Introduction to Metrology

Traceability in measurements

Traceability in measurements

1. Basic concepts
2. Why we need traceability?
3. Infrastructure ensuring availability of traceable measurements

1.1 Basic concepts

Terms

QUANTITY

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

(A reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such.)

- Quantity can be a general quantity (e.g. length) or particular quantity (e.g. wavelength of Sodium D line)

MEASURAND

- Quantity intended to be measured

ESTIMATE (of the measurand); called also MEASURED QUANTITY VALUE

- measured value of a quantity measured value
- quantity value representing a measurement result

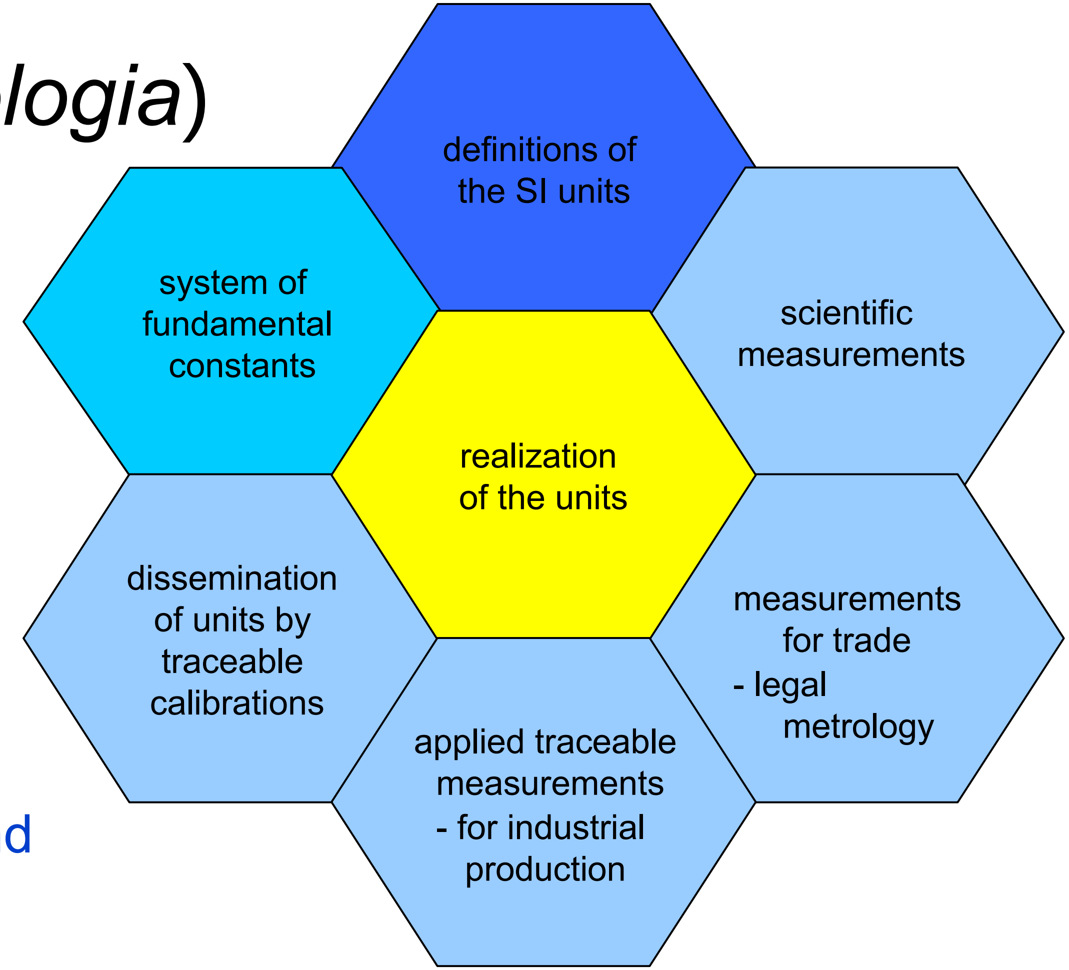
MEASUREMENT ERROR

- measured quantity value minus a reference quantity value

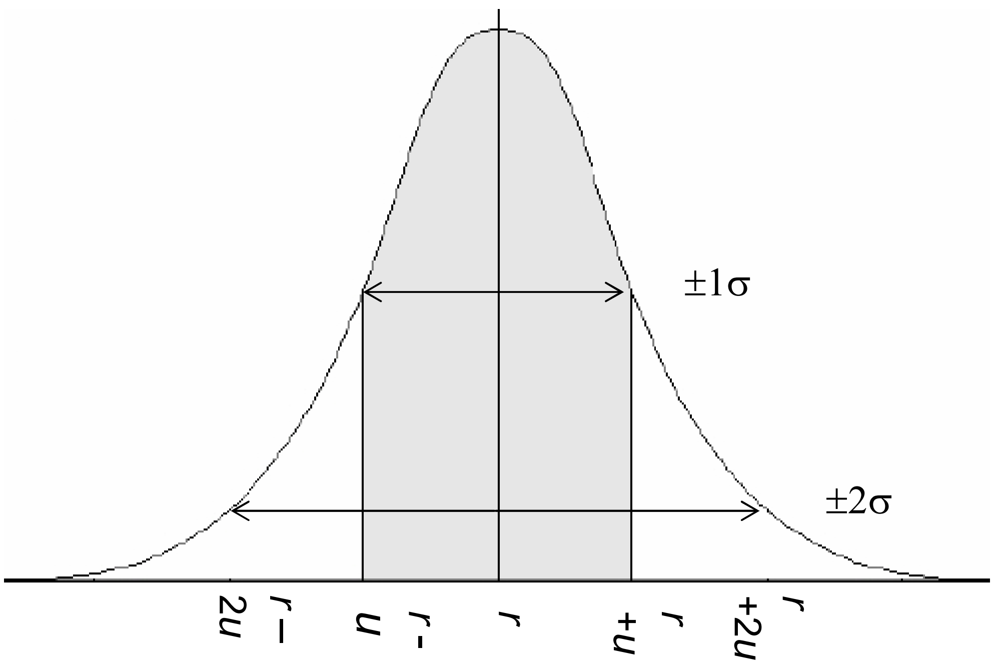
Metrology (*metrologia*)

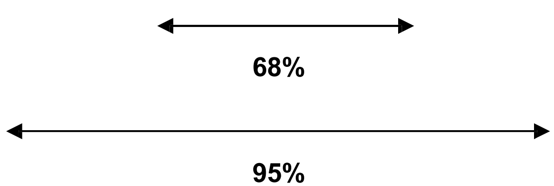
metrology is:
science of measurement and its application
[1.1, 1.2]

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



Uncertainty of measurement (*epävarmuus*)





non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used [1.1, 1.2]

r = estimate = mean value
u = standard uncertainty

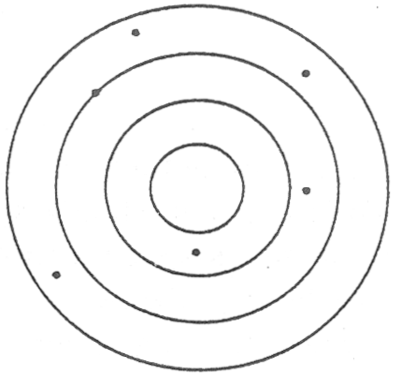
Facts about Measurement Results

- Usually a measurement disturbs its target affecting thus the measurement result.
- A measurement result is always a combination of many factors.

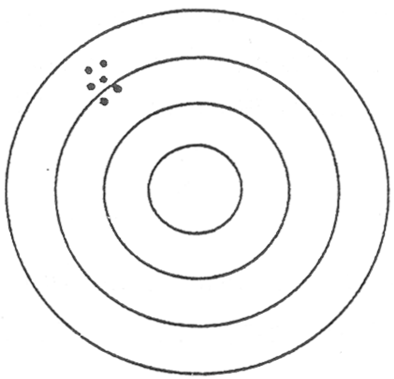
(reading or output signal of the measuring device is only one of them)

- We never know all the factors.
- We never know the “true value” of the factors (we can only estimate).
- The combined effect of unknown factors and inaccurate knowledge on the known factors is described quantitatively with the measurement uncertainty.
- “Absolute certainty is the privilege of uneducated minds ... or fanatics.”

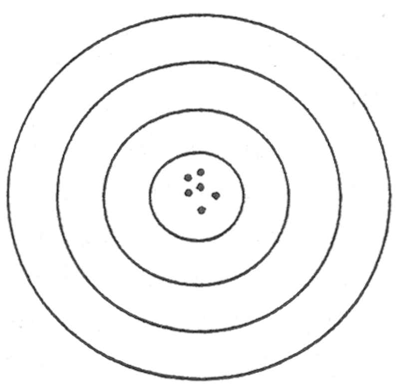
Accuracy and Precision



Low precision - low accuracy



High precision - low accuracy



High precision - high accuracy

accuracy (*tarkkuus*)
closeness of agreement between a measured quantity value and a true quantity value of a measurand

precision (*täsmällisyys*)
closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

[1.1, 1.2]

Calibration (*kalibrointi*)

operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. [1.1, 1.2]

The result of a calibration can be given as

- correction value(s) at discrete measurement point(s)
- calibration equation (curve)
- re-calculated constant(s)
- statement that the error is in given specifications.

A calibration result includes always the uncertainty. (also the probability level should be given)

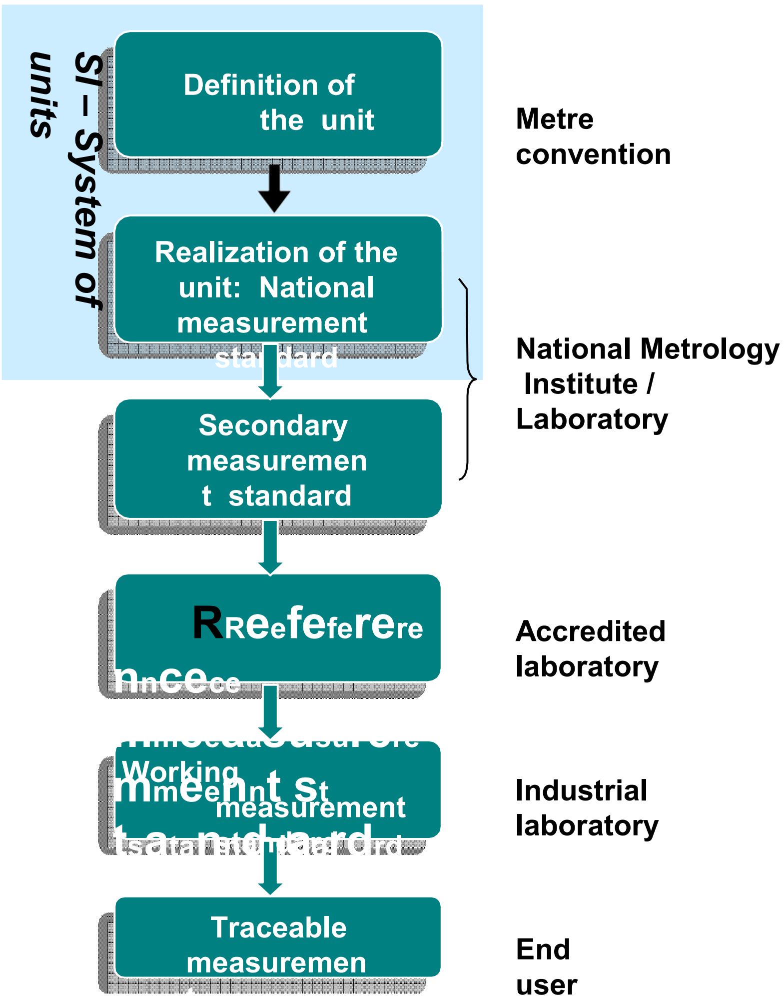
Conditions of calibration should be stated when reporting calibration results.

Adjustment (*viritys*)

set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured [1.1, 1.2]

NOTE 1: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).
NOTE 2: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.
NOTE 3: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

Traceability (*jäljitettävyys*)



Example of traceability chain

(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

Traceability chain:

sequence of measurement standards and calibrations that is used to relate a measurement result to a reference [1.1, 1.2]

Measurement standard (*mittanormaali*)

- realization of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference
- Measurement standard can be an instrument, a measuring system, material measure or a reference material.

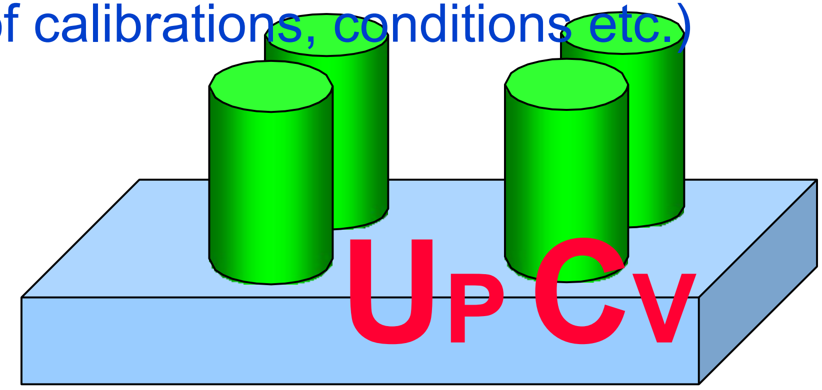
[1.2]

Characteristics of Unbroken Traceability

For each calibration of the chain:

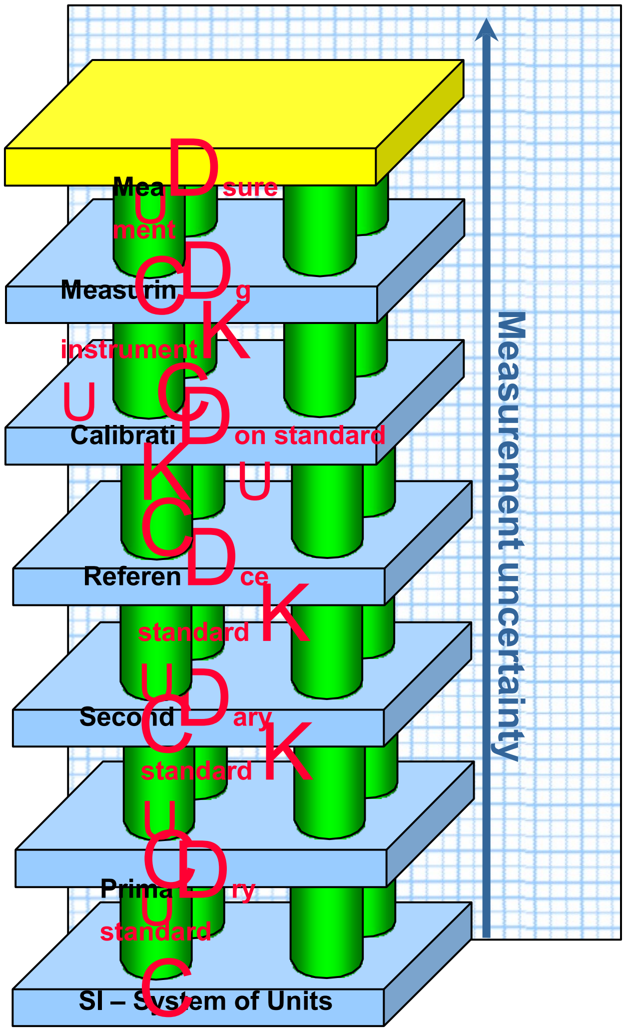
- Uncertainty estimation
- Documented and generally acknowledged procedures, documented results
- Competence
- Calibration is valid for the application.

(interval of calibrations, conditions etc.)



SI – System of Units

Traceability Tower



- The tower is collapsed if any part of it is missing or incomplete

  i.e.

  there is no traceability unless all levels include all the characteristics of traceability

- At any level the measurement uncertainty can´t be smaller than levels below.

Typical problems in traceability

No calibration

Calibration interval too long

No evidence on the traceability in calibration

Calibration was carried out in conditions too different from the application

Incompletetraceability chain

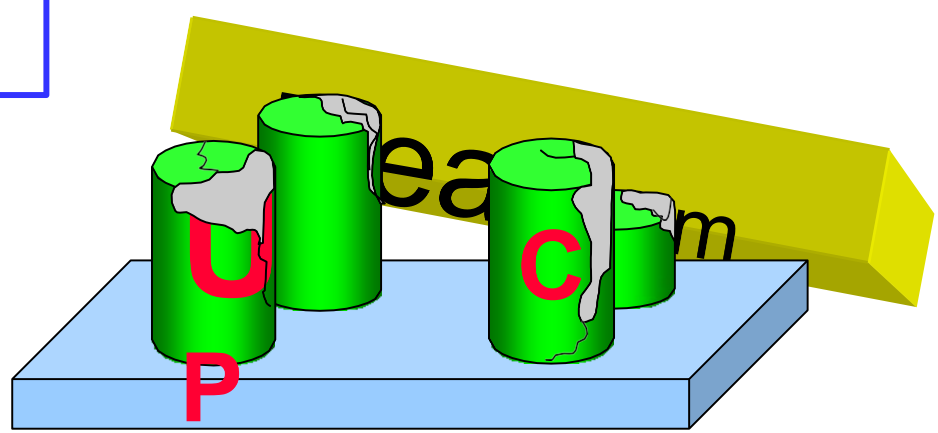
=

no traceability

Calibration results have not been used

Calibration covers only a part of the measuring system

There is no evidence on the traceability of the refence materials

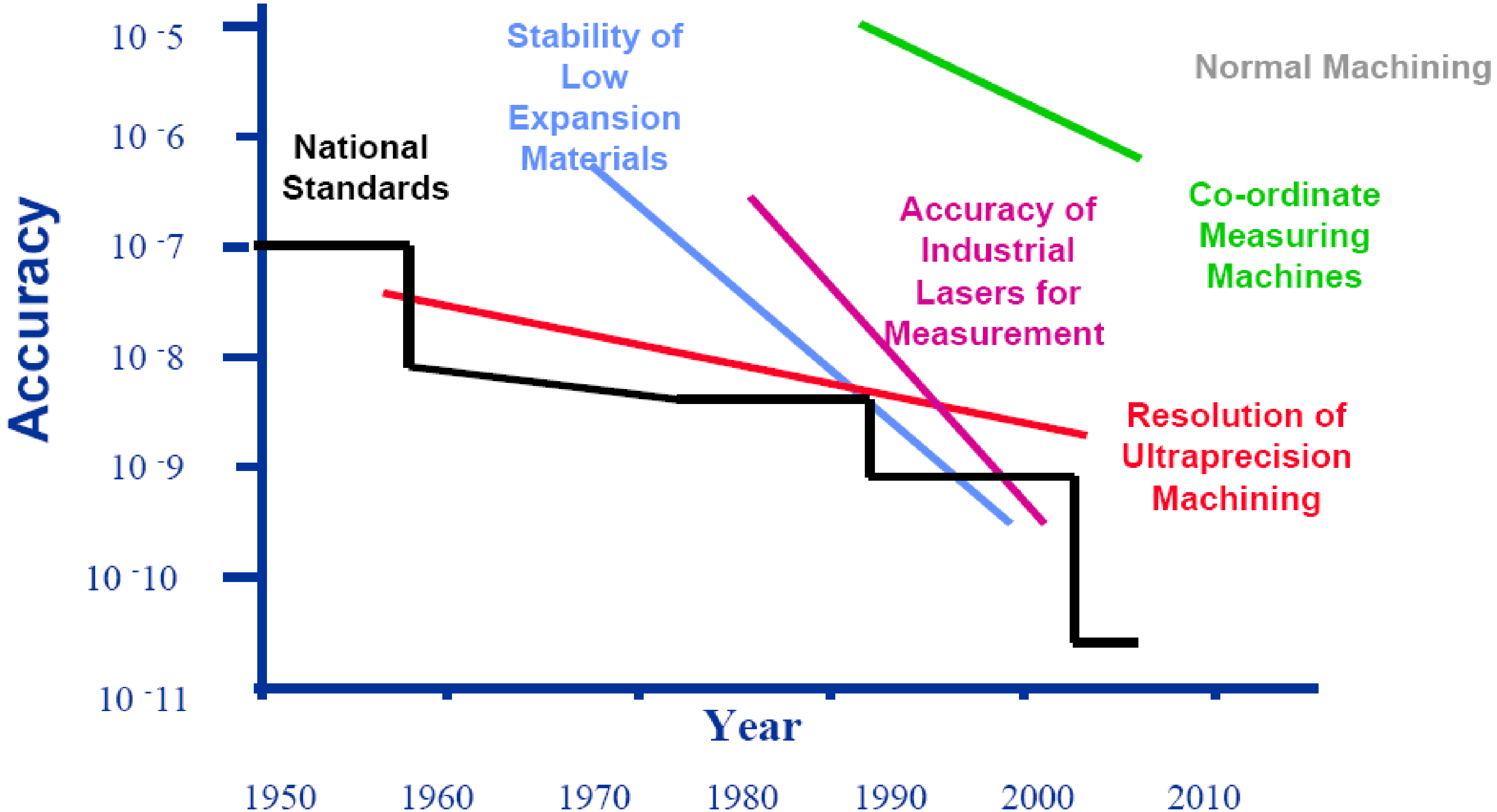


1.2 Why we need traceability?

Traceability – why?

- Modern industrial production is not possible if subcontractors have different scales
- Scientific technical research can not necessarily be repeated if it is done without traceably calibrated instruments
- Traceability is the answer to the questions:
  - From where can I find a reliable measurement standard?
  - How can I convince others of the reliability of my measurement standard?

Accuracy of Length Standards and Commercial Capability 1950 - 2010



Source: DTI UK

1.3 Infrastructure ensuring availability of traceable measurements

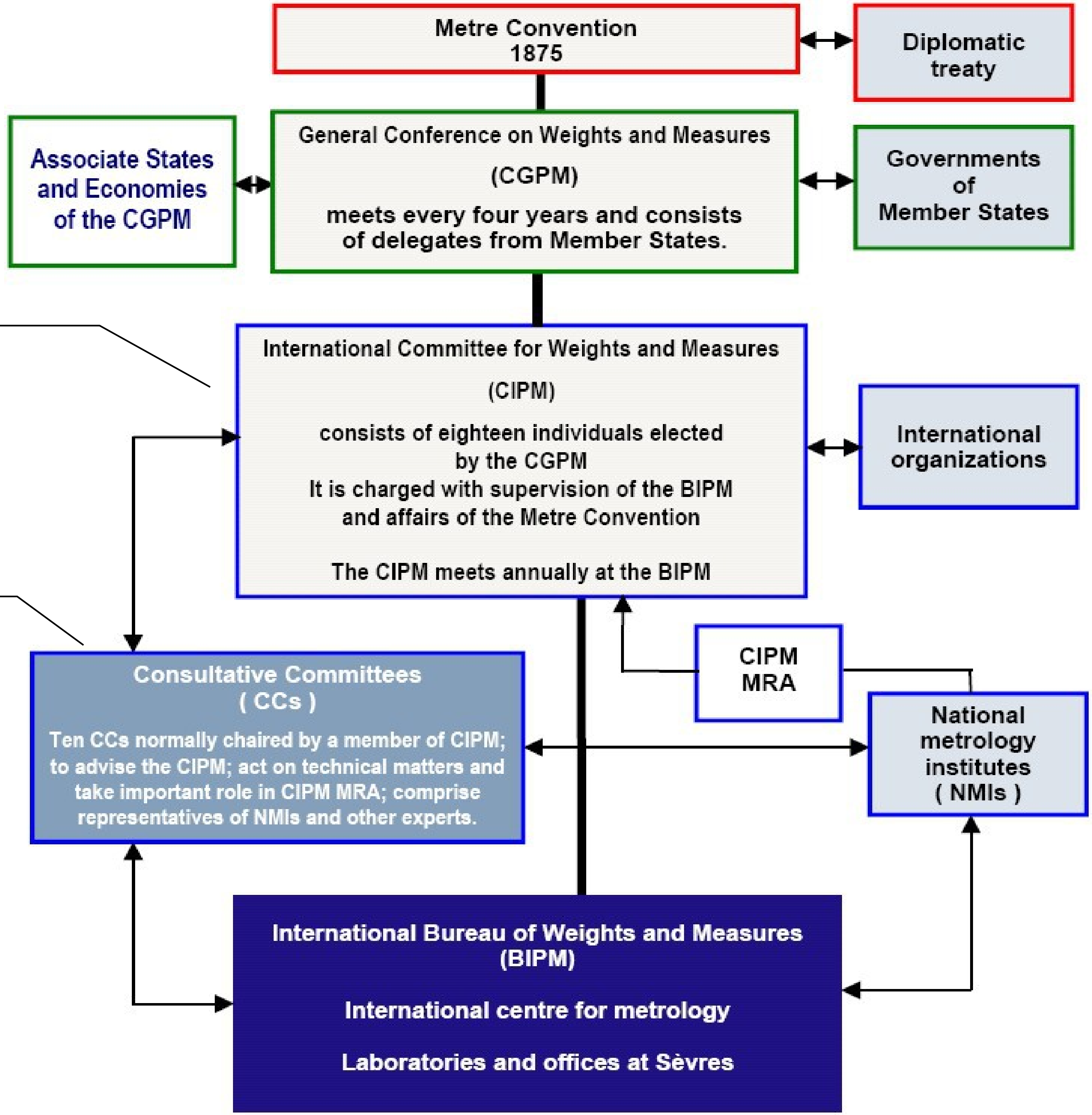
Metrology Infrastructure

- for ensuring global availability of traceable measurements
- foundation: The Metre Convention – a diplomatic treaty first signed in 1875 by representatives of 17 nations
- three levels:
  - Global
  - Regional
  - National

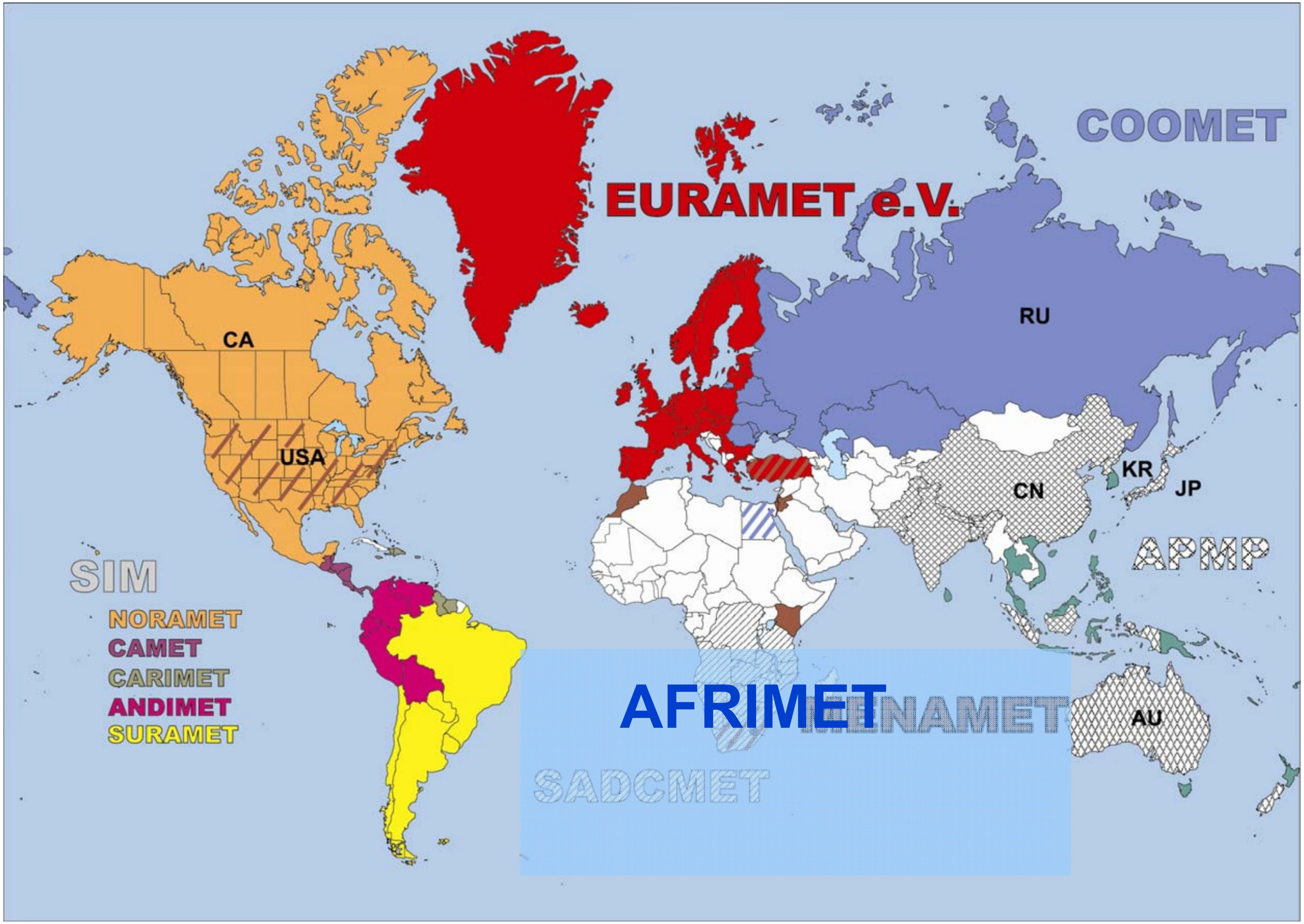
Global:

Finnish members: 1953-1971 Yrjö Väisälä
1992-1998 Olli Lounasmaa

MIKES is a member of:
- CC for Length,
- CC for Electricity and Magnetism
- CC for Thermometry
- CC for Photometry and Radiometry

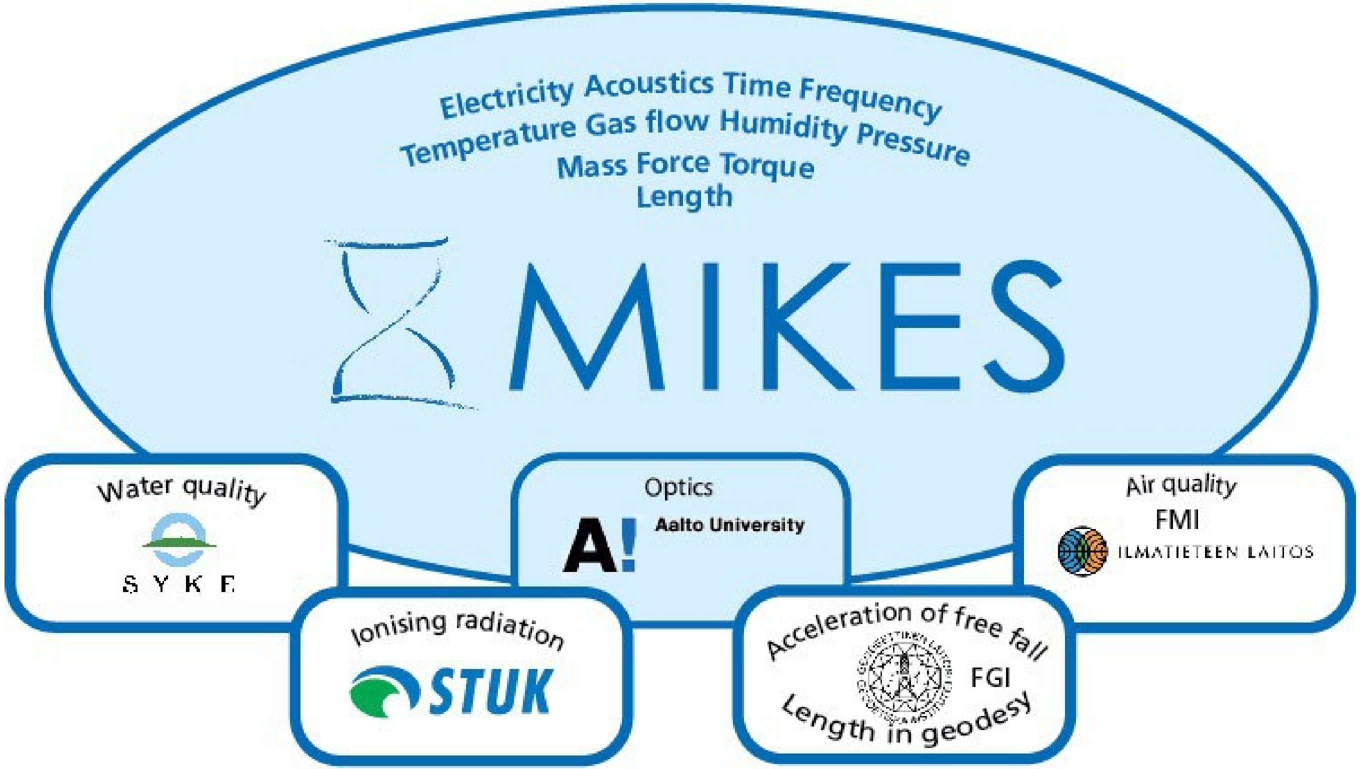


Regional:



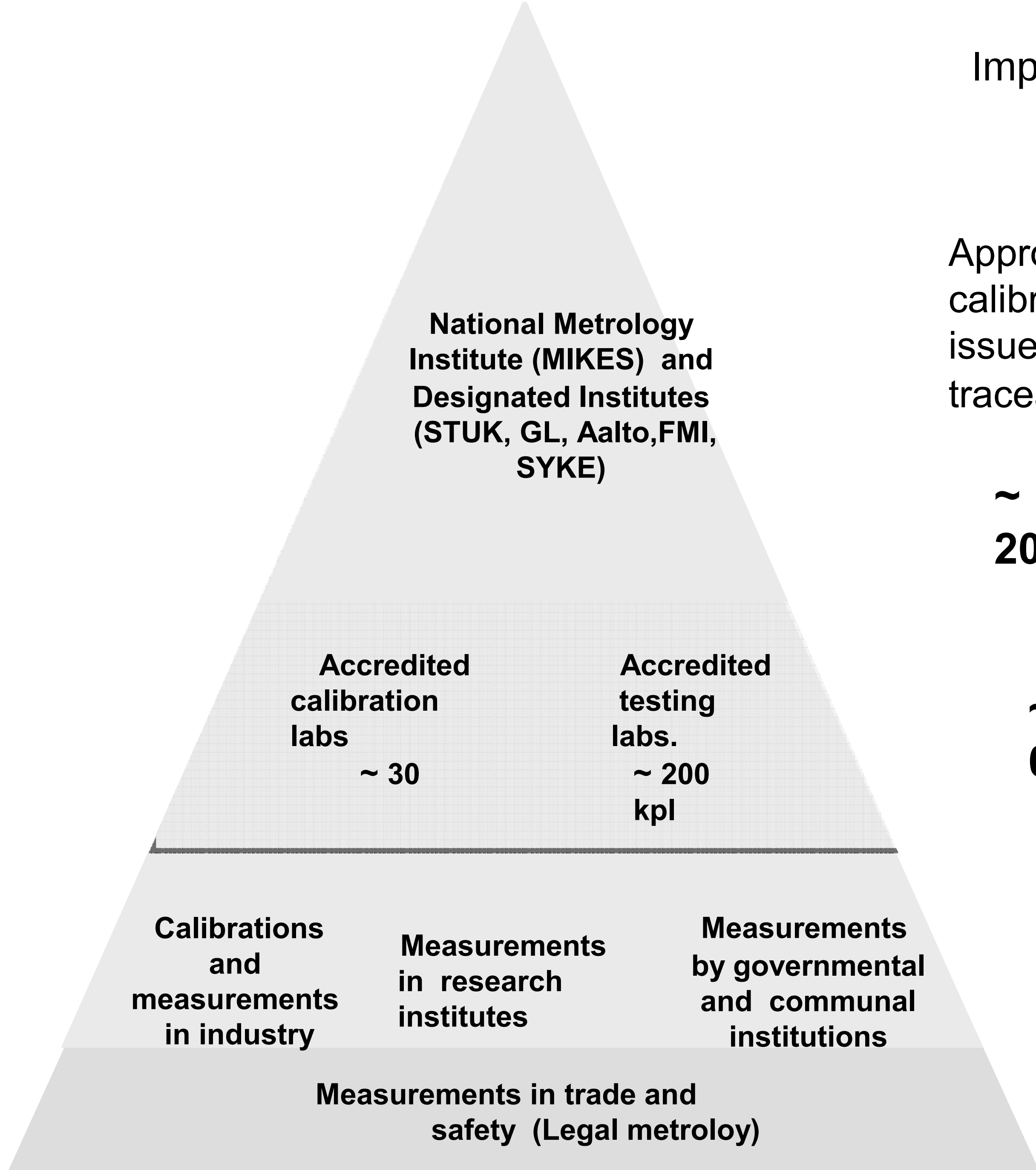
MIKES

National:



Electricity Acoustics Time Frequency
Temperature Gas flow Humidity Pressure
Mass Force Torque
Length
MIKES
Water quality
SYKE
Optics
Aalto University
Air quality
FMI
ILMATIETEEN LAITOS
Ionising radiation
STUK
Acceleration of free fall
FGI
Length in geodesy

Impact of metrology: Finnish numbers



Approximate amount of traceable calibration and testing certificates issued annually and traceable instruments/measurements

~ 2000

~ 20 000

~ 2 000 000

~ 2 000 000 000 (00?)

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

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

CIPM MRA objectives:

- to establish the degree of equivalence of measurement standards maintained by NMIs;
- to provide for the mutual recognition of calibration and measurement certificates issued by NMIs; thereby to
- to provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce and regulatory affairs

MRA has been signed by 67 NMIs from 45 states and 20 associate states

MRA includes database of NMIs reviewed calibration services with corresonding uncertainties (CMCs)

MIKES has several 100s of different CMC entries