

**National Institute of Standards and Technology (NIST) Quantitative Imaging Initiatives**  
 Stephen Russek  
 Project Leader: Biomagnetic Imaging Standards, NIST, Boulder, CO

NIST Boulder

F2 time standard

NIST Gaithersburg

Josephson junction voltage standard

AAPM MO-C-12A-6 July 21, 2014

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**Outline**

- 1. Role of NIST**
- 2. NIST Medical Imaging Standards: what's new**
  - Ionizing radiation standards (Radiation Physics Division)
    - > CT / PET phantoms
  - Optical imaging standards
  - Computational standards (Information Technology Lab)
    - > Virtual/ numerical phantoms
- 3. MRI standards/ phantoms (Electromagnetics Division)**
  - NIST/SMRM MRI system phantom
  - NIST/USCF breast phantom
  - NIST/RSNA QIBA isotropic diffusion phantom ([Mike Boss](#) TU-C-12A-8 Tuesday 10:15AM)

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**NIST's Role in Quantitative Medical Imaging**  
*NIST is a National Metrology Institute: measurement & standards*

**We are good at:**

- Standard reference materials (SRMs)
- Standard reference artifacts (phantoms)
- Enabling traceability
- Establishment of "ground truth"
- Long term monitoring
- Measurement development/ basic metrology research

**Not good at:**

- Setting standards, most standards are consensus
- Phantom mass production
- Moving very fast

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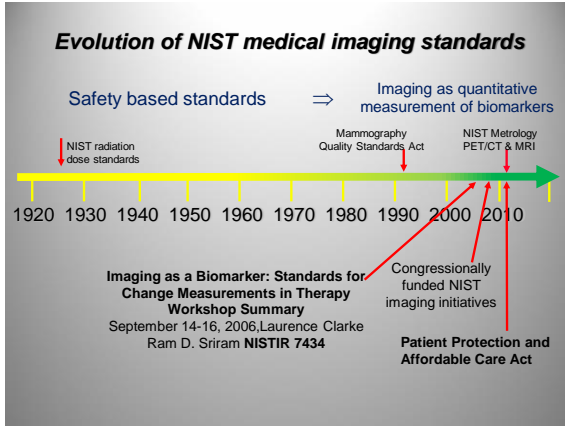
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### Metrology for Computed Tomography (CT)

- Calorimetry-based dosimetry (MO-E-17A-12)
- SRMs with calibrated attenuation coefficients
- Simple dimensional phantoms

Heather Chen-Mayer at the PET/CT scanner with HDPE phantoms.

SRM 2087 Dimensional Standard for Medical Computed Tomography

SRM 2088 Density Standard for Medical Computed Tomography

Z. H. Levine

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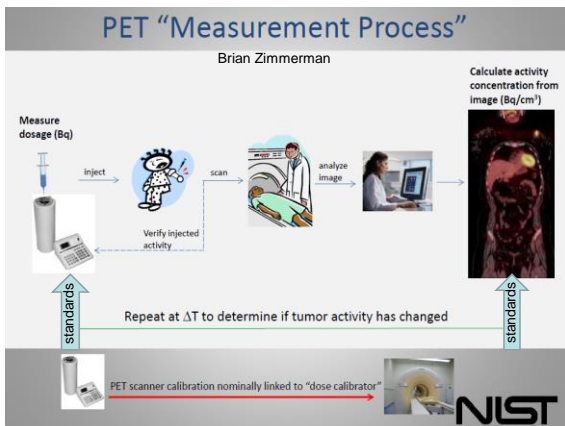
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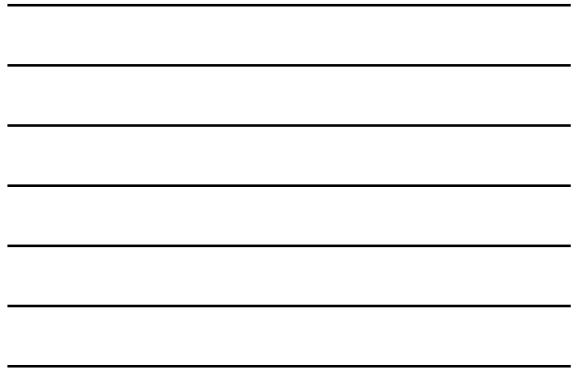
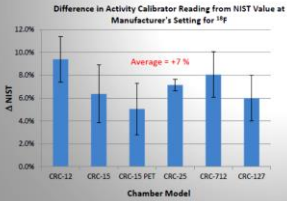
### Long-lived, traceable activity calibrator standards

Brian Zimmerman

- Developed by RadQual, LLC
- Calibration methodology developed by NIST in collaboration with RadQual
- Based on <sup>68</sup>Ge, calibrated for both <sup>68</sup>Ge and <sup>18</sup>F (equivalent activity)
- Multicenter trial with NIST-calibrated sources -> some commercial chambers are wrong by up to 9 %.



NIST

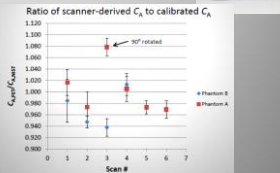
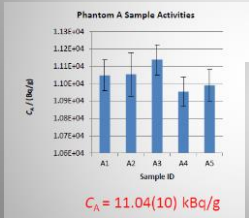
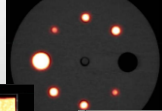


### PET Phantoms

Brian Zimmerman

- Monitor scanner performance during clinical trials
- Comparison across scanners and clinical sites
- Accuracy of reconstruction and scatter/attenuation corrections

<sup>68</sup>Ge in epoxy cylinders



Standard uncertainty on activity ~ 1 % Compatible with Jaczszak or ACR IQ phantoms



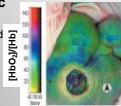
### Optical Medical Imaging Program at NIST

JeeSeong Hwang, David Allen, Toni Litorja (PML) Antonio Possolo (ITL)

#### Emerging Application Areas:

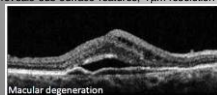
##### Tissue Oximetric Imaging

(surgery, combat and diabetic wounds)



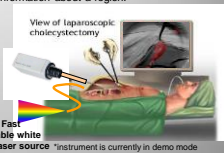
"Wet" and digital phantoms

**Optical coherence tomography:** Near-IR 3d imaging technique that collects scattered light that reveals sub-surface features, 1µm resolution



##### Calibrated Hyperspectral imaging:

imaging with a palette of 100s of contiguous spectral bands. Each pixel has a full spectrum and can reveal chemical information about a region.



Fast tunable white light laser source \*instrument is currently in demo mode

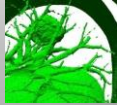
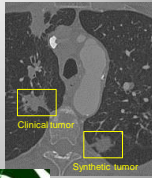
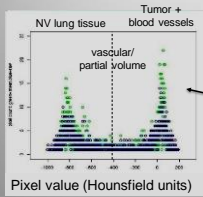
NIST Workshop on "Standards for the Advancement of Optical Medical Imaging," August 26-27, 2014 NIST Gaithersburg, Maryland



### Virtual/ numerical phantom for modeling clinical tumors

Adele Peskin, Alden Dima, Charles Fenimore, James Filliben, Joseph Chen, Richard Rivello (Information Technology Laboratory)

- Realistic CT lung tumor data (virtual phantom) with known tumor volumes based on clinical tumors
- Embed synthetic tumors in DICOM data sets from NCI RIDER at two time points to determine accuracy of volume change measurements



Peskin Lecture Notes in Computer Science (LNCS) series pp. 736 - 746 2010

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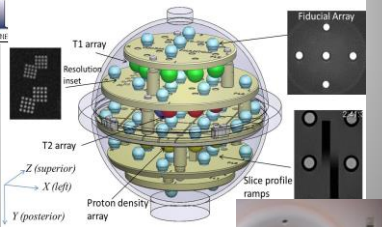
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### NIST/ISMRM MRI System Phantom



First MRI phantom with NIST traceability, temperature and field corrections, stability monitoring



**Measures:**

- Geometric distortion, B1 uniformity, B0 uniformity, T1, T2, Proton density, resolution, slice thickness, SNR

**Purpose:** Scanner QC and inter-scanner comparison, verify T1 T2 mapping protocols, off-the-shelf validation for some clinical trials




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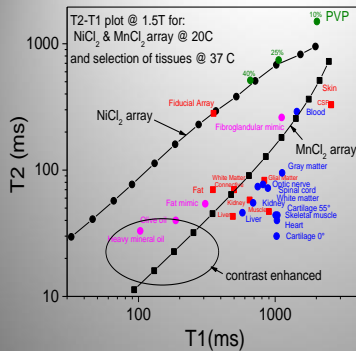
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### MRI Phantoms: must cover large parameter space



- Phantoms contain materials with well defined parameters!
- Many other dimensions required to mimic tissue: diffusion, conductivity, susceptibility!

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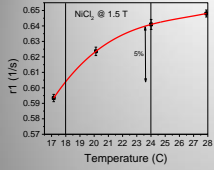
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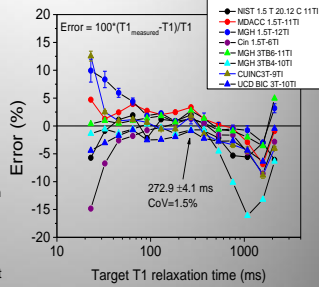
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### T1-Inversion Recovery gold standard: Need to understand variability



- Arrays have large ranges with short and long T1s, T2s that can be challenging to measure
- Need *in-situ* thermometry for accurate phantom measurement comparisons.



Katy Keenan

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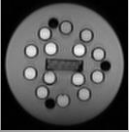
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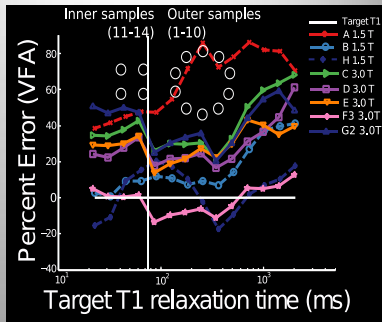
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### T1 Variable Flip Angle: Large variations in practical mapping sequences

NIST/ISMRM  
system phantom  
T1 array



Standard protocol:  
7 flip angles



Katy Keenan

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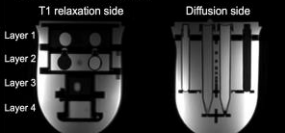
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### NIST/UCSF Universal Breast Phantom

Katy Keenan NIST, Nola Hilton UCSF

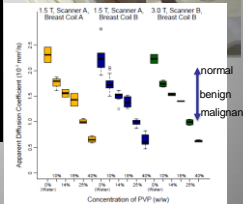
NIST/UCSF Breast phantom



Alternating layers of fibroglandular and fat mimics for T1, e.g. layer 1 is fat mimic bulk with fibroglandular spheres. The outer bulk solution is the fibroglandular T1 mimic.

Tubes are filled with 10, 25 or 40% PVP to mimic diffusion or filled with a fat mimic. The bulk solution is a mimic for fibroglandular T1.

An IDEAL water image: the fat is suppressed, as is the flexible silicone outer shell.



- For ACRIN 6698/ISPY 2 DWI Biomarkers for Assessment of Breast Cancer Response to Neoadjuvant Treatment
- T1, diffusion, geometric distortion, and tissue mimics

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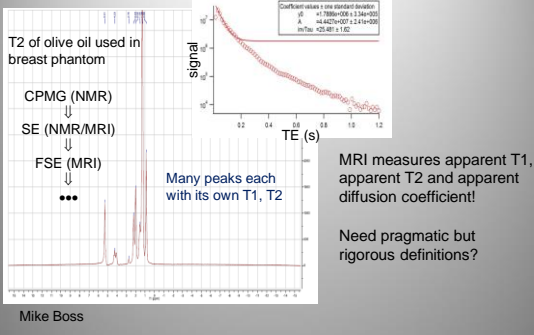
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**Do precise measurements of NMR parameters make sense in tissue?**




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**Breast Phantom: T2 ground truth?**

Spin echo includes chemical exchange  $r2 \propto \Delta\omega^2 \propto B0^2$

Material	1.5 T		3.0 T	
	MRI Multi-Echo Spin Echo	NMR CPMG* $\tau = 1.0\text{ms}$	NMR Multi-Echo Spin Echo* TE=15ms	NMR CPMG*
2.26 mM NiCl <sub>2</sub> & 0.25 mM MnCl <sub>2</sub> in water	55 ms	57.8 ms	39.0 ms	38.8 ms
35% w/w Corn Syrup in water	261 ms	266 ms	47.3 ms	84.7 ms
Grapeseed Oil	40 ms	160 ms	32.5 ms	171.8 ms

MRI measurements at 16.5 deg C. NMR measurements at ~20 deg C.

\* Integrated over all peaks

Mike Boss/ Katy Keenan

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**SI traceability for MRI?**

•Traceability in MRI not established (exception dimensional traceability through optical interferometry)

•composition traceability for Ni and Mn concentrations NIST Nickel SRM 3136 and Manganese SRM 3132 Standard Solutions using inductively coupled plasma optical emission spectroscopy (ICPOES).

• NIST can offer traceable measurements of T1, T2, ADC, susceptibility ... using calibrated variable field, variable temperature NMR , magnetometry *if we can agree on suitable definitions!*

PET dose calibrator

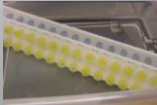


directly traceability to NIST

System phantom reference libraries



phantom reference libraries




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***NIST Perspective/ Goals***

- NIST is ramping up biomedical imaging standards for quantitative biomarkers
- Goal: extend precise traceable measurements inside the human
- Assist developing/ validation MR phantoms: anisotropic diffusion, active flow/perfusion
- NIST will help facilitate a roadmap for standards for quantitative MR
- NIST will investigate a study of economic impact of standards-based quantitative MR

Workshop on Standards for Quantitative MR  
NIST Boulder July, 2014

NIST MRI standards team: Mike Boss, Katy Keenan, Karl Stupic

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