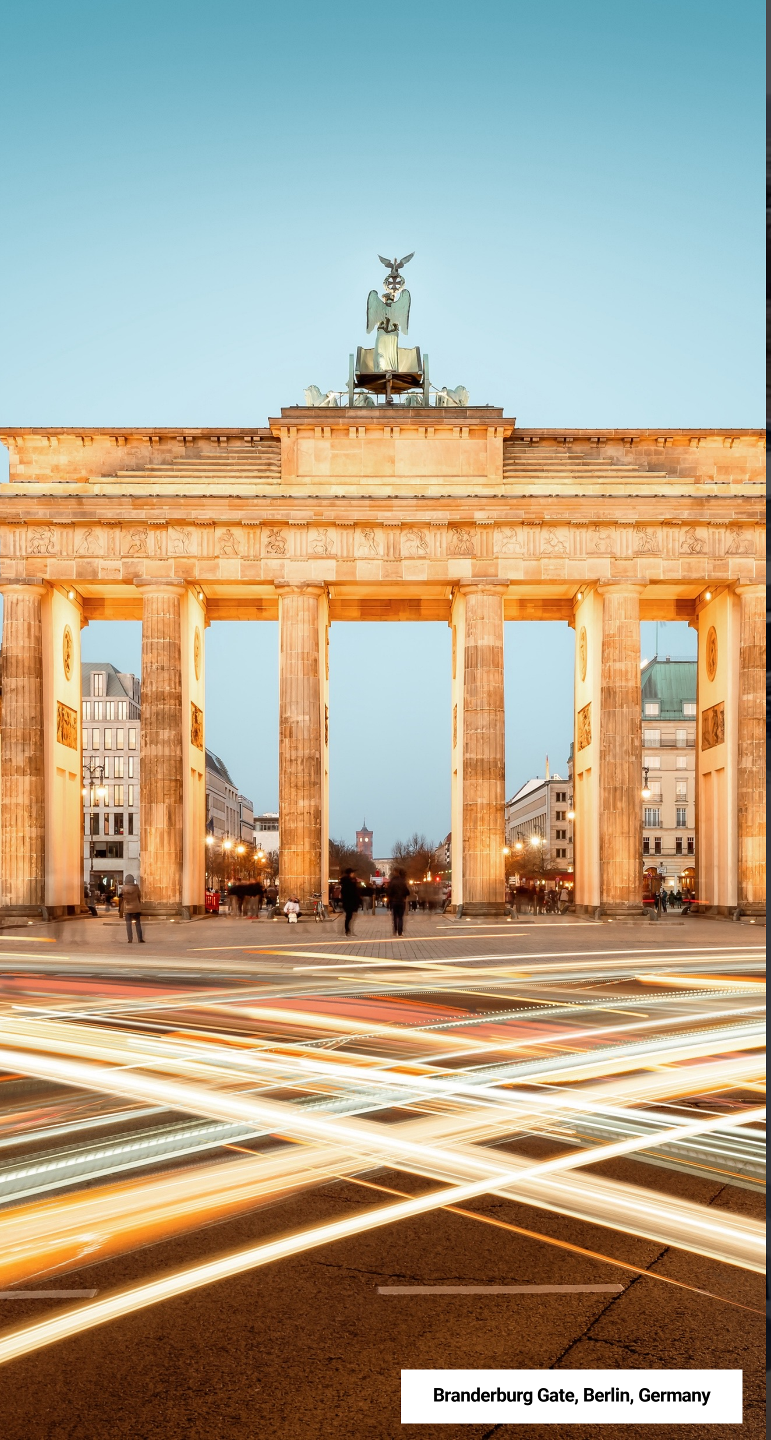


Branderburg Gate, Berlin, Germany

Dorothea Knopf, PhD. Eng.

Head of “Mass – Dissemination of the Unit” Department
Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig

In 1993, she completed her studies in electrical engineering at the Technical University of Ilmenau in Germany. She started her metrologists career as a PhD student in the department "Metrology in Chemistry" at PTB in Germany from 1993 to 1997. In 1997, she completed her PhD studies in engineering at the Technical University of Ilmenau. From 1998 to 2011, she continued her work in the field of "Gas Analysis" at PTB, came in contact with "Legal Metrology" and was a one-year trainee in the Presidential Staff. Since 2012, she is head of the "Mass" department of PTB. In addition to metrology and legal metrology, her experience also includes conformity assessment, work in standardization and other bodies, quality infrastructure and digital transformation.

METROLOGY SYMPOSIUM
DIGITALIZATION AND AUTOMATION IN MASS METROLOGY

Third Edition: Future and New Solutions

RADWAG

ČESKÝ METROLOGICKÝ INSTITUT

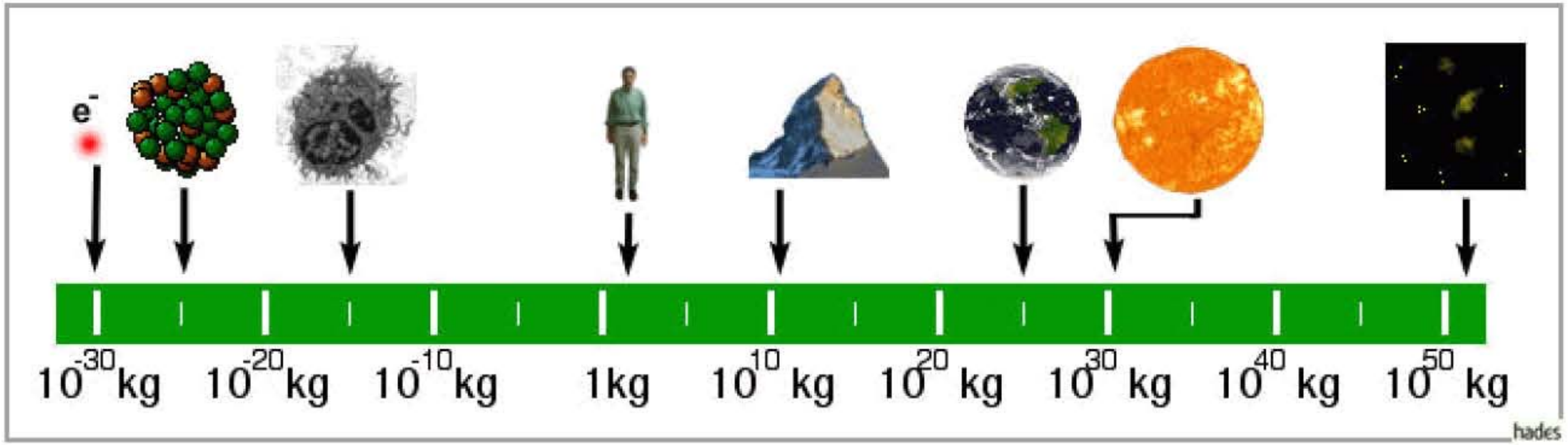
Mass Metrology at PTB

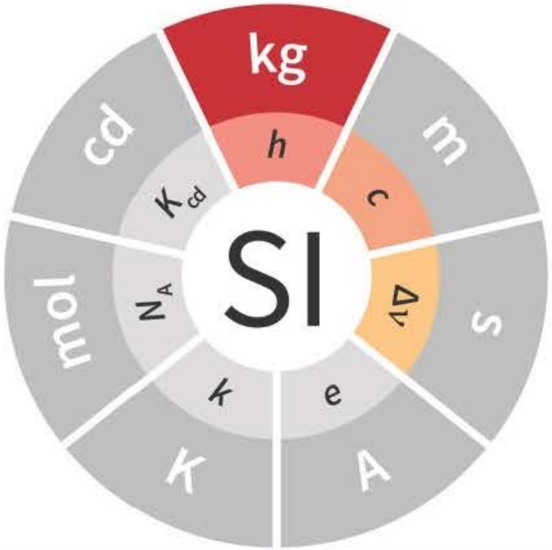
Dorothea Knopf, Physikalisch-Technische Bundesanstalt

PTB
Physikalisch-Technische Bundesanstalt
National Metrology Institute

What is Mass Metrology?

www.elearning.physik.uni-frankfurt.de





- Defining constants allows realisation everywhere
- 'mise en pratique' allows two realisation methods
- No need to stick to nominal value of "1 kg" as starting point
- Direct dissemination possible – at the moment 'consensus value'

...kg realisation using XRCD

V:	volume of a physical object
a_0^3:	lattice parameter of ^{28}Si
h:	Planck constant
R_∞:	Rydberg constant
c:	speed of light in vacuum
α^2:	fine structure constant
m:	**mass** in kg
f:	ratio of the Si isotopes (weight factor)
A_r^i:	relative mass of ^iSi isotopes (i=28, 29, 30)
A_r^e:	relative atomic mass of an electron
$m_{deficit}$:	mass of lattice vacancies and impurities in the sphere
m_{SL}:	mass of surface layers

$$m = \frac{8V}{a_0^3} \cdot \frac{2hR_\infty}{c\alpha^2} \cdot \sum_i f_i \frac{A_r^i}{A_r^e} - m_{deficit} + m_{SL}$$

"Re-activation" of the realisation – measure the quantities that may tend to change

- Determination of the spheres volume
- Determination of the surface layer

...comparison of realisations

- CCM.M-K8 – comparison of the kg realisations
- 'consensus value' basis for current kg dissemination
- CCM recommendation 2023 – resolve discrepancies!
- Resulting PTB activities
  - cooperation between BIPM and PTB mass experts
  - bilateral comparison with NMIJ (XRCD)
  - bilateral cooperation with NIST
  - Exchange between "Kibble" and "XRCD" communities

…dissemination of mass unit

(OIML) weights, methods and tools are established, robust and cost effective

Classical dissemination

mass standards of stainless steel or PtIr

Silicon dissemination

Spheres made of natural silicon (density comparison)

…dissemination via natural silicon

- ^{nat}Si spheres are available – commercial partner delivers high quality spheres
- Tools and equipment are available – commercial partner delivers materials
- Mass comparators ready for use of spheres available
- Cleaning method is well described and allows "reset" of the spheres – mass data with a good stability determined so far
- Improvements possible/desired – "Round & Established" WS 2022 (Si-Trust)
- Use of the spheres in a first step as a stable calibrated mass standard; additional characterisations possible

…mass determination via density comparison

$$\rho_{nat_{Si}} = k \cdot \rho_{28_{Si}}$$

- Well characterised ^{28}Si sphere is used as density standard
- Highly accurate density comparison system – “Pressure of Flotation” does not fit
  - first alternative concept failed, but implementation of a new concept is currently running

$$m_{nat_{Si}} = \rho_{nat_{Si}} \cdot V_{nat_{Si}} = k \cdot \rho_{28_{Si}} \cdot V_{nat_{Si}}$$

- Determine geometry of the ^{nat}Si sphere as accurate as possible
  - Determination of core volume with sphere interferometer
  - Determination of surface layer thickness with XPS/XRF

...dissemination of mass unit

(OIML) weights, methods and tools are established, robust and cost effective

Classical dissemination

mass standards of stainless steel or PtIr

Offers advantages especially in the range of small and individual mass values

Surface of silicon spheres is rather stable → spheres could be „reset“ by cleaning

Electrical dissemination

Use of Kibble principle (e.g.Planck balance)

Silicon dissemination

Spheres made of natural silicon (density comparison)

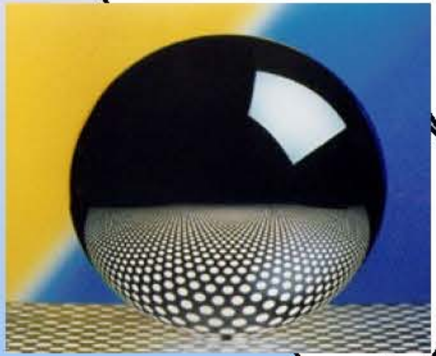
Resulting kg dissemination chain

Definition of the kilogram by fixing the value of the Planck constant

$$1\ \text{kg} = \left(\frac{h}{6{,}626\,070\,15 \times 10^{-34}}\right)\text{m}^{-2}\text{s}$$

‘Consensus value‘ determined of the primary **realisations** of the kilogram with the smallest reachable uncertainties, currently, ^{28}Si spheres and Kibble balances

…



“Secondary” standards

…

“Market“

huge number, different qualities and values

…

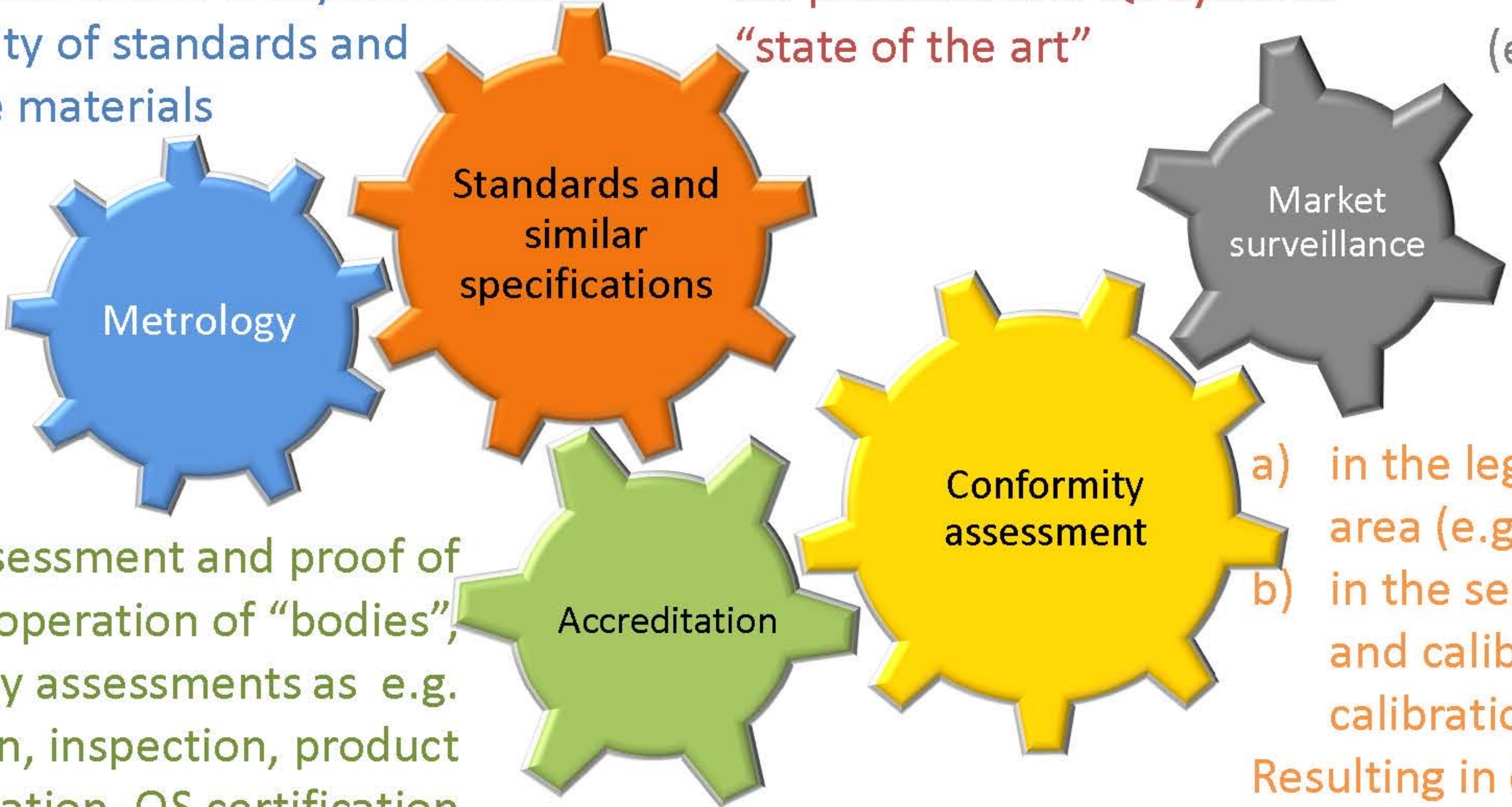
…metrology as part of quality infrastructure

Physikalisch-Technische Bundesanstalt
National Metrology Institute

International consistency of measurements and analytical results
Traceability of standards and reference materials

Standards and specifications for products and QS systems
“state of the art”

“Referee”
(e.g. verification)



Assessment and proof of operation of “bodies”, conformity assessments as e.g. calibration, inspection, product certification, QS certification

a) in the legally controlled area (e.g. type approval)
b) in the sense of testing and calibration (e.g. calibration certificate)

Resulting in certificates with conformity statement

…Quality infrastructure?

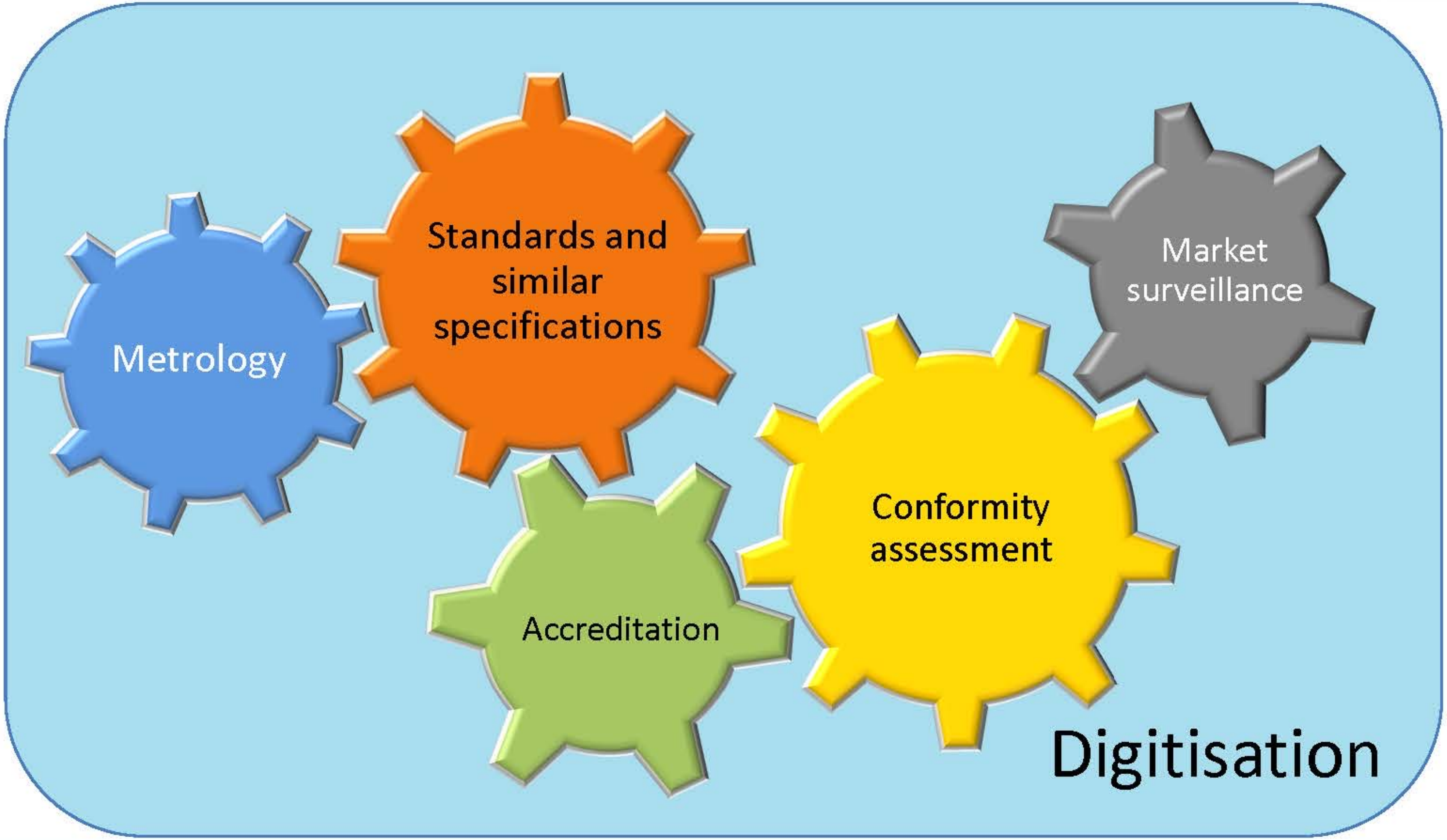
The system comprising the organizations (public and private) together with the policies, relevant legal and regulatory framework, and practices needed to support and enhance the quality, safety and environmental soundness of goods, services and processes.

"It relies on **metrology**, **standardisation**, **accreditation**, **conformity assessment**, and **market surveillance.**"

INet QI
International Network on Quality Infrastructure

https://www.inetqi.net/documentation/quality-infrastructure-definition/

Quality infrastructure in the 21st century

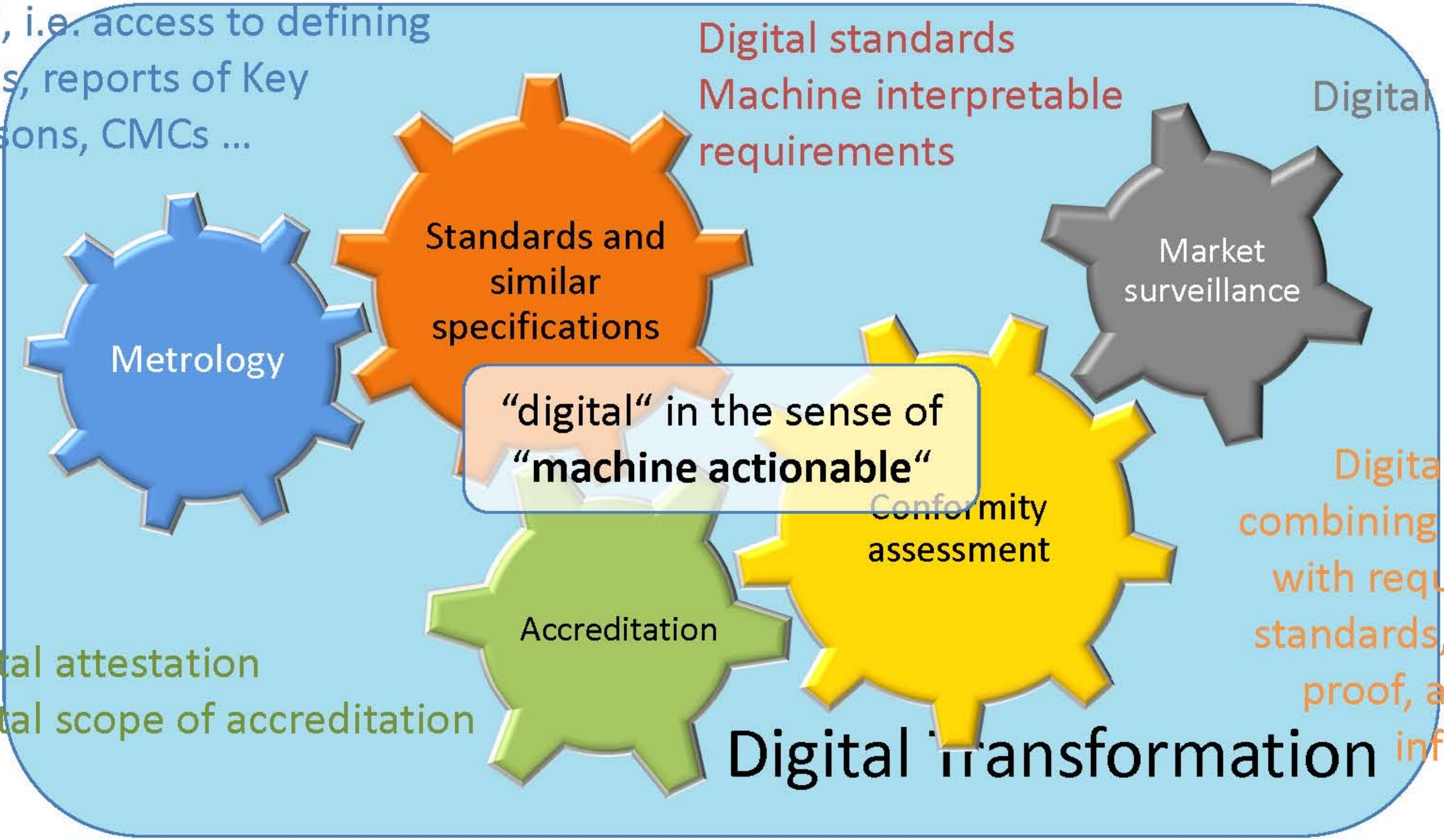


Quality infrastructure in the 21st century

Digital SI, i.e. access to defining constants, reports of Key comparisons, CMCs …

Digital standards
Machine interpretable requirements

Digital access to all necessary information



Digital certificates combining information with requirements of standards, traceability proof, accreditation information, …

Digital attestation
Digital scope of accreditation

Digitisation activities in all areas…

- Joint Statement of Intent on digital transformation in the international scientific and quality infrastructure (https://www.bipm.org/en/liaison/digital-transformation)
  - BIPM, OIML, ISO, IEC, ILAC, IMEKO, ISC, CIE, CODATA, NCSLI
- BIPM (https://www.bipm.org/en/digital-transformation)
  - Forum on Metrology and Digitalisation
  - SI Reference Point, KCDB CMCs, KCDB Service Categories (https://si-digital-framework.org/)
  - FAIR Data (https://www.go-fair.org/fair-principles/)
- OIML – Legal Metrology
  - Digitisation Task Group (DTG) 2022 (https://www.oiml.org/en/structure/digitalisation-task-group/digitalisation-task-group)
  - Exchange within OIML and cooperation with others

Digitisation activities in all areas…

- Standardisation Bodies (national, European, international)
    - SMART standards that allow "machine actionable" access
- Accreditation bodies - different solutions
    - e-certificate, digital symbol/attestation, …
- Market Surveillance (verification authorities)
    - digitised tools for information transfer
- Conformity Assessment
    - Digitised Certificates →
      Machine-actionable certificates
    - Important element of the product documentation

Digitisation activities at PTB…

- Digital Calibration Certificate (DCC)
  - Development of a data structure (https://www.ptb.de/dcc/) to transfer the needs of ISO/IEC 17025
  - Schema based on XML – only partly human readable but good adaptable
  - Annual DCC-Conference allows discussion and exchange
- Gemimeg – a tool for the transfer between the human-readable and the machine-readable presentation of the information

https://www.gemimeg.ptb.de/gemimeg-tool/#/

Digitisation activities at PTB…

- Digital Calibration Certificate (DCC) for weights
  - Discussion with German accredited labs for weights (DKD)
  - Experience of the practitioners – intensive discussions
  - Expert report DKD-E 7-2 "Instructions on how to use the DCC schema to create a digital calibration certificate for weights"
  - First edition 2022, second edition 01/2024
  - https://oar.ptb.de/files/download/550.20240119B.pdf

Digitisation activities at PTB…

- Digital Certificate of Conformity (legal metrology, based on ISO/IEC 17065)
  - Prepare structures for the certificates for "type evaluation", "assessment of quality assurance systems" and "verification" – corresponding to the modules B, D and F of the European NLF
  - Based on our experience with MID, NAWID and ATEX, but vision that it can also be used for other NLF products
  - Schema based as well on XML - first proposals are under discussion in a NoBoMet project group
  - Aims – machine-actionable certificate information for the use in data bases and/or product data folders, support of manufacturers etc.
  - Continuous interchange with NoBoMet and OIML DTG is established

...activities of PTB mass metrologists

Organisation of kg realisation (PTB)
Maintaining mass, density standards
Participation in comparisons
Development of "Planck balance", density comparison system
Gravimetry as potential new service
Active in EURAMET and CCM

Active in DIN and CEN/CLC JTC 18
REA project groups regarding WIM, grain bulk density, ...
OIML (9 recommendations +)
WELMEC and EURAMET guides
ISO regarding terminology

Authorities only, but intensive exchange and support
Interchange with respective ministry

Peer-assessed - metrological activities (EURAMET), CAB (DACH) and OIML CS issuing authority
Strong cooperation with DAkkS accredited labs in the field of mass and weighing instruments
DAkkS auditors

Calibrations and tests in the field of mass – weights, solid density, hydrometers, weighing instruments and modules (also OIML CS), ...
CAB (and NoBo) for NAWIs (NAWID) and AWIs (MID) (+ nationally regulated)
Issuing Authority OIML CS (5 OIML R+)

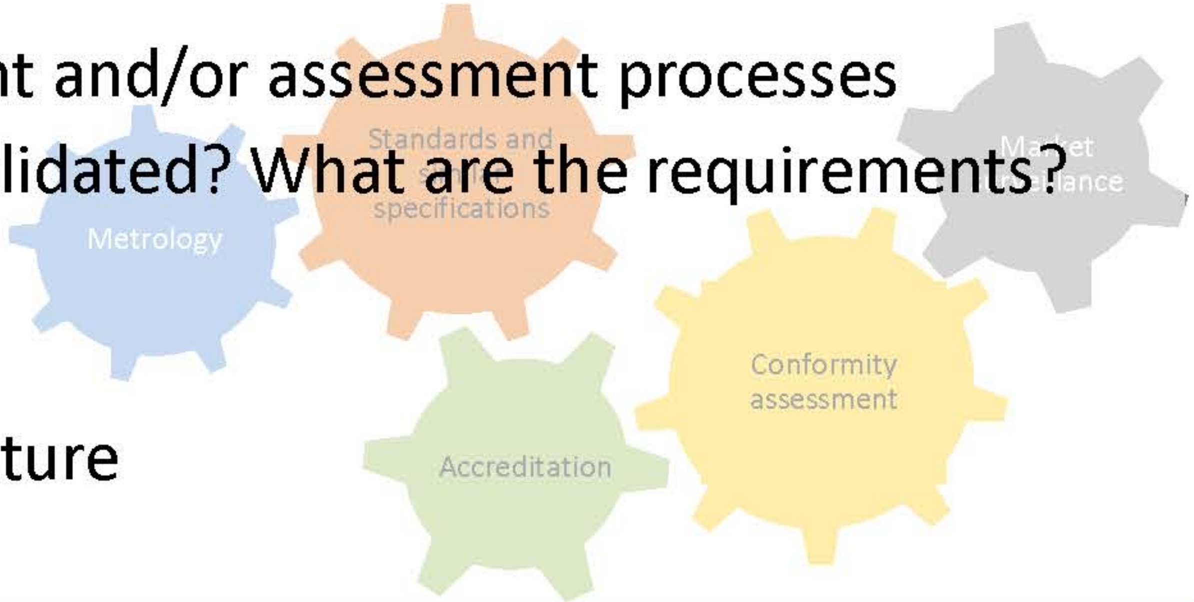
Experiences...Challenges?

- Mass metrology has a long history – Pro and Con at the same time
  - A lot of experience, high quality standards and machines all over the world
  - One and the same international standard for 130 years…
  - Established processes and terminology
- Changes (including digital transformation) need clarity in the analogue world
  → strong exchange with all stakeholders necessary

- One of the basic identified aspects – Terminology!
  - "Context" – we all have one, but a machine cannot understand
  - Used terms and definitions have to be "unambiguous"
  - Also confusions from other areas – e.g. what is a "certificate"?
- Here, too, an intensive exchange between the parties involved is necessary

...future challenges? ...a lot!

- Resolve discrepancies of kg realisations – enable individual dissemination
- Digital Twins
  - a first demonstrator of a digital twin of a weight at PTB in 2017
  - Expected - digital twins of more complex systems to possibly extend re-calibration/re-verification cycles
- Artificial Intelligence (AI)
  - Being part of or support measurement and/or assessment processes
  - How can such systems be checked/validated? What are the requirements?
- ...
- Let's care for TRUST even in future!
  - Think the complete Quality Infrastructure




METROLOGY SYMPOSIUM
DIGITALIZATION AND AUTOMATION IN MASS METROLOGY
Third Edition: Future and New Solutions
PTB
Physikalisch-Technische Bundesanstalt
National Metrology Institute
Thank you for your attention
Moin Hamburg
IMEKO 2024
Think Metrology
https://www.imeko2024.org
www.radwag.com