Overview

LGC

- Definition of metrology
- Why metrology matters
- Core activities
- Definitions of units
- Principles of traceability and comparability
- International metrology infrastructure

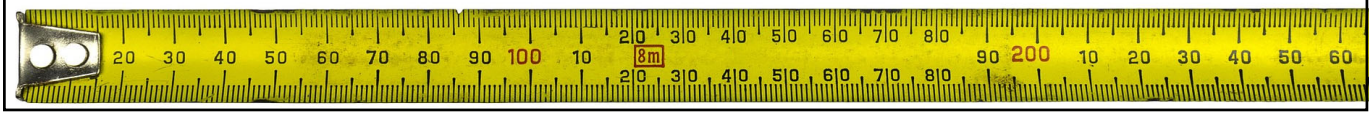
Metrology is…

"Messen ist Wissen – Measurement is knowledge" [Georg Simon Ohm]

2.2 (2.2)
metrology
science of **measurement** and its application

NOTE Metrology includes all theoretical and practical aspects of measurement, whatever the **measurement uncertainty** and field of application.

International vocabulary of metrology – Basic and general concepts and associated terms (VIM), JGCM 200:2012 (https://www.bipm.org/en/committees/jc/jcgm/publications)



What is metrology for?

- A recipe
  - Dried fruit
  - Butter
  - Flour
  - Sugar (brown)
  - Baking powder
  - Eggs

  mix

  - Oven

  bake

What is metrology for?

- A more consistent recipe
  - Dried fruit (about as much as everything else)
  - Butter (a pack)
  - Flour (enough for a stiff paste with the egg)
  - Sugar (about as much as the flour)
  - Baking powder (a pinch)
  - Eggs (4)

  - Oven (medium). Bake until cooked through

What is metrology for?

- A transferable recipe
  - Dried fruit (1 kg)
  - Butter (250 g)
  - Flour (175 g)
  - Sugar (200 g)
  - Baking powder (3 g)
  - Eggs (4)

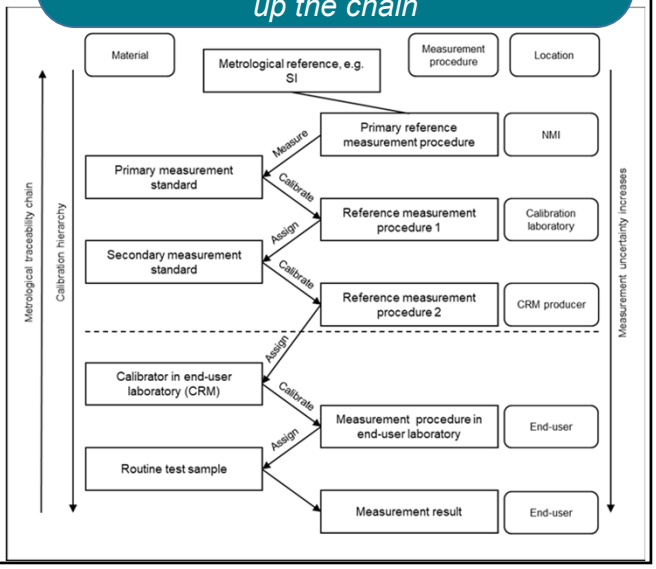
  - Oven (150 ^{o}C)*. Bake 2 hr
    - *130 ^{o}C Fan

Importance of metrology

- The ability to make measurements is insufficient
- Meaningful measurement results require
  - recognised measurement units
  - measurement standards that allow a practical realisation of those units
- Metrology provides a framework to ensure measurement results are
  - comparable
  - sufficiently accurate (acceptable measurement uncertainty)

Traceability is a mechanism for achieving comparability

The calibration hierarchy means results produced in laboratories are traceable to the values of reference materials higher up the chain



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Fundamental metrology activities

- Definition of units of measurement

1 metre = length of the path travelled by light in vacuum during a time interval with duration of 1/299 792 458 of a second

Defined in terms of speed of light in a vacuum (c = 299 792 458 m s^{-1}), where the second is defined in terms of the caesium frequency $\Delta\nu_{Cs}$

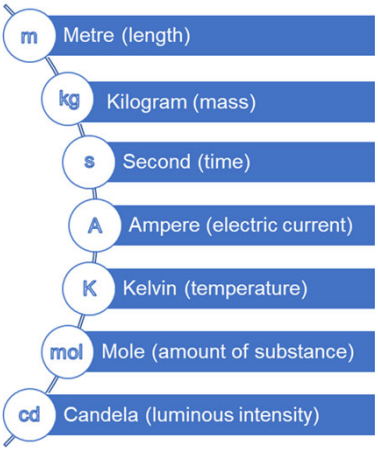
- m — Metre (length)
- kg — Kilogram (mass)
- s — Second (time)
- A — Ampere (electric current)
- K — Kelvin (temperature)
- mol — Mole (amount of substance)
- cd — Candela (luminous intensity)

8

Fundamental metrology activities

- Definition of units of measurement
- Practical realisation of units of measurement

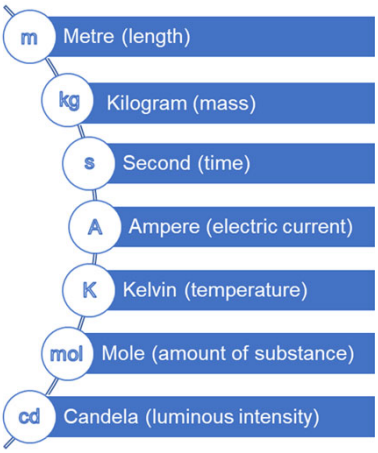
Indirect measurement of light travelling time using optical interferometry



Fundamental metrology activities

- Definition of units of measurement
- Practical realisation of units of measurement
- Establishing metrological traceability

Linking measurements of length made in industry to the definition of the metre via an unbroken chain of calibrations



Fundamental metrology activities

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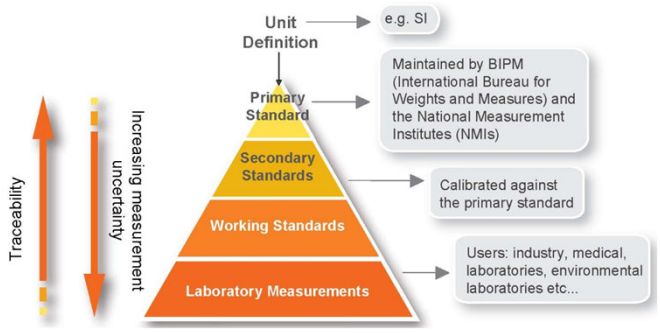
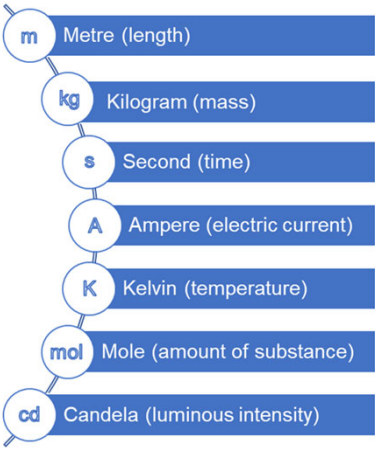




Metrology is critical to…

- Creating reliable products, services and production processes
- Ensuring processes can be repeated consistently and at scale
- De-risking innovation for industrial applications
- Ensuring consistency and quality of product performance
- Facilitating translation into industry
- Protecting consumers and the environment

Quantities and units

What is a quantity?

1.1 (1.1)
quantity

property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference

- Any property having size (magnitude)
  - magnitude usually evaluated through measurement
  - can be fixed by definition (e.g. speed of light)
- Possible references
  - measurement unit
  - measurement procedure
  - reference material

International vocabulary of metrology – Basic and general concepts and associated terms (VIM), JGCM 200:2012

What is a measurement unit?

1.9 (1.7)
measurement unit
unit of measurement
unit

real scalar **quantity**, defined and adopted by convention, with which any other quantity of the same **kind** can be compared to express the ratio of the two quantities as a number

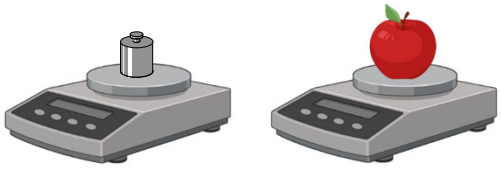
A unit is simply an agreed standard for reference

What is a measurement unit?

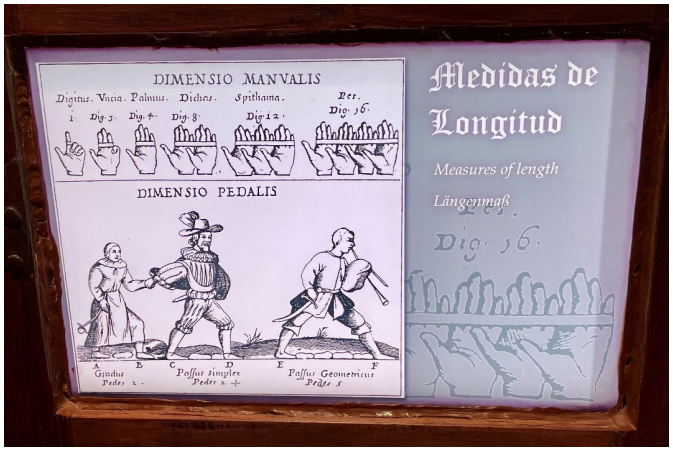
1.9 (1.7)
measurement unit
unit of measurement
unit

real scalar **quantity**, defined and adopted by convention, with which any other quantity of the same **kind** can be compared to express the ratio of the two quantities as a number

- Example – mass is a quantity
  - the kilogram (kg) is a unit of mass
    - represents a specific predetermined mass
  - A mass of an apple is 0.15 kg
    - i.e. 0.15 x the mass of the kg



Making units consistent
Use something widely accessible



Museo de Historia, Aguïmes, Gran Canaria

- Early units based on human dimensions
  - palm, foot, forearm, ...

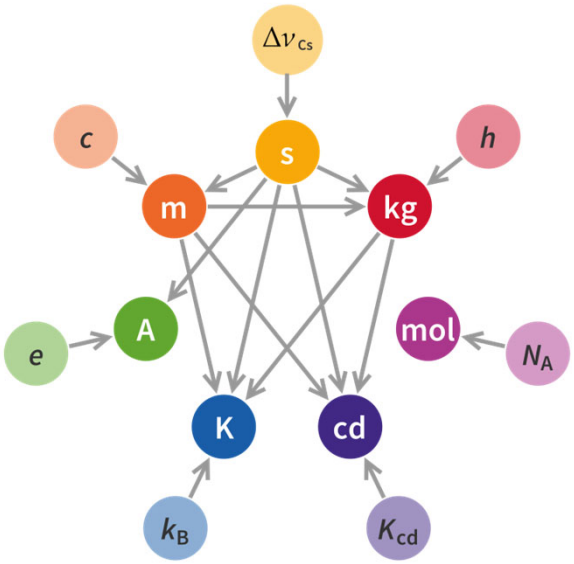
Making units consistent
Use something widely accessible

- Cubit
  - the length of the Pharaoh's forearm from elbow to tip of middle finger
- 'Royal Egyptian cubit' carved into black granite block
- Wooden and stone copies given to builders
- Standards checked by architects each full moon
  - on pain of death…

ca. 3000 BCE, Egypt

Making units consistent
Use something (very) widely accessible

- SI System of units now using universal constants
  - speed of light in a vacuum, *c*
  - Planck constant, *h*
  - Avogadro constant, N_A…



The international system of units (SI)

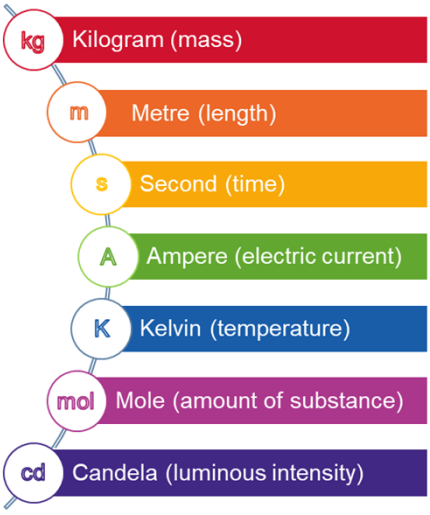
- Adopted by the General Conference on Weights and Measures (CGPM)
- The SI brochure* separates quantities and units
  - quantity – a measurable property (e.g. mass)
  - unit – chosen by convention as reference to which measurements of a property refer (e.g. kg)

☒ ‘Number of meters’ to describe a quantity

✓ Quantity – length

✓ Unit – metre

“length in metres”



*The International System of Units (SI), 9th Ed., 2019 (https://www.bipm.org/en/publications/si-brochure)

International system of quantities (ISQ)

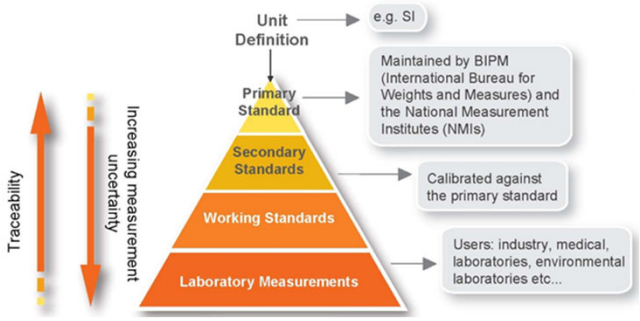
- ISQ is a system of quantities based on 7 base quantities
- 'Base quantity'
  - subset of a system of quantities
  - no base quantity can be expressed in terms of the others
- System of quantities for which units have been developed
  - the SI system

Measurement standards

5.1 (6.1)
measurement standard
etalon

realization of the definition of a given **quantity**, with stated **quantity value** and associated **measurement uncertainty**, used as a reference

- Required for the practical realisation of measurement units



Making units consistent
Use something widely accessible

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'Primary measurement standard'

ca. 3000 BCE, Egypt

Making units consistent
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Making units consistent
Use something widely accessible

- Cubit
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- 'Royal Egyptian cubit' carved into black granite block
- Wooden and stone copies given to builders

'Working measurement standard'

ca. 3000 BCE, Egypt

Traceability and comparability

Metrological traceability – what is it?

- To be able to compare results they
  - need to be on the same measurement scale
  - use the same measurement units
- Achieved by
  - linking results to a common stable reference
- Results can be compared
  - through their relationship to the chosen reference

Metrological traceability – the strategy of linking results to a reference

Metrological traceability – definition

2.41 (6.10)
metrological traceability
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**

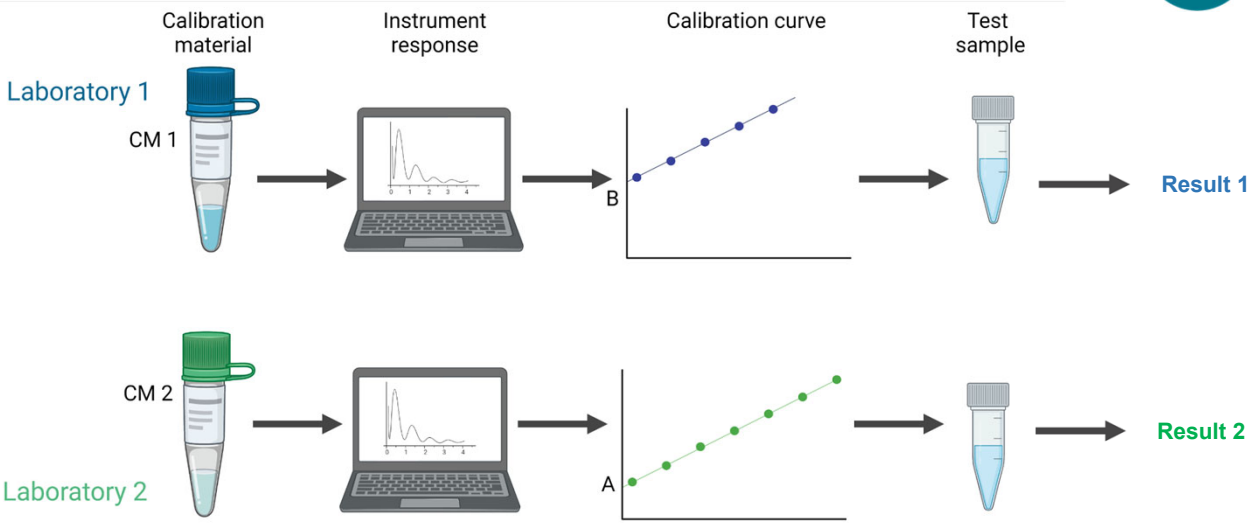
References

- Definition of a measurement unit
- Measurement procedure including the measurement unit
- Measurement standard

Calibration – fundamental to establishing traceability

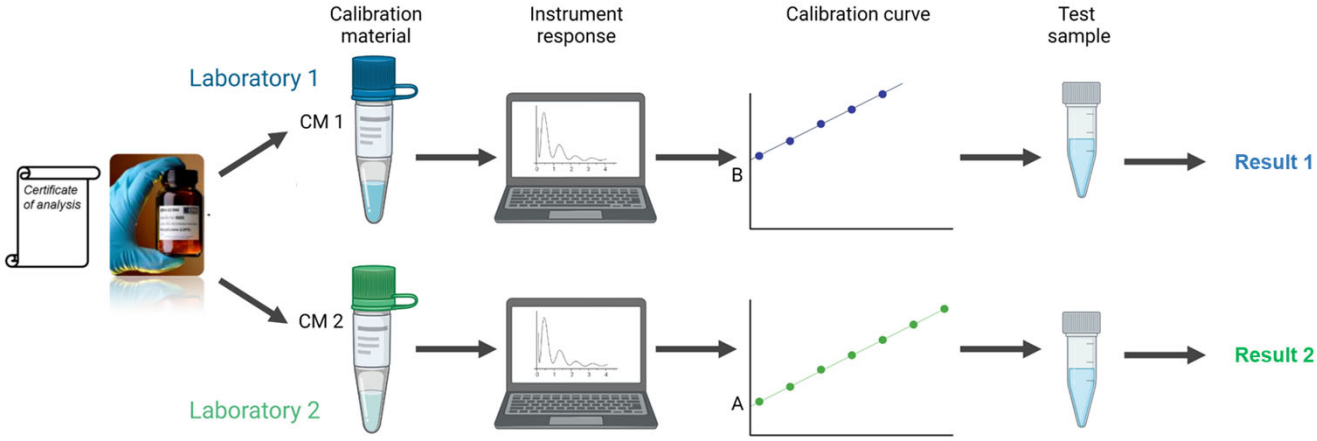
- Calibration usually applied to parts of a measurement process
  - analytical balance
  - pipettes
  - thermometers for monitoring temperature of a water bath
  - qPCR used for final measurement
- Requires suitable measurement standards/reference materials

Why we need traceability



Are the results from the two laboratories comparable?

Why we need traceability



Metrological comparability means…

- Results are traceable to the same reference
  - **not** that they have similar magnitude

- Can compare the distances between
  - Earth ➔ Moon
  - London ➔ Paris
- If they are traceable to the same measurement unit
  - e.g. the metre

International metrology organisations and infrastructure

Making units consistent

- Early standards often local ...

By © Y.ssk / Wikimedia Commons, CC BY-SA 4.0

- National and international trade needed wider agreement
- Metre convention
  - signed in Paris on 20 May 1875 by representatives of seventeen nations

The international metrology infrastructure

- Measurement laboratories
  - International Bureau of Weights and Measures (BIPM)
  - National Measurement (Metrology) Institutes (NMIs)
    - e.g. National Physical Laboratory (UK NMI)
  - Designated Institutes (DIs)
    - e.g. National Measurement Laboratory at LGC (UK DI)
  - Calibration laboratories

Primary standards, reference measurements and calibration services

The international metrology infrastructure

- Regional metrology organisations

Coordination of comparisons among NMIs; CMC* approval

*Calibration and Measurement Capabilities

The international metrology infrastructure

- Standards development organisations
- Responsible for standardisation
  - *"activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context"**
  - with a focus on the process of creating, issuing and implementing standards

*ISO/IEC Guide 2:2004 Standardization and related activities – General vocabulary

The international metrology infrastructure

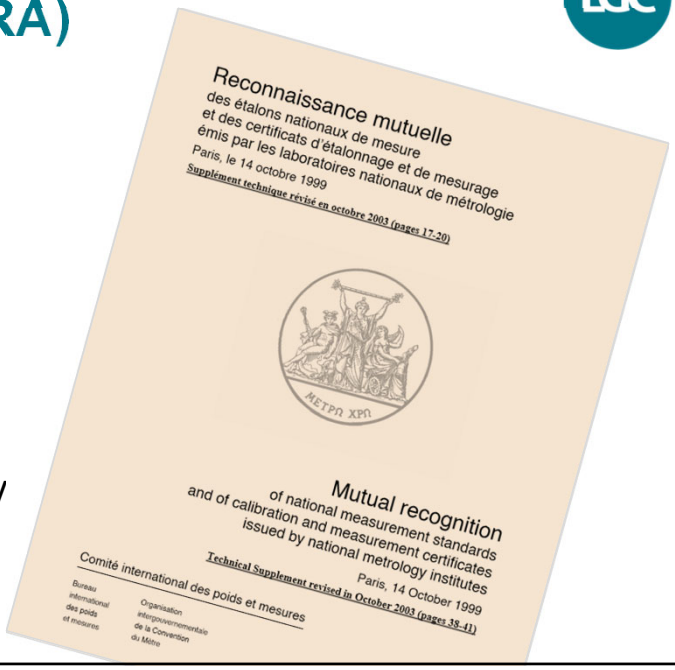
- Accreditation bodies

Harmonisation of measurement practice

The CIPM "mutual recognition arrangement" (MRA)

Provides for

- Internationally recognised "Calibration and Measurement Capabilities"
  - peer-reviewed and approved
- Demonstration of capability through "Key Comparisons"
- Publication of CMCs in the Key Comparison Database
  - the KCDB


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
Supplément technique révisé en octobre 2003 (pages 17-20)

Mutual recognition
of national measurement standards
and of calibration and measurement certificates
issued by national metrology institutes
Paris, 14 October 1999
Technical Supplement revised in October 2003 (pages 38-41)
Comité international des poids et mesures

Who looks after the SI units?

International Committee for Weights and Measures (CIPM)

CCT (Kelvin)	CCEM (ampere)	CCTF (second)	CCL (metre)	CCM (kilogram)	CCPR (candela)	CCQM (the mole)
K	A	s	m	kg	cd	mol

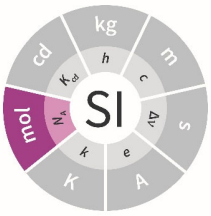
"Consultative Committees" (CCs)

Consultative committee roles

- "Realisation" of units
  - how to generate primary reference values
- Dissemination of units
  - comparisons among National Measurement Institute standards and BIPM
- Coordination of "key comparisons"
  - demonstration of NMI capabilities

CCQM

- Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology
- Split into 12 Working Groups (WGs)



- Strategic Planning
- Key Comparisons and CMC Quality
- Inorganic Analysis
- Cell Analysis
- Electrochemical Analysis
- Gas Analysis
- Isotope Ratios
- Nucleic Acid Analysis
- Organic Analysis
- Protein Analysis
- Surface Analysis
- Ad-hoc WG on the mole

What CCQM does

- Organises international comparison studies to test NMIs/DIs capability for measurements of *amount of substance fraction or mass fraction*
- Demonstrates skills and ability
- Develop measurement systems to achieve SI traceability
- Demonstrates "NMIs/DIs are getting it right" for their measurement services

- Key comparison (KC)
  - international benchmarking
  - institutes should participate if actively working in that field
  - ability to claim CMCs
- Pilot studies (P)
  - emerging fields
  - test of capability before KC
  - a chance for learning & development before a KC

Summary

- Metrology is the science of measurement and its application
- Essential for ensuring meaningful measurements
  - comparable – across borders; over time
  - sufficiently accurate
- Relies on
  - traceability to primary international standards
  - comparisons between NMIs
  - a wide and deep international infrastructure!

Thank you

Any questions?