DHS SCIENCE AND TECHNOLOGY

TSL Basis Material Decomposition for CT Analysis

ADSA16

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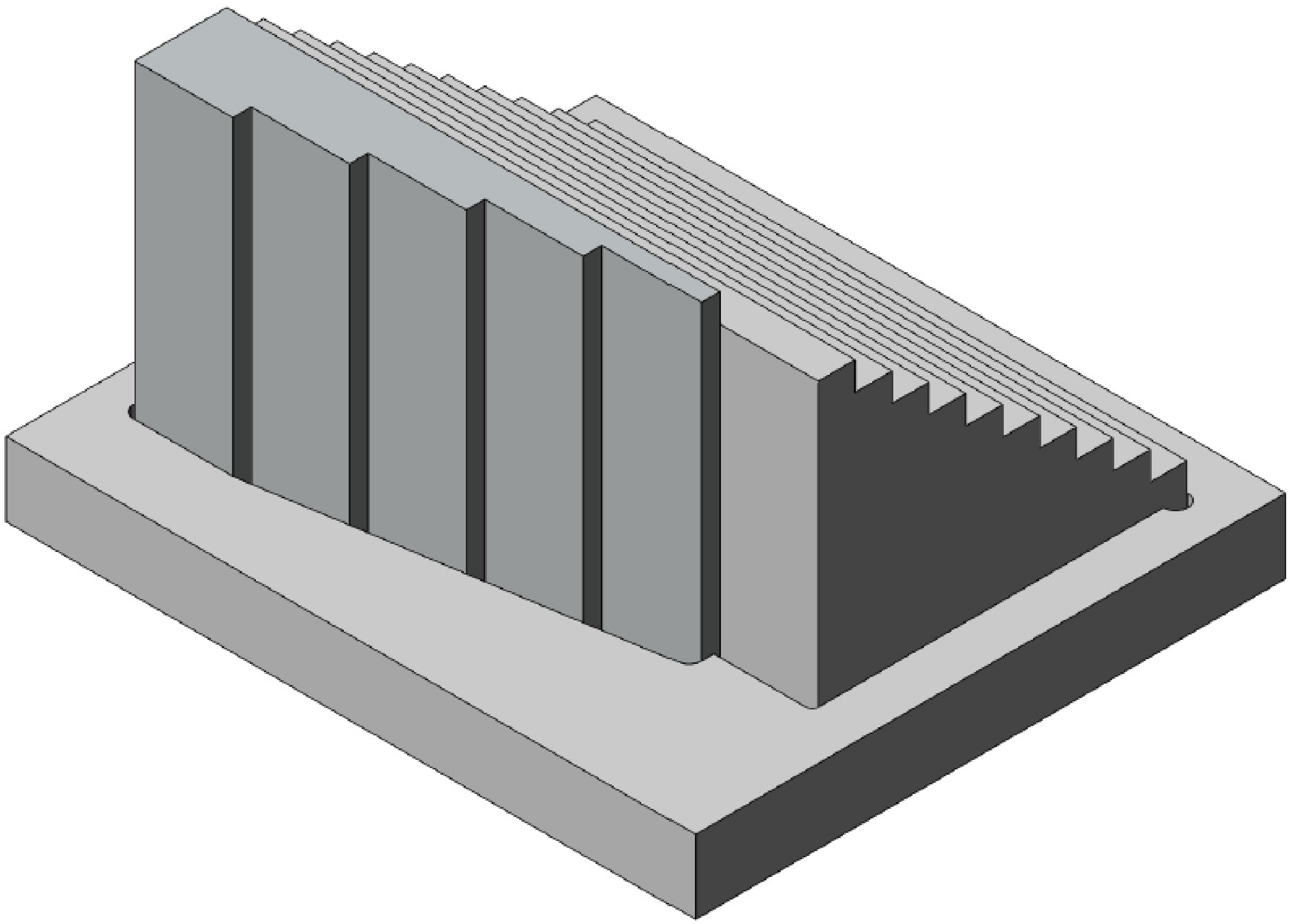
Conclusion

- Dual-energy CT based BMD results in material features (electron density, effective atomic number) that are reasonably system-independent
  - No need for beam hardening compensation
- Photon counting CT based BMD also results in material features that are commensurate with DECT based BMD
  - System dependence less of an issue due to photon counting
  - No need for beam hardening compensation
  - Single-row MultiX CZT detectors are reasonable to use for our purposes
  - Detector response imperfections cancel out when determining features, including LAC(E)
- Discussion: are these methods relevant and applicable to security screening systems?

Part 1: DECT BMD



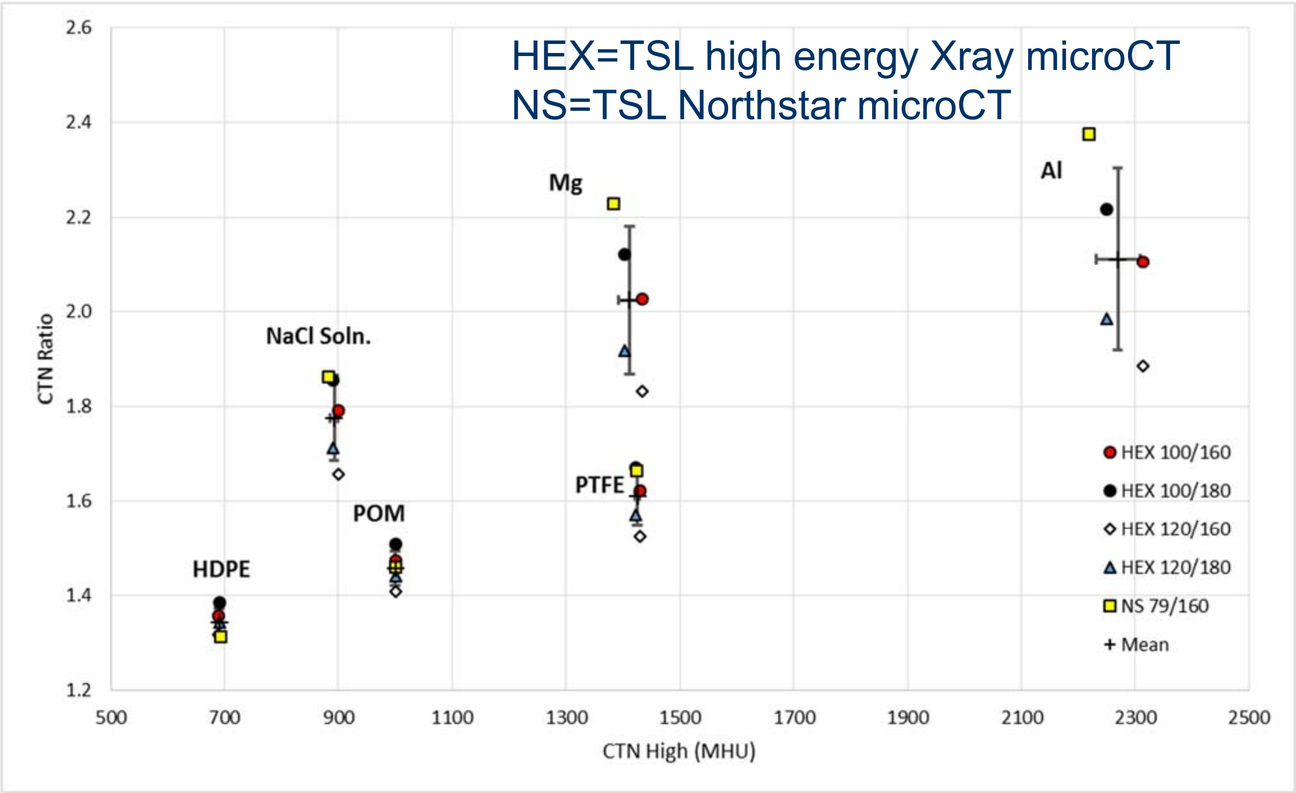
Introduction

- TSL MicroCT X-ray systems support material characterization studies
- TSL MicroCT systems are similar to systems at Tyndall Reactive Materials Group (TRMG) and Lawrence Livermore National Laboratory (LLNL), and results can be compared.
- Although each location uses standardized processes and procedures, results vary because of the system-dependent factors
- Basis Material Decomposition (BMD) is being developed as a method to reduce system-dependent factors and provide consistent measurements across different platforms at various labs.
- Sponsored by S&T HSARPA Explosives Division (EXD)
  - Awarded to Battelle
  - Phase 1 Complete
  - Phase 2 Ongoing

Motivation: Reduce System-Dependent Factors

MicroCT system-dependent factors:

- system geometry
- applied voltage
- X-ray Tube characteristics
- incident-beam filtration
- collimation
- detector characteristics
- signal processing methods
- beam-hardening correction



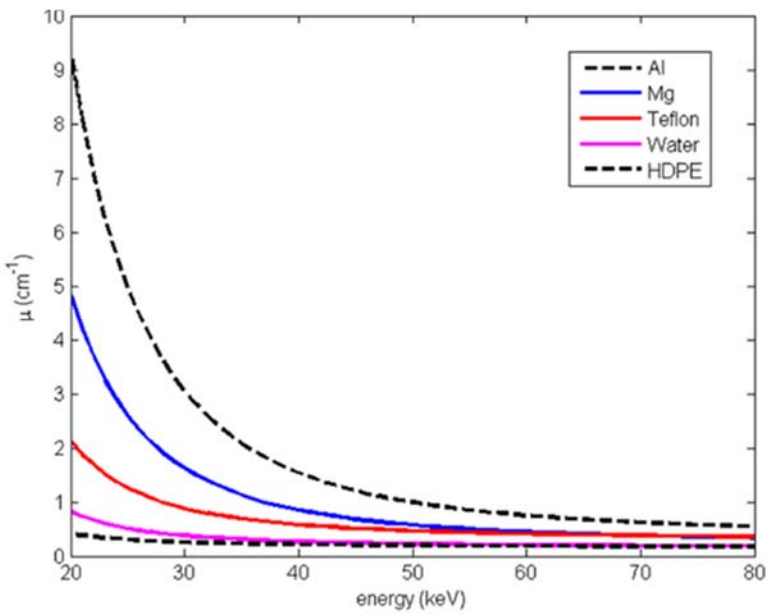
What is BMD?

- BMD is an X-ray imaging technique that characterizes materials in terms of the equivalent **mass density** (ρ) of two (or more) known and well-characterized basis materials
- In practice, two basis materials that have largely different mass attenuation coefficients work best
- For this study, Aluminum and HDPE were selected.

The attenuation of an arbitrary material (i.e. explosives or simulants) is represented as a linear combination of the two basis materials:

$$\frac{\mu(E)}{\rho} = a_1 \frac{\mu_1(E)}{\rho_1} + a_2 \frac{\mu_2(E)}{\rho_2}$$

Calculated attenuation

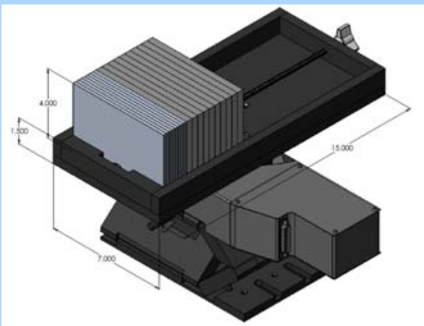


BMD coefficients

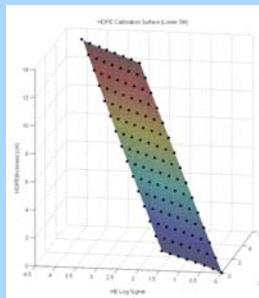
Material	a_1	a_2	RMS
HDPE	1.000	0.000	0.000
Water	0.867	0.126	0.005
Teflon	0.678	0.195	0.006
Mg	0.211	0.776	0.007
Al	0.000	1.000	0.000

Procedure

1) BMD Calibration (HDPE/Al)

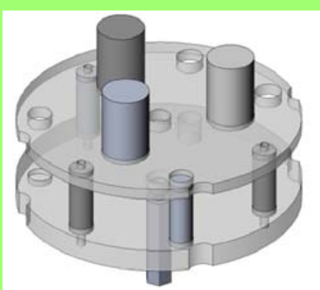


BMD Calibration Phantom

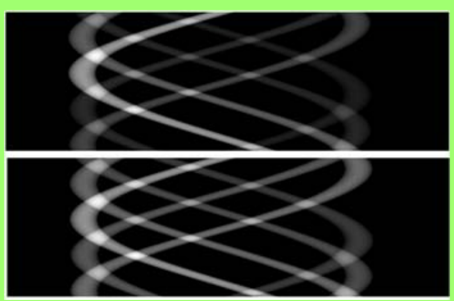


Inversion Tables

2) Dual-Energy CT Scan

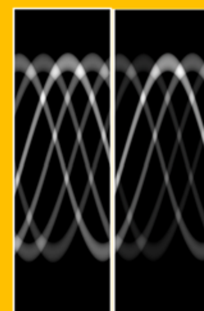


CT Sample Carousel

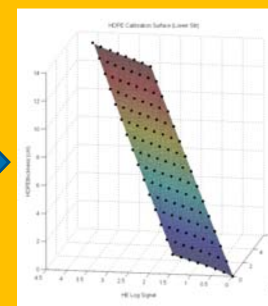


DE CT Sinograms

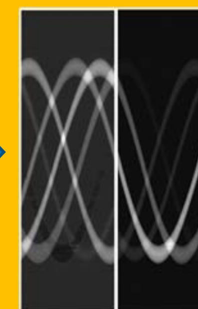
3) Decomposition



DE CT Sinograms



Inversion Tables



4) Reconstruction

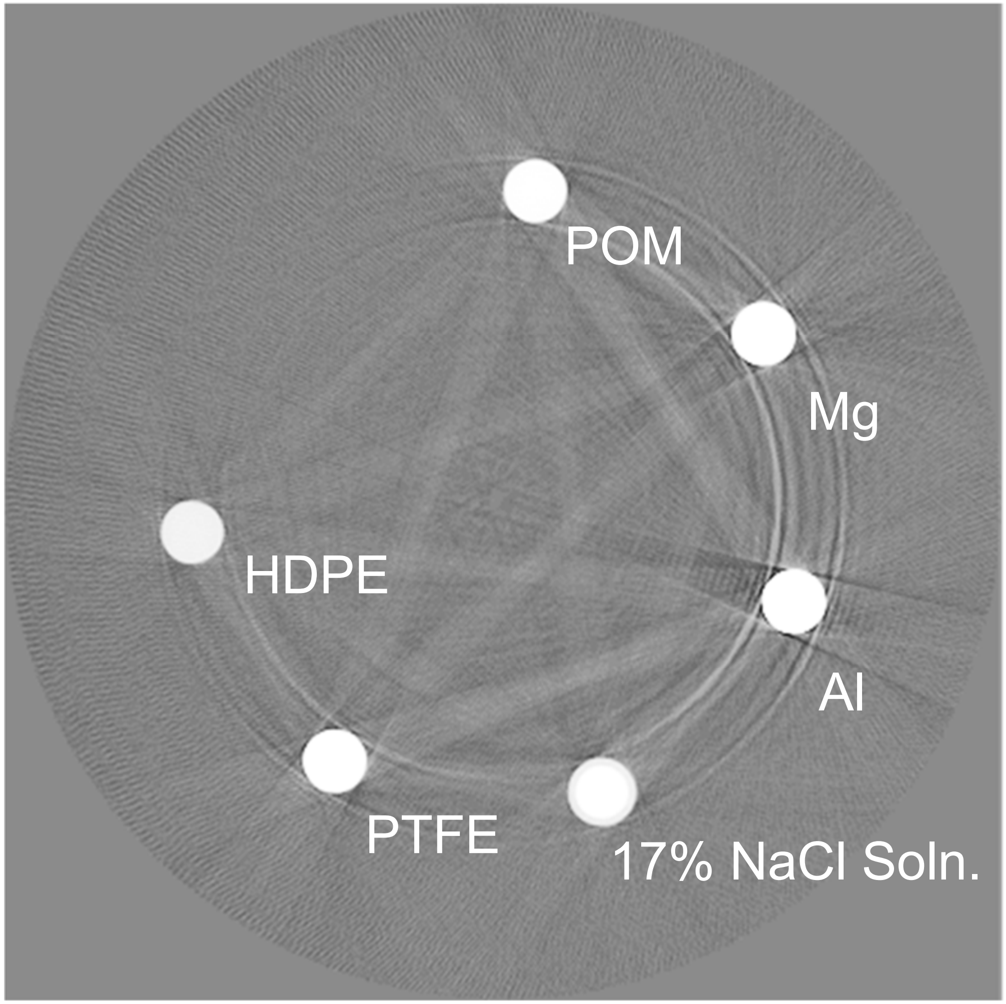
BMD Sinograms

FBP

Recon.

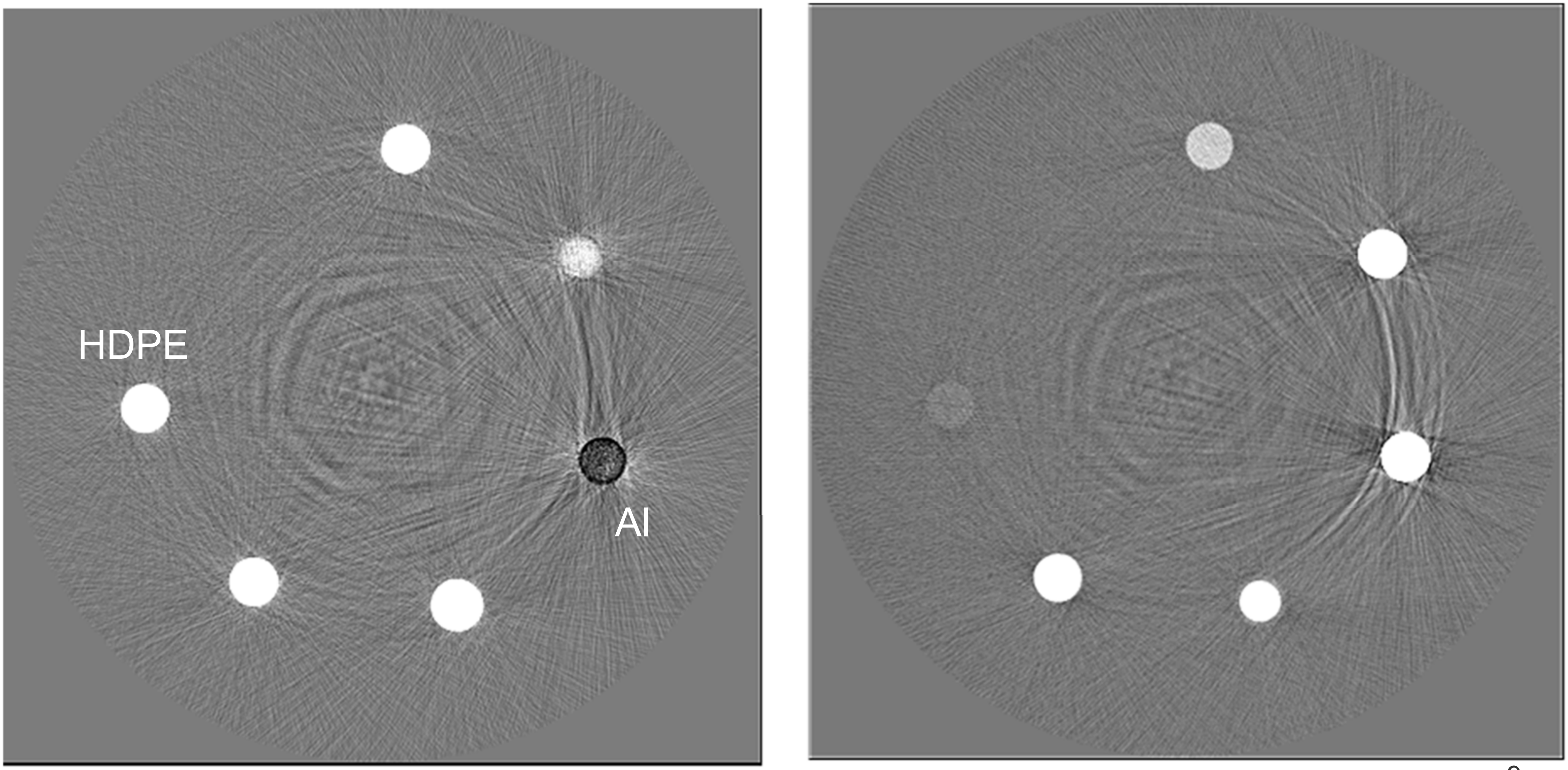
BMD Images

CT Image



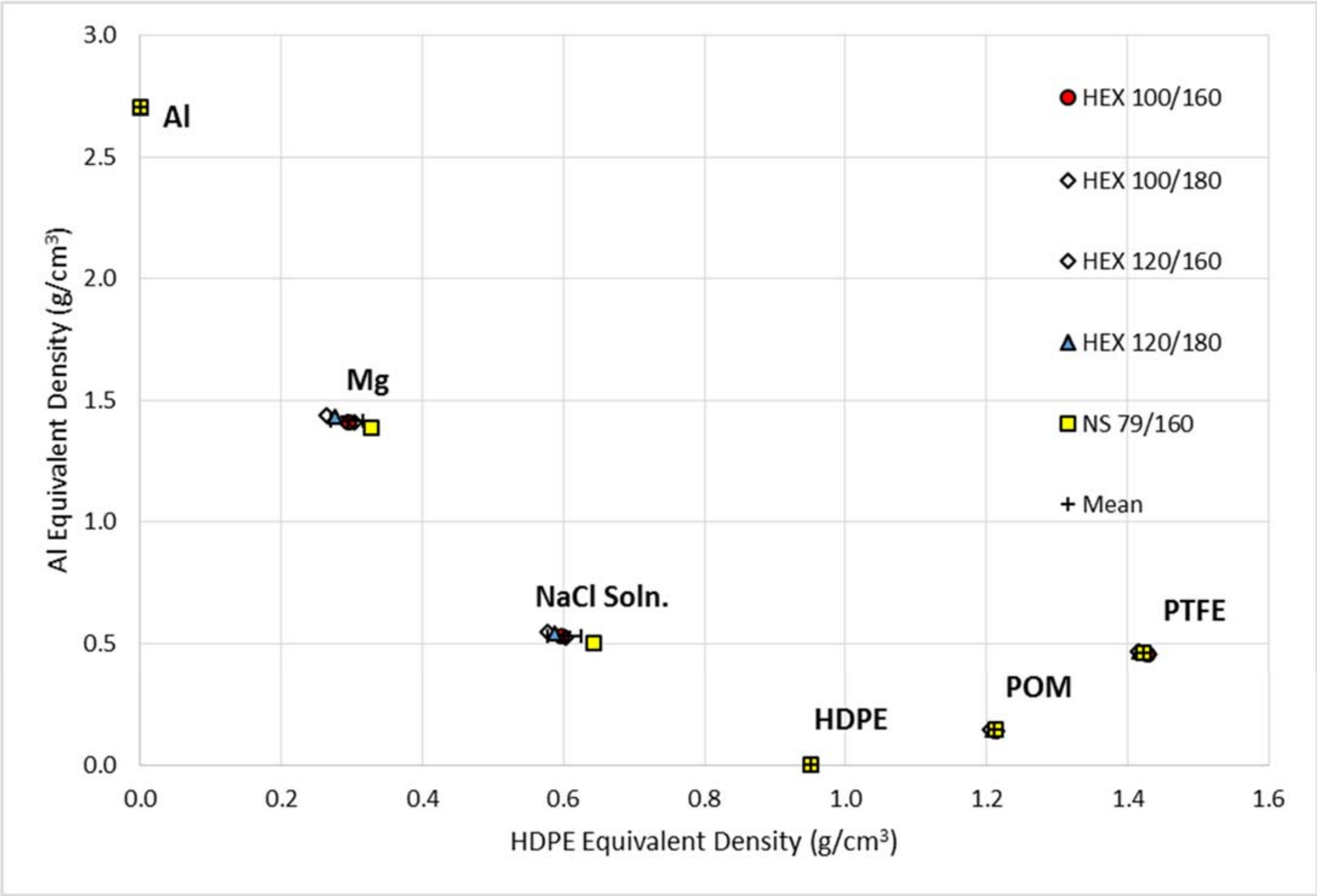
(Contrast-enhanced)

Basis Images



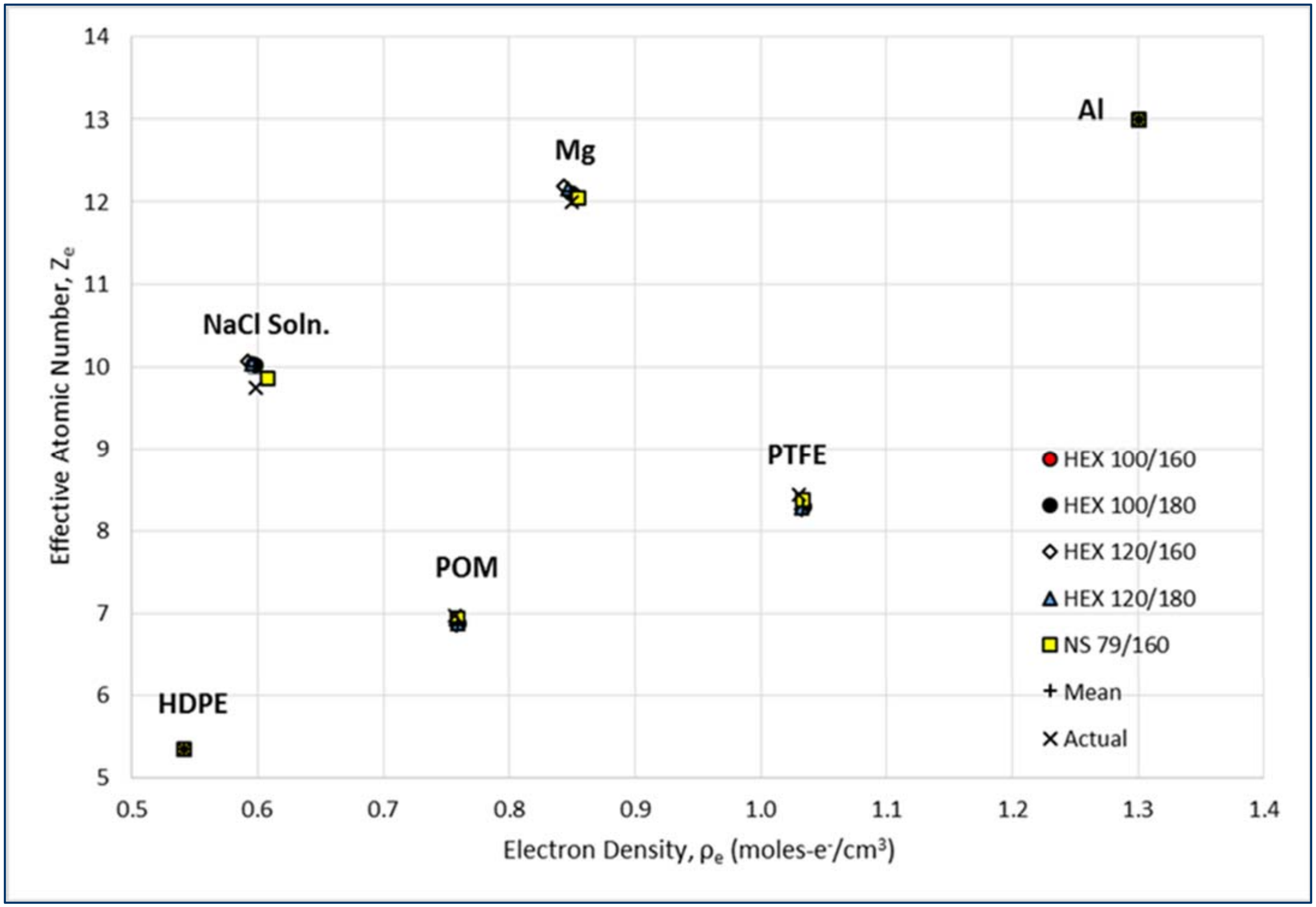
BMD Results: Equivalent Density

BMD Equivalent Density Feature Space



BMD Results: ρ_e and Z_e

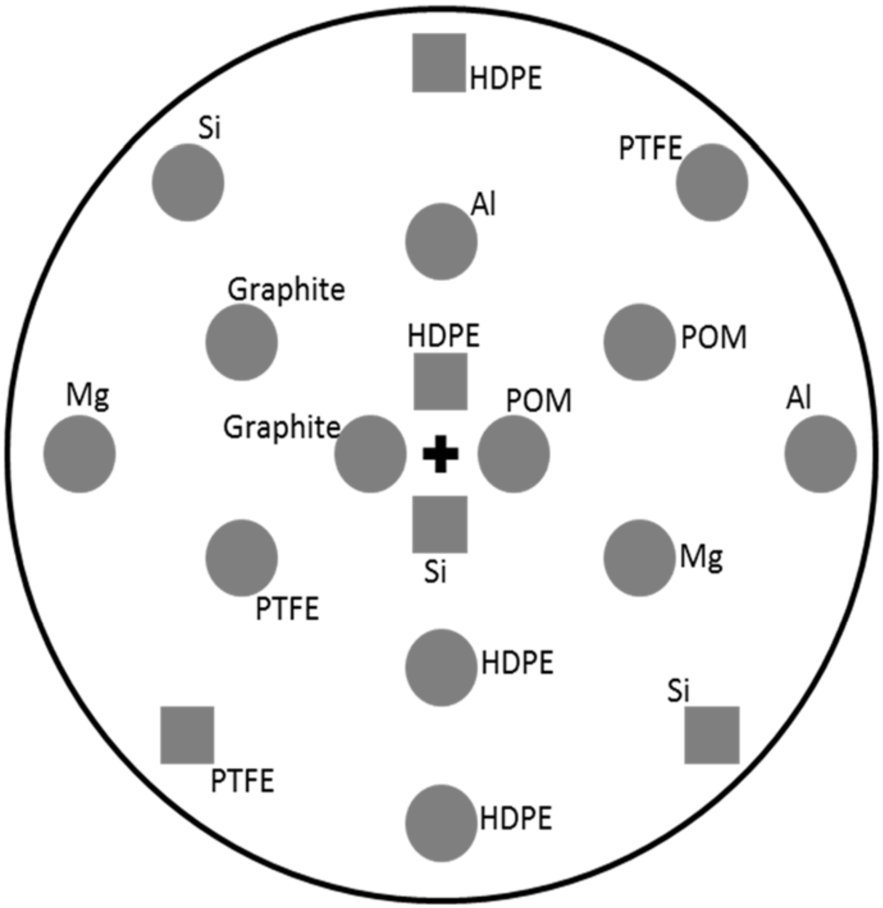
Optional Step: convert to Z_e and ρ_e Feature Space



Summary of Phase 1 Results

- ρ_e
  - inaccuracy < 1.1% for all materials expect 1” Al (3.1%)
  - Standard deviation < 1%
- Z_e
  - inaccuracy was under 2% for all materials
  - Standard deviation < 1%
- Materials characterization results were system–independent comparable to LLNL SIRZ (photoelectric/Compton decomp)
- Satisfactory results were obtained without the need for beam-hardening compensation

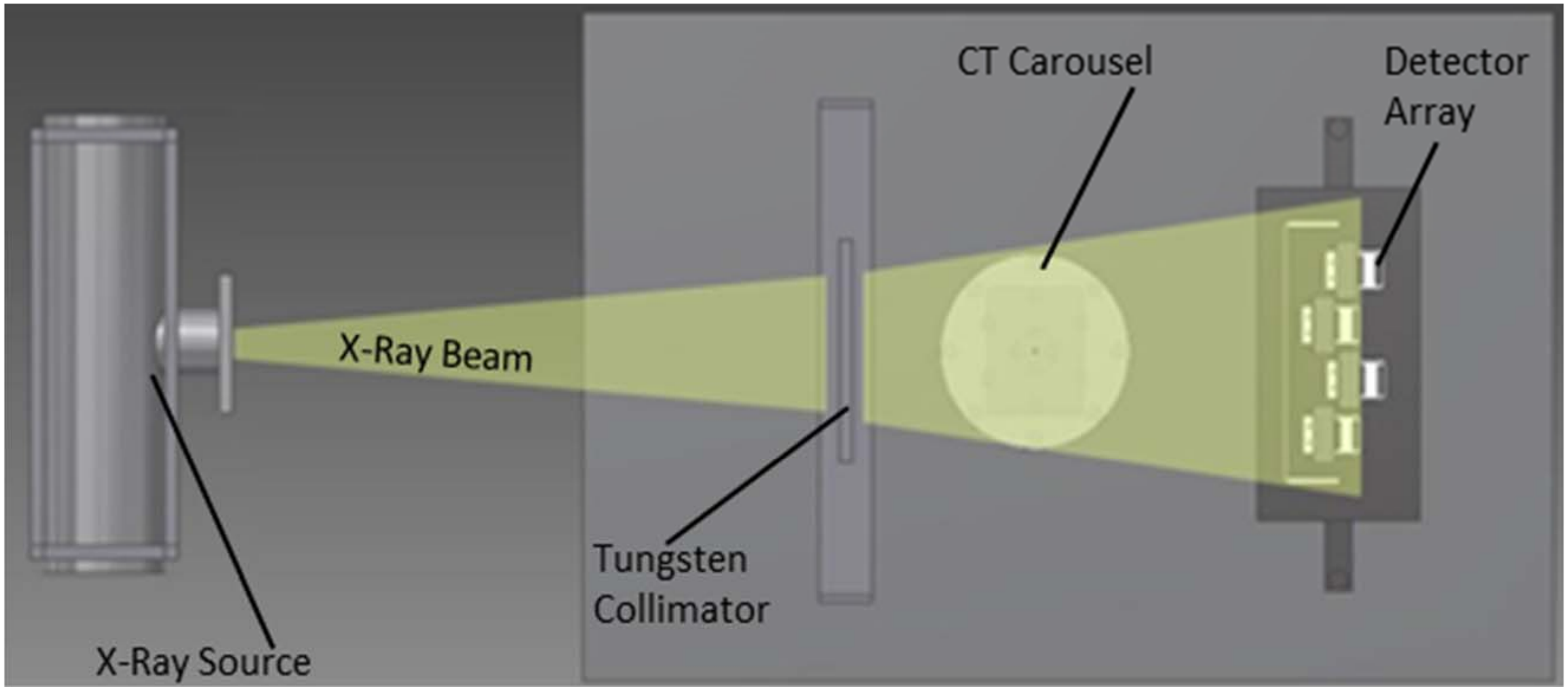
Part 2: Photon Counting BMD



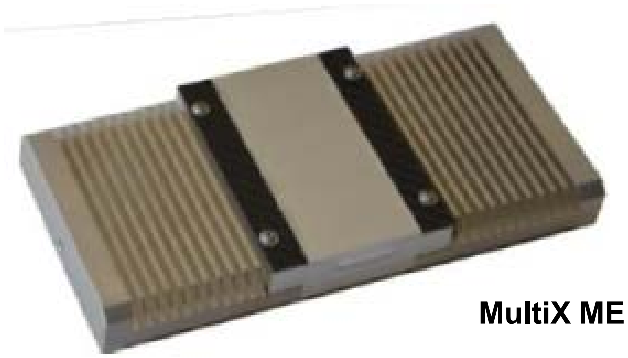
Introduction

- TSL was in possession of a MultiX ME100 photon counting detector array
- Photon counting is used in the medical field, but it is unknown whether it would be beneficial to security CT screening, whether to replace or supplement integrating detectors
- Project sponsored by TSL internal R&D
  - awarded to Signature Science
  - Phase 1 complete
  - Phase 2 ongoing

Spectral CT System



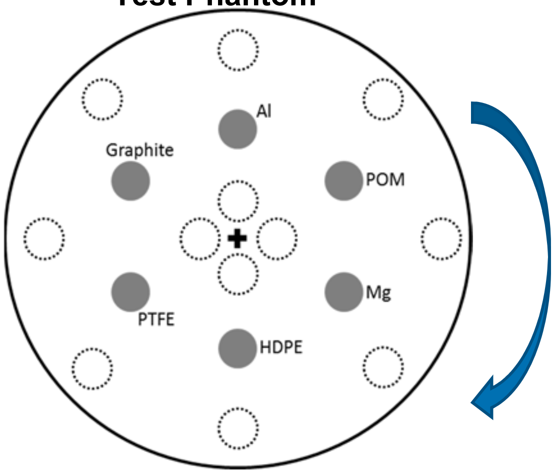
- 4 photon-counting linear detector arrays with 800µm resolution
- Attenuation information from up to 128 energy bins (20-160keV) is available.



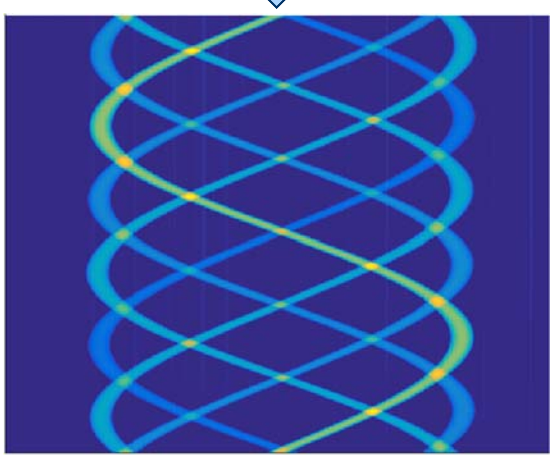
MultiX ME 100

Emulate Current Integration

Test Phantom



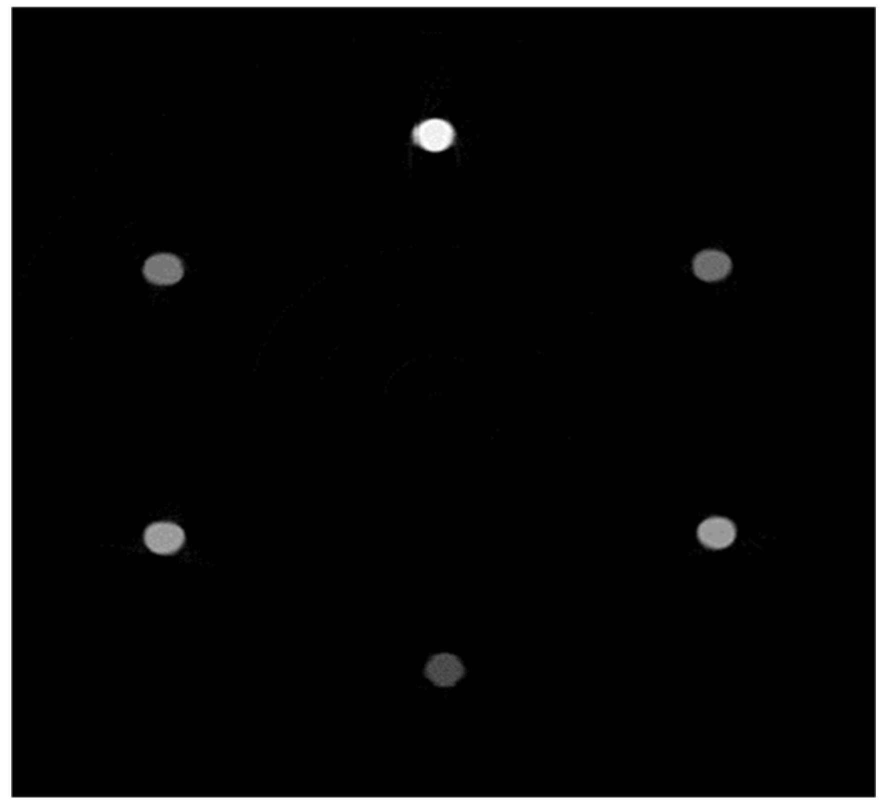
CT Scan



Energy-Averaged Sinogram

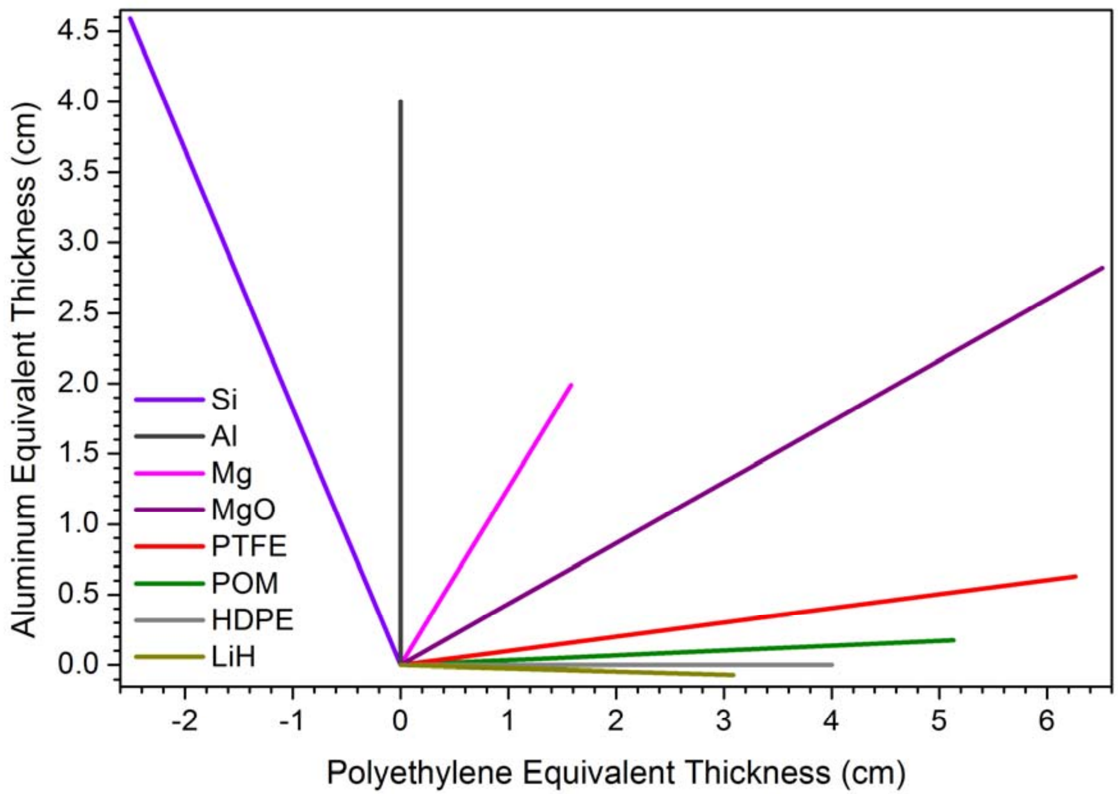
FBP

Reconstructed Image



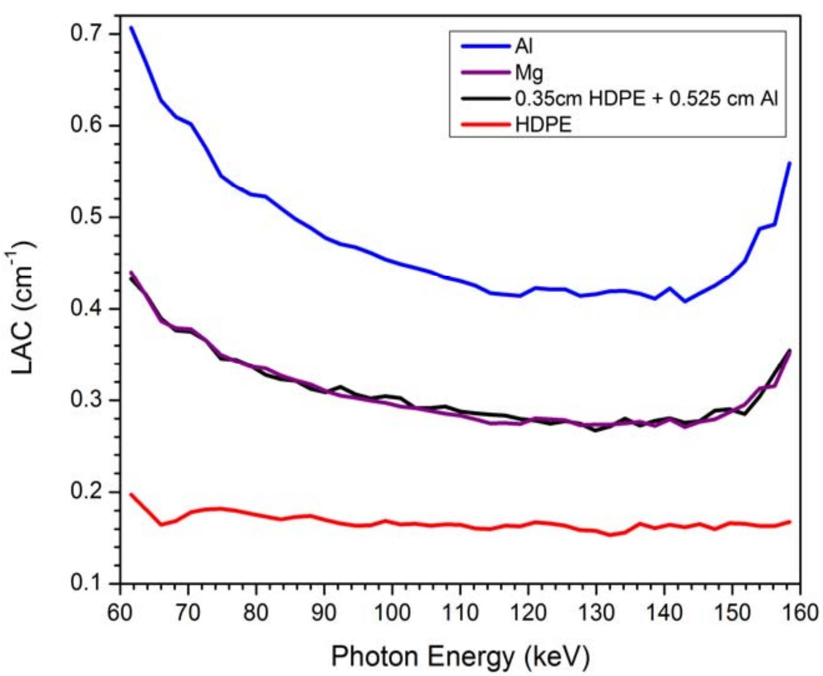
Basis Material Decomposition (BMD)

- HDPE and Aluminum again used as basis materials
- Calibration uses simple step wedges
- Materials outside the ρ_e,Z_e space of basis materials can have negative density/thickness



Example: Magnesium

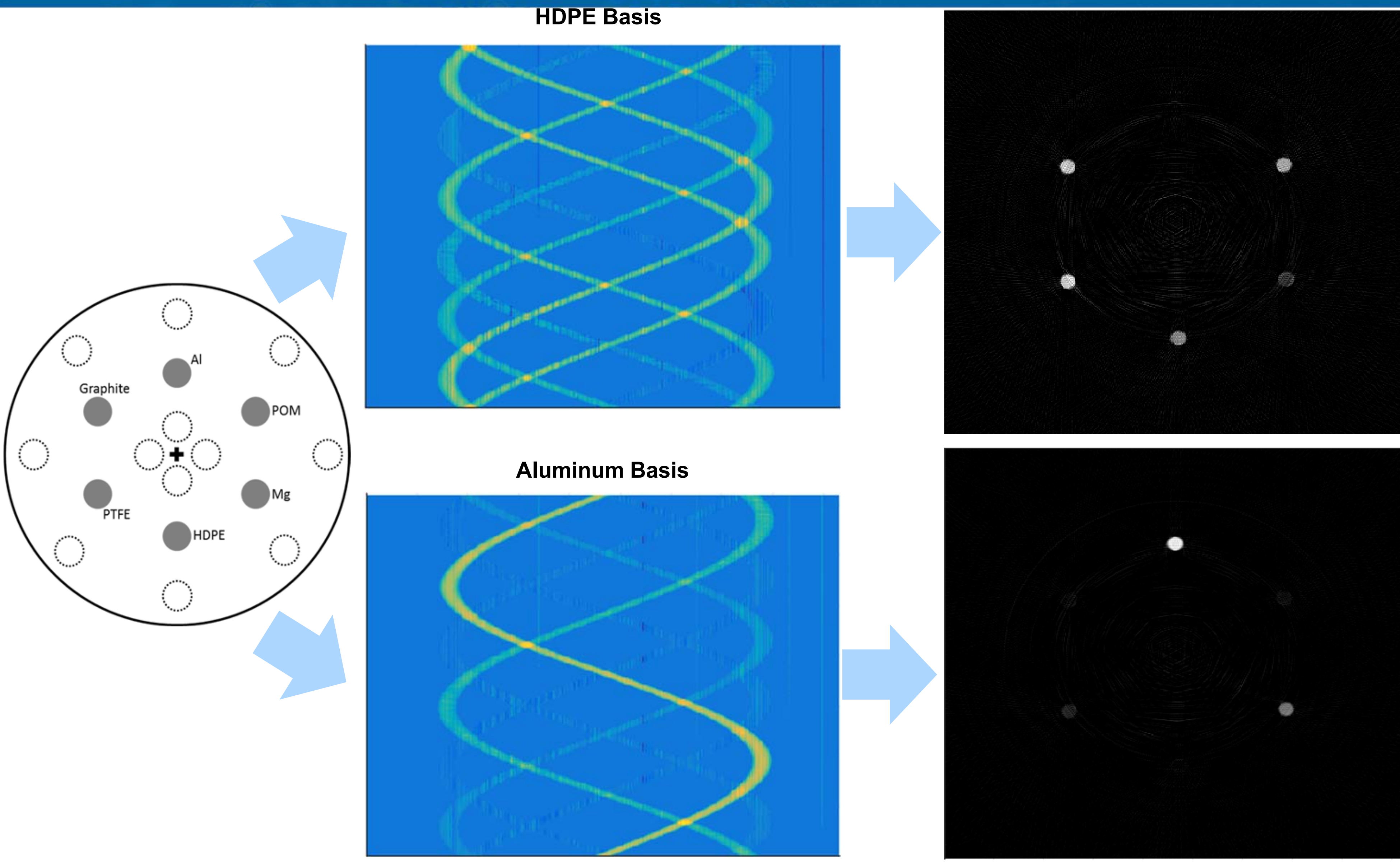
- Magnesium decomposition is valid over a wide range of energies, i.e. measurement matches prediction based on HDPE and Al
- $\mu_{Mg} = 0.35\ \mu_{HDPE} + 0.525\ \mu_{Al}$



Basis Material Decomposition (BMD)

- Decomposed sinograms are noisy, but noise is correlated.
- Each basis material is mostly absent from the other basis material reconstructions
- Data is renormalized according to the basis materials, HDPE and aluminum, present in the test phantoms.
- Reconstructed objects are segmented and basis material equivalent thicknesses are converted to ρ_e,Z_e values
- Using energy-dependent LACs of the basis materials, basis material equivalent thicknesses for a material are used to estimate its energy-dependent LAC
    - Traditional dual-energy CT can also calculate LAC values but only at two “effective” energies, using several reference materials

Basis Material Decomposition (BMD)

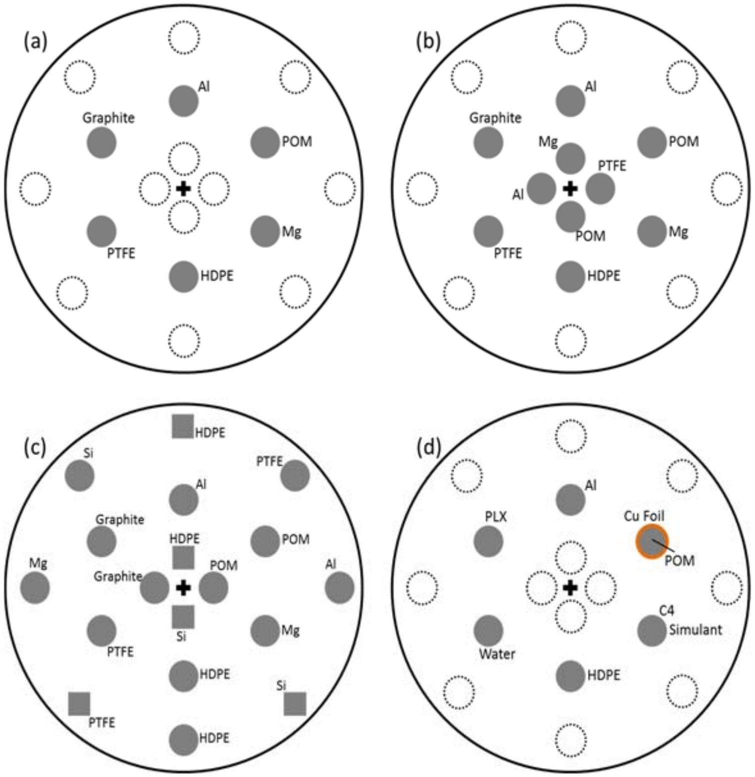


Phantoms

- 5 phantoms of increasing complexity were used

Standard (1/2”)
Thick (1”)

Occlusion

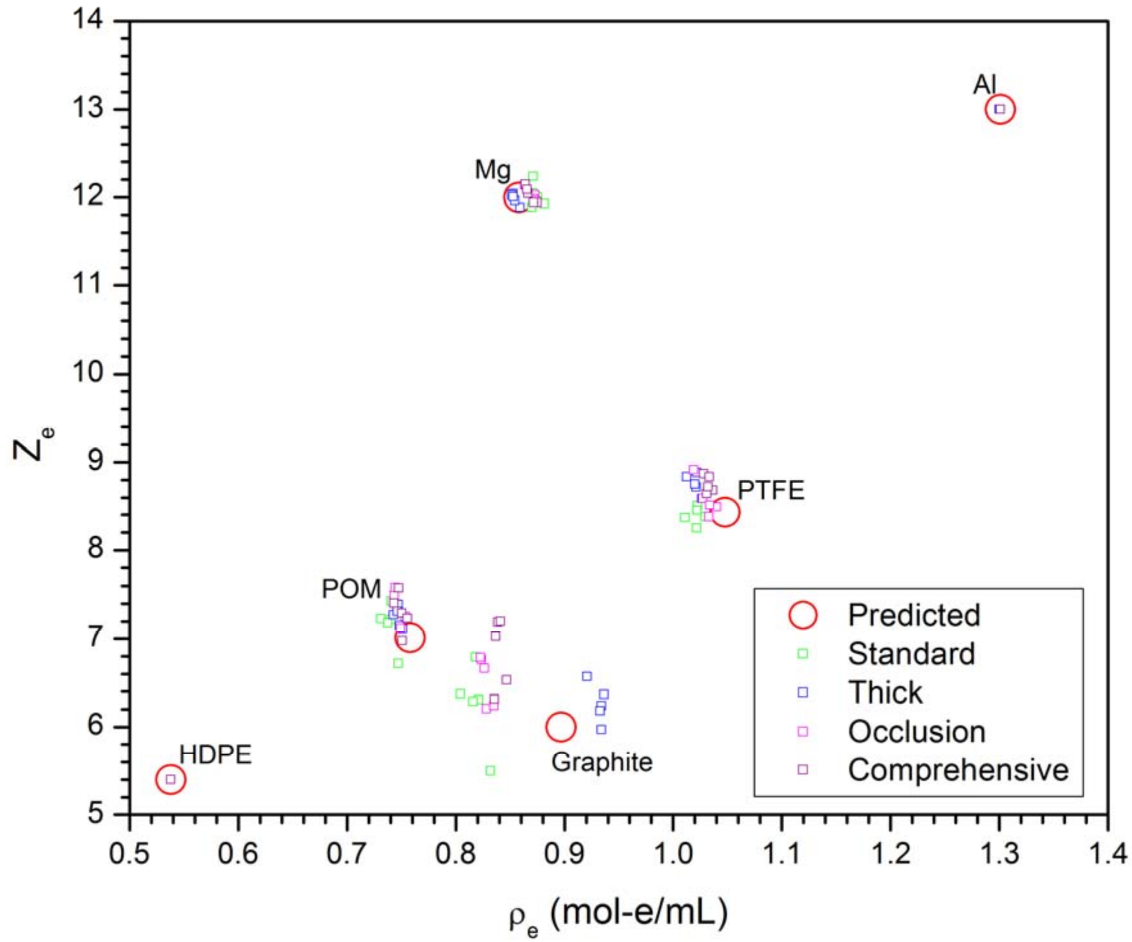


Comprehensive

Threat-like, data not shown

Phase 1 Results: ρ_e and Z_e

- Little variation in ρ_e,Z_e for POM, PTFE, and Mg despite the range of scattering environments



Graphite, in retrospect, was a poor choice of test material.

Phase 1 Results: LAC

- Excellent agreement between NIST and BMD-derived LAC throughout energy range