UF Herbert Wertheim College of Engineering
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NSUF award #14704 update: PIE progress of the MORPH experiment

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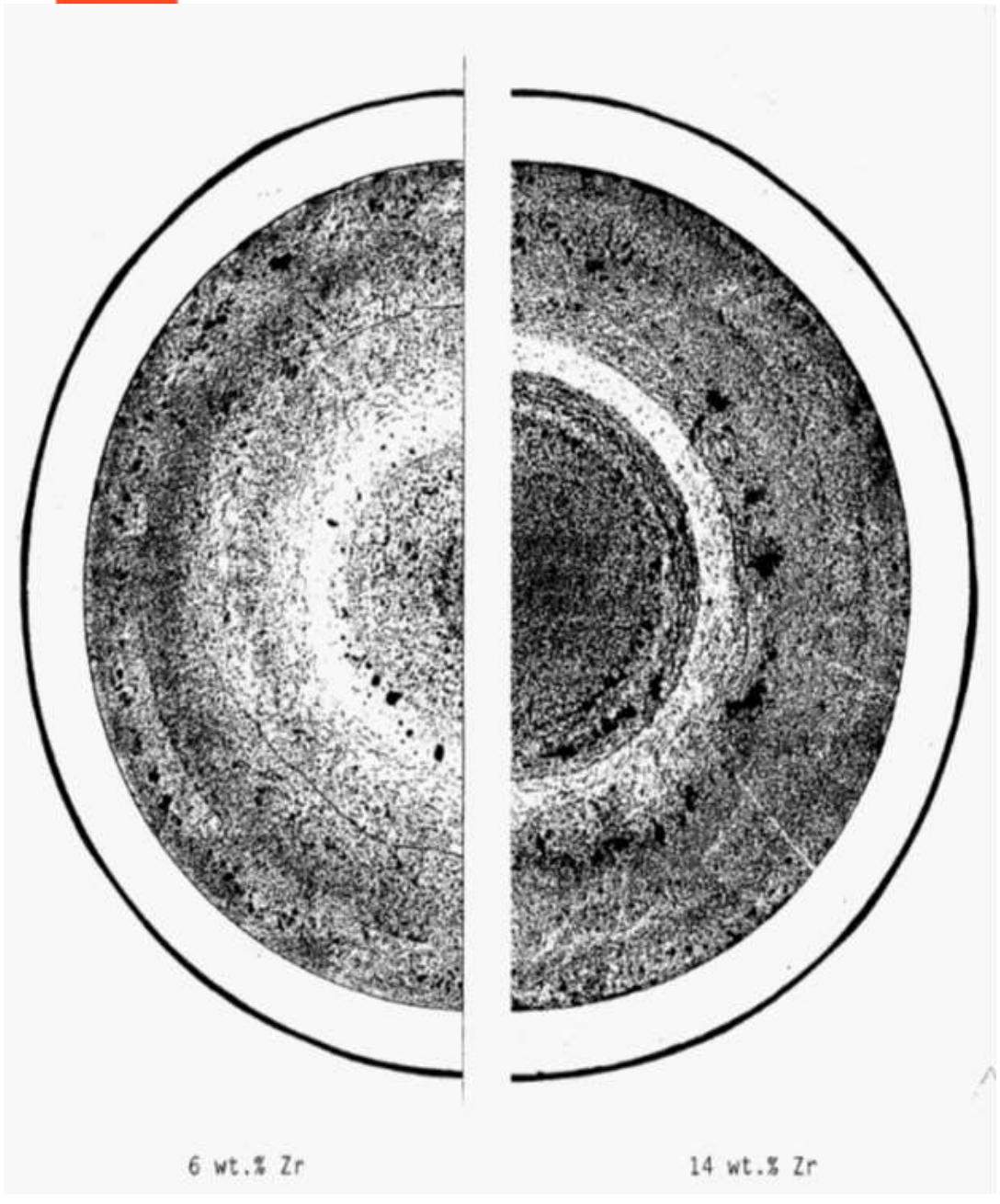


NSUF award #14704: *Facilitating MARMOT Modeling of Radiation Phenomena in U-Pu-Zr fuels through experiments (**MORPH**)*

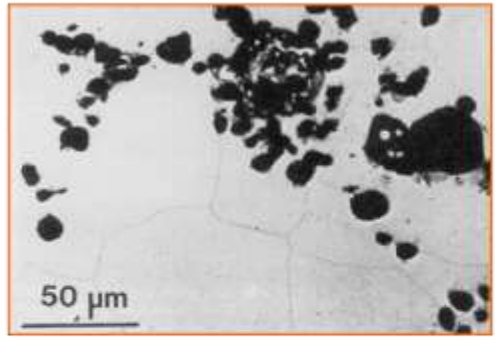
- U-19Pu-6Zr
- U-19Pu-10Zr
- U-19Pu-14Zr

NSUF Nuclear Science User Facilities

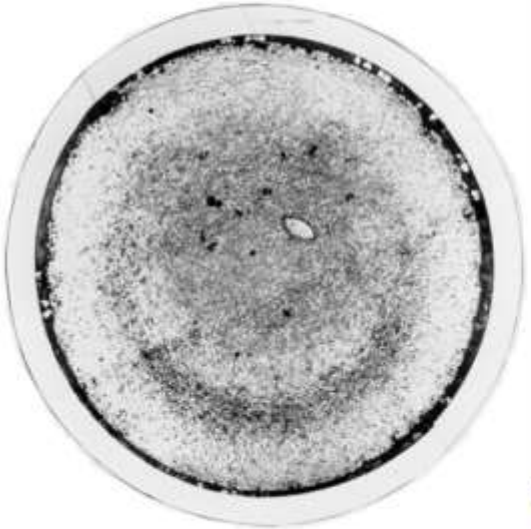
U-Pu-Zr metallic fuels

U-Pu-Zr metal fuels:

- Simple fabrication
- High burn-up
- Good thermal response
- Relatively simple recycling using melt refining or electro-refining processes

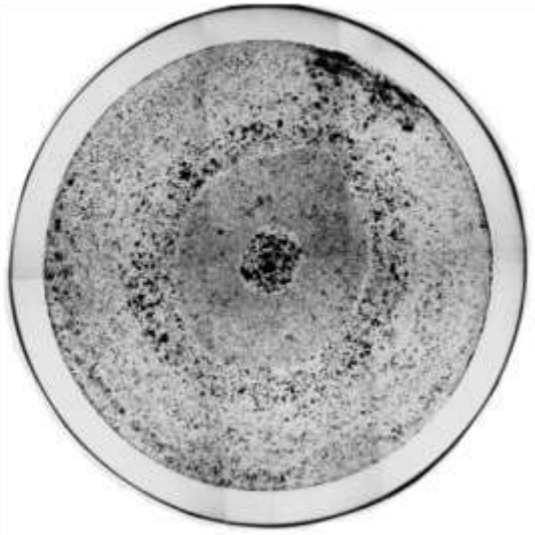


As fabricated U-20Pu-10Zr



X423A at 0.9% BU

X419 at 3% BU



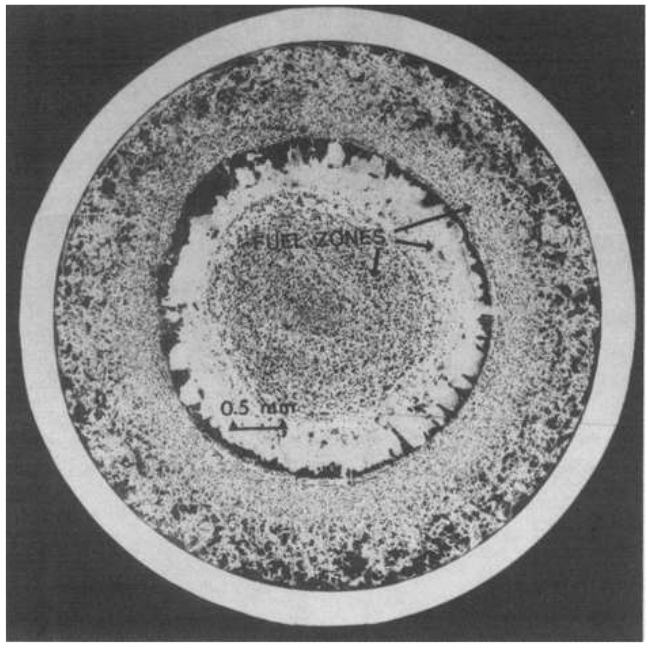
X420B at 17% BU

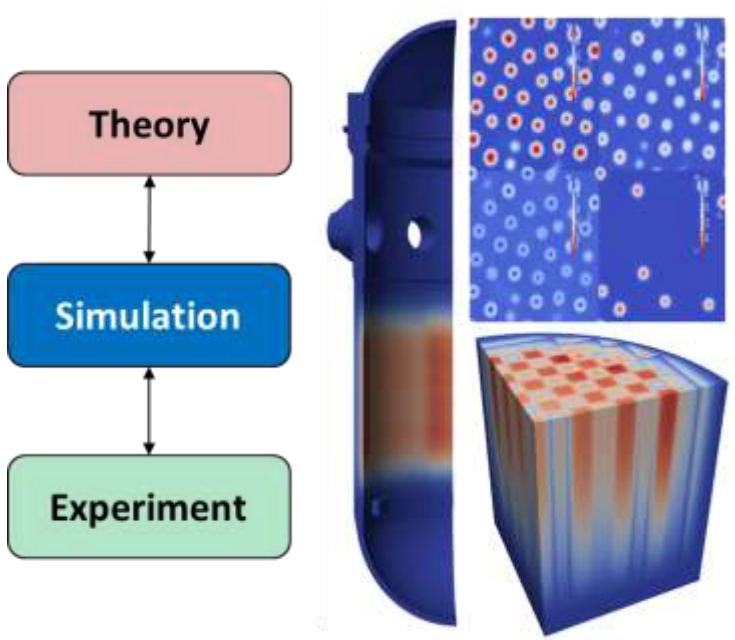
- Redistribution of U and Zr occurs early
- Inhomogeneity doesn't affect fuel life

Y.-S. Kim et al., J. Nucl. Mater. 327 (2004) 27-36

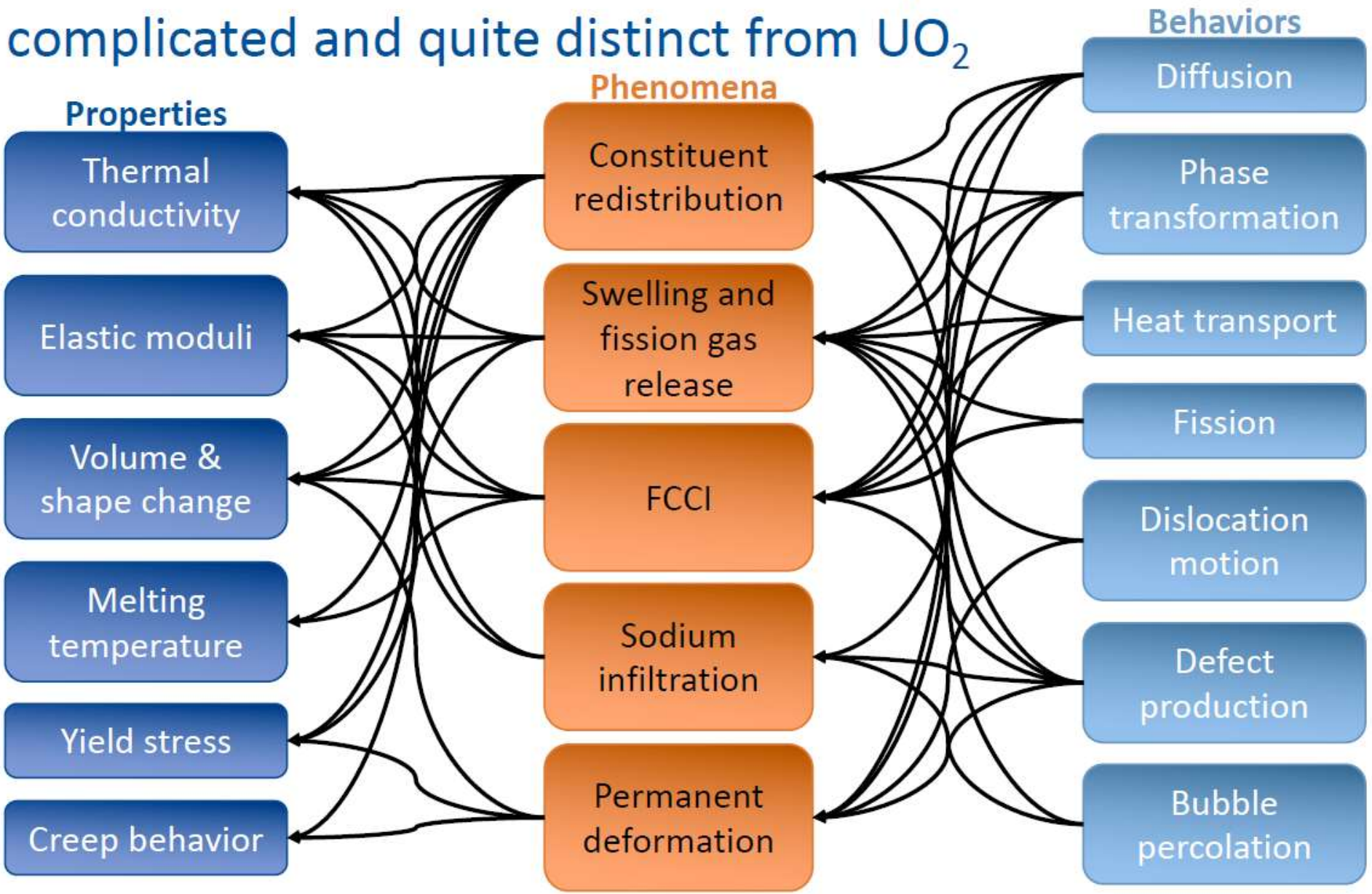
Challenges in scientific understanding of U-Pu-Zr fuels

- Lack of detailed systematic characterization data
- Lack of detailed microstructural and microchemical information needed for modeling efforts.





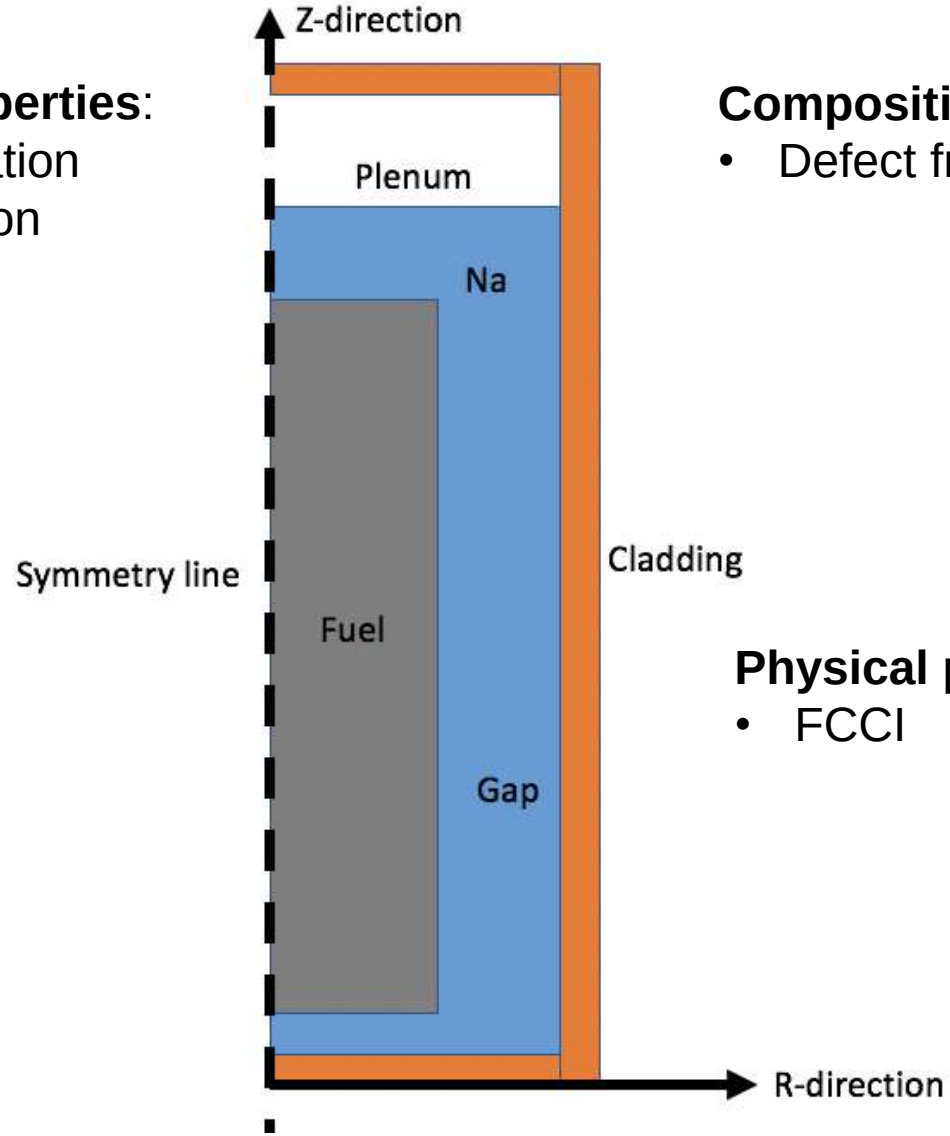
The behavior of U-Zr and U-Pu-Zr alloy fuels is complicated and quite distinct from UO_2



MORPH experiment objectives

Compositions/chemical properties:
- Species diffusion and migration
- Fuel constituent redistribution
- Phase fractions
- Fission product behavior

Physical phenomena:
- Fission gas and swelling
- FCCI

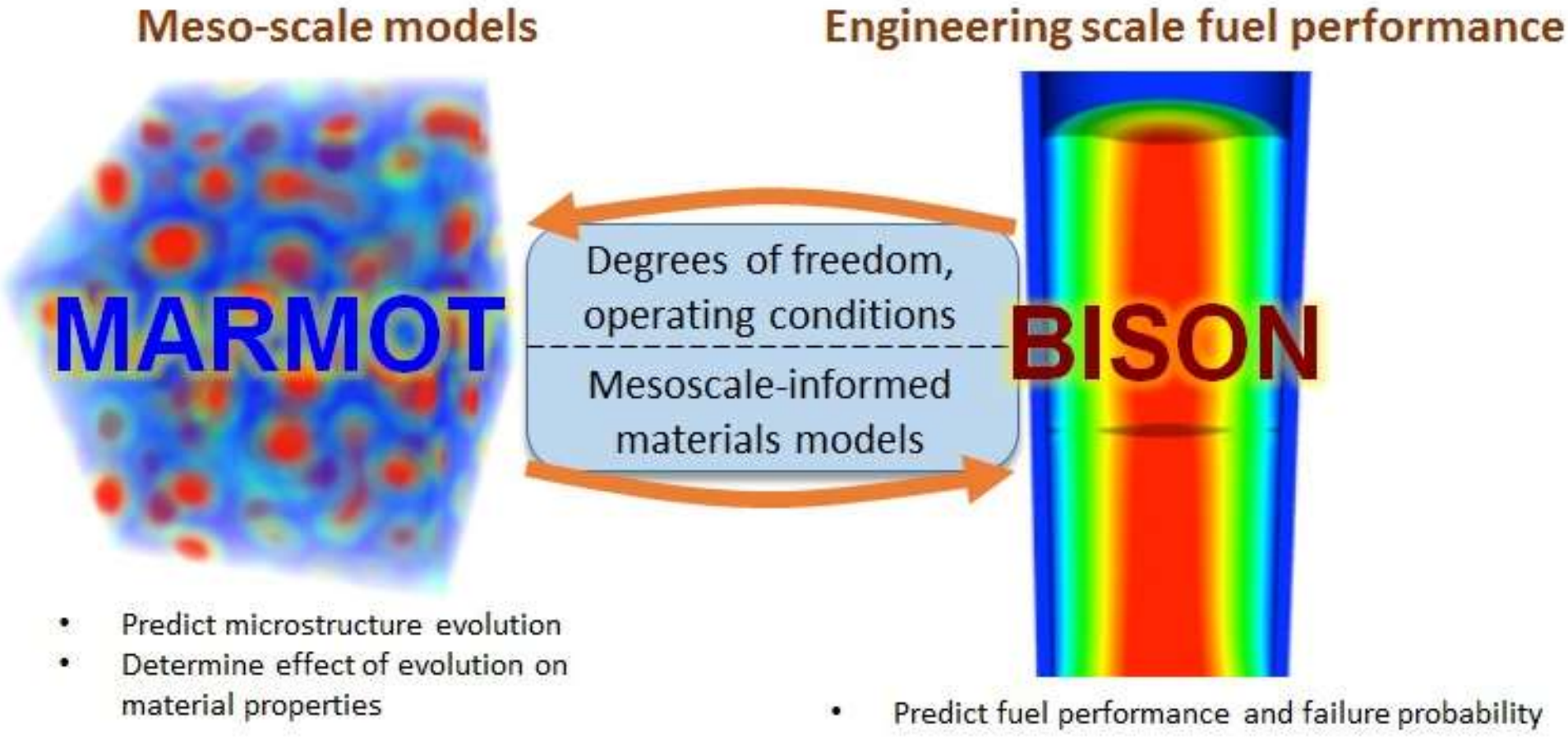


Compositions/chemical properties:
- Defect fractions

Gap:
- Fission gas concentration

Physical phenomena:
- FCCI

MORPH experiment objectives (continued)



How do the phase and constituent distributions in irradiated fuel compare with equilibrium conditions we would expect in an unirradiated microstructure?

Experiment details

X441A	A797/A812/A814
Composition	U-19Pu-6/10/14Zr
Pin diameter	0.23 in
Fuel diameter*	0.173 in
Fuel column height*	13.5 in
Plenum gas	75% He + 25% Ar
Tag gas	Xe
Smear density	75%
Cladding	D9
Cladding thickness	0.015 in
Av burnup reached	9/10.3/11.5

MORPH experiment PIE activities

ENGINEERING SCALE PIE:

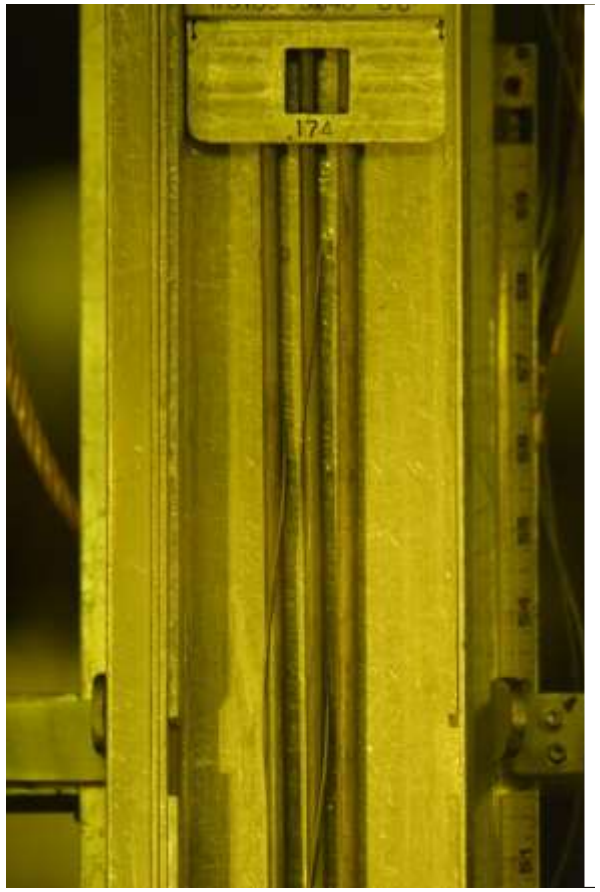
- Neutron radiography
- Profilometry (dimensional inspection)
- Gamma Spectroscopy/Tomography
- Fission gas release and retention
- Optical Microscopy

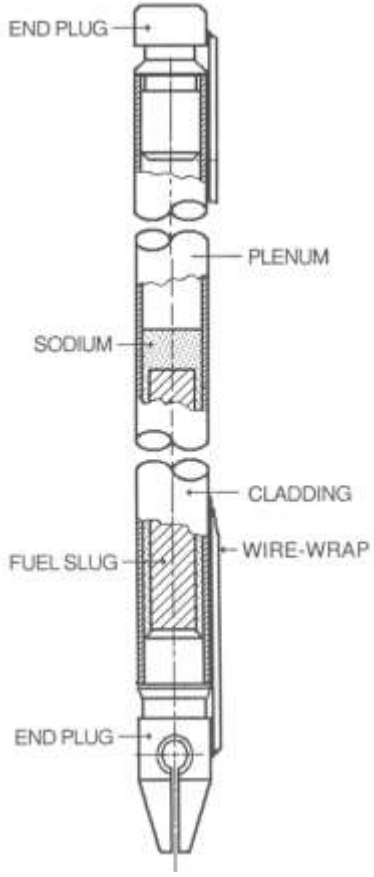
- Chemical analysis

ELECTRON MICROSCOPY:

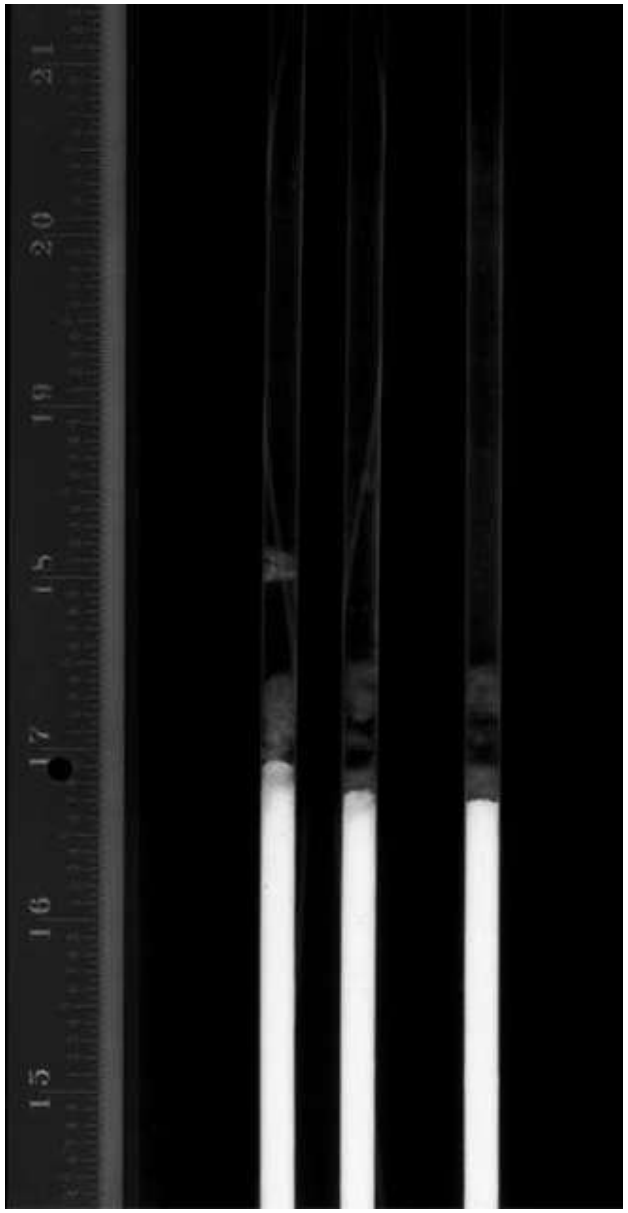
- SEM/WDS/EDS
- EPMA/WDS
- FIB
- TEM

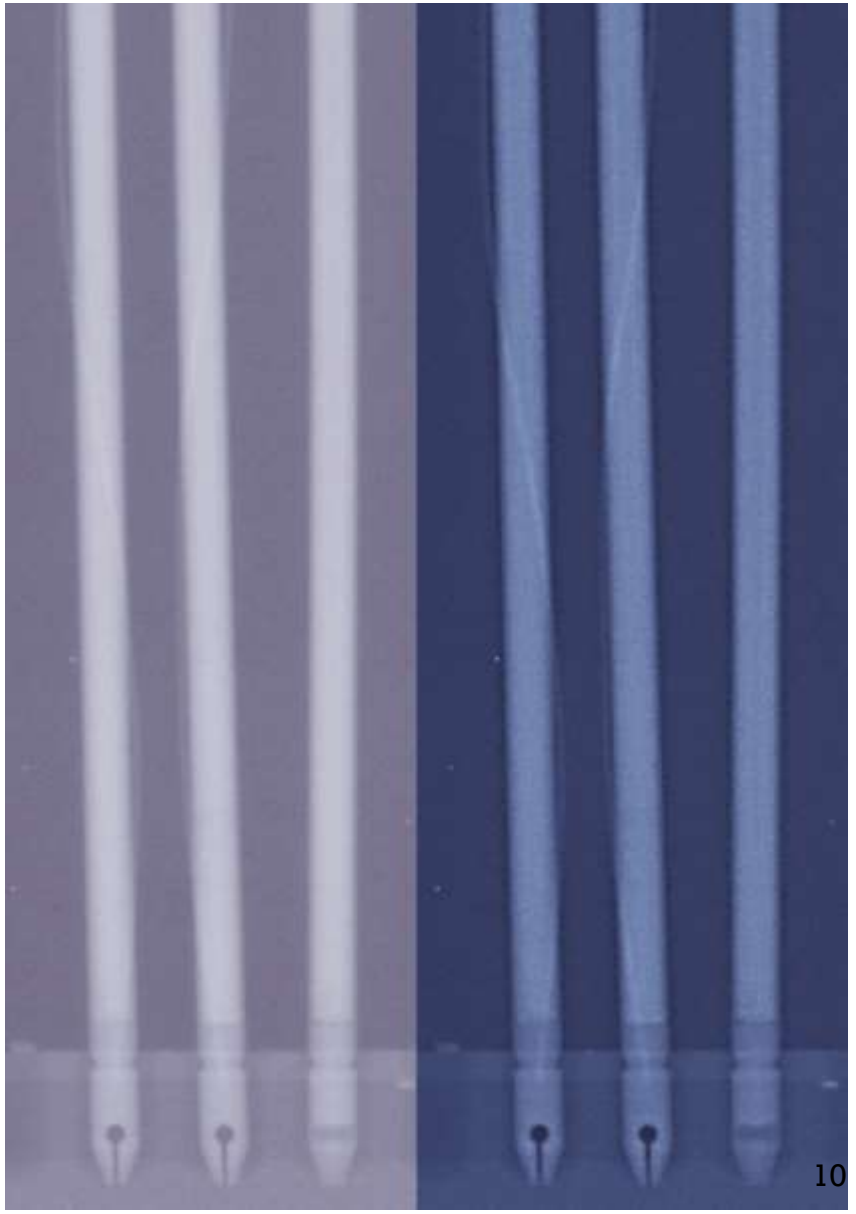
Axial growth of metallic fuel systems



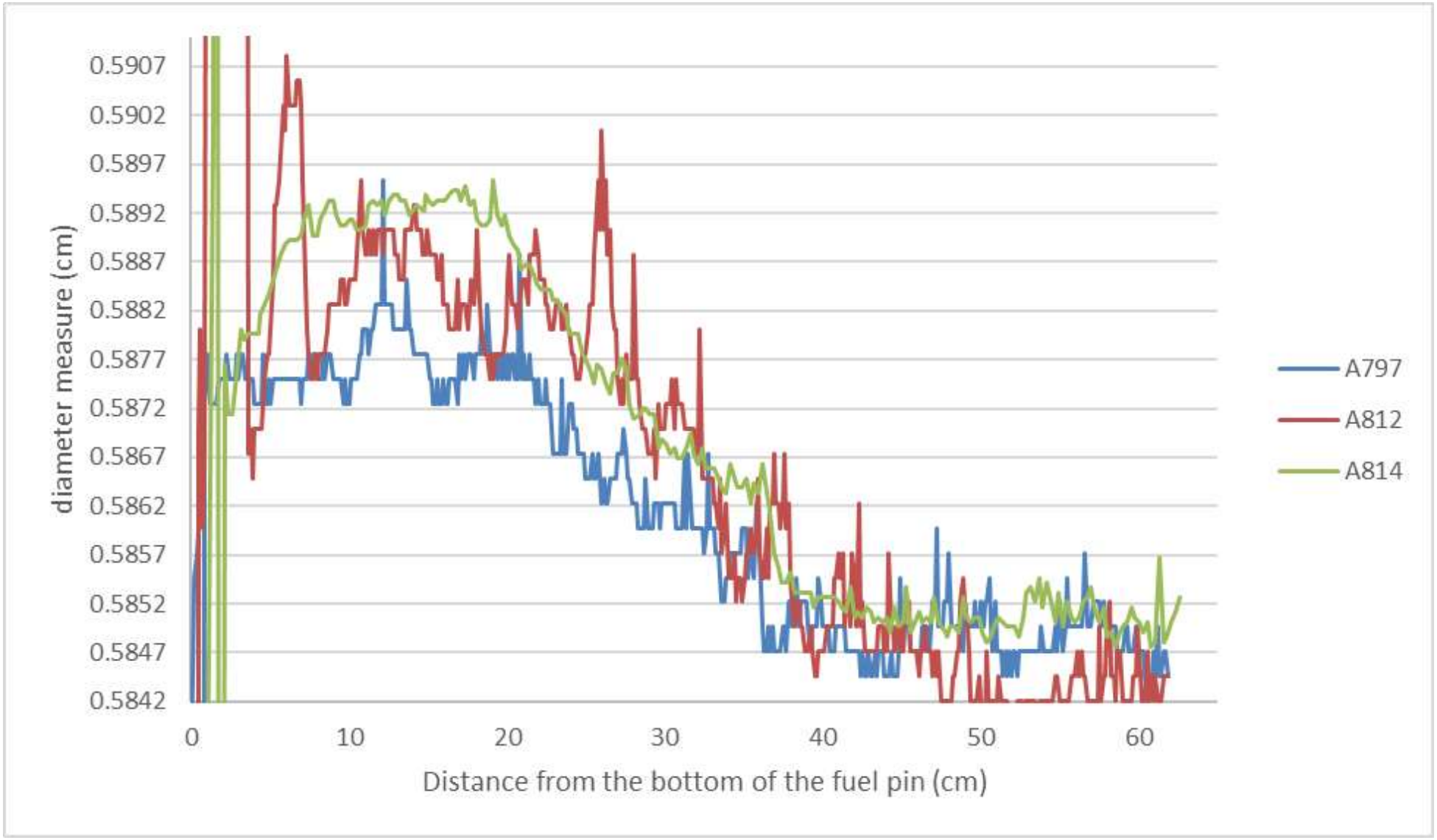


X441A fuel pin	Composition	Axial growth
A797	U-19Pu-6Zr	3%
A812	U-19Pu-10Zr	2.4%
A814	U-19Pu-14Zr	1.6%





Cladding deformation profile shows diametral strain

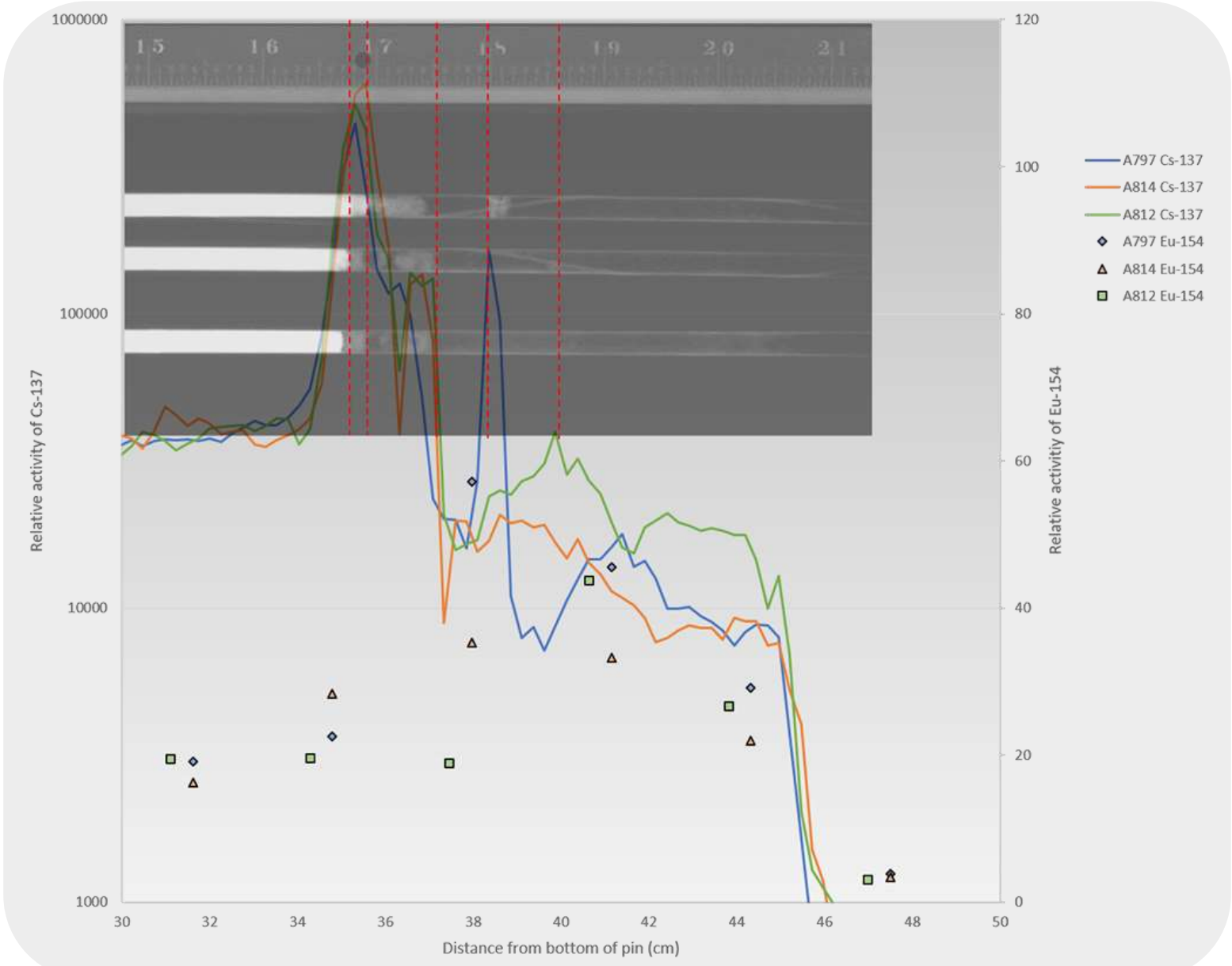


0.7%

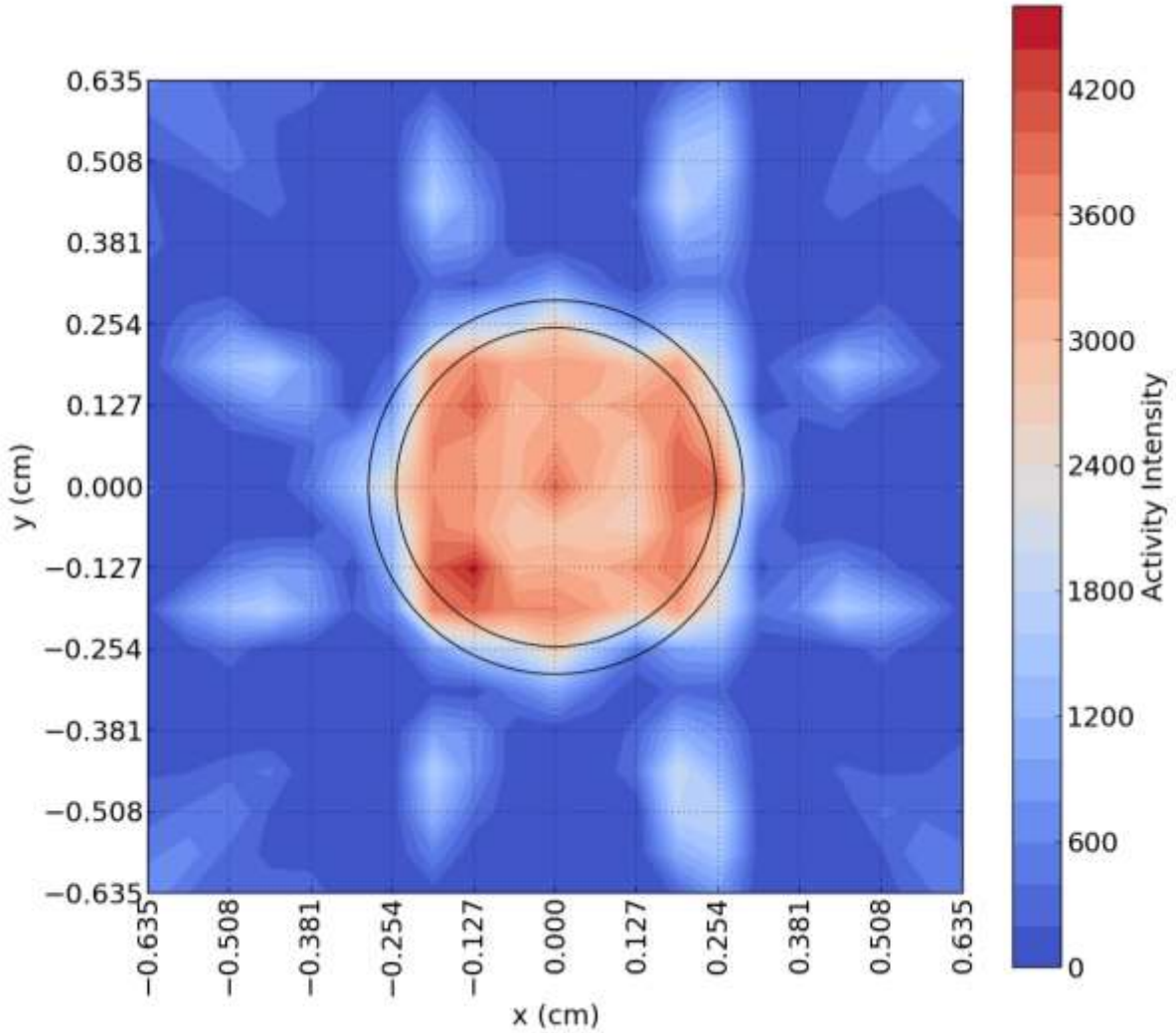
0.82%

0.87%

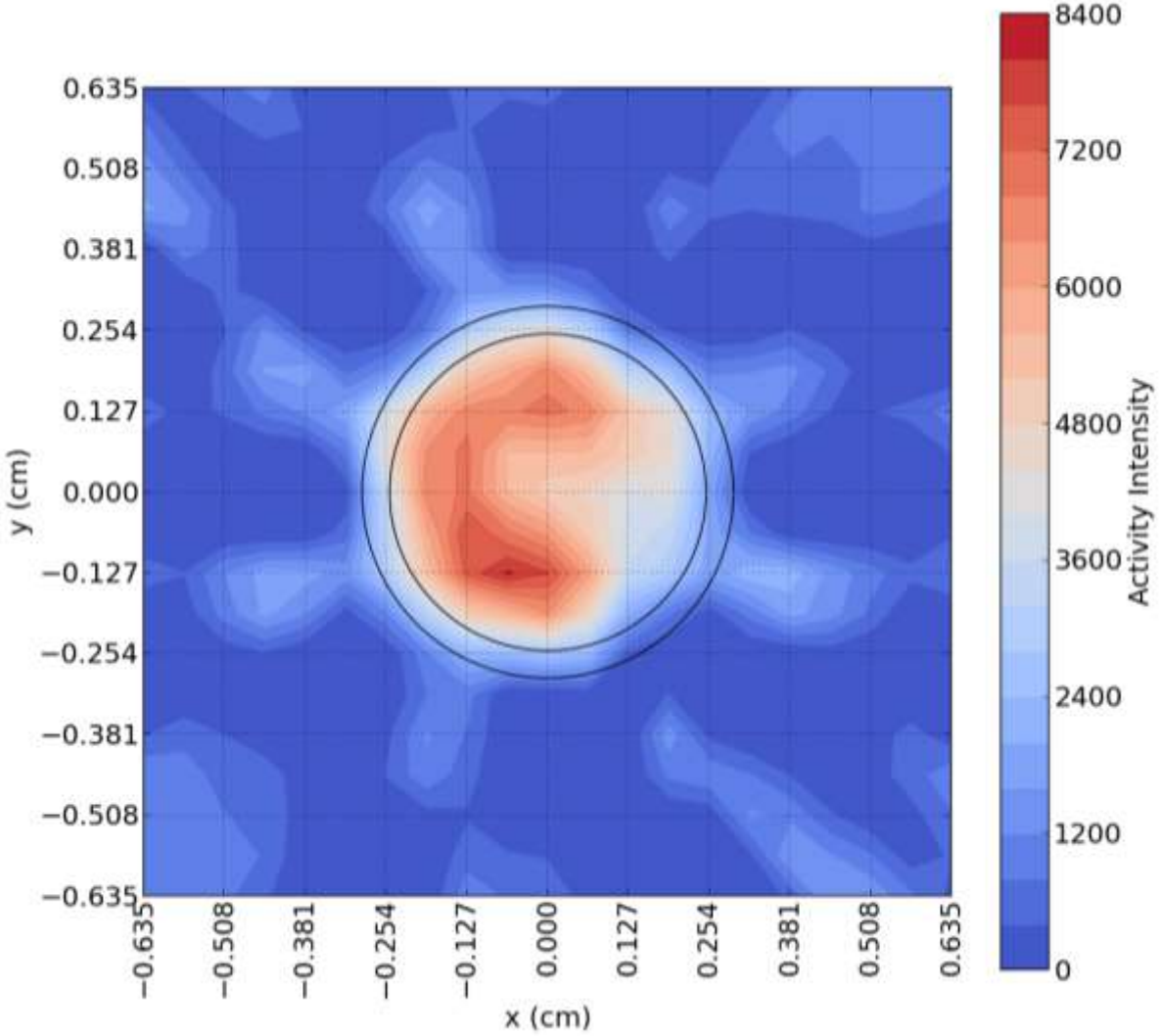
Integrity of the spins was verified using gamma spectroscopy



Cs-137 distribution changes at different heights

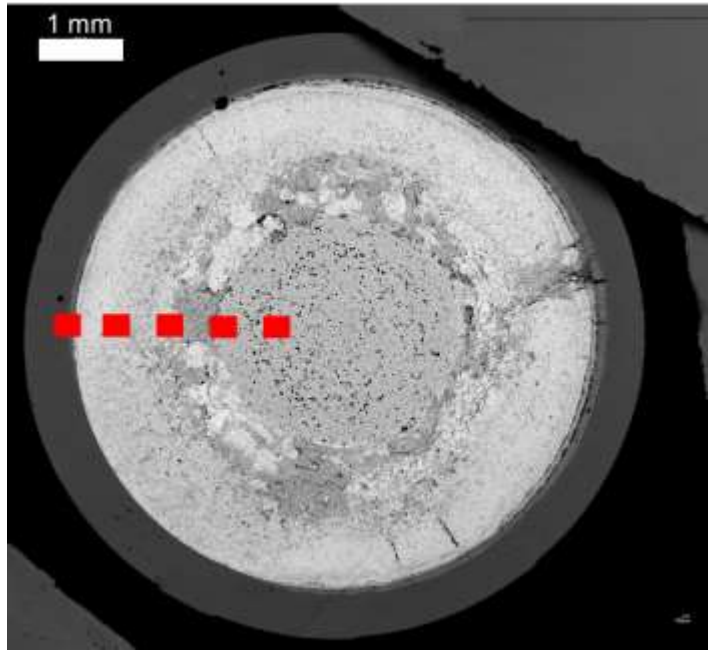


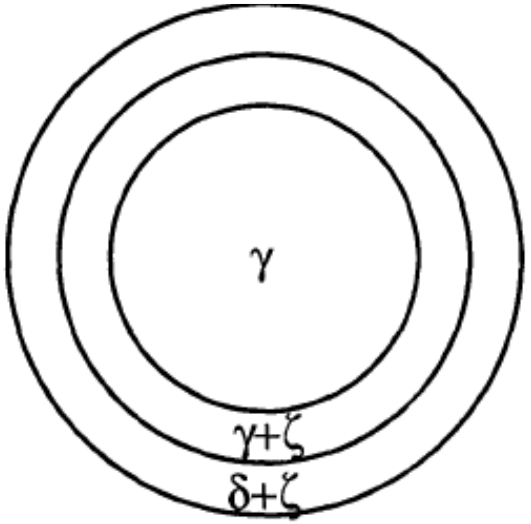
x/L=0.75

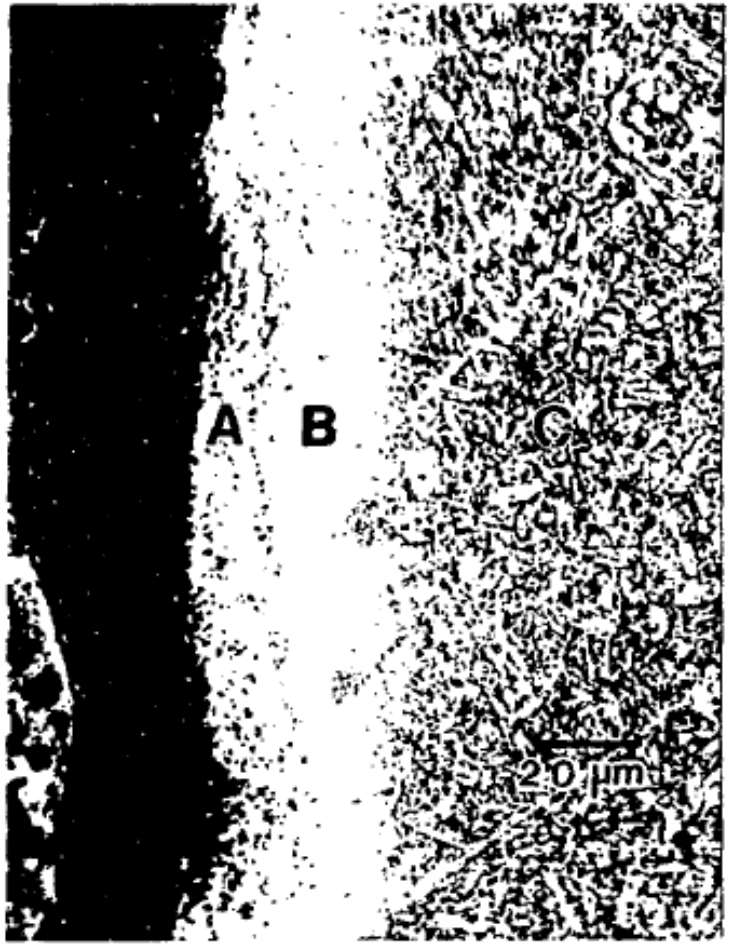


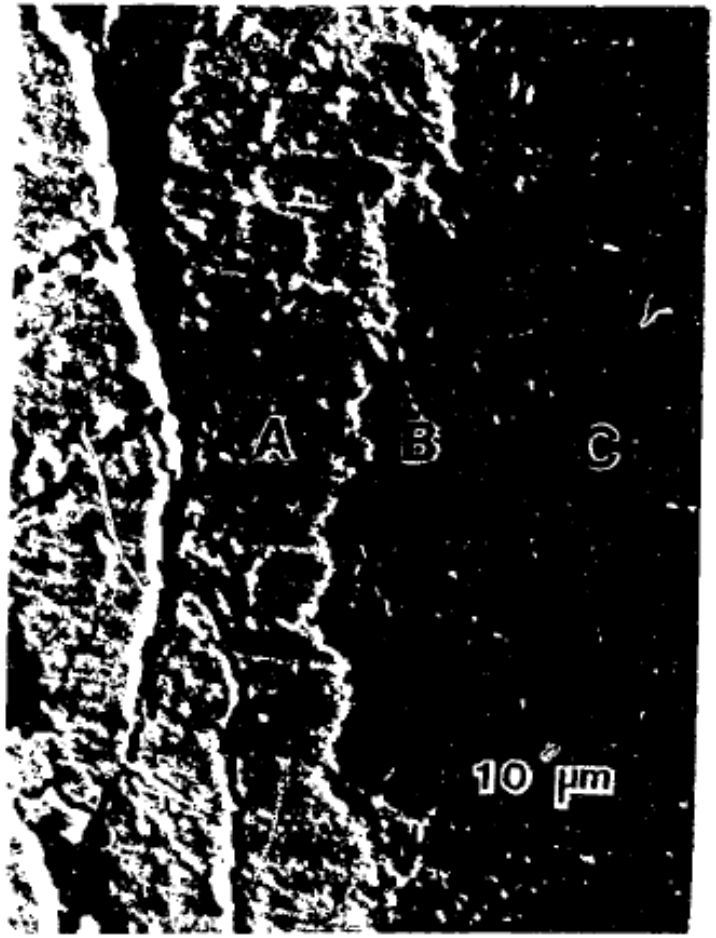
x/L=0. 9

MORPH experiment: electron microscopy







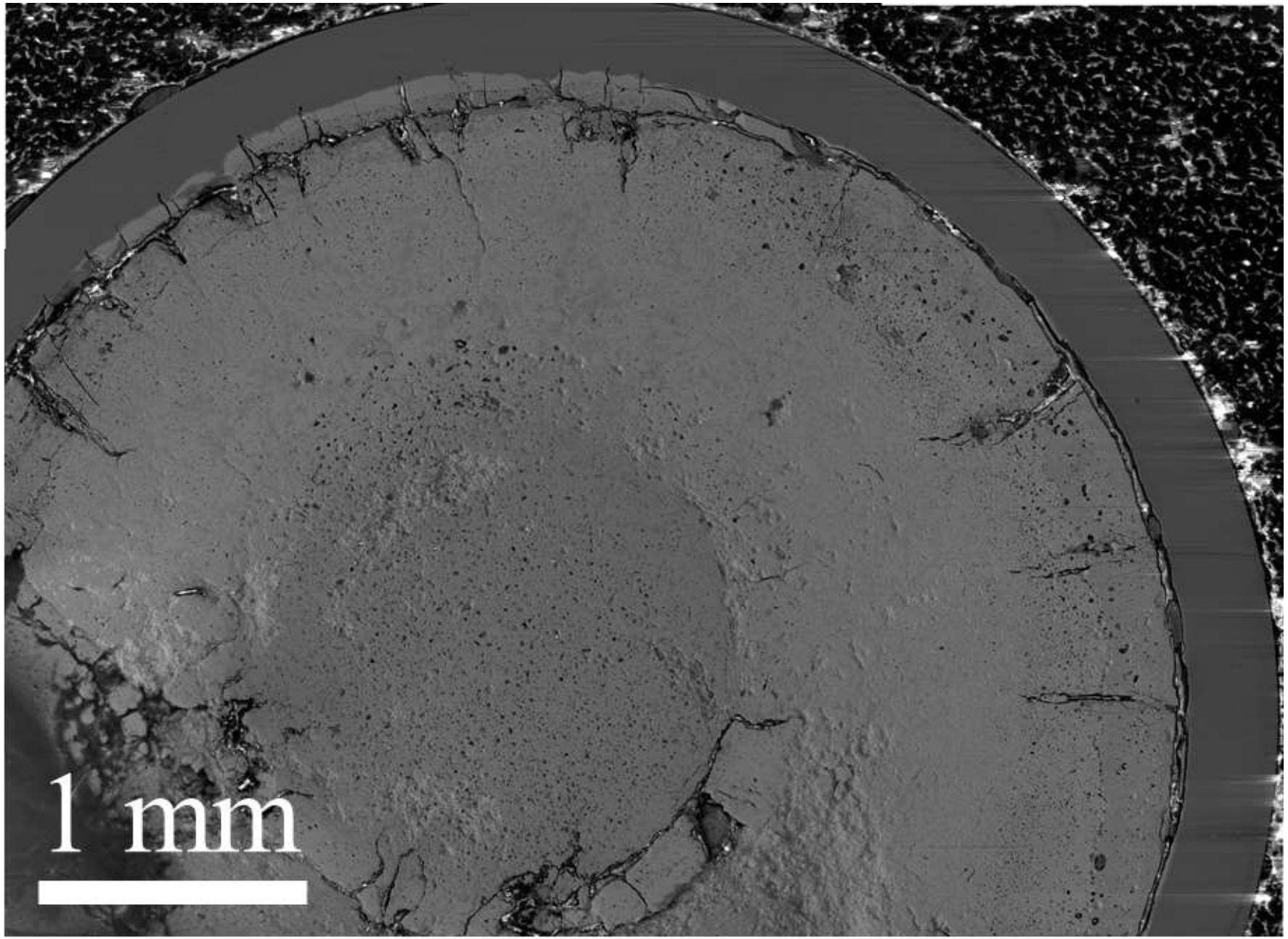


Optical SEM

H. Tsai et. al., ANL/ET/CP-82776, October 1994.

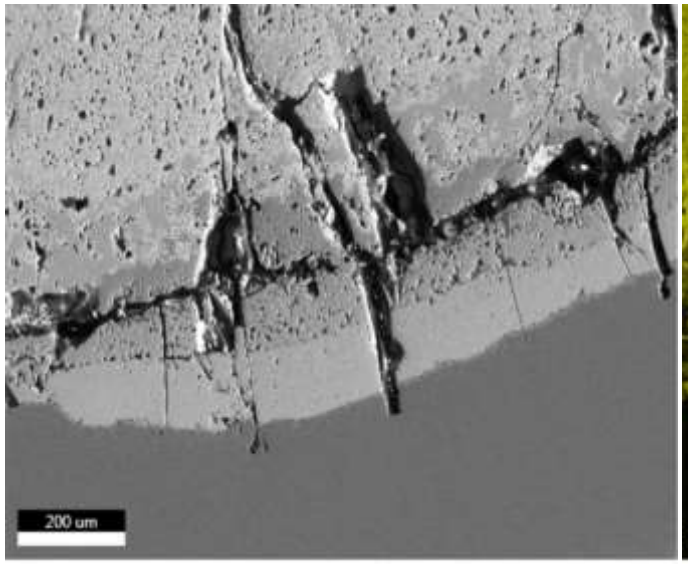
Approach:

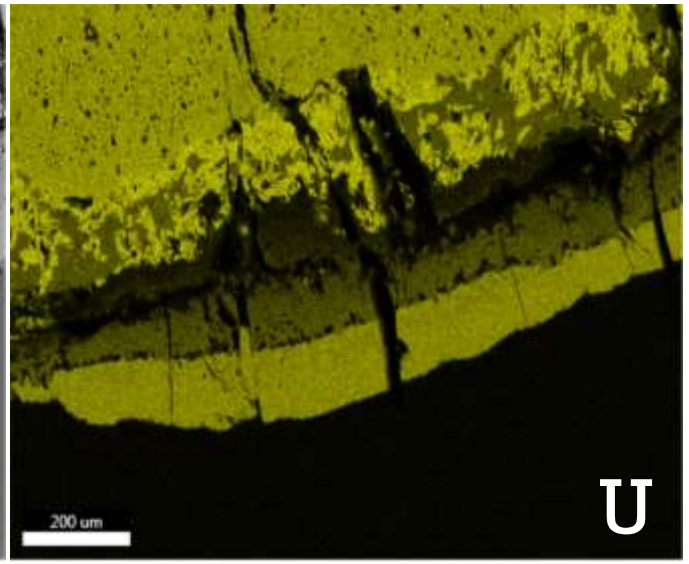
RTE #18-1533:
Investigation of FCCI in irradiated U-Pu-Zr fuel

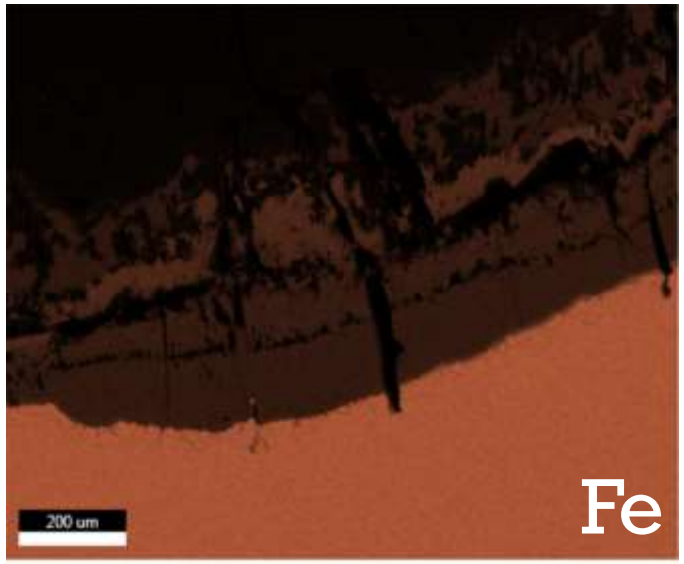


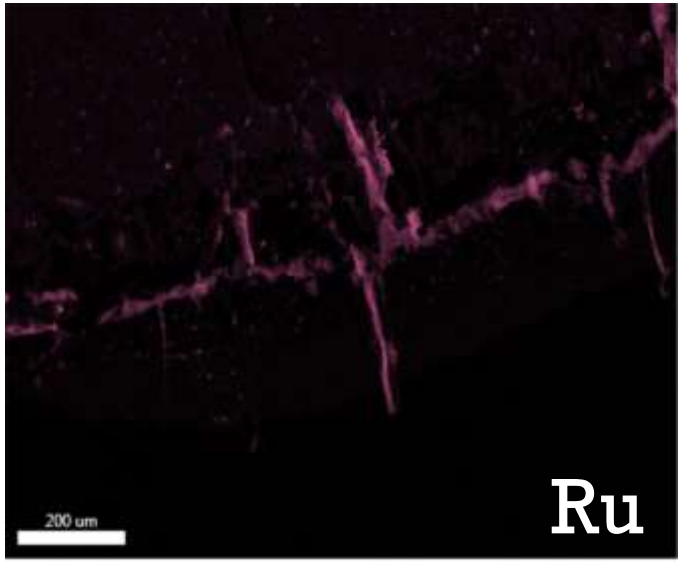
Approach:

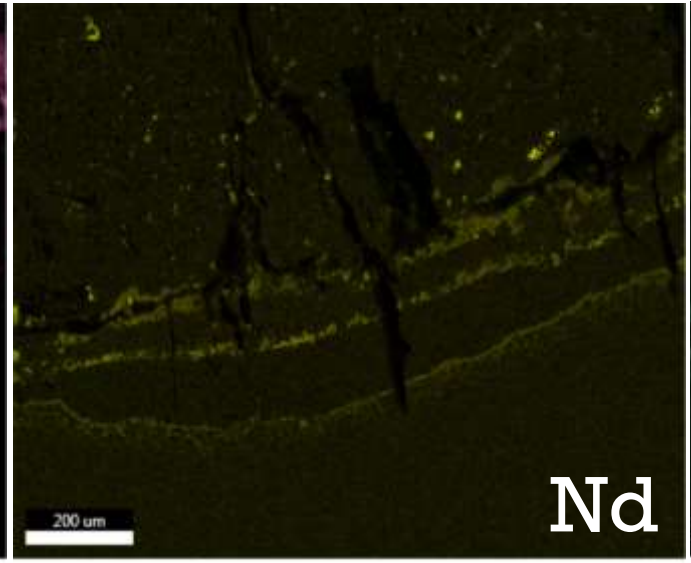
RTE #18-1533:
Investigation of FCCI in irradiated U-Pu-Zr fuel

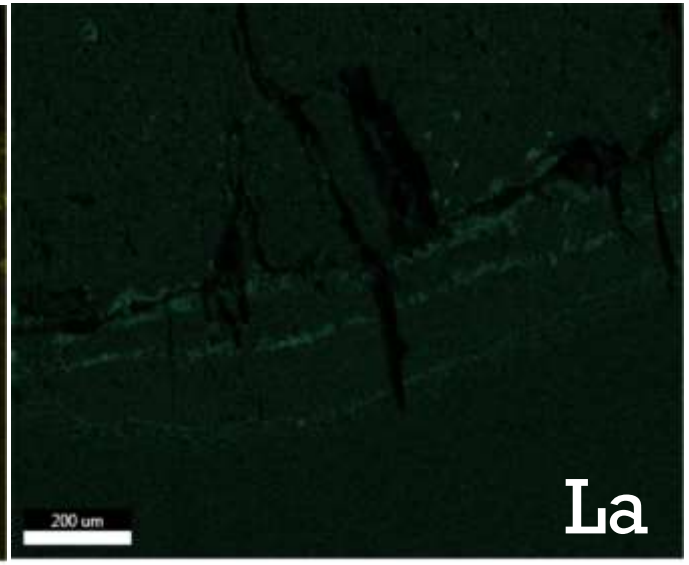






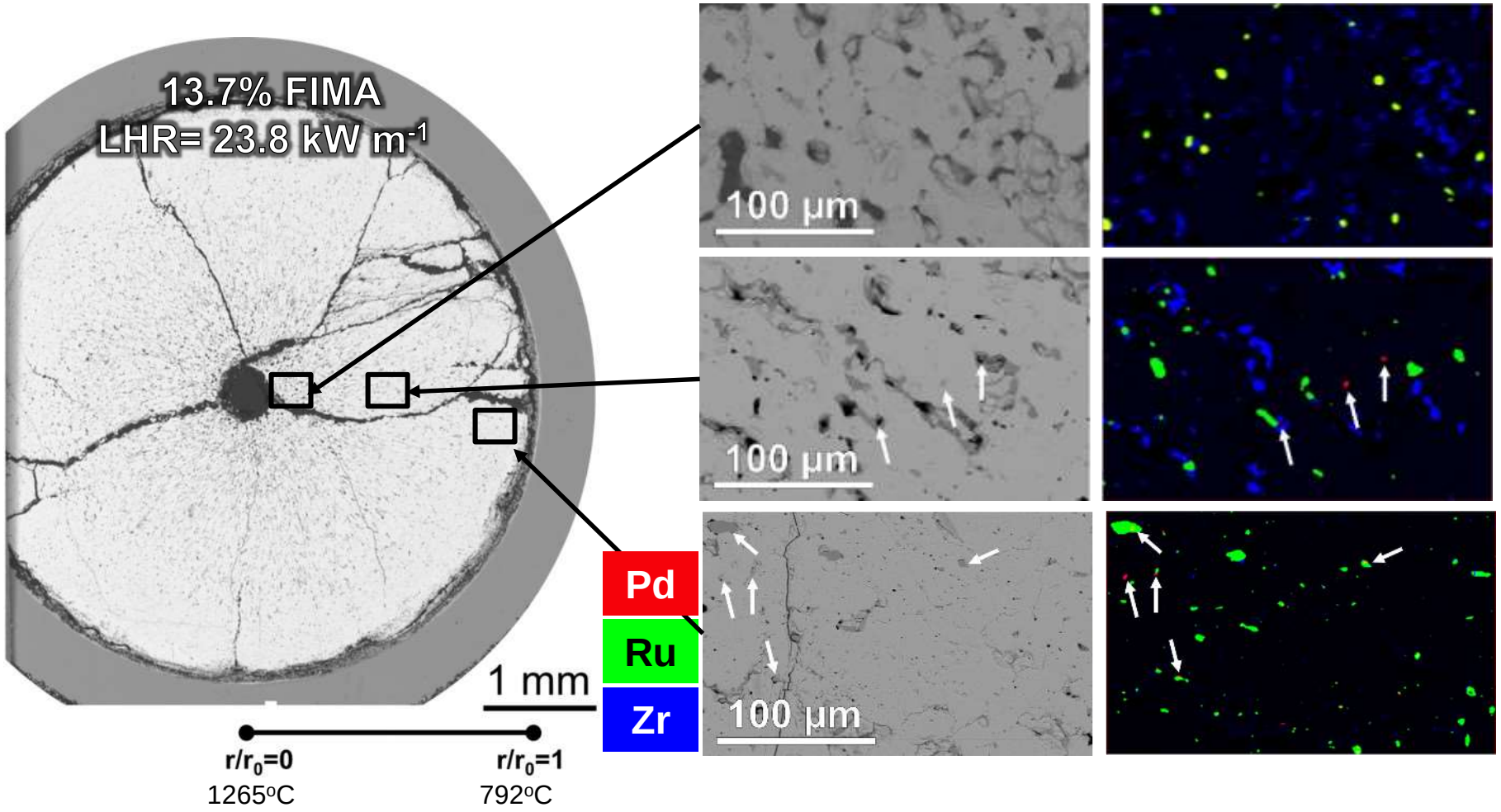


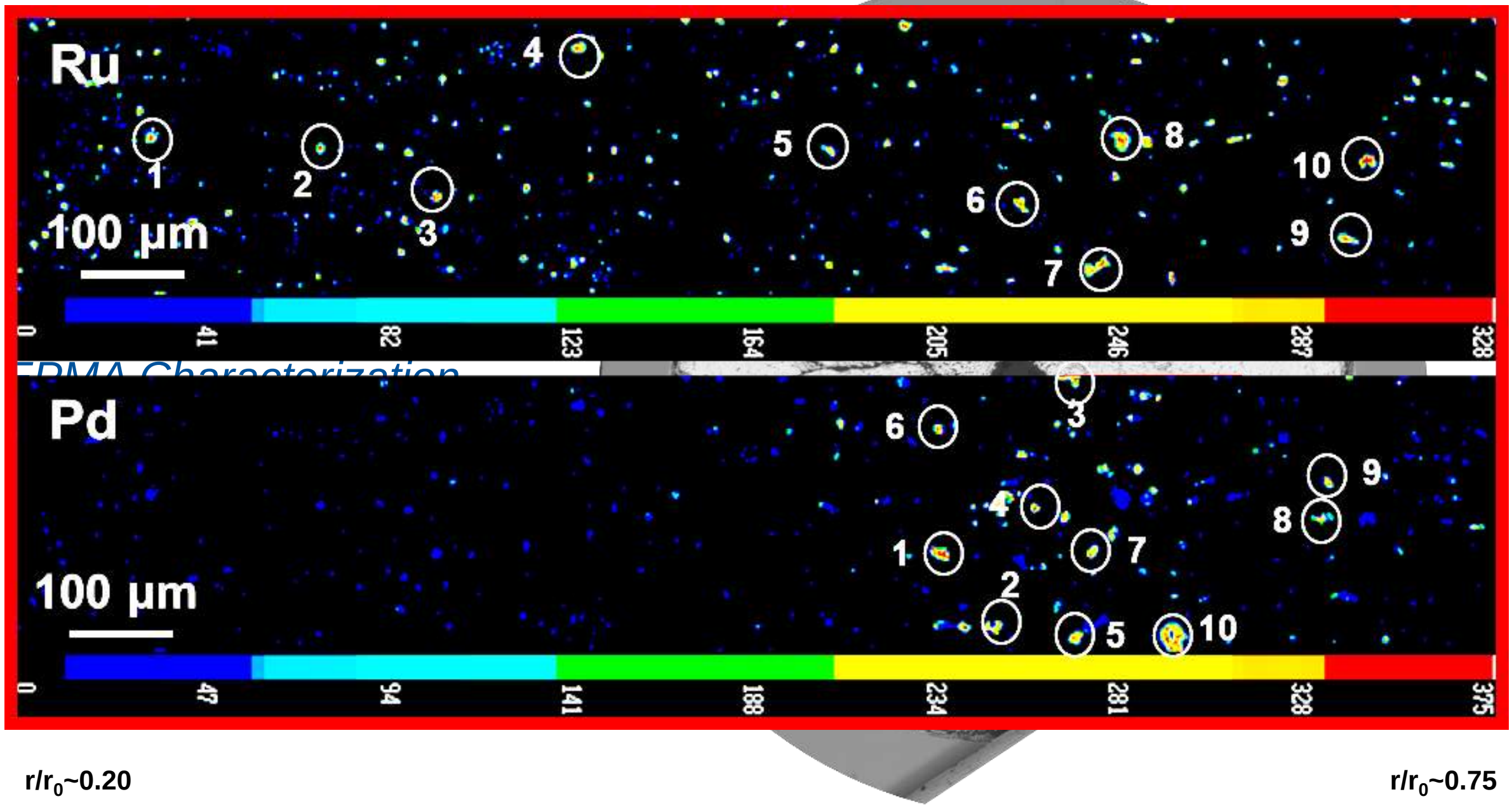




Approach:

RTE #17-1043:
Microstructural characterization of 13% burn-up MOX fuel

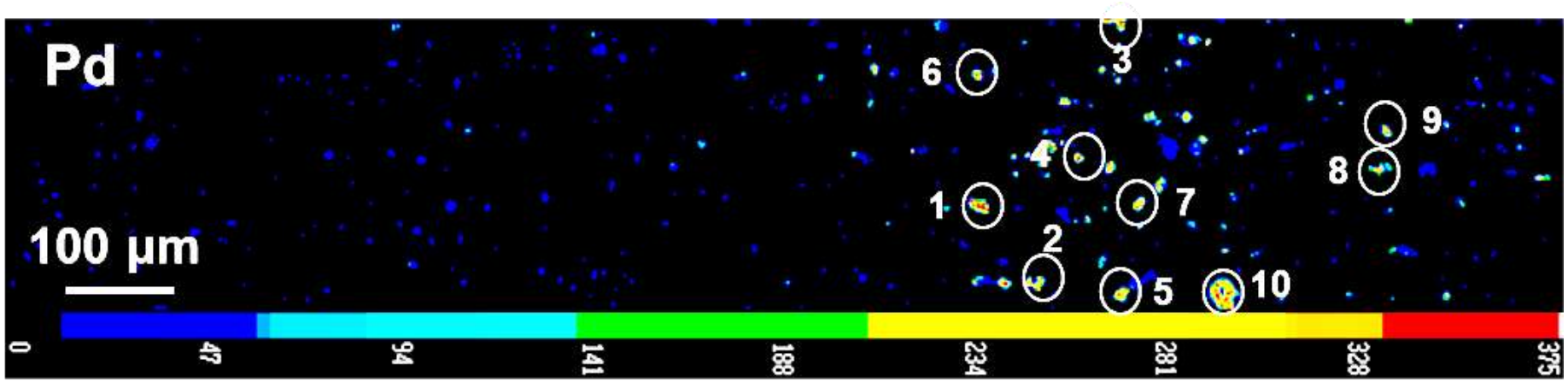




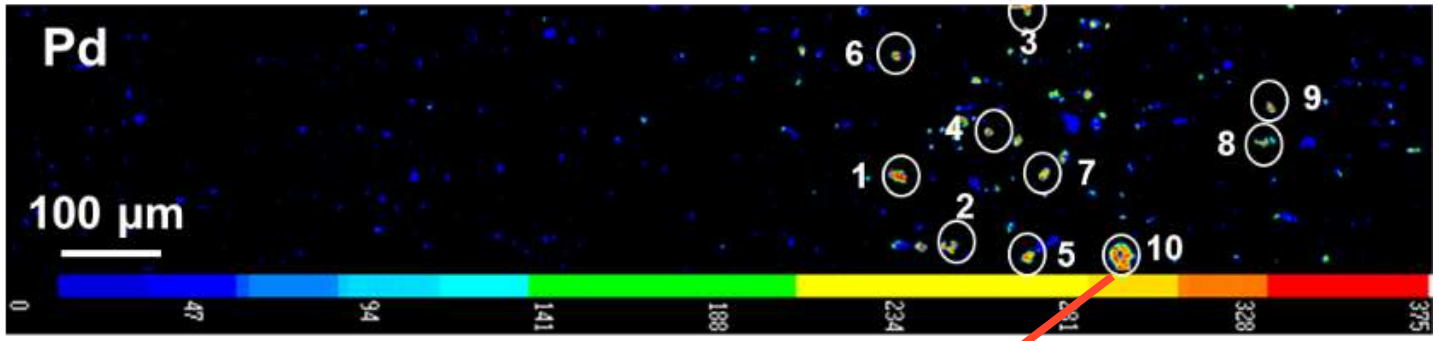
EPMA Characterization

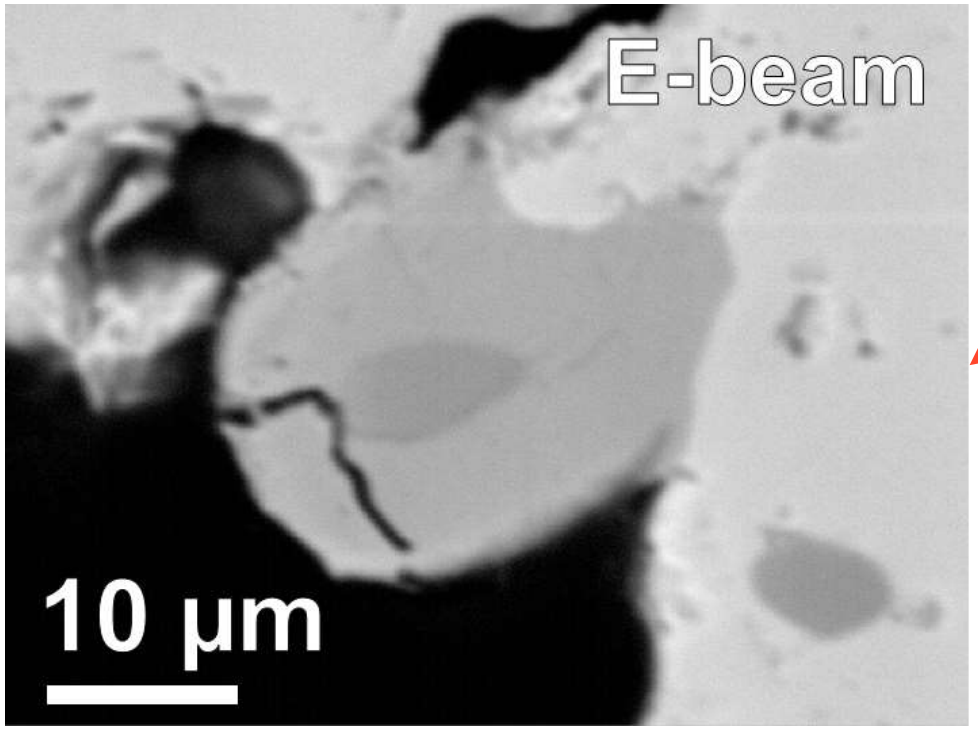
r/r_0~0.20

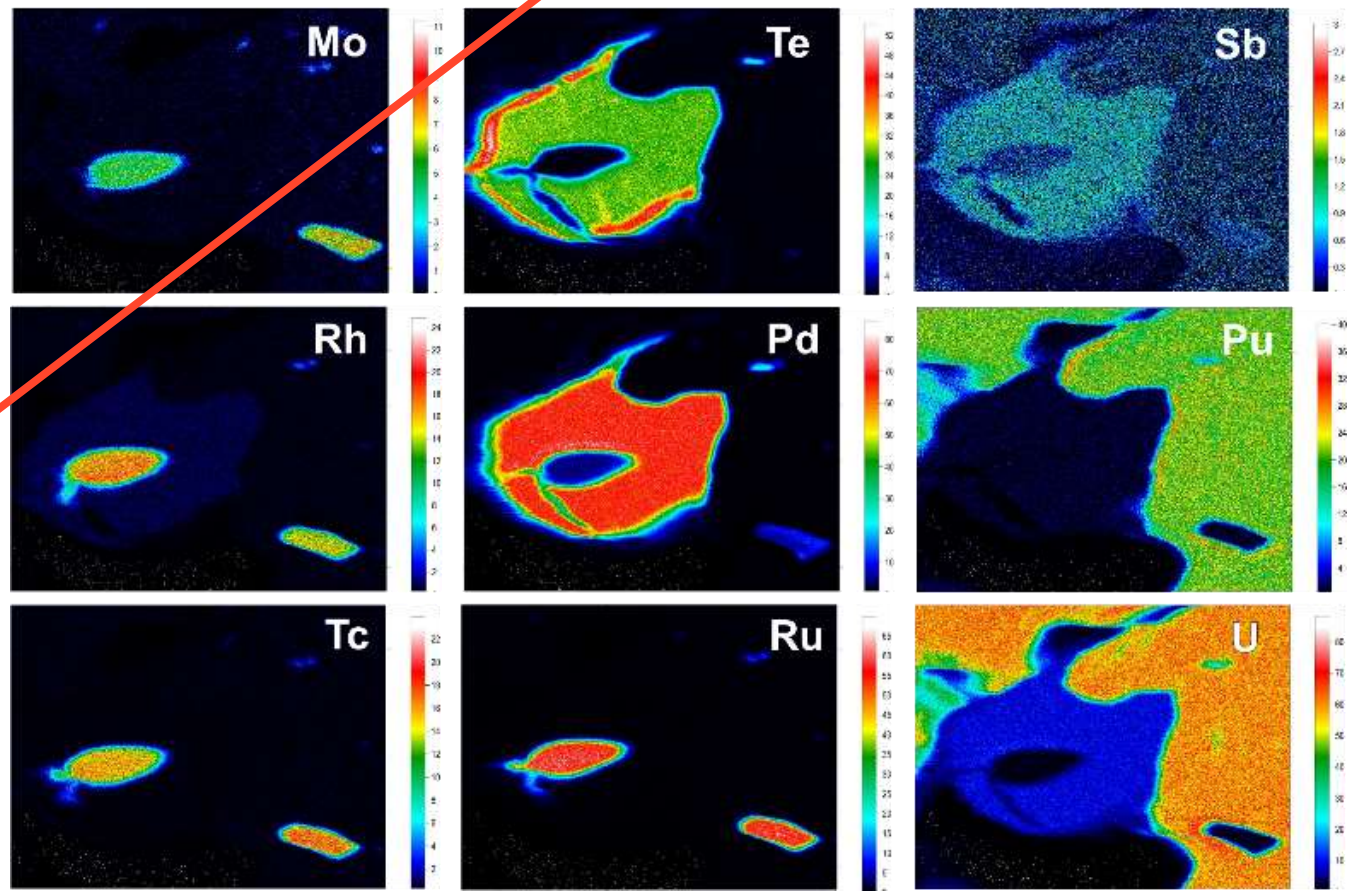
r/r_0~0.75



Precipitate	**Pd** (wt%)	**Te** (wt%)	**Rh** (wt%)	**Sn** (wt%)	**Sb** (wt%)	**U** (wt%)	**Pu** (wt%)
Average ± Std. Dev.	**65.3±5.8**	**15.3±12.1**	0.81±0.38	2.87±1.90	0.59±0.54	11.0±4.5	3.25±6.68
1	68.3	22.2	0.89	4.95	1.33	8.28	<0.09
2	59.7	21.4	1.10	3.30	0.44	8.29	<0.09
3	75.0	6.05	1.24	4.63	0.75	8.60	0.11
4	54.2	<0.05	0.22	3.11	<0.031	22.5	18.9
5	66.8	25.7	1.00	2.33	0.87	8.68	<0.09
6	66.0	19.7	1.12	6.11	1.55	11.7	<0.09
7	64.8	28.4	0.54	0.36	0.45	10.2	<0.09
8	61.9	<0.05	0.26	0.99	<0.031	14.2	12.19
9	70.3	1.39	1.17	1.86	<0.031	9.18	1.27
10	66.3	28.5	0.55	1.06	0.50	8.00	<0.09
Detection Limit (wt%)	0.053	0.05	0.024	0.04	0.031	0.117	0.09
Error (+/- 3σ)	0.60%	1.00%	3.90%	2.70%	9.60%	3.30%	14%

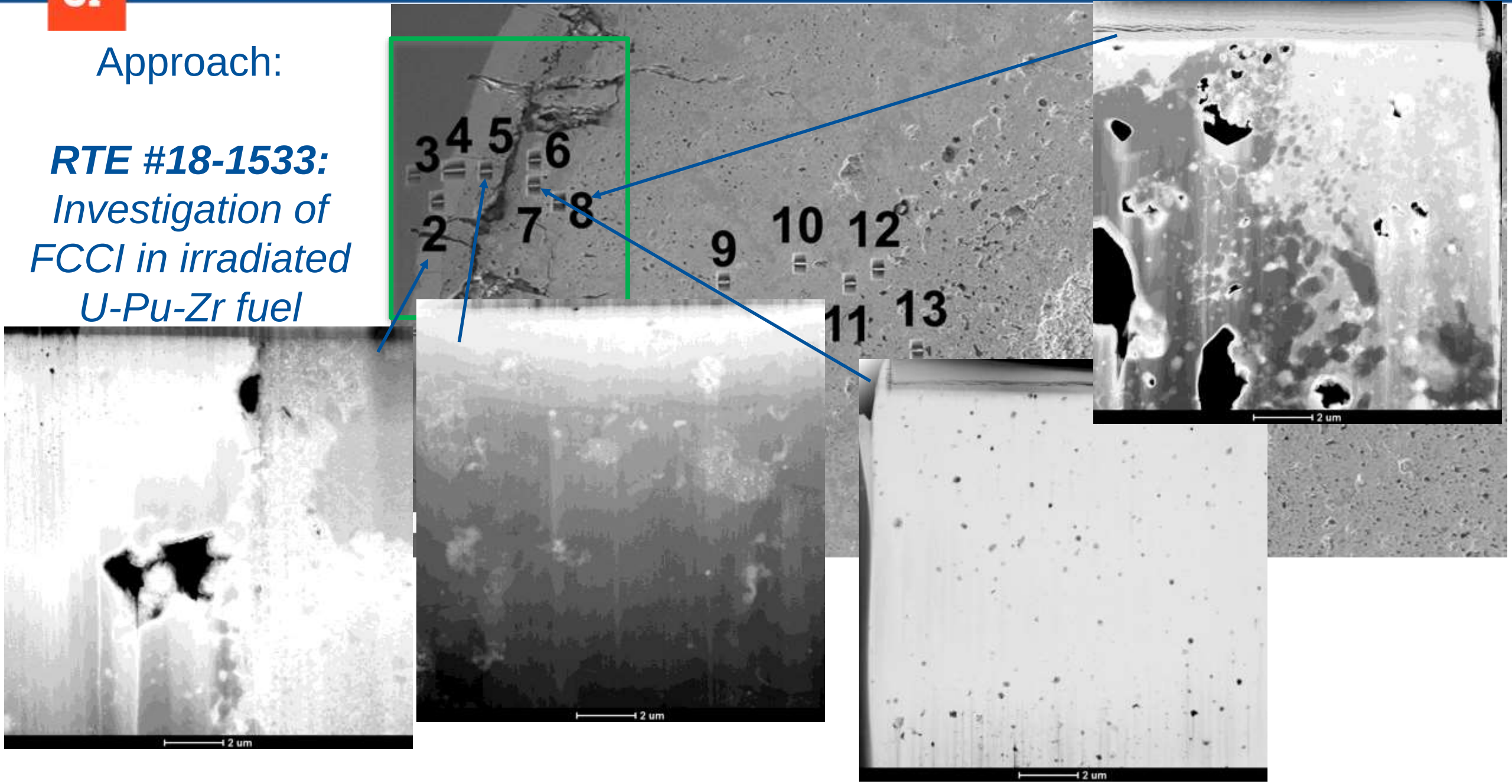

Pd
100 µm
1
2
3
4
5
6
7
8
9
10
0
47
94
141
188
234
281
328
375


E-beam
10 µm


Mo
Te
Sb
Rh
Pd
Pu
Tc
Ru
U

Approach:

RTE #18-1533:
Investigation of FCCI in irradiated U-Pu-Zr fuel

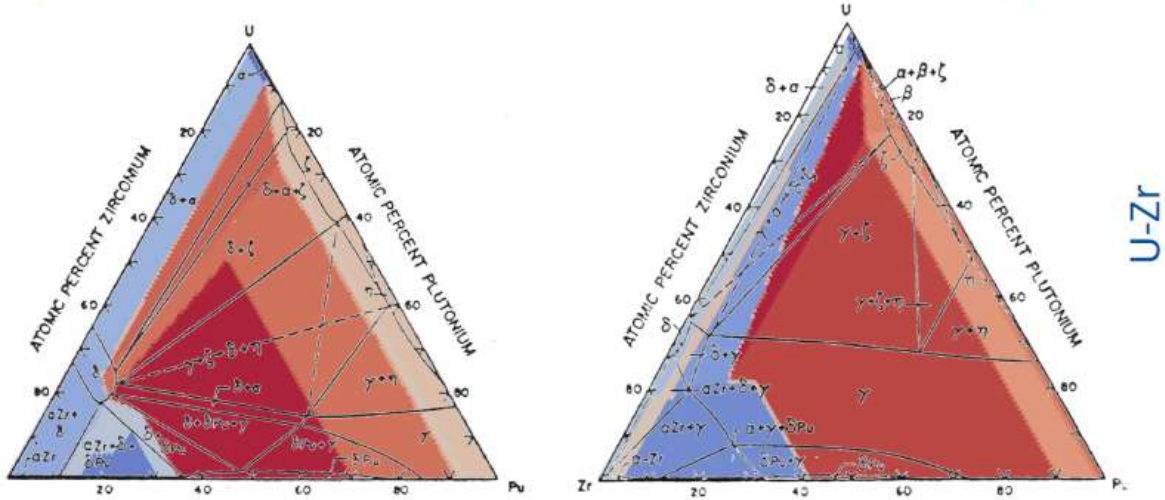


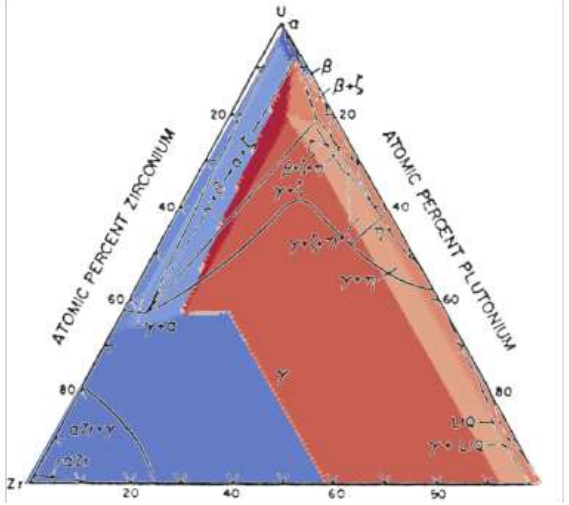
Microscopy – scheduled activities

- Microstructural information (electron micrographs in SEM)
- Chemical compositions (EDS/WDS in SEM, EPMA)
- Prepare TEM specimens using FIB
- Conduct phase identification in TEM
- Compare as-fabricated to irradiated fuels

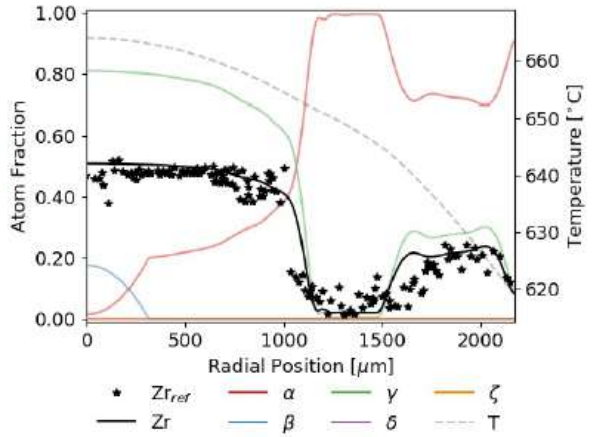
Phase field modeling – Mike will update

The U-Pu-Zr free energies are very uncertain; they don't predict the same behavior as the phase diagrams

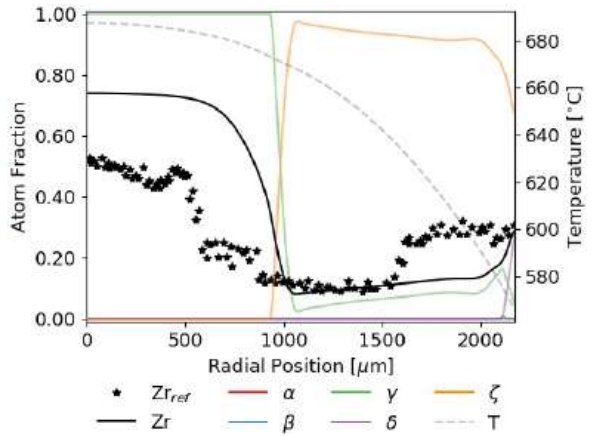




U-Zr



U-Pu-Zr



Summary

Engineering scale PIE

- Neutron radiography suggests fuel constituent redistribution
- Axial growth of the fuel column directly correlates to the decrease in Zr content
- No apparent relation between Zr content and cladding strain
- Gamma spectroscopy suggests good pin integrity
- Fission gas release was within expected ranges between 75-79%

Electron microscopy activities will be performed on irradiated fuels

- EPMA
- SEM/FIB
- TEM

Recent publications from NSUF RTEs

1. R. Parrish, F. Cappia, A. Aitkaliyeva, "Comparison of radial effects of burnup on fast reactor MOX fuel microstructure and solid fission products", J. Nucl. Mater. 531 (2020). https://doi.org/10.1016/j.jnucmat.2020.152003
2. R. Parrish, A. Winston, J. Harp, A. Aitkaliyeva, "TEM Characterization of High Burnup Fast Reactor MOX Fuel", J. Nucl. Mater. 527 (2019) https://doi.org/10.1016/j.jnucmat.2019.151794
3. R. Parrish, K. Wright, A. Winston, J. Harp, C. McKinney, A. Aitkaliyeva, "Characterization of solid fission products in 13.7% FIMA MOX fuel using electron microscopy techniques", J. Nucl. Mater. 524, 67-79 https://doi.org/10.1016/j.jnucmat.2019.06.042
4. R. Parrish, X. Liu, A. Winston, J. Harp, A. Aitkaliyeva, "Radial Microstructural Evolution in Low Burnup Fast Reactor MOX Fuel", J. Nucl. Mater. 523, 182-188 (2019) https://doi.org/10.1016/j.jnucmat.2019.06.009

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