# Young Metrologists' 2050+ vision

A collective vision created by young metrologists from National Metrology Institutes / Designated Institutes

# Foreword

Young metrologists of today will be the custodians of the measurement system in the future. Not only are they closely following and embracing the rapidly changing technology scene, but they will be the ones who have to deal with the aforementioned future challenges. The Young Metrologists Vision 2050+ Project is a foresighting exercise in which young metrologists from around the world have voiced their opinions regarding the impacts of technological changes on the future of metrology and their ideas on how to address these future challenges.

The future is full of possibilities and uncertainties. As we carve our path towards the future, there is little doubt that the world will face an unprecedented scale of global challenges, rapid technological developments, and drastic environmental and socioeconomic changes. In spite of these challenges, there is a possibility that we can navigate through these changing times successfully and emerge stronger and better if we are willing to adapt and prepare ourselves as best as we can.

For the metrology community, this presents us with a unique opportunity to reimagine what metrology can look like in the future and reshape the system for the years ahead. By anticipating these trends and adopting technological advancements as tools, we can perhaps elevate metrology to the next level and make metrology more universal while evolving with societal changes and paradigm shifts. Of course, addressing challenges of such scale will require diverse input and joint effort from all.

We, as the eleven RMO young metrologists coordinators from AFRIMETS, APMP, COOMET, EURAMET, GULFMET and SIM, have collated, analysed and summarized the inputs from our fellow young metrologists through over 170 questionnaire responses and a series of online discussion workshops with 380 young metrologists across all six RMOs. In this document, we present the consolidated views on what are the technological trends and impacts on metrology, what can be done now to respond to future challenges and to fulfil the aspirations of young metrologists. All this work culminated in a vision that metrology will progress together with technology and drive advances in technology while bringing the whole community together to embark on the journey into the future.

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*Our 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.*

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# 1. Introduction

The plan to launch the 'Young Metrologists' 2050+ Vision' initiative was presented by the CIPM President to the 27th General Conference on Weights and Measures (CGPM) in 2022. This mandate was the inspiration behind the initiative and gave the International Committee for Weights and Measures (CIPM) the opportunity to launch a consultation among young metrologists on their global vision for metrology in 2050+.

Foresight is the capacity to think systematically about the future to inform decision making today. As such, strategic foresight strengthens decision making and planning activities under uncertainty and enables structured responses to emerging trends and societal transformations. The young metrologists foresighting exercise was intended to trigger and facilitate debate on visionary ideas for metrology and to identify future trends, technologies, opportunities and challenges through workshops, debates and interviews among groups of young metrologists. The results of this exercise will be used to complement the CIPM Strategy 2030+.

The coordinators, who were nominated by the Regional Metrology Organizations (RMOs), acted as champions of this initiative, bringing together young metrologists from around the world.

Preparatory sessions with the RMO coordinators included the development of a questionnaire and appropriate platform for collating visionary ideas from young metrologists. There were ten questions classified into two themes (five questions each) which were published online: theme 1 focused on the challenges, opportunities and the changing environment in the metrology area / sub-field(s) where young metrologists are involved, while theme 2 covered broader questions, related to the delivery of metrology.

The first stage of the exercise – a series of online discussion workshops with more than 380 participants from all six RMOs - finished in April 2024. These workshops acted as a catalyst for many RMOs kickstarting internal communication channels for young metrologists. Following the workshops, we received over 170 responses to the online questionnaire by the end of June 2024.

The second stage involved consolidating the visionary ideas of young metrologists, which were received through an online questionnaire that ran for one year starting in June 2023. In July 2024, the RMO coordinators met to discuss the responses to the questionnaire that is, the visionary ideas at the BIPM Headquarters. The meeting included online interviews with five young metrologists who had submitted the best responses. The second stage resulted in a summary of these visionary ideas, which was made available for a "second round" of review and feedback from young metrologists.

This foresighting initiative provided an invaluable opportunity for participants to network, debate ideas, and formulate the way forward for metrology. Throughout this journey, we could identify key challenges, opportunities, and the key areas for action that will help to shape the future of metrology. The consolidated views and potential solutions are included in this report, reflecting the passion and dedication of many enthusiastic young metrologists.

# 2. Environmental scan: Opportunities and Challenges

This foresighting initiative gave us many interesting points to think about, which can directly affect the future of metrology. The RMO coordinators discussed and narrowed down the ideas to the 13 topics below which are key opportunities and challenges for metrology. Some topics are already prevalent; however, some are emerging and unfamiliar. The following sections will look deeper into the topics, which will as drivers to ensure metrology ready for the future.

## *2.1 Key opportunities and Challenges that will impact metrology*

### Quantum technology

Quantum technology is a field of physics that uses the specific features of quantum mechanics, primarily quantum entanglement. Quantum technologies based on the management of collective quantum phenomena have become firmly established in our daily lives.

Possible practical implementations include quantum computing and a quantum computer, quantum cryptography, quantum teleportation, quantum metrology, quantum sensors, and quantum images (Wikipedia).

Today, quantum metrology has made it possible to create universal quantum standards for fundamental physical quantities such as time, length, mass and electrical units.

The main visions of young metrologists about the future of metrology according to the challenges of quantum technology are as follows:

- Quantum technologies are beginning to be firmly established in research laboratories and universities as research begins to turn into useful applications. The financial and information technology sectors are investing more and more resources in quantum technologies and, in particular, in quantum computing.
- The introduction of quantum computing, automation and artificial intelligence will change all aspects of metrology. By 2050, the development of quantum metrology will stimulate innovation and support the continuous development of electronic devices, systems and industries.
- As quantum computing continues to evolve, its integration into the practice of metrology can lead to breakthroughs in accuracy, efficiency and innovation.
- Quantum technologies offer great prospects for revolutionizing metrology by providing new ways to implement and distribute fundamental units of measurement with unprecedented accuracy and stability.
- Methods of quantum secure metrology, such as quantum cryptography and quantum-resistant encryption, can protect metrological systems from quantum attacks, ensuring confidentiality, authenticity and protection against unauthorized access to measurement data and standards.

### Artificial intelligence

AI (Artificial intelligence) has been seen as a key future driver and area that will bring significant change to metrology. This fact is underlined by the number of mentions in the responses from the young metrologists throughout all RMOs.

As a summary artificial intelligence has the potential to change the nature of work that is being done by metrologists as it can replace the common tasks performed today as well as executing routine and medium complex analysis of data. This provides an opportunity for a more rapid development and optimization of work (both routine and research) in many areas of metrology. As a counterbalance to these benefits the overuse, overreliance and improper use of AI tools should be an area of focus in the near future. The actions that should be considered in this regard are the development of strategies and recommendations that could mitigate these risks. Another action that is more related to data processing and data security connected to AI in metrology is the detection of artificially generated measurement data and other kind of inputs that could jeopardize confidence in metrology. The immediate action in this area should consist of a deeper understanding of the capabilities of AI and its impact on metrology both in terms of risks and opportunities.

## Internet of Things (IoT), sensor networks, 6G+

Measurement science is shifting from individual sensor measurement to the metrological understanding of entire systems, thus demanding metrological management of sensor networks and low-cost sensor networks.

The integration of IoT functions into metrology instruments and sensors, including distributed sensor networks enables real-time monitoring, data collection, and remote control of metrological processes. To keep up with the rapid pace of technological change and innovation metrology must integrate advances in communication technologies, take advantage of the implementation of 5G and 6G+ networks with its possibilities for high-speed transfer of big data sets in order to improve its capabilities, integrate more easily into different industries and support their processes. IoT-enabled metrology solutions can improve the efficiency, accuracy, and reliability of measurements, as well as enable predictive maintenance and proactive quality control.

The use of IoT based sensor networks can be useful in different fields, where dynamic and widespread data collection is essential such as environmental monitoring, full-human body monitoring and other complex multiparametric systems.

In order to support such advanced sensor network systems and technologies a strong metrology basis is needed. Furthermore, with emerging technologies such as 5G, some specific challenges appear (for example a growing level of public mistrust). To address such challenges, it is essential to provide accurate measurements and establish clear, understandable limits. By doing so, we can still have confidence in these technologies, ensuring both safety and public acceptance.

## Cloud storage and cybersecurity

Nowadays it is possible to access thousands of millions of data sets to find information that we need. These data sets can be stored on your laptop, however, if they are too large, we normally use cloud storage. Ensuring the integrity and security of measurement data stored in the cloud is important when it comes to enabling us to make right decisions. It is also necessary to consider compliance with standards. Measurement data stored in the cloud should adhere to both cybersecurity standards and metrological standards. At the same time, we can also take into account technical development by leveraging advancements in cloud storage and cybersecurity to enhance metrological practices. We used to think of cloud storage as a supplementary means to ensure that we can access FAIR data, however, it also has the potential to advance the development of metrology.

## Self traceability

Metrological traceability is one of the key pillars of metrology and reliability of measured quantities, and as such this area is of high importance as it has the potential to change work practices within the metrological community. Young metrologists have not followed a unified approach in the traceability theme due to the different challenges throughout the various measurement quantities.

The young metrologists expressed an interesting and potentially revolutionary idea with regards to traceability. This was a development of a practical self-validating measurement device which can measure a specific quantity by a primary method. This would significantly reduce the need for repeated and time-consuming Inter-Laboratory comparisons or Key Comparisons with a direct traceability to the SI. Several alternatives to this approach were outlined introducing nano scale primary measurement devices of more than one quantity which could supplement each other in terms of uncertainty reduction. Another approach was to use a combination of advanced computing (available thanks to mastered quantum computing) and AI in sensor networks to gain self-traceability. The key area in which this idea of a self-traceable measurement could be applied cuts across all metrological fields and could change the process of validating results. Immediate action is required for the continuous development of practical measurement devices that can measure a specific quantity by primary methods, miniaturization of set devices and their self-validation.

## Climate and environmental changes

Climate and environmental change will profoundly impact metrology in the future. The rising levels of greenhouse gases contribute to global warming and climate change. These changes alter atmospheric conditions, affecting temperature, humidity, and pressure measurements, which are crucial for accurate weather forecasting and climate modelling. As the climate becomes more unpredictable, the demand for precise and reliable measurement techniques grows, requiring advancements in metrology to ensure accurate data collection and interpretation. This, in turn, will enhance our understanding of climate dynamics and improve the development of mitigation and adaptation strategies.

There must be well-established and robust mechanisms in metrology for measuring and monitoring both the consequential events of the rapidly changing climate and the new sustainability-focused practices adopted by all sectors of society. This is essential to ensure we are adequately prepared to address these challenges and devise effective solutions. The development of supercomputers, quantum computers, and AI will facilitate more detailed climate models and simulations, enabling non-intrusive data gathering and accelerated understanding of events related to climate change like forest fires and accurate weather forecasting.

## Nanobiometrology

Nanotechnology and biotechnology are relatively new fields. Researchers put considerable effort into developing and implementing technological applications for these areas worldwide. Metrology has been used to underpin the relevance of such developments. Foreseeing the future as a "joint venture" with both fields is reasonable. Nanobiometrology combines the principles of nanotechnology, biology, and metrology to measure and characterize biological systems at the nanoscale. Nanobiometrology is a burgeoning field that merges the precision of nanotechnology with the complexity of biological systems. Its advancements promise to revolutionize biomedical research, diagnostics, and therapeutics, leading to a deeper understanding of life at the nanoscale and the development of cutting-edge medical technologies.

At its core, nanobiometrology involves the precise measurement and analysis of biological structures and processes at the nanometre scale. One nanometre is one billionth of a metre, a scale at which many biological molecules and structures operate. Traditional metrology, which deals with measurement and standards, has been adapted and enhanced to address the unique challenges posed by nanoscale dimensions and the complex nature of biological systems.

Several advanced techniques are employed in nanobiometrology to achieve high-resolution measurements and detailed characterizations, such as Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Environmental or In-Situ Ultra-High Vacuum capabilities, Super-Resolution and Near-Field based Optical Microscopy, Fluorescence Microscopy, and Nanoparticle Tracking Analysis (NTA). All these techniques need robust metrological structures to provide results that can impact future human needs. Using label-free methods for the analysis of nanotoxicity is highly relevant due to their ability to provide real-time, non-invasive assessments of nanomaterials' impact on cellular and tissue levels. The ISO/TS 21633:2021 standard outlines methodologies for label-free impedance technology to evaluate the toxicity of nanbiomaterials in vitro, ensuring accurate and reproducible results without the need for additional labels or dyes that might interfere with the measurements. This approach not only enhances the reliability of cytotoxicity assessments but also presents a significant opportunity to develop standardized methods for 2D and 3D High Content Analysis (HCA), fostering more consistent and comprehensive evaluations of nanoproducts interactions within biological systems. New CMCs will be required to cover all the technical metrological aspects that nanobiometrology embraces.

The precise measurements and characterizations provided by nanobiometrology have a wide range of applications, such as toxicological sciences, medical diagnostics, drug delivery, tissue engineering, cancer research, and environmental monitoring. Despite its potential, nanobiometrology faces several challenges. The complexity of biological systems, the need for non-destructive and real-time measurements, and the standardization of measurement techniques and the assessment of the potential impact of nanomaterials on human health and the environment are ongoing research areas. Future advancements in instrumentation, computational modelling, and the development of new standards will further enhance the capabilities and applications of nanobiometrology.

## Perceptual metrology

Perceptual metrology is an emerging field that quantifies and analyses human perception. This interdisciplinary domain integrates psychology, neuroscience, engineering, and traditional metrology principles to create metrics and methodologies for assessing how humans perceive and interact with their environment. 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.

Perceptual metrology encompasses sensory and cognitive responses to stimuli such as sight, hearing, touch, taste, and smell. Unlike traditional metrology, which deals with physical measurements like length, mass, and time, perceptual metrology aims to capture subjective experiences and translate them into objective data. This requires a deep understanding of the human sensory system and the metrological methods used to interpret perceptual data. Approaches employed to measure and analyse human perception include psychophysical methods, electroencephalography, functional magnetic resonance imaging, eye tracking, haptic feedback, and psychoacoustics.

Perceptual metrology has various applications, including product design (by understanding how users perceive products, designers can create more intuitive and satisfying user experiences), quality control for the food, beverage, and cosmetics industries, healthcare, environmental design, and marketing. Whilst the fields for perceptual technology are vast and have not yet been wholly exploited, perceptual metrology is in its earliest stages of development. We should make a considerable effort in research and development to enhance the capacity and capability to address the perceptual metrology tasks that will arise. Perceptual metrology faces several challenges, including the inherent subjectivity of human perception, the variability between individuals, and the complexity of multisensory experiences. Advances in artificial intelligence and machine learning can enhance the field by providing more sophisticated tools for analysing perceptual data.

Standardization is another critical issue, as consistent methodologies and metrics are necessary to ensure reliable and comparable results across studies. Developing universal standards for perceptual measurements will facilitate progress in this field.

In conclusion, perceptual metrology is a rapidly growing field that seeks to quantify human experiences and perceptions. Its interdisciplinary nature and wide range of applications make it essential for designing products, environments, and systems that are in harmony with human sensory and cognitive processes. As technology evolves, perceptual metrology will play an increasingly important role in shaping the future of human-computer interaction and the broader human experience.

## Metrology in space and other planets

Measurements in space and for the purposes of space exploration will become more common in 2050 and beyond. In 2023 alone, more than 2,500 objects were launched into the space by both government space agencies and private spaceflight companies. Emerging challenges such as climate change and energy crises have encouraged more measurements to be launched into orbit for earth observations, for example greenhouse gases emission scanning, radiation sensing and climate monitoring. In the near future, commercial space travel will become a trend and more space missions with demanding measurement applications are expected to come onboard with our boundless quest of searching for exoplanets and understanding the universe. There are also some interests in fundamental metrology research such as optical clocks and Kibble balance under microgravity conditions. Looking further into the future, mining on asteroids, establishment of colonies on other planets and the moon are not remote possibilities as the intensifying challenges on earth will accelerate the implementation of these plans. All these missions and enterprises will necessitate measurements to be performed under extreme environmental conditions that humankind has never experienced before. Coupled with communication challenges at vast distances, timescale differences on different planets and shocks to measuring equipment in harsh conditions, one would wonder, how will traceability and validation of measurements in these situations take shape? Will metrology have to adapt or be fundamentally changed as humankind is venturing into uncharted territories? Perhaps it is prudent for the metrology community to begin considering these issues and to ensure that the concept of metrology will continue to be of importance as we explore beyond earth and into the future.

## Interdisciplinary challenges

Metrology confronts significant interdisciplinary challenges in today's world. These challenges stem from the growing complexity and diverse needs for measurements across sectors such as advanced manufacturing, healthcare, transportation and environmental monitoring. Integration of advanced technologies like quantum technology, bio-nano technology, automation, AI, and IoT presents a major challenge, necessitating collaboration between metrologists, data scientists, technologists and engineers to develop precise and traceable measurement systems capable of handling large data volumes in real-time. Collaboration across disciplines is essential to innovate measurement techniques, establish robust standards, ensure sustainability and engage future metrology professionals. This holistic approach in metrology can continue to drive technological progress and societal development worldwide.

## Science Scepticism and Ethics

Sceptics often focus their criticism on claims they consider implausible, dubious or clearly contradictory to generally accepted science. Scepticism in metrology often revolves around the accuracy and reliability of measurement methods and instruments. Sceptics may question whether a particular measurement technique truly reflects the quantity being measured or if there are inherent biases or errors. They try to introduce doubts in measurement by questioning the results from the measurement and questioning the validity of the methods and procedures used to achieve the measurement and try to undermine the credibility of the measurements. This will result in tarnishing the image of metrologists and contradicting with the saying that once's calibrated accepted everywhere.

The interpretation of the results needs to be well communicated because scepticism might interpret the results falsely and try to use it to contradict the true results and try to back up sceptic opinions or philosophy with the misinterpreted information. It includes how the data is analysed by the metrologist and the laid down methods and procedure which need to be uniform across the board in order to avoid such loopholes.

Scepticism can arise when new technologies or measurement techniques are introduced, especially with the new trends in artificial Intelligences and robotics. Sceptics may question whether these innovations have been adequately validated or if they introduce unforeseen biases or errors for example during the Covid 19 pandemic many people doubted the vaccines that were produced during that time and the associated validity and verification methods. Sceptics may question whether these standards are robust enough or if they adequately account for all relevant factors, especially with new technologies

## Political/legal/social influence

The means to deliver metrology worldwide is at constant risk of political, legal and social changes. Most NMIs are public sector organizations which respond directly to the policies dictated by governments. Constant shifts between political administrations also change the orientation of public funds, allocating more or less financial and human resources on scientific research and development; even threatening the continuity of public scientific organizations. These constant shifts in political orientations also have an impact on international politics, swinging from openness to collaborate with other countries to a rise in nationalism and jealousy of their scientific output. This instability affects the way NMIs collaborate with each other, which is necessary for the demonstration of equivalence and bridging technological gaps between institutes.

Additionally, the public nature of NMIs restricts their adaptability to change. The established legal frameworks in different countries limit the capability to deliver the metrological services required by the evolving private sector in a short time. On the other hand, international politics and the rise of conflicts between economies have an influence in the implementation of a global metrology system. These international affairs have an impact on the global supply chain obstructing the development of reference materials or instruments (standards), when prime materials and energy supplies (gas and oil) are outsourced.

With regard to social aspects, the need to ensure equality and to open opportunities for a more diverse workforce is constantly increasing. The migration of people in search of better opportunities opens the possibility for talented scientists and engineers to become involved within new metrological structures away from their country of origin. This allows the development of multicultural teams that strengthens the organization through everyone's experience and background.

## Human resources (Demand for future skills)

The key drivers and major talking points around the Human Resources (HR) were largely centered around the ability for metrologists to be multidisciplinary i.e metrologists being able to specialize in a specific field but have additional skills for e.g. a chemical metrologist may need some mechanical or electrical skills. This would entail upskilling of metrologists. Metrologists would also need to have some sort of knowledge in programming/computer-based skills.

The majority of young metrologists feel that the subject of metrology should be introduced to the education system at either the high school level or tertiary level. This is something that they feel requires immediate action and would help in familiarizing science students with the importance of metrology, so that even if they do not work in the field directly the importance of it is known, thus in-turn creating more demand for metrology work in the future.

There is a consensus that as budgets are being reduced and the number of metrologists is decreasing that preparation for 'future proofing' metrology is not at the level it should be. More demand is being placed on metrologists with less resources.

# 3. Key areas for actions

By analysing the circumstances within metrology and its surroundings, RMO coordinators could develop possible ways to prepare for the future. Here, we propose some actions which should be taken into consideration. These approaches are important for individual NMIs, however, they also need more wholistic and systematic schemes to coordinate with global metrology communities.

| Areas | Actions |
|---|---|
| New metrological capabilities | • Continuously develop strategy to cope with demands from rapid changes<br>• Collate existing measurement capabilities from global NMIs for new and emerging areas such as nanobiometrology<br>• Provide necessary technologies for remote/real time/virtual calibration services to NMIs<br>• Develop measurement devices with self-validation which can provide metrological traceability by a primary method |
| Collaboration | • Strengthen interdisciplinary and multidisciplinary collaboration with scientists, meteorological agencies and policy makers to better cope with global challenges including climate change, and food safety so that metrology can be aligned with SDGs<br>• Promote knowledge transfer among NMIs though intra and inter RMO structures to bridge the gaps in measurement capabilities<br>• Bring investments into metrology to support NMIs for applying quantum technology<br>• Create a scheme for public-private partnerships to better cope with conformity assessment issues<br>• Develop best practices on data management system |
| Capacity building and Education | • Broaden networking among young metrologists through online workshop/training so that they can explore new opportunities, and communicate collectively and effectively<br>• Develop interdisciplinary training programmes to cover a broad range of skills such as AI/ML, IT, software, data sciences<br>• Update the curriculum of STEM (Science, Technology, Engineering and Mathematics) courses to include metrology as a course within higher education centres (universities) |
| Standardization and Policies | • Engage with various experts to harmonize measurement practices and implementation on regulatory frameworks<br>• Establish cross-disciplinary standards to ensure the consistency and reliability of measurements<br>• Develop new measurement standards and policies for our stakeholders (industries, academies, etc) to provide common protocols and promote CMCs as a basis for quality infrastructure for reliable measurement data with respect to sensor networks<br>• Secure the compliance to cybersecurity standards in relation to measurement data |
| Public relations and Outreach | • Promote the capacity building and knowledge sharing by the metrology community to make worldwide applications<br>• Develop introductory metrology courses for schools and universities<br>• Perform cost-benefit ratio analyses on metrological services to generate awareness to policy makers |
| R&D | • Create opportunities for cross and inter-disciplinary joint research projects in metrology areas to encourage research cooperation among different NMIs<br>• Broaden research cooperation with space agencies and relevant stakeholders |
| Risk Management | • Develop strategies and recommendations for adopting AI into metrology to mitigate the risks<br>• Establish data standards to verify measurement data, especially for artificially generated data<br>• Integrated risk management strategy to cope with cybersecurity, especially on measurement data |

# 4. Closing with special thanks

Throughout the YM 2050+ initiative, we were able to envisage the future challenges and opportunities in metrology. There were many interesting discussions during the RMO workshops, along with answers from young metrologists to the online questionnaire. Looking back over the past decades, the speed of technological development has far exceeded our imagination. Thus, it is almost impossible to draw a clear picture of the future shape of metrology. Will it be similar to what we have now? or very different from the present? The answer is both yes and no. When we were young, we imagined everyone would have a mobile phone, and today that vision has become a reality with devices far more advanced than a simple telephone. Everyone now has a small computer combined with a camera, commonly referred to as a “smartphone.” However, we still do not have flying cars everywhere, and it might take more time than expected for that to happen.

Thirty years from now, the next generation might live in an underwater world due to climate change, or even on other planets. We will surely have a different definition of 'metrological traceability.' Again, it is hard to anticipate the future exactly; however, we must always try to prepare for the next steps that are necessary in terms of metrology. It is absolutely our duty and responsibility because there can be no improvement without precise and accurate measurements.

What should we do to deal with future challenges? As we have seen many interests and ideas from young metrologists, it is crucial to take appropriate action. By its nature, metrology progresses more slowly than the advancement of technology. We typically establish new measurement standards based on common needs and spend considerable time comparing them with each other to ensure they are reliable. Therefore, we cannot say that metrology is fast enough to keep up with the needs of various stakeholders.

Of course, there can be many different options and views on how to cope with future challenges. However, it is very clear that we need to consider a more aggressive approach so that metrology does not fall behind. In the same sense, it is extremely important to share the thoughts of young metrologists who care about the future of the field. We sincerely hope that these opinions and ideas will be useful to them, as they are the key players who will implement the necessary measures in the coming years to ensure a promising future beyond 2050.

## Special thanks to all the participants for Young metrologists' 2050+ vision initiative

We received more than 170 responses from young metrologists from around the world. We appreciated their sincere and heartfelt visions and ideas for the development of metrology. It is challenging to predict the future of metrology, however, the young metrologists were very enthusiastic and creative. We would like to deliver our sincerest thanks to all young metrologists who are constantly working towards a better tomorrow of metrology and human beings.

In particular, we would like to express our deep appreciations to Dr D. Wong (NMIA, Australia), Mr M. Klunin (BelGIM, Belarus), Ms F. Haymes (NPL, United Kingdom), Ms A. O'Rourke (NSAI, Ireland), Mr C. Paredes (INM, Colombia) who shared very impressive and ambitious visions for the future of metrology.

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# Annex 1: Our journey

The plan to launch the 'Young Metrologists' 2050+ Vision' initiative was presented by the CIPM President to the 27th General Conference on Weights and Measures (CGPM) in 2022. This mandate was the inspiration behind the initiative and gave the International Committee for Weights and Measures (CIPM) the opportunity to launch a consultation among young metrologists on their global vision for metrology in 2050+.

***Objectives and goal***

*To organize a foresighting exercise in collaboration with the RMOs to trigger and facilitate visionary ideas for future opportunities and challenges via workshops, debates and interviews among groups of young metrologists.*

*The goal is to complement the CIPM Strategy 2030+ with visionary ideas from young metrologists looking further into the future.*

## Summary of the work

This exercise had to be conducted from the bottom up, in collaboration with RMOs, with broad consultation from young metrologists across different regions, and aimed at collating visionary ideas for future opportunities and challenges. The process included two stages: collation of ideas and consolidation of these ideas into the report. The steps included the nomination of representatives (coordinators) by RMOs, who would act as regional champions, bringing together young metrologists from around the world; defining the term 'young metrologists'; setting up the entire process; developing questions; organizing online discussion workshops and debates; consolidating data; and preparing the report (Figure 1).

At the start of the initiative, it was important to cooperate with RMOs, as they work directly in NMIs across the globe. Therefore, we needed a group of young people who are familiar with RMOs and supportive of the initiative's goal. Considering these criteria, eleven RMO coordinators from six RMOs were nominated by each RMO during the 46th JCRB meeting (March 2023).

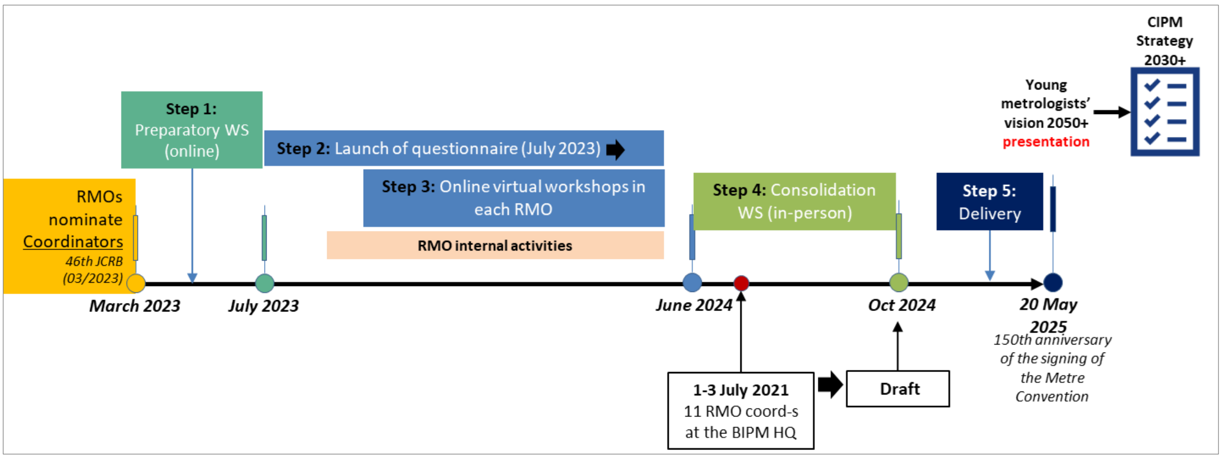


*Figure 1. Timetable for the process*

**Preparatory meetings.** In May 2023, the BIPM organized the first online preparatory meeting with the nominated RMO coordinators and discussed the background, motivations and definition of "young metrologists" to efficiently run the project as a team. Some RMOs indicated that the work experience of young metrologists at the NMI should not exceed five years, without imposing an age limit.

Ultimately, we decided not to set any restrictions for young metrologists, opting instead to be inclusive when gathering data through the online questionnaire.

**Online questionnaire**. Preparatory sessions with the RMO coordinators included the development of a questionnaire and an appropriate platform for collecting visionary ideas from young metrologists. We developed ten questions, classified into two themes (five questions each), which were published online. Theme 1 focused on the challenges, opportunities, and the changing environment in the metrology area/subfield(s) where young metrologists are involved, while Theme 2 covered broader questions related to the delivery of metrology. We aimed to post questions that were open and inclusive. It was challenging to prepare questions that were not biased toward current developments. After several iterations, we agreed to add a third theme with two questions that could provide insights into what we need to do today to be prepared for future changes. Additionally, to give prompts to young metrologists, each RMO coordinator took charge of a question and drafted a one-page background information document per question to explain and interpret them (Figure 2). With all these preparations, the online questionnaire was published on 10 July 2023.

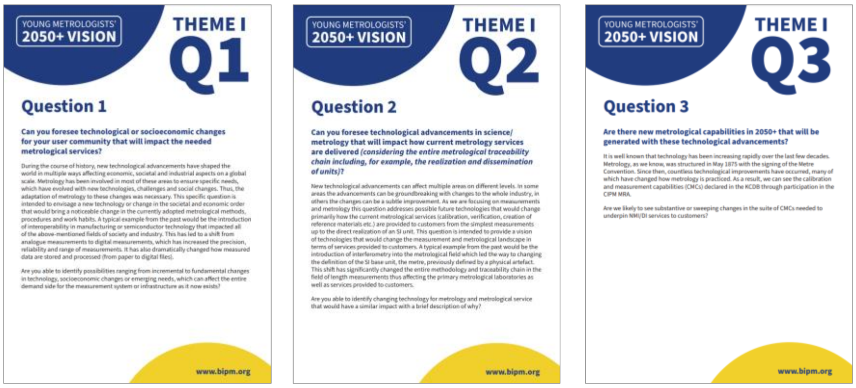


*Figure 2. Illustration of questions with prompts.*

**Online workshops in each RMO.** From the launch of the questionnaire, we conducted online workshops with all six RMOs ( Figure 3), engaging in discussions with young metrologists. We presented questions, explained the objectives, and encouraged them to respond to the questionnaire. Starting with the SIM region in September 2023, a series of online discussion workshops with all six RMOs was organized and concluded in April 2024, with over 380 participants. Young metrologists working at NMIs/DIs had the opportunity to discuss developments in this dynamic field, including emerging trends and technologies that could impact metrology in 2050 and beyond. They also contributed insights on the societal, economic, and environmental factors that may drive these changes and their potential influence on the future of metrology. From the words of a young metrologist who participated in the workshop: *"Dear Chingis, thank you very much for this workshop. It was fascinating and a great source of learning and sharing. I would also like to thank you for the interview I had with you. It was very inspiring".* These workshops served as a catalyst for many RMOs, initiating internal communication channels for young metrologists. Almost all RMOs have since organized their own internal workshops, encouraging young metrologists to actively participate in shaping the future of metrology, which they will eventually lead.

**Collecting visionary ideas.** The BIPM received more than 170 responses (average age: 33.6 years old from those indicated their age) by the end of June 2024. All responses were shared with the eleven RMO coordinators, who were asked to review and summarize them before the consolidation meeting. The coordinators were also tasked with anonymously selecting the five best respondents who were then invited to further elaborate on their ideas during the meeting. The RMO coordinators selected potential interviewees by evaluating key aspects such as creativity (visionary thinking), importance (meaningfulness), and clarity (logical coherence).


*Figure 3. Screenshot from the online workshops*

**<u>Consolidation workshops at the BIPM Headquarters.</u>** The eleven RMO coordinators gathered at the BIPM headquarters from 1 to 3 July 2024 for the consolidation meeting. The workshop programme included the following four main activities:

- debate on the summary of responses, where each RMO coordinator discussed the questions and responses and asked for comments if any ideas were missing;
- interview the five best respondents, who presented their ideas in detail;
- draft the outcomes of the 'Young Metrologists Vision 2050+' project based on the responses and interview outcomes;
- formulate the young metrologists' global vision, reflecting all the responses given to the questionnaire.

The consolidation workshop resulted in a summary of responses, which was made available for the second round of comments through the BIPM e-learning platform. All RMOs and those who responded to the questionnaire were informed about the second opportunity to 'fine-tune' their responses and adding any new ideas that might have been missing from the foresighting exercise.

**<u>Consolidated outcomes.</u>** Based on the responses and the second round of comments, the RMO coordinators identified the key opportunities and challenges for the future of metrology. All of these insights have been compiled in this document. One point to note is that the outcomes of this initiative are the collective view from young metrologists around the world. However, our general observation is that the implementation or consideration of the key opportunities and challenges for the future of metrology can be different based on the regional needs and strategy.

## Conclusion

This unprecedented initiative gave us many thought-provoking ideas to reflect on. Above all, it was both important and interesting to learn that many young metrologists are seriously considering the future of metrology. They are eager to share their thoughts and views by communicating with other young metrologists from all over the world. Most of them displayed a positive view on the future of metrology, with brilliant and visionary ideas; however, some expressed concerns that, without appropriate strategies and action plans, it will be challenging for metrology to maintain its role as the cornerstone of science, technology, and industrial innovation.

Many indicated that they are striving to make progress in their respective areas so that industries and academia can trust their measurement results. However, they are uncertain whether they have up-todate information on global metrology issues. In this regard, they wish to have greater access to information on global metrology issues, as they feel such information is currently available only to top management or scientists who attend CIPM Consultative Committees' meetings.

Furthermore, the entire journey of this initiative turned out to be quite different by the end compared to the beginning. We could not have imagined how far we would go in terms of responses from young metrologists and participation from the RMO coordinators. Every step exceeded our expectations. We witnessed many exciting ideas and interesting discussions from young metrologists during the online workshops and interviews. In this sense, it may be worth considering involving the younger generation of metrologists in the strategic discussions of the NMIs.

# Annex 2: Summary of answers from Young Metrologists

## THEME I: Challenges, opportunities and the changing environment in Metrology area / sub-filed(s) you are involved.

**THEME I. Question 1:** Can you foresee technological or socioeconomic changes for your user community that will impact the needed Metrological services?

(Summary prepared by Peter PAVLASEK, EURAMET)

Socioeconomic changes are seen in this case as a catalyst for a shift in the user community's regular demands for delivered metrological services. The community that is usually considered as the prime users of metrological services will change with a transformation of the socioeconomic landscape.

The user community for metrological services will not be restricted to the typical customers and will potently include sectors more related to human behaviour, IT security and social sciences. The user community's relationship with metrologists is subject to change and will be more focused on automated computation and measurement design tailored to a very specific measurement application. The role of experienced metrologists is predicted to be restricted predominantly for the role of consultants and guardians of measurement quality and reliability.

**Technologies that are foreseen as most likely to have a significant effect on socioeconomic changes are the following:**

- AI and advanced machine learning
- Quantum computation
- Highly reliable and available measurement sensors
- Advanced internet of things (6G and beyond).

**Socioeconomic changes that are expected:**

- The type of work done by people is going to be subject to change (humans will be used for more complex tasks and simple and moderately demanding work will be taken over by AI)
- The possibility of new sectors emerging in the field of data validation and verification (due to the fact that AI can generate vast quantities of data)
- Possibly the need for a sector that would regulate AI in terms of behaviour and relations to humans.

**All of the above changes will create a ripple effect on the metrological services in the following way:**

- More custom/tailored measurement setups that will imitate real-life conditions
- Dominant position of simulations, thanks to vastly improved computational power
- Usage on multilevel sensors that have embedded all the basic SI measurements (by primary methods)
- Self-validating sensors
- More emphasis on data evaluation and verification
- Possible AI evaluation based on its specific criteria
- Remote sensing using 6G and 6G+ networks (no need for specialized dedicated sensors)
- Metrological traceability and measurement capability will not only be demonstrated by means of key and supplementary comparisons.

**THEME I. Question 2:** Can you foresee technological advancements in science/metrology that will impact how current metrology services are delivered *(considering the entire metrological traceability chain including, for example, the realization and dissemination of units)?*

(Summary prepared by Oijai ONGRAI, APMP)

The young metrologists suggested that the following technologies will affect metrological services:

- Developing nano-biosensing technologies and new chemistries to understand complex biological systems.
- Applying quantum physics and principles to achieve higher precision and accuracy in measurement.
- Measuring science at the nanoscale, where new physical, chemical, and biological properties emerge.
- The development and characterization of nanomaterials and nanodevices, such as nano-sensors, nanoelectronics, or nanomedicine.
- Employing artificial intelligence, machine learning, cloud computing and the Internet of things in measurement systems, such as smart sensors, digital twins or augmented reality to improve efficiency. Digital metrology enables new ways of data acquisition, analysis and communication, such as using big data, blockchain, or 5G networks and beyond.
- Cutting the metrological traceability chain and calibration hierarchy to simplify primary measurement standards to eliminate the compounded measurement uncertainty accrued as one descends down the traceability chain. This gives all users enhanced measurement results.
- Employing in-situ calibration methods to reduce the need for user-input as equipment calibrations can be performed through automated methods, which may also be assisted by AI.
- Integrating automated hybrid bioelectronic sensors into (micro/bio) mechanical systems for delivering chemical and biological metrology services related to health sciences, food safety assurance, food quality assessment, precision agriculture and environmental monitoring.
- Addressing global and societal needs, ensuring the quality and reliability of measurements and fostering innovation and collaboration in metrology.

**THEME I. Question 3:** Are there new metrological capabilities in 2050+ that will be generated with these technological advancements?

(Summary prepared by Rodrigo COSTA-FELIX, SIM)

The young metrologists shared their visions on a wide range of technologies including artificial intelligence (AI), blockchain, quantum computing and metrological needs for nanobiotechnology applications. The young metrologists consider that new technologies that are yet to be developed, or presently available technologies, may in the future substitute for human activities in daily metrological tasks. Another critical remark is that nano and biotechnology are rapidly merging and sharing capabilities, indicating that a new metrology area is emerging: nanobiometrology, as it has been referred to in some NMIs. Online and self-calibration have been highlighted as possible ways to incorporate technology into metrology. Quantum metrology was foreseen as being a key enabler to improve CMCs regarding accuracy and precision or even to allow new CMCs types to be developed and offered by NMIs in the future. Digital transformation has been mentioned as a possible way for metrology approaches to be tailored to specific industry needs, replacing the available "on-the-shelf" services. There is an expectation that technological advances will shorten the track from fundamental science to industrial-level needs, with metrology continuing to act in its role of ensuring reliability through traceability.

**Summary:**

- Advances in AI applications will need better-prepared metrologists and metrological infrastructure to be used correctly.
- Biotechnology (nanobiometrology included) will demand that new metrological procedures be addressed.
- Communication shall be improved in many aspects, including better teaching of the fundamentals of metrology.
- Quantum computing and cloud storage are foreseen as being fundamental for metrology in the future.

**THEME I. Question 4:** Can you foresee major disruptive change in your metrology area?

(Summary prepared by Nikita ZVIAGIN, COOMET)

About 70 % of respondents answered yes and gave many different suggestions on possible disruptive changes in their specific fields of metrology or in metrology overall. The diversity of the answers depends on the individual's understanding of the term "disruptive".

**Most of the positive answers were focused on new technologies. Among them are:**

- Artificial Intelligence
- Quantum Metrology
- Robotization and automatization of metrological processes (for example automatization of calibration or robotized sample preparation in chemistry)
- The possibilities of portable (wearable) analysis tools
- Nanotechnologies
- Internet of things
- Remote calibrations
- Open access to reference and research data
- New materials
- Renewable energy sources
- Non-contact measurements

A lot of attention was focused on the redefinition of the SI Base Units and hence the eventual possibility of in-situ calibrations as the source of possible disruption in metrology processes.

The prevailing idea is that no matter what the changes will be (disruptive or predictable), new technologies will increase reliability and accuracy of measurements and will decrease time and simplify processes of measurements.

Some respondents also noted that new technologies could provide metrology with new areas of activity (i.e. communication technologies), but they should be used carefully and under the control of professionals.

About 30 % of the respondents answered "NO". They do not foresee major disruptive changes in their metrology area. Most of the "NO" answers were given without an explanation. One possible explanation is that "there will only be an evolution of the metrological principles not a revolution".

**THEME I. Question 5:** What do you think metrological traceability in your metrology area will look like in 2050+?

(Summary prepared by Yin Hsien FUNG, APMP)

The responses from the young metrologists can be categorized into seven main themes (number of responses): don't know (10), no changes to metrological traceability (16), establishment of metrological traceability (14), improvement in range and uncertainty (27), changes in the delivery mechanisms of dissemination and metrological traceability (52), fundamental changes in metrological traceability chain and dissemination (37), and utilization of quantum computing and optical methods for metrological traceability (20).

**Summary and visions from the respondents:**

- There will be no change/minimal changes to metrological traceability. These are ideal for measurement users and regulatory standards, the traceability chain in their areas are already very mature. CRMs are still and will continue to be very important in chemical metrology.
- There will be establishment of metrological traceability in certain areas. There are many measurands and quantities that are yet to have traceability, the most mentioned ones include medical metrology, environmental metrology and optical metrology. In addition there are interdisciplinary measurands such as those for electrochemistry and biochemistry.
- There will be improvements in standards, mises en pratique, uncertainty and range. This is particularly true for derived quantities such as those in ionizing radiation, pressure, gas flow, magnetism and vibration.
- There will be changes in the delivery mechanisms of dissemination and metrological traceability. These are mentioned many times in the responses. There will be digital dissemination of standards, self-calibrating systems, real-time data collection to cloud data storage leading to a global network of data collection systems. There are responses that point to the use of digital twins (virtual calibration) to verify accuracy and use of AI and automation to drive down uncertainties, standardize procedure and decision making.
- There will be fundamental changes in the metrological traceability chain and dissemination. The most mentioned changes are the shortening of the traceability chain due to portable primary standards and direct SI traceability. Some also suggested that the definition of traceability will have to change or be customized to address the challenges arising from the use of AI and digital twins. A few mentioned there will be changes to the SI base units, hydrogen gas impacting traceability and cooperation between NMIs to maintain traceability chains.
- There will be uses of quantum computing, optical methods and quantum standards. This is particularly true in electrical systems, gravimetry, photonics and nanotechnology. The impact of quantum computing on the metrological traceability has to be addressed.

## THEME II: Broad questions, related to the delivery of metrology.

**THEME II. Question 1:** What approach is needed for measurement practices to keep up with the rapid pace of technological change and innovation?

(Summary prepared by Rayan ALYOUSEFI, GULFMET)

Creating measurement standards and practices that are flexible and scalable can be one approach to accommodate technological advancements.

Education and training that includes the latest methodologies is critical for the metrology workforce. This will affect how we prioritize our progress in measurement science.

Focus on being transparent when collaborating with the private sector. Industries are often at the forefront of technological innovation. These partnerships accelerate the uptake of new measurement technologies and practices. The translation of scientific discoveries into commercial products could include new therapeutics or diagnostic tools.

Cooperating with international metrology institutions, standard-setting bodies, and the scientific community can further support this area. For example, we can coordinate with international measurement institutes and start exchange programs for training and development of staff. Creating an online hub for common projects so that one can directly compare their results with others who are working toward a common goal.

Metrologists should become more embedded in R&D across industry and adopt a consultancy role. This would require a proactive approach rather than a reactive approach. This will ensure that the metrology community remains at the forefront and allows us to anticipate what kind of requirements are emerging for measurement capacity in different domains.

Multidisciplinary teams are a keystone to keeping up with technological developments. The differences and diversity among people have proven to enrich human experiences to an extent that could hardly be achieved without the intermingling of different cultures and thoughts. These benefits might be extrapolated to metrology more efficiently if national metrology institutes transform into integral research centres that increasingly incorporate people with a science and engineering background who are tasked with constantly communicating with each other.

**THEME II. Question 2:** Is there more we (NMIs/DIs) could do to ensure that metrology continues to play a critical role in innovation and progress in 2050+?

(Summary prepared by Fernando José ANDRÉS MONGE, SIM)

Promoting education and training in metrology is deemed to be essential. Supporting educational programs and training initiatives will ensure a skilled workforce capable of handling advanced measurement technologies. Integrating metrology into university curricula and public outreach programs can raise awareness about its importance and attract more young people to pursue careers in this field.

Collaboration with industry and academia is highlighted as a pivotal strategy for advancing metrology. By fostering strong partnerships with industrial partners and academic institutions, NMIs and DIs can align their research priorities with real-world challenges, facilitating the practical application of metrological advancements. Such collaborations can lead to the development of new standards and innovative measurement technologies, ensuring that metrology remains at the forefront of scientific and industrial progress.

NMIs and DIs can play a critical role by investing more resources (financial and human) in research and development (R&D). Allocating resources to cutting-edge technologies and innovative measurement techniques allows these institutions to stay ahead of industry needs and contribute significantly to technological advancements.

Global collaboration is crucial for ensuring uniformity and consistency in measurements and standards. NMIs and DIs are encouraged to participate actively in national and international standardization activities, ensuring that metrological standards are continually updated to reflect technological advancements and remain relevant in evolving industries.

Embrace the concepts of digitalization and Industry 4.0 and beyond within metrology. In this way, NMIs and DIs can provide solutions that are faster and more accurate, aligning with the evolving needs of modern industries. The adoption of technologies such as quantum metrology, artificial intelligence, and the Internet of Things (IoT) is crucial for ensuring that metrology remains relevant and effective in the face of rapid technological changes.

**THEME II. Question 3:** Are changes needed in the way we collaborate internationally to help advance metrology and ensure consistency across different industries and applications in 2050+?

(Summary prepared by Moza Khalfan ALMEMARI, GULFMET)

International collaboration in metrology needs to be dynamic and adaptive to address the evolving technological landscape and societal needs of 2050+. Strengthening existing structures, fostering new partnerships and enhancing knowledge exchange are pivotal. The international community can ensure that measurement science continues to advance and support global consistency across industries and applications by aligning efforts with global challenges and advocating for the critical role of metrology.

- **Exchange of knowledge and experiences.** The exchange of knowledge and experiences in the field of measurement is achieved through scientific research and academic partnerships. These efforts include encouraging joint projects and initiatives that bring together researchers from different countries and disciplines to develop innovative measurement solutions, exchanging articles and technical bulletins and organizing conferences and workshops. This can be achieved by opening access to research by facilitating the sharing of research findings, methodologies and data across borders. Establishing international networks and platforms for knowledge exchange to improve the quality of measurements and ensure consistency among different countries and industries.
- **Capacity Building.** Invest in capacity building programs to empower emerging economies with the knowledge and resources necessary for high-quality metrology. This includes providing training, education and support for the establishment of metrology infrastructure in developing regions.
- **Global Interoperability.** Promote global interoperability of measurement standards by harmonizing and aligning them across industries and regions. This includes an ongoing commitment to international standards such as ISO and IEC, which can serve as a foundation for consistent metrological practices.
- **Public-Private Partnerships.** Promote collaborations between public metrology organizations, private industry and research institutions. This can accelerate and harmonize the development and adoption of measurement standards that cater to the specific needs of various industries.
- **Data Sharing and Cybersecurity.** Establishing secure mechanisms for data sharing and developing cybersecurity standards are critical for protecting sensitive metrological information. There should be a global framework for data governance in metrology, with clear guidelines on data ownership, access rights and ethical considerations. Regular cybersecurity audits and updates can help maintain data integrity and trust.
- **Advocacy for Metrology.** Advocate the role of metrology in various international organizations, trade agreements and policy frameworks. Raise awareness of the importance of metrology in ensuring consistency and quality in global trade and innovation.
- **Alignment with Sustainable Development Goals (SDGs).** Consideration of the environmental impact of international collaboration efforts and adopt sustainable practices where possible. Contributions to Global Challenges by aligning collaborative projects with global challenges, such as climate change, healthcare, and resource sustainability, to showcase the societal impact of metrology.

**THEME II. Question 4:** How do you envisage the role of metrology evolving in various industries (for example healthcare, manufacturing, energy, IT, aviation etc.) by 2050+?

(Summary prepared by Alphonsus KIPKEMBOI/ Pritesh JIVAN, AFRIMETS)

In healthcare, metrology will play a vital role in ensuring the quality and safety of medical devices, diagnostics and treatments, as well as in advancing the fields of biotechnology, nanotechnology and personalized medicine. Metrology will enable the development and validation of new and improved medical devices, such as implants, prosthetics, sensors, etc., that can enhance the functionality and performance of the human body. Metrology will also support the innovation and regulation of new and emerging technologies, such as gene editing, stem cell therapy, nanomedicine, etc., that can offer new and novel solutions for healthcare challenges.

In manufacturing, metrology will play a crucial role in ensuring the quality and efficiency of production processes, products and services, as well as in facilitating the adoption and integration of new and emerging technologies, such as additive manufacturing, digital manufacturing, smart manufacturing, etc. Metrology will provide accurate and reliable measurements. Metrology will also enable the monitoring and control of various production processes.

In energy, metrology will play a key role in ensuring the security and sustainability of energy supply and demand, as well as in advancing the fields of renewable energy, energy efficiency and energy storage. Metrology will provide accurate and reliable measurements of various energy parameters, such as power, voltage, current, frequency, etc., as well as of various environmental parameters, such as temperature, humidity, pressure, wind, solar radiation, etc., that are essential for the generation, transmission, distribution and consumption of energy.

In IT, new and emerging information and communication solutions, such as big data, cloud computing, blockchain, etc, will support metrology as they can offer new and novel solutions for metrological challenges.

In aviation, metrology will play an important role in ensuring the safety and efficiency of aviation operations, products, and services, as well as in advancing the fields of aerospace engineering, air traffic management and space exploration. Metrology will also support the innovation and regulation of new and emerging aviation solutions, such as drones, supersonic jets, rockets, satellites, etc., that can offer new and novel opportunities for aviation and space exploration.

**THEME II. Question 5:** What factors have not been widely recognized that might impact the needs, methods of delivery, science and technology, and international collaborations and networks in metrology?

(Summary prepared by Gulaikhan SUYEUBAYEVA, COOMET)

Economic factors and lack of resources, including materials needed for measurement technologies, may affect priorities in the field of metrology. This may lead to increased attention on sustainable metrology, the reuse of instruments and the development of alternative materials and technologies.

Methods of data collection, exchange and analysis may affect metrological practices, as standards containing genetic information may need to be protected.

It would be useful to develop a standardized guideline on best practices in software development in the field of metrology, including the importance of software testing and validation. Software skills are becoming more common among employees starting a career, but not everyone understands how to evaluate code quality.

To develop recommendations on the use of artificial intelligence, since in the future it is likely to be more widely used in general and in metrology, in order to prevent misuse and over-reliance on this tool.

The growing demand for metrological solutions and services from various industries such as healthcare, manufacturing, energy, information technology, aviation, etc., which require more accurate, reliable and efficient measurements of various physical quantities and phenomena. This will require metrologists to innovate and improve new and existing methods and technologies, such as optical, digital, quantum and nanoscale methods, which can provide faster, more accurate and reliable measurements of various physical quantities and phenomena, as well as providing new and innovative applications and discoveries in the field of metrology.

The increasing complexity and diversity of metrological data and information such as data, signals, images, spectra, etc., which are generated, collected, stored, transmitted and analyzed using various metrological methods and technologies such as optical, digital, quantum and nanoscale methods.

The growing need for metrological education and training for both metrology professionals and users of metrology and stakeholders such as researchers, industry, regulators and the public.

The growing problem of the sustainability and resilience of metrology, both in terms of environmental and social aspects. This will require metrology to adopt and promote more sustainable and sustainably functioning methods and policies in the field of metrology, such as reducing the environmental impact and carbon footprint of metrological activities such as energy consumption, waste generation, etc., as well as increasing the social impact and value of metrology, such as improving the quality of life, health, safety and the well-being of people and society.