Capacity Building & Knowledge Transfer

The Metre Convention and the BIPM

Dr Martin J.T. Milton

Director of the BIPM

Bureau International des Poids et Mesures

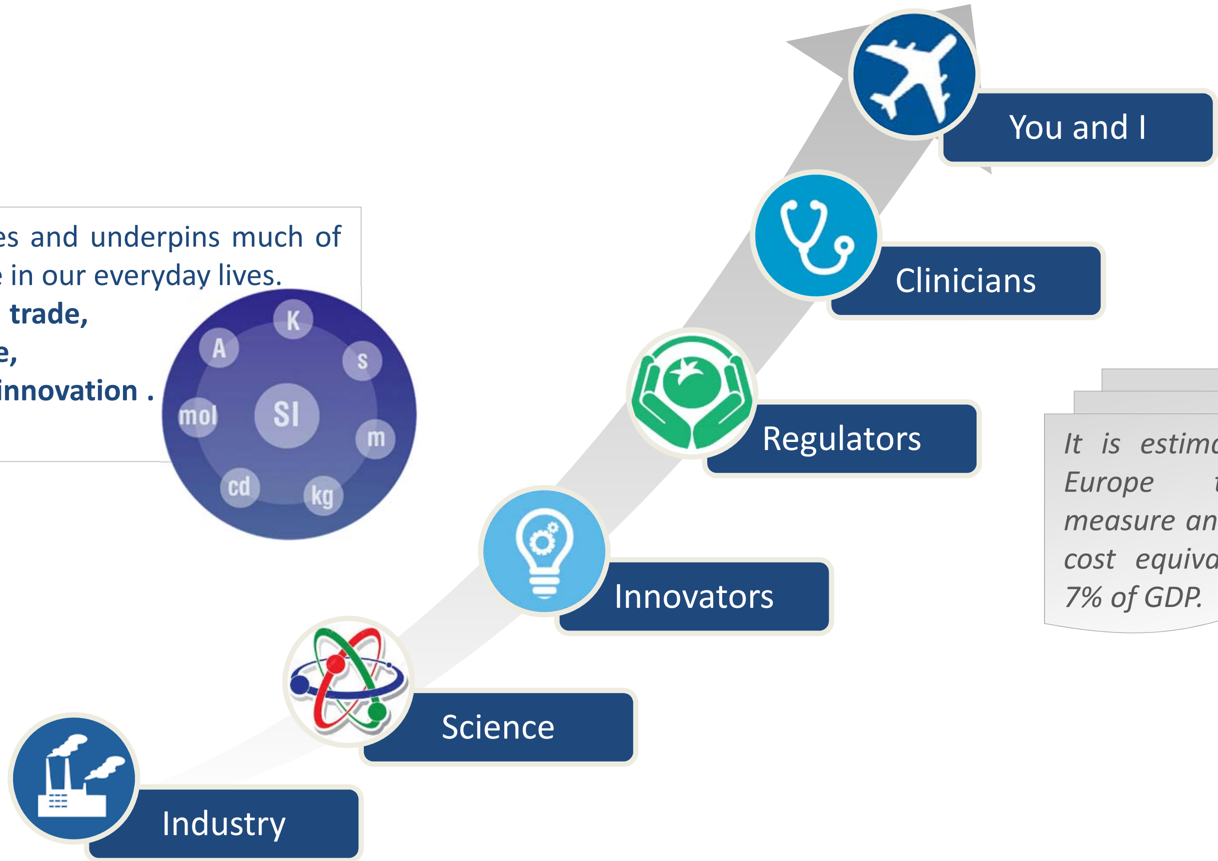
Outline

Today's growing demand for better measurements

Metrology influences, drives and underpins much of what we do and experience in our everyday lives.

- **Industry and trade,**
- **quality of life,**
- **science and innovation .**

all rely on metrology.



It is estimated that in Europe today we measure and weigh at a cost equivalent to 2%-7% of GDP.

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The objectives of Metrology

Metrology is the “science and practice of measurement”, its objectives are

Measurements that are stable

- Long-term trends can be used for decision making

Measurements that are comparable

- Results from different laboratories can be brought together

Measurements that are coherent

- Results from different methods can be brought together

To meet the needs of the economy, society and citizens

The objectives of Metrology

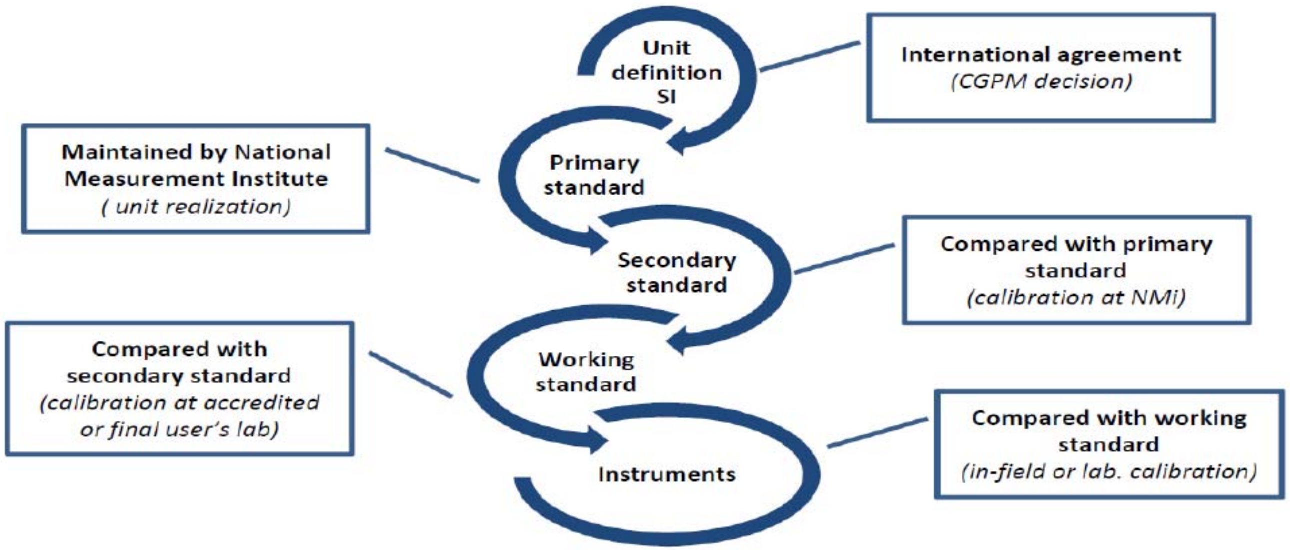
The objectives of metrology are achieved through providing the framework for traceable measurements.

“Traceability” - the 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

From the International Vocabulary of Basic and General Terms in Metrology; VIM, 3rd edition, JCGM 200:2008

Note: traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory

The traceability “chain”



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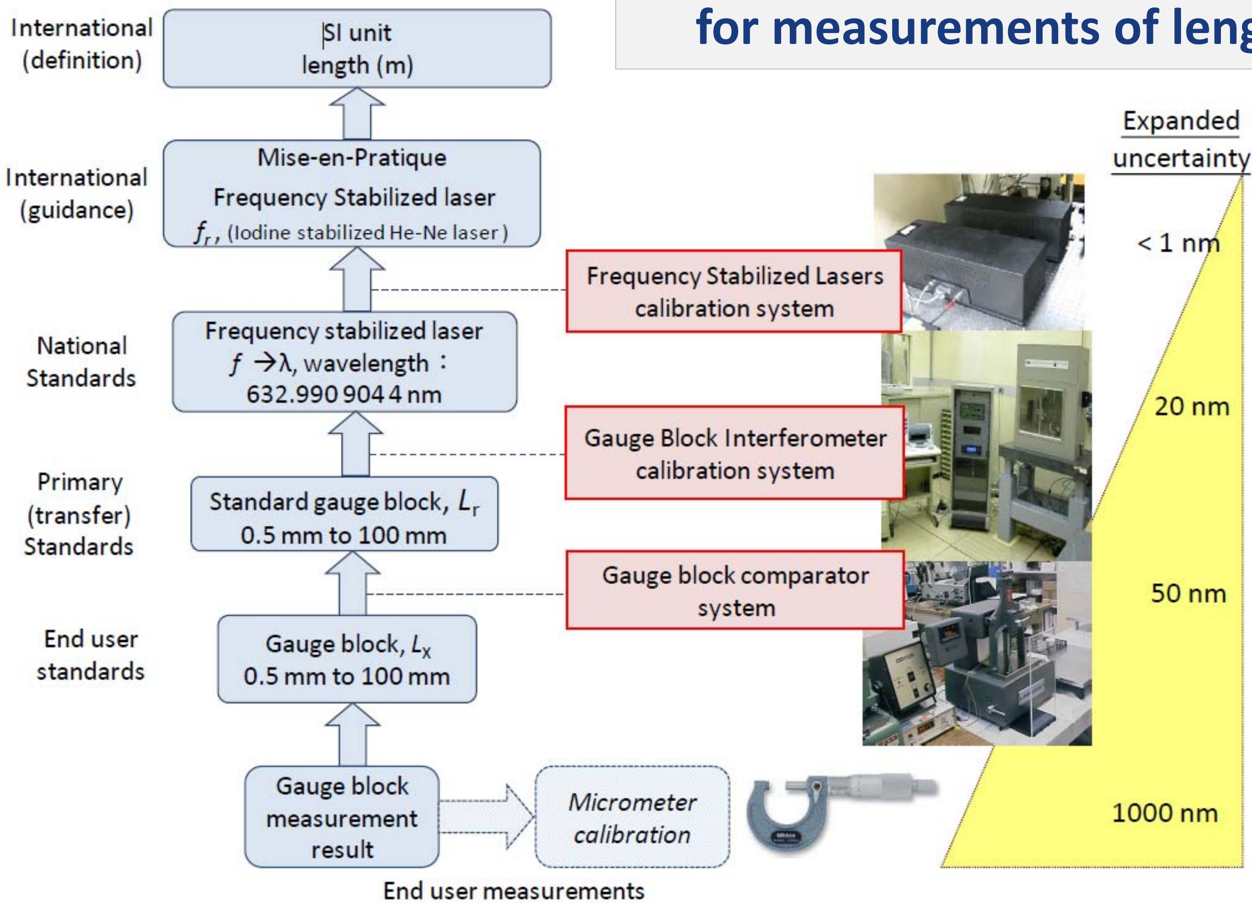
Slide courtesy
Dr S Davidson, NPL, UK

A traceability chain for measurements of length



Slide courtesy
Dr S Davidson, NPL, UK

Outline

01 - The key elements of metrology and why it is important?

02 – The Metre Convention and the BIPM.

03 - The SI units – recent progress towards revising the SI.

04 - Worldwide impact of metrology through the CIPM MRA.

05 - World Metrology Day.

Why was the Metric system of so much interest?

The Metric System was first introduced after the French Revolution:

to allow fair trade by weight and length.

The definitions were:

- **The metre** = one ten millionth of the meridian of the earth (through Paris).
- **The kilogram**= the mass of 1dm^3 of water (at its temperature of maximum density).

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But, in 1812 – Napoleon abandoned the Metric System !

Why was the Metric system of so much interest?

In the middle of the 19th century

- **The Metric System was introduced again in France.**

But confusion grew about which which the true realisations of the metre and the kilogram:

- the old revolutionary standards, or the artefact standards held in the National Srchives.

And there were new demands for more accurate measurements.

Provost, Exposition universelle de 1855, vue de la grande nef du Palais de l'Industrie, 1855, Lithographie en couleurs, musée d'Orsay

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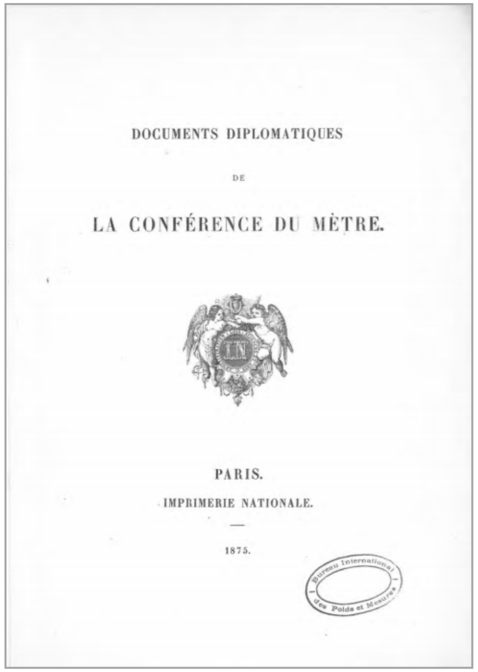
the Metre Convention


DOCUMENTS DIPLOMATIQUES

DE

LA CONFÉRENCE DU MÈTRE.

PARIS.

IMPRIMERIE NATIONALE.

1875.

20 May 1875 - The Metre Convention was signed in Paris by 17 nations which established the BIPM

ARTICLE PREMIER (1875)

Les Hautes Parties contractantes s'engagent à fonder et entretenir, à frais communs, un *Bureau international des poids et mesures*, scientifique et permanent, dont le siège est à Paris(1).

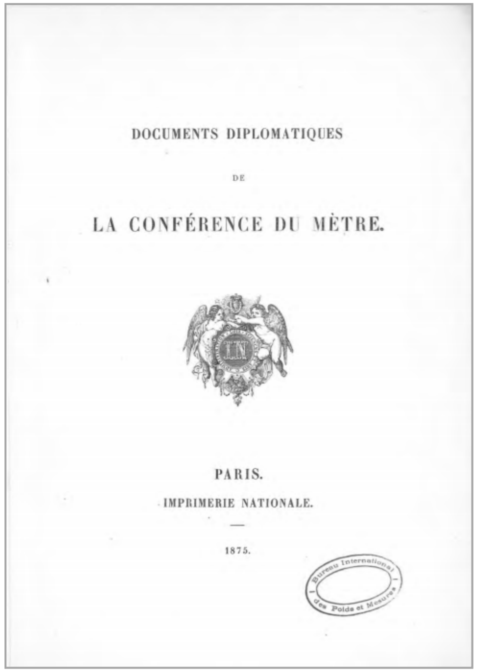
The First Article states about creation of the International Bureau of Weights and Measures (BIPM)

ART. 3 (1875)

Le Bureau international fonctionnera sous la direction et la surveillance exclusives d'un *Comité international des poids et mesures*, placé lui-même sous l'autorité d'une *Conférence générale des poids et mesures*, formée de délégués de tous les Gouvernements contractants.

The Article 3 states that the BIPM shall operate 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 Metre Convention


DOCUMENTS DIPLOMATIQUES

DE

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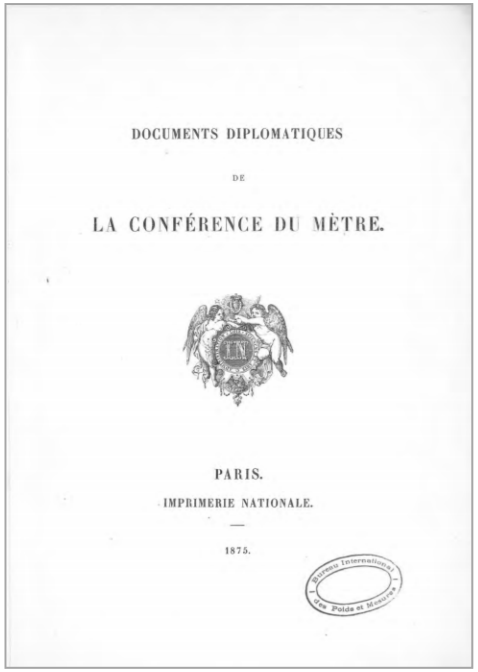
1875.

ART. 10 (1921)

The International Committee directs all metrological work the High Contracting parties shall decide to have carried out in common.

the Metre Convention


DOCUMENTS DIPLOMATIQUES

DE

LA CONFÉRENCE DU MÈTRE.

PARIS.

IMPRIMERIE NATIONALE.

1875.

ART. 6 (1.875)

Le Bureau international des poids et mesures est chargé :

1° De toutes les comparaisons et vérifications des nouveaux prototypes du mètre et du kilogramme ;

2° De la conservation des prototypes internationaux ;

3° Des comparaisons périodiques des étalons nationaux avec les prototypes internationaux et avec leurs témoins, ainsi que de celles des thermomètres étalons ;

4° De la comparaison des nouveaux prototypes avec les étalons fondamentaux des poids et mesures non métriques employés dans les différents pays et dans les sciences ;

5° De l'étalonnage et de la comparaison des règles géodésiques ;

6° De la comparaison des étalons et échelles de précision dont la vérification serait demandée, soit par des Gouvernements, soit pàr des sociétés savantes, soit même par des artistes et des savants.

ART. 7 (1921)

Après que le Comité aura procédé au travail de coordination des mesures relatives aux unités électriques, et lorsque la Conférence générale en aura décidé par un vote unanime, le Bureau sera chargé de l'établissement et de la conservation des étalons des unités électriques et de leurs témoins, ainsi que de la comparaison, avec ces étalons, des étalons nationaux ou d'autres étalons de précision.

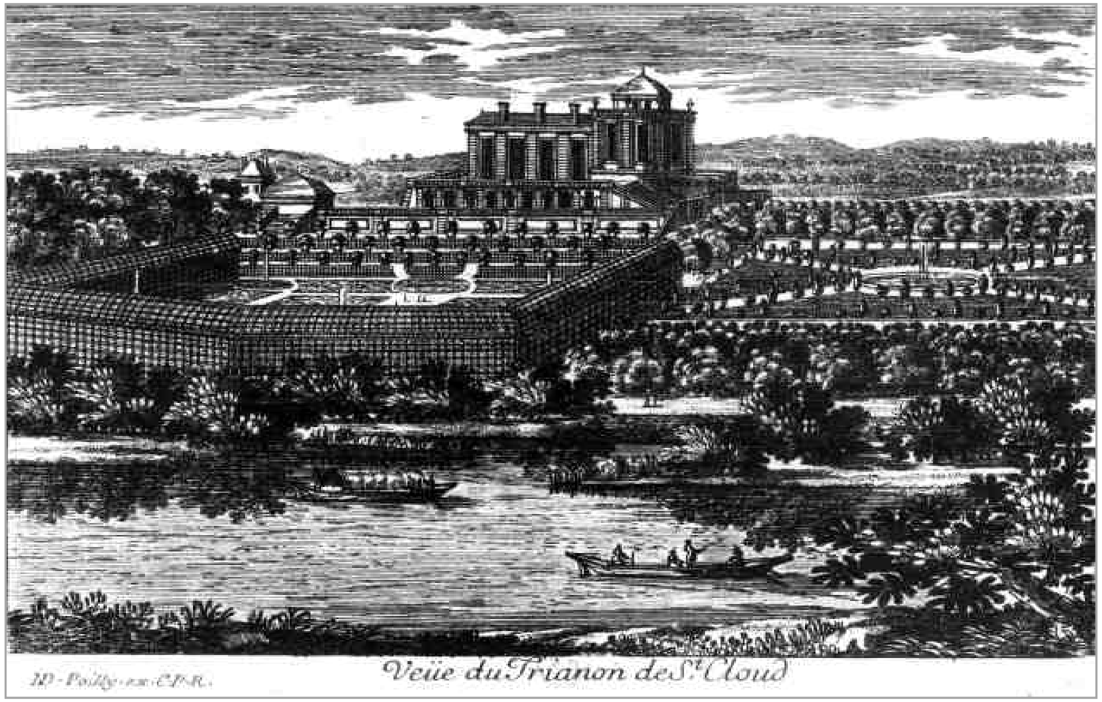
Le Bureau est chargé, en outre, des déterminations relatives aux constantes physiques dont une connaissance plus exacte peut servir à accroître la précision et à assurer mieux l'uniformité dans les domaines auxquels appartiennent les unités ci-dessus mentionnées (article 6 et 1[er] alinéa de l'article 7).

Il est chargé, enfin, du travail de coordination des déterminations analogues effectuées dans d'autres instituts.

Articles 6 (1875) and 7 (1921) of the Metre Convention provide for the international mission attributed to the BIPM

The BIPM


Philippe Monsieur Fils de France
Duc d'Orleans Frere Unique du Roy


Veüe du Trianon de S.t Cloud

The BIPM

Abbé de Breteuil

Barón de Breteuil
1785

The BIPM

The Pavillon de Breteuil when given to the BIPM in 1870

The BIPM

The Pavillon de Breteuil today

The BIPM

"The BIPM is the intergovernmental organization established by the Metre Convention, through which Member States act together on matters related to measurement science and measurement standards".

- Founded in Paris in 1875 by 17 Member States and based at the *Pavillon de Breteuil* in Parc St Cloud, Sevres.
- Now involving about 100 states and economies as Members or Associates.

The BIPM

The mission of the BIPM is to ensure and promote the global comparability of measurements, including providing a coherent international system of units for:

- Scientific discovery and innovation,
- Industrial manufacturing and international trade,
- Sustaining the quality of life and the global environment.

Objectives of the BIPM

To be a centre for scientific and technical collaboration between Member States providing capabilities for international measurement comparisons on a shared-cost basis.

- *We coordinate international comparisons of national measurement standards agreed to be of the highest priority.*
- *We establish and maintain appropriate reference standards for use as the basis of key international comparisons at the highest level and provide selected calibrations from them.*

To represent the worldwide measurement community aiming to maximise its uptake and impact

- *We liaise with relevant intergovernmental organizations and other international bodies in order to develop opportunities for the application of metrology to global challenges.*

Bureau International des Poids et Mesures

To be the coordinator of the worldwide measurement system ensuring it gives comparable and internationally-accepted measurement results

- *We coordinate activities between the NMIs of Member States and the RMOs, including the provision of technical services to support the CIPM MRA and the infrastructure for the development and promotion of the SI.*

Fulfilling our mission and objectives is underpinned by our work in:

- *capacity building, which aims to achieve a global balance between the metrology capabilities in Member States.*
- *knowledge transfer, which ensures that our work has the greatest impact.*

The BIPM – an international organisation

Established in 1875 when 17 States signed the Metre Convention, now with 58 Member States.

CGPM – Conférence Générale des Poids et Mesures

Official represntatives of Member States.

CIPM – Comité International des Poids et Mesures

Eighteen individuals of different nationalities elected by the CGPM.

BIPM – Bureau International des Poids and Mesures

- *International coordination and liaison*
- *Technical coordination – laboratories*
- *Capacity building*

Consultative Committees (CCs)

CCAUV – Acoustics, US & Vibration
CCEM – Electricity & Magnetism
CCL – Length
CCM – Mass and related
CCPR – Photometry & Radiometry
CCQM – Amount of substance
CCRI – Ionizing Radiation
CCT – Thermometry
CCTF – Time & Frequency
CCU - Units

Membership of the BIPM provides states with the opportunity

- *To gain global recognition and acceptance for measurement capabilities*
- *To participate in the structures that support and develop the SI*
- *To be active in scientific and technical forums that support the development of measurement capacity*

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Bureau International des Poids et Mesures

Institutional and legal

- *Legal*
- *HR*

International Liaison

- *Member States*
- *Associates*
- *IGOs*
- *RMOs*
- *CIPM MRA*
- *DCMAS Network*
- *Publications*
- *Web services*
- *CBKT*

Technical Coordination

- Executive Secretaries of CCs
- JCTLM
- JCGM
- JCRB
- KCDB

Laboratories

- Physical Metrology
- Time
- Ionizing Radiation
- Chemistry

Support services

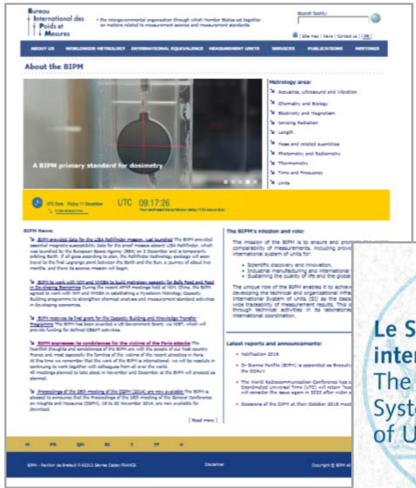
- *Administration*
- *Finance*
- *Secretariat*

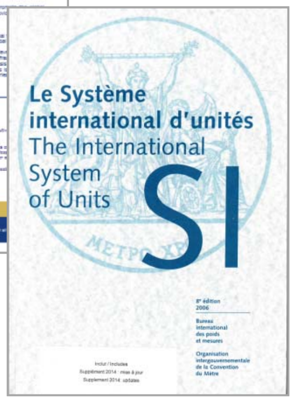
BIPM – Bureau International des Poids and Mesures

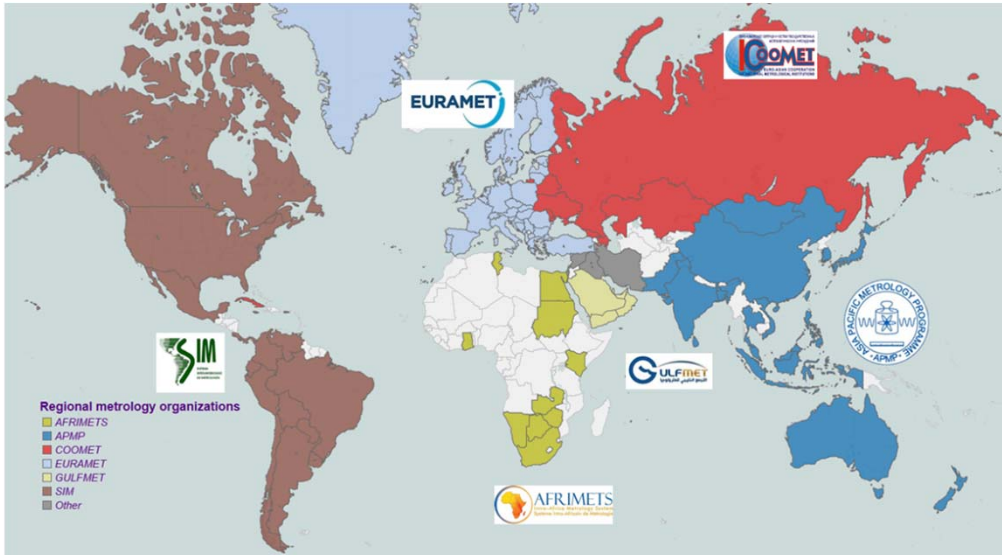
- *International coordination and liaison*
- *Technical coordination – laboratories*
- *Capacity building*

Liaison and Coordination

- BIPM liaises with the National Metrology Institutes (NMIs) of Member States and the Regional Metrology Organizations







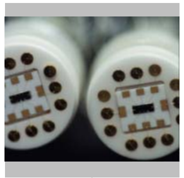
Bureau
International des
Poids et
Mesures

Liaison and Coordination

Bureau International des Poids et Mesures

BIPM works to foster cooperation with international organizations and promotes the world-wide comparability of measurement.

The main technical roles of the BIPM



Travelling standards

Maintains travelling standards to compare fixed national references e.g., Josephson Junctions for the volt, Quantum Hall devices for the ohm, etc.

kilogram

Maintains the kilogram in the near future until replaced, probably by Watt Balances.

Coordinated Universal Time

Creates and disseminates Coordinated Universal Time (UTC) based on weighted averages of ~ 400 clocks from over 70 National laboratories worldwide.

Traceable measurements

Promotes traceable, accurate measurement for physical, engineering, chemical and medical quantities worldwide.

Unique world reference facilities

Maintains unique world reference facilities e.g., SIR (ionizing radiation and isotopes), ozone spectrophotometers

Outline

the Metre Convention and the SI

Convention du Mètre

ART. 7 (1921)

Après que le Comité aura procédé au travail de coordination des mesures relatives aux unités électriques, et lorsque la Conférence générale en aura décidé par un vote unanime, le Bureau sera chargé de l'établissement et de la conservation des étalons des unités électriques et de leurs témoins, ainsi que de la comparaison, avec ces étalons, des étalons nationaux ou d'autres étalons de précision.

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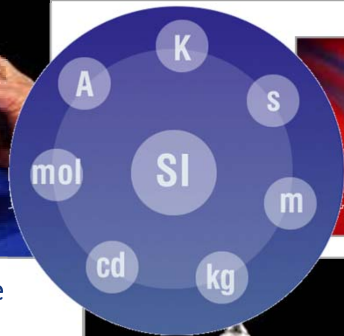


1889 - The international prototypes for the metre and the kilogram, together with the astronomical second as unit of time, create the first international system of units.

1954 - The ampere, kelvin and candela are added as base units.

1960 - The unit system is named as the International System of Units (SI)

1971 - The mole is added as the unit for amount of substance, extending the application of the SI to chemistry.

The International System of Units (SI)

Prefixes

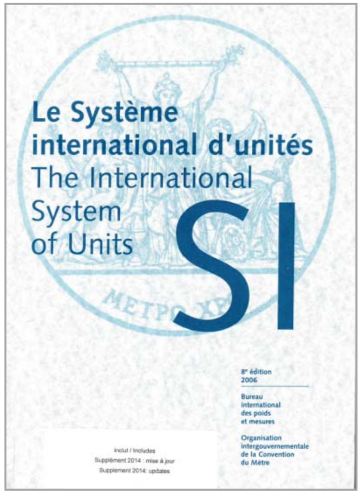
Table 5. SI prefixes

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

Base units

Table 1. SI base units

Base quantity		SI base unit	
Name	Symbol	Name	Symbol
length	l, x, r, etc.	metre	m
mass	m	kilogram	kg
time, duration	t	second	s
electric current	I, i	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mole	mol
luminous intensity	I_v	candela	cd



Derived units

Table 3. Coherent derived units in the SI with special names and symbols

	SI coherent derived unit (a)			
Derived quantity	Name	Symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
plane angle	radian (b)	rad	1 (b)	m/m
solid angle	steradian (b)	sr (c)	1 (b)	m^2/m^2
frequency	hertz (d)	Hz		s^{-1}
force	newton	N		$m\ kg\ s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1}\ kg\ s^{-2}$
energy, work, amount of heat	joule	J	N m	$m^2\ kg\ s^{-2}$
power, radiant flux	watt	W	J/s	$m^2\ kg\ s^{-3}$
electric charge, amount of electricity	coulomb	C		s A
electric potential difference, electromotive force	volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$
capacitance	farad	F	C/V	$m^{-2}\ kg^{-1}\ s^4\ A^2$
electric resistance	ohm	Ω	V/A	$m^2\ kg\ s^{-3}\ A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2}\ kg^{-1}\ s^3\ A^2$
magnetic flux	weber	Wb	V s	$m^2\ kg\ s^{-2}\ A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg\ s^{-2}\ A^{-1}$
inductance	henry	H	Wb/A	$m^2\ kg\ s^{-2}\ A^{-2}$
Celsius temperature	degree Celsius (e)	°C		K
luminous flux	lumen	lm	cd sr (c)	cd
illuminance	lux	lx	lm/m^2	m^{-2} cd
activity referred to a radionuclide (f)	becquerel (d)	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2\ s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert (g)	Sv	J/kg	$m^2\ s^{-2}$
catalytic activity	katal	kat		s^{-1} mol

The 8th edition of the SI Brochure is available from the BIPM website.

www.bipm.org

The base units of the SI

3 definitions based on **fundamental (or conventional) constants:**

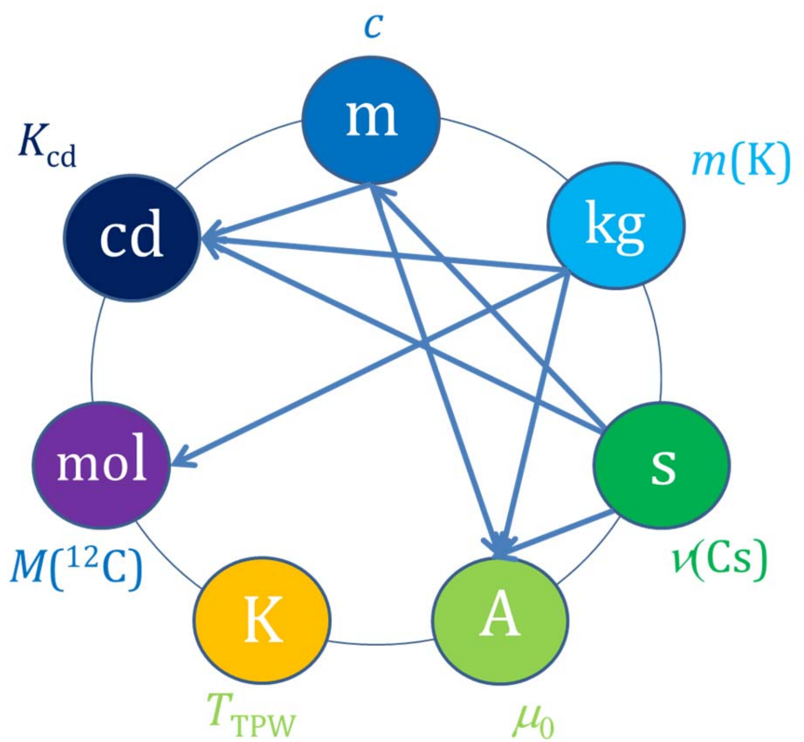
- metre (c)
- ampere (μ_0)
- candela (K_{cd})

3 definitions based on **material properties:**

- second (^{133}Cs)
- kelvin (H_2O)
- mole (^{12}C)

1 definition based on an **artefact:**

- kilogram (IPK)



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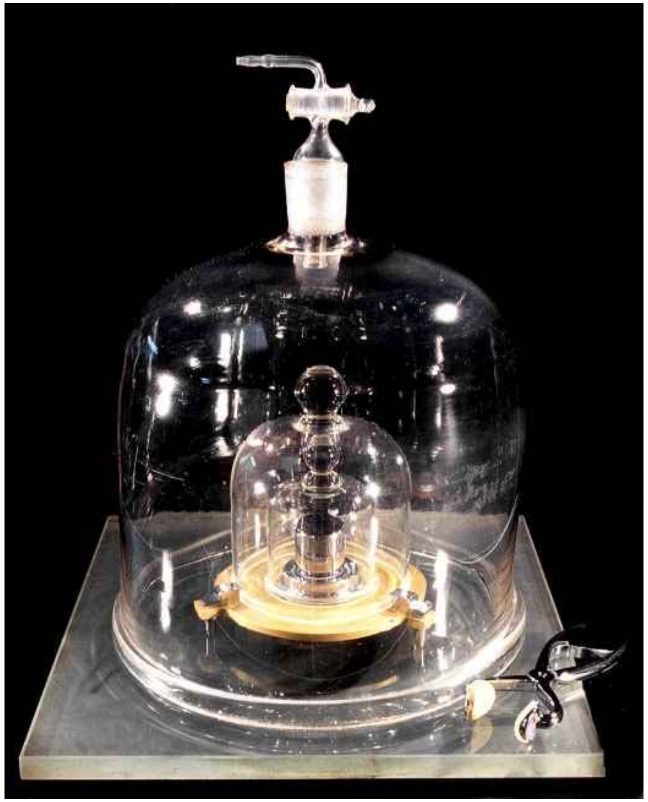
The definition of the kilogram in the SI

**The kilogram is the unit of mass -
it is equal to the mass of the
international prototype of the kilogram.**

- manufactured around 1880 and ratified in 1889
- represents the mass of 1 dm^3 of H_2O at its maximum density (4 °C)
- alloy of 90% Pt and 10% Ir
- cylindrical shape, Ø = *h* ~ 39 mm
- kept at the BIPM in ambient air

The kilogram is the last SI base
unit defined by a material artefact.



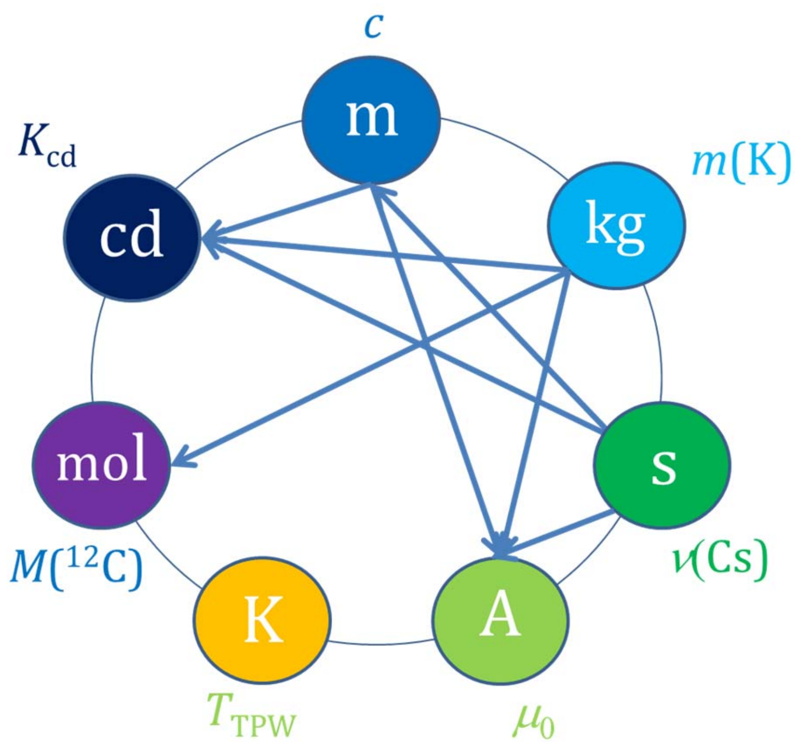
Proposal for 4 new definitions

Definitions based on fundamental (or conventional) constants:

- **metre (*c*)**
- **kilogram (*h*)**
- **ampere (*e*)**
- **candela (K_{cd})**
- **mole (N_A)**
- **kelvin (*k*)**

Definition based on material property:

- **second (^{133}Cs)**



(I. Mills et al., *Metrologia*, 2006, 43, 227-246)

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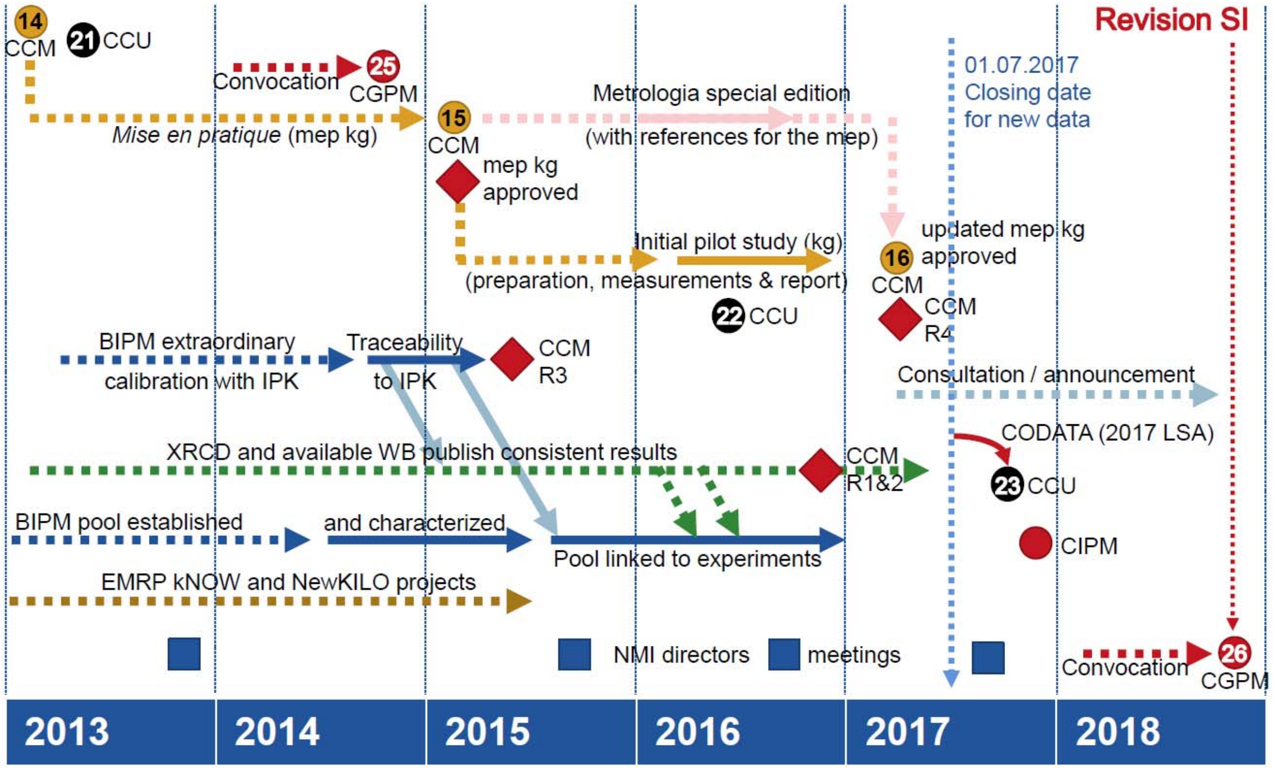
Joint CCM and CCU roadmap towards a re-definition in 2018



Conditions from CCM Recommendation G1 (2013)

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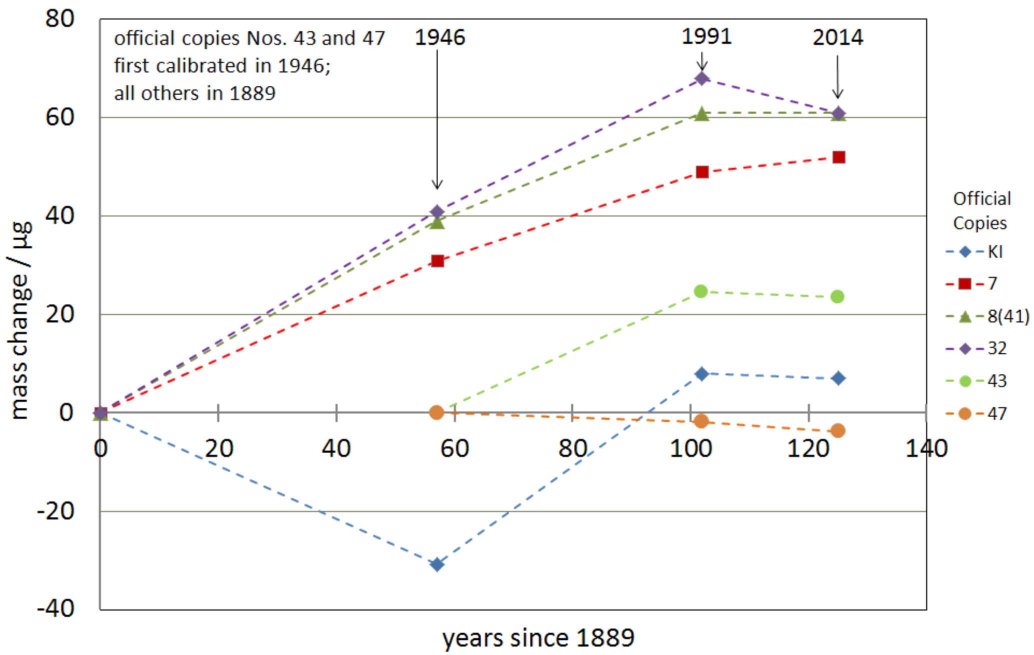
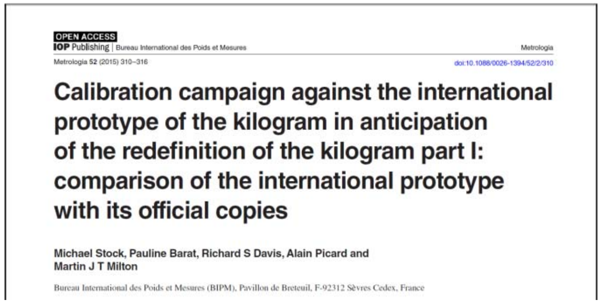
“Extraordinary Calibrations” with the International Prototype of the Kilogram and official copies



- Results published in Metrologia



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IOP Publishing | Bureau International des Poids et Mesures — Metrologia

Metrologia 52 (2015) 310–316 — doi:10.1088/0026-1394/52/2/310

Calibration campaign against the international prototype of the kilogram in anticipation of the redefinition of the kilogram part I: comparison of the international prototype with its official copies

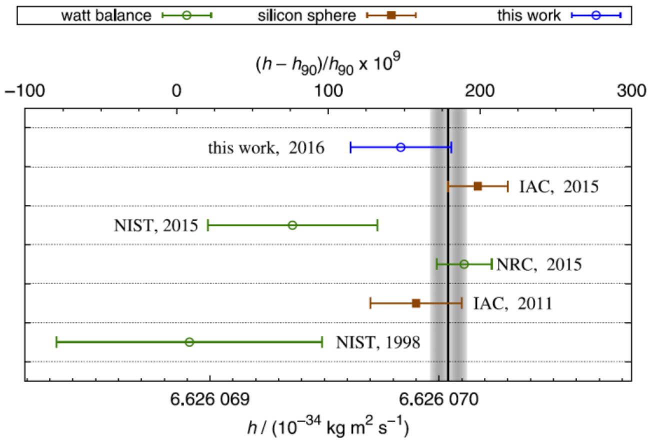
Michael Stock, Pauline Barat, Richard S Davis, Alain Picard and Martin J T Milton

Bureau International des Poids et Mesures (BIPM), Pavillon de Breteuil, F-92312 Sèvres Cedex, France

- Consequences for mass calibration certificates issued by the BIPM have been managed through the CCM.
- All corrected certificates have been issued.

Bureau International des Poids et Mesures

Results published for *h* and *k* during 2015



REVIEW OF SCIENTIFIC INSTRUMENTS 87, 061301 (2016)

Invited Article: A precise instrument to determine the Planck constant, and the future kilogram

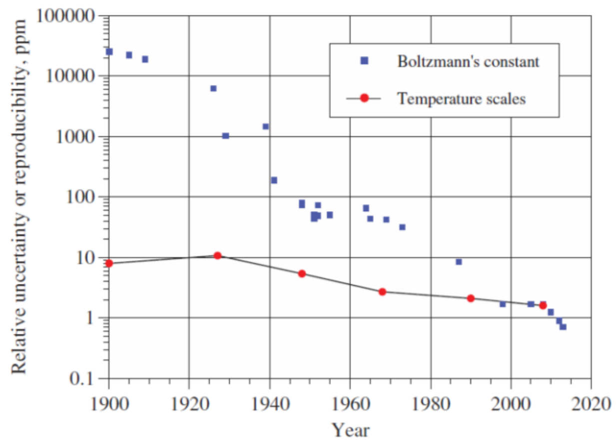
D. Haddad,[1,2,a)] F. Seifert,[1,2] L. S. Chao,[1] S. Li,[1,b)] D. B. Newell,[1] J. R. Pratt,[1] C. Williams,[1,2] and S. Schlamminger[1,c)]
[1]*National Institute of Standards and Technology (NIST), 100 Bureau Drive Stop 8171, Gaithersburg, Maryland 20899, USA*
[2]*University of Maryland, Joint Quantum Institute, College Park, Maryland 20742, USA*

CCM criteria

At least 3 experiments, using 2 different methods with u_r<50 ppb,
at least one with u_r<20 ppb.

CCT criteria

Value of k with u_r<1 ppm based on two “fundamentally different” methods with u_r<3 ppm.



from **The Boltzmann constant and the new kelvin** White and Fischer, Metrologia 52 (2015) S213–S216

Bureau International des Poids et Mesures

How can we explain the new definitions?

- **The new definitions will "facilitate universality of access to the agreed basis for worldwide measurements".**
  - This has been an ambition for the "metric system" that goes back more than 200 years. The 2018 definitions will make it possible for the first time.

- **The changes will underpin future requirements for increases in accuracy**
  - As science and technology advances, the demands for the accuracy of measurements will continue to increase accuracy. The 2018 definitions will provide for these needs for many years to come.

- **The new definitions use "the rules of nature to create the rules of measurement".**
  - The use of constants in nature enable you to link from the smallest to the largest measurements quantities. It will tie measurements at the atomic (and quantum) scales to those at the macroscopic level. This introduces the appeal of a fundamental ("quantum") basis for the changes.

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05 - World Metrology Day.

CIPM MRA participation

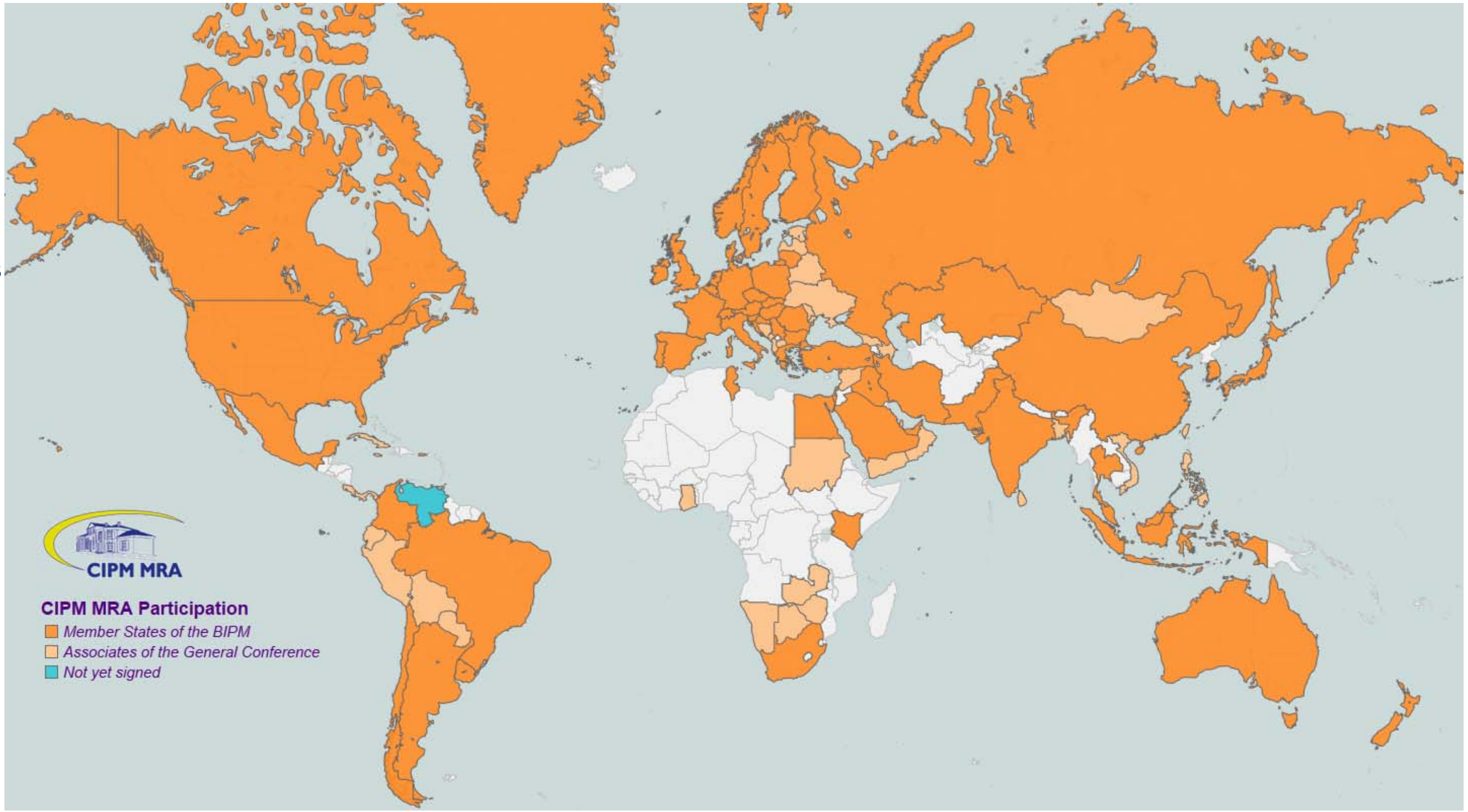
Participation

98 National Metrology Institutes
- *57 Member States*
- *41 Associates*

4 International organizations
(ESA, IAEA, IRMM, WMO)

plus 156 Designated Institutes

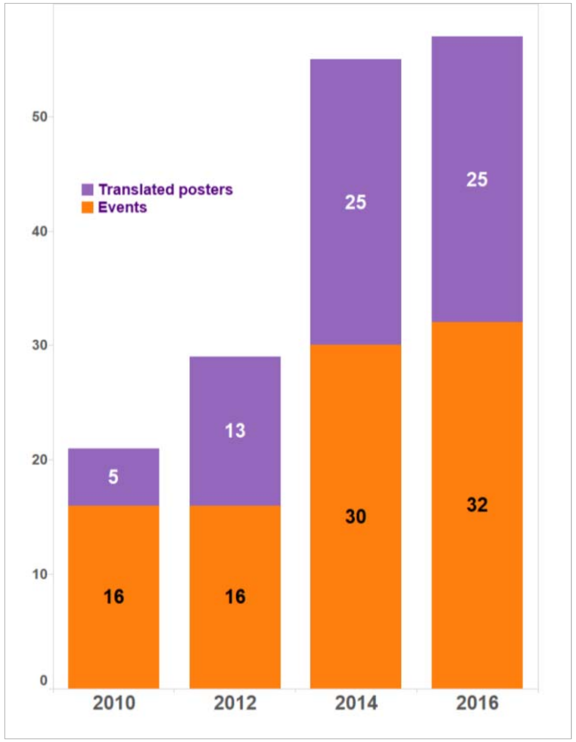
Total: 258 Institutes



Outline

World Metrology Day joint BIPM and OIML initiative

Growing impact of World Metrology Day



World Metrology Day 2016 – “Measurement in a dynamic world”

The accurate knowledge of dynamic quantities is pivotal to progress in high technology whether it is

- the high-speed movements in a disk drive,
- the drive for environmental improvement and fuel efficiency in the aerospace industry,
- the variations in supply and demand from renewable energy sources on electricity grids.

Typical seek time for acceleration and deceleration of read heads is 4 ms.

Typical peak pressure of 50 Mpa at 30 kHz.

Price of poor power quality due to voltage fluctuations estimated at 500 beuro pa.

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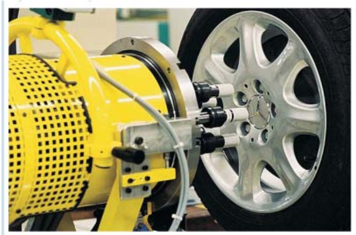
World Metrology Day 2016 – “Measurement in a dynamic world”

Dynamic quantities also play an increasing role in established industries, such as

- the dynamic weighing of trains and trucks, and

- the monitoring of vibration and impact arising from the tyres and engines of cars.

Dynamic calibration drives the need for very large torque and force values.



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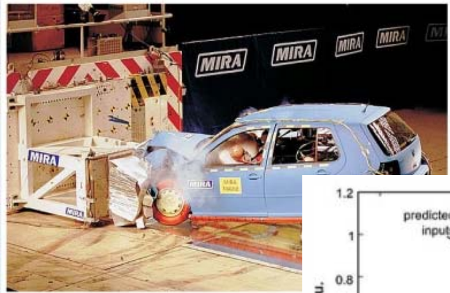
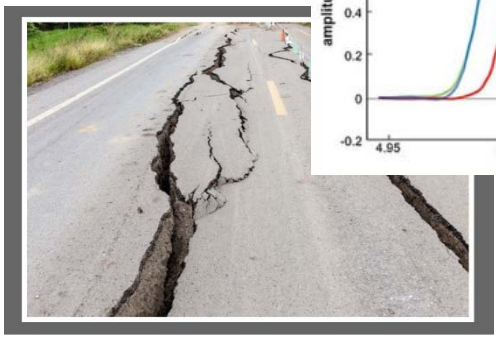
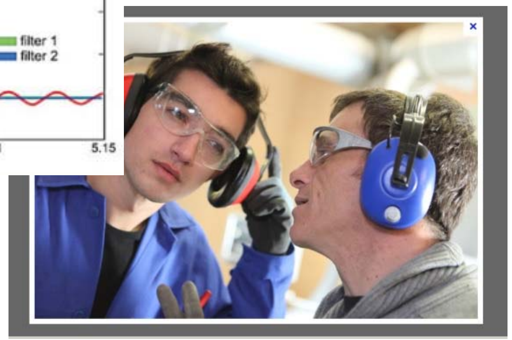
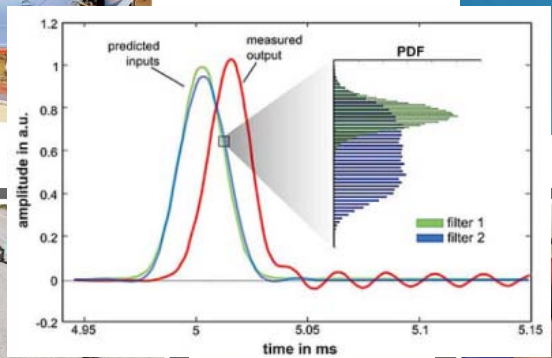
Dynamic measurements address noise, vibration and impact









Dynamic calibration drives the need for very short response times

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Conclusions

- The world economy, society and citizens depend on the international “quality infrastructure” which depends on metrology.
- Metrology provides:
  - Measurements that are stable … comparable … and coherent.
- These are provided by chains of traceability based on the work of the National Metrology Institutes (NMIs).

Capacity Building & Knowledge Transfer

Thank you

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