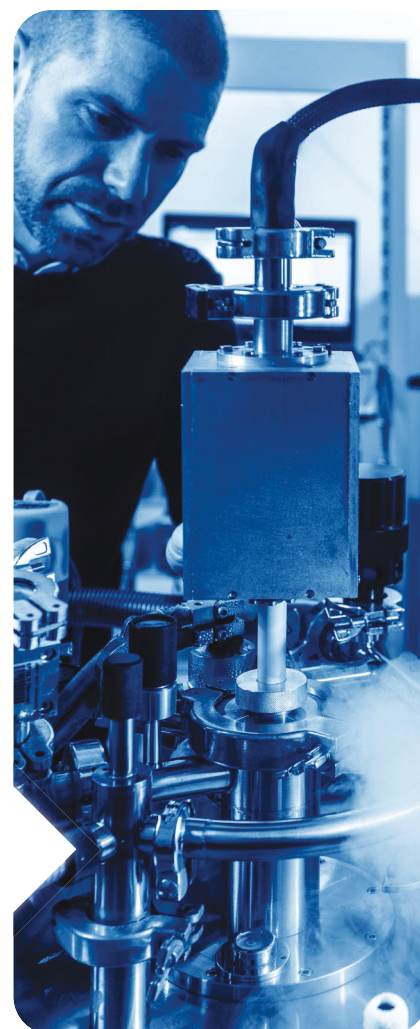
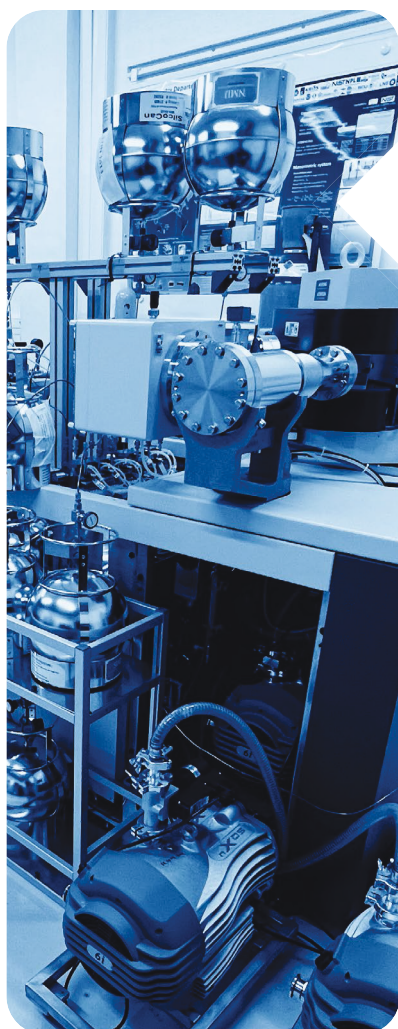


# Annual Review 2023/2024





# 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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# Introduction

I am delighted to introduce this report of our achievements during 2023.

One of the major milestones of the year was the endorsement by the UNESCO General Assembly of May 20th as World Metrology Day. This achievement, the result of extensive lobbying among UNESCO Member States, opens the opportunity to engage more than 80 states that are currently not participating in BIPM activities. It is a significant step forward in our work to promote the global importance of metrology (see page 11).

In the same month, the World Radiocommunications Conference, the governing body of the International Telecommunications Union (ITU), agreed a resolution committing to collaborate with BIPM on developing a technical agreement by 2035 to ensure that Coordinated Universal Time (UTC) remains a continuous timescale. This decision underscores our commitment to ensuring that UTC continues its crucial role in accurate timekeeping for global communications and technology (see page 7).

We also report the final steps in preparing for the implementation of more accurate surface ozone measurements world-wide, supporting global efforts to improve air quality. A more accurate value for the absorption cross-section of ozone determined in 2019, will be implemented in ozone standards globally starting in 2025, and we report here the final steps in ensuring global uptake across all monitoring networks (see page 9).

During the year, we have also made significant strides with our digital transformation agenda, which is a priority action set by the CGPM. The launch of the SI Reference Point, the first entirely digital service authorized by the CIPM, represents a landmark achievement in providing reliable digital references (see page 16). Additionally, we have expanded our Capacity Building and Knowledge Transfer (CBKT) activities, with notable developments including a workshop for the secretariats of the RMOs and e-learning resources being made available of all six Regional Metrology Organizations (RMOs) (see page 12).

Despite the challenges presented by rising energy and operating costs, we have maintained our strong financial record. I offer my gratitude to all staff and NMI secondees who have been instrumental in delivering their objectives whilst also supporting initiatives to control costs.

Finally, I would like to invite you to “save the dates” in 2025 shown below for the events to celebrate the 150th Anniversary of the signing of the Metre convention.

**Dr Martin Milton**  
BIPM Director



## SAVE THE DATE

We will be organizing special events on **20, 21 and 22 May 2025** to celebrate the 150th anniversary of the signing of the Metre Convention.

Please save the date for these events in Paris and Versailles.

Details will be available from the BIPM website.

# Physical Metrology

## Dissemination of the kilogram from the second Consensus Value

The new definition of the kilogram gives any NMI the possibility to realize the kilogram, either by operating a Kibble balance or by using the X-ray Crystal Density (XRCD) method. Since the Consultative Committee for Mass and Related Quantities (CCM) considers the world-wide uniformity of such independent realizations to be insufficient, the dissemination of the mass unit is presently internationally coordinated by basing it on the so-called “consensus value”, until satisfactory agreement between independent realizations is achieved. The consensus value is determined and regularly updated as the arithmetic mean of the key comparison reference values (KCRVs) of the last three key comparisons, which the BIPM organizes every two or three years.

The second key comparison, CCM.M-K8.2021, was launched in the second half of 2021 and completed at the beginning of 2023 [1]. Seven institutes, including the BIPM, participated with Kibble balances and two with the XRCD method. The comparison confirmed a statistically significant difference between the two realizations with the smallest uncertainties, which had already been observed in the first key comparison, CCM.M-K8.2019. Following the completion of the second key comparison, the second consensus value was determined as  $1 \text{ kg} - 7 \mu\text{g}$ , with an uncertainty of  $20 \mu\text{g}$ . It came into force on 1 March 2023. The CCM requested NMIs to adjust the values of their reference mass standards by  $-7 \mu\text{g}$  with respect to the previous values based on the International Prototype of the Kilogram or by  $-5 \mu\text{g}$  with respect to the first consensus value of 2021. The CCM is developing a roadmap with actions to solve the persistent lack of agreement between realization experiments. The third key comparison, which was initially planned to start in late 2023, was postponed by one year to give the NMIs additional time to investigate the origin of the discrepancy.

The BIPM continues to provide calibrations of  $1 \text{ kg}$  Pt-Ir prototypes and stainless steel mass standards for the NMIs of its Member States. During 2023, five Pt-Ir prototypes and twenty-one stainless steel standards were calibrated for twelve NMIs. Traceability to the new definition was achieved via the second CCM consensus value of 2023. The calibration uncertainty was  $21 \mu\text{g}$ , dominated by the uncertainty of  $20 \mu\text{g}$  of the consensus value.

### BIPM Kibble balance

The BIPM continued to improve the operation of its Kibble balance in preparation for the third key comparison of kilogram realizations. For electrical measurements, a  $2 \text{ V}$  programmable Josephson voltage standard (PJVS) operated in a cryocooler was successfully compared against the PJVS system belonging to the voltage laboratory, operated in a liquid helium dewar, with a relative agreement within  $1.5 \times 10^{-9}$  for a voltage of  $1 \text{ V}$ . The use of the cryocooler overcomes the problem of the shortage of liquid helium supply. Improved electronic boards for low electromagnetic force switches were designed and fabricated by an external

company. The calculation of the gravitational self-attraction correction due to the mass of the mechanical set-up, based on commercial FEA software, was reviewed and found to be in agreement with the values obtained using a simplified evaluation within  $10^{-9}$  in relative terms.



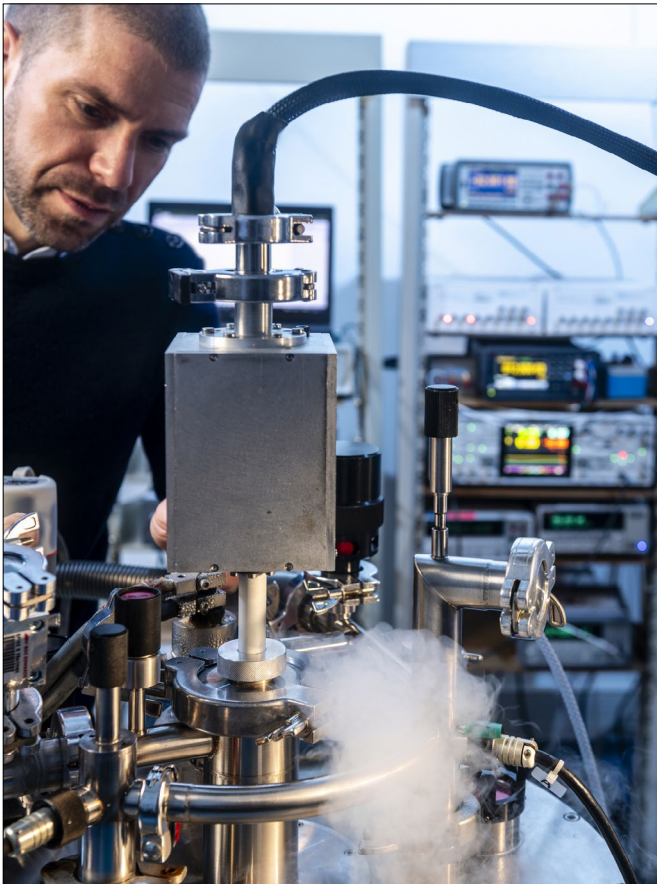
The BIPM Kibble balance

In parallel, the development of a new balance-beam mechanism was pursued with the objective of reducing the largest uncertainty component, due to misalignment of the Kibble balance apparatus. The work was done with the support of a secondee from NMIJ (Japan) from February 2023. The first prototype mechanism, based on an equal-arm double-pan balance beam, was characterized on a test set-up in air. The key features of the first prototype design were successfully checked. However, oscillations of the counterweight suspension were observed when the horizontal movement of the coil suspension due to the arc-motion of the end of the beam was dynamically corrected using a translation stage. To avoid this, an improved equal-arm single-pan beam was designed and fabricated by the BIPM mechanical workshop. A high-resolution digital voltmeter (DVM) is under development to be used together with a high-precision standard resistor to improve the static phase measurement.

### QHR key comparisons

The study of commercial  $1 \Omega$  resistance standard prototypes, based on the design of the AIST/NMIJ (Japan), which started in 2021 for possible use in the BIPM.EM-K12 on-site quantum Hall resistance (QHR) key comparisons, was completed in 2023. The main objective of this study, carried out in collaboration with PTB (Germany) and AIST/NMIJ, was to evaluate the low-frequency dependence (below  $1 \text{ Hz}$ ) of these resistors as well as the possible experimental parameters that could influence this measurement. It has been shown that the frequency dependence of the tested resistors is sufficiently low that they can be advantageously used for precision  $1 \Omega$  measurements in the key comparisons. In addition, it was observed that the wiring configuration used to connect the resistors to the resistance bridge may have a significant influence on the measured frequency dependence. This leads to the conclusion that reducing the measurement uncertainty attributed to the frequency

dependence of  $1\ \Omega$  standards implies, on the one hand, using a resistor with a very low frequency coefficient and, on the other hand, to consider this resistor and its attached measuring cable as a single entity.



Cryostat for the quantum Hall resistance standard

A low frequency current comparator (LFCC) of ratio 129:1, intended to equip a new bridge for resistance standard comparisons at 1 Hz, has been assembled and tested. The test consisted of comparing the new LFCC to an existing one, the ratio errors of which from 1 Hz to dc are well known - from calibrations against a cryogenic current comparator (CCC) - for a set of selected reference resistance ratios. It has been found that the difference between the two LFCCs is within a few  $n\Omega/\Omega$  indicating that they have very similar ratio errors. The exact 1 Hz to dc errors of the new LFCC will be evaluated through direct comparison measurements between a 1 Hz bridge equipped with this LFCC and a CCC bridge.

The PTB provided the BIPM with two epitaxial graphene-based doped QHR devices in 2023. Such devices had already been tested at the BIPM in 2021, where they were operated at 4.2 K and a magnetic flux density as low as 4 T. They demonstrated a very good comparability to a GaAs-based QHR device. The devices were shipped in ambient air rather than in a sealed nitrogen-filled container, as used in 2021. An initial series of characterization measurements showed that transport in air does not significantly affect the carrier density. It was proved again that these devices are very comparable to the reference GaAs-based QHR standards used for routine measurements at the BIPM, but they can be operated under relaxed temperature and magnetic field conditions.

Measurements were carried out on the calculable capacitor to study the influence of the positioning of the alignment probe's centring bearing on the accuracy of setting the position of the main electrode bars. The influence on

the measurement of the distance between adjacent and opposite electrodes was evaluated as well as on the angular measurement. This study allowed verification of the stability of the main electrodes' position adjustments that were made during the last year.

To maintain traceability for resistance and capacitance calibration and comparison services, the ohm and the farad were realized from the quantum Hall effect twice in 2023. The farad was realized from the ohm using a multi-frequency quadrature bridge. A total of 83 calibrations in the field of impedance have been provided for 18 NMIs: 54 certificates for resistance and 29 for capacitance. Additionally, BIPM.EM-K13.a&b resistance comparisons with INRIM (Italy) and CEM (Spain) have been completed and the final reports published [2, 3]. Moreover, one BIPM.EM-K14.a & b capacitance comparison with the NMIM (Malaysia) has been completed and the final report published [4].

### PJVS key comparisons

Following the completion of the new technical protocol for the on-site comparison of programmable Josephson voltage standards (PJVSs) for DC and sinusoidal AC voltages, BIPM.EM-K10.a&b, a survey on the interest of NMIs in participation in such a comparison was carried out. A total of 79 % of the replies showed an interest in the new AC voltage options of the protocol and 62 % for the DC voltage options. In preparation for this future comparison, the programme of pilot studies on AC differential sampling continued with two exercises performed in 2023, with the PTB team at the BIPM in March and the BIPM team at KRISS (Republic of Korea) in August.

The first pilot study led to the finding that a leakage current of several hundreds of microamperes was flowing through the BIPM PJVS, introducing systematic errors on the measured rms voltage. This discovery was the key point for further technical improvements on the BIPM PJVS travelling standard. During the second pilot study, particular attention was paid to the suppression of any possible source of leakage current between the two systems. For this study, the two PJVSs were set up to be fully identical. In this very particular configuration, the BIPM AC source serving as a transfer standard was measured alternatively by the two independent quantum voltage standards, once the optimal grounding/earthing configuration of the measurement setup was found. Highly repeatable differences of the rms values and comparable uncertainties were obtained. The errors and uncertainties increase with frequency as a direct consequence of the capacitive residual coupling between the measurement output leads of the PJVS. The BIPM will improve the immunity of its PJVS to spurious capacitive effects, which combined to leakage current, can lead to systematic errors of several hundreds of microvolts at 1 kHz. To further improve the achievable comparison uncertainty, the BIPM is continuing with its programme of pilot studies in 2024.

The reports on a comparison of Zener calibrations, BIPM.EM-K11, with the NPLI (India) and with DEFNAT (Tunisia) were published [5, 6] and two further comparisons are being carried out with SASO (Saudi Arabia) and INRIM (Italy). A total of fourteen Zener voltage standards were calibrated for eight NMIs in 2023.

# Ionizing Radiation

In 2023, the BIPM Ionizing Radiation Department continued its commitment to help ensure safe and effective use of ionizing radiation in healthcare and industry. The department plays a key role supporting radiation dosimetry and radioactivity metrology in the Member States by providing bilateral comparison services in a very efficient way as well as calibration services for dosimetry.

## Comparisons and calibrations for radiation dosimetry

Requests for comparisons and calibrations for radiation dosimetry are still growing. The number of comparisons carried out in 2023 was low due to several NMIs cancelling their participation for technical reasons. The department carried out six comparisons for: Germany (one), USA (three), Austria (one) and Spain (one). The number of calibrations, on the other hand, was at one of its highest levels to date. Forty-four calibrations were made for: India (six), Portugal (one), Mexico (five), Egypt (nine), South Africa (eight), Norway (nine) and the IAEA (six). Calibrations for the IAEA are of particular importance in extending BIPM traceability to national institutes that are not signatories to the CIPM MRA. Among the services that were provided, one comparison (USA) and six calibrations for four NMIs (India, Egypt, South Africa and Norway) were performed using the linear accelerator at the DOSEO platform in Saclay (France). In addition, quality control checks continued throughout 2023 to ensure that the BIPM standards and radiation beams remain stable.

In addition to the calibration certificates, seven comparison reports for Australia (one), Hungary (four), Germany (one) and Japan (one) were published in the *Metrologia* Technical Supplement [7-13].

## Medium-energy x-ray facility

The radiation beams of the new medium-energy x-ray facility at the BIPM were characterized in terms of radial profile, air attenuation and penetration (HVL). The new primary standard instrument for these beams, a free-air ionization chamber, has been fully tested and validated, showing excellent results, although final modifications to the shielding remain to be completed.

## <sup>137</sup>Cs comparison service

The dosimetry key comparison K5 was relaunched in 2023 after a break of several years using the International Atomic Energy Agency's (IAEA) <sup>137</sup>Cs irradiation facility. The KCRV has been re-established and two comparisons were successfully completed for Austria and Spain.

## International Reference System

Comparisons of national activity standards of gamma-ray emitting radionuclides rely on the International Reference System (the SIR) [16]. SIR participations in 2023 have supported eight radionuclides that have applications in nuclear medicine, industry and the environment (<sup>54</sup>Mn, <sup>57</sup>Co, <sup>67</sup>Ga, <sup>153</sup>Sm, <sup>177</sup>Lu with two participations, <sup>201</sup>Tl, <sup>203</sup>Pb and <sup>225</sup>Ac). The discussion of the <sup>177</sup>Lu results at the Consultative Committee for Ionizing Radiation (CCRI) Section II: Measurement of radionuclides (CCRI(II)) triggered the organization of a related EURAMET comparison and further SIR participations are expected in

the near future. In 2023, eight SIR comparison reports were produced and eight were published [15-22]. These reports now include machine-readable data [23], with this format having been applied to the whole SIR database allowing a meta-analysis of the long-term robustness of the SIR over decades of operation [24].

The development of the new SIR (named SIR 2.0) has continued, with the establishment of a new laboratory to house the equipment and the installation of the ionization chambers and lead shielding.

The International Reference System Transfer Instrument (SIRTI) [25] enables comparisons to be carried out on-site at a metrology institute of many of the short-lived radionuclides used for medical imaging, avoiding radioactive decay during shipment. The SIRTI can be operated by staff from a metrology institute with remote oversight by BIPM staff. This remote mode has been used successfully for SIRTI comparisons in 2023 at the ANSTO (Australia) and in a hybrid mode (partly on-site and partly in remote mode) at the LNMRI (Brazil). Two comparison reports were published [26-27].

Within the framework of the project to develop regional SIRTI, the CCRI(II) has validated the traceability scheme of the "RMO SIRTI" to the BIPM SIRTI, the latter providing the link to the SIR. The aim of this project, which is supported by the BIPM, is to allow more comparisons to be carried out at the regional level for radioelements critical to nuclear medicine and to expand these comparisons to institutes that are not from Member States.

The SIR and the SIRTI can only be used if a radionuclide emits x- and gamma-rays of energy such that attenuation by the entrance window of the detectors is not prohibitive. Comparisons involving pure (or almost pure) beta-emitting, electron-capture-decaying or some alpha-emitting radionuclides will be performed with the extension of the international reference system (ESIR), which is a recently developed instrument based on a liquid-scintillation counting technique (the Triple-to-Double Coincidence Ratio (TDCR) method). After validating the ESIR against the reference SIR in a pilot study using the <sup>60</sup>Co radionuclide and the participation of 13 NMIs/DIs [28], a list of eleven radionuclides, validated by the CCRI, has been defined to open the ESIR (BIPM.RI(II)-K5) comparison service in 2024.

The BIPM presented the results of the international key comparison CCRI(II)-K2.Cd-109.2021 as well as the link to the SIR in a CCRI(II) dedicated workshop. Some discrepancies were discussed by the participants who were giving input to the draft A report that was in preparation. This comparison allowed the BIPM Ionizing Radiation Department to implement a specific method to measure the activity of <sup>109</sup>Cd solution by counting the electrons from internal conversion with a liquid scintillation counter based on 3-photomultiplier tubes [29].

The importance of the metrology of radionuclide activities was highlighted by a paper in *Nature Physics* [30].

# Time

## Redefinition of the second and continuous UTC

Resolution 4 of the 27th CGPM (2022) “On the use and future development of UTC” focused on the need to make UTC a (quasi)continuous time scale, by extending the tolerance between UTC and the rotational angle of the Earth, UT1, which is currently fixed at one second. This resolution started a process to which the Time Department is contributing. A Consultative Committee for Time and Frequency (CCTF) Task Group will, among other tasks, draft a resolution for the 28th CGPM (2026) with a new maximum tolerance and the date of application. The CCTF will also prepare a draft resolution to address the necessary choices for the redefinition option and species and the remaining work, with a roadmap, to redefine the second in 2030 [31]. A number of papers have been published in preparation for the redefinition of the second [32].

### ITU-R and BIPM work together at the WRC-23

Dr Patrizia Tavella, Director of the BIPM Time Department, together with NMI representatives, successfully contributed to the negotiation of several important outcomes for the global time metrology community at the ITU World Radiocommunication Conference 2023 (WRC-23), which was held in Dubai (United Arab Emirates) from 20 November to 15 December 2023.



The negotiations centered around the importance of UTC becoming a continuous time scale and the revision of ITU-R resolution 655 (WRC 2015). Key outcomes included:

- Formal recognition of Resolution 2 of the 26th CGPM (2018) and Resolution 4 of the 27th CGPM (2022).
- Continuation of the collaboration between BIPM and ITU-R, in preparation for the decision at the 28th meeting of the CGPM (2026) regarding the new maximum tolerance for UT1-UTC and its application date.
- Provision for a potential delay in the transmission of UT1-UTC by radio stations providing time and frequency services, if essential equipment needs to be updated.

The support of the NMIs and CIPM collaborating with their ITU national delegations was instrumental in achieving this milestone and further strengthening the collaboration with the ITU R.

## Reference time scale for the Moon

A preliminary study on a possible definition of a reference time scale for the Moon has started following an invitation by the European Space Agency (ESA). The work will be carried out by a joint ESA-NASA group to develop recommendations for future navigation and communication projects. The aim is to establish time and reference frames for Moon projects in agreement with the relevant International Organizations to define a common base for all future developments.

### Secondary representation of the second

The Time Department and CCTF colleagues examined and compared the algorithms and software used to estimate the value of the frequency which is used as a secondary representation of the second, in support of the CCL-CCTF *mise en pratique* of the metre and the second. This work determined that there is excellent confidence in the achievable results [37]. These algorithms, maintained by CCTF colleagues and the BIPM will be used for the next evaluation of the secondary representation of the second by the CCTF in 2025 and will play a fundamental role in the redefinition of the second.

### Computation of UTC

The regular collection of data, computation of UTC, rapid UTC, and the key comparison CCTF-K001.UTC continued without interruption. Three new laboratories entered UTC in 2023: IBM (Bolivia), UTE (Uruguay) and UzNIM (Uzbekistan).

### First official use of Galileo measurements in the computation of UTC

On 9 June 2023, *Circular T* no. 425 published by the BIPM Time Department featured, for the first time, a comparison of local time scales UTC(*k*) using measurement data obtained from Galileo, the European Global Navigation Satellite System.

For the computation of *Circular T* no. 425, one of the contributing laboratories was officially compared by using the Galileo measurements, which were the most reliable for the month. The use of Galileo and the planned integration of other techniques is of major significance. The redundancy of measurement methods enables the detection of sudden anomalies or gradual long-term drifts, thus improving reliability and accuracy in the computation of UTC.

### Capacity building in time and frequency

A new CCTF project on capacity building, based on shared resources and supported by the IEEE UFFC Society, started with a secondee from NPLI (India) from October 2023. The project will collate existing training tools and new ones will be developed and proposed to the UTC laboratories, with the aim of improving the quality of the data submitted to the BIPM and therefore of UTC and the national UTC(*k*) time scales.

# Chemistry

The Chemistry Department progressed 12 interlaboratory comparisons in 2023, including comparisons of standards for greenhouse gases, food contaminants and diagnostic markers. The on-site visiting scientist programme continued with six visiting scientists joining the department throughout the year.

The department hosted on-site meetings of the Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM) working groups and the Joint Committee for Traceability in Laboratory Medicine (JCTLM) and its stakeholder meeting and workshop, with outcomes from two previous JCTLM workshops being published [38,39]. The report [40] from BIPM-World Meteorological Organization (WMO) Workshop on Metrology for Climate Action (September 2022) was published as well as the outcomes from the CCU-CCQM Workshop on “The metrology of quantities which can be counted” [41].

## Gas metrology activities: Greenhouse gases

The final report [42] of the comparison of CO<sub>2</sub> isotope ratio measurements (CCQM-P204) on pure CO<sub>2</sub> samples, coordinated jointly by the BIPM and the IAEA was published, confirming the impact on the compatibility of results caused by applying different realizations of the Vienna Pee Dee Belemnite (VPDB) scale. The protocol for a comparison of CO<sub>2</sub> isotope ratios in air standards was completed, and the isotope-ratio mass spectrometry (IRMS) cryogenic extraction line for CO<sub>2</sub> in air isotope measurements was optimized, with visiting scientists from the NPL (UK) and KRISS (Republic of Korea).

Papers [43,44] describing the BIPM’s primary manometric system for CO<sub>2</sub> amount fraction measurements in air were published. The CCQM-P225.a and b comparison was completed and report published [45], with the performance of the BIPM system aptly demonstrated to enable progression to the ongoing key comparison (BIPM.QM-K2.a and b) scheduled to start in 2024.

The BIPM continued to support the work of the CCQM Working Group on Gas Analysis (CCQM-GAWG) Task Group on GHG Scale Comparisons and Task teams to develop the protocol for the CO<sub>2</sub> in air scales comparison BIPM.QM-K5. A first set of comparative and absolute measurements have been completed on the two ensembles of nine CO<sub>2</sub> in air standards maintained at the BIPM. A joint technical project with VSL (Netherlands) has progressed to develop specifications for regression models and a database for GHG Scale measurements and comparisons. A visiting scientist from the University of Colorado/National Oceanic and Atmospheric Administration (NOAA) joined the BIPM to start to develop the database in the last quarter of 2023, with the development to be completed in 2024.

The final reports for the nitrous oxide (N<sub>2</sub>O) in air standard comparisons (CCQM-K68.2019 [46] and CCQM-P206 [47]), were published. Validation of the Cavity Ring Down Spectroscopy (CRDS) and Gas chromatography - Flame ionization detector (GC-FID) measurement systems for the comparison CCQM-K82.2023 (Methane in air standards)

was completed, and 25 standards from participating NMIs were received at the BIPM, with comparative measurements planned for early 2024.



Isotope ratio mass spectrometer for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  measurements in CO<sub>2</sub> in air standards with cryogenic extraction system

## Gas metrology activities: Air quality gases

Four bilateral comparisons were performed for the ozone standard comparison, BIPM.QM-K1, and six comparison reports were published [48-53]. The BIPM continued to support the CCQM GAWG Task Group for Ozone Cross-Section (CCQM-GAWG-OZONE-TG) including liaison with ISO/TC 146/SC 3, which progressed amendments to ISO 13964 and ISO 10313 standards to the draft international standard stage, and now incorporating the same value for the ozone cross section as was approved by the CCQM for BIPM.QM-K1.

A joint technical project was progressed with the NPL for development of future ongoing comparisons for NO<sub>2</sub> in nitrogen at 10  $\mu\text{mol/mol}$  (BIPM-QM-K6). Stability studies on six NPL prepared standards in three different cylinder treatments were performed at the BIPM headquarters using the NO<sub>2</sub> dynamic magnetic suspension balance (MSB) facility which incorporated a correction factor for HNO<sub>3</sub> determined with the study CCQM-P172 [54]. The extension of the BIPM’s NO<sub>2</sub> capabilities to cover the amount fraction range of 1000 nmol/mol to 50 nmol/mol in nitrogen and air was progressed in a joint technical project with METAS (Switzerland).

BIPM staff completed six-month intensive on-line Metrology for Clean Air Courses on ‘FTIR Measurements on Gas Standards’ (NO<sub>2</sub>, NO, HNO<sub>3</sub>, CO<sub>2</sub>) for scientists from TÜBITAK-UME (Türkiye) and PTB (Germany) resulting in operational Fourier-transform infrared spectroscopy (FTIR) facilities using the BIPM B-FOS operating system at TÜBITAK-UME.



## Metrology for Safe Food and Feed

The department completed and published the final report of the comparisons of Patulin calibration solutions (CCQM-K154.d) [64]. The characterization of ochratoxin A material was continued in preparation for the CCQM-K154.e comparison. Measurements for the bilateral subsequent comparison CCQM-K154.b.1 (Afb1 mycotoxin calibrant) were completed and the draft report circulated for approval. For veterinary drugs, results from 20 participating laboratories for the oxytetracycline purity comparison (CCQM K148.b) were compiled into the Draft A.1 report that was circulated to participants. A first online meeting to discuss results with participants was organized and completed and potential sources of measurement bias in some results identified, allowing a draft proposal of KCRV options to be completed. qNMR characterization of chlortetracycline and doxycycline materials were completed at the BIPM by a visiting scientist from INTI (Argentina) as part of Joint Technical Project with TÜBITAK-UME. The qNMR Internal Standard Reference Data - Benzoic Acid [ISRD-08] document [65] was published as part of Joint Technical Project with NIM (China). For future comparison of pesticide standards, qNMR characterization of chlorpyrifos, acetamiprid and glyphosate materials was completed at the BIPM as part of Joint Technical Project with NIM. A review paper on Methods for the SI-traceable value assignment of the purity of organic compounds (IUPAC Technical Report) [66] was published. Measurements on  $^{19}\text{F}$  versus  $^1\text{H}$  qNMR purity evaluation of organic materials were completed by visiting scientists from INMETRO (Brazil) and INTI, and draft Internal Standard Reference Data (ISRD) for  $^{19}\text{F}$  qNMR using BTFMBA was circulated to external authors for comment.



LC-MS/MS instrument used for CCQM peptide and protein comparison sample characterization

## Metrology for Health

As part of the programmes related to Metrology for Health and diagnostic markers, the final report of part II of the CCQM SARS-CoV-2 antibody quantification pilot study, CCQM P216, coordinated by NIM (China), with the BIPM and NRC (Canada), was published [67]. A CITAC best paper award was received for the NPL and BIPM paper on compositional analysis of C3-triskelion in *iScience* [68]. An on-site hybrid meeting was held at the BIPM headquarters in February 2023, with representatives NRC (Canada), NIBSC (UK), NIM (China), LNE (France), CDC (USA) and International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) to plan for the parathyroid hormone (PTH 1-84) comparison and use of such material in calibration hierarchies for the measurement of PTH (1-84) in serum or blood. PTH material, to be used for method development, was received from NIM and an initial screening method for related structure impurities completed. The PTH material to be used for the comparison was received from the NRC. The PTH comparison protocol and call for participation was drafted, discussed and agreed by the CCQM Working Group on Protein Analysis (CCQM-PAWG) in its November 2023 meeting. For the therapeutic drug purity comparison on digitoxin, a material was sourced and filled by UME for the BIPM as part of a Joint Technical Project. Related structure impurity method development using liquid chromatography - diode array detection - mass spectrometry (LC-DAD-MS) and LC-DAD-CAD was undertaken by a visiting scientist from GLHK (Hong Kong, China).

## JCTLM

An applications programming interface (API) for the JCTLM Database was made available in April 2023. The secretariat's workload in 2023 included: preparation of 111 nominations for JCTLM database entry review; and publication of 51 new entries in the JCTLM database from 2022 nominations. Financial support was secured for the second phase of development of the JCTLM Database to move to a web-based nomination and review platform, the development of which will start in 2024, and will be timed with the publication of new ISO 15193 and 15194 standards, for which JCTLM Database entries need to show compliance.

### More accurate surface ozone measurements to be implemented world-wide from 1 January 2025

Surface ozone is one of the major air pollutants, with mitigation strategies to reduce human exposure requiring continuous monitoring and reliable measurement data. The accuracy of ground-level ozone measurement results is about to improve, based on more accurate measurements of the cross section of ozone from the international metrology community. A campaign to adopt the new more accurate ozone cross section value throughout the world at the same time was initiated following the BIPM workshop on Accurate Monitoring of Surface Ozone (2020). This is being coordinated by the CCQM Task Group for Ozone Cross-Section, with input from key stakeholders including environmental agencies, regulators, standards writing bodies, instrument manufacturers, air quality laboratories and networks, atmospheric scientists and others.

A dedicated webpage has been established to inform the stakeholder community of the change and provide guidance on implementation.

<https://www.bipm.org/en/ozone>

The implementation of the new ozone absorption cross-section value is planned to start on 1 January 2025 with a transitional period until 1 January 2026, at which time all stakeholders should adopt the new cross section value.

# International Liaison and Communication

## UNECE

In November 2023, the revised version of Recommendation K on Metrological Assurance of Conformity Assessment and Testing (the revised version also included the Guidelines to the implementation of Recommendation K on “*Metrological Assurance of Conformity Assessment and Testing*”) was adopted by the 33rd Session of the Working Party on Regulatory Cooperation and Standardization Policies (WP.6) of the United Nations Economic Commission for Europe (UNECE). The BIPM took the lead in the project updating Recommendation K under paragraph 10c of the Programme of Work of the WP.6. Recommendation K was written in 1998 and last revised in 2008. The project scope was to update Recommendation K with minor adjustments in order to modernize the language and to align it with current working methods and best practices (for example the CIPM MRA), to update terms and references and develop a brief guideline to demonstrate how users can comply with the recommended practices.

## OECD

In November 2023 the BIPM participated in the 10th Annual Meeting of the Partnership of International Organisations for Effective International Rulemaking (IO Partnership) “*Multilateral Co-operation for Global Resilience: Towards*

*the Next Decade*” (anniversary event of the IO Partnership), which was hosted by the Organisation for Economic Co-operation and Development (OECD). To mark its 10th anniversary, the IO Partnership met to define common priorities for quality international rulemaking for the future. The topics discussed included the future of the IO Partnership, trust in international rulemaking, cases of climate change and artificial intelligence, and addressing the gaps of multilateralism.

Session 1 of the meeting “*Trust in International Rulemaking to Better Address Global Challenges*” gave the BIPM Director the opportunity to highlight the global challenge of ensuring that the international measurement system, that is coordinated by the BIPM, is used effectively and efficiently in the implementation of:

- the outcomes of the Conference of the Parties (COP)
- digital transformation as an area where further enhancement of the bonds of cooperation between international organizations (IOs) is needed
- future plans regarding universality of the Metre Convention to ensure more inclusiveness.

In May 2023, the BIPM attended the kick-off meeting of the OECD-PTB joint study “*Highlighting the Interrelations in Quality Infrastructure and Regulation*”.

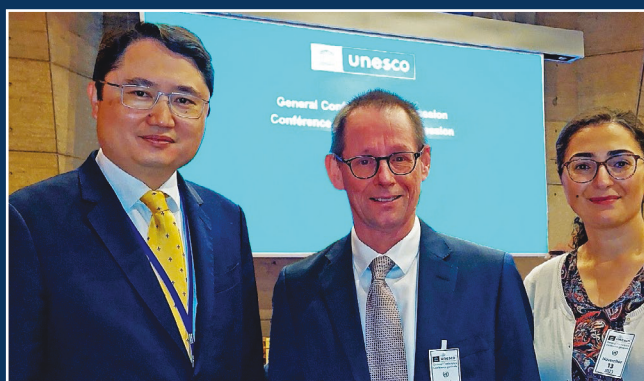
## World Metrology Day endorsed by UNESCO

The UNESCO General Conference held from 7-22 November 2023 adopted 20 May as a UNESCO International Day, following the proposal presented by Kazakhstan and supported by 43 additional nations, alongside the BIPM and the OIML.

The declaration of World Metrology Day by UNESCO, to be observed annually on 20 May, will significantly enhance global awareness of metrology’s role in everyday life and the BIPM’s actions in capacity building with developing economies.

The BIPM expresses its sincere thanks to Ambassador Gulsara Arystankulova and the Permanent Delegation of the Republic of Kazakhstan to UNESCO as the main sponsor of the World Metrology Day proposal, as well as the 43 UNESCO Member States who gave their written support following decision 41 at the 215th Executive Board meeting in 2022.

World Metrology Day is the annual celebration of the signature of the Metre Convention on 20 May 1875 by representatives of seventeen nations. The Convention set the framework for global collaboration in the science of measurement and in its industrial, commercial and societal applications. The original aim of the Metre Convention - the world-wide uniformity of measurement - remains as important today as it was in 1875.



From left to right: His Excellency Ambassador Askar Abdrakhmanov (Permanent Delegation of the Republic of Kazakhstan to UNESCO in Paris), Dr Martin Milton (Director, BIPM), Ms Rahima Guliyeva (Institutional liaison and membership, BIPM).

## New Director of the BIPM International Liaison and Communication Department

The BIPM welcomed Anna Cypionka as Director of the ILC Department from 1 March 2023, following the retirement of Andy Henson. Anna was the Head of the PTB Presidential Staff before joining the BIPM. Referring to her aspirations in the new position, Anna commented: *“The BIPM is unique in how it brings together world-wide communities through science – a spirit that I want to promote as ILC director”.*

Considering the BIPM's top priorities, she explained: *“We live in an era of constant change, hence the BIPM must keep up with the pace. The ILC department will play a key role in the coordination required to address the challenges related to the evolving needs in global metrology – together with our stakeholders and in transdisciplinary forums.”*

### BIPM attends COP28 as an observer for the first time

The BIPM gained observer status at the United Nations Framework Convention on Climate Change (UNFCCC) during the Conference of the Parties (COP27) in 2022.

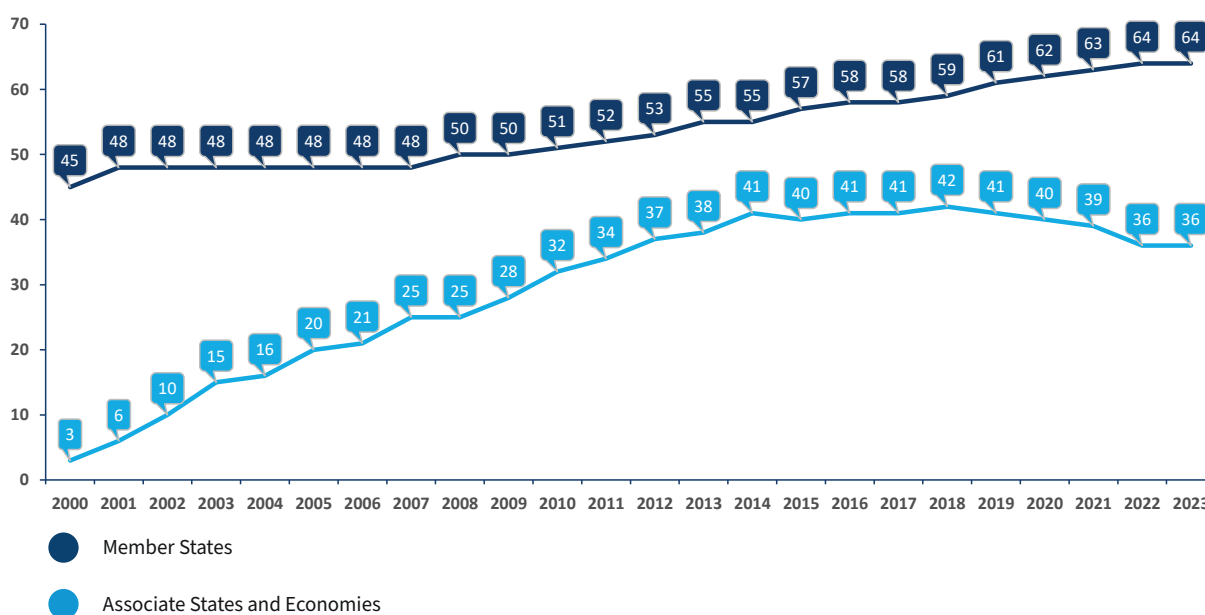
The BIPM used this newly granted status to attend COP28, which took place between 30 November to 12 December 2023 at Expo City, Dubai (United Arab Emirates). The BIPM was represented by Dr Anna Cypionka (Director of the BIPM International Liaison and Communication Department) and Dr Edgar Flores Jardines (Executive Secretary of the CIPM Sectorial Task Group on Climate Change and Environment). The BIPM's initial attendance was used as a fact-finding mission and to demonstrate the BIPM's commitment to promoting the importance of metrology with key stakeholders.

COP28 was attended by 85 000 participants and offered 152 Global Climate Action events and 366 side events.



Dr Edgar Flores Jardines and Dr Anna Cypionka.

### Evolution in Member States and Associate States and Economies from 2000 to 2023



# CBKT and e-learning

The **BIPM Capacity Building and Knowledge Transfer (CBKT) Programme** aims to increase the effectiveness with which Member States and Associates engage in the world-wide coordinated metrological system. It is delivered through theoretical (workshops), practical (laboratory placement) and remote (on-line) activities.

The **BIPM e-learning platform** provides online assistance to NMI/DI staff from Member States and Associates to strengthen their capabilities, including their involvement in the CIPM MRA mechanisms.

## The BIPM hosted the forum “Supporting RMO Secretariats” on 27-29 September 2023

The objective of the forum was to deepen the secretariats' understanding of the BIPM's activities and services, enabling them to participate effectively in tasks related to the international aspects of metrology. Lectures and discussions covered topics such as stakeholder engagement and global digital transformation, as well as RMO projects, interests and specific needs.

An online toolbox was made available to the RMO Secretariats as an outcome of the forum. The RMO Toolbox is intended to be used by RMO Secretariats as a basic reference source for information with links to current topics of interest in metrology. The aim is to allow Secretariats to quickly gain access to important information to assist in their day-to-day activities. <https://www.bipm.org/en/toolbox>



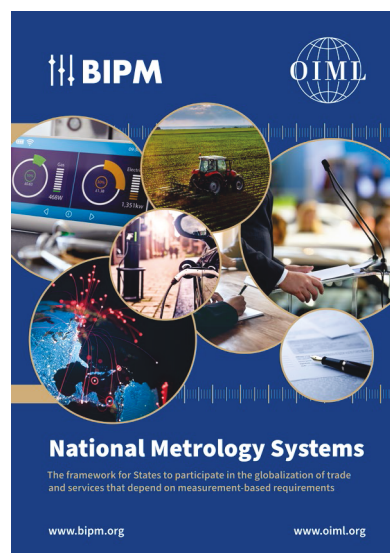
## BIPM and OIML joint knowledge transfer initiative - National Metrology Systems

The BIPM/OIML has jointly published a Brochure and six accompanying inserts on different aspects of the National Metrology Systems. The contents are taken from the BIPM and OIML joint publication “*National metrology systems - Developing the institutional and legislative framework*” (OIML D 1:2020).

Written in an accessible way, the brochures are aimed at:

- supporting countries and economies with emerging metrology systems, and to
- underpin the 27th CGPM’s Resolution 6 “On universal adherence to the Metre Convention”

Full details of the BIPM/OIML Brochure can be found here: <https://www.bipm.org/en/committees/cb/cbkt/bipm-oiml-brochure>



## AFRIMETS and SIM join the BIPM e-learning platform

All six Regional Metrology Organizations have now joined the BIPM e-learning platform following the signing of arrangements with SIM in March 2023 and AFRIMETS in October 2023.

Since the launch of the e-learning programme in 2021, both the quantity and diversity of training materials provided by the BIPM and Regional Metrology Organizations (RMOs) have expanded. As of December 2023, the BIPM offered 20 courses that have attracted 950 registered users. These courses cover a wide range of topics, from technical

guidance on calibration and uncertainty estimation to quality-related aspects such as CMC submission and other CIPM MRA-related procedures.

A system upgrade, completed in August 2023, improved navigation, introduced new functionalities, and enhanced both accessibility and security. The platform is now accessible to all six RMOs, allowing them to distribute training materials in their preferred languages. <https://e-learning.bipm.org/>

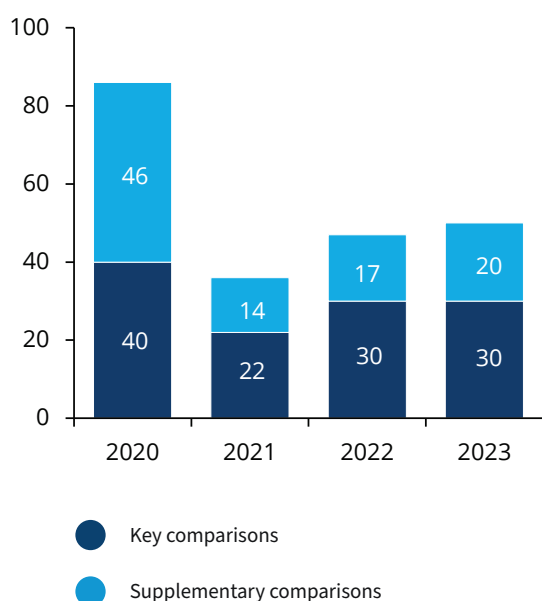
## The CIPM MRA

- The CIPM MRA is a framework through which national metrology institutes demonstrate the international equivalence of their national measurement standards and calibration and measurement certificates.
- The KCDB supports the CIPM MRA activities and publishes internationally recognized Calibration and Measurement Capabilities (CMCs) for services provided by participating institutes and key and supplementary comparisons supporting these CMCs.
- The Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB) is charged with coordinating the activities among the RMOs in establishing confidence for the recognition of CMCs according to the terms of the CIPM MRA.

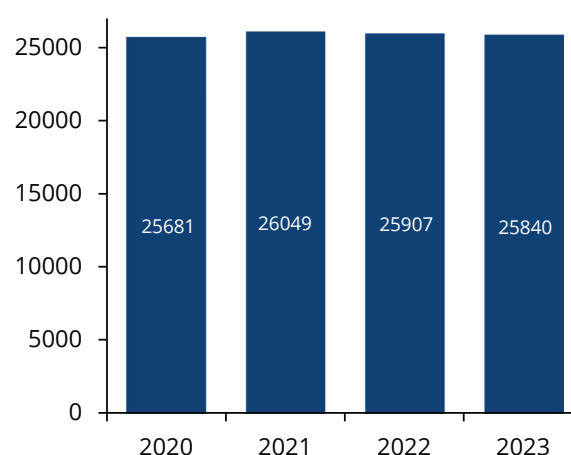
### Statistics (on 31 December 2023)

- 25 840 CMCs published in the KCDB: 15 798 in general physics, 3 651 in ionizing radiation, 6 391 in chemistry.
- 1 179 key comparisons and 687 supplementary comparisons listed in the KCDB.
- 90 comparisons were completed and published.
- In 2023, two KCDB Reports providing detailed statistics were made available via <https://www.bipm.org/en/cipm-mra/kcdb-reports>.

**Number of new comparisons registered in the KCDB**

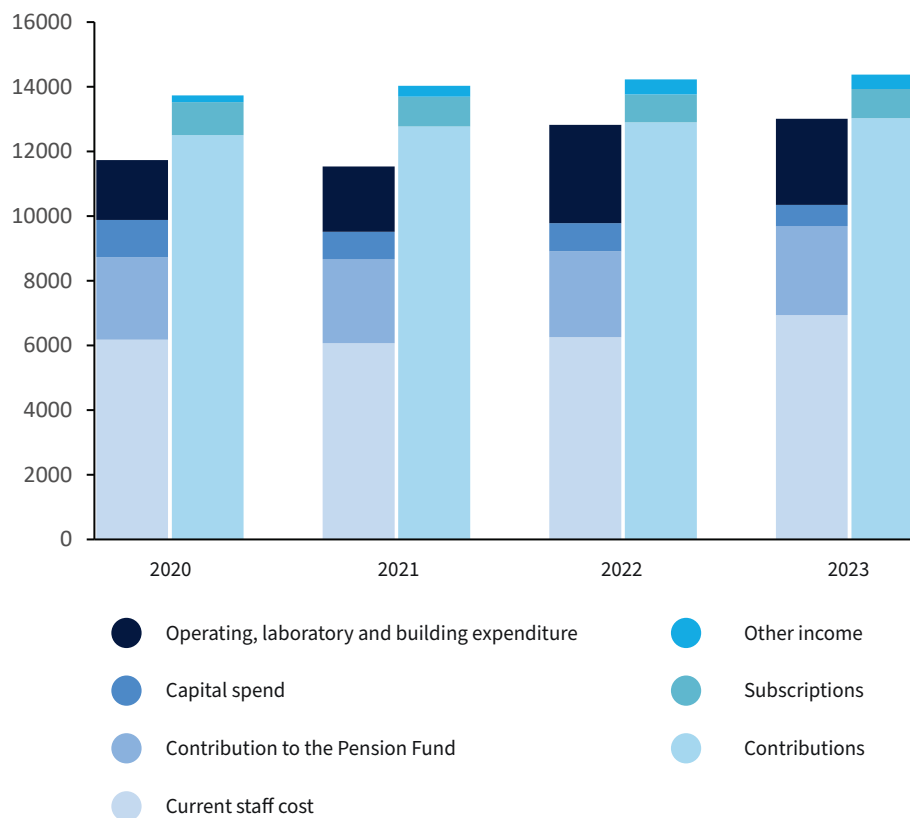


**Total number of CMCs registered at 31st December**



# Financial Summary

## Revenue and expenditure (2020 to 2023)

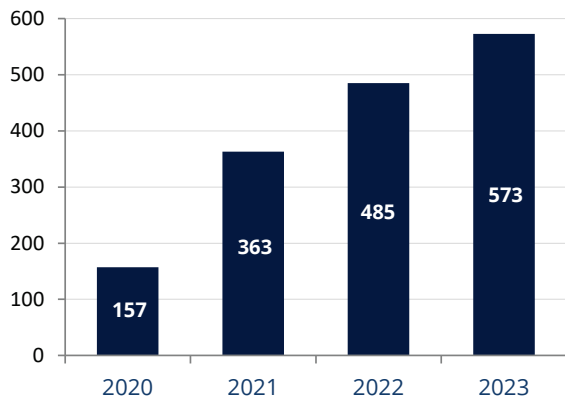


in k€		2020	2021	2022	2023
	Operating, laboratory and building expenditure	1 848	2 020	3 045	2 657
	Capital spend	1 153	844	869	655
	Contribution to the Pension Fund	2 550	2 600	2 650	2 750
	Current staff cost	6 180	6 072	6 261	6 946
	Other income	209	390	466	442
	Subscriptions	1 022	928	867	906
	Contributions	12 503	12 767	12 897	13 026

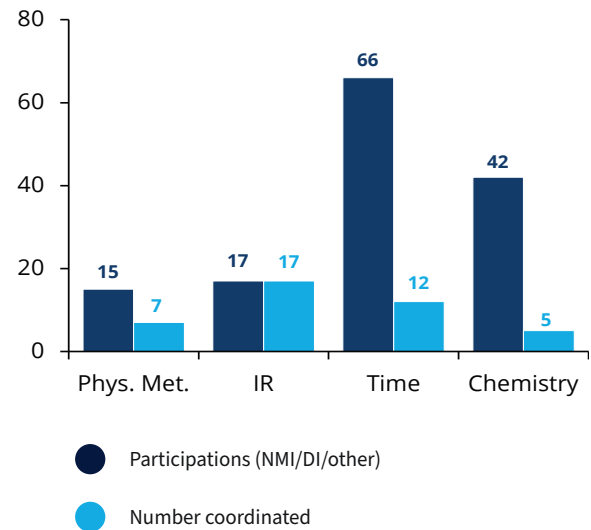
# Comparisons and calibrations

## Comparisons

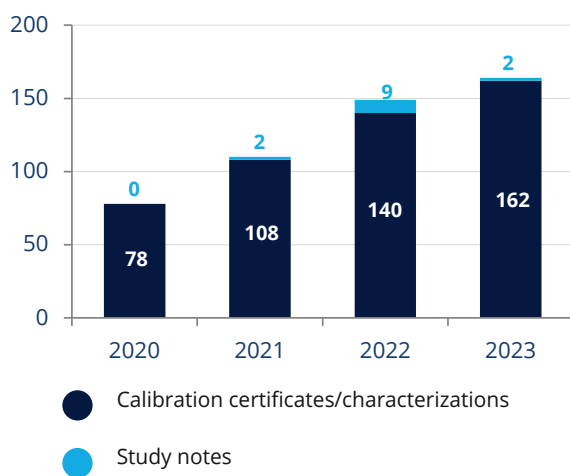
**Cumulative total of comparisons coordinated by the BIPM during the Work Programme 2020-2023**



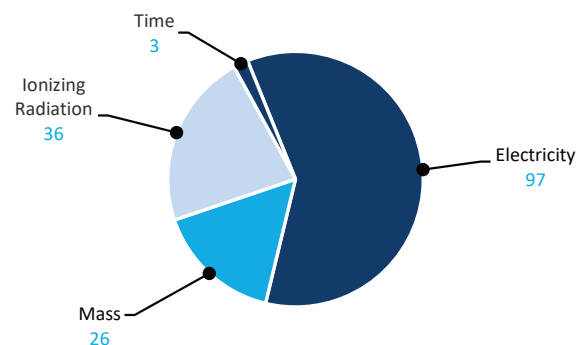
**2023 - Breakdown by department**



## Calibrations and study notes



**2023 - calibrations by metrology area**



# Digital Transformation

## Forum on Metrology and Digitalization

The CIPM's new Forum on Metrology and Digitalization has the mission to advise the CIPM on the SI Digital Framework and the wider implications of the global digital transformation for metrology and the international Quality Infrastructure.

The first plenary meeting of the FORUM-MD was held at the BIPM in March 2024, in conjunction with a workshop organized by the ten co-signatories to the Joint Statement of Intent "On the digital transformation in the international scientific and quality infrastructure".

The Forum brought together metrologists and experts in digitalization from around the world, including representatives from all the Regional Metrology Organizations and all the CIPM's Consultative Committees. Reports on updates were complemented by breakout sessions during which dedicated groups brainstormed on priorities in the following areas:

- Traceability, DCCs and DCRMs, Services and Applications
- Interoperability and quality of data
- RMOs, capacity building and interaction between CCs and the BIPM
- Future technologies

## SI Digital Framework

The first three digital services released for beta-testing are:

- the SI Reference Point: providing permanent digital identifiers for the SI units and prefixes and the SI defining constants
- a Reference Point for the CC Service Categories in Physics and Ionizing Radiation, to digitally underpin the structure of the KCDB for CMCs in AUV, EM, L, M, PR, RI, T and TF
- permanent access for CMC records.

These three services are machine-readable and have been designed to underpin FAIR measurement data, as recommended by the CGPM. The FAIR Guiding Principles (see [go-fair.org](http://go-fair.org)) provide criteria for ensuring that data are Findable, Accessible, Interoperable and Reusable. Ensuring that data are FAIR is essential for enabling machine

actionability, and the metrology community is encouraged to make use of the permanent identifiers (PIDs) given in the above services as a step towards making their own measurement data FAIR. At the BIPM, the next step in the digital transformation process will be to link the data in the KCDB to the above reference points, and experts in the Consultative Committees are already working with us to prepare for this.

In addition to the above "Reference Points", programming interfaces (APIs) are being developed (or are already available in beta-testing form) to facilitate access to:

- Data underpinning the international reference timescale UTC
- Data on the frequency standards approved for the practical realization of the metre
- Data supporting the ITS-90 and PLTS-2000.

## SI Reference Point

The cornerstone of the SI Digital Framework is the SI Reference Point, which is a suite of tools designed to provide an authoritative digital reference for the International System of Units (SI), traditionally published by the BIPM in the form of the SI Brochure.

The novelty of the SI Reference Point lies in its underpinning knowledge base, which constitutes a "single point of truth" accessible by both humans and machines. A set of API calls to interrogate the knowledge base is provided for the use of programmers and to generate the web interface, but the knowledge base can also be interrogated directly by machines, through the so-called "SPARQL" interface.

The development of the SI Reference Point was undertaken as part of the BIPM's Work Programme in Digital Transformation with contributions from seconding NMIs. We warmly thank the seconding institutions and acknowledge the important support provided by secondees from METAS, NPL, PTB and the University of North Florida.



FINDABLE



ACCESSIBLE



INTEROPERABLE



REUSABLE



# Organizational structure

## The CIPM (since March 2024)

### President

W. Louw (South Africa)

### Secretary

T. Usuda (Japan)

### Vice-Presidents

J. Olthoff (United States of America)

P. Richard (Switzerland)

### Other CIPM Members

V.G. Achanta (India)

V. Coleman (Australia)

D. del Campo Maldonado (Spain)

C. Denz (Germany)

N. Dimarcq (France)

H.A. Frøystein (Norway)

J.T. Janssen (United Kingdom)

H. Laiz (Argentina)

G. Macdonald (Canada)

S.-R. Park (Republic of Korea)

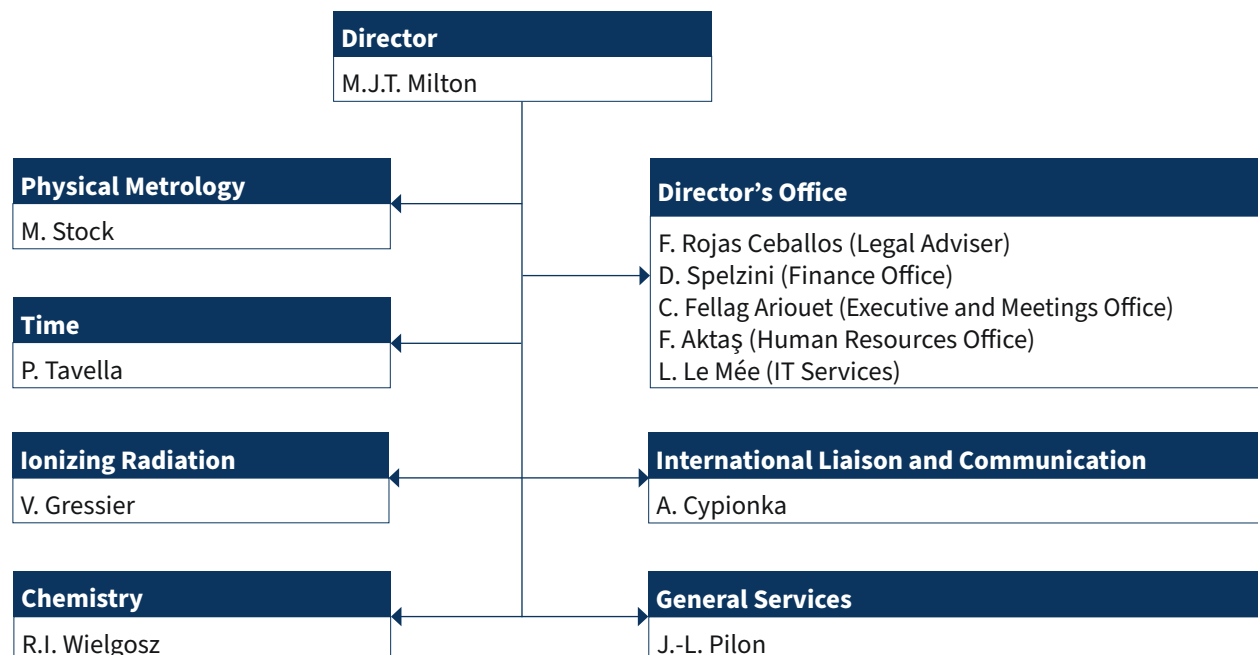
J. Qu (China)

M.L. Rastello (Italy)

G. Rietveld (Netherlands)

G.P. Ripper (Brazil)

## Organigram of Headquarters' Departments and Services (since March 2024)







World Metrology Day



We  
measure  
today  
for a  
sustainable  
tomorrow



Bureau  
International des  
Poids et  
Mesures



In support of the UNESCO World Metrology Day 2024



20 May 2024  
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Pavillon de Breteuil  
F-92312 Sèvres Cedex  
France  
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