INL/CON-25-84678-Revision-0

Pre-Transient Characterization of MLOF-1 Test Pin

May 2025

Allison Roberts Probert, Colby B Jensen, Jason L Schulthess

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Advanced Fuels Campaign

Pre-Transient Characterization of MLOF-1 Test Pin

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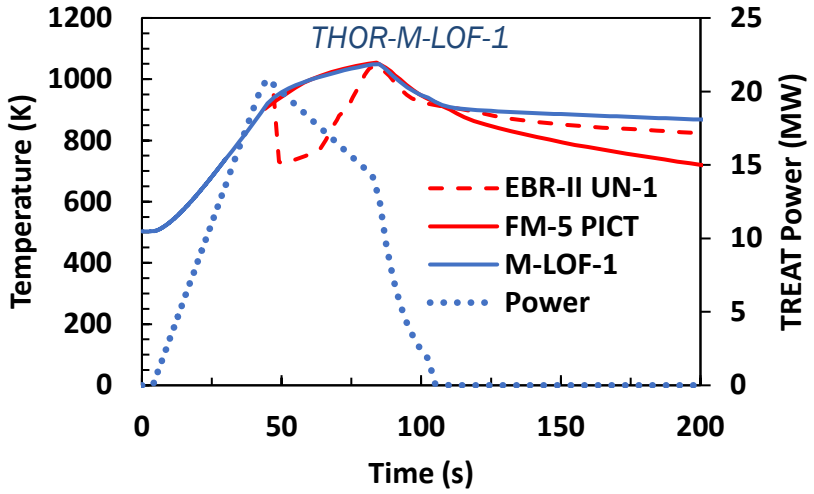
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Addressing Gaps in Transient Behavior of Metallic Fuel

- THOR-M will study irradiated metallic fuel performance in transient overpower and loss of flow conditions
- Evaluate in-pile LOF performance, like historic furnace test FM-5
- Measure in-pin fuel expansion, cladding deformation, axial location and detailed characterization of any potential failure sites

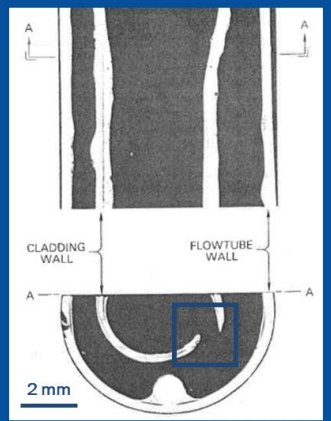


Low-Melting Eutectic Formation

0.8 at. %
U-19Pu-10Zr
D9 Clad

Bauer et al. Nuclear Fuel Cycles, 1990

Thermal Creep Rupture



7.9 at. %
U-5Fs
316 SS Clad

Bauer et al. Technical Report, 1989

Pin Burnup

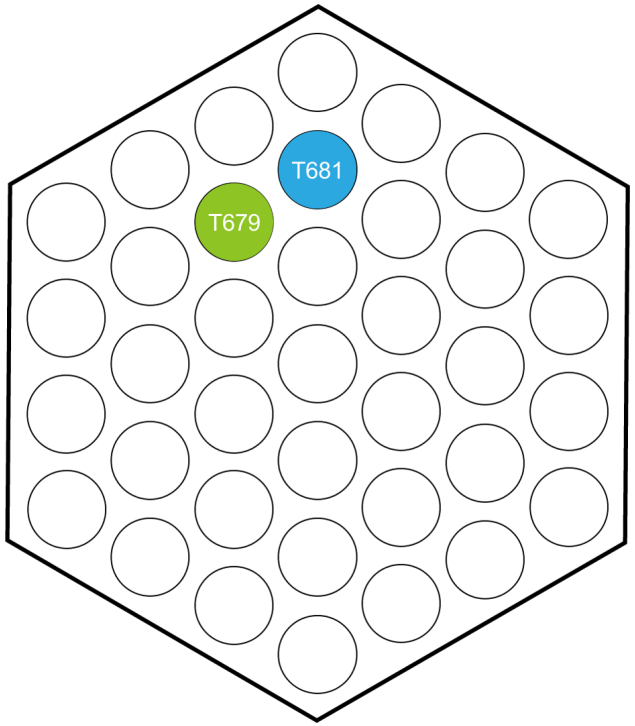
THOR-M-LOF Test Plan and Pin Specifications

IV. Comparisons drawn between pre- and post-transient results and historical irradiation/test database

I. Pre-transient non-destructive and destructive examination using test and sibling pins

II. Full pin LOF irradiation in TREAT

III. Post-transient non-destructive and destructive examination on test pin



	Test Pin	Sibling Pin
Subassembly and Pin ID	X430A-T679	X430A-T681
Composition	U-10Zr	U-10Zr
Fuel Diameter (mm)	5.71	5.71
Cladding Material	HT-9	HT-9
Cladding Outer Diameter (mm)	7.37	7.37
Cladding Thickness (mm)	0.406	0.406
Plenum to Fuel Volume Ratio	1.4	1.4
Smear Density	75%	75%

THOR-M-LOF Test and Sibling Pin Irradiation Histories

IV. Comparisons drawn between pre- and post-transient results and historical irradiation/test database

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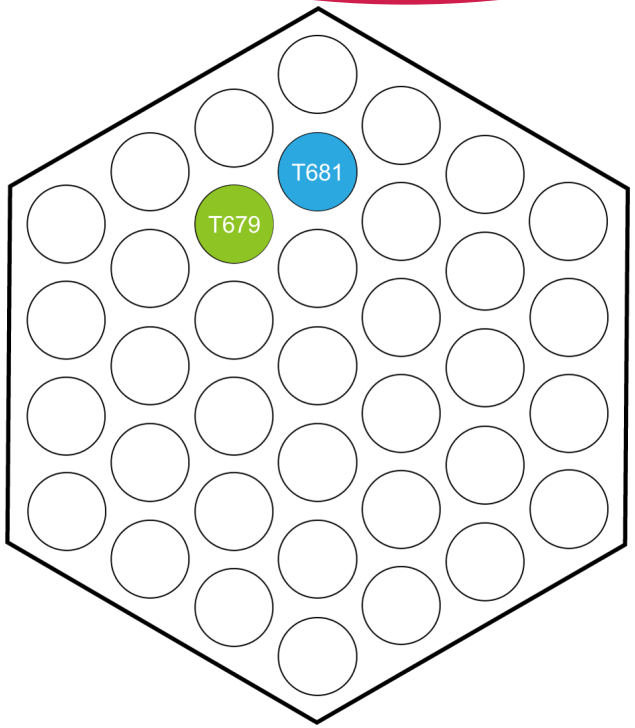


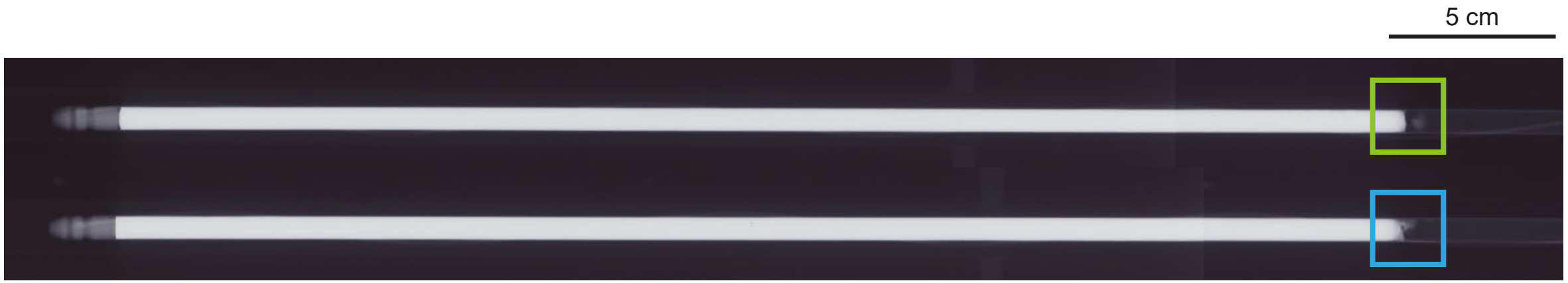
	Test Pin	Sibling Pin
Subassembly and Pin ID	X430A-T679	X430A-T681
Composition	U-10Zr	U-10Zr
Calculated Peak Burnup (at.%)	7.4	7.3
Pin Peak Power (kW/m)	49.2	49.2
Pin Peak Clad. Temp (°C)	579	569
Pin Peak Fuel Center Temp. (°C)	675	667
Pin Fast Fluence ($\times 10^{22}$ n/cm^2)	20.6	20.6

Status of Planned Pre-Transient Characterization

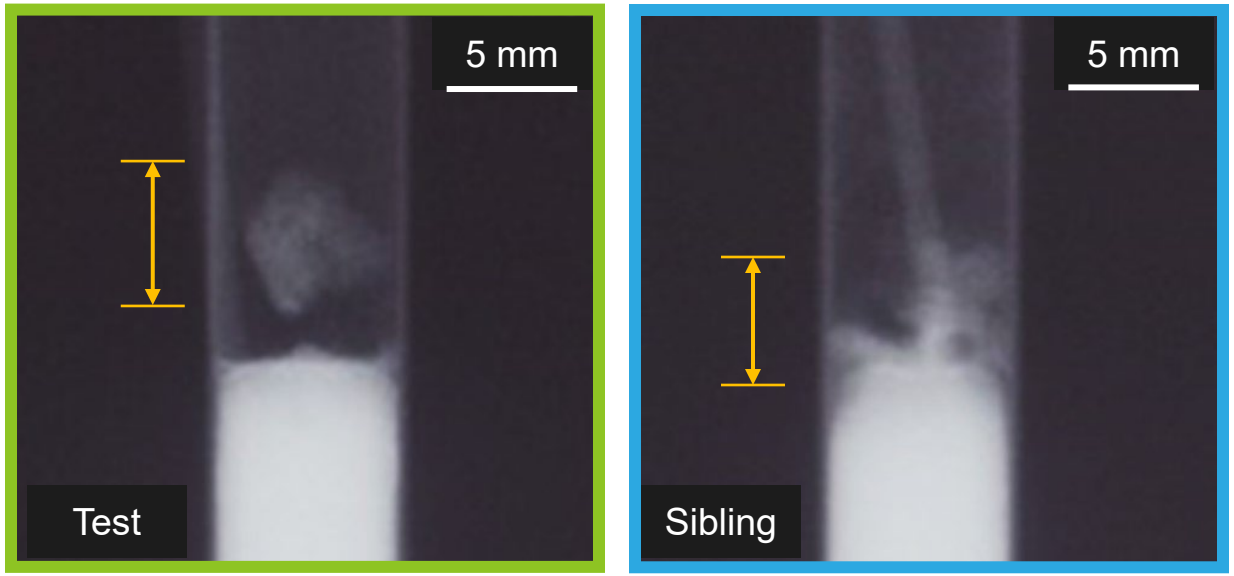
	Examination	X430A-T681	X430A-T679
Non-Destructive	Visual (VEM)	C	C
	Neutron Radiography (NR)	C	C
	Element Contact Profilometry (ECP)	C	C
	Precise Gamma Scan (PGS)	C	C
Destructive	Fission Gas Assay, Sample, and Recharge (GASR)	C	-
	Optical Microscopy (OM)	C	-
	Scanning Electron Microscopy (SEM)	FW	-
	Electron Probe Microanalysis (EPMA)	FW	-
	Laser Flash Analysis (LFA)	FW	-
	Burnup (BU) Analysis	FW	-

C = Completed, FW = Future Work

Axial fuel strain and fluff structure length measured with neutron radiography



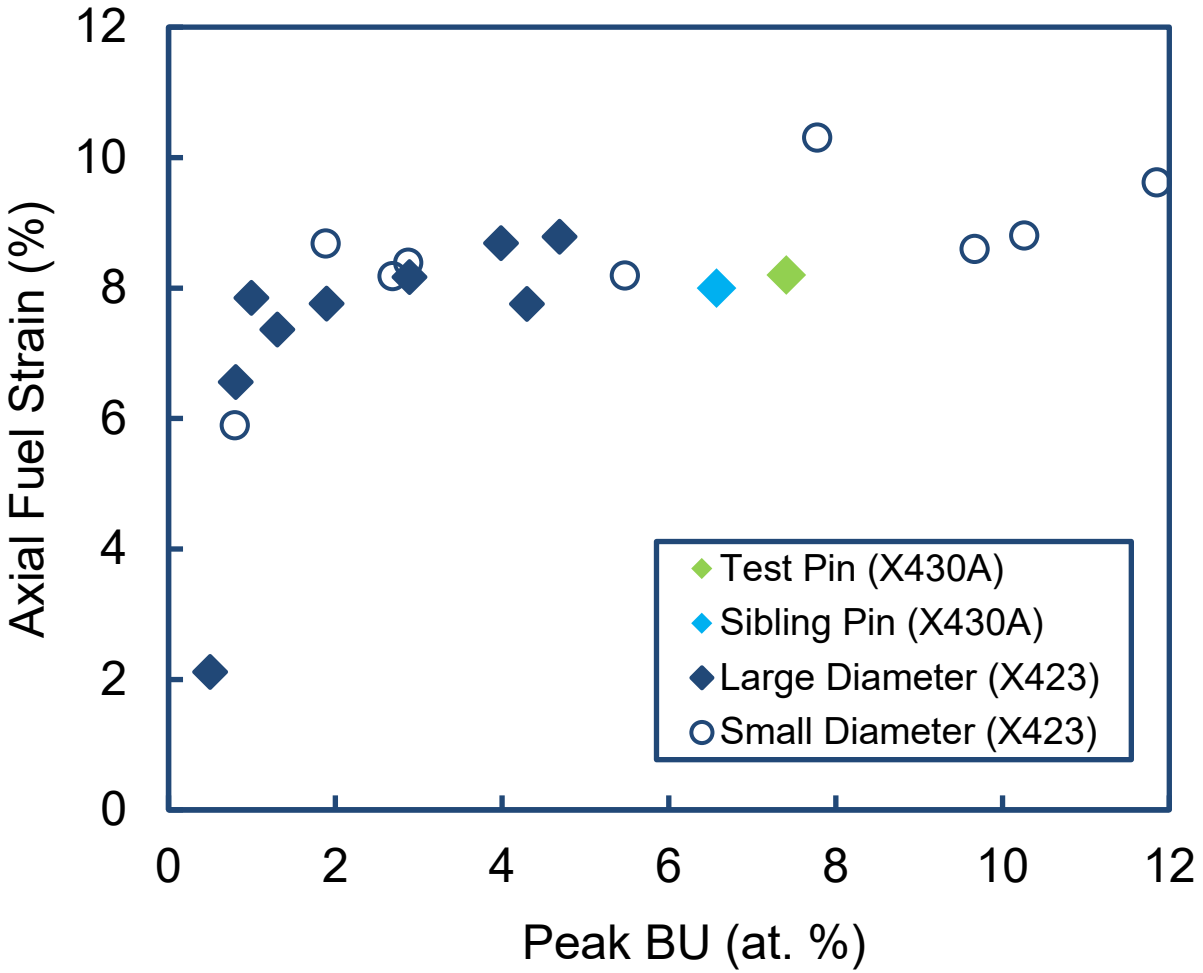
Pin	Test	Sibling
Fuel Pin ID	T-679	T-681
Peak BU (at. %)	7.4	7.3
Axial Strain (%)	8.2	8.0
Fluff Length (cm)	0.44	0.71



Low Density Fluff Structures at the top of the fuel column

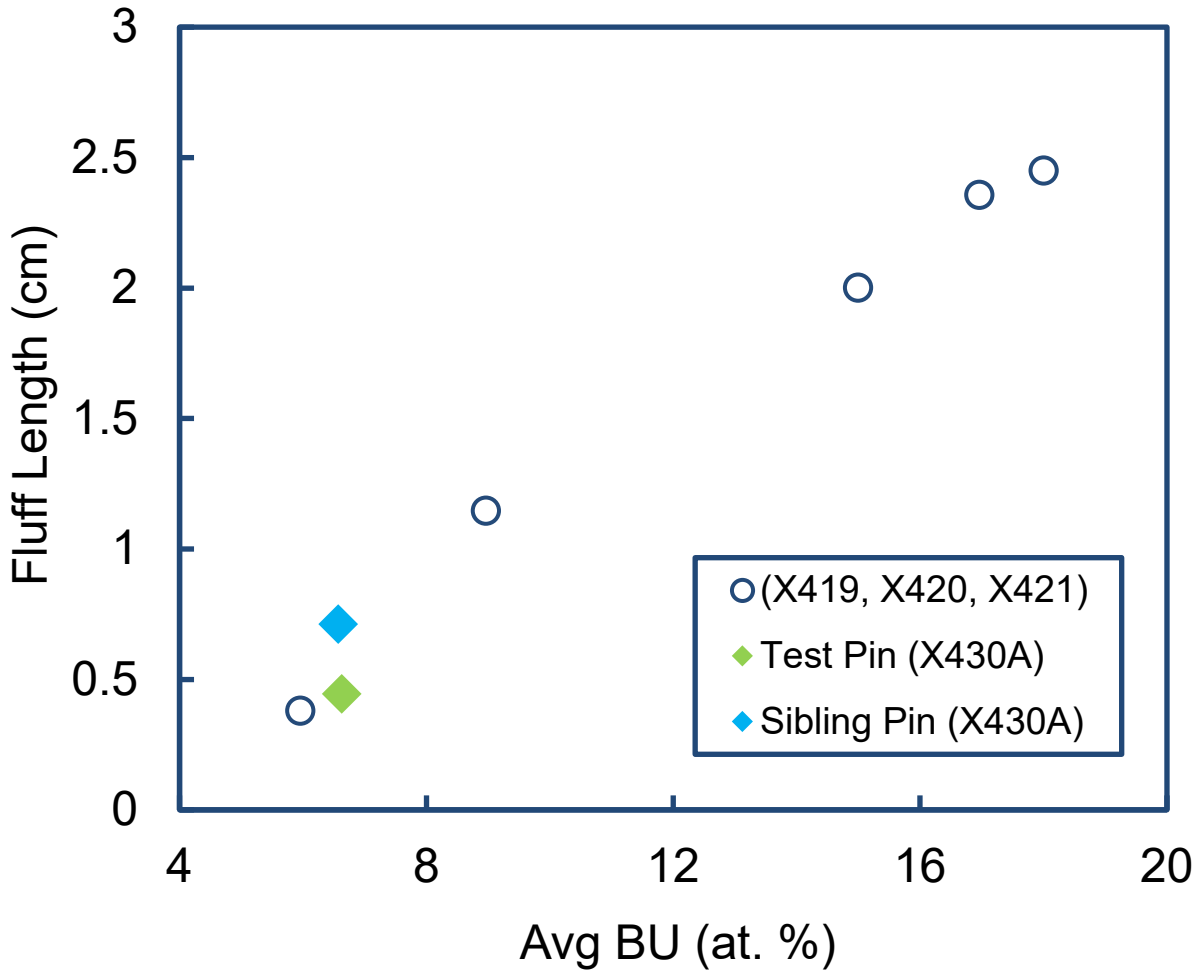
Axial fuel strain and fluff structure length compare well with reported values

Typical behavior observed for U-Zr alloys
To consider: X423 ran at lower temp. and 316SS-clad



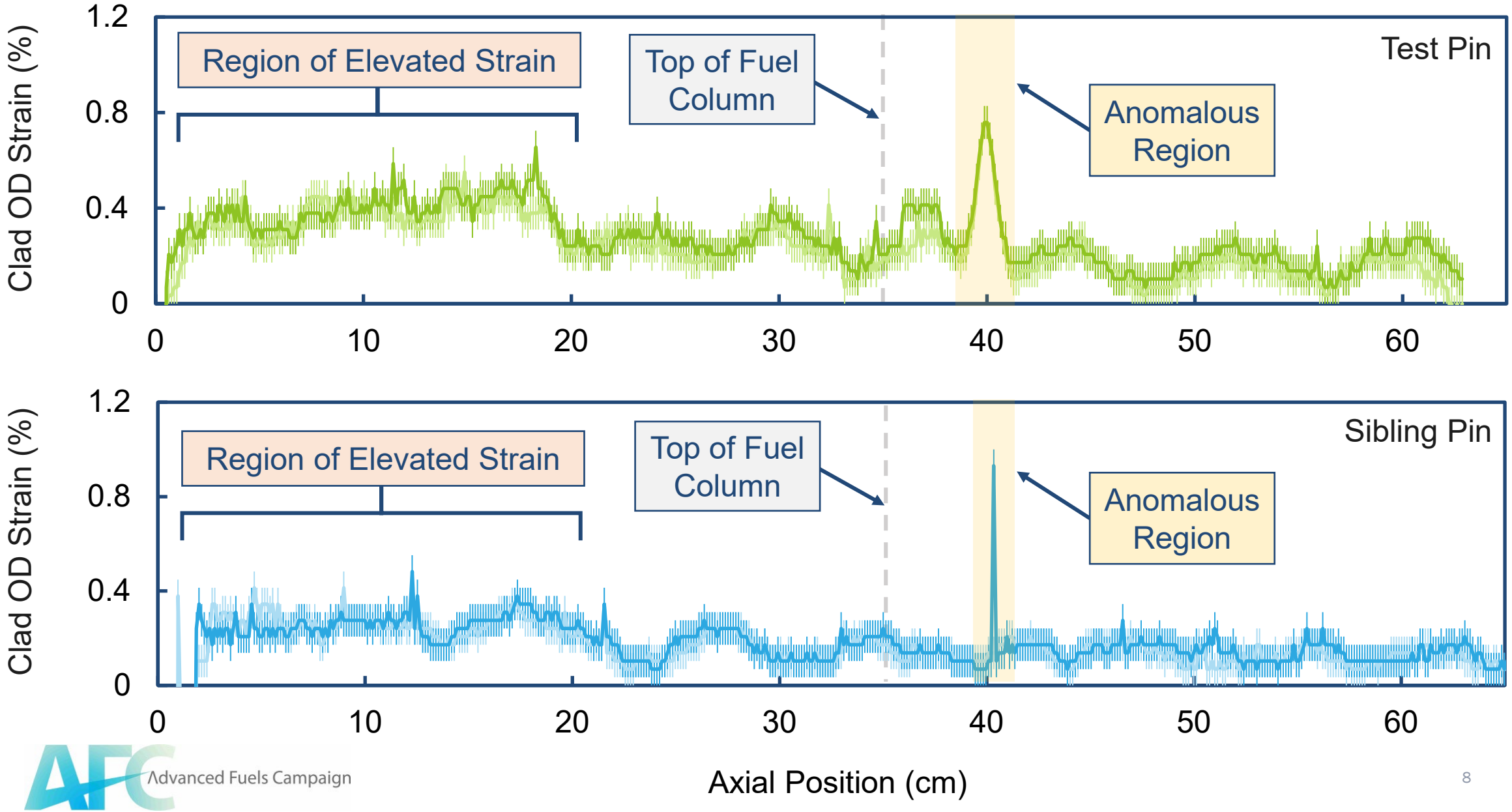
Hofman, G. L., et al. "Swelling behavior of U-Pu-Zr fuel" Metall Trans (1990)

Aligns well with fluff structure trend for U-Zr alloys
To consider: Smaller diameter pins and D9-clad

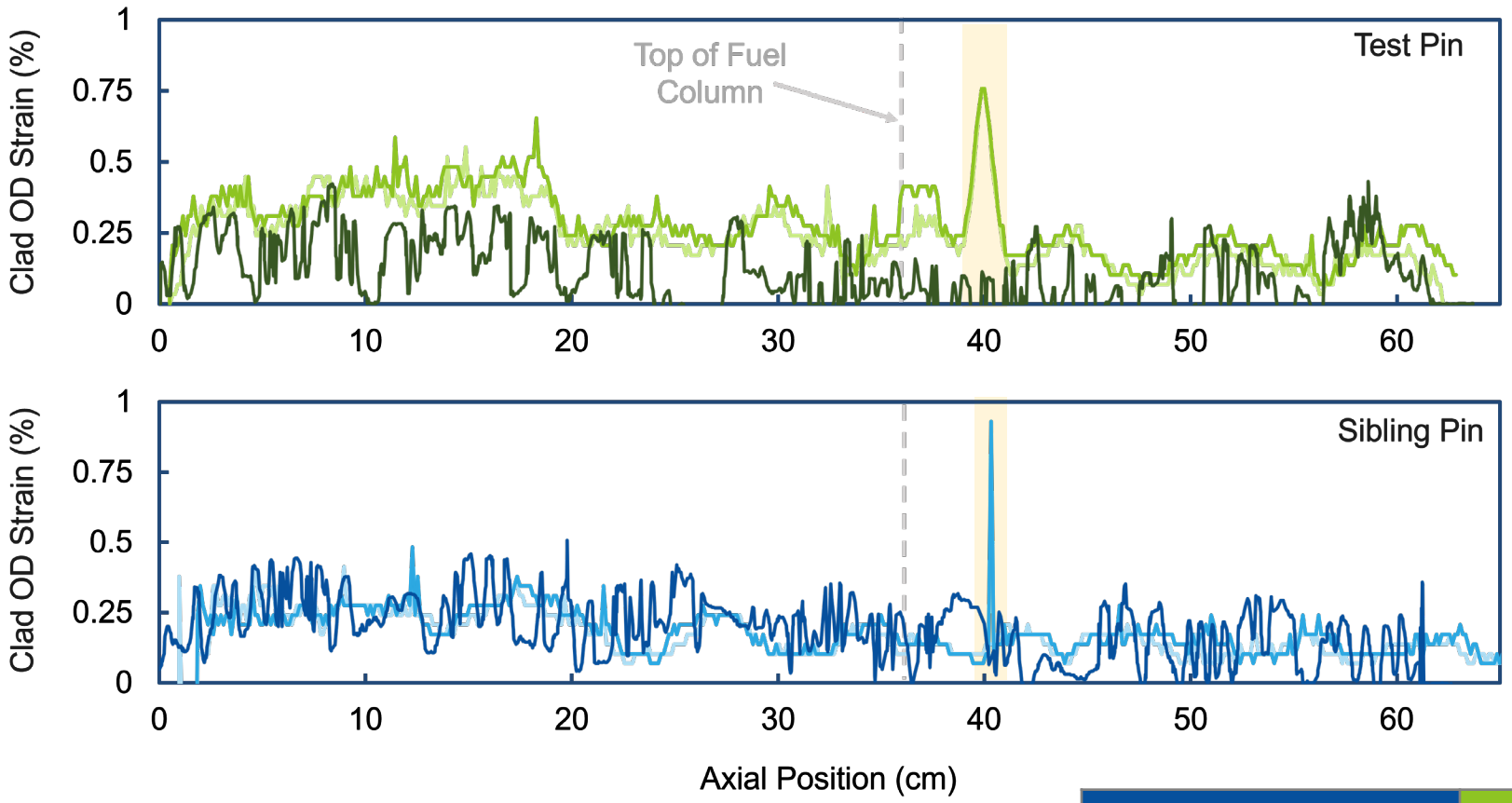


Fay, J., et al. "An analysis of fluff formation in metallic fuel via data analyzes from EBR-II experiments and BISON fuel code modeling" JNM (2022)

Typical diametral strain value and location, but anomaly above fuel



Mild strain accumulation in X430A, but still within expected values

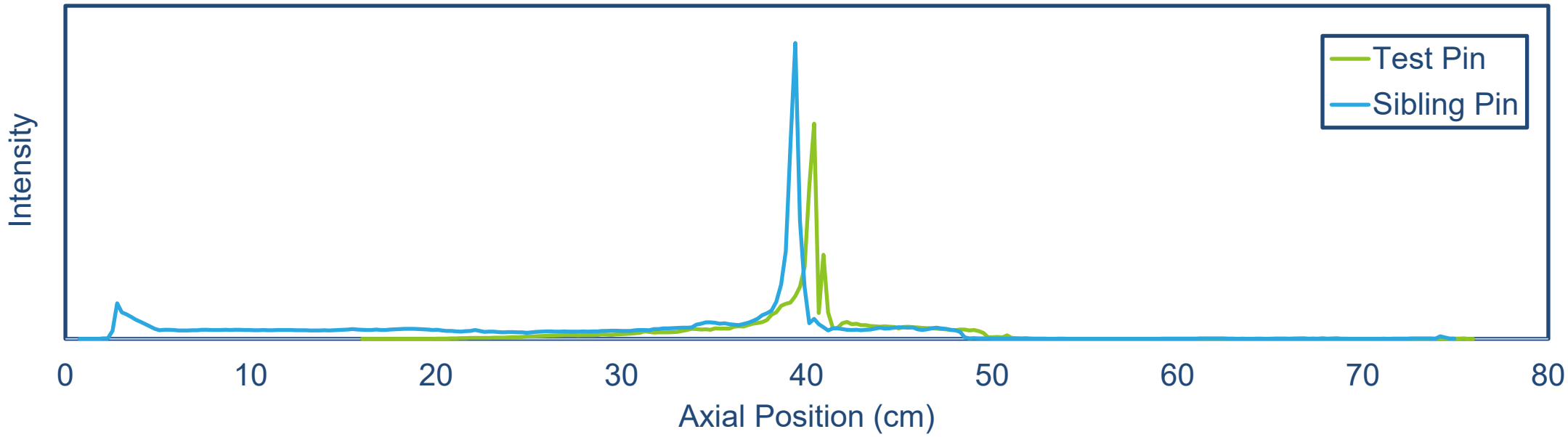


- Peak above fuel column attributed to loose wire wrap present on the pins
- Strain in lower half of the fuel column shown to be statistically larger than upper half
- Modest and expected outer cladding strain behavior

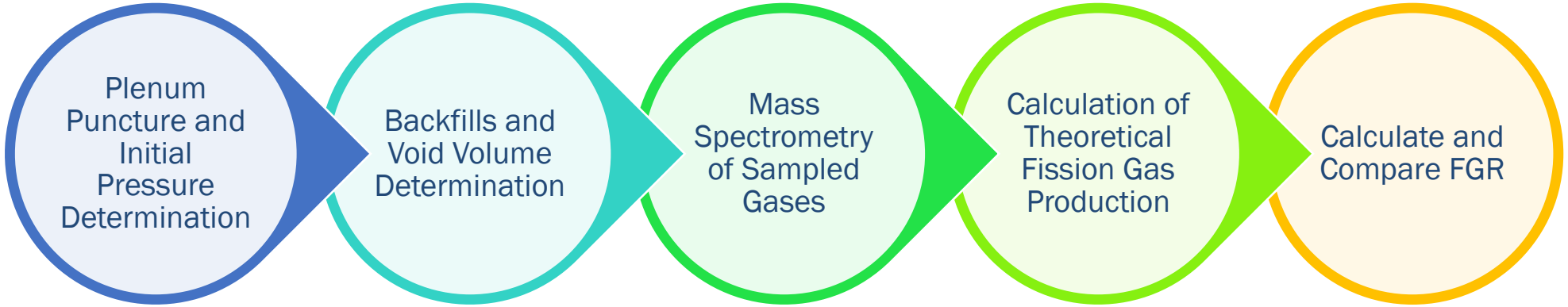
Pin	Test		Sibling	
Fuel Pin ID	T-679		T-681	
Peak BU (at. %)	5.1	7.4	5.1	7.3
Max. Clad Strain (%)	0.24	0.68	0.34	0.34

Axial distribution of Cs-137 measured using Precise Gamma Scanning

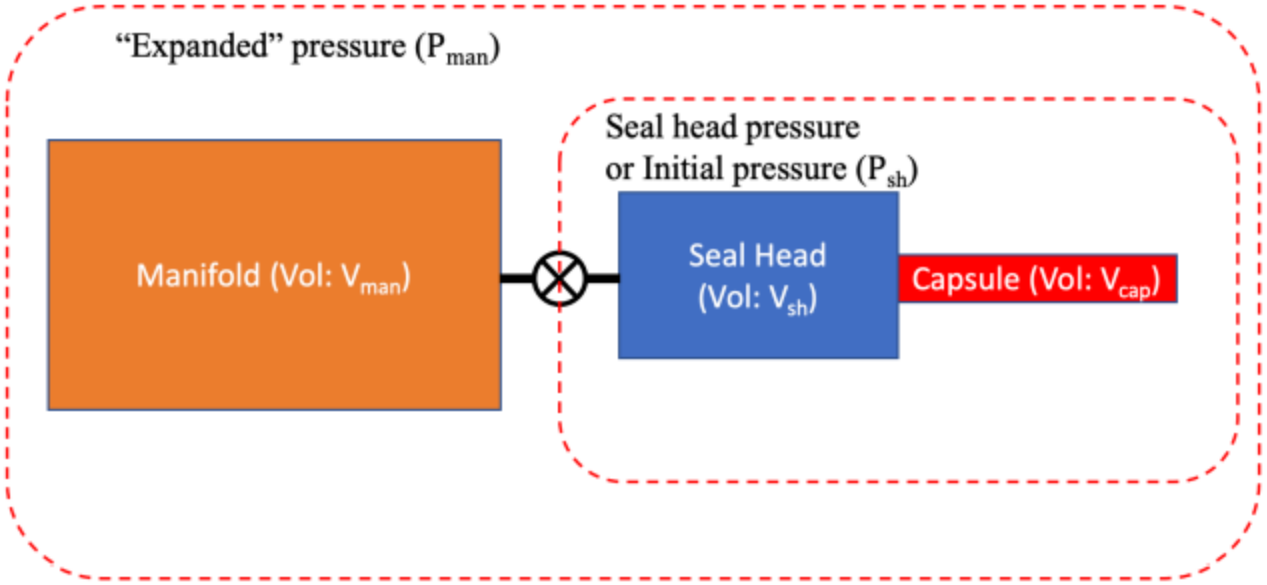
- Increased concentration of Cs-137 above the fuel column within Na bond, which suggests fuel is intact
- Limited undulation along the fuel column, which agrees with no visible features from radiography



Fission gas analyzed from destructive examination of sibling pin



- Initial laser the upper plenum region of a fuel element (capsule)
- Releases fission gas into the seal head
- Record the gas pressure in the seal head
- Release the fission gas from seal head to manifold and record expanded pressure



M. Kun and A. Oaks, "Specifications of FIPD Fission Gas Release Data", No. ANL/CFCT-23/15 (2023)

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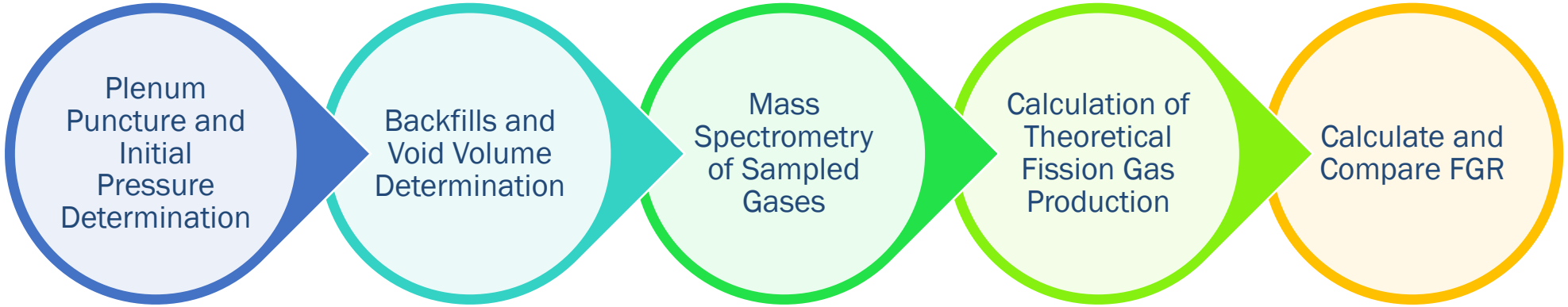
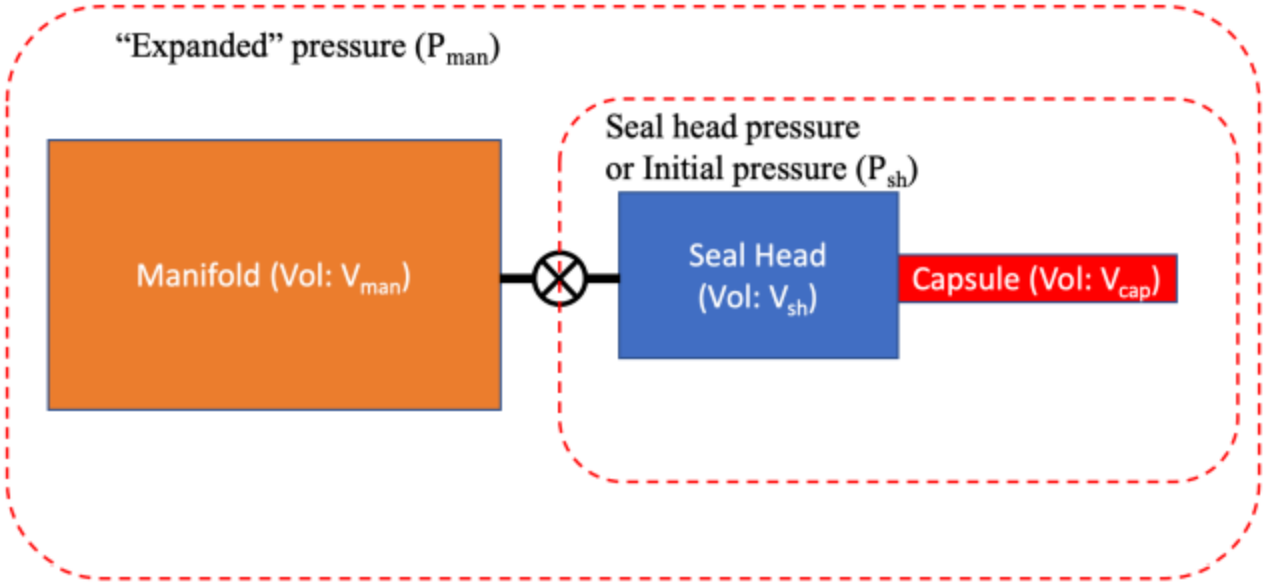


- Sampled fission gas collected in bottle
- Mass spectrometry to determine molar % of fission gas composition
- In mass spectrometry report air contamination of sample was reported
  - Determined by $3 \leq N_2/O_2 \leq 5$
- Correction factor applied based on natural N_2/O_2 and Ar/O_2 ratios and O2 as the tracer



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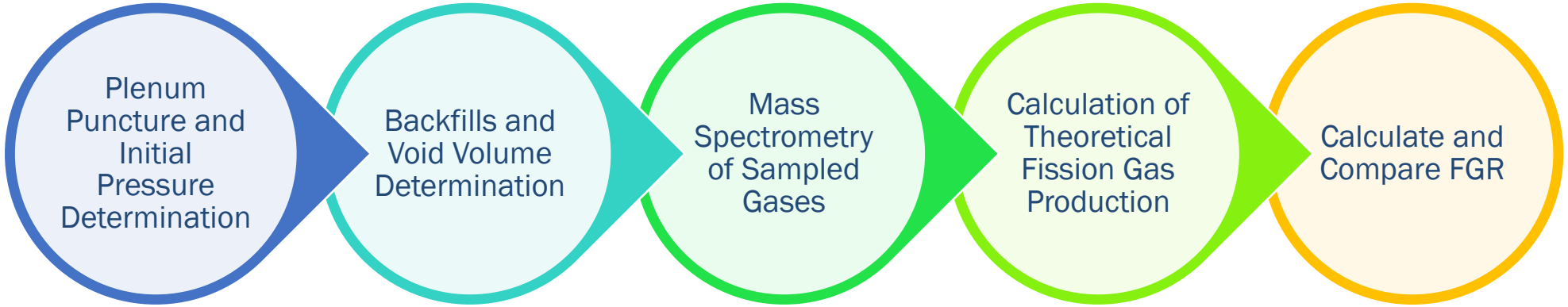
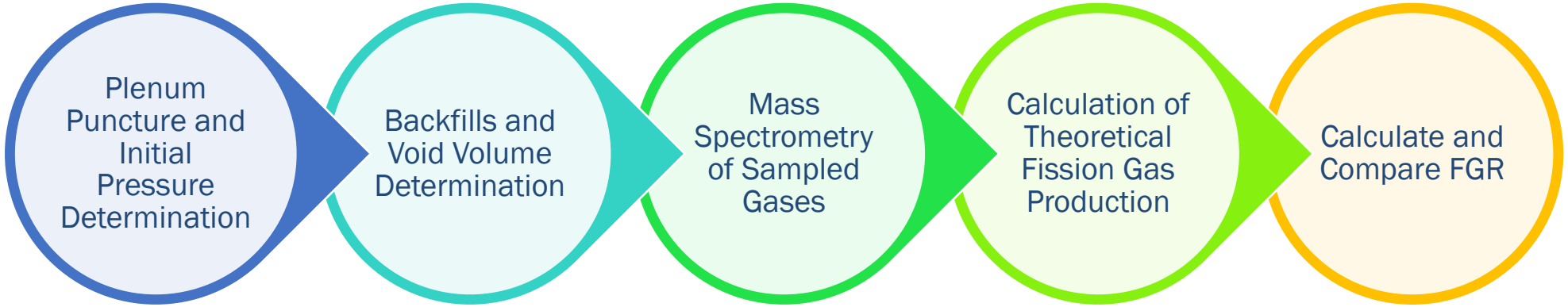


- Theoretical Fission Gas Production calculated based on total fissions in the fuel pin
- Kr/Xe ratio used to determine probability of fission form U-235 or Pu-239
- ENDF/B-VII.1 library for a 500 keV neutron interaction with U-235 and Pu-239

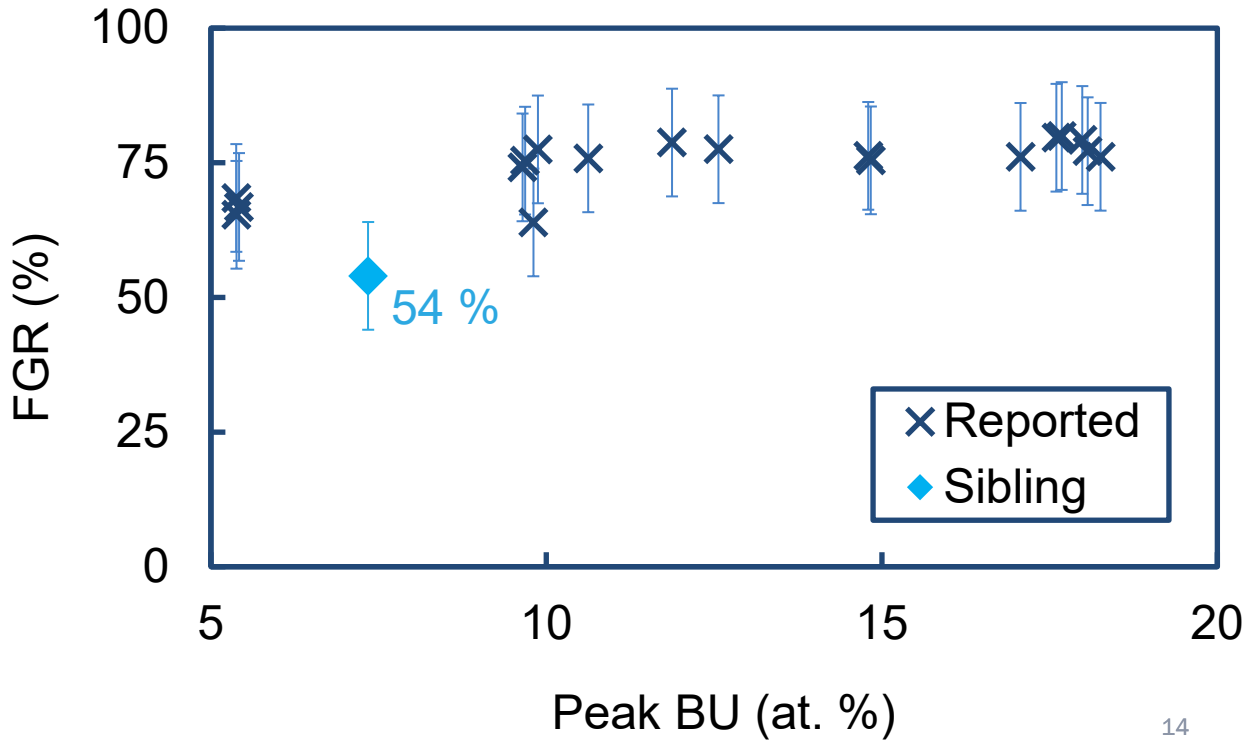
$$(n_{X'})_{predicted} = BU_{avg} \cdot \frac{\rho_{fuel} \cdot V_{fuel}}{\bar{M}} \cdot \pi_X \cdot Y_X$$

$(n_{X'})_{predicted}$ = Predicted yield of daughter fission product (mol)
BU_{avg} = average fuel pin burnup (at. %)
ρ_{fuel} = fuel density (g/cm^3)
V_{fuel} = fuel volume (cm^3)
$\bar{M}$ = weighted average molar mass of heavy metal composition (g/mol)
π_X = probability of fission from parent nucleus
Y_X = expected atomic yield of daughter fission product from parent nucleus

Measured Fission Gas Release Lower than Expected



- Air contamination likely during sample bottle removal from GASR system, shipping, or attachment to mass spectrometer
- Correction provided by PNNL increased FGR 44% → 54%
  - Higher than expected N %
- Considered decay half life contribution
- Potentially affected by non-uniform mixing



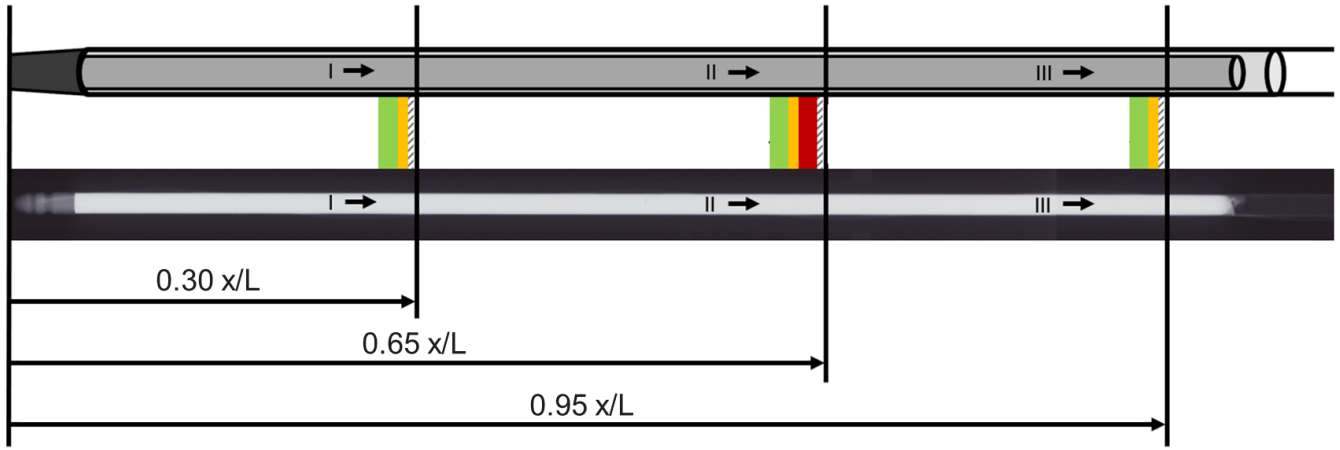
R.G. Pahl et al., "Irradiation Behaviors of Metallic Fast Reactor Fuels", JNM (1992)

Sibling pin sectioned for optical imaging, laser, and burnup analysis

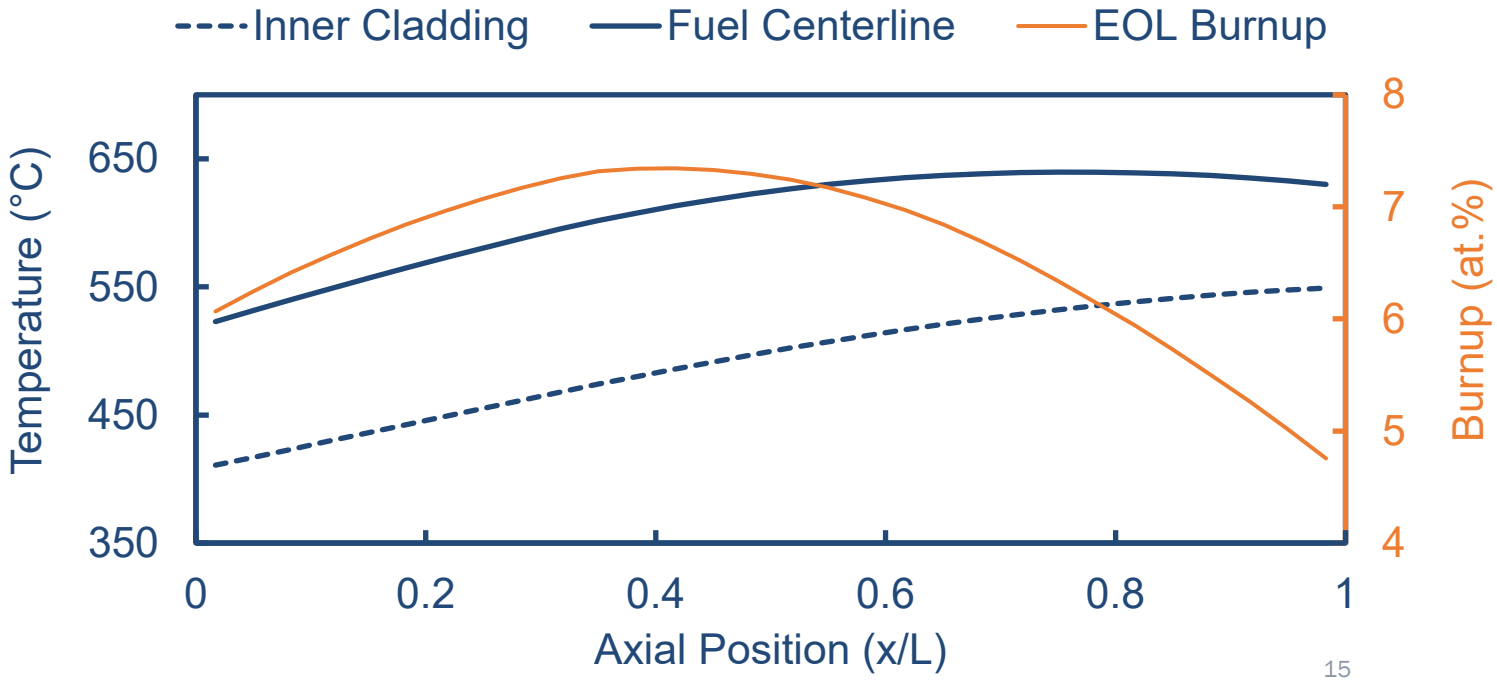
Transverse Metallography Mount

Laser Flash Analysis Sample

Burnup Analysis Sample



- 3 LFA samples sectioned for future work
- 1 burnup sample sectioned for future work
- 3 met mounts sectioned to be analyzed for microstructural properties under varied conditions:
  - 0.30 x/L → High Burnup, Low Temp.
  - 0.65 x/L → High Burnup, High Temp.
  - 0.95 x/L → Low Burnup, High Temp.



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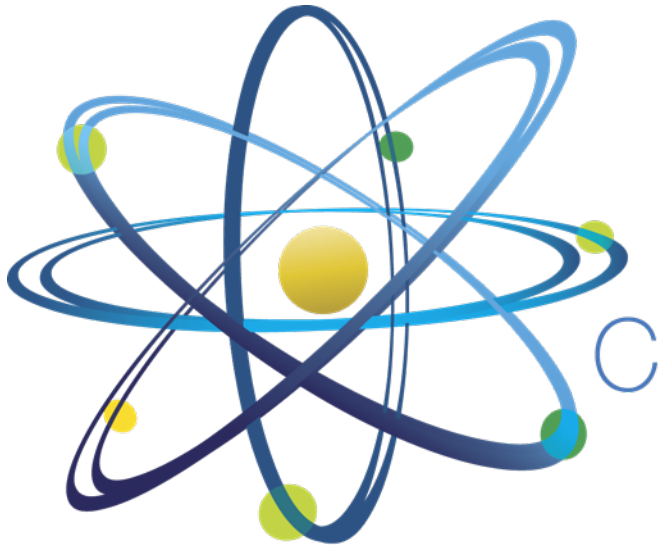
M. Yacout, et al., "FIPD: The SFR Metallic Fuels Irradiation & Physics Database," *Nuclear Engineering and Design* (2021)

Summary and Future Work

- Confirmation of test and sibling pin suitability:
  - No visual corrosion from storage
  - No uncharacteristic features observed in radiography
- Established baseline steady-state behavior
  - Axial elongation within range of reported values for U-10Zr
  - Fluff structure length aligns with reported values for U-10Zr of similar burnup
  - Diametral strain within range of reported values for U-10Zr
  - Cs-137 distribution consistent with expected results for Na-bonded pins
  - Measured steady-state fission gas release, which will inform transient fission gas measurements
- Sibling pin metallography, SEM, EPMA, LFA, and BU will be analyzed
  - Informs microstructure, composition, FCCI behavior, and thermal properties
- Comparisons to Post-Test Pin PIE to extract contribution of transient behavior

Thank you
Questions?



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