

July 25, 2023

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Idaho National Laboratory

2023 AGR-5/6/7 Compact Cross-Section Microscopy

This presentation contains information that is preliminary in nature, and the results and conclusions may change as experiments and analyses continue.

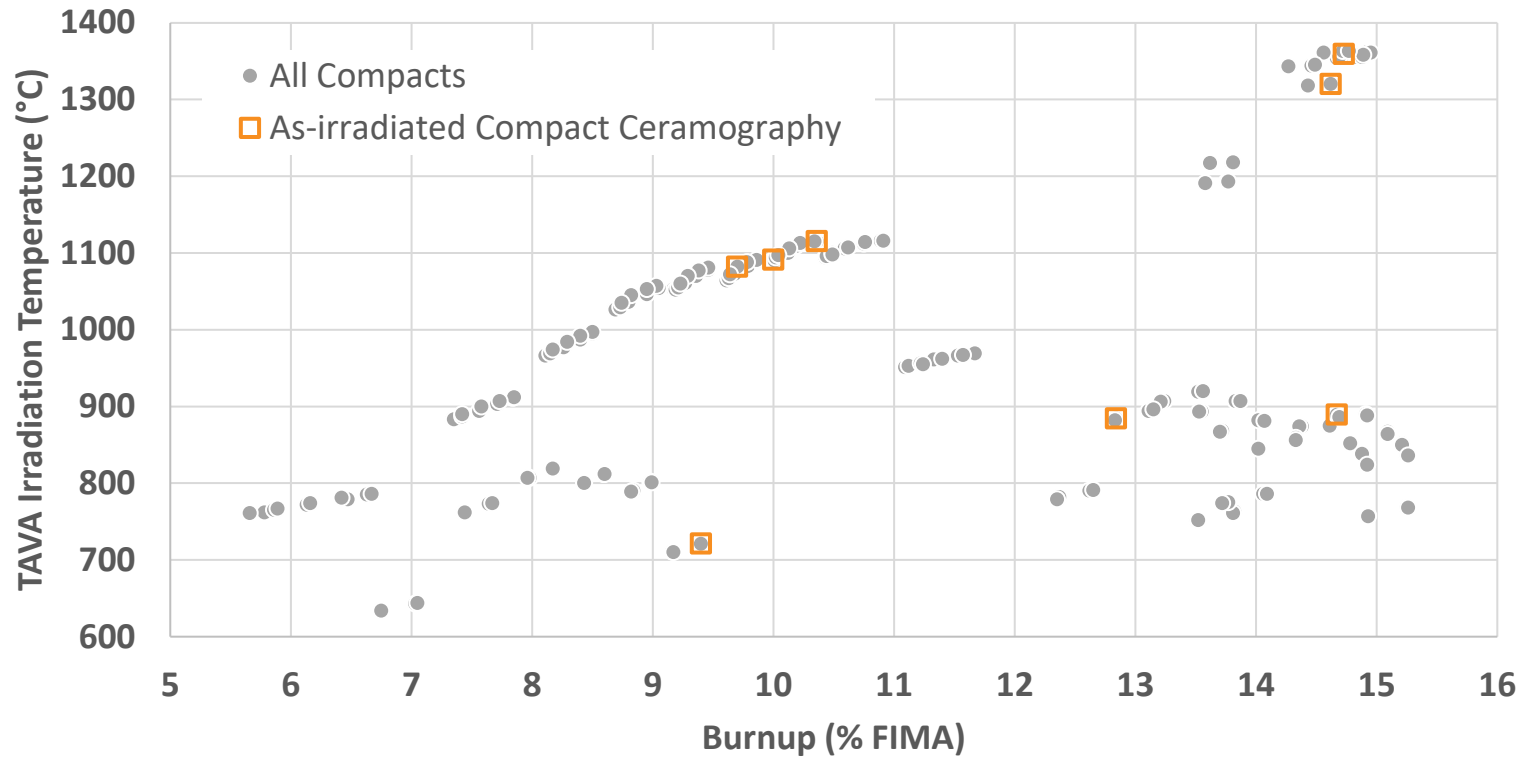
DOE ART Gas-Cooled Reactor (GCR) Review Meeting

Virtual Meeting

July 25 – 27, 2023

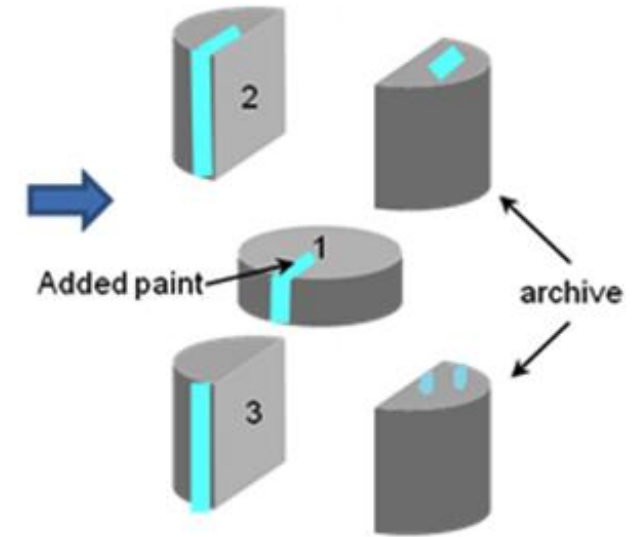
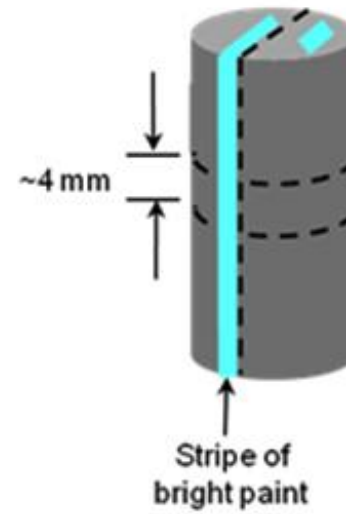
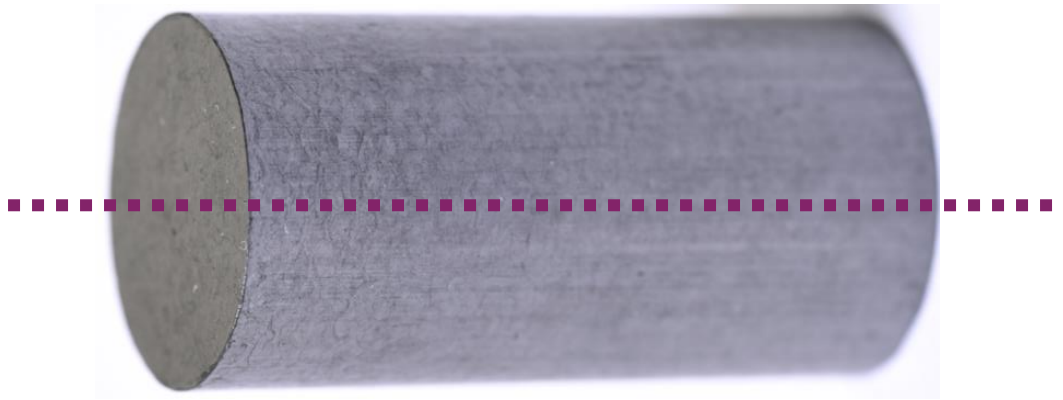


Compact Ceramography Completed

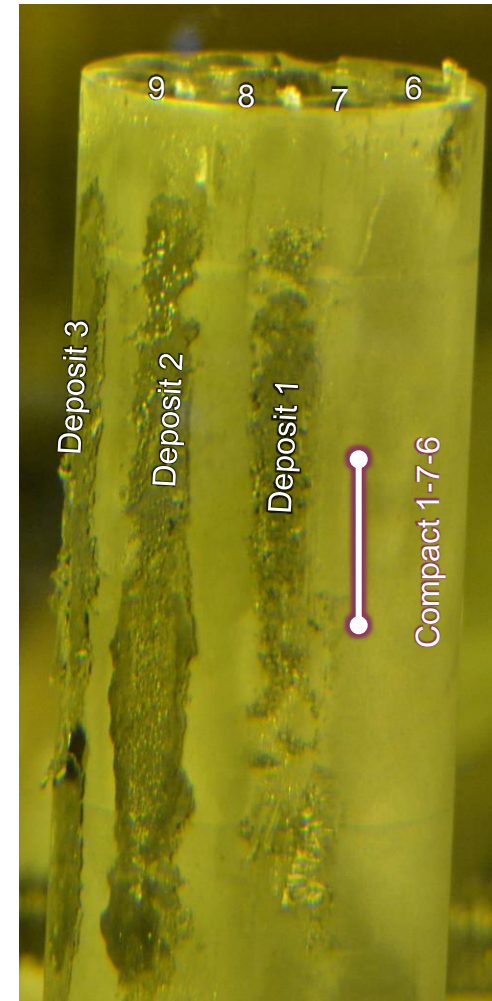
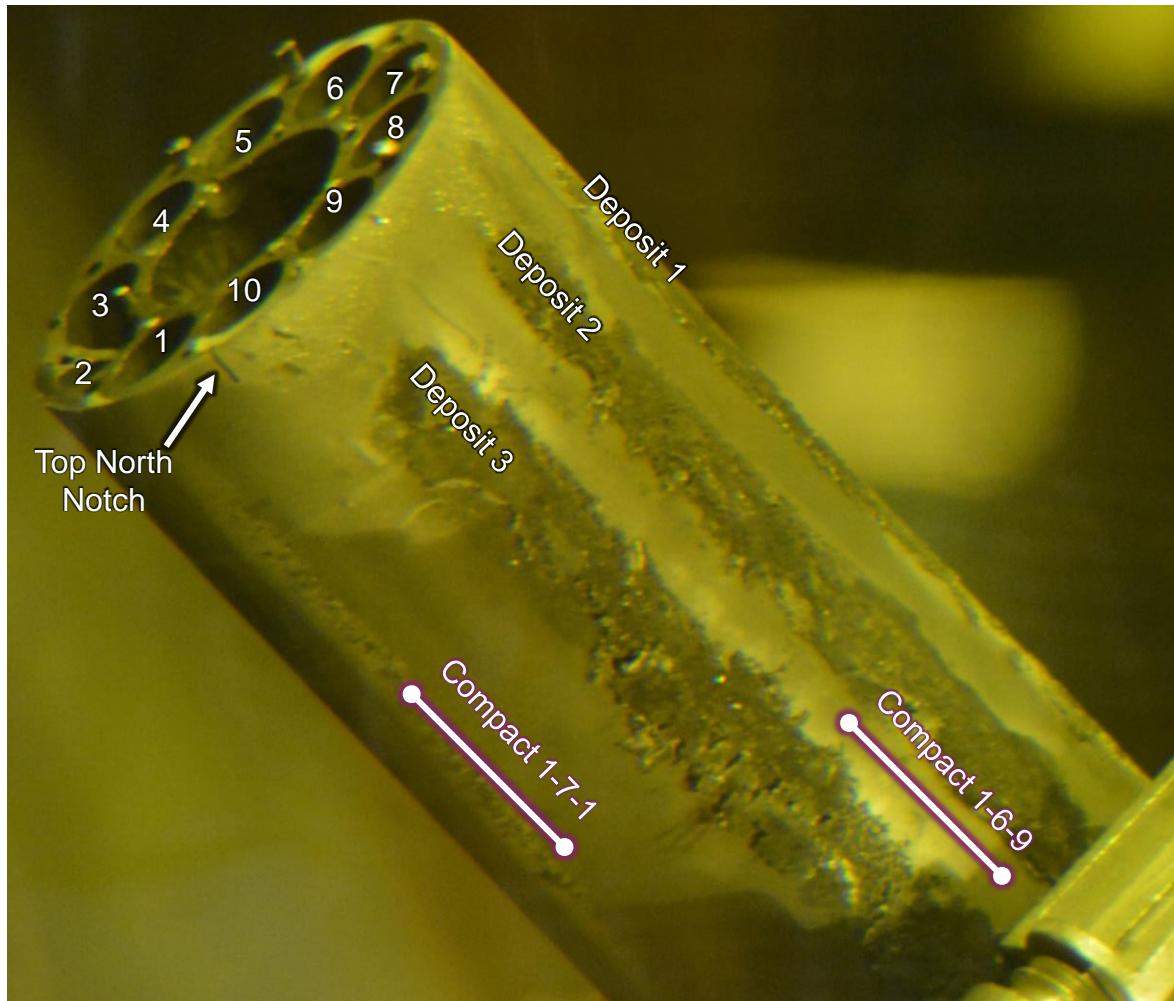


	Compact	Burnup	Fluence	TA Min	TAVA	TA Max	Lab	Year
As-irradiated Compact Ceramography	1-6-9	9.7	3.62	889	1082	1196	INL	2022
	2-3-3	14.67	5.07	794	889	947	INL	2022
	3-4-1	14.73	5.41	1268	1359	1419	INL	2022
	5-1-4	9.4	3.4	506	721	834	INL	2022
	1-7-1	10	3.76	893	1091	1205	INL	2022/FY23
	1-7-6	10.36	3.99	911	1115	1229	INL	2022/FY23
	3-2-3	14.62	5.54	1203	1320	1401	INL	2022/FY23
	4-5-1	12.84	4.24	787	884	947	INL	2022/FY23

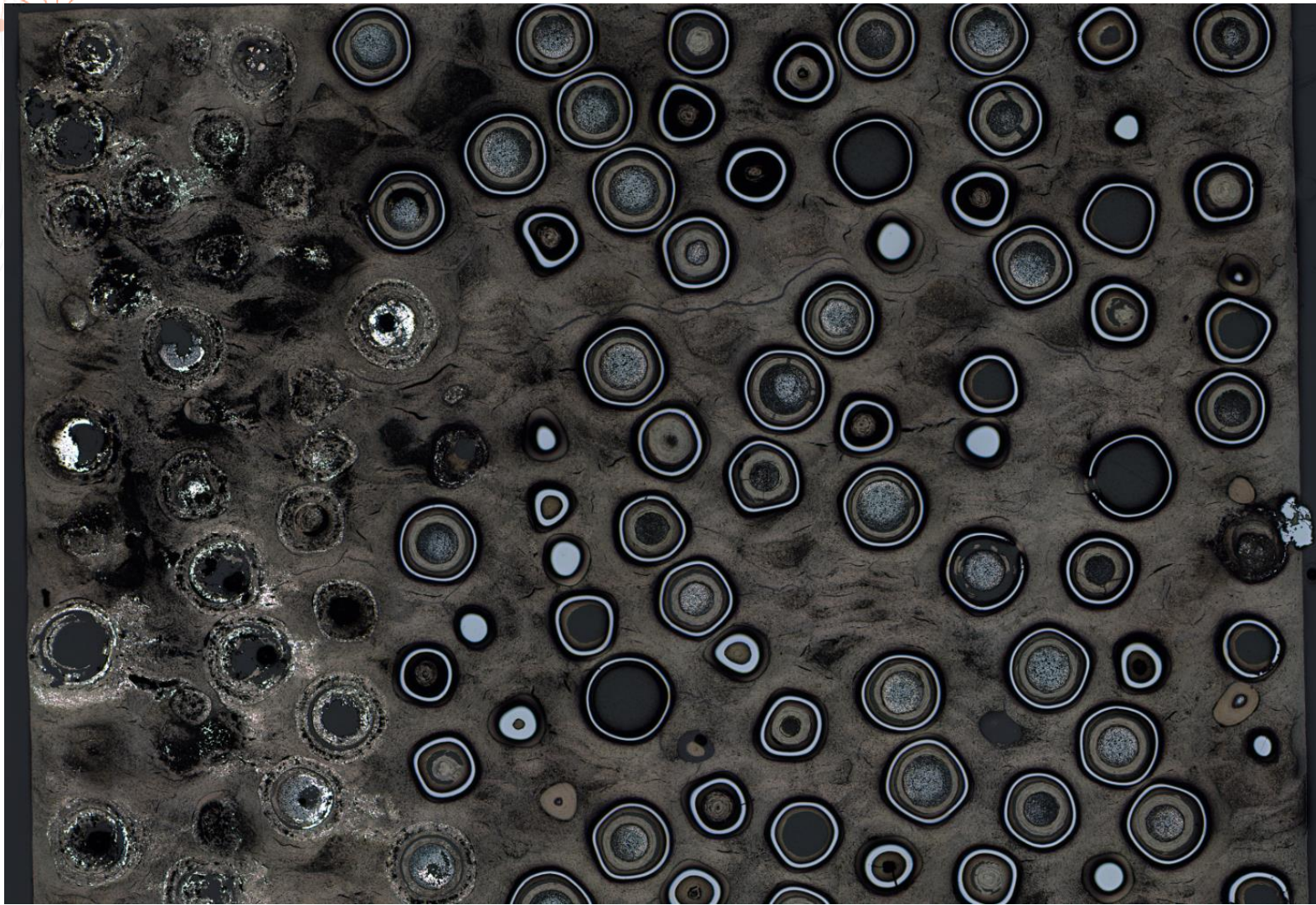
Two Styles of Sectioning Were Used



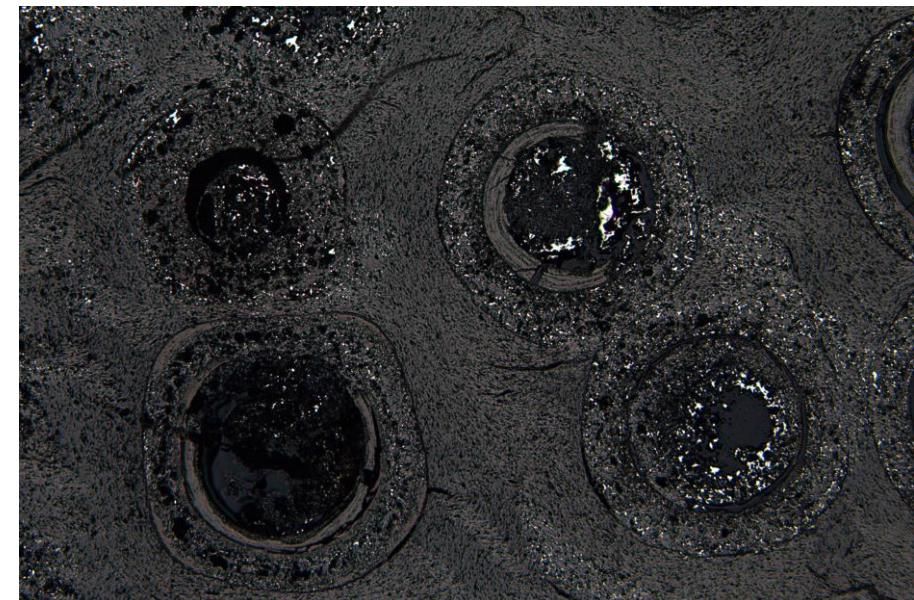
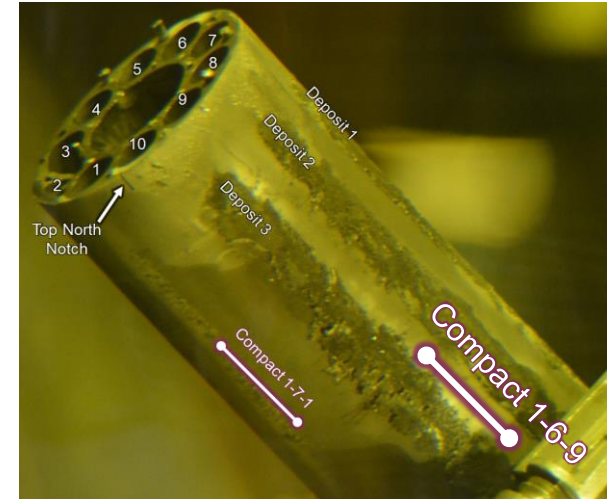
Capsule 1 Compacts Chosen for Proximity to Ni Deposits on Graphite Holder Traced to Overheated Thermocouples



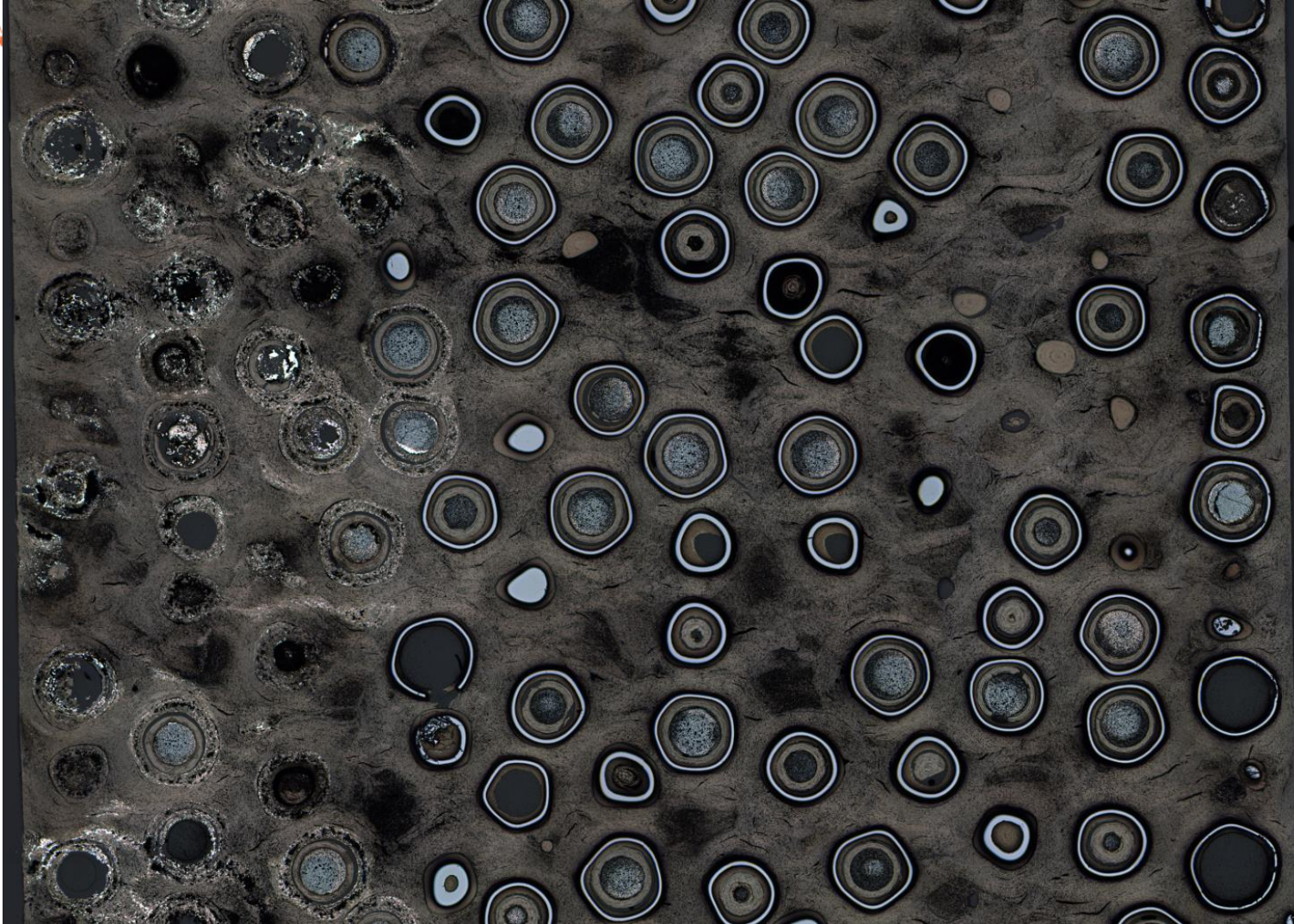
Bulk Foreign Material, Likely Ni, Found in Compact 1-6-9



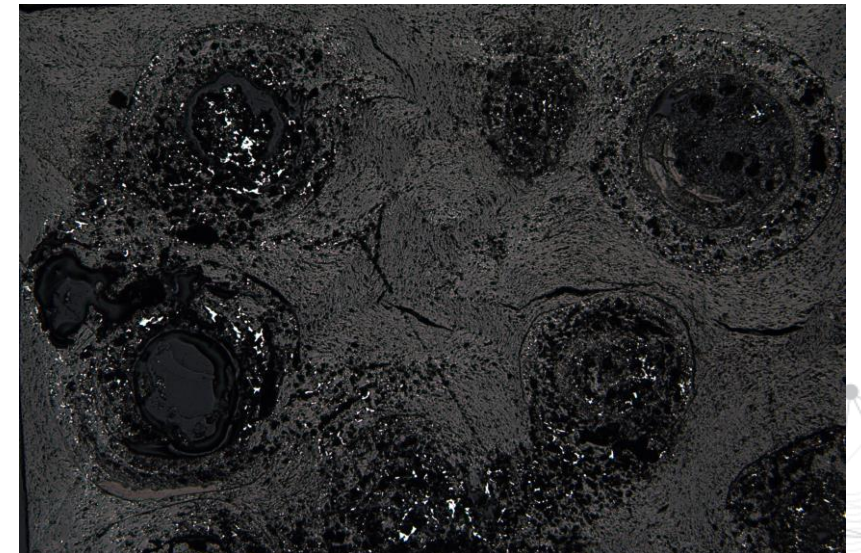
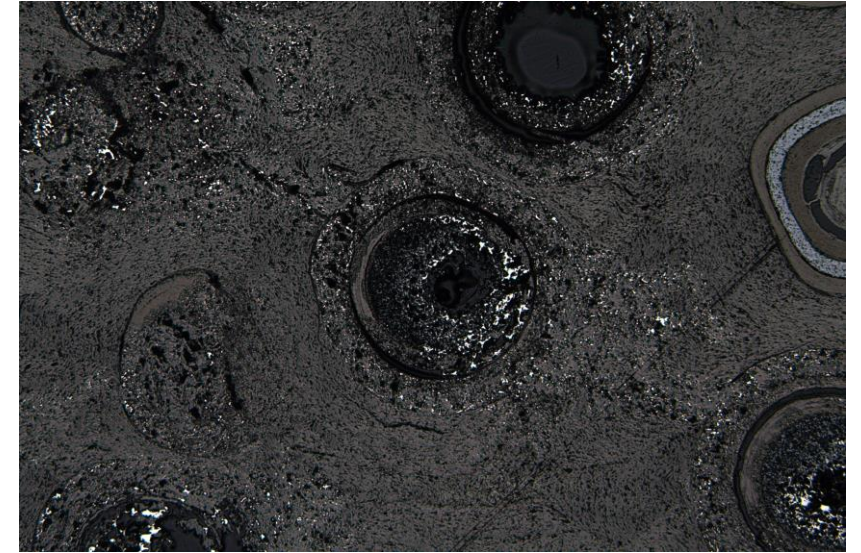
Compact Top



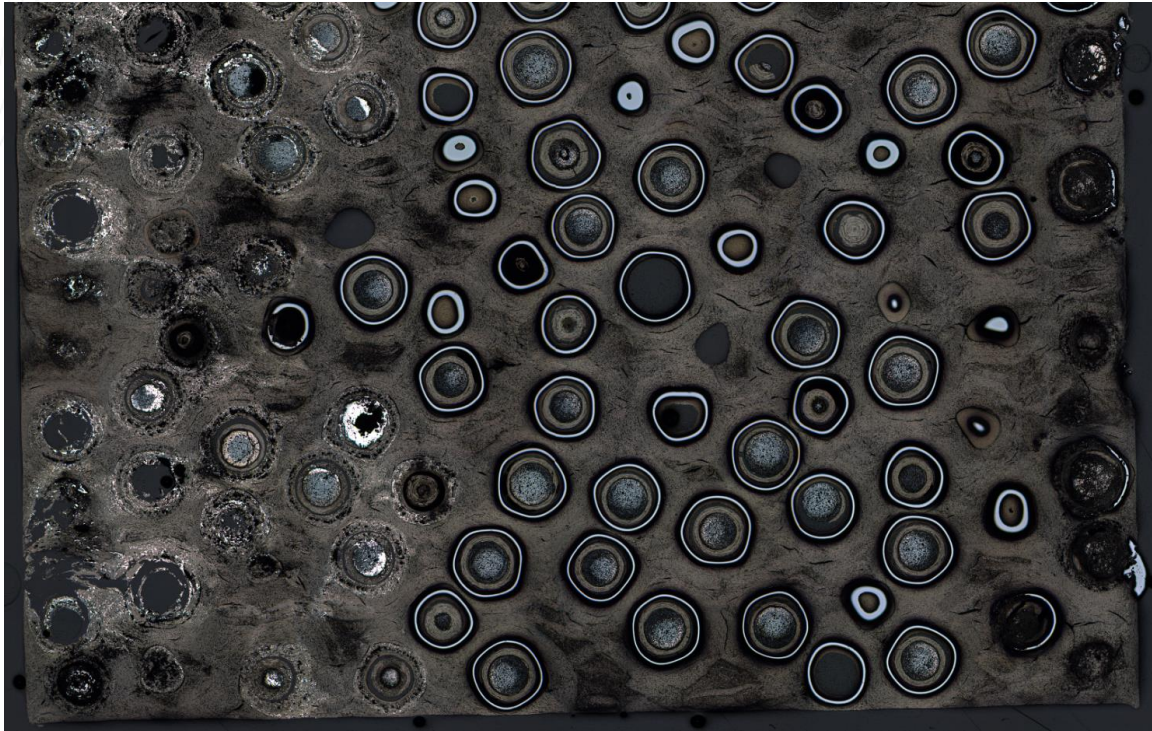
Bulk Foreign Material, Likely Ni, Found in Compact 1-6-9



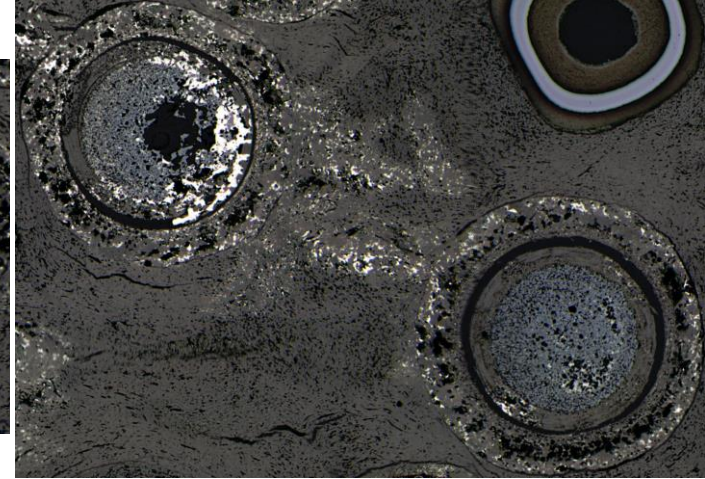
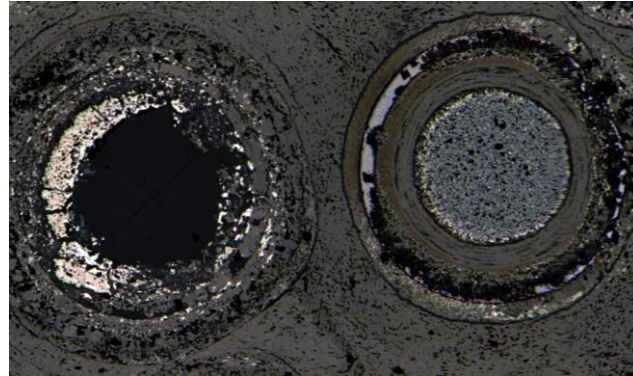
Compact Middle



Bulk Foreign Material, Likely Ni, Found in Compact 1-6-9

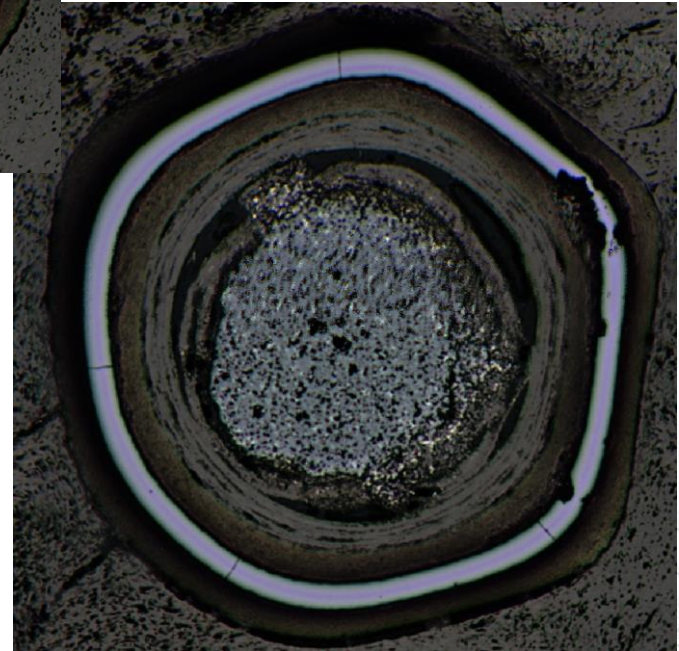
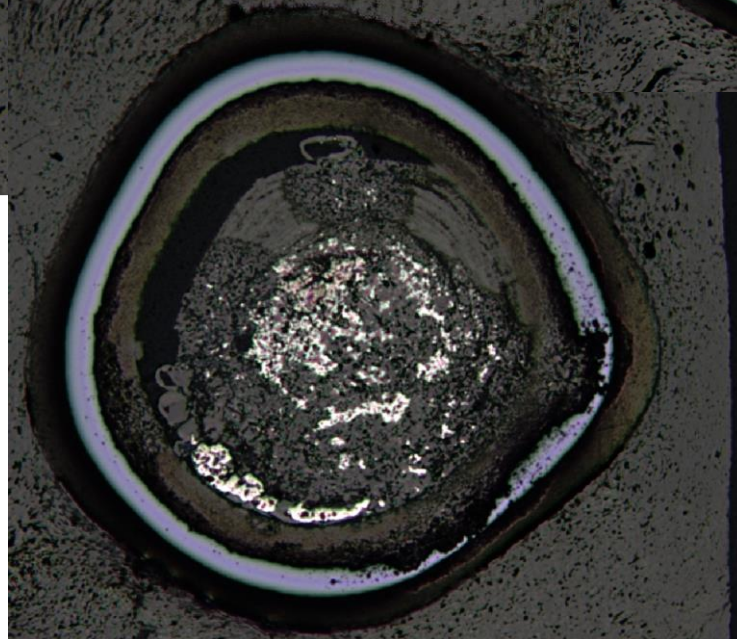
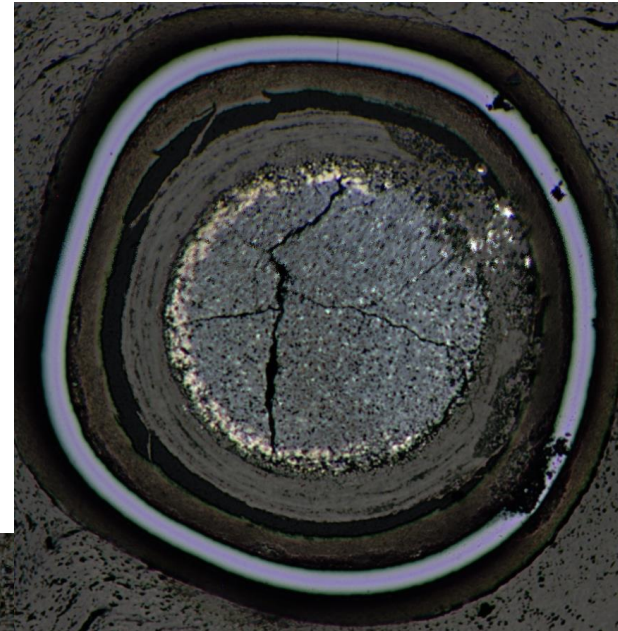
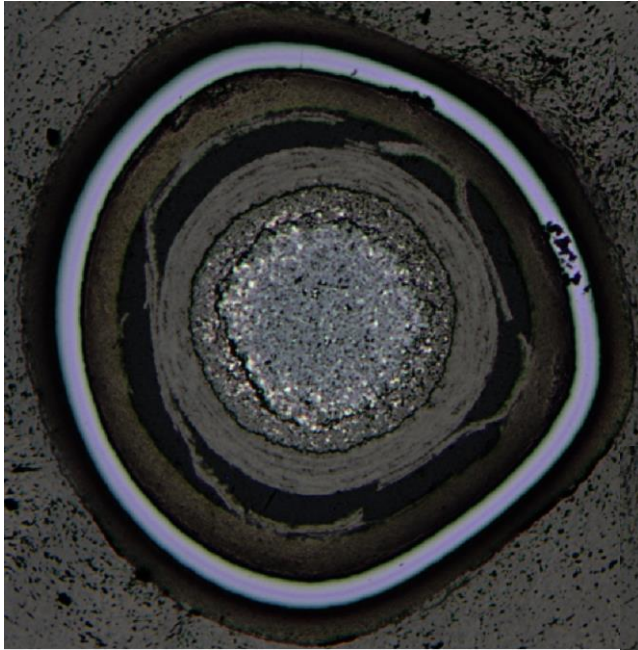


Compact Bottom



Seemingly good fuel may exist among the damaged fuel

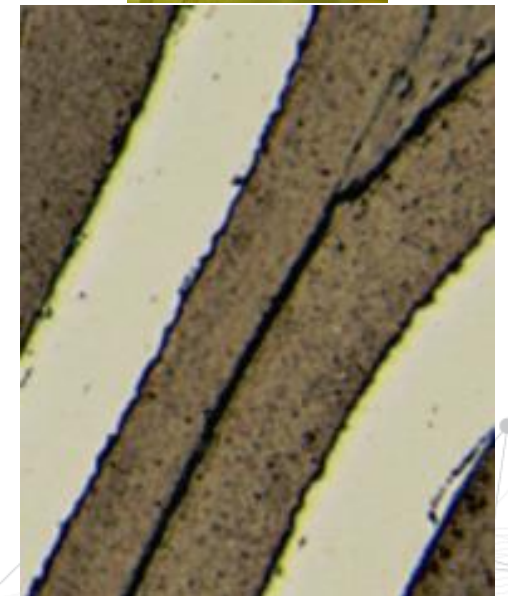
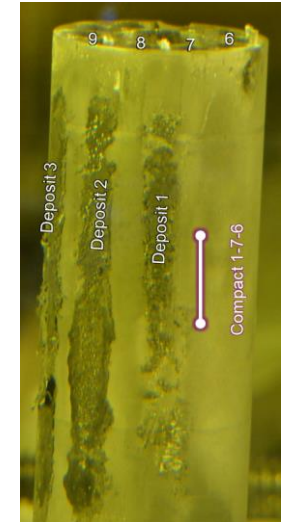
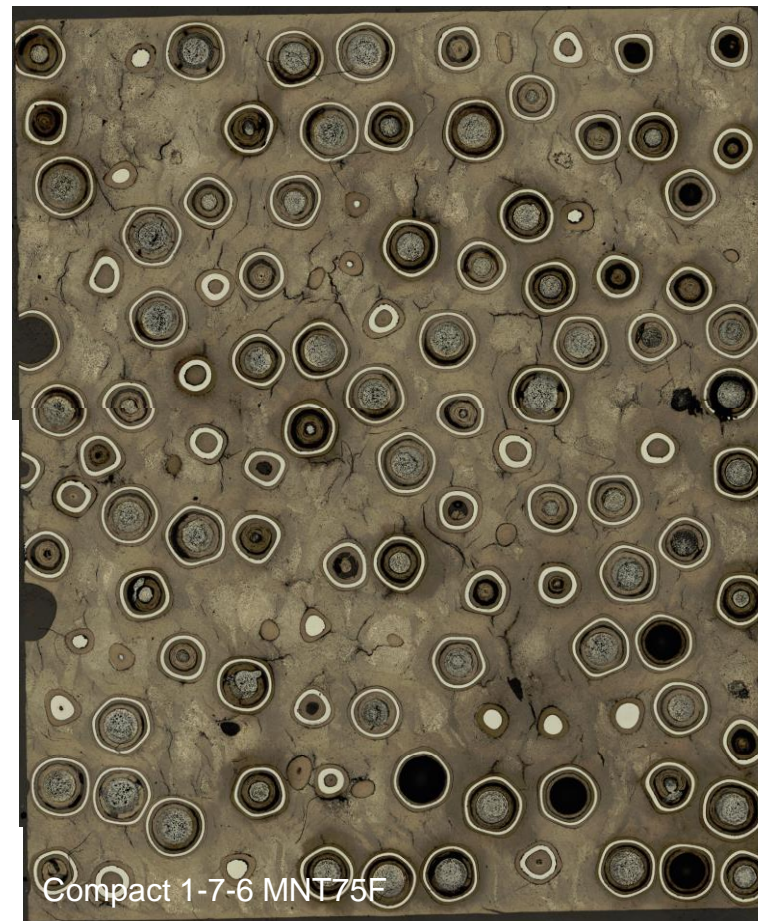
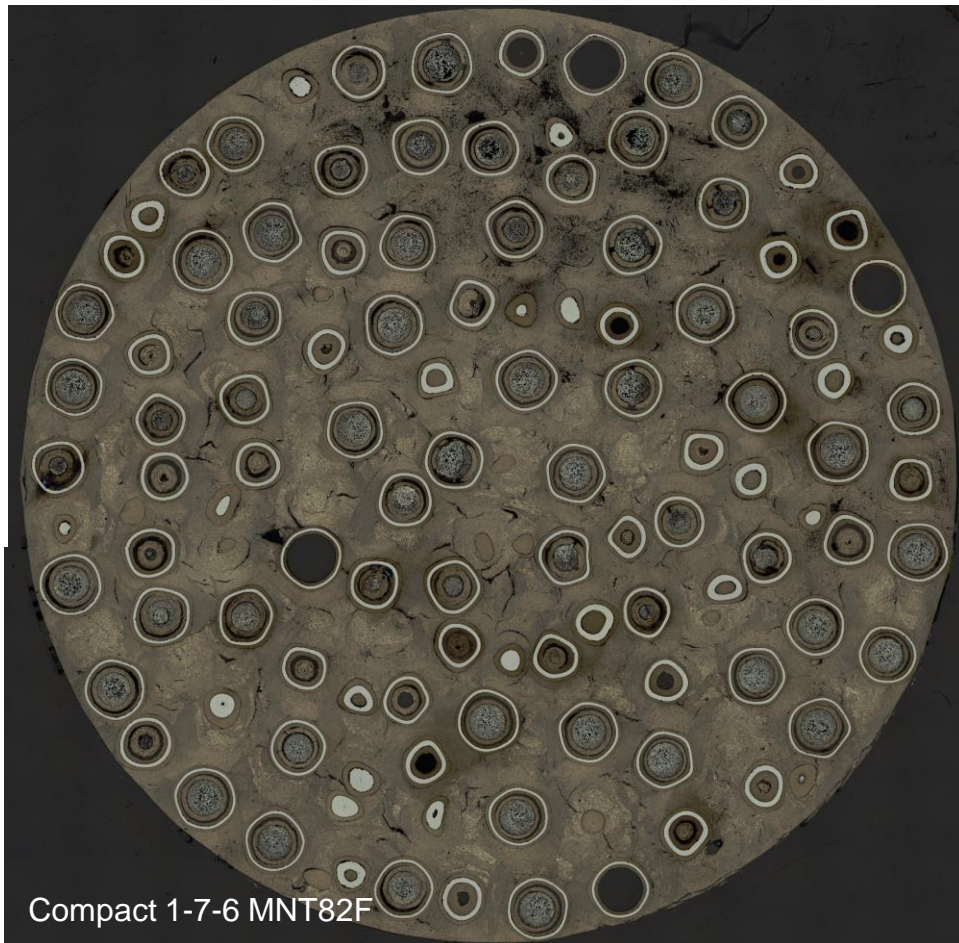
Compact 1-6-9: Directional Ni Attack Can Give Appearance of Inside-Out Attack



Compact 1-7-6 Shows no Visible Ni

- Very little buffer fracture
- Few small IPyC tears
- Particle-to-particle contact common with no obvious damage

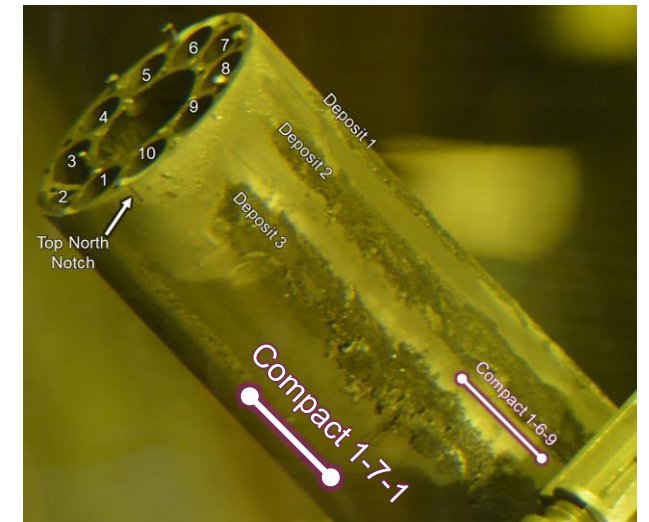
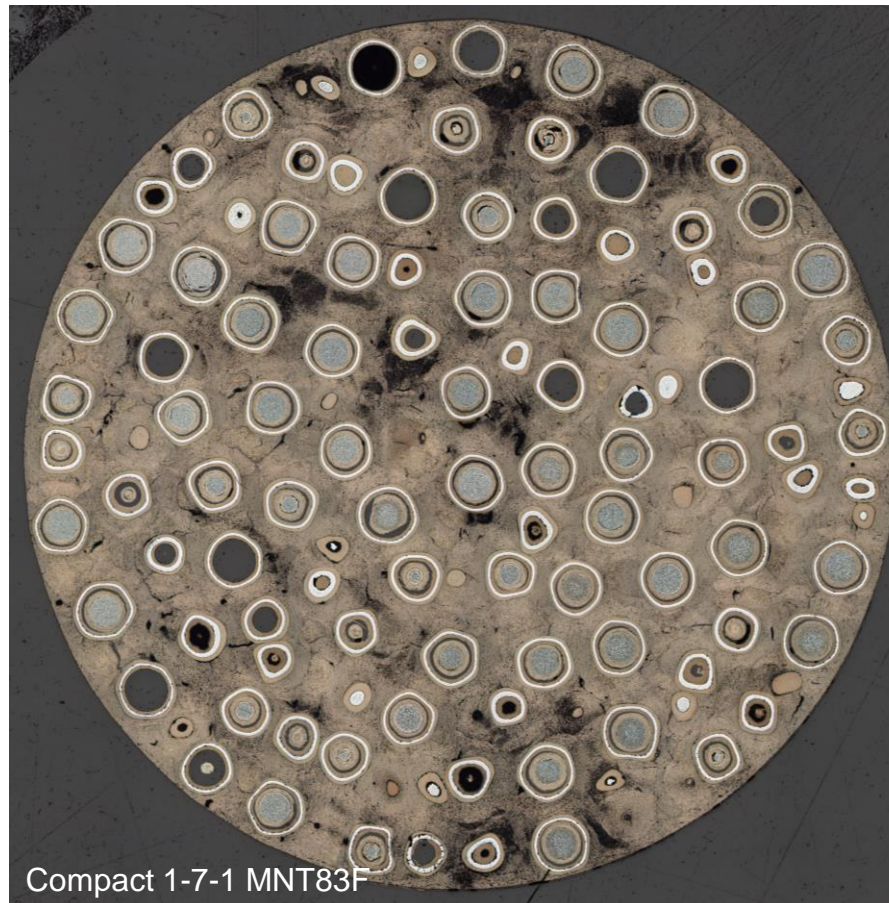
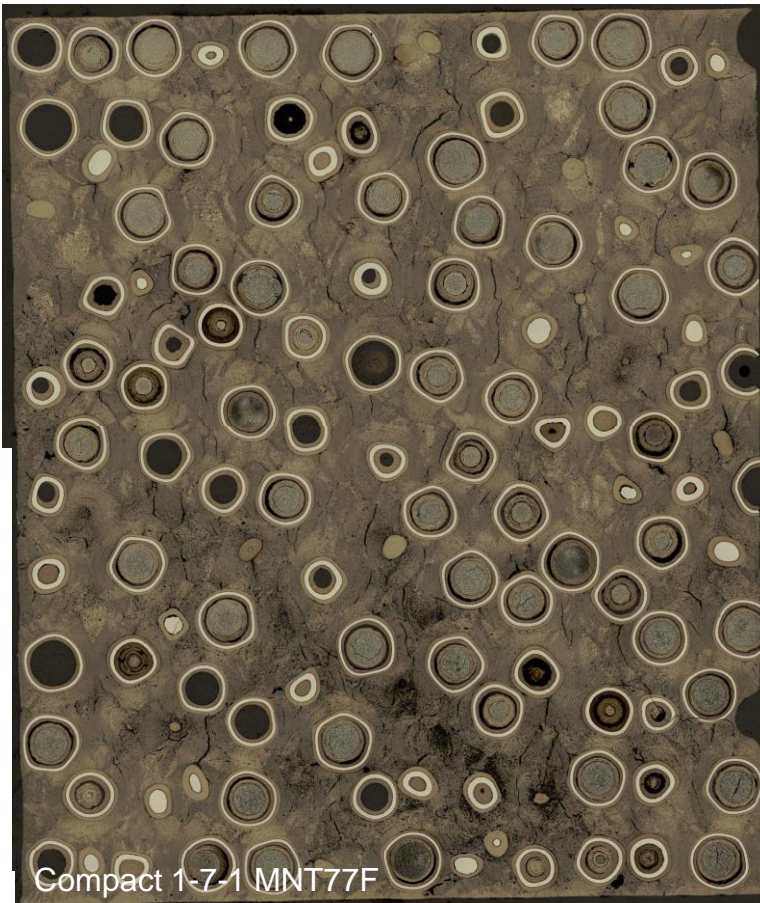
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
1-7-6	10.36	3.99	911	1115	1229



Compact 1-7-1 shows no signs of Ni

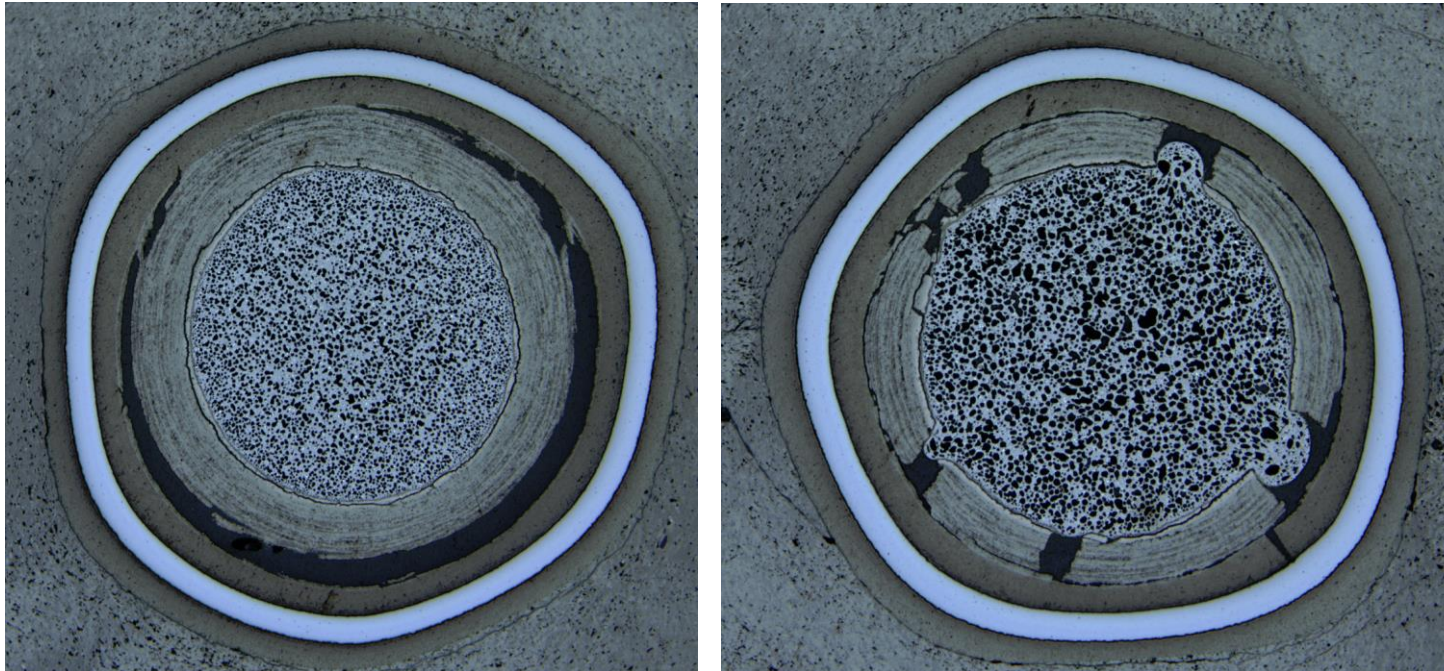
- Little buffer fracture
- No apparent IPyC tears
- Kernel morphology suggests fuel considerably cooler than 1-7-6 and 1-6-9

Compact	Burnup	Fluence	TA Min	TAVA	TA Max
1-7-1	10	3.76	893	1091	1205

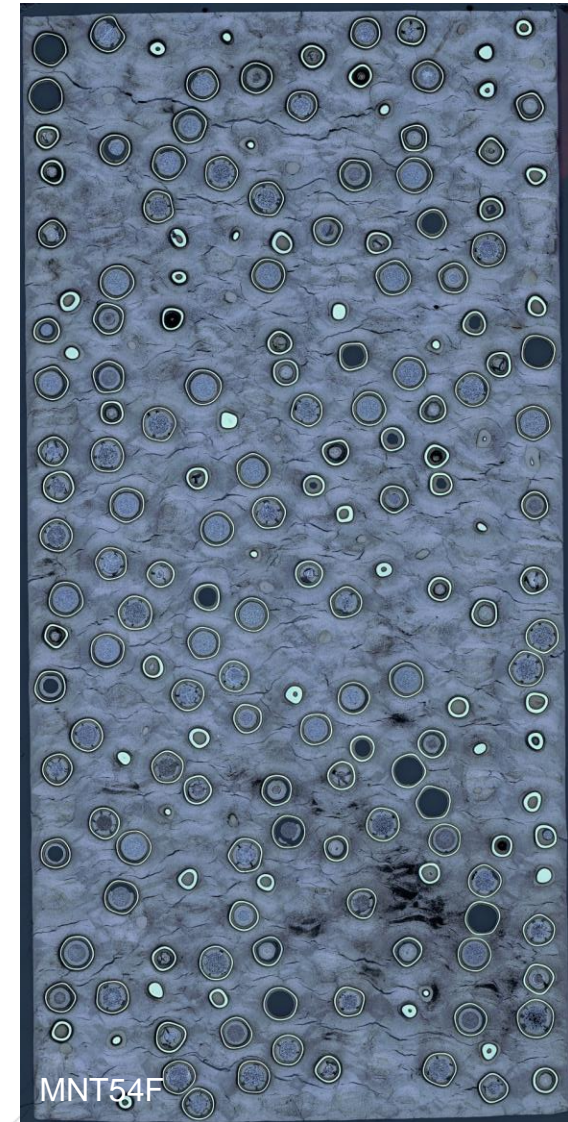


Compact 2-3-3

- Observed one IPyC fracture
- Occasional incipient tearing of PyC
- No apparent SiC degradation
- Buffer fracture common with multiple small fractures around circumference



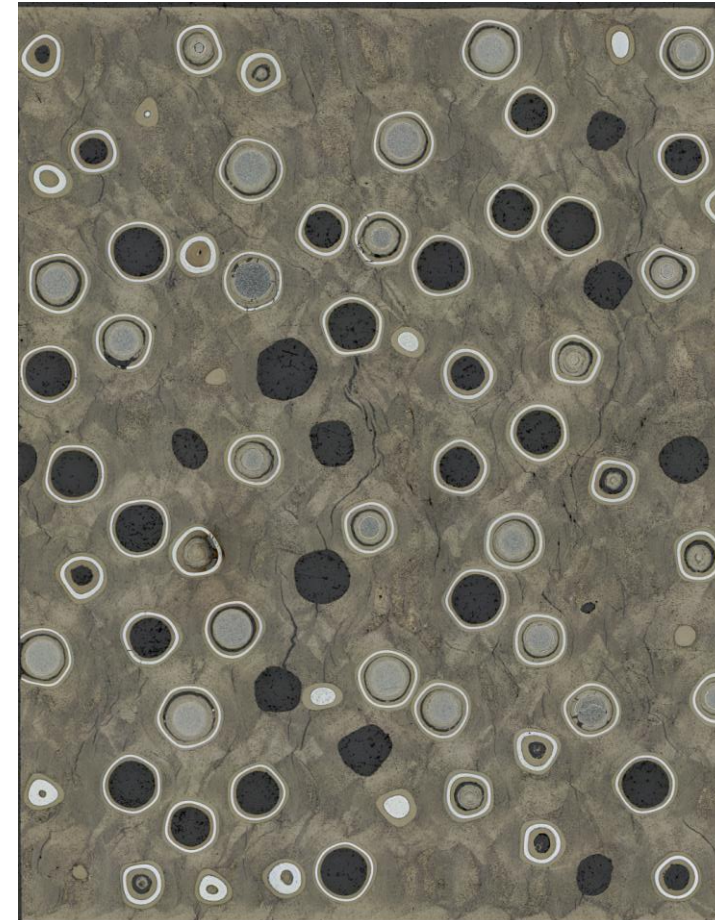
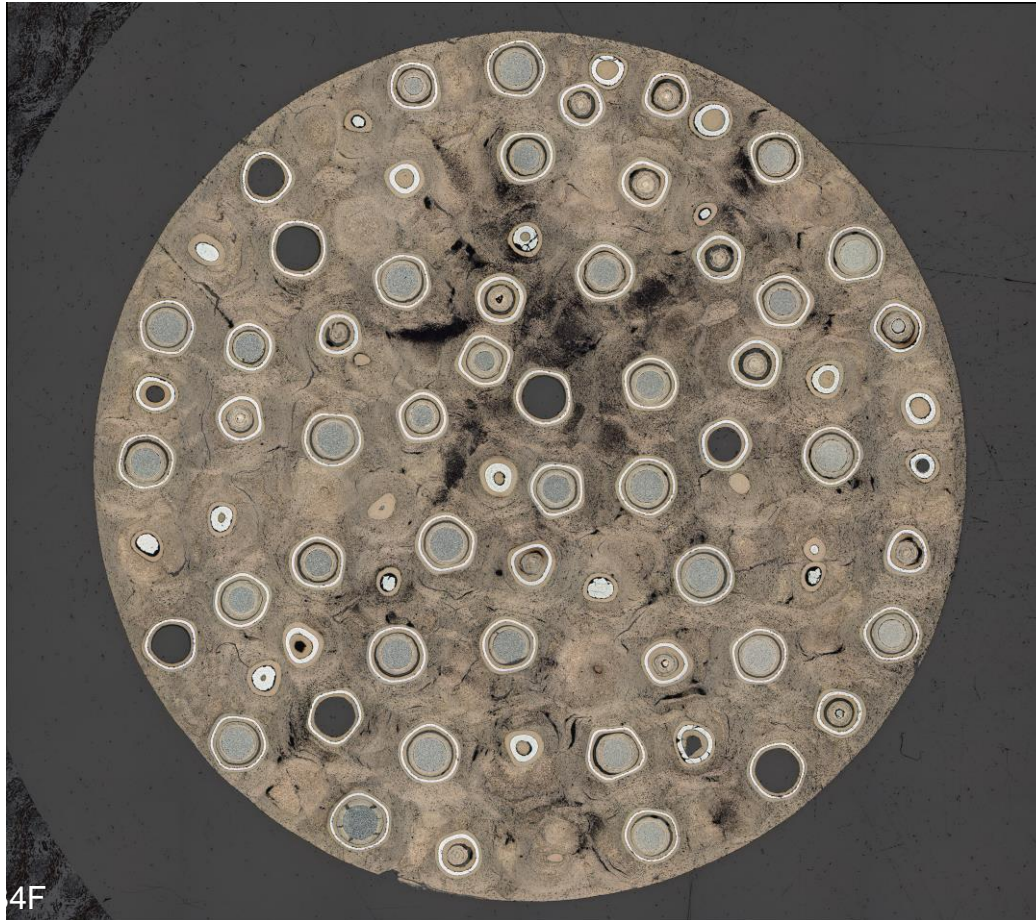
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
2-3-3	14.67	5.07	794	889	947



Compact 4-5-1

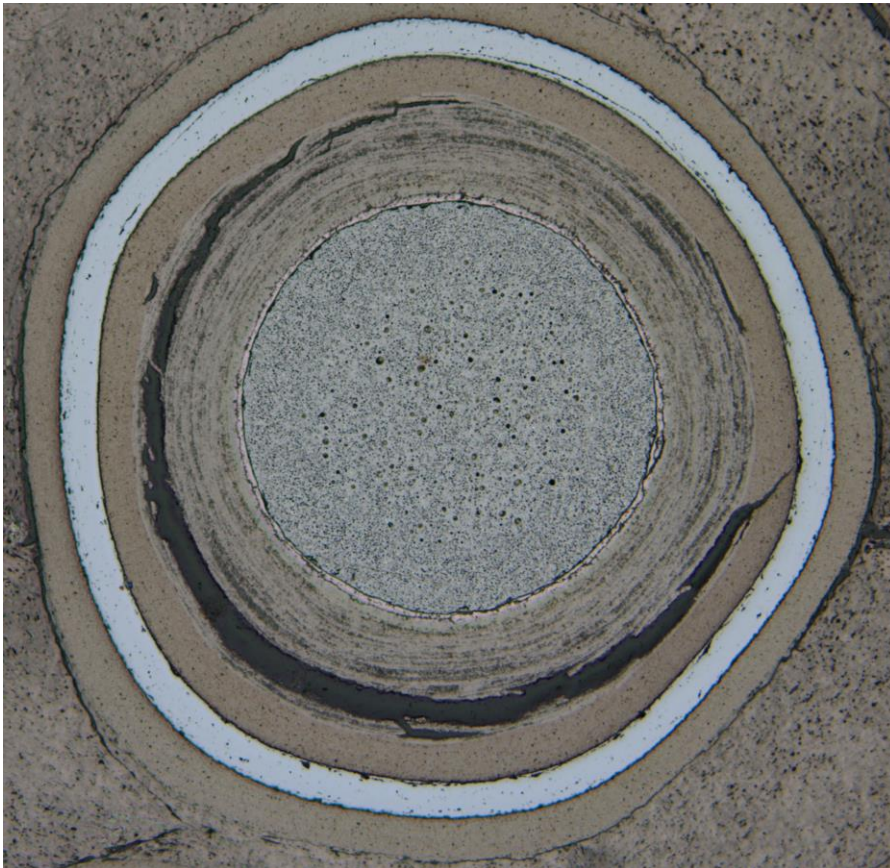
- Buffer fracture much less common than in Compact 2-3-3
- Very rare small IPyC tear from buffer detachment

Compact	Burnup	Fluence	TA Min	TAVA	TA Max
4-5-1	12.84	4.24	787	884	947



Compact 5-1-4

- Some small, incomplete IPyC tearing
- Rare IPyC cracking
- Seems to have no buffer fracture (like 4-5-1 and unlike 2-2-3)

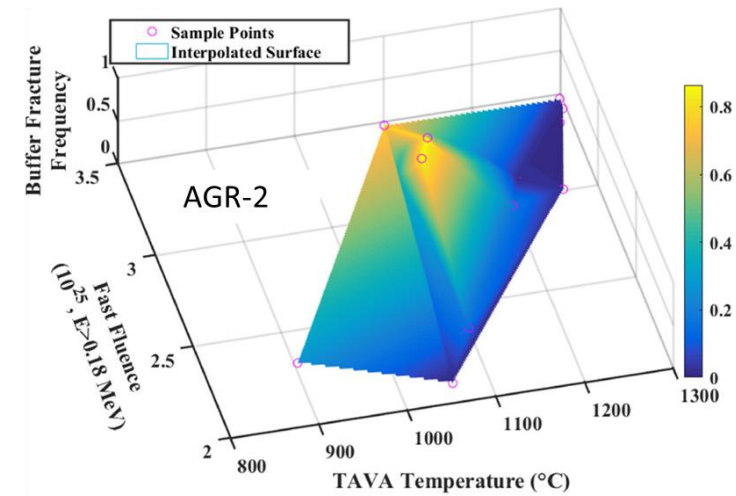
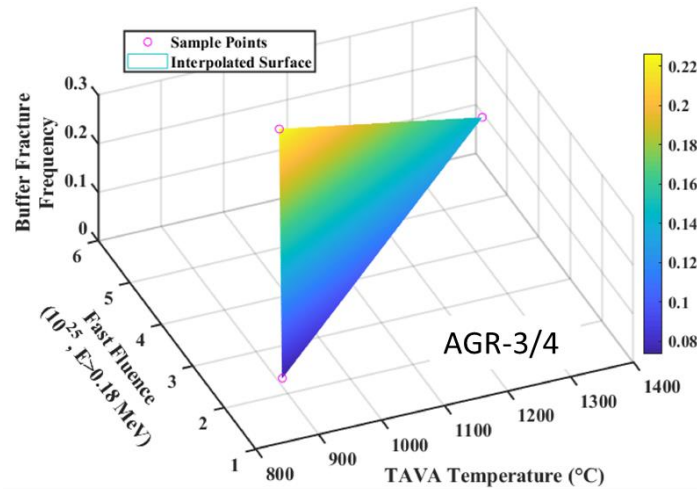


Compact	Burnup	Fluence	TA Min	TAVA	TA Max
2-3-3	14.67	5.07	794	889	947
4-5-1	12.84	4.24	787	884	947
5-1-4	9.4	3.4	506	721	834



Buffer Fracture Frequency

- Observed previously to be a function of temperature and neutron fluence

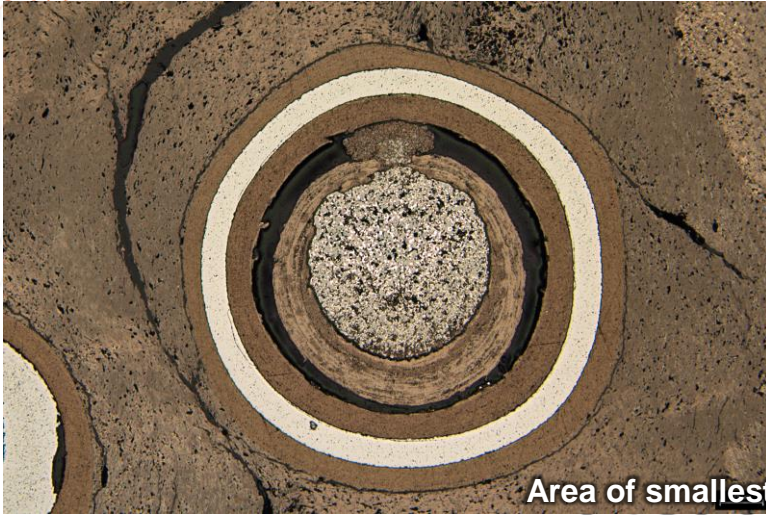


- Not surprising to see a qualitative difference in buffer fracture among the lower temperature AGR-5/6/7 fuel

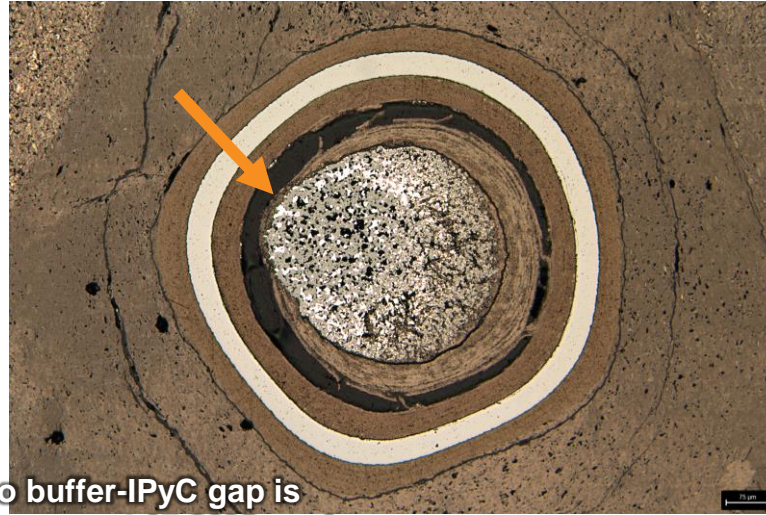
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
2-3-3	14.67	5.07	794	889	947
4-5-1	12.84	4.24	787	884	947
5-1-4	9.4	3.4	506	721	834

Kernel Migration? Compact 3-2-3 MNT74F

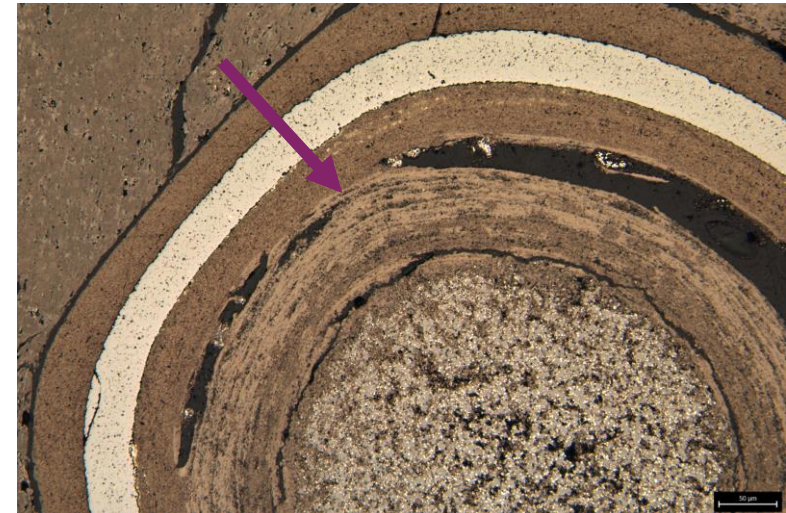
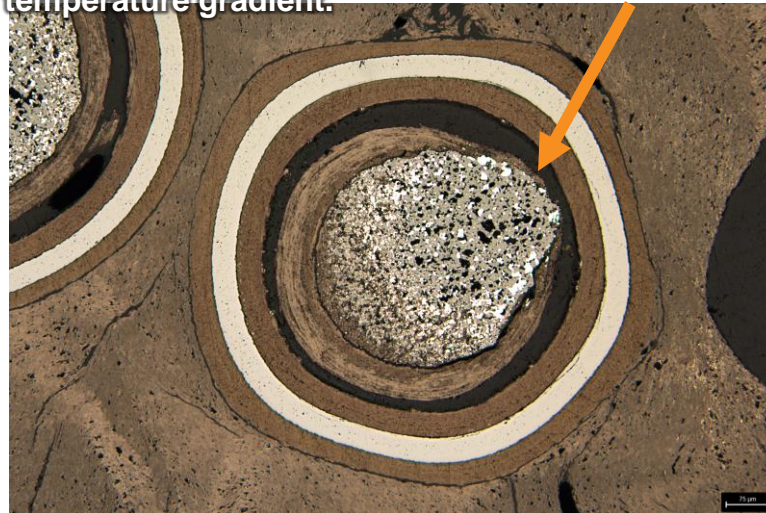
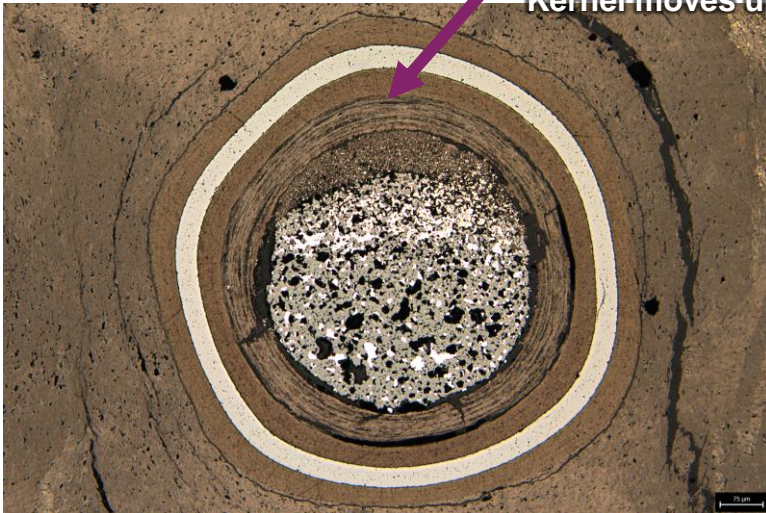
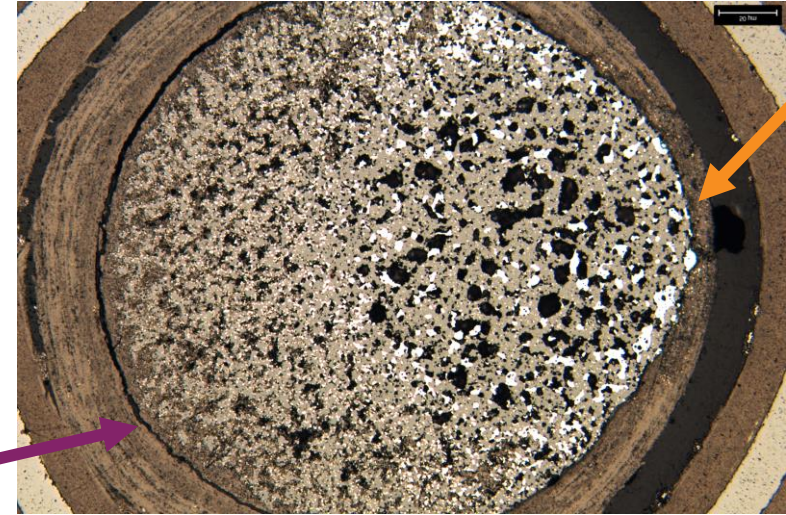
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
3-2-3	14.62	5.54	1203	1320	1401



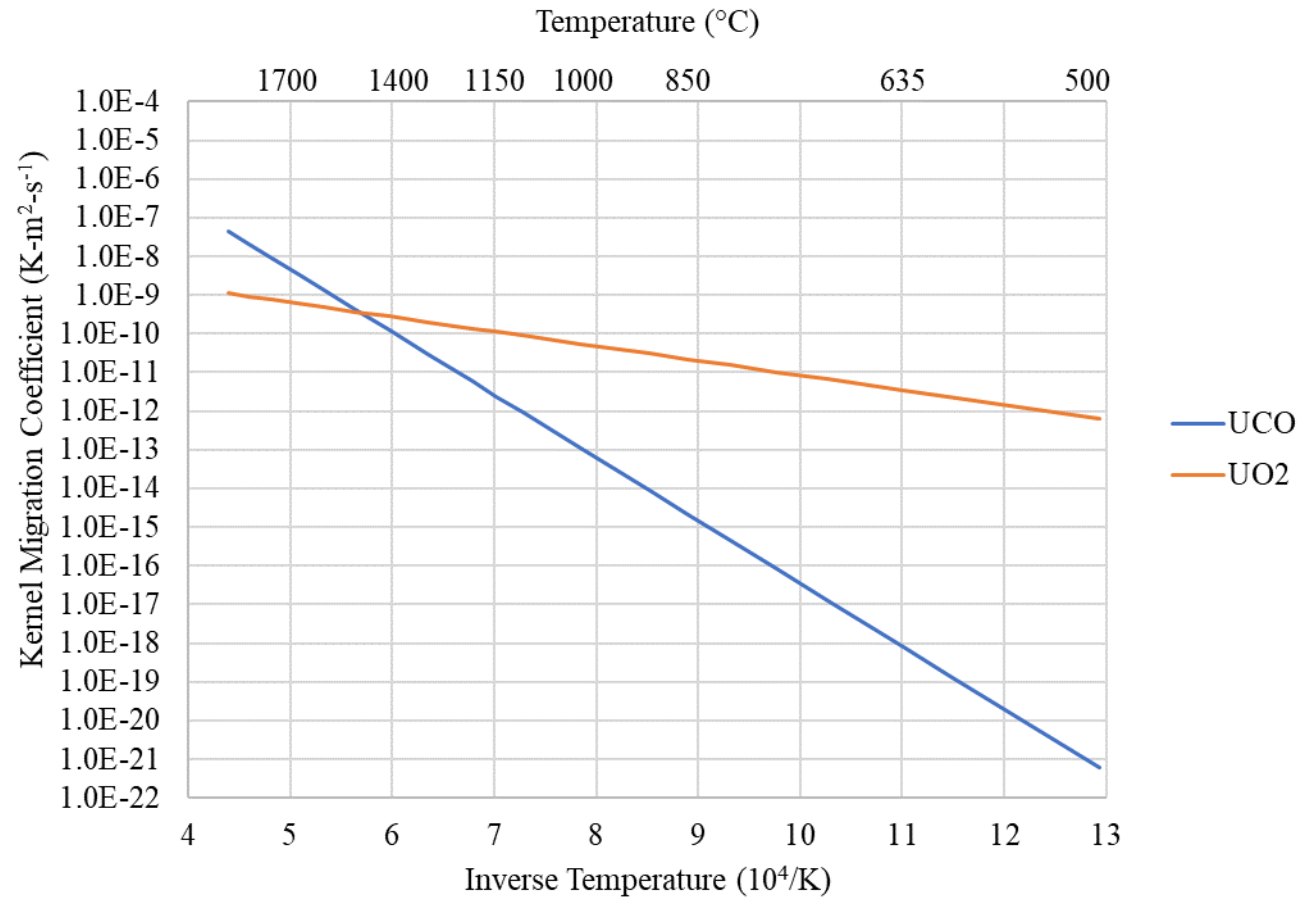
Area of smallest or no buffer-IPyC gap is coolest. Calculations suggest 15-20°C cooler. Kernel moves up the temperature gradient.



Buffer thinning at hot side of particle.

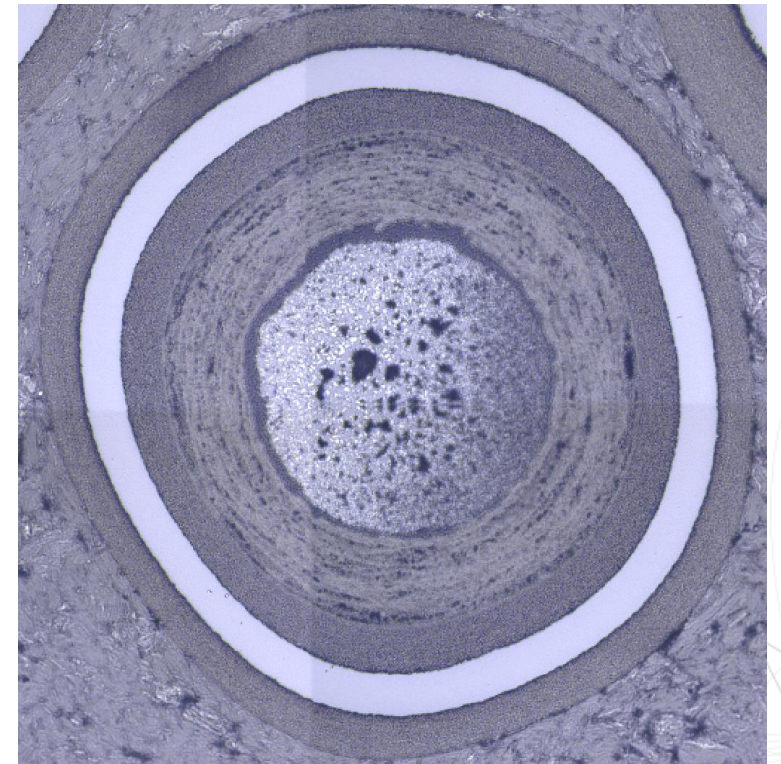
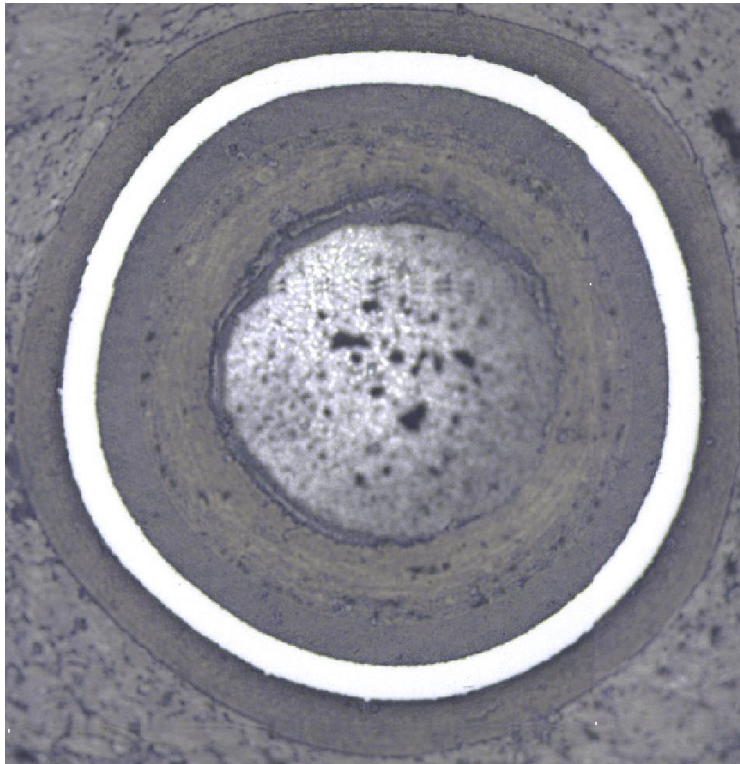
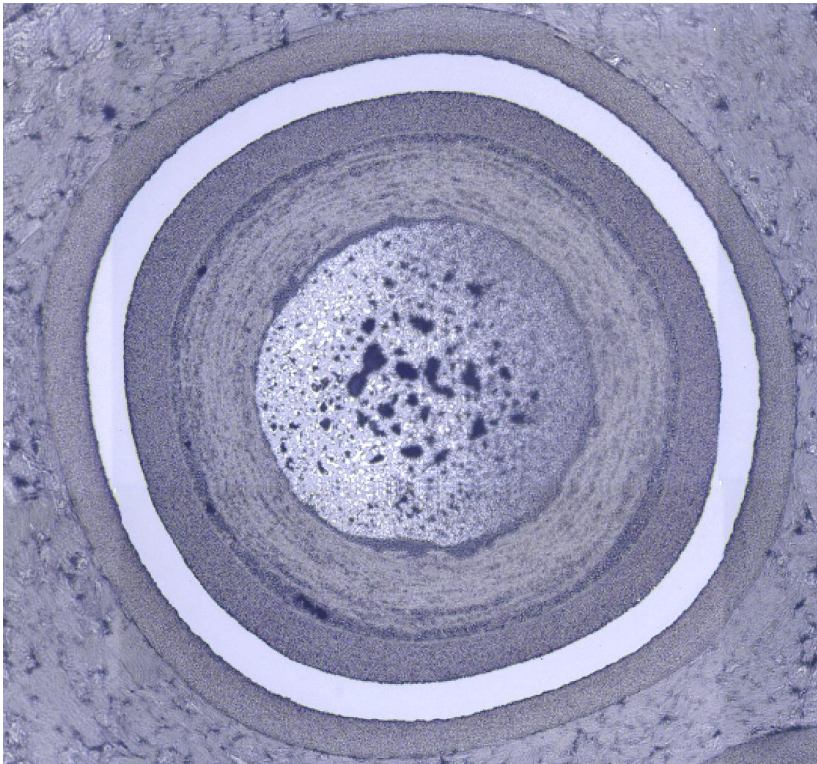


Some amount of UCO kernel migration is not unreasonable at higher temperatures $\gtrsim 1300^{\circ}\text{C}$



Similar Kernel Morphology Seen in AGR-3/4 Compact 7-2 (TAVA 1375°C, TA Peak 1417°C, 15.0% FIMA)

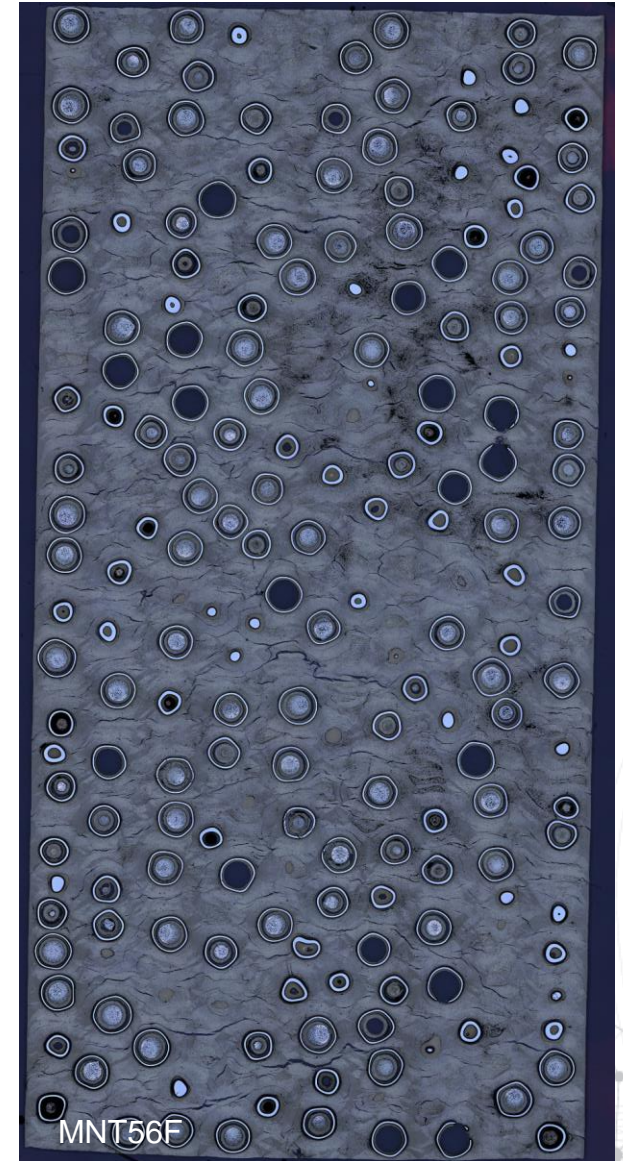
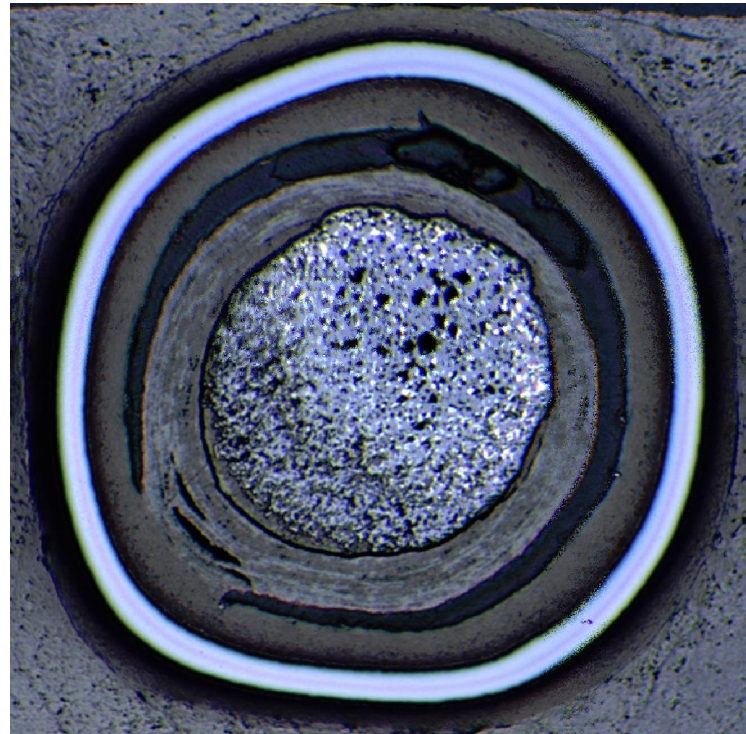
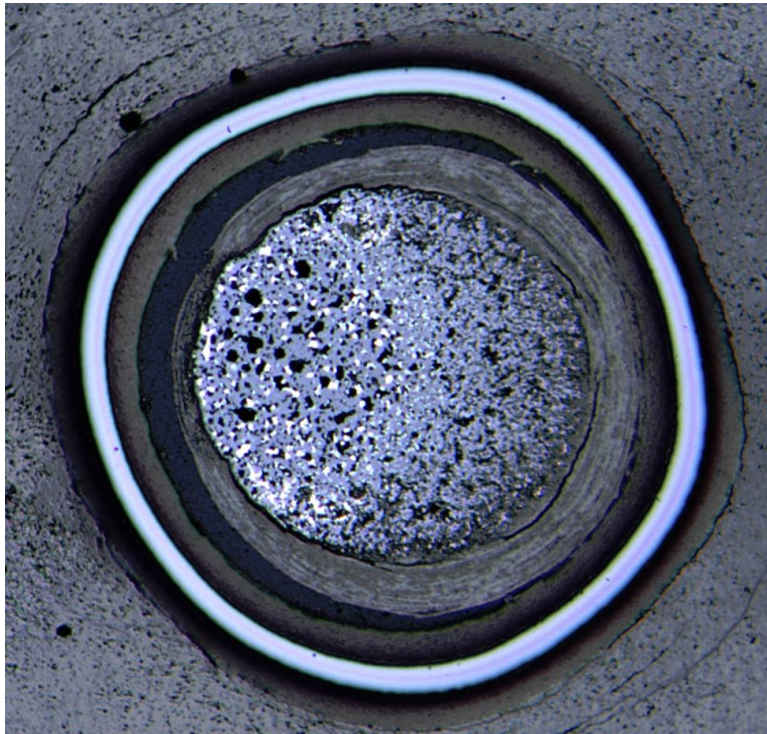
- Evidence of kernel migration in hot AGR-3/4 fuel
- Generally, not as pronounced as in AGR-5/6/7 Capsule 3



Compact 3-4-1 Appearance Similar to 3-2-3

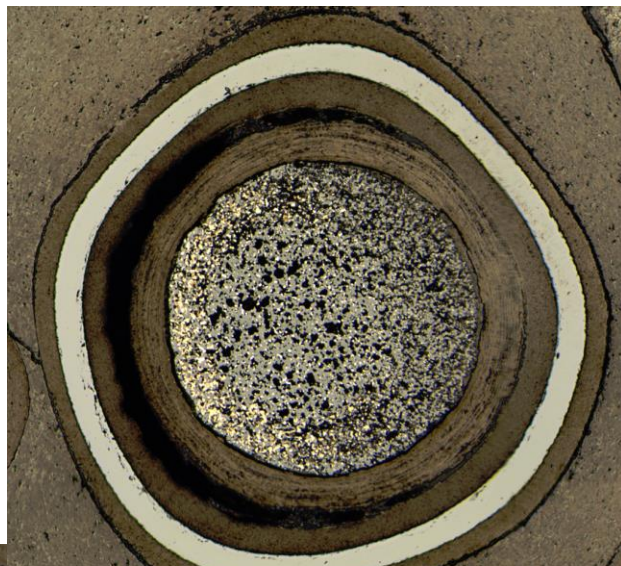
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
3-4-1	14.73	5.41	1268	1359	1419
3-2-3	14.62	5.54	1203	1320	1401

- Some apparent kernel migration
- A little IPyC tearing



Compact 1-7-6 Incipient Kernel Migration

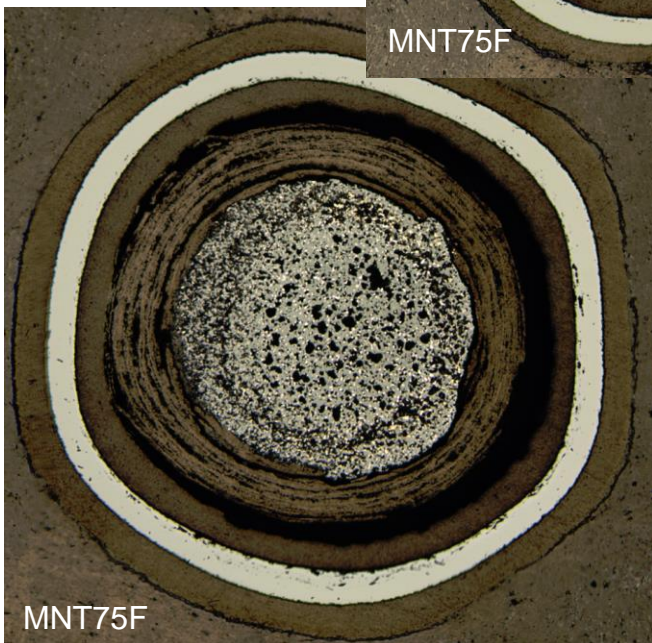
Compact	Burnup	Fluence	TA Min	TAVA	TA Max
1-7-6	10.36	3.99	911	1115	1229



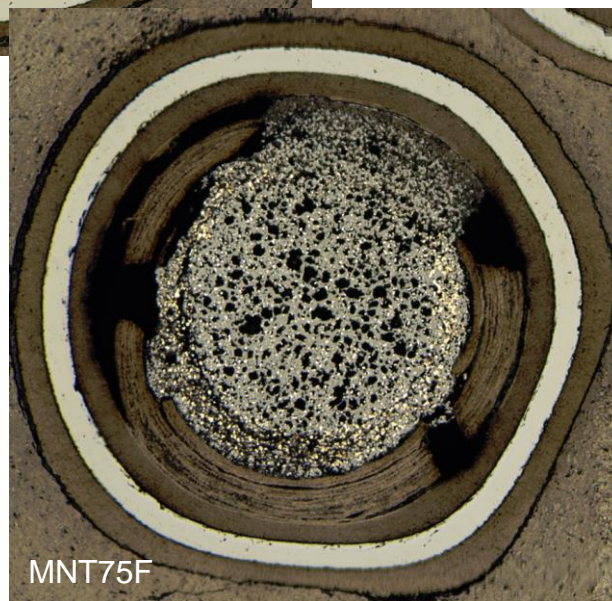
MNT75F



MNT75F



MNT75F

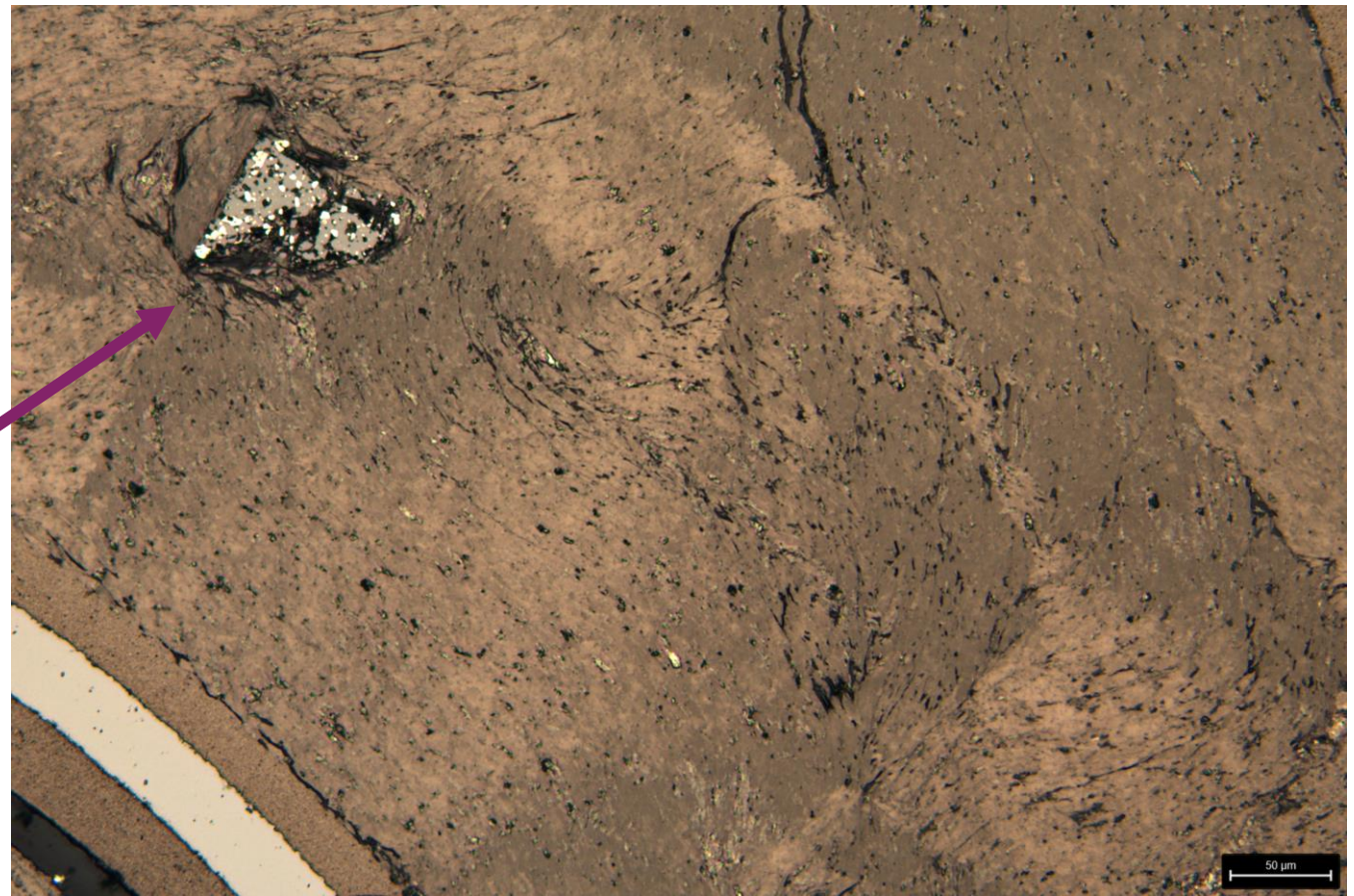
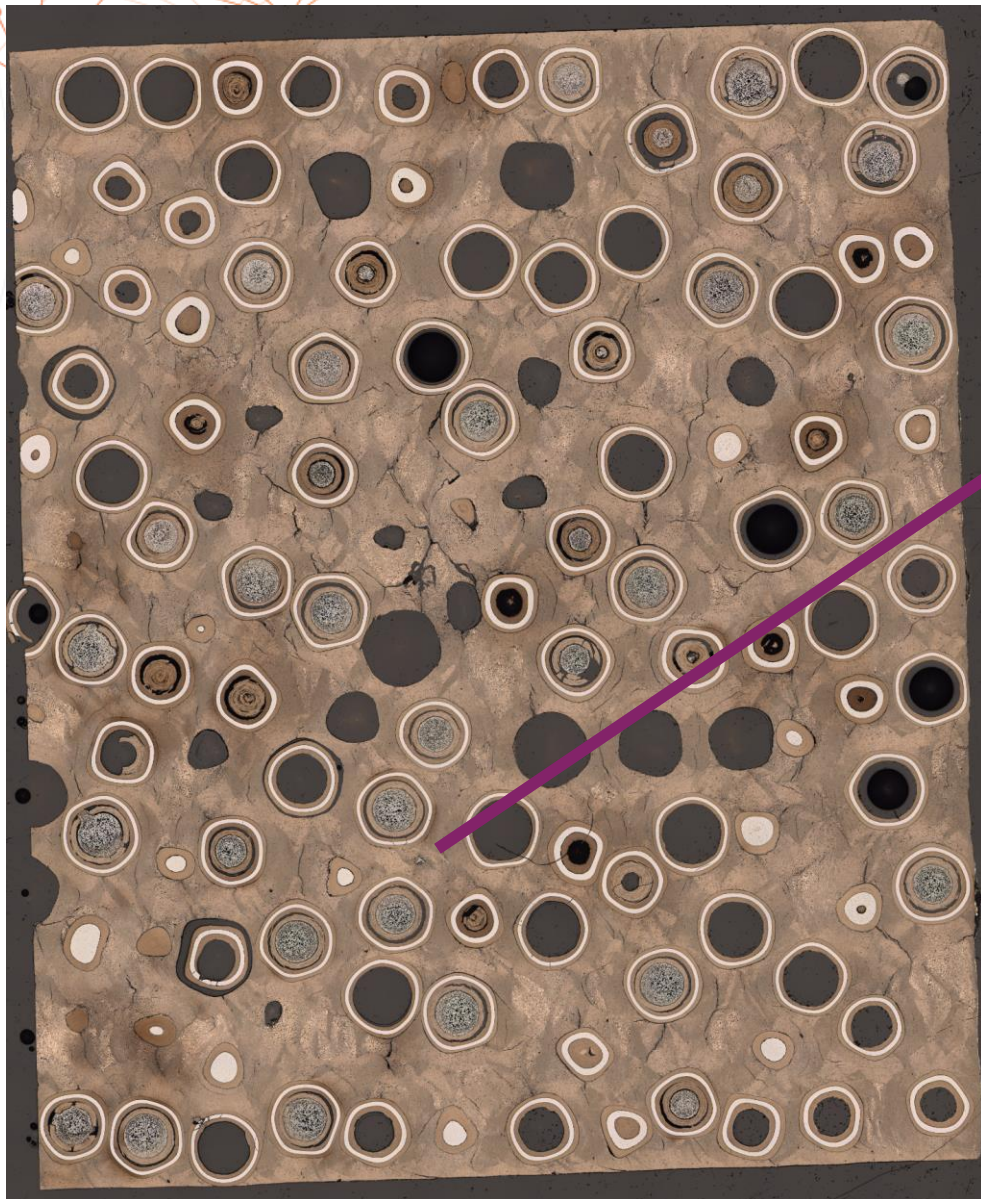


MNT75F

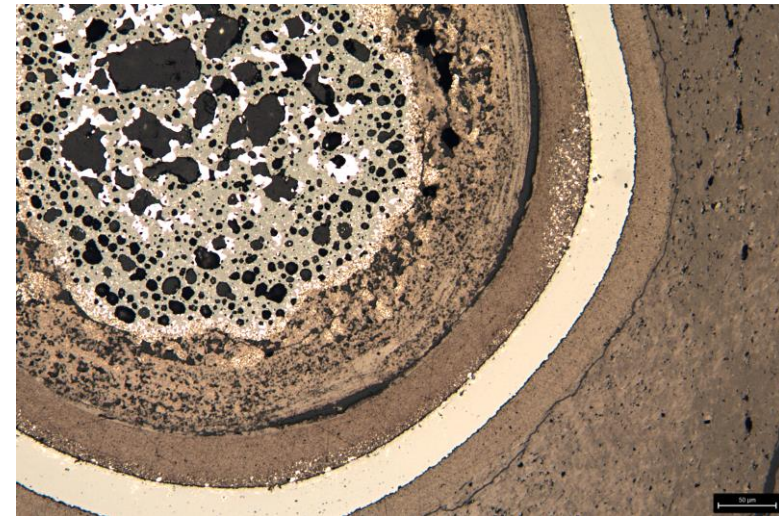
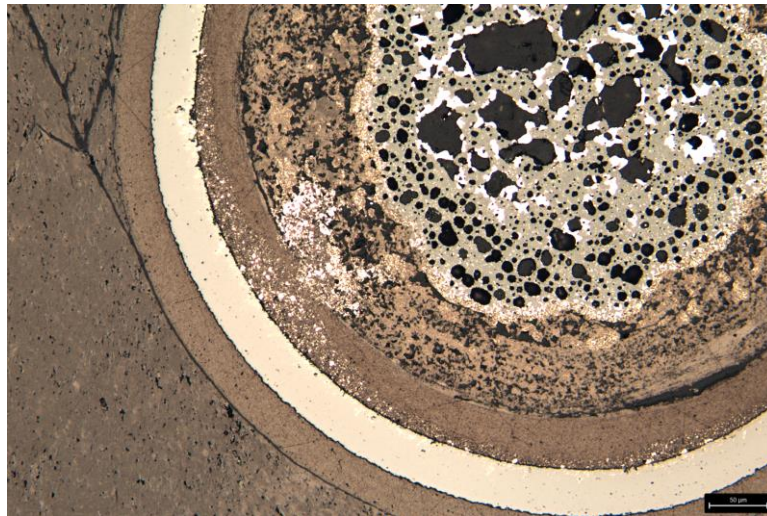
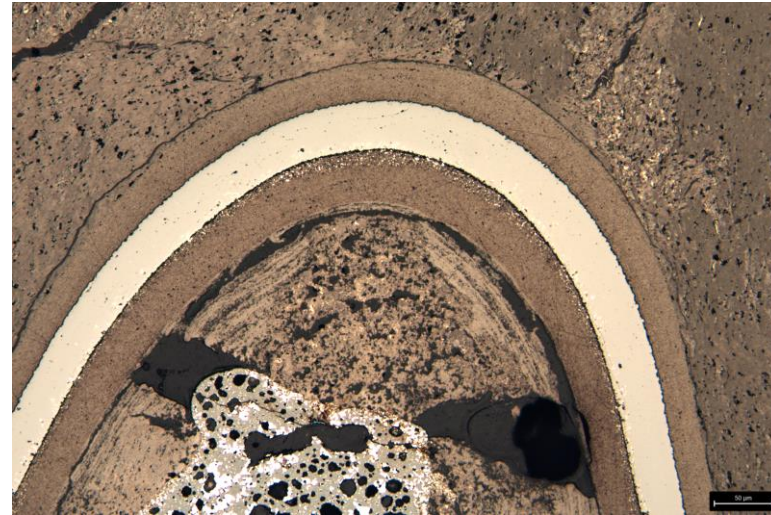
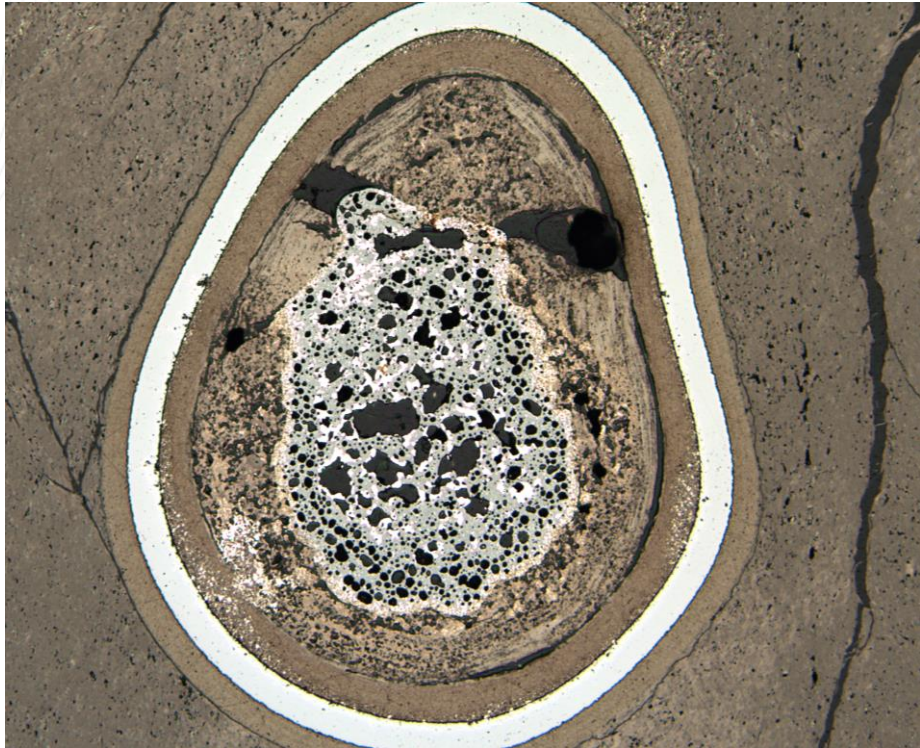


"Do or do not. There is no try."

Compact 1-7-6 MNT75F Shard



Compact 4-5-1 MNT79F



Summary

- Compact ceramography is generally consistent with prior work; however, there appears to have been some kernel migration in the hot fuel
- Capsule 1 fuel from near the failed thermocouples contains significant quantities of Ni that failed the fuel
- Very little buffer-IPyC interaction was observed
- Very few signs of IPyC degradation were observed
- Only one particle had evidence of SiC degradation (that was the odd particle from 4-5-1)
- Matrix has relatively large fissures that have gone around the particles not through them
- Compact ceramography complete except for possibly some Capsule 1 fuel from low-temp/low-burnup range



Idaho National Laboratory