Combining measurement science and quality to achieve global success in industry

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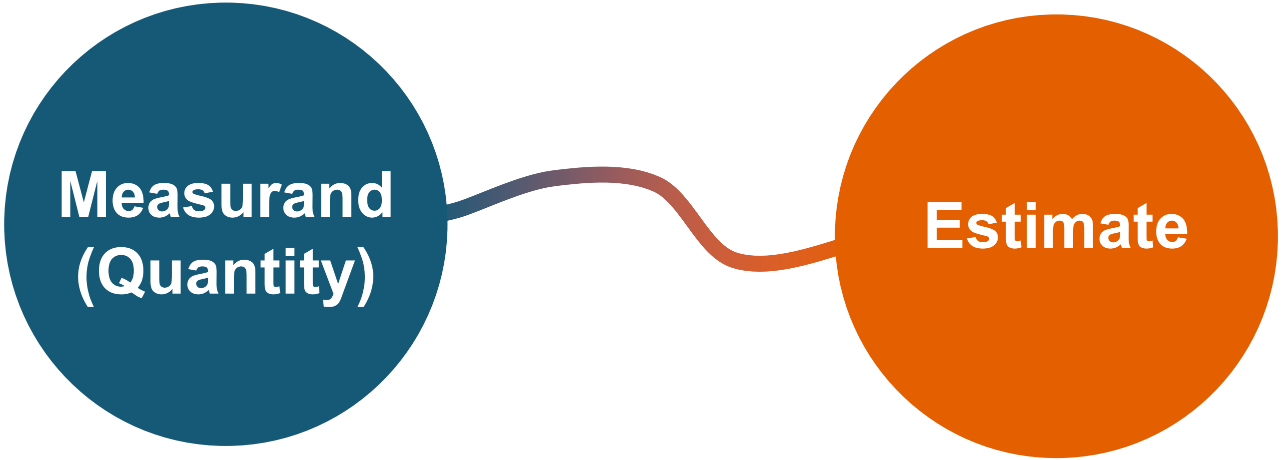
Content

- Metrology infrastructure: key enabler for success, safety and welfare
- Evolving SI unit system as the corner stone of quality
- Global cooperation and recognition is must but a result of hard work
- Research and quality as vital building blocks in metrology
- Summary

Metrology infrastructure:
key enabler for success, safety and welfare



Metrology: Science of measurement studying the relationship between measurands and their estimates [1]

Controlling this relationship is a key factor in manufacturing, trade, safety & security, health care and sciences

[1] In Vocabulary of Metrology (VIM) [JCGM 200:2012], metrology is defined as “science of measurement and its application” but in most cases the word is used in this more limited meaning.





Challenges:

- How to determine the relationship, i.e. quality of measurement?
- How to convince others?

Metrology in practice (1/3)

Case: Wood drying for furniture manufacturing

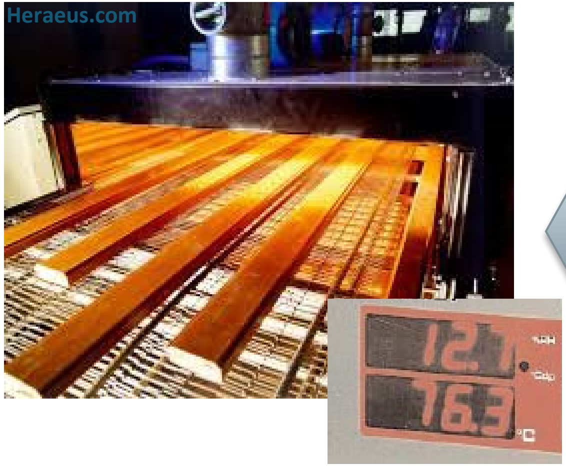
Temperature reading lower than expected
⇒ Wood is not dry enough
⇒ Deformation of wood in (and after) furniture assembly
⇒ Increased waste production and unsatisfied customers
⇒ Poor customer reputation and loss of income

Temperature reading higher than expected
⇒ Significant increase in energy usage
(+ reduced quality due to decomposition)
⇒ Increased energy cost of production
(+ increased waste production)
⇒ Loss of profitability

Metrology in practice (2/3)

Case: Wood drying for furniture manufacturing

Internationally recognised standardised procedures



Fixed and validated measurement procedure

- Control of error sources related to process environment and measurement procedure

Maintenance of the thermometer

- Calibration & adjustment: min-max error criterion

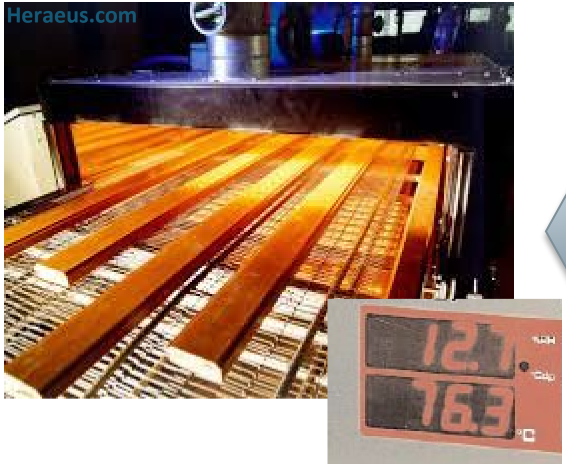
Internationally recognised measurement standards (SI)

Globally recognised evidence on competence and conformity

Metrology in practice (3/3)

Case: Wood drying for furniture manufacturing

International standardisation



Fixed and validated measurement procedure

- Control of error sources related to process environment and measurement procedure

Maintenance of the thermometer

- Calibration & adjustment: min-max error criterion

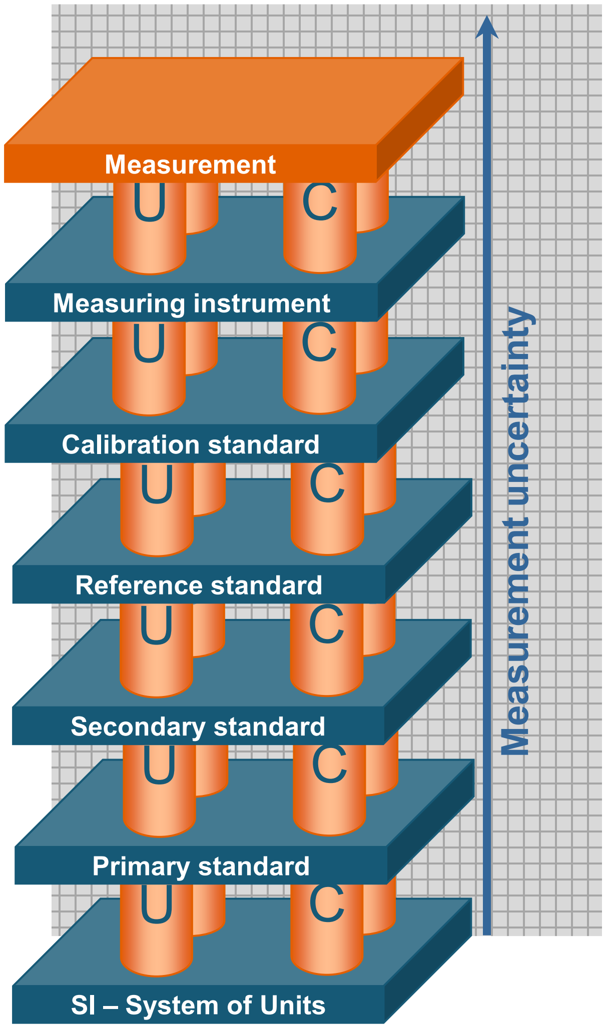
Accreditation
(3rd party assessment)

Measurement traceability to SI

Metrological traceability

- Traceability is property of a **measurement result** whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty
- Traceability chain is a sequence of measurement standards and calibrations that is used to relate a measurement result to a reference
- Traceability provides evidence that your unit is of the same size as the internationally accepted one

Note: Here ”standard” refers to a reference measurement instrument or system



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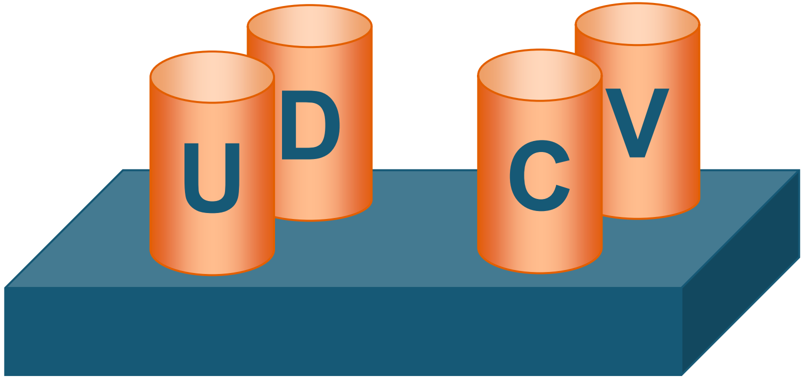
Complete traceability chain

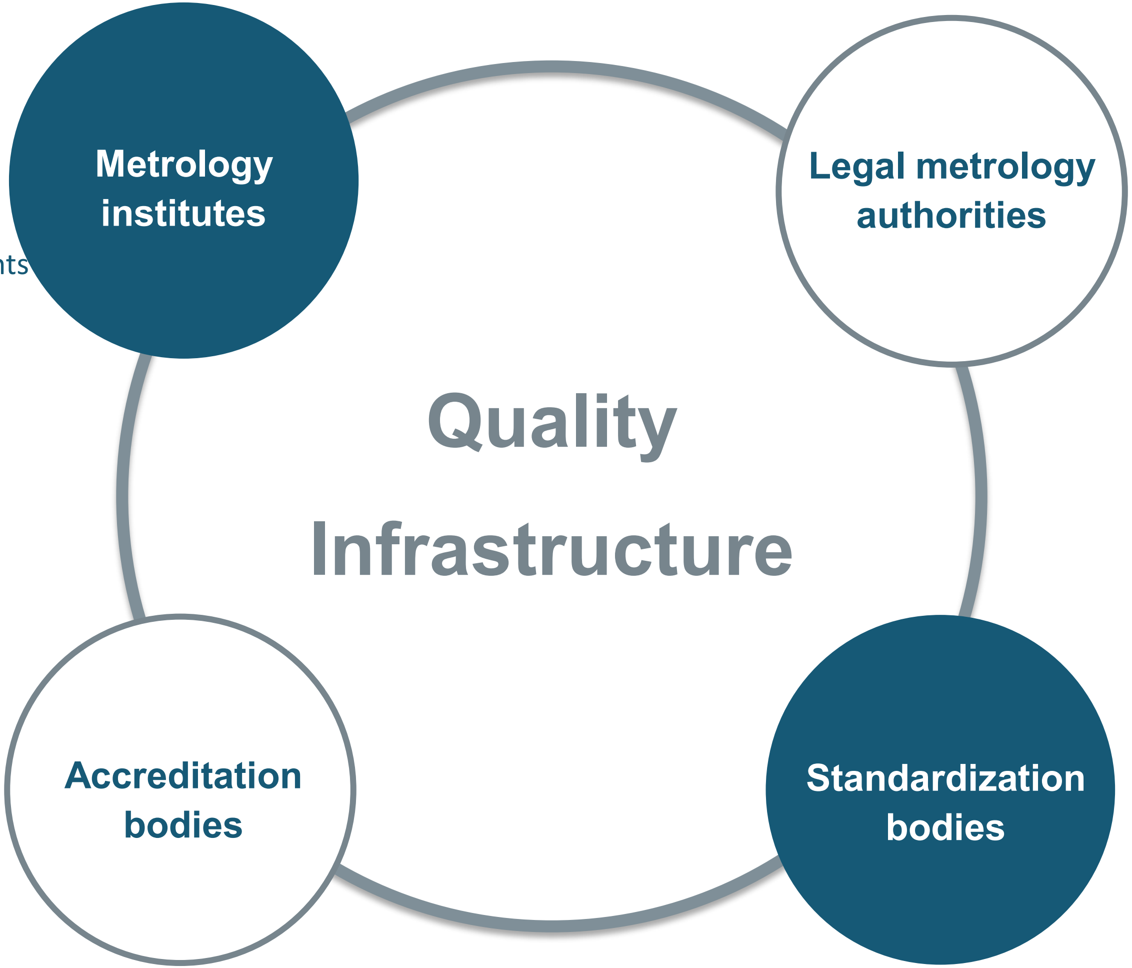
For each calibration of the chain:

- **U**ncertainty estimation
- **D**ocumented and generally acknowledged procedures, documented results
- **C**ompetence
- Calibration is **V**alid for the application. (interval of calibrations, conditions etc.)



Note: Here ”standard” refers to a reference measurement instrument or system

- Metrology research
- Expert in metrology
- Services :
  - Calibrations
  - Reference measurements
  - Interlaboratory comparisons
  - R & D

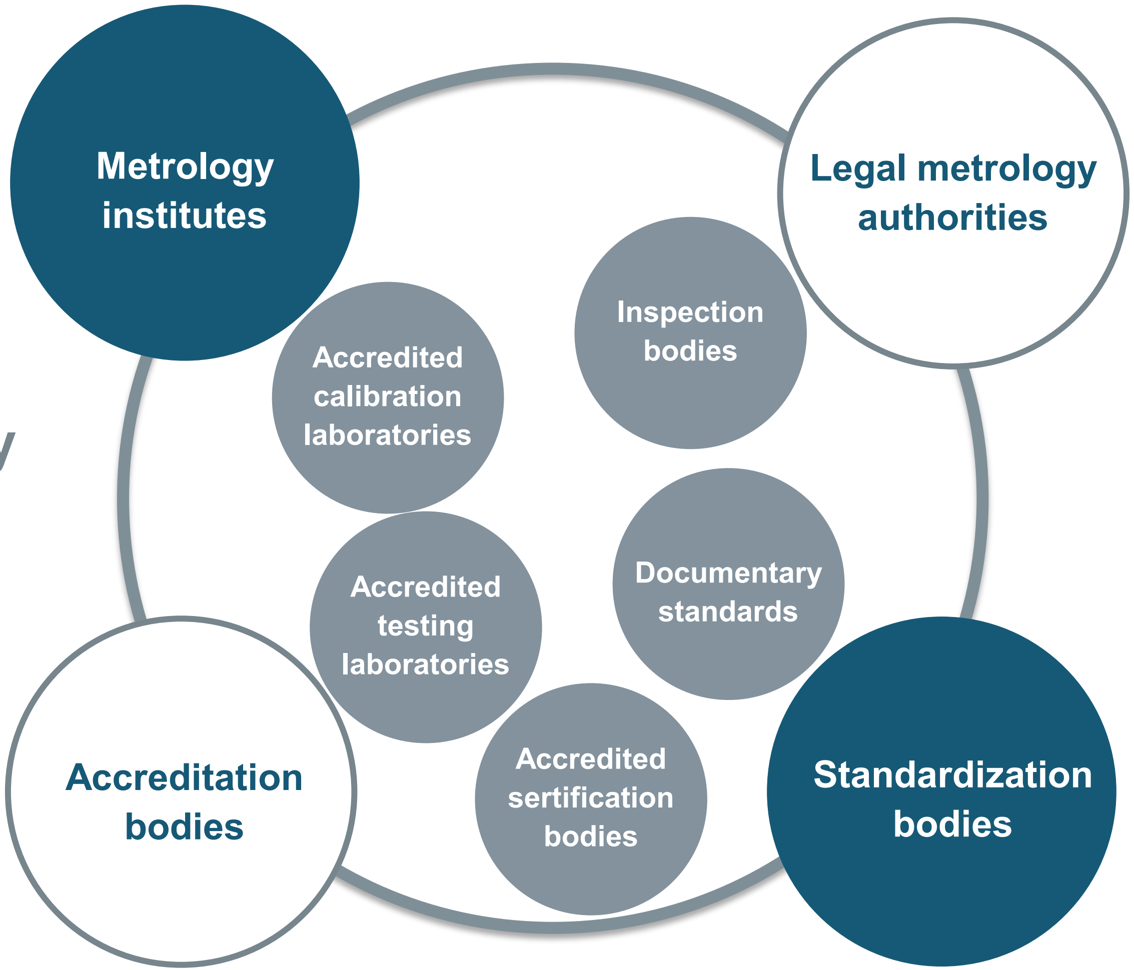


- Preparation of legislation
- Surveillance of measurement instruments (trade & safety)
- Market surveillance

Accreditation services for
- Calibration laboratories
- Testing laboratories
- Inspection bodies
- Sertification bodies
- Verifiers
- Proficiency test providers
- Notified bodies

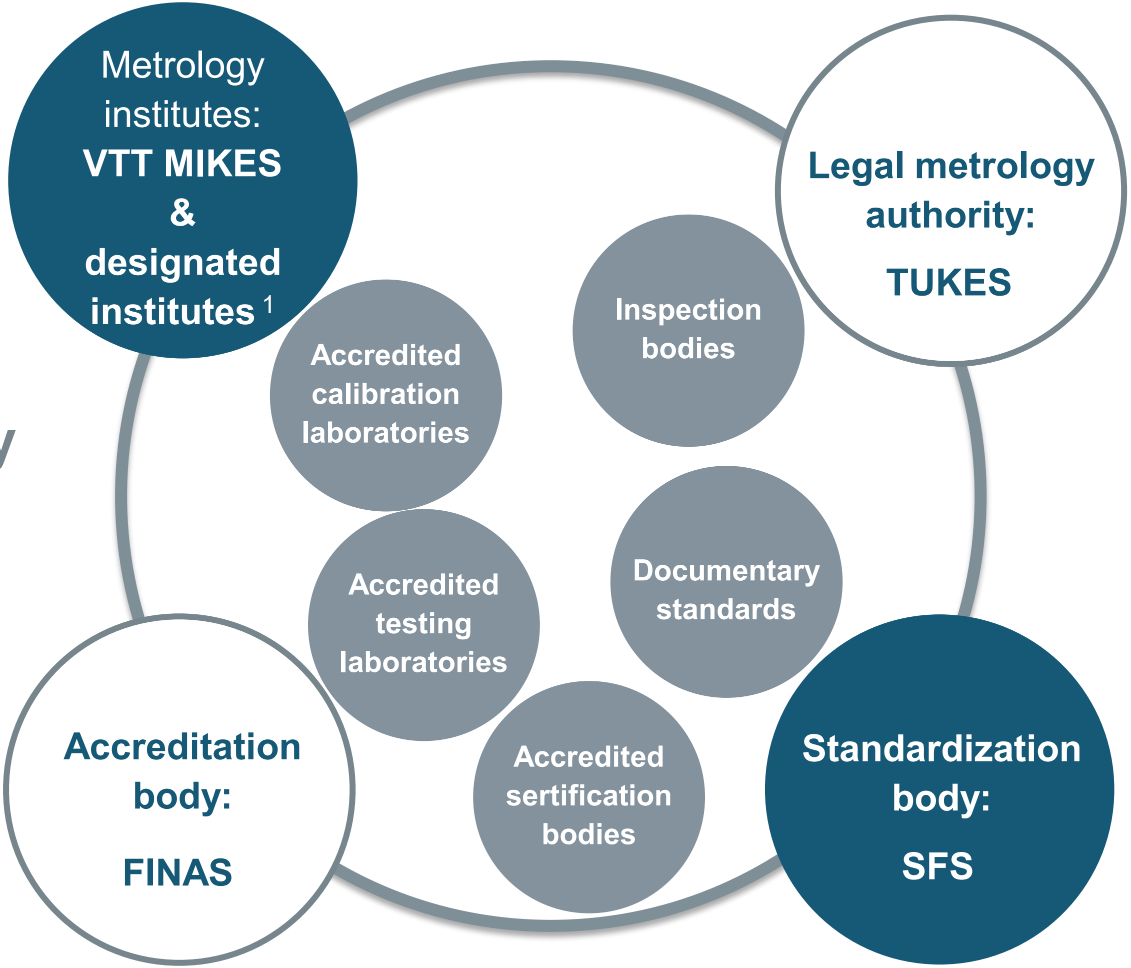
Develop, approve and publish documentary standards

Enabling metrology in industry and trade



Enabling metrology in industry and trade

FINLAND

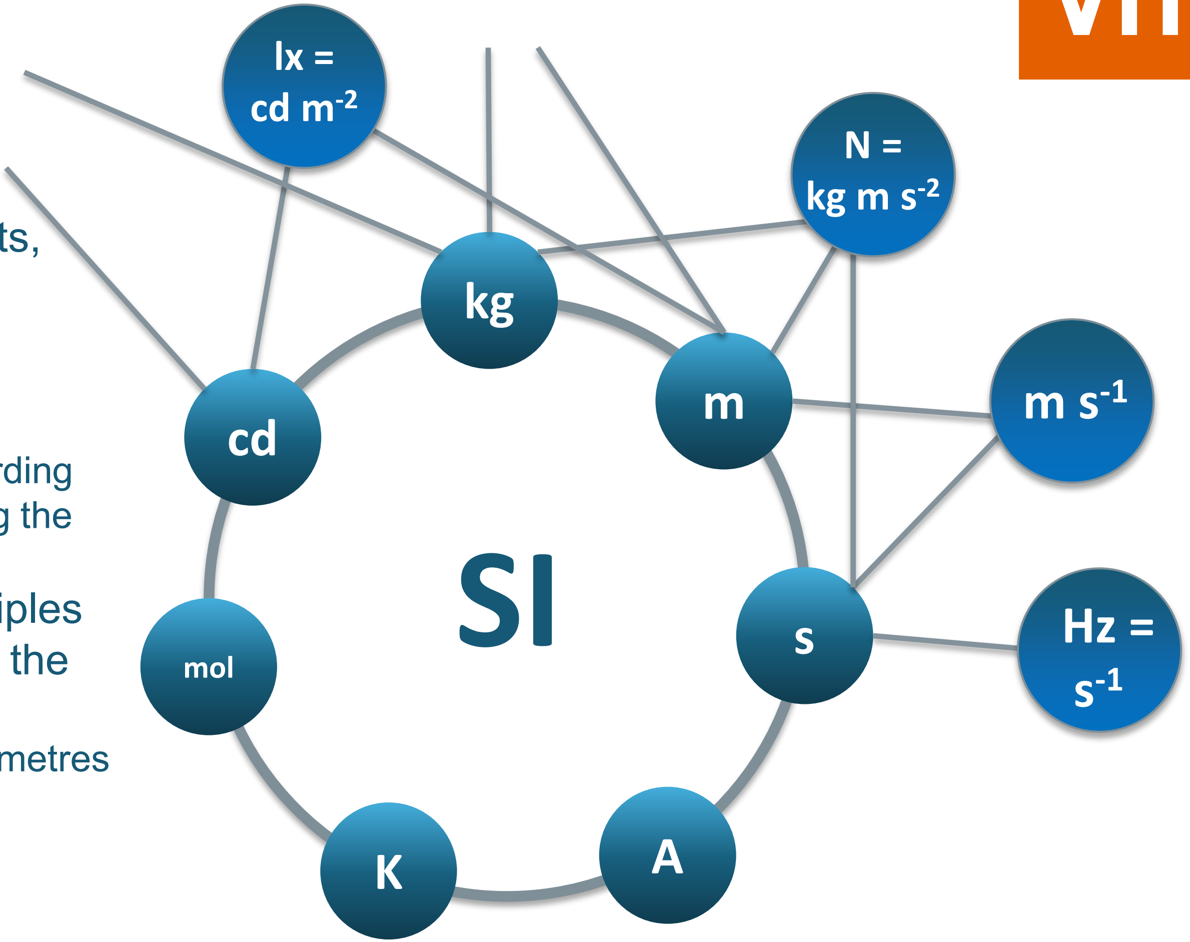


[1] Aalto Univ., SYKE, FMI, NLS/FGI, STUK
see further details on slide 31

Evolving SI unit system as the corner stone of quality

SI system until 20.5.2019

- SI consists of a set of base units, prefixes and derived units:
  - 7 base units and various units derived from base units
  - Derived units are formed by combining the base units according to the algebraic relations linking the corresponding quantities
- Decimal multiples and submultiples of SI units can be written using the SI prefixes
  - e.g. one kilometre is thousand metres (1 km = 1000 m)



Evolving SI system to match the needs

- 1871 Metre Convention
- 1889 MKS system (m, kg, s)
- 1954 Six base units m, kg, s, A, K, cd
- 1960: Named as Système international d'Unités (SI)
- 1971 Mole to 7th base unit
- 2019: New SI

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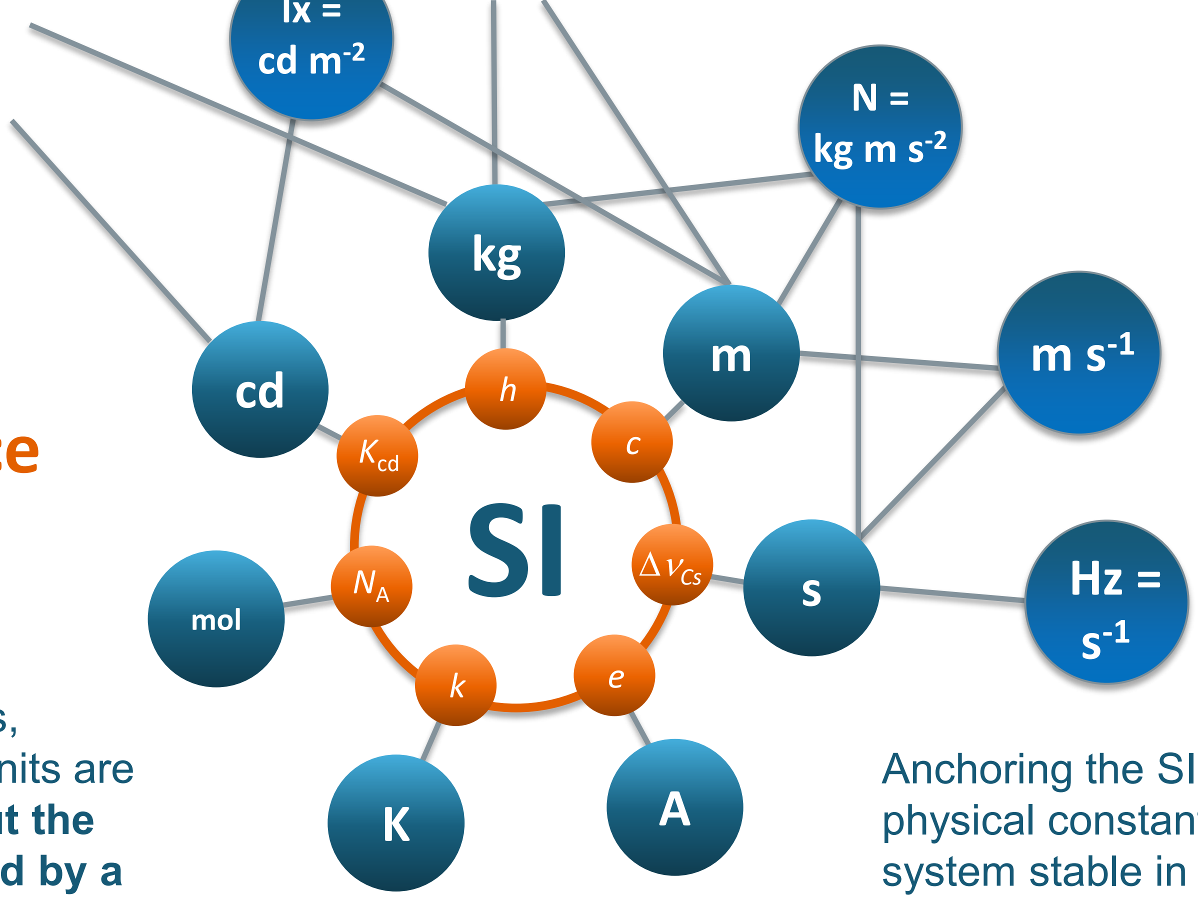
SI system since 20.5.2019



The set of 7 base units, prefixes and derived units are the same as before **but the base units are defined by a set of 7 defining constants.**

Anchoring the SI units to physical constants makes the system stable in time and enables improving accuracy.

New definition of SI

International System of Units, the SI, is the system of units in which:
▪ the unperturbed ground state hyperfine transition frequency of ^{133}Cs atom $\Delta\nu_{Cs}$ is 9 192 631 770 Hz
▪ the speed of light in vacuum *c* is 299 792 458 m/s
▪ the Planck constant *h* is 6.626 070 040 × 10^{-34} J s
▪ the elementary charge *e* is 1.602 176 620 8 × 10^{-19} C
▪ the Boltzmann constant *k* on 1.380 649 × 10^{-23} J/K
▪ the Avogadro constant N_A is 6.022 140 857 × 10^{23} mol^{-1}
▪ the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz, K_{cd}, is 683 lm/W

where where the hertz, joule, coulomb, lumen, and watt, with unit symbols Hz, J, C, lm, and W, respectively, are related to the units second, metre, kilogram, ampere, kelvin, mole, and candela, with unit symbols s, m, kg, A, K, mol, and cd, respectively, according to Hz = s^{-1}, J = m^2 kg s^{-2}, C = A s, lm = cd m^2 m^{-2} = cd sr, and W = m^2 kg s^{-3}.

SI unit system

- List of base units remains the same: kg, m, s, A, K, mol, cd
  - Definitions of the units can be found at: https://www.bipm.org/en/measurement-units/base-units.html and in The International System of Units (SI), 9th edition, BIPM 2019
- All base units are defined by in terms of constants that describe the natural world
- All base units are uniformly expressed using the explicit-constant formulation
- Specific *mise en pratique* documents explain the realization of the definitions of each of the base units in a practical way.

Prefixes

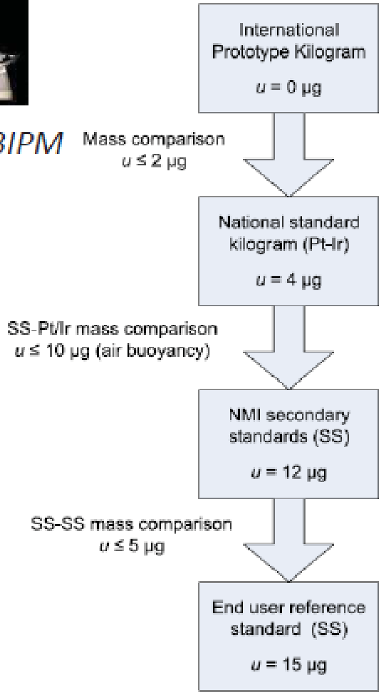
- The list of prefixes was amended by CGPM in November 2022

  CGPM = General Conference on Weights and Measures

Name	Symbol	Factor	Name	Symbol	Factor
quetta	Q	10^{30}	quecto	q	10^{-30}
ronna	R	10^{27}	ronto	r	10^{-27}
yotta	Y	10^{24}	yocto	y	10^{-24}
zetta	Z	10^{21}	zepto	z	10^{-21}
exa	E	10^{18}	atto	a	10^{-18}
peta	P	10^{15}	femto	f	10^{-15}
tera	T	10^{12}	pico	p	10^{-12}
giga	G	10^{9}	nano	n	10^{-9}
mega	M	10^{6}	micro	µ	10^{-6}
kilo	k	10^{3}	milli	m	10^{-3}
hector	h	10^{2}	centi	c	10^{-2}
dec	da	10^{1}	deci	d	10^{-1}

The IPK, at the BIPM

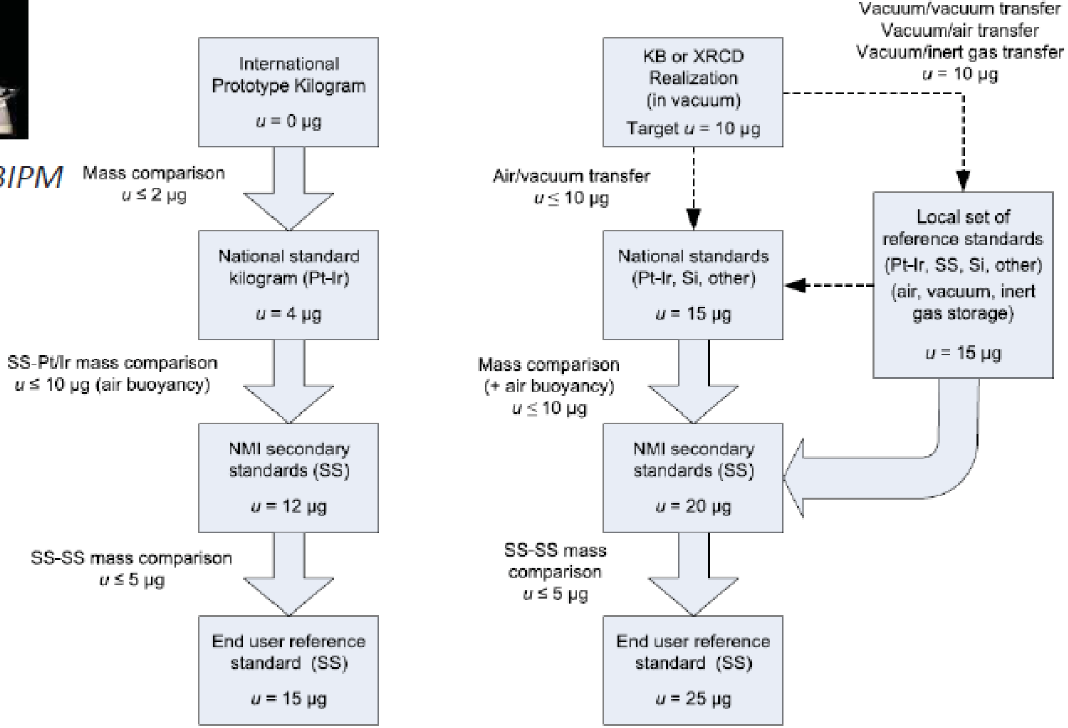
Artefact-based definition of kg



The IPK, at the BIPM

Artefact-based definition of kg

h-based definition of kg



Kibble Balance

XRCD

Traceability chains for mass measurements

[G. H. Beastall, CGPM 2018]

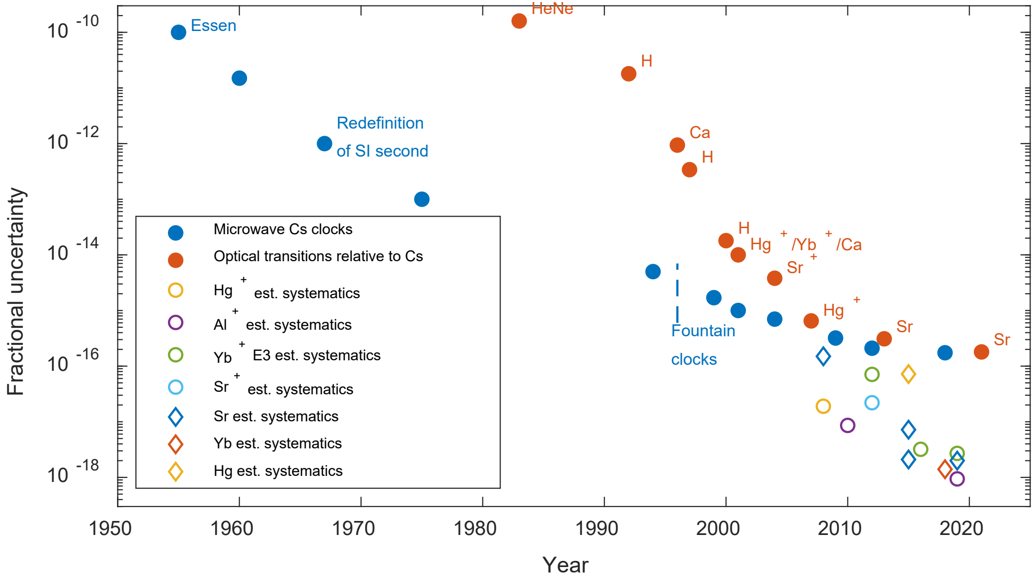
For the future

Evolving SI unit system enables innovative technologies and scientific discoveries

- Examples from the past:
  - Redefined second (1960) enabled accurate GPS navigation
  - Redefined metre (1983) was proven ahead of its time; frequency comb enabled 20 years later significantly better and easier realisation of metre enabling various applications ever since
- Foreseen prospects
  - Applications of quantum technologies
  - Measurements at atomic and molecular level
  - Miniature sensors
  - New scientific discoveries in physics

Evolvement continues…

- Optical frequencies enable realising second with relative uncertainty smaller than 10^{-16}
- New definition of second is expected to take place in 2030



1973 Optical single-ion frequency standards proposed by Dehmelt
1980s Experimental single-ion work (NBS/NIST, NRC, NPL,PTB)
2000 Optical frequency comb
2006 Optical transitions chosen as secondary representations of the second
2011- VTT MIKES ion-clock development starts

Global cooperation and recognition is must but a result of hard work

Metrology infrastructure

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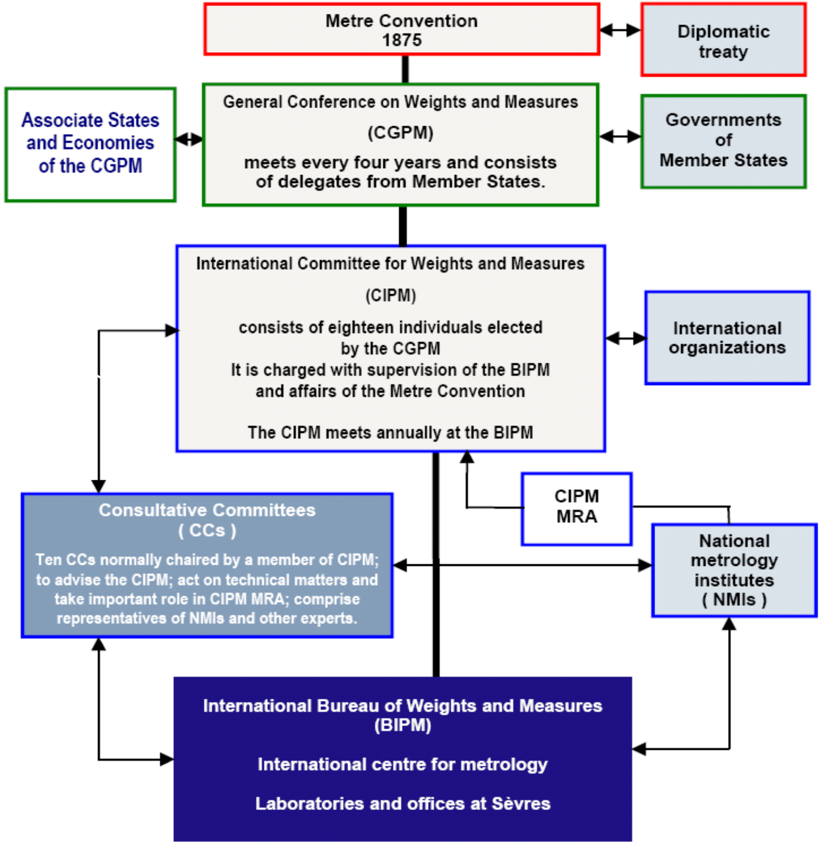
	Metre Convention	Diplomatic treaty 59 Member States and 42 Associate States and Economies
Global	General Conference on Weights and Measures (CGPM)	Delegates of goverments
Global	International Committee for Weights and Measures (CIPM)	Members elected by CGPM
Global	Consultative Committees (CC) for 10 metrology fields	Members named by CIPM
Global	International Bureau of Weights and Measures (BIPM)	Intergovernmental organization
Regional	Regional Metrology Organisations (RMO)	International association of National Metrology Institutes in a region
National	National Metrology Institutes (NMI)	Institute responsible of national measurement system
National	Designated Institutes (DI)	Organisation designated to provide national measurement standard in a specific field

Global metrology organisation



Consultative Committees:

CCAUV	Acoustics, Ultrasound and Vibration
CCEM	Electricity and magnetism
CCL	Length
CCM	Mass and Related Quantities
CCPR	Photometry and radiometry
CCQM	Amount of Substance: Metrology in Chemistry and Biology
CCRI	Ionizing Radiation
CCT	Thermometry
CCTF	Time and Frequency
CCU	Units

VTT MIKES coordinates with Ministry of Economic Affairs and Employment the participation of Finland to CGPM

VTT MIKES is a member of CCEM, CCL, CCPR and CCT

Vice President of VTT MIKES is the NMI representative of Finland (NMI director)

Regional metrology organisations

European RMO: EURAMET

General Assembly (GA)

Chairperson + 2 Vice-Chairpersons

Research Council

EMPIR Committee

Board of Directors (BoD)

EURAMET Management Support Unit (MSU)

Technical Committees (TC)

European Metrology Networks (EMN)

EURAMET Secretariat

Technical Committees:

TC-AUV	Acoustics, Ultrasound and Vibration
TC-EM	Electricity and magnetism
TC-F	Flow
TC-IM	Interdisciplinary metrology
TC-IR	Ionizing Radiation
TC-L	Length
TC-M	Mass and Related Quantities
TC-MC	Metrology in Chemistry
TC-PR	Photometry and radiometry
TC-Q	Quality
TC-T	Thermometry
TC-TF	Time and Frequency

Metrology Networks:

Advanced Manufacturing
Climate and Ocean Observation
Energy Gases
Laboratory Mdicine
Mathmet
Pollution Monitoring
Quantum technologies
Radiation Protection
Safe and Sustainable Food
Smart Electricity Grids
Smart Specialisation in Northern Europe

National Measurement System in Finland

VTT

VTT MIKES

- Electricity
- Acoustics
- Time & frequency
- Temperature
- Humidity
- Pressure
- Length
- Geometry
- Flow
- Mass
- Force
- Torque

Aalto University School of Electrical Engineering
Photometry and radiometry

SYKE
Water quality

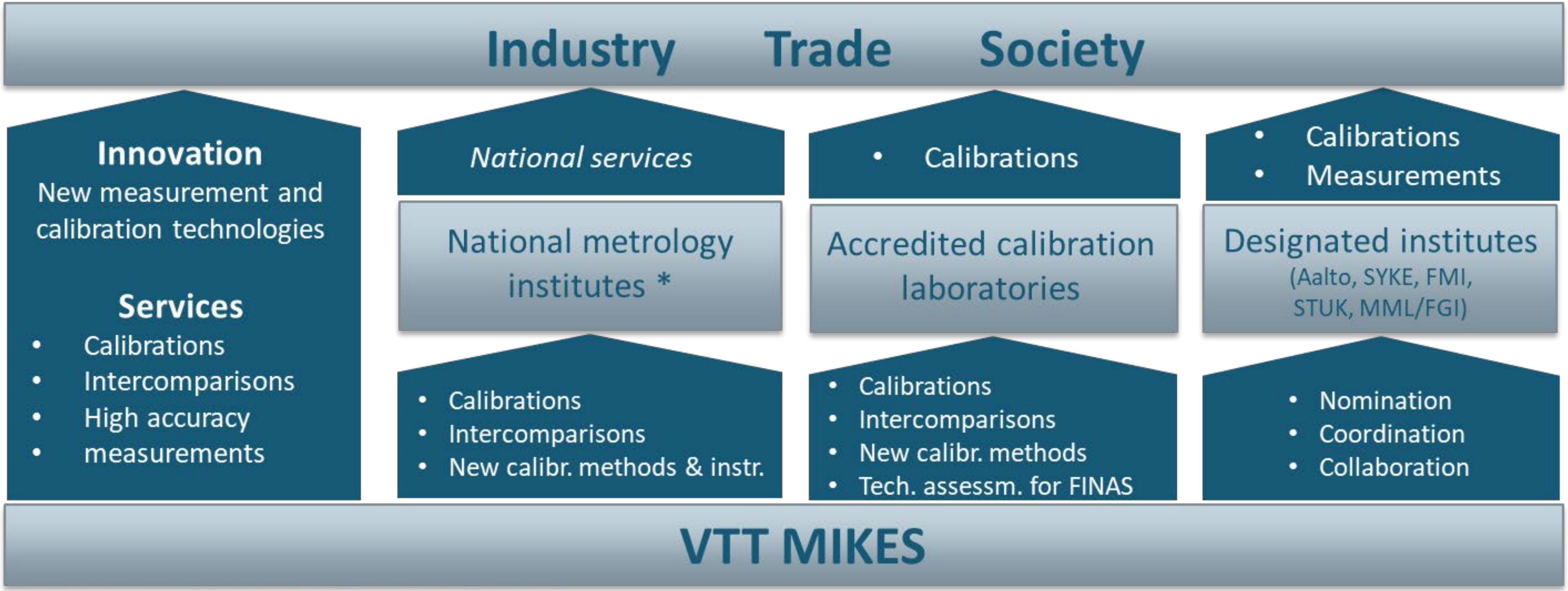
FMI
Air quality

stuk
Ionizing radiation

NLS NATIONAL LAND SURVEY OF FINLAND
Geodetic lenght and acceleration of free fall

ACCREDITED LABORATORIES

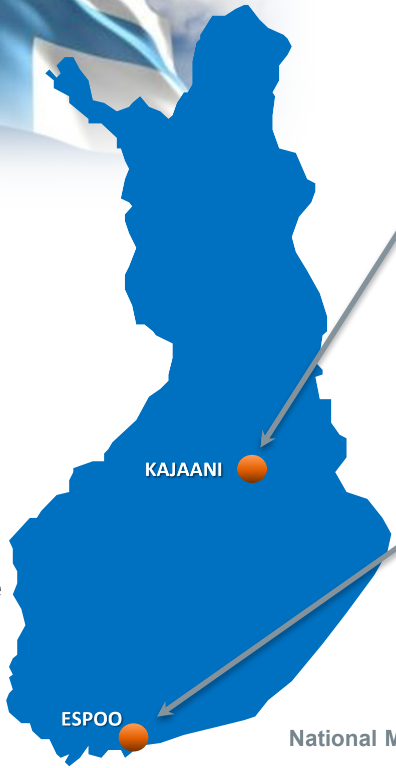
Metrology in Finland



* National metrology institutes of some countries

VTT MIKES Infrastructure

- **Kajaani:** premises for liquid flow, force and torque
  - Maximum flow pipe size DN500
  - Test rig for pulp flow
- **Otaniemi:** metrology building with high performance laboratory rooms
  - Ultra-low air temperature and humidity variations, vibration levels and electromagnetic noise levels
  - Laboratories for electrical quantities, length, geometry, temperature, humidity, mass, pressure, flow, force, torque, time, frequency, acoustics, optical spectroscopy
  - Special facilities for atomic clocks, atomic force microscopy, interferometry and cryogenic measurements



VTT MIKES supporting success of industry

Maintaining quality of current production

Measurem. instruments

In-hous calibr. Instr.

Calibrations

Repair etc.

Calibration services

Measurement analysis

Tests, validations etc.

Training

Improving business by focusing in measurements

New meas. Instruments

New calibr. instruments

New meas. methods

New calibr. methods

New meas. technology

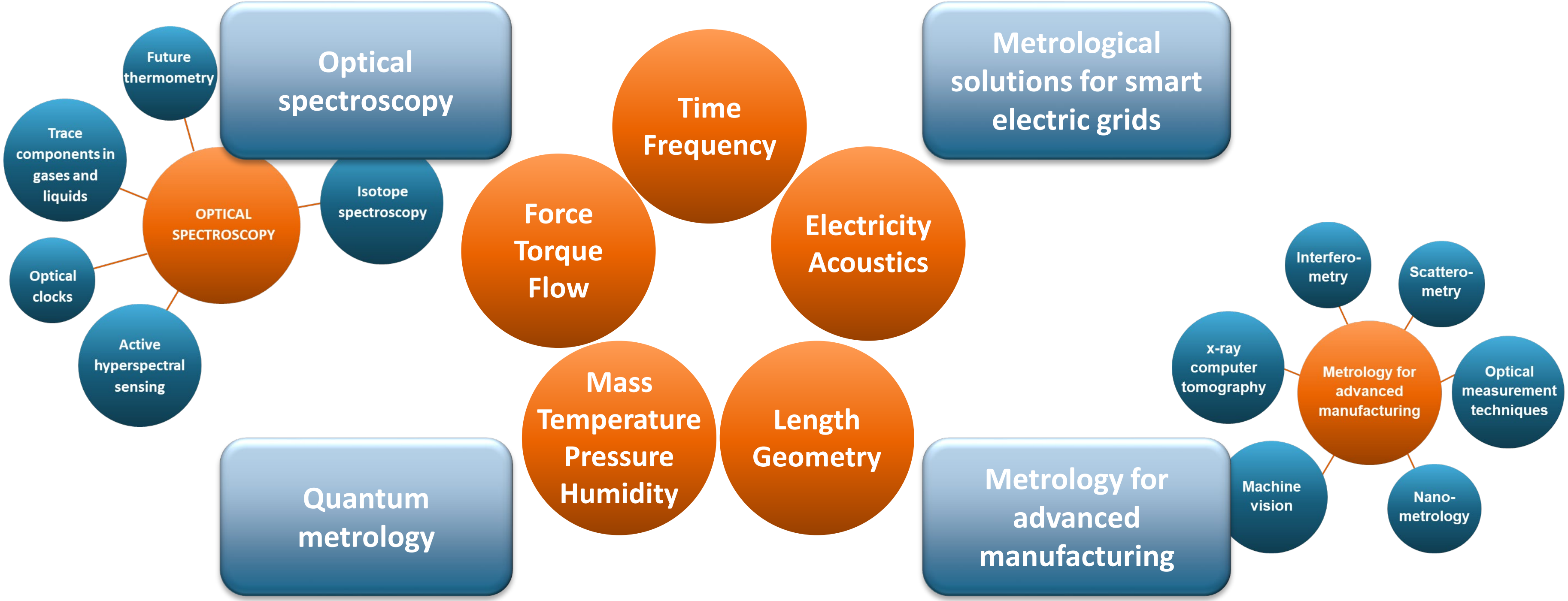
New calibr. technology

Proof of concept, tests, validations

Measurement analysis

Feasibility studies

VTT MIKES Technologies

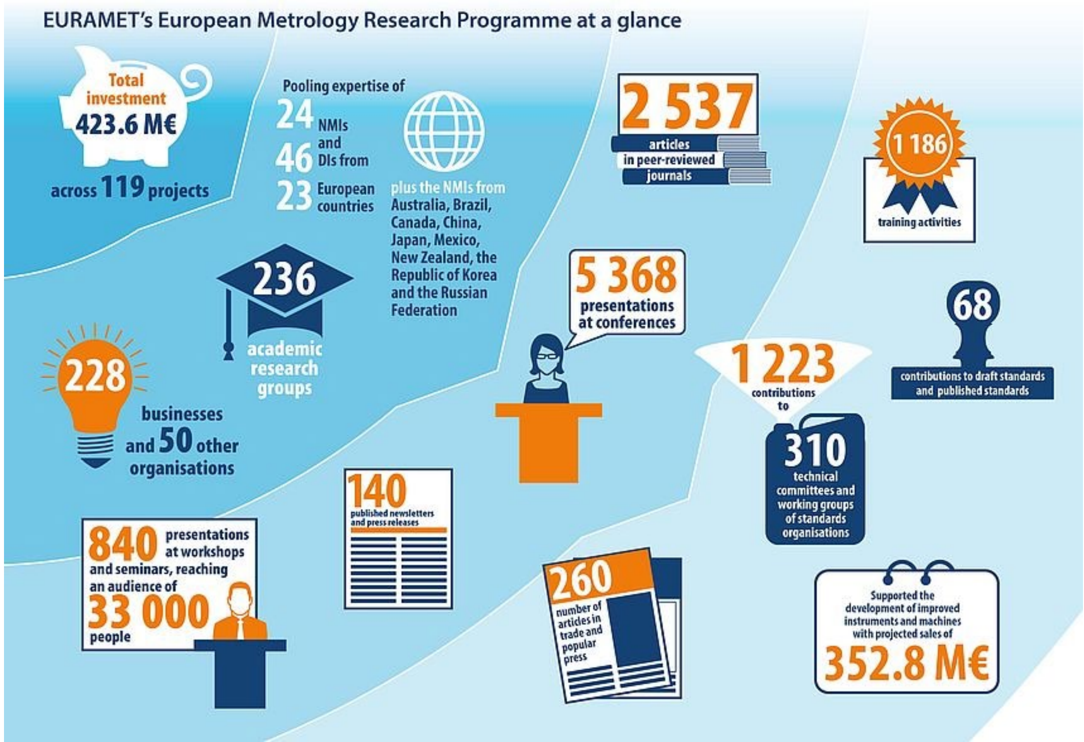


Research and quality as vital building blocks in metrology

Metrology Research

- Aim:
  - Develop SI system to match the requirements of industry and society
  - Develop national measurement standards to meet national needs
  - Develop improved and new tools and methods to disseminate SI traceability
  - Develop improved and new tools and methods for SI traceable measurements in industry and society
- Past European metrology research programmes:
  - EMRP: European Metrology Research Programme 2009 - 2013
  - EMPIR: European Metrology Programme for Innovation and Research 2014 - 2020
- European Partnership on Metrology 2021 - 2027
  - Part of Horizon Europe (EU 9th Framework programme Horizon Europe)
  - National coordination: VTT MIKES

Impact of European Metrology Research Programme



As of February 2020

EMRP & EMPIR: Industrial uptake

* of European turnover from new or significantly improved products and services that can be attributed to the research activities of the European Metrology Research Programmes

[www.euramet.org]

Recognition and quality

- CIPM Mutual Recognition Arrangement (CIPM MRA) is for demonstrating the international equivalence of national measurement standards and the calibration and measurement certificates issued by NMIs and DIs
- Internationally recognized (peer-reviewed and approved) Calibration and Measurement Capabilities (CMCs) of the participating institutes are publicly available at the CIPM MRA database (KCDB): https://kcdb.bipm.org/appendixC/default.asp
- MRA has been signed by 105 institutes from 59 member states and 42 associate states of the CGPM

Reconnaissance mutuelle
des étalons nationaux de mesure
et des certificats d'étalonnage et de mesurage
émis par les laboratoires nationaux de métrologie

Paris, le 14 octobre 1999

ΜΕΤΡΩ ΧΡΩ

Mutual recognition
of national measurement standards
and of calibration and measurement certificates
issued by national metrology institutes

Paris, 14 October 1999

Comité international des poids et mesures

Bureau international des poids et mesures

Organisation intergouvernementale de la Convention du Mètre

NMI = National Metrology Institute
DI = Designated Institute
CGPM = General Conference on Weights and Measures

Reviewing quality

- Review of quality at each institute is essential to achieve international recognition within CIPM MRA
- Major elements of review:
  - Interlaboratory comparisons (key comparisons): regional and inter-regional
  - Technical peer review of CMC claims: regional and inter-regional
  - Peer review onsite visits: within groups of countries within regions
  - Quality review: regional

CIPM MRA = CIPM Mutual Recognition Arrangement
CMC = Calibration and Measurement Capabilities

Review process

RMO quality review

- Review of quality management system
- Carried out by RMO's TC Quality

CMC claim → RMO review → Inter-RMO review → Publish at KCDB

CMC claim

- Parameter, range and uncertainty
- Comparison results
- Other supporting evidence

RMO review

- Review against comparison results
- Review of other supporting evidence
- Carried out by RMO's relevant technical committee

Inter-RMO review

- Review of RMO review results

CMC = Calibration and Measurement Capabilities
RMO = Regional Metrology Organisation
TC = Technical Committee
KCDB = CIPM MRA database

Summary

- Metrology infrastructure is needed for controlling quality of measurements in practice in industry and society
- Metrology research delivers new measurement and calibration technologies as well as achievement of improved accuracy
- SI unit system is evolving: new era began in May 2019 and developments continue
- Extensive peer review processes are in place to achieve global recognition

Further reading

- Metrology infrastructure and equivalence of national measurement standards: www.bipm.org
- European metrology organisation EURAMET and metrology research programmes: www.euramet.org
- National Measurement System in Finland and VTT MIKES:
  https://www.vttresearch.com/en/technology-infrastructures/metrology
  https://www.vttresearch.com/en/research-expertise/metrology-vtt-mikes
  https://www.vttresearch.com/en/news-and-ideas/si-system-finland
- SI unit system:
  - https://www.bipm.org/en/measurement-units/
  - The International System of Units (SI), 9th edition, BIPM 2019
- Vocabulary of Metrology (VIM) and Uncertainty in Measurement (GUM): https://www.bipm.org/en/publications/guides/

Further information

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