

Metrology 101

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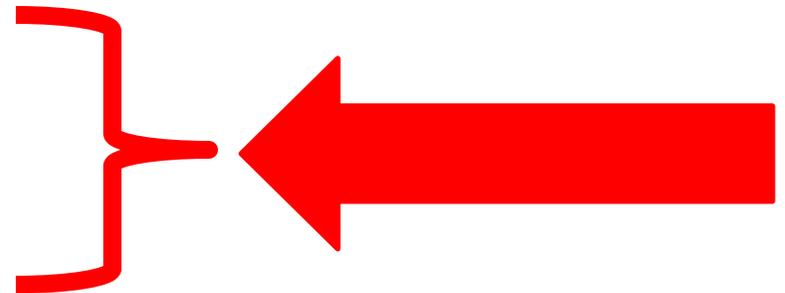




Metrology 101

Potential audience:

- NIST technical staff
- NIST administrative staff
- Congressional staff
- Fifth graders
- Congressional members
- NIST Day Care children





Some Definitions

- **Metrology** – science of measurement and its application
- **Accuracy** – closeness of agreement between a measured value and the true value (a concept, not a number)
- **Measurement error** – the difference between a measured value and a reference value
- **Precision** – closeness of agreement among replicate measured values
- **Measurement uncertainty** – an indication of the range about a measured value that we believe contains the true value*

* non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

Relationship of Metrology Concepts

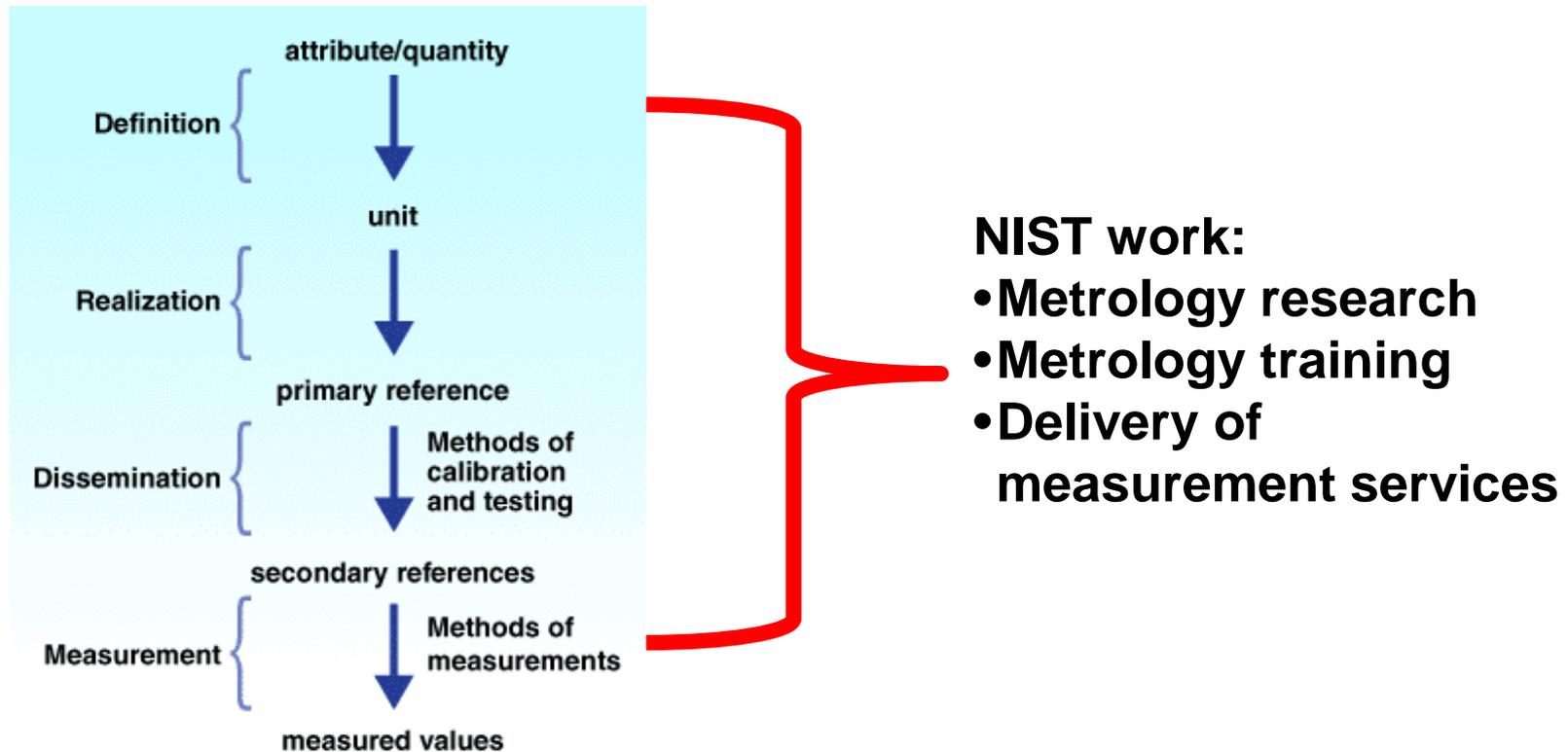


Figure 1 Logical relationship among metrology concepts for use in standardization in measurements.



Metrology Research

- New and/or better ways to measure things
 - More selective, more accurate or more precise

Primary Atomic Frequency Standards at NIST

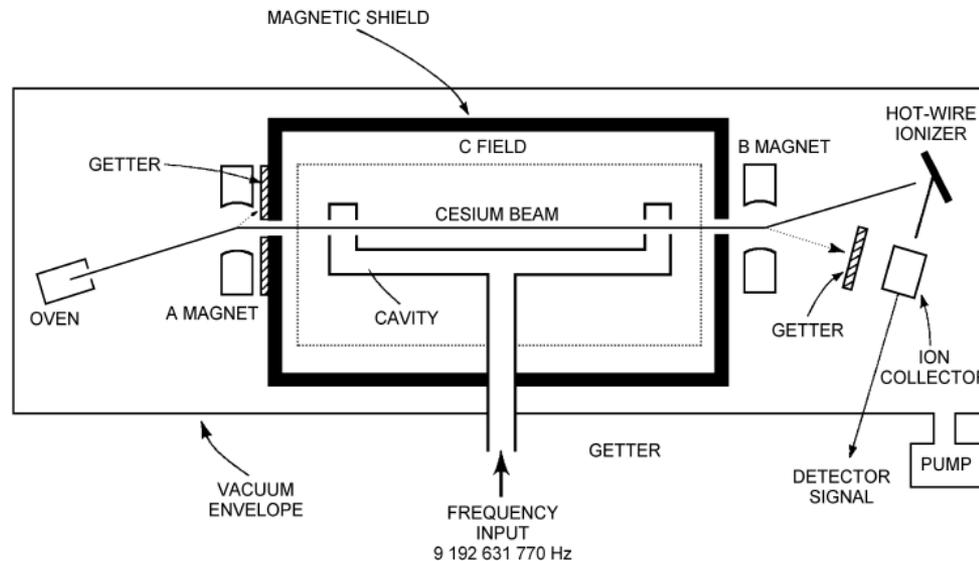


Fig. 1. Diagram of a cesium-beam frequency standard using magnetic state selection and detection. The form of Ramsey interrogation involves a U-shaped microwave cavity, called a Ramsey cavity, where the oscillatory fields are spatially separated.



Metrology Research

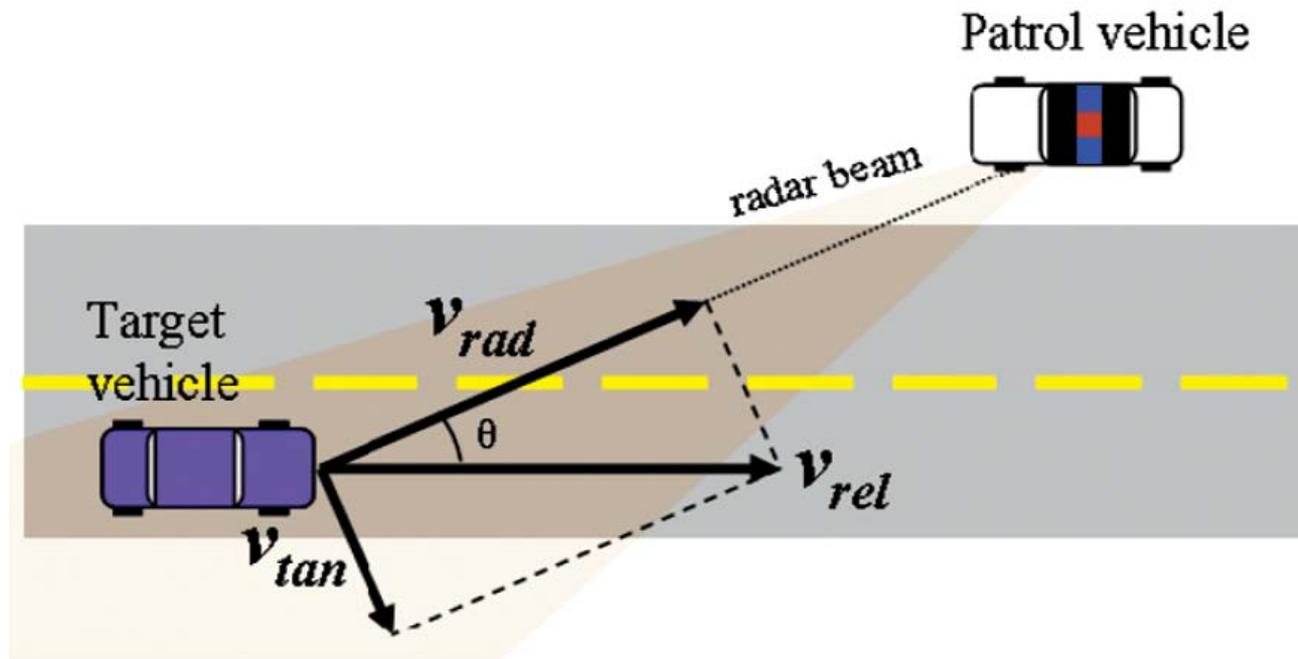
- New and/or better ways to measure things
 - More selective, more accurate or more precise
- Better characterizations of the sources of measurement uncertainty

Uncertainty and Dimensional Calibrations

1. Master Gage Calibration
2. Long Term Reproducibility
3. Thermal Expansion
 - a. Thermometer calibration
 - b. Coefficient of thermal expansion
 - c. Thermal gradients (internal, gage-gage, gage-scale)
4. Elastic Deformation - Probe contact deformation, compression of artifacts under their own weight
5. Scale Calibration
 - a. Uncertainty of artifact standards, linearity, fit routine
 - b. Scale thermal expansion, index of refraction correction
6. Instrument Geometry
 - a. Abbe offset and instrument geometry errors
 - b. Scale and gage alignment (cosine errors, obliquity, ...)
 - c. Gage support geometry (anvil flatness, block flatness, ...)
7. Artifact Effects
 - a. Flatness, parallelism, roundness, phase corrections on reflection

[J. Res. Natl. Inst. Stand. Technol. 114, 137-148 (2008)]

Calibration of Speed Enforcement Down-The-Road Radars





Metrology Research

- New and/or better ways to measure things
 - More selective, more accurate or more precise
- Better characterizations of the sources of measurement uncertainty
- **Better ways to estimate uncertainties**

Maximize

$$\begin{aligned}
 \min_{\sigma^2, \sigma_1^2, \dots, \sigma_p^2} RL &= \min_{\lambda, \sigma^2, \sigma_1^2, \dots, \sigma_p^2} \left[\sum_i \frac{(x_i - \bar{\mu})^2}{\lambda(\sigma^2 + \sigma_i^2)} + \sum_i \frac{v_i s_i^2}{\lambda \sigma_i^2} \right. \\
 &+ \log \left(\sum_i \frac{1}{\lambda(\sigma^2 + \sigma_i^2)} \right) + \sum_i \log(\lambda(\sigma^2 + \sigma_i^2)) \\
 &\left. + \sum_i v_i \log(\lambda \sigma_i^2) \right] \\
 \mathcal{L} &= \min_{\sigma^2, \sigma_1^2, \dots, \sigma_p^2} \left[\min_{\lambda} \left[\frac{1}{\lambda} \left(\sum_i \frac{(x_i - \bar{\mu})^2}{\sigma^2 + \sigma_i^2} + \sum_i \frac{v_i s_i^2}{\sigma_i^2} \right) \right. \right. \\
 &+ (n-1) \log \lambda \left. \right] + \log \left(\sum_i \frac{1}{\sigma^2 + \sigma_i^2} \right) + \sum_i \log(\sigma^2 + \sigma_i^2) \\
 &\left. + \sum_i v_i \log \sigma_i^2 \right] \\
 &= \min_{y_0, y_1, \dots, y_p} \left[(n-1) \log \left(\sum_i \frac{(x_i - \bar{\mu})^2}{y_0 + y_i} + \sum_i \frac{v_i s_i^2}{y_i} \right) \right. \\
 &+ \log \left(\sum_i \frac{1}{y_0 + y_i} \right) + \sum_i \log(y_0 + y_i) + \sum_i v_i \log y_i \left. \right] \\
 &+ n - 1 - (n-1) \log(n-1).
 \end{aligned}$$

(57)

subject to

n

$\geq S$

Relationship of Metrology Concepts

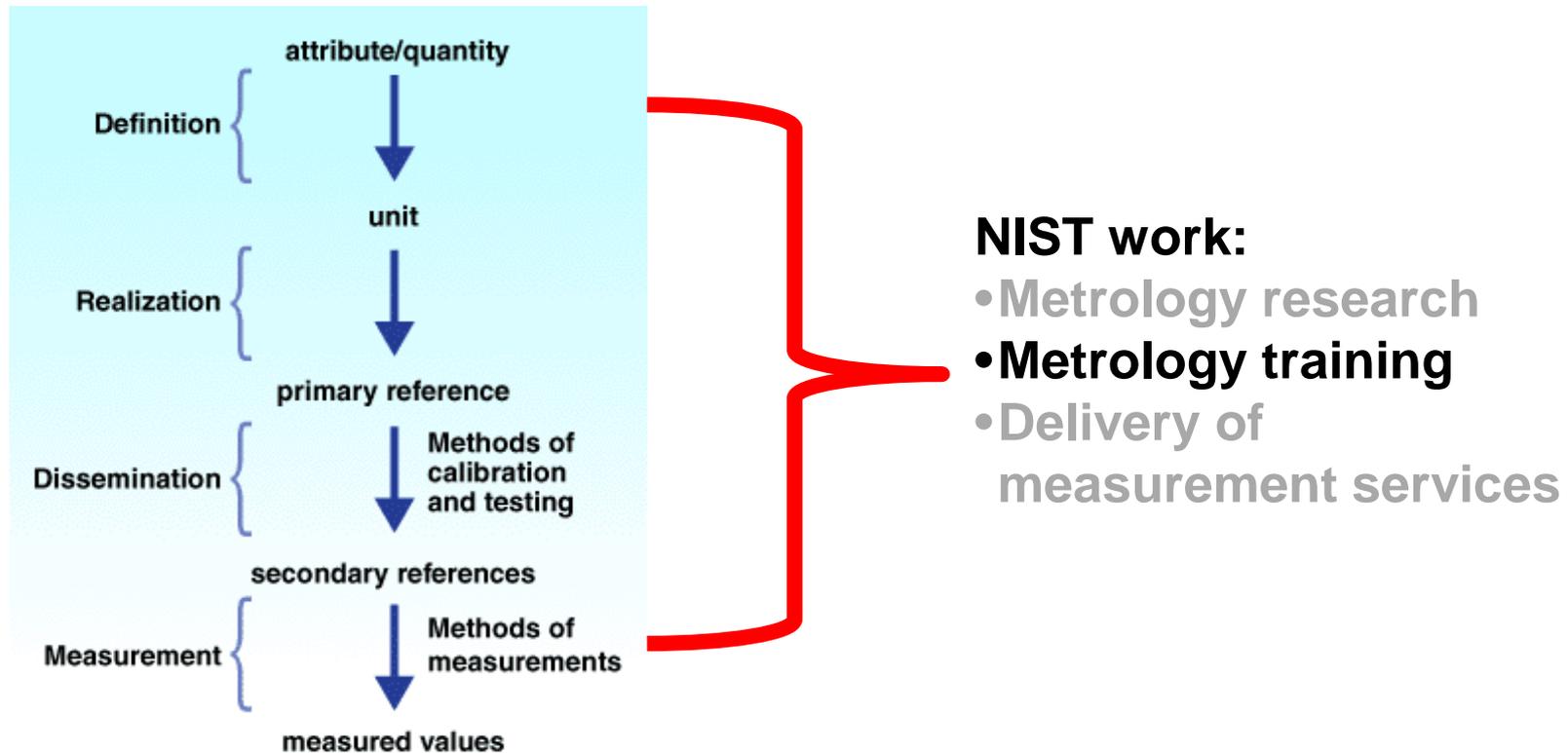
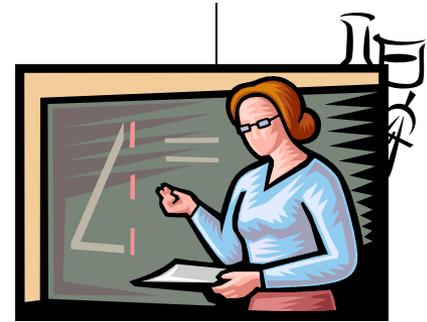


Figure 1 Logical relationship among metrology concepts for use in standardization in measurements.

Metrology Training



- Weights and Measures Enforcement
 - Specifications and Tolerances for Commercial Devices (Handbook 44)
 - Checking the Net Contents of Packaged Goods (Handbook 133)
 - Price Verification
- Laboratory/Metrology Seminars
 - Balance and scale metrology
 - Measurement Assurance Programs
 - Accreditation (NVLAP), Practical Measurement Assurance
- Specific metrology workshops
 - Microwave, antennas, and electrical
 - Pressure, flow, thermometry
 - Time and frequency
 - Dimensional
- Summer Programs for Students and Teachers
- User Facilities and Associated Instrumentation

60 classes

1000

students

Relationship of Metrology Concepts

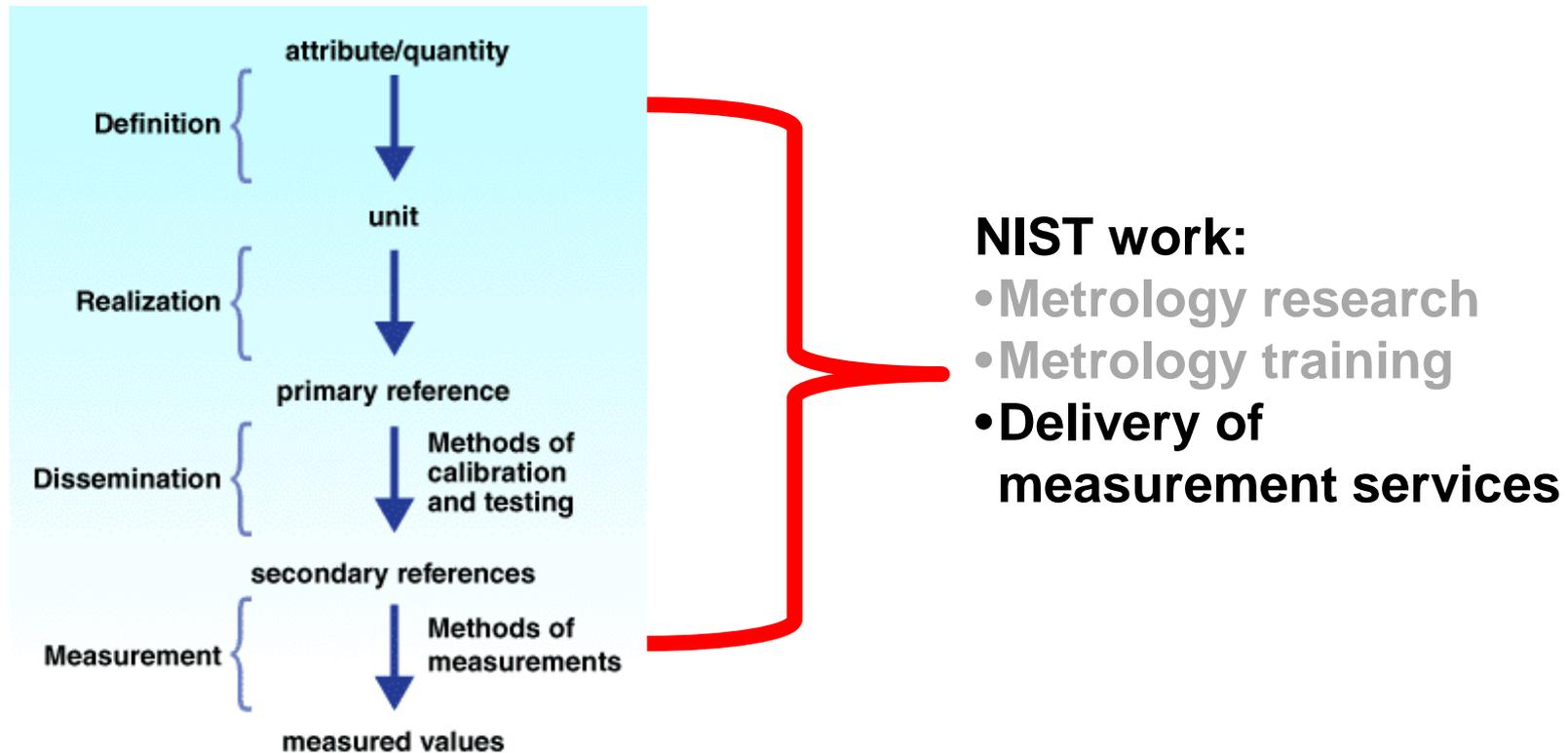
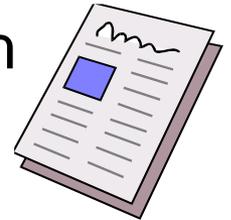


Figure 1 Logical relationship among metrology concepts for use in standardization in measurements.



NIST Measurement Services

- NIST does it:
 - Publications on measurement science research
 - Fee-supported services
 - Standard Reference Data
 - Calibration services
 - Standard Reference Materials
 - Laboratory accreditation services (NVLAP)
- DIY – *You can do it; we can help.*
 - Services for legal metrology labs
 - Metrology training
 - Measurement practice guides
 - User facilities (CNST and NCNR)





Measurement Comparability

... when measurements agree to within a level of uncertainty that is small enough to be useful.



- User community depends on comparability of measurements
 - Buyers – sellers
 - Contributors to characterization of complex or time-dependent systems
 - Regulatory conformance

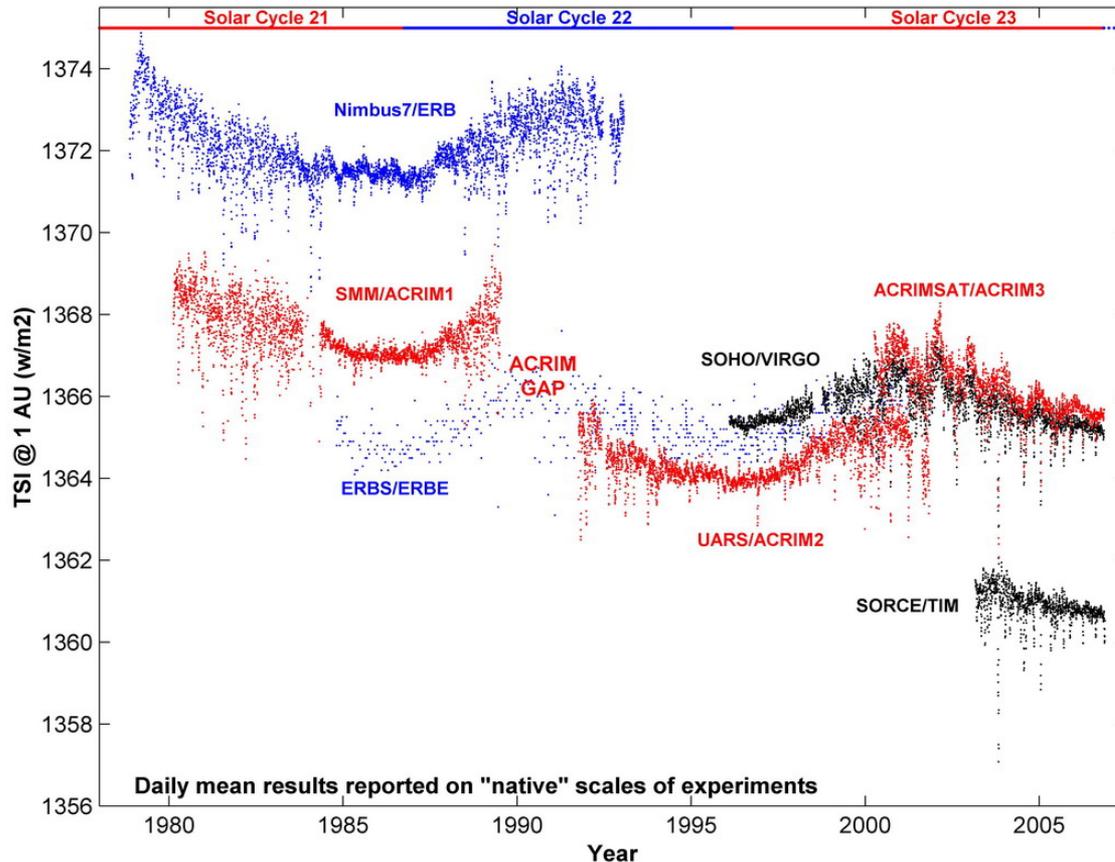
However, the state of measurement practice is challenged

- By current or future accuracy requirements
 - Primary calibrations and currently available voltmeters
- When comparability of measurement results is required among *all* stakeholders, and the stakeholder group is too large or diffuse

Total solar irradiance uncertainty requirements not met



TOTAL SOLAR IRRADIANCE MONITORING RESULTS: 1978 to Present



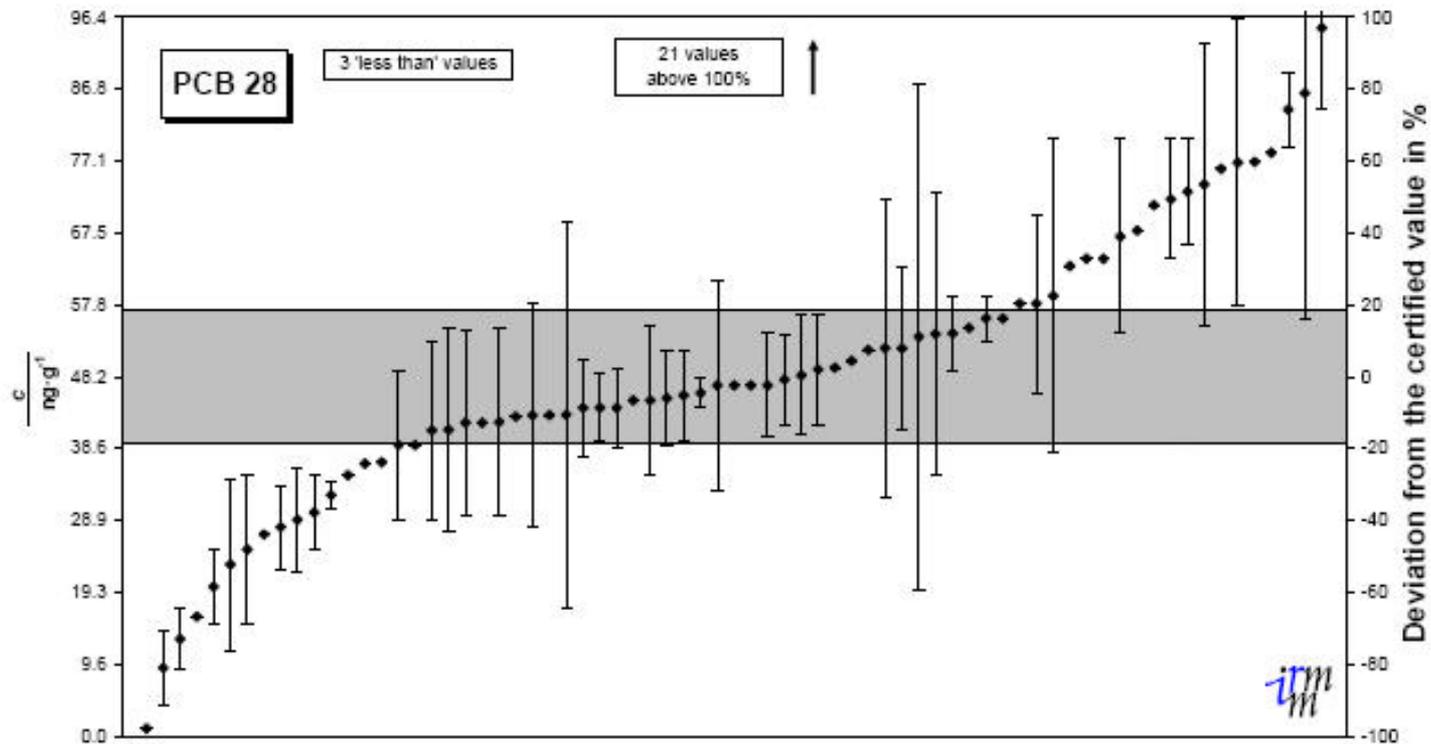
RC Willson, earth_obs_fig1 11/30/2006

**TSI
Measurement
Uncertainty
Requirement
 $\sim 0.2 \text{ W m}^{-2}$
decade⁻¹**

Comparability for PCB measurements does not exist



IMEP- 21: Trace elements, PCBs and PAHs in Sewage Sludge
Certified value for PCB 28 : $48.2 \pm 9 \text{ ng}\cdot\text{g}^{-1}$ [$U=k\cdot u_c$ ($k=2$)]

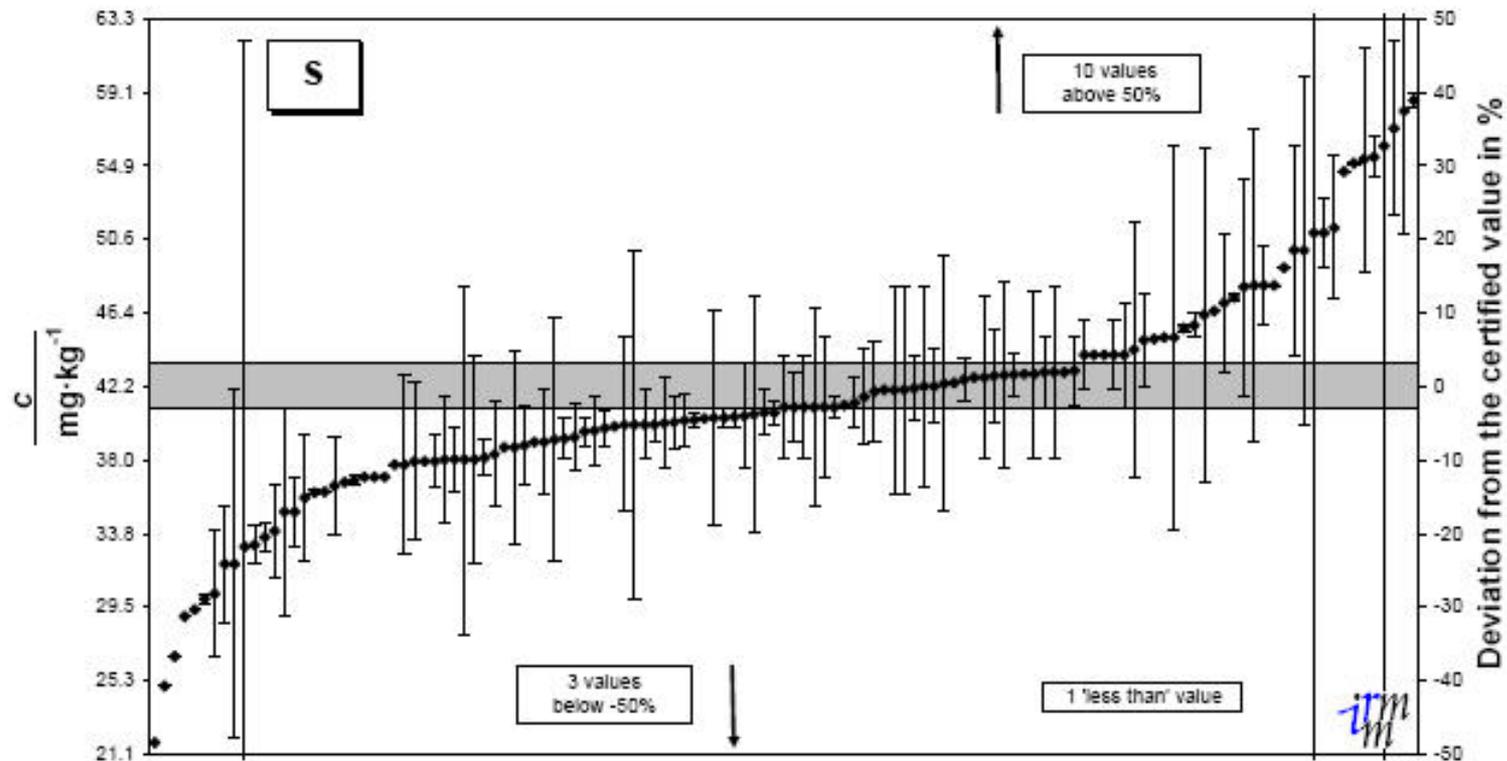


Results for PCB 28 from all participants

Measurement support for commodity pricing is lacking



IMEP- 18: Sulphur in diesel fuel
Certified value : $42.2 \pm 1.3 \text{ mg}\cdot\text{kg}^{-1}$ [$U=k\cdot u_c$ ($k=2$)]



Results from all participants



Comparability vs. Traceability

- Comparability through consensus
 - Can be achieved with a quality control standard
 - Cannot be extended beyond consensus base or beyond the life of the QCS
 - Subject to long-term drift
 - No anchor point





Comparability vs. Traceability

- Traceability
 - Achieved by the use of a realization of a base or derived unit of measurement
 - Introduces the concept of *accuracy*
 - Comparability based on a standard: SI Units or well-defined method-dependent unit
 - Extended beyond consensus group through realization of the SI
 - Anchored to ensure stability

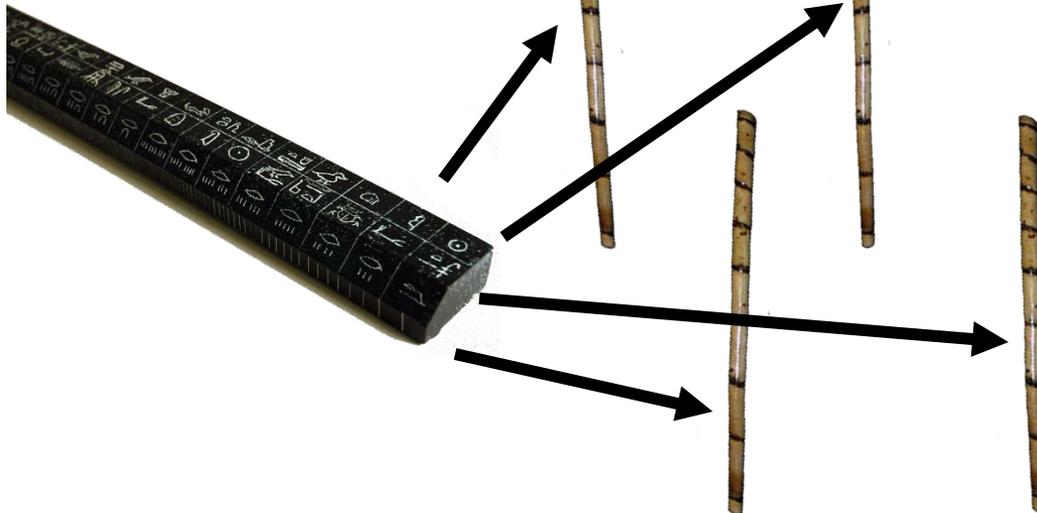


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Comparability Achieved through Traceability



OR...

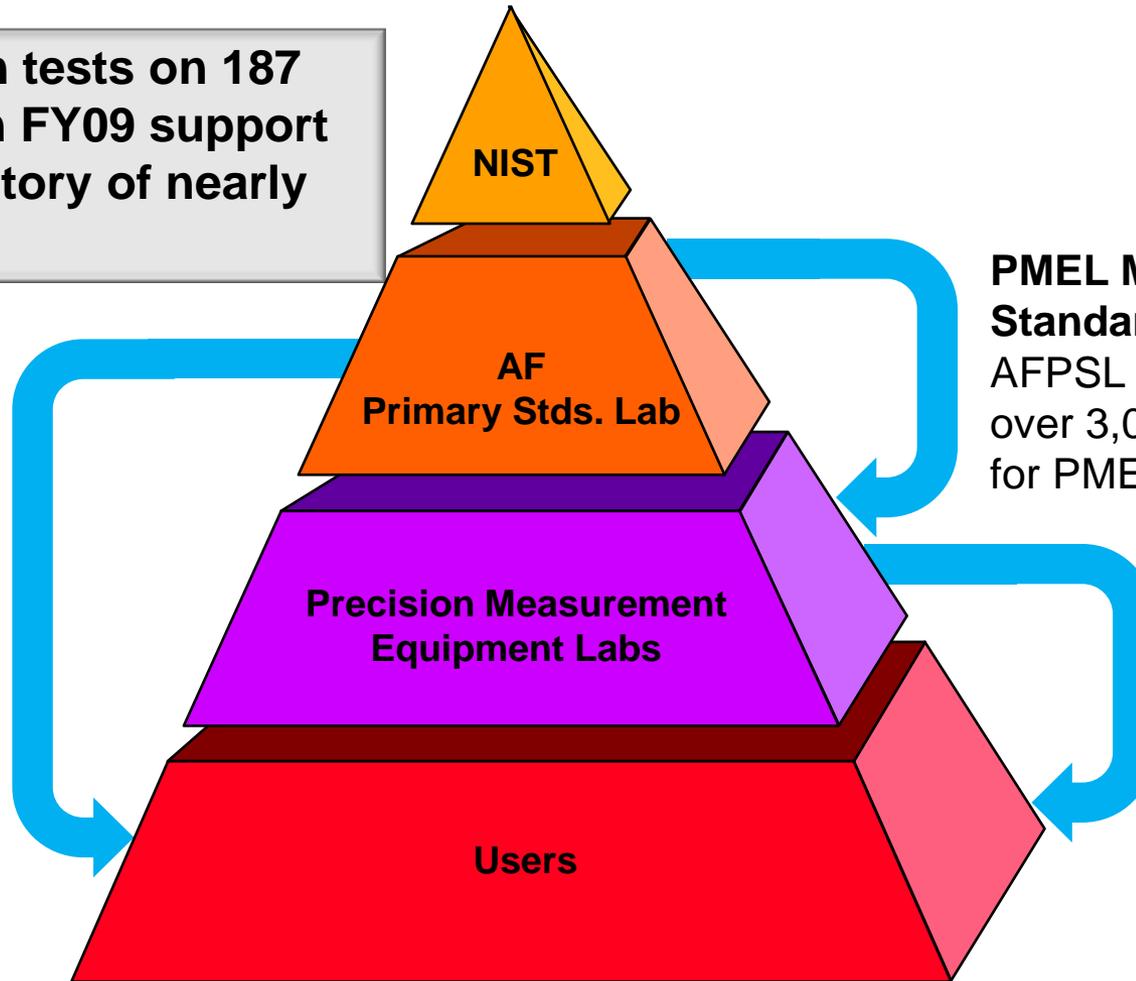


- Requires, wherever possible, an anchor point – a realization of an SI unit

AFMETCAL Calibrations



1238 calibration tests on 187 items at NIST in FY09 support a total AF inventory of nearly 700,000 items



PMEL Measurement Standards: The AFPSL calibrates over 3,000 annually for PMELs

End Items: The AFPSL calibrates over 20,000 end items annually for PMELs and Major Command Customers

End Items: The PMELs in turn calibrate over 400,000 end items annually for Major Command Customers

Metrology to Support Regulations and Trade Worldwide

