GAIN-EPRI-NEI ADVANCED REACTOR SAFEGUARDS & SECURITY WORKSHOP

Argonne NATIONAL LABORATORY

MATERIAL CONTROL TECHNIQUE VALIDATION FOR PEBBLE FUELED REACTORS

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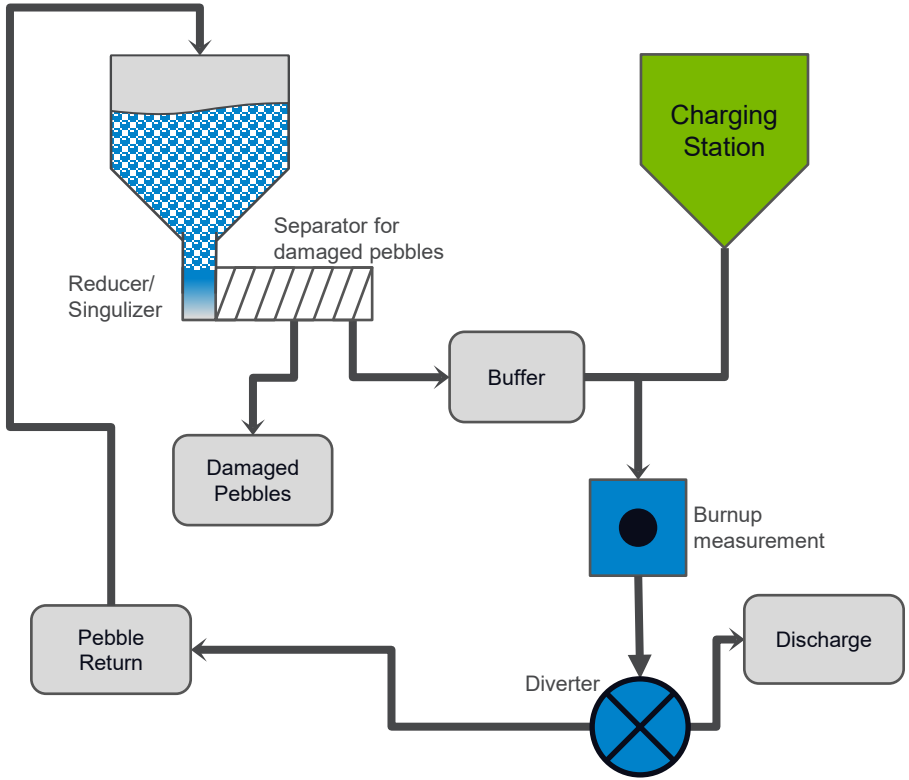
INTRODUCTION

- Developing a unique technique for rapid-identification of pebble types for material accountancy/process control
- Based on material control concept:
  - Embedded inert microspheres in outer graphite layer of the pebble
  - Imaging outer graphite layer for pebble classification
- Batch accounting – categorized by sets of item specifications
  - Initial enrichment
  - Date of core introduction
- Experimental validation under way between Argonne National Laboratory and Texas A&M University
- Project plan uses surrogate (non-nuclear) fuel pebbles

ACCOUNTING PEBBLE FUEL

- Material accounting and control is essential for effective safeguards implementation
- Item accounting of pebbles is unfeasible
  - ~10^5 pebbles in reactor vessel
- Challenges of radiological (gamma) scanning of pebbles for burnup measurements
  - Uncertainty of using burnup as distinguishing characteristic
  - Similar burnup achieved by different paths
  - Required cooling time for burnup measurements



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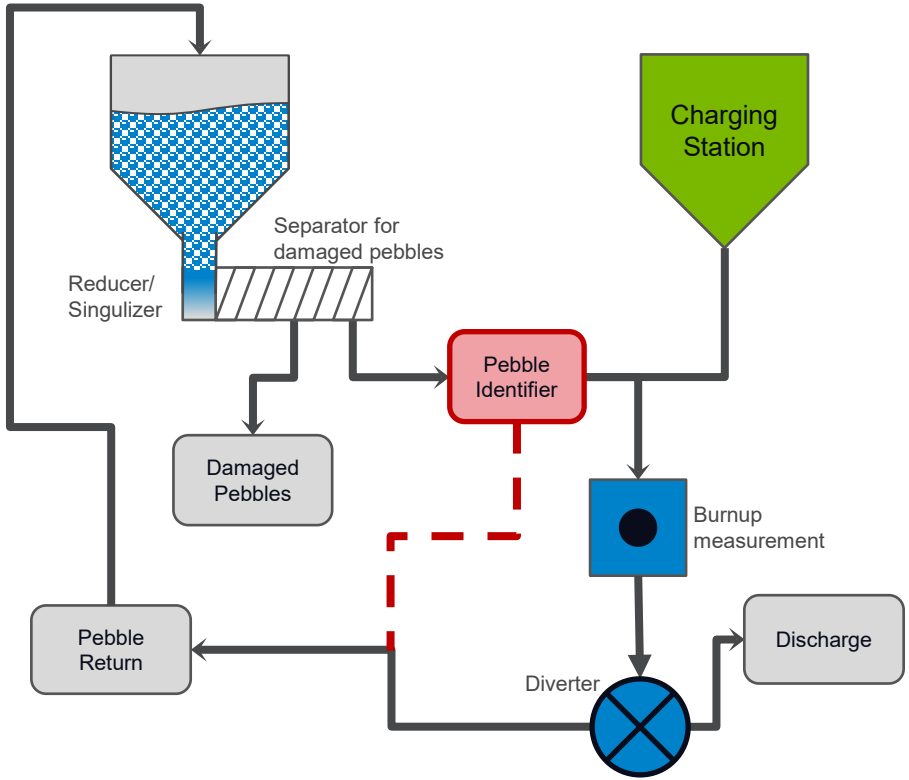
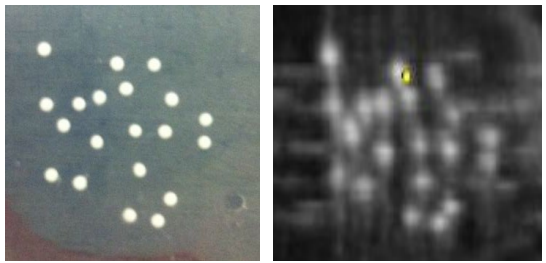
- Radiological (gamma) scanning of pebbles for burnup measurements

- Extrinsic, non-radiological features to be used for accounting and control
  - Shortened ex-core time for pebbles
  - Dependent on fidelity of engineered features
  - Unique identification is challenging

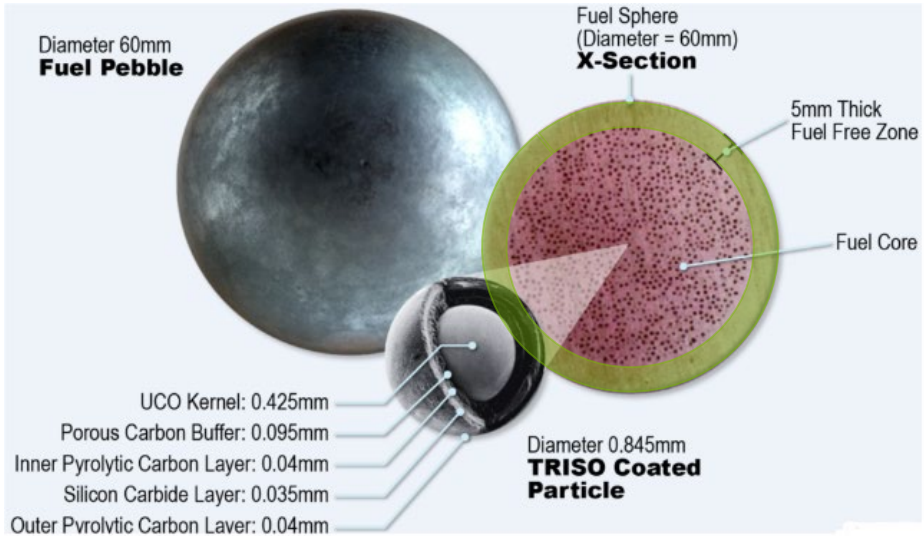


MATERIAL CONTROL & ACCOUNTING CONCEPT

- Pebble tracking using microspheres as an engineered unique identifier for material control/pebble tracking
  - Minimal impact on neutron multiplication factor (*k-eff)*
  - High thermal conductivity
  - Configuration of microspheres serve as unique identifier
- Item-type MC&A approach
  - Items-in/items-out

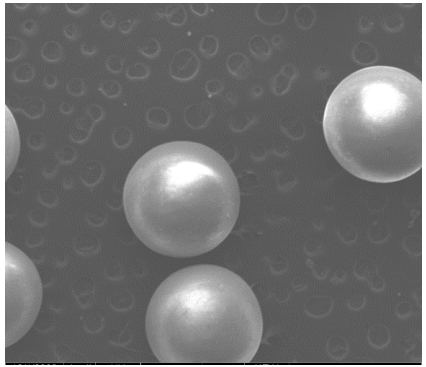


Comparison of initial image and ultrasound image and microspheres used to approximate a resolution for the imaging system.

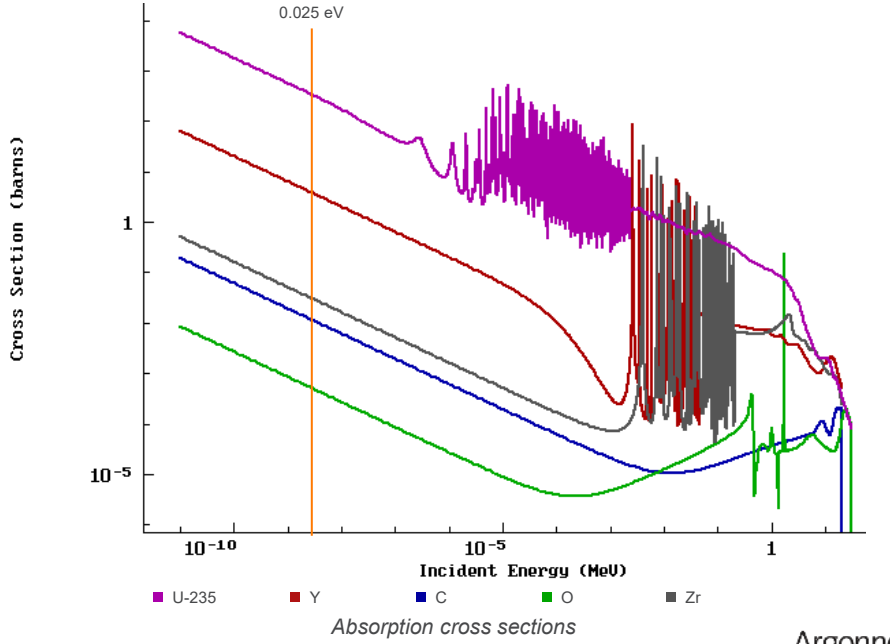


SURROGATE PEBBLE FABRICATION

- Embedding YSZ microsphere within graphite matrix
  - Yttria Stabilized Zirconia (Y_2O_3-ZrO_2) microspheres (1mm- and 2mm diameter)
    - Neutronically neutral
    - High thermal conductivity
    - Varying diameters



SEM micrographs of YSZ microspheres [2mm-diameter]



Absorption cross sections

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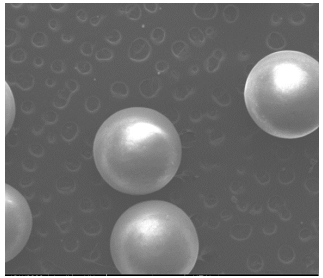
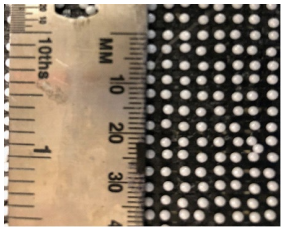
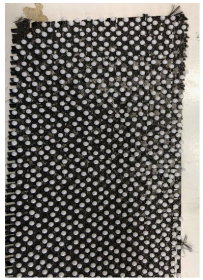
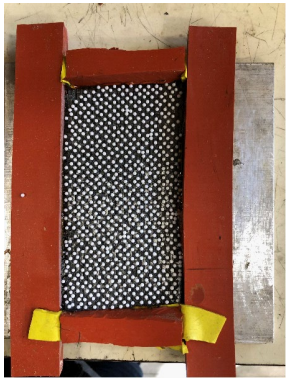
SURROGATE PEBBLE FABRICATION

- Embedding YSZ microsphere within graphite matrix
  - Yttria Stabilized Zirconia (Y_2O_3-ZrO_2) microspheres (1mm- and 2mm diameter)
  - Controlled square and triangular orientations of varied spacings
  - Planar and curved surfaces







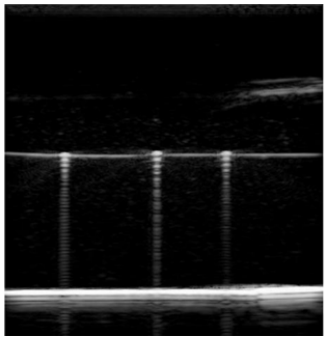


YSZ microsphere distribution in CF matrix (square and triangular lattices)

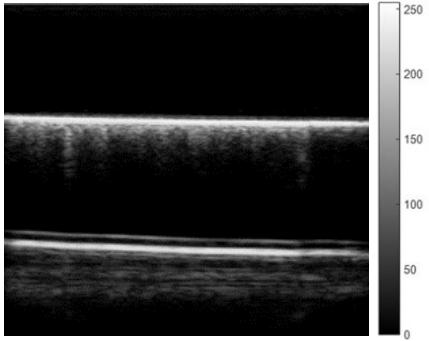
Surrogate glass pebble with YSZ microspheres

IMAGING SYSTEM FOR UNIQUE IDENTIFICATION

- Ultrasound imaging system (COTS):
  - Ultrasonix Sonix Touch ultrasound imaging system
- Preliminary controlled experiment for assessing echogenicity properties of YSZ microspheres
  - Medium:
    - Gelatin phantom
    - Graphite matrix
  - Orthogonal scanning paths
  - Configurations:
    - Sample 1: 3-mm spacing
    - Sample 2: 6-mm spacing



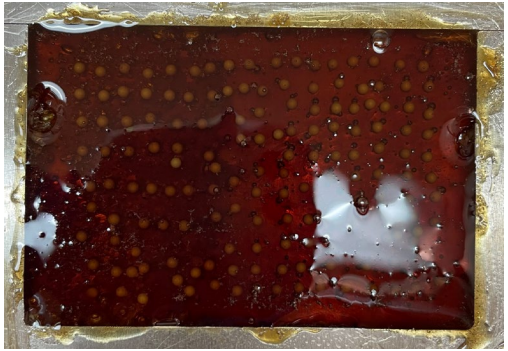
Microspheres in transparent gelatin phantom



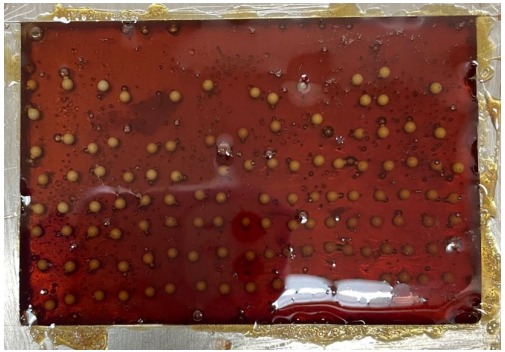
Microspheres in graphite matrix

IMAGING SYSTEM FOR UNIQUE IDENTIFICATION

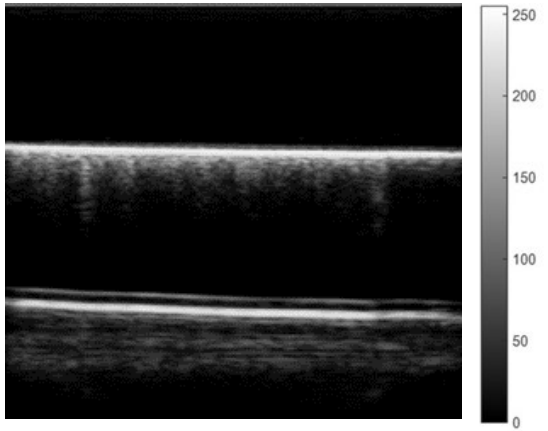
- Microsphere configurations
  - Sample 1: 3-mm spacing
  - Sample 2: 6-mm spacing
- Histogram data
  - In opaque medium, microspheres are darker than background
    - More darker pixels correlate to more microspheres
  - Lower histogram peak = higher number of microspheres in VOI



Sample 1: 3mm spacing



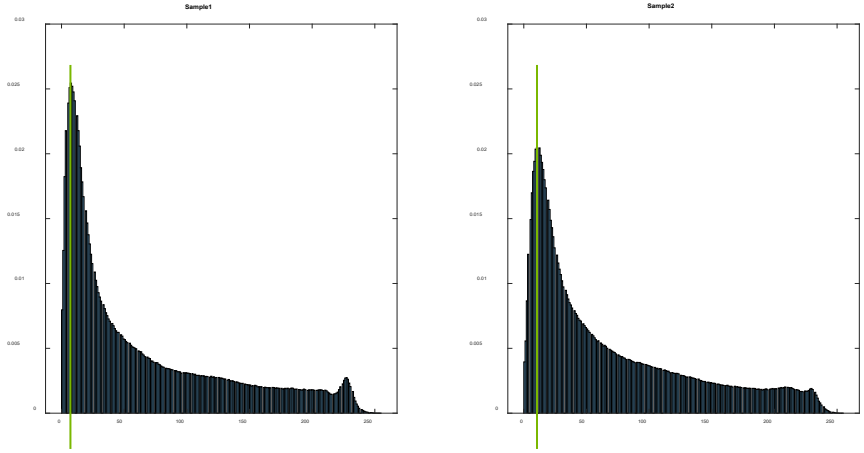
Sample 2: 6mm spacing



Microspheres in graphite matrix

IMAGING SYSTEM FOR UNIQUE IDENTIFICATION

- Identification of batches or types of pebbles possible based on microsphere density
  - Between samples 1 & 2 (3mm-spacing and 6mm-spacing), resolution is 1.17%
  - Discretized densities for differing types of pebbles
    - Lack of microspheres can be identified
    - Resolution of microsphere imaging can be used for varying pebble enrichment levels



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In Sample 1, a lower peak implies more images have darker pixels which signifies higher density of microspheres.

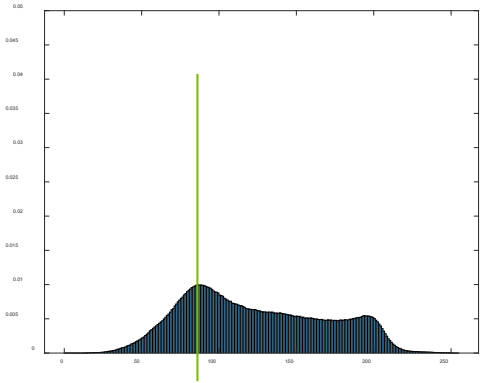
More spacing samples needed for better characterization of uncertainty

IMAGING SYSTEM FOR UNIQUE IDENTIFICATION

- Second attempt yielded 17 intensity peak separation between 3mm and 6mm spacing
  - Allows for more confidence in discretization
  - Alternative graphite matrix curing process provides easier microsphere identification

Better understanding of pebble fabrication process in graphite matrices is needed for identifying YSZ microspheres

Sample 1



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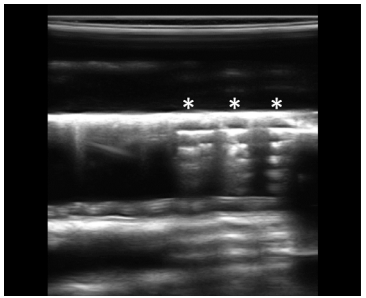
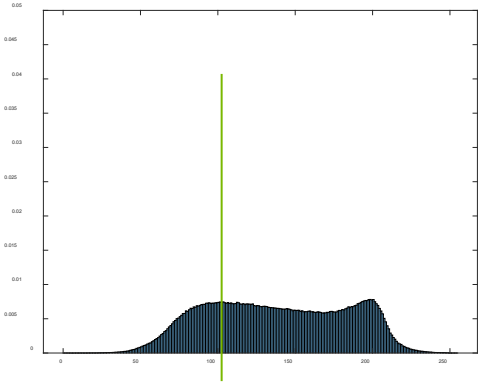


Sample 2



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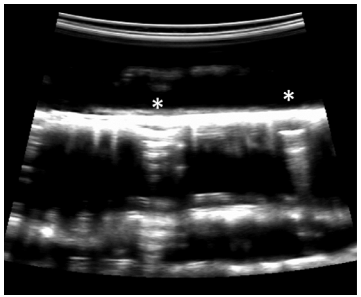

Asterisks denote identified microspheres

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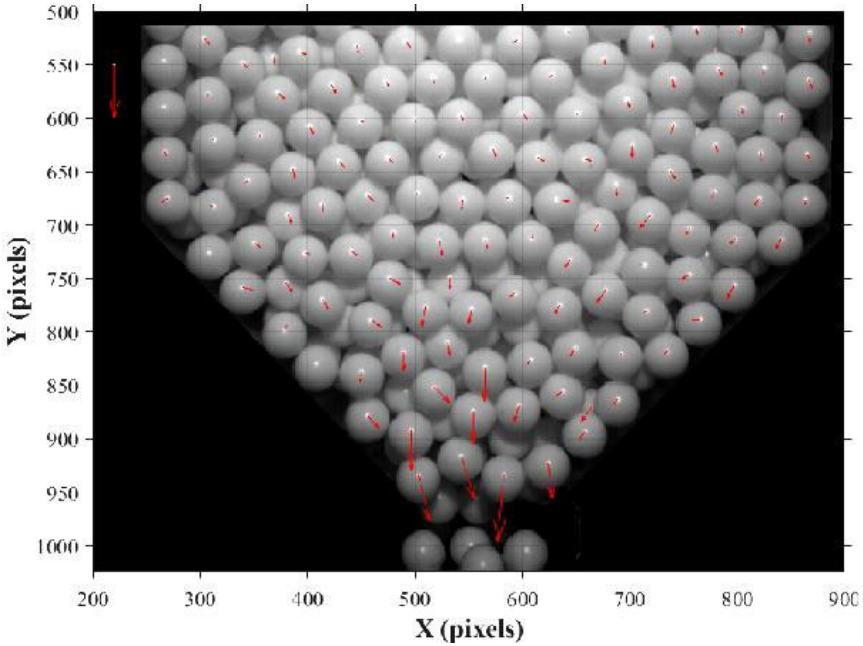
PEBBLE SAMPLING SYSTEM

- Review of pebble sampling/separator systems
  - THTR
  - HTR-10
  - AVR
- Modeling movement through reactor vessel upon discharge
  - Experimental model scaled to 25.4mm-diameter spheres
- Pebble singulizer for individual scans
  - Statistical sampling of pebbles/batches



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IMPLEMENTATION APPROACH

- Imaging/identification system as complementary to burnup measurement system
  - Pebble singulizing occurring regardless
  - No cooling time required
  - Decrease pebble time ex-core
  - Expedited adjudication of pebble type by
    - Uranium enrichment
    - Input batch
  - Secondary classification of pebbles with extrinsic feature (additional to burnup measurement)
- Pebble scanning system prototype to be laboratory deployed in summer 2021

REMAINING WORK

- Determining limitations of system being used to discretize pebble types instead of uniquely identifying individual pebbles
  - Static scans of spherical surface assuming homogeneous distribution of microspheres
  - Based on resolution of imagining system and volume density of microspheres in graphite coating
  - Limited by YSZ microspheres in graphite matrix
    - Required engagement with fuel fabricators

CONCLUSIONS

- Potential for simplified monitoring/accounting approach via determination of pebble type and subsequent re-insertion
  - Non-radiological measurement
  - Rapid identification
  - Number of types dependent on system resolution
- Prototype system for in-situ use
  - Target: end of FY21

Questions?