The Importance of Metrology for Standards, Industry and Trade

Dr M. Milton

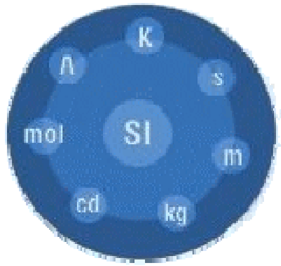
Director of the BIPM

Bureau
International des
Poids et
Mesures

Outline of today's talk

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

- The role and mission of the BIPM



- The SI units – recent progress towards a "new SI"

- Worldwide impact through the CIPM MRA.

Today's growing demand for better measurements

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

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.

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 for different compounds and from different methods can be brought together

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To meet the needs of the economy, society and citizens

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The objectives of Metrology

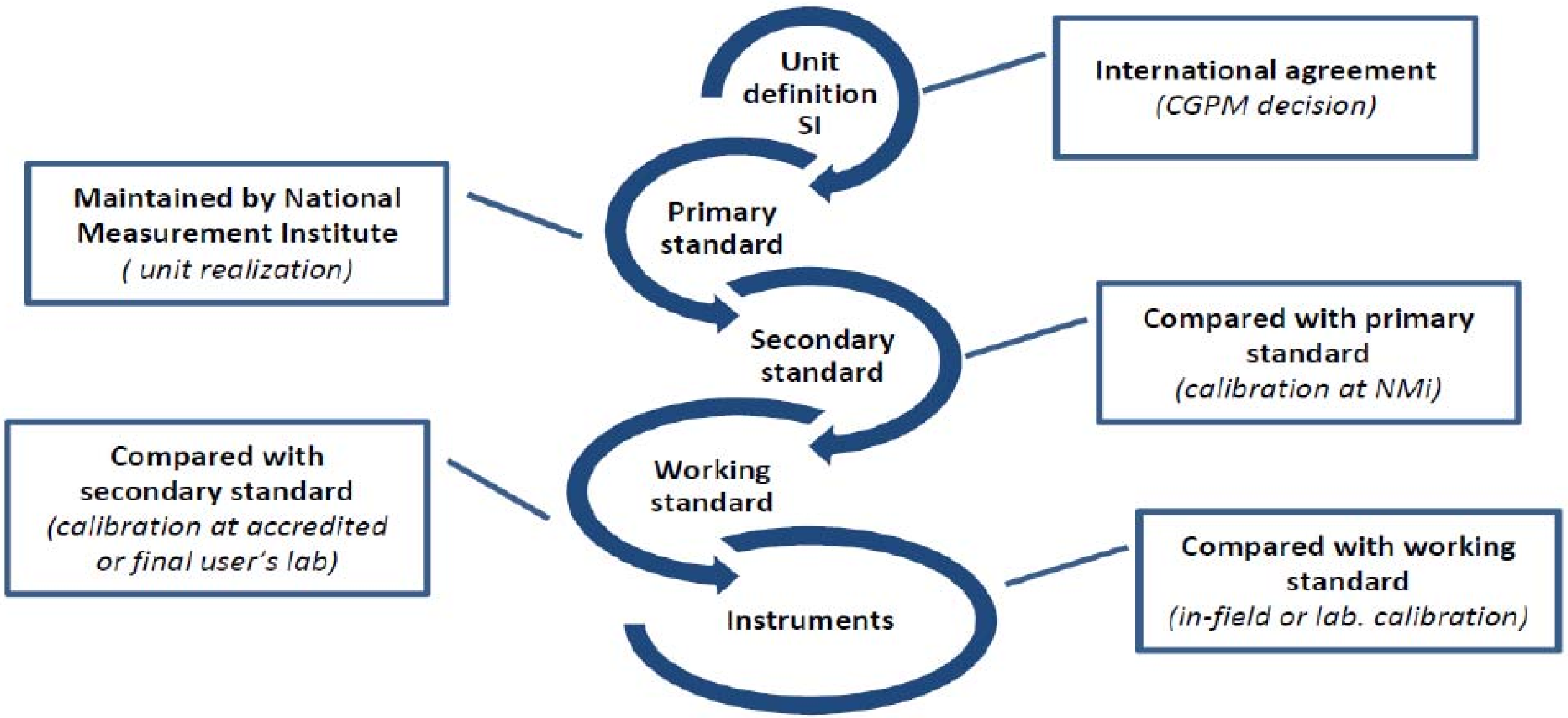
The objectives of metrology are achieved through providing the framework for traceable measurements.

“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

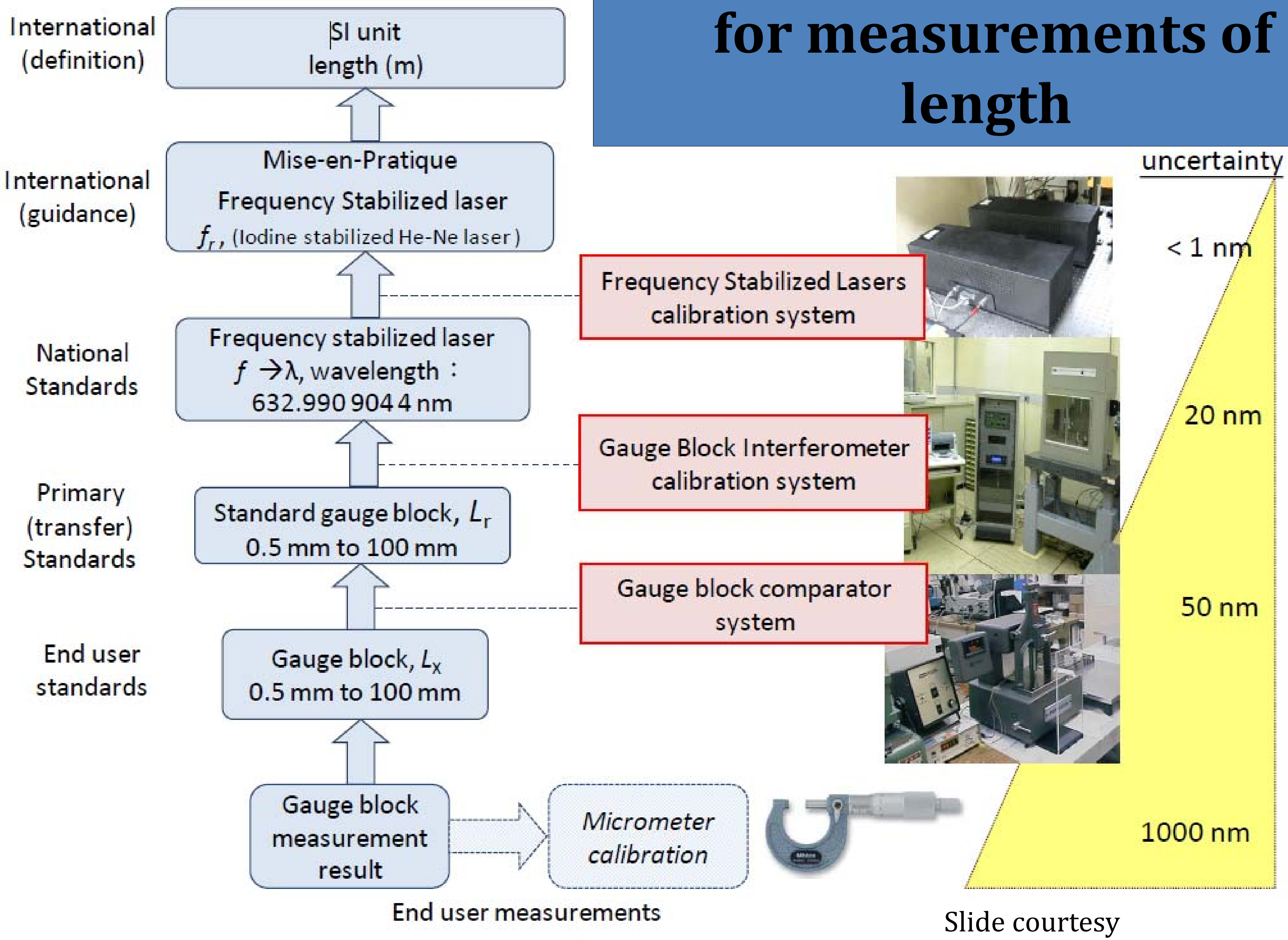
Note: traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory

The traceability "chain"



Slide courtesy
Dr S Davidson, NPL, UK

A traceability chain for measurements of length



Slide courtesy
Dr S Davidson, NPL, UK

Importance of measurement traceability

Health

Traceable to SI

Meas.
Instr.

Laboratory in medicine

Traceable measurements

=

Insulin for diabetics

Chemical therapy
for treatment of cancer

Overdose

+

Dose

−

No results

=

Human Health

Industry

Meas.
Instr.

Traceable measurements

=

Components manufactured in different countries

=

Interchangeable/interoperable components

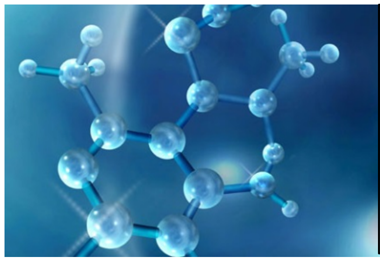
Science

Research

Meas.
Instr.

Traceable measurements

=



Internationally recognized technical evidence

=

Results of science

Innovation

The BIPM

“The BIPM is an 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 Metre Convention

THE METRE CONVENTION
established in 1875 by 17 States, now with 56 Member States in 2014.

CGPM – Conférence Générale des Poids et Mesures

Composed of Member State representatives.
Typically meets every 4 years to decide on matters relating to the Metre Convention and the SI

CIPM – Comité International des Poids et Mesures

18 individuals of different nationalities appointed by CGPM.

BIPM – Bureau International des Poids and Mesures

International Coordination:

- Infrastructure for committees
- Technical coordination

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

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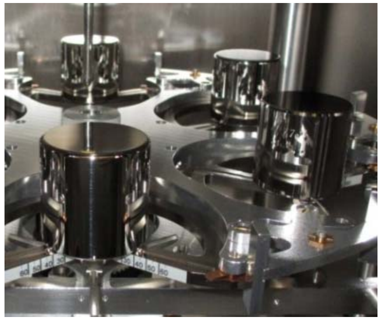
The mission statement of the BIPM

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.



Liaison and Coordination

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

Liaison and Coordination

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

Memoranda of Understanding with WMO and IAEA

Annual 4-way summit meeting BIPM +ISO, ILAC and OIML

The laboratory program at the BIPM

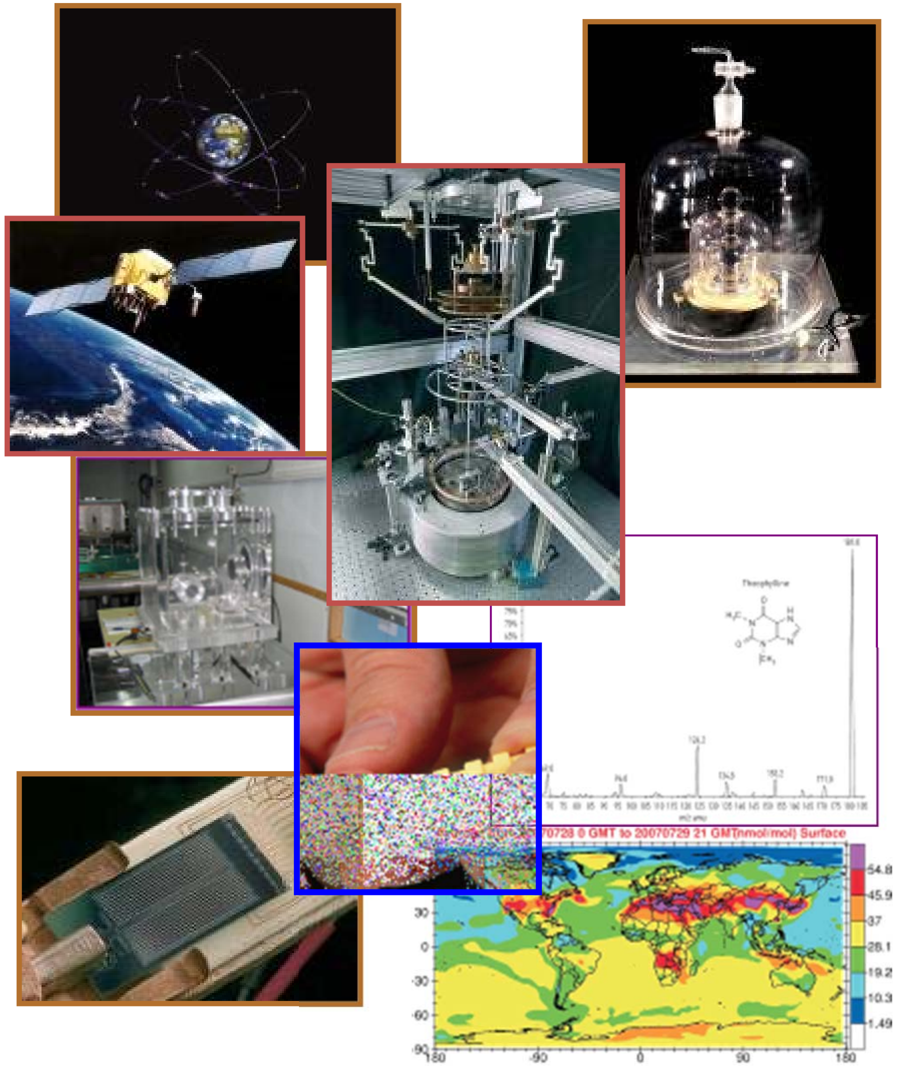
The role of the BIPM scientific programme

- **To establish and maintain appropriate reference standards** for use as the basis of a limited number of key international comparisons at the highest level.

- **To coordinate international comparisons** of national measurement standards through the Consultative Committees of the CIPM; taking the role of coordinating laboratory for selected comparisons of the highest priority and undertaking the scientific work necessary to enable this to be done.

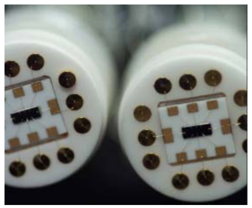
Current BIPM scientific activity in:

- Mass and electricity
- Time
- Ionizing Radiation and chemistry



The main technical roles of the BIPM

- Maintains the kilogram in the near future until replaced, probably by Watt Balances.
- Creates and disseminates Coordinated Universal Time (UTC) based on weighted averages of ~ 400 clocks from over 70 National laboratories worldwide.
- Maintains unique world reference facilities e.g., SIR (ionizing radiation and isotopes), ozone spectrophotometers.
- Maintains travelling standards to compare fixed national references e.g., Josephson Junctions for the volt, Quantum Hall devices for the ohm, etc.
- Coordinates international comparisons and networks e.g., organic chemistry reference materials for laboratory medicine.
- Promotes traceable, accurate measurement for physical, engineering, chemical and medical quantities worldwide.





The Metre Convention and the SI

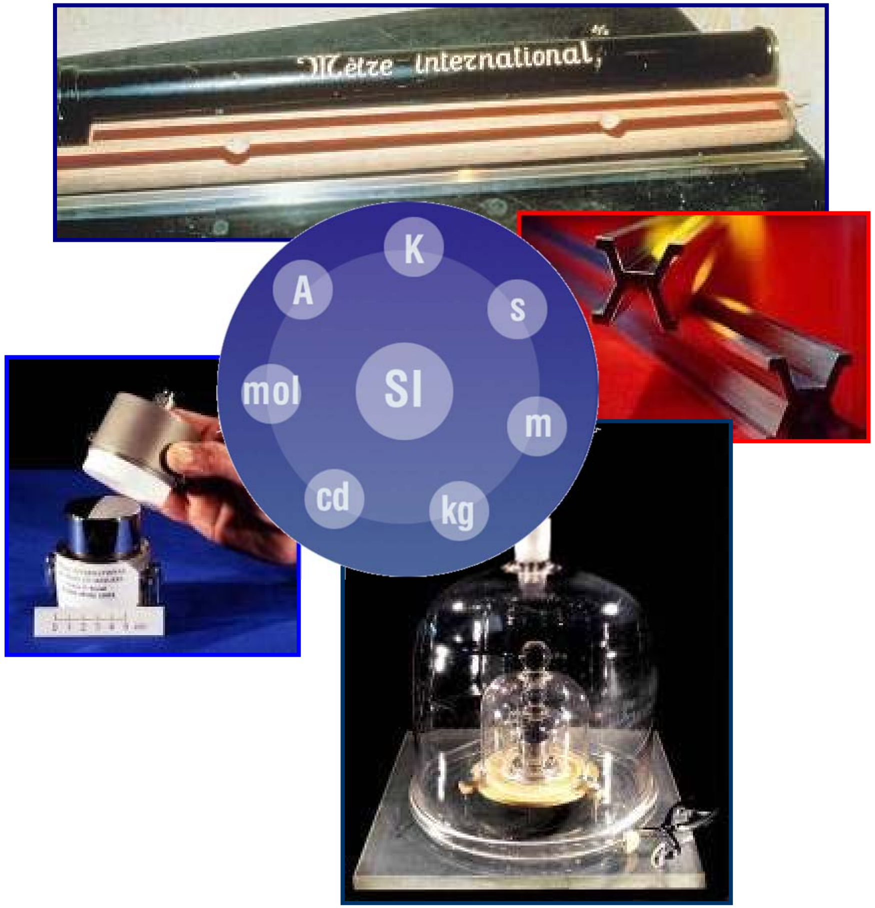
20 May 1875 - The Metre Convention was signed in Paris by 17 nations which established the BIPM

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

Derived quantity	SI coherent derived unit [a] 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.

The base units of the SI

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

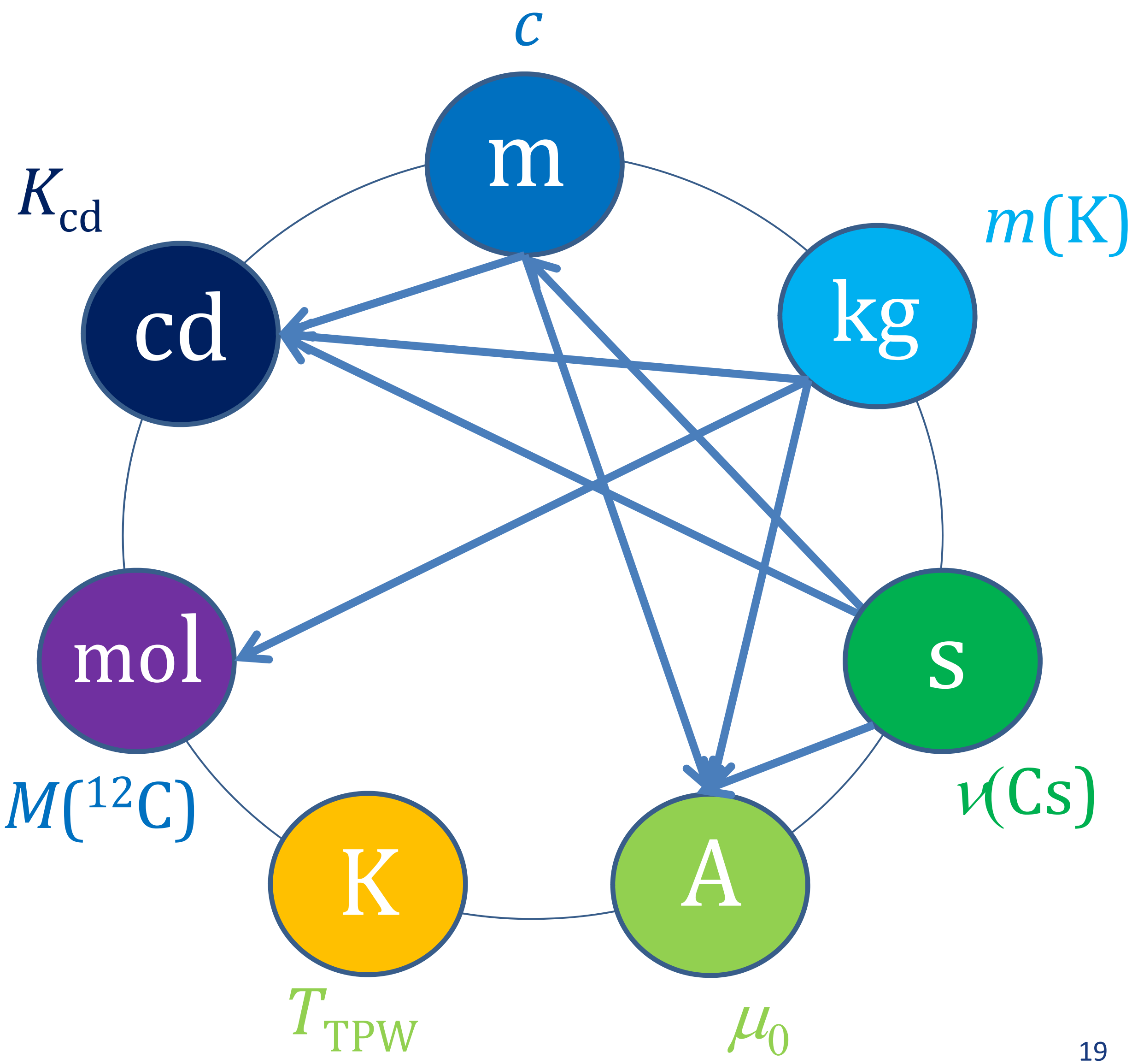
- metre (c)
- ampere (μ_0)
- candela (K_{cd})

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.

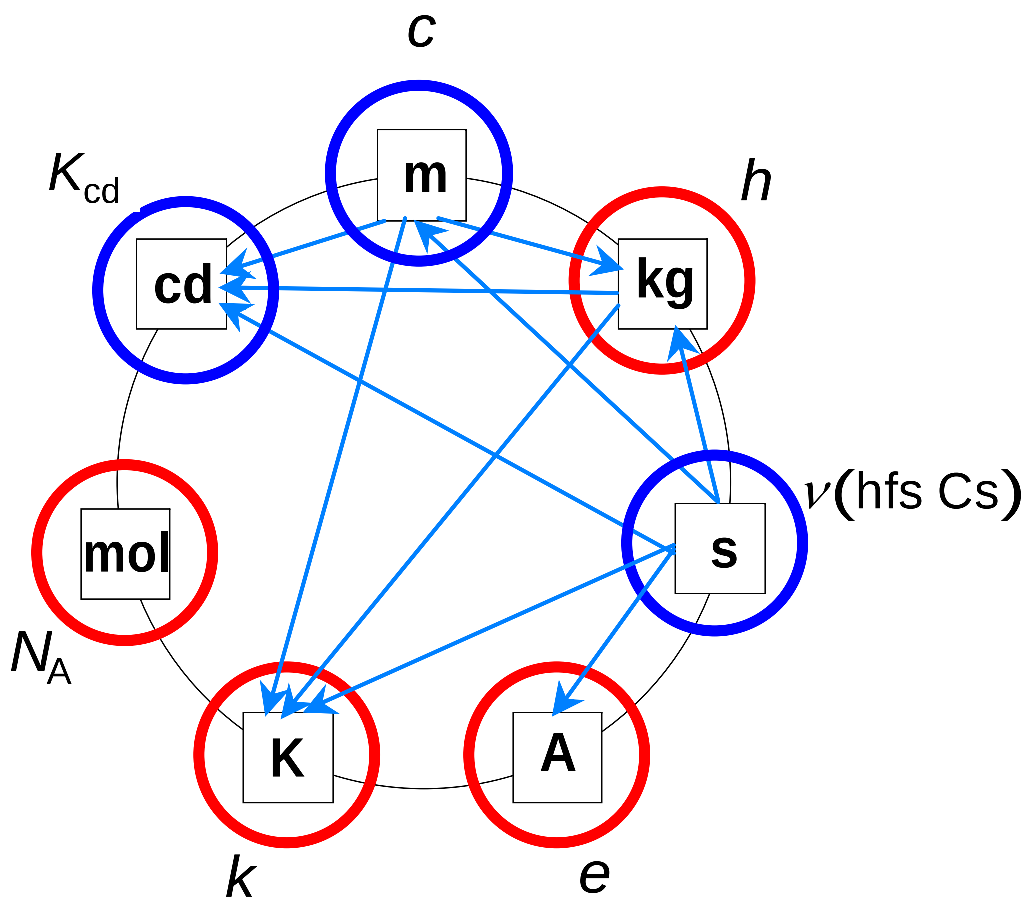
Proposal for a new SI, with 4 new definitions

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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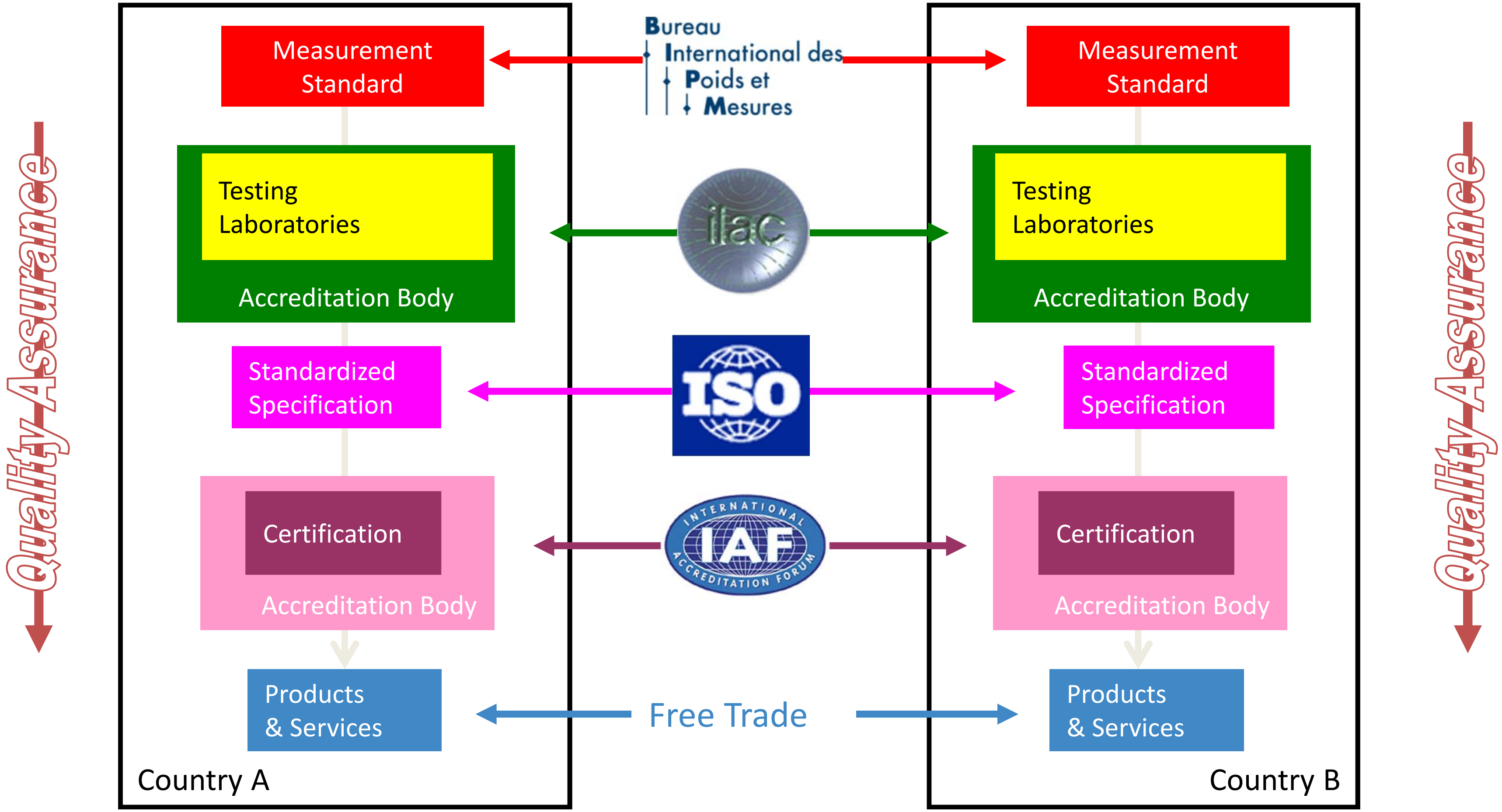
The international "quality" infrastructure

Measurement standards are provided through an internationally recognized framework through which suppliers of products can demonstrate compliance with specification.



The CIPM Mutual Recognition Arrangement

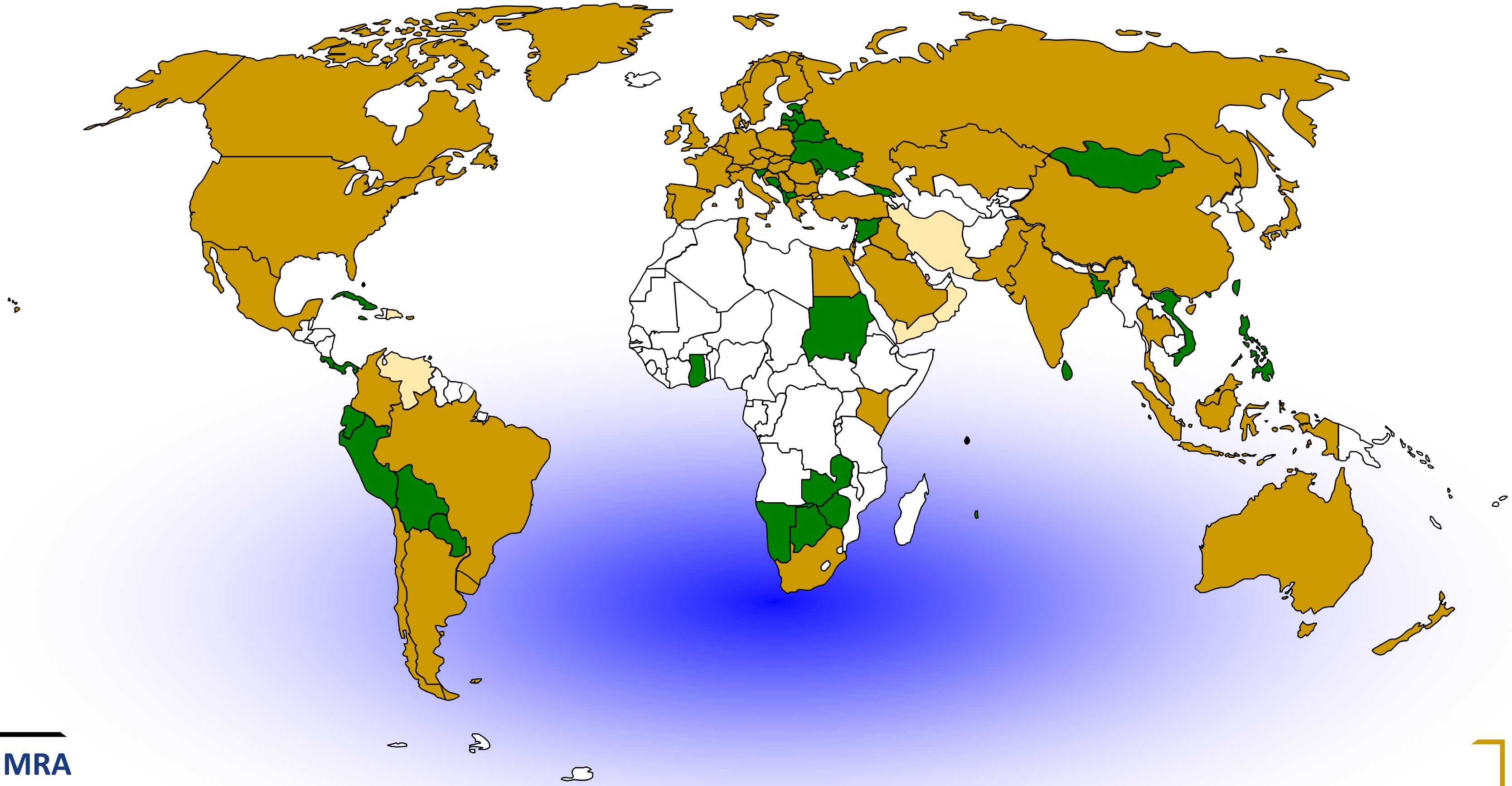
In 1999, and in support of world trade, the CIPM established a Mutual Recognition Arrangement (CIPM MRA) of national measurement standards and of calibration and measurement certificates issued by NMIs.

The aim of the MRA is to provide the technical basis for the worldwide acceptance of national measurement standards and calibration and measurement certificates from NMIs.

CIPM MRA Participation

Metre Convention

56 Member States & 41 Associates and Economies



CIPM MRA

95 NMIs + 150 Designa

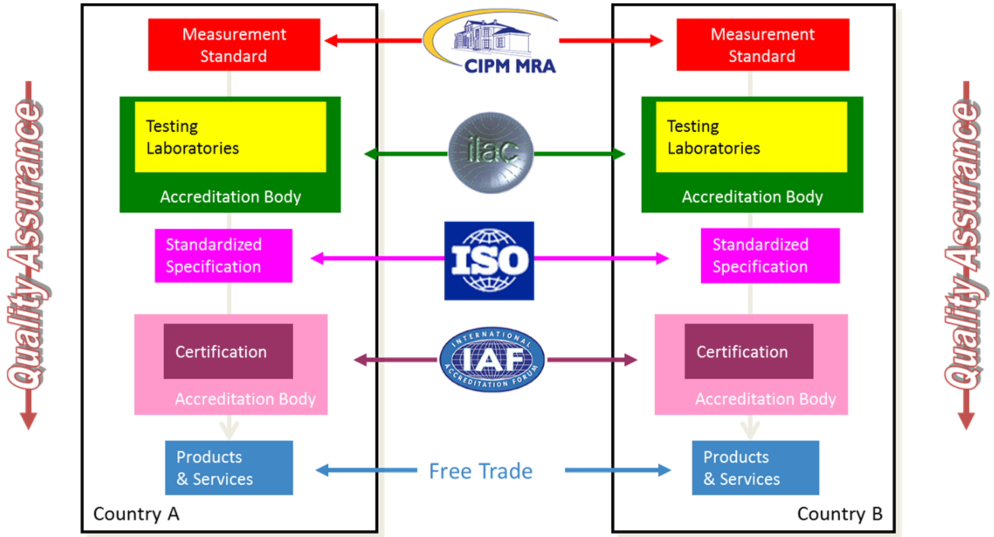
& 4 international organizations

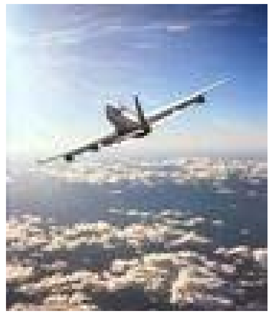
RA

not yet signed the CIPM MRA

Overcoming technical barriers to trade

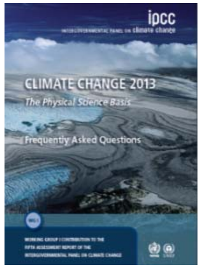
- Lack of compliance with standards reduces trade:
  - developed and G22 countries lose between 1% and 15%
  - developing and LDCs lose between 10% and 40%.
- 70% of the burden on developing countries' manufactured exports comes from trade barriers erected by other countries

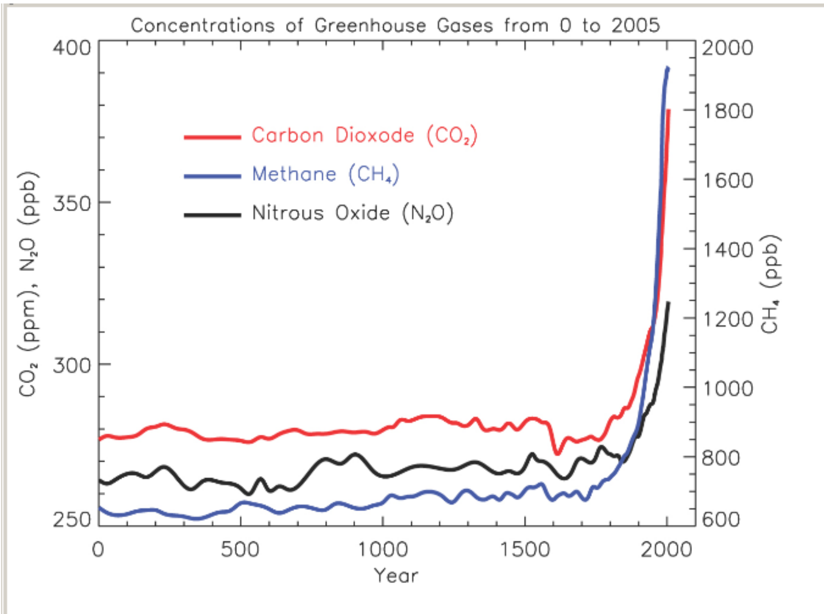




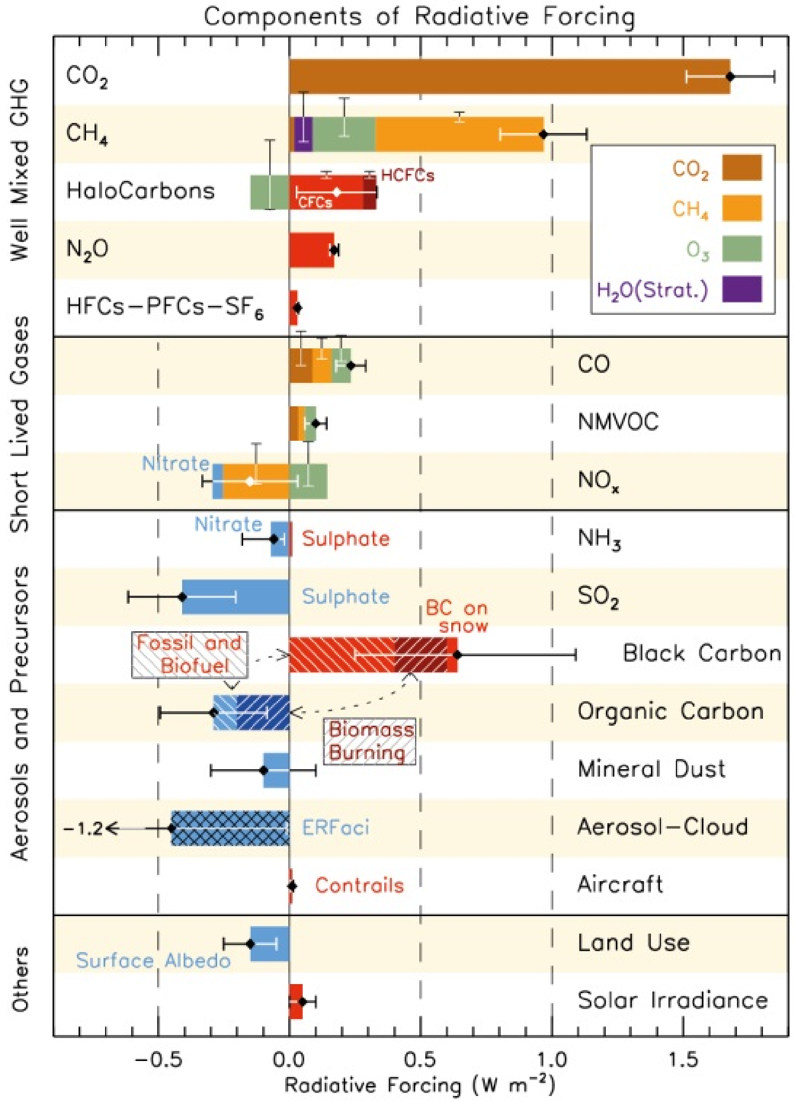
Contributions to radiative forcing

- Radiative forcing for the period 1750–2011 based on emitted compounds (gases, aerosols or aerosol precursors) or other changes.

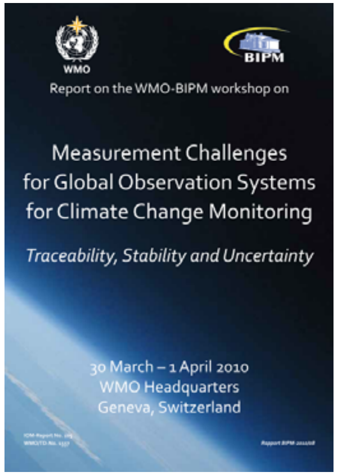


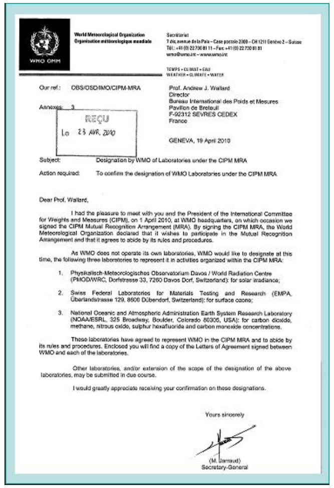


WMO Global Atmosphere Watch
GAW
WDCGG
World Data Centre
for Greenhouse Gases



WMO sign the CIPM MRA (April 2010)





WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

Secrétariat
7 bis, avenue de la Paix – Case postale 2300 – CH 1211 Genève 2 – Suisse
Tél.: +41 (0) 22 730 81 11 – Fax: +41 (0) 22 730 81 81
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WEATHER • CLIMATE • WATER

Our ref.: OBS/OSD/IMO/CIPM-MRA

Annexes: 3

REÇU
Le 23 AVR. 2010

Prof. Andrew J. Wallard
Director
Bureau International des Poids et Mesures
Pavillon de Breteuil
F-92312 SEVRES CEDEX
France

GENEVA, 19 April 2010

Subject: Designation by WMO of Laboratories under the CIPM MRA

Action required: To confirm the designation of WMO Laboratories under the CIPM MRA

Dear Prof. Wallard,

I had the pleasure to meet with you and the President of the International Committee for Weights and Measures (CIPM), on 1 April 2010, at WMO headquarters, on which occasion we signed the CIPM Mutual Recognition Arrangement (MRA). By signing the CIPM MRA, the World Meteorological Organization declared that it wishes to participate in the Mutual Recognition Arrangement and that it agrees to abide by its rules and procedures.

As WMO does not operate its own laboratories, WMO would like to designate at this time, the following three laboratories to represent it in activities organized within the CIPM MRA:

1. Physikalisch-Meteorologisches Observatorium Davos / World Radiation Centre (PMOD/WRC, Dorfstrasse 33, 7260 Davos Dorf, Switzerland): for solar irradiance;
2. Swiss Federal Laboratories for Materials Testing and Research (EMPA, Überlandstrasse 129, 8600 Dübendorf, Switzerland): for surface ozone;
3. National Oceanic and Atmospheric Administration Earth System Research Laboratory (NOAA/ESRL, 325 Broadway, Boulder, Colorado 80305, USA): for carbon dioxide, methane, nitrous oxide, sulphur hexafluoride and carbon monoxide concentrations.

These laboratories have agreed to represent WMO in the CIPM MRA and to abide by its rules and procedures. Enclosed you will find a copy of the Letters of Agreement signed between WMO and each of the laboratories.

Other laboratories, and/or extension of the scope of the designation of the above laboratories, may be submitted in due course.

I would greatly appreciate receiving your confirmation on these designations.

Yours sincerely

(M. Jarraud)
Secretary-General

WMO-BIPM Workshop
Geneva
April 2010

Shared objective:
to bring the WMO "scales" and NMI standards in line.

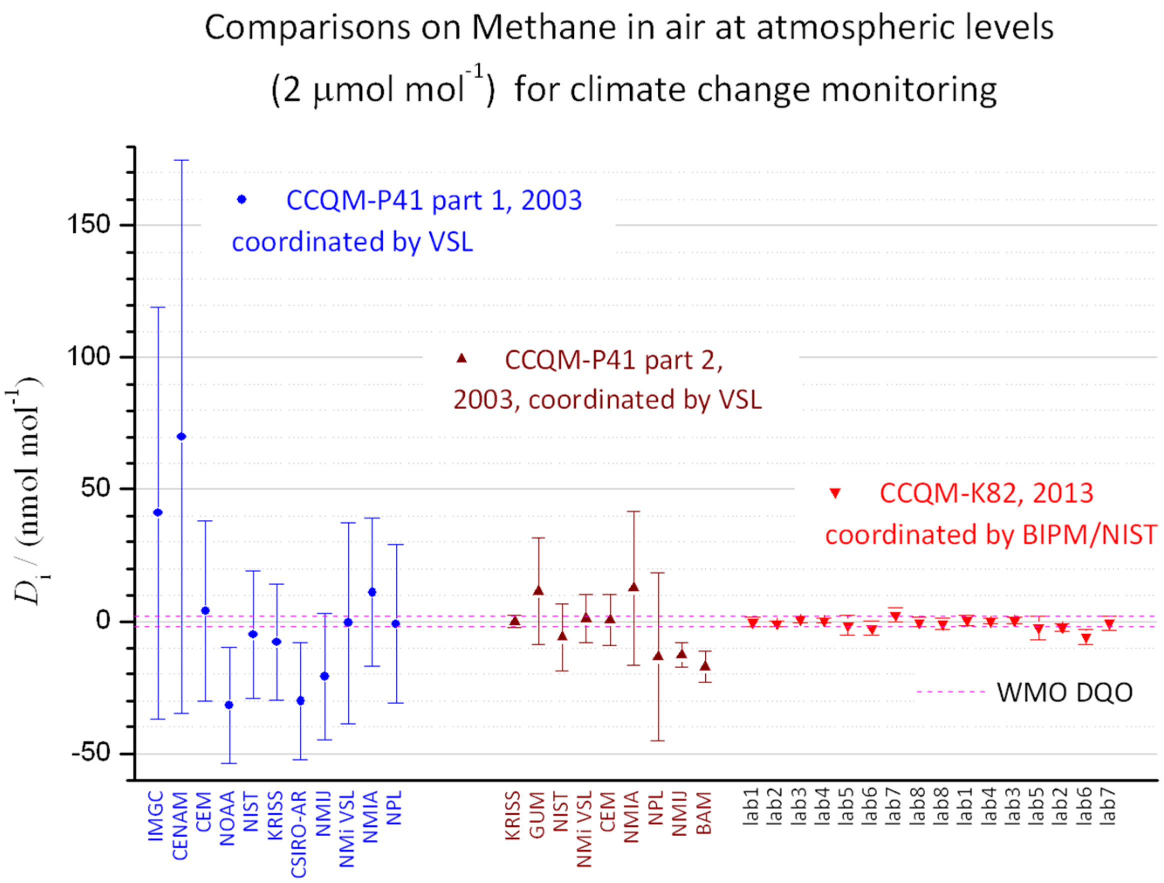
Three laboratories designated by the WMO

NOAA/ESRL for CO_2, CH_4, N_2O, SF_6 and CO
EMPA for surface ozone
PMOD/WRC for solar irradiance

- will take part in future international comparisons organised by the NMIs

- gives visibility of the relationship between SI traceable values from the NMIs and the WMO scales

Demonstrating the comparability of standards and scales for CH_4 in air



Comparison results vs. Data Quality Objectives of WMO-GAW

DQO = ± 2 nmol/mol

For CCQM-K82:

Smallest $u(x)$ = 0.5 nmol/mol

$\sigma_{(CCQM-K82)}$ = 1.17 nmol/mol

For interchangeability of standards

$u(x), \sigma_{(CCQM-Kxx)} \leq$ DQO/8

$u(x), \sigma_{(CCQM-Kxx)} \leq$ 0.25 nmol/mol

Conclusions

- The economy, society and citizens depend on the national and international "quality infrastructure".
- The "quality infrastructure " has several elements – all of which are essential.
- It depends on metrology to provide:
  - Measurements that are stable
  - Measurements that are comparable
  - Measurements that are coherent
- These are provided by chains of traceability based on the work of the National Metrology Institutes (NMIs).
- The NMIs are part of a regional and international measurement system supported by the work of the BIPM.

Thank you.

Dr M. Milton

Director of the BIPM

Martin.Milton@bipm.org

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