SIM | Metrology School

International Metrology

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In what sense is metrology international?

- Measurements made in your lab need to agree with measurements elsewhere
- Uncertainties claimed must be accepted internationally

Why?

- International trade: measurements made across the globe must agree
- Scientific discovery: measurements must agree

Some other examples

- For monitoring of health, measurements must agree
- For monitoring our environment, measurements must agree

The Cubit

The "Royal Egyptian Cubit" was decreed to be equal to the length of the forearm from the bent elbow to the tip of the extended middle finger plus the width of the palm of the hand of the Pharaoh or King ruling at that time.

The "Royal Cubit Master" was carved out of a block of granite to endure for all times. Workers engaged in building tombs, temples, pyramids, etc. were supplied with cubits made of wood or granite. They were required to bring back their cubit sticks at each full moon to be compared to the Royal Cubit Master. Failure to do so was punishable by death.

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Many early measures were based on natural objects

Chinese length standards based on the resonance tone of 'standard' bamboo whistles

Carob seeds, used to derive the carat

photo by gourmetsleuth.com

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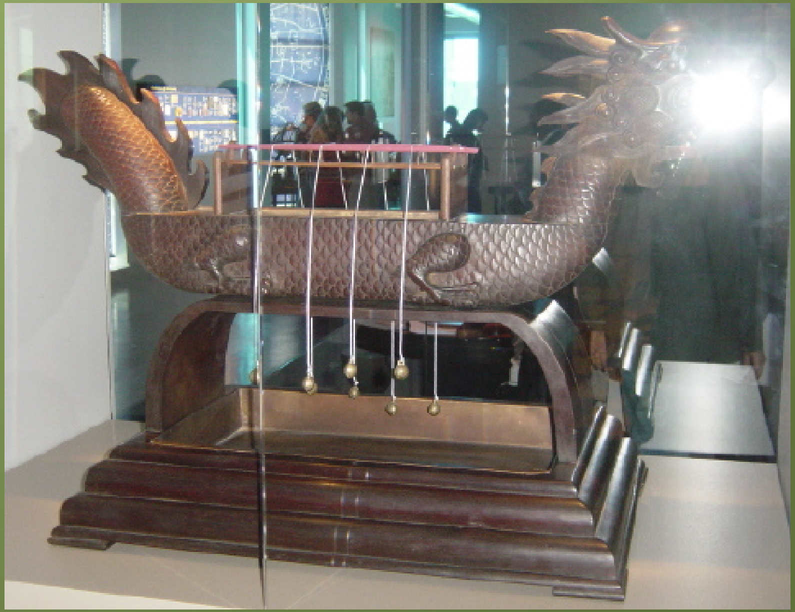
Ancient time keeping – Chinese Incense Clock

- Sequence of bells tied to a horizontally mounted burning incense
- When incense burns & breaks the threads, the bells fall at preset interval to sound an alarm

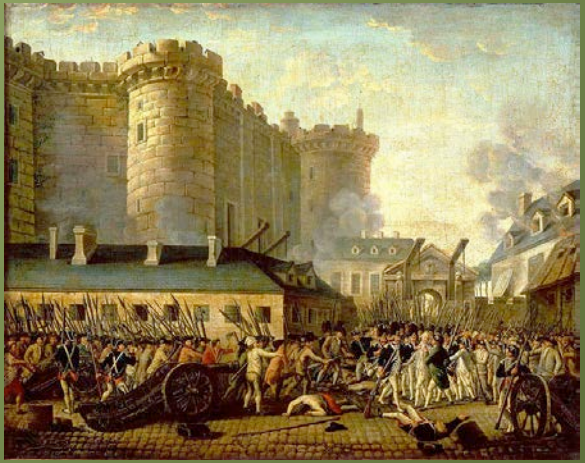


香鐘, 香钟, xiāng zhōng

Song Dynasty (960-1279)

The Metric System was Born in the Spirit of The French Revolution in the 1790s

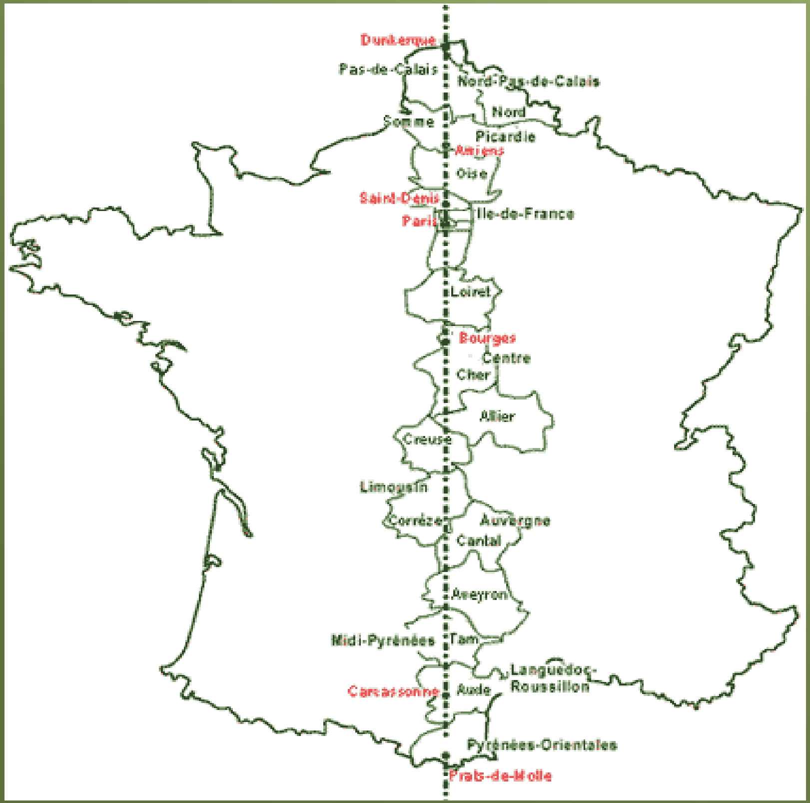
- A measurement system based based on equality and natural law
  - Meter: 1/10,000,000 of Earth's meridian (North Pole to Equator)
  - Kilogram: weight of 1/1000 cubic meter of pure water
- Nationalistic systems to be replaced by internationally accepted one



Storming of the Bastille
July 14, 1789

Both of these principles remain at the center of the SI today.

Realizing the meter
Survey of the Earth, 1792–1799



Survey of the Meridian, Dunkirk to Barcelona

Jean-Baptiste Delambre (1749–1822)

Pierre Méchain (1744–1804)

Treaty of the Meter, 1875
First, set up a system of international governance

The Convention of the Metre (*Convention du Mètre*) is a treaty that created the International Bureau of Weights and Measures (BIPM), an intergovernmental organization under the authority of the General Conference on Weights and Measures (CGPM) and the supervision of the International Committee for Weights and Measures (CIPM). The BIPM acts in matters of world metrology, particularly concerning the demand for measurement standards of ever increasing accuracy, range and diversity, and the need to demonstrate equivalence between national measurement standards.

The Convention was signed in Paris in 1875 by representatives of seventeen nations. As well as founding the BIPM and laying down the way in which the activities of the BIPM should be financed and managed, the Metre Convention established a permanent organizational structure for member governments to act in common accord on all matters relating to units of measurement. The Convention, modified slightly in 1921, remains the basis of international agreement on units of measurement. The BIPM now has 55 Member States, including all the major industrialized countries.

The International System of Units (SI)

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BIPM's
Member
States

General Conference on Weights and Measures
Conférence générale des poids et Measures
[CGPM]

Consists of delegates from Member States and meets every four years

Intl. Committee for Weights and Measures
Comité international des poids et mesures
[CIPM]

Consists of 18 individuals elected by the CGPM, charged with the supervision of the BIPM and of its activities, meets annually

International Bureau of Weights and Measures
Bureau international des poids et mesures
[BIPM]

Intergovernmental organization with headquarters located in Sèvres, France

Treaty of the Meter, 1875
Second, authorize the production of international prototype standards

After the signing of the Metre Convention on 20 May 1875, which created the BIPM and established the CGPM and the CIPM, work began on the construction of new international prototypes of the metre and kilogram. In 1889 the 1st CGPM sanctioned the international prototypes for the metre and the kilogram. Together with the astronomical second as the unit of time, these units constituted a three-dimensional mechanical unit system with the base units metre, kilogram, and second, the MKS system.

The International System of Units (SI)

Standard Meter prototypes

Shown: National Prototype Meter No. 27, received by the U.S. in 1890

Standard Kilogram prototypes

Shown: International Prototype of the Kilogram, kept at BIPM

The International System of Units (SI)

Then, more units . . .

- 1948 – CGPM adds the ampere to the SI
- 1948 – CGPM adds the candela to the SI
- 1954 – CGPM adds the kelvin to the SI

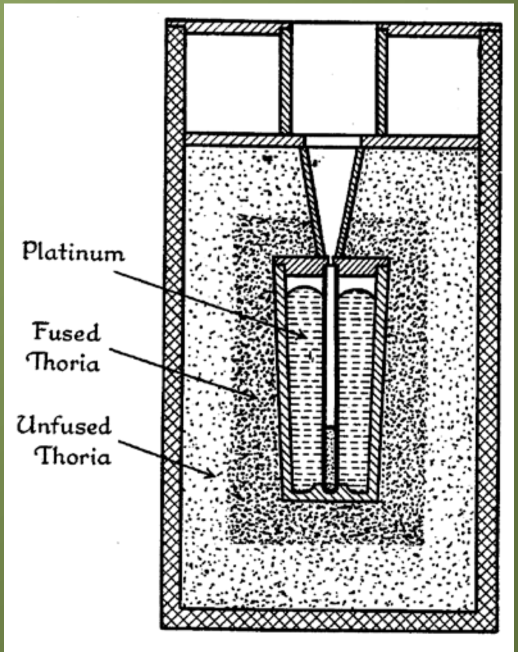


FIG. 99. The Primary Standard of Light.

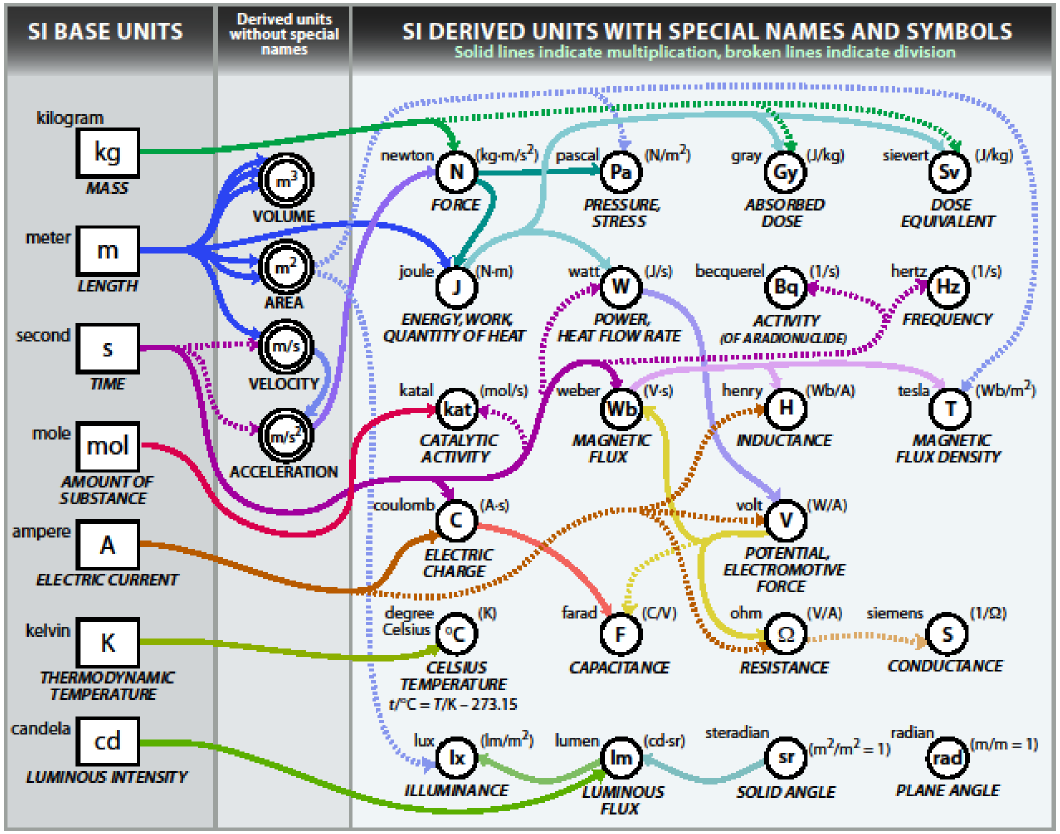
A comprehensive system of units

1954: 10th CGPM, Resolution 6: practical system of units

In accordance with the wish expressed by the 9th Conférence Générale des Poids et Mesures (CGPM) in its Resolution 6 concerning the establishment of a practical system of units of measurement for international use, the 10th CGPM decides to adopt as base units of the system, the following units:

length	meter
mass	kilogram
time	second
electric current	ampere
thermodynamic temperature	degree Kelvin
luminous intensity	candela

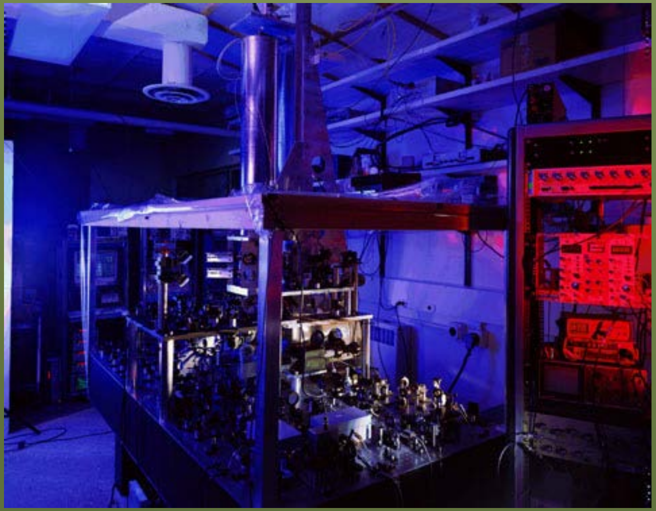
The International System of Units (SI)



"Quantum" definition of the second

The second was defined originally as 1/86,400 of the "mean solar day." The exact definition was left to astronomers.

1967: *The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the ^{133}Cs atom.*



NIST-F2, today's U.S. primary atomic frequency standard

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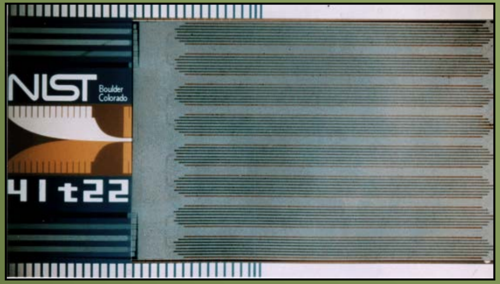
"Quantum" definition of the meter

1889: International Prototype Meter

1960: Based on wavelength of ^{86}Kr radiation

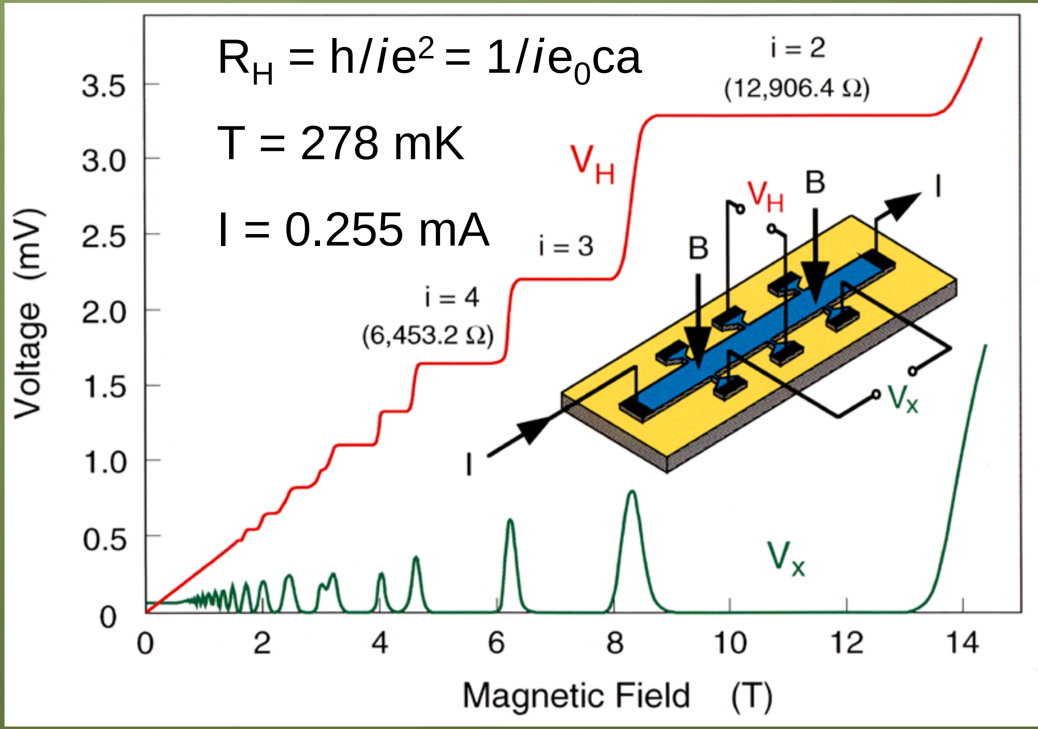
1983: *The meter is the length of the path travelled by light in vacuum during a time interval of* 1/299,792,458 *of a second.*

"Quantum" standards for the electrical units



The "volt" realized by Josephson Junction devices, with K_{J-90} = 483,597.9 GHz/V

The "ohm" realized by Quantum Hall Effect devices, with R_{K-90} = 25,812.807 Ω



The International System of Units (SI)

- Similarly, the CIPM is currently considering possible redefinitions of:
  - kilogram
  - ampere
  - kelvin
  - mole
- Determined by fixing the values of:
  - Planck constant
  - Elementary electric charge of the electron
  - Boltzmann constant
  - Avogadro constant
- Perhaps in 2018

Without standards . . .

1904

Out-of-town fire companies arriving at a fire in Baltimore, Maryland cannot couple their hoses to the hydrants. 1526 buildings razed.

1912

41,578 U.S. train derailments in previous decade due to inferior steel

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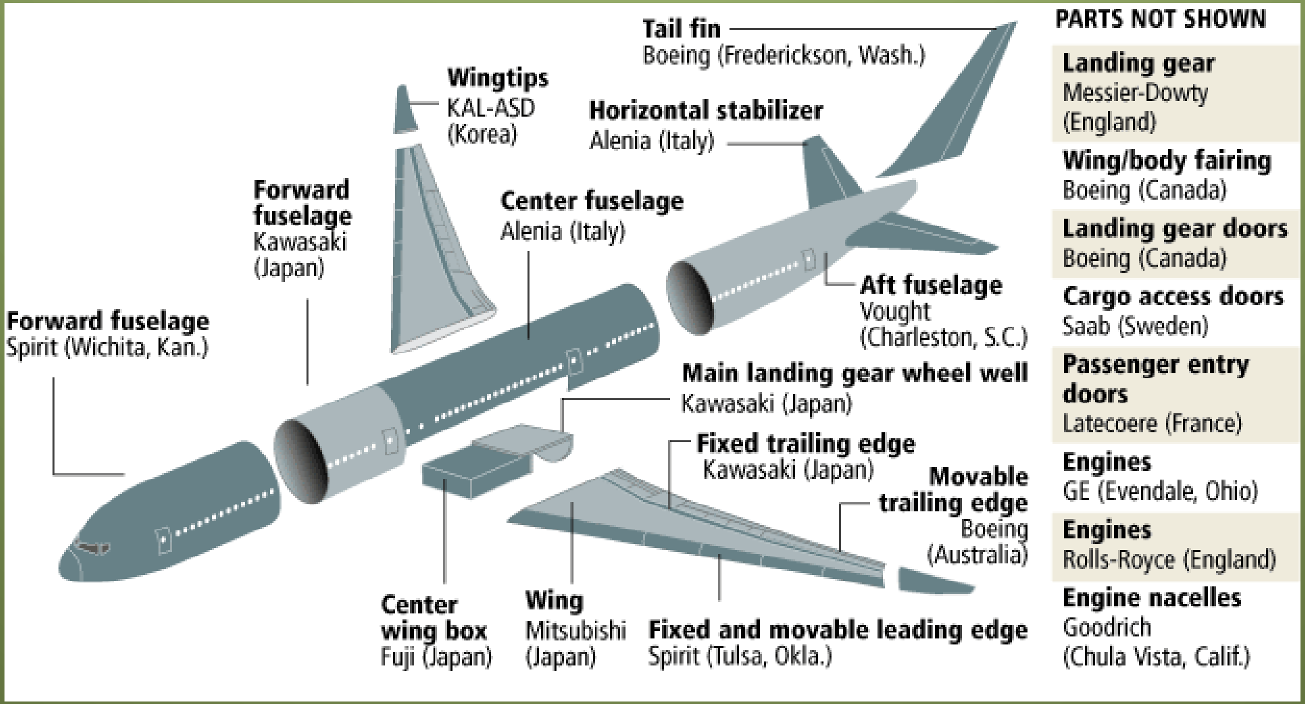
Ensuring equivalent measurements everywhere



- Major subassemblies of the Boeing 787 Dreamliner are produced by a distributed network of suppliers
- Airplanes require maintenance wherever their port of call

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How does a nation ensure that their measurements are acceptable to another nation?

Bilateral comparisions between all nations

- Why not?
    - Assuming 81 nations that would be 81 x 80 /2 or 3,240 bilaterals in each of many subject areas

That is an impossible challenge . . .

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The CIPM Mutual Recognition Arrangement

- Signed October 14, 1999 by 38 member states
- It requires the signatories to accept the published capabilities of each other
- Today the MRA includes 52 Member States, 37 Associates of the CGPM, and 4 international organizations – and covers a further 149 institutes designated by the signatory bodies
- The MRA outlines the process to assure mutual recognition of capabilities including the requirement of participation in key comparisons and having quality systems

The CIPM MRA

BIPM's Member States

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Consultative Committees

National Metrology Laboratories

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Intergovernmental organization with headquarters located in Sèvres, France

CIPM MRA

JCRB

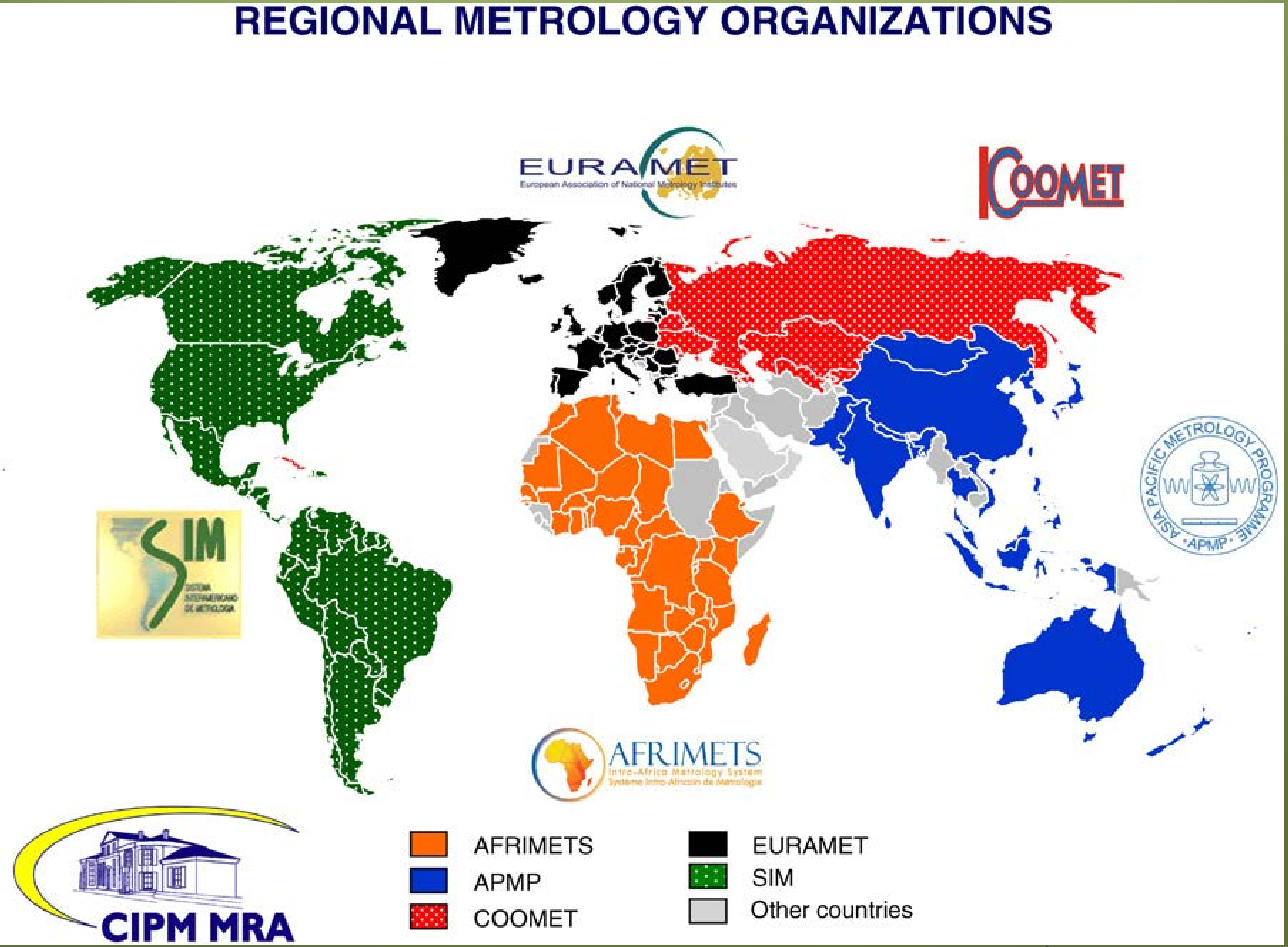
The CIPM MRA - RMOs

The CIPM MRA requires that NMIs and Designated Institutes prove their technical capability to provide a particular measurement service and demonstrate that they have a suitable quality system in place to help ensure reliable dissemination of that measurement service to their customers.

In order to do that the world was divided into Regional Metrology Organizations or RMOs. There are currently 5 RMOs:

- AFRIMETS
- APMP
- COOMET
- EURAMET
- SIM

The CIPM MRA - RMOs



What do RMOs Do?

- Encourage collaborations between NMIs
- Raise competence of the region
- Transfer knowledge
- Help implement BIPM's global policies at the regional level
- Regional technical review of the CMCs of each National Metrology Institute and Designated Institute (DI)
- International review of other RMO's CMCs
- Review of the Quality Systems of each NMI and DI (note that the Quality Systems are only reviewed regionally)

The CIPM MRA - CMCs

Calibration and Measurement Capabilities (CMC)

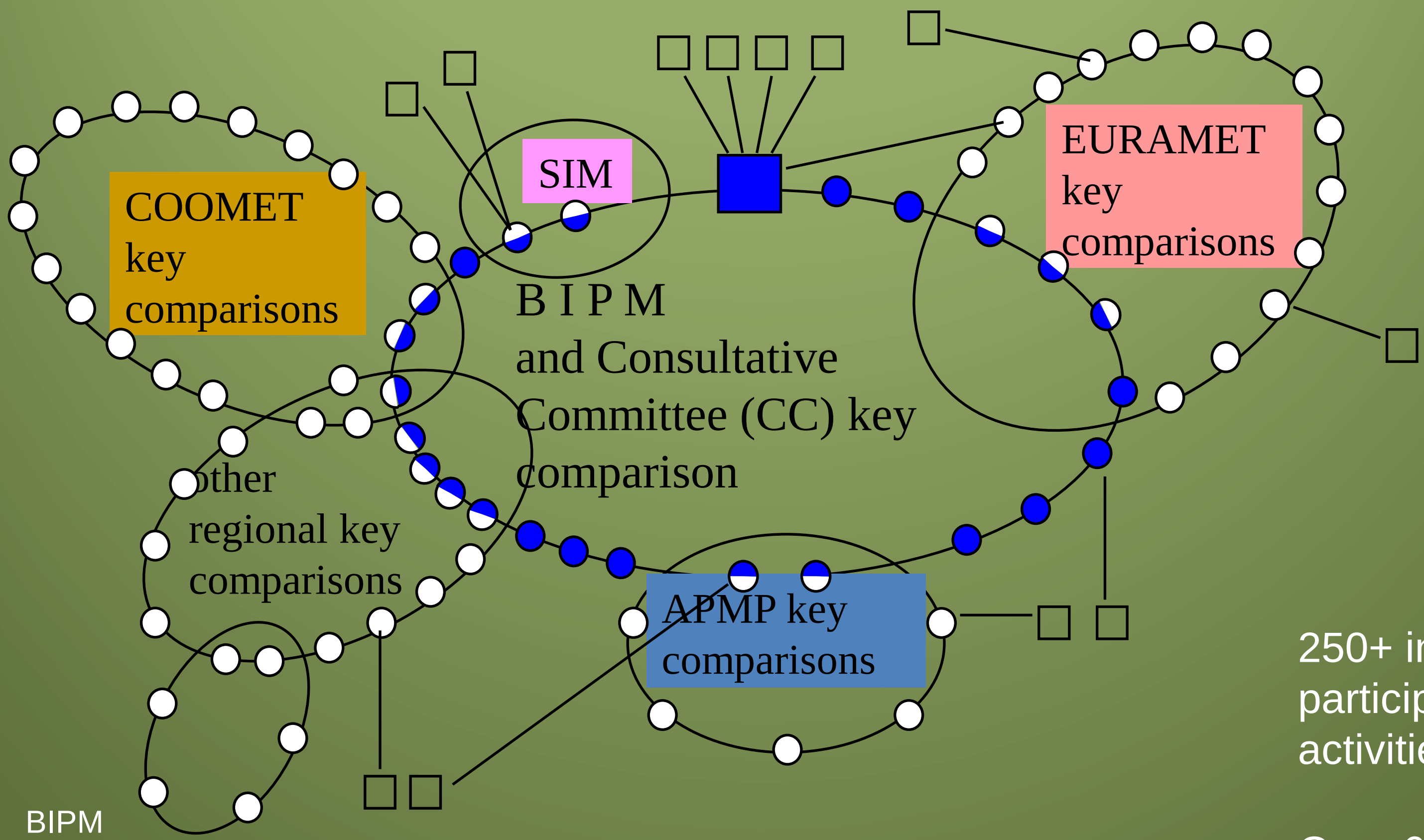
CMCs are first reviewed regionally to determine if claimed capability is supported by evidence of:

- Comparison results (key, supplemental, or bilateral)
- Technical reputation (publications, other technical activities)

Traceability to the SI must be demonstrated either by a local realization of the SI or by traceability to an NMI that realizes the SI for that quantity

After regional approval, the other 4 RMOs have an opportunity to review the CMCs before they are published in Appendix C

The CIPM MRA – Key Comparisons



- BIPM
- NMI participating in BIPM / CC key comparisons
- NMI participating in BIPM / CC key comparisons and in regional key comparisons
- NMI participating in regional key comparisons
- NMI participating in neither BIPM / CC nor regional key comparisons but making bilateral comparisons

250+ institutes participate in CC activities

Over 600 key comparisons have been identified

Quality System Review

All NMIs and DIs must have a quality system consistent with ISO/IEC 17025 for calibration services and ISO Guide 34 for certified reference materials

NMIs and DIs may be either accredited or self-declared regarding their quality systems. External peer review is required.

Each RMO has a quality committee that determines if the quality systems are acceptable for supporting the CMCs. SIM has the Quality System Task Force (QSTF)

Their approval is final but each quality system must be reapproved every 5 years.

NMIs and DIs must report problems to the RMO quality committee such as loss of key personnel, loss of equipment, failure in a key comparison that might indicate a problem in providing their measurement services consistent with their CMCs.

The CIPM MRA

If you want your measurements internationally accepted

- Your NMI must be a signatory to the CIPM MRA
- You must participate in key or bilateral comparisons to establish your technical capabilities
- Your CMCs must be approved by SIM and internationally
- Your Quality Systems must be approved by the SIM QSTF.

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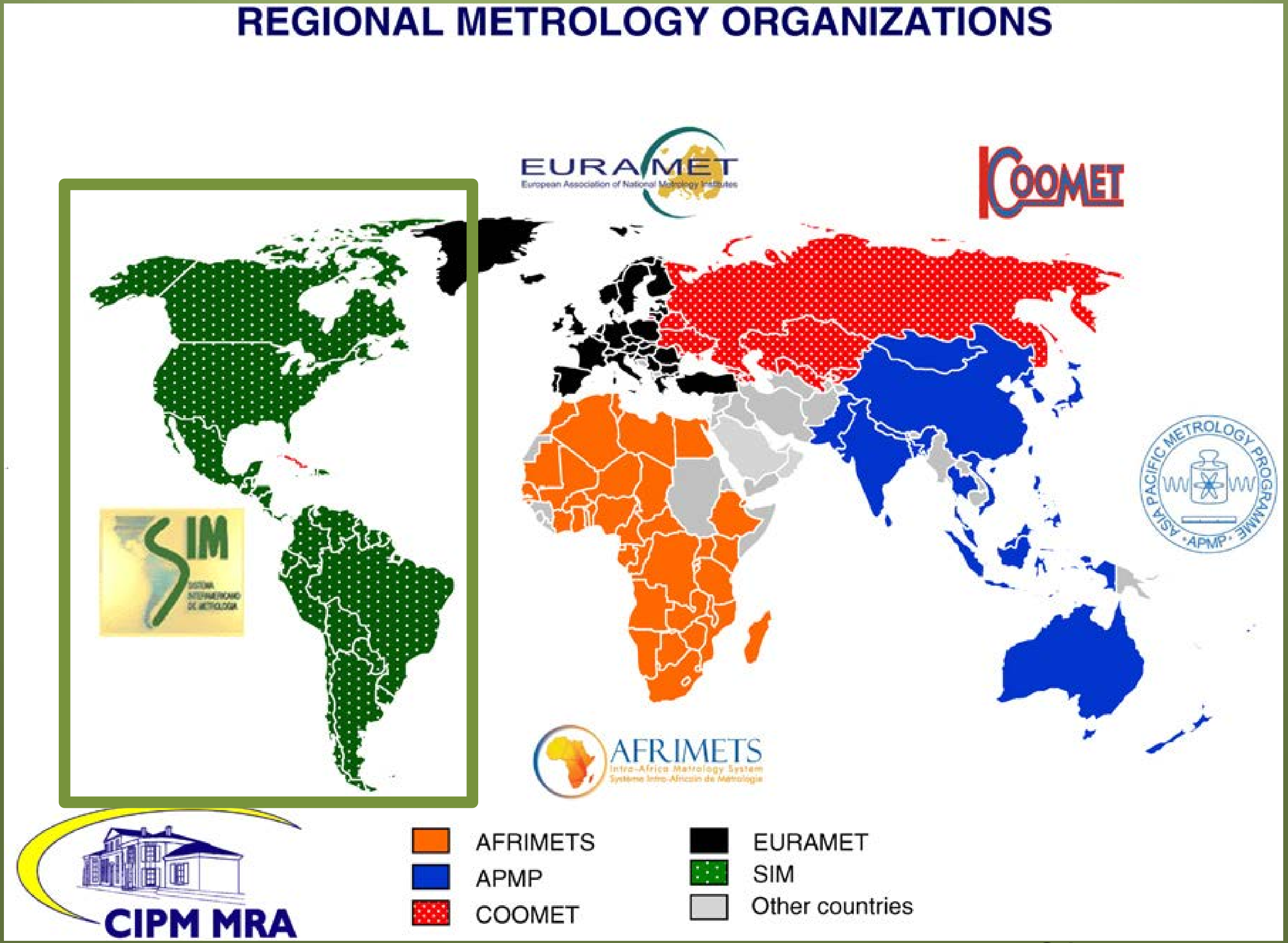
REGIONAL METROLOGY ORGANIZATIONS
EURAMET
European Association of National Metrology Institutes
COOMET
SIM
ASIA PACIFIC METROLOGY PROGRAMME
APMP
AFRIMETS
Intra-Africa Metrology System
Système Intra-Africain de Métrologie
CIPM MRA
AFRIMETS
APMP
COOMET
EURAMET
SIM
Other countries

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Questions?

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Group Photo!