CIPM Strategy 2030+

May 2025

CIPM

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May 2025

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Foreword

Measurement underpins every aspect of human society. Practically everything we use and do daily depends upon the International System of Units (SI) that is used worldwide by almost every country. The SI is the definitive reference for establishing accurate and comparable measurements in all technical domains and is an essential tool for commerce, technological advances, healthcare, communications and science. The SI must continue to evolve and advance to remain at the forefront of these fields and to meet the ever-changing needs of society.

The International Bureau of Weights and Measures (BIPM), since its creation by the signing of the Metre Convention in 1875, fulfills the essential purpose of ensuring the SI is uniformly implemented around the world and that it always meets global measurement needs. Without the BIPM, different implementations of the SI across international boundaries would undermine trade and disrupt the introduction of new technologies. All countries benefit greatly from the universally accepted measurement system that the BIPM supports and maintains.

Beyond ensuring that the SI meets the ever increasing and changing needs of the world, the BIPM plays the indispensable role of ensuring that the measurement systems of every member country are mutually recognized. In 1999, a major step was taken by the signing of the CIPM Mutual Recognition Arrangement (CIPM MRA) between National Metrology Institutes (NMIs) that arranged the mutual recognition of national measurement standards and of calibration and measurement certificates. The CIPM MRA underpins freedom of trade, the development of mutually implementable technologies, and the international advancement of science. This accomplishment can only be achieved by the BIPM serving as the nexus of international measurements.

The International Committee for Weights and Measures (CIPM), which is tasked with promoting world-wide uniformity in units of measurement and governing the organization, could understandably have concluded that the task has been fulfilled. However, modern technology and the expansion of knowledge of the universe increasingly provide multi-disciplinary measurement challenges that need to be addressed. In 2019 the CIPM therefore set out to develop a Strategy 2030+ that would position the Organization for the next 30 to 50 years. Five themes were identified for the development of a new Strategy:

1. Responding to evolving needs for metrology.
2. Addressing key scientific challenges to advance the global measurement system.
3. Strategy for deepening engagement with other international organizations on measurement.
4. Universal adherence to the Metre Convention.
5. Modernizing the operations of the Organization.

The CIPM presented its first report with recommendations for the plenary body of the BIPM, the General Conference on Weights and Measures (CGPM), in November 2022, and after receiving unanimous support for its future plans, continued to develop the *Strategy 2030+* towards implementation.

This strategy will be available to stakeholders and the wider public ahead of the celebrations of the 150th anniversary of the signing of the Metre Convention. It will guide the Organization into the future by:

- Establishing horizontal platforms to address multi-disciplinary measurement challenges.
- Forming new networks between NMIs to continuously address key scientific challenges.
- Presenting the model for engagement with other International Organizations (IOs).
- Proposing a category of "Observer to the BIPM" to further universal adherence to the Metre Convention.
- Proposing several decisions to further improve governance in the Organization, rules of procedure for the CGPM, and a new vision for the "future CIPM" and the headquarters of the Organization.

The CIPM invites you to join us in the final implementation of the Strategy 2030+.

1. A Strategy for the International Measurement System

Introduction

Since the signing of the Metre Convention in 1875, metrology has been key in the advancement of science, trade and quality of life world-wide. However, the world has never faced so many measurement challenges in parallel. Metrology is crucial to solving these global problems that also necessitate fundamental changes to its own systems.

It is difficult to predict the future in times of rapid change. Nevertheless, it is possible to identify three groups of global drivers for decision making, both technological and societal:

Well-being: The health, security and safety of a growing population with evolving social attitudes and values.

Sustainability: Reduced human impact on the environment and management of natural resources.

Enterprise: Digital innovation to increase prosperity, productivity, and growth, and to enable equality and fairness.

In its report to the 27th meeting of the CGPM (2022), the CIPM considered these global challenges and drivers as well as the anticipated changes for the BIPM as the international organization for scientific metrology. The present strategy builds on this report and reflects feedback received from members of the BIPM in an online survey, continued discussions with the CIPM, experts at NMIs and other IOs, and Young Metrologists[1] to add information on the latest developments in

[1] Young Metrologists' 2050+ vision
A collective vision created by young metrologists from National Metrology Institutes / Designated Institutes

the different fields.

Never has the development of metrology been driven so strongly by external factors as it is today. This strategy outlines the focus areas of metrology for the next three to five decades as far as they are foreseeable today. It intends to address questions such as:

- What impact do measurements have in solving global challenges?
- Where is high-precision metrology a key factor in the advancement of new technologies such as quantum technology?
- How do new technologies and digitalization change the way we think about metrology?
- What will metrological services of the future look like?
- How does the BIPM, as an organization, need to change to be prepared for the challenges of the future?

This Strategy includes guidance and direction for developing the strategies of the CIPM Consultative Committees (CCs), the new "horizontal" structures proposed by the CIPM and the BIPM Headquarters. It also provides a reference point for NMIs and Designated Institutes (DIs) in laying out their own future strategies. Finally, it is directed towards the liaison organizations and stakeholders of the BIPM to inform them about the future objectives of metrology and to highlight opportunities for collaborations.

The Strategy is presented in two parts. The first part is dedicated to thematic areas that will be the focus of the international metrology community in the next 30 to 50 years. It addresses the needs that arise for metrology from current global challenges as well as from fast developing new technologies, and highlights cutting edge research in metrology. The second part proposes how these new areas can be addressed by the BIPM and how the BIPM itself must be transformed to stay relevant in the future.

2. Evolving needs for metrology

New technologies and the increasing focus on universal issues necessitates a more encompassing approach to advance the global comparability and traceability of measurements for scientific discovery and innovation, industrial manufacturing and international trade, and overall to improve the quality of life and sustainability of the environment.

Metrology for Global Challenges

Metrology will remain critical to enabling prosperity and well-being whilst addressing global challenges. However, to do so it must evolve and metrologists from different disciplines will increasingly need to work together to address these challenges and support global objectives.

The CIPM has identified five areas in which the need for metrology arises from global challenges:

Metrology provides the scientific basis to monitor the global environment and to ensure fair implementation of mitigation policies.

We live in the "Anthropocene", the geological epoch in which humanity is the dominant influence on the planet. There is evidence that we have passed or reached several "planetary boundaries" and with this mankind faces an existential threat. Metrology is, and will continue to be, critical in ensuring reliable monitoring of the global climate and the broader environment, in establishing mitigation policies based on firm evidence, and in tracking their implementation.

Metrology is a cornerstone of reliable health services and enables innovation in health technologies.

Global healthcare and life science activities are critically supported by metrology, and the global measurement system is crucial to the effective delivery of healthcare around the globe as highlighted by the role of metrology during the Covid-19 pandemic in the years 2019 to 2021. Improvements in metrological capabilities and metrology-enabled innovations for the healthcare system have potential for significant social and economic impacts and benefits. Metrology is evolving to keep pace with the development of new advanced technologies and the increasing healthcare costs associated with rapidly ageing populations.

Metrology is needed for safe food and water.

Unsafe food and polluted water poses a substantial threat to global health. Food contaminants, such as parasites, bacteria, viruses, prions, mycotoxins, pesticide residues, and other chemical or radioactive substances, threaten health in many ways – ranging from infectious diseases to cancers. Measurement plays an important role in ensuring that food is safe for human consumption and meets national and international regulatory requirements. Metrologists around the world, including those from developing countries, are becoming more and more active in developing measurement procedures to reliably monitor the quality and safety of food in production, transport and storage as well as in the market as well as providing safe drinking water.

Metrology provides a scientific basis for developing and establishing renewable energy sources.

World energy consumption continues to grow and despite a significant growth in energy supply from renewables, fossil fuels presently still dominate the supply across all regions. The challenge faced by governments, industries and societies across the world is to reduce pollution whilst maintaining energy affordable and securing sufficient energy supply. This challenge can only be tackled by significant investment into research and development, with metrology a critical aspect of this investment by providing the underpinning measurement capabilities, standards and guidance needed to foster innovation and to ensure that policy and

regulatory targets are met.

Metrology is developing new services to support advanced manufacturing.

Advanced manufacturing is inextricably linked to the digital transformation of industrial processes, and it calls for a similar transformation in metrology. For example, the efficient control of increasingly complex and at the same time flexible production processes require detailed, real-time knowledge of the process parameters. The multitude of necessary sensors and measuring devices must deliver reliable and accurate measurement data with machine-readable metadata on units and data quality. A proper understanding of the accuracy of the measurements involved and the associated metrology parameters, is crucial for industry.

New technologies spawning new metrologies

Metrology has always developed in parallel to important scientific discoveries. It has both made new technologies possible as well as benefiting from new technologies. In the next ten years, it is expected that digitalization will have a significant impact on our understanding of metrology and on metrological services. Additionally, the application of artificial intelligence (AI), the widespread use of connected sensors and new quantum-based technologies will create new requirements for metrology and might fundamentally change current concepts of traceability.

The opportunities for metrology to progress new technologies are summarized under four headings:

Digitalization opens the door to new metrological services.

Digitalization changes our world in the most fundamental way. It allows for new approaches to work together, new ways in which people and objects can be connected, and new methods to deal with data and information. It sets off a new era in metrology providing the opportunity for fundamentally new concepts in metrology and new metrological services.

On the other hand, metrology has an important role in ensuring consistency and confidence in measurement results in this new digital world. New digitally available references, respecting the FAIR principles (Findable, Accessible, Interoperable and Reusable) as well as ontologies and methodologies for machine-readable and machine-actionable information on measurements, are needed. As new reference systems are constructed, new cross-disciplinary standards are required and collaboration with other quality international infrastructure bodies becomes increasingly important.

Artificial intelligence opens new pathways for metrological traceability.

AI is rapidly transforming our world and is leading to a wide range of technological innovations, in areas such as automated mobility, smart homes or automated medical diagnostics. The training of AI relies heavily on data and AI-based innovations are expected to transform metrology. On the one hand, there is a demand to develop services to ensure the quality and safety of data, especially of those used as reference and for training AI. On the other hand,

applying AI opens completely new pathways to realizing traceability, where the quality of a measurement result is no longer ensured by a single route to a single device.

Metrology, therefore, needs to provide principles and standardized approaches for the metrological traceability required for AI. It will focus on the development of harmonized requirements for reference data sets and concepts for new services for validations of algorithms as well as the use of digital twins as a source of synthetic data.

In an interconnected world the focus of metrology is no longer the individual device.

Large amounts of interrelated measurement data are becoming available through digitalization; complex systems consisting of interconnected sensors are increasingly common. It will be the role of metrology to guarantee trust, reliability and security of such interconnected systems in the future. Exactly as the international prototypes of the metre and the kilogram served as the standards for metrology in the past, novel quality standards for distributed sensor networks should be traceable to quantities which can be measured.

Thus, it is important to establish trustworthy references for data acquired from sensor systems as well as to understand the propagation of measurement uncertainties in sensor networks. Practical methods for the metrological evaluation of interconnected sensors need to be developed.

All these challenges pave the way to the new field of “system metrology” that will support a “systems understanding” of the world where many interrelated, non-standardized or unforeseen factors outside the traditional SI system of measurement need to be considered.

The quantum revolution is based on metrology.

Quantum-based technologies are advancing so rapidly that some people are referring to it as a “second quantum revolution”. To bring these technologies into practice, a measurement infrastructure and relevant standards must be developed in parallel.

Metrological characterization is needed for different types of quantum sensors and optical clocks as well as for certain components used in quantum technologies, such as single photon sources for quantum computing.

At the same time, applying quantum physics allows metrology laboratories around the world to extend their capabilities to smaller uncertainties and new measurement ranges, for example in the areas of time and frequency, and electricity.

New metrological developments to address new challenges

The future holds both opportunities and uncertainties for metrologists. As we move forward, the world will encounter significant global challenges, rapid technological advancements, and major environmental and socioeconomic shifts. The Young Metrologists1 identified areas that may

impact the needs, ways to deliver metrological services, science and technology, as well as collaborations in measurement science. Four new areas they identified are highlighted below.

Perceptual metrology helps shape the future of human-computer interactions.

As technology advances and human-computer interactions become more sophisticated, perceptual metrology will become essential in designing products and systems that align with human experiences and expectations. This requires a deep understanding of the human sensory system, and the metrological methods used to interpret perceptual data. Advances in artificial intelligence and machine learning can enhance the field by providing more sophisticated tools for analyzing perceptual data.

Metrology in space demands precise measurements under extreme environmental conditions.

Emerging challenges such monitoring the global ecosystem and the energy crisis are pushing advances in space-based earth observation technologies. Commercial space travel is expected to grow in the future, and more space missions with complex measurement applications will emerge, driven by the exploration and understanding of the universe. Additionally, there is growing interest in fundamental metrology research, including optical clocks, under microgravity conditions. It is prudent for the metrology community to consider these issues and to ensure that the concept of metrology will continue to be of importance as we explore beyond the earth and into the future.

Metrological self-traceability and shortened metrological traceability chains.

Metrological traceability chains may become shorter with the development of portable primary standards that can be remotely calibrated. Self-validating measurement devices can reduce the time and the need for repeated calibrations and may obtain direct metrological traceability to the SI. This will be possible through the development of practical measurement devices that can measure a specific quantity by primary methods, the miniaturization of devices and their self-validation. The utilization of predictive analytics, along with data analytics and machine learning will expedite the development of reference standards and reference measurement procedures, and real-time verification and quality assurance could be facilitated.

Nanobiometrology is an evolving field to measure and characterize biological systems.

Nanobiometrology is a burgeoning field that merges the precision of nanotechnology with the complexity of biological systems, together with the need for non-destructive and real-time measurements and the standardization of measurement techniques. The assessment of the potential impact of nanomaterials on human health and the environment, are also ongoing research areas. Measurement advances in this field are, and promise to, further revolutionize biomedical research, diagnostics and therapeutics, leading to a deeper understanding of life at the nanoscale and the development of cutting-edge medical technologies.

Key scientific challenges in metrology

Since the signing of the Metre Convention, the aim of the CIPM has always been to further develop and improve the metric system, which eventually led to the SI. Fundamental research on the realization of the units is at the heart of this effort and has been conducted for 150 years. This research, accomplished through international collaboration, has ensured that metrology stays “fit-for-purpose” and relevant to the stakeholders through different technological eras.

Revised definitions for the SI base units pave the way for scientific discoveries and new calibration services.

Following the revision of the SI, the primary realization of a unit is now theoretically possible anywhere in the world. This raises legal and technical questions with regards to the concept of traceability. Together with digitalization and the application of AI, the new SI might provide innovative possibilities for remote, real-time and self-calibration of measurement instruments.

A survey amongst NMIs (and DIs) indicated that although more than half of the institutes already implement the Revised SI, up to one third have identified a need for further action.

The Consultative Committees progress the objectives of the CIPM in all areas of metrology.

For many decades the CIPM Consultative Committees have been the forum to coordinate scientific collaboration in metrology in nine measurement areas: Acoustics, Ultrasound and Vibration; Electricity and Magnetism; Length; Mass; Photometry and Radiometry; Chemistry and Biology; Ionizing Radiation; Temperature; Time and Frequency.

The technical work of the CCs, which has been laid out in detailed strategic plans, supports all the above-mentioned domains by developing the relevant world-wide measurement capabilities, harmonizing procedures, as well as facilitating dialogue with relevant stakeholders. The continuous development of the realization of the SI remains a challenge and was stimulated by new pathways introduced with the redefinition of the SI base units. This redefinition allowed for sigificant improvement in the realization of the units, but the methods to realize some of them (*mise-en-pratique*) have reached a technical limit. Therefore, in the next ten years, scientific and technical efforts on the base units of the SI will focus on the redefinition of the second and candela.

3. Implementation of the strategy

Responding to Evolving Needs in Metrology: New horizontal approach and increased cooperation with international stakeholders

"The CIPM created, and will create appropriate joint task groups and horizontal forums to shape and coordinate the metrology community's response to the identified grand challenges"

Role of horizontal groups and forums

Whilst the metrology grand challenges and the key scientific challenges to advance the global measurement system identified above pose significant (and different) technical challenges for metrology, they also pose a common challenge for our community. The present CIPM structures, particularly the Consultative Committees that advise the CIPM, are organized and focused on 'vertical' metrological lines (for example, measurement of specific quantities/units or one-unit definitions). At the same time, an effective response to the identified metrology challenges requires a multidisciplinary approach that addresses these challenges in a more holistic and 'horizontal' way.

A survey carried out among NMIs of current metrology programmes, anticipated programmes and future interests, found that up to half of the respondents identified a need to address cross-cutting challenges.

The multi-disciplinary nature of measurements for the modern world, and especially the challenges identified, introduces the need for a system that is more horizontal in structure than the CCs, and allows for broad participation from the wider community involved in addressing the "grand challenges".

Joint Task Groups will coordinate the new possibilities for metrology so that they have an impact on global cross-cutting challenges. These Joint Task Groups will address specific multi-dimensional measurement challenges that require the input of a relatively small group of experts in specific fields and will collaborate with specific international organizations and institutes.

Horizontal Forums will create networks to coordinate activities across a broad group of institutes, international organizations and industry, to work towards a common goal across the Quality Infrastructure.

"The BIPM will deepen engagement with IOs and institutes outside the metrology domain"

In the modern era with the development of multi-disciplinary measurement challenges, the BIPM is increasingly collaborating with other International Organizations (IOs). The CGPM encouraged these interactions with several resolutions that supported closer cooperation with the *Organisation internationale de métrologie légale (OIML)* and others. The CGPM also called for a strengthening of collaboration between NMIs and recognized National Accreditation Bodies, and

with networks involved in global environmental and ecosystem monitoring, with the aim to make it traceable to the SI.

Relations with the OIML were further strengthened through the establishment of a Joint BIPM-OIML task group in 2019[2]. This Joint Task Group, in collaboration with the CIPM Task Group on the Digital SI, concluded a Joint Statement of Intent *On the digital transformation in the international scientific and quality infrastructure* and invited other IOs to sign the joint statement. To date, CODATA, IMEKO, ILAC, ISO , IEC, IFC, IUPAC, IUPAP and NCSLI have joined the CIPM (for the BIPM) and CIML (for the OIML) in signing the Joint Statement.

The Joint Committee of Traceability in Laboratory Medicine (JCTLM), established through a *Declaration of Cooperation* with the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) and the International Laboratory Accreditation Cooperation (ILAC), can serve as a model for deepened future activities with other IOs with interest in particular measurement fields.

The CIPM concluded that the strategy for engagement with other IOs is mature and the present CIPM oversight provides good governance. The BIPM International Liaison and Communication Department (ILC) has been strengthened to maintain and further expand the relationships and interactions.

In the coming years, in-depth collaboration is foreseen at a more practical level with laboratories with special instrumentation and capabilities, and/or universal contacts, such as the International Atomic Energy Agency (IAEA).

Addressing key scientific challenges

The role of the NMIs and RMOs

"In support of the Revised SI and the horizontal structures, the CIPM will foster new collaborations to address the most challenging measurement requirements, and to establish universal standards for space exploration and joint universal projects"

When the BIPM and its Headquarters were established in 1875, the CIPM members and top metrologists from the Members States conducted their research at the laboratories of the Headquarters to establish traceability to the agreed units. Since then, all Member States have established their own national institutes, that have become centres of excellence at the forefront of research and development of measurement technologies. With the Revised SI, their roles increased in importance and would continue to do so, at the forefront of work to develop new ways and methods to address the global measurement challenges. It is envisaged that new collaborations will emerge to address the most challenging measurement requirements, and to

[2] *The CIPM supported the establishment of a Joint Task Group at an operational level to further improve the cooperation between the BIPM and the International Organization of Legal Metrology (OIML), following the proposal made by the President of the International Committee of Legal Metrology (CIML).*

establish universal standards for space exploration and joint universal projects (Metrology laboratories in space, Lunar Coordinated Time, etc.). The role of the CIPM Consultative Committees will expand in coordinating these activities.

The regional metrology organizations (RMOs) are indispensable for the efficient operation of the CIPM MRA, and with the new horizontal structures, will become increasingly important for the global measurement system. The RMO technical committees and special programmes will become more involved in the activities of the CIPM in the future.

The evolving role of the CIPM and the CCs

"The CIPM and its Consultative Committees will evolve to become more inclusive to embrace the modern world and the horizontal structures"

"The coordinating role of the structures established by the CIPM is becoming more important, whilst the direct technical role of the CCs and the laboratories are changing with the implementation of the Revised SI. The BIPM Headquarters responded to the changing environment and adapted its work programme accordingly. The CIPM is re-interpreting its role and responsibilities, and the guides, rules and processes for its election.

A future CIPM, within the stipulations of the Metre Convention, needs to:

- be more universally representative
- have improved equity
- have members with the appropriate governance skills that include financial and pension fund management oversight, human resource oversight, technical expertise to lead CCs, and the ability to liaise with the multi-dimensional joint task groups and horizontal forums
- utilize expertise from the wider measurement community for the efficient functioning of the horizontal structures.

This is challenging to achieve with the current Membership of only 18 representatives from different Member States, and CIPM therefore envisages greater involvement of external expertise in the future. This can take several forms, such as:

- RMOs not represented in the CIPM will be invited to participate in CIPM activities related to the CIPM MRA and cross-cutting activities
- The CIPM will consider how to engage with the "younger generation" of metrologists regarding specific tasks in support of CIPM activities
- The balance and needs of the CIPM will be determined before renewal of the CIPM at each CGPM, and Members States will be requested to nominate individuals that can contribute to specific needs
- Should the elected CIPM not include the expertise for specific CCs, Joint Task Groups and Horizontal Forums, greater use will be made of NMI experts to chair such activities.

It is anticipated that CCs will continue to introduce joint activities with other CCs, but where more than two CCs are required to address a multi-disciplinary challenge, new JTGs and Horizontal Forums will be established as described in §3 of this strategy.

4. Universal adherence to the Metre Convention

"Fulfilling the CGPM mandate of Resolution 6 (2022) of universality as a substantial step towards achieving wider participation, a new category of Observer to the BIPM will be introduced. It will accommodate members of RMOs not yet participating in the BIPM within the organization and further improve collaboration with other international organizations "

The idea of universality was embodied in the wording of the Metre Convention where the first page of the text signed by seventeen nations in Paris on 20 May 1875 makes mention of "*the High Contracting Parties desiring to ensure the international unification and the perfection of the Metric System and having resolved to conclude a convention to this effect*". This ambitious aim of universality has been reinforced by the States Parties to the Metre Convention (Member States) many times since, notably via several Resolutions[3] adopted by the CGPM that specifically advocate for greater, or universal, participation. In recent years, the RMOs have also played an important role in encouraging their members that are not yet engaged in the activities of the BIPM to participate. These efforts were aided by the support given to interested states by several international organizations, which encourage participation in their own policies and support programmes. Universality of participation is also supported by the World Trade Organization (WTO) to reduce and avoid trade barriers and facilitate mutual recognition of conformity assessment.

Membership of the BIPM is currently via one of two categories: as a Member State (64) or as an Associate of the CGPM (36). These two categories account for 110 of the 193 States listed by the UN as Member States, (where it is noted that CARICOM, one of the Economies participating in the BIPM as an Associate, has eleven participating states).

Other international organizations often grant some form of participation status to non-Member States. In addition, many international organizations also take part in the work of other international organizations. Both are usually granted "observer status" and are therefore able to participate in the activities of an organization, usually in a purely representative or advisory role.

Based on these considerations, in 2022 the CGPM invited the CIPM to review the membership practices of other international organizations, to examine the current application of Article III of the Metre Convention and to report to the 28th meeting of the CGPM (2026) on how this Article might be applied in order to facilitate lasting and universal adherence to the Convention. The CIPM was tasked with considering the implications of wider participation in the work programme and services

of the BIPM and proposing appropriate actions for consideration by the CGPM at its 28th meeting[3].

In response to this invitation, a new participation model "Observer to the BIPM" is being introduced for states and economies that do not officially participate in the BIPM's activities. This model shares an interest in the work of the organization and should aim to achieve the development and promotion of the SI and UTC. The new model for "Observer to the BIPM" is in principle cost-neutral and is also extended to intergovernmental organizations. This form of participation can vary greatly given that the rights and duties are different from one organization to another.

There are many benefits for a state to become an Observer, but most notably the state will establish links to the world's measurement system via the SI and by being listed on the BIPM website as a state having Observer status at the BIPM.

The benefits to existing states would include better communication with Observer States on measurement issues, improved harmonization of measurements for trade purposes, and a BIPM that is globally representative.

Should the 28th meeting of the CGPM (2026) accept the resolution proposing BIPM Observership, it is anticipated that most of the States and Economies currently participating in RMOs, and international organizations with formal liaisons with the BIPM, will join the BIPM as Observers in a short period of time.

5. Modernizing the operations of the organization

"Ensuring that the BIPM remains relevant in the future, past-and current practices are being entrenched, and international best-practice is being introduced by developing modern governance practices for the Organization"

The founding parties of the Metre Convention showed great foresight in the establishment of an organization that could, with minor additions to its founding documents in 1921, grow to become the organization it is today. The current participants in the Convention all agree on the importance of the unified measurement structure for the world, and on the crucial role played by the original BIPM, and everything introduced since. The development of the ten Consultative Committees of the CIPM and the CIPM MRA, building on the already established RMOs and the structures introduced by it, could not have been foreseen in 1875. The framework developed in 1875 allowed the development of the BIPM to become a truly international organization, and what is being done in common in all corners of the globe.

To ensure an organization that can efficiently respond to the demands of a modern world, the governance structures, rules and procedures and physical facilities need to be current and

[3] *CGPM Resolution 6 (2022) On universal adherence to the Metre Convention*

forward looking. The CIPM embarked on a programme to:

- Develop Rules and Procedures for the organs
- Modernize the operations of the BIPM Headquarters
- Propose the best models and practices for the CIPM and the secretariat and laboratory facilities at the Headquarters.

When these measures are fully implemented and adopted, where appropriate, by the CGPM, the BIPM will retain its high standing globally as an exemplary International Organization, for the decades to come.

The Headquarters of the future

"The Headquarters of the future is a centre of scientific excellence with expertise and services that assists multi-disciplinary teams addressing global measurement challenges and coordinate the development of accurate measurement in the world at large"

The BIPM Headquarters will continue to enhance research integrity and to be a leader in new metrology, but the future Headquarters will also need to follow the modern trends and proposals in the Strategy.

The delivery of services of all types (for example, comparisons, meetings, capacity building etc.) has increased much faster than the increase in Member State funding, and the strategy prioritizes actions that can enable this growth to continue with improved efficiency. It is also acknowledged that in future there may be increased provision of traceability to Member States without primary realizations of the units covered by the BIPM Headquarters' technical programme.

Strategic impact activities that will continue to be a high priority in the future include:

- Maintain the scientific expertise required for the effective coordination of CIPM MRA activities, including the Key Comparison Database (KCDB) and high-impact comparisons.
- Coordination of UTC; to build the global community of UTC laboratories and promote its uptake with users.
- Liaison with priority IOs to promote metrology solutions to grand challenges and to open access for NMIs to international stakeholders.
- Expand Capacity Building and Knowledge Transfer and e-learning activities, in partnership with the RMOs.
- Coordinate sectorial activities (for example, linked to horizontal forums) and particularly those that are co-funded by other IOs (for example the JCTLM).
- Facilitate online participation to provide fair access to meetings and resources to all Member States.

New activities that are expected to increase in importance:

- Coordination and implementation of new digital services including new database services to provide the SI "digital anchor of trust".

- Use of new digital tools to facilitate equitable access across all NMIs and regions.
- Promoting the “Observer” model for states and IOs to increase global participation.

New directions to improve efficiency to deliver high-priority actions include:

- Transition in the balance of staff skills to best address future priority requirements (for example, coordination for cross-cutting activities and representational actions).
- Resources redirected to address growing future commitments to digital transformation and new database activities.
- More outsourcing of access to external facilities to achieve greater efficiency and utilization of established partner networks to minimize the need for routine services at the BIPM Headquarters (for example, the DOSEO facility of CEA-List in France, the International Atomic Energy Agency (IAEA) and other Centres of Excellence that could assist developing NMIs, especially those from Observers, to obtain traceability).

CIPM message for the future

The International Committee invites all stakeholders to join the Organization in not only the implementation of this Strategy, but in the further development of an international measurement system that will serve science, trade and industry, healthcare, food security and consumer protection not only globally, but universally as well.

6. Consultative Committee strategies

The work in the CCs will concentrate on improvements to, and extension of, the dissemination of units, with the following focus areas for the near future.

Consultative Committee for Acoustics and Vibration (CCAUV)

- Development of a new generation of sensors and instrumentation, especially focusing on their miniaturization, as well as extension of the operation range of realized measurement standards (down to few mHz for the fields of sound in air and vibration, and up to 100 MHz for the field of ultrasound) for ensuring traceability.
- Standard methods and protocols need to be developed for calibration of sensors with digital outputs.
- Direct realization of the unit of sound pressure in air employing optical technics.
- Research for a better understanding and modelling of the human auditory process.
- Development of effective and efficient techniques for environmental noise assessment both in air and in water.
- Development of validated methods for determination of acoustic properties of materials,

like absorption, attenuation and scattering are important subjects to be worked out in the field of ultrasound.

Consultative Committee for Electricity and Magnetism (CCEM)

- Development of novel quantum technologies and expansion of the application range of quantum technologies (new quantities, wider range), including turn-key systems
- Support development of emerging technologies like smart electrical grids incorporating renewable energy production, nanotechnology, high-frequency communication
- Digitalization of electrical metrology including sensor networks supporting Industry 4.0 and the Internet of Things (IoT)
- Calibration of dynamic (non-static) quantities
- Integration of metrological standards, 'NMI on a chip'

Consultative Committee for Length (CCL)

- Advanced manufacturing has led to new traceability routes at the sub-nanometre scale being identified, and their application is an area of focus where a framework for effective take-up and dissemination of traceable dimensional (nano)metrology is required.
- The preference of industry for non-contact optical-based measurement *in situ* continues and is critical to manufacturing, health, energy production and consumption.
- Long-range metrology/geodesy is gaining importance for companies that manufacture large products where metrology-enhanced automation.
- *In situ* metrology will reduce manufacturing cycle times and can lead to cost savings and improved energy efficiency (for example, aerospace).

Consultative Committee for Mass (CCM)

Research will focus on

- more accurate and reliable primary mass realization experiments and on the development of simpler instruments for commercial use
- measurements directly traceable to the SI at point of need.

Further work will include:

- the supply of traceable refractive index standard liquids for the food industry and agriculture
- improved in-line flow measurement for new energy areas
- measurement of dynamic force and torque for wind and tidal energy
- gravity gradiometers with cold-atom sensors
- new hardness test methods for in-process evaluation of advanced manufacturing
- traceability for diagnostic measurements of blood pressure, intraocular pressure and for continuous cardiac output instruments.

Consultative Committee for Photometry and Radiometry (CCPR)

The development of optical quantum communication, quantum computing and quantum sensing stimulates the demand for a “quantum candela” in many areas, extending to vision science and AI. A “photon-number based”, more fundamental definition is thus considered. The candela could then be realized more accurately and without dependency on other base units.

Further work focuses on:

- traceability for lighting measurements with the widespread usage of light emitting diodes (LED) and Organic LED
- optical properties of materials with novel visual appearances
- the energy sector in particular photovoltaics technologies
- earth observation with more than 25 of the Essential Climate Variables involving optical radiometric measurements
- robust metrology infrastructure for quantum photonics.

In response to the evolution of the candela, in a longer-term, implementation of a scientifically rigorous photometric system based on cone-fundamentals is envisaged to provide a new link between photometric and radiometric quantities. This will be the focus of a newly formed task group that includes members of the International Commission on Illumination (CIE).

Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM)

Nine key challenges have been identified covering Organic, Inorganic, Gas, Isotope Ratio, Surface, Electrochemical, Protein, Nucleic Acid and Cell analysis, leading to thirty-three activities. These will contribute to the development of new greenhouse gas, isotope ratio and microplastic standards, and the development of reference measurement systems for biomarkers, surface chemical composition, RNA quantification, food authentication, and cell counting, as examples.

Consultative Committee for Ionizing Radiation (CCRI)

- Radiation simulations for a robust framework for validating the results of dose calculations using different systems
- Environment monitoring involving the measurement of very small amounts of various radionuclides, often embedded in complex matrices
- Establishing traceable metrology for neutron energies higher than the well-established range up to 20 MeV. This is needed for dosimetry in mixed high-energy radiation fields, which are relevant for aircrew dosimetry, in space missions and for dosimetry of patients treated with modern forms of radiotherapy using protons and heavy ions.

Consultative Committee for Thermometry (CCT)

The dissemination of thermodynamic temperature (T) over the entire range of temperature is a particular challenge, where a transition is needed from the dissemination of the present defined scales, such as the International Temperature Scale of 1990 (ITS-90), to dissemination of

thermodynamic temperature.

Supported by further research and in close collaboration with industry and major stakeholders, a transition to dissemination of thermodynamic temperature should be made in the coming decade that is both cost-effective and minimally disruptive.

Further work focuses on:

- new metrology to ensure the global temperature metrology system retains its robustness and integrity as primary thermometry emerges as a competitor traceability route (compared to defined scales), and temperature traceability with the advent of self-validating/practical primary thermometry supplying, “traceability at the point of measurement”.
- metrology to ensure reliable measurement of Essential Climate Variables (ECVs) (for example temperature and humidity).
- energy issues to measure carbon generation of energy (nuclear, renewables, hydrogen) and energy efficiency.
- health issues on non-contact thermometry and fever screening required to address future pandemic challenge.
- advanced manufacturing, especially on traceability to thermal quantities for ensuring *in situ* traceability and for optimum use of resources and process control.

Consultative Committee for Time and Frequency (CCTF)

Since 1967, the definition of the SI second has relied on the caesium atom hyperfine transition frequency. Caesium primary frequency standards are currently realizing this unit with a relative frequency uncertainty at the low 10^{-16} level, but in recent years they have been surpassed by optical frequency standards, whose uncertainties are typically two orders of magnitude lower. Therefore, optical atomic clocks will drive the revision of the definition of the second, based on an optical transition.

Further work within the CCTF focuses on:

- a revision of the leap-second procedure to realize a continuous Universal Coordinated Time (UTC)
- the requirements for supporting the traceability to UTC through GNSS measures
- the development of a common Lunar time scale with traceability to UTC
- the establishment of a capacity building programme based on shared resources among the time laboratories to enhance the quality of the local time scale UTC(*k*), and hence of UTC.

Consultative Committee for Units (CCU)

The CCU will continue to concern itself with the development and improvement of the International System of Units (SI), the preparation of successive editions of the SI Brochure and supporting documents, and any other summaries relevant for metrology institutes, industry,

academia and schools, etc. It will also ensure the overall consistency of the SI and provide advice about this and also about measurement units in general. Activities of particular future importance include:

- Monitoring how the SI is applied across all fields and consequently suggesting relevant updates to the SI Brochure as appropriate.
- Ensuring that relevant developments in science, particularly in areas related to units not covered by other CCs, are monitored.
- Review of key topics related to the SI such as: non-SI units, the distinction between base and derived units, and units for physiological quantities.
- Supporting efforts to integrate the SI with digital metrology systems via the SI Reference Point.
- Providing support for the definition of units and the consistency of the SI to the CCTF as it progresses along the roadmap for a redefinition of the second.

May 2025

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