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X-ray Computed Tomography of Irradiated and Unirradiated AGR-3/4 Compacts

A preliminary examination

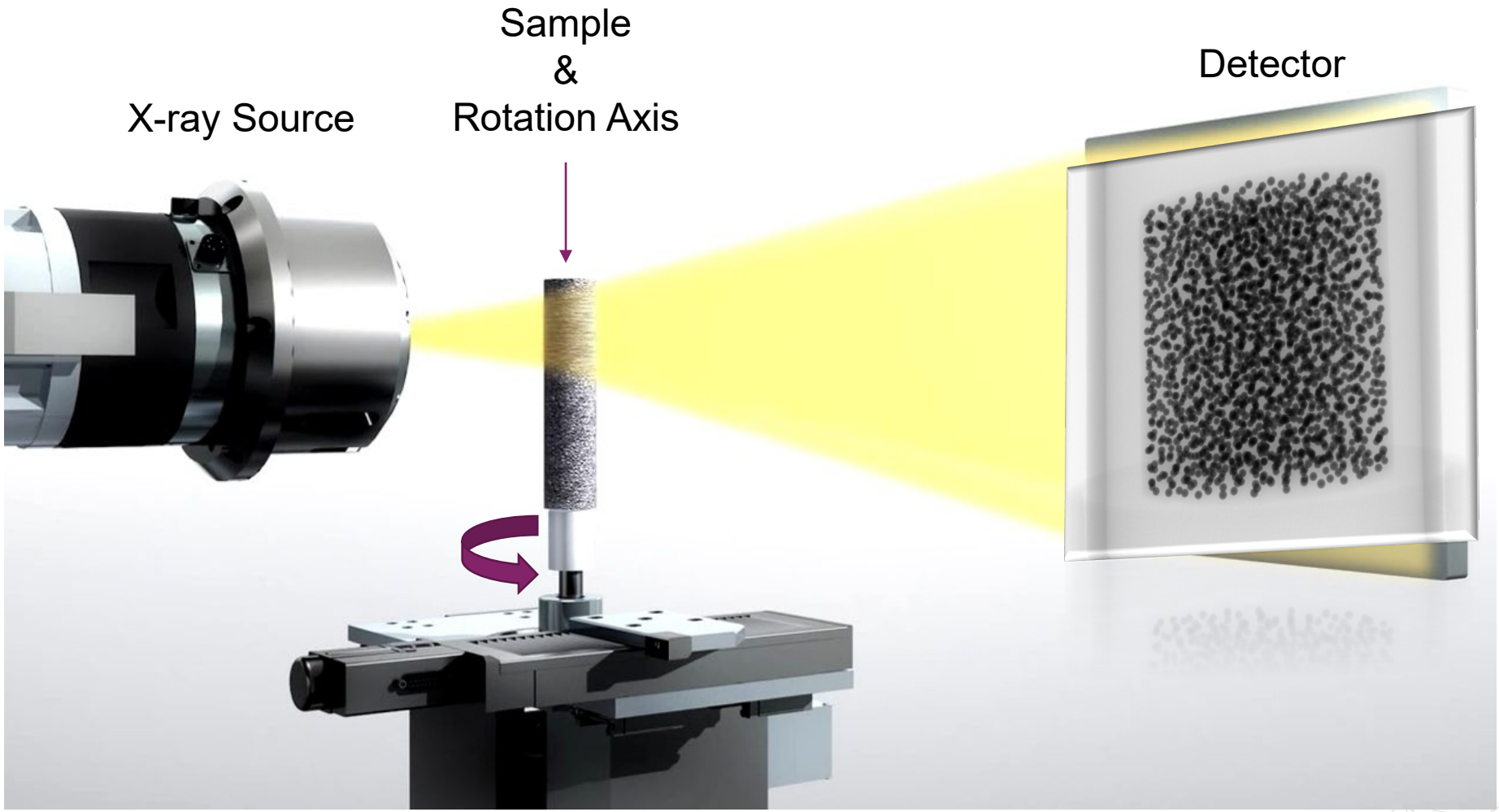
ART Advanced Reactor Technologies
GAS-COOLED REACTORS

What and Why?

- **What?**
  - Performed X-ray CT (XCT) on irradiated AGR-3/4 compacts
    - Apparatus design
    - Imaging results
    - Preliminary analysis
      - Extruded kernels
      - DTF Identification

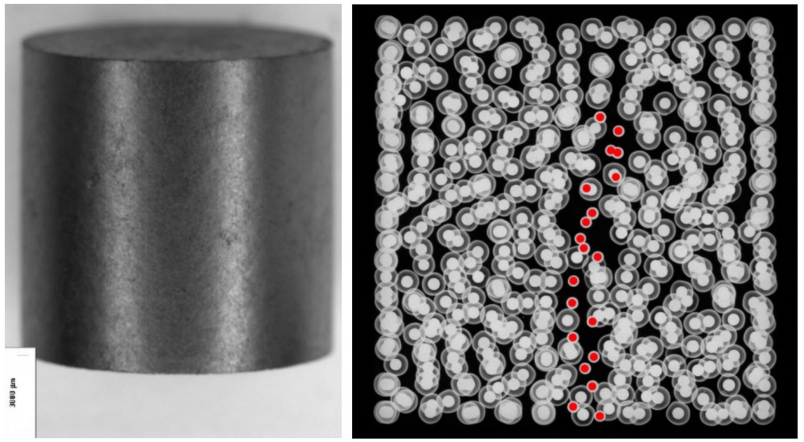
- **Why?**
  - Can provide non-destructive 3D perspective to enhance/compliment current PIE
    - Potentially better quantitative measurements of certain features
    - Better means of understanding any spatial distribution(s)

X-ray Computed Tomography (XCT)



Compacts Examined

- **AGR-3/4 compacts**
  - Compact Dimensions:
    - Length- ~12.5 mm
    - Diameter- ~12.3 mm
  - Particles:
    - ~1898 TRISO-coated driver particles
    - 20 Designed To Fail (DTF) particles



- **Examined 2 Irradiated Compacts and 2 Unirradiated Compacts**

Irradiated Compact Details:

Compact ID	Capsule #	Compact Position	Burnup (% FIMA)	Fast Neutron Fluence ($\times 10^{25}$ n/m^2, E>0.18 MeV)	Temperature (°C)[a]
12-4	12	4	4.85	1.19	845
7-1	7	1	14.92	5.28	1276

Radiograph from Hunn, J., Trammell, M. P., Montgomery, F.C., 2011, Data Compilation for AGR-3/4 Designed-to-Fail (DTF) Fuel Compact Lot (LEU03-10TOP2/LEU03-07DTF-OP1)-Z, Oak Ridge National Laboratory, ORNL/TM-2011/124, 2011.

Imaging Challenge

Irradiated Compact:

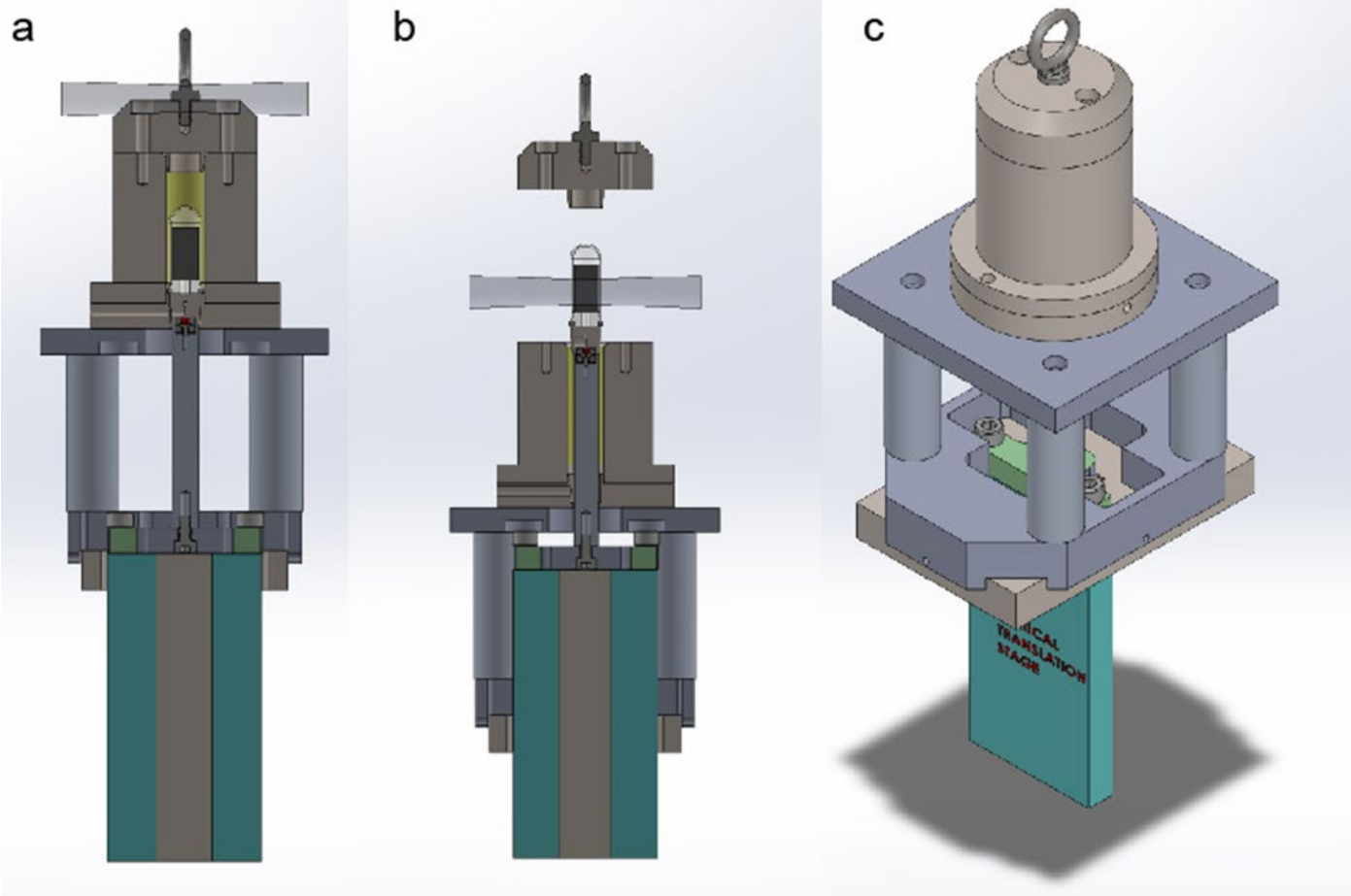
Compact ID	γ dose (mrem/hr)*	γ dose (mrem/hr)+	β dose (mrem/hr)*	β dose (mrem/hr)+
12-4	3,100	350	23,700	3,150
7-1	12,000	800	>50,000	3,900

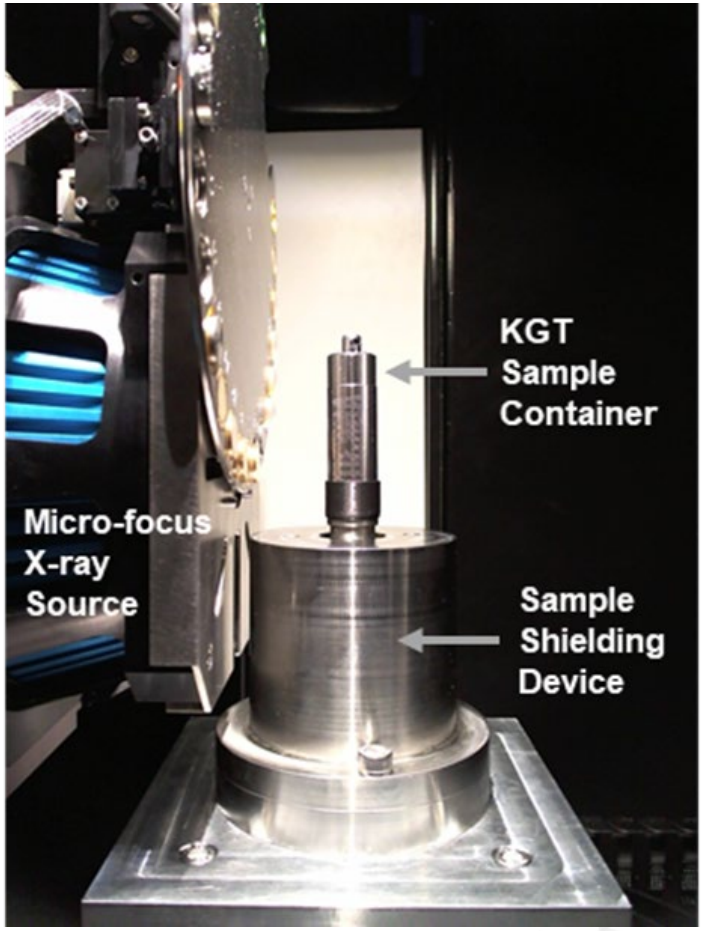
*- Dose at contact with sample

+- Dose at 30 cm from sample

- **Possible Challenges**
  - Minimizing dose to handling personnel and instrumentation
    - Significant γ dose difficult to shield for during sample handling
    - X-ray detector sensitive to γ and any x-rays generated from deaccelerating β particles
  - Preventing HFEF contamination from impacting XCT system

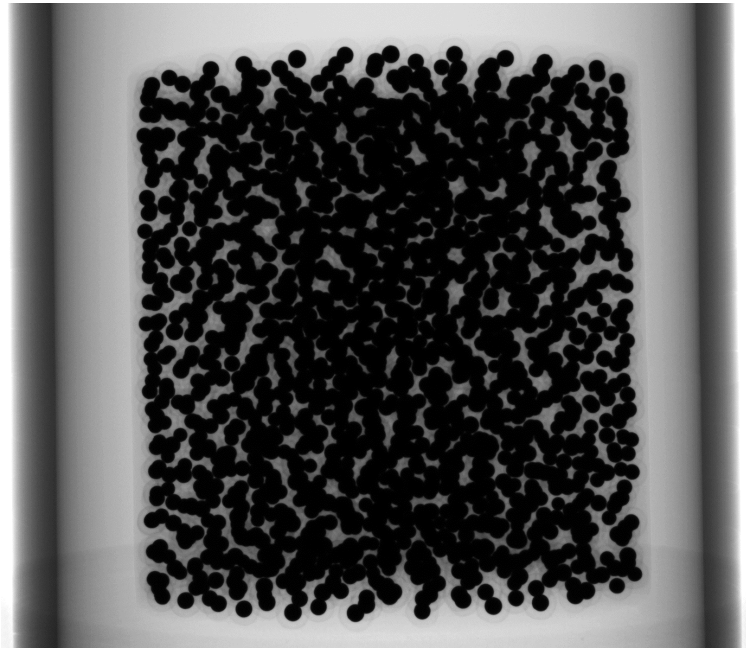
Sample Shielding Device

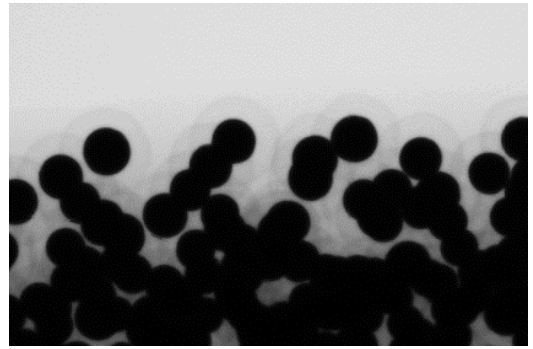


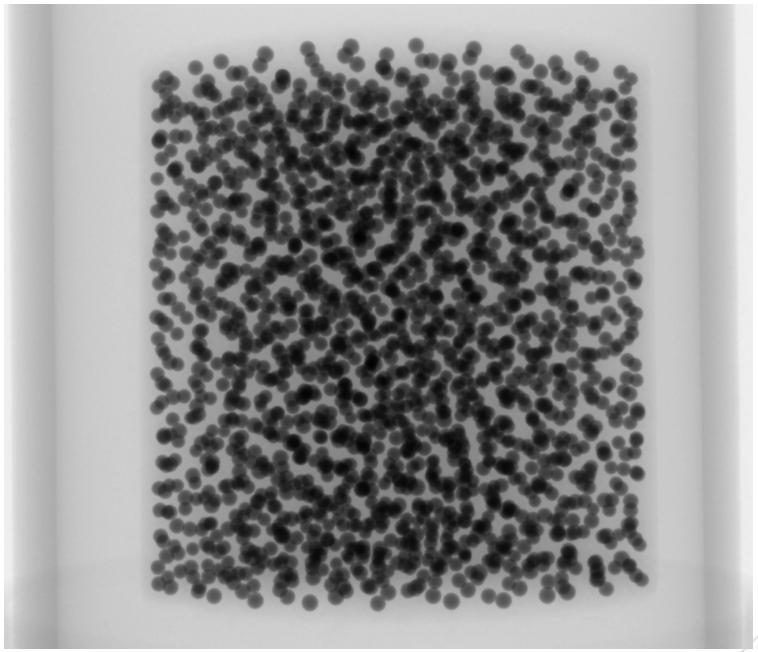


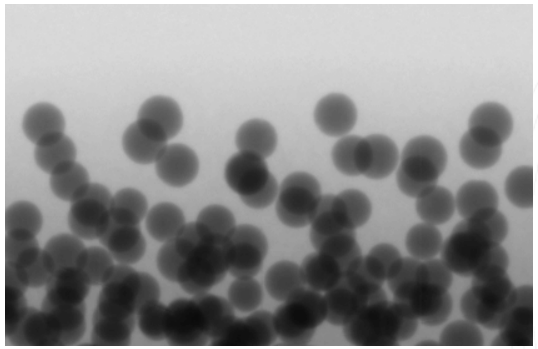
X-ray Imaging Conditions

- Low and high energy scans:
  - ~40 keV X-ray energy
  - ~110 keV X-ray energy
- Source to object distance:
  - 42.03 mm
- Source to detector distance:
  - 245.6 mm
- Radiographs:
  - 5001 over 360 degrees
- Frame averaging:
  - 20 frames per radiograph
- Detector pixel pitch:
  - 75 µm
- Reconstructed pixel size:
  - 10.93 µm

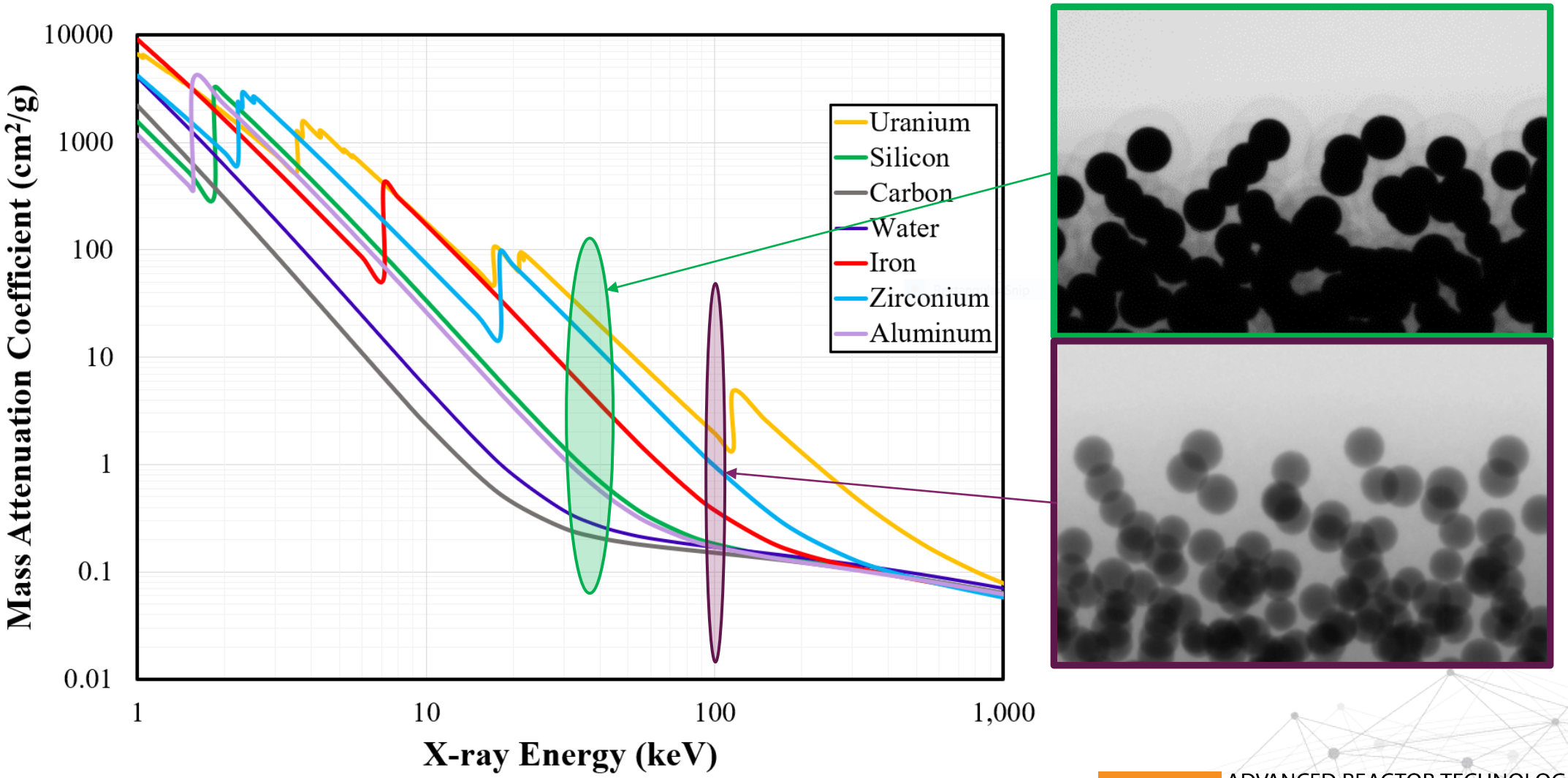




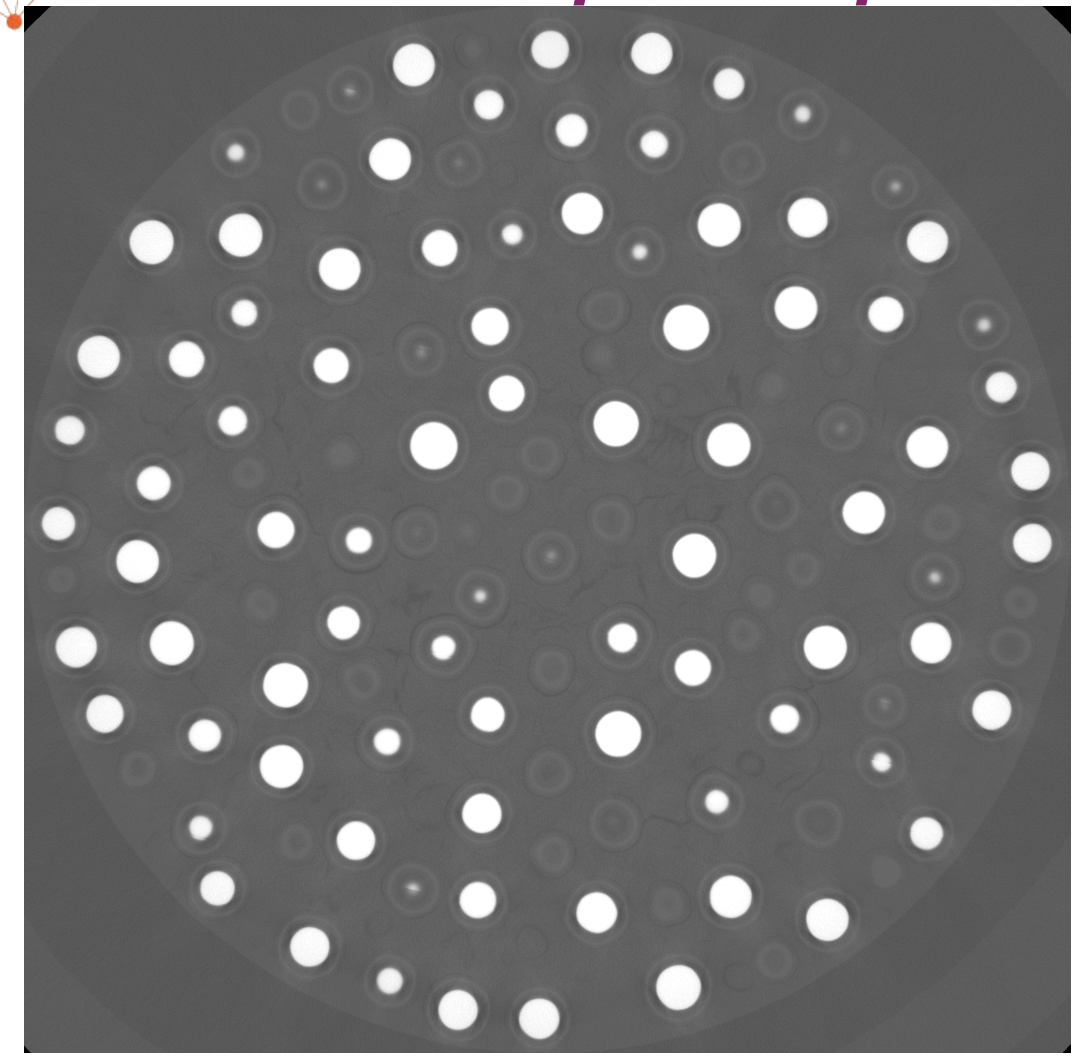




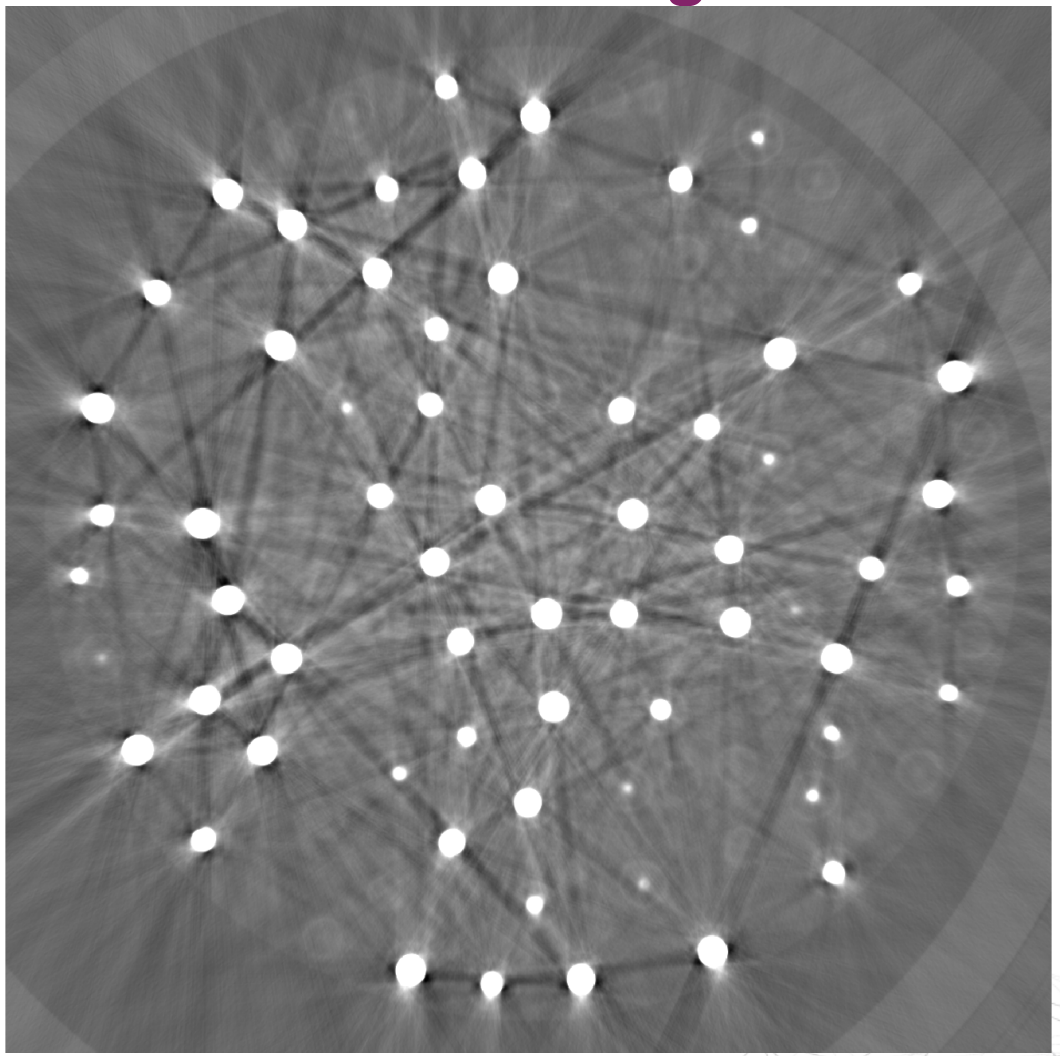
The compromise for X-ray imaging of TRISO fuel



The compromise for X-ray imaging of TRISO fuel:
Fueled sample comparison to more ideal surrogate

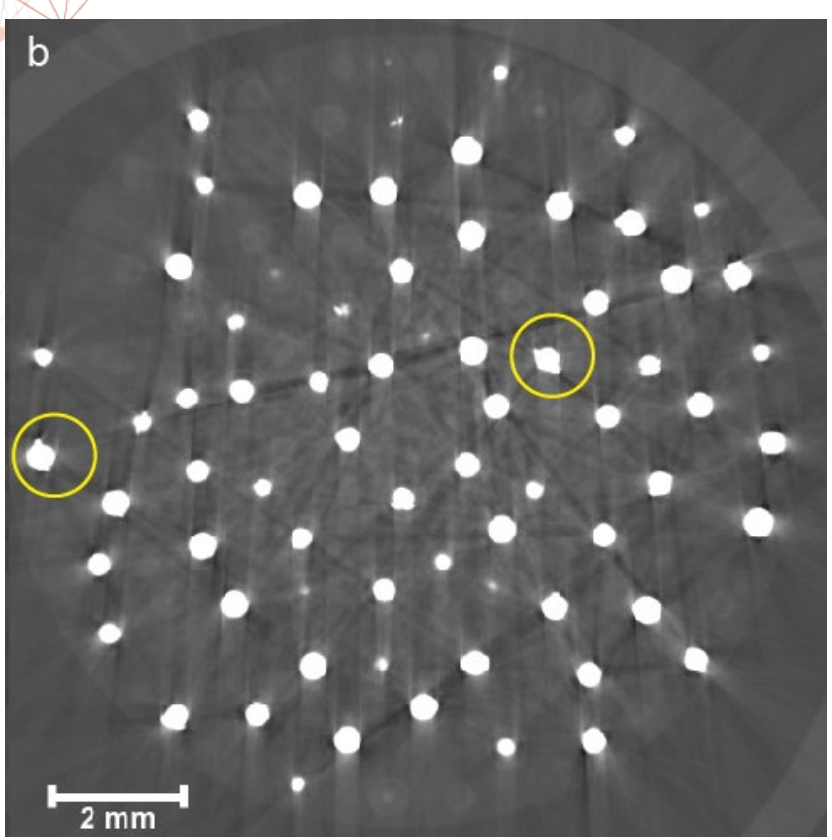


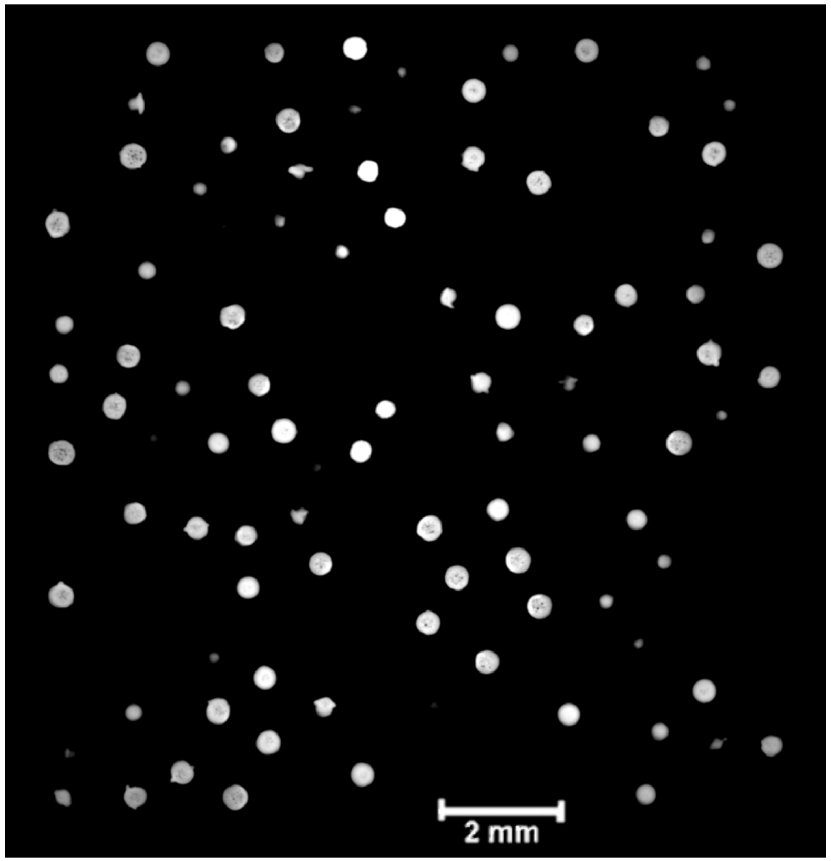
Zirconia Kernel Surrogate TRISO

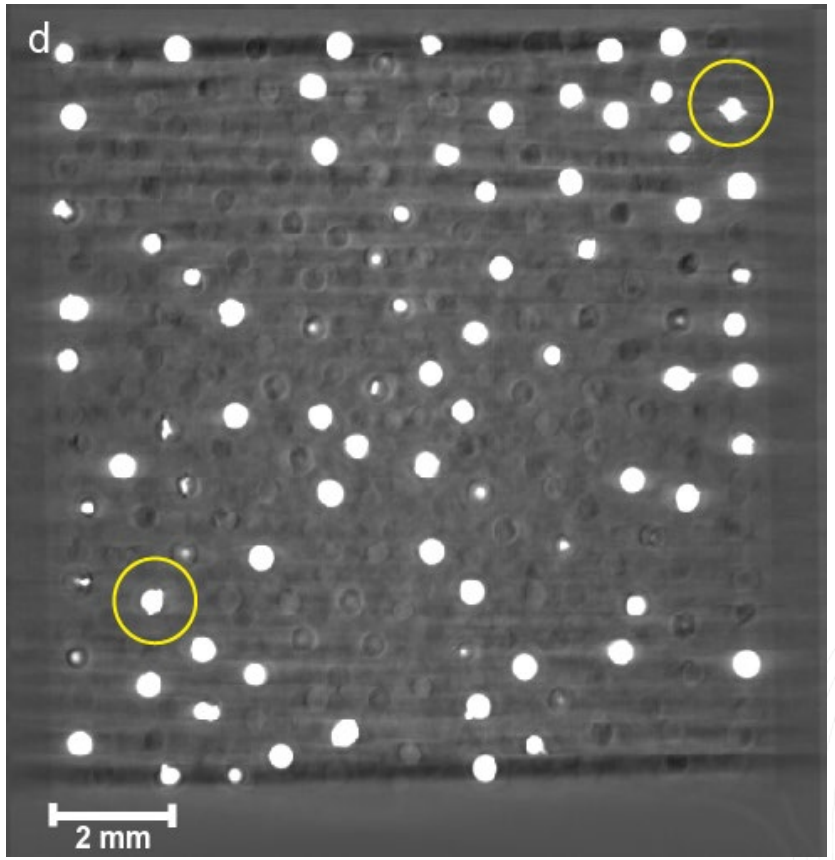


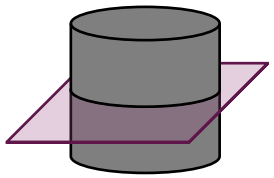
AGR-3/4 Unirradiated Compact Z104

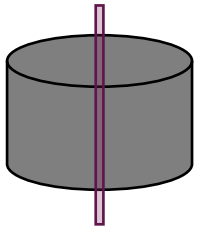
X-ray CT Imaging Results: Compact 7-1

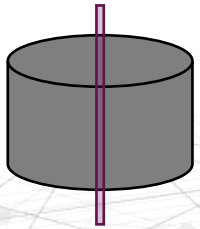




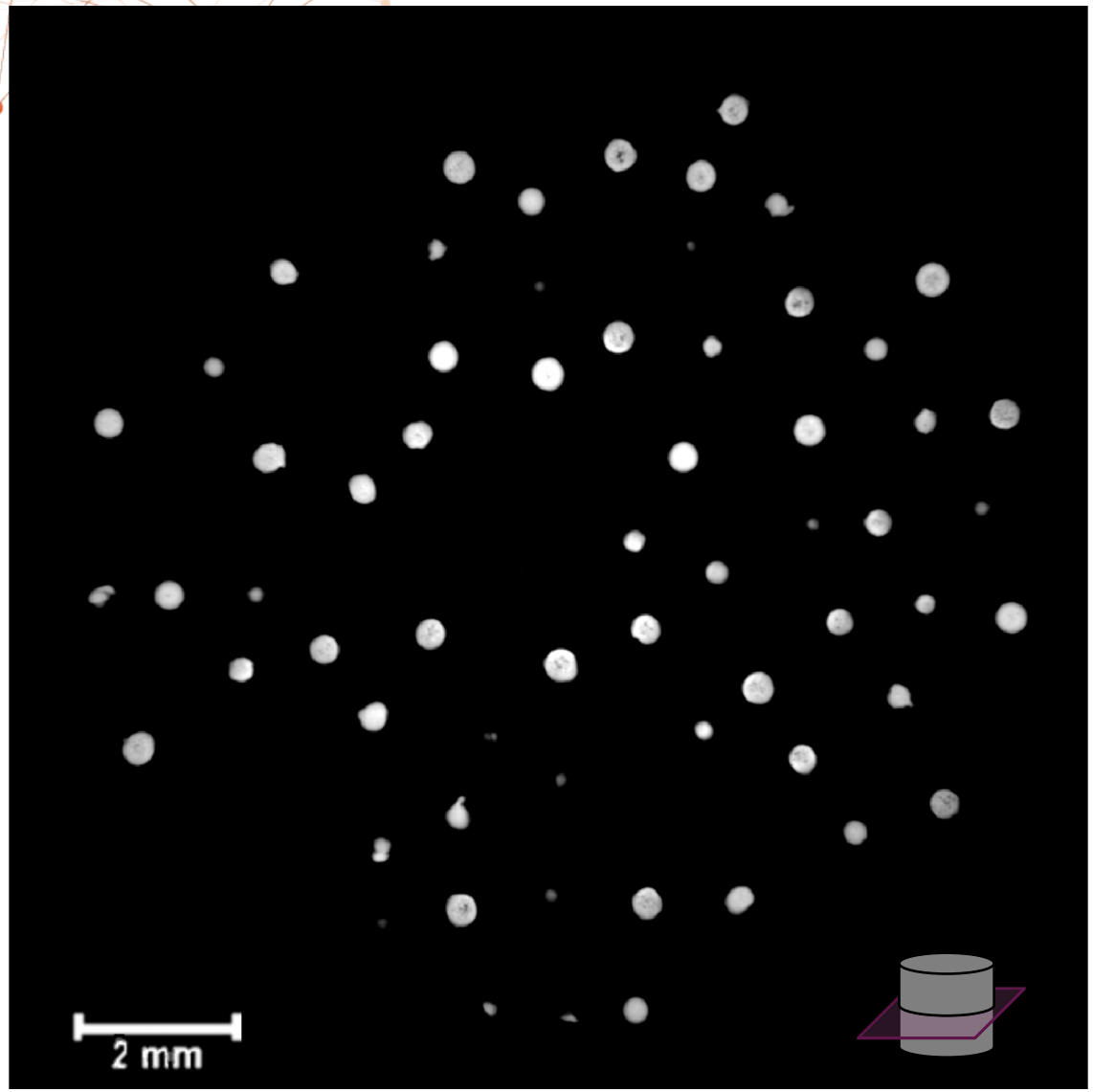


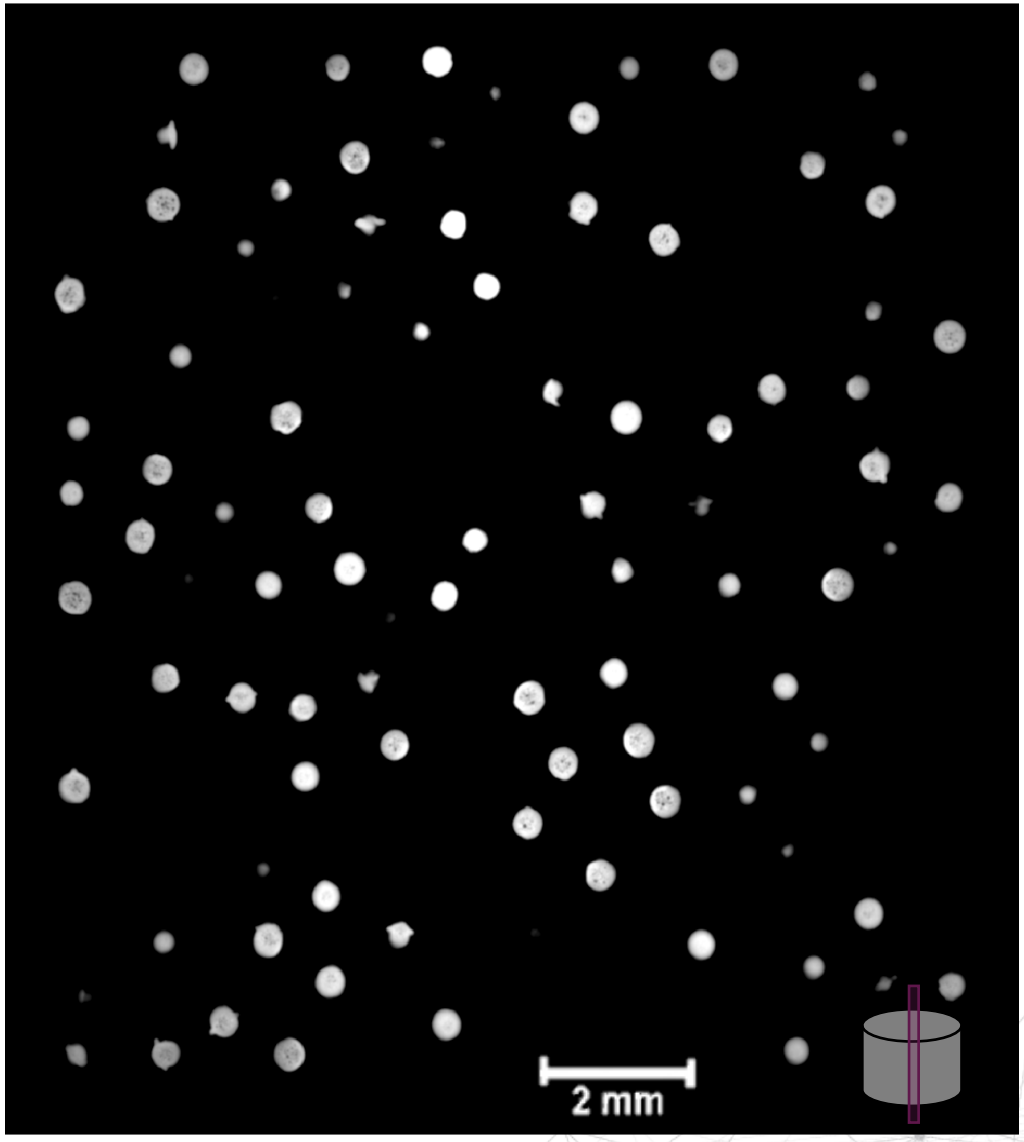




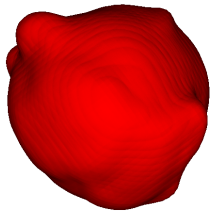


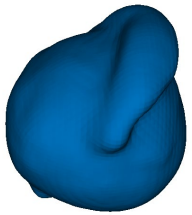
X-ray CT Imaging Results

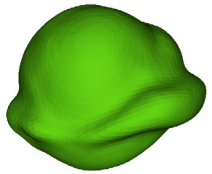


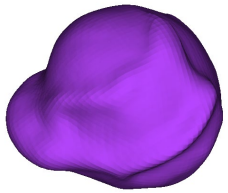


Extruded Kernels Compact 7-1









Sphericity used as metric to screen extruded kernels:

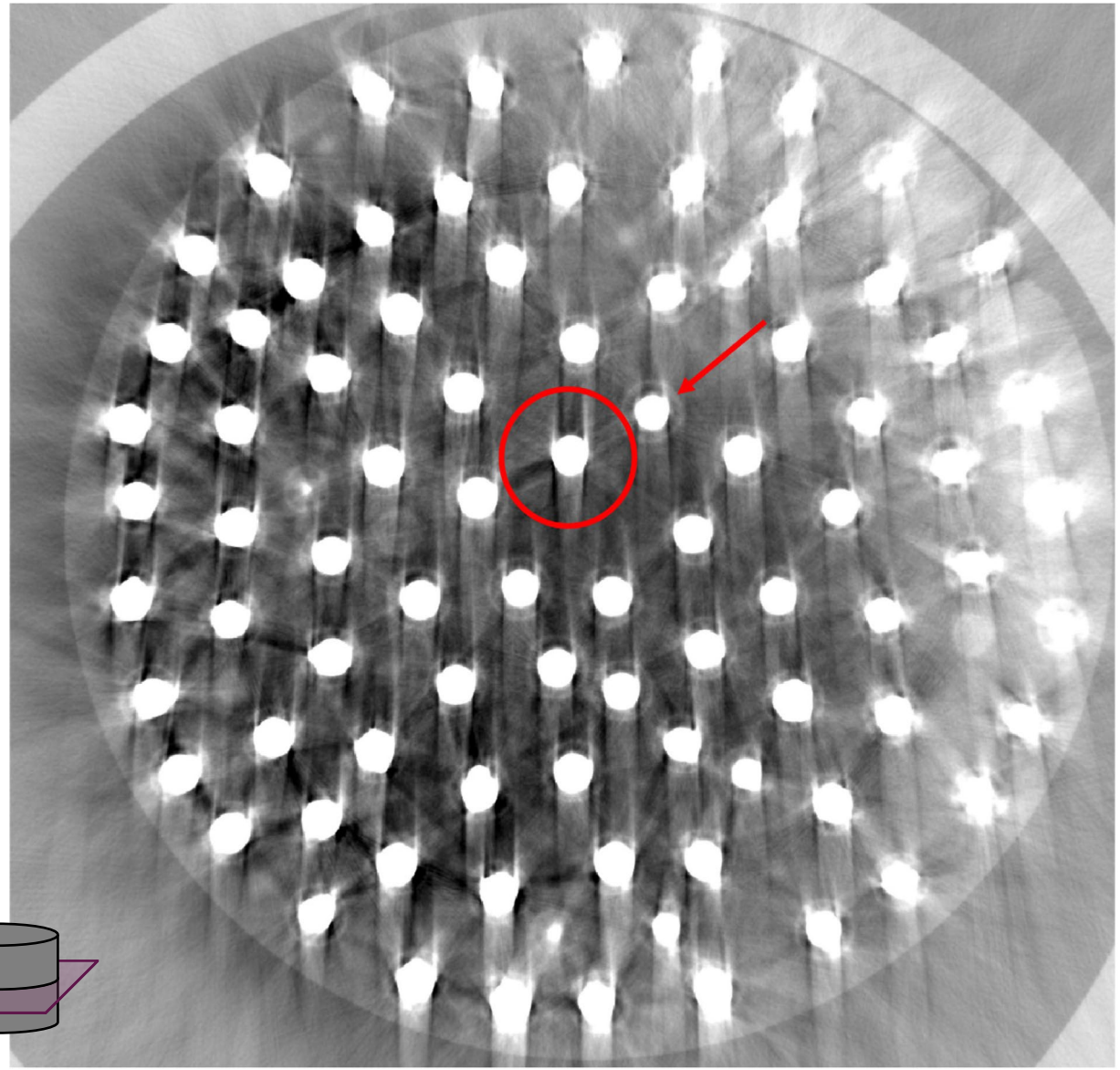
Kernel Sphericity $<$ 0.964

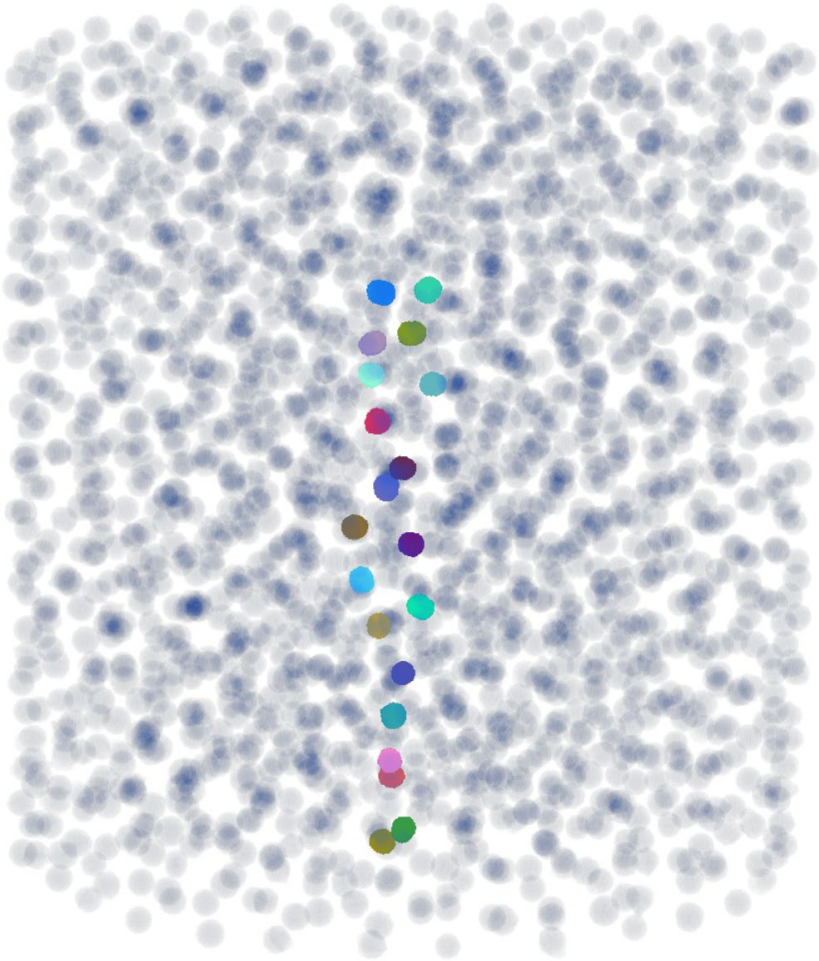
~33%, 635 of 1924 Kernels in 7-1 possess some degree of extrusion

From cross-sections of adjacent compact, Compact 7-2, extruded kernels resulting from buffer fracture was estimated to be 14.3% of total particles*.

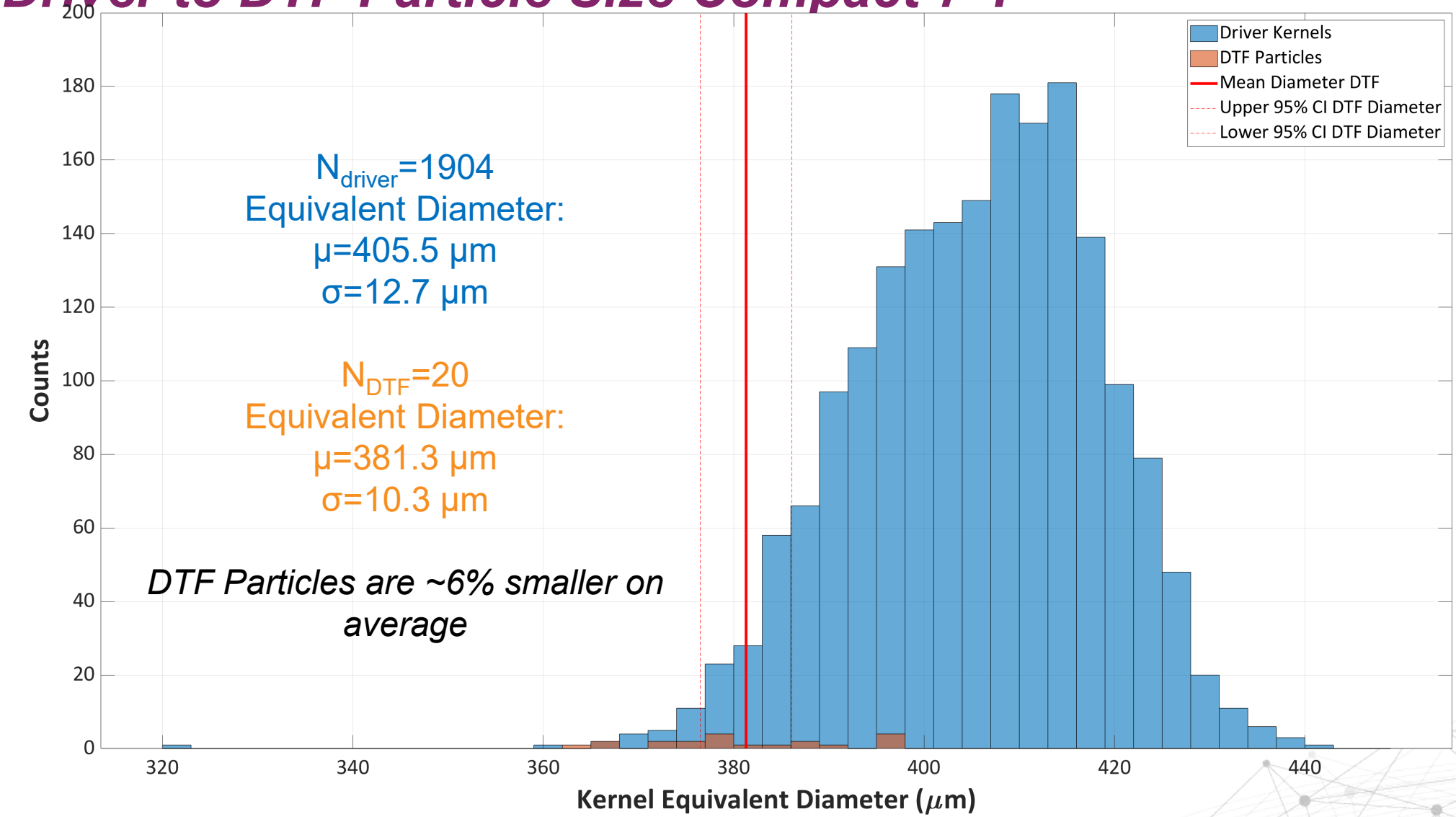
*Stempien, J. D. and Schulthess, J. L. 2020. "AGR-3/4 TRISO Fuel Compact Ceramography". INL/EXT-20-57610-Rev 0. Idaho National Laboratory.

DTF Identification:





Preliminary Comparison:
Driver to DTF Particle Size Compact 7-1



Note that equivalent diameters may not be correct, however a relative comparison is still likely valid.

Conclusions & Planned Work

- X-ray CT demonstrated on irradiated AGR-3/4 compacts
  - Provides a means for complimentary analyses to current AGR PIE
  - Enables quantification of spatial variation in features within compact

Remaining in FY2022:

- Planning to further examine and quantify kernel dimensional change, kernel extrusions, and DTF particles.
- Examine a limited number of deconsolidated particles from AGR-5/6/7 experiment

In FY2023:

- Image additional AGR-3/4 compacts at intermediate burnups to provide a broader range of fuel conditions for comparison
- Explore imaging AGR-5/6/7 compact (More challenging due to significantly higher radiation dose)
- Refine reconstruction methodology for “low-energy” CT scans of irradiated compacts
  - Ideally would enable additional information on matrix and potential pores and cracks to be extracted

Thank you for your attention

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