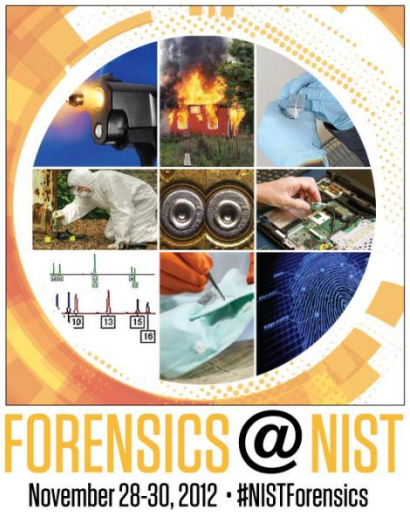


Trace Evidence Measurement Science & Standards Research at NIST

Eric Steel (eric.steel@nist.gov)

Greg Gillen (j.gillen@nist.gov)

Material Measurement Laboratory

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

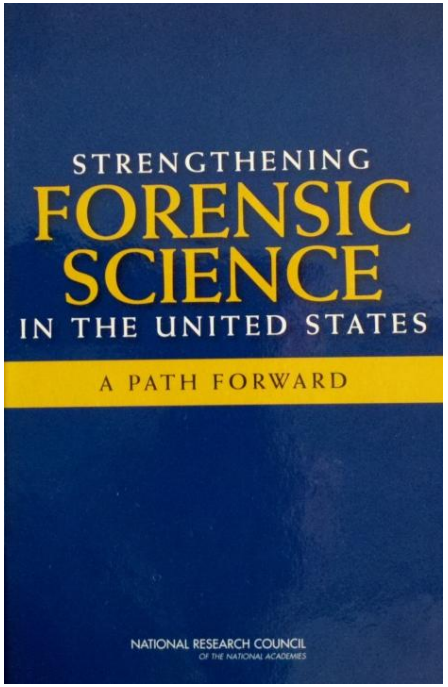
What is this talk about?

- Why are we here?
- Why NIST is working in this field?
  - What NIST can do for the forensic science community (and does not do)
- The Standards process and NIST
- Analytical uncertainty
  - One of NIST's strengths
- NIST and trace evidence

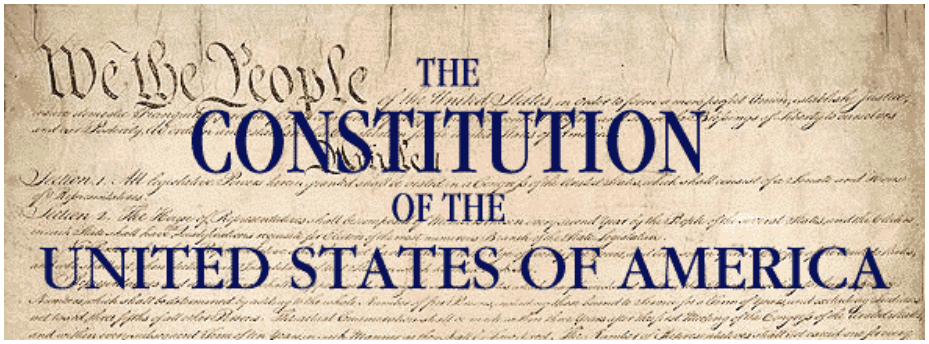
Why we are here? NRC Study

Strengthening Forensic Science in the United States: A Path Forward (2009)

- Long Term, Broad Issues Highlighted by NAS
  - Trust
  - Validity
  - Reliability
- Commented on
  - Need for Standardization, Certification, and Accreditation
    - NIST: Conformity Assessment
  - Problems Relating to the Interpretation of Forensic Evidence
    - NIST: Measurement services – reference materials & data
  - Need for Research to Establish Limits and Measures of Performance
    - NIST: Measurement Science and Uncertainty Analysis
  - Problems Relating to the Broad Range of Forensic Science Disciplines
    - Breadth of NIST measurement expertise



Why NIST?



Article I, Section 8: "The Congress shall have the power to…*fix the standard of weights and measures*"

For Commerce, Regulations, and Forensics… places where quantity or quality of a technology is critical to the nation

- to develop a fundamental basis and methods for testing materials, …
- to assure the compatibility of United States national measurement standards with those of other nations
- to advise government and industry on scientific and technical problems
- to compare standards used in scientific investigations, … and to coordinate the use by Federal agencies of private sector standards
- to coordinate Federal, State, and local technical standards activities and conformity assessment activities …

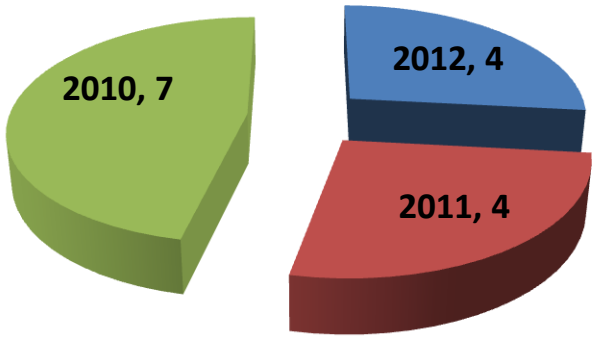
What does NIST offer the Forensic Community?

- ✓ Independence
  - ✓ Outside of the U.S. adversarial legal system
    - ~~× case work~~
    - ~~× court testimony~~
  - ✓ Nonregulatory
- ✓ Interagency coordination of standards
- ✓ Broad and Deep Expertise
  - ✓ Measurement Science
    - ✓ Validity testing, Traceability, Uncertainty Characterization, Measurement Innovation
  - ✓ Quality systems
  - ✓ Standards
- ✓ Facilities
  - ✓ Chemical, Materials, and Physical Properties Measurement
- ✓ Services
  - ✓ Standards
    - ✓ Key Reference Materials
    - ✓ Key Calibrations
    - ✓ Key Reference Data
    - ~~× ALL reference materials/data/calibrations~~
  - ✓ Measurement & Standards Research
  - ✓ Documentary Standards, Research Publications, Guides to Practice, …

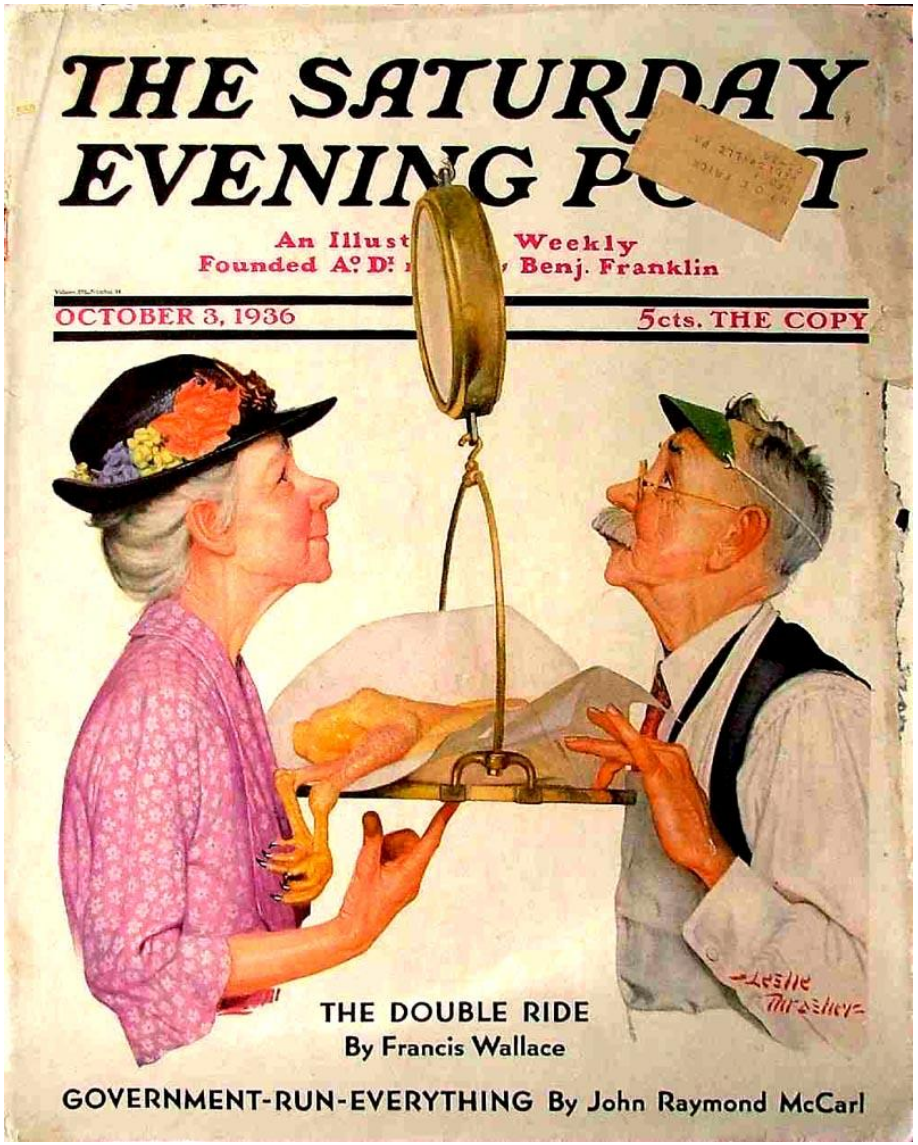
NIST: Basic Stats and Facts

- **Major assets**
  - ~ 3,000 employees
  - ~ 2,800 associates and facilities users
  - ~ 1,600 field staff in partner organizations (Manufacturing Extension Partnership)
  - Locations: Gaithersburg, Md. and Boulder, Co.
  - Four external collaborative institutes: basic physics, biotech, quantum, and marine science

FY 2012 Appropriations $750.8 M



Forensic Science Agencies and NIST have a symbol in common



Standards

- Flag
- Ethical/Moral
- Level of performance
- Regulatory
- Written rules of practice
  - Documentary
- Authoritative basis for comparison or use
  - Physical reference
  - Known information

- NIST:
  - Documentary Standards
    - Via Standards Developing Organizations (ASTM Int., ISO, IEC, IEEE, …)
  - Physical Standards
    - Reference Materials
    - Reference Data
    - Calibration Services

Examples of NIST Knowledge Transfer & Traceability

- **Collaborations**
- ~ 2800 Associates and Facility Users
- ~100 CRADAs/year
- **Measurement Research**
- ~ 2,200 publications per year
- ~ 8,000 attendees at >60 technical workshops/conferences
- Training symposia
- **Standard Reference Data**
- ~ 100 different types
- ~ 6,000 units sold per year
- ~ 25 million data downloads per year
- **Standard Reference Materials**
- ~ 1,300 products available
- ~ 30,000 units sold per year
- **Patents and Inventions**
- ~ 10-50/year
- **Baldrige National Quality Program**
- 99 Award recipients
- **Manufacturing Extension Partnership**
- ~28,000 Clients

- **Calibration Tests**
- ~ 18,000 tests per year
- **Laboratory Accreditation**
- ~ 800 accreditations of testing and calibrations laboratories per year
- **Standards Committees**
- ~ 400 NIST staff serving on 1,000 national and international standards committees
- **Other Agency R&D**
- Agreements with ~80 Fed. Agencies
- ~$100M/year

NIST Forensic Activities

- **DNA Profiling**
  - NIST Human Identity Project Team
  - Standard Materials for DNA profiling
  - Short Tandem Repeat Database and Research
- **Fingerprint Analysis**
  - Fingerprint Research and Standards
- **Firearms, Toolmarks, and Impressions-**
  - Standard Bullets and Casings
- **Digital and multimedia analysis**
  - Computer Forensics Tools Testing (CFTT)
  - National Software Reference Library (NSRL)
  - Real Time Forensics Analysis for Analog and Digital Video Tapes
  - Mugshots and Facial Recognition
  - Forensics for Mobile Phones and Devices
- **Forensic Toxicology**
  - Standard material for alcohol for blood testing
  - Standard material for alcohol for breath testing
  - Toxic metals in blood
  - Drugs of Abuse
- **Homeland Security Applications of Forensic Science**
  - Biodefense
  - Detecting trace explosives
  - Finding dirty bombs and other radiation threats
- **Questioned Documents**
  - Northern Softwood Pulp Paper
  - Eucalyptus Hardwood Pulp Paper
- **Trace Evidence**
  - Glass, Paint, and Coatings-
    - Commercial glass elemental composition standards
    - Trace elements in glass
    - Refractive index of glass
    - Lead in paint
  - Explosives/Fire Debris Evidence-
    - Standard Material for Additives in Smokeless Powder
    - Standard Material for Arson Investigation
    - Standard Material for Trace Particulate Explosives
  - Trace narcotics detection
  - Arson Investigation Research
  - Chemical Characterization Powders and Particulate Matter
- **Forensic Engineering**
  - Building and Fire Safety Investigation
- **Chemical Analysis**
  - Review of Advances in Analytical Chemical Methods for Forensics 2009

Our Measurement System: Timelines for Standards

Time

Increasing difficulty, decreasing uncertainty

Measurement Methods

- Research
- Draft protocol
- Interlaboratory Comparisons
- Guidelines
- Draft method
- Standard method
- Applied method
- Rewrite
- Accreditation, Certification, Conformity Assessment
- International Traceability, Interoperability, Recognition

Materials/Data/Calib

- Whatever you can get
- In-house stds
- Consensus stds
- Reference Materials/Data
- Certified materials/data
  - Calibration (pure/simple)
- Certified materials/data/calib
  - Quality Assurance (complex/matrix)
- Proficiency testing materials, data, algorithms, artifacts
- NMI comparisons

New or Low Use Technology

Mature or High Use Technology

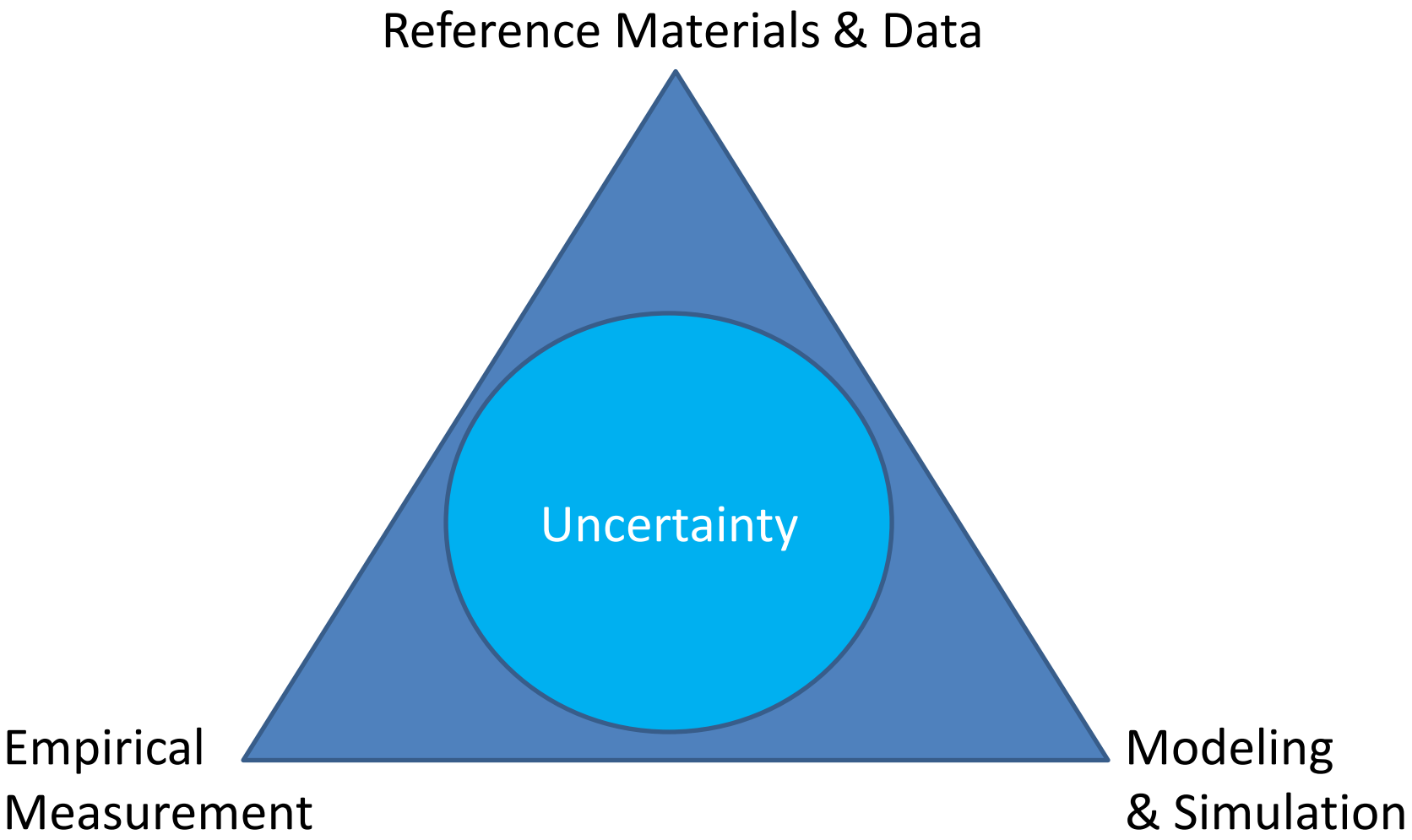
+ Performance Excellence & Innovation

Measurement Science

- How sure are you of your measurement result?
- Is it biased? … how close to “true” is it?
- How do you figure this out?

- **Uncertainty Determination**
  - NIST is the most uncertain place in the US!

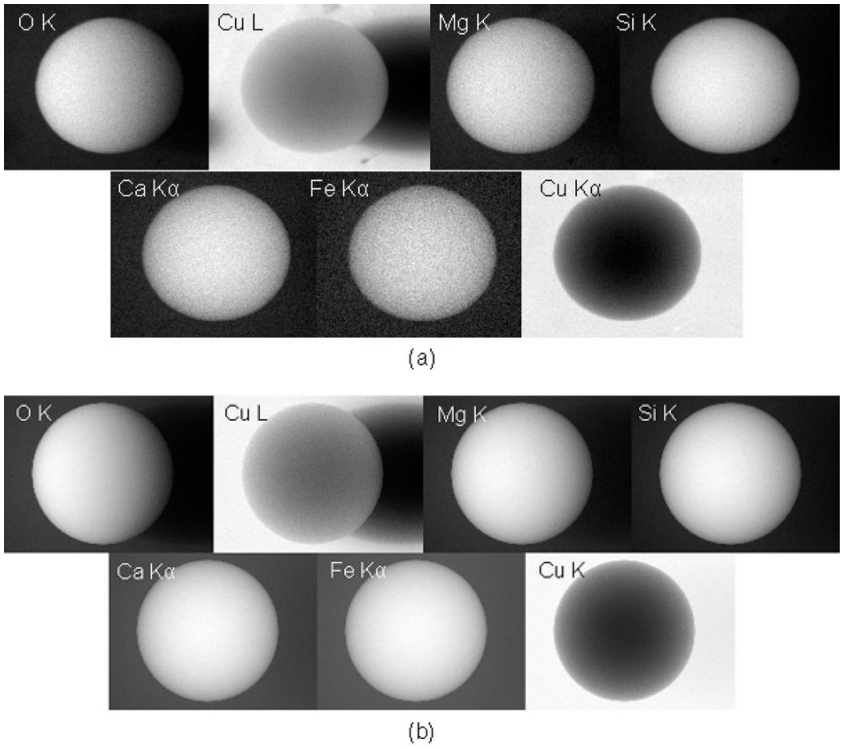
The Uncertainty Triangle



The Uncertainty Triangle

- SEM imaging and elemental analysis
  - Ref. Mat.: mineral-glass spheres of known composition
  - Ref. Data: x-ray generation physics, characteristic x-ray line energies
  - Simulation: Monte Carlo of electron, x-ray interactions in solids
  - SEM x-ray spectrum image measurement
- Understand and quantify estimate of uncertainty for elemental analysis in inorganic particle, thin film, and bulk specimens

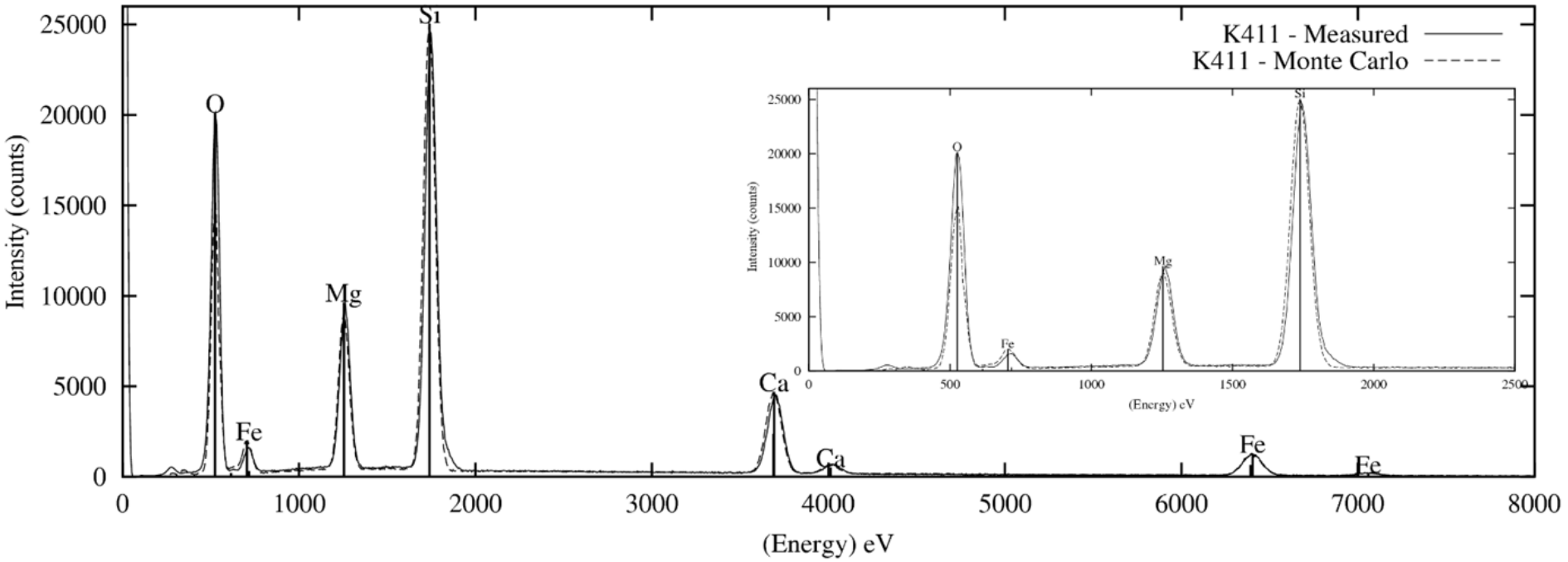
Measured



Calculated

Nicholas W.M. Ritchie, Microsc Microanal, 16, pp 248-258, 2010

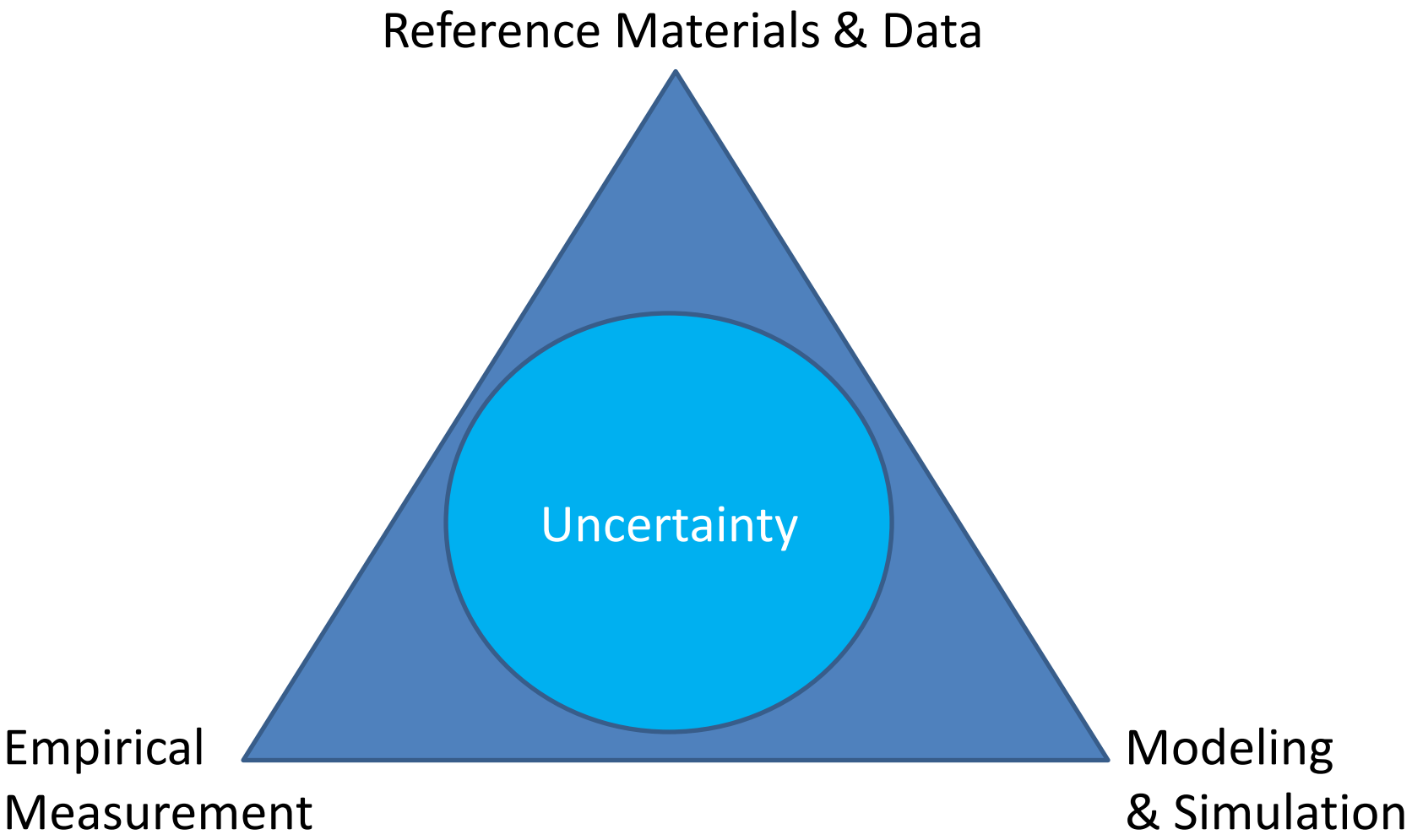
The Uncertainty Triangle



Collected and calculated spectrum from sphere

Nicholas W.M. Ritchie, Microsc Microanal, 16, pp 248-258, 2010

The Uncertainty Triangle



Trace Evidence

- Broadest area in Forensic Science
  - Encyclopedic
- Often do not know what type of clue to look for or what you will find
- Makes sampling, analysis, and interpretation very difficult
- But, sometimes it is the only physical evidence

Roles of NIST in Trace Evidence

- Measurement Science
- Standards
- Technology

- **BUT** NIST is a small agency with a large and broad measurement and standards mandate
- What does the forensic community need?
  - How important? How useful? How common a need?

- Trace Sampling
- Standard Test Materials
  - Reference Materials
  - Reference Data
  - Calibration
- Operational Protocols
  - Documentary Standards
- Technique Development for Trace Evidence
  - Advanced technologies
- Data analysis
  - Statistical analysis
  - Uncertainty determination

Trace Analysis: Three Distinct Functions

- Crime Scene Investigation
  - Sampling, evidence collection & tracking, documentation
- Materials Analysis:
  - Uncertainty, accuracy, precision, sensitivity, selectivity, … of *technique or analytical approach*
  - Reliability, trust, quality control, chain of custody, … of an *individual result*
- Interpretation:
  - Significance of results
    - How well does the analytical result identify a perpetrator or explain a crime
    - Uncertainty of this interpretation

Sampling

- Crime Scene/Suspect/Reference
  - Searching for/collecting one analyte
    - Is there Anthrax? Drugs? Blood?...
  - Sampling for unknown component(s)/analyte(s)
    - Is there something added to the scene by the criminal, the victim, or the criminal activity?
  - Sampling for normal (background/reference)
    - Becomes more important as techniques become more sensitive
  - Sampling the sampler/process (blanks)

Materials Analysis

- Measurement Expertise:
  - Morphologic, Molecular, Elemental, Isotopic, Crystallographic, Physical properties, …
  - Comparison techniques
    - One or more of above
  - Sample state:
    - Liquid, Vapor, Solid
    - Particles: single to populations
  - Imaging by composition or physical property
    - Spatial resolution from cm to nm
    - 1D, 2D, 3D
  - Most chromatographies, spectroscopies and microscopies:
    - GC, LC, UV-Vis, Mass, Raman, IR, X-ray, XPS, Electron, Auger, Ion Mobility, Gamma, Alpha, Beta, Neutron…
- Characterization of Accuracy, Sensitivity, Specificity, Precision, Repeatability, Reproducibility, Validation
- Statistical Analysis and Uncertainty Determination

Validating Analytical Approaches

- Accuracy & Precision
  - Qualitative:
    - Sensitivity
      - Sufficient analyte sample and concentration
    - Selectivity
      - Matrix and interference issues
  - Quantitative
    - All Qualitative items
    - Calibration
    - Matrix Effects
  - Repeatability & Reproducibility
- Quantifying comparison between crime scene and suspect evidence
- Quality Control
  - Blind repeats, inter-operator, inter-lab, proficiency test

Interpretation

The hardest part for trace evidence?

- Significance of results
  - How well does the analytical result identify a perpetrator(s) or explain a crime
  - Uncertainty of this interpretation

- Unique/Ubiquitous nature of single or combinations of components and characteristics
  - Bullet lead, hair, …
  - Change over time
    - Glass: refractive index, elemental composition, other

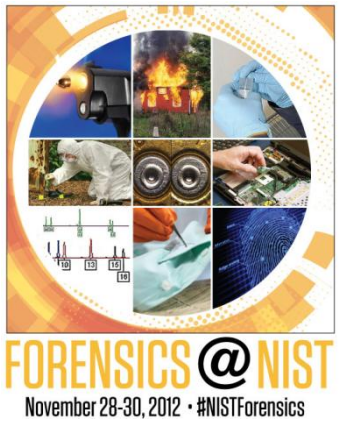
- Existence of data on frequency and locations of occurrence

Roles of NIST in Trace Evidence

- Measurement Science
- Standards
- Technology

- Trace Sampling
- Standard Test Materials
  - Reference Materials
  - Reference Data
- Operational Protocols
  - Documentary Standards & Guides
- Technique Development for Trace Evidence
  - Advanced technologies
- Data analysis
  - Statistical analysis
  - Uncertainty determination

Trace Evidence

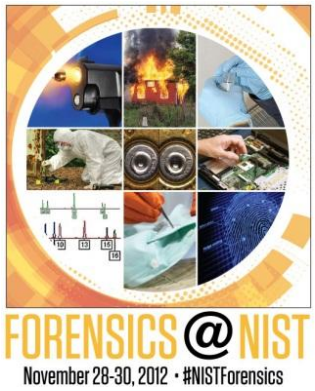


- Very Broad Application Space
  - Can use hundreds of our products
- NIST is always prioritizing, replacing and creating new products
  - What products do you need for trace applications?

- Will ask later … keep question in mind all day.

Forensic Science: A NIST Priority

- Develop, critically evaluate, and publish **new reference methods and technologies** for understanding crime scenes and identifying criminals.
- **Test and measure the uncertainty**, including such factors as bias, precision, and human errors, in existing forensic methods.
- **Improve the accuracy, reliability, and interoperability of forensic methods and data** through research in underlying science, rigorous testing, and methods for assessing conformance to standards.



- **Develop calibration systems, reference materials and databases, and technology test beds** for reliable and accurate forensic practice.
- Work with national and international standards developing organizations, academia, instrument manufacturers, database creators and disseminators, and the forensic science user communities to **encourage adoption of scientifically rigorous and well-characterized methods and practices.**
- **Create rigorous training programs** to facilitate basic understanding of underlying metrology **in applied forensic procedures and methods**

Trace evidence talks

Trace Sampling

9:30-9:50 Enabling Forensics Investigations of Biothreat Incidents through Sampling Standards – Jayne Morrow, Biochemical Science Division, MML

9:50-10:10 Surface Wipe Sampling for Trace Narcotics and Explosives Collection – Jennifer R. Verkouteren, Surface and Microanalysis Science Division, MML

10:10-10:30 Aerodynamic Sampling – Matthew E. Staymates, Surface & Microanalysis Science Division, MML

10:30-10:50 Break and Poster Viewing/Exhibitor Displays

Standard Test Materials/Operational Protocols

10:50-11:10 Production of Seized Drug Analysis Standards by Inkjet Printing– Jeanita S. Pritchett, Analytical Chemistry Division, MML

11:10-11:30 Nuclear Forensics Reference Materials – Kenneth G. W. Inn, Radiation & Biomolecular Physics Division, PML

11:30-11:50 Following the Scent – Development of Canine Training Aids – William A. MacCrehan, Analytical Chemistry Division, MML

11:50-12:10 Performance Validation for Trace – R. Mike Verkouteren, PhD, Microanalysis Science Division, MML

12:10-12:30 NIST Trace Explosives Test Bed – Marcela Najarro, Materials Measurement Science Division, MML

12:30-12:50 Mass Spec Reference Libraries for Forensics: Past, Present and Future – Steve E. Stein, Biomolecular Measurement Division, MML

12:50-2:20 Lunch and Poster Viewing/Exhibitor Displays/Deployable Laboratory/Mobile Decontamination Vehicle (Hands-on Biothreat Response and Sample Collection Demo)

Technique Development for Trace Evidence

2:20-2:40 Automated Particle Analysis – Nicholas W. M. Ritchie, Materials Measurement Science Division, MML

2:40-3:00 Combined IMS and Biometrics – Jessica L. Staymates, Surface and Microanalysis Science Division, MML

3:00-3:20 Atmospheric Pressure MS – Tim M. Brewer, Surface and Microanalysis Science Division, MML

3:20-3:40 Improvements in Trace Involatile Vapor Analysis – Tom J. Bruno, Applied Chemicals and Materials Division, MML

3:40-4:00 Unified Organic, Inorganic, and Morphological Analysis of Forensic Samples via SEM-based, High-Resolution X-ray Spectroscopy – W. B. Doriese, Quantum Electronics and Photonics Division, PML

4:00-5:00 Optional Open House and Trace Analysis Lab Tours of NIST Facilities

4:00-5:00 Poster Viewing/Exhibitor Displays

Posters

- Ethanol in Water Standard Reference Materials to Support Forensic Testing, Michele M. Schantz, Analytical Chemistry Division
- Towards Improvement of Trace Detector Screening for the Analysis of Illicit Drugs, L.T. Demoranville, J.R. Verkouteren, G. Gillen
- Nano Particle Generation from Heated Explosives, Robert Fletcher, Marcela Najarro, Tim Brewer, Matthew Staymates and Greg Gillen
- Techniques for the Production of Standard Explosive Test Particles, Matthew Staymates, Michael Verkouteren, Jessica Staymates, Robert Fletcher, Tim M. Brewer, and Greg Gillen
- Analysis of Trace Quantities of Explosive Materials Using Laser Diode Thermal Desorption-Atmospheric Pressure Chemical Ionization-Tandem Mass Spectrometry, Eric Windsor
- Forensic Applications of DART MS, Ed Sisco, USACIL/NIST
- Electrostatic Effects in Swipe Sampling, R. Fletcher, NIST
- Age Dating of Fingerprints, Ed Sisco
- Forensic Analysis Methodology and Database of Statistically Combined HME Thermal, Mass, and Spectral Signatures, Ashot Nazarian
- Surrogate Controls for Confidence in Field Measurements, Vang
- HPLC for Quant of Explosives and Narcotics Standards, Tim Brewer
- SRMS for Trace Explosives, Bill MacCrehan
- Inkjet Printing for Trace Detection Standards, Greg Gillen
- Micro CT Scanning of Explosives, Greg Gillen
- Confocal Raman of Single Particles, Chris Michaels
- Fundamental Measurements for Trace Detection of Energetic Materials and Fire Debris, Tara M. Lovestead, Jason A. Widegren, Samuel Allen, and Thomas J. Bruno
- Reproducible Dynamic Vapor-Time Profiles of Explosives and Nonexplosive Canine Training Aids, Bill MacCrehan, Michele Schantz, Stephanie Moore; Chemical Sciences Division
- Optimization of Negative Chemical Ionization Mass Spectrometry for Explosives for Two Gas Chromatographic/Mass Spectrometric Instruments from Different Manufacturers, Bruce A, Benner, Jr. and Marcela Najarro

NIST Research Example Focus Areas

TebNad

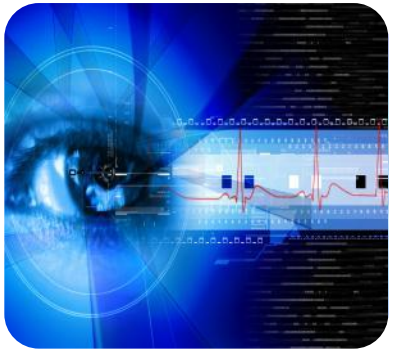
Energy

Y. Arcurs

Healthcare

S.Bonk

Environment



designersart

Information Technology and Cybersecurity

Fotocrisis

Manufacturing

Jovan Nikolic

Physical Infrastructure

All photos courtesy Shutterstock.com