



# Digital transformation of metrology

## The Forum Digitalization and Metrology

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The National Metrology Institute of Germany

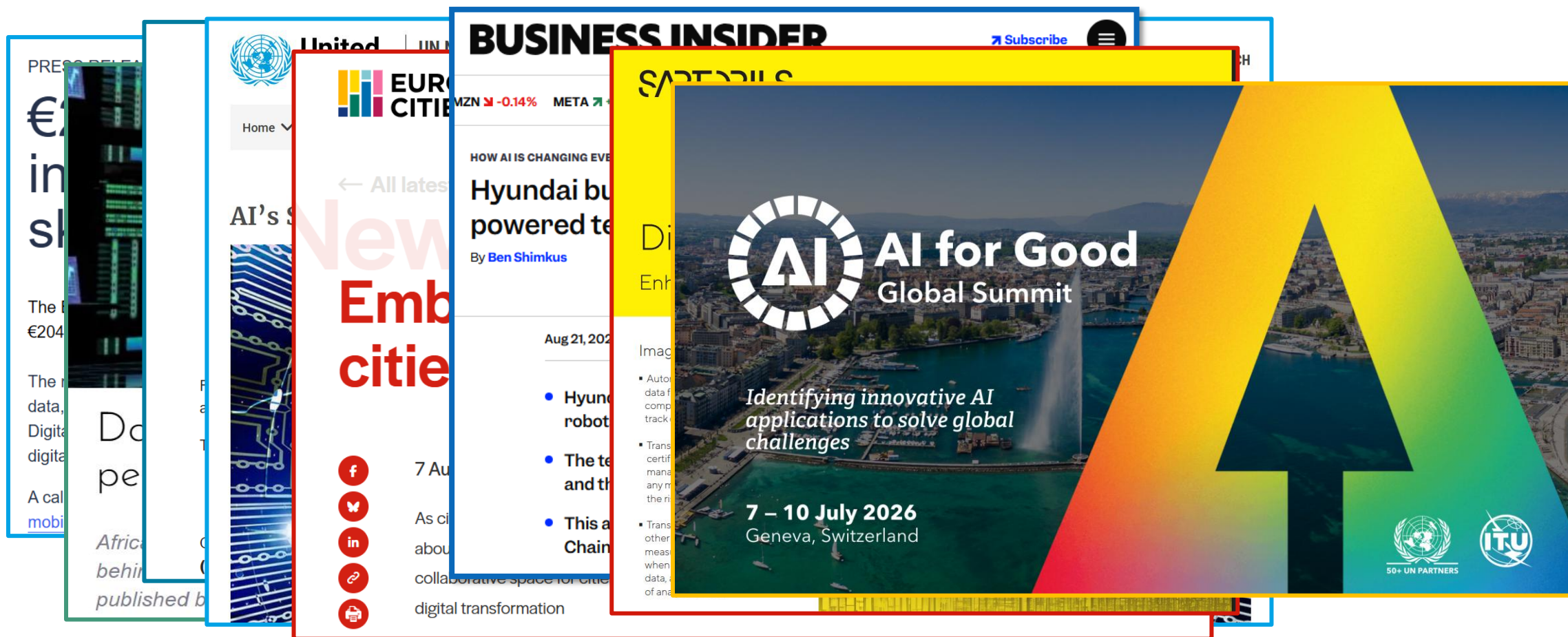
24<sup>th</sup> Meeting | Directors of NMIs and  
Member State Representatives  
October 16-17, 2025 | Day 2



# Digitalization in metrology | A hot and timely topic



Digitalization is important world-wide as a true cross-cutting theme



# Digitalization in metrology | A change in three acts



Digitize

The action to transform  
an image or a pdf

Digitization

Transformation of an analog process  
a new digital form

Digitalization

The formation of digital technologies with new  
ecosystems, business models, and markets



# Digitalization in metrology | A transformative change

Since 150 years, metrology has long-established principles

- World-leading science by defined units
- Realizations in practice with smallest uncertainties
- Traceability to reliable reference standards
  - ▶ **Trust for science, industry, society**

## The role of digitalization in metrology

- Need for precise, trustworthy measurements of SI
  - ▶ Transfer to the **digital representation of the SI**
- Services for industry in applied areas
  - ▶ **Digital quality certificates & digital twins**
- Timely research in emerging metrological fields
  - ▶ **Smart networks** connected to the **use of AI**



## Why is a digital metrological ecosystem including QI is needed?

- Starting point: transition to digital data formats ▶ Eliminating paper-based workflows
- Digital transformation also includes data ▶ Data quality metrics across systems
  - ▶ Must be **interpretable, exchangeable, and verifiable across systems**
  - ▶ **A digital ecosystem is an enabler ▶ Metrology needs cross-discipline structure**



Paper documents are easily verifiable, and



Exchanging data between systems FAIR data and quality metrics a



Interoperability is one of the challenges of machine-to-machine communication & automation © controlDesign.com

# Contents | Three episodes on a holistic, horizontal forum



## Forum MD's mission

- Motivation & purpose
- Terms of Reference
- Forum MD organs, structure & members

## Activities of Forum MD

- Forum MD workshops
- Forum MD Highlights

## Future visions

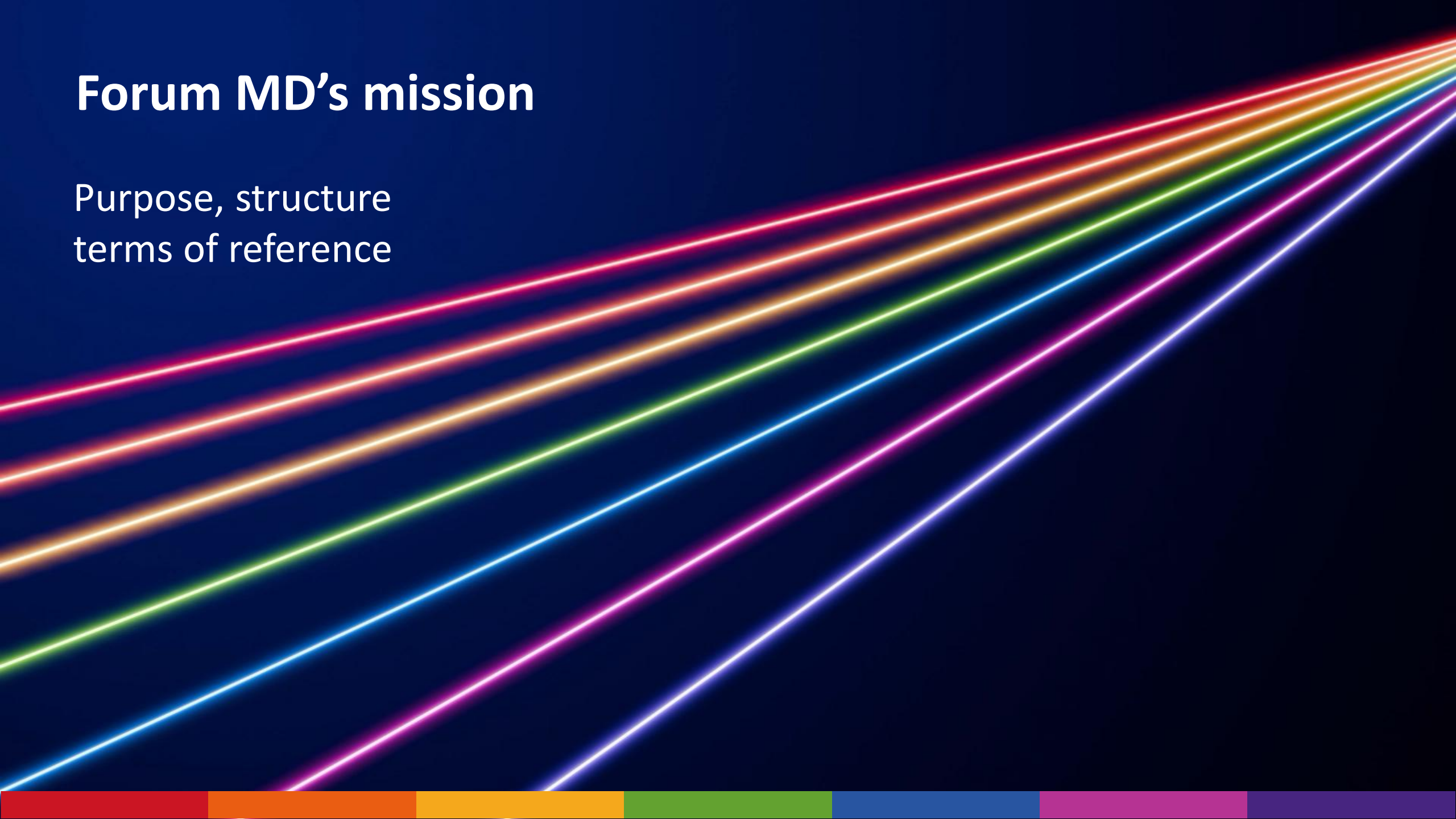
- Perspectives & strategic development
- Draft resolution for CGPM 2026





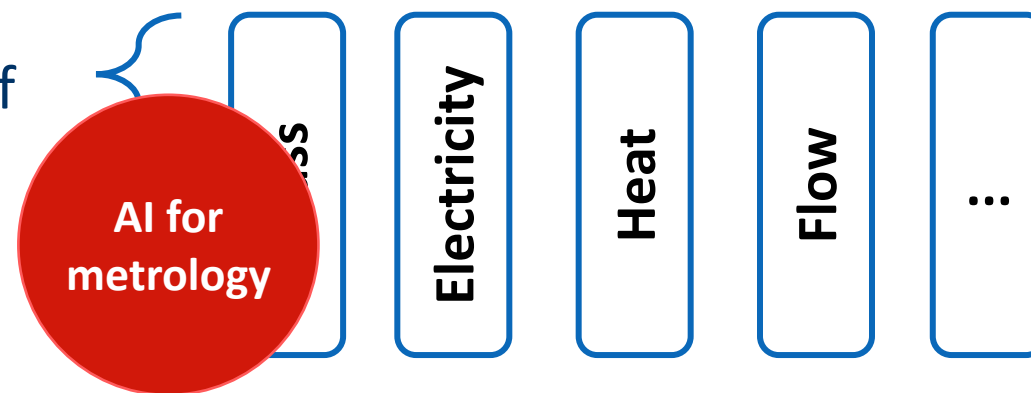
# Forum MD's mission

Purpose, structure  
terms of reference



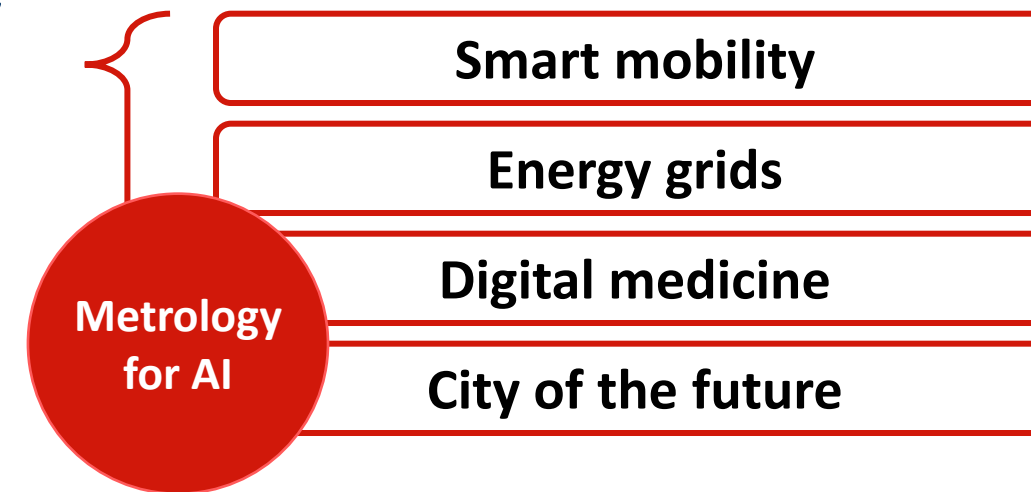
## Classical metrology fields: The need for clear regulations

- Digitalization of components and devices
- Conformity assessment in regulated areas of legal metrology and in services for industry
  - ▶ AI may become a tool for metrology



## Emerging fields: Assessment of quality

- Open questions on traceability, uncertainty, and on harmonization of digitized systems
- Combination of digitalization with AI
  - ▶ Metrology may develop metrics for AI





# Early CIPM Vision in digitalization

## Transforming the SI for a digital world

*... ensure that the Metre Convention naturally extends its role as the globally accepted anchor of trust for metrology into the digital era ...*

Resolution 2 of the 27th CGPM (2022)

- Adoption of FAIR principles in digital metrological data
- Creating a digital reference point of the SI
- Facilitating the use of digital certificates
  - ▶ Digital transformation of all important services of BIPM
  - ▶ Addressing emerging digital needs of CIPM member NMIs
  - ▶ Fostering a digital quality infrastructure
  - ▶ **1st „horizontal“, interdisciplinary and cross-disciplinary Forum**



# Mission of Forum MD



To advise CIPM on the **SI Digital Framework** and on the wider implications of the **global digital transformation** for metrology and for the **international digital Quality Infrastructure**

Adoption of **FAIR principles** for metrological data

Providing metrological input in **emerging areas**

Create **authoritative digital reference** for core SI

**Digitally transform services & products** of BIPM

Consider implications of digitalization on **CIPM-MRA**

**Objective 1:**  
**To harmonize internal processes** of digitalization of NMIs, CCs, RMOs, and services of BIPM

**Objective 2:**  
**To act as a forum** to exchange information and to **create synergies & opportunities for collaboration**

# Membership | Criteria and current members



## Criteria

- Member States
- Member of the General Conference
- Horizontal
- Inclusion

## Group

Member States  
(14)

Observers  
(14)

Liaison



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# CIPM Forum MD | Group structure



## TG AI

Build. Safe & Trustworthy AI  
*Louise Wright (NPL)*



## TG MS

Metrological Semantics  
*Ryan White (NRC)*



## WG CC

Coord. between CCs  
*Peter Blattner (METAS)*



## TG DQ & FPM

Data Quality & Fair Practices in Metrology  
*Daniel Hutzschenreuter (PTB) & Paul Duncan (NPL)*



## WG RMO

Coord. between RMOs  
*Nikita Zviagin (VNIIM, interim)*



## TG H-DCC DRMC

Harmonizing DCC & DRMC  
*Martin Koval (CMI)*

## TG SIDF

SI-digital Framework  
*Anna Cypionka (BIPM)*



## WG S

Strategy  
*Cornelia Denz (PTB)*



## DG SN

Sensor networks  
*Shan Cui (NMC, A\*STAR), Wan-Ho Cho (KRISS)*



# Strategy & tasks of Forum MD



Propose a **long-term vision** for Forum MD

**Monitor and react** to relevant developments in digitalization

Ensure an **effective linkage** between organizations in liaison

Advise the FORUM-MD on its **optimal operational structure**

**Prepare plenary meetings,** propose conferences & events

**Common goals** of task & working groups as **understanding, use cases, dissemination**

From a strong SI Digital Reference Point to a machine-actionable **SI Reference Frame**

**Leverage synergies:** within CIPM, CCs, RMOs, NMIs, include liaisons and stakeholders

Monitor development of FAIR **data quality, digital certificates, semantic approaches, AI assessment**

Workshops on emerging fields, General meetings, Discussion groups, potential **CGPM Resolution**

# Activities of Forum MD | Workshops



Workshop every year at General Meeting or for special topics stand-alone

## Metrological Traceability

*August 28, 2024,*  
Organizers: Blair Hall & Frank Härtig

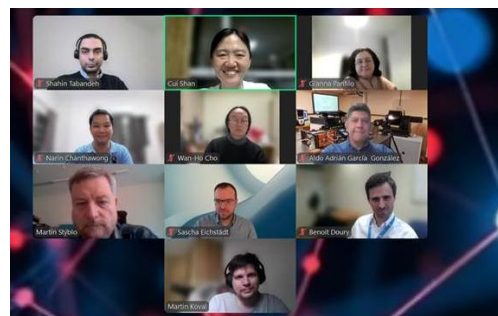
- Foundational principles
- New developments
- Examples of certificates



## Metrology for Complex Sensor Networks

*February 11-12, 2025,*  
Organizers: Shan Cui & C. Cho

- Defining sensor network
- Basic questions in SN
- Real-world examples



## Meeting of NMI Directors and State Representatives

*October 17-18, 2024*  
Organizers: BIPM & Chair Forum MD

- Digitalization – FAIR data
- Digitalization – AI
- Quantum Technologies



## Emerging Topics in Digitalization of Metrology

*February 19, 2025*  
Organizers: Chairs Forum MD

- Basic Themes of AI
- Digital data & tools
- Trustworthy AI





# Forum MD's highlights

A glimpse onto actual themes

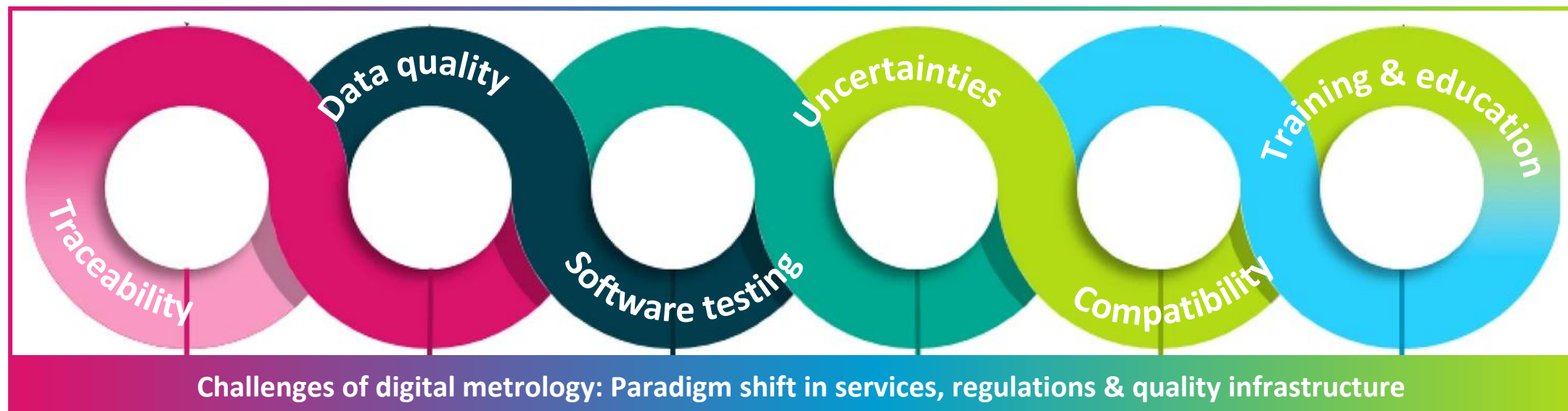


# Metrology for digitalization | A multi-faceted task



## Facets of quality in digitalization

- Fundamental key areas where digital metrology is necessary
  - ▶ Research for digital traceability ▶ **International digital SI unit system** & framework
  - ▶ Transformation of metrological services ▶ **Digital certificates** & product passports
  - ▶ Digital approaches to measurements ▶ Virtual metrology & **digital twins**
  - ▶ Establishment of metrological data analysis ▶ Large data bases & **„AI-ready data“**



# Task Group on SI-digital Framework



## TG dedicated to the SI digital framework

- Provide input to SIRF & advice on SIDF
- Collaborate with CCs and RMOs



### SI Reference Point

This service constitutes the authoritative digital reference for the International System of Units (SI), the named SI units, SI prefixes, and defining constants, and a parsing tool for SI expressions.

- [SI Reference Point](#)
- [Units](#) Lists the named SI units
- [Prefixes](#) Lists the SI prefixes
- [Defining Constants](#) Returns the defining constants of the SI
- [Decisions](#) Returns the decisions of the CGPM and the CIPM bearing on the SI, and conventions for the writing of unit symbols and names

### Quantities

This service provides PIDs for the kinds of quantity included in the SI Base Units, for compound quantities, and shows the related Service Categories in the SI Base Units.

- [Quantities](#) Lists the kinds of quantity included in the KCDB.
- [Quantity expressions](#) A parsing tool to provide the PID and semantic information for SI expressions
- [Service Categories](#) This service shows the related service categories for the SI

### SI Units

Lists the set of named SI units.

The knowledge base can be downloaded from this link: [UNITS.TTL](#)

CHECKSUM: SHA-256 - 90 ac 02 33 2a 65 08 fd 08 63 5f 6e ad 9f a1 09 62 19 33 b2 19 e3 77 97 5f d1 e9 5b 64 03 76 33

Enter a keyword and search

| Unit                           | Symbol |
|--------------------------------|--------|
| <a href="#">ampere</a>         | A      |
| <a href="#">becquerel</a>      | Bq     |
| <a href="#">candela</a>        | cd     |
| <a href="#">coulomb</a>        | C      |
| <a href="#">degree Celsius</a> | °C     |
| <a href="#">farad</a>          | F      |
| <a href="#">gray</a>           | Gy     |

### Quantities

Lists the kinds of quantity included in the KCDB.

The knowledge base can be downloaded from this link: [QUANTITIES.TTL](#)

CHECKSUM: SHA-256 - 4b 9d fe 73 fa ea 51 26 02 71 cc eb 1e 76 fe c8 c1 ca 98 ce bb 4b 54 39 8f 8d eb bf 06 e4 0a a0

Enter a keyword and search

| Quantity                           | PID (Quantity)                                                                        | SI unit              |
|------------------------------------|---------------------------------------------------------------------------------------|----------------------|
| <a href="#">absorbance</a>         |    |                      |
| <a href="#">absorbed dose</a>      |    | Gy                   |
| <a href="#">absorbed dose rate</a> |  | Gy s <sup>-1</sup>   |
| <a href="#">acceleration</a>       |  | m s <sup>-2</sup>    |
| <a href="#">acoustic impedance</a> |  | Pa s m <sup>-3</sup> |
| <a href="#">action</a>             |  | J s                  |



# Task group on data quality & FAIRness



## TG dedicated to all aspects of data and its metrological standards

- Disseminating FAIR data use in research and industry-related data infrastructures
- Develop data quality metrics - „fitness for purpose“ assessment of data
- Harmonizing existing standards – full advantage of quality, traceability, uncertainty
  - ▶ **Agreed framework for data quality from the viewpoint of metrology**

The International  
System of Units (SI)  
**in FAIR digital data.**



FINDABLE



ACCESSIBLE



INTEROPERABLE



REUSABLE

FAIR data is an important topic of the Forum MD: Harmonizing data & metadata formats,  
ensuring accessible, interoperable, and reusable data for all members © BIPM



# Task group on DCC and DRMC



## Flagship DCC | Transfer to DX-Family | High acceptance in industry

- Machine-usable modular format ► Inspection by human or “digital metrologic experts”
- Machine-interpretable use for data analysis, digital twins, AI ► **Machine communication**

```
</> dcc_structure.xml
1 <?xml version="1.0" encoding="utf-8"?>
2 <dcc:digitalCalibrationCertificate
3   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
4   xmlns:dcc="https://ptb.de/dcc"
5   xmlns:si="https://ptb.de/si"
6   xsi:schemaLocation="https://ptb.de/dcc
   → https://ptb.de/dcc/v3.3.0/dcc.xsd"
7   schemaVersion="3.3.0">
8   <!-- [...] -->
9   <dcc:administrativeData> <!-- [...] --> </dcc:administrativeData>
10  <dcc:measurementResults> <!-- [...] --> </dcc:measurementResults>
11  <!-- [...] -->
12  <!-- [...] -->
13  <!-- [...] -->
14  <!-- [...] -->
15  <!-- [...] -->
16 </dcc:digitalCalibrationCertificate>
```

Digital QI is extremely important for Germany as a business location. We live from the fact that our products are of the highest quality. What the global market for digital products expects.

Antonio Matamala, Beamex GmbH

If you thought that a PDF is a digital calibration certificate, think again!

<https://blog.beamex.com/>

The decisive advantage of digital QI: electronic data can be used directly! This relieves employees and creates

space for productive work - a benefit for efficiency, innovation and motivation.

Klaus Fickinger, Boehringer Ingelheim



DCC is the “MP3 of metrology”

► Revolutionizing processing industry as a flexible, secure game changer



# Task group on metrological semantics



## Digitalization requires new analytical and computational

- Conceptual & provenance models, semantic architectures
- Inverse problems for modeling indirect measurements
  - ▶ **Digital twins** of for predictive maintenance
  - ▶ Data analysis & **uncertainties of complex systems**
  - ▶ **Explainability & robustness** of artificial Intelligence



New methods in mathematics promote the digitization of metrology:  
Semantics, uncertainties, traceability, explainability, robustness © umsl.edu



# Task group data quality & FAIR data aspects



## Quality assurance of data | The usability of data for data-based metrology

- **Quality dimensions** ▶ Accurate, complete, compliant, consistent, credible, relevant, timely
- The quality of AI strongly depends on data
  - ▶ **Data uncertainty** (“noise”, “bias”)
  - ▶ **Annotation inconsistencies** (“label noise”)
- **Knowledge** about composition of data , increases **robustness**, facilitates interpretation
  - ▶ **Define metrics to assess data quality**
- Constructing **reference training datasets**
  - ▶ **Validating training data** („audit“)
  - ▶ **Designing test data**





# Discussion group on sensor networks

## Emerging metrology needs in complex systems

- **Large heterogenous networks**
  - ▶ Responsive, adaptive, self-organized
  - ▶ Uncertainties needs to be defined
  - ▶ Quality of data needs to be assessed
  - ▶ Self- and co-calibration approaches
  - ▶ Self-traceability by use of massive AI
- **Examples of sensor swarm applications**
  - ▶ Gas detection wearables for safety
  - ▶ Spatio-temporal climate monitoring
  - ▶ Sensitive electric / magnetic field detection





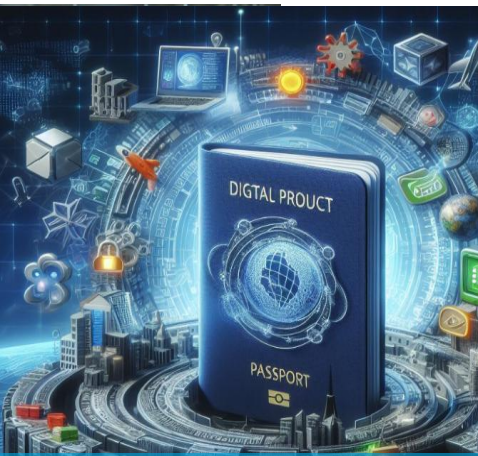
# Task Group on Building Safe and Trustworthy AI

## AI for Metrology – Metrology for AI

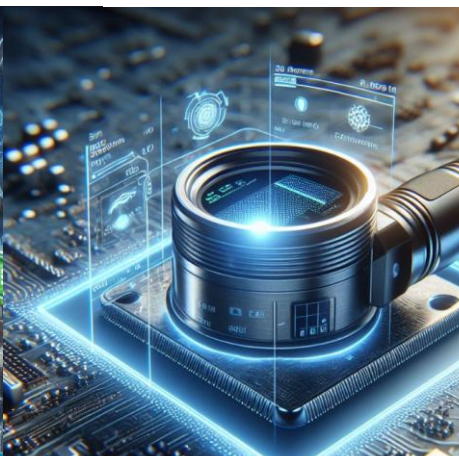
- Use of AI for metrology ► Automation in services as e.g. DCC or comparisons
- Trust in AI through metrology ► Define traceability, uncertainties, data quality
- Evaluation of existing legislation ► Standardisation and test procedures for EU AI Act
- Precondition for all AI applications and tests is digitalization & quality of data



Automatization  
Quality management



Digital Calibration Certificate  
Digital Product Passport



Computer-based metrology  
& digital twins



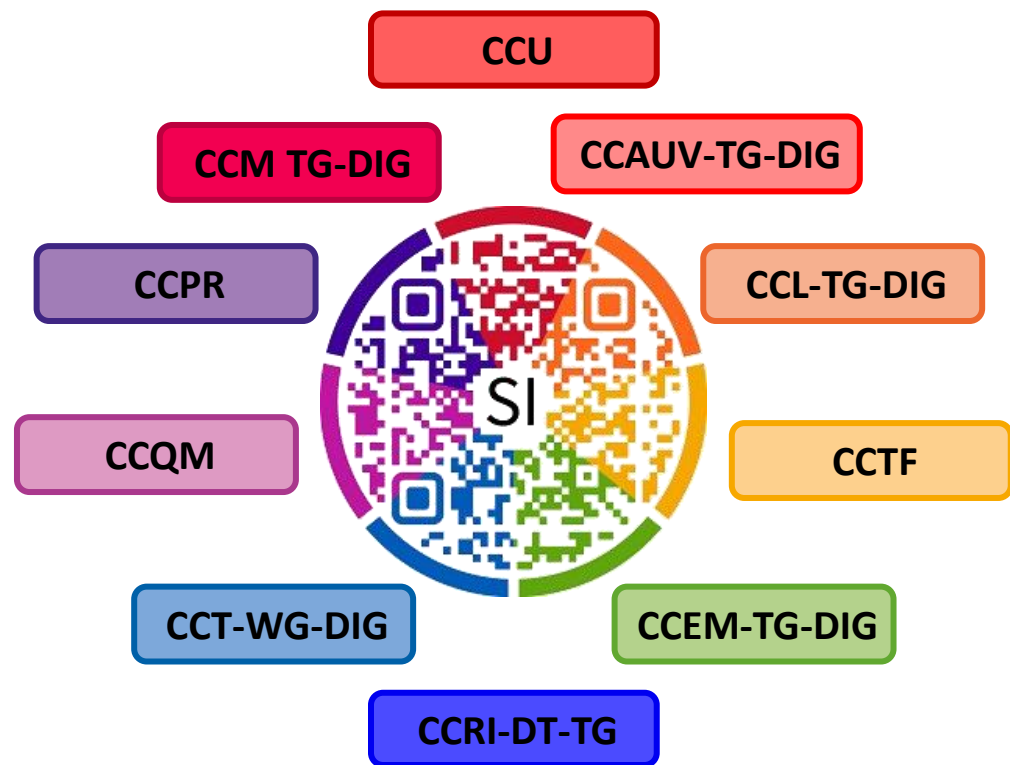
Intelligent sensor network  
and networked systems



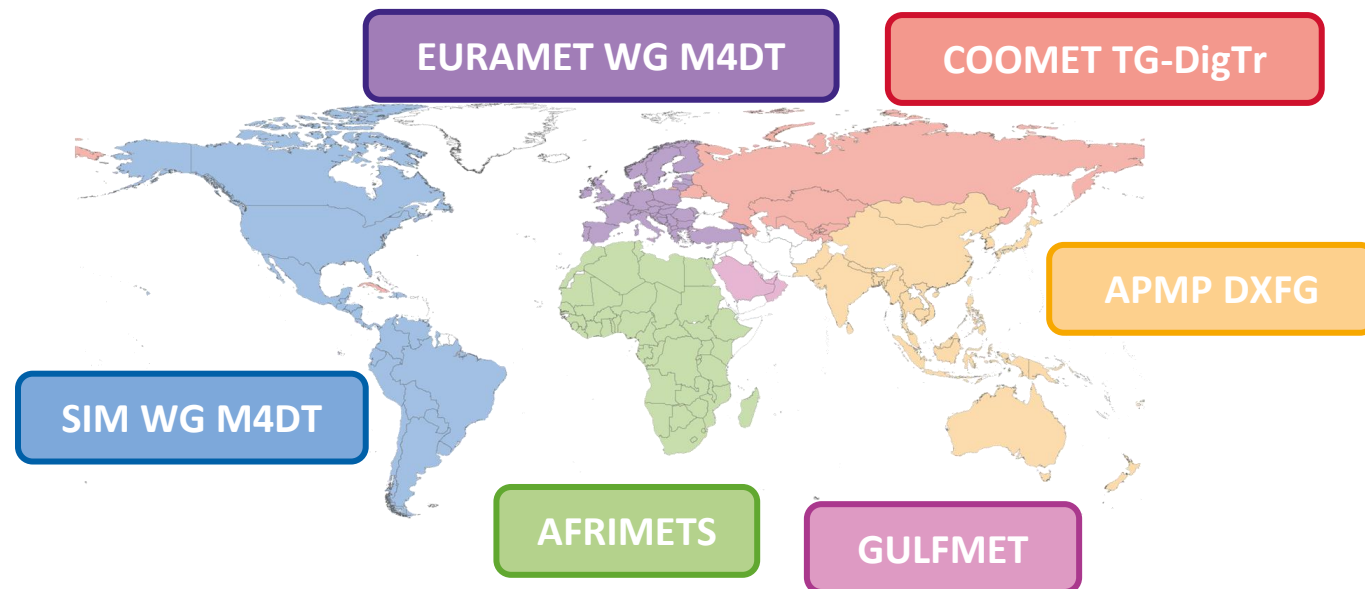
Quality for AI-based products and  
services in sandbox labs

These images  
were  
generated  
with AI

# Highlights of Working Groups



- Digitalization TG in almost all CCs
- Strong interaction with TG-SIDF



- Analysis of status & needs in aspects of digitalization
- High interest in FAIR data & tools as DCC



# Future visions

Perspectives, strategies &  
Draft Resolution CGPM





## Digital metrological experts concept

- Taking over tedious human work in
  - ▶ **Calculation of measurands**
  - ▶ **Evaluation of comparisons**
- Exchange of information related to QI
  - ▶ **SI-based data and FAIR services**
- Assess data and propose ways of processing
  - ▶ **Verification, filter, uncertainty propagation**
- Creates machine-actionable reports
  - ▶ **Disclosing traceability of outputs to inputs**
- Is itself a digital stakeholder in QI
  - ▶ **When operated and maintained by an authoritative organization**



## Assesment of algorithms of AI

- Investigation of bias and stereotypes
  - ▶ Definition of **clear metrics for evaluating AI**: Robustness, explainability, transparency, controllability, customisability, confidentiality, ...
  - ▶ **Data as 'black box' test instruments**
- Creation of reference data sets for quality standards of learning in complex scenarios
  - ▶ Development of accurate, **verified "ground truth" data** ▶ **Trustworthy "golden" data** e.g. by **physics-informed learning**



Uncertainty



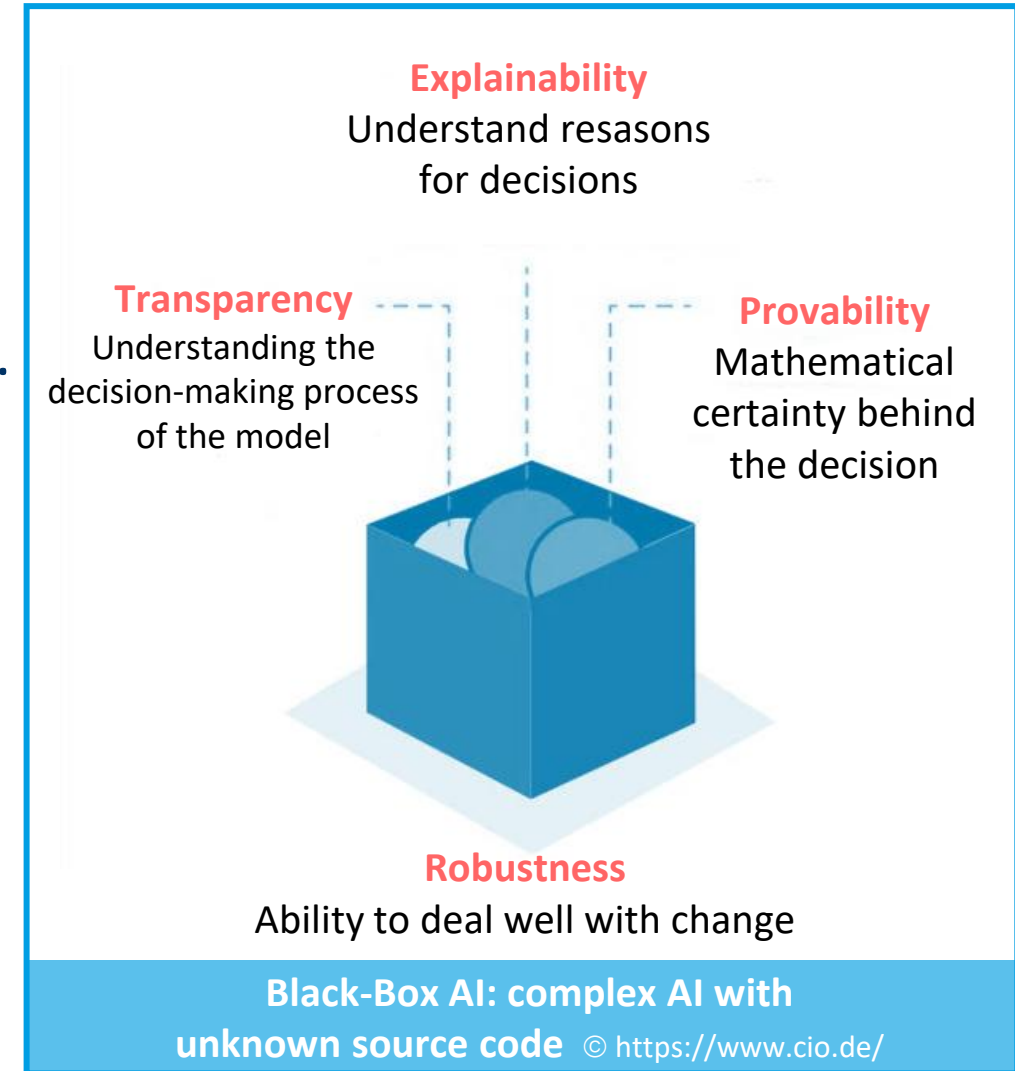
Robustness



Explainability



Data quality



# Frontiers for AI | Creating a quality infrastructure for AI



## Digital QI 2.0 | Quality infrastructure including AI: AI QI

- Development of an efficient **AI-supported digital QI**
  - ▶ **Quality metrics** for digital measurement data
  - ▶ Assessment of AI by **making “black box” transparent**

## Establishing a machine-interpretable QI

- **Digital metrological experts / avatars**
  - ▶ Reduction of market barriers
  - ▶ Process acceleration

## Establishing a QI for machine learning

- Conformity assessment of robotics application
  - ▶ **Efficiency and quality gains in industry**





# Draft Resolution | On the further digital transformation



## Recalling that

- **resolution 2 adopted by the CGPM at its 27th meeting** "On the global digital transformation and the International System of Units" encouraged the CIPM to **extend the Metre Convention to an anchor of trust for metrology into the digital era**,
- the **accelerating pace of digital transformation** is intrinsically linked to **data as a key asset for the future**, to the widespread **deployment of sensor networks** enabling sophisticated digital ecosystems, and to the **integration of artificial intelligence across all areas of metrology**
  - ▶ Further digital transformation needs to be **global, inclusive, participative**
  - ▶ Ensures **role of metrology in accelerated pace of digital transformation**, being a **cornerstone of industrial development and continuous prosperity world-wide**
  - ▶ **Resolution “On the further digital transformation of global metrology”**

## Recognizing strong achievements in digital transformation

- Significant progress in the development of **comprehensive digital metrological concepts and tools** including the **implementation of the SI reference point**, the **promotion of FAIR data**, as well as the **introduction and dissemination of digital certificates**,
- Establishment of a **global network of collaboration** has been established, engaging a **broad spectrum of stakeholders**, aimed at **harmonization all dimensions of digitalization**,
- FORUM MD has **successfully brought together the international metrology community** to discuss topics of future relevance, **demonstrating its power of strategic foresight** and its **capability to respond to emerging digital challenges and opportunities**,

## Further coordinated efforts are necessary

- United efforts of CIPM, BIPM and its structures, RMOs, NMIs to address long-term challenges associated with strong pace of digitalization
  - ▶ **Machine-actionable** access to all **services of CIPM MRA**
  - ▶ Dissemination of digitalization practices to **empower all countries** to enter into own digital transformation
  - ▶ Addressing global **challenges associated with digitalization of societies needs coordinated approach** in the measurement community and quality infrastructure

## Benefit of coordinated, responsible standardization and harmonization

- **Economic growth** and industry reach next level of automation
- Use potential of artificial intelligence to **transform society for the better**
  - ▶ Inclusive healthcare, reshaping work, improving complex decision-making
  - ▶ Greater accessibility and participation for education and lifelong learning



## Further digital transformation focuses on emerging topics

- **Strengthen impact of metrology in next, most transformative phase of digitalization**
  - ▶ Conceptual consistency and interoperability in digital metrological framework, including **standardized data exchange formats** and **full automation of services**,
  - ▶ Develop metrology for **quality and safety of artificial intelligence** in a metrological context, fostering the role of metrology in the next generation of digitalization,
  - ▶ Facilitate the advancement of **digital metrology for complex systems**, including the reliable integration and quality assurance of **large-scale sensor networks**

## Commitment of community: an invitation to participate

- NMIs and RMOs and other stakeholders may join forces to enter novel digital assets
- Organizations of digital quality infrastructure join collaborative venture
  - ▶ **Digitalization of future transforms metrology, industry, and societies for better**

Thank you

↑||↓ **FORUM-MD**

