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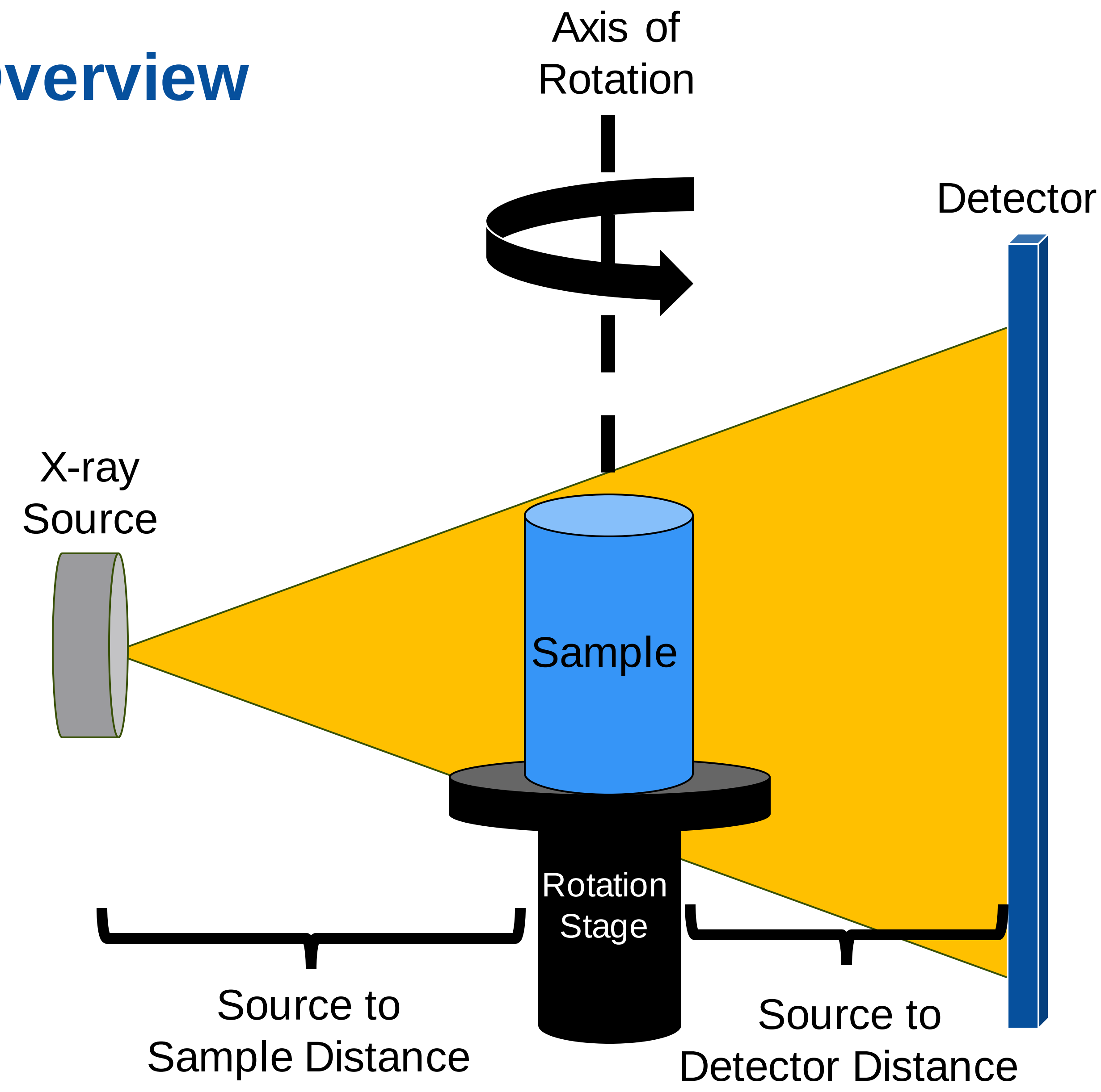
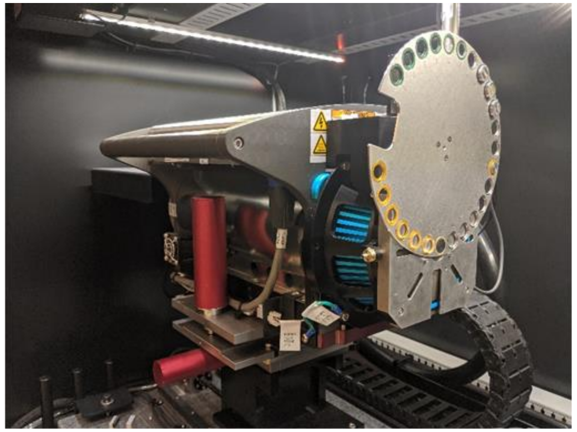
Data Acquisition and Analysis Techniques for X-ray Computer Tomography

X-ray Computed Tomography Overview

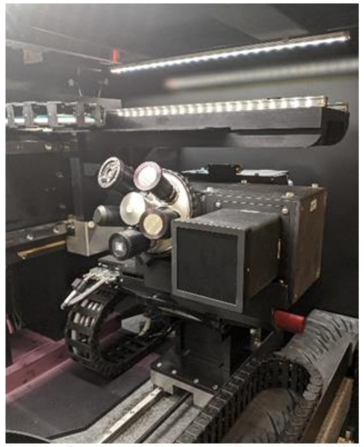
- X-ray computed tomography (XCT) acquires a series of 2D radiographs as a function of sample rotation
- 2D radiographs are mathematically reconstructed to produce a 3D volume
  - Gives surface and internal information of sample
- **<u>XCT is a nondestructive technique</u>**
- In systems with geometric magnification, spatial resolution is determined by distances between X-ray source, sample, and detector
  - Sample size, geometry, and material composition effect image quality



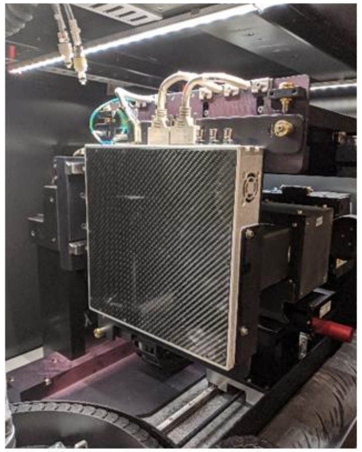
ZEISS Xradia 620 Versa at IMCL



Photograph of the ZEISS Versa XRM X-ray source and filter wheel



Photograph of the ZEISS Versa XRM Objective Lens Assembly



Photograph of the ZEISS Versa XRM Flat Panel Detector

X-ray Source
Micro-focus
Tungsten Target
30 kVp - 160 kVp

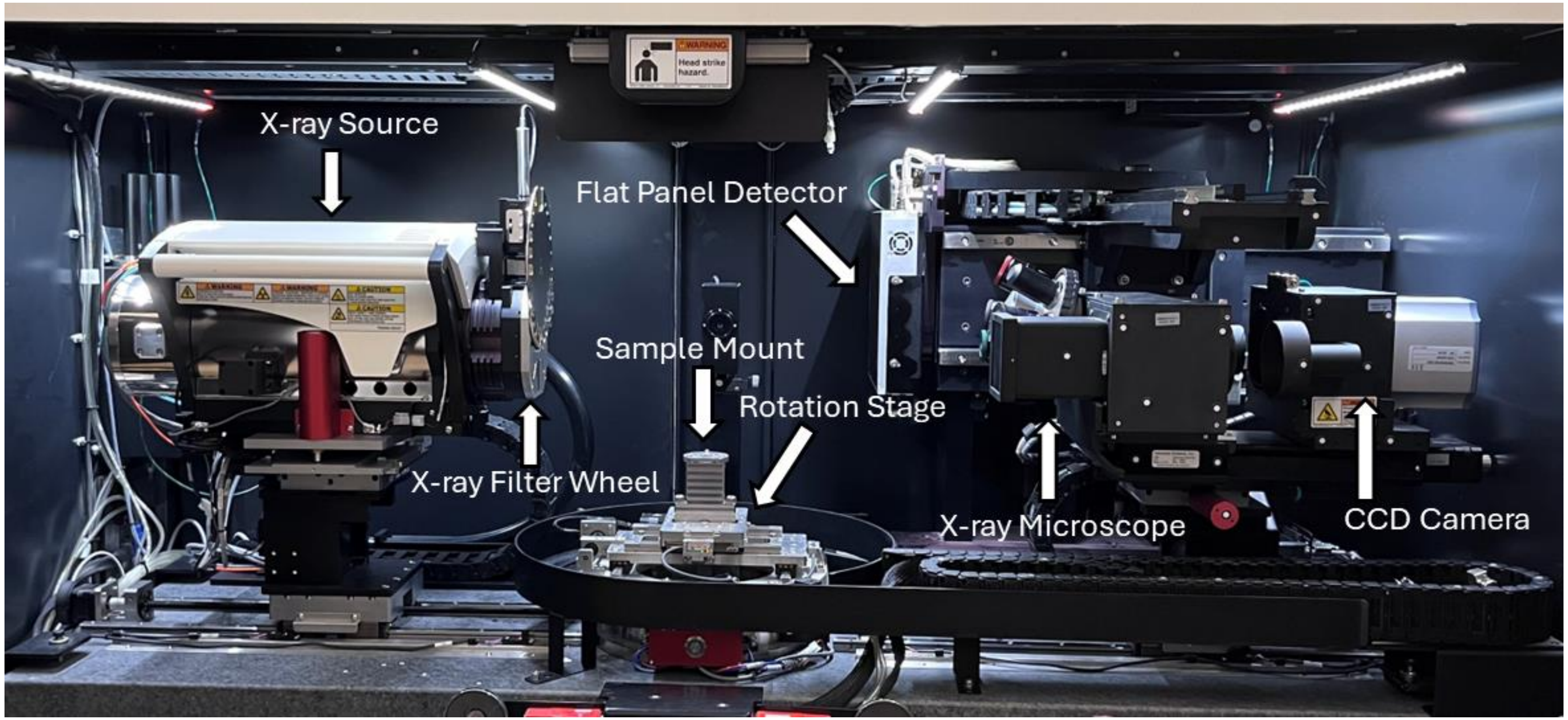
Optics & Detectors
Flat Panel Detector
30.7 cm x 19.4 cm Max FOV
100 - 6 µm pixel size

Thermomechanical Load Stage
5000 N Max Load
-20 °C – +160 °C Temp Range
Compression & Tension

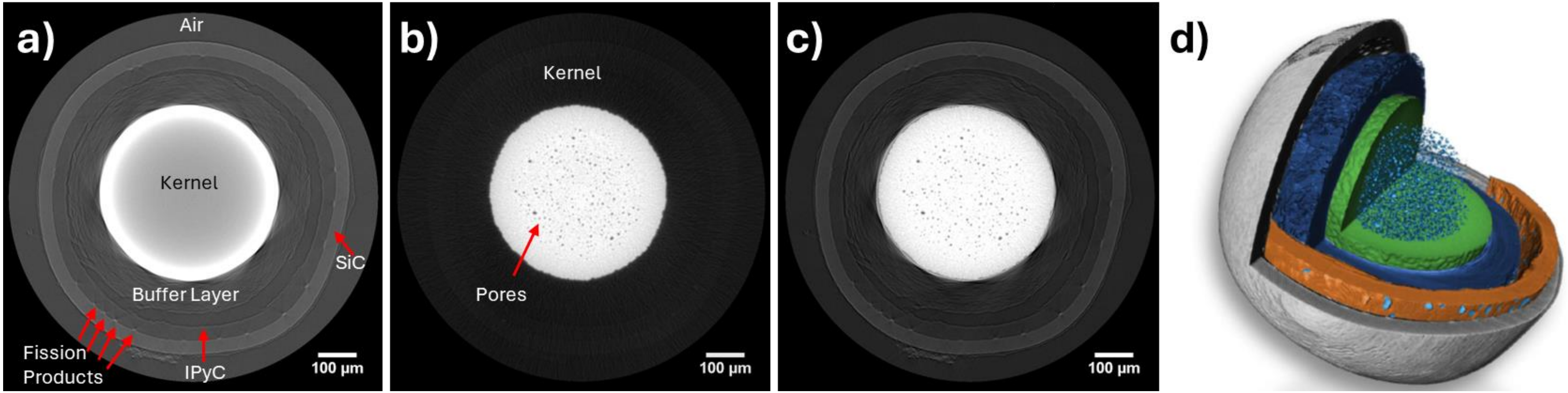
Optics & Detectors
4 Objective Lenses
CCD Camera
0.6 mm x 0.6 mm Min FOV
55 - 0.2 µm pixel size

ZEISS Xradia 620 Versa at IMCL

- Instrument is maintained as radiologically “clean”
- X-ray source upgraded in September 2023
- 10 W → 25W
  - ~2x quicker
    - Cost reduced
    - Throughput Increased
  - Higher resolution
    - Improved data



XCT of Nuclear Materials

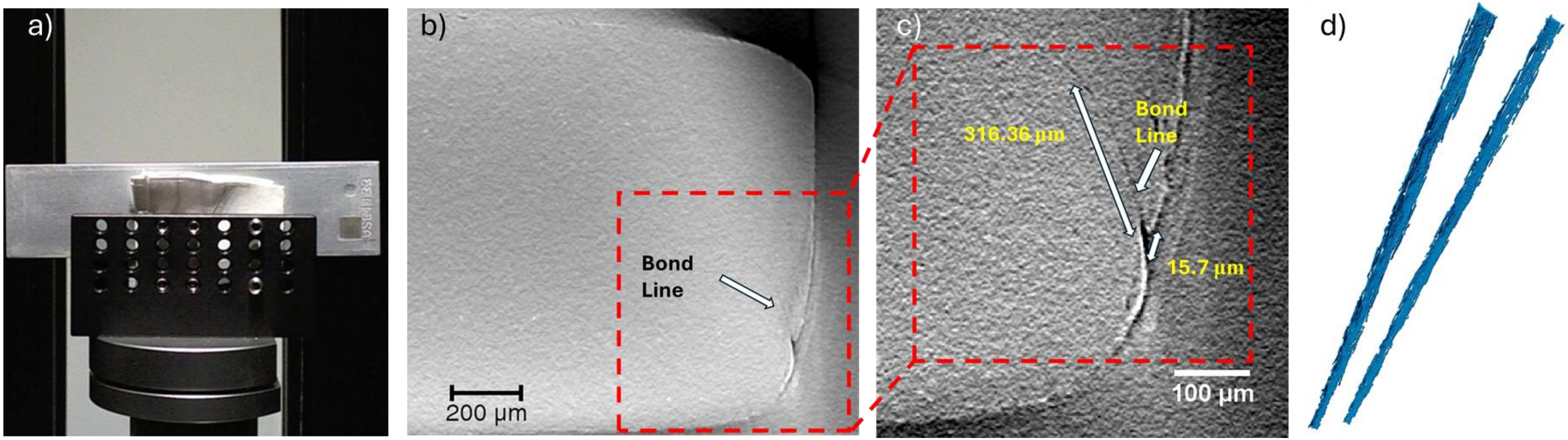


2D slices of a 3D reconstructed volume showing a) a low-energy (40 keV) scan on an irradiated AGR-2 TRISO particle, b) the corresponding high-energy (110 keV) scan of the same particle, c) the images fused together, and d) a 3D rendering of the particle using information from both datasets.

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.

FY 23 NSUF Supported Work

XCT of Nuclear Materials

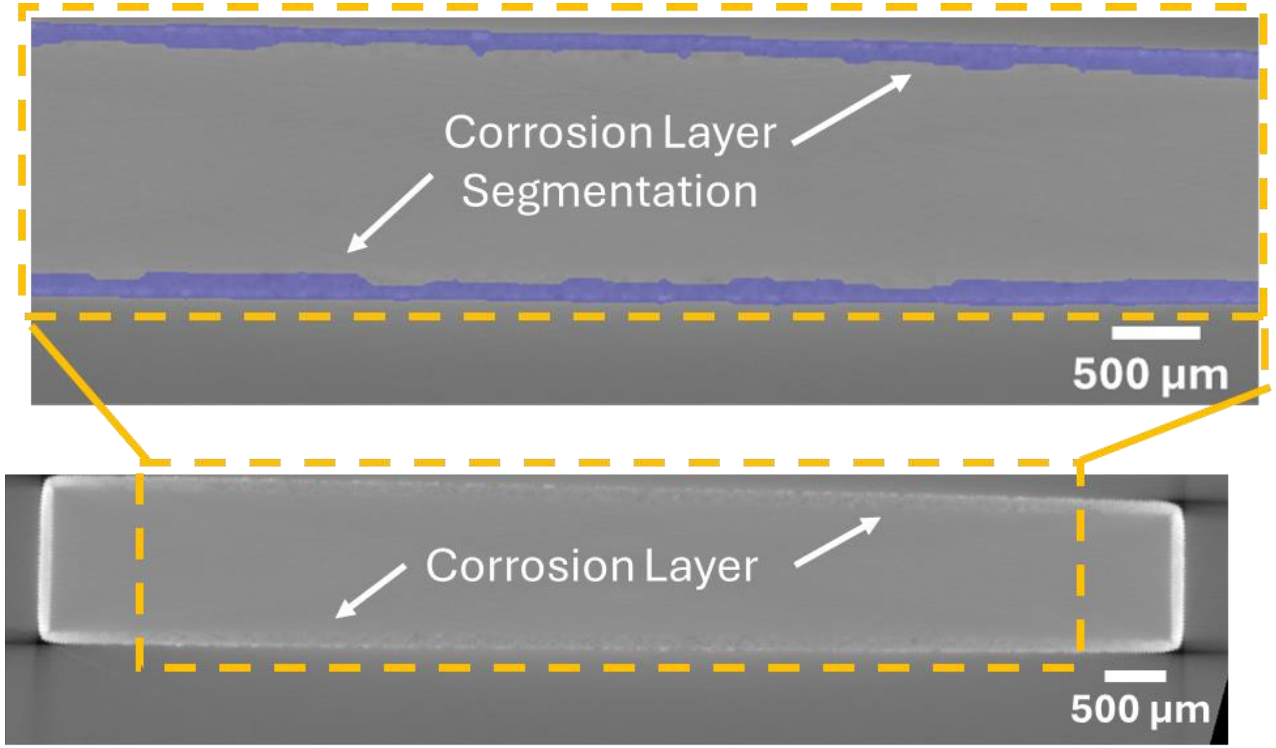


a) An optical image of a mini-plate mounted in the VERSA. b) A 2D slice of the bond line within the cladding material. c) The inset magnifies the area around the bond line while enhancing the contrast to emphasize it. Quantitative bond line measurements are also displayed. d) A 3D rendering of the two discontinuities within the cladding.

William Chuirazzi, Nikolaus L. Cordes, Jan-Fong, Jue, Maxine Johnson, James Cole, and Jeffrey Giglio. "Micro X-ray computed tomography examination of mini plate fuel with hot isostatic pressed aluminum cladding." *Materials Today Communications* 37 (2023): 107345.

Segmentation Development

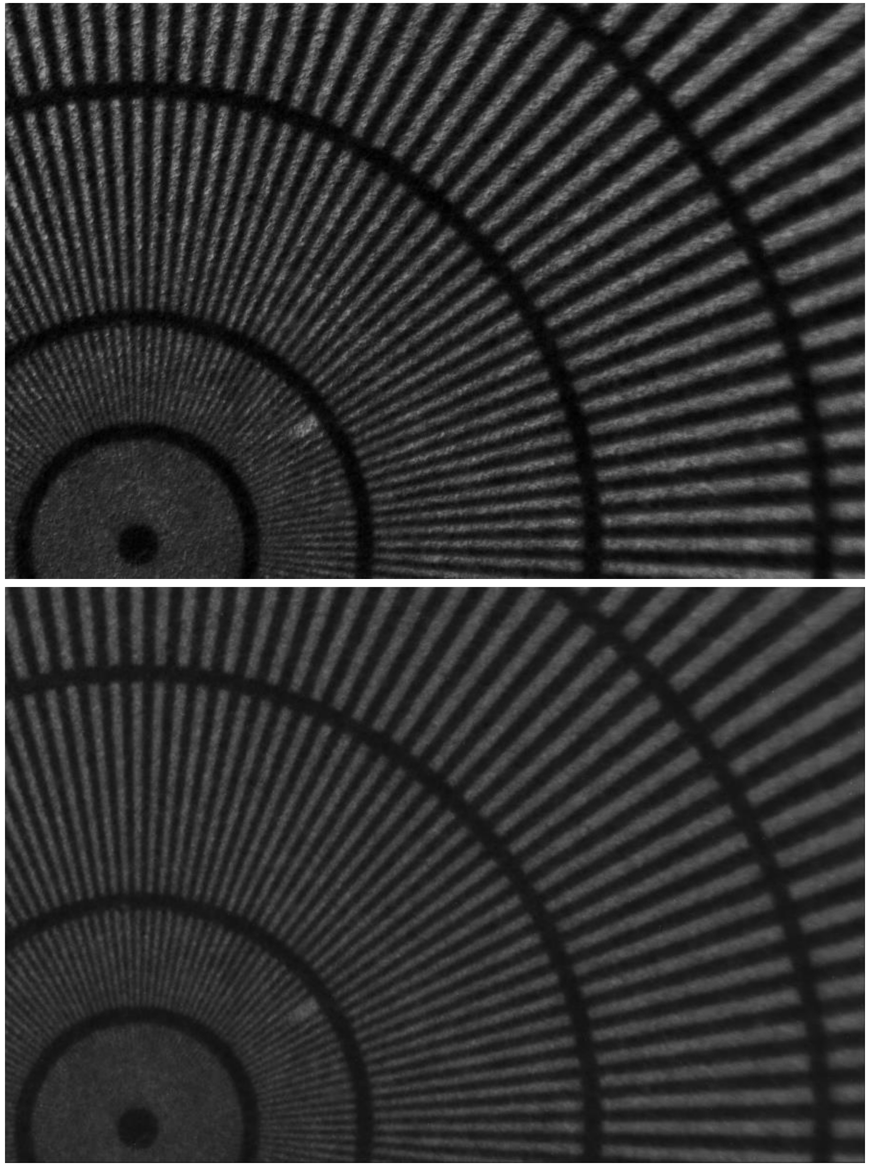
- Molten salt corrosion layer on a Ni-based alloy
- Beam hardening artifacts, other noise (due to low X-ray penetration), and poor contrast make segmentation difficult
- **Goal:** Create a method to segment and measure thickness of corrosion
- **Manual result: 118.84 ± 17.36 μm** (average of 10 measurements)
- **Our result: 119.18 μm ± 2.17 μm**
- Improvement over existing manual methods as it can measure thickness at each column of pixels
  - More datapoints = less uncertainty



A 2D slice though the vertical plane of a rectangular corrosion coupon. (bottom) A slice of the entire sample, complete with beam hardening artifacts on the ends of the sample. The corrosion layer can be seen near the top and bottom. (top) Zoomed in view cropped region complete with segmentation (blue).

Image Realignment

- Sample movement during CT can degrade or corrupt data
- Open beam images correct for beam and detector abnormalities
- Developed a method for aligning open beam and radiograph images where movement occurred between acquisitions
- Dataset not acquired with the XRM, but technique is instrument agnostic
- Can salvage data in the event of future misalignments with the instrument
- Can attempt to improve “bad” data caused by misalignment



Images of a Siemen’s Star- the open beam image and radiograph were originally misaligned resulting in (top) a noisy image. Realigning the two images produced (bottom) an improved image.

Burkhard Schillinger, William Chuirazzi, Steven Cool, Aaron Craft, Zoltan Kis, László Szentmiklósi, and Alessandro Tengattini. “New Measurements on Borated Neutron Imaging Screens at Budapest Neutron Centre (BNC)." *Journal of Physics: Conference Series*, vol. 2605, no. 1, p. 012009. IOP Publishing, 2023.

FY 23 Accomplishments

- **2 Journal Publications**:

    1. Burkhard Schillinger, William Chuirazzi, Steven Cool, Aaron Craft, Zoltan Kis, László Szentmiklósi, and Alessandro Tengattini. “New Measurements on Borated Neutron Imaging Screens at Budapest Neutron Centre (BNC)." *Journal of Physics: Conference Series*, vol. 2605, no. 1, p. 012009. IOP Publishing, 2023.
    2. William Chuirazzi, Nikolaus L. Cordes, Jan-Fong, Jue, Maxine Johnson, James Cole, and Jeffrey Giglio. "Micro X-ray computed tomography examination of mini plate fuel with hot isostatic pressed aluminum cladding.” *Materials Today Communications* 37 (2023): 107345.

- Advancements coupled with source upgrade **increase instrument throughput** by **at least twofold**
- Data analysis and segmentation algorithms will aid future users in **expedited data analysis**.

FY 24 Outlook

- Pushing the limits of spatial resolution (sub 500 nm/voxel)
- Segmentation for low-Z materials
- Computed Laminography
- Others:
  - Phase contrast imaging
  - Data analysis
  - Additional publications

Importance of XCT

- **Nondestructive, volumetric** information on specimens
  - Inform targeted destructive analysis
  - Provide real-world, measured data for modeling inputs

- **More than just "pretty pictures"**
  - Segmentation and data analysis techniques **provide quantitative information**

- **NSUF Support** enables instrument and data segmentation/analysis technique development to **provide users** with **improved, quality data** that can be obtained **quicker and cheaper**.

Questions?

Special thanks:

<u>NSUF</u>

- Brenden Heidrich, *NSUF Director*
- Collin Knight, *NSUF Deputy Director*
- Jeff Giglio, *NSUF Chief Scientist*

<u>XCT</u>

- Rahul Reddy Kancharla, *Staff Scientist*- data analysis support
- Swapnil Morankar, *Postdoc*- instrument development

Idaho National Laboratory

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