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From Cubits to Qubits: New Trends in Metrology

Hratch G. Semerjian
National Institute of Standards and Technology, USA

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Metrology and Innovation for Competitiveness
São Paolo, Brazil
November 5, 2003

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Outline

- Metrology and Competitiveness
- Metrology in History
- Evolution of Measurement Standards
- Trade as a Driver for Metrology
- Technology Driving New Trends
- Summary

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Competitiveness

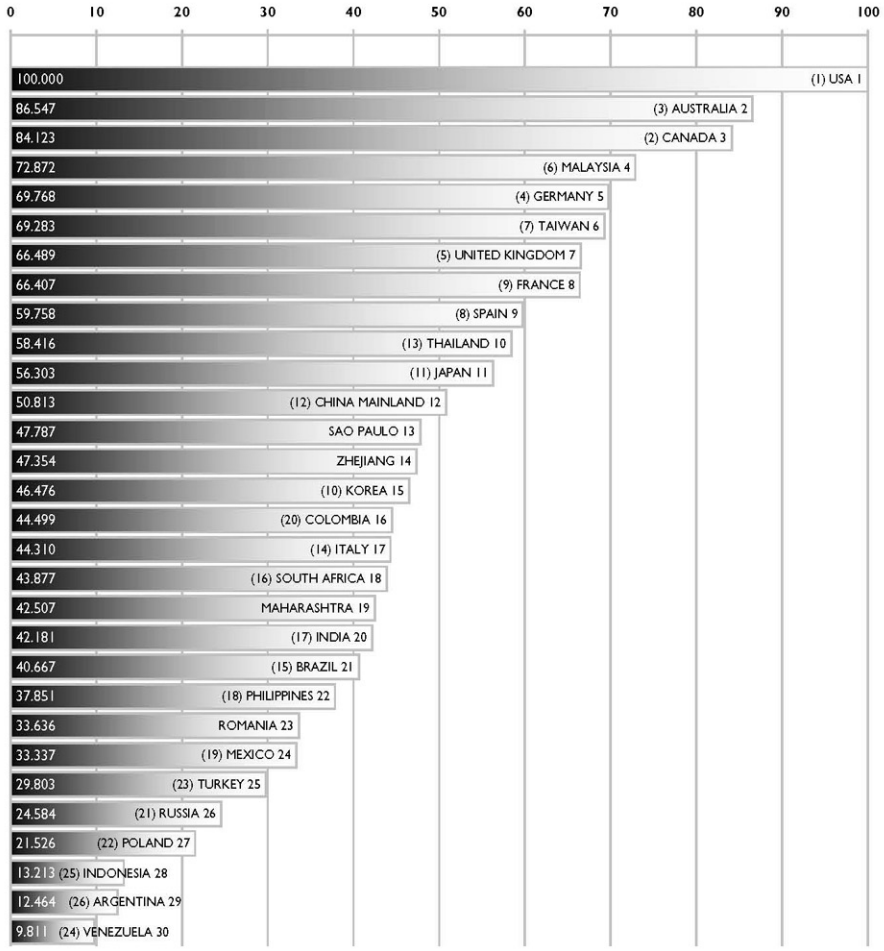
- a measure of a country's advantage or disadvantage in selling its products in international markets. *Organization of Economic Cooperation and Development (OECD)*

- the ability of an entity to operate efficiently and productively in relation to other similar entities ...the overall economic performance of a nation, particularly its level of productivity, its ability to export its goods and services, and its maintenance of a high standard of living for its citizens. *Joan Spero and Jeffrey Hart*, *The Politics of International Economic Relations, http://www.indiana.edu/~ipe/glossry.html*

- how successful one party is in offering favorable terms and securing the business. More favorable terms may involve a lower price, higher quality, a faster delivery time, and other aspects of the product. *Operations Management Course, William J. Stevenson*

THE WORLD COMPETITIVENESS SCOREBOARD 2003

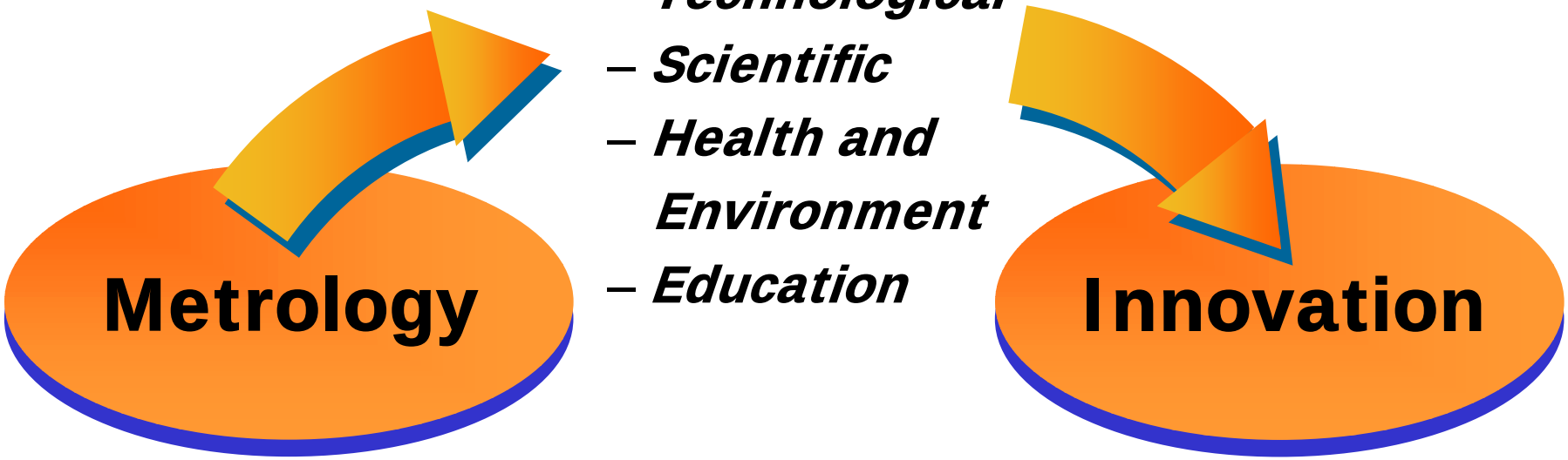
Population greater than 20 million



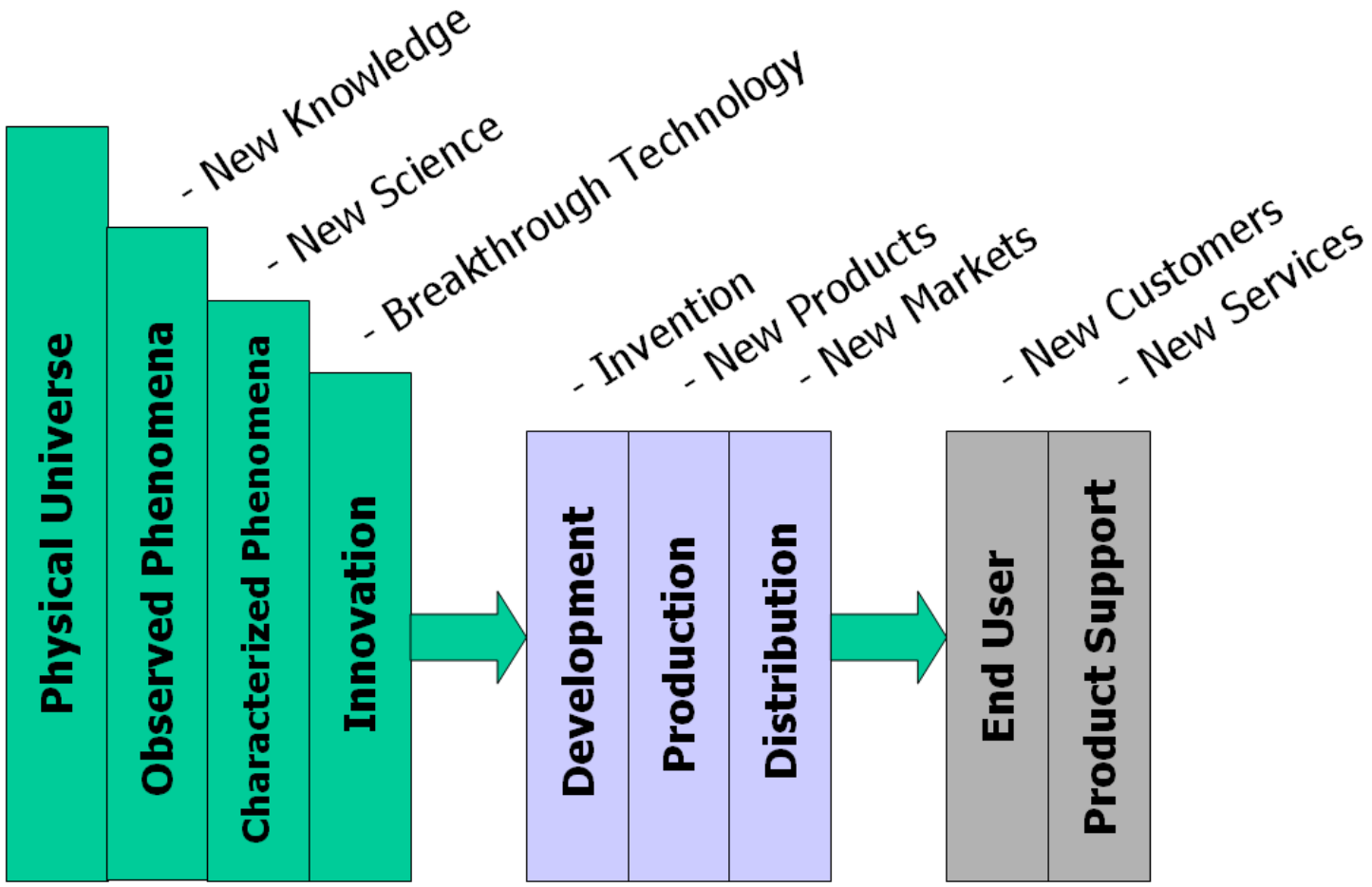
(2002 rankings are in brackets)

IMD World Competitiveness Yearbook Competitiveness Factors

- **Economic Performance**
- **Government Efficiency**
- **Business Efficiency**
- **Infrastructure**
  - ***Basic***
  - ***Technological***
  - ***Scientific***
  - ***Health and Environment***
  - ***Education***

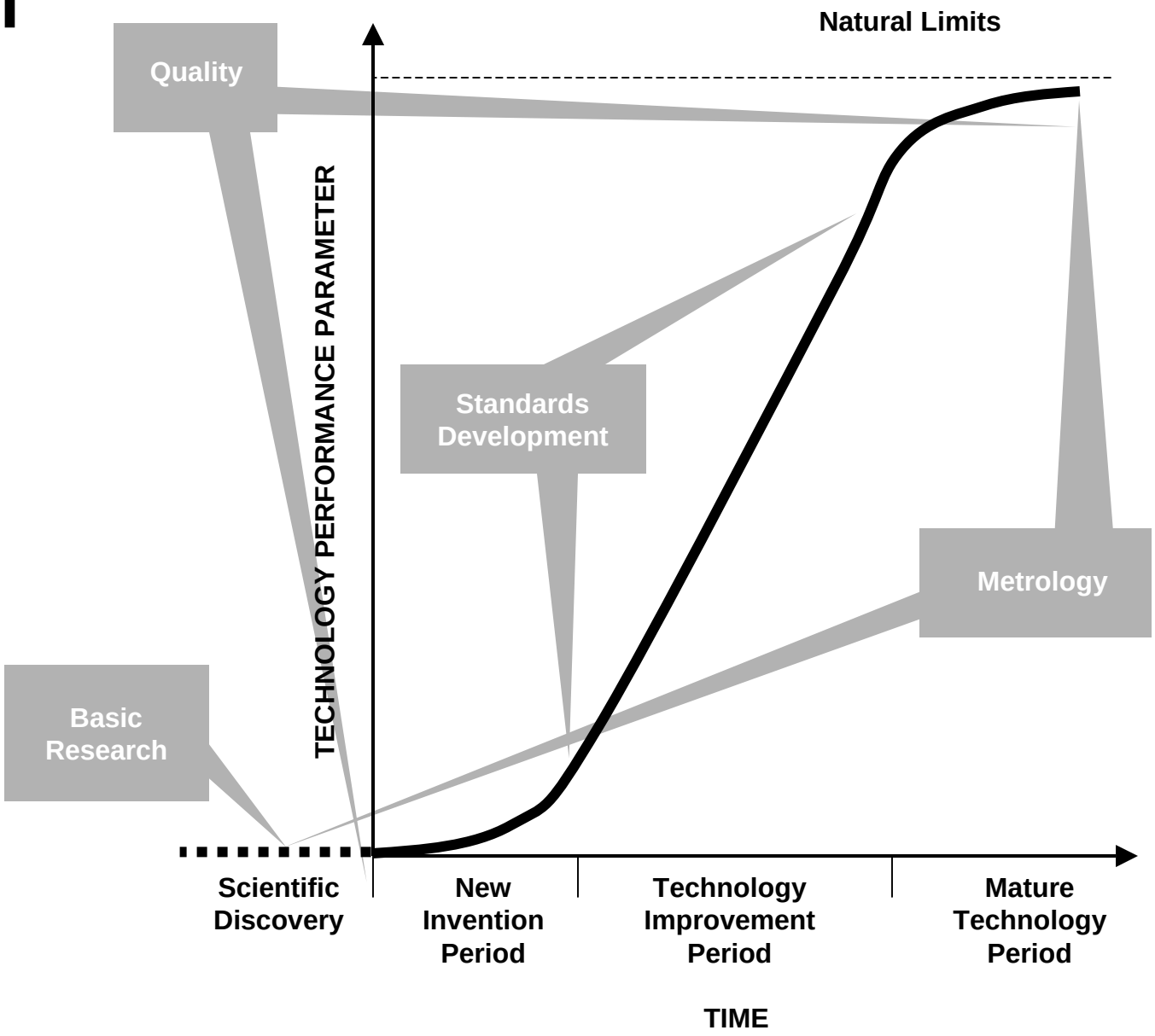


Innovation Life Cycle



- Measurements
- Physical Standards
- Reference Materials & Data
- Technology

- Calibrations
- Technical Information
- Documentary Standards
- S & T Expertise
- Cooperative R&D


Natural Limits
Quality
TECHNOLOGY PERFORMANCE PARAMETER
Standards Development
Metrology
Basic Research
Scientific Discovery
New Invention Period
Technology Improvement Period
Mature Technology Period
TIME

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“commerce begins with measurement

…and ends with measurement”

Metrology in Ancient Times

- **Standard unit of length - the length of Pharaoh's forearm plus the width of his palm**
  - **The Cubit**
- **Realization of the Cubit: A stick of wood**
  - **Working Standard / Comparability**
- **The "Royal Cubit Master"**
  - **Primary standard in granite**
- **Re-calibration of cubit stick on each full moon**
  - **Calibration / Traceability**
  - **Severe penalty for non-compliance**
- **Uniformity of length measurement in Egypt was achieved to a relative accuracy of 0.05 % over a distance of 230 meters**

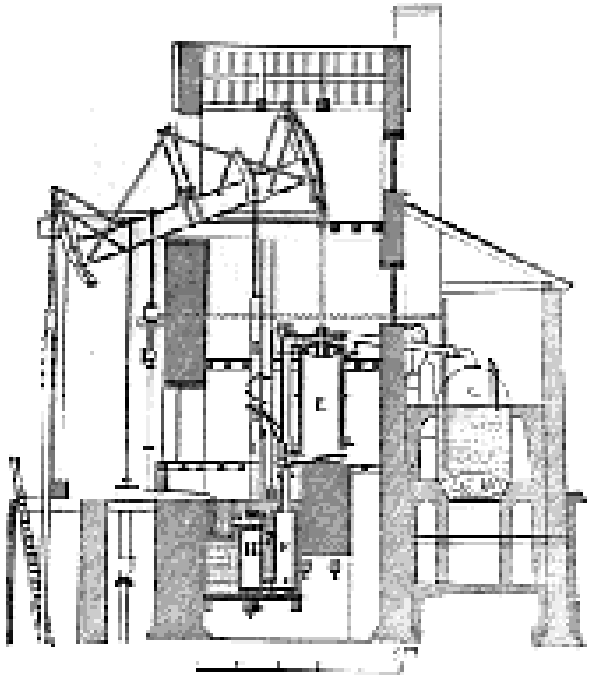
Long term stability? "Standard" Pharaoh?

Technology Starts to Drive Metrology

"Throughout the realm there shall be the same yard of the same size and it should be of iron"

Assize of Measures, 1196

The Industrial Revolution created the need for accurate measurements (1760 – 1850)



The first Watt engine (1769)

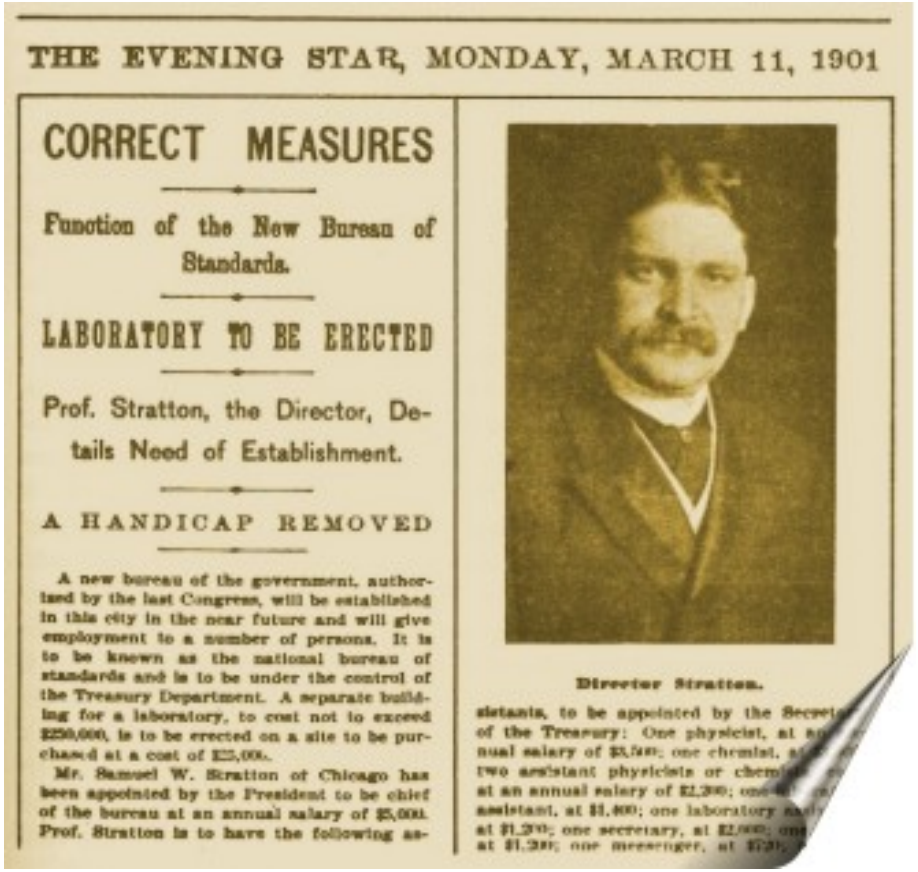
"to prevent such abuses, to facilitate exchanges, and thereby to encourage all sorts of industry and commerce, it has been found necessary, in all countries that have made considerable advances toward improvement, to affix a publick stamp upon certain quantities of such particular metals, as were in those countries commonly made use of to purchase goods. Hence the origin of coined money, and of those publick offices called mints; institutions exactly of the same nature with those of the aulnagers and stampmasters of woollen and linen cloth. All of them are equally meant to ascertain, by means of a publick stamp, the ***quantity and uniform goodness*** *of those different commodities when brought to market."*

Adam Smith
"The Wealth of Nations"
1776

"It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of the Government, of schools, colleges, and universities than by the establishment of the institution proposed in this bill."

House Committee on
Coinage, Weights and Measures
May 3, 1900

on the establishment of the National Bureau of Standards (now NIST)



THE EVENING STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

A new bureau of the government, authorized by the last Congress, will be established in this city in the near future and will give employment to a number of persons. It is to be known as the national bureau of standards and is to be under the control of the Treasury Department. A separate building for a laboratory, to cost not to exceed $250,000, is to be erected on a site to be purchased at a cost of $25,000.

Mr. Samuel W. Stratton of Chicago has been appointed by the President to be chief of the bureau at an annual salary of $5,000. Prof. Stratton is to have the following as-

Director Stratton.

sistants, to be appointed by the Secret... of the Treasury: One physicist, at a... nual salary of $3,... two assistant physicists or chem... at an annual salary of $2,... assistant, at $1,...; one laboratory ... at $1,...; one secretary, at $2,...; one ... at $1,...; one messenger, at $...

NBS NIST NIST NIST

1901-2001
NIST CENTENNIAL

SI Units – The Basis for Scientific Advancement

- The Meter Convention created BIPM in 1875
- The 11th CGPM established the SI system in 1960

SI Base Units		
Base Quantity	Name	Symbol
Length	Meter	M
Mass	Kilogram	Kg
Time	Second	S
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	Mole	Mol
Luminous intensity	Candela	cd

Evolution of Standards

CIPM Consultative Committees

Electricity and Magnetism (CCEM) (1927)

Photometry and Radiometry (CCPR) (1933)

Thermometry (CCT) (1937)

Length (CCL) (1952)

Time and Frequency (CCTF) (1956)

Ionizing Radiation (CCRI) (1958)

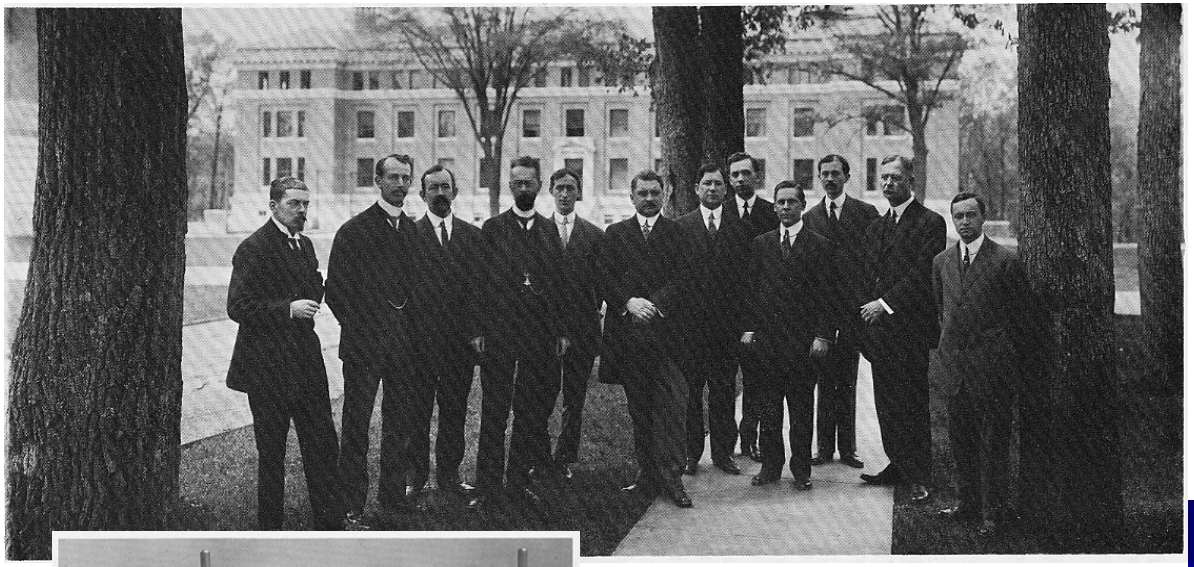
Units (CCU) (1954)

Mass (CCM) (1980)

Amount of Substance (CCQM) (1993)

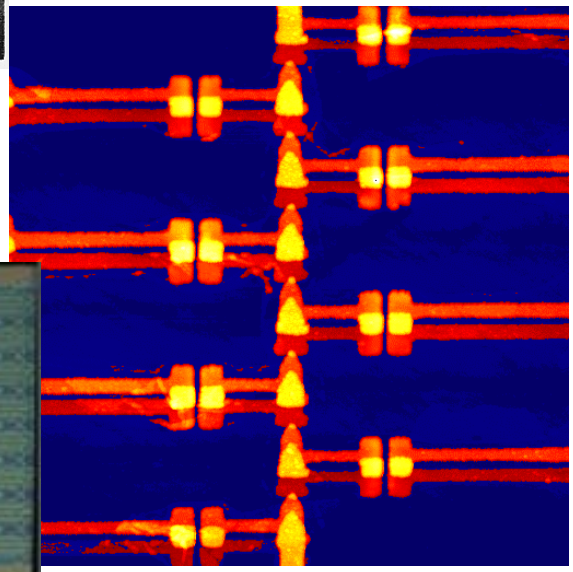
Acoustics, Ultrasound, and Vibration (CCAUV) (1998)

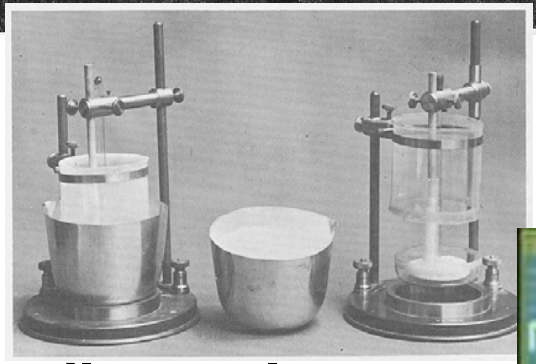
Evolution of Standards - *The Volt*



International Technical Committee of 1910

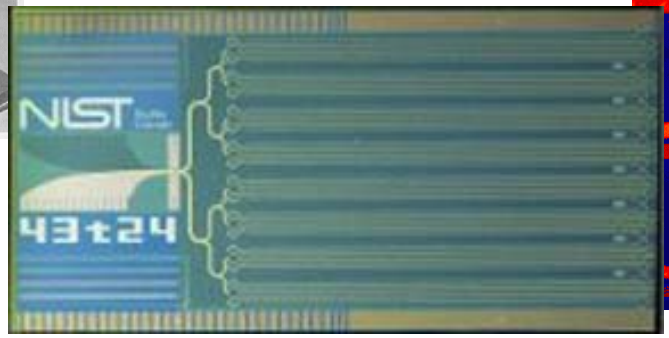
Single electron counter





Silver Voltmeter Standard

10 V Josephson Voltage Standard

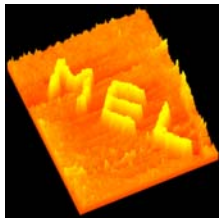


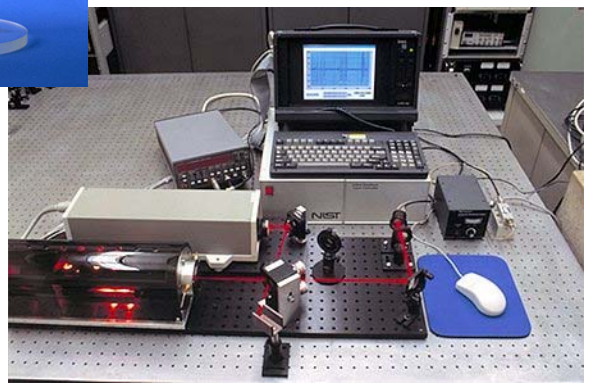
Evolution of Standards - *The Meter*

1889 - Platinum iridium meter bar

1960 – Krypton-86 lamp

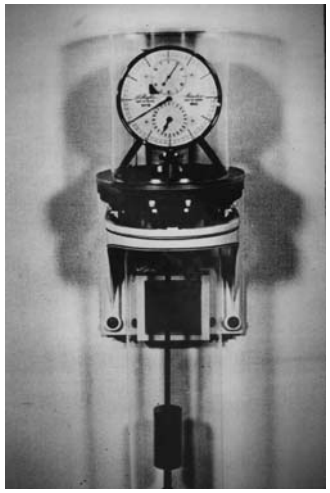
Atomic-scale Standards



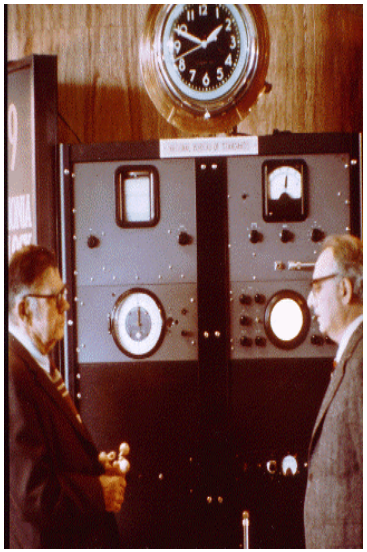


1983 – Iodine stabilized He-Ne laser

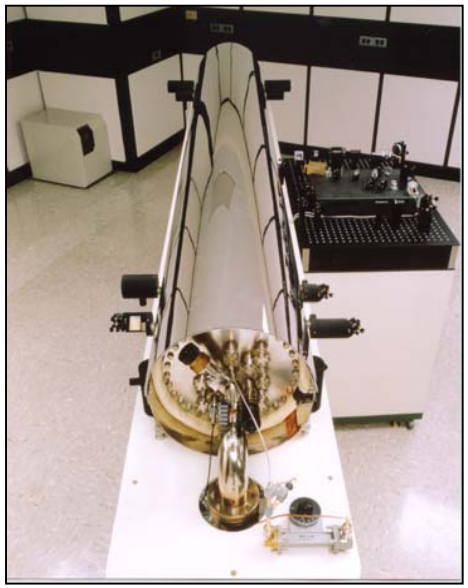
Evolution of Standards - *The Second*



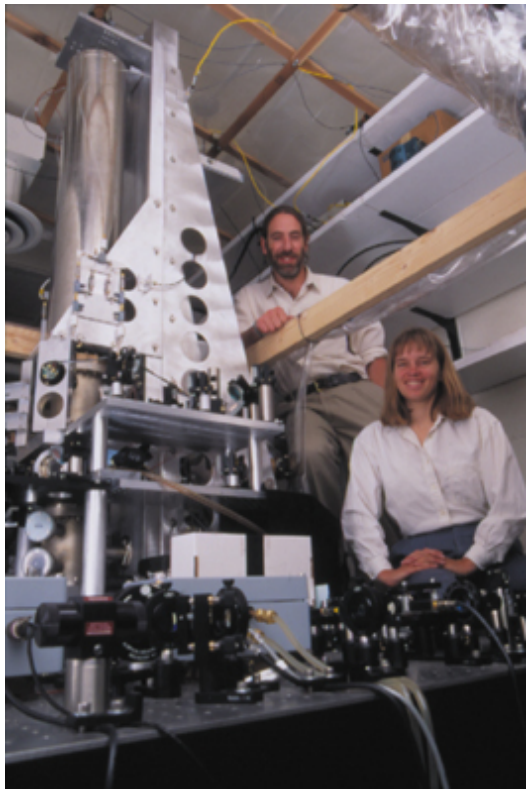
NBS Pendulum clock 1s in 3 years (1904)



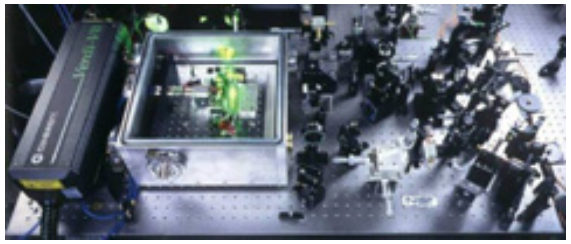
Ammonia resonator 1s in 300 years (1949)



NIST 7 1s in 6 million years (1993)

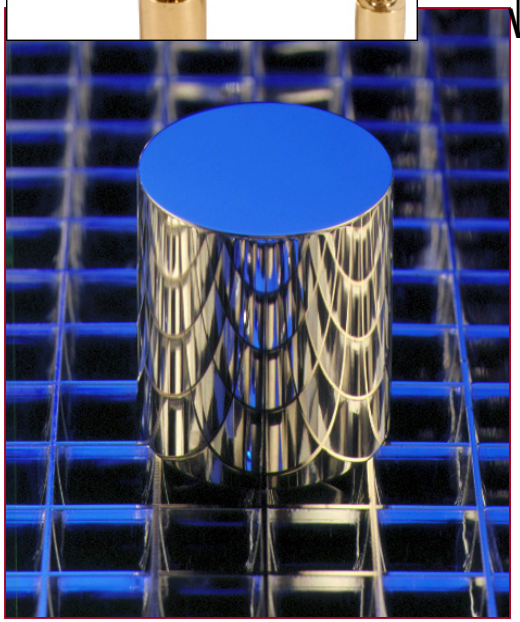


NIST F1 1s in 30 million years (1999)

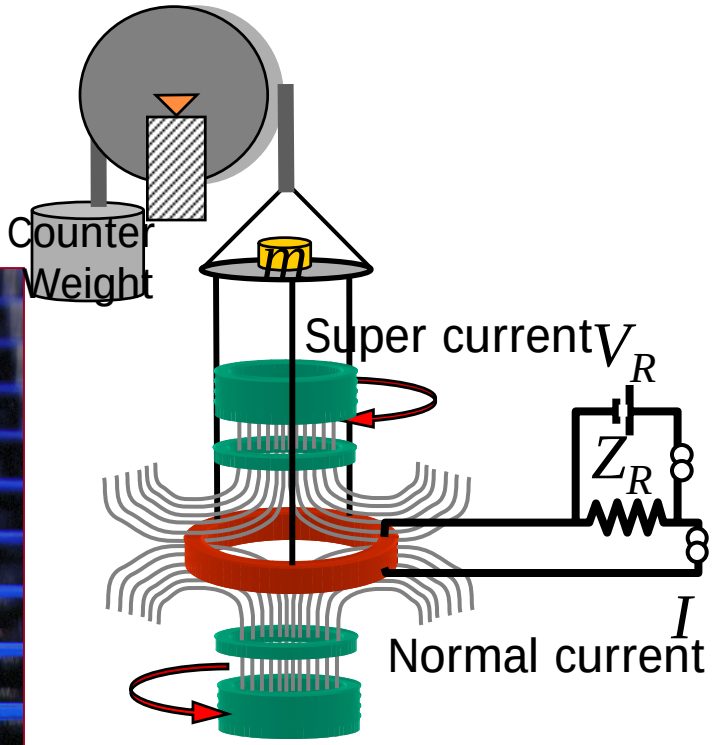


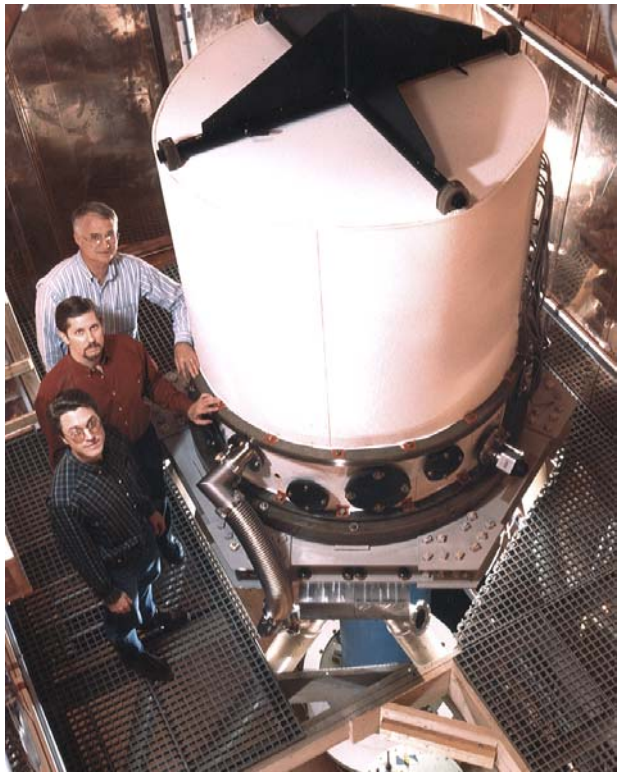
Optical clock: 1s in 30 billion years (?)

Evolution of Standards - *The Kilogram*



$$F = -\partial\Phi/\partial z\, I$$

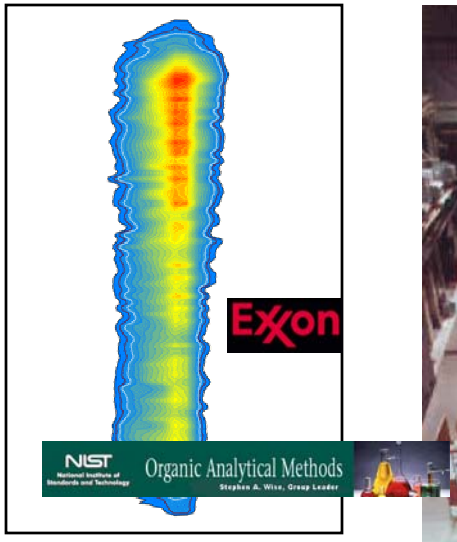


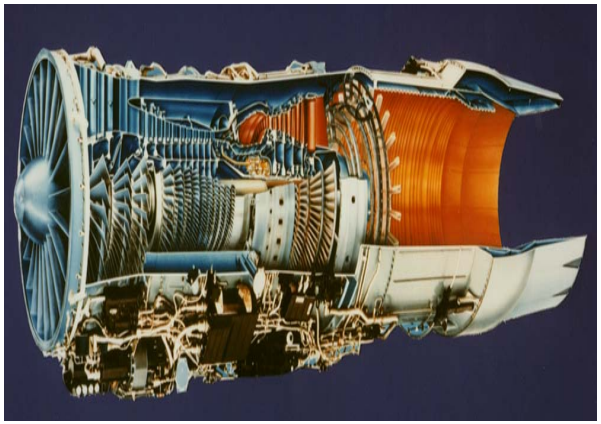


The Electronic Kilogram

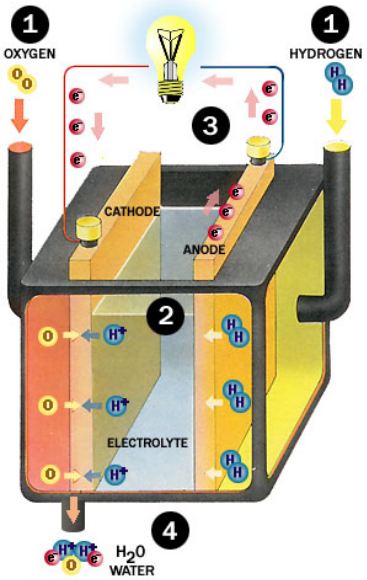
H_2! Where art thou?

Wet Chemistry





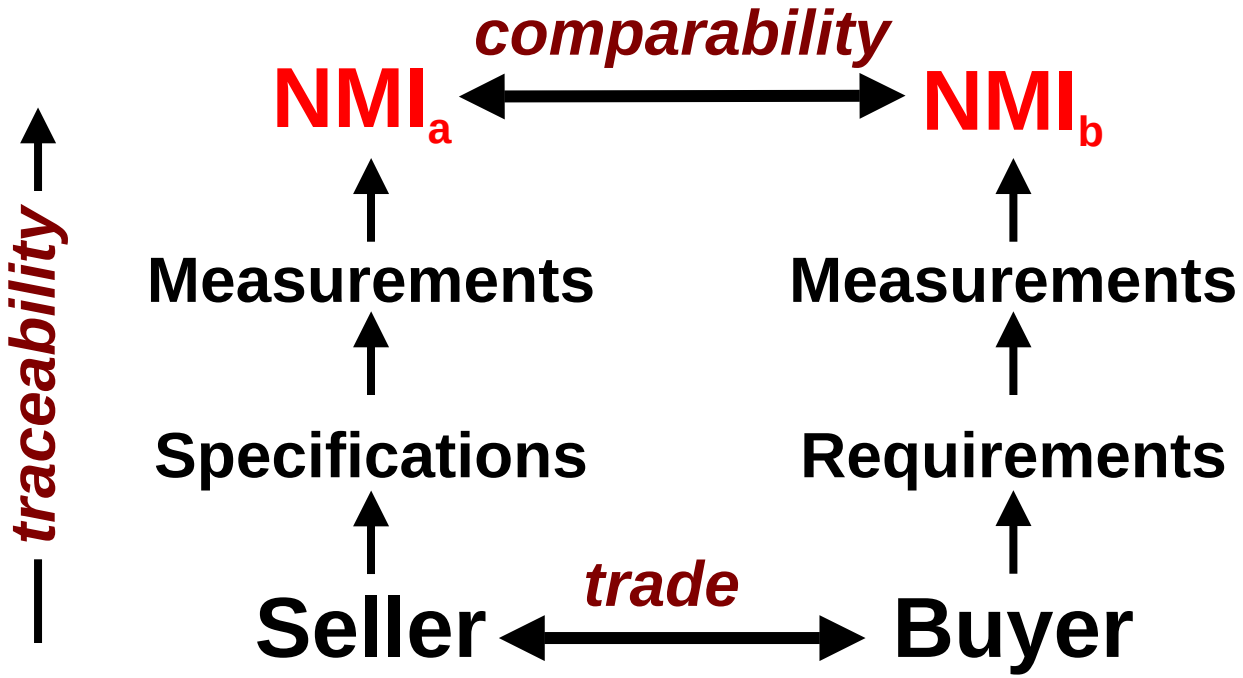
Jet Engine



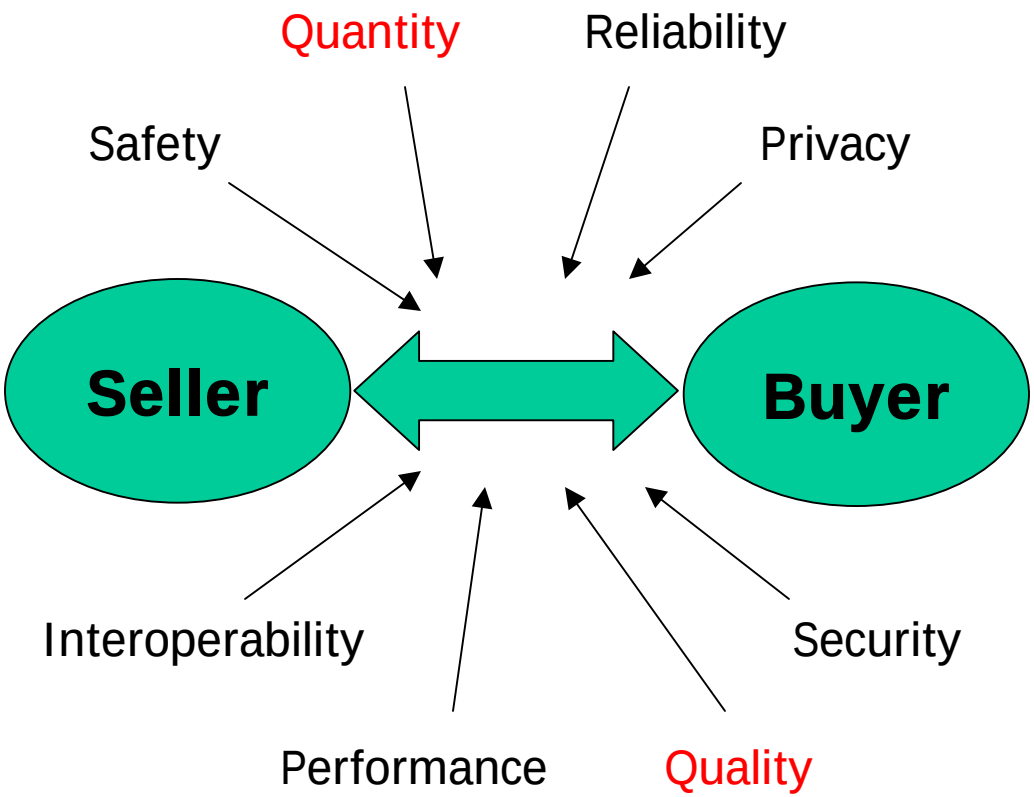
Fuel Cell

Neutron Chemistry?

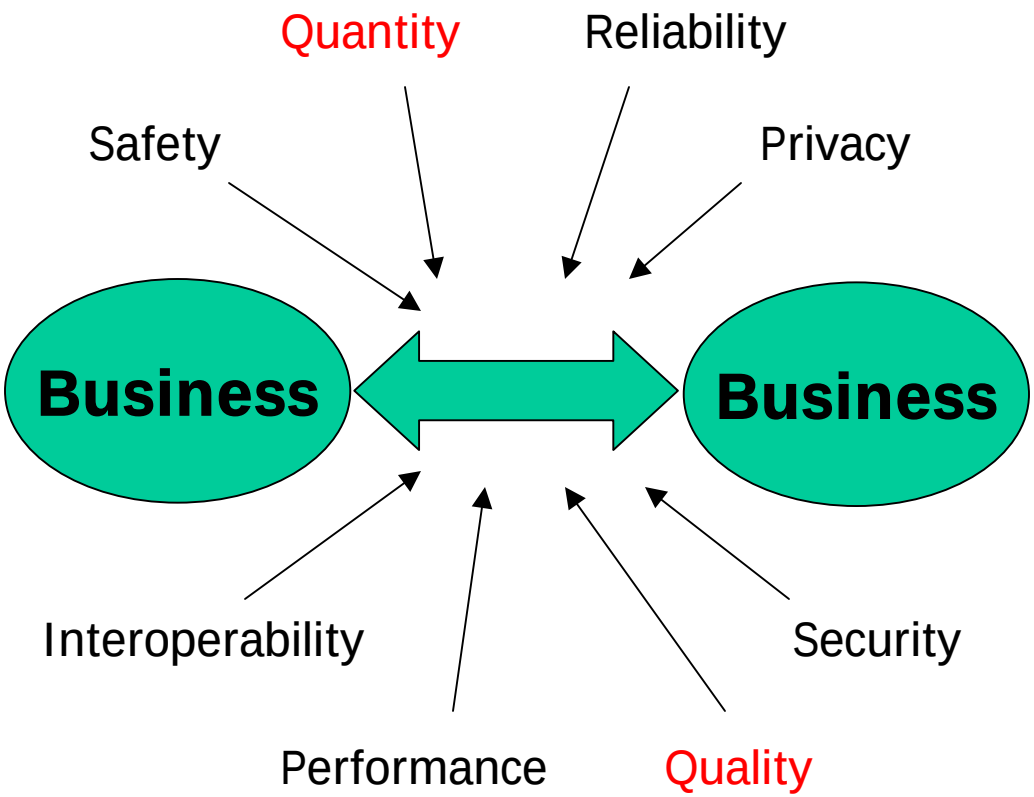
International Trade Requires Traceability *and* Comparability



CIPM MRA (1999)



"quantity and uniform goodness"



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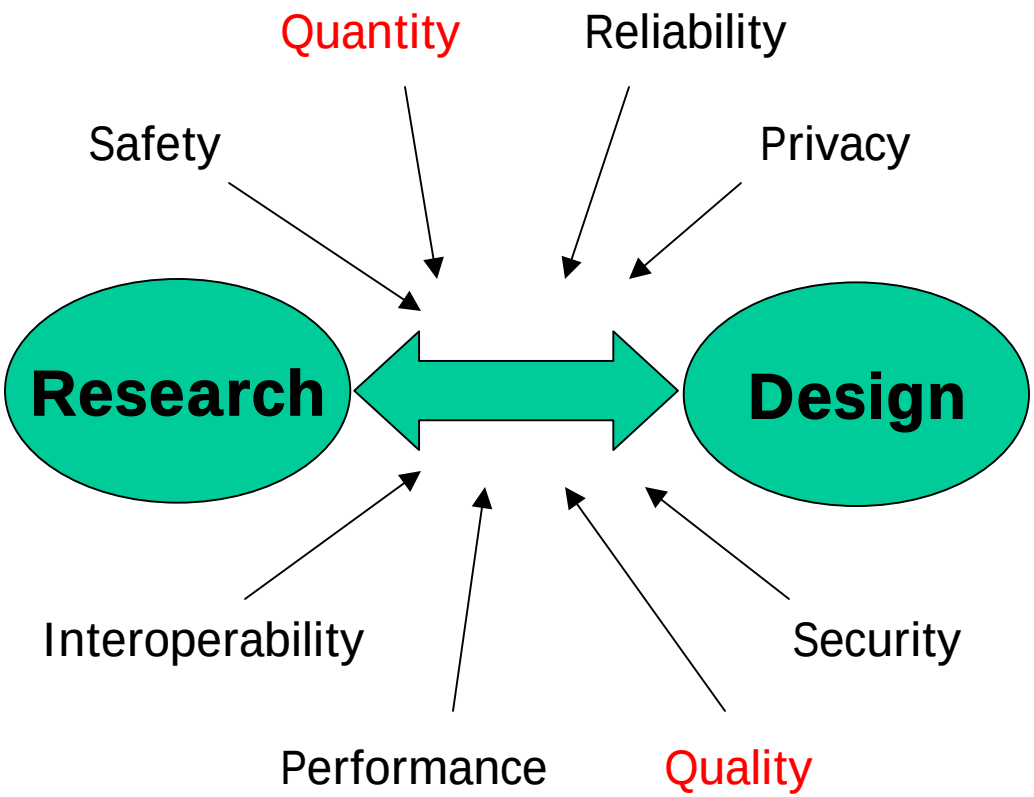
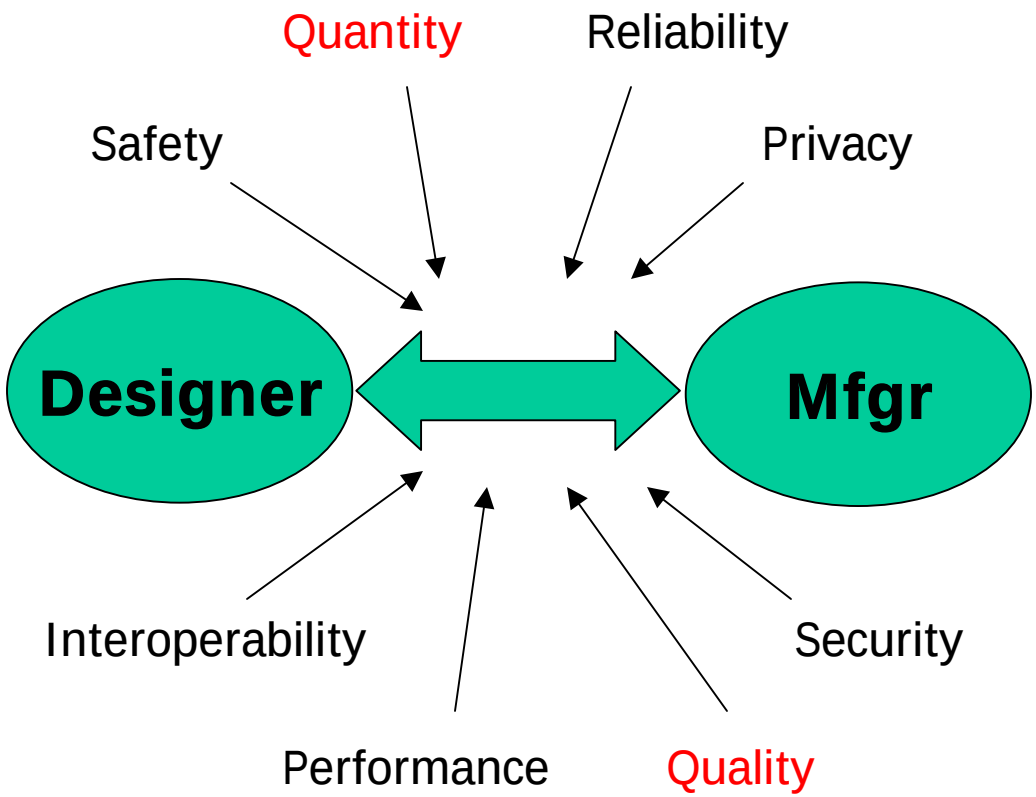


“quantity and uniform goodness”



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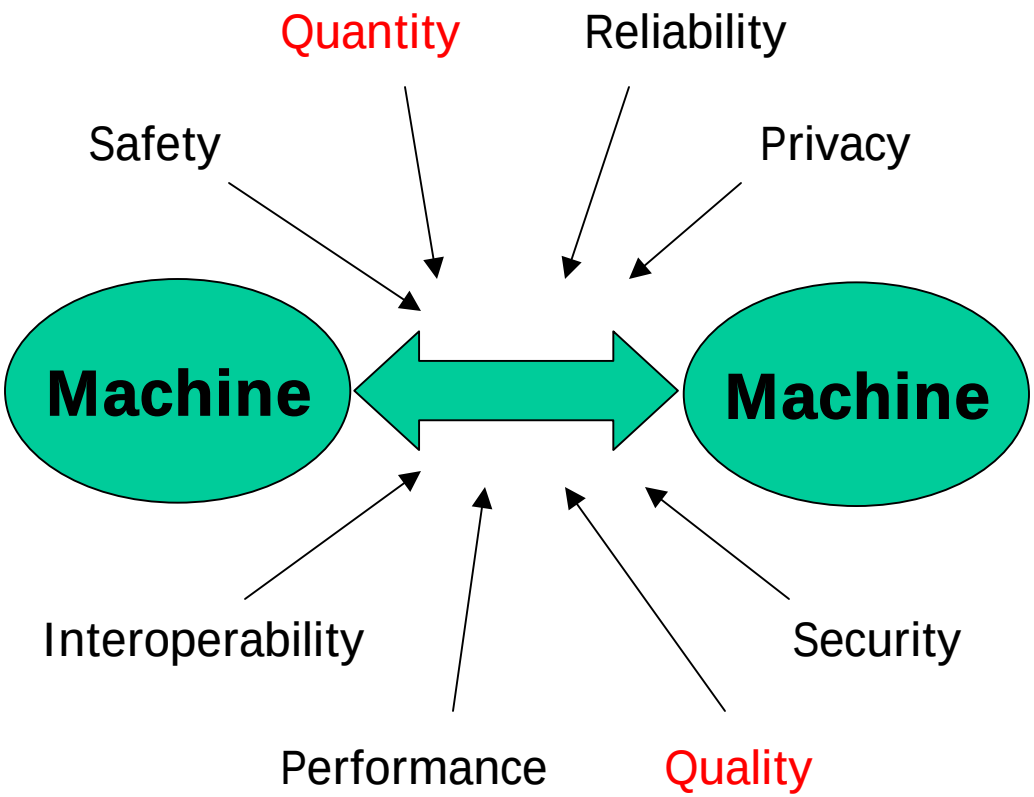


"quantity and uniform goodness"

New Driving Forces for Metrology

- Globalization of Commerce
- Telecommunications
- Health Care
- Global Environment
- Global Policy Issues
- Homeland Security

A New Driver: *EU IVD Directive*

EU IVD Directive to go into effect 2003

- **Worldwide *in vitro* diagnostic device market is ~$20B;**
- **>70% of European market is supplied by U.S.**

Stated Purpose of Directive

- **Eliminate trade barriers *within Europe* by ensuring access to the entire EU market with one single product approval (CE Mark)**

Essential Requirements

- **IVD Calibrators and/or control materials must be traceable to *"standards of a higher order"***
  - **nationally/internationally recognized *certified reference materials***

Joint Committee on Traceability in Laboratory Medicine (JCTLM) coordinating development of new certified reference materials

Implementation

- **First IVD product with CE Mark may be placed from June 2000 onwards**
- **All *new* IVD products *must* have mark by December 2003**
- **Existing IVD products may be sold without the CE mark until December 2005**

A New Driver: *Genetically Modified Organisms (GMOs)*

Reference Methods and Standards for GMOs

Developing reference methods for detection of:

- **genetic modification of foods**
- **proteins expressed by the genetic modification**

Needs Assessment

NIST sponsored workshop held in December 2001 with representation from the EU, Asia-Pacific Rim, and all five subregions within the Americas (SIM), to discuss:

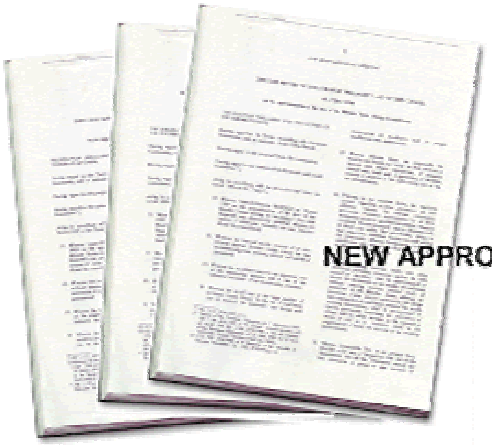
- **Regulatory differences**
- **Existing measurement methods**
- **Gap analysis**
- **Plan of action**

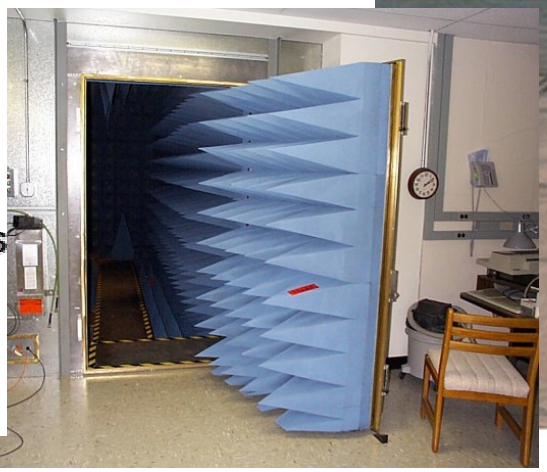
Current Activities with USDA/GIPSA – Biotech Grains

- **Material (biocrops) transfer agreement complete**
- **Round-robin testing underway**
- **Joint workshop/survey with GIPSA to fine-tune standards needs, June 2003**
  - **World-recognized matrix reference material required**
  - **Biotech event material in non-event material should have a range of concentrations that span relevant regulations**
- **Internationally collaborative development of candidate reference material planned**

A New Driver: *EU Directive on Electromagnetic Compatibility*

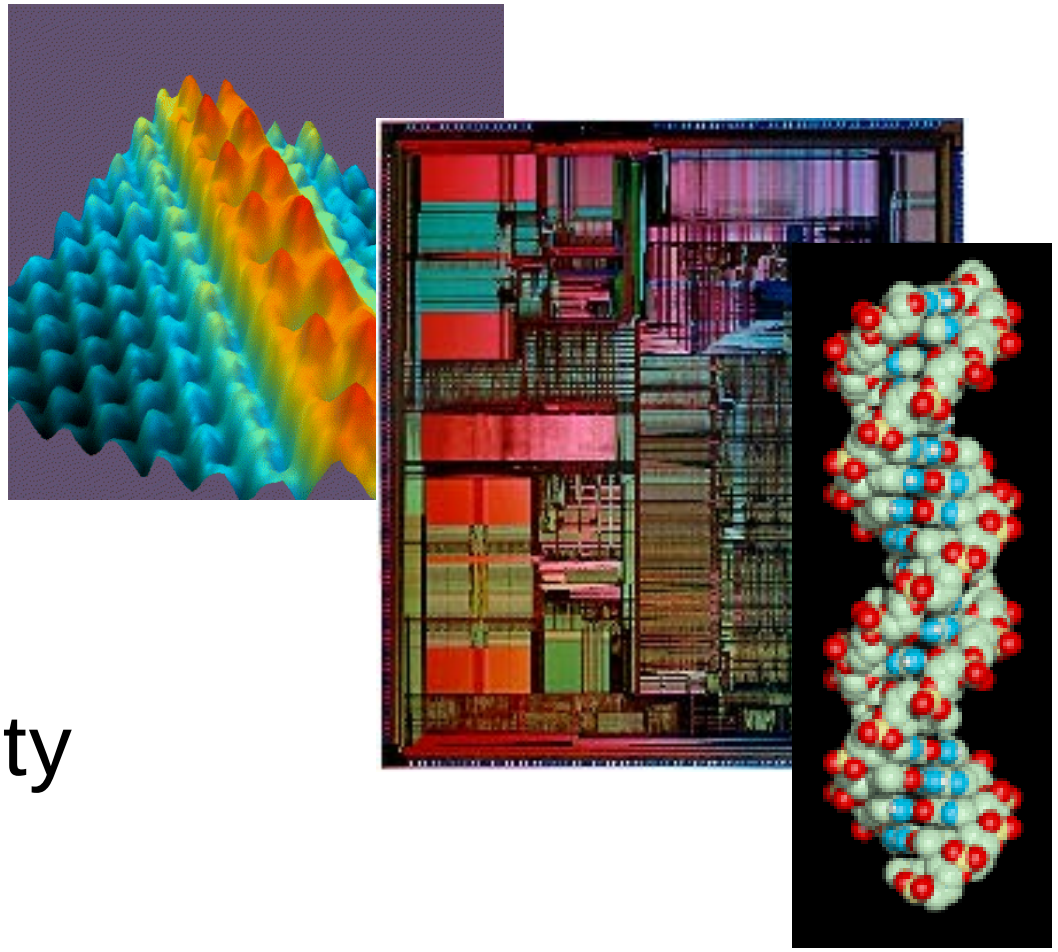
- The EU EMC Directive: establishes requirements on emission and immunity (CE Mark)
- Manufacturers may decide who performs the conformance testing





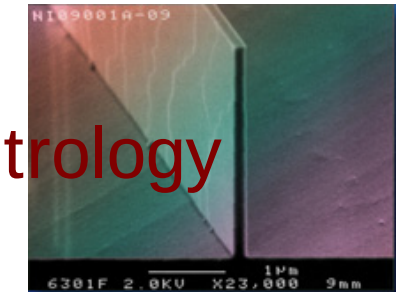
NIST 2010 : Advanced Technologies Driving Metrology Needs

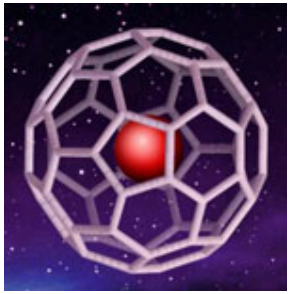
- Nanotechnology
- Biotechnology
- Informatics
- Homeland Security



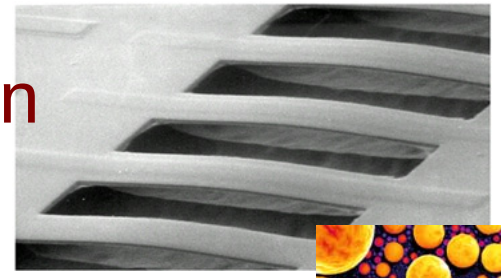
Nanotechnology

Basic nanoscale metrology

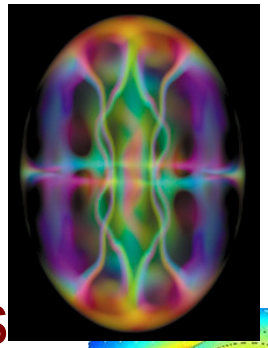


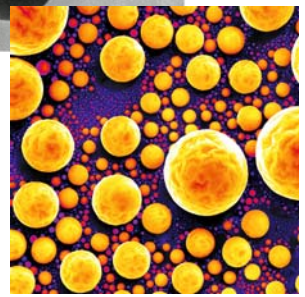


Nanomaterials characterization

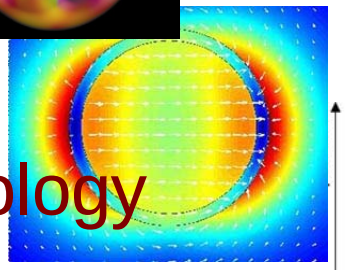


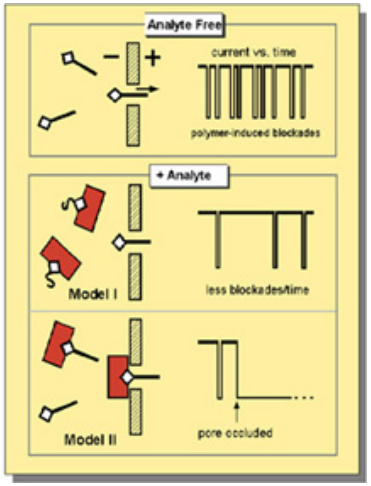
Nanoelectronics



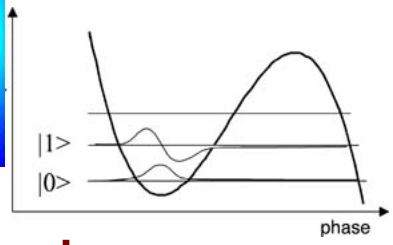


Nanomagnetics



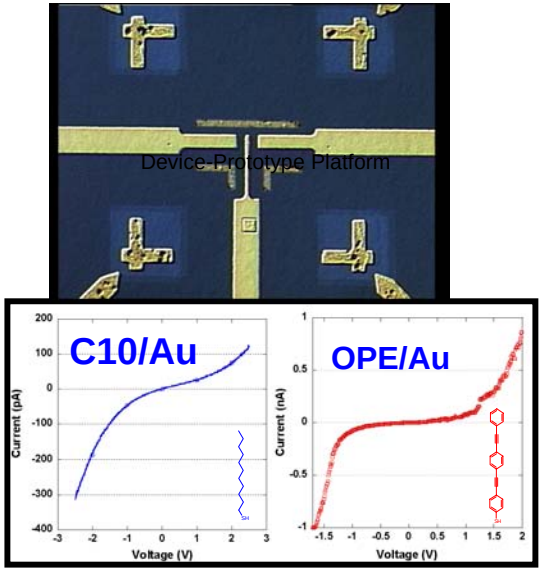


Nano-biotechnology

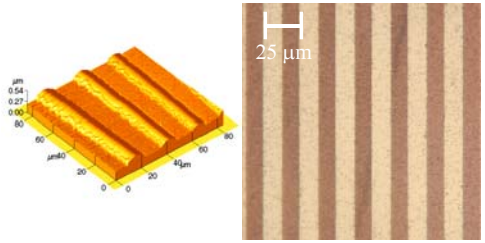


Quantum devices and measurements

Nanotechnology – *Molecular Electronics*



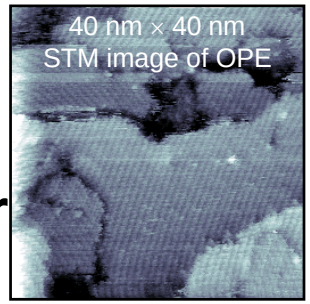
I(V) Curves for SAMs on Au



Electroless Deposition of SAMs

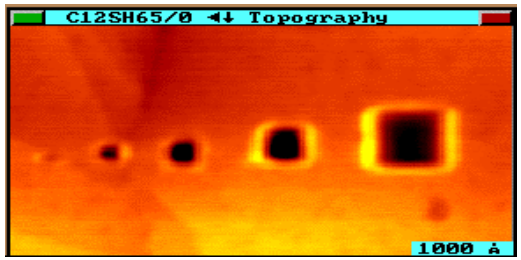
Program Objectives:

- **Develop "Molectronics Metrology" for next-generation electronic components based on molecular ensembles.**
- **Connect device performance and electrical properties to molecular structure.**



Recent accomplishments:

- **Develop device-prototype platform for measuring conductance.**
- **Spectroscopic measurement of valence-electronic structure of conductive molecules.**
- **I(V) and C(V) measurements on devices and molecules.**
- **Develop methods for electroless deposition of molecular contacts.**



Resources & Capabilities

- **CMOS Fabrication**
- **Vacuum STM/AFM**
- **Wet-cell AFM**
- **Ultrafast Lasers**

Collaborators

- **Hewlett-Packard**
- **Naval Research Lab**
- **Penn State University**
- **Yale University**
- **Rice University**

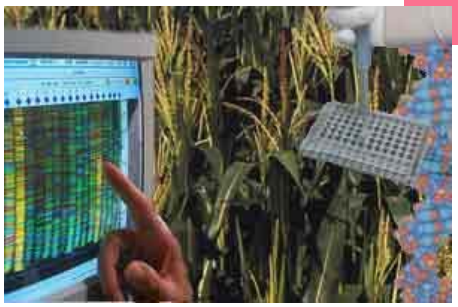
NIST

Biotechnology

Economic/Societal Areas of Impact

- ***Health Care***

- ***Food & Agrobiotechnology***



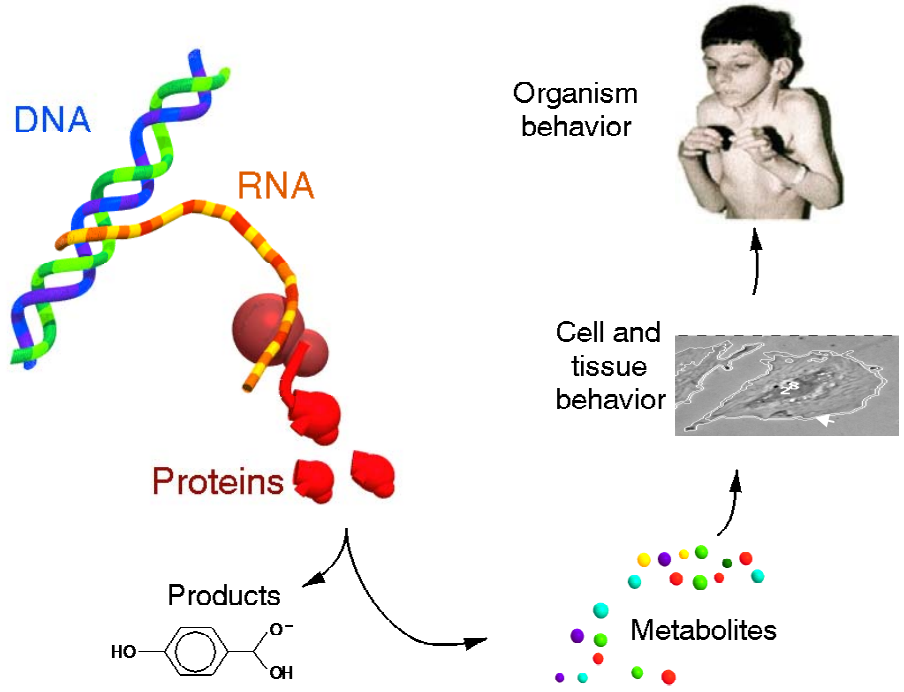
- ***Biomanufacturing***
- ***Homeland Security (Forensics & Biodefense)***

- ***International Trade***

Metrology Needs in Bioscience

Biometrology refers to measurement and data activities that provide quantitative characterization of biology

- Gene Typing (Genomics)
- Gene Expression
- Proteins & Proteomics
- Cellular & Tissue Biology
- Bioinformatics

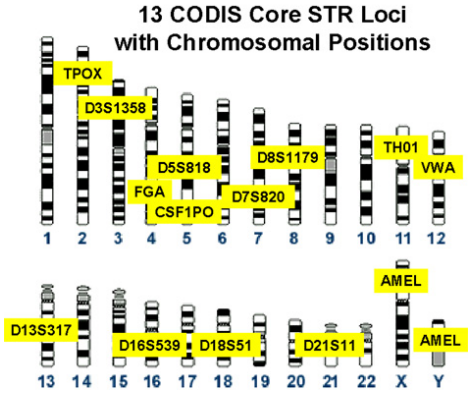


Metrology Needs in Bioscience

Bioinformatics

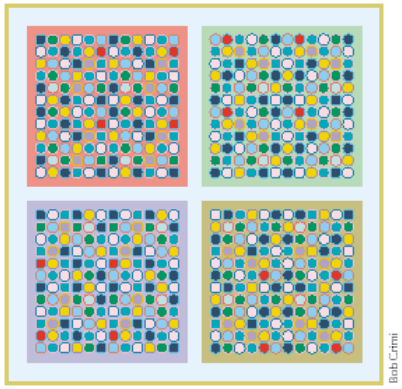
Genotyping

Short Tandem Repeat
STRBase for Forensics



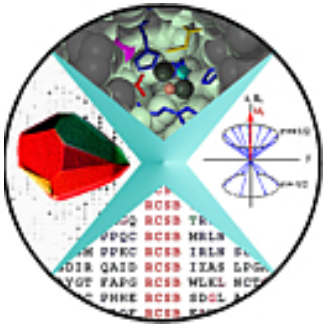
Gene Expression

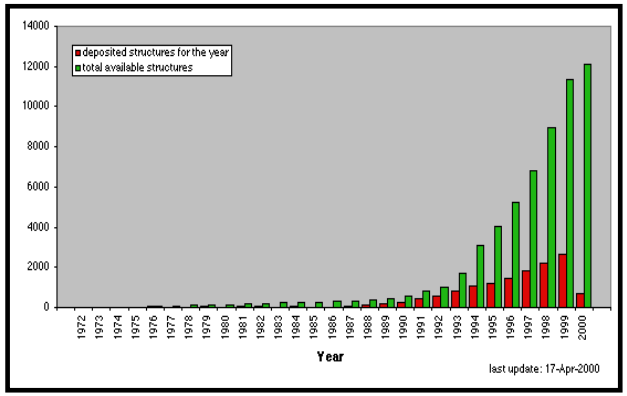
Microarrays and MIAME Convention for preserving pattern data



Proteins & Proteomics

Protein Data Bank

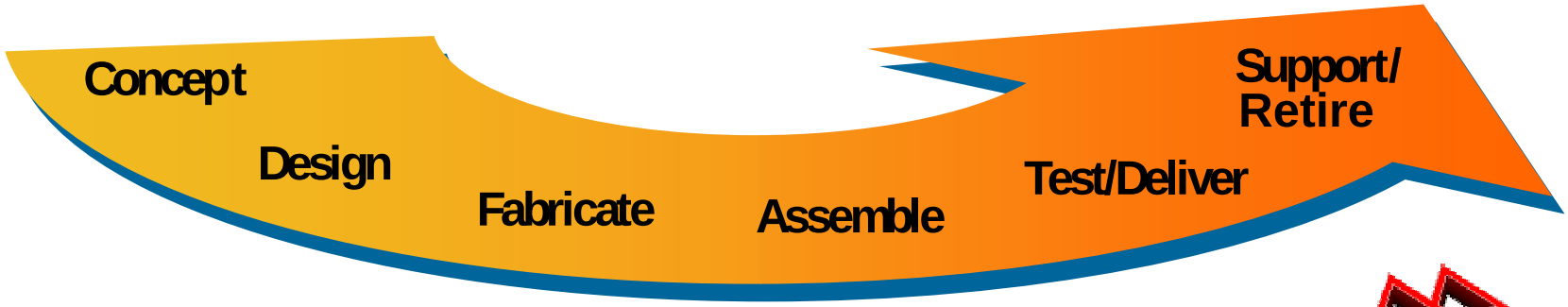




Cellular / Tissue Biology

Tissue specific biomarkers in the future.

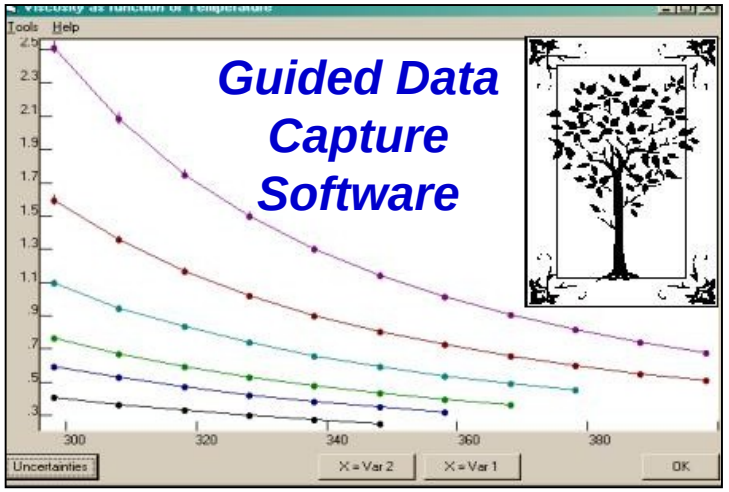
Informatics



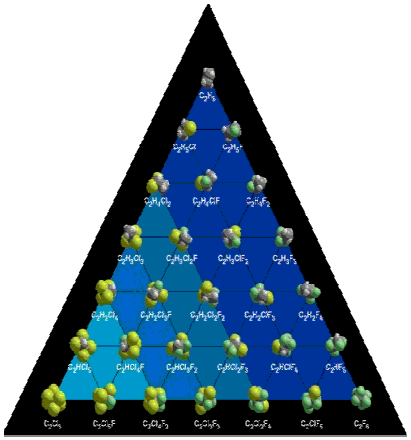
Product Life Cycle

PDES, Inc.®

- Intelligent Interconnected Systems
- Interoperability for Collaboration and Sharing
- Virtual Measurements and Dynamic Data Infrastructure



Informatics



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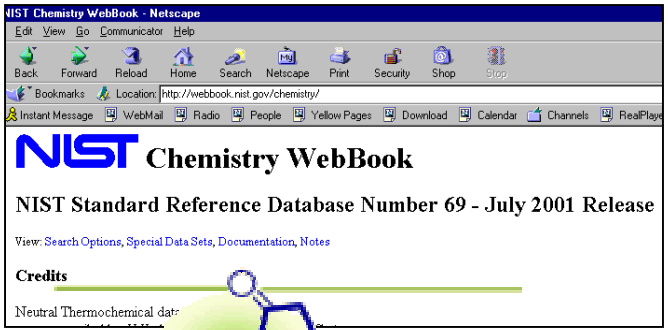
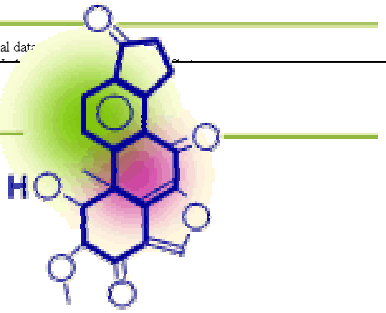
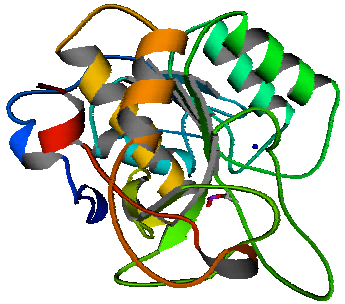
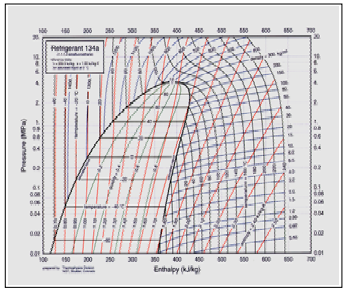








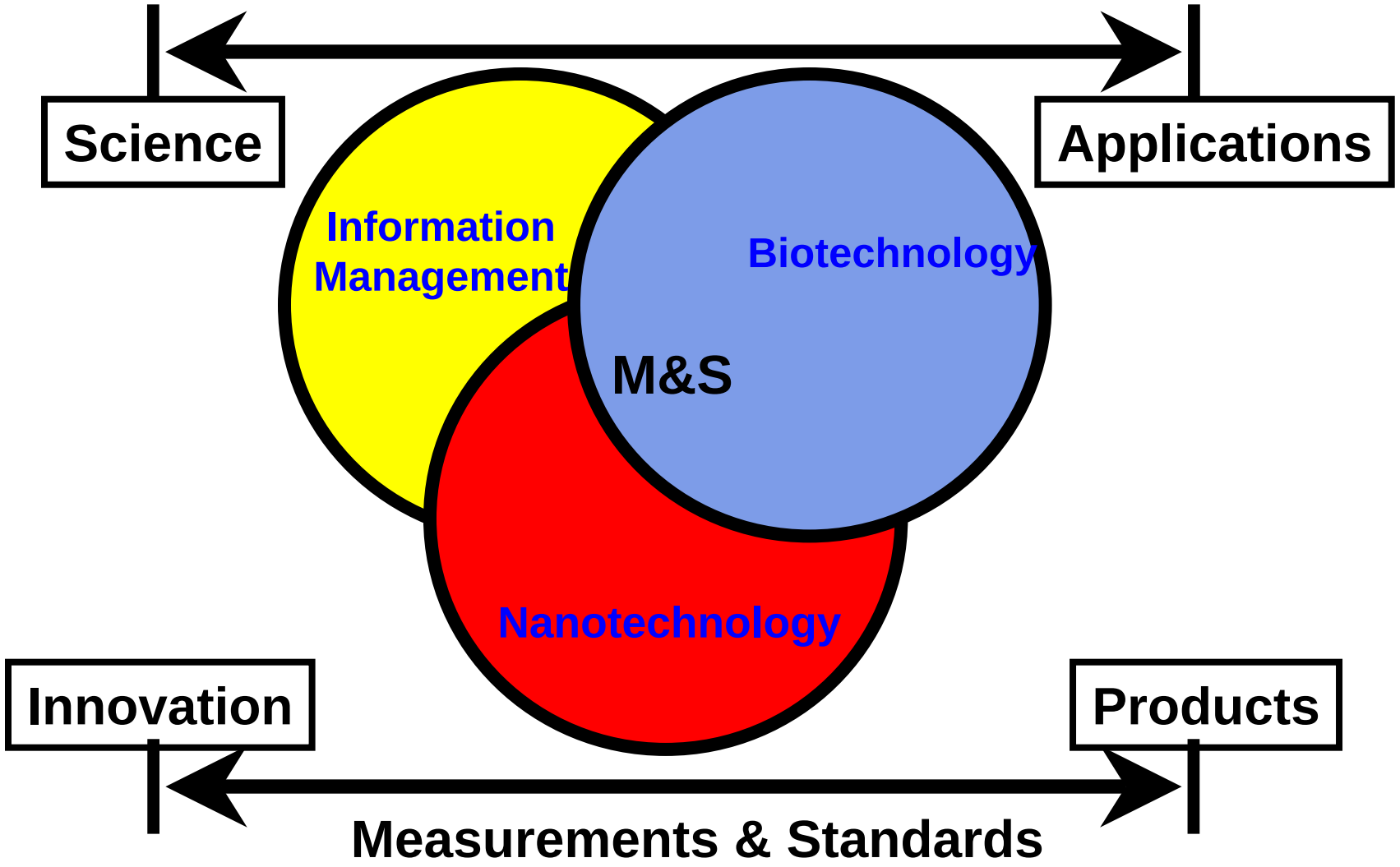
TRC

Thermodynamics Research Center

NIST DATA

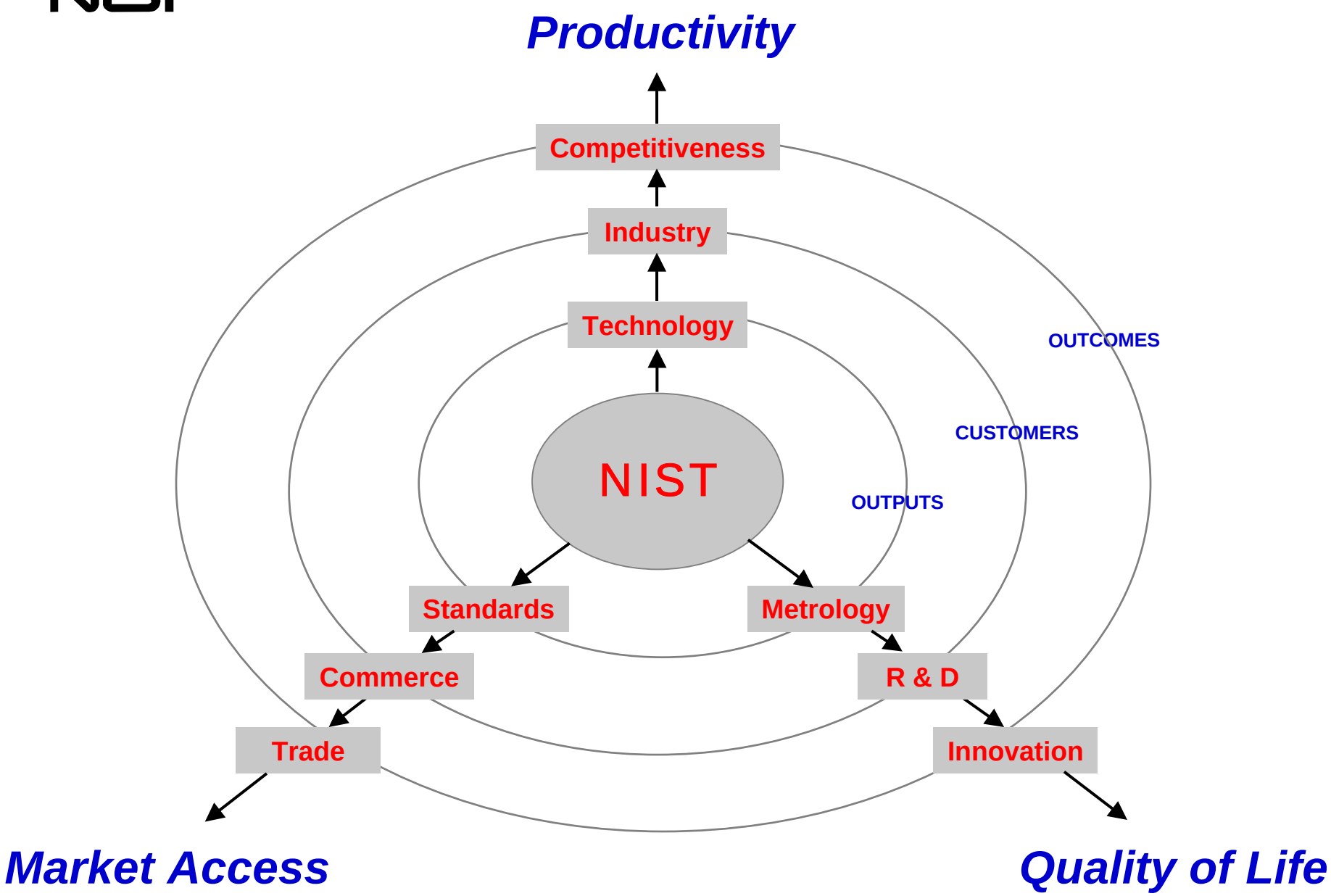
FTIR Database

Convergence Through Measurement



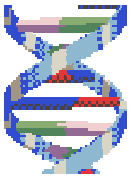
Summary

- The forces driving metrology needs have taken us from the development of the cubit 5000 years ago to the qubit of today
- International trade has been the major driving force for metrology in recent years
- The new driving forces for metrological advances in the 21st Century come from new technologies, as they have since the industrial revolution


Productivity
Competitiveness
Industry
Technology
NIST
OUTCOMES
CUSTOMERS
OUTPUTS
Standards
Metrology
Commerce
R & D
Trade
Innovation
Market Access
Quality of Life

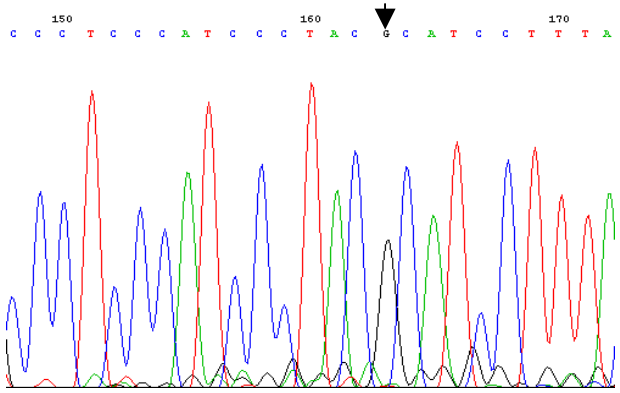
Metrology Needs in Bioscience

Gene Typing (Genotyping)



In disease diagnosis

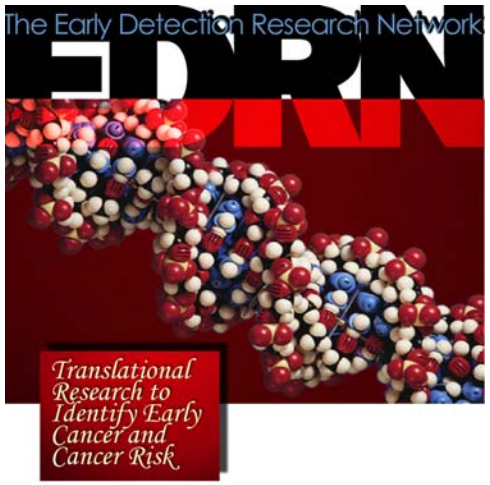
lung cancer disease marker



Oligonucleotide Sequence Determination

Red = T **Blue = C**

Green = A **Black = G**



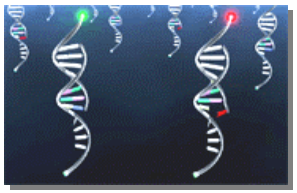
NIST Biomarker Validation Lab

Early Detection Research Network

National Cancer Institute (NIH)

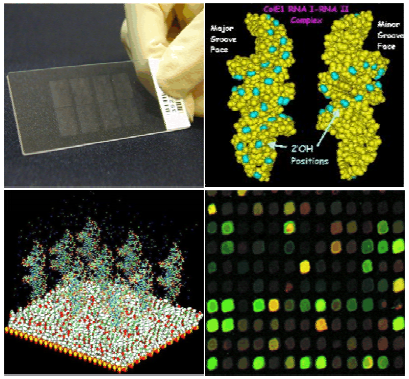
Metrology Needs in Bioscience

Gene Expression

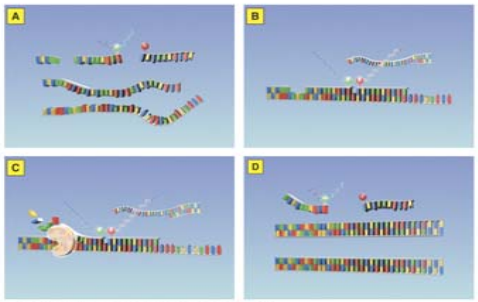


Hybridization of fluorescently labeled cDNA from RNA

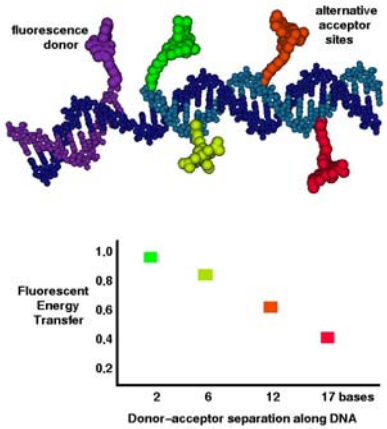
In disease diagnosis using gene arrays (e.g. microarrays, gene chips)



Labeled cDNA hybridizes to chip arrays – spots indicate presence of a gene, brightness indicates amount of gene product



Fluorescence Resonant Energy Transfer (FRET) indicates presence or absence of hybridized gene products



How DNA is labeled affects spot intensity!