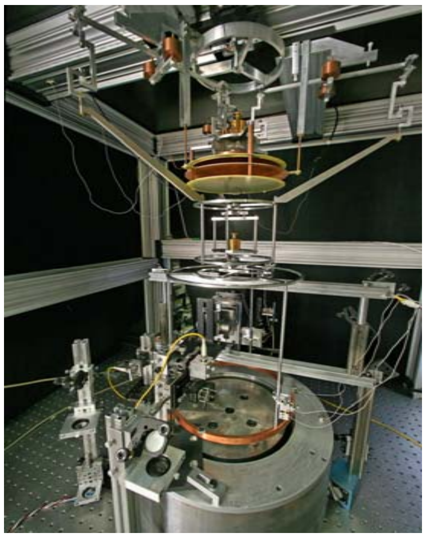
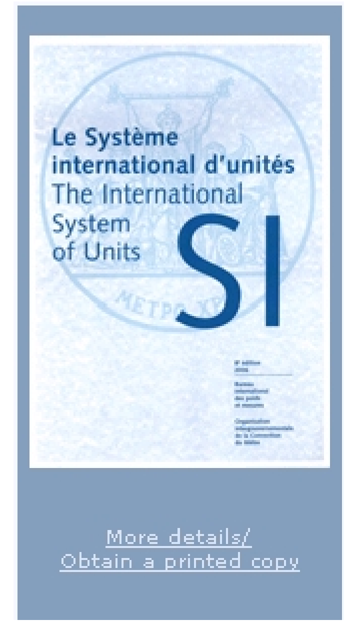
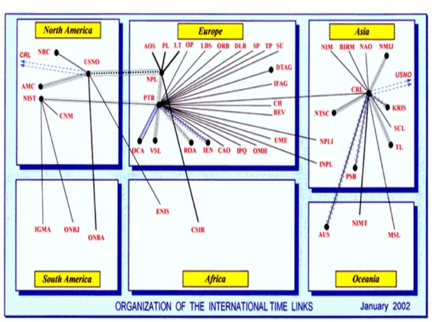
THE FUTURE OF SCIENTIFIC METROLOGY.
ANDREW WALLARD, DIRECTOR OF THE BIPM.





Organization of the international time links that provide data for the calculation of TAI



IMEKO,
Portugal 2009

SUMMARY

- Metrology meets a wide range of needs and is always changing.
- Some of the main issues for the future are with us today.
- Changes to the SI.

BIPM

The challenge in 1875: mission of the Metre Convention and the BIPM

BIPM

"establish new metric methods, conserve the metre and the kilogram, carry out comparisons necessary to assure the uniformity of measures throughout the world"

CIPM MRA

TODAY'S CHALLENGES ARE FAR WIDER THAN THE SCIENTIFIC MISSION OF THE BIPM IN 1875

- International trade depends more and more on metrology.
- "New" areas , where we have only just begun, have been stimulated by metrology in chemistry - medicine, food, meteorology, drugs, forensics..
- Materials technologies…nano materials, composites….
- Biology and biotechnology.
- Systems…in the factory with internet connections... as well as the body.

The challenge for metrology is to balance these new areas with the demands of classical metrology which themselves develop:

- improved clocks for navigation;
- smaller dimensions;
- higher temperatures;
- lower temperatures.

INTERNATIONAL EQUIVALENCE OF NATIONAL STANDARDS DRIVEN BY METROLOGY IN TRADE

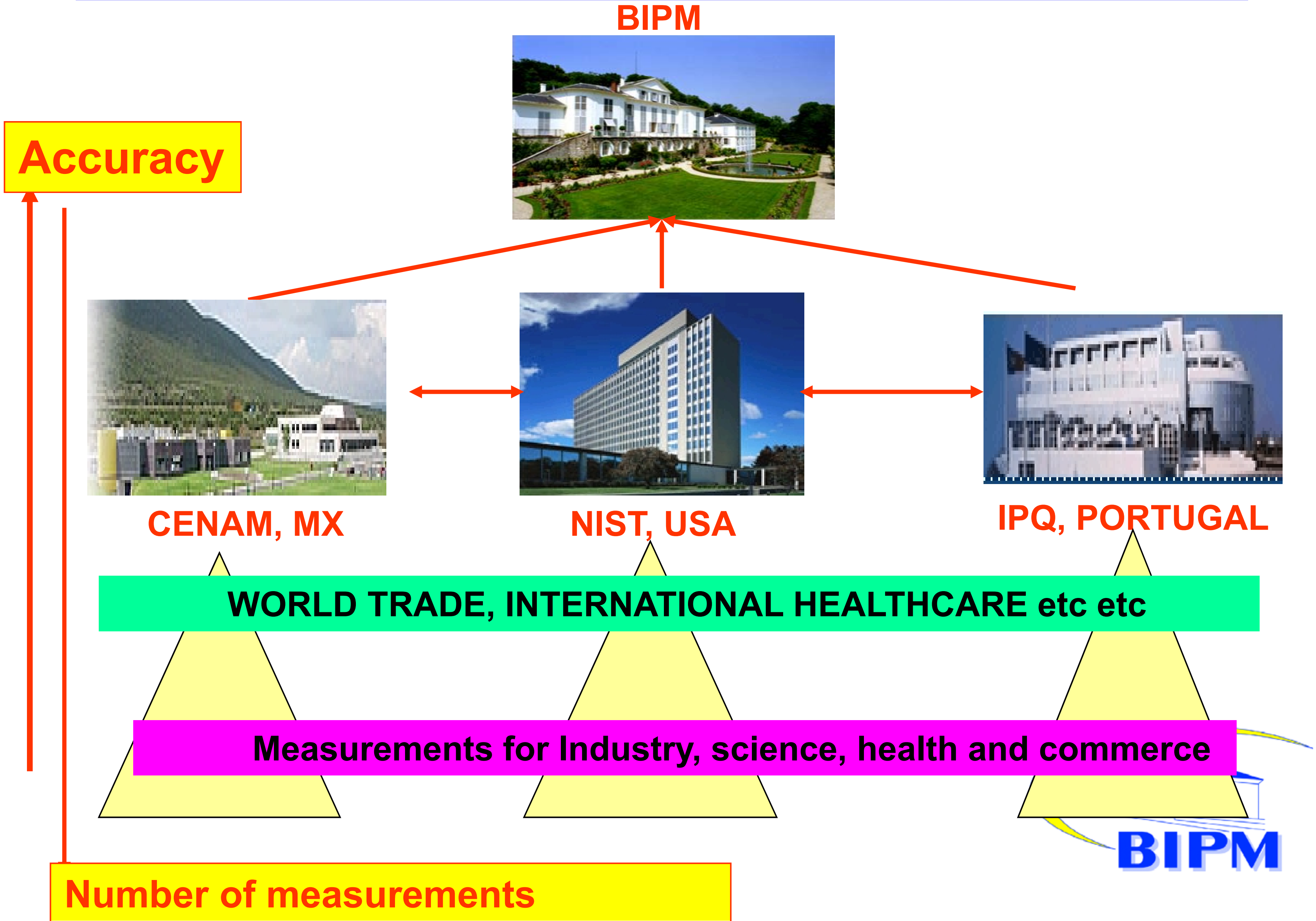
INTERNATIONAL TRADE

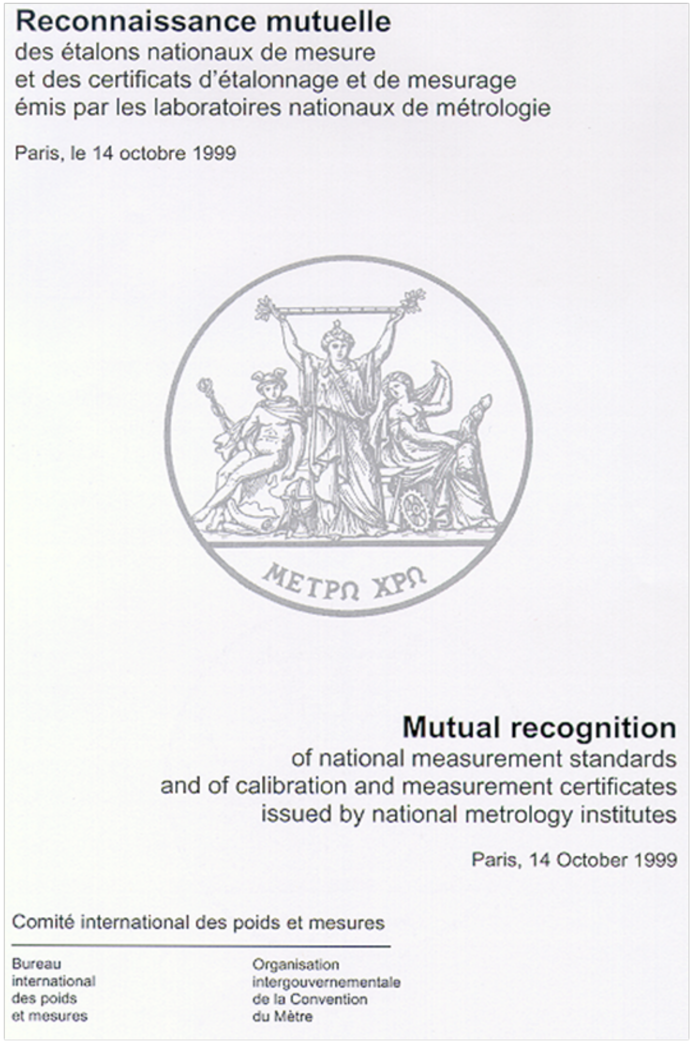
- World trade grows at about 15 % pa
- About 80% of global trade is affected by standards or regulations (OECD)

CIPM MRA

BIPM

THE INTERNATIONAL MEASUREMENT SYSTEM





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

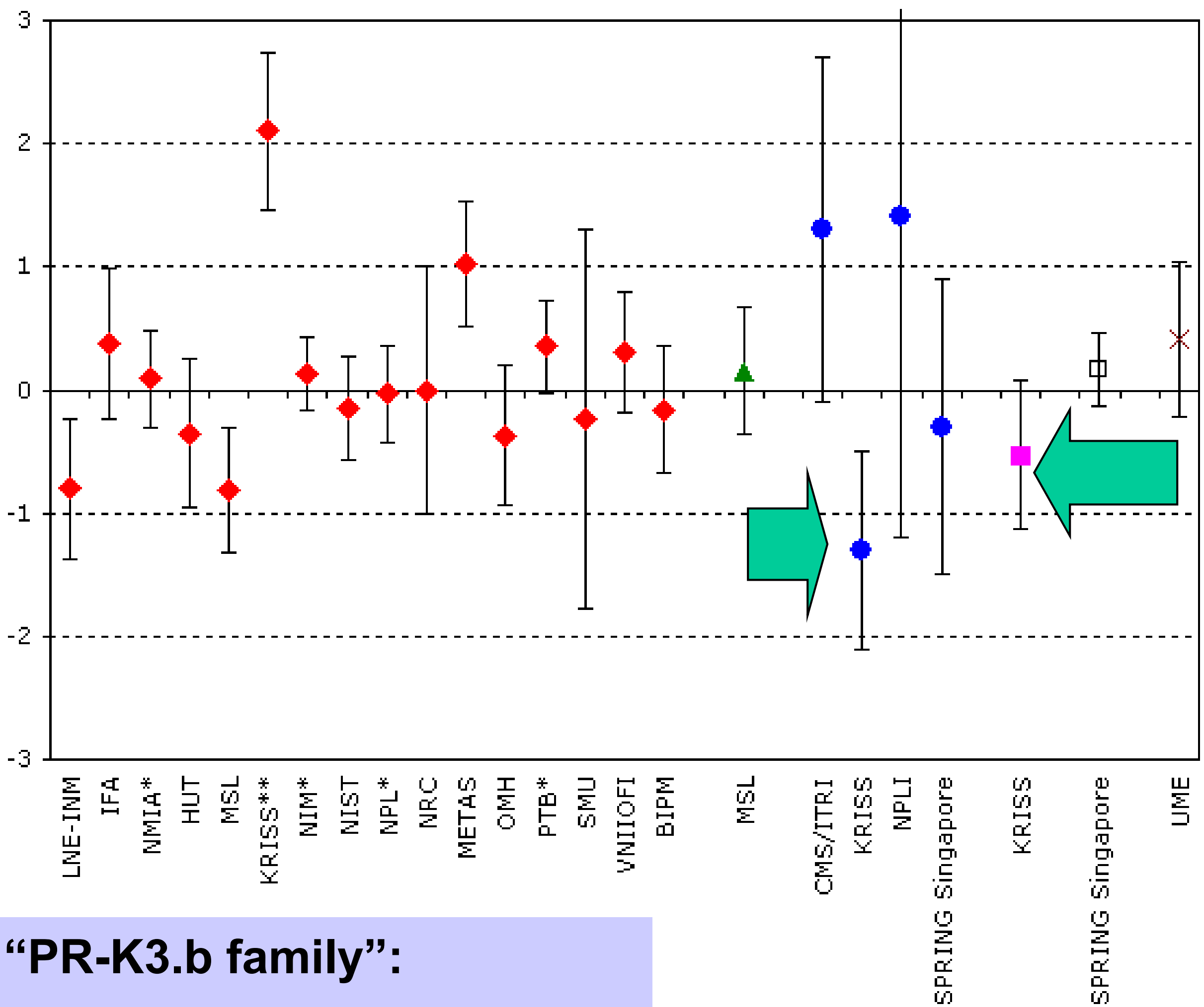
The CIPM MRA addresses technical barriers to trade caused by lack of traceability and equivalence.

Complying with the CIPM MRA means that an NMI's calibration certificates are acceptable by signatories world-wide and have a validated accuracy.

BIPM

RESULTS OF KEY COMPARISONS

Extension through common participation



- **diamonds: CCPR-K3.b participants**
- **triangle: one value amended after the CC key comparison**
- **circles: APMP.PR-K3.b participants**
- **squares: participants in two subsequent bilateral key cc**

"PR-K3.b family":

Luminous responsivity

A SUCCESSFUL EXAMPLE: KOREA

BP requested all 130 instruments be traceable to the National Institute of Standards and Technology (NIST). It would have incurred additional cost of $ 1 million to DSME for having its instruments calibrated abroad and acquiring substitute equipment to replace existing ones for the period of calibration, which normally takes more than 2 months. What was worse, the amount of penalty DSME would incur if the project is not completed until the deadline was $10 million...

BIPM

The system worked

DSME requested KRISS and NIST to confirm mutual recognition of calibration and measurement certificates issued by both national metrology institutes (NMIs) based on the CIPM-MRA. NIST confirmed that as far as DSME is keeping traceability to KRISS, there would not be a problem in calibration...

THE FRAMEWORK IS BEING EXTENDED INTO SOME OF THE MAJOR AREAS OF ACTIVITY FOR SCIENTIFIC METROLOGY

The framework of the CIPM MRA is copied in laboratory medicine, and comparisons in new areas of need are being established, particularly in chemical metrology, with applications to food, forensic science, environment and climate change, testing for sports drug use etc.

Just some of the new areas…...

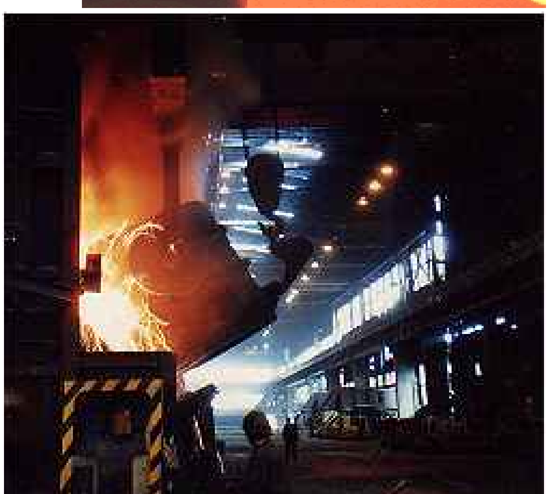
MEASUREMENT STANDARDS IN THE ENVIRONMENT AND THE ATMOSPHERE

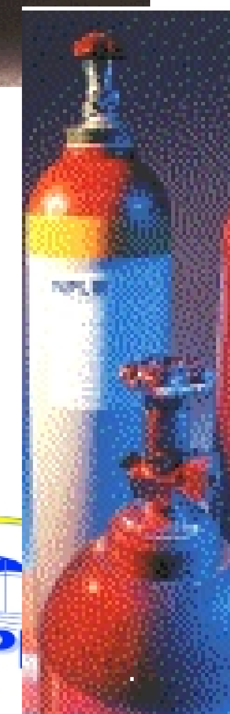
Measuring low pollutant concentrations

Automobile exhaust gas standards.

Comparability of data over time

Measurements in harsh environments





Satellite Instrument Calibration for Measuring Global Climate Change

Report of a Workshop

BY GEORGE OHRING, BRUCE WIELICKI, ROY SPENCER, BILL EMERY, AND RAJU DATLA

s the earth's c
Are the caus
will the clim
critical environ
times. Increase
to these questio
appropriate re
change. Accura
a critical part o
Measuring th
term global clin

TABLE 2. Required accuracies and stabilities of satellite instruments to meet requirements of Table 1. The instrument column indicates the type of instrument used to make the measurement.

	Instrument	Accuracy	Stability (per decade)
Atmospheric variables			
Temperature			
Troposphere	MW or IR radiometer	0.5 K	0.04 K
Stratosphere	MW or IR radiometer	1 K	0.08 K
Water vapor	MW radiometer	1.0 K	0.08 K
	IR radiometer	1.0 K	0.03 K
Ozone			
Total column	UV/VIS spectrometer	2% (λ independent), 1% (λ dependent)	0.2%
Stratosphere	UV/VIS spectrometer	3%	0.6%
Troposphere	UV/VIS spectrometer	3%	0.1%
Aerosols	VIS polarimeter	Radiometric: 3% Polarimetric: 0.5%	Radiometric: 1.5% Polarimetric: 0.25%
Precipitation	MW radiometer	1.25 K	0.03 K
Carbon dioxide	IR radiometer	3%	Forcing: 1%; Sources/sinks: 0.25%

NISTIR 7047

November 2002

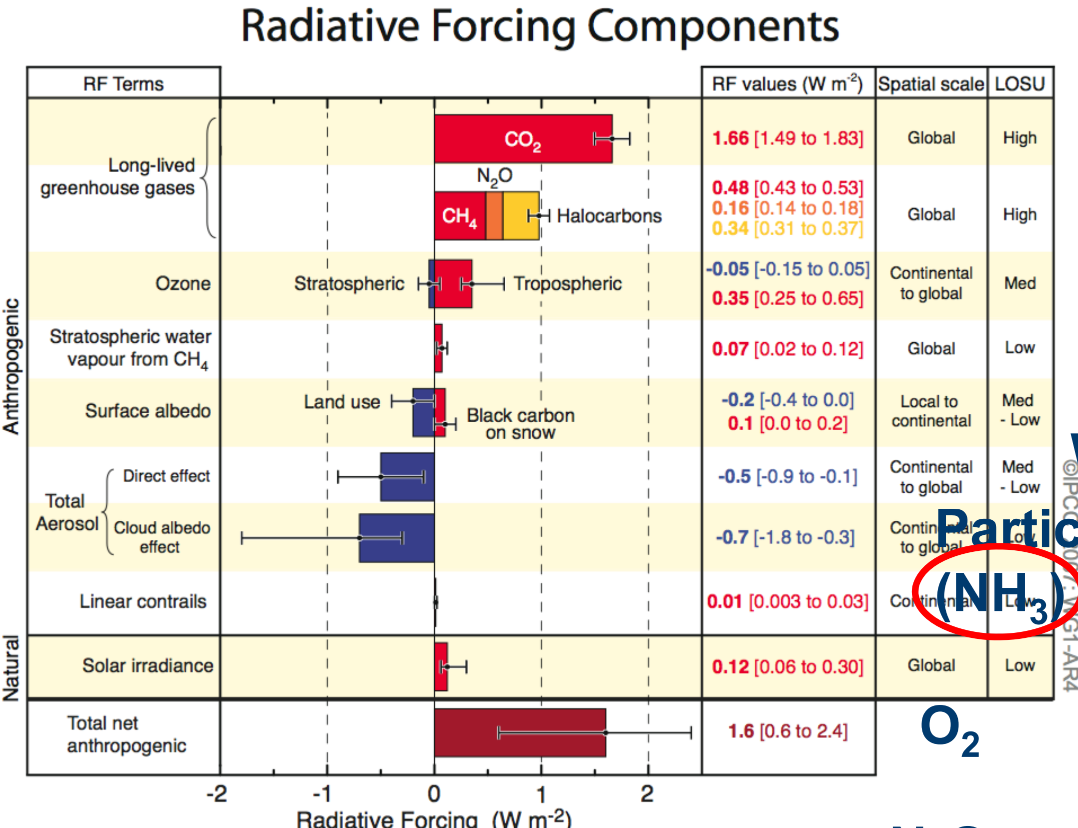
BIPM

CIPM-MRA and the WMO
MoU with the WMO

Calibration Standards and Practices In the WMO Global Atmosphere Watch (GAW) Programme for Greenhouse Gases, UV, Ozone and Reactive Gases

BIPM

Climate Change Gases



CO_2 , CH_4
& halocarbons

Water vapour

Carbon trading

Particles
(NH_3)

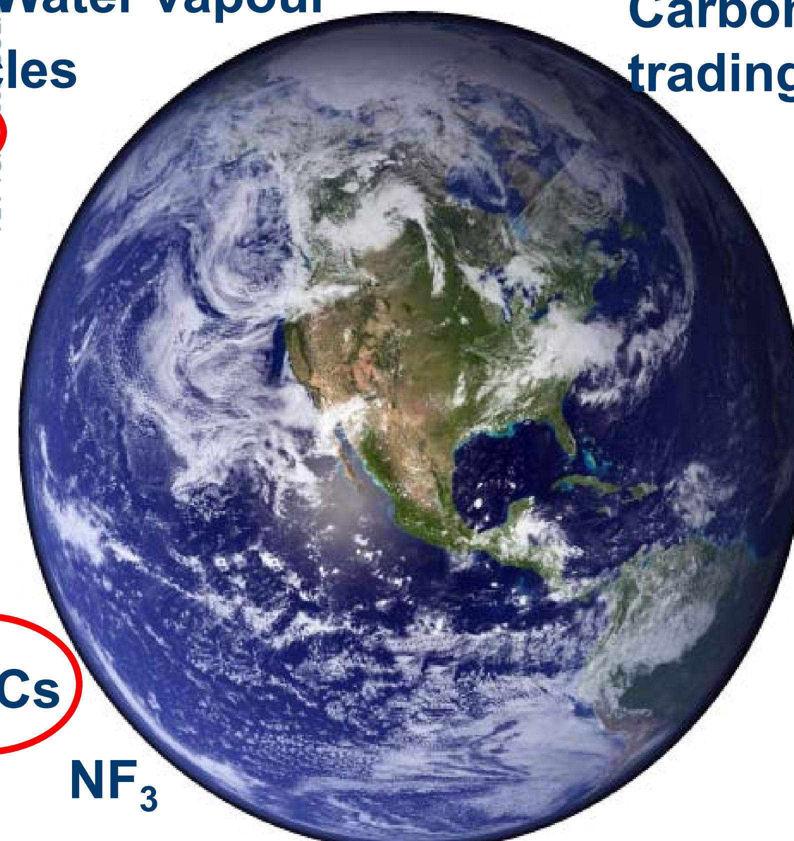
O_2

N_2O

Ozone

VOCs

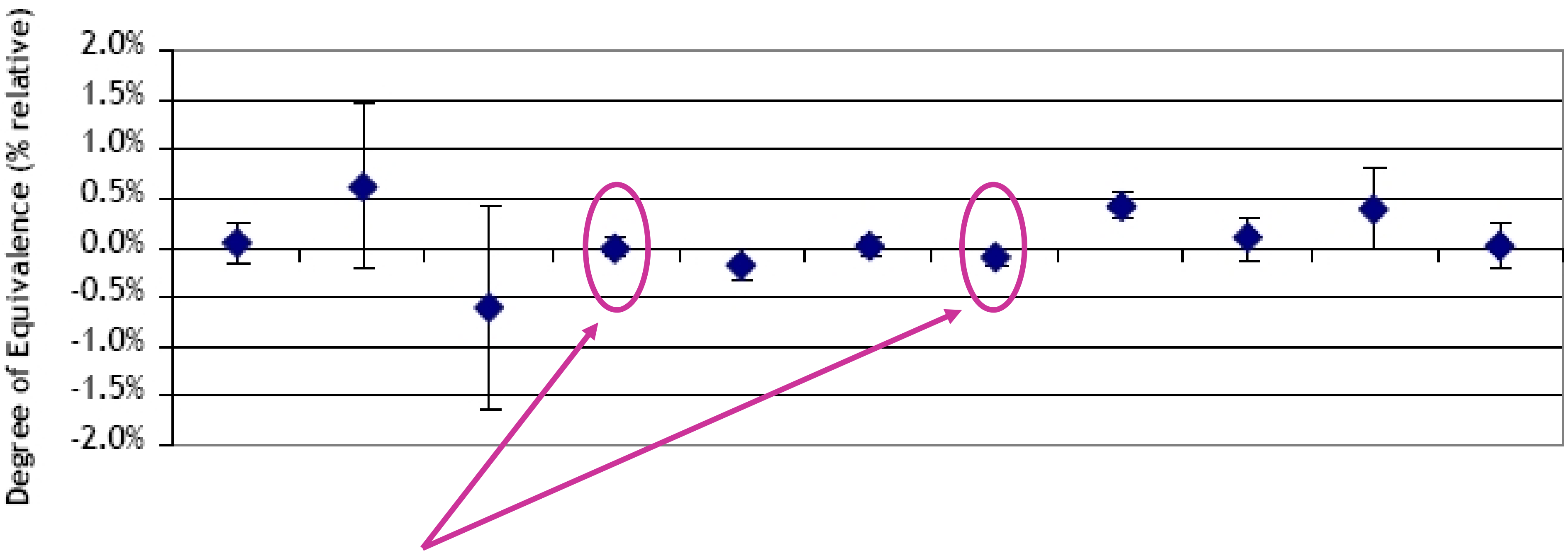
NF_3



Quantification & Control

CCQM-P41, Carbon dioxide, 365 µmol/mol (2003)

Comparison coordinated by NMi-VSL (NL)



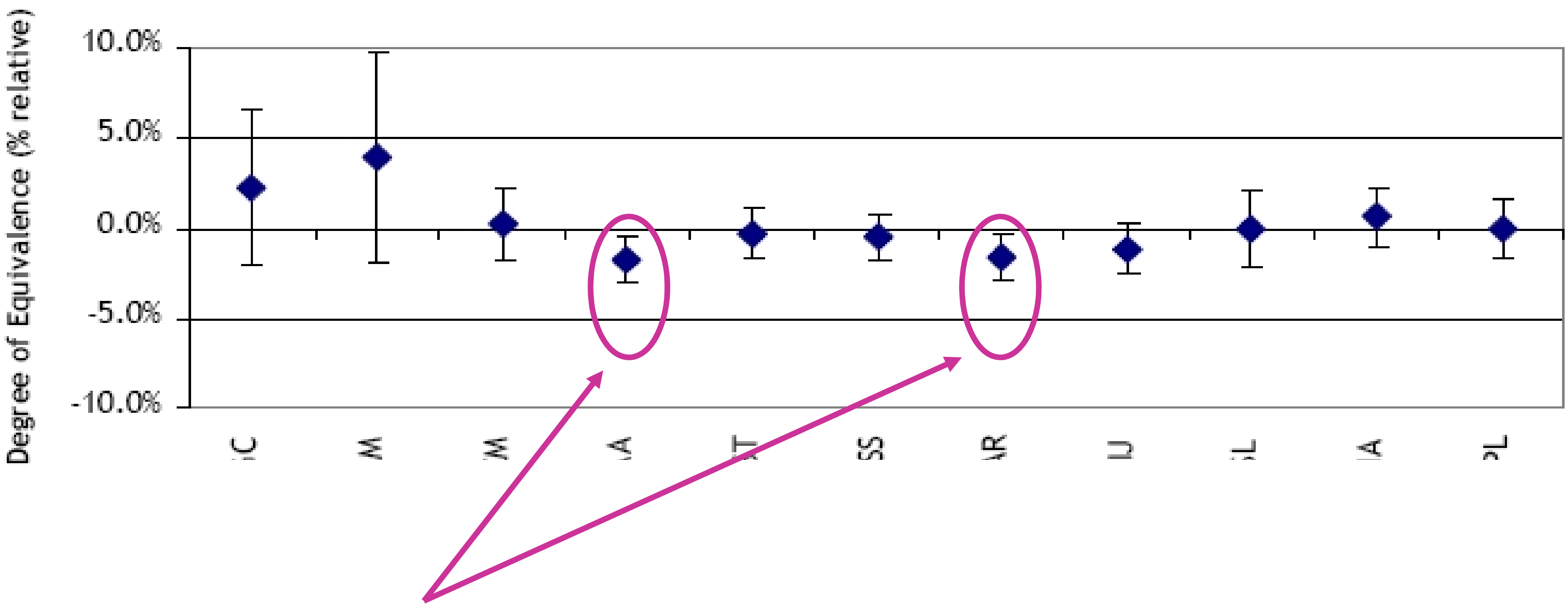
WMO-GAW Laboratories

Agreement with gravimetric value

(WMO-GAW labs used independent, non-gravimetric method)

CCQM-P41, Methane 1.8 µmol/mol (2003)

Comparison coordinated by NMi-VSL (NL)



WMO-GAW Laboratories

1.7 % difference from gravimetric value

WMO scale is being revised

BIPM

FOOD SCIENCE - TRACE ELEMENTS

Food and feed safety and quality

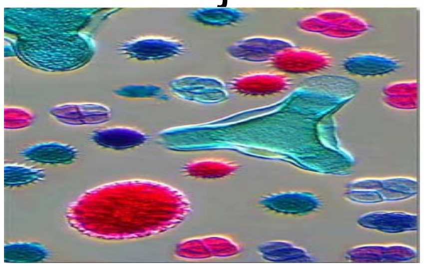
- Major current and developing area of activity
- Of interest to all NMIs with active programmes

- Food contact materials
- Dietary supplements
  - Vitamins (water or fat soluble)
  - Herbs and botanicals
- Food contaminants and residues
  - Contaminants
  - Residues

- Pure substance and calibrant solution infrastructure is lacking

FOOD- GMOs

- A major trade issue with millions of € at stake
- A major issue of public concern.



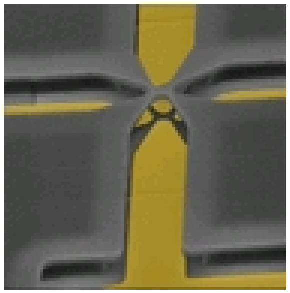
•There can be no “zero” detectable level as it depends on the method used - Brazilian chicken!!

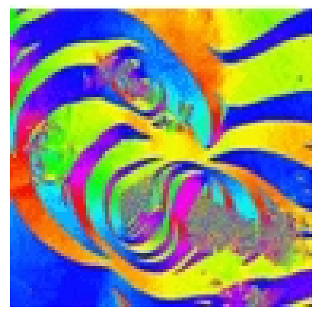
- EU foods must be labelled as GM derived if there is more than 1% biotech material: Australia’s limit is 2%, Japan’s 5%.

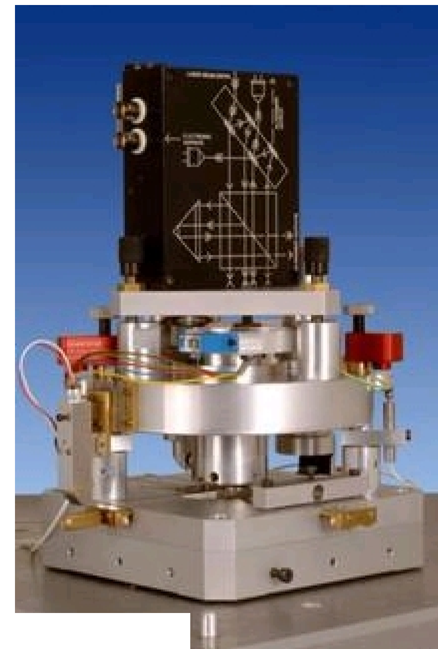
- The current reference materials and methods are not adequate and we are taking on the role of running international comparisons and validating the standards.

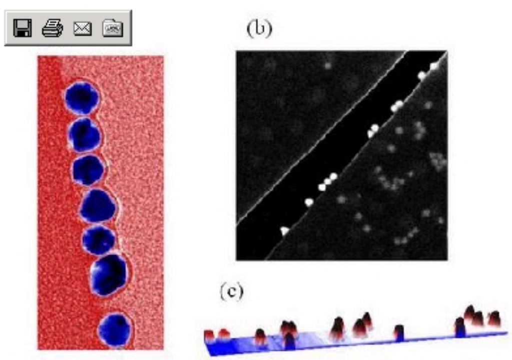
BIPM

NANOSCIENCE









30 nm gold nanoparticles imaged by (a) TEM, (b) SEM and (c) AFM

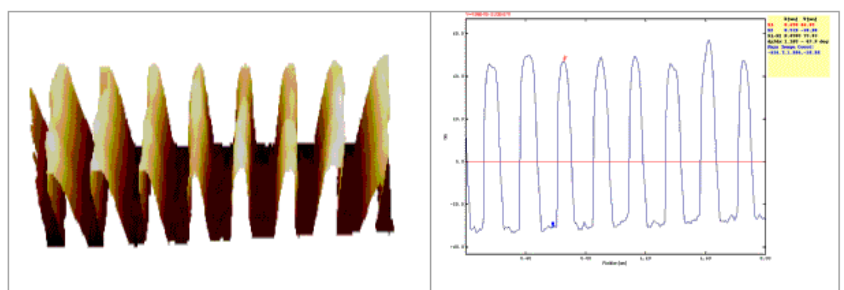


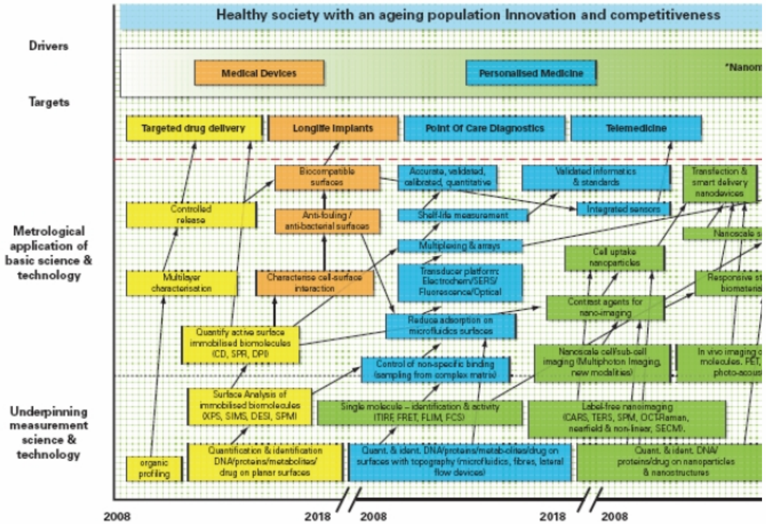
Figure 5. Ridges of photoresist on silicon wafer approximately 80 nm high, approximately 100 nm wide and spaced with approximately 250 nm. The trace to the left shows details of importance for the performance of the device.[ix]

BIPM

Chemical Metrology at the Nano-scale

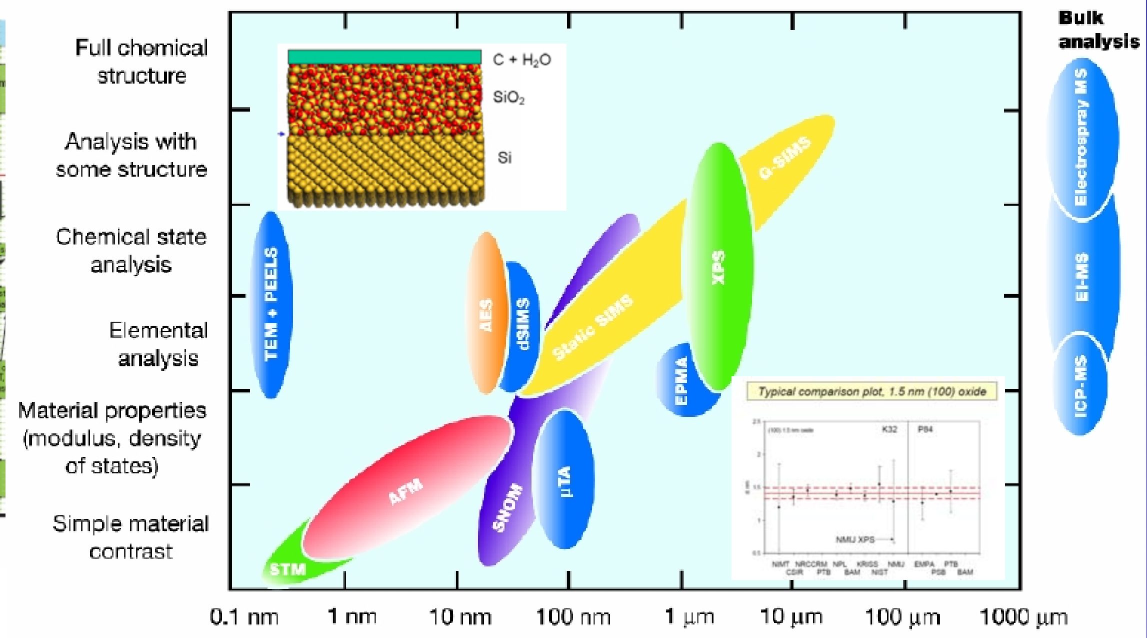
Requirements

Roadmap for nanobiometrology (Healthcare)



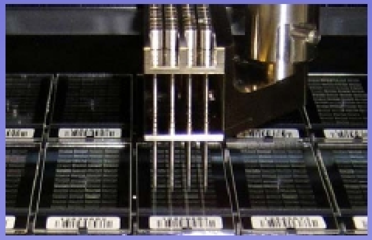
Draft Roadmap From NANOSTRAND Report (2008), NMP-CT-2006-033167

Surface and Nanoanalysis

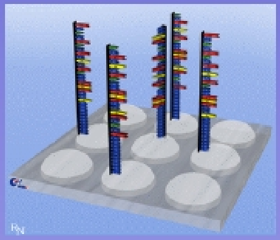


CCQM SAWG, BAWG, GAWG

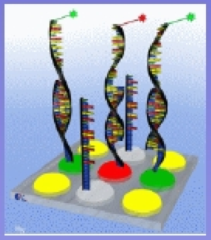
Functionality of bio-chips depends on control of functional groups as amines, epoxy, …



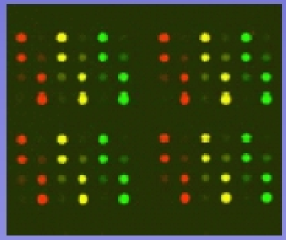
Blotting robot



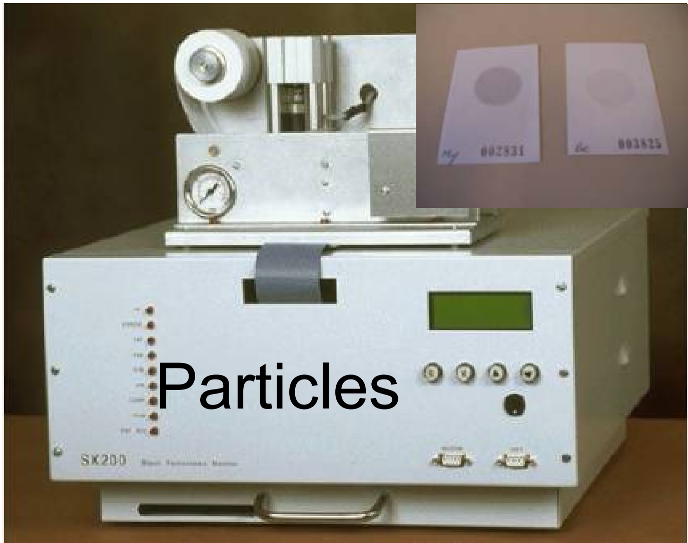
Blots with single stranded DNA



Hybridization



Information read out by fluorescence techniques,



NANOSCIENCE

- a few NMIs are active - mainly in nanoparticles
- Nanoelectrical measurements are expected as CMOS technology is outpaced- nanocircuits and molecular electronics, carbon nanotubes…..Are the properties we traditionally measure (capacitance, voltage etc) suitable for nanoscale. Is the physics different?
- Nanodosimetry?
- But there is little international consensus on what needs to be done and, in due course, want needs to be compared.
- BIPM workshop in 2010 addresses the challenge.

SCIENTIFIC MEASUREMENTS IN MEDICINE

Support of Laboratory Medicine

Database of higher-order reference materials, measurement methods/procedures and services

BIPM
Bureau International des Poids et Mesures

JCTLM
JCTLM Database
Laboratory medicine and *in vitro* diagnostics

> You are here : JCTLM-DB > Reference measurement services > List

Results of the search

DGKL, Germany

Phone: +49 228 287 15911
Fax: +49 228 287 15033
Web: http://www.dgkl-rfb.de/

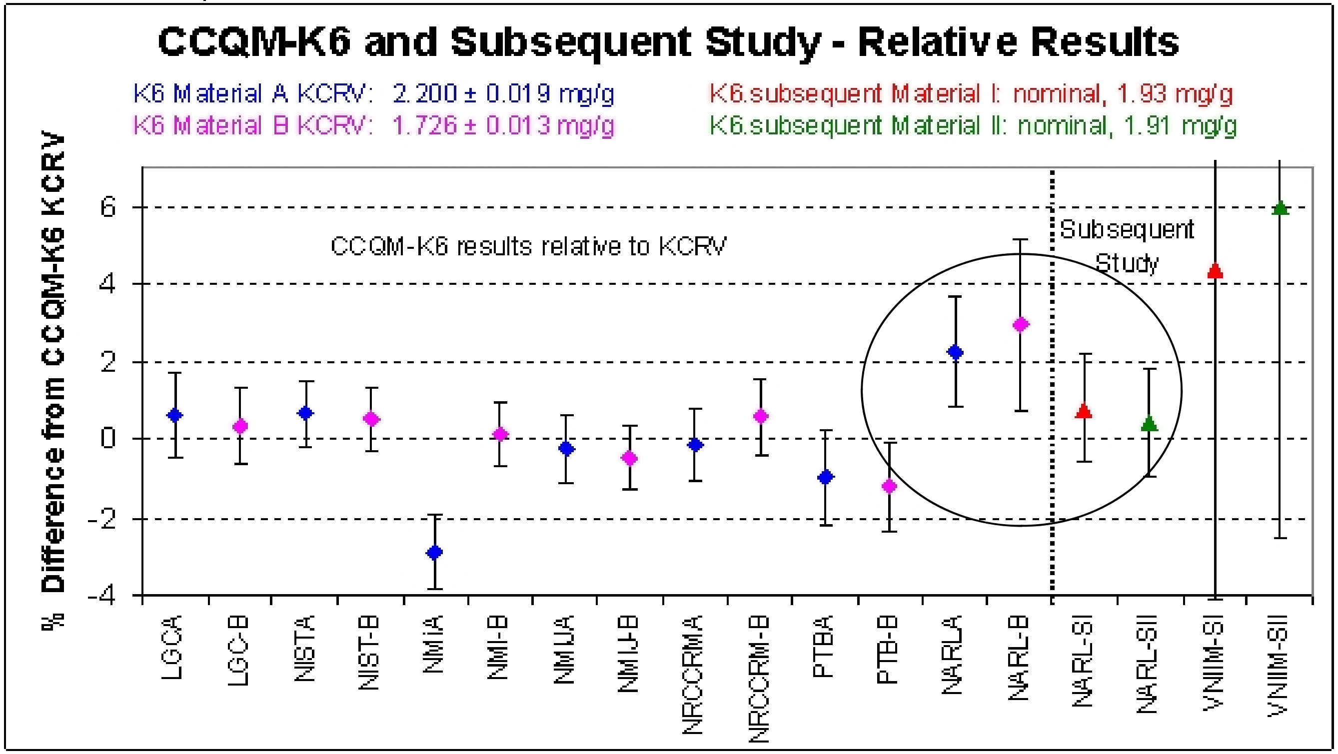
Contact person: Prof. Dr. Lothar Siekmann, Dr. Anja Kessler
Email: lothar.siekmann@ ukb.uni-bonn.de

Analyte	digoxin
Material or matrix	blood serum, blood plasma
Quantity	Amount-of-substance concentration
Service measurement range	0.1 nmol/l to 40 nmol/l
Expanded uncertainty (level of confidence 95%)	0.6 % to 2.2 % The given uncertainties do not relate to the lower and higher limits of determination
Interlaboratory comparison results	RELA - IFCC External Quality assessment scheme for Reference Laboratories in Laboratory Medicine at http://www.dgkl-rfb.de:81/index.shtml
Measurement principle	Isotope dilution mass spectrometry (IDMS)
JCTLM reference measurement method/procedure	DGKC definitive method for serum digoxin

Cholesterol in Human Serum

A subsequent comparison to CCQM-K6 to provide Appendix B data for cholesterol in human serum for NARL and VNIIM with NIST serving as the link to CCQM-K6.

CCQM-K6-Subsequent Materials: Frozen Human Serum - IMEP 17 Materials I and II



K6 results are plotted as % differences from KCRVs

Subsequent results are plotted relative to NIST results in K6S and are offset by average (NIST-KCRV) result from K6 (NIST Ref Pt)

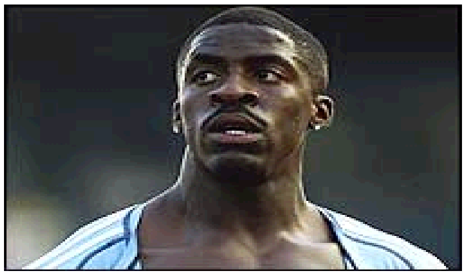
CHOLESTEROL MEASUREMENTS IN CLINICAL LABORATORIES

- 1986 ACCURACY, 6%.
- WITH IMPROVED PURE REFERENCE MATERIALS, IN 2000 THE ACCURACY HAD IMPROVED TO 3%
- a +/- 3% BIAS FROM THE TRIGGER POINT OF 240 mg/dL FOR TREATMENT MEANS THAT NEARLY 10% OF PEOPLE ARE WRONGLY TREATED.
- SAVINGS OVER THE LAST 30 YEARS ARE OVER €100M A YEAR

BIPM

DRUG TESTING IN SPORT

Many careers can be threatened by testing procedures.



Chambers admits positive test

Dwain Chambers tests positive for a banned steroid but denies taking it wilfully.

- Dwain Chambers profile
- Moorcroft plays down drug fears
- Four US athletes test positive

BIPM

THE PROBLEMS

- There is no world-wide agreement on testing procedures. The IOC uses accredited labs that compare their results made on standard samples.

- The concentrations of drugs are usually very small and are in a “matrix” like blood or urine.

- The uncertainties of measurements can be rather large but the regulators want a “yes/no” answer
- After the Athens Olympics WADA can now measure effects of drugs after 4 days

Armstrong was cleared.
A report criticised the science.

"SOFT METROLOGY"

How do we measure shine, softness, comfort…?

HOW DO WE MEASURE THE INTERACTION WITH THE BODY?

- In photometry, we need the v/λ curve for the eye.
- In acoustics and noise measurement, we need to model the ear.
- In ionizing radiation we need to measure absorbed dose to water.

- Now we are being asked to be concerned with electromagnetic radiation and the brain, touch and sensation……….

- BIPM initiated a major workshop with ISO and IEC on physiological quantities

SOME CONCLUSIONS ABOUT SCIENTIFIC METROLOGY

- The classical job is not done…maybe it never will be.

- NMIs are active in carbon nanotubes, quantum computing, terahertz technologies for security, measurements of lower and lower concentrations of pollutants, pesticide residues, drugs etc. New skills are needed.

- What do we do about biology? The SI doesn’t (yet) apply but we must deal with “accepted values” which change from time to time eg insulin references in the WHO.

- Metrologists know about traceability and uncertainty …but little about biology. Partnerships are needed.

- As NMIs, how do we balance the needs of existing customers and the challenge of new areas?

BIPM

I DON’T HAVE ALL THE ANSWERS - DO YOU?

It will be difficult to persuade governments to fund all this new work.

Universities can start the process but rarely can make long term commitments.

In Europe, NMIs are collaborating in iMERA. Is this the answer?

THE SI

FUNDAMENTAL CONSTANTS AND THE SI

- The fundamental constants clearly play a major part in the inter-relationships between the units.
- We believe they are stable in time.
- All the trends were…are…to replace the definitions where possible by definitions based on a fundamental constant of nature.
- In general this has been done, with the exception of the kilogram.

The kilogram could be redefined, based on
a fixed value of either the Planck Constant or the Avogadro Number

BIPM

The kilogram

- Replace the kilogram by a definition based on “quantum” phenomena. Fix the Planck Constant or the Avogadro Number

- $$h = \frac{c\, A_r(e)\, M_u\, \alpha^2}{2\, R_{oo} N_A}$$

$A_r(e)$…. Relative atomic mass of the electron

M_u…… Molar mass constant

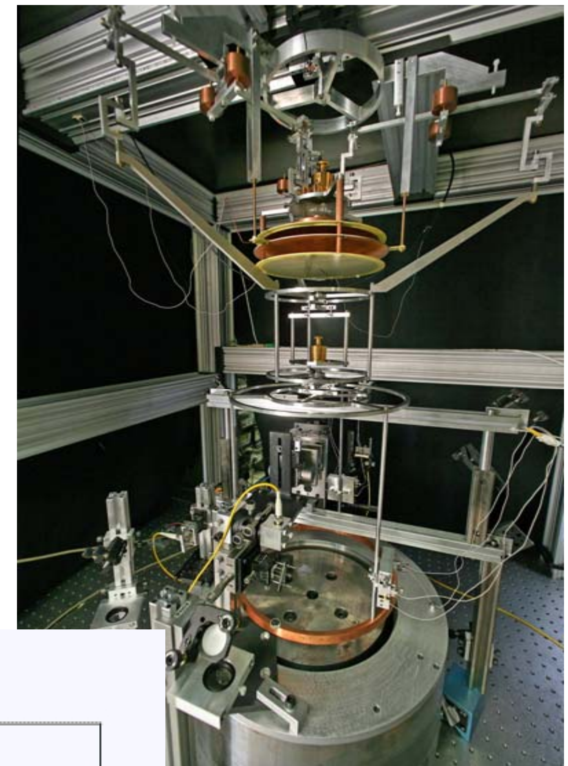
α……….Fine structure constant

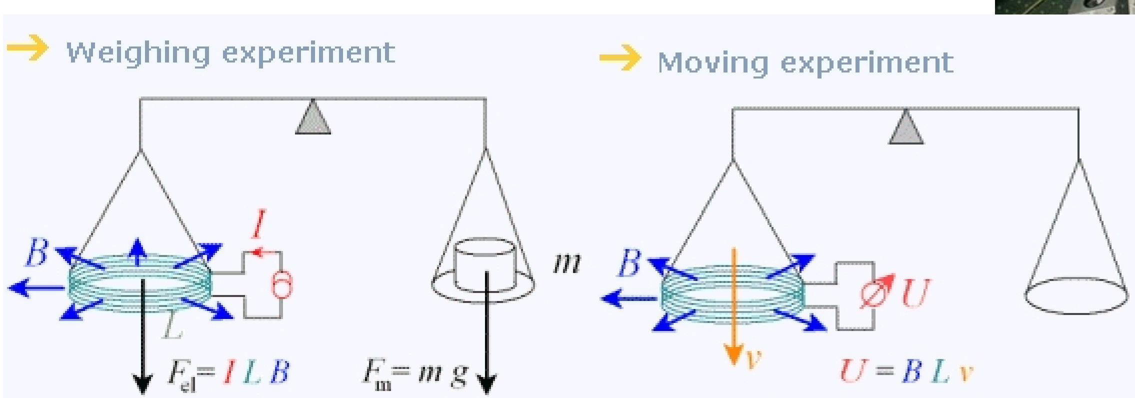
R_{oo}…….Rydberg Constant

All the constants in red are known to better than 10^{-9}

We are looking for a way to redefine the kilogram at 1 part in 10^8 or so

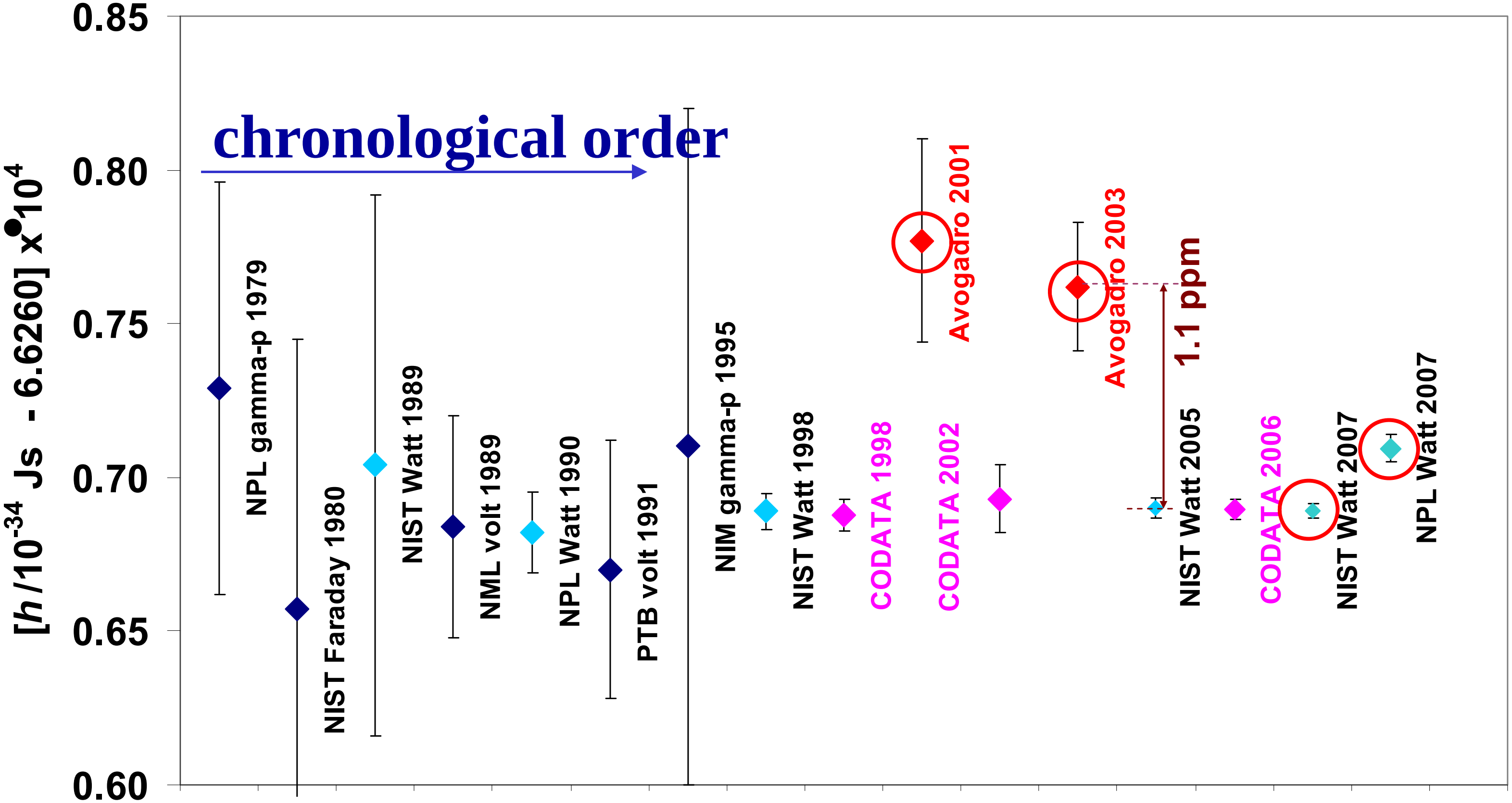
Watt balances





BIPM

History of measurements of the Planck constant



N_A and h are related by

$$N_A\ h = 0.012 \frac{m_e}{m\left({}^{12}\mathrm{C}\right)} \frac{c\alpha^2}{2R_\infty} \qquad u_r\left(N_A\ h\right) = 1.4 \times 10^{-9}$$

IF WE REDEFINE THE KILOGRAM …..

- **There would be a benefit to the fundamental constant community, and electrical standards could be truly “SI”.**

- **If the kilogram is defined using either h or N_A then the mass of the international prototype, m($\mathcal{K}$) will no longer be exactly 1 kilogram and would have an uncertainty of about 0.17ppm.**

- **Later results may change the value of m(k) and could be 5 parts in 10^8 if we get it wrong.This certainly would not please the world of practical mass measurement.**

BIPM

BASE QUANTITIES AND UNITS - WHERE ARE WE NOW?

QUANTITY	BASE UNIT	PRESENT DEFINITION FIXES
time	second	hyperfine splitting in the Cs atom
length	metre	speed of light
mass	kilogram	the mass of the prototype
electric current	ampere	μ_0 the magnetic constant
thermodynamic temperature	kelvin	temperature of the water triple point
Amount of substance	mole	molar mass of carbon
luminous intensity	candela	luminous efficacy of a specified source

BASE QUANTITIES AND UNITS - WHERE WE COULD BE

QUANTITY	BASE UNIT	A NEW DEFINITION MAY FIX
time	second	hyperfine splitting of the Cs atom
length	metre	speed of light
mass	kilogram	the Planck, h or Avogadro constant N_A
electric current	ampere	the elementary charge,e
thermodynamic temperature	kelvin	the Boltzmann Constant k_B
Amount of substance	mole	the Avogadro constant N_A
luminous intensity	candela	luminous efficacy of a specified source

RE-DEFINITIONS?

- Current thinking is that, at the 2015 General Conference on Weights and Measures, we may redefine the kilogram, the ampere, the mole, the kelvin and the candela.

- But only if there is greater confidence than now in the values we choose and, in particular if we can give a satisfactory explanation for any difference in the value of h obtained by Watt Balances and by the X ray crystallography method

- Between now and then we shall be consulting widely, and especially with user communities who need to plan for any such changes

AND WE HAVE TO BE CAREFUL (1)

- Lets say that the various approaches to the kilogram redefinition can only be reconciled to about 3-4 in 10^{8}.

- The uncertainty would be transferred to the realization of the kilogram definition- say about 30-40 micrograms.

- However OIML class E1 weights need calibrations to about 60 micrograms.

- How should the uncertainty in the kilogram realization be handled bearing in mind that comparisons between weights can be done at the level of a few micrograms?

- a “Practical mass scale?

AND WE HAVE TO BE CAREFUL (2)

- Watt balances will be unlikely to be used to realize the definition. They will probably all have different uncertainties of measurement and may not agree.

- Watt balances will need to be compared.

- Current BIPM policy is that we shall maintain a watt balance to monitor possible drifts of an ensemble of masses made from different materials and use them as a travelling standard to compare watt balances AND to disseminate mass by conventional weighings

BIPM

CONCLUSIONS

- Metrology always has been exciting and challenging

METROLOGY IS NOT SCIENTIFICALLY DULL!!!

"ACCURATE MEASUREMENT IS AT THE HEART OF PHYSICS, AND IN MY EXPERIENCE NEW PHYSICS BEGINS AT THE NEXT DECIMAL PLACE"

Steve Chu, Stanford, Nobel Prize Laureate, 1997

CONCLUSIONS

- Metrology always has been exciting and challenging
- And there's no sign that the challenges are going away.
- Good luck to you all!!