INL/MIS-25-84834-Revision-0

Advanced Post-Irradiation Fuel Characterization Methods for TRISO Fuel

May 2025

Changing the World's Energy Future

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Idaho National Laboratory

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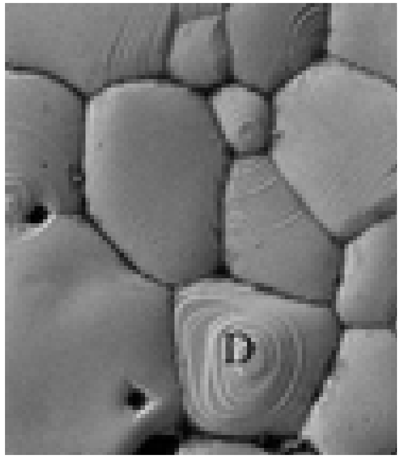
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

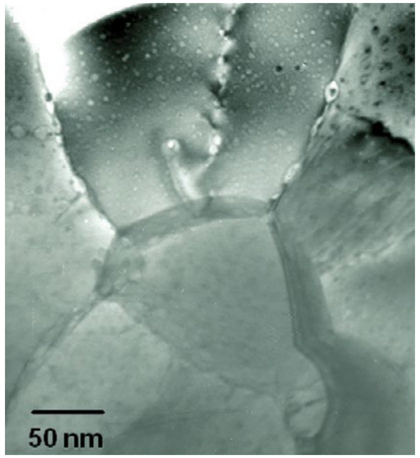
Post-Irradiation Examination (PIE) at Idaho National Laboratory (INL)

Fuel assembly (3 m)

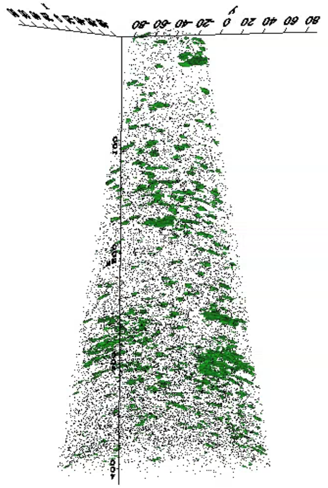
Fuel pellet
1 cm (10^{-2})



UO_2 grain 10 µm (10^{-5})



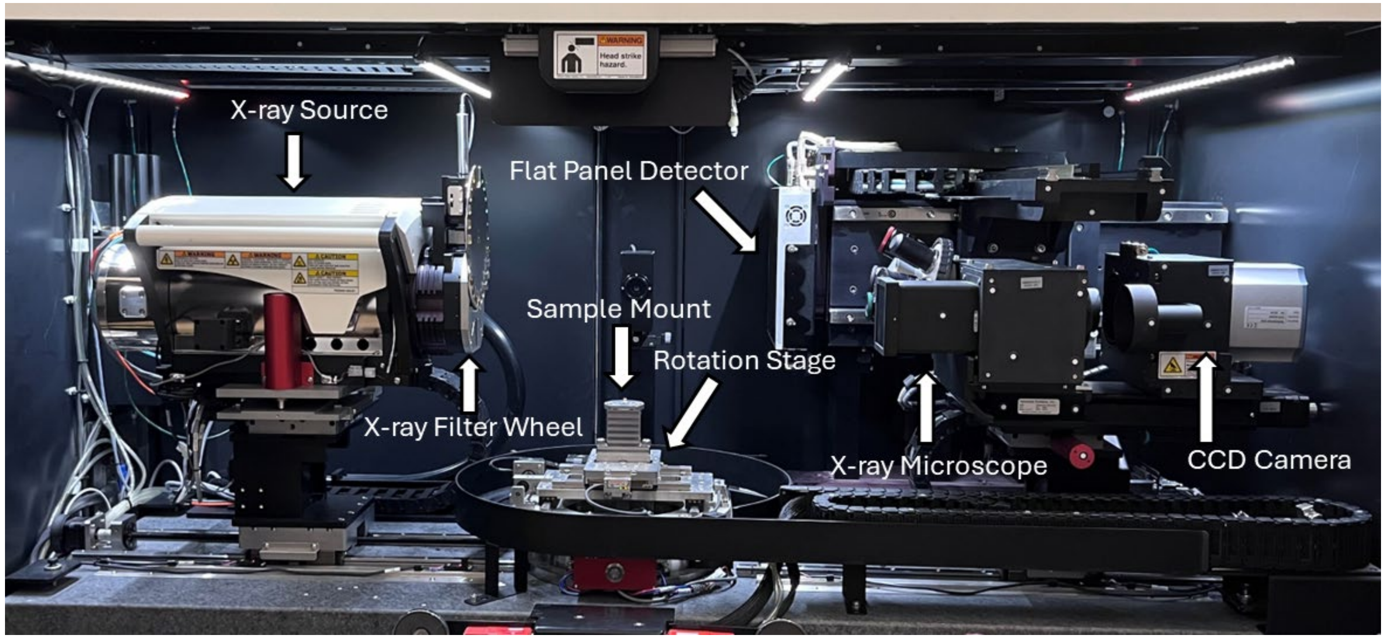
UO_2 grain boundary
2 nm (10^{-9})



Individual atoms 3 Å (10^{-10})

- PIE takes place at INL at the Materials and Fuel's Complex (MFC)
- MFC's PIE Characterization capabilities span 10 orders of magnitude
- The Irradiated Materials Characterization Laboratory (IMCL) houses a variety of PIE instrumentation

X-ray Computed Tomography



- **ZEISS Xadia 620 Versa**
- Lowest spatial resolution: **~500 nm/voxel**
- Hottest sample to date: **120 R/hr on contact**
- Instrument is maintained as **radiologically clean**

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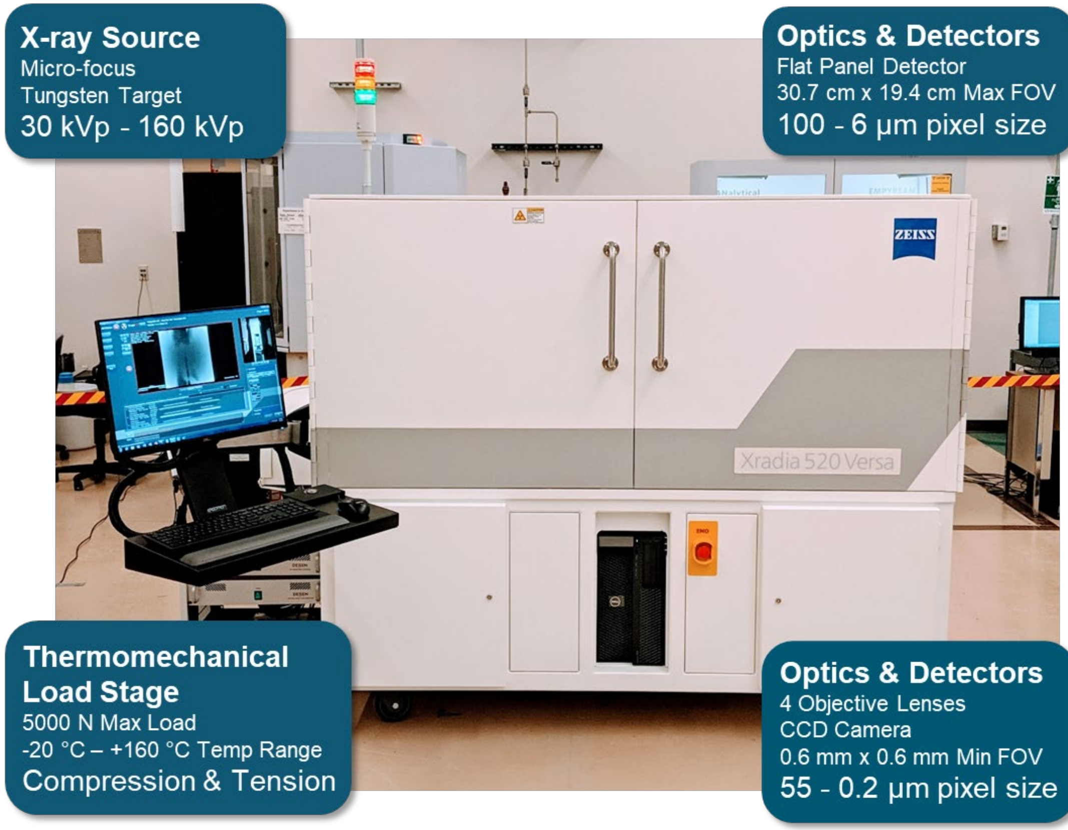
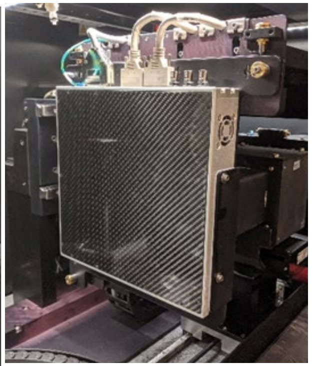
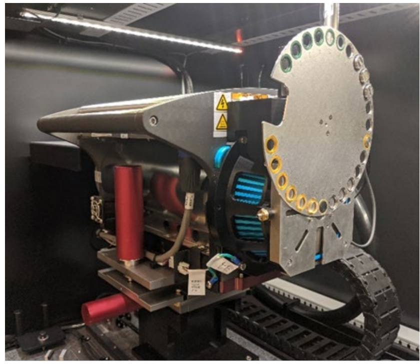


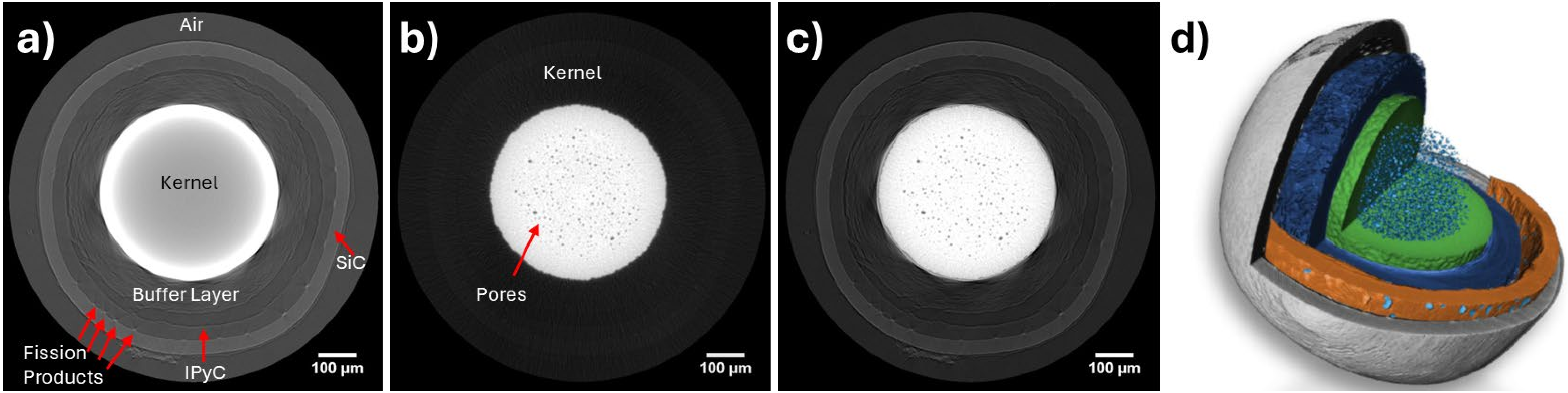




Nondestructive Examination of TRISO Fuel Goals

- PIE of individual particles investigates:
  - Changes in individual particles layers
    - Layer thickness values, buffer delamination, etc.
  - Kernel porosity and fission product migration
- PIE XCT of intact fuel compacts yields different information. Fuel compact examination provides:
  - Kernel morphology
  - Variations in morphology as a function of spatial position
  - Quantification of the buffer fracture frequency
  - Preserves compact for additional exams
    - Impossible following traditional examinations

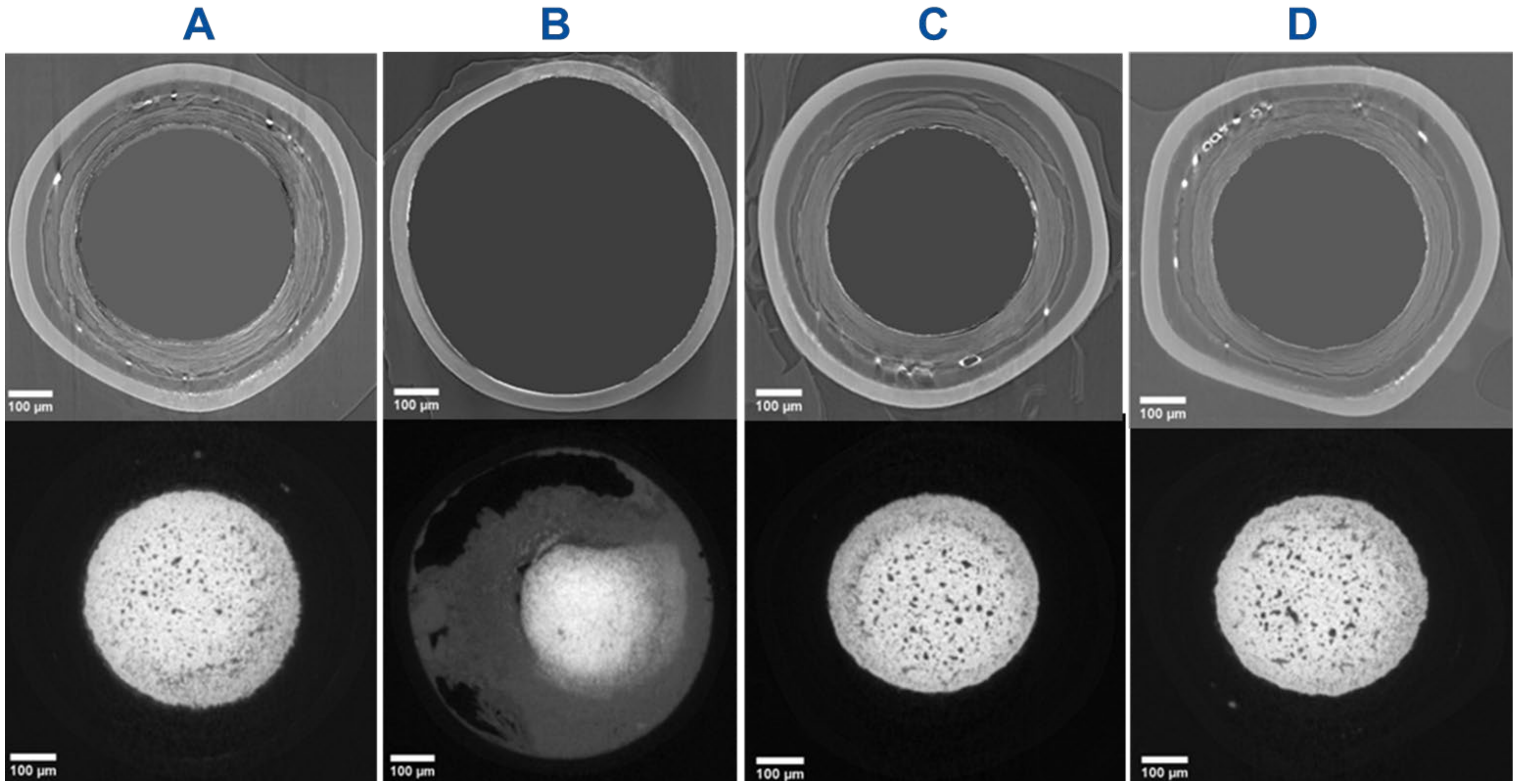
XCT of Irradiated TRISO Fuel Particles

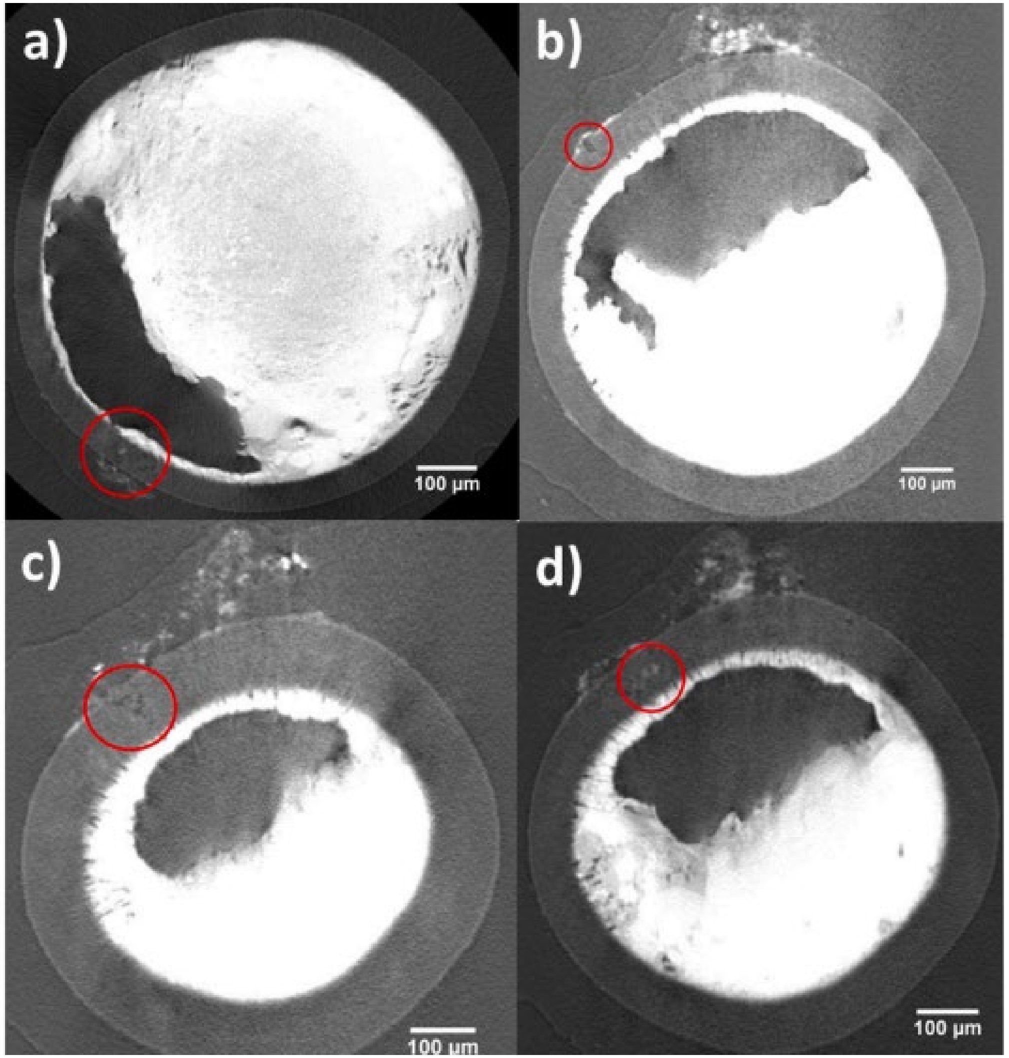


2D slices of a 3D reconstructed volume showing a) a low-energy (40 keV) scan on an irradiated AGR-2 TRISO particle, b) the corresponding high-energy (110 keV) scan of the same particle, c) the images fused together, and d) a 3D rendering of the particle using information from both datasets.

William Chuirazzi, Joshua J. Kane, Nikolaus L. Cordes, John D. Stempien, Rahul R. Kancharla, and Fei Xu. "Seeing the whole picture: Methods for getting the most from micro X-ray computed tomography of TRISO nuclear fuel particles." *Tomography of Materials and Structures* 2 (2023): 100005.

XCT of Irradiated TRISO Fuel Particles (continued)



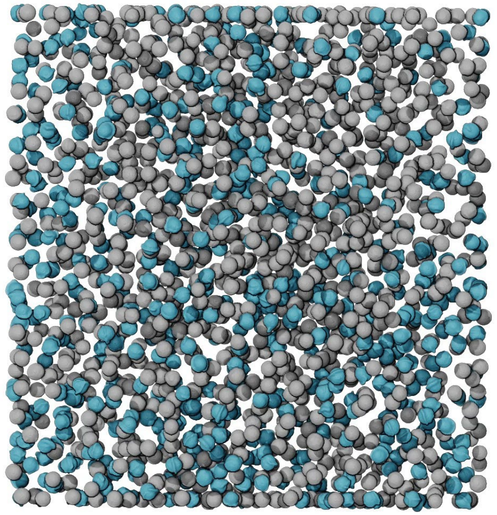


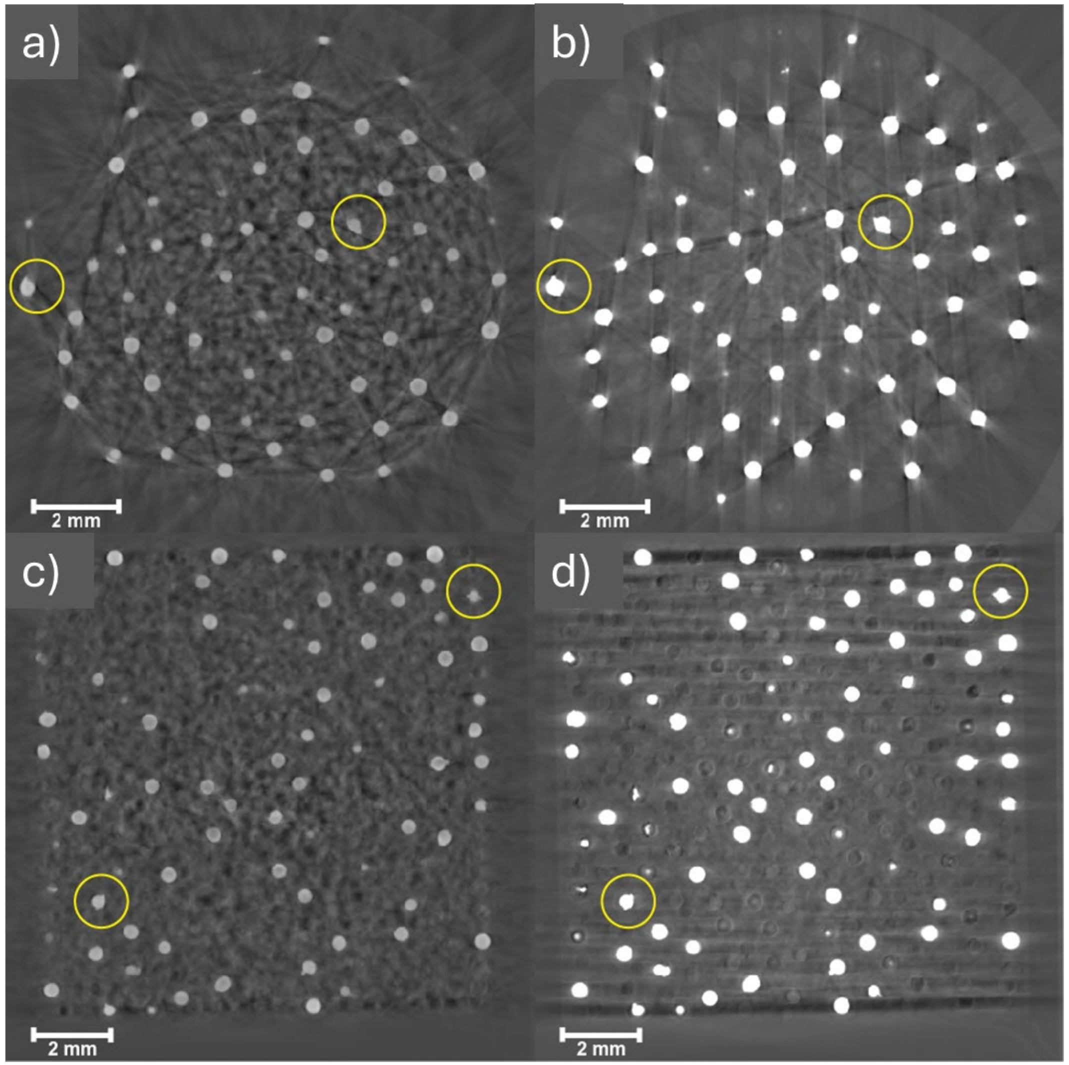
Particles from AGR-5/6/7 Compact 1–7–9. Tomographic slices from low- (top row) and high-energy (bottom row) XCT scans.

(Right) Dense material (relative to the TRISO layers) degraded areas along the SiC layer in Particle B. Red circles and ellipses highlight regions of interest.

Kancharla, Rahul Reddy, William C. Chuirazzi, Joshua J. Kane, John D. Stempien, Cameron Howard, Swapnil Morankar, Miles T. Cook, and Quintin D. Harris. "X-ray computed tomography of deconsolidated TRISO Particles from the AGR-5/6/7 irradiation experiment capsule 1 Compact." Journal of Nuclear Materials 607 (2025): 155704.

XCT of Irradiated TRISO Compacts





(Left, Top) Video demonstrating the push-pop shield for AGR Compacts (4X speed). (Left, Bottom) A video of a 3D rendering of TRISO particles within a compact. Blue particles highlight irregular Particles. (Right) 2D slices of a TRISO 3/4 compact, circles indicate irregularly shaped particles.[7] (right) 3D rendering of the reconstructed data. Blue particles show irregular particles.

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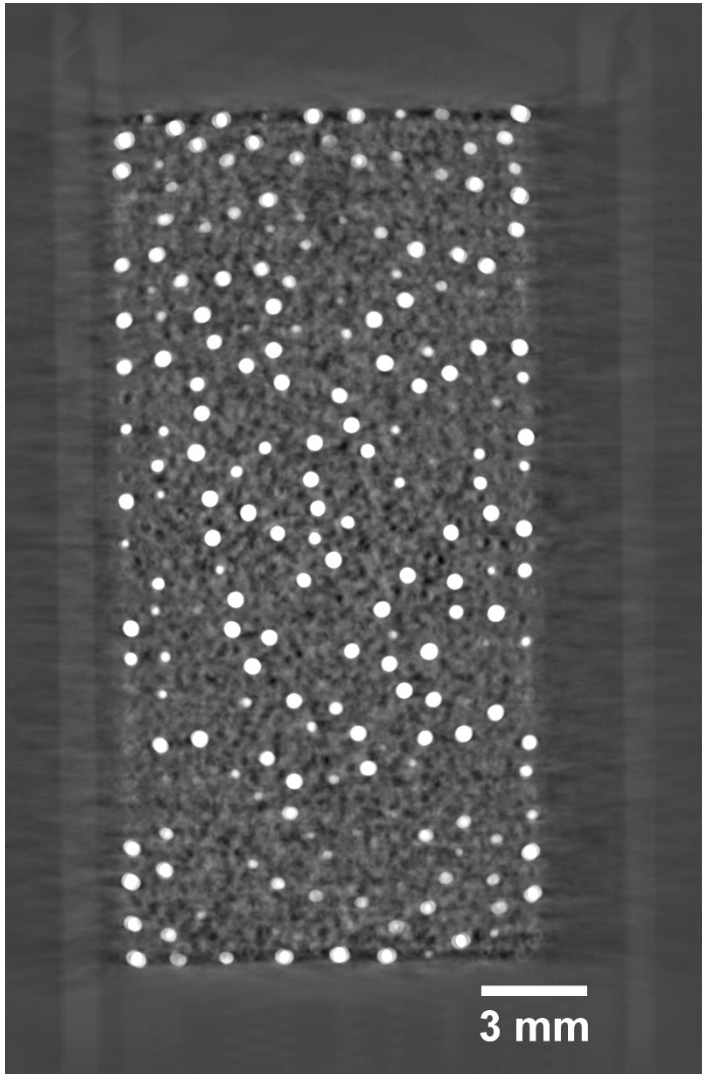
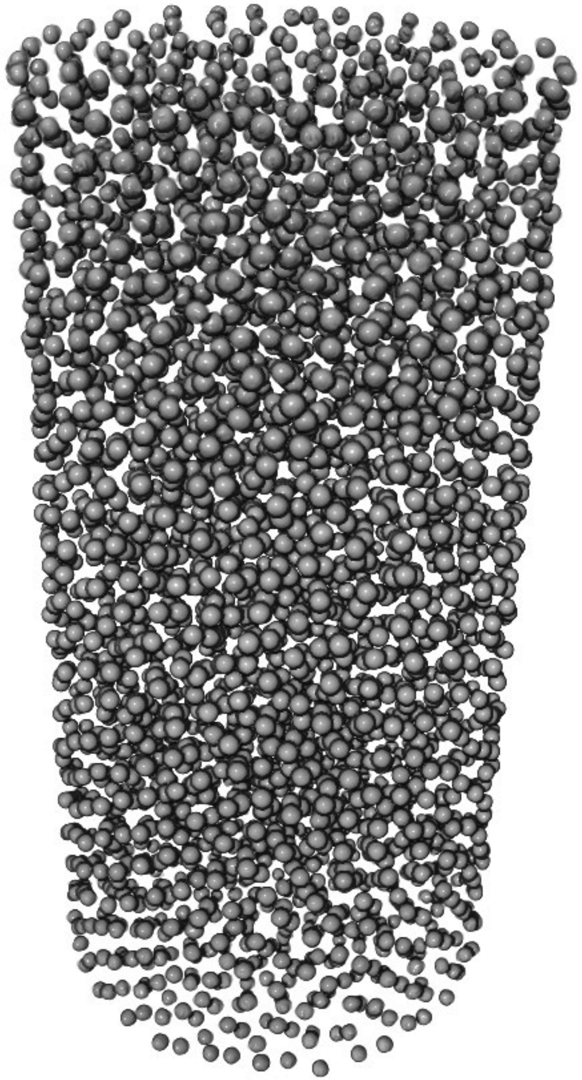
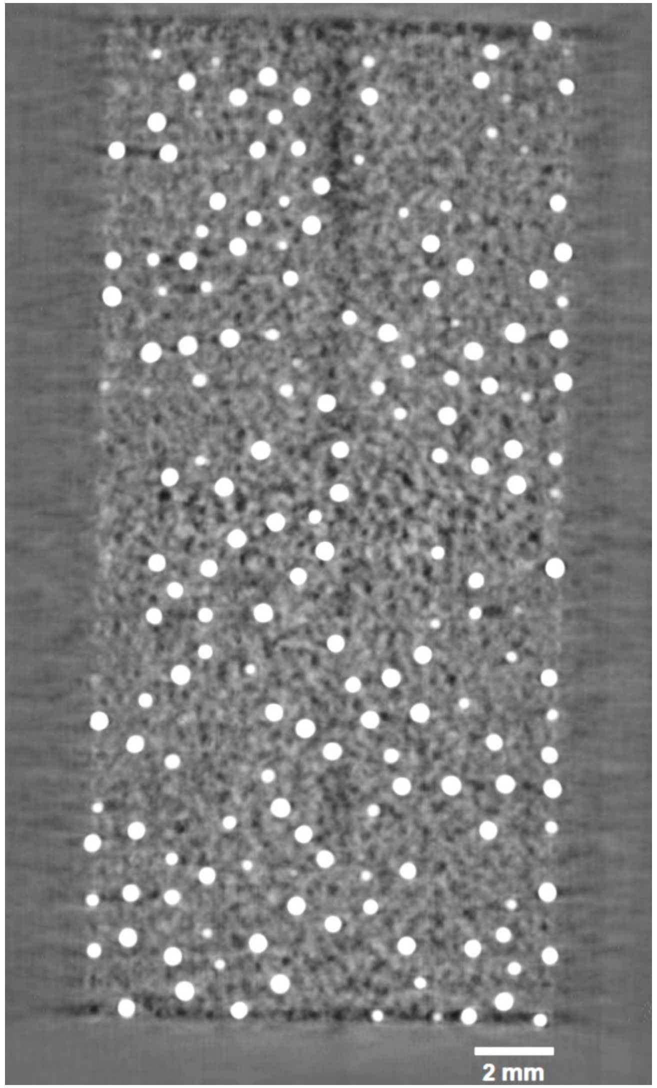
XCT of Irradiated TRISO Compacts (Continued)

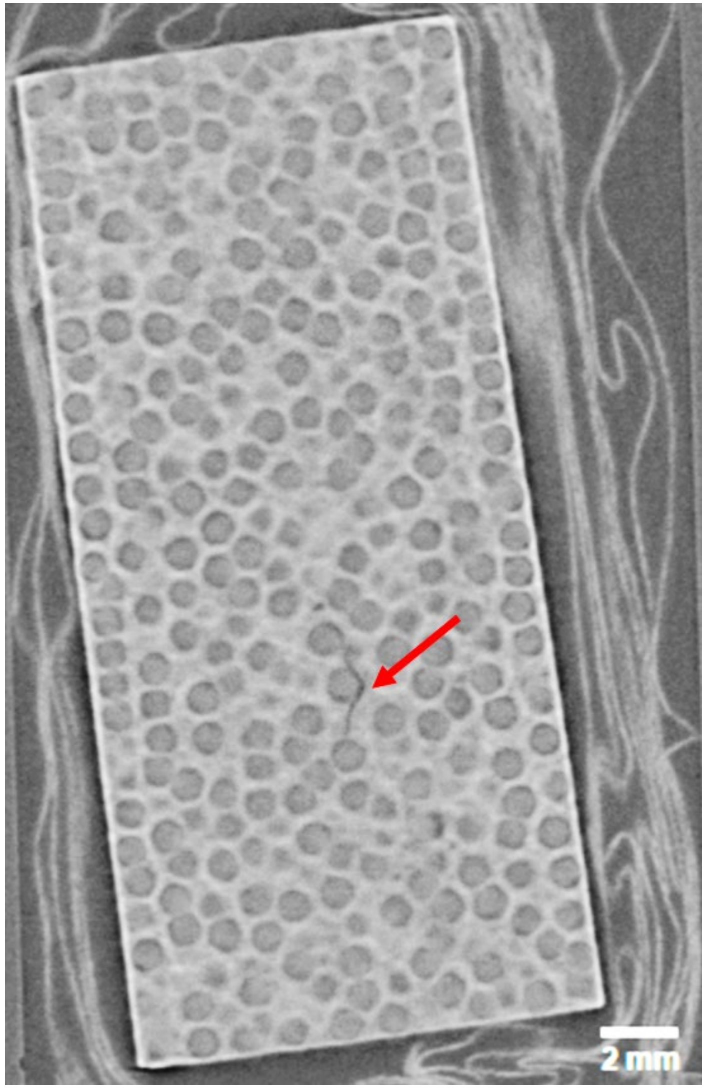


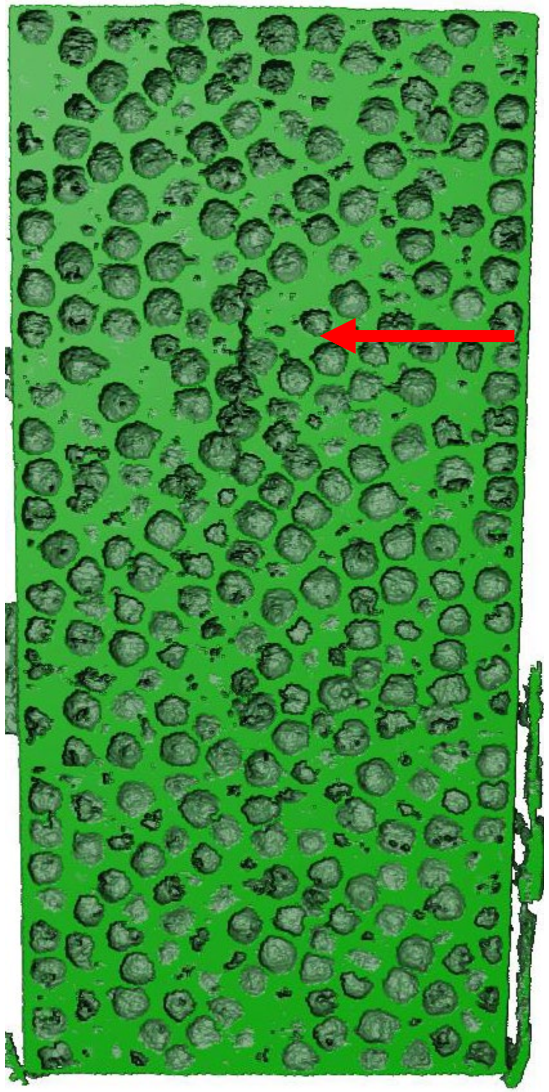


AGR-5/6/7 Compact 5-3-1 had a dose rate of 1318 R/hr on contact from both β and γ-ray radiation with 120 R/hr of the dose rate coming exclusively from γ-rays.

Neutron CT for Matrix Examination







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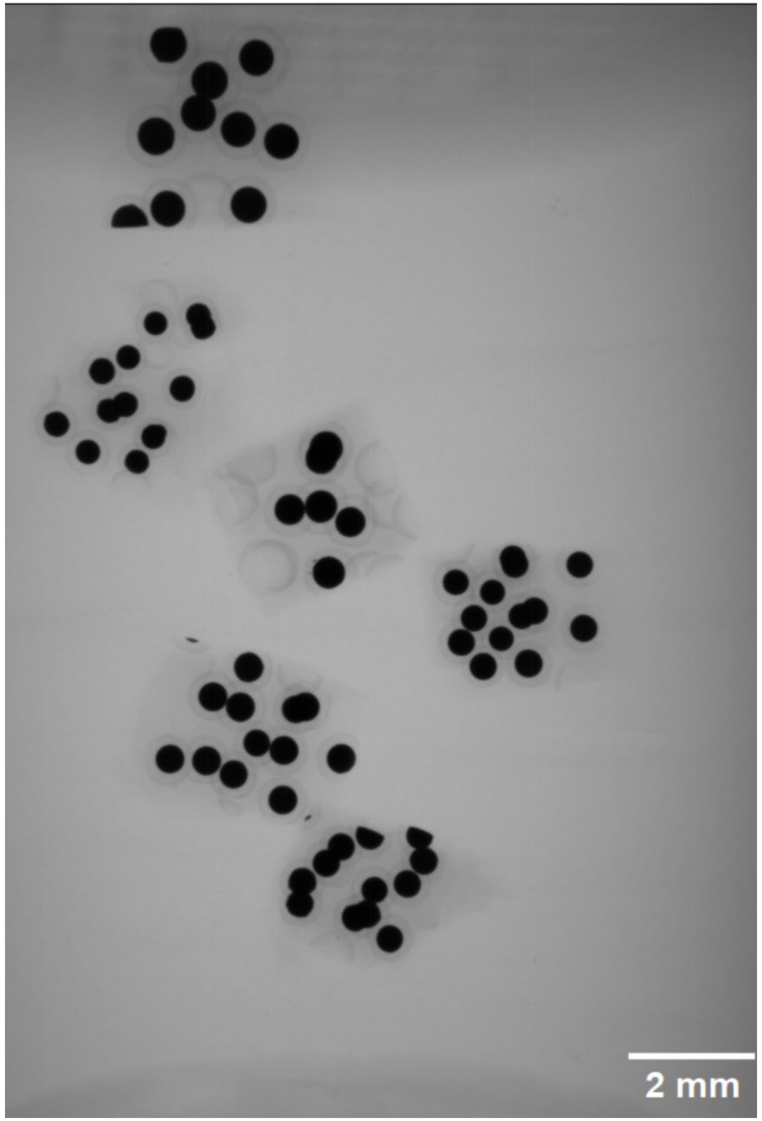
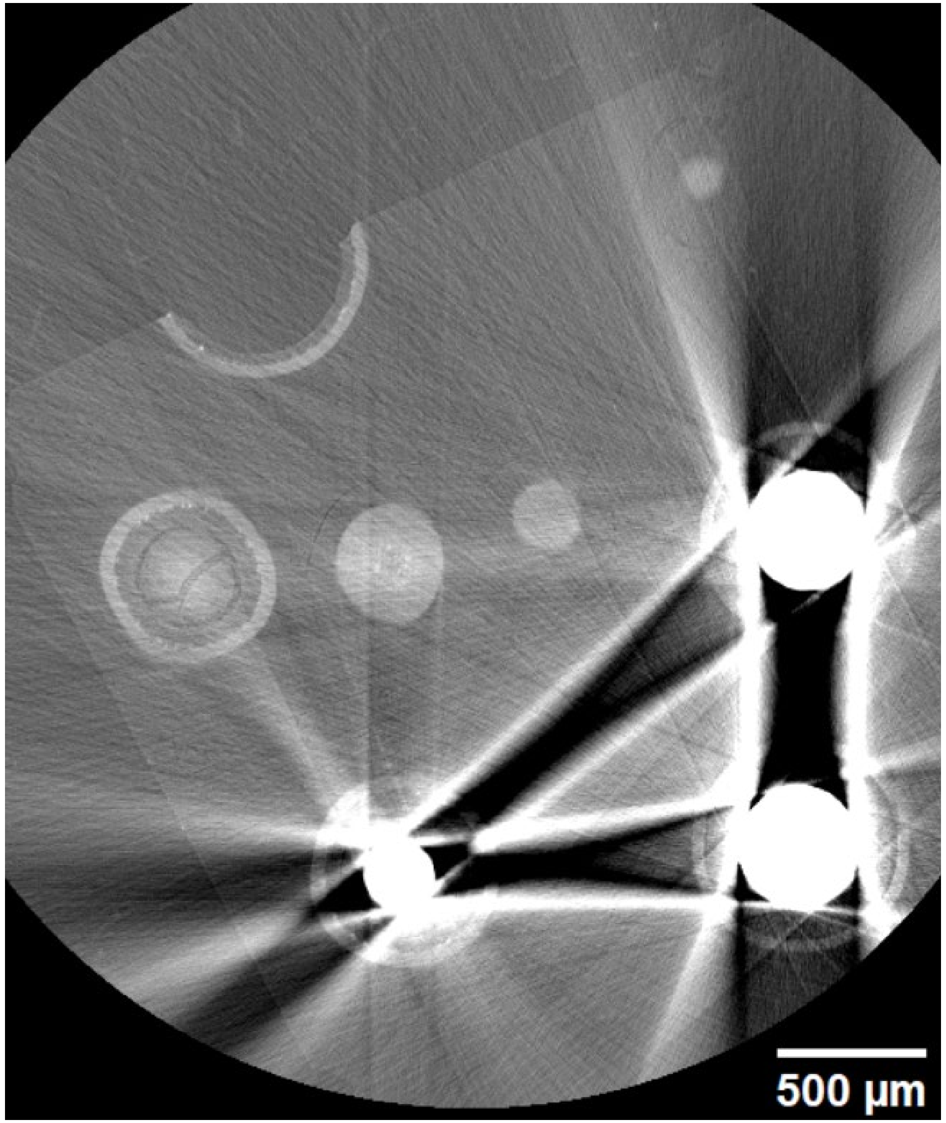
(Left) XCT slice of an unirradiated natural uranium compact, artifacts caused by X-ray attenuation prevent examination of matrix features; (Center) Neutron CT slice of the same compact, a crack is clearly resolved; (Right) A 3D rendering emphasizing the crack.

XCT of Irradiated TRISO Compact Chunks

- Subvolumes of AGR-2 compacts
- “Sweet spot”
  - Image multiple particles
  - Higher resolution
    - Resolve layers
    - Kernel porosity
- Will be coupled with thermal property measurements
  - Number of particles
  - Layer gaps
  - Densities





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