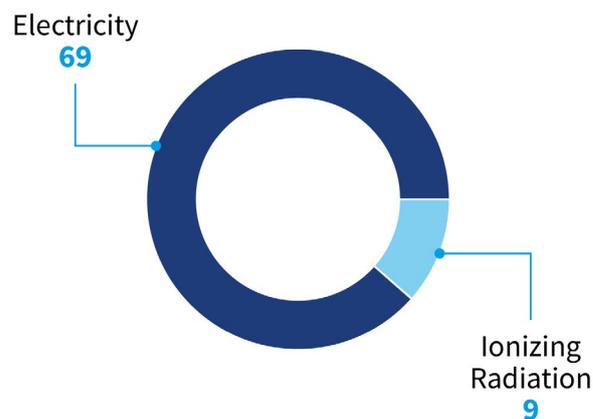


Calibrations and Study Notes

Calibrations and Study Notes from the BIPM laboratories



2020 - Calibrations by metrology area



BIPM organizational structure

The CIPM

President

Dr W. Louw (South Africa)

Secretary

Dr T. Usuda (Japan)

Vice-Presidents

Dr J. Olthoff (United States of America)

Prof. J. Ullrich (Germany)

Other CIPM members

Dr F. Bulygin (Russian Federation)

Dr I. Castelazo (Mexico)

Dr D. del Campo Maldonado (Spain)

Dr Y. Duan (People's Republic of China)

Dr N. Dimarcq (France)

Dr H. Laiz (Argentina)

Dr T. Liew (Singapore)

Prof. P. Neyezhnikov (Ukraine)

Dr S.-R. Park (Republic of Korea)

Dr M.L. Rastello (Italy)

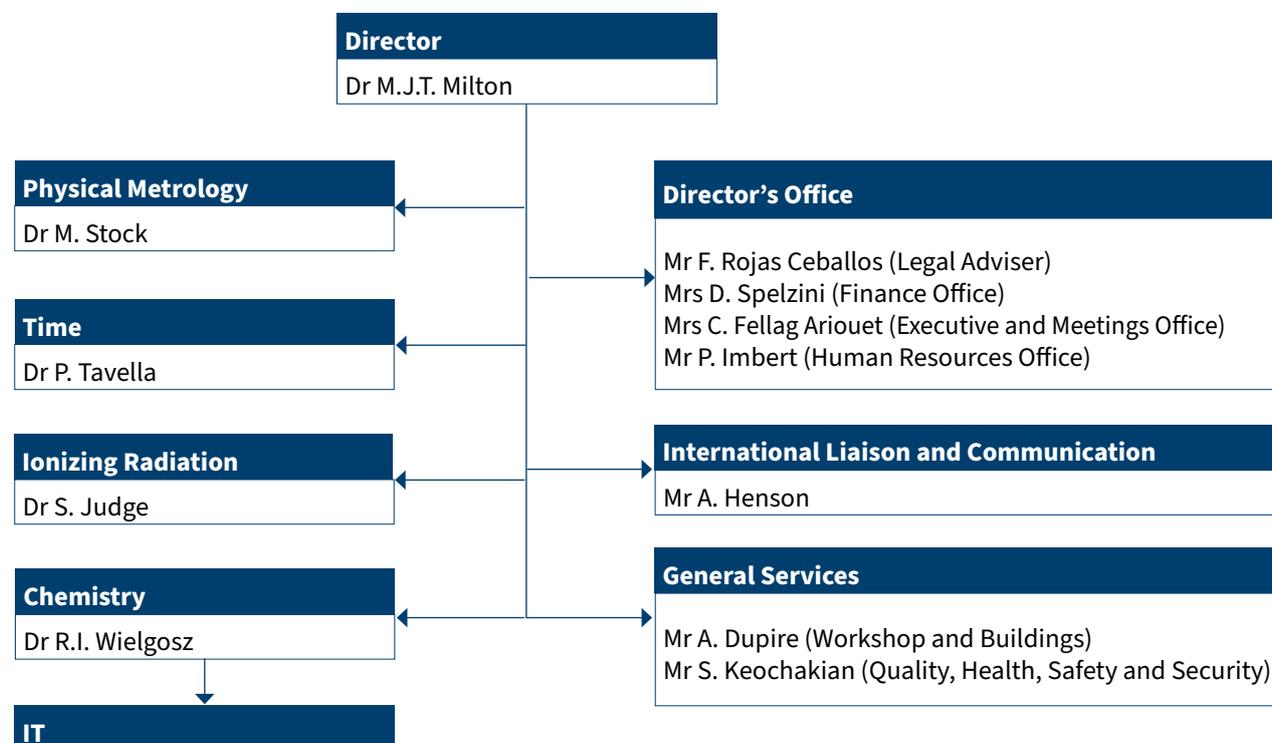
Dr P. Richard (Switzerland)

Dr G. Rietveld (Netherlands)

Dr M. Sené (United Kingdom)

Dr A. Steele (Canada)

The BIPM staff





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Measurement for Health



20 May 2021
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