

Imaging with Neutrons

Hassina Bilheux
VENUS Instrument Scientist

Yuxuan Zhang
MARS Instrument Scientist

Jean Bilheux
Computational Instrument Scientist

August 9, 2023

ORNL is managed by UT-Battelle, LLC for the US Department of Energy



U.S. DEPARTMENT OF
ENERGY

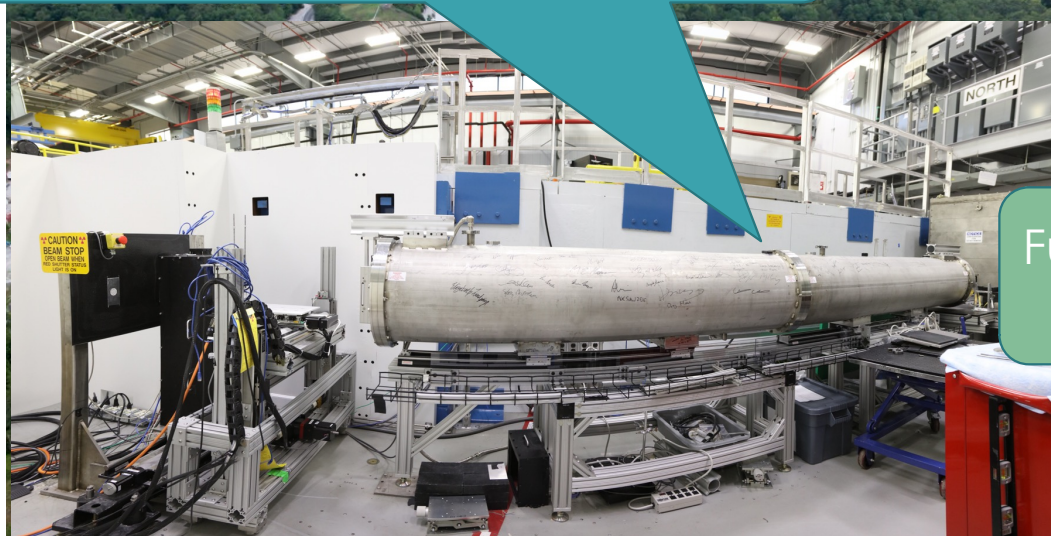
Imaging is a Growing Part of the ORNL Neutron Sciences Program

High Flux Isotope Reactor (HFIR)

Intense steady-state neutron flux and a high-brightness cold neutron source



Dedicated Imaging Instrument (MARS)
Steadily improving capabilities
Expanded support



Spallation Neutron Source (SNS)

World's most powerful accelerator-based neutron source

VENUS is under construction (start of commissioning in July 2024)



Future CUPID beamline at STS (Bragg edge and grating interferometry)



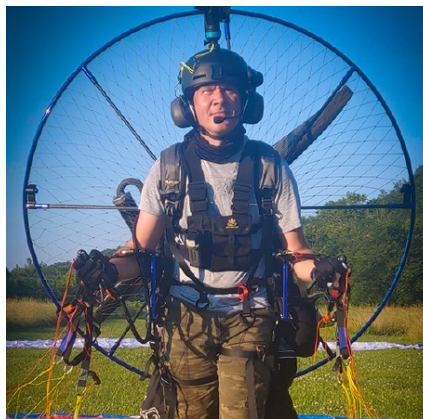
The Neutron Imaging Team



Yuxuan Zhang,
HFIR MARS Scientist



James Torres,
HFIR MARS Scientist



Jean Bilheux,
Computational
Instrument Scientist



S. Venkat
Venkatakrisnan, Adv.
Reconstruction
/Machine Learning



Shimin Tang, Artificial
Intelligence, Machine
Learning, Hyperspectral
Imaging



Erik Stringfellow,
Imaging Scientific
Associate (SA)



Mary-Ellen Donnelly,
Imaging SA



Harley Skorpenske,
SNS Group Leader

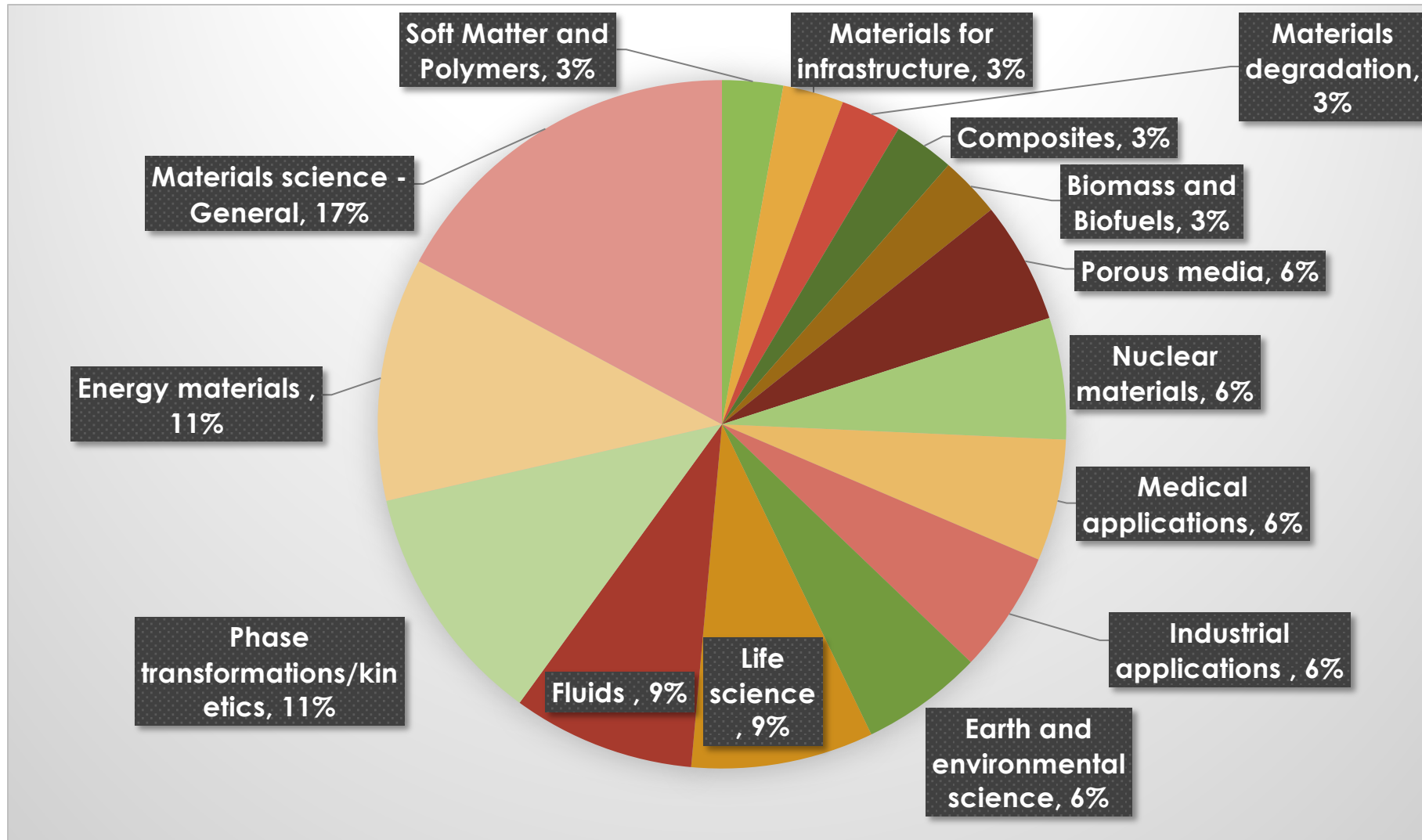


Jamie Molaison,
SNS SNAP SA



Hassina Bilheux,
SNS VENUS Scientist

HFIR imaging has a broad scientific portfolio



Outline

- Imaging at the High Flux Isotope Reactor MARS beamline:
 - Principle of neutron radiography and computed tomography at a continuous source
 - The CG-1D imaging beamline
 - Examples
- Imaging at the Spallation Neutron Source:
 - Principle of neutron radiography at a pulsed source
 - Examples
 - The VENUS construction project
- Software tools for imaging

Yuxuan

Hassina

Jean

Outline

- **Imaging at the High Flux Isotope Reactor MARS beamline:**
 - Principle of neutron radiography and computed tomography at a continuous source
 - The CG-1D imaging beamline
 - Examples
- Imaging at the Spallation Neutron Source:
 - Principle of neutron radiography at a pulsed source
 - Examples
 - The VENUS construction project
- Software tools for imaging

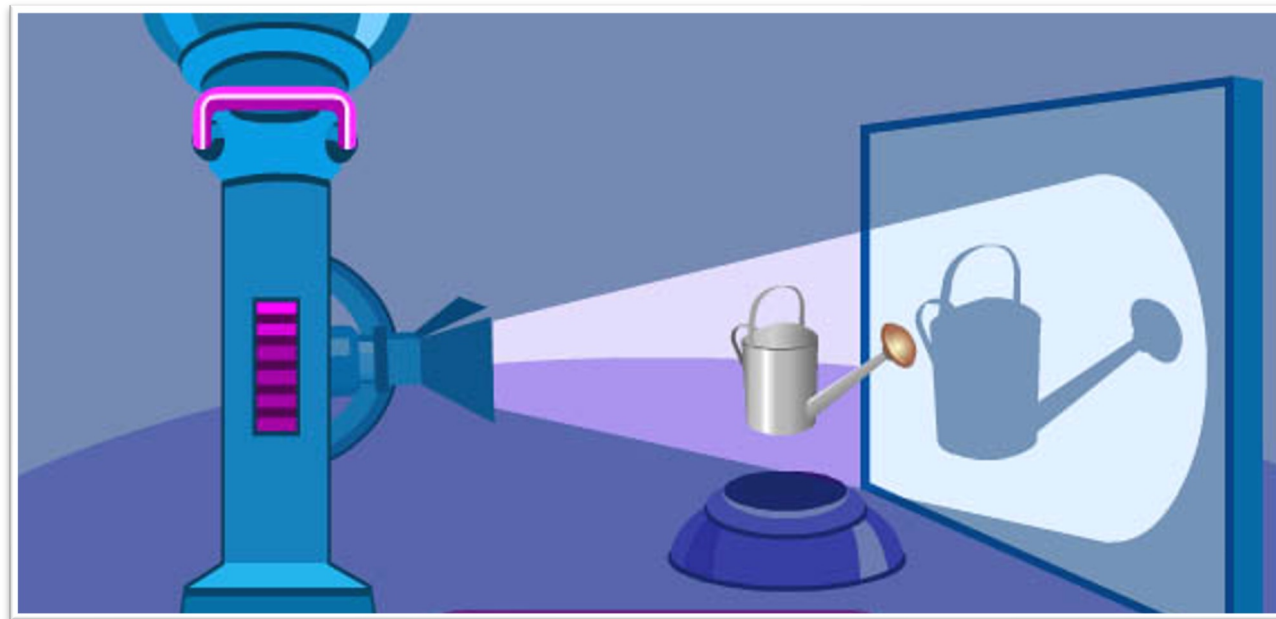
Yuxuan

Hassina

Jean

What is Neutron Imaging?

- Similar to X-ray Imaging, **Neutron Imaging** is a **non-destructive** technique that can **spatially resolve** the structure of a sample



Source

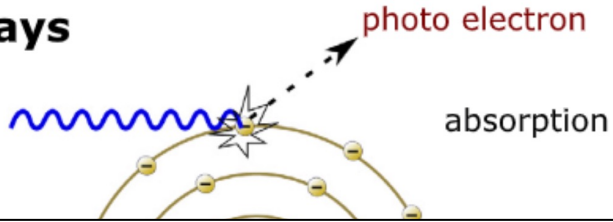
Object

Detector

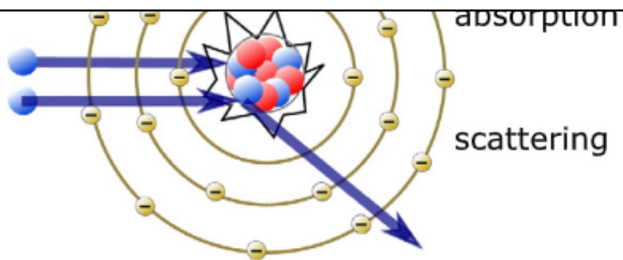


Neutrons interact uniquely with matter (cont'd)

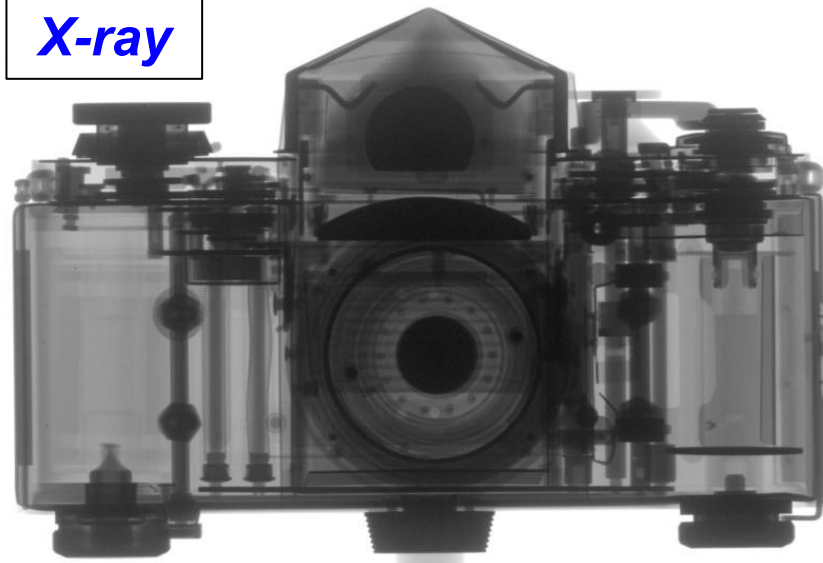
x-rays



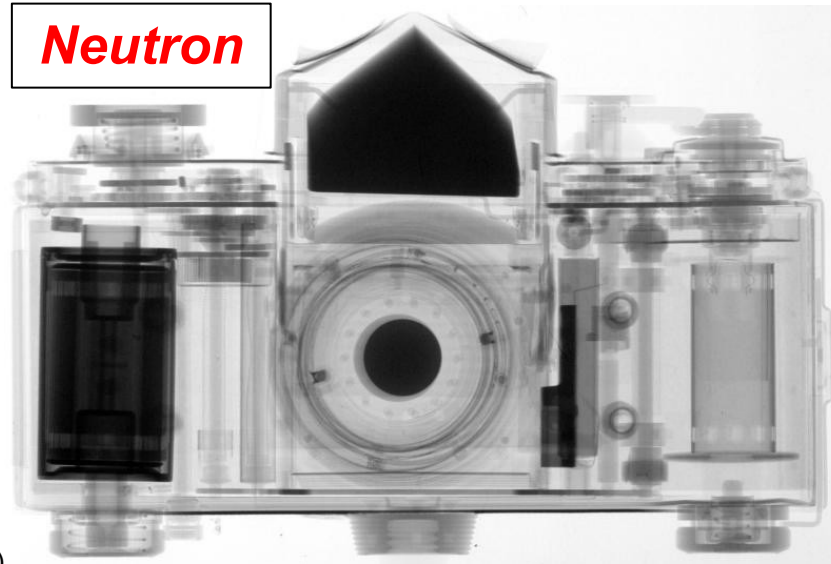
- Non-destructive
- High penetration
- Sensitive to light elements (H, Li, etc.)
- Isotopic contrast



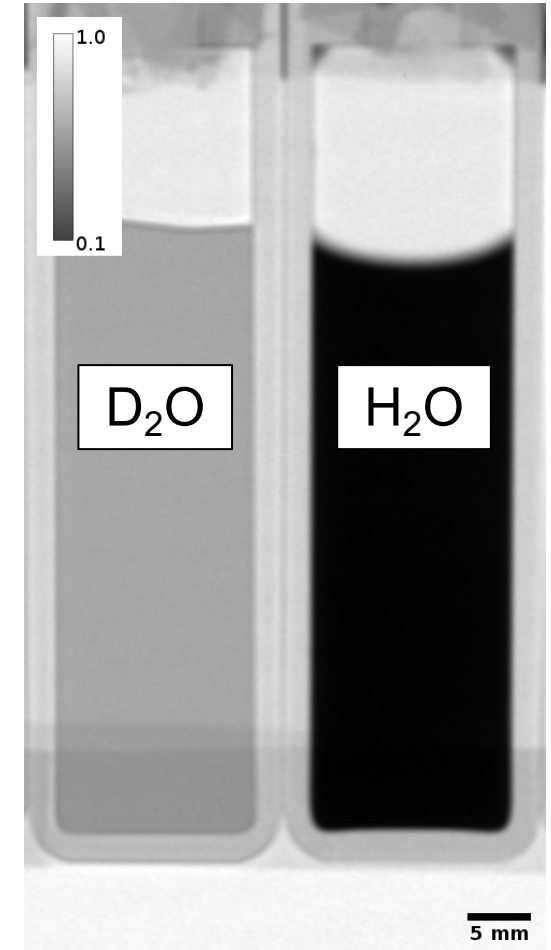
X-ray



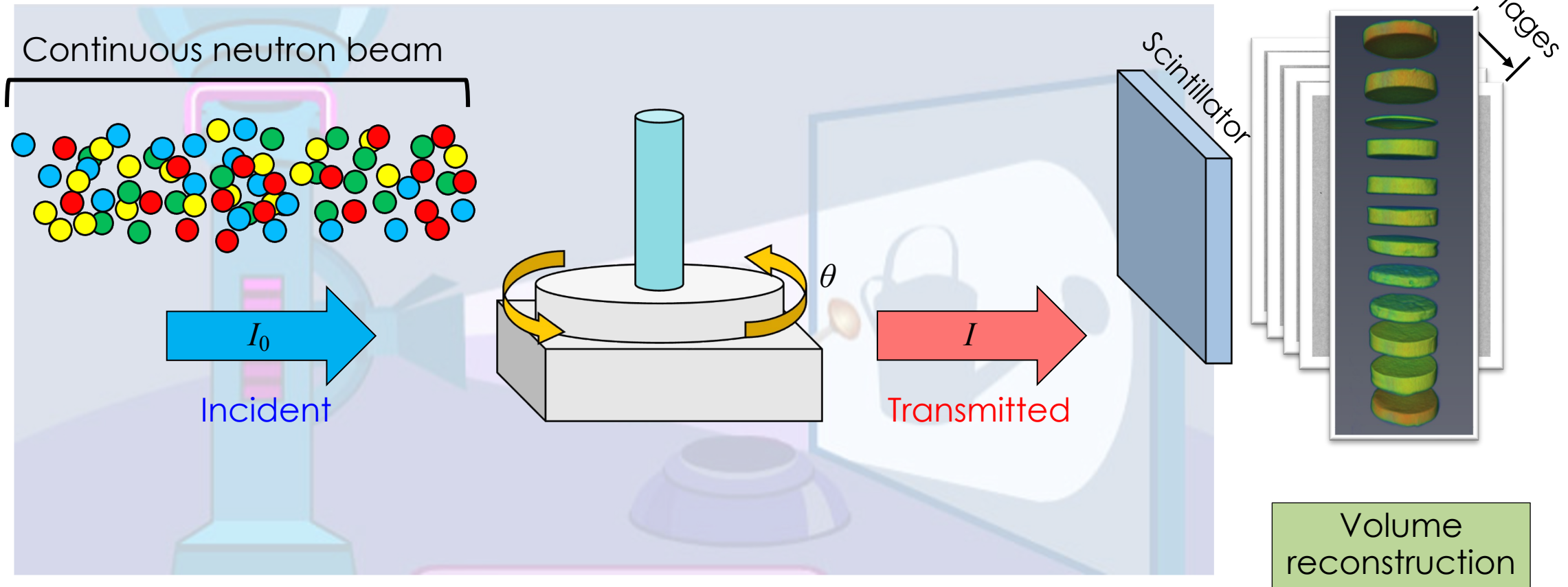
Neutron



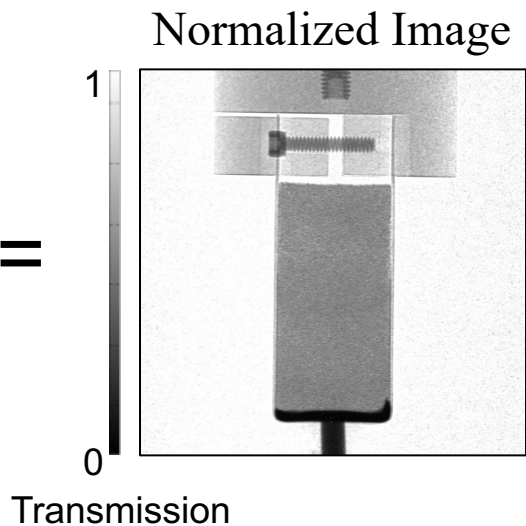
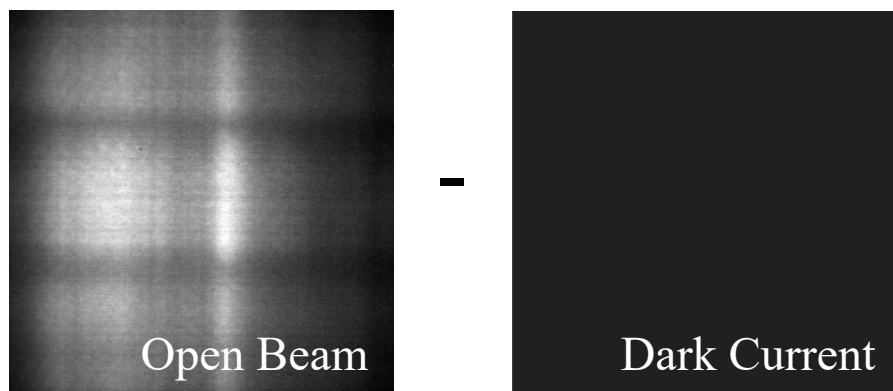
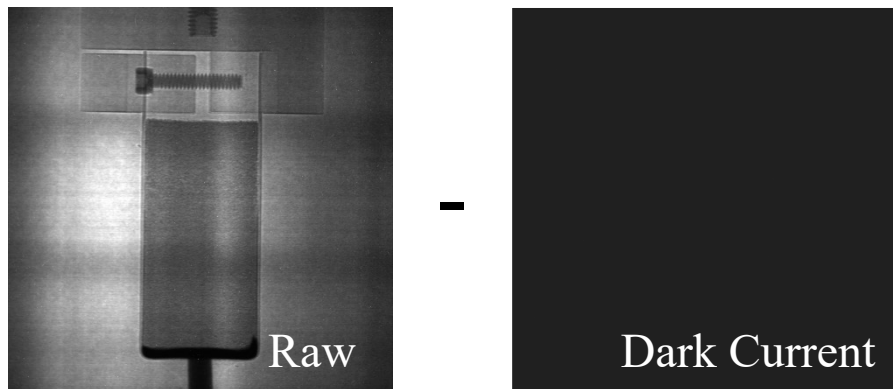
Neutron



Transmitted neutrons recorded as image



From raw image to normalized image



$$\frac{Raw(x, y) - DC(x, y)}{OB(x, y) - DC(x, y)} = \text{Normalized Image}$$

Lambert-Beer Law

Transmission

Sample thickness

$$T = \frac{I}{I_0} = e^{-\mu x}$$

Attenuation co.

Density

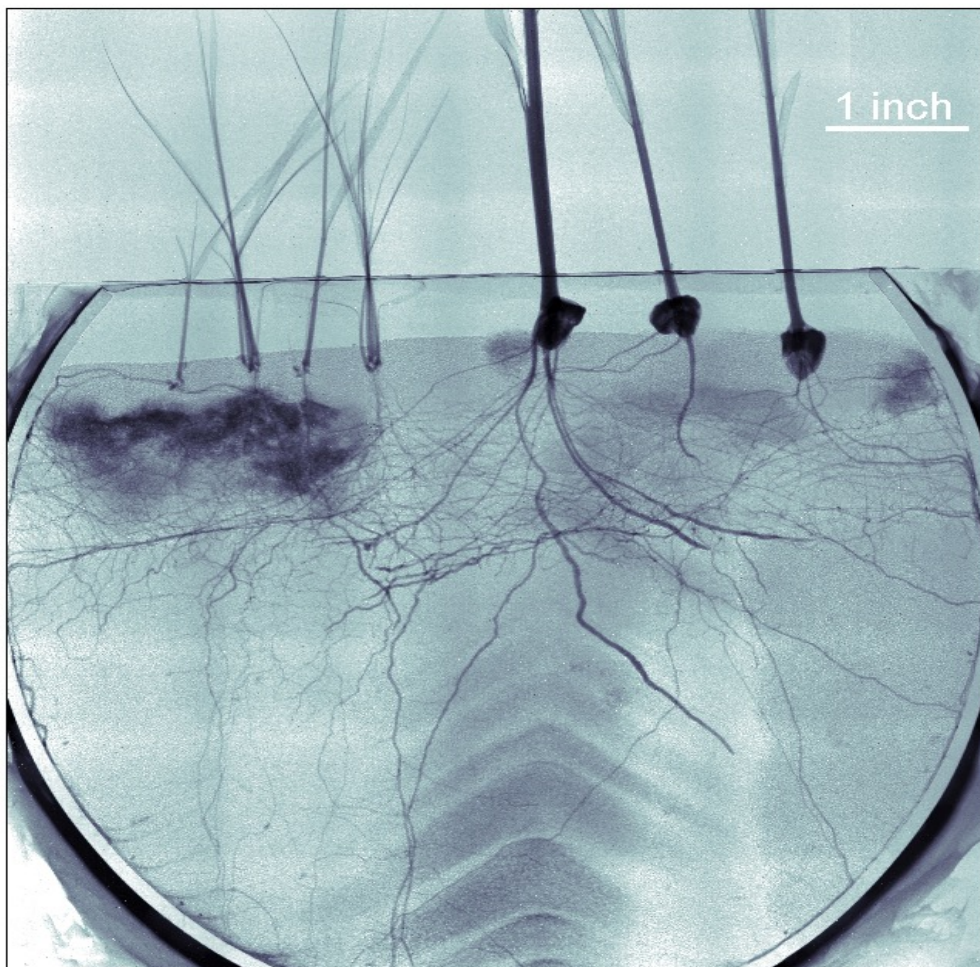
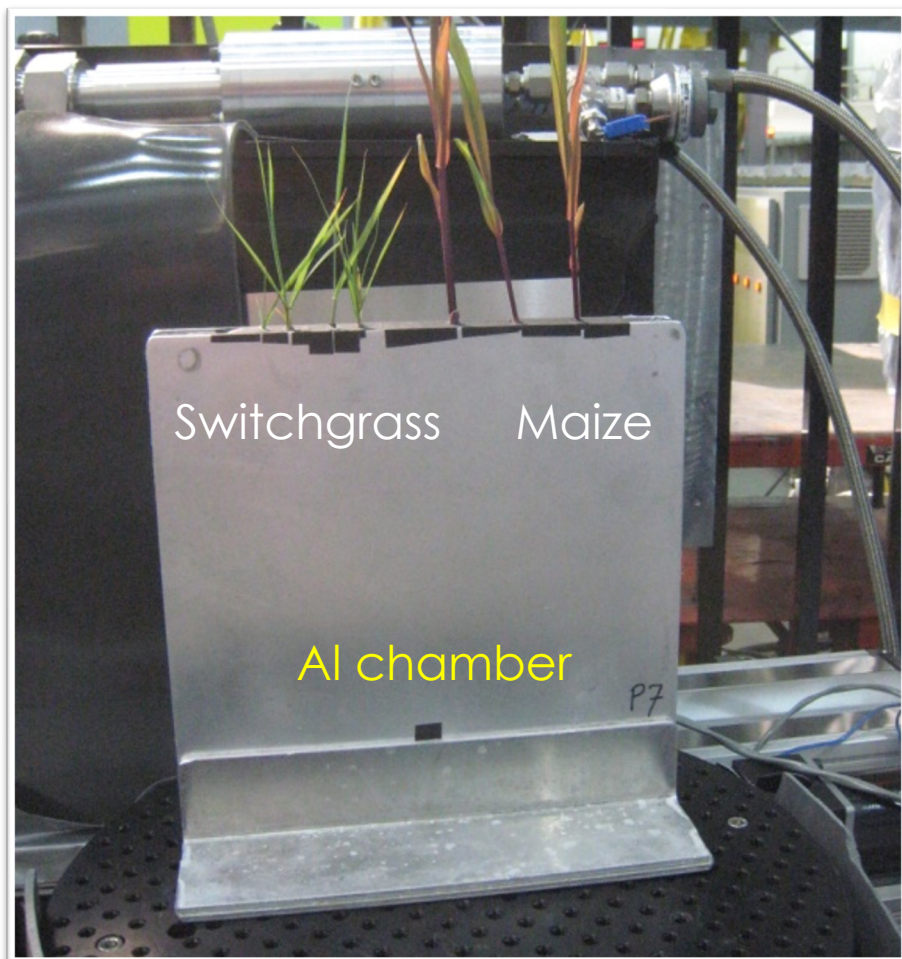
Avogadro constant

$$\mu = \sigma_{tot} \frac{\rho N_A}{M}$$

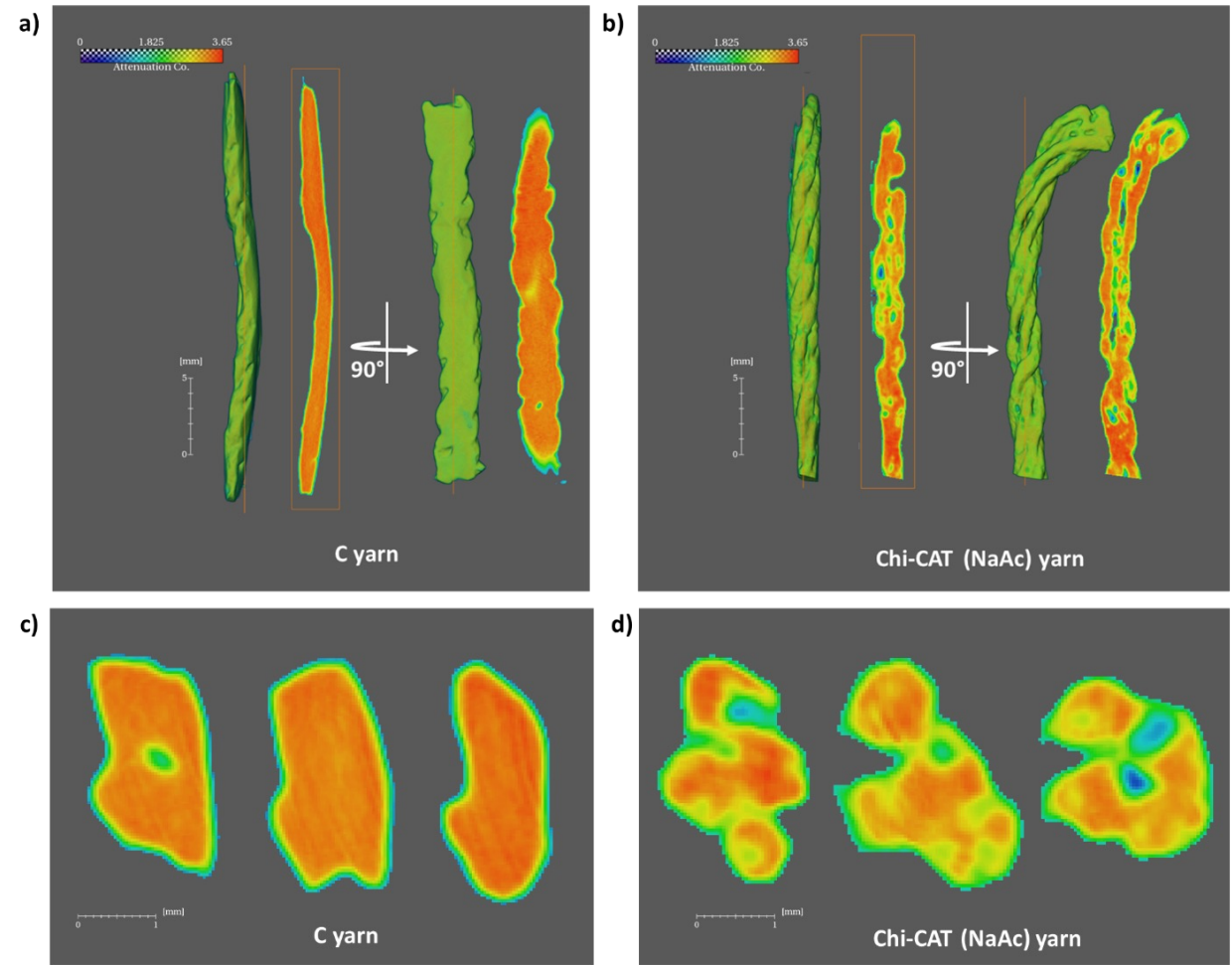
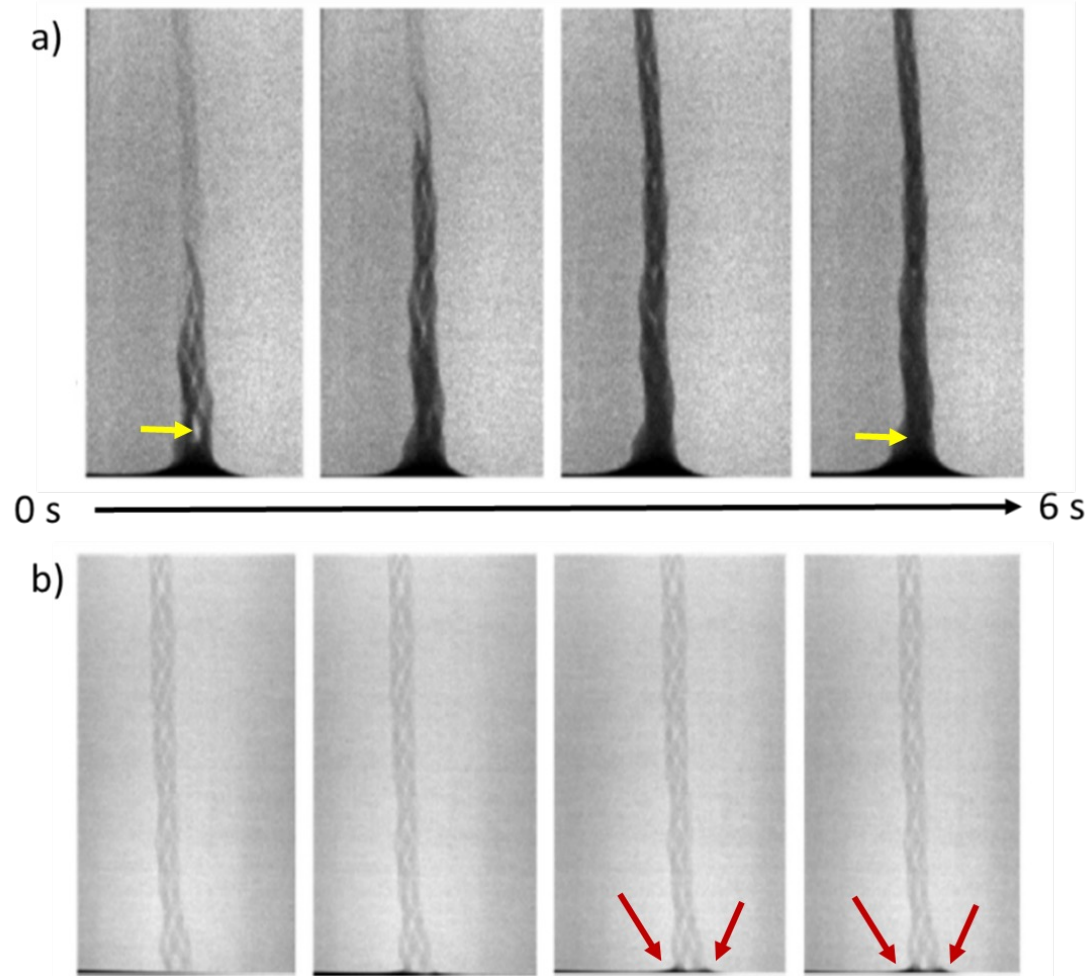
Total cross-section

Molar mass

Example: visualize live root system

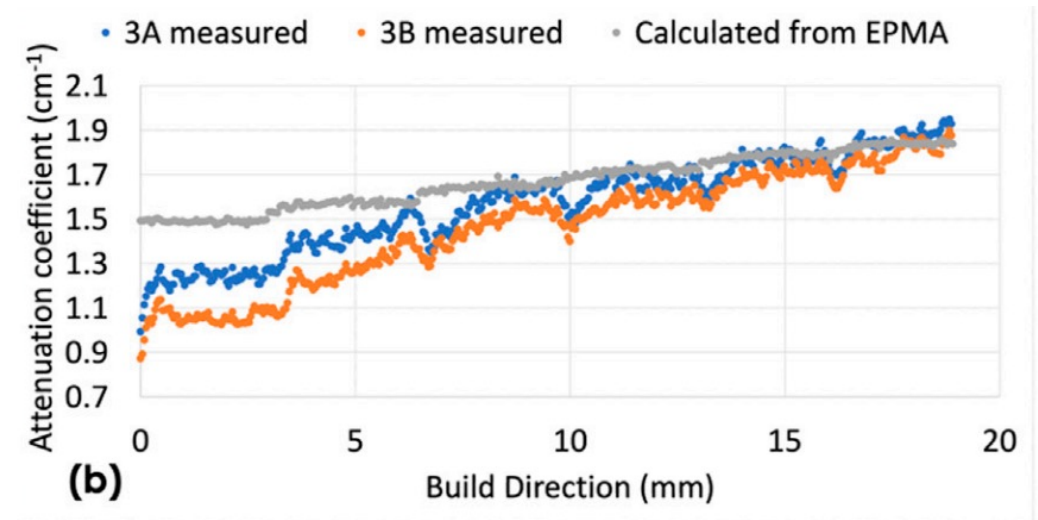
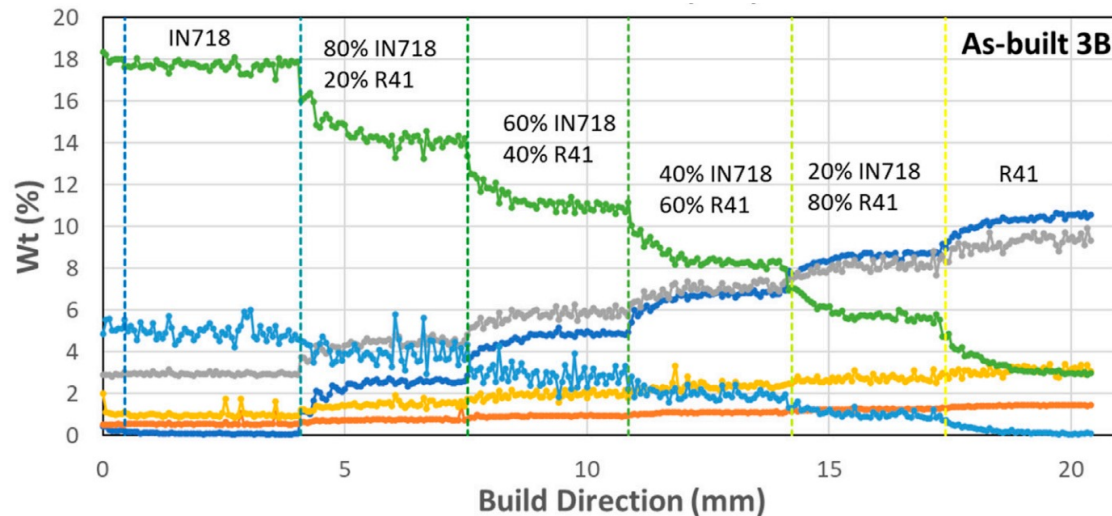
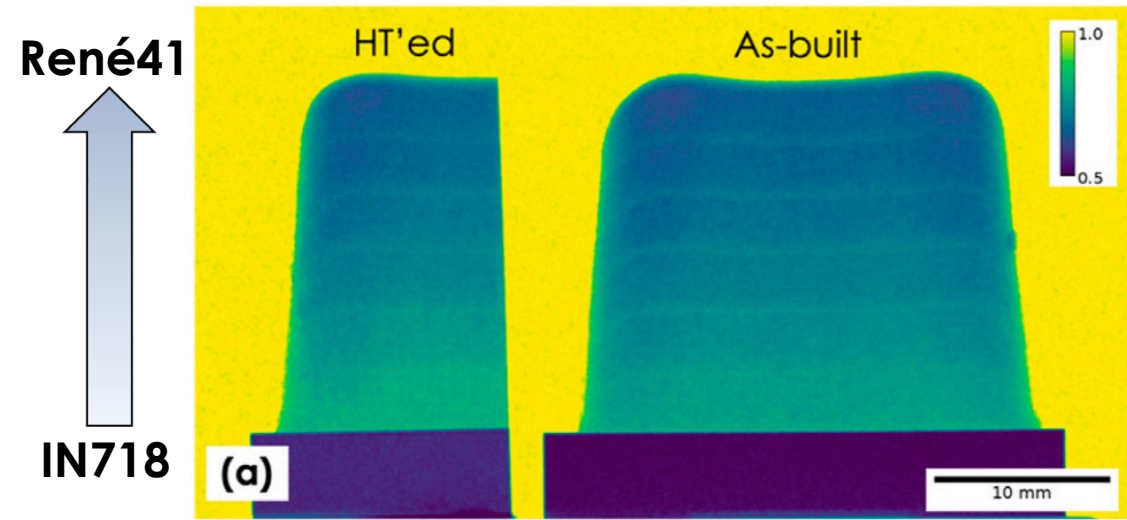
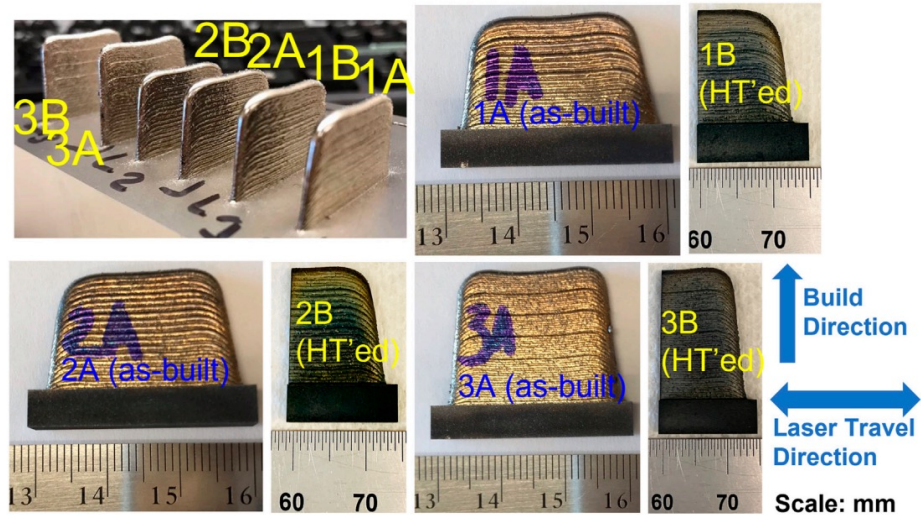


Wicking exp. with yarn

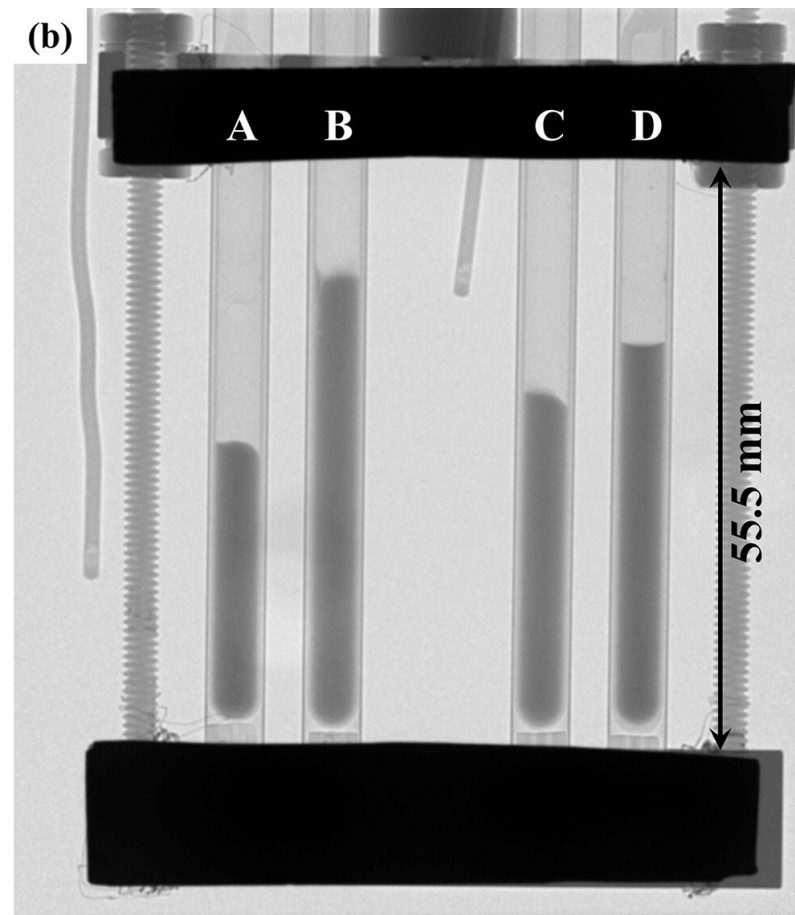
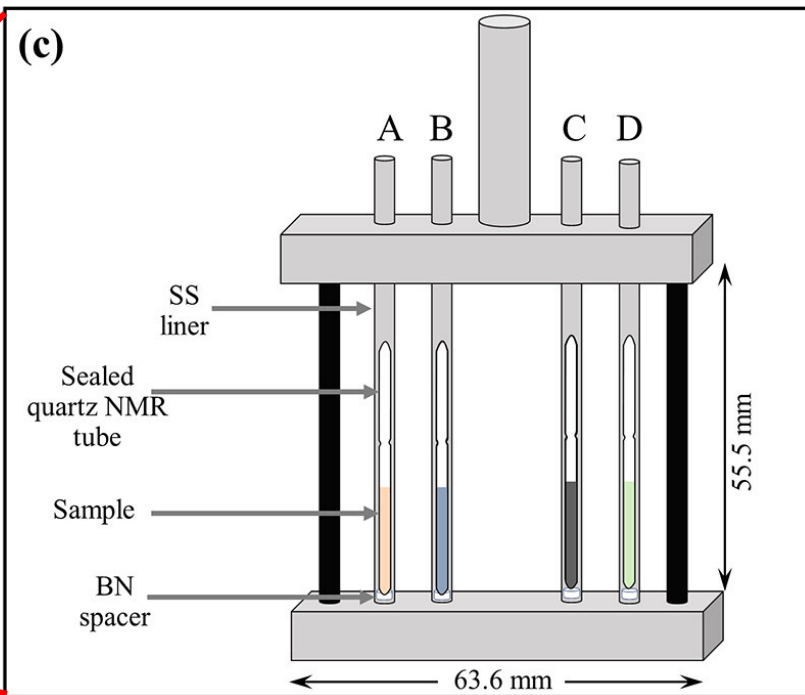
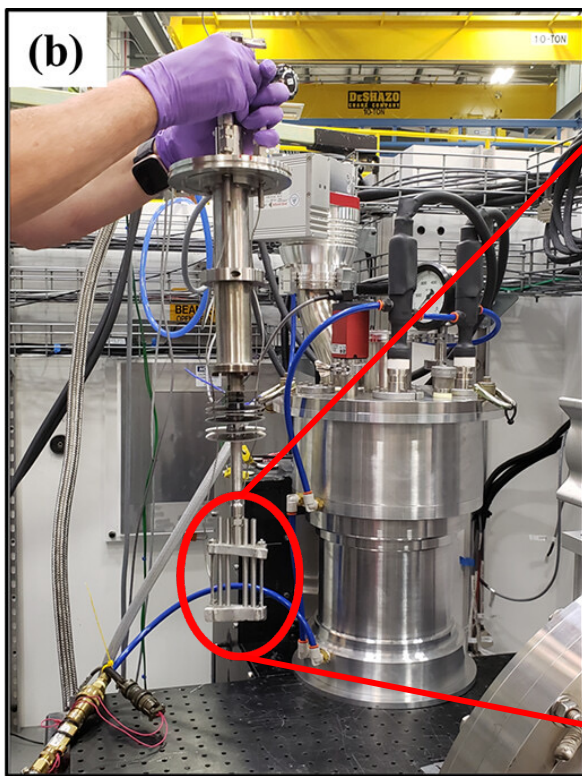


Y. Yuan, Y. Zhang, H. Bilheux, and S. Salmon. "Biocatalytic yarn for peroxide decomposition with controlled liquid transport," *Advanced Materials Interfaces*, 2021, DOI: 10.1002/admi.202002104

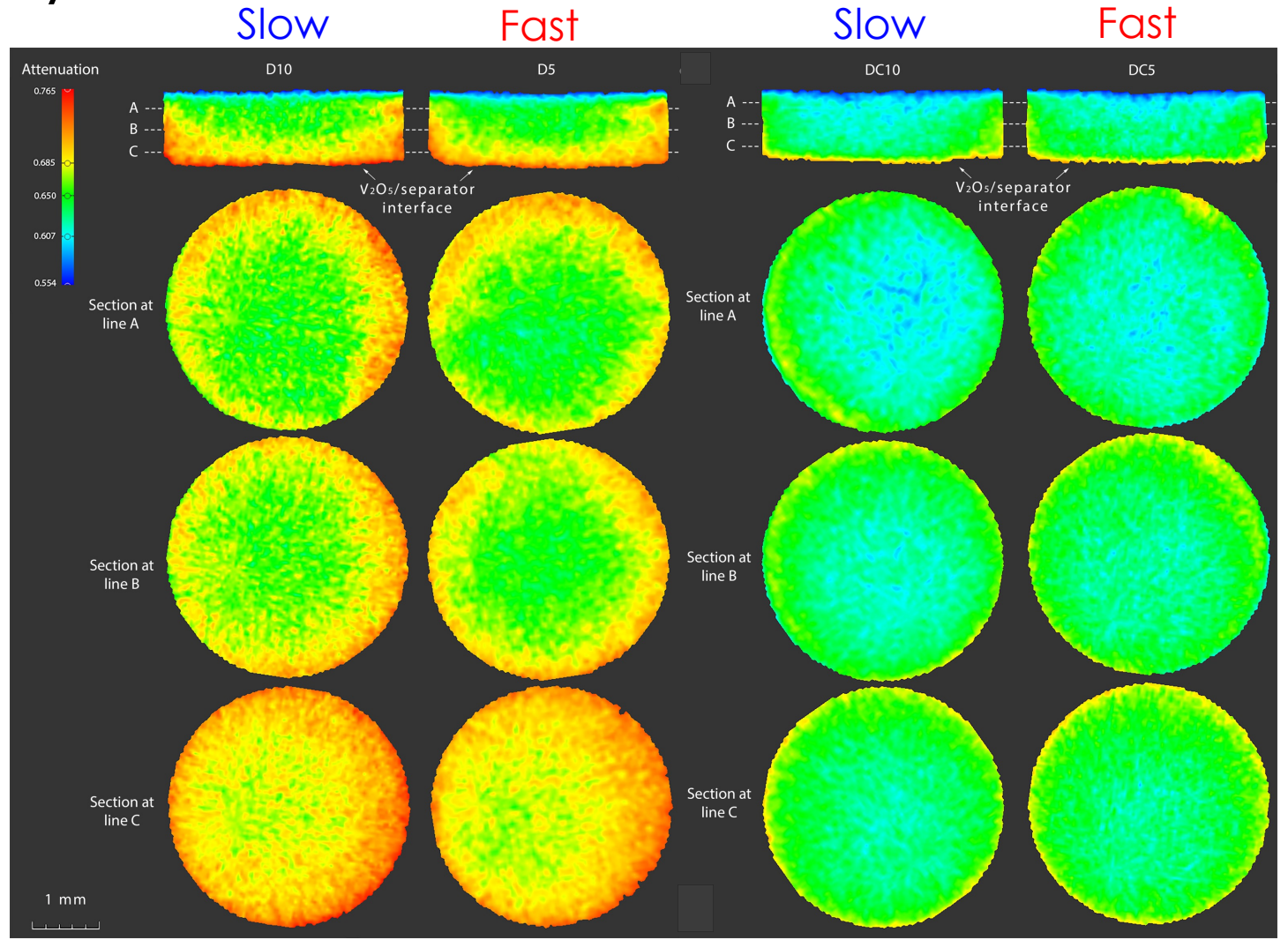
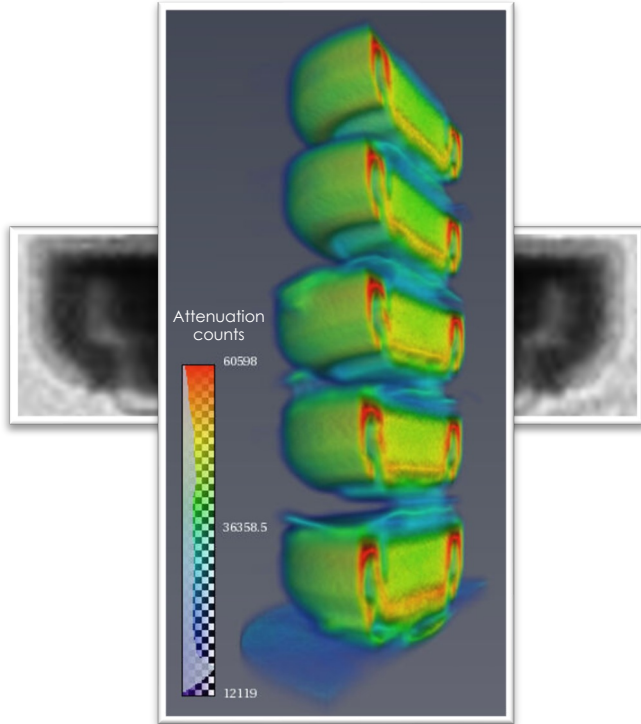
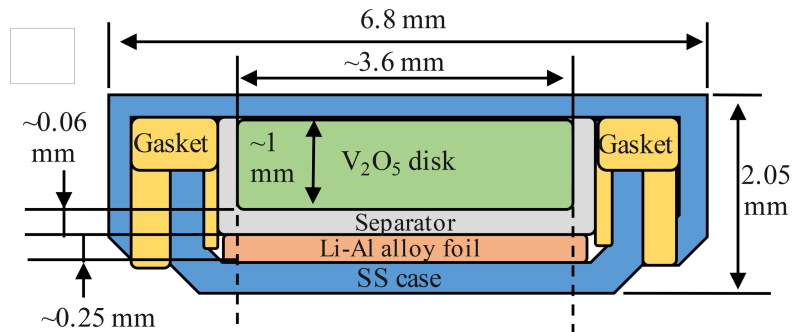
Measures the composition gradient in graded superalloy



Measures molten salt densities at MSR operating temperatures



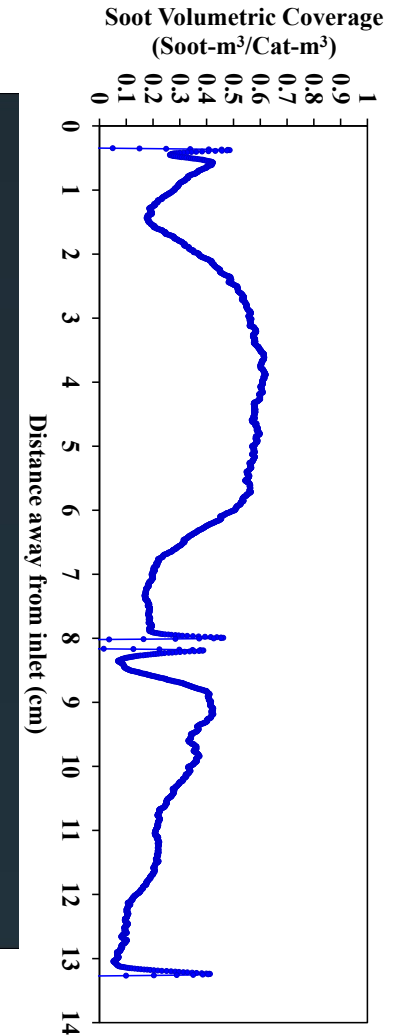
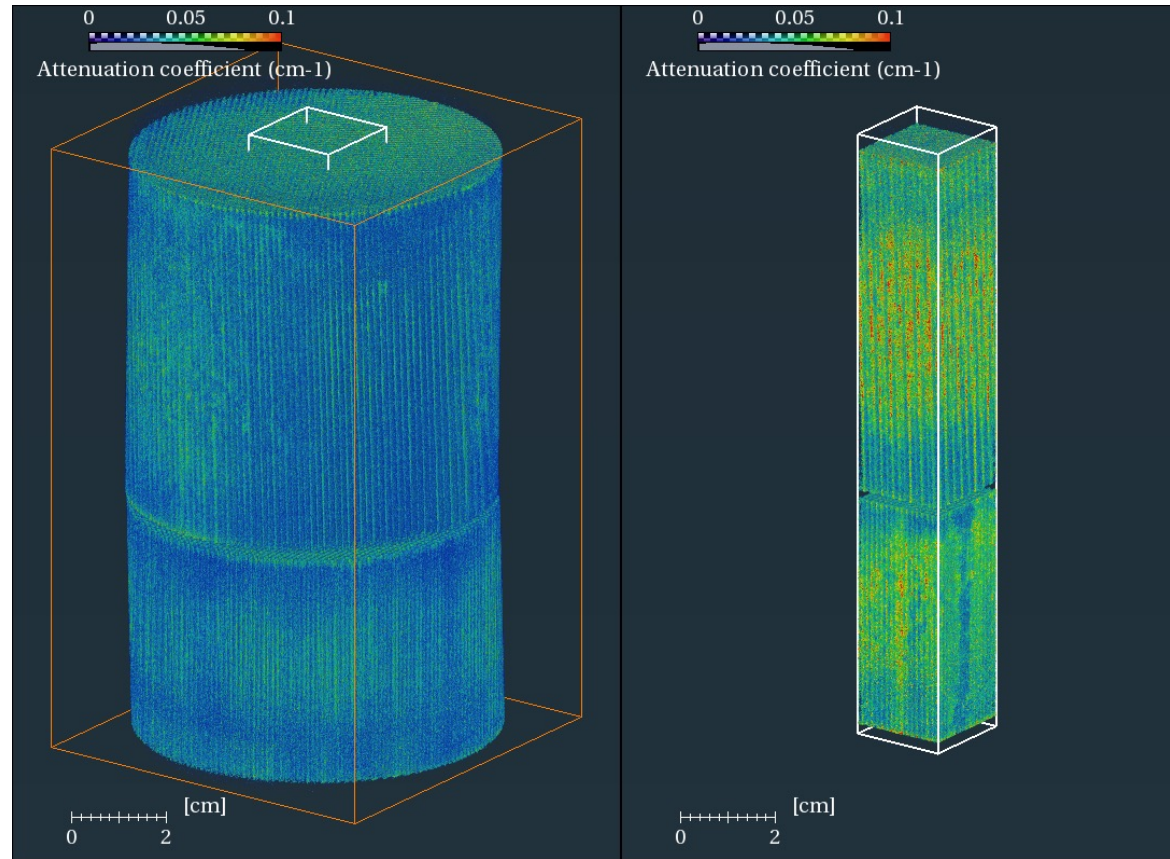
Li distribution is heterogenous and faster C-rates lead to more non-uniformity after lithiation



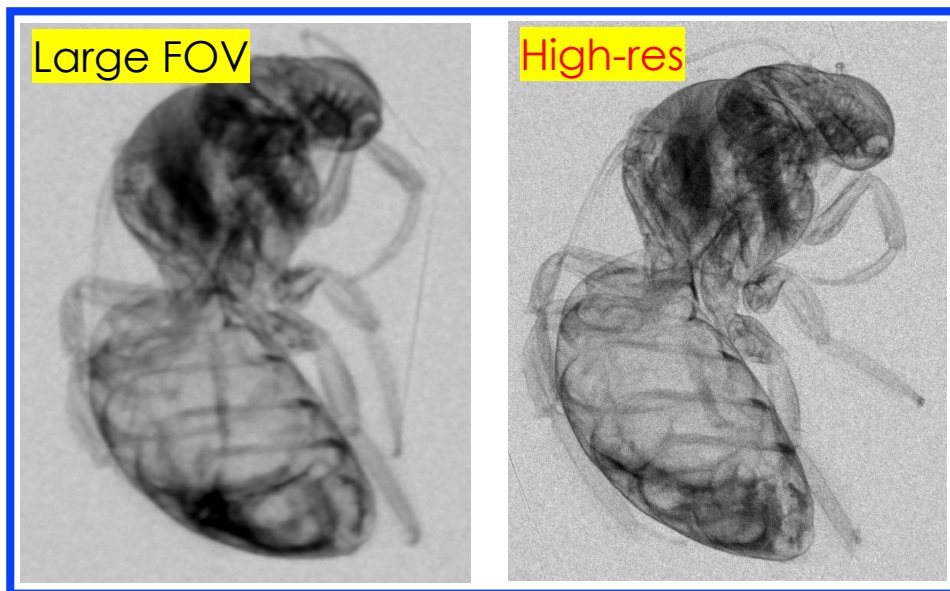
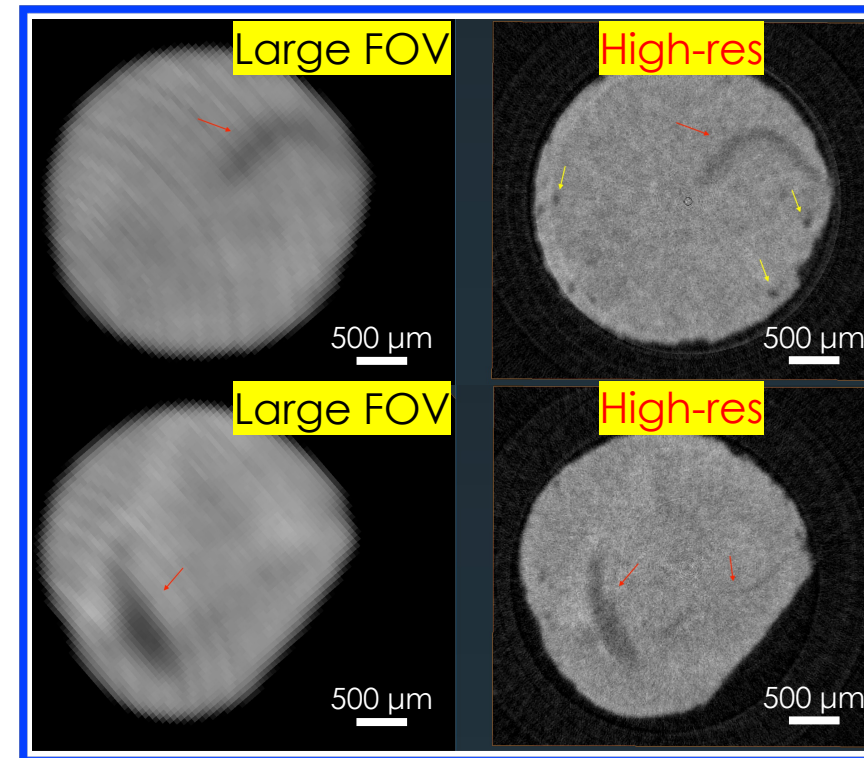
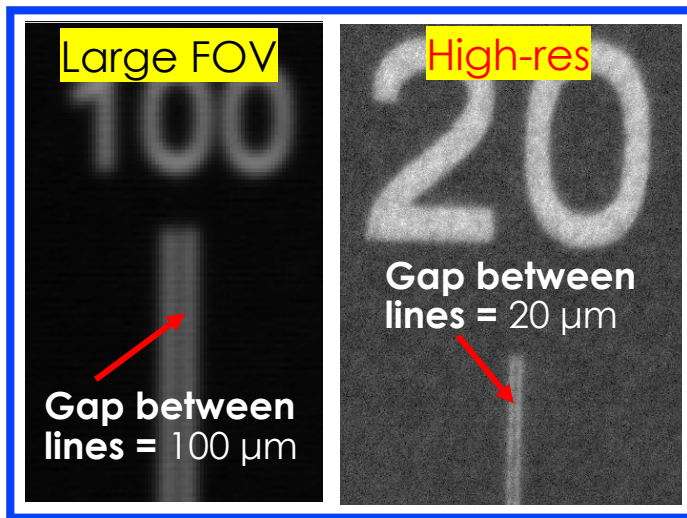
Lithiation

Delithiation

Measures soot distribution in Acidic Gas Reduction device



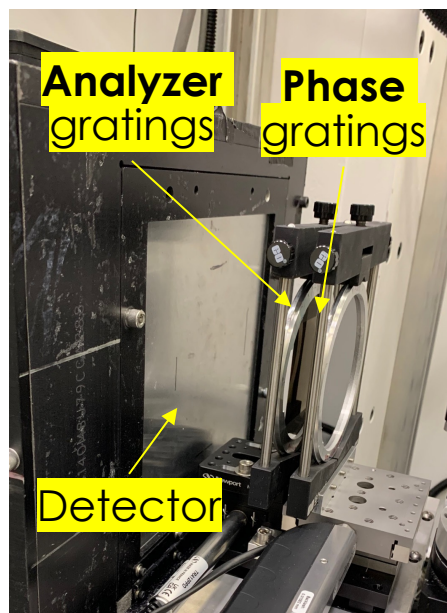
Recently improved spatial resolution for finer details



Setup	Max. FOV	CT scan time	Spatial resolution
Large FOV	80 x 80 mm ²	≥7 hours	75-100 μm
High-res	50 x 50 mm²	≥70 hours	20-25 μm

Implementation of nGI to probe smaller length scale

Neutron Grating Interferometry (nGI)



nGI setup at the downstream



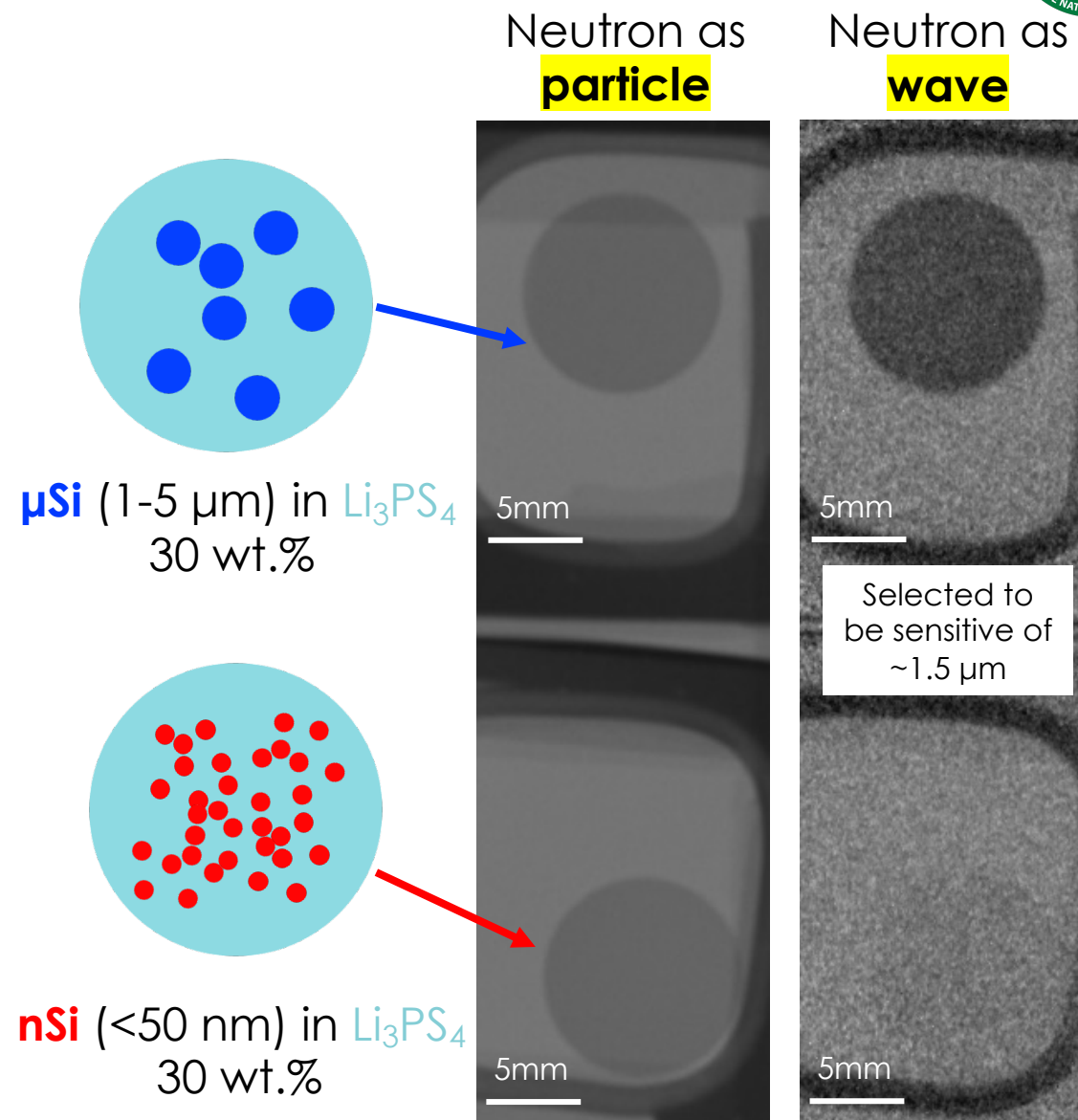
nGI setup at the upstream

- Spatial resolution stay unchanged
- But sensitive to much smaller length scales (~ 40 nm – 2.2 μ m) **selectively**

Sensitive
to nm or μ m
size feature

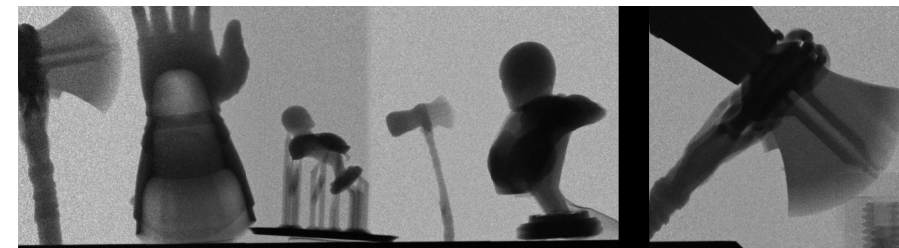


Spatial resolution
of nm or μ m



Neutron Imaging Capabilities at Steady-State (HFIR) Sources

- Radiography
- Tomography
- Grating Interferometry
- Polarized Neutron Imaging
- Monochromatic Imaging



(Sample credit: George Williams)

Type of detector	Field-of-view (FOV)	Pixel size (μm)	Highest spatial resolution (μm)	Typical acquisition time of 1 radiograph	Maximum speed @16 bit
High-res	50 x 49 mm ²	7.63	20-25	360 s	1 image/second
High-speed	88 x 88 mm ²	43	~100	—	74 image/second
Balanced	88 x 88 mm ²	16	~50	30-90 s	1 image/second

Outline

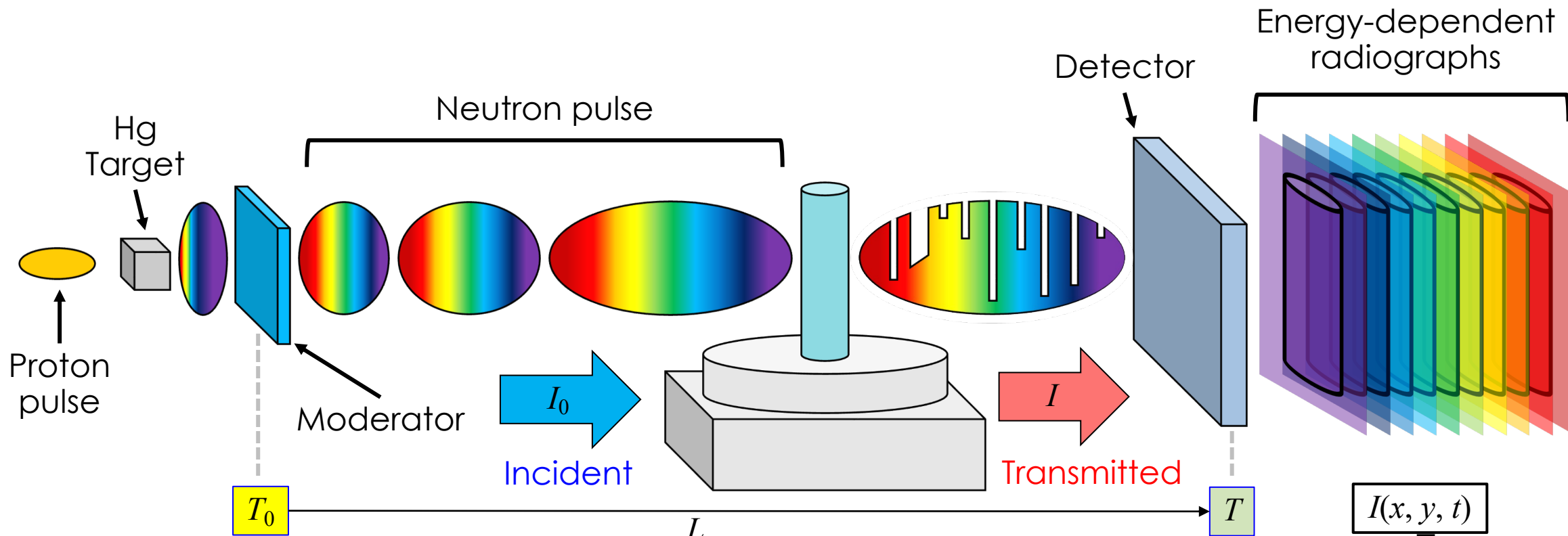
- Imaging at the High Flux Isotope Reactor MARS beamline:
 - Principle of neutron radiography and computed tomography at a continuous source
 - The CG-1D imaging beamline
 - Examples
- **Imaging at the Spallation Neutron Source:**
 - **Principle of neutron radiography at a pulsed source**
 - **Examples**
 - **The VENUS construction project**
- Software tools for imaging

Yuxuan

Hassina

Jean

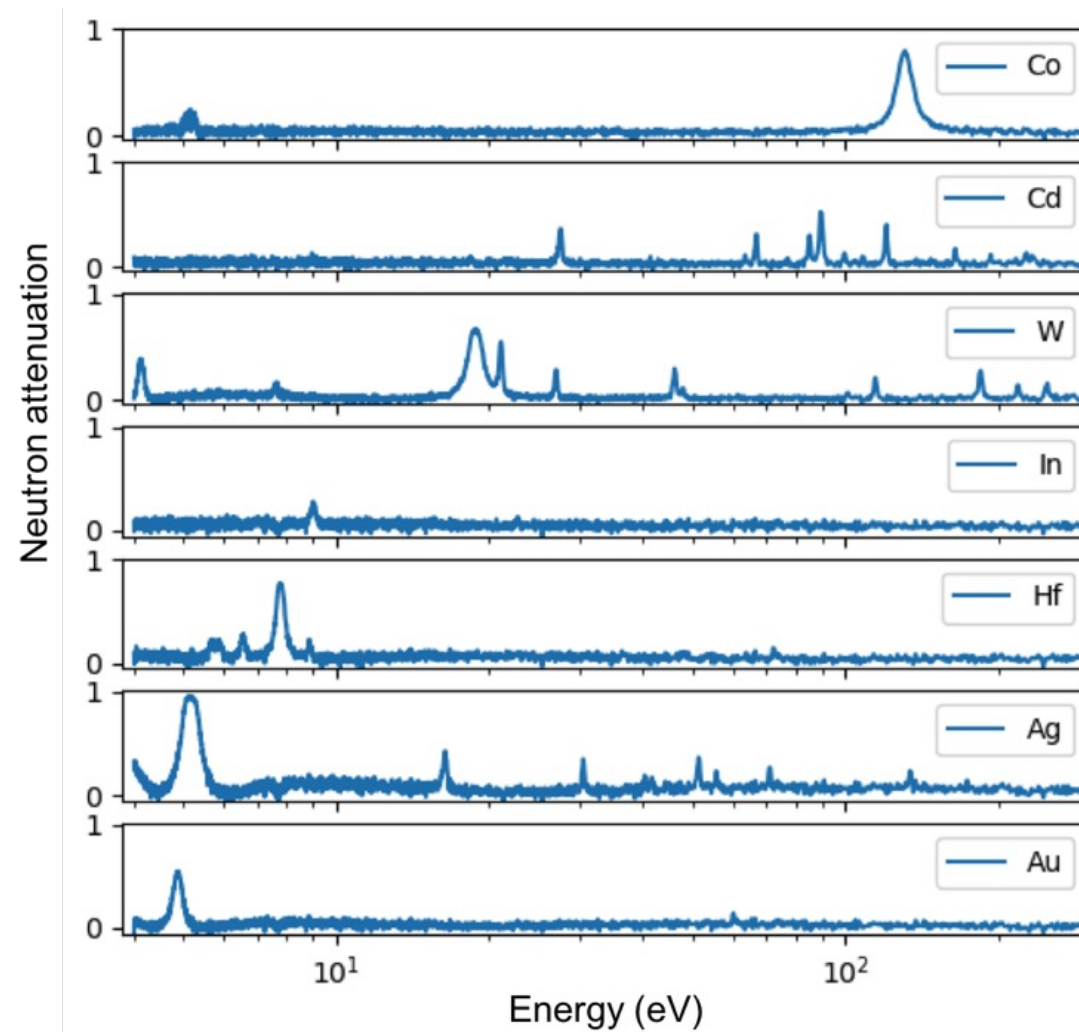
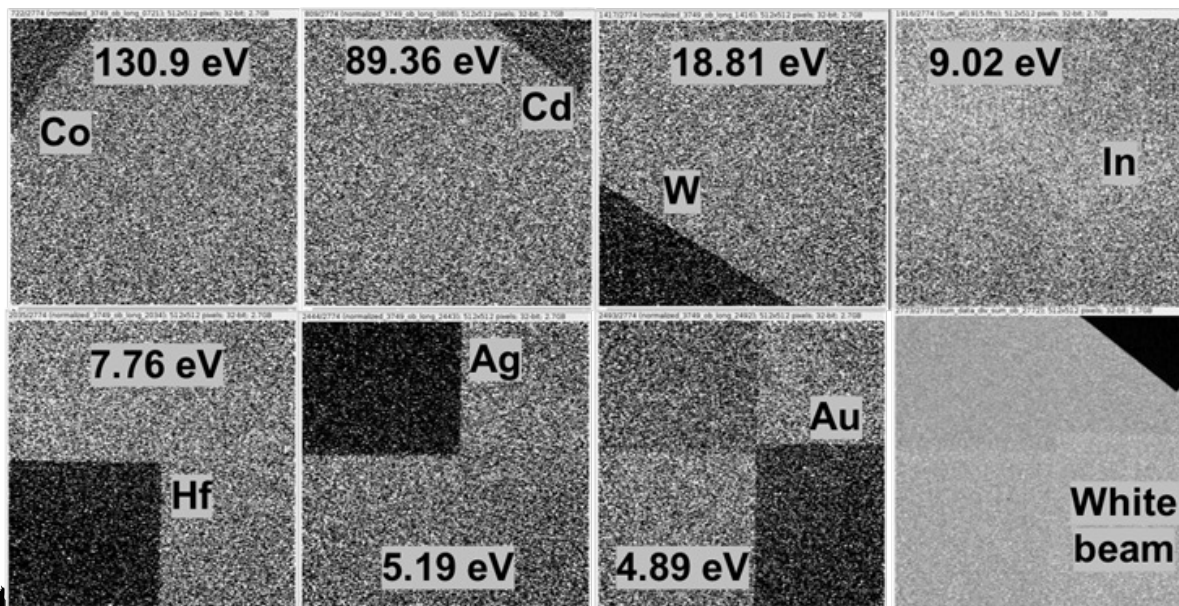
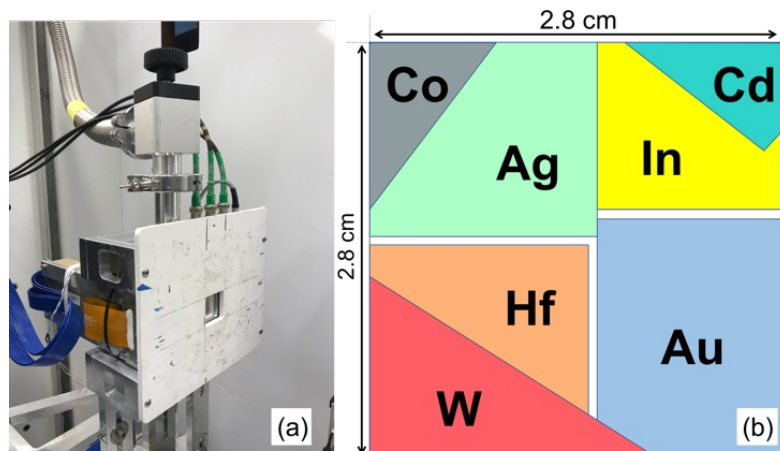
Imaging at a pulsed source (SNS)



Courtesy of Y. Zhang, ORNL

$$I(\lambda) = I_0(\lambda)e^{-\mu(\lambda)x} \quad \mu(\lambda) = \sigma_t(\lambda) \frac{\rho N_A}{M}$$

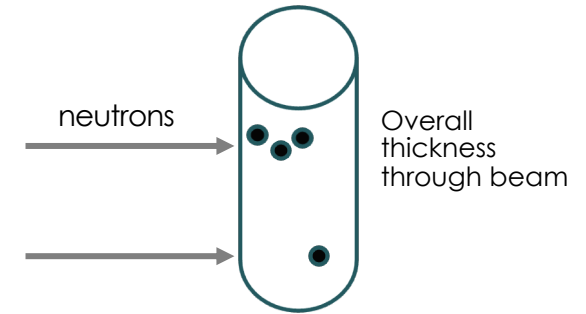
Higher energy neutrons can also be used for imaging (neutrons of energies higher than 1 eV): Resonance Imaging



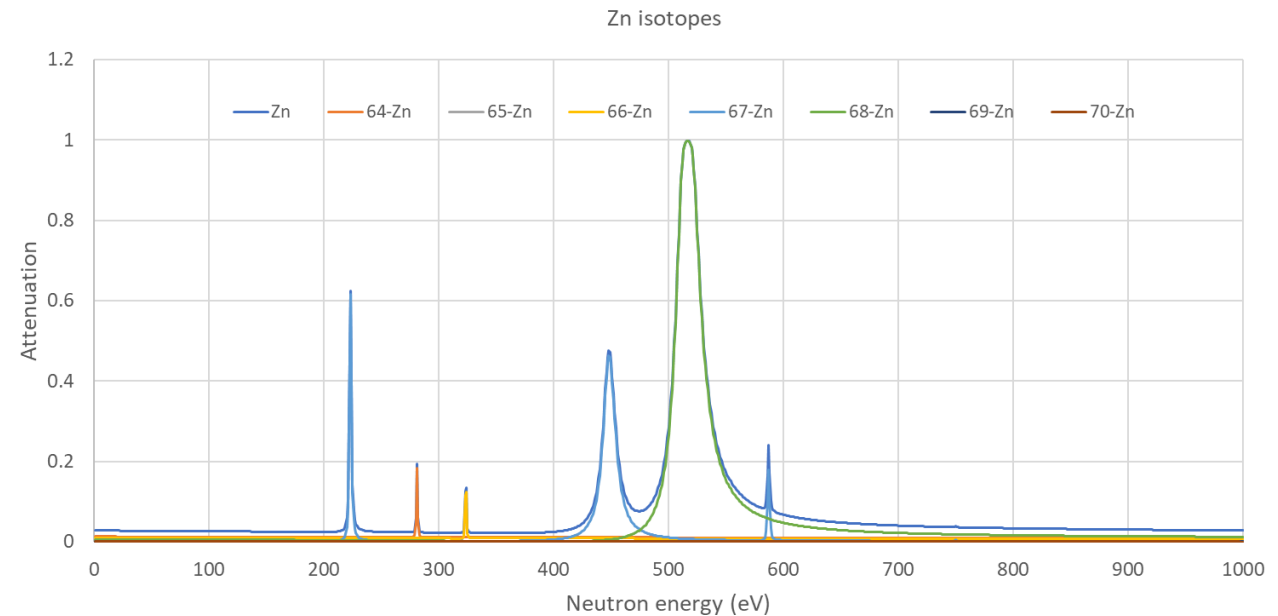
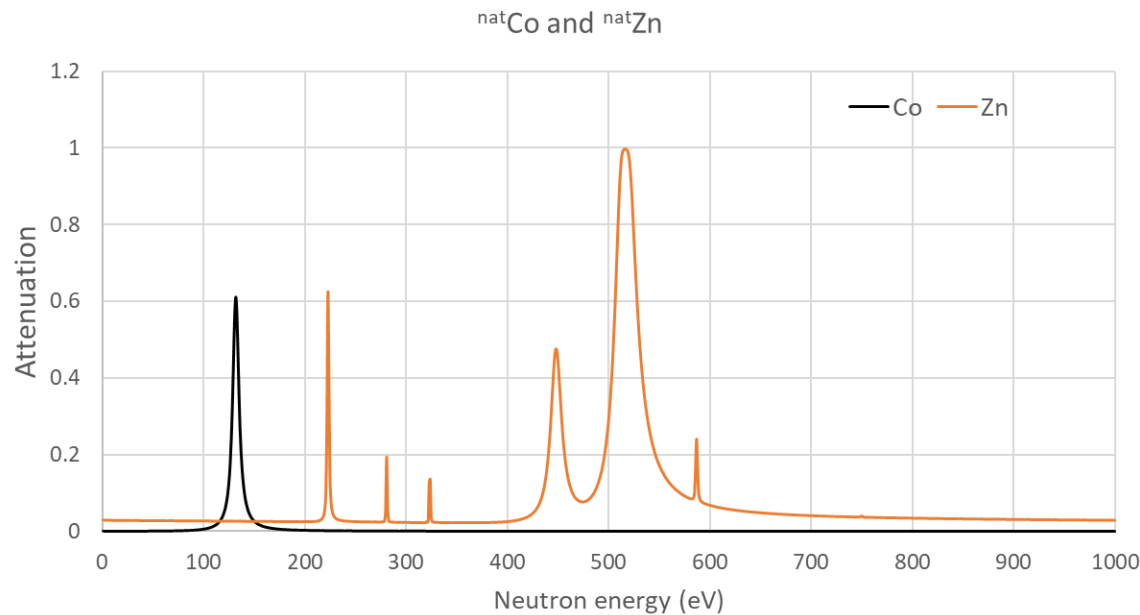
Zhang Y., Myhre K.G., Bilheux H.Z., Tremsin A.S., Johnson J.A., Bilheux J., Miskowicz A., Hunt R.D., Santodonato L., Molaison J.J., "[Neutron Resonance Radiography and Application to Nuclear Fuel Materials](#)", *Transactions of the American Nuclear Society*, (2018).

Resonance imaging: preparing your experiment

- Soil surveys, contaminants in soil, etc.:
 - transmission through 0.01 mm thickness of ^{nat}Co (between 1 and 5 Å) = 99.5 %
 - transmission through 1 mm thickness of ^{nat}Zn (between 1 and 5 Å) = 96.4 %



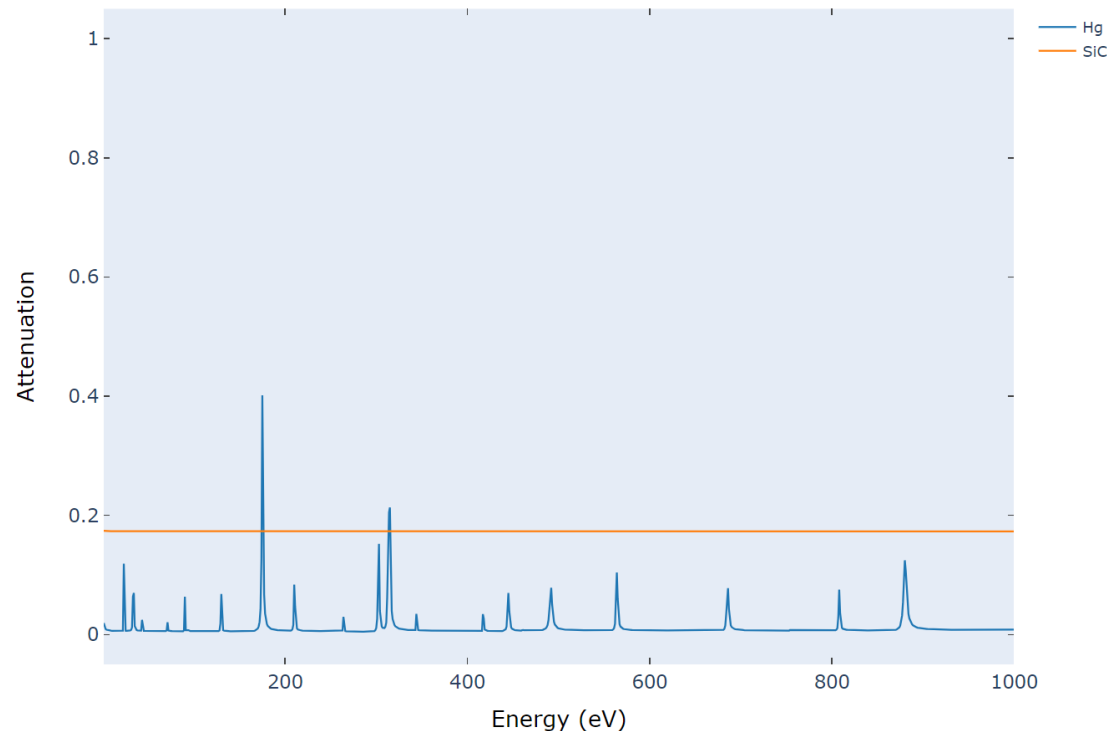
Simulated resonance for elements of interest(*)



Resonance imaging: preparing your experiment (cont'



- Hg contamination in soil
 - Assumptions: 0.1 mm Hg (13.6 g/cm^3) + 12.5 mm SiC (with 1.5 g/cm^3)
 - Transmission (1 and 5 Å) = 66.4 %



Resonance peaks plotted with:

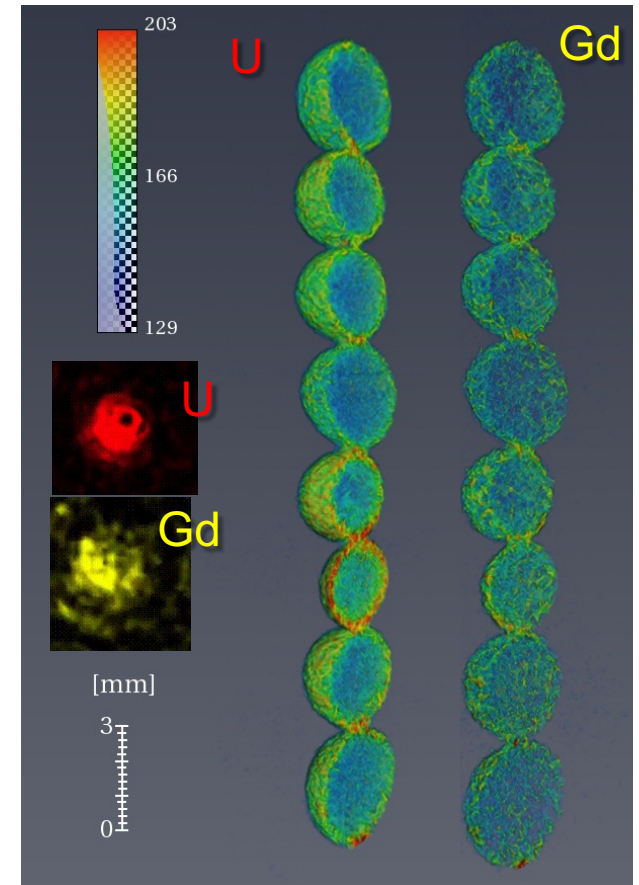
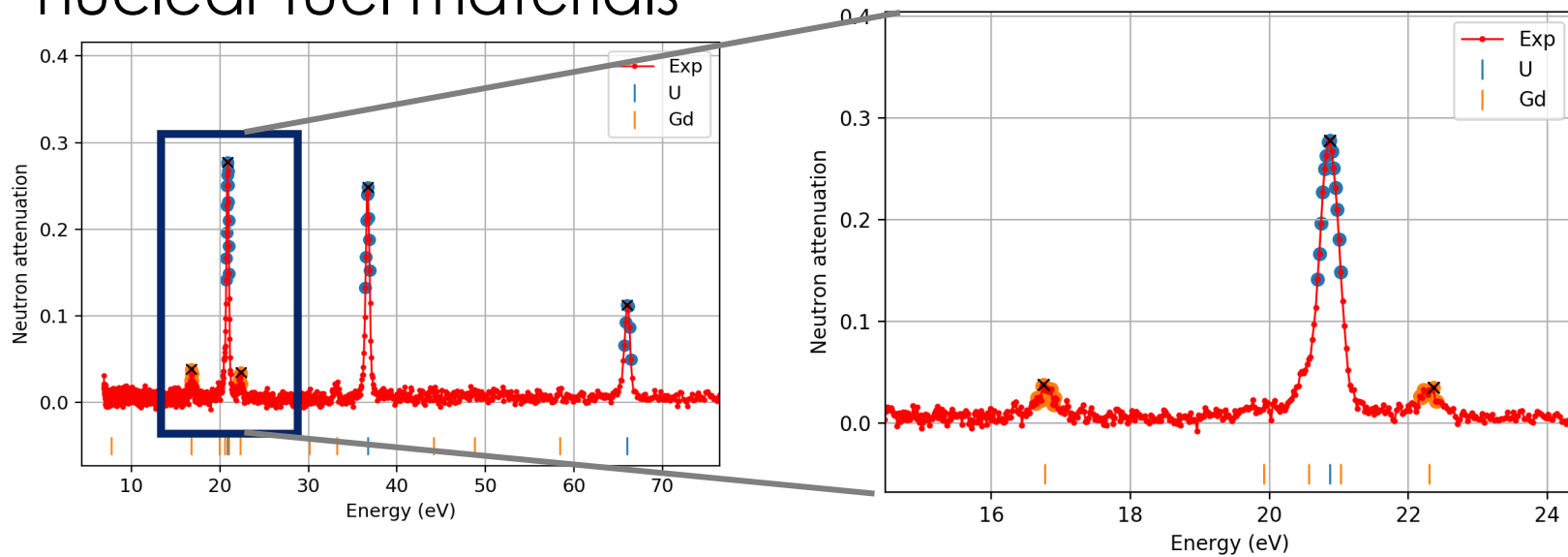
iNEUIT (*"I knew it"*)



iNEUtron Imaging Toolbox

Using epithermal neutrons (energy > 1 eV), resonance imaging can map the isotopic content in advanced nuclear fuel materials in 3D

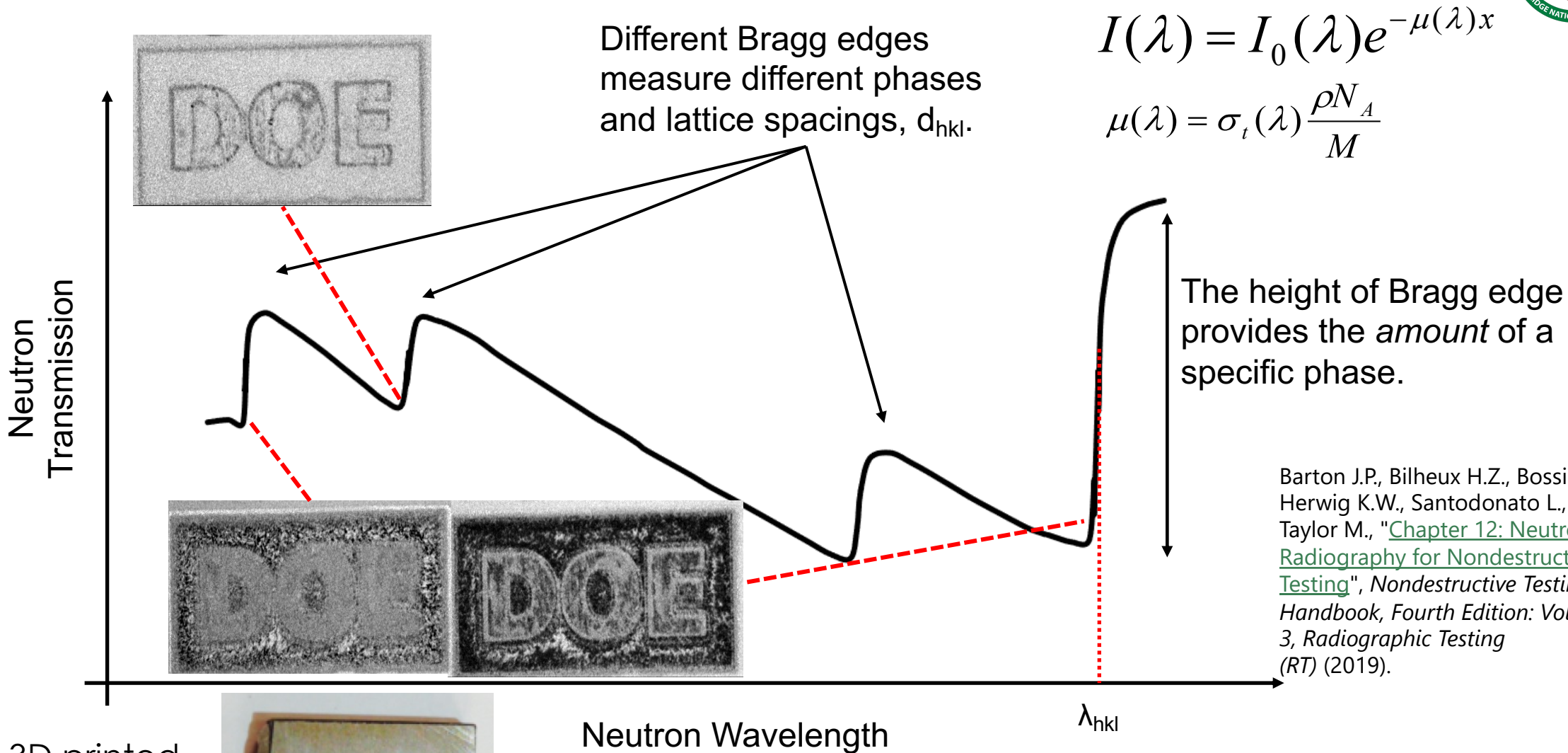
- Distribution of elements drive the performance of the novel advanced nuclear fuel materials



- Quantitative analysis is being developed using in-house open source Python package (ResoFit)

Myhre K.G., Zhang Y., Bilheux H.Z., Johnson J.A., Bilheux J., Miskowiec A., Hunt R.D., ["Nondestructive Tomographic Mapping of Uranium and Gadolinium Using Energy-Resolved Neutron Imaging"](#), *Transactions of the American Nuclear Society*, (2018).

Bragg edge imaging: how does it work?



Barton J.P., Bilheux H.Z., Bossi R., Herwig K.W., Santodonato L., Taylor M., "[Chapter 12: Neutron Radiography for Nondestructive Testing](#)", *Nondestructive Testing Handbook, Fourth Edition: Volume 3, Radiographic Testing (RT)* (2019).

3D printed Inconel 718



1 cm



Radiograph at HFIR

The position of the Bragg edge, $\lambda_{hkl} = 2 d_{hkl}$, is a measure of the *strain* in the sample

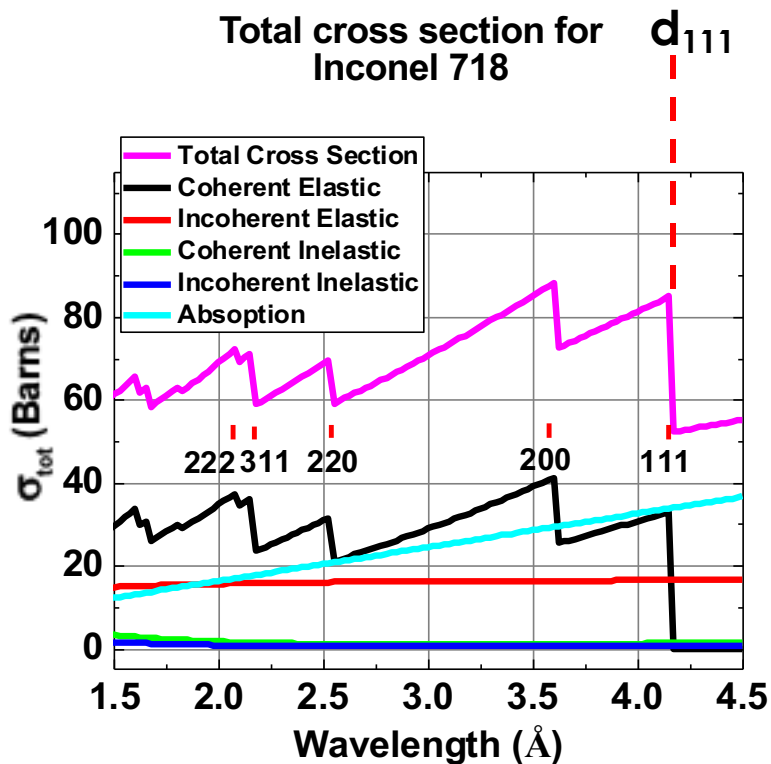
Principle of Bragg edge Transmission

- ✓ Utilizes thermal and cold neutrons (approximately between 1 and 10 Å)
- ✓ Obeys Bragg's Law $\lambda_{hkl} = 2d_{hkl} \sin \theta_{hkl}$ simplifies: $\lambda_{hkl} = 2d_{hkl}$

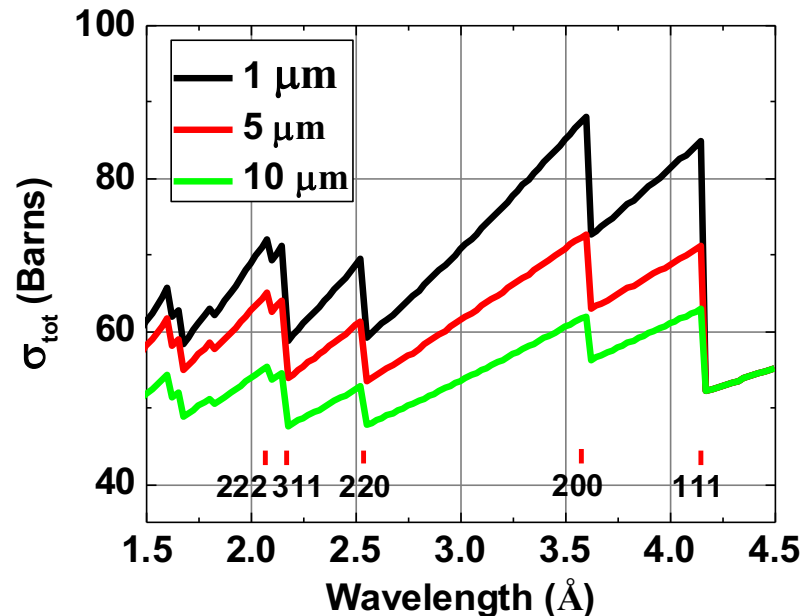
$$\sigma_{Bragg}(\lambda) = \frac{\lambda^2}{2V_0} \sum_{hkl}^{2d_{hkl} > \lambda} |F_{hkl}|^2 d_{hkl} \underbrace{P(\alpha_{\vec{h}}(\lambda))}_{\text{March-Dollase model}} \underbrace{E_{hkl}(\lambda, F_{hkl})}_{\text{Sabine's primary extinction model}}$$

V_0 : volume of unit cell
 F_{hkl} : Structure factor including Debye-Waller factor

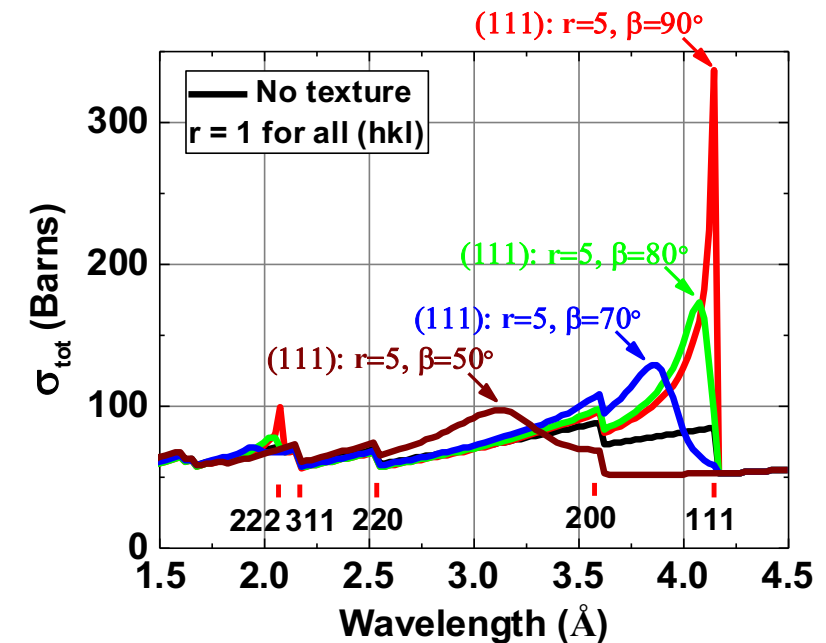
Total cross section for Inconel 718



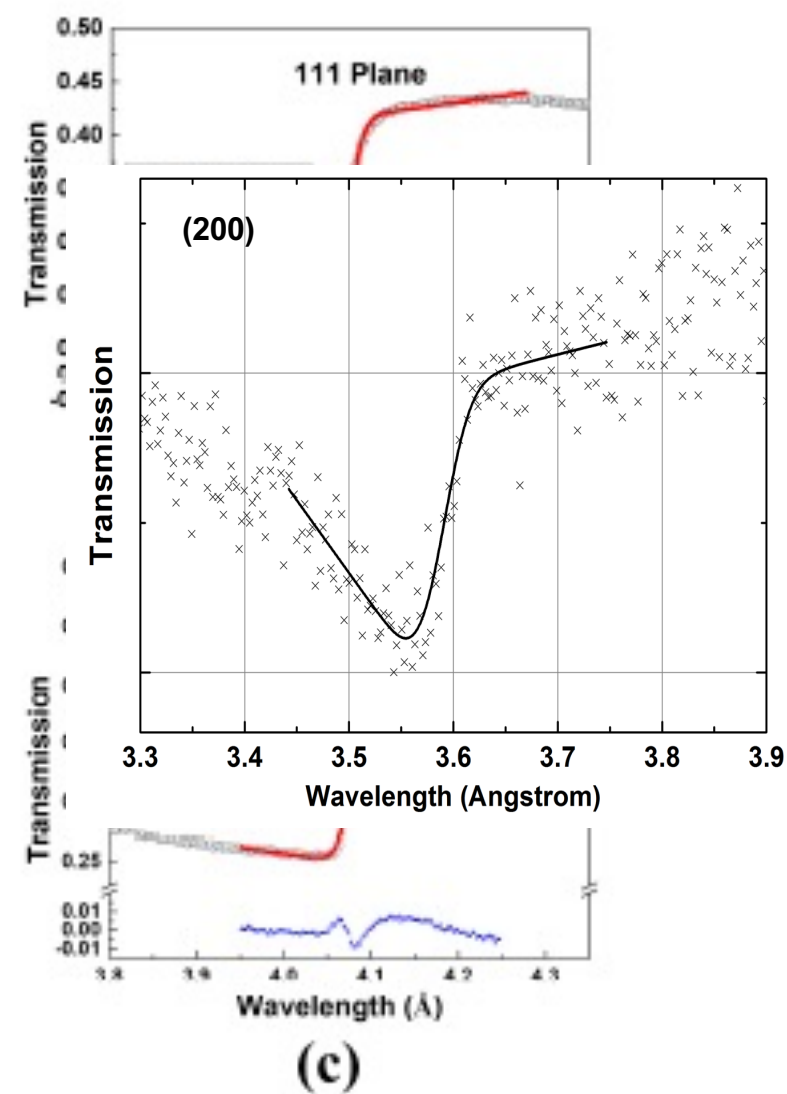
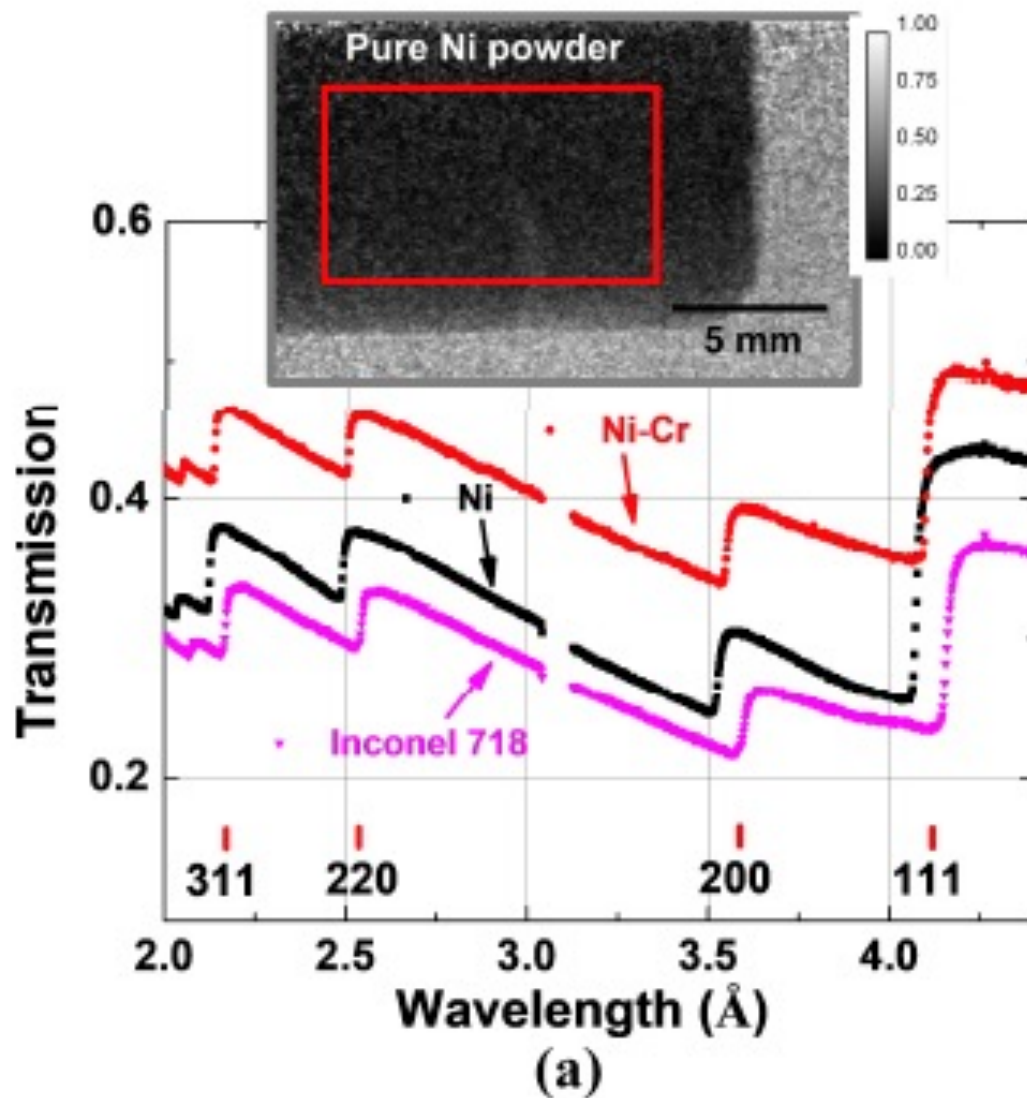
Crystallite size effect (E_{hkl})



Crystallite orientation effect ($P(\alpha_{\vec{h}}(\lambda))$): r and β)



The perfect case study: powders



Song G., Lin J.Y., Bilheux J., Xie Q., Santodonato L., Molaison J.J., Skorpenske H.D., dos Santos A.M., Tulk C.A., An K., Stoica A.D., Kirka M.M., Dehoff R.R., Tremsin A.S., Bunn J.R., Sochalski-Kolbus L.M., Bilheux H.Z., ["Characterization of Crystallographic Structures Using Bragg-Edge Neutron Imaging at the Spallation Neutron Source"](#), *Journal of Imaging*, **3**, 4, 65 (2017).

Materials Behavior: Monitoring residual strain relaxation and preferred grain orientation of additively manufactured Inconel 625 by in-situ neutron imaging

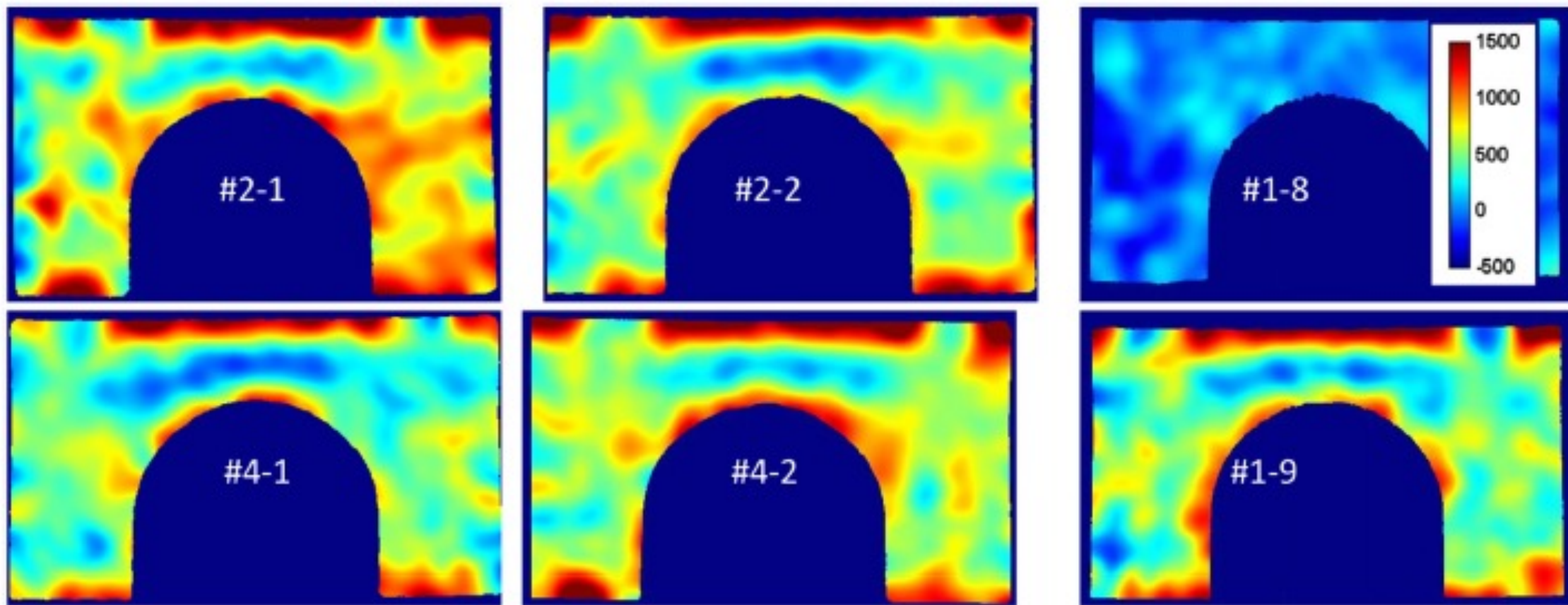
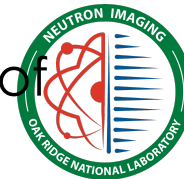
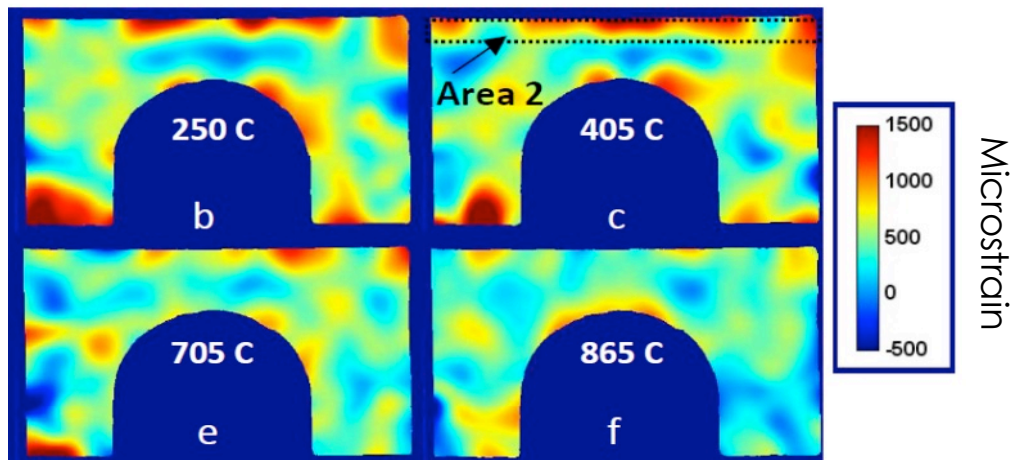
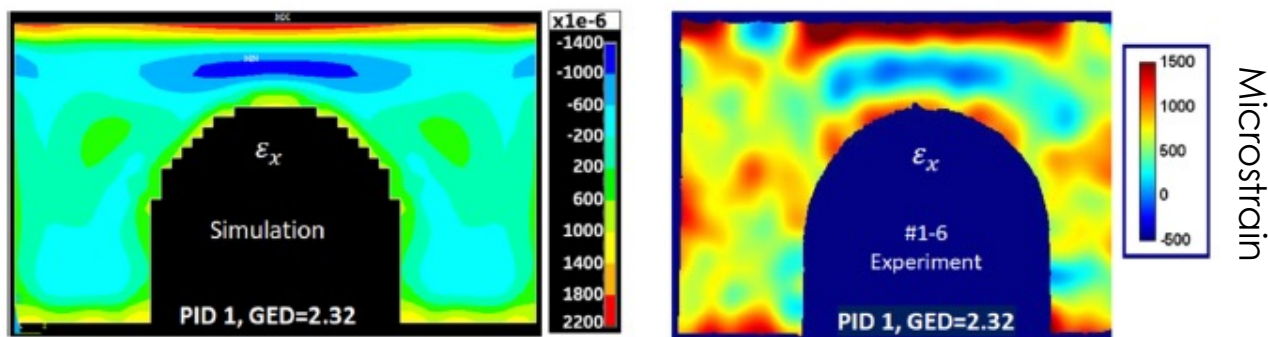
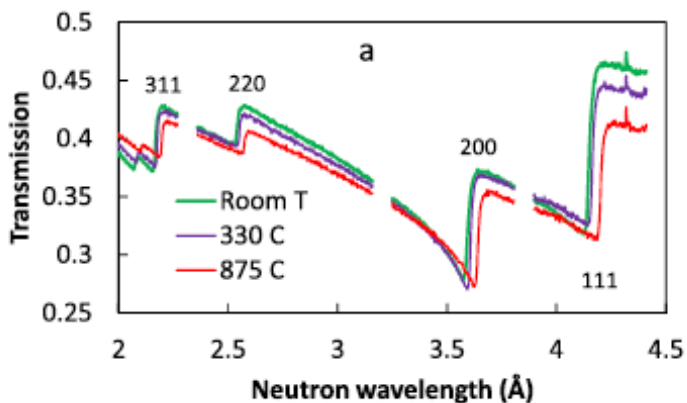


Fig. 8. Strain distribution (in microstrain) at the (111) Bragg edge measured at room temperature along the sample thickness direction X. SNAP beamline. The image integration time was about 2 h at SNAP. λ_0 value is taken from the annealed sample #1-8 (average across the entire sample). The legend indicates the strain values in microstrain.

Engineered Materials: Monitoring residual strain relaxation and preferred grain orientation of additively manufactured Inconel 625 by in-situ neutron imaging (10 min measurements)



AM Inconel 625 strain evolution as a function of temperature



Modeled and experimental results.

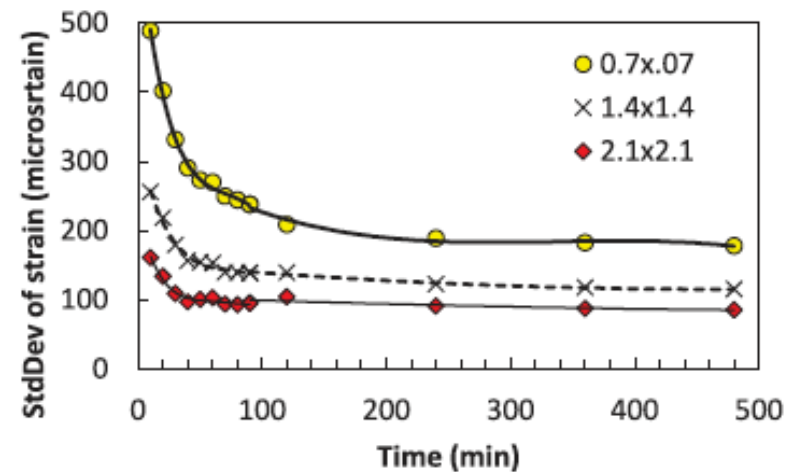
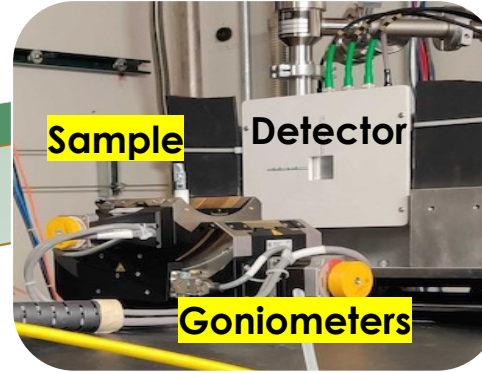
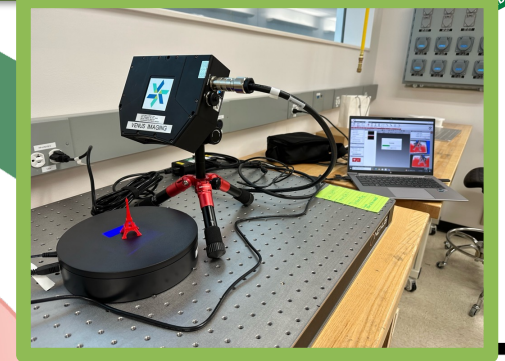


Fig. 16. Variation of the standard deviation of the reconstructed strain as a function of image integration time. Three different sizes of the area used for pixel grouping are used for strain reconstruction, as indicated by the legend (in mm²).

Autonomous Hyperspectral Neutron CT Experiment at ORNL



Light scan and preselection of projection angles

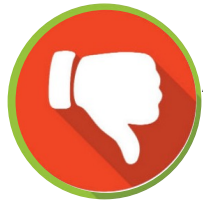


Continue

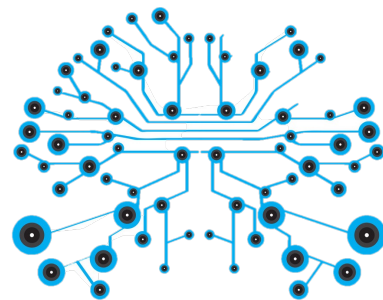
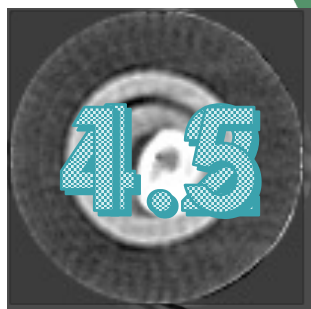
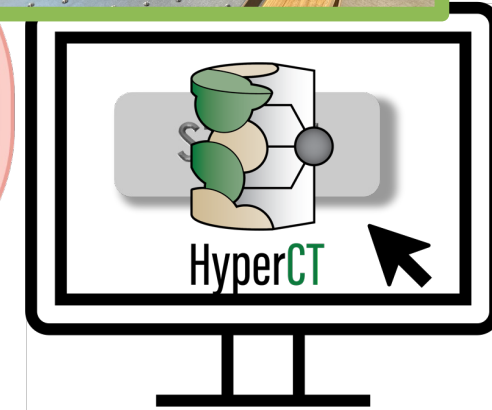
Stop

Up to factor 5 improvement in time

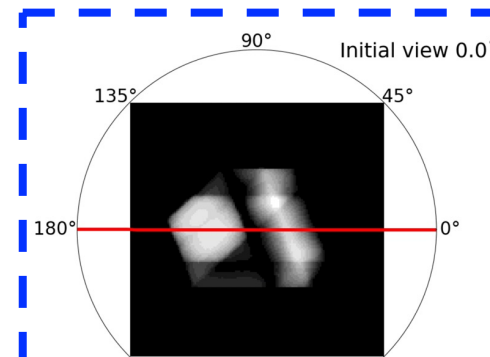
- ▶ Optimization of the scan based on the unique sample geometry
- ▶ Ability to provide real-time reconstructed data using advanced iterative reconstruction methods



Autonomous Decision



AI Quality Evaluation



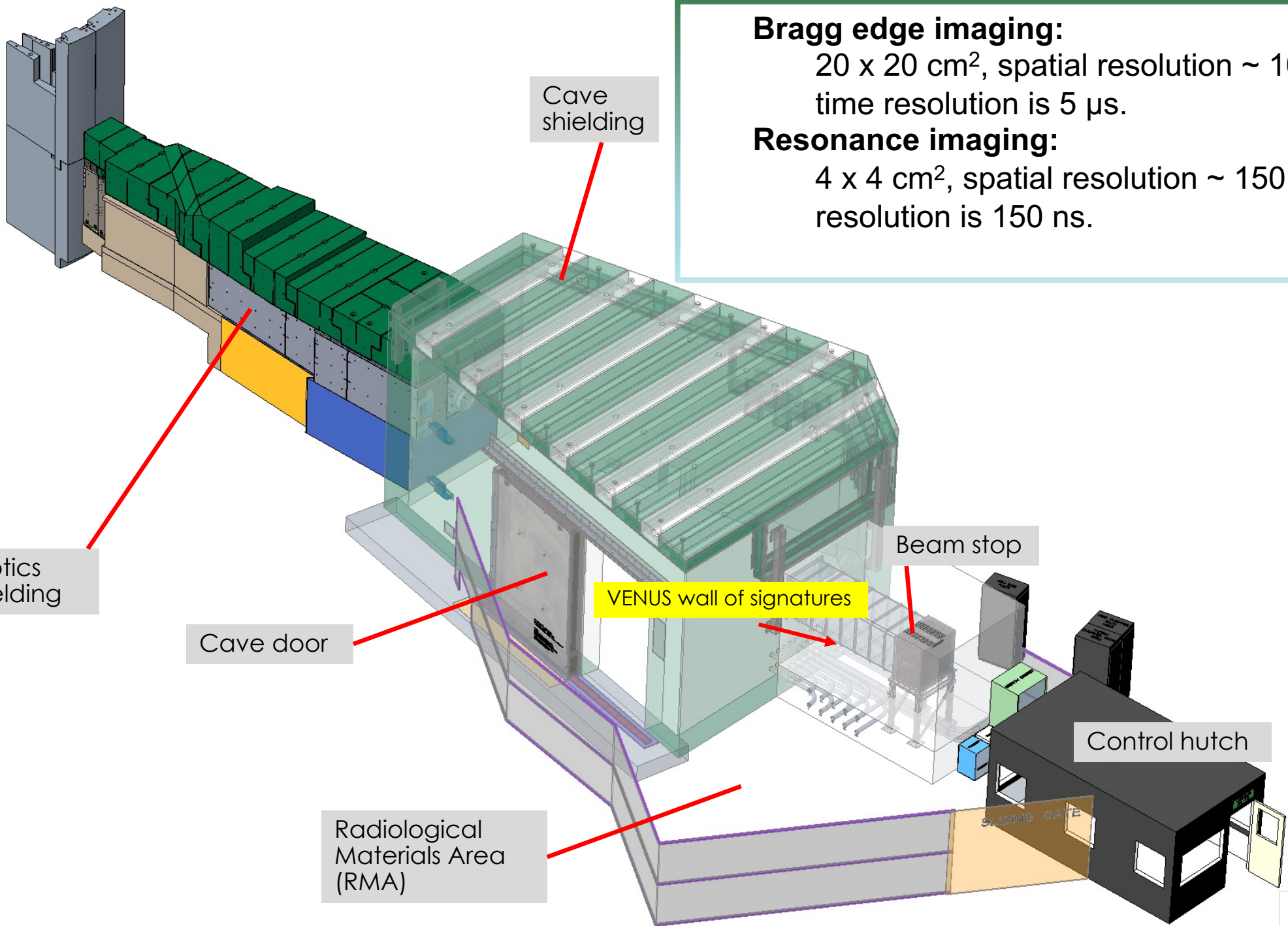
Sample Adaptive Scanning Angles (active learning)

Bragg edge imaging:

20 x 20 cm², spatial resolution ~ 100 μm,
time resolution is 5 μs.

Resonance imaging:

4 x 4 cm², spatial resolution ~ 150 μm, time
resolution is 150 ns.



Front-end optics
buried in shielding

Cave
shielding

Cave door

Radiological
Materials Area
(RMA)

VENUS wall of signatures

Beam stop

Control hutch

SLIDING GATE

February 2020 to now



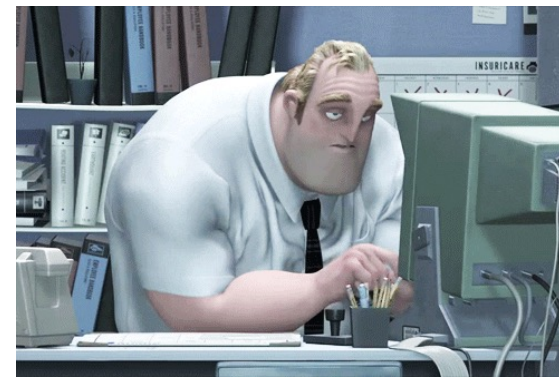
Outline

- Imaging at the High Flux Isotope Reactor MARS beamline:
 - Principle of neutron radiography and computed tomography at a continuous source
 - The CG-1D imaging beamline
 - Examples
- Imaging at the Spallation Neutron Source:
 - Principle of neutron radiography at a pulsed source
 - Examples
 - The VENUS construction project
- **Software tools for imaging**

Yuxuan

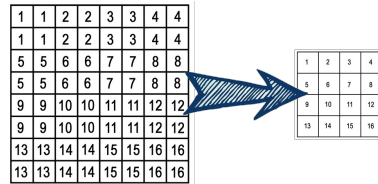
Hassina

Jean



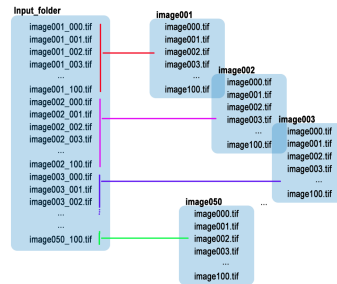
Simple tasks that could be showstoppers because of the amount of files

- Renaming thousand of files (keep/don't keep part of the initial file name)



- Binning pixels

- Combining images (tiff, fits) 2 by 2, 3 by 3, etc. using different algorithms



- Combining folders

- Dealing images

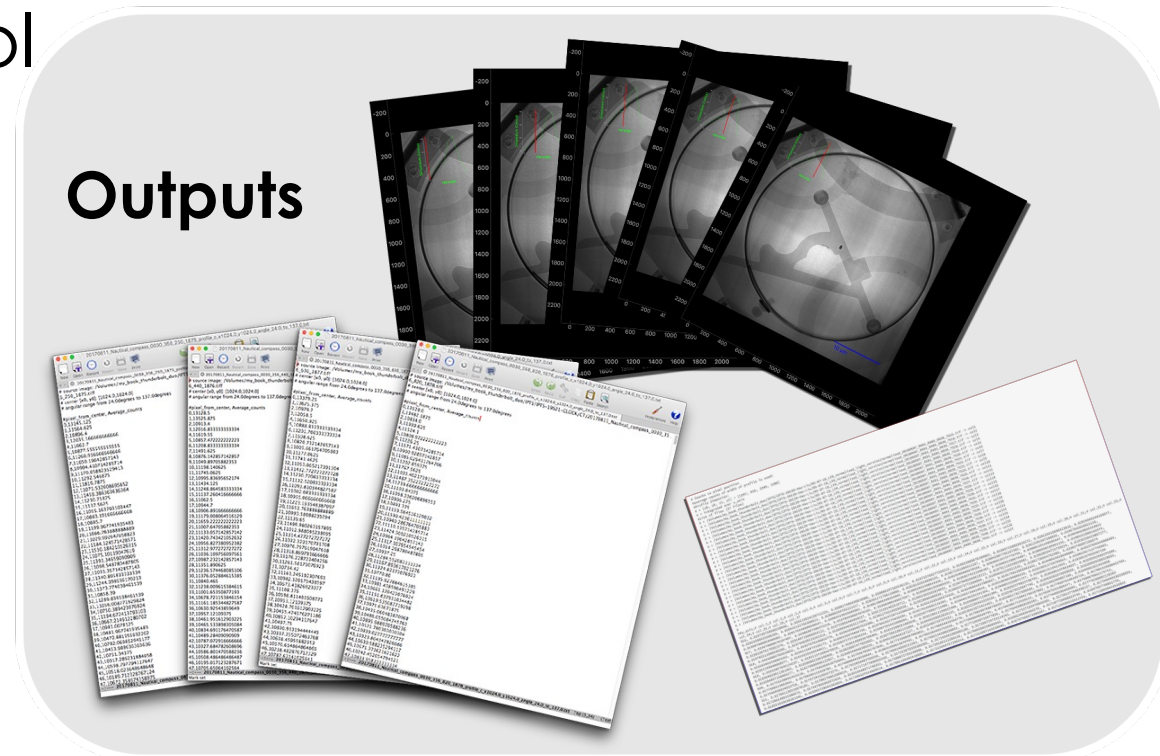
- Extract evenly spaced files

Imagine yourself as a user who does not program, how would you do those?



More complicated tasks

- Create a list of file name vs time stamp
- Display and export images with metadata/time stamp
- Display the change of a given metadata over time on top of images
- Gamma filtering optimization tool
- Profiles
 - Linear
 - Radial
- Calibrate transmission
- Normalization



Advanced tasks

Bragg Edge

OAK RIDGE NATIONAL LABORATORY'S
MANUFACTURING DEMONSTRATION FACILITY (MDF)
AND
SPALLATION NEUTRON SOURCE
PRESENT
BRAGG EDGE NEUTRON RADIOGRAPHY
OF
INCONEL 718 MADE BY ADDITIVE MANUFACTURING
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

$$I(\lambda) = I_0(\lambda)e^{-\mu(\lambda)x} \quad \mu(\lambda) = \sigma_t(\lambda) \frac{\rho N_A}{M}$$

White-beam (or reactor-based) neutron radiograph: sums over all neutron wavelengths

Position of the edge gives the d-spacing of $\langle hkl \rangle$ or displacement gives the strain

Wavelength-dependent (or TOF) neutron radiographs (Discrete neutron wavelengths)

Panoramic Stitching

Impact of plant roots and mycorrhizal fungal hyphae on soil water retention parameters. Ed Perfect et al.

Cylindrical Geometry Correction

Inhomogenous Sample

Sample

Transmitted signal through sample

Integrated Signal

Water-intake Profile Calculator

Eagle Ford shale (1.25cm diameter) under acoustic excitation with an acoustic array (frequencies from 100 to 50,000Hz)

Duration: 37 minutes

Research Team
Richard Hale
Jean-Christophe Bilheux
Bruce Patton
Joanna McFarlane
Ayyoub Momen
Paris Cornwell
Hassina Bilheux
Steve Oliver

The CG-TD beamline at the High Flux Isotope Reactor of Oak Ridge National Laboratory

Water Intake Position (mm) vs Time Stamp (ms)

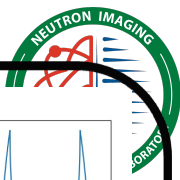
Acoustic fracturing in shale samples. Richard Hale et al.

Images and Metadata Extrapolation Matcher

High Temperature Grain Growth Characterization of FeCrAl alloys by Time of Flight Neutron Radiography. Sebastien Dreyepndt et al.

Registration

Characterization of different stages of hydrogen loss in biomass under pyrolysis by radiography and tomography. Frederik Ossler et al.



Solution: Jupyter notebooks

IP[y]: Notebook spectrogram Last Checkpoint: a few seconds ago (autosaved) Python (Python 3)

File Edit View Insert Cell Kernel Help

Code Cell Toolbar: None

Simple spectral analysis

An illustration of the [Discrete Fourier Transform](#) using windowing, to reveal the frequency content of a sound signal.

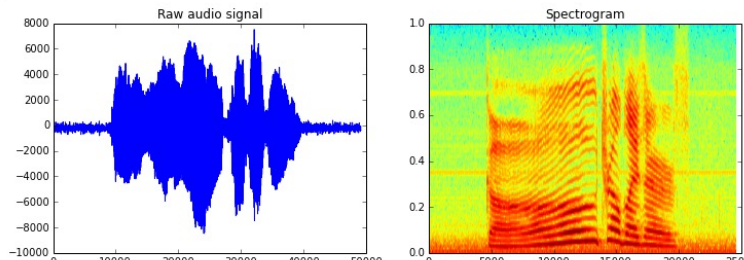
$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} kn} \quad k = 0, \dots, N-1$$

We begin by loading a datafile using SciPy's audio file support:

```
In [1]: from scipy.io import wavfile
rate, x = wavfile.read('test_mono.wav')
```

And we can easily view its spectral structure using matplotlib's builtin specgram routine:

```
In [2]: %matplotlib inline
from matplotlib import pyplot as plt
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(12, 4))
ax1.plot(x); ax1.set_title('Raw audio signal')
ax2.specgram(x); ax2.set_title('Spectrogram');
```



Notebook Rules

Rule 1 Click inside a cell and **SHIFT + ENTER** to execute it.

Rule 2 Re-executing a cell will reset it (any input will be lost)

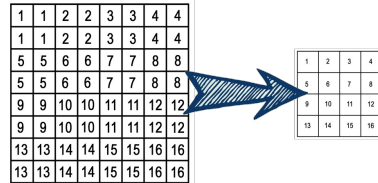
Rule 3 Wait for busy cell signal to go away before executing another cell



Rule 4 Execute the cells **Top to Bottom**

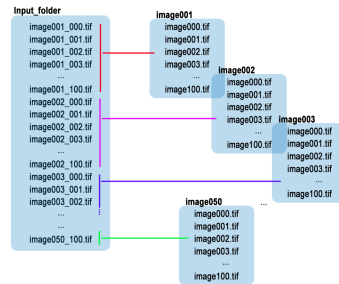
Simple tasks that could be showstoppers

- Renaming thousand of files (keeping or not part of the initial file name)



- Binning pixels

- Combining images (tiff, fits) 2 by 2, 3 by 3, etc. using different algorithms



- Combining folders
- Dealing images
- Extract evenly spaced files

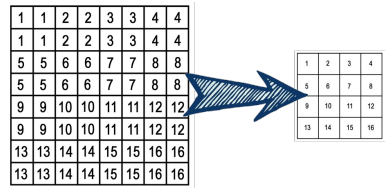
Imaging yourself as a user who does not program, how would you do those?





Simple tasks for the notebooks

- Renaming thousand of files (keeping or not part of the initial file name)

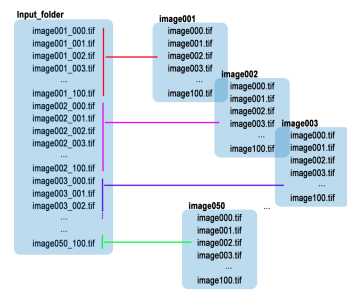


- Binning pixels

- Combining images (tiff, fits) 2 by 2, 3 by 3, etc. using different algorithms

- Combining folders

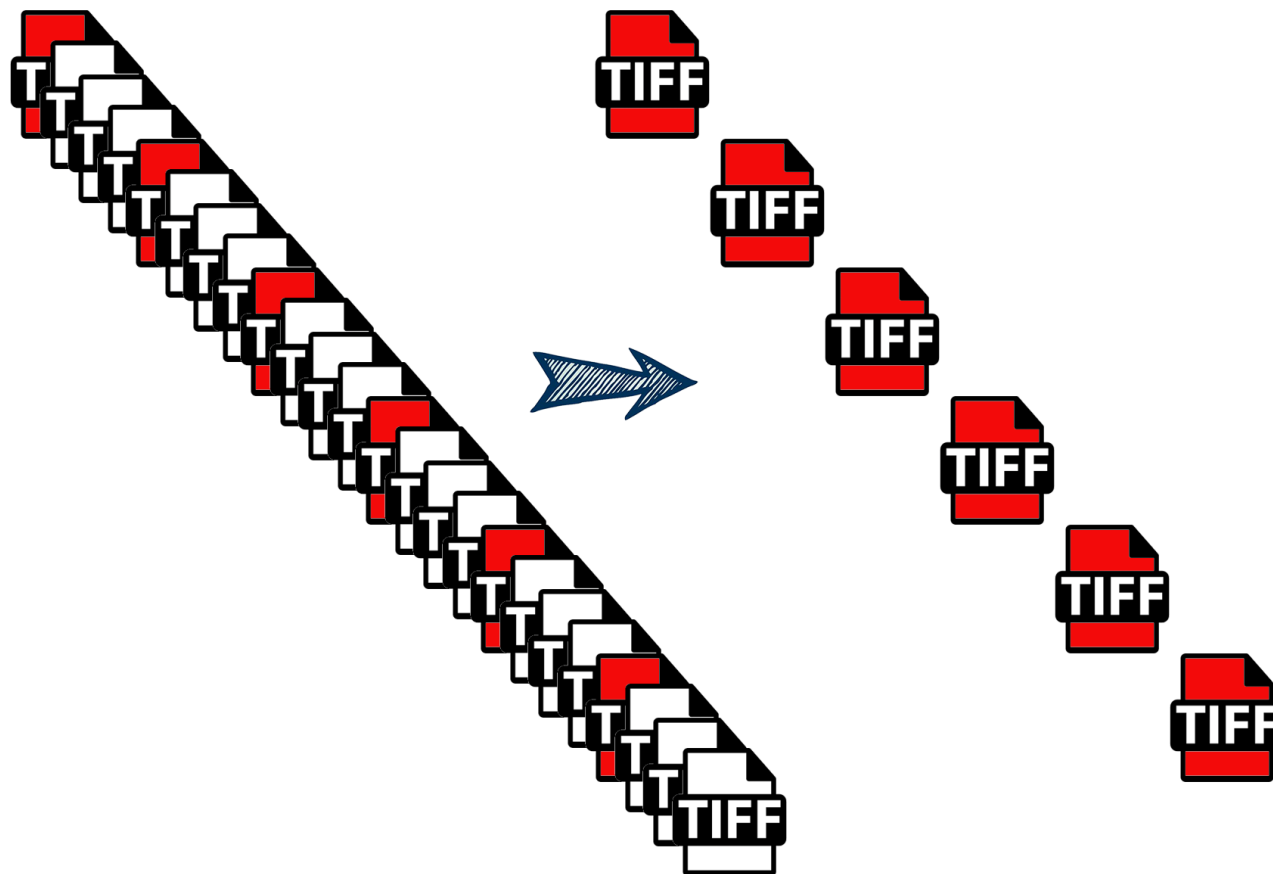
- Dealing images



- **Extract evenly spaced files**

Simple tasks for the notebooks

Extract evenly spaced files



Extract from list of files every n spaced files

Simple tasks for the notebooks



Do not know how to run this notebook? Click ME!

Notebook Rules

- Rule 1 Click inside a cell and SHIFT + ENTER to execute it.
- Rule 2 Re-executing a cell will reset it (any input will be lost)
- Rule 3 Wait for busy cell signal to go away before executing another cell
- Rule 4 Execute the cells Top to Bottom

Select Your IPTS

```
In [ ]: from __code.extract_evenly_spaced_files import ExtractEvenlySpacedFiles as EESF
from __code import system
system.System.select_working_dir()
from __code.__all import custom_style
custom_style.style()
```

Select Folder with Images to Extract

```
In [ ]: o_extract = EESF(working_dir=system.System.get_working_dir())
o_extract.select_folder()
```

Extraction Method to Use

```
In [ ]: o_extract.how_to_extract()
```

Renamed files ?

This will replace the last part of the name (file counter digit)
for example:

original_file_name_001020_01001_0020_004_504_0003_1155



neutronimaging.pages.ornl.gov/tutorial/notebooks/extract_evenly_spaced_files/

EXTRACT EVENLY SPACED FILES

Notebook name: extract_evenly_spaced_files.ipynb

Description

This notebook allows you to copy into a new folder (extract) 1 every n files from the source folder. You will need to provide the **skipping** factor n in the notebook. You will also have the option to rename those files, as they are copied, in order to keep a linear increasing index starting at index 0.

Example:

let's pretend you selected a folder (*/Users/j35/my_data/*) containing the following 21 images

Input

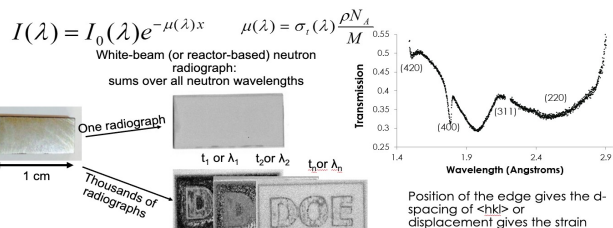
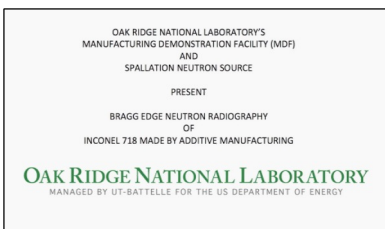
- image_001.fits
- image_002.fits
- image_003.fits
- image_004.fits
- image_005.fits
- image_006.fits
- image_007.fits
- image_008.fits
- image_009.fits
- image_010.fits
- image_011.fits
- image_012.fits
- image_013.fits
- image_014.fits
- image_015.fits
- image_016.fits
- image_017.fits
- image_018.fits
- image_019.fits
- image_020.fits
- image_021.fits

and you decided to extract **1 every 5 files** in the **Desktop**.

The notebook will create the folder called */Users/j35/Desktop/my_data_1_every_5_files* and will copy the following files

Advanced tasks

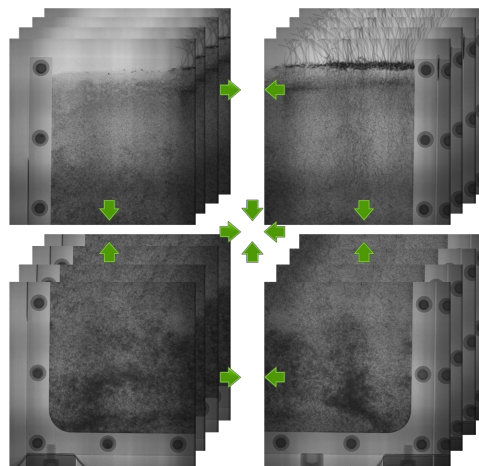
Bragg Edge



Wavelength-dependent (or TOF) neutron radiographs (Discrete neutron wavelengths)

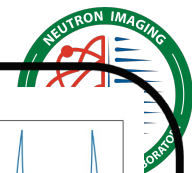
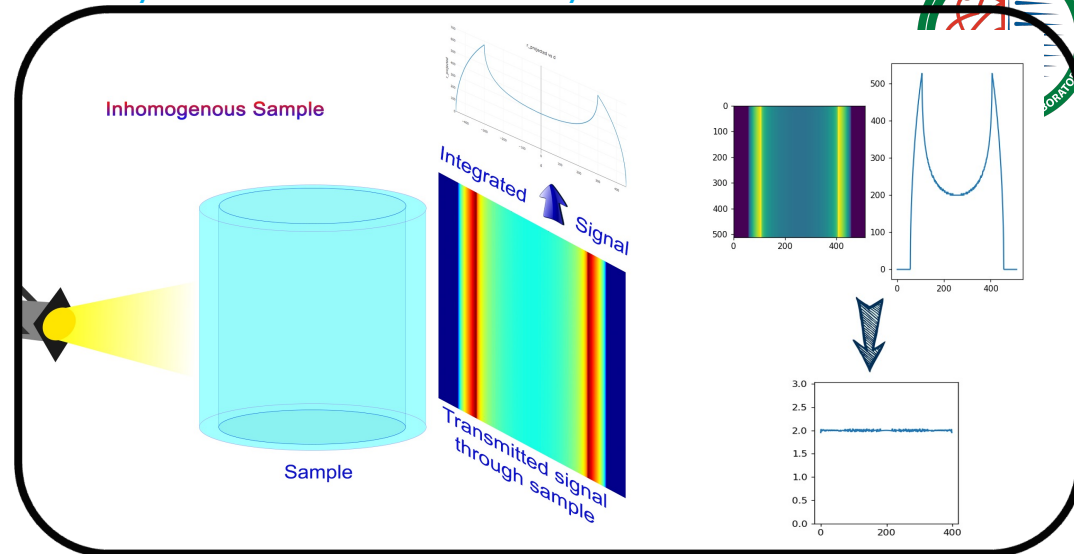
Credit: H. Bilheux

Panoramic Stitching



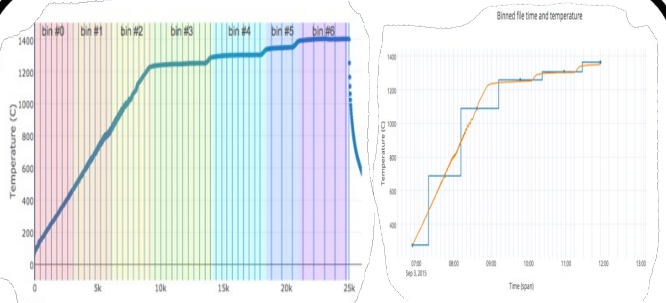
Impact of plant roots and mycorrhizal fungal hyphae on soil water retention parameters. Ed Perfect et al.

Cylindrical Geometry Correction



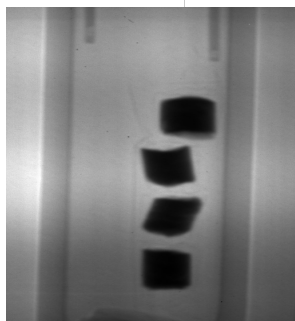
Water-intake Profile Calculator

Images and Metadata Extrapolation Matcher



High Temperature Grain Growth Characterization of FeCrAl alloys by Time of Flight Neutron Radiography. Sebastien Dryepont et al.

Registration



Characterization of different stages of hydrogen loss in biomass under pyrolysis by radiography and tomography. Frederik Ossler et al.

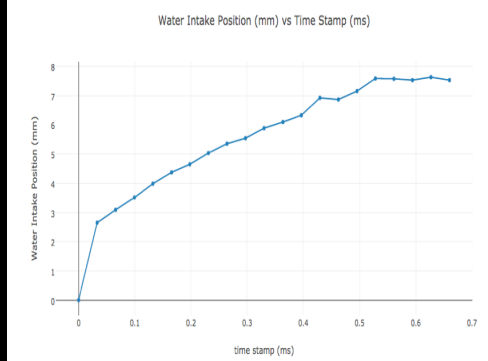
Eagle Ford shale
(1.25cm diameter)
under acoustic excitation
with an acoustic array
(frequencies from 100 to 50,000Hz)

Duration: 37 minutes

Research Team

- Richard Hale
- Jean-Christophe Bilheux
- Bruce Patton
- Joanna McFarlane
- Ayyoub Momen
- Paris Cornwell
- Hassina Bilheux
- Steve Oliver

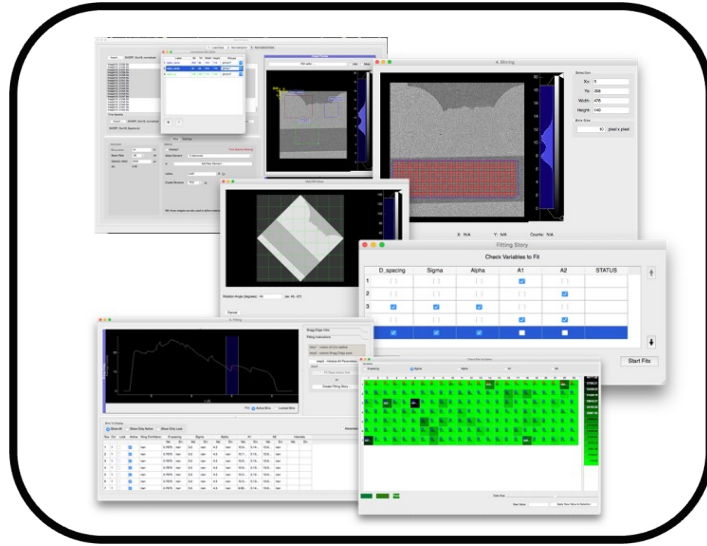
The CG-TD beamline at the High Flux Isotope Reactor of Oak Ridge National Laboratory



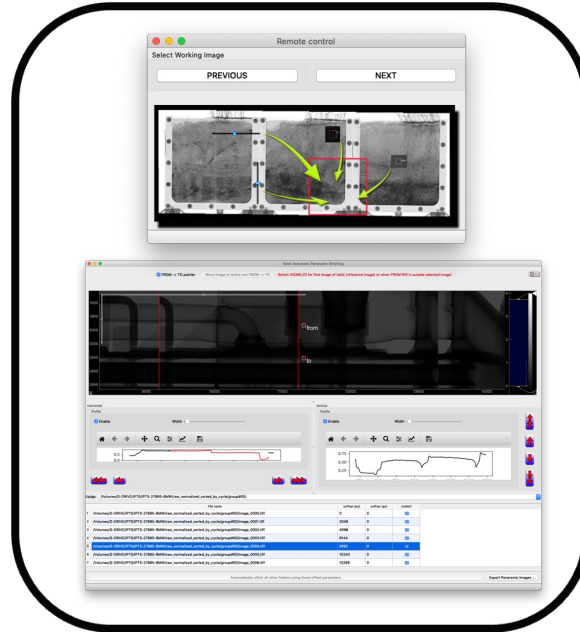
Acoustic fracturing in shale samples. Richard Hale et al.

Advanced tasks

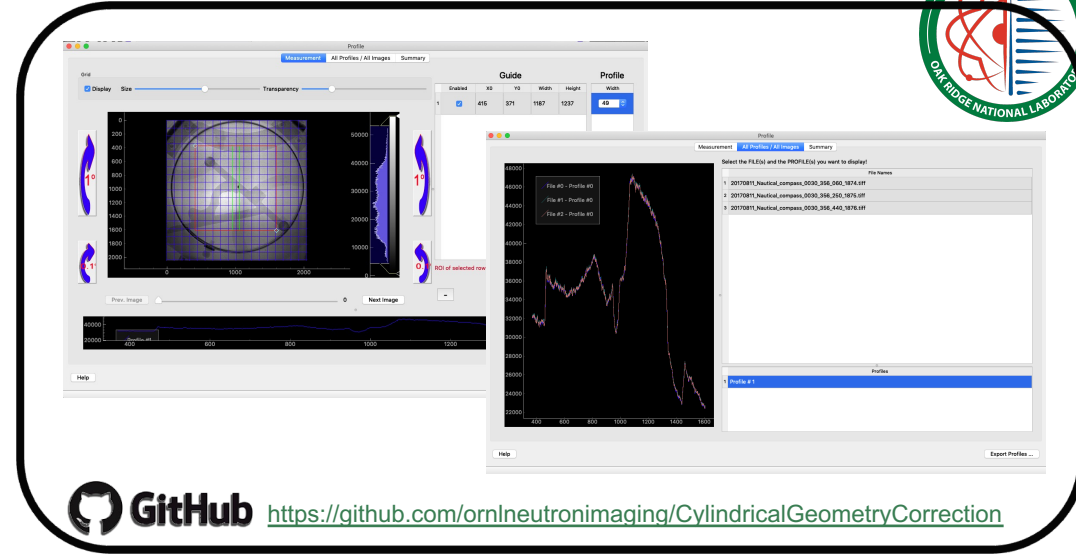
Bragg Edge



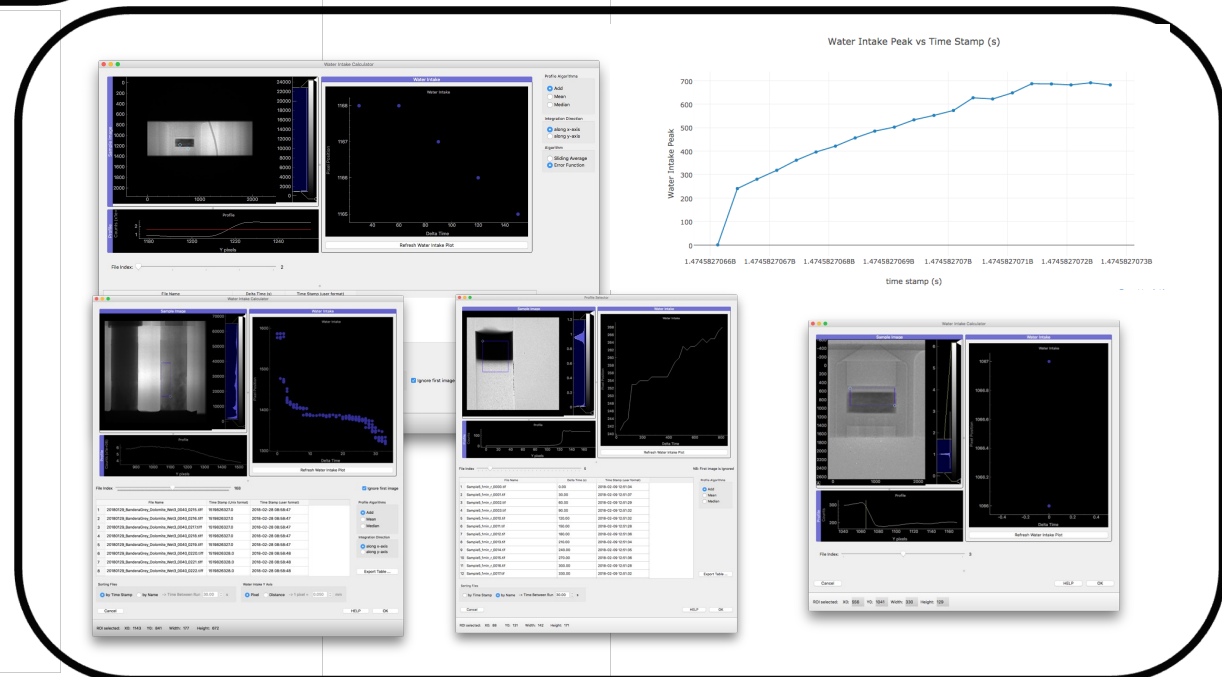
Panoramic Stitching



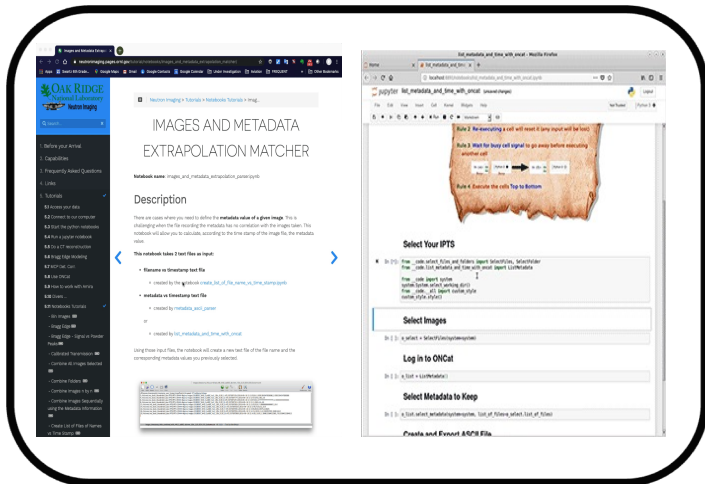
Cylindrical Geometry Correction



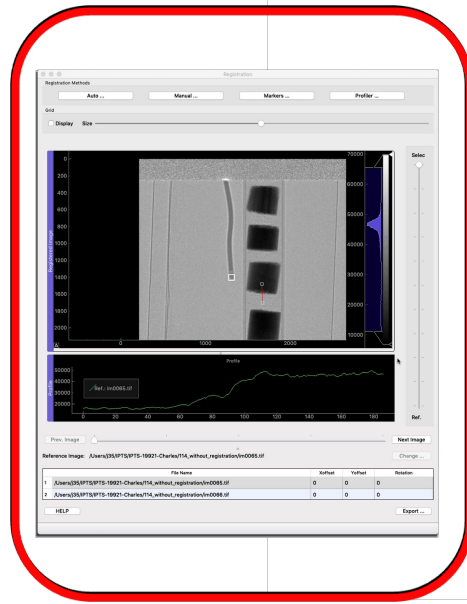
Water-intake Profile Calculator



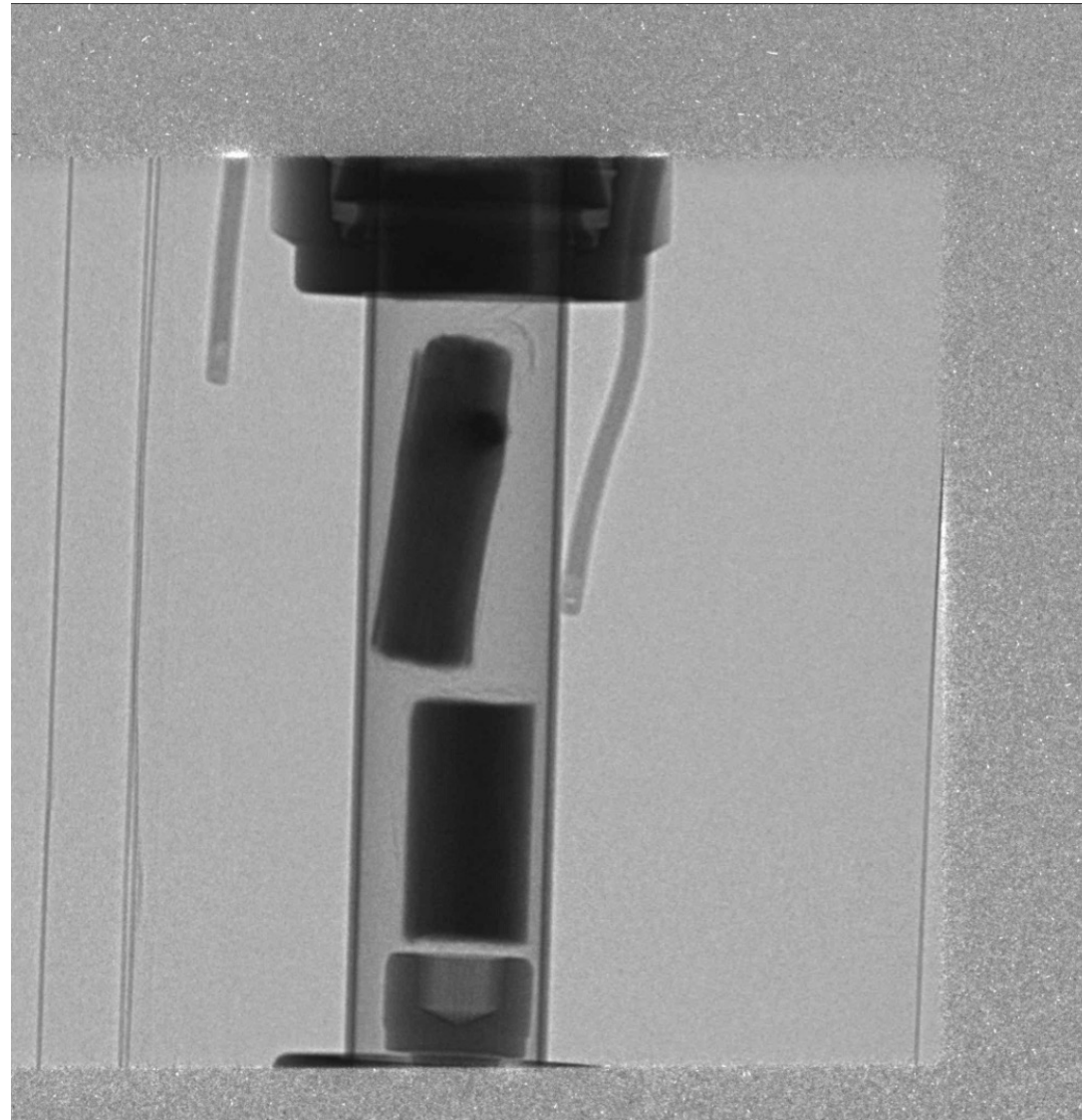
Images and Metadata Extrapolation Matcher



Registration



Registration



Courtesy of Charles Finney and Frederik Ossler.

Registration



The screenshot shows a Jupyter Notebook titled "registration" running on a local host. The notebook contains a central instruction box and several code cells. The instruction box, titled "Notebook Rules", lists four rules for running the notebook. Below the rules are four code cells: "Select your IPTS", "Python Import", "Select Images to Process", and "Launch Registration UI".

Do not know how to run this notebook? Click ME!

Notebook Rules

- Rule 1 Click inside a cell and SHIFT + ENTER to execute it.
- Rule 2 Re-executing a cell will reset it (any input will be lost)
- Rule 3 Wait for busy cell signal to go away before executing another cell
- Rule 4 Execute the cells Top to Bottom

Select your IPTS

```
In [ ]: import warnings
warnings.filterwarnings('ignore')

from __code.registration.file_selection import FileSelection
from __code.registration.registration import RegistrationUI

from __code import system
system.System.select_working_dir(notebook='registration')
from __code__all import custom_style
custom_style.style()
```

Python Import

```
In [ ]: %gui qt
```

Select Images to Process

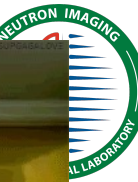
```
In [ ]: o_selection = FileSelection(working_dir=system.System.get_working_dir())
o_selection.select_data()
```

Launch Registration UI

```
In [ ]: o_registration = RegistrationUI(data_dict=o_selection.data_dict['sample'])
o_registration.show()

In [ ]:
```

How to access all those tools?



- Go to **analysis.sns.gov**
- Select **Applications > Analysis-Imaging**

PROS

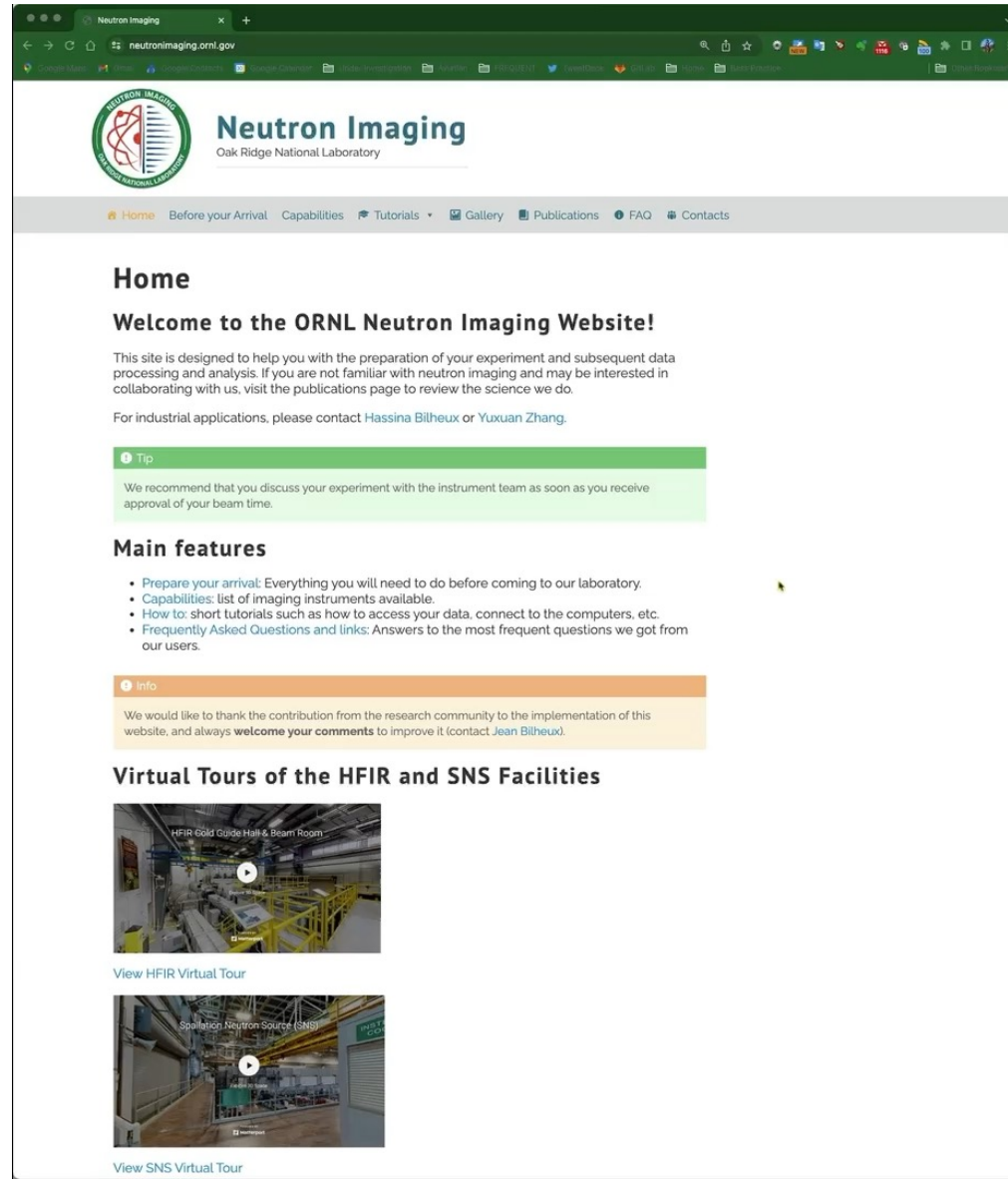
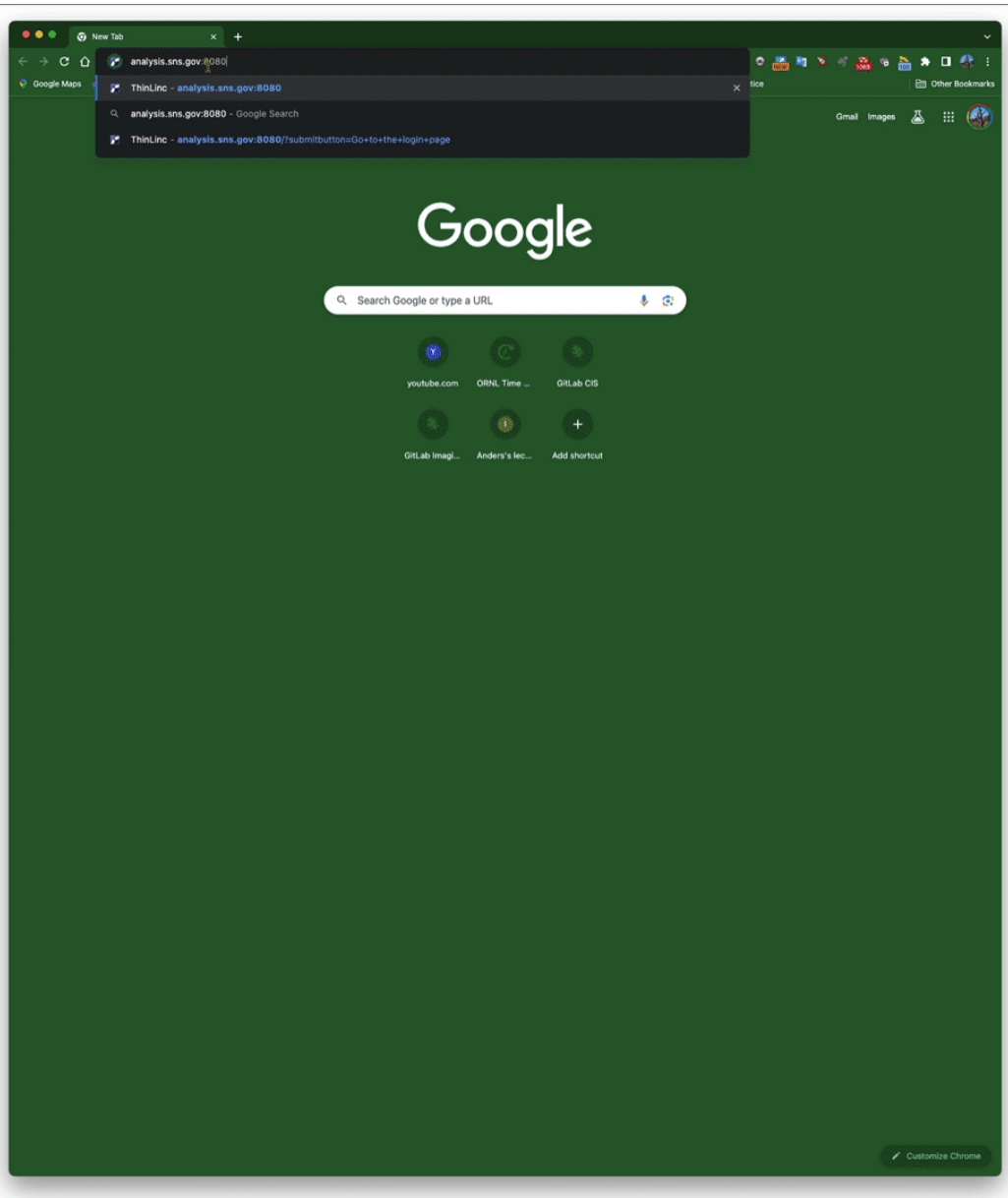
- Nothing to install
- You always get the latest up-to-date version of the software
- No need to move the data (fast access)
- Availability of many other tools (Matlab, IDL, ImageJ, ...)



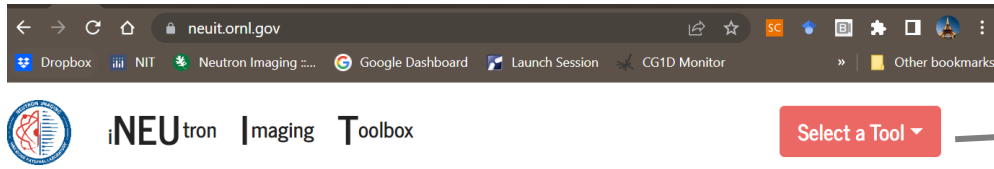
How to access all those tools?



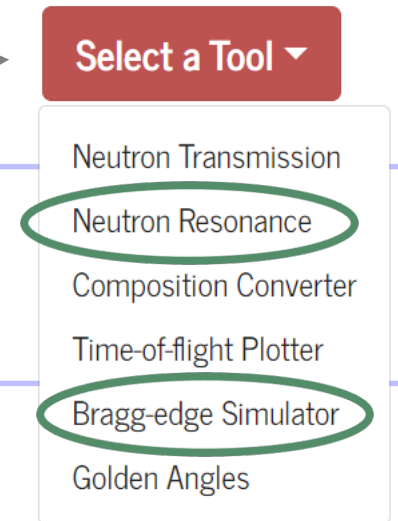
neutronimaging.ornl.gov



Experiment planning tools: *iNEUIT* (**iNEU**tron **I**maging **T**oolbox)



- Available tools:



Introduction

Here we present a toolbox to provide interactive and user-friendly applications that can be used for Neutron Imaging related calculations.

Tools available here are build upon open source libraries, such as [ImagingReso](#), [periodictable](#), [braggedge modeling](#), [diffpy.structure](#), etc., using [Dash](#) framework.

Detailed functionality description is available inside each application.

Disclaimer

The energy dependent cross-section data used are from [National Nuclear Data Center](#), a published online database. [Evaluated Nuclear Data File ENDF/B-VIII.0](#) and [ENDF/B-VII.1](#) are currently supported. More evaluated database will be added in the future.

Please note that the energy dependent cross-section of hydrogen in ENDF/B database is for a free H atom. When interacting with slow neutrons in the cold range, the cross-section of a bonded H could be underestimated when using this tool. In a recent update to support [ImagingReso \(v1.7.4\)](#), some experimentally measured cross-sections ([ref1](#) and [ref2](#)) of a bonded H are now available.

Cite this work

1.Yuxuan Zhang, Jean Bilheux, Hassina Bilheux and Jiao Lin, (2019) "[An interactive web-based tool to guide the preparation of neutron imaging experiments at oak ridge national laboratory](#)", *Journal of Physics Communications*, 3(10), 103003.

2.Yuxuan Zhang and Jean Bilheux, (2017), "[ImagingReso: A Tool for Neutron Resonance Imaging](#)", *Journal of Open Source Software*, 2(19), 407.

Contact us

Yuxuan Zhang -- zhangy6@ornl.gov

Jean Bilheux -- bilheuxjm@ornl.gov

Acknowledgments

This work is based upon research sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle LLC for the US Department of Energy. This research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by Oak Ridge National Laboratory.

(iNEUIT v0.0.25)

- Nuclear database supported
 - ENDF/B-VIII.0 (BNL)
 - ENDF/B-VII.1 (BNL)
- Elemental/isotopic info
 - PeriodicTable 1.5.0 (NIST)

iNEUTron Imaging Toolbox (iNEUIT)



<https://neuit.ornl.gov>



[Home](#)
[Cold neutron transmission](#)

Neutron resonance

Energy range:

Energy (eV)	Wavelength (Å)	Speed (m/s)	Time-of-flight (μs)	Neutron classification
1	0.286	13832.93	1189.1914	Epithermal
100	0.0286	138329.29	118.9191	Epithermal

Energy step:

Source-to-detector (optional): (m)

NOTE: Pick a suitable energy step base on the energy range selected.

NOTE: Please ignore the above input field if **NOT** interested in display of time-of-flight (TOF).

Sample info

Chemical formula	Thickness (mm)	Density (g/cm ³)
Ag	1	

iNEUTron Imaging Toolbox Select a Tool

Bragg Edge Simulator

More about this tool

Global parameters:

Temperature (K): Source-to-detector (m): Delay (μs):

Min. (Å): Max. (Å): Step (Å):

Input elements

Structure #1	Structure #2	Structure #3	Structure #4	Structure #5
Drag & Drop or Select File (.cif or previously exported structure from this page)				
<input type="button" value="Add row"/>				
Atom				
a b c				
Texture				
<input type="button" value="Add row"/>				
h k l r beta (rad)				
Grain size (mm)				
<input type="text" value="0.001"/>				
a (Å)	b (Å)	c (Å)		
<input type="text" value="3.5238"/>	<input type="text" value="3.5238"/>	<input type="text" value="3.5238"/>		
alpha (°)	beta (°)	gamma (°)		
<input type="text" value="90"/>	<input type="text" value="90"/>	<input type="text" value="90"/>		
<input type="button" value="Export structure #1"/>				
<input type="button" value="Submit"/>				

Resonance

Bragg edge simulator

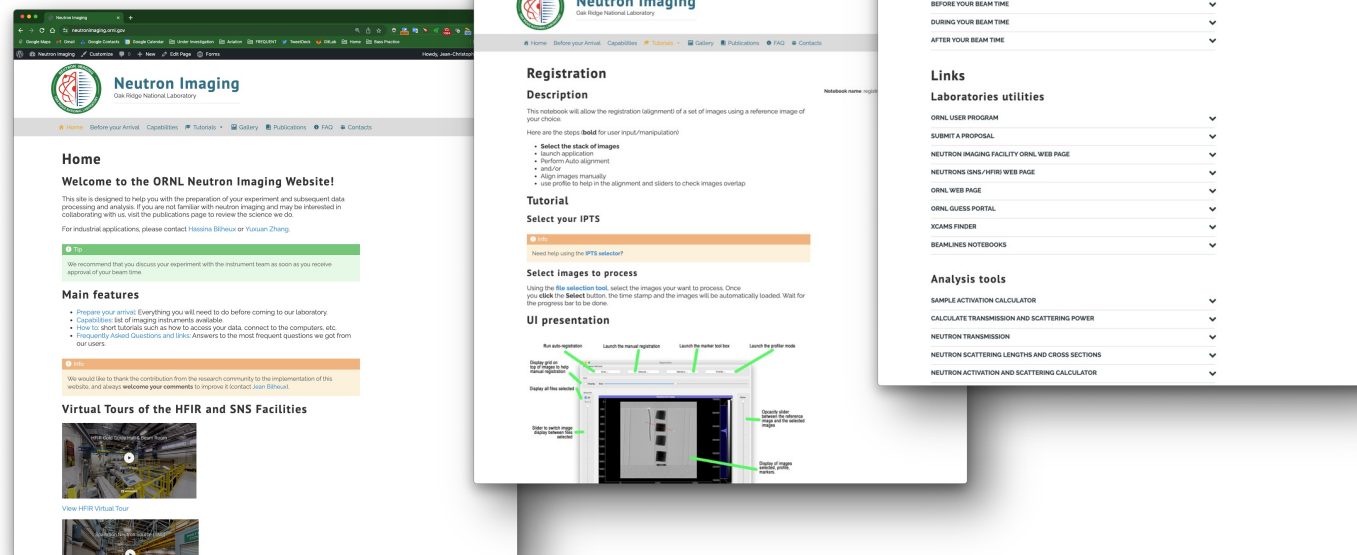
Thank you



neutronimaging.ornl.gov

The portion of this research used resources at the SNS and HFIR, DOE Office of Science User Facilities operated by the Oak Ridge National Laboratory.

neutrons.ornl.gov

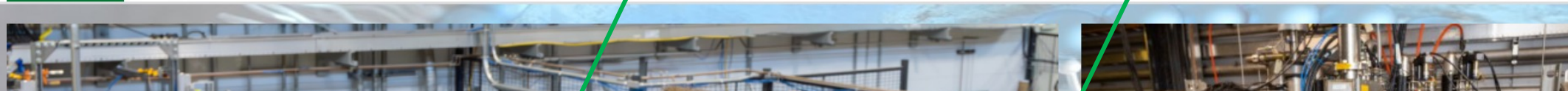


About Us User Facilities Science & Discovery News Our People Careers

Neutron Sciences Directorate

SNS VIRTUAL TOUR HFIR VIRTUAL TOUR REQUEST BEAM TIME

Home About Future Science For Users For Industry Publications Instruments News/Events Staff



How to collaborate with us

Our beamlines and contact information