nanoEHS

MEL innovation & productivity
Precision Engineering Division

Nanomaterials and the Environment & Instrumentation, Metrology, and Analytical Methods

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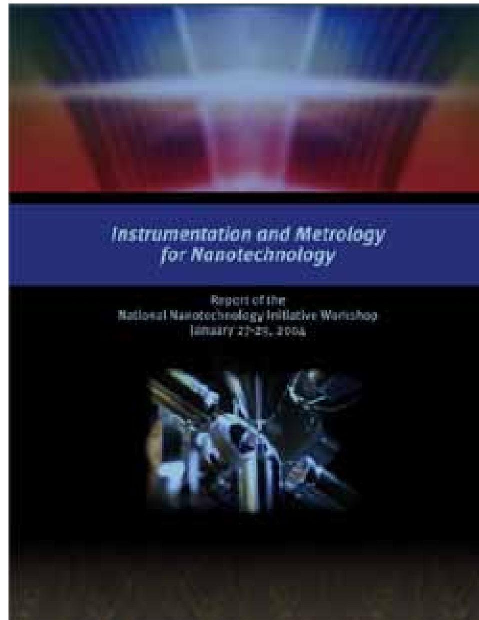
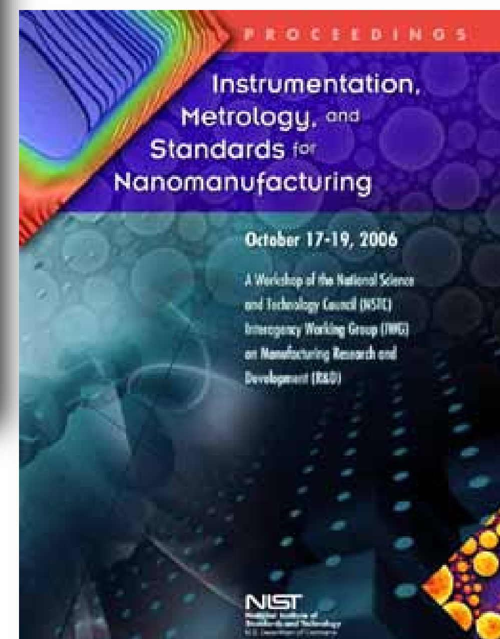
- **National Institute of Standards is the National Measurement Laboratory**
  - **Precision Engineering Division has the responsibility of length measurement and traceability to the International System of Units (SI) – meter.**
  - **Responsibility extends over 12 orders of magnitude from kilometers to nanometers**
- **Subject matter expert comments are for measurement of length – size and dimensionality**
  - **Infrastructural measurements**
  - **Many of the comments can be broadly applied.**

- **Two previous NNI Workshops spoke directly to the instrumentation, metrology and analytical methods needed to broadly measure nanomaterials.**





Earlier Workshops

- **Much of the measurement infrastructure currently available for nanoparticle metrology good and getting better but, progress is only incremental in nature:**
  - Optics
  - Transmission Electron Microscope
  - Scanning Probe Microscope
  - Scanning Electron Microscope

- **Automated, operator-independent instrumentation adapted to nanomanufacturing must be developed and is indispensable to future manufacturing**
- **New, potentially revolutionary metrology and measurement tools are needed for many applications**
  - Helium Ion Microscope

- **Over the past 20+ years, the semiconductor industry has been the main financial and technical driver for revolutionary advances in many areas of micro and nanomanufacturing systems and processes.**
  - **Resulted in smaller, faster and less expensive devices.**
    - **Common to go to the computer store and obtain microprocessors with 45 nanometer and smaller technology**
- **We should look to that industry for a successful model for development of the needed infrastructural instrumentation for measurement of small structures – nanomaterials in the environment**

The evolution of microelectronics to nanoelectronics, following Moore's Law, has been facilitated through:

- Industrial consortia such as SEMATECH
- The Semiconductor Industry Association (SIA)
- SEMI
- International Technology Roadmap for Semiconductors (ITRS)

ITRS   SIA SEMICONDUCTOR INDUSTRY ASSOCIATION   SEMATECH Accelerating the next technology revolution.   semi

- **NNI Workshops concluded that**
  - **A coordinating consortium-type organization (or organizations) could make huge strides in the development of needed instrumentation and metrology**
    - **Reduce duplication of effort**
    - **Focus resources**
  - **Nanotechnological commonalities of need in instrumentation, metrology and standards must be identified and a focus must be developed**
    - **Act as the focal point for any road mapping exercises.**
- **The "Bible" of the semiconductor industry has been the International Technology Roadmap for Semiconductors**

- **The ITRS has successfully guided:**
  - General technology development
  - Instrument manufacturers guidance to provide the needed tools with reasonable lead time.
- **Demanding industry that has continually pushed the capabilities to measure small structures**
  - Were able to do this because of the wealth of the industry
- **Instrument development associated with the semiconductor manufacturing industry was/is an evolutionary process**
  - Fueled by the defined needs of the ITRS and funded by the established semiconductor industry.
- **Instruments for measurement of nanomaterials especially those in the environment (nanoparticles) will likely follow a similar path**
  - But, the manufacturers need credible guidance in order to risk investment
- **Today, the emerging nanomanufacturing industry does not have sufficiently deep pockets to fund similar high risk instrument development.**
  - Potentially creates a significant funding gap leading to an impending technology gap.

Accuracy vs. Precision

- Most instruments can demonstrate a high degree of precision, but are they accurate?
- Size matters where nanotechnology is concerned
  - Knowing dimension with a known uncertainty is primary to understanding the function of nanomaterials
  - Measurements rely on instrument response functions – varies substantially between instruments
  - Often more complex than realized and is why different instruments give different measurements
    - Scanning electron microscope – electron beam interactions dominate
- Many of the databases currently under development are incorporating data from multiple sources.
  - Are these sources accurate in the generation of these data?
  - Nanomaterial database development relies on the quality and consistency of the data submitted.
  - In order to describe the properties of a nanomaterial, accurate measurement infrastructure is needed and adopted so that these data are valid and useful.
  - Data is being generated for:
    - Nano-risk Framework (DuPont and Environmental Defense Fund),
    - NIH NanoHealth Initiative,
    - EPA – Nanoscale Materials Stewardship Program and others
- Interlaboratory studies having well defined measurement procedures using accurate samples are critical to achieving confidence in the overall data.

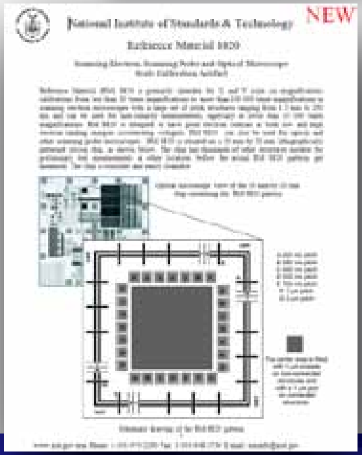
Accuracy vs. Precision

- **The need for accurate measurements is greater than ever because there is so little tolerance for error**
  - **Accuracy is telling the truth (within some measurement uncertainty)**
  - **If accuracy is not assured precision is telling the same lie over and over again.**
- **The need for clear, concise standardized assessment of shape and surface area requires much attention**
  - **Consistent measurement algorithms**

Accuracy vs. Precision

- **NIST is working with the other agencies, industry and academia to develop the needed metrology and standards. For example:**
  - **NIST/FDA/NCI**
    - **Three gold nanoparticle standards (RM 8011, RM 8012, and RM 8013)**
    - **(others in the pipeline)**
  - **NIST/NIOSH/RJ Lee Associates**
    - **Carbon nanotube metrology**

- **NIST/SEMATECH**
  - **Accurate scanning electron microscope calibration standards**



- **Accurate standards require:**
  - **Quantity of high-quality relevant material**
  - **Homogeneous material**
  - **Needed metrology**
  - **Accurate measurement instrument**
  - **Determine the total uncertainty of the measurement**

- **In the real world materials do not always cooperate:**
  - **Carbon nanotube – two words for many different possible materials**
  - **At least 50 different CNT species have been identified**
  - **Only half of these species are semiconducting**
  - **Current manufacturing processes do not simply make one type of CNT**
    - **Inherently produce a mixture of CNT species along with 3-60%+ unwanted chemical impurities**
  - **Early studies have found that residual catalyst and other contaminants can make the material inhomogeneous.**

MWCNTs 270 tons/yr (245 000 kg/year)
SWCNTs 7 tons/yr (6 350 kg/year)
8 000 US$/kg to 500 000 US$/kg

http://www.wtec.org/cnm/

Modeling is Critical

- **With the large amount of potential nanoparticles and the nanoparticle combinations possible, predictive modeling will become crucial.**
  - **Workshop on Cross Industry Issues for Nanomanufacturing**
  - **Predicting exposure limits and effects**
- **Model development is only as good as the input data**
- **Data needs to be accurate so informed decisions can be made regarding the suitability of these materials as a commercial product, a component of a commercial product, or release into the environment are made on a strong *scientific* basis and not hype.**

Final Comments:

- ***If a nanomaterial cannot be measured it cannot be manufactured.***
- ***If a nanomaterial cannot be made safely it should not be manufactured.***
- ***If a nanomaterial cannot be measured how would you even know?***

...working with industry to foster innovation, trade, security and jobs


Thank you
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- **Instrumentation and Metrology for Nanotechnology http://www.nano.gov/NNI_Instrumentation_Metrology_rpt.pdf**
- **Instrumentation, Metrology and Standards for Nanomanufacturing http://www.manufacturing.gov**
- **Cross Industry Issues for Nanomanufacturing (in preparation)**

Back up slides

- NCI/NIST/FDA

Gold Nanoparticle Size Standard RM

RM 8011 - 10 nm
RM 8012 - 30 nm
RM 8013 - 60 nm

Report of Investigation available at:

http://ts.nist.gov/measurementservices/referencematerials/index.cfm

- **The NIST Manufacturing Engineering Laboratory (MEL) has been supporting nanomanufacturing through the development of programs for measurements and standards since about 1999.**
  - **MEL plays a leading role in developing Standard Reference Materials (SRM), metrology and measurement instrumentation.**
- **Semiconductor manufacturing has clearly benefitted and has demonstrated the value of this work**
- **RTI International Report estimates that for every $1 spent on measurement, the industry as a whole saw a $3.30 return.**
- **Metrology is and has proven to be value added.**

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Economic Impact of Measurement in the Semiconductor Industry

Final Report

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