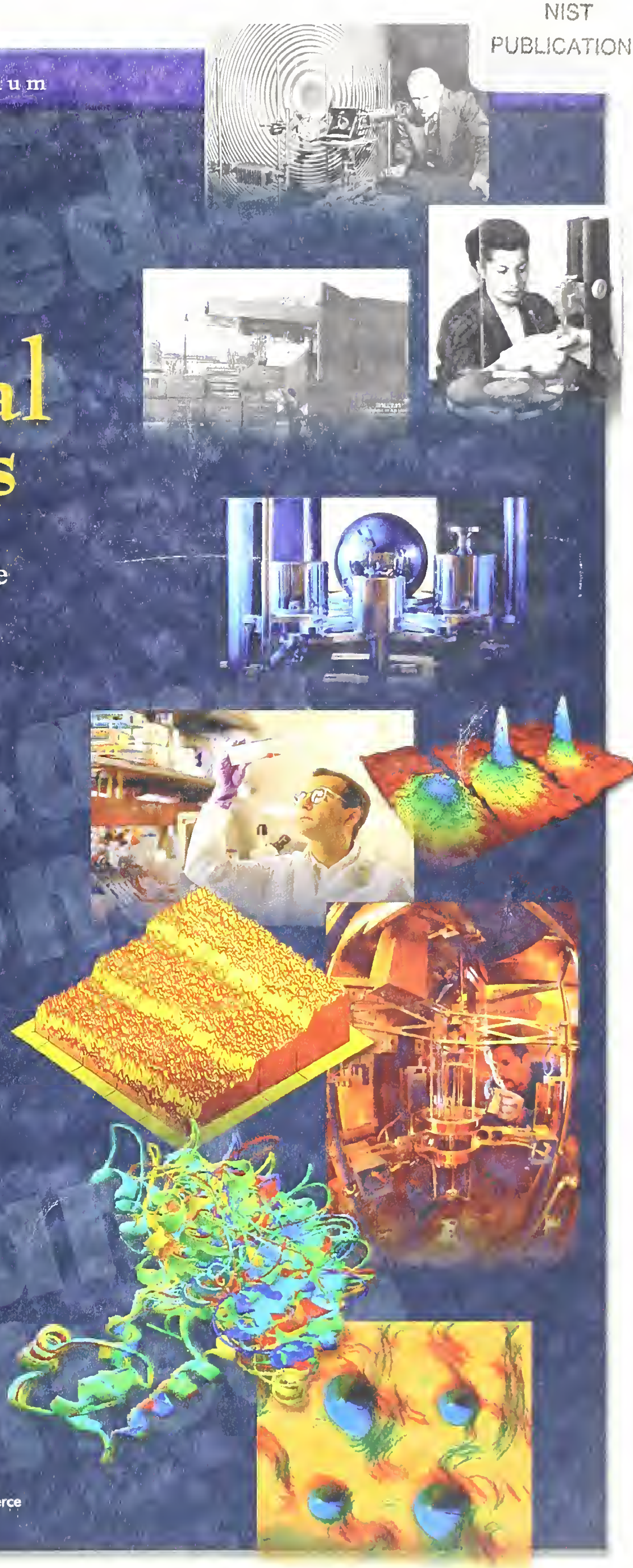
NCSL International Symposium

NIST CENTENNIAL 1901-2001

NIST Centennial Sessions

August second
Two thousand & one



NISTIR 6769

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

NIST Centennial Sessions

U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

Technology Administration
Karen H. Brown, Acting Under Secretary for Technology

National Institute of Standards and Technology
Karen H. Brown, Acting Director

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You also can write to Public Inquiries, 100 Bureau Drive, Stop 3460,
Gaithersburg, MD 20899-3460.

NISTIR 6769
July 2001

From NBS to NIST

Over the past century, the National Institute of Standards and Technology has had several different names. Founded as the National Bureau of Standards in 1901, it was renamed Bureau of Standards in 1903. In 1934, the word "national" was affixed again to its name. For more than 50 years it remained the National Bureau of Standards, or NBS. It became the National Institute of Standards and Technology, or NIST, in 1988.

During its first 100 years, NIST was led by the following directors:

Samuel W. Stratton, 1901 – 1922

George K. Burgess, 1923 – 1932

Lyman J. Briggs, 1932 – 1945

Edward U. Condon, 1945 – 1951

Allen V. Astin, 1951 – 1969

Lewis M. Branscomb, 1969 – 1972

Richard W. Roberts, 1973 – 1975

Ernest Ambler, 1975 – 1989

John W. Lyons, 1990 – 1993

Arati Prabhakar, 1993 – 1997

Raymond G. Kammer, 1997 – 2000

NIST at 100
Foundations for Progress

The new millennium is opening with the Information Age shining on its horizon, just as the last century unfolded with the dawn of the Age of Electricity. Americans have experienced a 100-year span of extra-ordinary improvements in the U.S. economy and quality of life. Since 1901, the National Institute of Standards and Technology has contributed to these advances by building the foundations for technological progress.

NIST has been a reliable source of assistance to industry, science and government. Its research, measurement tools, and technical services are integrated deeply into many of the systems and operations that drive the economy. Factories, communication and transportation networks, laboratories, hospitals, educational organizations, service companies, and the extended enterprises of the new economy all rely on NIST.

On the threshold of its second century, NIST is committed to partnering even more vigorously with industry, science, and government to build an advanced science and technology infrastructure–the foundations needed to ensure future progress and prosperity for U.S. industry and then nation.

The National Bureau of Standards: The First 60 Years

The Economic and Intellectual Environment for the new NBS

The first sixty years of the National Bureau of Standards were marked by the maturation of the United States as an industrial nation and the birth of modern science. From the very first, NBS staff supported the growth of industry through the establishment of national standards and measurement services, and gained an international reputation for fundamental advancements in science and metrology. Experiments at NBS contributed heavily to the move away from then-prevalent recipe-and-artifact based units to the physics-based Absolute System of Units, the predecessor to the present SI, which was adopted in 1960.

Three things are obvious and interesting when I look at the establishment and the performance of NBS in its very first years: (1) the lack of a sophisticated industry and of high level educational institutions in the US, (2) the staggering number of technical tasks with which NBS was so quickly burdened, and (3) the outstanding stature of NBS s first Director, Dr. Samuel W. Stratton. Traditionally we look at the large number of projects that NBS was urged to undertake soon after its initiation. We are also proud of the scientists who did such an outstanding job in developing NBS and assisting US industry. But often we fail to realize that the economy of the US in the second half of the 19th century was dominated by extractive industries, by agriculture, and by a large railroad industry. There were very few universities and almost no sophisticated industries that could assist NBS. The task confronted and completed by Dr. Stratton and his staff is all the more remarkable.

This brief report reviews a few major events in the second half of the 19th century that illustrate the environment into which NBS was placed. We begin with the list of Presidents and the major wars in which the young republic was involved, and continue with a brief review of the fields of Agriculture, Railroads, Industry, Automobiles, and Learned Institutions.

Dr. Stratton at his desk in South building, 1905. The Bureau was still in its infancy but already, according to Rosa, second only to the great German Reichsanstalt among government standards laboratories. The portrait of Michael Faraday on the wall, symbolizing the age of electricity, did not come down until 1950.

Time Scale

Mexican War, 1846 to 1848; Texas, New Mexico, California, and Arizona

1857 James Buchanan

1858 Abraham Lincoln

Civil War, 1861 to 1865

1865 Andrew Jackson

1869 Ulysses S. Grant

1877 Rutherford Hayes

1881 James Garfield, Chester Arthur

1885 Grover Cleveland

1889 Benjamin Harrison

1893 Grover Cleveland

1897 William McKinley

Spanish American War, 1898

1901 Theodore Roosevelt

NBS established under Dr. Samuel W. Stratton

1909 Howard Taft

1913 Woodrow Wilson

World War I

Agriculture

1834	Cyrus McCormick invented the reaper
1855	Canning to preserve food
1855	Price of wheat: 1851 $0.93 per bushel 1855 $2.50 per bushel
1862	Morril Act: 30,000 acres for each Senator and Representative to be given to the States for schools for agriculture, home economics, engineering, and mechanical art; land-grant colleges
1862	Department of Agriculture
1865	Union Stockyards in Chicago
1874	Barbed Wire 10,000 lbs in 1874, 80,500,00 lbs in 1880
1875	Sectoral protectionism against American (and Russian) grain products in Europe
1890	Increasing agricultural exports 1890: agricultural products 75% of total 1900: agricultural products 61% of total

Railroads

1862	Subsidy for completion of transcontinental rail line
1863	Standard for rail gauge 4' 8 1/2" set by Congress
1865	35,000 miles of railroads in the US
1866	Cog-railroad on Mt.Washington first in the world
1866	Steam-driven elevated railroad in NY city
1868	Westinghouse air brake
1880	93,671 miles of railroads in the US
1898	60% of stocks listed on NYSE are railroad stocks
1891	167,191 miles of railroads in the US; the large rail network enables a national market economy
1900	198,964 miles of railroads in the US

Industry

1857	Petroleum discovered in Pennsylvania
1861	Monitor, steam driven
1862	Gatling gun
1865	First transatlantic cable laid
1865	US steel production exceeds that of Britain
1868	US patent for typewriter
1876	US patent for telephone to Graham Bell
1879	First public electric street lighting in Cleveland
1881	First central electric power plant in the world in NY city
1882	Patents for electric flat iron and for fan
1888	AC motor and AC transmission
1888	First electrical automobile (Philip W. Pratt)
1892	Patent for wireless telegraphy (Edison)
1895	Hydroelectric generators installed at Niagara
1900	US steel production 10 million tons/year, more than Britain and Germany combined

Automobiles

1888	First electrical automobile (Philip W. Pratt)
1892	Prototype of modern car built in France: Panhard Levassor with Daimler engine
1894	US patent for an automobile developed by Karl Benz in Germany
1895	US patent for a gasoline-driven automobile developed by Charles Duryea in the US
1895	Automobile contest in Chicago; an imported Benz was the only car to finish the race
1896	First Ford automobile completed at 2 am on June 4, 1985
1901	Olds introduced quantity production for automobiles; 425 sold in 1901, 6500 in 1905
1903	Ford Motor Company founded
1909	10,000 Ford T sold
1912	78,000 Ford T sold
1914	472,000 Ford sold from the new assembly line

Learned Institutions

Mind, acting through the useful arts, is the vital
principle of modern civilized society
Edward Everett 1857

1847 **Silliman established the Sheffield Scientific School of Yale University**

1862 **Land grant colleges**

1863 **National Academy of Sciences founded**

1865 **Cornell University chartered**

1867 **Johns Hopkins University chartered**

1868 **University of California chartered**

1869 **Harvard reorganized from a small religious undergraduate college into a modern university**

1871 **Harvard pamphlet on the need for laboratory courses in science education**

1876 **American Chemical Society formed**

1878 **Fundamentalism vs. Science; Alexander Winchell dismissed from Vanderbilt University for a scientists contradiction of biblical chronology**

1880 **American Society of Mechanical Engineers founded**

The Emergence of Modern Metrology

Metrology at NBS/NIST over the past forty years continued to be driven by science, particularly atomic physics, and increasingly by technology, particularly in semiconductors. This era saw the development of quantum standards, wide-spread automation of measurement systems, better understanding of uncertainty and better ways to quantify and express it. Measurement technology affected and is affected by the increasingly global nature of trade and international adoption of protocols to ensure universal compatibility of measurement results.

Dr. Schooley has selected photographs of researchers to illustrate his lecture.

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Chemical Metrology: Future Developments

Hratch G. Semerjian

Chemical Science and Technology Laboratory

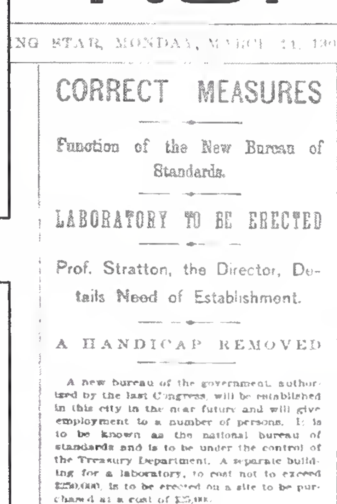
NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Chemistry

From the 1900's to … … a new millennium

Division I
Heat and Thermometry
"As primary standards, this section had acquired a number of specially constructed … thermometers in Europe and was prepared to certify almost any precision thermometers used in scientific work, industrial and commercial thermometers."

Division III
Chemistry
"This section was increasingly involved in its investigation of properties for the Government testing program and produced standard samples of alloys, steels, iron ores, copper slags, cements, and lubricating oil."



NG STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

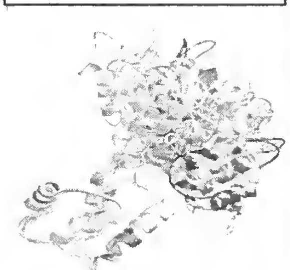
Prof. Stratton, the Director, Details Need of Establishment.

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

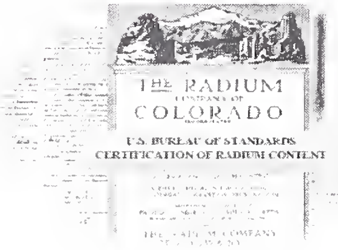
CSTL
Core programs
Thermodynamic Meas.
Analytical Chemistry
Reference Data



New Research Areas
Tissue Engineering
DNA Tech., Biocatalysis
Health Care Markers
Environmental Measurements
Computational Chemistry

Standards: Anticipating Changing Needs

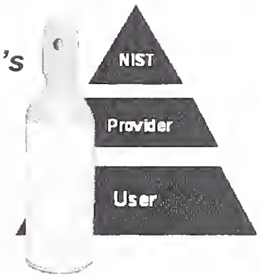
The Bureau's Standard Samples ...to... NIST 's Standard Reference Materials



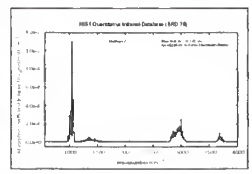
Health & Industrial Hygiene
Fossil Fuels
Food and Agriculture
Ores, Metals
High Purity Materials

NIST Traceable Reference Materials NTRM *introduced in the mid 1990's*

Gas Mixtures
Optical Filters
Elemental Solutions
Metal Alloys



Looking to "Virtual" Standards



FTIR database

Remote, interactive, web-based approach to instrument calibration

IT Revolution: Impact on Data Dissemination

IR Spectral Data

- 1905 - NBS IR Spectra program established by Coblentz
- 1910 - first book of spectra
- Mid-century - IR Spectra resided with Coblentz Society
- Currently at NIST - preparing for web-based dissemination

NIST/EPA/NIH Mass Spectral Library

- First Published in 1976
- 3 volumes and 3 supplements
- Disseminated via CD and Web
- Installed on >3000 instruments annually
- Evaluated spectra for >100,000 compounds
- Growth: new measurements and addition of high quality data

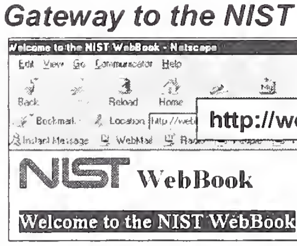
NIST '98 ASCII Version ONLINE PURCHASE FAX OR MAIL ORDER

PROTEIN DATA BANK

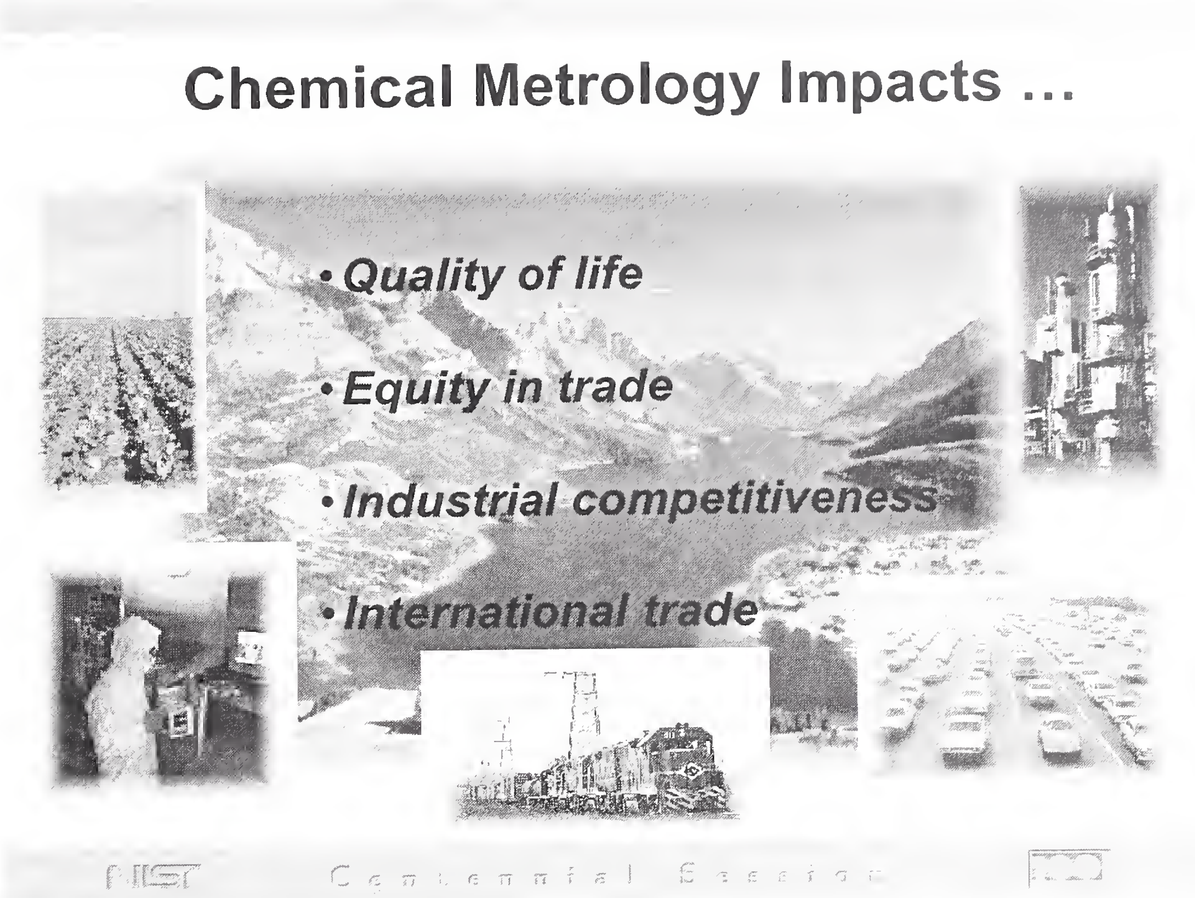
Protein Data Bank

Single international repository for the processing and distribution of 3-D structure data of biological macromolecules determined experimentally by NMR and X-ray crystallography

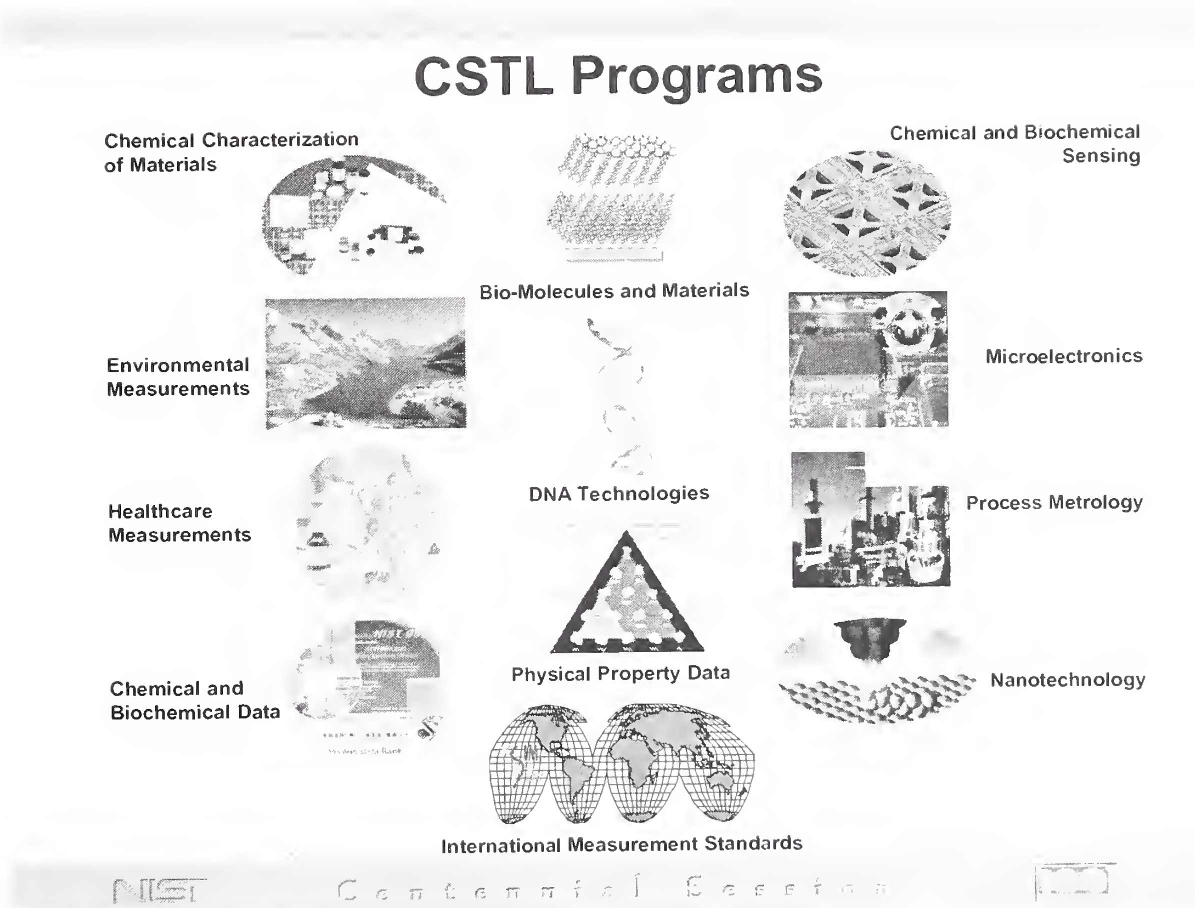
A Gateway to the NIST Data Collections



http://webbook.nist.gov/



Chemical Metrology Impacts ...
• Quality of life
• Equity in trade
• Industrial competitiveness
• International trade
NIST
Centennial Session



CSTL Programs
Chemical Characterization of Materials
Bio-Molecules and Materials
Chemical and Biochemical Sensing
Environmental Measurements
Microelectronics
Healthcare Measurements
DNA Technologies
Process Metrology
Physical Property Data
Chemical and Biochemical Data
Nanotechnology
International Measurement Standards
NIST
Centennial Session

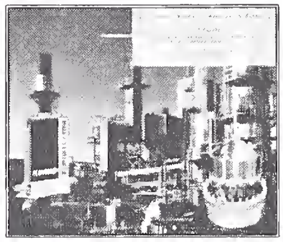
Process Metrology

Temperature ... Flow ... Pressure and Vacuum ... Humidity ... Density
Globally Recognized Fundamental Standards

Physical Standards

Thermometry

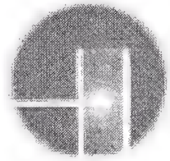
ISSC



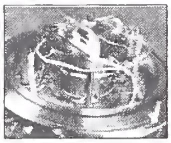
Chemical Standards

Catalysts

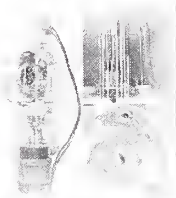
Raman Standards



Humidity



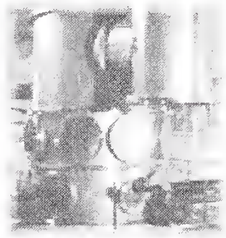
Pressure & Vacuum
Flow



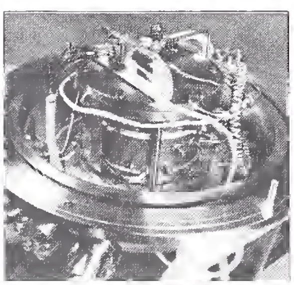
MEMS UTA
Flow Sensor

Measurement Technology

Spray
Combustion
Data

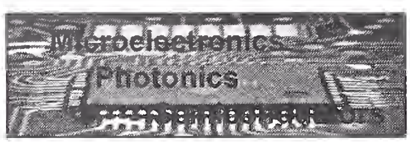


Standards for Process Gas Purity



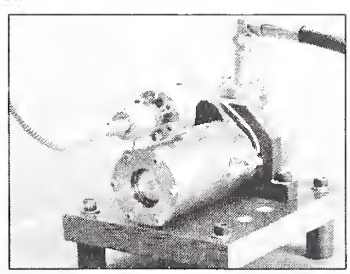
Low Concentrations of Water Vapor in Gases
Low Frost-Point Generator

- Reference for commercial precision humidity generators
- LFPG output is linked to thermodynamic properties of water
- Precise temp. control enables measurements at ppb level
- Direct traceability to national humidity standards



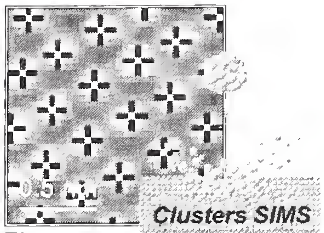
Optical Measurements of Partial Pressure
Single Mode Cavity Ring-Down Spectroscopy

- Quantitative, high sensitivity optical absorption measurements for wide range of species
- Water vapor measurements at 100 ppt a key to next generation devices
- Robust technique with demonstrated precision of 0.3%



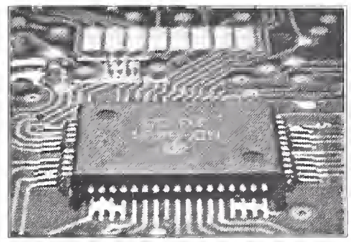
Microelectronics

Surface Characterization



Electron Micrograph

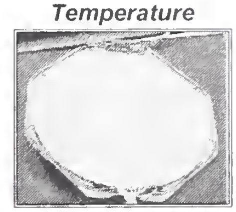
Value of Semiconductor Shipments Nearly $200B



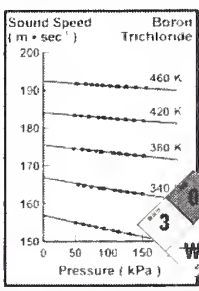
SIA

Standards for Process Control

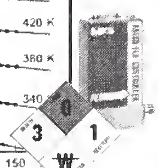
Temperature

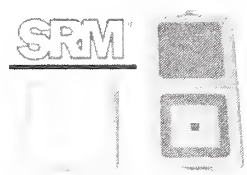


Data for Process Modeling



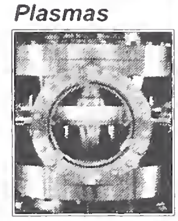
Thermophysical Properties





SRM 2134, Arsenic in Silicon

Plasmas

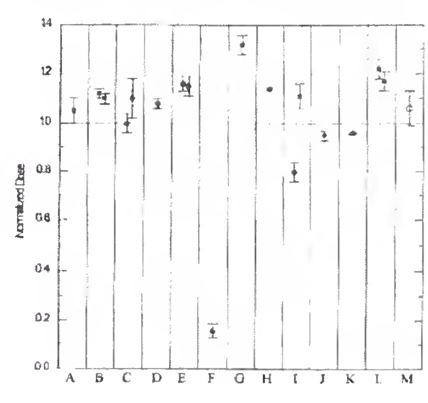


Humidity

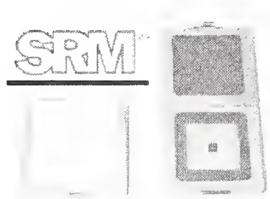
Ion-Implanted As and B in Silicon

New SRMs Improve Quality Control in Silicon Wafer Production

- Arsenic and Boron doped Si artifacts are used to calibrate SIMS measurements of concentration-depth profiles
- An accurate transfer standard enables
  - *Technology transfer from site-to-site*
  - *Comparison of experimental data with theoretical process models*



Laboratory Comparison of Implanted As in Si



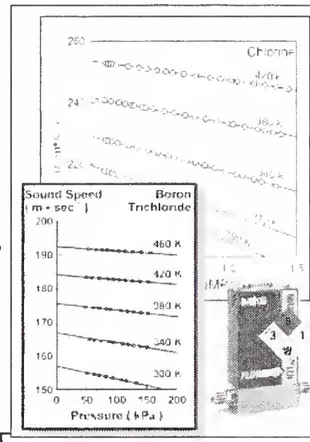
SRM 2134, Arsenic in Silicon

$$\frac{N_{x,unk}}{N_{x,std}} = \frac{A_{0,unk}(<\sigma>\phi\Gamma\varepsilon)_{std}}{A_{0,std}(<\sigma>\phi\Gamma\varepsilon)_{unk}}$$

Expanded and rigorously evaluated uncertainty of 0.38%

Thermophysical Properties of Semiconductor Processing Gases

- *Accurate thermophysical data needed to model the hydrodynamics of chemically aggressive gas streams*
  - Flow in CVD reactors
  - Flow through Mass Flow Controllers (MFCs)
- *Measurements completed on seven high priority gases identified by SEMATECH WG on Mass Flow Meters*
  - CF_4, Cl_2, HBr, BCl_3, WF_6, C_2F_6, SF_6
  - Data collected from boiling point to ~475 K, 25 kP to 1.5 MP
- *Recommendations – NIST Workshop on Mass Flow Controllers (5/2000)*
  - Increase the range of transfer standards for use in round-robin tests (0.01 sccm to 1000 slm)
  - Improve primary (0.025%) and transfer (0.1%) standards for gas flow
  - Properties of more gases – work with industry group to identify and prioritize
  - Develop metrology to characterize liquid flow controllers

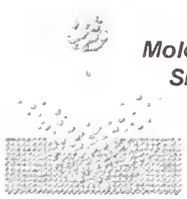


- *Ideal-gas heat capacities, EoS uncertainties of ~0.1%*
- *Effective pair-potentials derived for all seven gases*

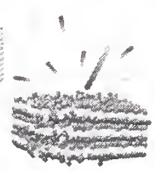
- Properties for NF_3, CH_4O, $(CH_3)_3Ga$ to be published FY 2001
- Start measurements on HCl, NO, N_2O
- Commission apparatus for transport property measurements

Nanotechnology

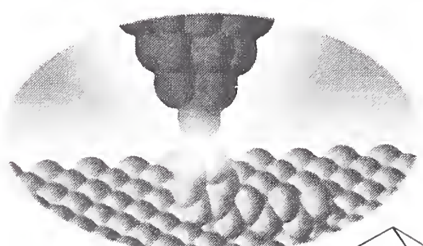
Tools to correlate "nanospatial" relationships to macroscopic properties

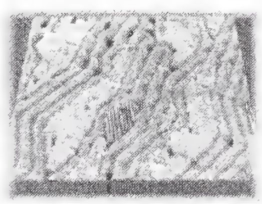


Molecular SIMS

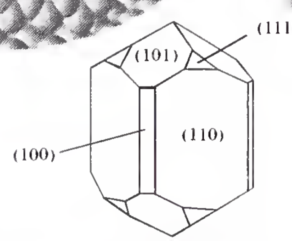


Ultra-Shallow Depth Profiling by ToF-SIMS



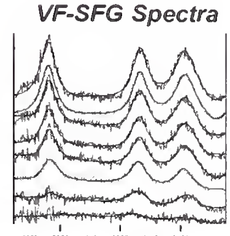


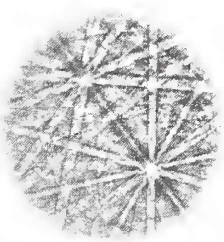
Self-Assembled Monolayers



Proposed Model for TiO_2 Nanostructure

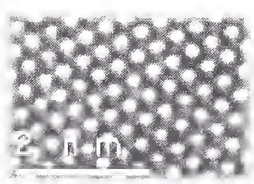
VF-SFG Spectra

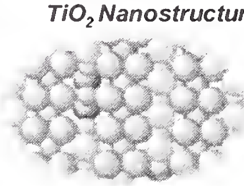




Phase Identification EBSD

High Res TEM Ultra-Thin Dielectric Film on Silicon

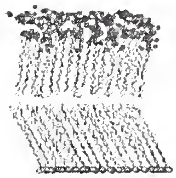




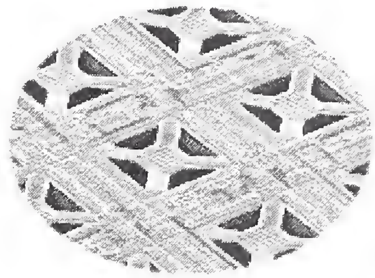
SnO_2 Cluster

Chemical and Biochemical Sensing

Biological Sensing Molecules …Gas Sensing Nanodevices
Single Molecule Detection … Single Chip Devices

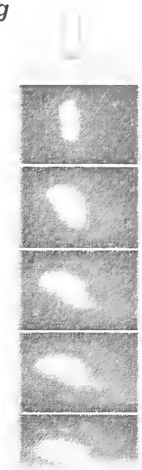


Hybrid Bilayers

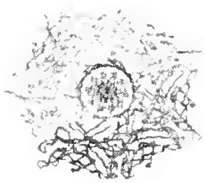


Micro-hotplate Sensor Arrays

Flow Imaging Techniques

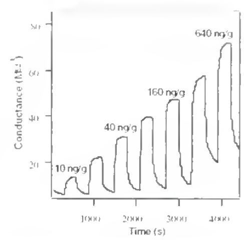


Fluorescent Labeling



Nanopores

Optical Methods for Chemical Sensing



Gas Sensing

STM Image of SAMs

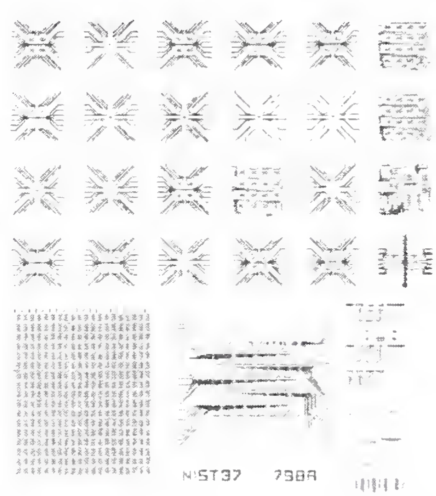
MEMS Microarray Device Platforms
Novel Device Designs

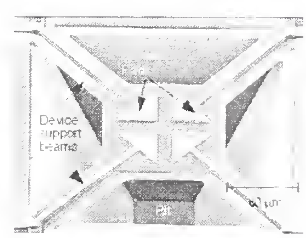
4-element array **for gas microsensor prototypes**

16-element array **for process/property studies on sensing films**

48-element array **for process/property and proximity effect studies**

340-element array **for investigating adsorbate transients and surface coverage-conductance relationships**





Electrode variations

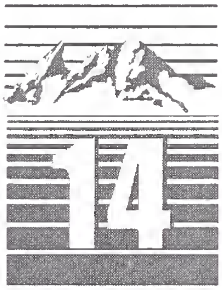
29 device designs per 13 mm x 15 mm die
~ 80 die per 15 cm wafer

- **Improved working devices produced**
- **Device flexibility demonstrated**

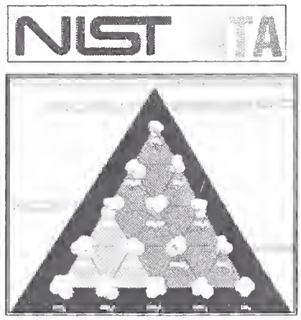
Physical Property Data

TRC

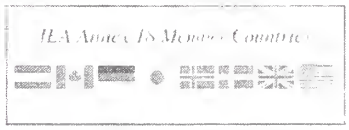
Thermodynamics
Research Center
... returning home!



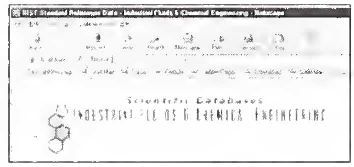
Fourteenth Symposium on Thermophysical Properties June 2000



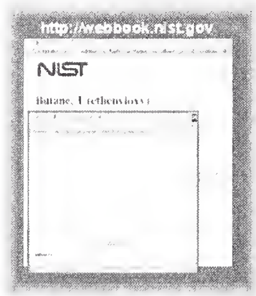
REFPROP



Industrial Fluids Database



NIST Chemistry WebBook

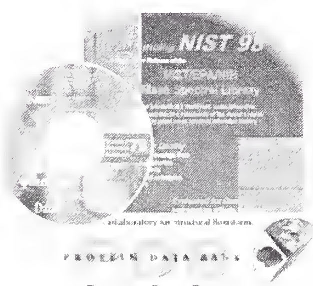


Thermophysical property data for 16 fluids

Chemical and Biochemical Data

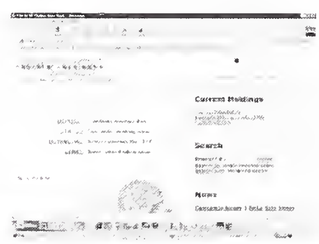
FTIR Database

Spectra for 31 out of 189 HAPs traceable to NIST primary standards



Protein Data Bank

Protein Data Bank

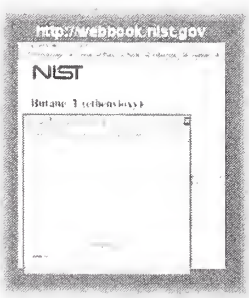


>14,000 structures

Rutgers SDSC NIST

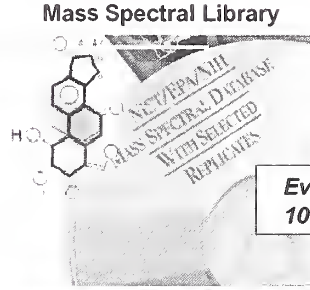
NIST Chemistry WebBook

Data for more than 35,900 compounds with up to 17,000 users per week.



NIST 98

Mass Spectral Library

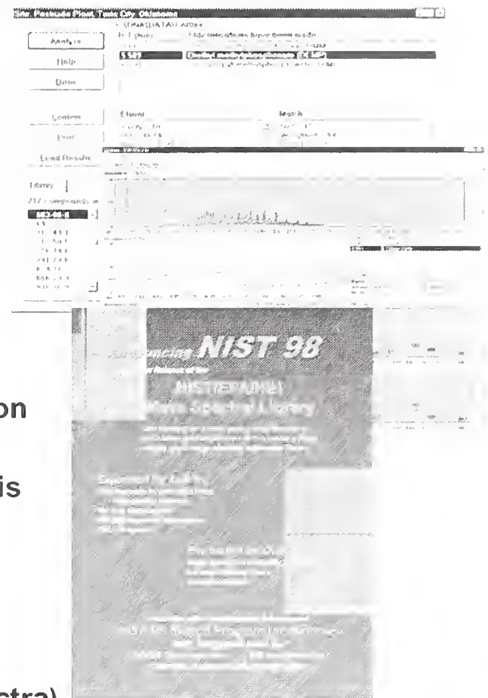


Evaluated spectra for 108,000 compounds

NIST 98 - Mass Spectral Library

The World's Most Widely Used Mass Spectral Library

- Installed on > 3000 instruments per year (over 1/2 of all GC/MS's sold world-wide)
- Evaluated spectra for 108,000 compounds
- Growth: new measurements and incorporation of high quality collections



Derivative Programs:

- Verification of the Chemical Weapons Convention by Automated MS Deconvolution and Identification System (*AMDIS*)
- Chemical Structure Mass Spectrum Analysis Tool (*MS Interpreter*)
  - For finding errors (NIST)
  - For identifying compounds (users)
- Auxiliary data collections for confirming identification (retention index, infrared spectra)

Web-Based Dissemination of Reference Data

The NIST Chemistry WebBook ... *a gateway to the NIST data collections*

Features of New Release (February 2000)

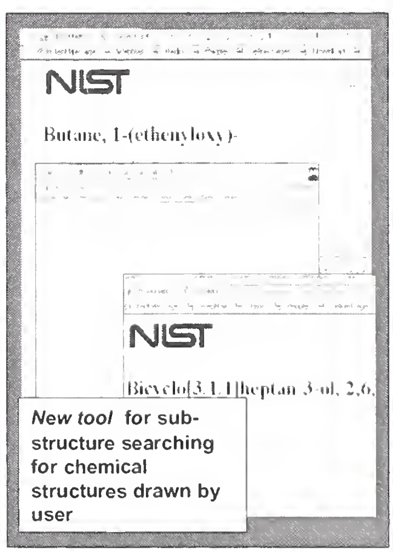
- Data for >35,900 compounds
- Henry's Law Data,
- UV/Visible Spectral Data
- New data on critical constants
  - vapor pressure
  - ion energetics
- Thermodynamic data types increased

User Profile:

- Between 8000 and 17,000 users per week
- Industry (12%), Government (5%), Academia (25%), Commercial Users (30%), non-US (28%)
- About 50% are return users

Data expansion areas support chemical process design

- Thermochemical and thermophysical properties of pure fluids and aqueous solutions
- Vapor-Liquid Equilibrium
- Equation of state information



http://webbook.nist.gov

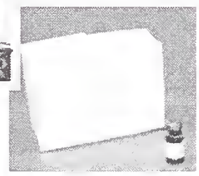
Healthcare Measurements

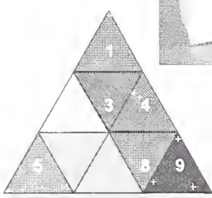
Health care costs amount to ~ 14% of the GDP, an estimated $1.5 trillion

Prevention

Diagnosis

Treatment/Therapy





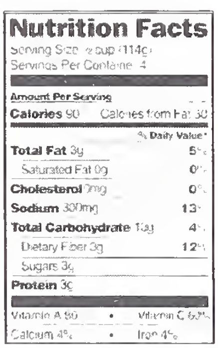
Nutrition

CSTL Maintains and Refines Definitive Methods for 12 Health Status Markers	
Calcium	*Cancer, Blood Clotting*
Chloride	*Kidney Function*
Cholesterol	*Heart Disease*
Creatinine	*Kidney Function*
Glucose	*Diabetes*
Lithium	*Antipsychotic Treatment*
Magnesium	*Heart Disease*
Potassium	*Electrolyte Balance*
Sodium	*Electrolyte Balance*
Triglycerides	*Heart Disease*
Urea	*Kidney Function*
Uric Acid	*Gout*

New Driver

EC IVD Directive requires that all IVD products sold in Europe must show "traceability to standards of a higher order".

Accuracy in Nutrition Labeling of Food

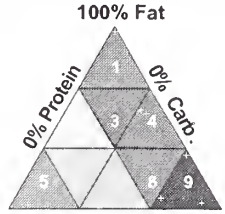


Nutrition Facts
Serving Size ½ cup (114g)
Servings Per Container 4

Amount Per Serving	
Calories 90	Calories from Fat 30
	% Daily Value*
Total Fat 3g	5%
Saturated Fat 0g	0%
Cholesterol 0mg	0%
Sodium 300mg	13%
Total Carbohydrate 13g	4%
Dietary Fiber 3g	12%
Sugars 3g	
Protein 3g	
Vitamin A 80 • Vitamin C 60%	
Calcium 4% • Iron 4%	

> *"Nutrition Labeling is Mostly Accurate on Packaged Food"*
> "However, 46 percent of foods contained less Vitamin A . . . than their labels claimed, and the labels were accurate for iron just 69 percent of the time."
> US FDA
> *Washington Post 1/1/97*

AOAC Food Triangle



- *SRM 1544 - Fatty Acids and Cholesterol in a Frozen Diet*
- *SRM 1563 - Cholesterol and Fat-Soluble Vitamins in Coconut Oil*
- *SRM 1846 - Infant Formula*
- *SRM 2383 - Baby Food Composite*
- *SRM 1548a - Typical Diet*
- *SRM 1546 - Meat Homogenate*
- *In Progress: Fish Fillet, Baking Chocolate, Frozen Spinach*

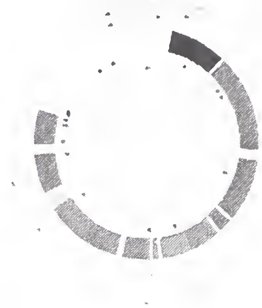
NIST developed a number of SRMs for use by the entire food testing/nutritional laboratory community to facilitate:

- compliance with new nutritional labeling laws
- traceability for food exports needed for acceptance in many international markets
- the provision of accurate labeling information to assist consumers in making sound nutritional choices

Health and Biotechnology

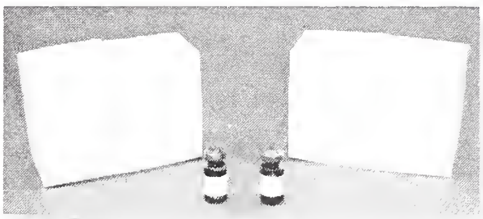
Human Mitochondrial DNA Standard Reference Material (SRM 2392)

Used for QC in Sequencing, Forensic Identification, Medical Diagnostics and Mutation Detection



New SRM includes:
- Extracted DNA
- Information to perform PCR amplification, cycle sequencing, gel separation and data analysis
- Cloned DNA from the HV1 region of the CHR cell line

Fat-Soluble Vitamins, Carotenoids, & Cholesterol in Human Serum (SRM 968c)

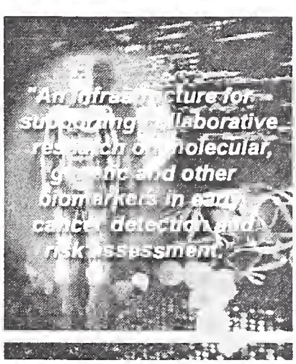


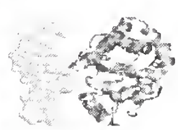
- Widely used in the clinical laboratory
- Basis of NIST Micronutrient QA Program
  - Annual workshop, site visits, and tutorials
  - 65 participating labs (incl. international)
- Vitamins A, E, C and Beta Carotene *PLUS* Cholesterol values using NIST IDMS definitive method

DNA Technologies

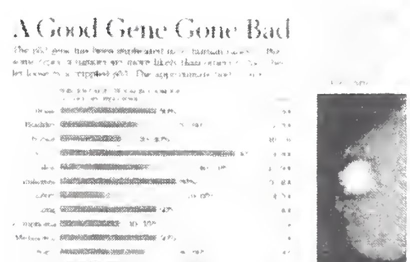
Detection of Genetic Disease ... Medical Diagnosis ... Forensics

Early Detection Research Network

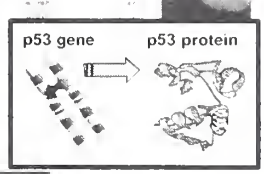




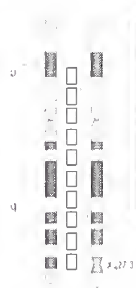
DNA Damage and Repair

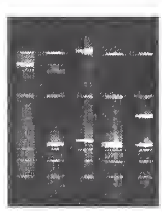


p53 SRM



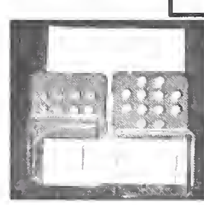
fragile X syndrome



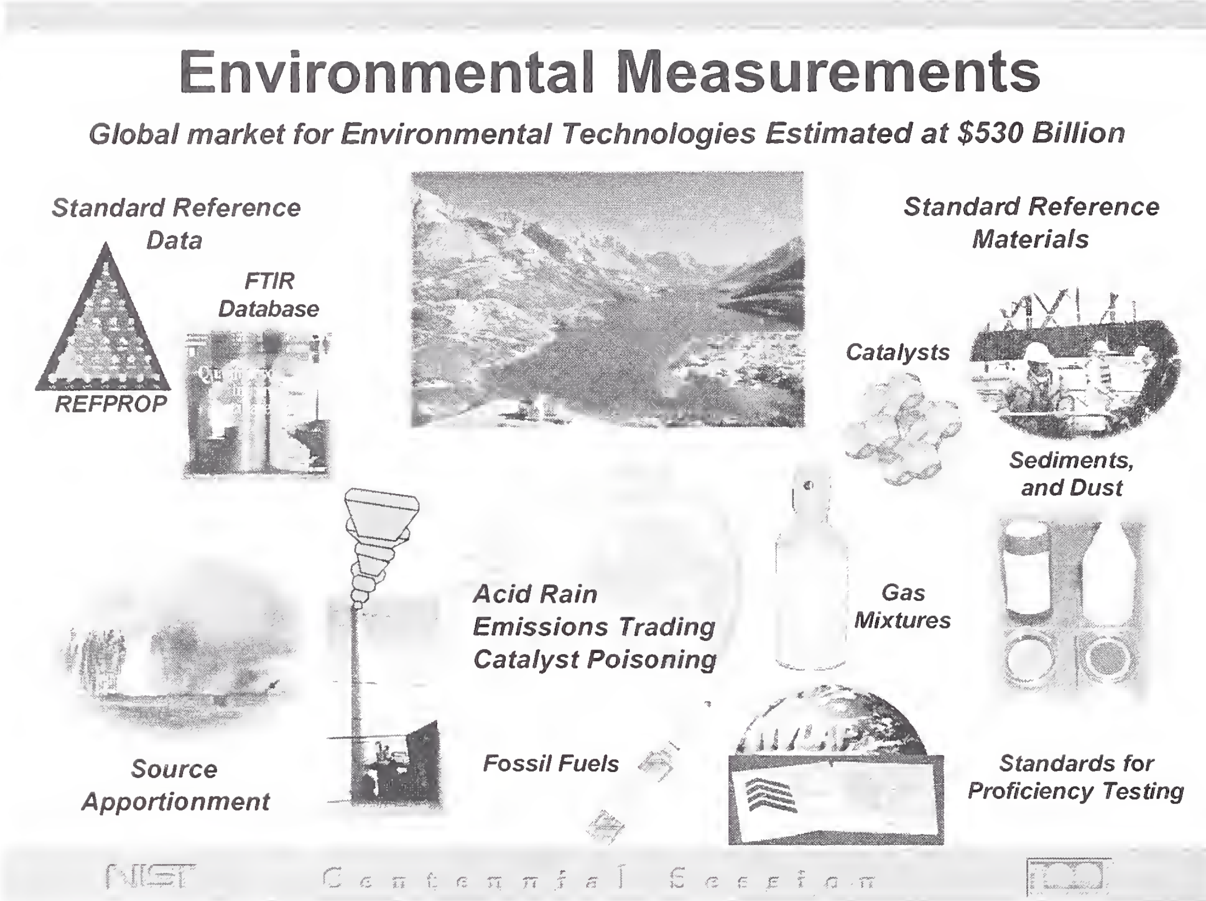


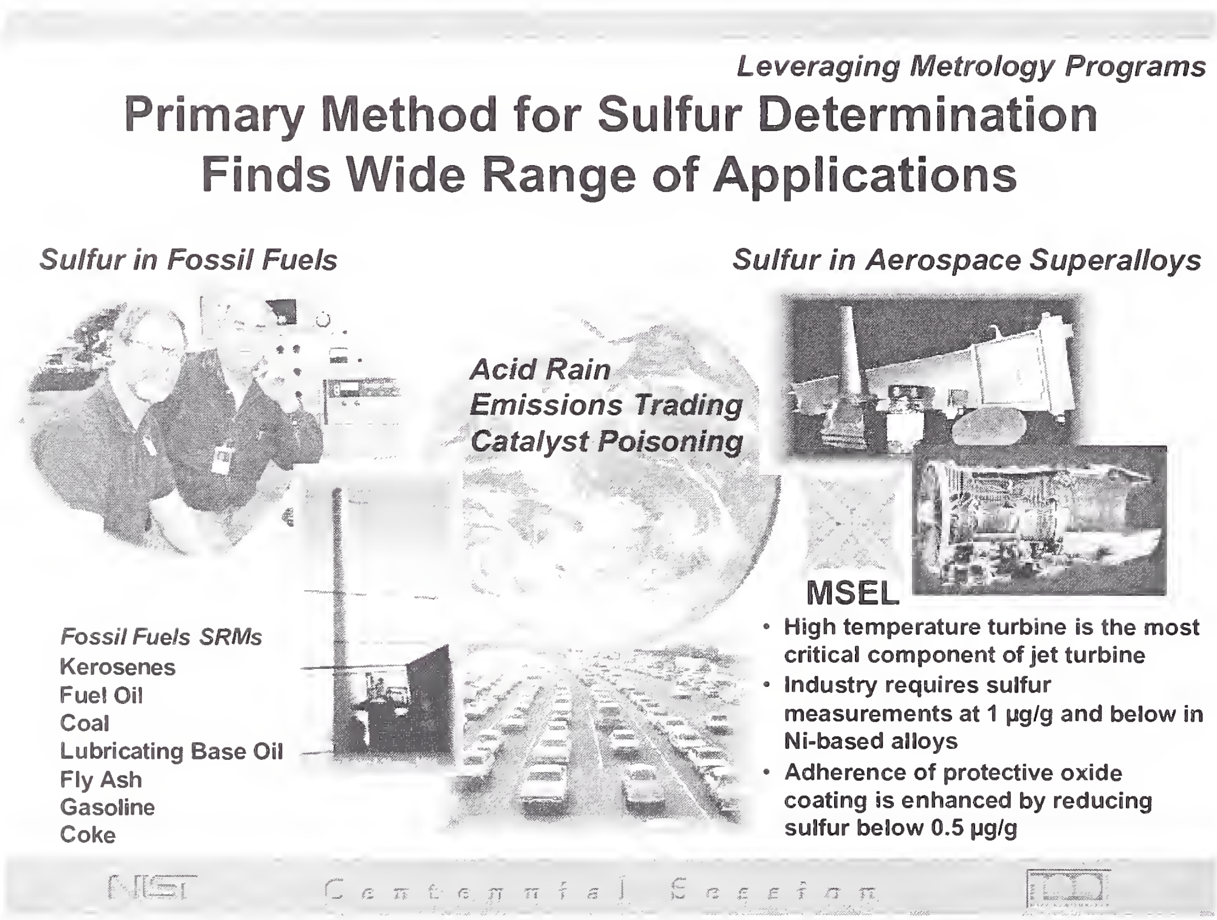
Standards for triplet repeats

Human Mitochondrial DNA



DNA SRMs

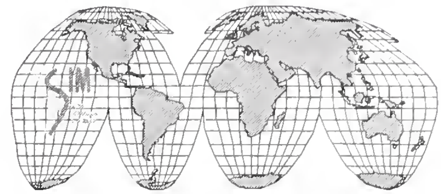

Environmental Measurements
Global market for Environmental Technologies Estimated at $530 Billion
Standard Reference Data
FTIR Database
REFPROP
Standard Reference Materials
Catalysts
Sediments, and Dust
Gas Mixtures
Acid Rain
Emissions Trading
Catalyst Poisoning
Fossil Fuels
Source Apportionment
Standards for Proficiency Testing
NIST
Centennial Session


Leveraging Metrology Programs
Primary Method for Sulfur Determination Finds Wide Range of Applications
Sulfur in Fossil Fuels
Sulfur in Aerospace Superalloys
Acid Rain
Emissions Trading
Catalyst Poisoning
Fossil Fuels SRMs
Kerosenes
Fuel Oil
Coal
Lubricating Base Oil
Fly Ash
Gasoline
Coke
MSEL
• High temperature turbine is the most critical component of jet turbine
• Industry requires sulfur measurements at 1 µg/g and below in Ni-based alloys
• Adherence of protective oxide coating is enhanced by reducing sulfur below 0.5 µg/g
NIST
Centennial Session

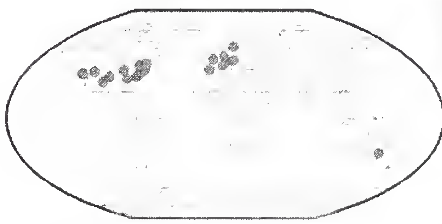
International Measurement Standards

Global Recognition of Measurements and Standards

CIPM MRA
Key Comparisons
(CCQM,CCM, CCT)

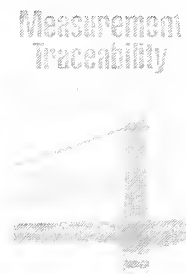


Training
SIM Metrology Workshops



Ozone measurements

US Standards in International Marketplace



IVD Traceability
Workshop, Nov 2000

EU IVD Directive

A New Driver:
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

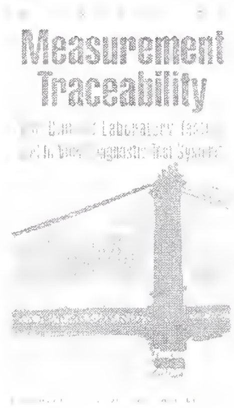
- **IVD Calibrators and/or control materials must be traceable to *"standards of a higher order"***
  - **nationally/internationally recognized *certified reference materials***

US IVD Manufacturers have requested that NIST develop internationally recognized reference methods and SRMs to meet the traceability requirement

Implementation

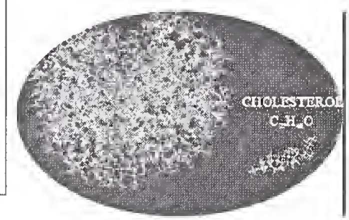
- **First IVD product with CE Mark may be placed from June 2000 onwards**
- **All *new* IVD products *must* have mark by December 2003**
- **Existing IVD products may be sold without the CE mark until December 2005**

Standards to Support IVD Industry



Establish Reference Systems for New Clinical Markers - Highest Priorities

Troponin-I	*Myocardial Infarction*
Gylcated Hemo.	*Diabetes Status*
Homocysteine	*Risk of Heart Disease*
P_{53} DNA	*Breast Cancer*
TSH	*Thyroid Function*
Speciated Iron	*Hemochromatosis, Anemia*
Human Serum Alb.	*Renal Failure*
PSA	*Prostate Cancer*
Cadmium & Mercury	*Toxic Metal Poisoning*
Cortisol	*Endocrine Function*
Thyroxine	*Thyroid Function*
Folic Acid	*Neural Tube Defects*



Classes of Analytes:

"A list" - approximately 100 well-defined chemical species, potentially traceable to SI units

"B list" – less well defined, potentially not traceable to SI units, and number >500 (for example: method dependent analytes such as liver enzymes)

Measurement Challenges:

- High molecular mass proteins (>20,000 daltons)
- Heterogeneity of the protein
- Separation of different forms of the proteins
- Serum matrix complex; analyte level low
- Stability of analytes
- *Standardization necessary before medical diagnostic benefit can be realized*

International Comparisons Database (ICDB)

Supports the implementation of the CIPM MRA and the removal of trade barriers

- ICDB developed and maintained at NIST
- Serves the Inter-American System of Metrology with information based on Appendices B and D of the CIPM MRA

TS ITL CSTL

http://icdb.nist.gov

SIM

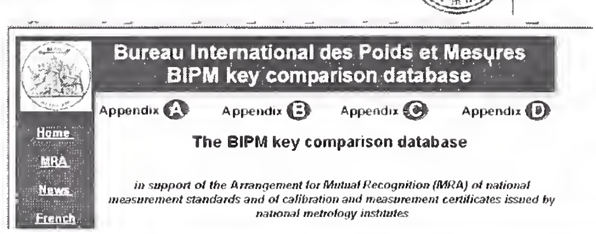
Key and supplementary comparisons search form

Search the database by:

1. A metrology area
2. One or two institutes
3. One or two countries
4. Combinations of the above

- ICDB *contains* official data from *the BIPM key comparison database*
- BIPM *maintains* the official database which contains Appendices A, B, C, D of the CIPM "Mutual Recognition Arrangement"

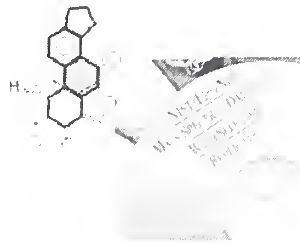
http://kcdb.bipm.org/BIPMKCDB/



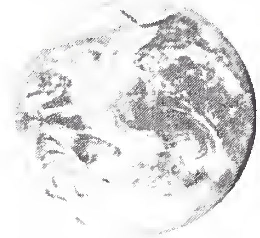
Strategic Directions

Biotechnology

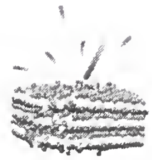
Informatics



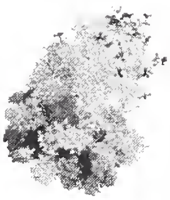
International



Standards



Healthcare



Nanotechnology

Troponin I

- The measurement of cTnI in serum provides a highly selective and sensitive means for diagnosing myocardial infarction
- NIST, the AACC and the IFCC have formed a subcommittee to address inter-method variability problems in clinical cTnI measurement, through development of a cTnI reference material to harmonize results

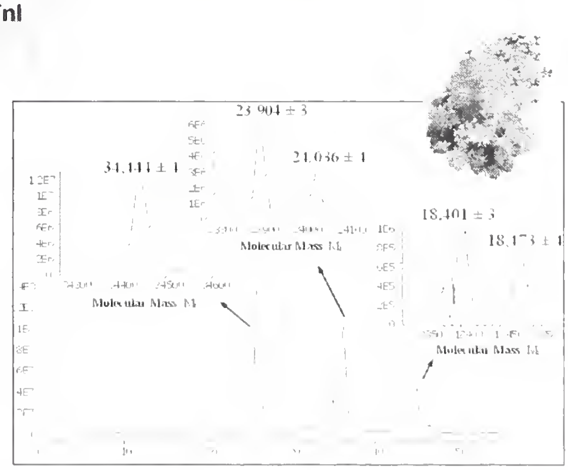
"Failure to use effective treatments . . . for acute myocardial infarction for all patients who could benefit from these interventions may lead to as many as 18,000 preventable deaths each year in the United States."
JAMA, 280, 1000, September 16, 1998.

Example of Variability of Results Among Currently Used Clinical Immunoassays:

Results of Measurements of Troponin-I from Same Sample Pool Using Immunoassay Kits from Three Different Manufacturers

Assay Manufacturer	Conc. ng/mL	# labs
Behring	19.9	115
Dade	6.7	489
Sanofi	0.85	27

From G. S. Bodor, Denver Health and Hospitals -- personal communication 1997

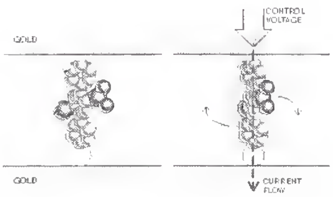


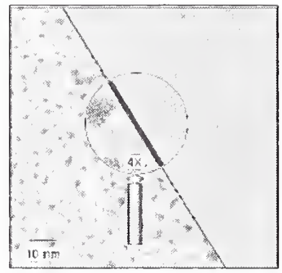
Molecular Electronics

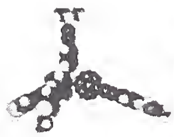
Theory
- Molecular Geometries
- Conduction
- Electrical function

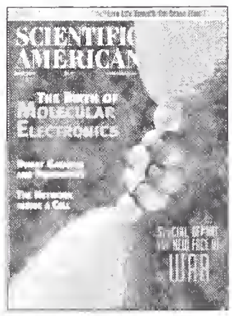
Developing "molectronics metrology" for next-generation electronics based on small aggregates of molecules.
- Test vehicle for molecular components
- Validated models
- Characterized prototype
- Quantitative measurements and insights into molecular conductance

Test Vehicle
- Stability
- Ensemble Effects
- Device Performance









Spectroscopy
- Structure
- Conduction
- Electrical function

Scanned-Probe
- Monolayer Structure
- Molecular Frequency Response

EEEL

Protein Data Bank

Research Collaboratory for Structural Bioinformatics
PROTEIN DATA BANK

Protein Data Bank

GENETIC ENGINEERING GEN NEWS

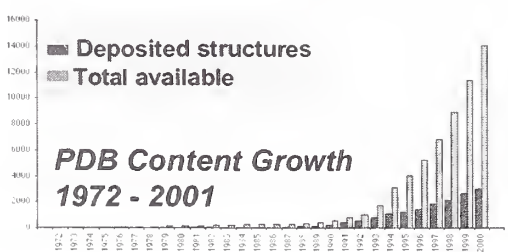
PDB Web Site is among the 50 most influential and important biotechnology Web Sites in 1999

Single international repository for the processing and distribution of 3-D structure data of biological macromolecules determined experimentally by NMR and X-ray crystallography

As of 6/12/2001 the PDB contained 15,385 publicly accessible structures
- 82% determined by X-ray methods
- 16% determined by NMR
- 2% theoretical models

Rutgers
SDSC
NIST

http://nist.rcsb.org/pdb/



Web Statistics
Monthly Average
Second Quarter FY01

Gigabytes	*Sites*	*Hits*	*Files*
82	52K	3.7 M	2.8 M

PDB Mirror Sites: *Singapore, Japan, U.K., Brazil.*

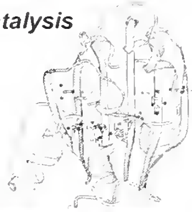
Bio-Molecules and Materials

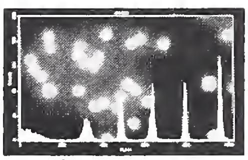
Biotechnology: a rapidly growing industry, impacting all aspects of our lives

Process

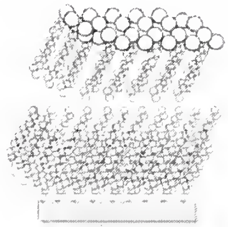
BioSeparations

BioCatalysis



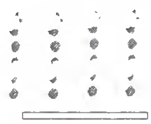


BioSpectroscopy



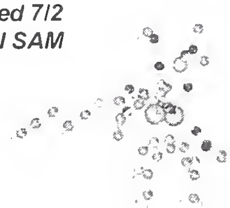
Hybrid Bilayers

Mechanisms



Ordered 7/2 helical SAM

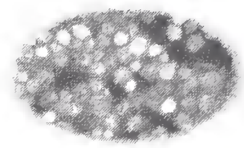
Transcription Mechanisms



Enzyme Studies Structures and Mechanisms

Standards

Fluorescence Standards



Telomere Quantitation for Tissue Engineering

Summary

CSTL Programs

- Century of infrastructural support for industry to facilitate global technological transformation
- Proud history of partnership with stakeholders

... and poised to address future measurement needs of industry

NCSL International Symposium

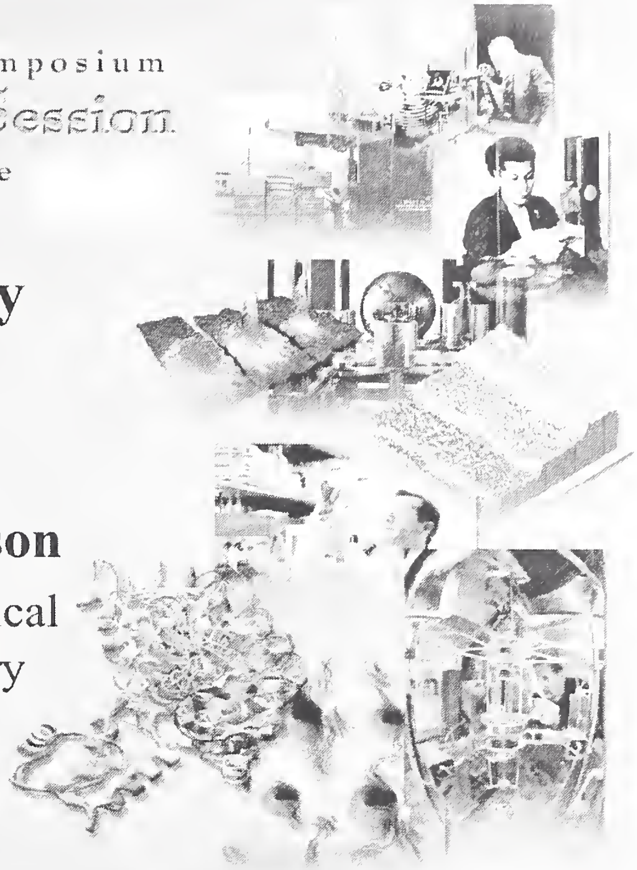
NIST Centennial Session

August second, Two thousand & one

Electrometrology and NIST – New Directions

William E. Anderson

Electronics and Electrical Engineering Laboratory



NIST

National Institute of Standards and Technology

Technology Administration, U.S. Department of Commerce

Transferring NIST accuracy

- Calibration services, including Measurement Assurance Programs
- Standard Reference Materials
- Standard Reference Data sets

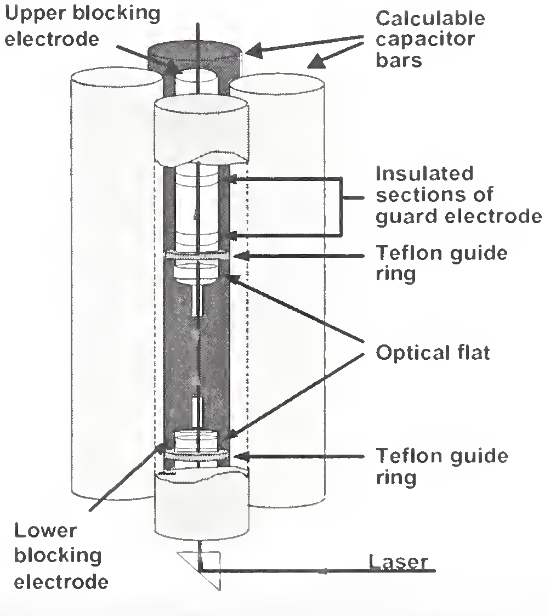
Some NIST URLs for metrology

- Calibrations: **http://ts.nist.gov/ts/htdocs/230/233/calibration/users/index.html;**
  Paper document, Calibration Services Users Guide, NIST Special Publication 250
  For electrical services, see Chapter 9, *Electromagnetic Measurements*
- Standard Reference Materials: **http:ts.nist.gov/ts/htdocs/230/232/232.htm:**
  Paper document, Special Publication 260
- Standard Reference Data sets: **http://www.nist.gov/srd/index.html;**
  Paper document, Special Publication 782
- Electronics and Electrical Engineering Laboratory: **http://www.eeel.nist.gov**

Our goal: working with you, to deliver NIST accuracy to the factory floor

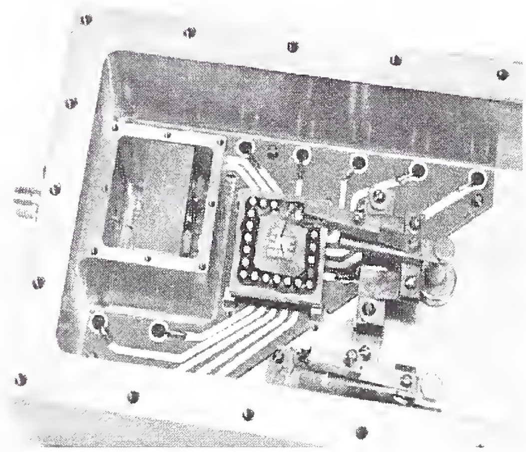
Realization of a quantity

- Example: calculable capacitor
- Generally a challenging experiment carried out at a National Metrology Institute, such as NIST



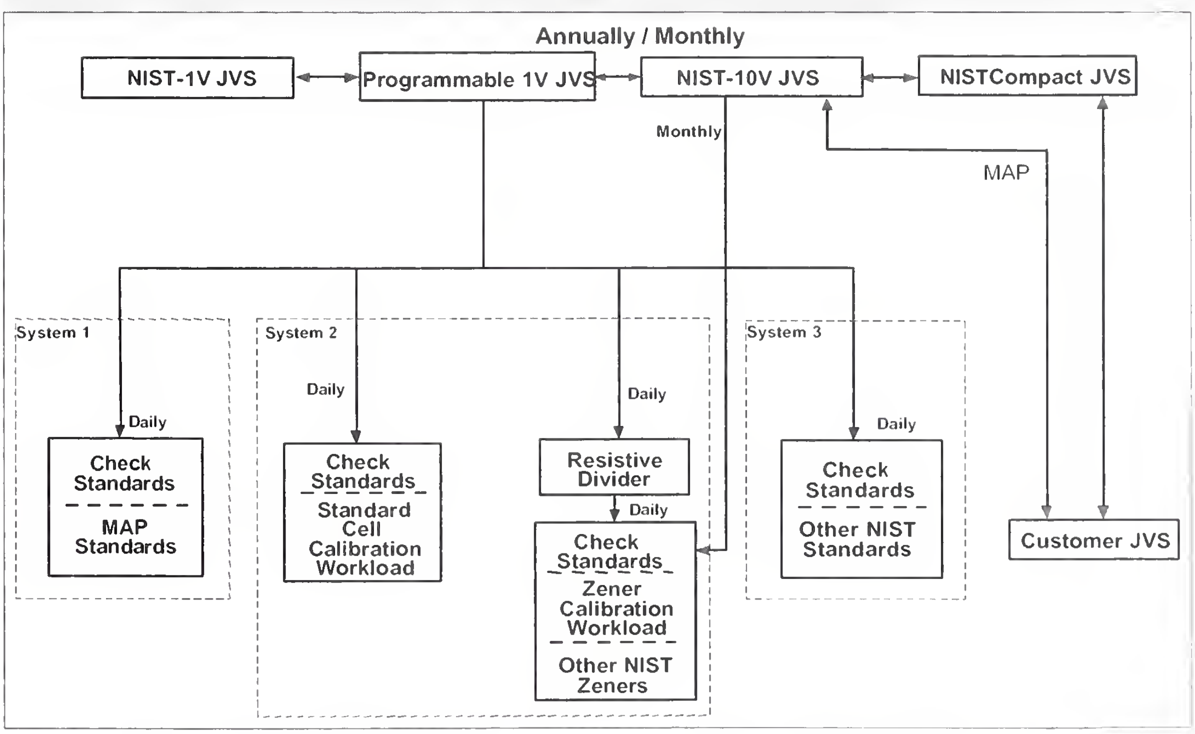
Representation of a quantity

- Example: capacitance or current standard based on counting electrons
- Generally used as a link between primary realization and practical dissemination



(Electrical) metrology trend 1 – ever-reduced uncertainties

(Electrical) metrology trend 2 – shifting to quantum-based standards



Future dissemination path for volt using three different Josephson-junction systems

(Electrical) metrology trend 3 – miniaturization

(Electrical) trend 4 – introduction of new materials systems

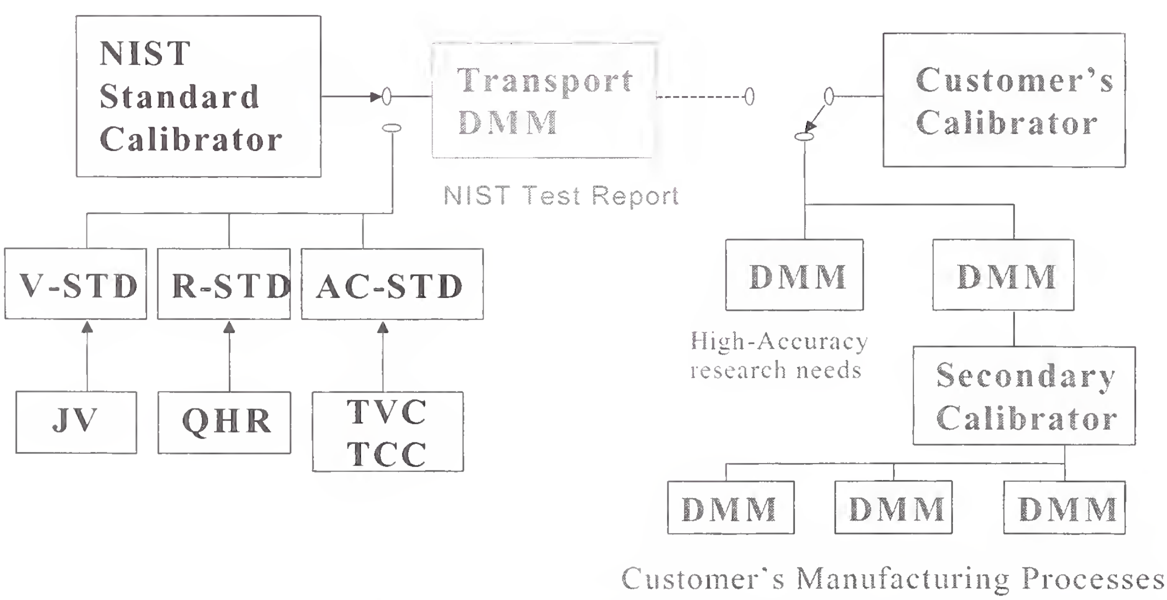
(Electrical) metrology trend 5 – increasing dependence on software and models

(Electrical) metrology trend 6 – telemetrology: exploiting web-based/wireless technology

Present NIST Multifunction Calibration Laboratory

- Digital multimeter and calibrator evaluation
- Internet-based and calibrator evaluation SIMnet DMM project

Present DMM Test Service

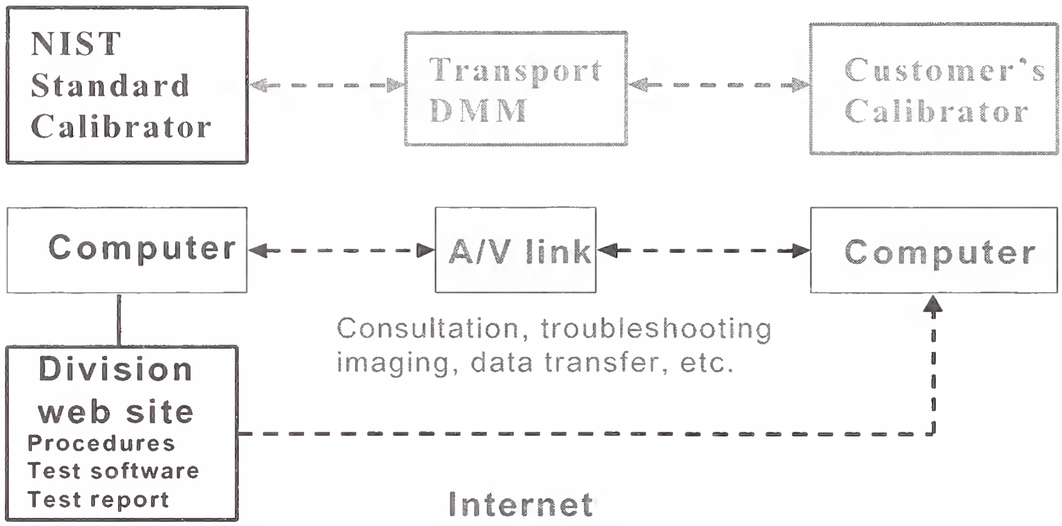


Metrology system of the Americas: Map of SIM metrology regions

SIMnet DMM project

- Internet-based SIM international comparisons
- Audio/video/data links with the SIM laboratories (growing from pilot project)
- SIMnet DMM web site providing
  - Test procedures
  - Downloadable software
  - Password-accessible data

Proposed New Test Service

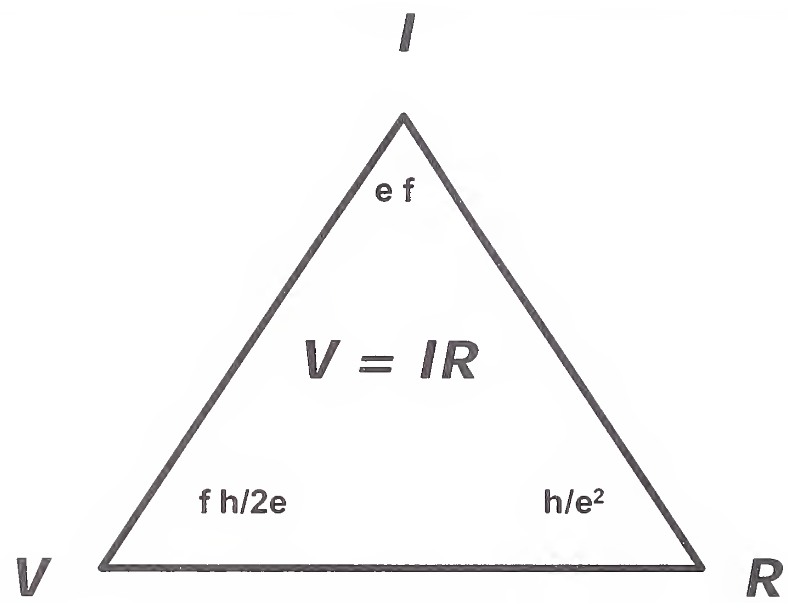


(Electrical) metrology trend 7 – the marriagae of integrated digital and wireless technologies

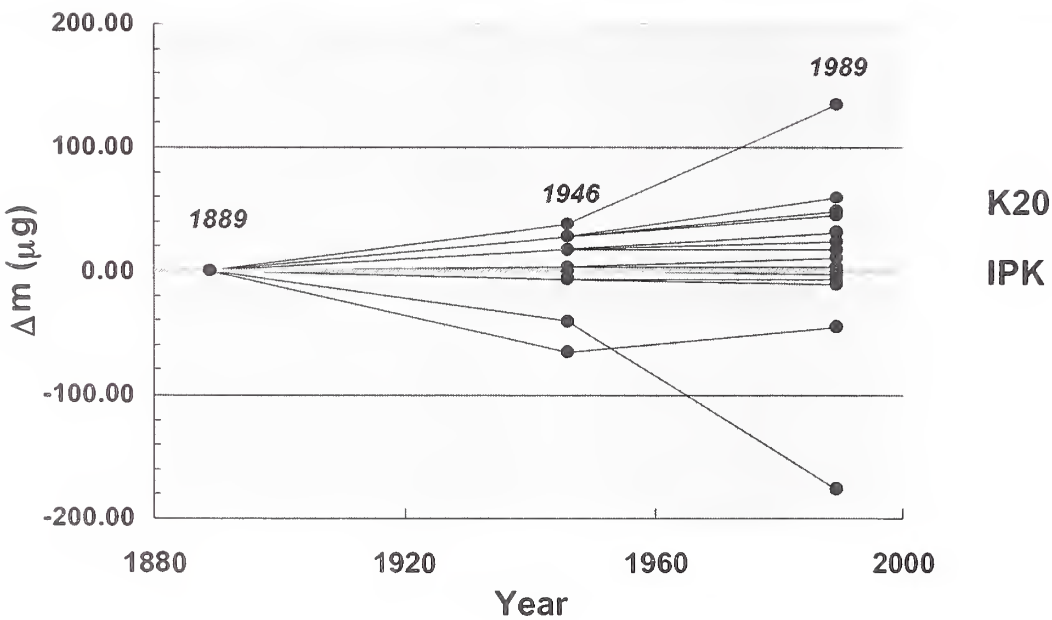
Implications for NIST
Implications for you

Electrical Grand Challenges at NIST

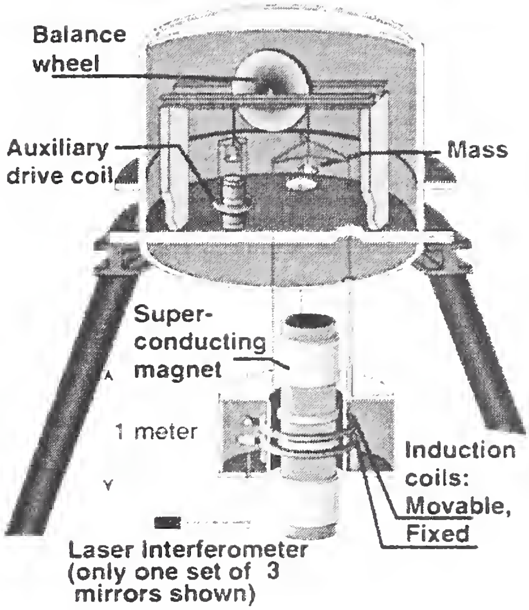
- The Metrology Triangle
- The Electronic Kilogram



Metrology Triangle



A motivation for monitoring mass through electrical measurements



As electric motor

electric current, I, to balance gravitational force, f = mg

mg/I = geometric factor

As electric generator

open loop voltage, U, at constant velocity, v

U/v = geometric factor

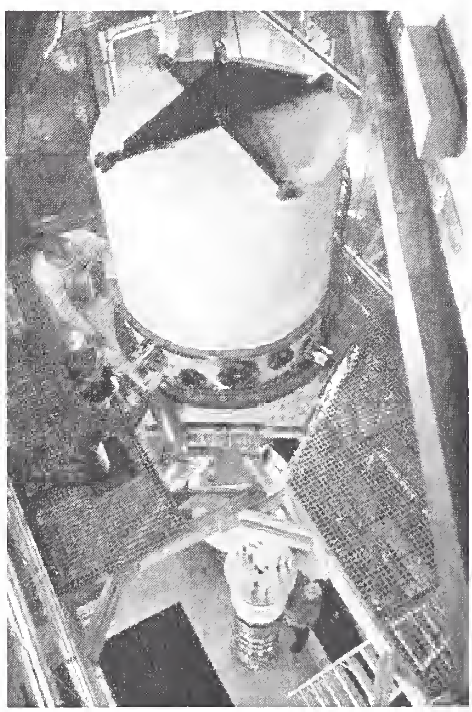
Ratio eliminates geometric factor

$(mg/I) / (U/v) \equiv (mgv) / (UI)$

ratio of mechanical power $\{W_{SI}\}$ to electrical power $\{W_{90}\}$

Must ≡ 1 !! (or adjust constants)

Schematic of the new NIST apparatus, which provides a mild vacuum environment



Electronic Kilogram

An invitation to dialog…

- NIST needs to work with you
- All of us who are stakeholders in the metrology enterprise need to work together to develop the future

NCSL International Symposium

NIST Centennial Session

August second, Two thousand & one

NIST Length and Dimensional Metrology in 2015

Dennis A. Swyt

Chief, NIST Precision Engineering Division

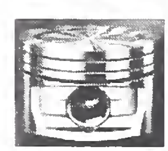
NIST

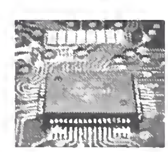
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

NIST's Precision Engineering Division

Length and Dimensional Measurements

- Responsible for providing practical access to the SI unit of length
- Principal customers are in manufacturing from aircraft, autos to computers , microelectronics
- To support these industries
  conduct research,
  provide measurement services,
  participate in development of
  industry documentary standards





Purpose

On occasion of 100th year of NIST

look at NIST work in the area of

length and dimensional metrology

in terms of what is being done now

and what might be expected for year 2015

Contents

- Three Industry Trends
- Three Definitions of Meter
- NIST Work Present and Future

Trend

Continuing Tightening of Dimensional Tolerances

- Tolerances for mechanical-part products
  from aircraft
  to computer read-head suspensions
  shrink by a factor of ~ 3 every 10 years

- Industry needs ever-more-accurate dimensional measurements to keep pace with ever-shrinking dimensional tolerances

- Traceability of measurements seen as a means to accuracy

Trend

Increasing Role of Accreditation

- Increased backing of shop-floor measurements with quality systems
- Quality systems call for accreditation of laboratories supplying calibrations
- Accreditation requires traceability

American Association for Laboratory Accreditation A2LA

National Voluntary Laboratory Accreditation Program NVLAP

Trend

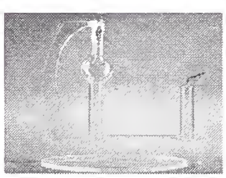
New ISO Standards on Measurements on Mfd Parts

- There is a developing set of ISO TC213 standards called Global Product Specification
- The GPS set of standards deals with assessing conformity of manufactured parts to tolerances
- The set requires traceability of measurements of part dimensions to the SI unit of length

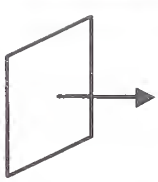
International Standard of Length

Three Definitions of the Meter

1st 1870
Physical Artifact
Meter Bar
Distance Between Scribed Lines



2nd 1960
Wavelength of Light
Krypton-86 Lamp
Distance Between Wavecrests



3rd and present 1983
Propagation of Plane E-M Wave
Operational Definition
Path Traversed in Interval of Time

Present Definition of Meter

Two Methods of Realization

Definition: Meter is length of the path traveled by light in vacuum during time interval of 1 / 299 792 458 second

Methods:

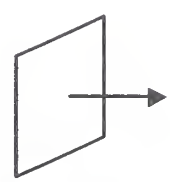
1. Length of path traveled by plane e-m wave in measured time t using $L = c \cdot t$,
   where c is the (defined constant) speed of light

2. Length of path between crests of plane e-m wave of frequency f using $L = n \cdot \lambda$ and $f \cdot \lambda = c$
   where frequency is measured
   a) directly or
   b) by comparison with recommended radiation

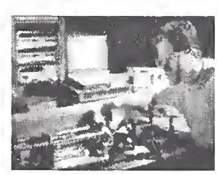
NBS-NIST Present

Realizing SI Unit of Length

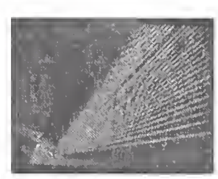
- Start with the definition of the meter



- Use high-precision laser interferometry (method 2b) embedded directly into a measuring machine



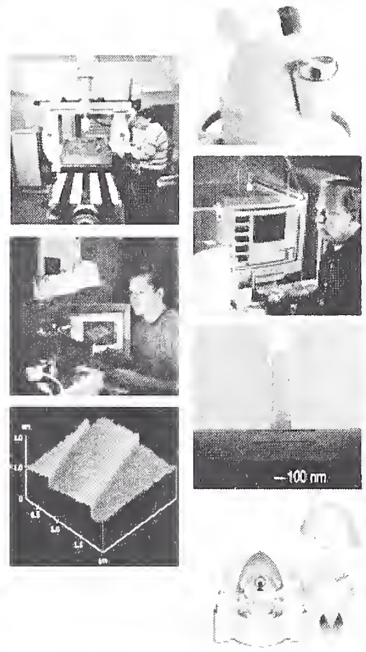
- Reference the frequency of laser to frequency of iodine-stabilized HeNe, one of recommended radiations



NBS-NIST Present

Dissemination of SI Unit of Length

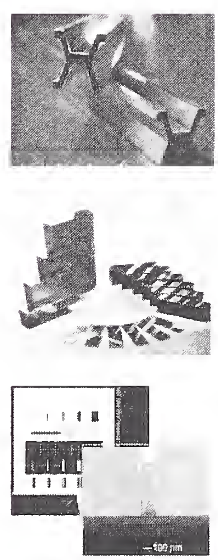
- Provides SI-based length calibrations
  - over range of 12 orders
  - from 100s of m to 100s of pm
- Uses range of technologies
  - laser trackers and CMMs through
  - stylus- and wavefront-profiling to
  - SEMs, AFMs, STMs
- Calibration uncertainties include
  - lowest relative U provided by an NMI
    7×10^{-8} on 1 m scale
  - lowest absolute U reported in literature
    8 pm on 304 pm Si atom step



Current Developments Shaping Future of 2015

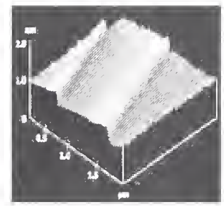
Conventional Calibration Artifacts

- Material standards of length have included
  - meter-long prototype meter of 1870
  - mm-long industrial gage blocks of 1920
  - µm-long photomask linewidths of 1980
- Material-shaping manufacturing process
  - define dimension and geometry
  - produce geometric variations
- Process-determined geometric variations define lower limit of calibration uncertainty
- At the nanometer-scale, desired accuracy is less than that which state-of-art mfg processes allow



Current Developments Shaping Future of 2015
Atom-Based Artifacts

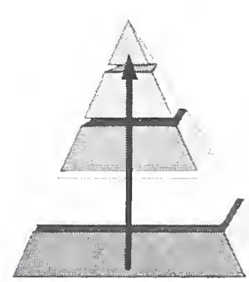
- Atom-based dimensional standards would have dimensions, geometry defined by crystal lattice
- Degree of geometric perfection would be higher than that by material-shaping mfg processes
- Current NIST work is on
  - linewidths based on counted atom spacings
  - step heights based on single-atom steps
  -
- Prospect for 2015
  - Expect NIST and others to be supplying family of atom-based dimensional standards with nm dimensions and pm uncertainties



Current Developments Shaping Future of 2015
Conventional Traceability of Measurements

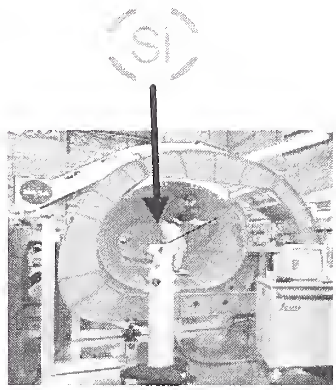
- Traditional path of traceability: hierarchy proceeding
  - from an NMI primary standard
  - through an NMI dimensional calibration
  - through intermediary calibrations
  - to a shop-floor instrument
- Where NMI provide calibrations
  - for each specific measurand
  - with uncertainty U_{NMI} less than $1 / R^{N} U_{SHOP}$

    (where N is the number of levels in the hierarchy,
    R is accuracy ratio imposed at each level, typically 4 or 10)
- Traditional path unsustainable for the multiplicity of industry dimensional measurements



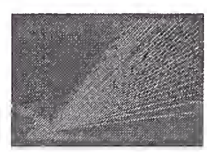
Current Developments Shaping Future of 2015
Direct Traceability of Shop-Floor Measurements

- Alternative path: shop-floor measurement
  - traceable directly to definition of meter
  - satisfying VIM definition of traceability
  - using commercial laser interferometry
- Current NIST work on
  - in-path index of refraction
  - thermal expansion of gages, parts
  - distortion of parts at non-std temperatures
  - shop-floor "calibration / certification"
- Prospect for 2015
  - Expect shop-floor measurements that are traceable directly to SI, not through an NMI, to be a practical option supported by documentary standards, accepted by accreditation systems, and used by industry



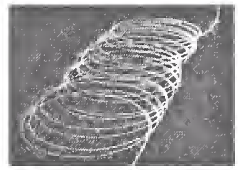
Current Developments Shaping Future of 2015
Single Optical-Frequency Tie of Meter to Second

- Meter is defined in terms of the second
- Second defined by frequency of atomic clock
- Realization of meter based on the second is through optical frequency of laser used in the interferometry
- Laser tied to atomic clock by arduous 20-step chain
- Only optical frequency available is red HeNe laser



NIST Centennial Session

Current Developments Shaping Future of 2015
Multiple Optical Frequencies Tied



- Current NIST work in time-and-frequency
  - use pulsed laser and optical fiber to generate "optical frequency combs"
  - closely-spaced lines of known frequencies
  - covering entire visible spectrum
  - with one-step tie to atomic clock
- Prospect for 2015
  - Expect that frequency-combs tied to GPS will allow length interferometry using SI-traceable optical frequencies anywhere in visible, not just at I-HeNe red

Conclusion
Length and Dimensional Metrology in 2015

- Trends driving demand for traceability will continue
  - tightening of dimensional tolerances
  - increasing accreditation of measurement providers
  - int'l standards requiring measurement of mfd parts
- New NIST calibrations, reference artifacts will be provided
- Calibration landscape will have new elements
  - atom-based dimensional standards
  - traceability directly to SI supported by documentary stds
  - new optical frequencies tied to second beyond HeNe red

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Optical and Ionizing Radiation Metrology in 2015

Thomas O'Brian

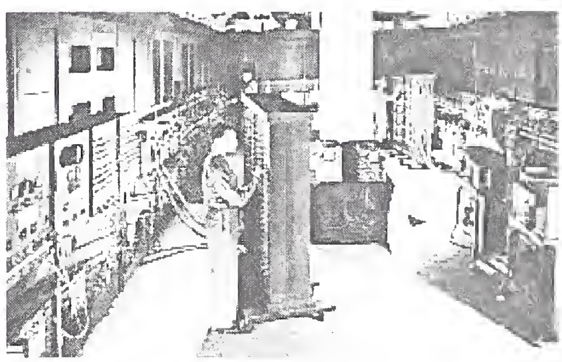
Physics Laboratory

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Predicting the Future?

ENIAC - 1946

- First stored-program electronic computer
- 17,500 vacuum tubes
- 60,000 pounds
- 174 kilowatts
- 5000 operations/second



1949 Prediction: Some day a computer as powerful as ENIAC will contain only 1,500 vacuum tubes, weigh only 3,000 pounds, and consume only 10 kilowatts

Viewing the future through the old paradigm...

NIST Physics Laboratory Metrology for 2015

Key New Metrology Challenges

- Nanotechnology
- Biosciences
- Information Technology
- Environmental Technology

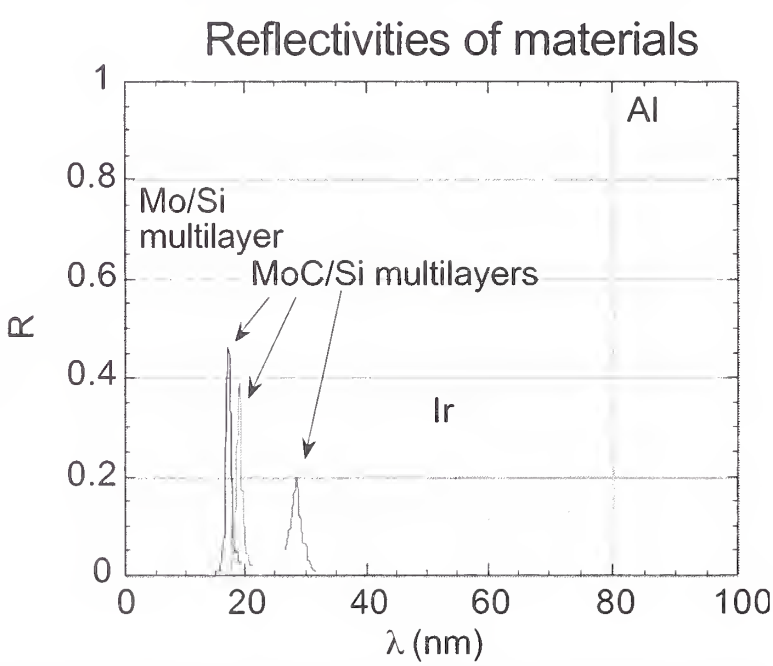
NIST Physics Lab Metrology Resources

- Optical Radiation
- Ionizing Radiation
- Nanoscale Metrology
- Quantum Information

Metrology for Extreme Ultraviolet (EUV) Lithography

Industry need

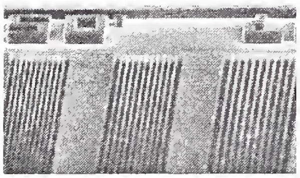
- In 5-10 years EUV lithography at 13 nm may replace conventional optical UV lithography.
- EUV mirrors depend on constructive interference created by a multilayer structure deposited on an extremely smooth substrate.



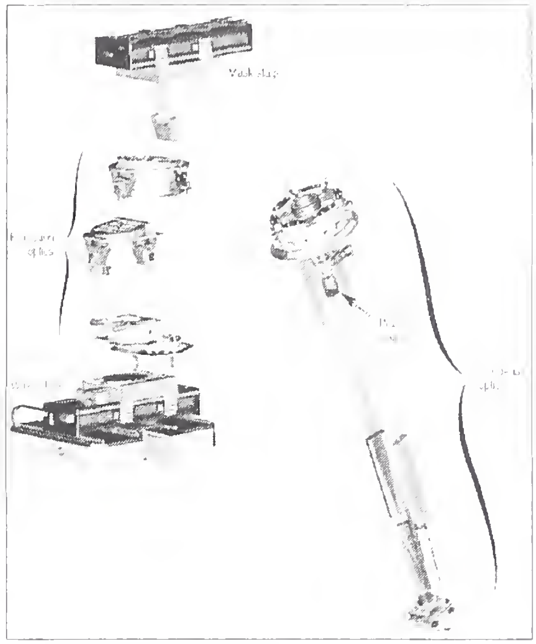
Metrology for Extreme Ultraviolet (EUV) Lithography

NIST is working to meet the stringent requirements for preparation and measurement of these mirrors.

Multilayer mirrors with:
- **figure accuracy of about 0.3nm**
- **surface finish to 0.1 nm**
- **reflectivity measurements ~0.1%**
- **wavelength accuracy to 0.002 nm**
- **on general aspheric surfaces**
- **optics with diameters up to 50 cm**
- **masses of 50 kg.**

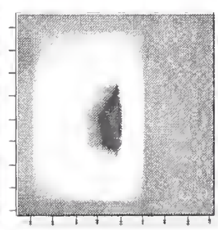


100 nm period dense lines and spaces printed using EUV Lithography.



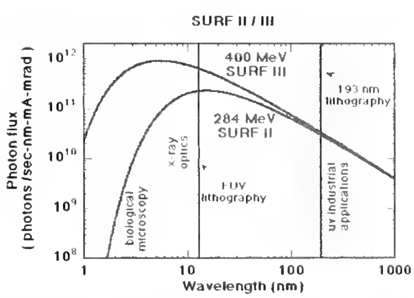
SURF III Upgrade: New Standards and Science
400 MeV storage ring optimized for radiometry

Cryogenic spectroradiometry at SURF II



VUV detector damage studies

First light from SURF III December 1998

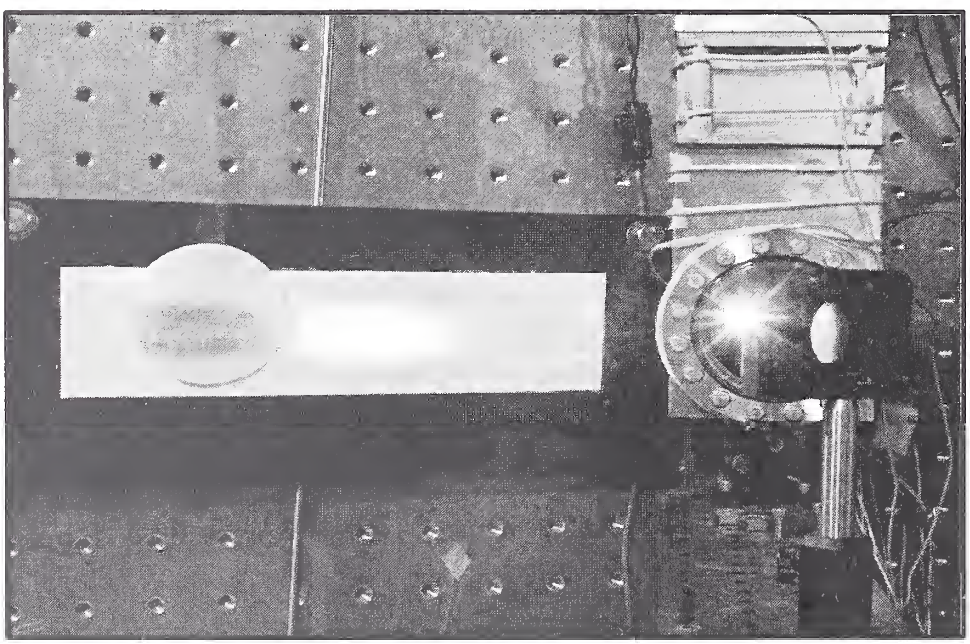


SURF III applications:
- **Measurement of EUV multilayer optics**
- **EUV optical properties**
- **X-ray radiometry**
- **DUV radiometry**

200 Years of Ultraviolet Radiation

Johann Wilhelm Ritter (1776-1810) discovered the ultraviolet end of the spectrum on February 22, 1801. In 1801 Ritter made the startling discovery that silver chloride, which decomposes in the presence of light, is more rapidly decomposed when exposed to the invisible, theretofore unknown radiation beyond the violet end of the spectrum.

SURF Ultralow Resolution Beamline

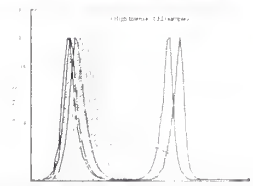


Future needs in Photometry and Colorimetry

1. Solid State Lighting - LED metrology

It is expected that LEDs will replace many of conventional light sources for signaling and general lighting - incandescent lamps and discharge lamps

New measurement methods, new calibration standards (standard LEDs rather than standard lamps), and standardization of measurements will be needed.



Economics of Solid State Lighting

Reasonable goal: Project 50% market penetration of solid state lighting at efficiency of 200 lumens/watt by 2025:

- **50% worldwide reduction of lighting consumption**
- **10% reduction in global electricity demand, saving $100 billion per year**

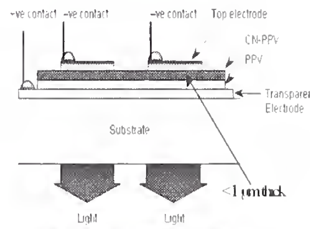
<u>To reach these economic targets industry needs:</u>

- **New measurements and process metrology**

Future needs in Photometry and Colorimetry

2. Digital Color Imaging - Display metrology

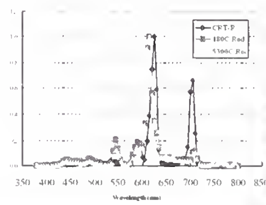
- Applications of color imaging are expanding in graphics arts, digital photography, Internet shopping, online catalog, digital archive of art, telemedicine, e-book, etc.
- Higher and higher accuracies in color reproduction are in demand.
- New type of displays are emerging - OLED displays, reflective displays, …..

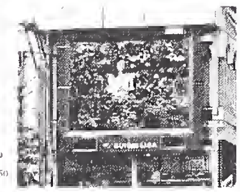


OLED display

New technologies will be needed for accurate characterization and measurements of new types of displays and digital imaging devices (cameras,scanners).

LED display



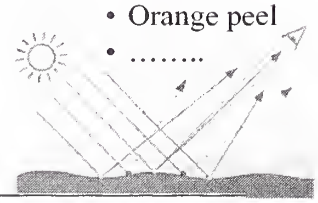


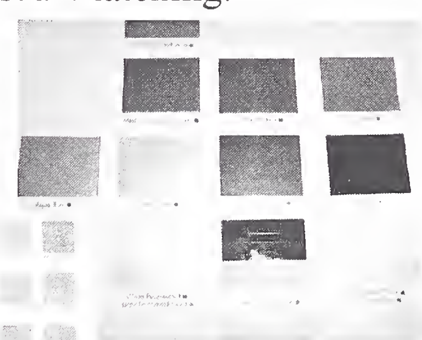
Future needs in Photometry and Colorimetry

3. Color and Appearance - Multi-dimension metrology

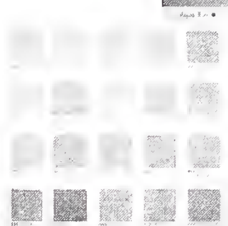
Specifications and reproduction of samples for paint, plastic, and textile, will be computerized and automated to replace human visual matching.

- Gloss
- Haze
- Sheen
- Orange peel
- ……..

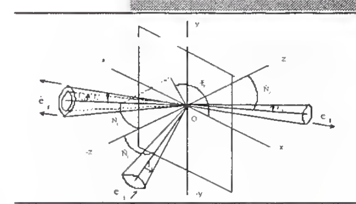




Metallic paint



Fabric



New measurement technologies to be developed to be able to measure “appearance”.

NIST works with industry

- Optoelectronics Industry Development Association (OIDA)
- Council for Optical Radiation Measurements (CORM)
- Illuminating Engineering Society of North America (IESNA)
- International Commission on Illumination (CIE)
- Direct interactions with lighting companies

Optoelectronics Industry Development Association

OIDA *Multiple Roadmaps*

NIST Office of Optoelectronics Programs

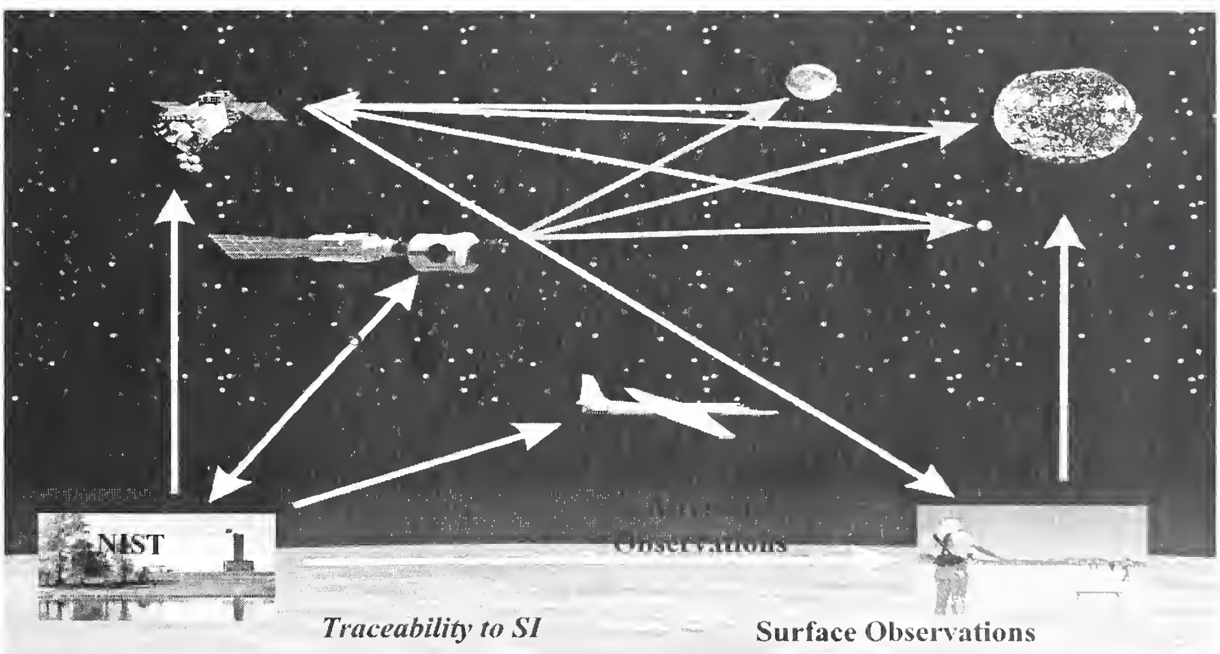
CIE

CORM

Support for Spaced-Based Optical Sensing

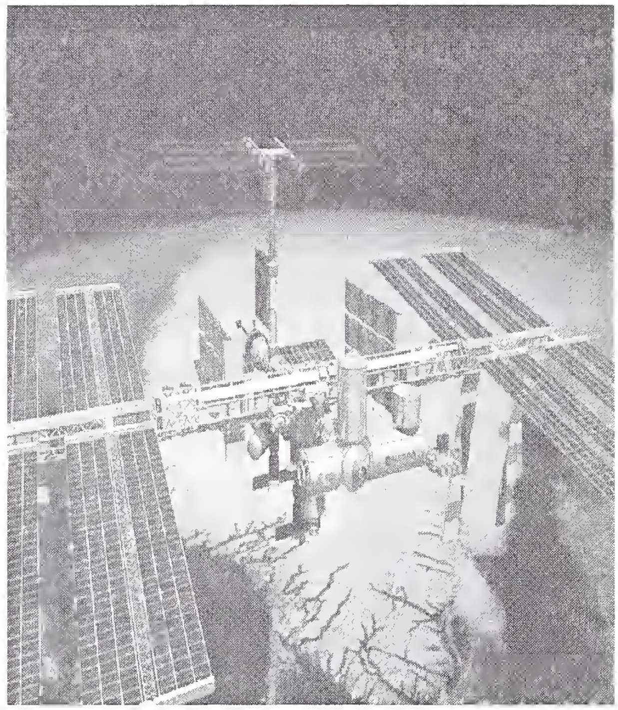
Needs:

•Accurate radiometric measurements of the Earth from space
•Accurate radiometric calibrations traceable to SI units



NIST and the International Space Station (ISS)

- Support for earth orbit satellite systems of: NOAA, NASA, DOD, DOE
- Research platform for standards and metrology needed for the exploration of Space
- What are the advantages for radiometric calibration and verification of spacecraft sensors



NIST Physics Laboratory Metrology for 2015

Key New Metrology Challenges

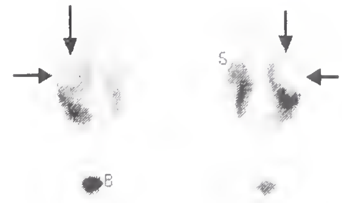
- Nanotechnology
- Biosciences
- Information Technology
- Environmental Technology

NIST Physics Lab Metrology Resources

- Optical Radiation
- Ionizing Radiation
- Nanoscale Metrology
- Quantum Information

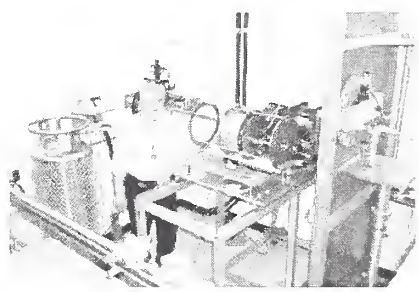
NIST support for Cancer Treatment

- **Radio-immunotherapy has the potential for site-directed treatment for specific diseases**
- **NIST research begun in late 1980's as result of NIH collaborations**
- **NIST work has allowed new products to enter clinical trials**
- **At NIST several novel approaches to treating soft-tissue tumors are under development**
- **NIST is working with manufacturers on radioactively-labeled drugs to non-invasively image physiological processes such as cancer, heart disease and stroke**

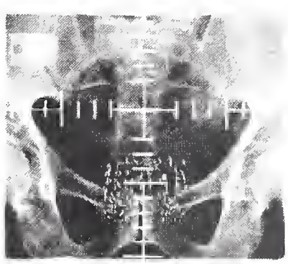


Standards for New Methods of Radiation Treatment

Brachytherapy is applied to the treatment of prostate cancer by insertion of small, sealed radioactive sources directly into the prostate



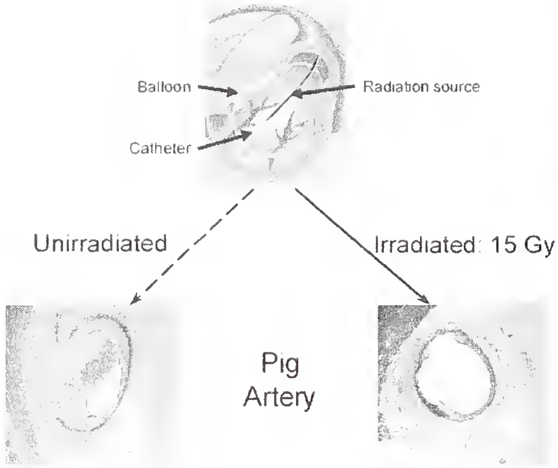
The primary standard quantity air-kerma strength is measured using the NIST Wide-angle Free-air Chamber (WAFAC)



180,000 new prostate cancers/year
80-120 seeds used per patient

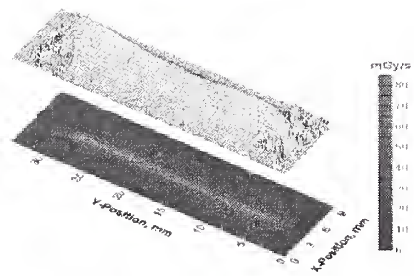
Transferred to seed manufacturers and clinics using well-ionization chambers

Standards for Intravascular Brachytherapy



Intravascular Brachytherapy is used in the treatment of restenosis (re-closing) of arteries following balloon angioplasty

Medical extrapolation chamber measures absorbed dose at a reference point in a tissue equivalent medium



Radiochromic film used with tissue-equivalent phantoms yields information on source uniformity and spatial dose profile

Radiation Sterilization of Medical Products

- **Ionizing radiation kills pathogenic microorganisms**

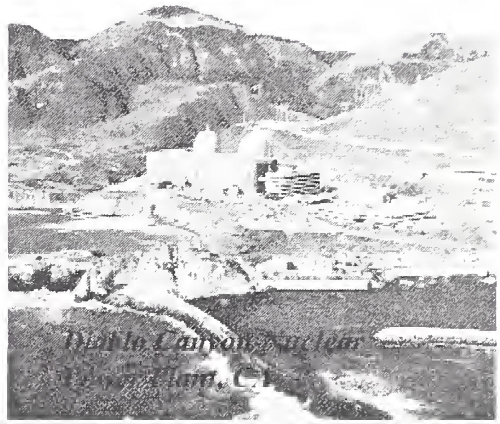
- **Radiation sterilization currently applied to a broad range of disposable medical products**

- **More than 200 industrial irradiators are currently operating throughout the world and about one-third of these are in North America.**

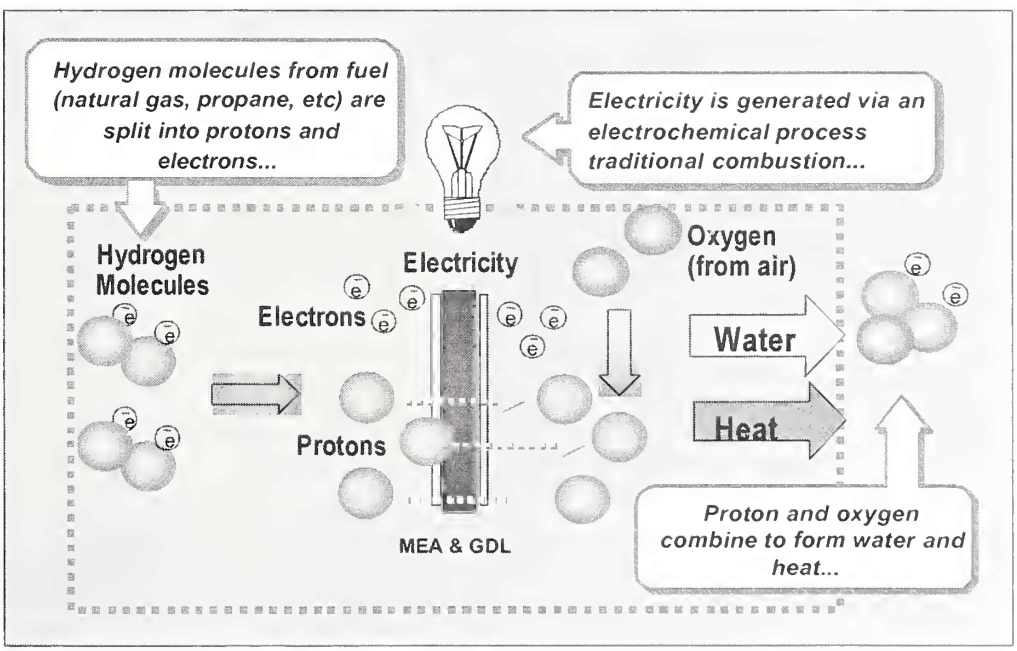
- **Sterilization by irradiation represents about 50% of the market share for sterilization (an increase of nearly double that of 1990)**

Nuclear Power Plant Re-licensing

- The present generation of nuclear power plants is nearing the end of their initial operating license periods
- Plant life extension and re-licensing efforts are being pursued with increasing vigor
- NIST working with industry to develop ASTM consensus standards for testing neutron dosimetry and reactor safety calculations
- NIST scientists also worked closely with NRC and industry representatives to develop Regulatory Guide 1.190 (published earlier this year)
- NIST's efforts are critical to assuring the safety of aging nuclear power plants



Fuel Cells and the NIST Center for Neutron Research



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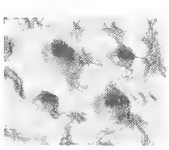
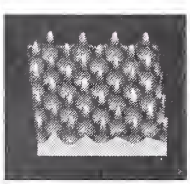
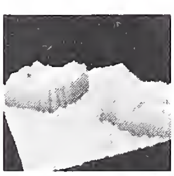
Nanotechnology Metrology Issues in 2015

- In 2015 NIST expects to be able to fully characterize nanostructures, to make all the metrology measurements we presently make in the nanoscale regime

Areas of interest are:
- Quantum and spin electronics
- Autonomous atom assembly
- Single atom manipulation
- Spin polarized STM

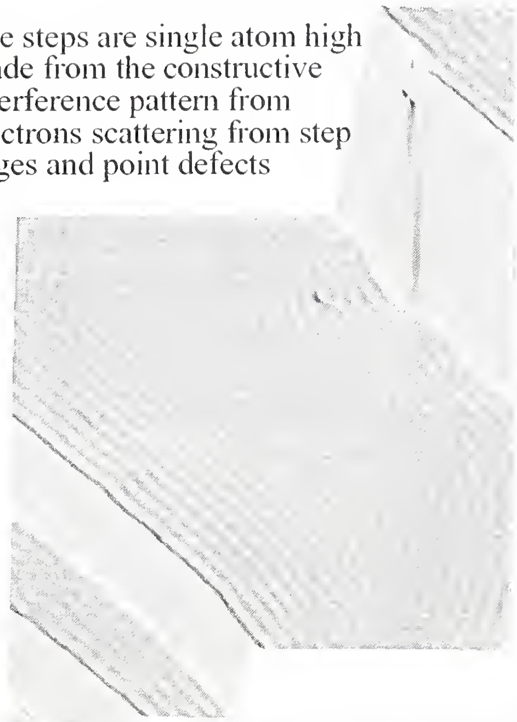


NIST Centennial Session

Autonomous Nanofabrication

The steps are single atom high made from the constructive interference pattern from electrons scattering from step edges and point defects



- **Nanofabrication on the atomic scale without human control, is used to create "ideal" boundary structures atom-by-atom which then allows experimental electron energy level structure to be directly compared with theoretical models.**
- **Systematic variations in the geometries, and large structures with intricate patterns, are possible with this new nanofabrication technology.**

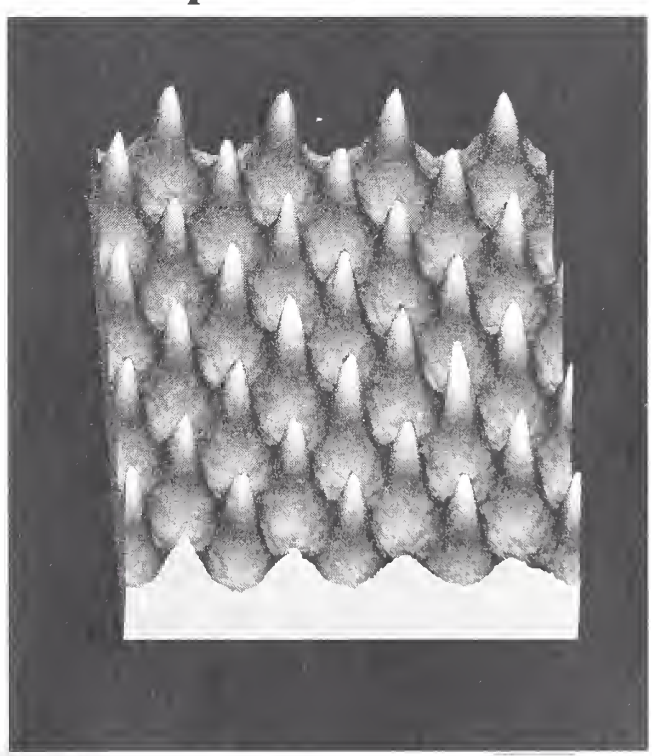
Single Atom Manipulation

•Position single atoms with a precision of 0.1nm

•Develop a fully deterministic source of single atoms

•Use magnetic and electric fields to manipulate atoms above a surface, e.g., atom-on-a-chip technology

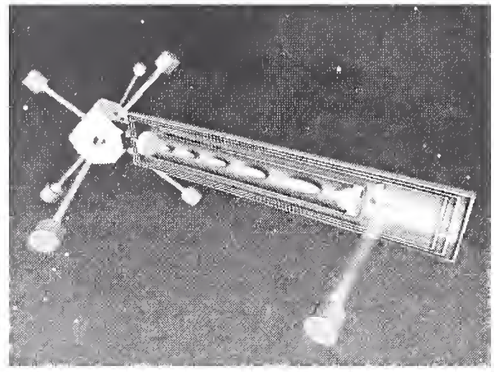
•The interaction of such individual atoms with each other and with the surface are topics of interest with application to quantum computing and single atom probing of surface properties



Time and Frequency Metrology

Cesium Fountain Primary Standard
Uncertainty
Now 1.7 x 10^{-15}
2015 5 x 10^{-16}

Trapped-Ion Optical Frequency Standards (with microwave output)
Uncertainty
2015 < 10^{-17}



Primary Atomic Reference Clock in Space (PARCS)
Flight on ISS in 2005-2006
Uncertainty
2005 5 x 10^{-17}

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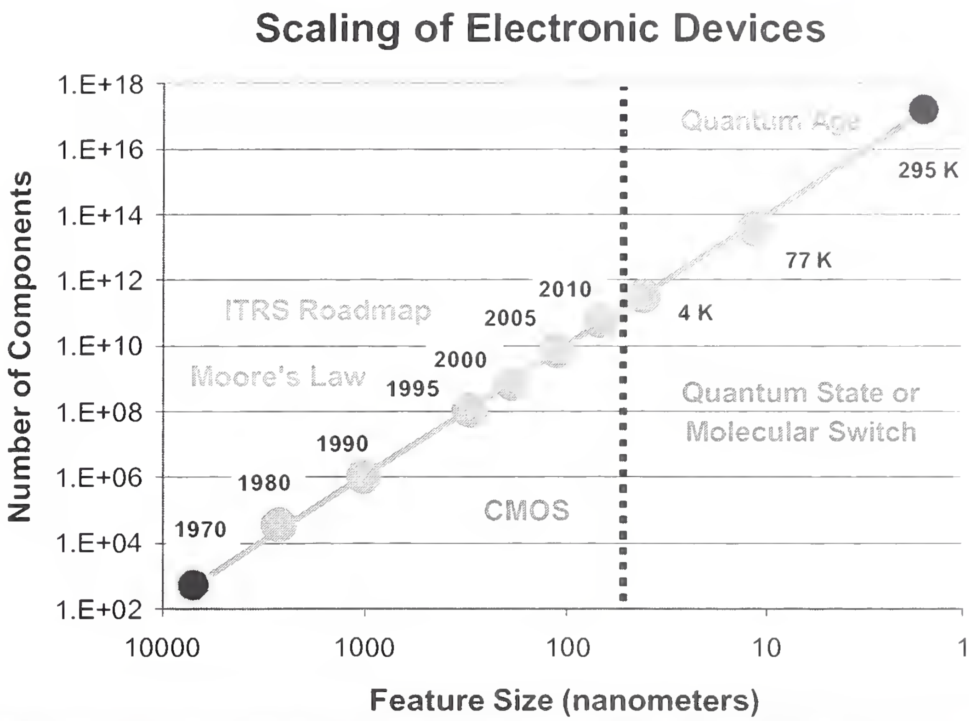
When Moore's Law Hits the Wall?



New Technology Solutions?

- Packaging/architecture advances with CMOS
- Molecular Electronics
- Quantum computing

What is Quantum Information?

- Classical Bit: 0 **or** 1

- Quantum Bit (Qubit): a quantum superposition of ↑ **and** ↓

$$|\Psi\rangle_1 \sim |\uparrow\rangle_1 + |\downarrow\rangle_1$$

Scaling of Quantum Information

- **Classically**, a 3-bit register can store **one** number, from 0 to 7.

1	0	1

- **Quantum mechanically**, 3-qubit register can store **all** eight numbers simultaneously through entanglement:

$$a|000\rangle + b|001\rangle + c|010\rangle + d|011\rangle + e|100\rangle + f|101\rangle + g|110\rangle + h|111\rangle$$

- **Result:**
  - **Classical:** one N-bit number
  - **Quantum:** 2^N N-bit numbers simultaneously

A 300-qubit register has more storage capacity than a classical memory containing as many bits as the number of particles in the universe ($\sim 10^{80}$)

Interest in Quantum Information

Leading active research programs include:

- IBM
- Hewlett-Packard
- Lucent
- AT&T
- Several universities world-wide
- Several US National Laboratories
  - NIST

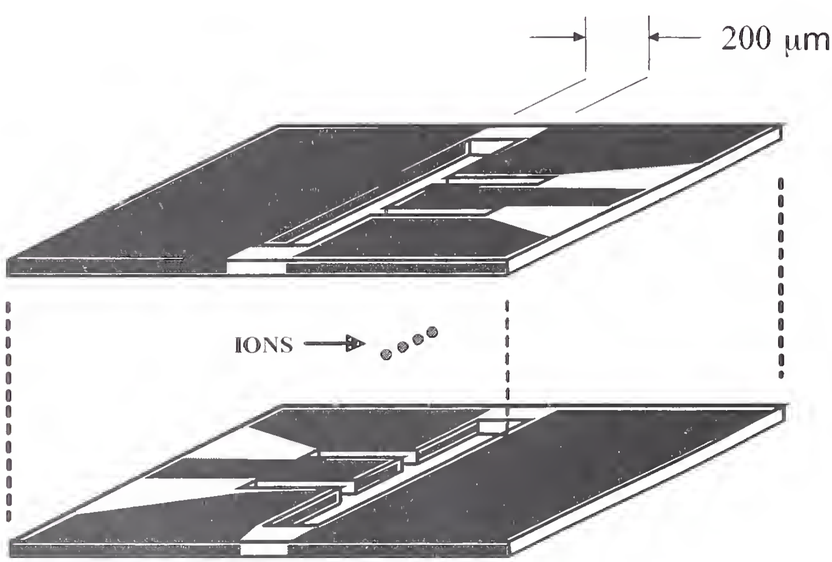
Technical Approaches to Quantum Information Processing

- **Nuclear magnetic resonance (NMR)**
  - IBM Almaden (Chuang) demonstrates 5 qubit NMR "quantum computer" August 2000
  - NMR probably not scalable beyond ~15 qubits
- **Solid-state implementations**
  - Isolated ion implantation, Josephson junctions, single electron transistors, quantum dots, etc.: severe decoherence problems
- **Atomic physics**
  - Ion traps
  - Trapped neutral atoms/Bose-Einstein condensates
  - NIST using both approaches

NIST demonstrated quantum entanglement of four Be^+ ions using lasers and electromagnetic traps. Approach is scalable in principle to very large number of ions.

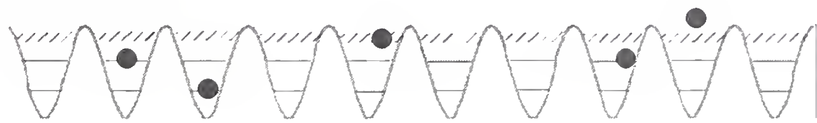
March 2000

NIST Lithographic Ion Trap for Studies of Quantum Entanglement



NIST Use of Neutral Atoms as Qubits

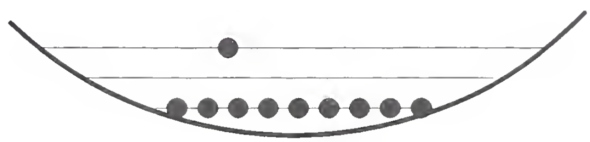
- **Optical Lattices**



Natural register for atomic qubits, but randomly filled, various states

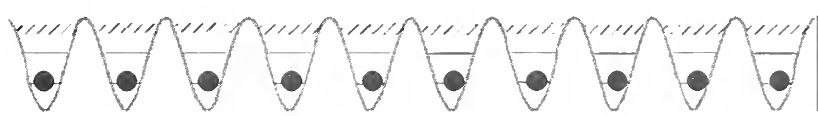
- **Bose-Einstein Condensation**

Huge number of atoms in lowest state



NIST Use of Neutral Atoms as Qubits

- Next:



One atom per lattice; all in lowest state (recently demonstrated at NIST)

- Later: Microfabricated atom trap arrays

Quantum Information Technology

- Establish physical standards for secure quantum communication
- Measurement and standards for IT beyond Moore's Law
- NIST has demonstrated the ability to produce a maximally-entangled state of four qubits
- Improved fundamental metrology
  - Attain Heisenberg limit in quantum measurements
  - Better atomic clocks

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