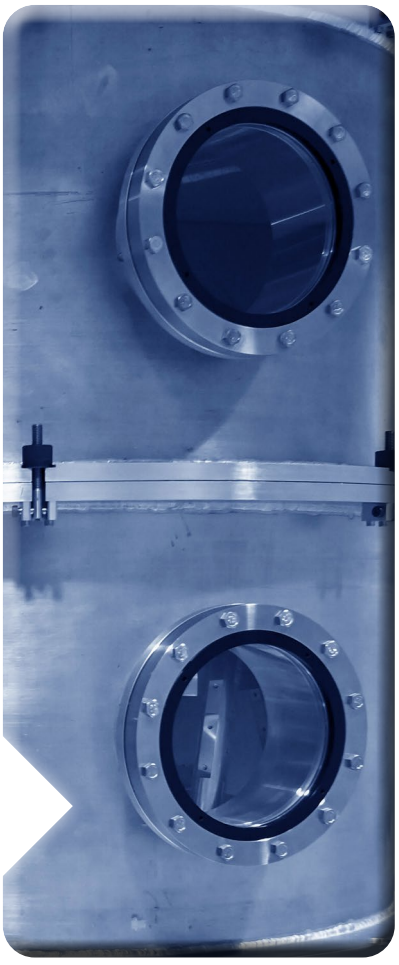
BIPM 1875 – 2025 CELEBRATING 150

Annual Review **2024/2025**



www.bipm.org

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

In 2024, we marked a historic milestone with the first World Metrology Day event hosted by UNESCO in partnership with OIML, which officially recognizes 20 May as a UNESCO International Day. This acknowledgment highlighted the global importance of metrology and our collective commitment to advancing measurement science.

This year also saw the launch of our first digital service, the SI Reference Point, which offers an authoritative, FAIR, and machine-readable digital resource for the International System of Units (SI). It will enhance access, transparency, and interoperability for stakeholders worldwide, building upon the information in the SI Brochure.

Preparations are underway for the global revision of the cross-section data used for accurate surface ozone measurements. This effort, led by the NMIs in the CCQM, and based on accurate measurements in the BIPM Chemistry laboratories will reduce uncertainty in environmental monitoring worldwide.

Other advances reported here in the laboratories include: precision measurements with the new Extension of the International Reference System (ESIR) in the Ionizing radiation laboratories and collaboration with NIST which led to a successful pilot study improving ac voltage comparison accuracy.

Collaborations during the year included new capacity building initiatives, including the participation of scientists from fifteen countries in a week-long quantitative NMR course at the BIPM, fostering expertise in advanced measurement techniques.

Lastly, we are supporting the CCTF and the broader time and frequency community as they explore redefining the second to leverage breakthroughs with optical clocks. This transformative work promises to shape the future of time measurement.

Looking ahead, preparations are now underway for the 28th meeting of the CGPM in October 2026. As part of the process to put forward a new strategy at the CGPM, we initiated a pioneering exercise to develop a future vision for metrology driven by young metrologists, aiming to inspire the next generation of leaders. This is now available from the website.

Photo by Krystal Kenney for the BIPM.

Dr Martin Milton at the BIPM Conference in Versailles
From units to the universe - future revolutions in metrology
21-22 May 2025

As this report goes to press we can report on the success of World Metrology Day in 2025 (Page 16), which marked the **150th Anniversary of the Metre Convention**. The events during May 2025 are just part of a plan for events throughout the year to celebrate this milestone for the organization.

Dr Martin Milton
BIPM Director

Physical Metrology

Mass metrology and the new kilogram definition

The redefinition of the kilogram, transitioning from the International Prototype of the Kilogram (IPK) to the new SI definition, has opened up new pathways for realizing the kilogram. National Metrology Institutes (NMIs) can now achieve this either through the Kibble balance method or by using the X-ray crystal density (XRCD) technique. However, despite these advances, there remains a lack of sufficient uniformity across independent realizations, as noted by the Consultative Committee for Mass and Related Quantities (CCM). As a result, the dissemination of the kilogram is coordinated internationally via a "consensus value." This value, determined as the arithmetic mean of the key comparison reference values (KCRVs) from recent BIPM coordinated Consultative Committee for Mass and Related Quantities (CCM) key comparisons, is periodically updated to maintain consistency.

The consensus value and CCM.M-K8.2024

The second consensus value, determined after the completion of the second key comparison CCM.M-K8.2021, was set at 1 kg − 7 µg with an uncertainty of 20 µg. This new value came into effect on 1 March 2023. Following this update, the CCM instructed NMIs to adjust their reference mass standards accordingly. A third key comparison, CCM.M-K8.2024, initially scheduled for late 2023, was postponed to 2024 to allow NMIs to resolve discrepancies identified in previous comparisons. This delay provides NMIs with additional time to enhance the uniformity of kilogram realizations by examining the origins of uncertainties in previous measurements.

The third comparison, which started in 2024, included ten NMIs; seven using Kibble or joule balances and three using the XRCD method. These laboratories will assess the masses of a set of travelling 1 kg standards, with comparison measurements taking place at the BIPM in early 2025 and the first comparison report is expected in August 2025.

Mass standards

During 2024, five Pt-Ir prototypes and twelve stainless steel standards were calibrated for eleven NMIs. In addition, one volume and three centre-of-gravity measurements were performed. A bilateral centre-of-gravity comparison was performed between the BIPM and the NPL (UK) for one mass standard of 500 g. The working standards for limited use were recalibrated after five years against the working standards for exceptional use. The new mass values are 3 µg below the expected values, within the uncertainty. Traceability to the new definition was achieved via the second CCM consensus value introduced in 2023. The calibration uncertainty was 21 µg, dominated by the uncertainty of 20 µg of the consensus value.

The BIPM Kibble balance

The BIPM Kibble balance continued to be improved for realizing the mass unit at the 1 kg level and for participating in the periodic series of CCM.M-K8 key comparisons of realization experiments [1]. In response to the CCM recommendation of 2023 asking for more collaboration between laboratories having a realization experiment, a member of the Kibble balance team spent five months on secondment in the NIST (USA) Quantum Electro-Mechanical Metrology Suite (QEMMS) team. The experience gained during this collaboration allowed an improvement by a factor of three on the signal-to-noise ratio of the voltage-to-velocity ratio measured on the BIPM Kibble balance during the dynamic phase. The BIPM also collaborated with the LNE (France) on a new determination of the absolute gravitational acceleration in the laboratory by transferring the well-known absolute gravity value at the LNE to the BIPM using a relative gravimeter. Mass measurement of a Pt-Ir mass standard was carried out for participation in the third key comparison of kilogram realizations, CCM.M-K8.2024, which is still dominated by the type B uncertainty due to imperfect alignment of the apparatus.

The BIPM Kibble balance

A new, single-pan version of the balance was fabricated and characterized [2]. This version demonstrated high sensitivity, repeatability and improved performance during the dynamic phase of measurements. The parasitic coil translation due to the arc-motion of the end of the balance beam was corrected and no unwanted oscillations were observed. There is still room for optimizing the beam behaviour by adjustments, which were not possible with the previous device. Further characterization of the system requires better measurement conditions and a vacuum chamber was designed and fabricated for this purpose.

The new balance-beam mechanism serves as a basis for a compact Kibble balance for masses of 500 g and below. A compact apparatus is easier to align, operate, maintain and is more adapted for knowledge transfer activities. As a first step, a simple, low-cost and high-resolution voltmeter was designed and fabricated by the BIPM. The first characterization showed a noise level comparable to that of the commercial digital voltmeter (DVM) presently used in the Kibble balance apparatus. A compact closed magnetic circuit was provided by Tsinghua University (China) in the framework of a joint technical cooperation. The magnetic circuit is based on an original BIPM design but which incorporates an innovative feature allowing opening of the magnetic circuit without extracting it from the Kibble balance. The uniformity of the magnetic field produced by the circuit was successfully measured using a home-made gradient coil.

Electrical metrology

Electrical metrology at the BIPM focused on advancing systems for resistance, capacitance, and voltage comparisons and calibrations. A new dual current source is being developed for a resistance comparison bridge. This bridge will be instrumental in future quantum Hall resistor (QHR) comparisons during the BIPM.EM-K12 on-site comparisons.

A new cryogenic current comparator (CCC) using a superconducting quantum interference device (SQUID) was assembled and underwent preliminary testing. This new CCC showed exceptional performance. Further tests on the new CCC are planned to improve its noise performance.

Two studies were pursued in 2024: the long-term stability of a graphene-based quantum Hall resistor provided to the BIPM by the PTB as part of a scientific collaboration; and the analysis by finite element modeling (FEM) of the alignment errors of the calculable capacitor currently being assembled. Concerning the first study, it was observed that the conservation of the graphene device in air (for about 17 months) has the effect of reducing the charge carrier density but that - to date - its quantification remains possible at a reduced field of the order of 5 T [3]. As for the calculable capacitor, the FEM calculations confirm the measurement results obtained in previous studies, which are available in the published bibliography on the subject. The simulation of more complex misalignment cases will be carried out soon. A study carried out with the PTB (Germany) and the NMIJ (Japan) on the low-frequency dependance of 1 Ω resistors used for the BIPM.EM-K12 comparison was completed and the results presented at the CPEM conference [4].

The BIPM is a member of the pilot group of the EURAMET.EM-K4 comparison of electrical capacitance, which is a follow-up of the CCEM-K4 comparison organized by the BIPM in 2017. A preliminary study has been carried out of the influence of electrostatic and thermal environmental conditions on the capacitance value of Andeen-Hagerling AH11A type standard capacitors, which will be used by most of the NMIs for this comparison. The study showed that there is no need to modify these standards to compensate for a supposed lack of electrostatic shielding (by adding a specific additional shield) as has been done by many institutes so far.

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 2024. The farad was realized from the ohm using a multifrequency quadrature bridge. Calibrations of the BIPM resistance and capacitance references and working standards for services were also made twice from the realizations. A total of 52 calibrations in the field of impedance have been provided for eight NMIs: 24 certificates for resistance and 28 for capacitance. In addition, a BIPM.EM-K13 a&b comparison (resistance at 1 Ω and 10 k Ω) and a BIPM.EM-K14 a&b comparison (capacitance at 10 pF and 100 pF) have started with UME TÜBITAK (Türkiye) and CENAM (Mexico), respectively.

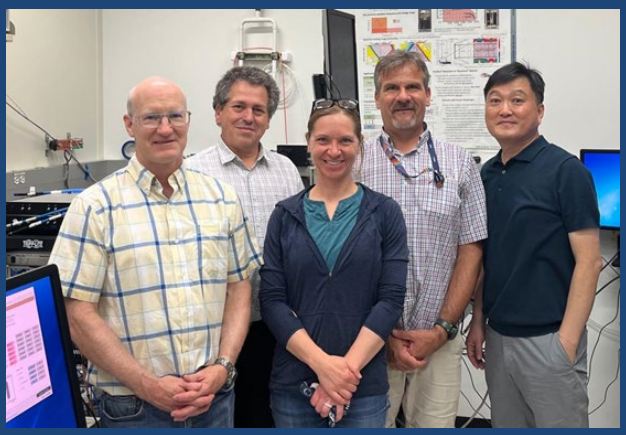
The reports on a comparison of Zener calibrations, BIPM. EM-K11, with SASO (Saudi Arabia) and INRIM (Italy) were published [8,9] and two further comparisons are being carried out with NSAI (Ireland) and SMD (Belgium). A total of four Zener voltage standards were calibrated for three NMIs in 2024.

Pilot study enhances accuracy of AC voltage comparisons

The BIPM and NIST successfully conducted a new pilot study, marking a significant advancement in the accuracy and reliability of ac voltage comparisons. This achievement represents a major step forward for on-site comparisons of ac voltages.

Since 2016, the International Bureau of Weights and Measures (BIPM) has conducted multiple pilot studies to expand its on-site comparison programme from dc (direct current) Josephson voltage standards to ac (alternating current) voltages. These studies aim to decrease the uncertainties associated with the differential sampling technique applied to Programmable Josephson Voltage Standards (PJVSs) within the range of 10 Hz to 1 kHz, for root-mean-square (rms) voltages of 0.7 V and 7 V. This effort has been supported by several NMIs.

In August 2024, two scientists from the BIPM spent three weeks at the NIST Boulder laboratories, alongside a KRISS scientist, to carry out a new pilot study. The BIPM's transportable PJVS was directly compared to NIST's Josephson Arbitrary Waveforms Synthesizer (JAWS). As a primary standard, JAWS produces sinusoidal voltage signals in the hertz to megahertz range with very high spectral purity up to 2 V. Importantly, unlike other ac voltage sources, the JAWS does not exhibit any voltage drift, ensuring reliable results.



Particiapnts in the Pilot Study at NIST, from left to right: A. Rüfenacht (NIST), R. Chayramy (BIPM), R. Johnson (NIST), S. Solve (BIPM), M.-S. Kim (KRISS)

Key achievements of this study include:

- The NIST JAWS system allowed the BIPM PJVS to be tested under a wide variety of configurations, pushing the limits of reliability of the differential sampling setup.
- For the first time, the study achieved a Type A uncertainty (a measure of statistical uncertainty) of a few parts in 10^9 for a 10 Hz sine wave at 2 V rms. At 1 kHz, a relative level of 2×10^{-7} was reached.

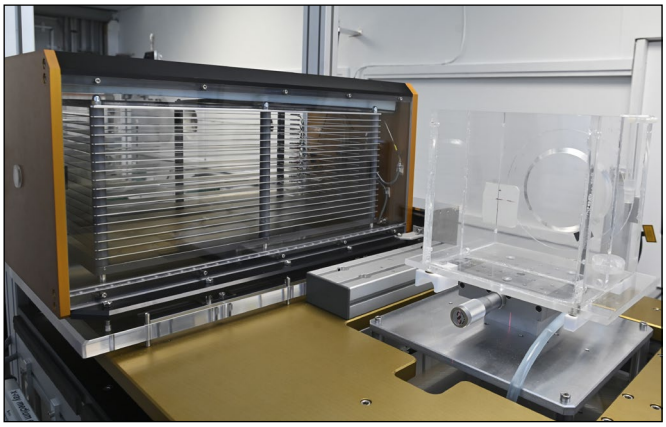
These successful pilot comparison results confirm the high reliability of the BIPM's transportable system and pave the way for on-site comparison exercises for ac voltages in the coming years. This will help NMIs to demonstrate the performance of their ac voltage measurement systems and helps to underpin equivalence of ac voltage measurements worldwide. The official comparison programme will start in 2025 with two on-site comparisons already planned.

Ionizing Radiation

In 2024, requests for radiation dosimetry comparisons and calibrations remained high, with the BIPM conducting ten comparisons and thirty calibrations. Comparisons included five for Germany, two for Poland, two for France, and one for China, while calibrations were performed for Greece (six), Finland (three), Brazil (seven), Switzerland (two), Denmark (five), and the IAEA (seven). Calibrations for the IAEA are of particular importance in extending BIPM traceability to national institutes that are not signatories to the CIPM MRA. Specific calibration activities utilized both the linear accelerator at the DOSEO platform in Saclay, France, and the IAEA's ^{137}Cs irradiation facility. Continuous quality control checks ensured the stability of BIPM's standards and radiation beams.

In addition to calibration certificates, ten comparison reports were published in the *Metrologia Technical Supplement* for Austria, France, Hungary, Germany, Netherlands, Poland, and Spain [11-20].

The development of a new primary standard for medium-energy x-ray dosimetry is nearly complete. This new reference facility, set to replace the 1970s-era equipment, will improve the efficiency and assure the continuity of calibrations and comparisons for the next decades. The new x-ray beams were fully characterized in 2024, with validation involving calibration of various ionization chambers. These results indicated no measurable difference in radiation qualities between the new and existing facilities, ensuring continuity and consistency in BIPM's services.



New primary standard free-air ionization chamber and water phantom

In response to the metrology community's needs, the BIPM resumed the BIPM.RI(I)-K5 key comparison at the IAEA's ^{137}Cs irradiation facility in 2024, re-offering calibration services for radiation protection levels to NMIs and Designated Institutes from Member States. This included offering services to the IAEA, thus extending calibration support for radiation protection to the network of Secondary Standards Dosimetry Laboratories (SSDLs).

The BIPM continued its work on comparing national activity standards for gamma-ray emitting radionuclides through the International Reference System (SIR). In 2024, nine radionuclides used in nuclear medicine, industry, and environmental applications were measured, including ^{47}Sc, ^{54}Mn (two NMIs), ^{106}Ru, ^{113}Sn, ^{123}I, ^{133}Ba (two NMIs), ^{177}Lu, ^{212}Pb and ^{225}Ac. Eight SIR comparison reports were published in 2024, including machine-readable data [21-28].

Substantial progress was made on two fronts with the SIR system. First, a mathematical approach has been developed to facilitate the transfer of key comparison reference values (KCRVs) to backup the SIR ionization chamber, reducing the need for direct sample measurements. Second, the development of the new SIR 2.0 was pursued, including improvements in the acquisition system for the Ultra Low Current Amplifier (ULCA-1©) and its digital voltmeter. The relative precision of 25 pA ionization current measurements reached 3×10^{-4}, matching the historic SIR performance.

The SIRTI (International Reference System Transfer Instrument) enables on-site comparisons of short-lived radionuclides. In 2024, remote operations were successfully carried out at the LNMRI (Brazil) and hybrid operations at the IRA (Switzerland). Efforts to expand SIRTI services to include additional radionuclides have advanced with the support of a secondee from CIEMAT (Spain), who carried out Monte Carlo simulations to evaluate the SIRTI relative uncertainty for ^{153}Sm and ^{56}Mn comparison of 2.1×10^{-3} and 6.2×10^{-4}, respectively. The development of a digital acquisition system for the SIRTI using a CAEN® module advanced, with first measurements demonstrating that it has the capability to handle counting rates of up to 20 000 s^{-1}.

Additionally, the BIPM developed criteria for regional metrology organizations (RMOs) to establish their own SIRTIs, aiming to facilitate more regional comparisons for radionuclides critical to nuclear medicine. This initiative aims to extend these comparisons to non-Member States as well.

Significant efforts were made in 2024 to prepare a long-term strategic document for the BIPM ionizing radiation department. Driven by the CIPM and CCRI strategies, as well as the needs expressed by the Member States, it outlines the department's current role, future challenges, and key objectives in ionizing radiation metrology.

Improved metrological traceability of challenging-to-measure radionuclides

The BIPM received the first standard solution of Technetium-99 from the LNE-LNHB (France) for measurement using the newly implemented Extension of the International Reference System (ESIR). This marks the launch of the BIPM.RI(II)-K5 comparison, with the first of the eleven isotopes selected as a first phase by the Consultative Committee for Ionizing Radiation (CCRI). The launch in 2024 followed software analysis optimization [29] and a full setup of the related quality system.

Technetium-99, a long-lived by-product of medical diagnostics, nuclear industry activities and fallout testing, is a significant concern for the environment. The BIPM and NMIs are proud to contribute to enhancing the metrological traceability of this pure beta-emitting radionuclide.

The ESIR was developed and implemented at the BIPM after three years of collaborative effort. It enables the measurement of radionuclides that could not previously be compared by the SIR system, allowing NMIs and Designated Institutes (DIs) to obtain degrees of equivalence for these specific isotopes.

Time

CCTF capacity building project to improve the quality of UTC(*k*) and UTC time scales

The joint project between the Consultative Committee for Time and Frequency (CCTF) and the Ultrasonic, Ferroelectrics and Frequency Control (UFFC) Society, started in late 2023. Its goal is to improve the capabilities of Coordinated Universal Time (UTC) laboratories, NMIs and the broader Time and Frequency community by sharing the resources available in UTC laboratories as well as developing new tools for the analysis and validation of time and frequency measures.

The CCTF programme is supported by secondees from the NMI community at the BIPM headquarters working together with the staff of time department. An interactive software tool for the analysis of global navigation satellite system (GNSS) measures in the Common GNSS Generic Time Transfer Standard (CGGTTS) format has already been made available and it is ready for testing. Future plans include time scale algorithms for averaging clock data.

Other new learning tools, such as e-courses, have been developed and published on the BIPM e-learning website. These courses cover topics such as GNSS pseudorange measurements, time and frequency fundamentals, and best practices in NMIs. Additional courses are under development, focusing on clock data analysis and time scale algorithms. The programme has been well-received by UTC laboratories and contributed to training events organized by the European Association of National Metrology Institutes (EURAMET) and the Asia Pacific Metrology Programme (APMP) in 2024. Future contributions to the Inter-American Metrology System (SIM) and a BIPM summer school are planned for 2025 [30]

In June 2024, two novel changes were introduced into *Circular T*. The first update addresses the treatment of time transfer equipment in section 5. Uncalibrated equipment is now marked as "NC" (Not Calibrated), and its uncertainty in the offset UTC-UTC(*k*) is listed without the type B uncertainty related to calibration. Only the type A uncertainty is included. This change, based on revised uncertainty propagation models [31,32], properly handles uncalibrated equipment and facilitates the inclusion of correlations between time transfer measurements. While uncalibrated equipment does not maintain traceability to Coordinated Universal Time (UTC) in time, traceability to UTC in frequency is preserved. These adjustments have been reflected in the key comparison database (KCDB) for the UTC key comparison CCTF-K001.UTC.

The second change involves section 4 of *Circular T*, which reports the difference between UTC and its GNSS broadcast predictions (bUTC_GNSS). Previously, this data was only provided for GPS and GLONASS systems. The updated section now includes Beidou and Galileo systems as well. Alongside this addition, a revision of the computation methods was made. These methods now rely on a robust combination of four MultiGNSS calibrated receivers placed in UTC laboratories. These laboratories are part of group G1, meaning they are regularly visited by the BIPM's travelling GNSS equipment, which characterizes receiver delays [33].

In response to a customer satisfaction survey, the BIPM has launched a new web page with tutorials and explanations of *Circular T*, helping users better understand its contents. The Time Department is also engaged in several other CCTF activities, such as the redefinition of the second, continuous UTC, and the evaluation of a common time scale for the Moon. Contributions have been made at regional events to inform the broader time and frequency community about these initiatives [34-41].

The CCTF Working Group on Frequency Standards (CCL-CCTF-WGFS) has collaborated on validating algorithms and software used to estimate the secondary representation of the second, which will play a key role in the redefinition of the second [42]. In addition, the Time Department is working with universities to improve the statistical treatment of UTC clock data, including efforts to automatically detect time jumps [43] and optimize predictions for UTC clocks [44].

The 2022 G1 calibration exercise concluded in 2024, with updated receiver delay values applied. COOMET was not included in the calibration exercise due to shipping difficulties. In collaboration with the Joint Research Centre (JRC) in Italy and the European Space Agency, the calibration of BIPM GNSS receivers has been completed. Additionally, the calibration of Two-Way Satellite Time and Frequency Transfer (TWSTFT) stations in Europe was finalized at the end of 2023. The Time Department also provided data analysis support.

A project on Integer Precise Point Positioning (IPPP) has been carried out in collaboration with a Postdoctoral researcher and the French Space Agency. This project developed an IPPP suite capable of computing an IPPP link between two UTC laboratories through a user-friendly interface, which is currently undergoing testing at the Paris Observatory [45]. A global comparison of different IPPP algorithms was also conducted in collaboration with the CCTF Working Group on GNSS Time Transfer (CCTF-WGGNSS) and other coleagues [46,47], showing good consistency among the algorithms. Studies have continued on the operational use of IPPP in UTC [48], the stability of GNSS receiver delays [49], and comparisons with optical fibre synchronization techniques [50].

The department is also focused on the complete digitalization of data. Ongoing testing is being conducted on databases and application programming interfaces (APIs) related to the secondary representation of the metre and second, as well as UTC data. The BIPM is also supporting the development of SI Reference Point coding.

Regular tasks such as data collection, computation of UTC, rapid UTC, and the CCTF-K001.UTC key comparison continued without interruption. In 2024, two new laboratories, BSJ (Jamaica) and IFZG (Croatia), joined UTC.

Chemistry

The Chemistry Department progressed fourteen interlaboratory comparisons in 2024, including comparisons of standards for food contaminants, diagnostic markers and greenhouse gases. New knowledge transfer activities were established with a summer school and e-learning modules on qNMR for organic primary reference material characterization, as well as e-learning modules on isotope ratio measurements and standards for carbon and oxygen. The on-site visiting scientist programme continued with five visiting scientists working in the department during the year, and the department produced fourteen publications including eight comparison reports and three papers in peer reviewed journals.

Department staff 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). An online CCQM workshop on Digital and FAIR Chemical and Biological Reference Data and Certificates: Challenges and Opportunities, was organized with pre-recorded presentations, attracting over four hundred and fifty participants, and concluding with a recommendation to establish a CCQM Task Group.

Metrology for Safe Food and Feed

As part of the department's programmes related to Metrology for Safe Food and Feed, the final reports of comparisons CCQM-K148.b and CCQM-K179, the oxytetracycline hydrochloride and salt purity comparison used as a veterinary drug, were submitted for final review and publication. In the mycotoxins area, the characterization of ochratoxin A (OTA) material continued in preparation for the CCQM-K154.e comparison, with characterization of OTA pure material completed, gravimetric preparation of stock and calibration solutions completed as well as homogeneity and stability studies. The final report [51] of the bilateral subsequent comparison CCQM-K154.b.1 (AfB1 mycotoxin calibrant) was completed and published. For pesticides, the final report of CCQM-K78.b (Methoxychlor and Trifluralin: Pesticide Calibration Solution Comparison) was completed and submitted for final review and publication. Preparations for CCQM-K78.b 2026 (Multicomponent pesticide calibration solution comparison) continued, with nine months of a twelve-month secondment by a scientist from NIM (China) being completed for the development and validation of liquid chromatography-diode array detection-charged aerosol detector (LC-DAD-CAD) methods for multicomponent solution analyte quantification, focusing on atrazine, carbofuran, dimethoate and endosulfan.

Metrology for health

As part of the programmes related to Metrology for Health and diagnostic markers, a second on-site hybrid meeting was held at the BIPM headquarters in February 2024, with representatives from 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. Nine months out of a twelve-month secondment by a scientist from NIM was completed with development of liquid chromatography–high-resolution mass spectrometry (LC-hrMS) method for the quantification of structurally related impurities in PTH material completed and liquid chromatography-mass spectrometry (LC-MS) method based on quantification of proteotypic peptides ongoing. Samples for the CCQM-K155.d / P55.2.d comparison of PTH (1-84) were shipped to 10 of 12 participants, noting that the shipment of samples on dry-ice required considerable resources. A paper [52] on the methods developed for the purity assignment of the SARS-CoV-2 monoclonal antibody in the CCQM-P216 material was published. Potential sources of cyclosporin A material for the CCQM-K115.c.2026 purity comparison have been identified in collaboration with the UK National Measurement Laboratory hosted at LGC. For the therapeutic drug purity comparison on digitoxin (CCQM-K148.c), a purified material was filled by UME (Türkiye) for the BIPM as part of a Joint Technical Project, with 150 units containing 50 mg received by the BIPM. Measurements of homogeneity and stability of the samples were completed by a visiting scientist from GLHK (Hong Kong, China) during a 3 month secondment. A review [53] on "*Reliable biological and multi-omics research through biometrology*" was published.

JCTLM

The Chemistry Department continued to support the Joint Committee for Traceability in Laboratory Medicine (JCTLM), by providing the secretariat, supported jointly by the IFCC. The Secretariat completed the technical specification for the upgrade of the JCTLM database to transition to a web-based nomination and review process and a contract for the development was placed. The secretariat's workload in 2024 included: preparation of 110 nominations for JCTLM database entry review; and publication of 64 new entries in the JCTLM database from 2023 nominations. A paper [54] on JCTLM database entries for total bilirubin was published.

Gas metrology: Greenhouse gases

The Chemistry Department continued its programme of comparisons related to Metrology for the Environment.

The quality documentation for the BIPM's primary manometric system for CO_2 amount fraction measurements in air was completed and the ongoing comparison BIPM.QM-K2.a and b was launched, with measurements for the first participant E+E Elektronik (Austria) completed. The protocol for the CO_2 in air scales comparison BIPM.QM-K5 was completed in collaboration with the CCQM Working Group on Gas Analysis (CCQM-GAWG) Task Group on GHG Scale Comparisons (CCQM-GAWG-TG-GHG). A second set of absolute measurements have been completed on the two ensembles of nine CO_2 in air standards maintained at the BIPM. A database for GHG comparison data was developed via collaboration with the University of Colorado / National Oceanic and Atmospheric Administration (NOAA) and a joint technical project with VSL (Netherlands).

Measurements for CCQM-K82.2023 (Methane in air standards) were completed, with 25 standards from participating NMIs

measured using both cavity ring down spectroscopy (CRDS) and gas chromatography-flame ionization detection (GC-FID) systems at the BIPM. The standards were returned to NMIs for stability testing, which was completed and the Draft A report of the comparison was initiated.

The CCQM-P239 (CO_2 Isotope Ratios ($\delta^{13}C$ and $\delta^{18}O$) in air) study was launched as a pre-comparison for the future BIPM.QM-K4 on-demand comparison. Fifteen participants registered for the comparison and 27 standards were received at the BIPM headquarters out of the total of 41 standards of CO_2 in air mixtures that were expected. Measurements on 12 standards were completed at the BIPM, with the remainder scheduled for 2025. A 3-month secondment, from the University of Groningen, was completed resulting in a revised nitrous oxide correction being implemented into the CCQM-P239 protocol, development of data treatment for clumped isotope data and assessment of the impact of non-equilibration of CO_2 isotope mixtures on isotope-ratio mass spectrometry (IRMS) measurements evaluated. e-learning modules on an introduction to $\delta^{13}C$ and $\delta^{18}O$ standards and measurements in CO_2 were developed and made available on the BIPM's e-learning platform. BIPM staff contributed to an IAEA experts meeting, which resulted in the development of a new format and definitions for $\delta^{13}C$ and $\delta^{18}O$ scales for isotope ratio measurement, with a publication expected in 2025. Four months of a 6-month secondment of a scientist from NIM were completed focusing on calibration methods for an optically-based instrument for CO_2 isotope ratio measurement, with two different analysers tested and compared. Sixteen CO_2 pure gas isotopic research samples were prepared at the BIPM headquarters, value assigned and shipped to the NPL (nine samples) and KRISS (seven samples). Six further samples were in preparation for NIST.

Gas metrology: Air quality gases

A focus for the department was measurement standards for ozone and nitrogen dioxide. Three bilateral comparisons were performed for the ozone standard comparison, BIPM.QM-K1, including an electronics upgrade performed on the Ozone Standard Reference Photometer maintained by the JRC and seven comparison reports were published [55-61]. 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 published amendments to ISO 13964 and ISO 10313 standards incorporating the same value for the ozone cross section as was approved by the CCQM for BIPM.QM-K1. The BIPM published two guidelines [62-63] to assist with the transition to the cross-section value, with the first being a guideline on how to implement the new absorption cross-section for ozone concentration measurements, the second on recommendations for metadata provision.

A joint technical project continued with the NPL for the development of future ongoing comparisons for NO_2 in nitrogen at 10 µmol/mol (BIPM-QM-K6). The NPL returned three cylinders to the BIPM, where measurements were completed, validating the future comparison protocol that would be used. The extension of the BIPM's NO_2 capabilities to cover the amount fraction range of 1000 nmol/mol to 50 nmol/mol in nitrogen and air was progressed in joint technical projects with METAS (Switzerland) and LNE (France). The BIPM's second Magnetic Suspension Balance (MSB) facility was modified and characterized over the ranges (1100 to 500) nmol/mol and (500 to 50) nmol/mol. The BIPM received a batch of permeation tubes that had been calibrated by METAS for use with a transportable permeation oven and the LNE has started the preparation of a standard at nominally 1000 nmol/mol for comparison with the BIPM.

Successful qNMR Summer School at the BIPM

The BIPM hosted its first onsite summer school on quantitative nuclear magnetic resonance (qNMR) in support of the NMIs organic standards programmes. The week-long course in the Chemistry Laboratories brought together scientists from fifteen different countries, with instructors from NMIs and the BIPM Chemistry Department as well as experts in qNMR techniques. The instructors from NMIJ (Japan), INTI (Argentina), BAM (Germany) and NIM (China) had all previously been visiting scientists at the BIPM and contributed to the characterization of an ensemble of internal reference standards that allow qNMR measurements to be performed on virtually any organic compound.

qNMR is becoming the method of choice for the value assignment of purity of organic compounds as primary reference materials for diagnostic, food safety, pharmaceutical, forensic and drug testing and other applications.

The online version of the course is available through the BIPM eLearning portal.

The first Internal Standard Reference Data (ISRD) report [64] for ^{19}F qNMR using BTFMBA was published, adding to the octad of internal standard documents already published for proton qNMR.

International Liaison and Communication

UNESCO and World Metrology Day 2024

World Metrology Day, celebrated annually on 20 May, marks the anniversary of the signing of the Metre Convention and the creation of the BIPM in 1875. World Metrology Day was established by the International Committee for Weights and Measures (CIPM) in 1999, with the first celebration held in 2000. Since then, it has become an annual global event organized by the BIPM and the OIML, in close collaboration with national metrology institutes and regional metrology organizations around the world. This day recognizes the vital role of metrology in international trade, science, and technology and each year, the day highlights the critical role of measurement science in addressing global challenges and supporting sustainable development.

In 2022, building on the growing success and global impact of World Metrology Day, the Executive Board of the United Nations Educational, Scientific and Cultural Organization (UNESCO) officially endorsed a proposal to formally recognize 20 May each year as "World Metrology Day." This proposal was presented to UNESCO by the Republic of Kazakhstan in collaboration with the BIPM and the OIML and supported by 43 UNESCO Member States. This decision was subsequently ratified during the 42nd session of the General Conference of UNESCO in November 2023. This official recognition marks a significant milestone, reinforcing the essential role of metrology in everyday life and its contribution to science, technology, industry, and sustainable development world-wide.

The 2024 World Metrology Day launch event, held at the UNESCO Headquarters on 14 May 2024, featured the theme "We Measure Today for a Sustainable Tomorrow." Keynote speeches emphasized how metrology contributes to sustainable economies and environments. A BIPM staff member served as the Master of Ceremonies for the event. The event was attended by approximately 200 stakeholders, including members of international organizations, embassies, and the metrology community. A video illustrating the everyday importance of measurements and their contribution to sustainable development goals was presented.

The BIPM, in collaboration with EURAMET and TÜBITAK UME (Türkiye), designed the official 2024 World Metrology Day poster, available in over 20 languages. The 2024 World Metrology Day Resource Website lists 37 global celebratory events and provides access to related documents, including press releases and official posters.

Collaboration with the OECD

The BIPM and the Organisation for Economic Co-operation and Development (OECD) continue to work together toward their shared goal of strengthening the interaction between quality infrastructure and regulation, ensuring their collaborative efforts contribute effectively to addressing today's most pressing global challenges.

Strong quality infrastructure, including metrology, is essential for effective regulatory delivery and enforcement. Conversely, regulatory systems play a crucial role in enabling dynamic regulations, sustainable standards, accurate measurements and reliable test results. Recognizing this potential, on 6 December 2024, the BIPM and the OECD hosted a full-day event "Building Stronger Connections Between Quality Infrastructure and Regulation" to illustrate the diverse regulatory and quality infrastructure system and to explore the critical links between them. Held at the BIPM's headquarters in Sèvres, France, and streamed on Zoom, the event brought together close to 180 leading experts, policymakers and practitioners from around the world.

The event showcased key findings from a new report, the expected outcome of an OECD-led project "Interlinkages between regulation and quality infrastructure" funded by the National Metrology Institute of Germany (PTB) which was launched in May 2023. The BIPM was one of the initiators of this project and seconded a staff member to the OECD for seven months during 2023-2024 under a part-time loan programme to assist the OECD Regulatory Policy Division in its implementation efforts.

The outcome, a report detailing the components and benefits of quality infrastructure systems, is expected to be published in 2025.

Beta-version of the SI Reference Point now available

The SI Reference Point is a set 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 SI Reference Point is designed to be fully FAIR* and machine-actionable.

The resource is currently based on five pillars:

- units
- prefixes
- decisions
- constants
- quantities

Each pillar encloses information in the form of a knowledge graph (that can be downloaded as a TTL file). These knowledge graphs can be accessed through different means: an application programming interface provides a set of pre-programmed calls, which also underpin the website; a SPARQL endpoint is provided for direct machine queries. The TTL files can also be browsed visually using a graphical interface such as GraphDB.

A preliminary user guide, along with the TTL files, can be accessed on a dedicated GitHub platform. The current release is a BETA version, so we strongly encourage user testing and feedback.

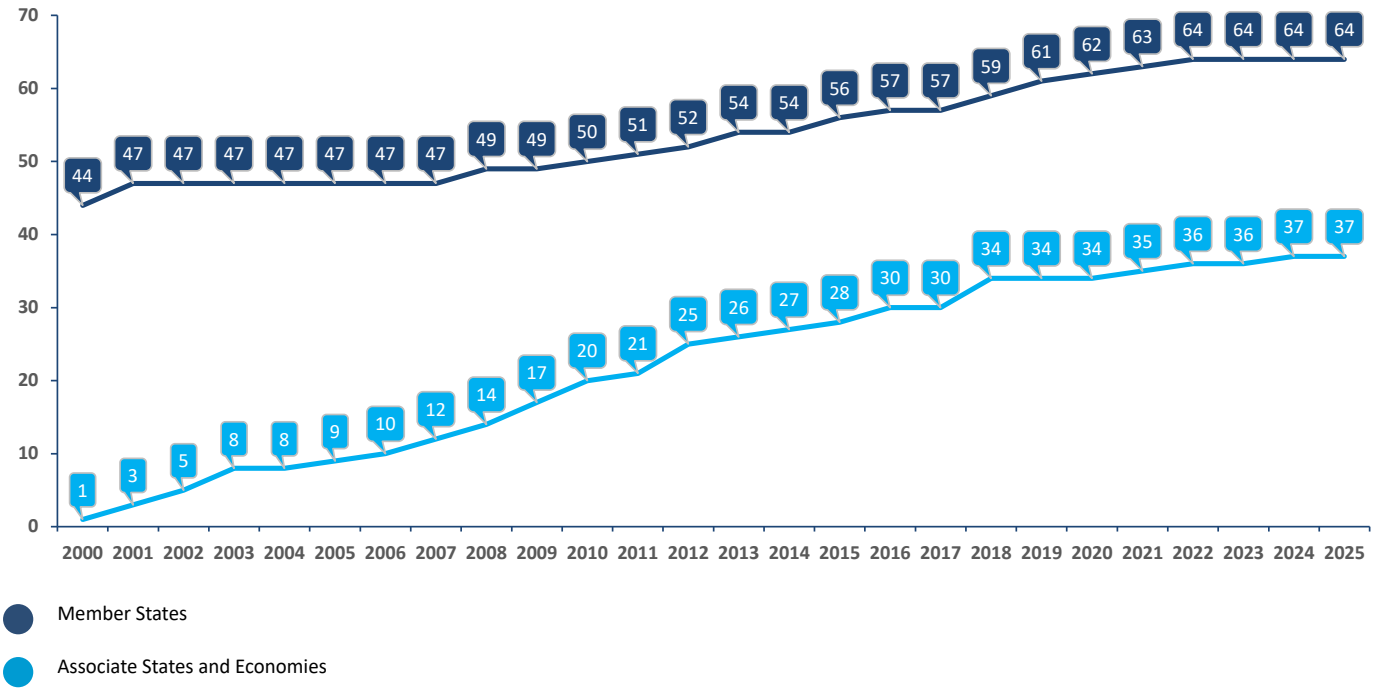
This project was undertaken as part of the BIPM's Work Programme in Digital Transformation, with contributions from seconding NMIs.

* FAIR: Findable, Accessible, Interoperable and Reusable

https://si-digital-framework.org/

https://github.com/TheBIPM/SI_Digital_Framework/tree/main/SI_Reference_Point/docs

Evolution in Member States and Associate States and Economies from 2000 to 2024



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.

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 programme has a highly appreciated portfolio that continues to expand. The CBKT initiatives are delivered through various activities such as workshops, laboratory placements and remote-learning activities, including the BIPM e-learning platform, which also hosts knowledge transfer material from the Regional Metrology Organizations (RMOs).

Around 63 CBKT initiatives, designed to support national and regional metrology activities, have been delivered with the involvement of more than 70 lectures and experts from NMIs, RMOs and International Organizations. There have been over 4 500 participations in-person and online from 126 countries, covering all six RMOs. The e-learning platform hosts more than 25 courses and has more than 1 960 registered users.

Successful completion of the 7th BIPM–TÜBİTAK UME project placements

In this cycle, ten young metrologists from ten NMIs spent 1-3 months conducting research in TÜBİTAK UME's world-class laboratories, working on projects that contribute to the advancement of precision measurements world-wide. In addition to their research, participants took part in a CIPM MRA seminar, designed to reinforce their understanding of the international metrology system and strengthen global collaboration in measurement science.

BIPM and OIML e-learning course - National Metrology Systems

The BIPM and International Organization of Legal Metrology (OIML) have published an e-learning course based on the BIPM and OIML joint publication: National Metrology Systems Developing the institutional and legislative framework (OIML D 1:2020).

The aim of the course is to assist countries and economies with emerging metrology systems (CEEMS), that are still in the process of developing or reshaping their national metrology systems, in preparation for effective participation in the international measurement system. This self-study course contains five e-learning modules. It provides information to national authorities, NMIs and other interested parties on the issues to be considered when developing policies regarding their national metrology systems, when setting up or re-shaping their institutions and when drawing up national laws related to metrology. The course is intended to be taken in the order of the modules.

https://e-learning.bipm.org/

Young Metrologists' 2050+ Vision

The 27th General Conference on Weights and Measures (2022) marked the launch of the "Young Metrologists' 2050+ Vision" initiative. The mandate from the CGPM inspired a global consultation with young metrologists on the future of metrology. This consultation engaged over 380 young professionals in workshops, debates and interviews to explore future trends, technologies and challenges that will impact metrology in 2050 and beyond. It was aimed at creating a global roadmap for metrology beyond 2050, complementing the CIPM's Strategy 2030+. To make the Young Metrologists' Vision 2050+ initiative a reality, a diverse group of young minds from NMIs came together to reimagine what metrology will look like decades from now, from next-level technology to exploring space metrology and the emerging world of nanobiometrology.

The eleven coordinators nominated by RMOs brought together young metrologists from their respective regions to hear their vision of metrology beyond 2050.

The tasks included developing questions, organizing online discussions, analysing responses from the participants and preparing a report. Driven by passion and a sense of responsibility to tackle global challenges through collaboration and innovation, the young metrologists anticipated the future trends, technological developments and challenges coming our way. They also formulated their vision for global metrology: "Metrology, as a cornerstone of natural sciences, must evolve together and drive advances in technology, supporting all stakeholders based on collaborative capacity and capability, building to co-shape the future."

Through this initiative, we have seen how young metrologists are stepping up as leaders, with fresh ideas and passion. They are not just ready to face the challenges of the future, they are set to lead the transformation of metrology to keep it relevant. The outcomes of this initiative were presented at the 150th anniversary of the signing of the Metre Convention in 2025.

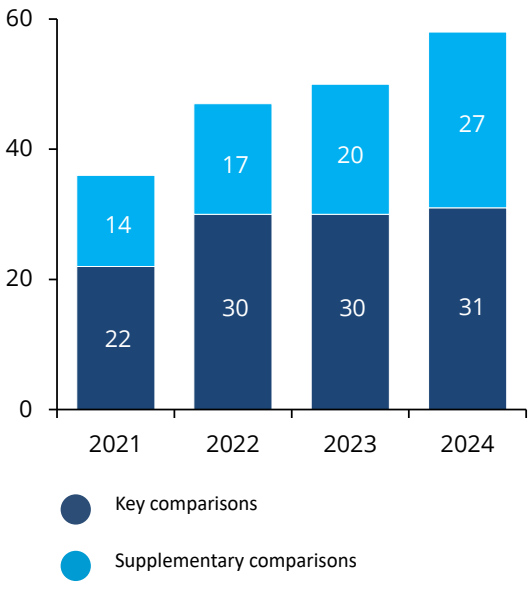
The CIPM MRA

- The CIPM MRA is a framework through which NMIs 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.

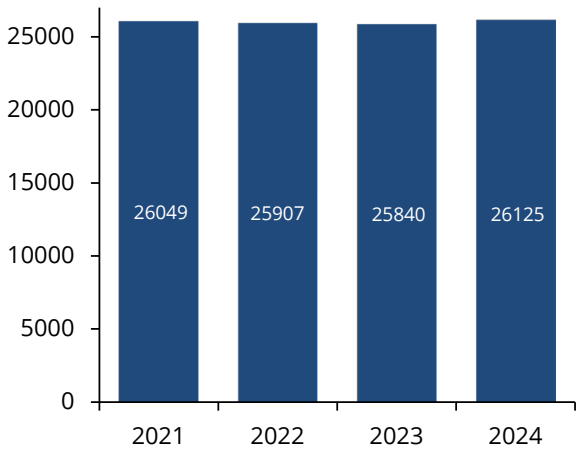
Statistics (on 31 December 2024)

- 26 125 CMCs published in the KCDB: 15 939 in general physics, 3 707 in ionizing radiation, 6 479 in chemistry.
- 1 211 key comparisons and 713 supplementary comparisons listed in the KCDB.
- In 2024, two KCDB Reports providing detailed statistics were made available in March and September via https://www.bipm.org/en/cipm-mra/kcdb-reports.

Number of new comparisons registered in the KCDB

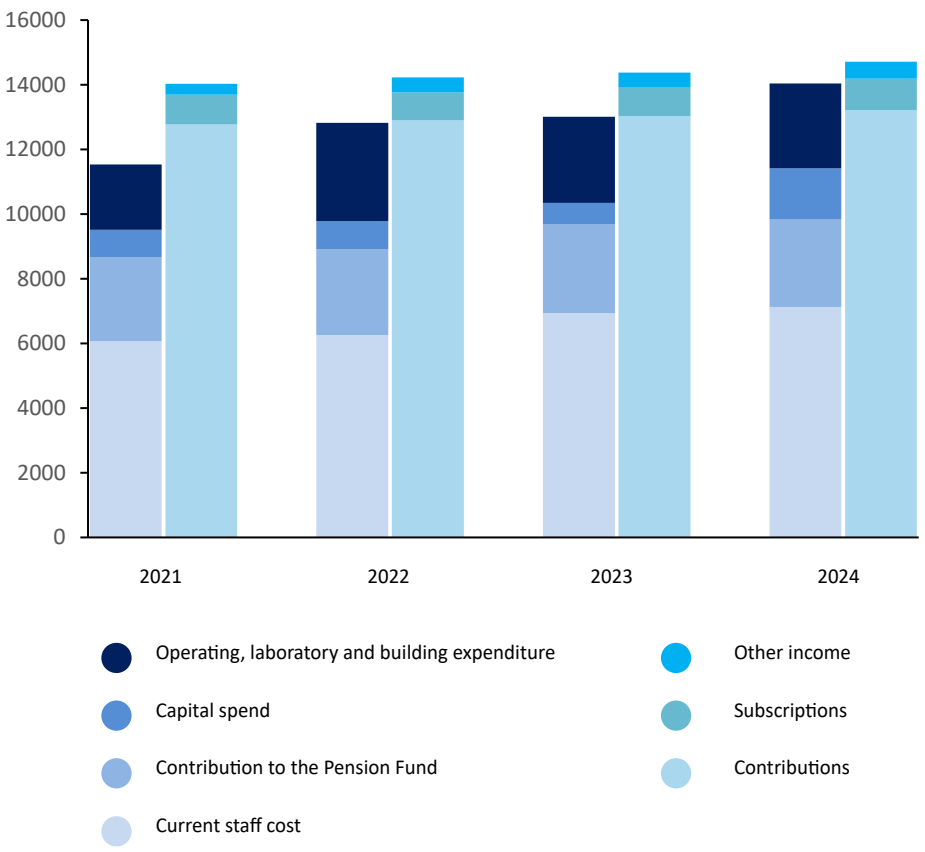


Total number of CMCs registered at 31st December



Financial Summary

Revenue and expenditure (2021 to 2024)

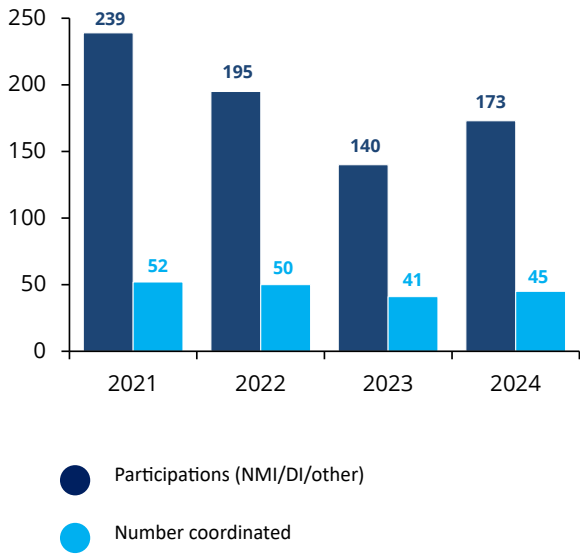


in k€	2021	2022	2023	2024
Operating, laboratory and building expenditure	2 020	3 045	2 657	2 623
Capital spend	844	869	655	1 580
Contribution to the Pension Fund	2 600	2 650	2 750	2 700
Current staff cost	6 072	6 261	6 946	7 134
Other income	390	466	442	522
Subscriptions	928	867	906	968
Contributions	12 767	12 897	13 026	13 221

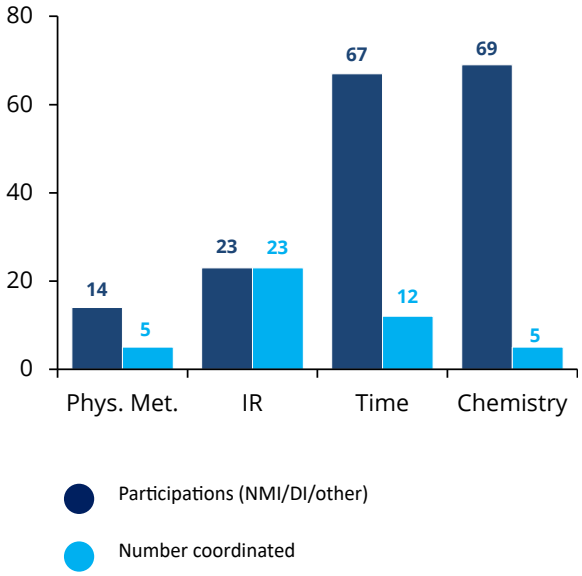
Full details of the financial and administrative situation of the BIPM are available in the "*Financial Report 2024*"

Comparisons and calibrations

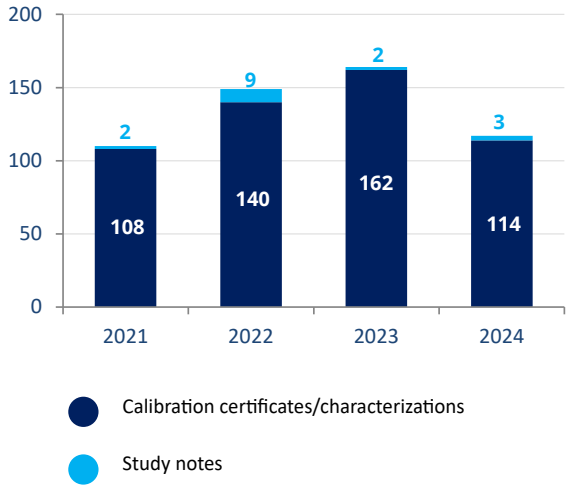
Comparisons coordinated by the BIPM in 2024



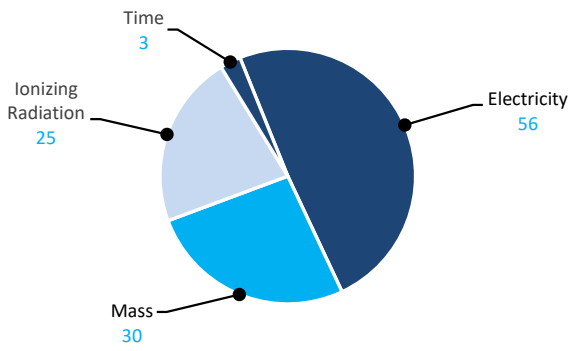
2024 - Breakdown of comparisons by department



Calibrations



2024 - calibrations by metrology area



150th Anniversary of the Metre Convention

On 20 May 2025, the international metrology community celebrated the 150th anniversary of the signing of the Metre Convention and the founding of the BIPM. The BIPM held a week of celebrations to mark this historic occasion.

World Metrology Day symposium: 150 Years of the Metre Convention: Science, Innovation and Global Impact

The celebrations commenced on 20 May 2025, World Metrology Day, with a symposium hosted at the UNESCO Headquarters in Paris. The event highlighted the importance of accurate measurement for global trade, sustainable development and scientific collaboration.

The symposium included two keynote addresses:

The SI - a tool for all humankind

Prof. William D. Phillips, Nobel Prize laureate 1997, NIST (USA)

Photo by Krystal Kenney for the BIPM.

Prof. William D. Phillips

From the Metric System to the Metre Convention

Prof. Ken Alder, Professor of History and author of "*The Measure of All Things*", Northwestern University (USA)

Photo by Krystal Kenney for the BIPM.

Prof. Ken Alder

Panel discussions were held on:

– Navigating the future of metrology: addressing the challenges of scientific and technical multilateralism.
– Future challenges for global metrology.

The panel discussions allowed an exploration of emerging challenges and future directions in metrology and its role in addressing the UN Sustainable Development Goals (SDGs). In addition, they fostered multilateral dialogue among policymakers, scientists and international organizations on capacity building and innovation in metrology.

BIPM Conference in Versailles: From units to the universe - future revolutions in metrology

The BIPM hosted a two-day conference at the Palais des Congrès in Versailles on 21-22 May 2025 to continue the celebrations. Sessions at the conference covered:

– Metrology in the quantum era
– Metrology for climate science
– The FAIR digital revolution
– New science and the definition of the second
– Future revolutions - measuring for the life sciences
– Future revolutions - metrology in space.

Each session featured presentations from leading experts and included a panel discussion on the strategic direction of metrology in the coming decades.

Photo by Krystal Kenney for the BIPM.

Session 5 panel discussion

A poster preview session allowed the authors of nine outstanding posters selected by a panel of CIPM members to give two-minute presentations of their work. An additional tenth poster was selected from the contributions to the "Young Metrologists' Vision 2050+", a foresight exercise that brought together young metrologists from around the world. More than 350 posters were submitted following an open invitation to show the state-of-the-art in the nine areas of metrology that were highlighted in the CIPM Strategy 2030+.

Full details of the 150th anniversary celebrations, including videos, events and the posters can be found at:

https://www.bipm.org/en/bipm-anniversary

Photo by Krystal Kenney for the BIPM.

BIPM staff enjoying the evening reception

Organizational structure

The CIPM

President

W. Louw (South Africa)

Secretary

T. Usuda (Japan)

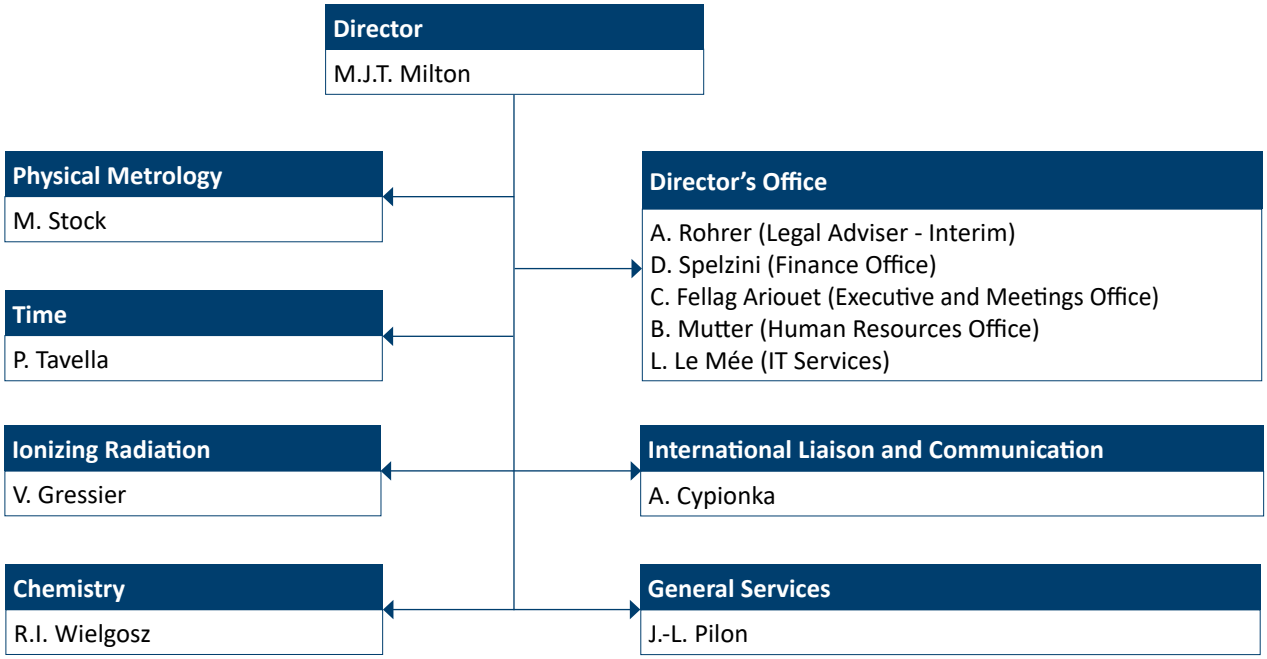
Vice-Presidents

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 2025)



Publications

Physical Metrology

1. **Status report on the BIPM Kibble balance**
   Proc. Conf. on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10646089
   Fang H., Bielsa F., Kiss A., Fujita K., Stock M.

2. **Development of a beam mechanism for the BIPM Kibble Balance**
   Proc. Conf. on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10646070
   Bielsa F., Fujita K., Kiss A., Fang H.

3. **Graphene quantum Hall resistance standard for realizing the unit of electrical resistance under relaxed experimental conditions**
   accepted for publication in Phys. Rev. Appl.
   Yin Y., Kruskopf M., Gournay P., Rolland B., *et al*.

4. **Sub-Hz frequency dependence of new 1 Ω standard resistors based on nickel-chromium alloy metal foil technology**
   Proc. Conf. on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10645988
   Gournay P., Rolland B., Kaneko N.-H., Oe T., Pesel E., Götz M.

5. **Impact of sampler characteristics in a PJVS-based differential sampling: a comparative analysis of measurements using Fluke 8588A and NI PXI-5922**
   Proc. Conf. on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10646110
   Kim M.-S., Cho H., Chayramy R., Solve S.

6. **Progress of the BIPM pilot studies on differential measurements of an ac source with programmable Josephson voltage standards**
   Proc. Conf. on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10646091
   Solve S., Kim M.-S., Behr R., Palafox L., Budovsky I., Rüfenacht A.

7. **Differential measurements of an ac source with a Josephson arbitrary waveform synthesizer**
   Conference on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 2024, https://doi.org/10.1109/CPEM61406.2024.10646054
   Rüfenacht A., Johnson-Wilke R., Mejia J.M., Fox A.E., Flowers-Jacobs N.E., Solve S., Burroughs C.J., Benz S., Dresselhaus P.D.

8. **Bilateral comparison of 1.018 V and 10 V standards between SASO-NMCC (Saudi Arabia) and the BIPM, September to November 2023 (part of the ongoing BIPM key comparison BIPM.EM-K11.a and b)**
   Metrologia, 2024, **61**, 01005, https://doi.org/10.1088/0026-1394/61/1A/01005
   Solve S., Chayramy R., Stock M., Alrobaish A., Aljomaie A.

9. **Bilateral comparison of 1.018 V and 10 V standards between INRIM (Italy) and the BIPM, November to December 2023 (part of the ongoing BIPM key comparison BIPM.EM-K11.a and b)**
   Metrologia, 2024, **61**, 01004, https://doi.org/10.1088/0026-1394/61/1A/01004
   Solve S., Chayramy R., Stock M., Durandetto P., Enrico E.

10. **On the rationale for recent updates to the SI Brochure concerning angles and quantities with the unit one**
    Metrologia, 2025, **62**, 013001, https://doi.org/10.1088/1681-7575/ad9479
    Brown R.J.C., Stock M.

Ionizing Radiation

11. **Key comparison BIPM.RI(I)-K8 of high dose-rate ^{192}Ir brachytherapy standards for reference air kerma rate of the PTB and the BIPM**
    Metrologia, 2024, **61**, 06002, https://doi.org/10.1088/0026-1394/61/1A/06002
    Kessler C., Behrens R., Kasper A., Grote F.

12. **Key comparison BIPM.RI(I)-K7 of the air-kerma standards of the BFKH, Hungary, and the BIPM in mammography x-rays**
    Metrologia, 2024, **61**, 06003, https://doi.org/10.1088/0026-1394/61/1A/06003
    Kessler C., Burns D., Finta V.

13. **Key comparison BIPM.RI(I)-K5 of the air-kerma standards of the BEV, Austria and the BIPM in ^{137}Cs gamma radiation**
    Metrologia, 2024, **61**, 06006, https://doi.org/10.1088/0026-1394/61/1A/06006
    Kessler C., Roger P., Steurer A., Tiefenboeck W., Doria J.

14. **Key comparison BIPM.RI(I)-K5 of the air-kerma standards of the CIEMAT, Spain and the BIPM in ^{137}Cs gamma radiation**
    Metrologia, 2024, **61**, 06007, https://doi.org/10.1088/0026-1394/61/1A/06007
    Kessler C., Roger P., Cornejo Díaz N.

15. **Key comparison BIPM.RI(I)-K8 of high dose-rate ^{192}Ir brachytherapy standards for reference air kerma rate of the VSL and the BIPM**
    Metrologia, 2024, **61**, 06010, https://doi.org/10.1088/0026-1394/61/1A/06010
    Kessler C., Jansen B.J., de Pooter J.A., Aviles Lucas P.

16. **Key comparison BIPM.RI(I)-K8 of high dose-rate ^{192}Ir brachytherapy standards for reference air kerma rate of the LNE-LNHB and the BIPM**
    Metrologia, 2024, **61**, 06015, https://doi.org/10.1088/0026-1394/61/1A/06015
    Kessler C., Hernandez-Elvira V.

17. **Key comparison BIPM.RI(I)-K2 of the air-kerma standards of the PTB, Germany, and the BIPM in low-energy x-rays**
    Metrologia, 2024, **61**, 06016, https://doi.org/10.1088/0026-1394/61/1A/06016
    Burns D.T., Kessler C., Pojtinger S.

18. **Key comparison BIPM.RI(I)-K3 of the air-kerma standards of the PTB, Germany, and the BIPM in medium-energy x-rays**
    Metrologia, 2024, **61**, 06017, https://doi.org/10.1088/0026-1394/61/1A/06017
    Burns D. T., Kessler C., Pojtinger S.

19. **Key comparison BIPM.RI(I)-K5 of the air-kerma standards of the GUM, Poland and the BIPM in ^{137}Cs gamma radiation**
    Metrologia, 2024, **61**, 06018, https://doi.org/10.1088/0026-1394/61/1A/06018
    Kessler C., Roger P., Derlacíński M., Szymko M.

20. **Key comparison BIPM.RI(I)-K7 of the air-kerma standards of the PTB, Germany, and the BIPM in mammography x-rays**
    Metrologia, 2024, **61**, 06019, https://doi.org/10.1088/0026-1394/61/1A/06019
    Kessler C., Burns D.T., Pojtinger S.

21. **Update of the BIPM comparison BIPM.RI(II)-K1.Zn-65 of activity measurements of the radionuclide ^{65}Zn to include the 2015 result of the LNMRI-IRD (Brazil) and the 2018 result of the LNE-LNHB (France)**
    Metrologia, 2024, **61**, 06004, https://doi.org/10.1088/0026-1394/61/1A/06004
    Michotte C., Courte S., Coulon R., Nonis M., Ratel G. *et al*

22. **Update of the BIPM comparison BIPM.RI(II)-K1.Tb-161 of activity measurements of the radionuclide ^{161}Tb to include the 2022 result of the NPL (United Kingdom)**
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