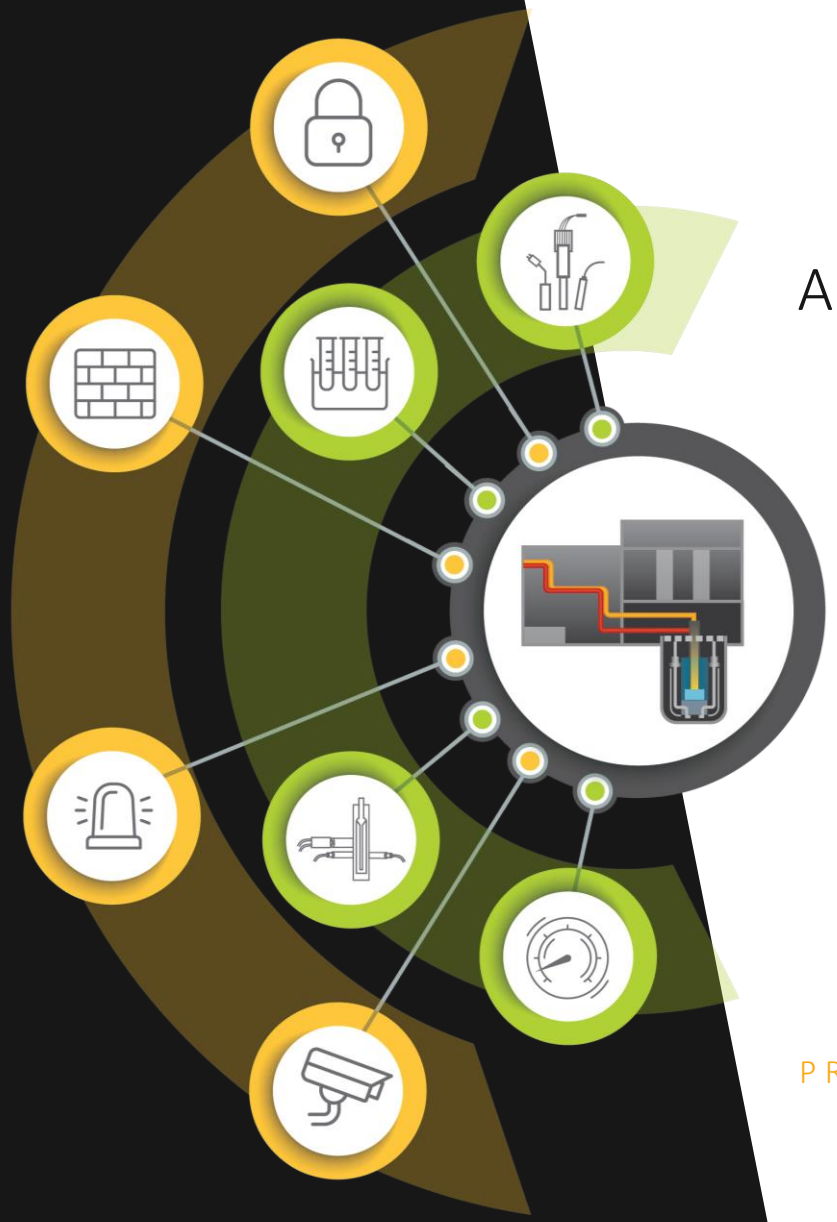

ADVANCED REACTOR SAFEGUARDS

A Novel Nuclear Material Control Technique for Pebble Fueled Reactors (PFR): FY22 Mid-year Review

PRESENTED BY

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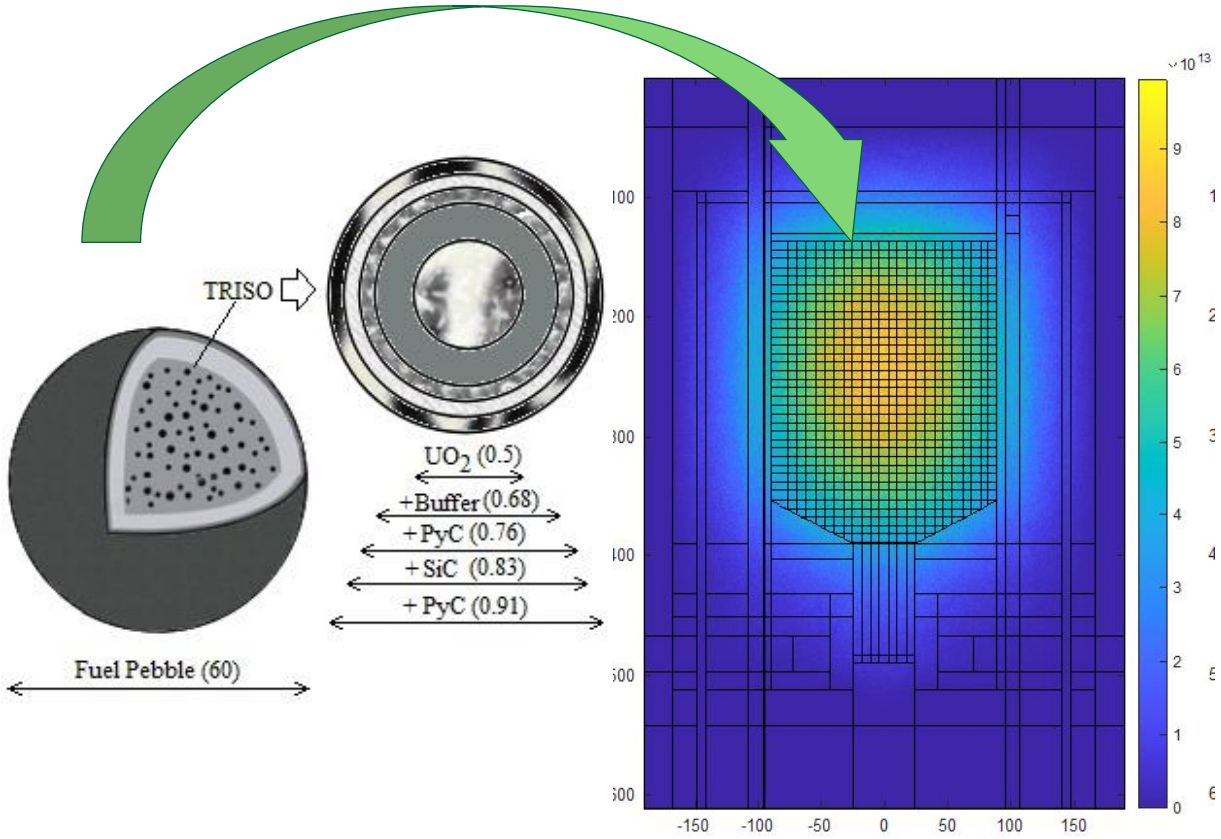
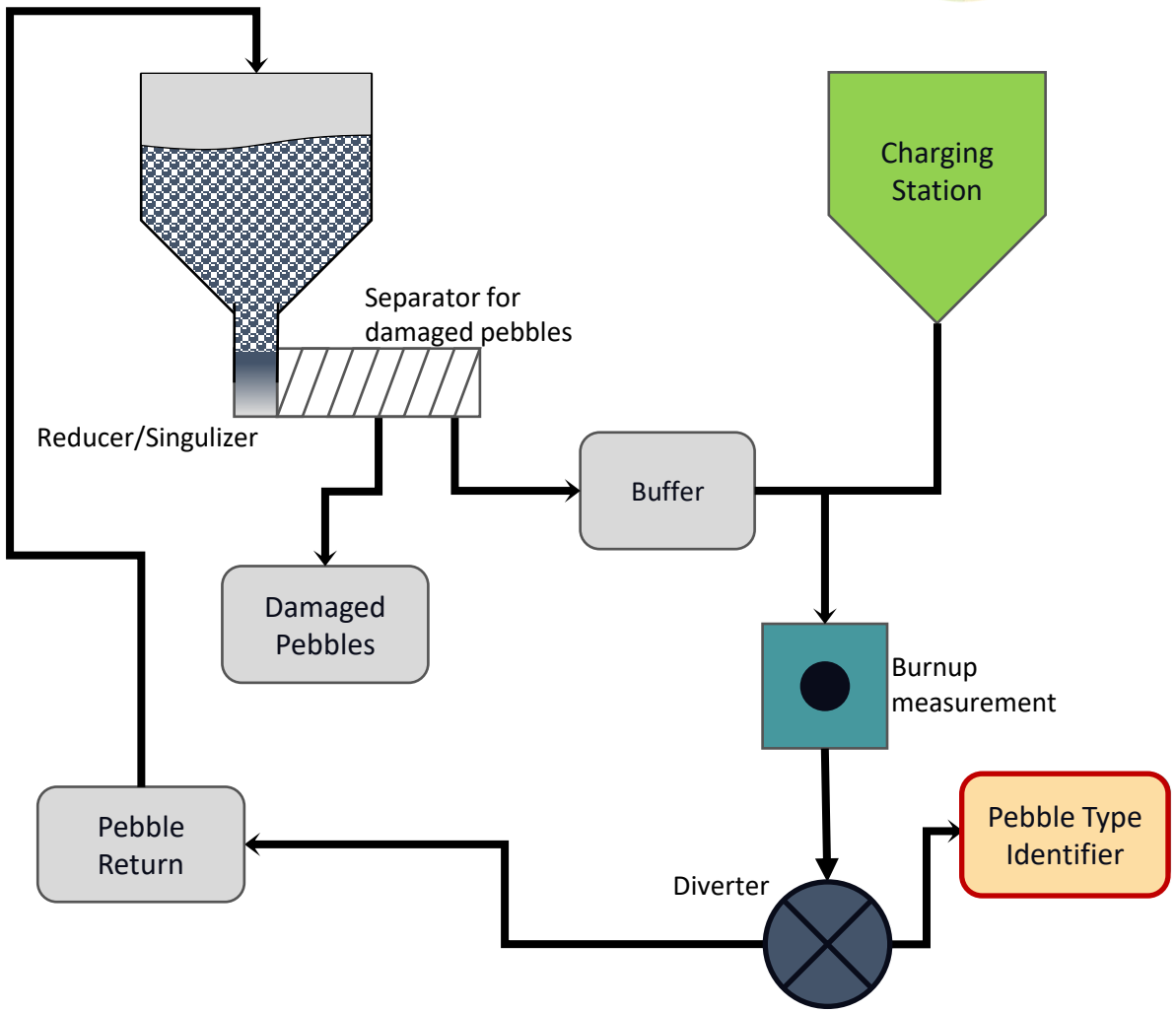
Introduction

- A PFR uses several hundred-thousands of fuel pebbles
  - 5 to 10 g of LEU per pebble
- Different batches of pebbles in the same PFR, based on
  - ^{235}U enrichment
  - Date of introduction
  - Neutron moderating (graphite)
  - Neutron absorbing
- Pebbles continuously flow through the reactor, discharged at the PFR vessel bottom, and re-inserted at the PFR vessel top depending on the re-fueling scheme.



Motivation for Study

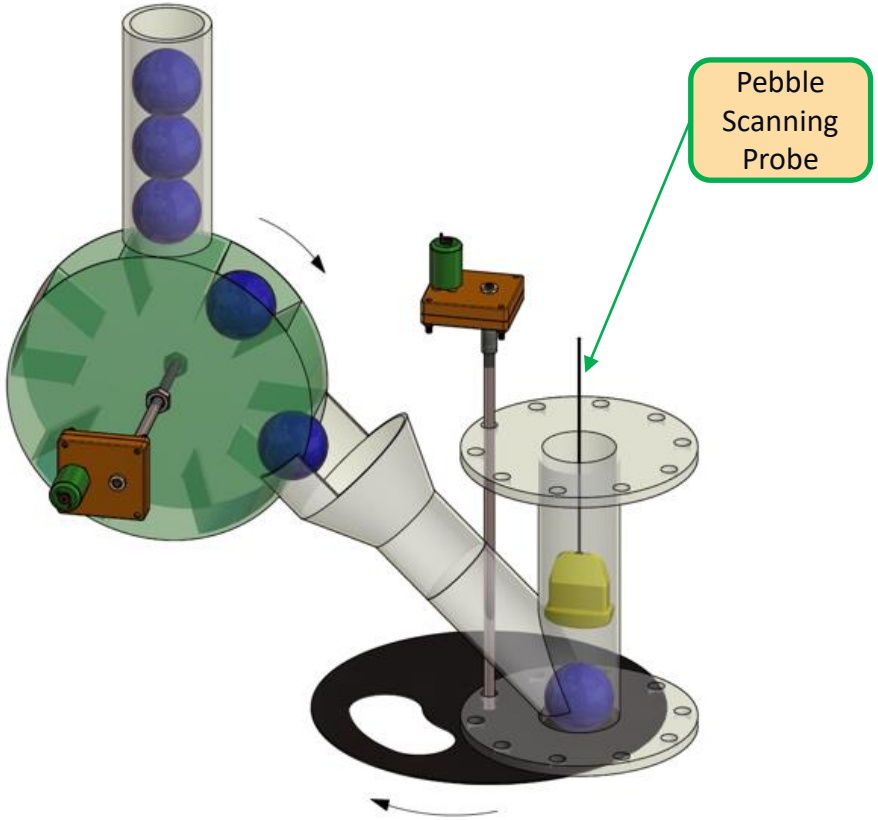
- Nuclear Material Accountancy and Control (NMAC) are essential for implementing safeguards
- Item accounting of pebbles is unfeasible
  - ~10^5 pebbles in reactor vessel
- Burnup measurements (gamma spectroscopy) are part of process
  - Uncertainty of using burnup as distinguishing characteristic
  - Similar burnup achieved by different paths
  - Complementary research
- Vendor stated interest in identifying pebble types:
  - "A capability to distinguish pebbles by batch is needed"



Objective

- Develop a unique technique for identifying pebble type for nuclear material accountancy and process control

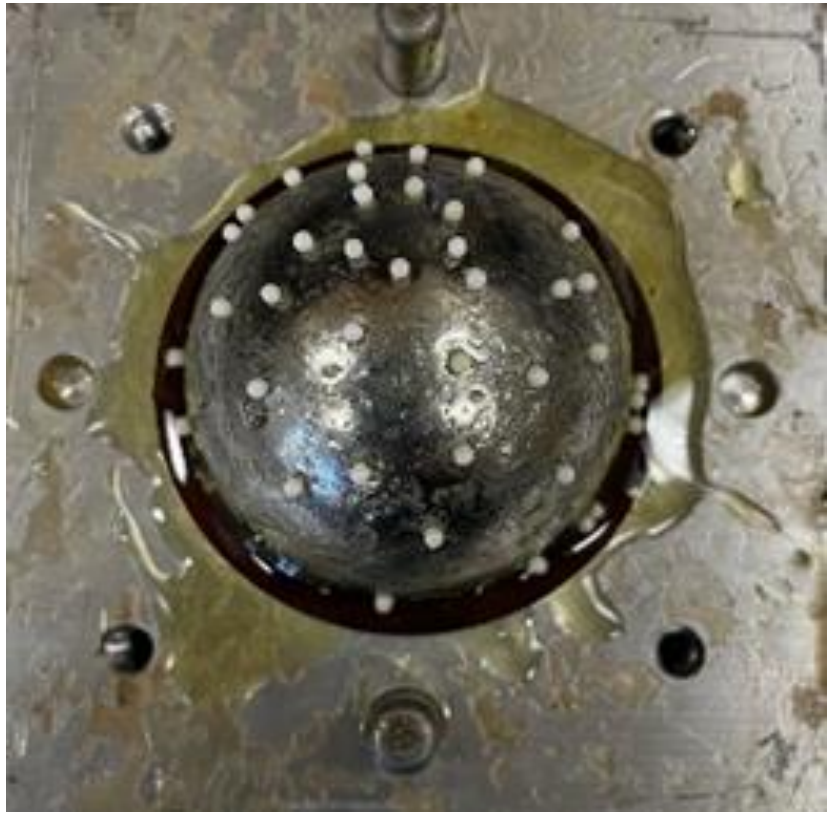
Extrinsic, non-radiological features to be used for accounting and control



Pebble Sorting Assembly Prototype

Methodology

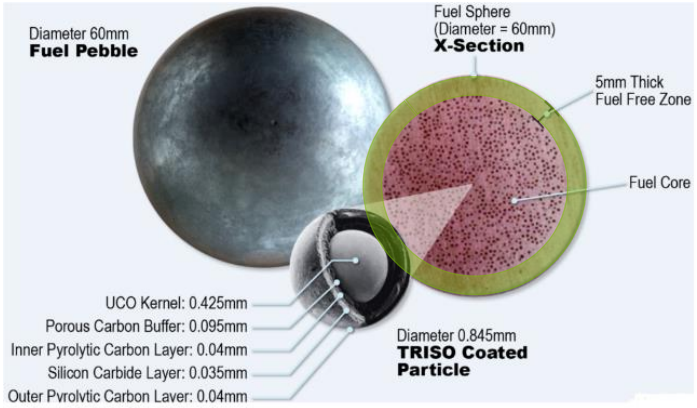
- Embedded inert identifiable microspheres in the outer graphite layer (5 mm thick) of the pebble
- Imaged (ultrasound scan) outer graphite layer for pebble classification
- Batch accounting – categorized by sets of item specifications
  - Enrichments
  - Pebble purpose (fuel, absorber, moderator)
  - Date of core introduction

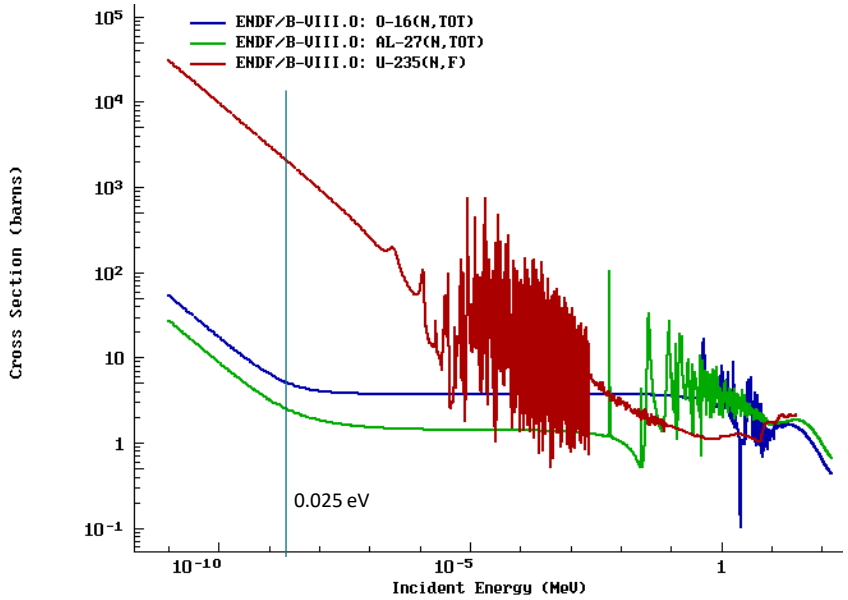


Surrogate pebble with YSZ microspheres in graphite mold

Operational Impact

- Microsphere specifications:
  - Neutronically inert
  - Maximum thermal conductivity
  - Minimal thermal expansion
  - 1-mm diameter
  - Initially yttria-stabilized zirconia (YSZ), later alumina (Al_2O_3)
- Pitch (interstitial spacing) of microspheres serve as unique pebble-type identifier
  - Averaged



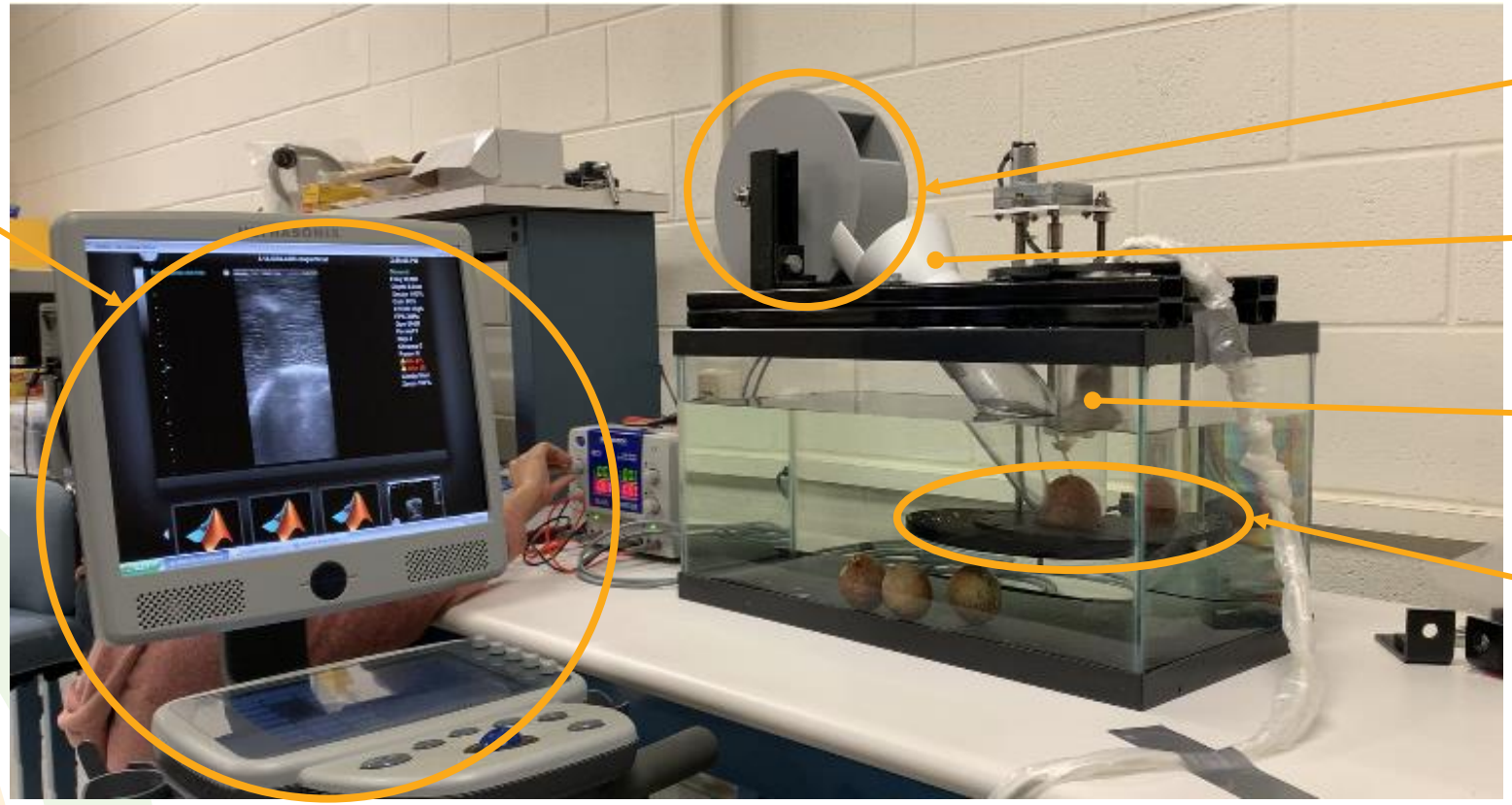


Pebble Preparation

Sample Number	Qualitative Description
Sample #1	Spherical, 6cm diameter, no YSZ microspheres
Sample #2	Spherical, 6cm diameter, approximately 100 YSZ microspheres in the pebble
Sample #3	Spherical, 6cm diameter, approximately 200 YSZ microspheres in the pebble

Ultrasound Experimental Setup

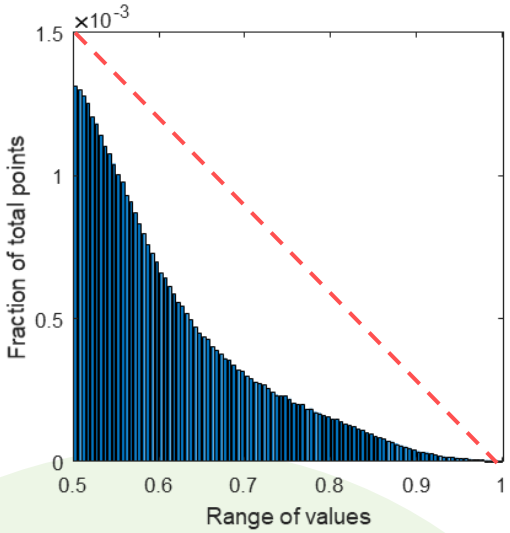
- Experimental setup with pebble sorting system



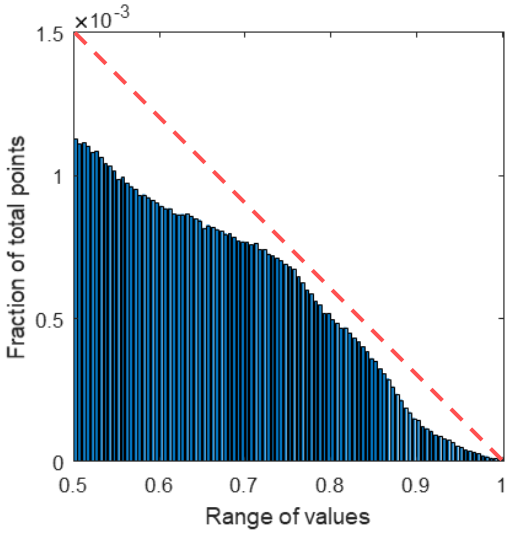
Ultrasound Imaging – Static Scans

x-axis: Normalized voxel intensity (range 0.5 to 1.0)

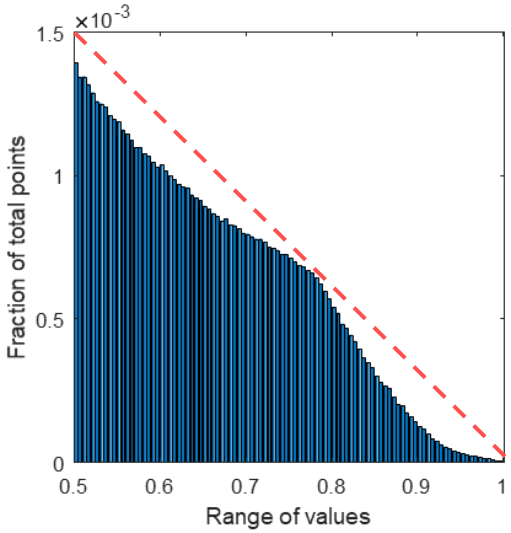
y-axis: Percent of voxels for a given intensity



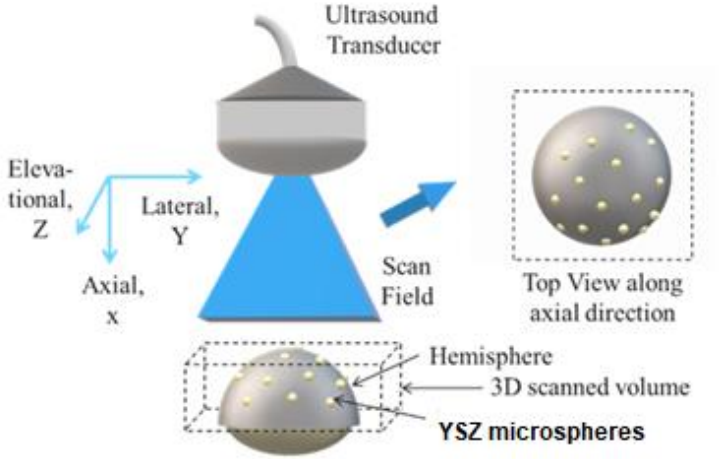
Sample #1 with no microspheres



Sample #2 with 100 microspheres



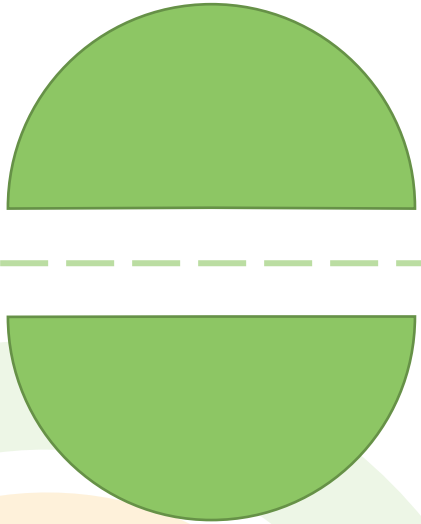
Sample #3 with 200 microspheres

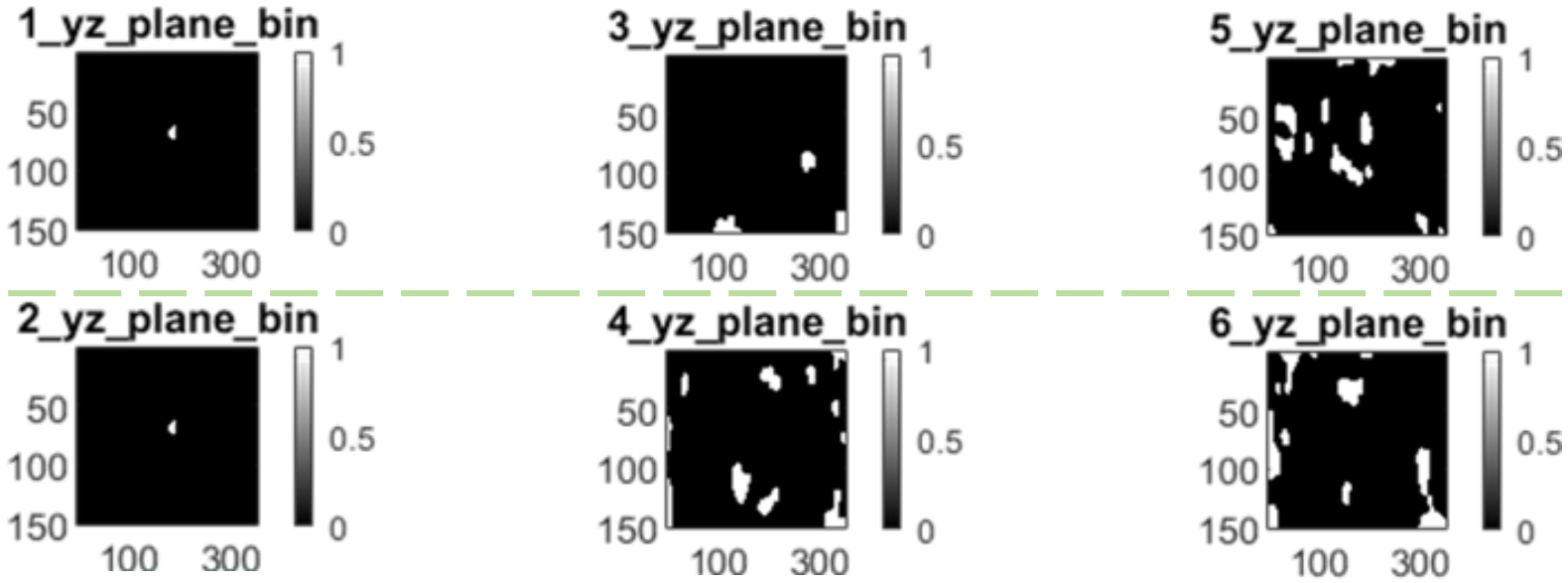


Sample	Mean % of Voxels
1	3.61
2	5.81
3	6.34

Ultrasound Imaging – Static Scans

- Segmented images for pebble samples





Sample #1 with no microspheres

Sample #2 with 100 microspheres

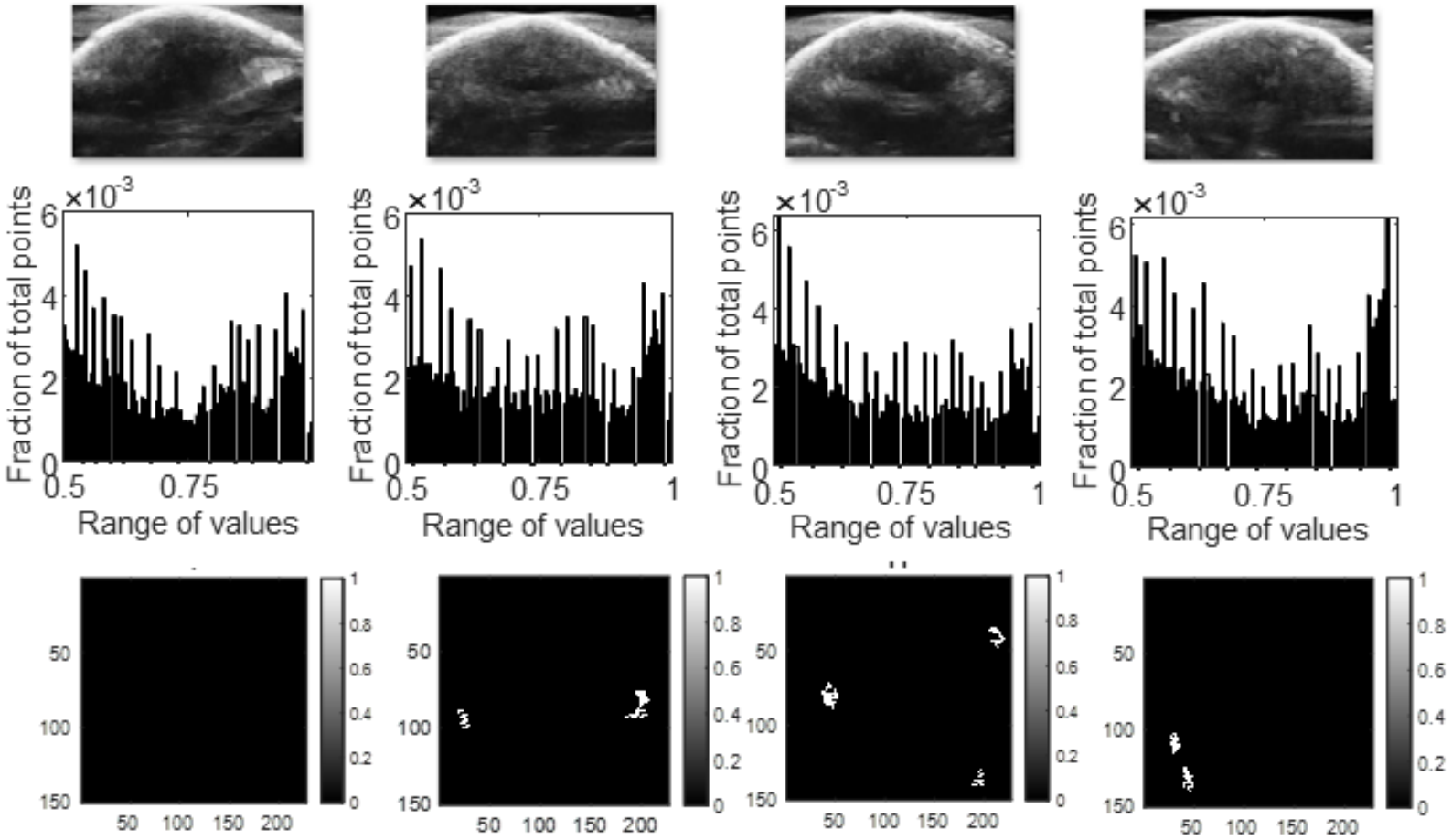
Sample #3 with 200 microspheres

Ultrasound Imaging – Rotating Scans

2D views of Sample #1 (no microspheres)

Histograms of upper half region from captured images

Segmented 2D images

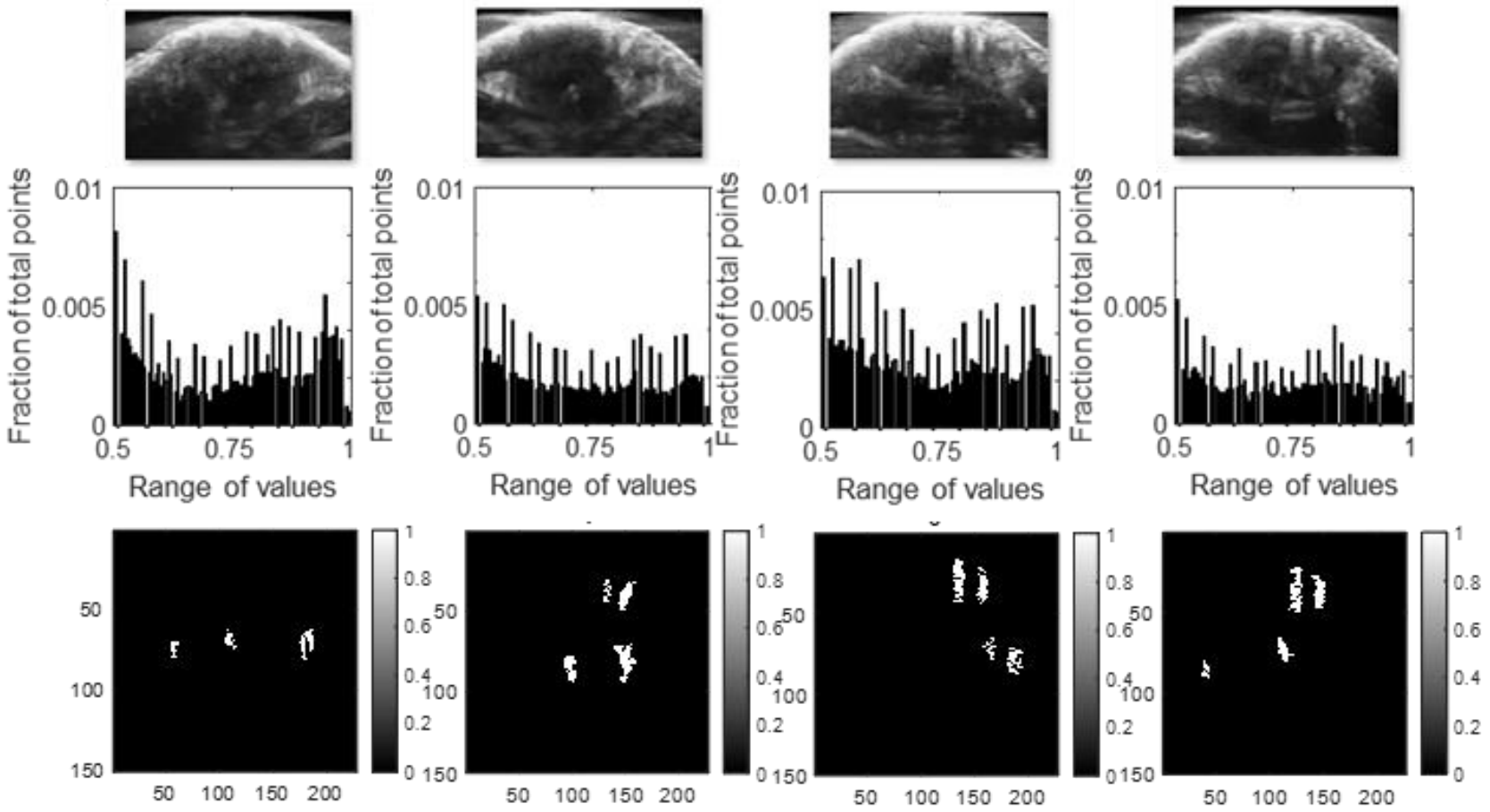


Ultrasound Imaging – Rotating Scans

2D views of Sample #2 (100 microspheres)

Histograms of upper half region from captured images

Segmented 2D images

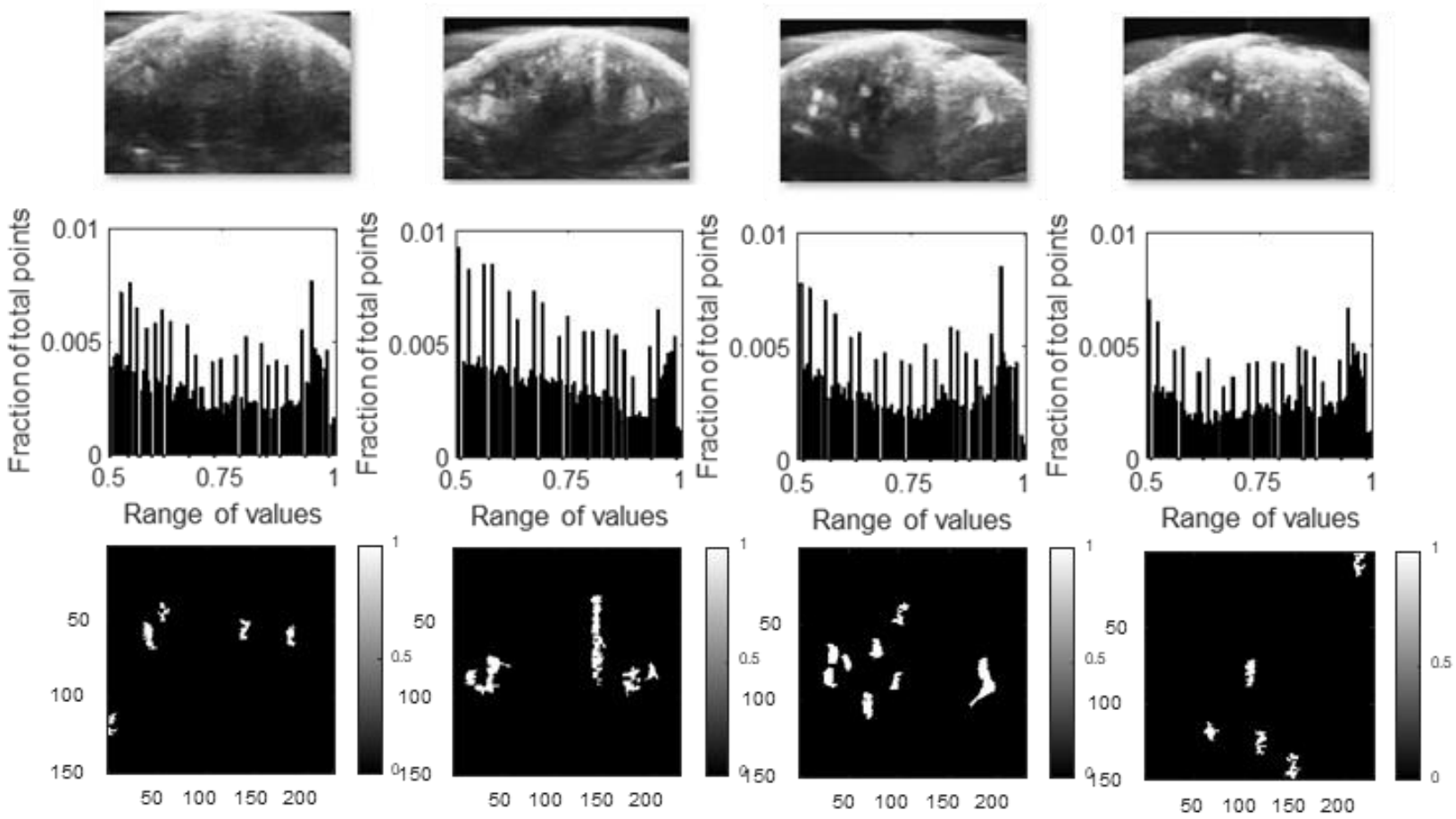


Ultrasound Imaging – Rotating Scans

2D views of Sample #3 (200 microspheres)

Histograms of upper half region from captured images

Segmented 2D images

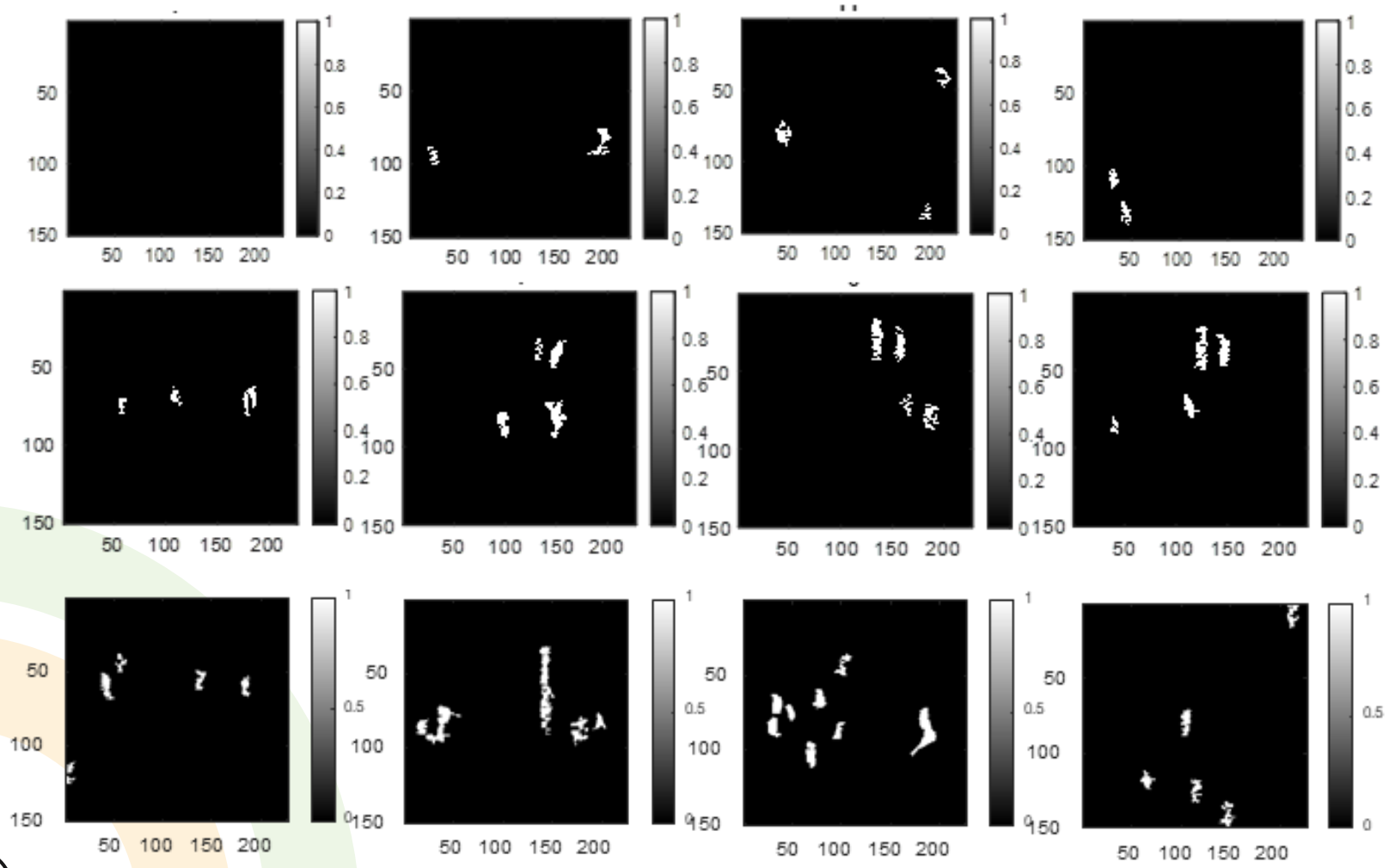


Ultrasound Imaging – Rotating Scans

Sample #1

Sample #2

Sample #3



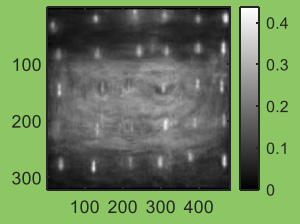
Sample	Mean % of Voxels
1	19.16
2	21.55
3	26.80

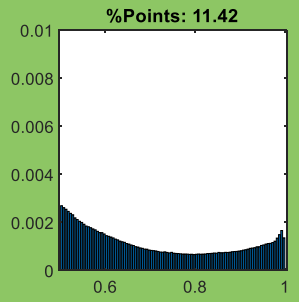
Microsphere Modification

YSZ Microspheres

6mm spacing

Projection Image

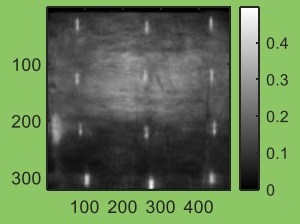


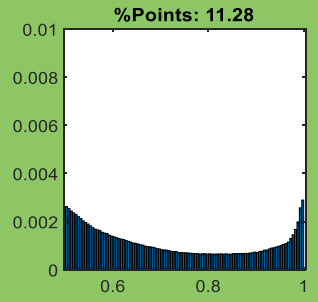


Hist.% (0.5 to 1)

12mm spacing

Projection Image



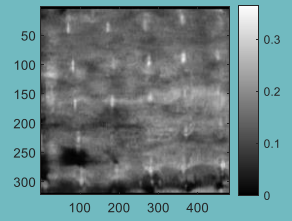


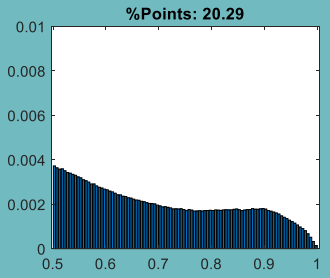
Hist.% (0.5 to 1)

Alumina Microspheres

6mm spacing

Projection Image

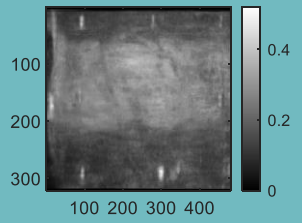


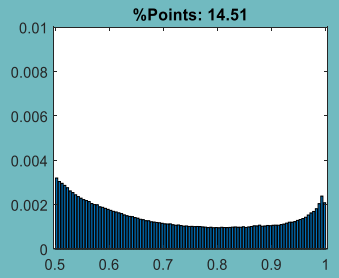


Hist.% (0.5 to 1)

12mm spacing

Projection Image

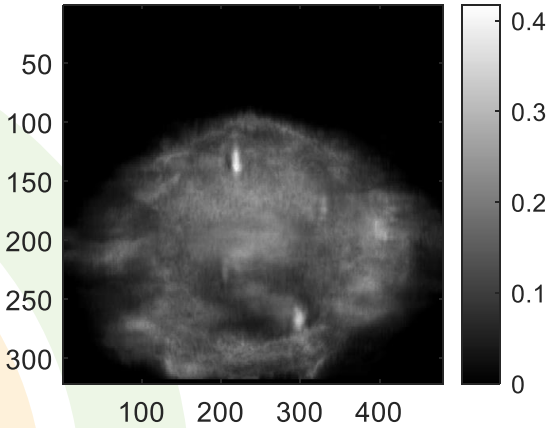


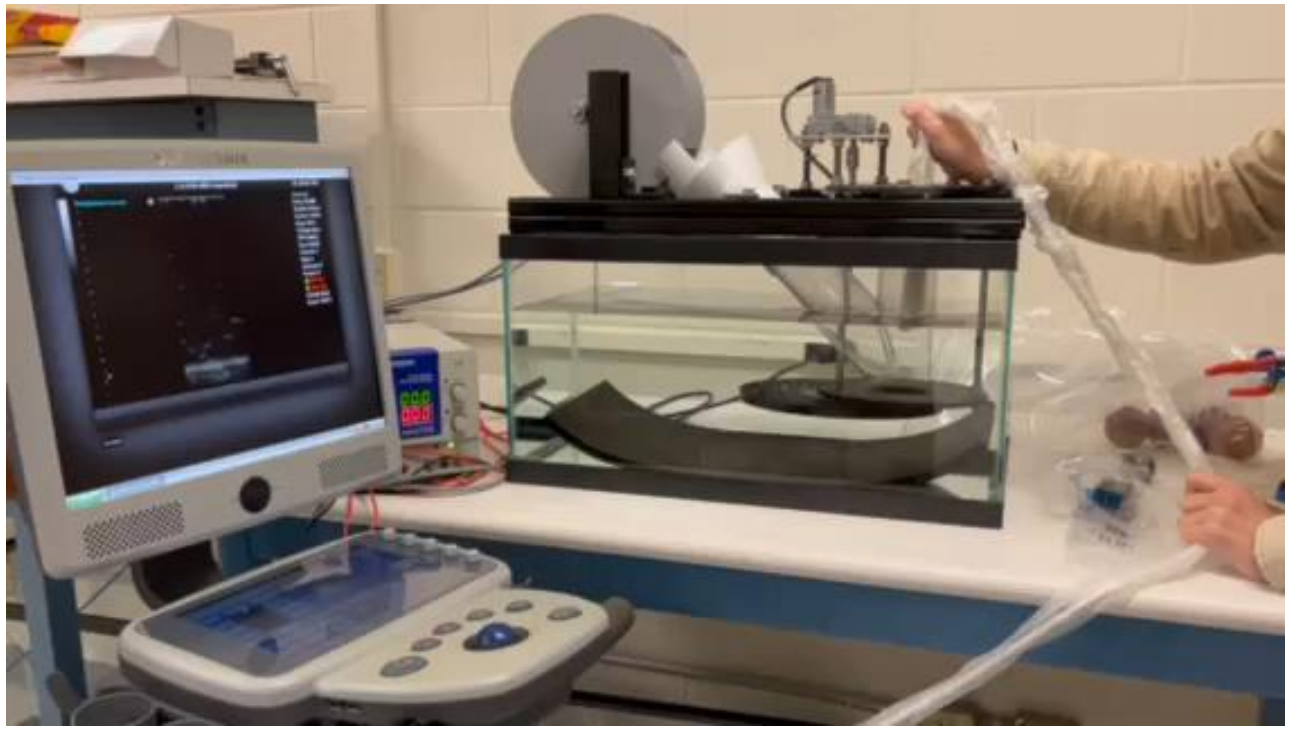


Hist.% (0.5 to 1)

Pebble Mockup

Projection Image





Recent Development

- Microsphere material changed
  - YSZ → Alumina
- Graphite (moderator) pebbles provided by Kairos
  - 4cm diameter (not 6cm)
  - Extrinsic features: grooves on surface
  - 10 pebbles for testing
- Scanning medium cannot be any liquid or liquid-like substance
  - Scans must be completed dry
  - Option for scanning after pebble discharge for batch accounting: TBD
- Other scanning methods/technologies under consideration

Remaining FY22 Work

- Exploring non-liquid medium for scans
- Engaging with designers and fuel fabricators
- Investigating other imaging technologies
  - Candidate technologies under consideration at TAMU and Argonne

Conclusions

- Laboratory setup deployed with sorting and scanning technology
  - At TAMU by EOCY22
- Engagement with industry requires reconsideration of scanning technologies
  - Candidate technologies available

Questions?