July 25, 2023

**Lu Cai, Ph.D.**
Nuclear Engineer
Idaho National Laboratory

# AGR-5/6/7 Disassembly and Metrology

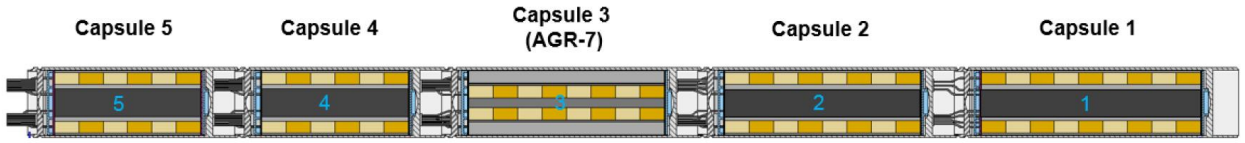
**DOE ART Gas-Cooled Reactor (GCR) Review Meeting**
Virtual Meeting
July 25 – 27, 2023

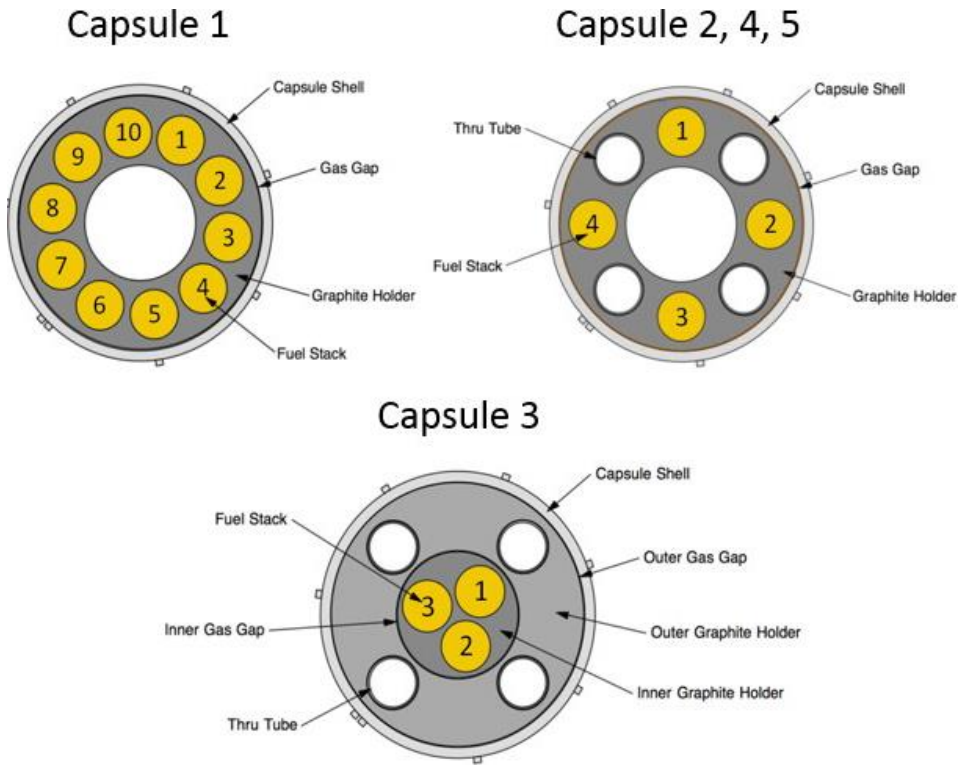
ART Advanced Reactor Technologies
GAS-COOLED REACTORS

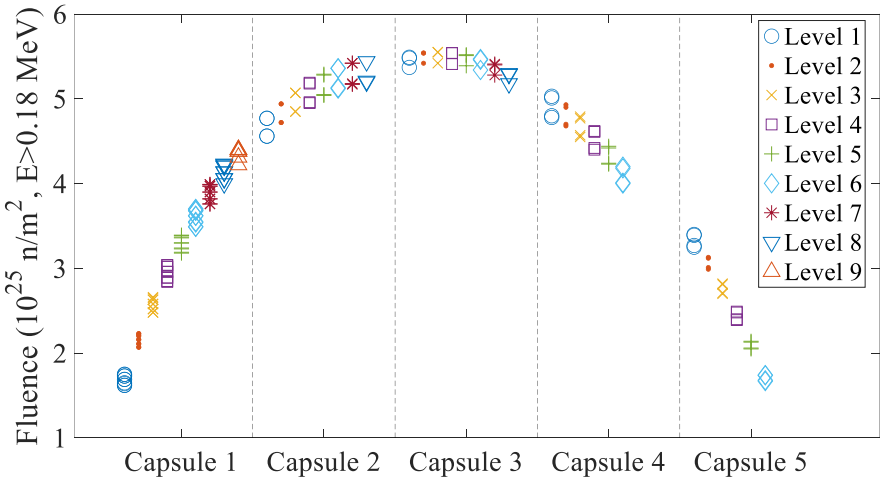
# Outline

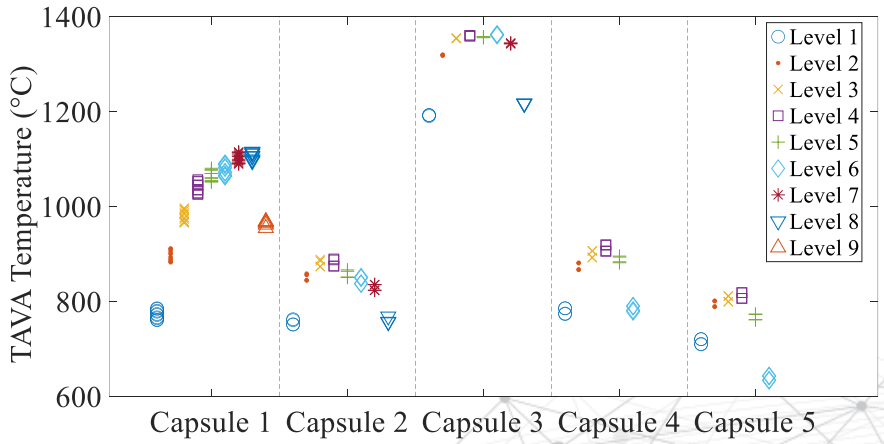
- Background
- AGR-5/6/7 disassembly
  - Observations on graphite holders and fuel compacts
- AGR-5/6/7 metrology
  - Fuel compacts
  - Graphite holders
- Summary

# Background - AGR-5/6/7 Design and Irradiation Conditions



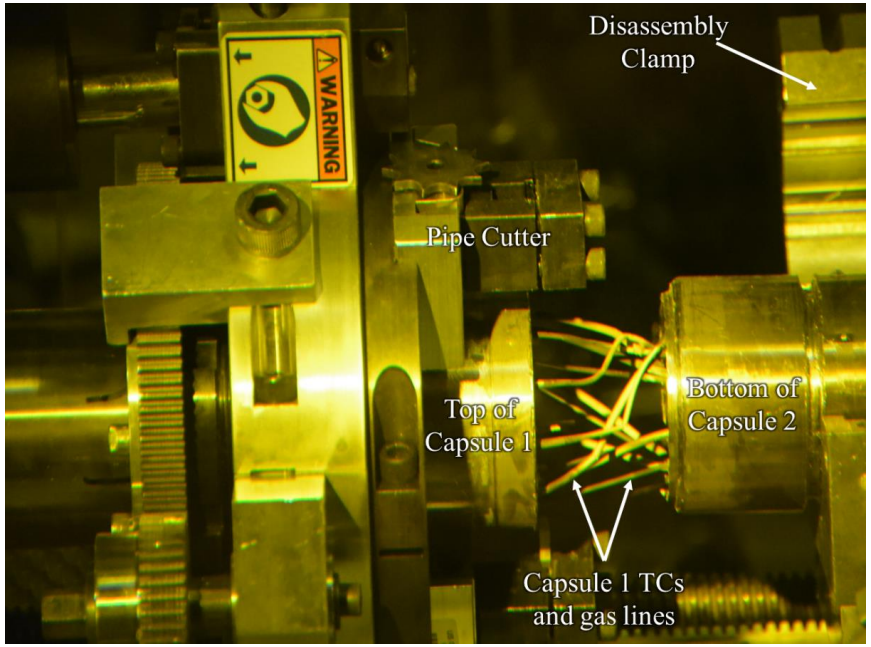



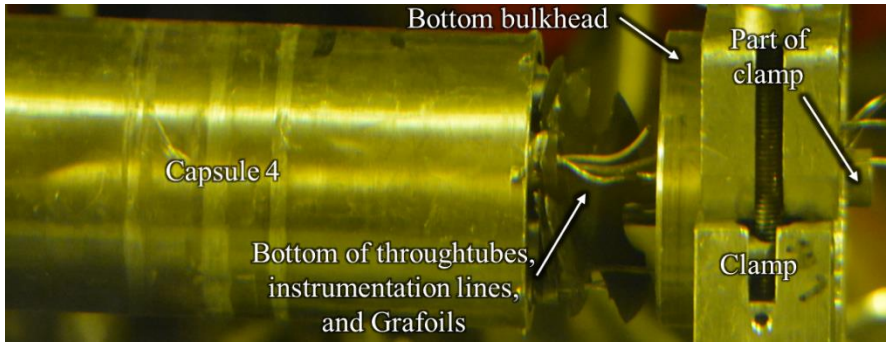
# Disassembly and Metrology Complete

## Level 2 Milestone report completed February 2023

| Components | Number |
|---|---|
| Capsules Disassembled | 5/5 |
| Holders Measured | 6/6 |
| Compacts Recovered | 194*/194 |

*Compact 2-8-4 was broken during disassembly

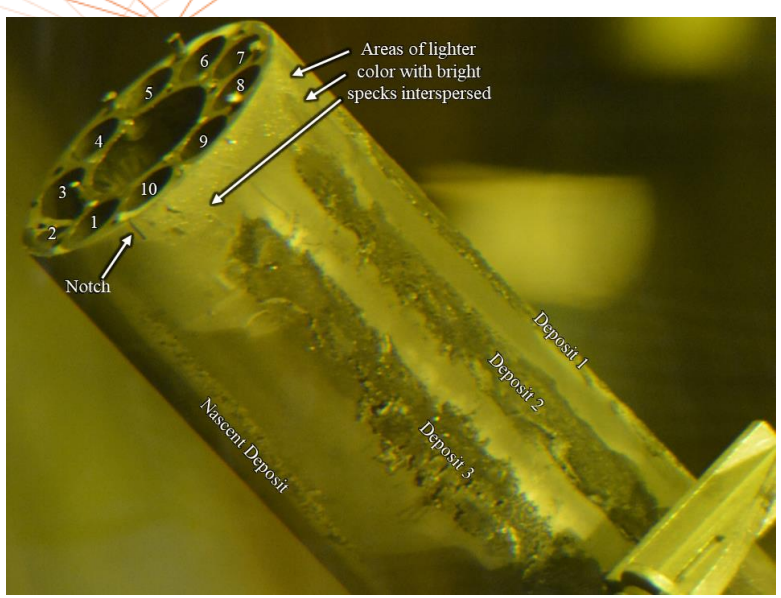




# AGR-5/6/7 Disassembly

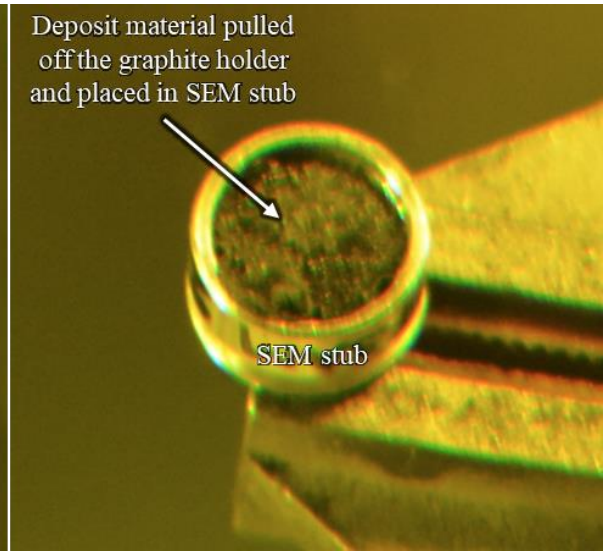
Collaborators:

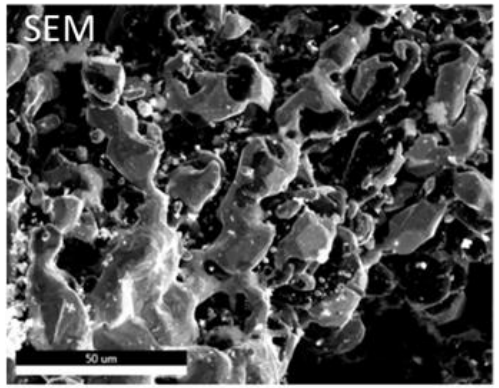
John D. Stempien
Philip Winston
Cad Christensen
Cassie Anderson-Thueson
Skyler James
Daniel Murray
John Hunn

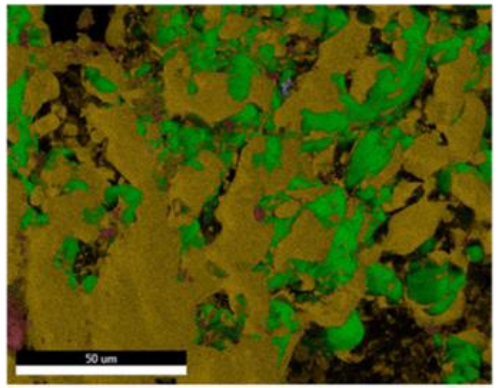
# Graphite Holder – Capsule 1



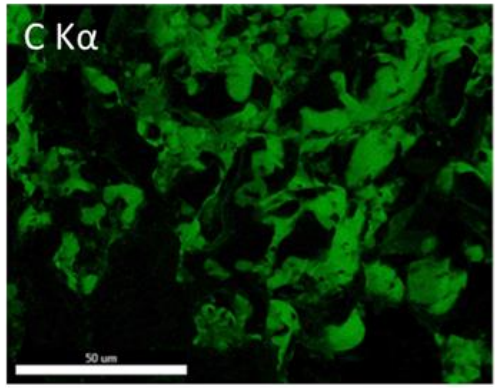


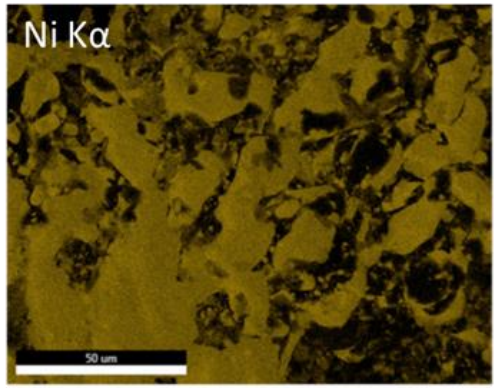


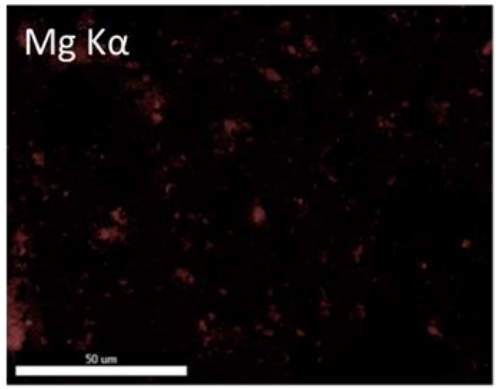



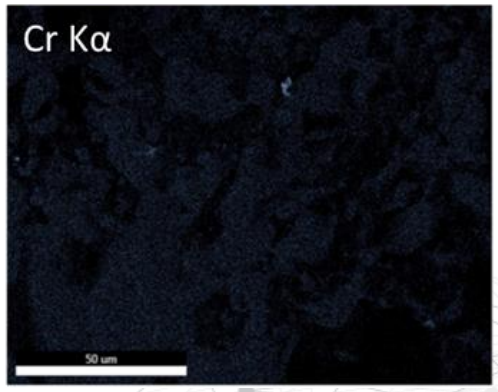




32% C
5% Mg
4% Cr
59% Ni

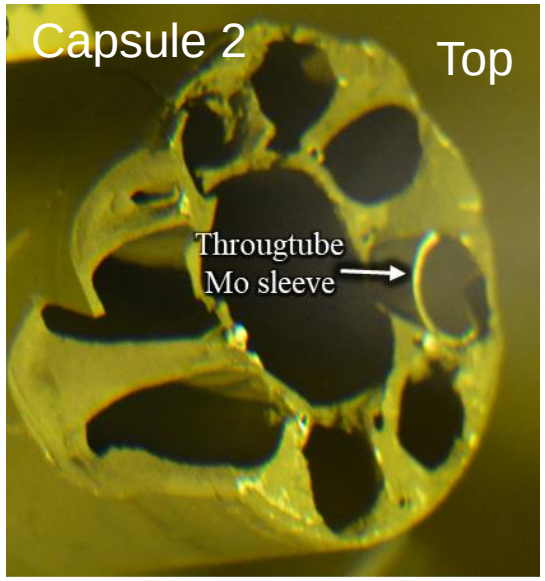


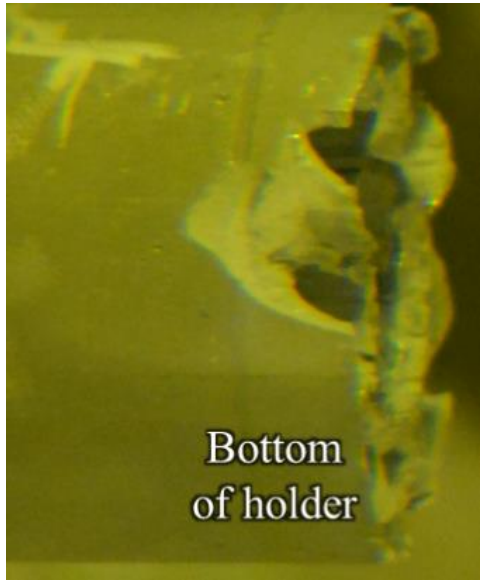



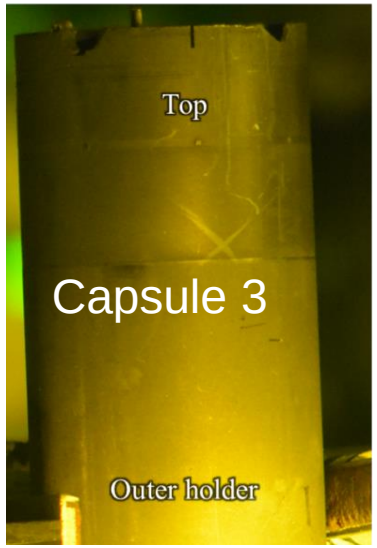



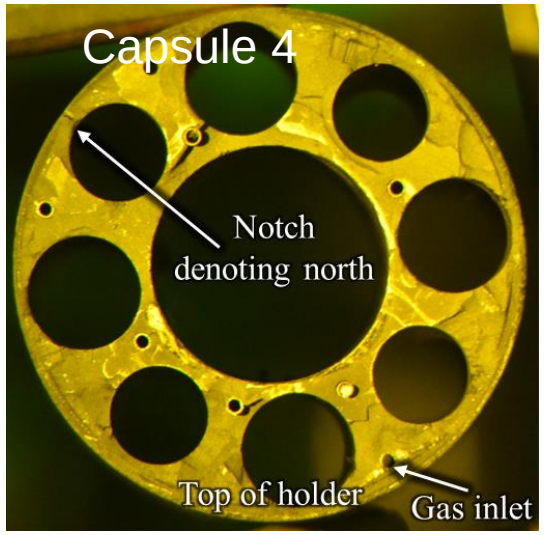
# Graphite Holders – Capsules 2-5




For Capsule 2 graphite holder, the bottom was damaged when the shell was mistakenly cut in the wrong place, and the top was damaged when the through-tubes were pulled out.



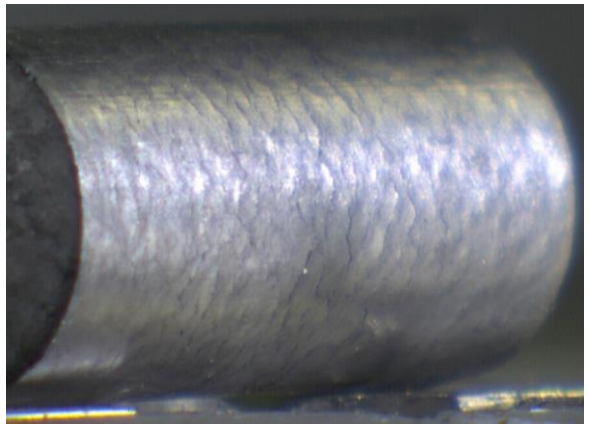

Minor chipping occurred mainly around the throughtube holes of the graphite holders of Capsules 3 (outer holder), 4 and 5.

# Typical As-irradiated Matrix Appearance

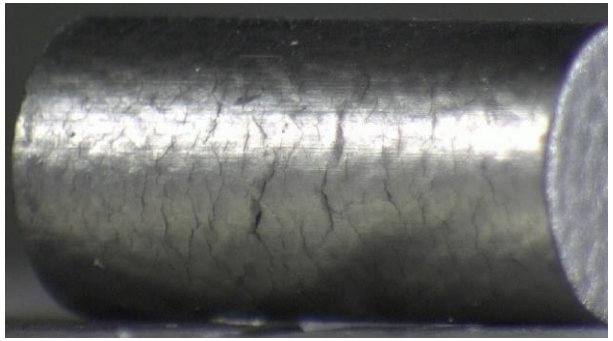
Compact 2-6-4

Compact 2-7-1

Compact 2-7-3

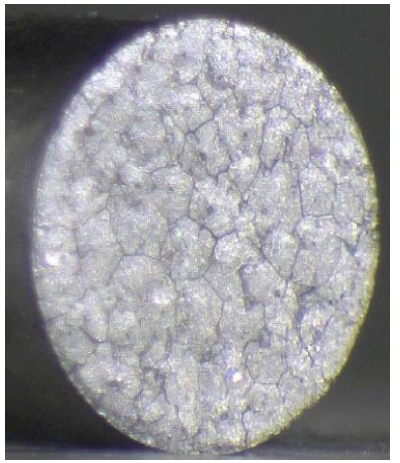


Compact 2-7-4

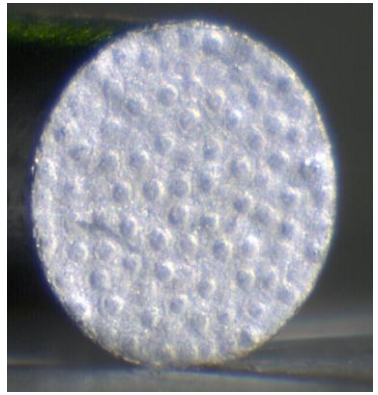


Compact 3-8-3

Compact 2-8-1

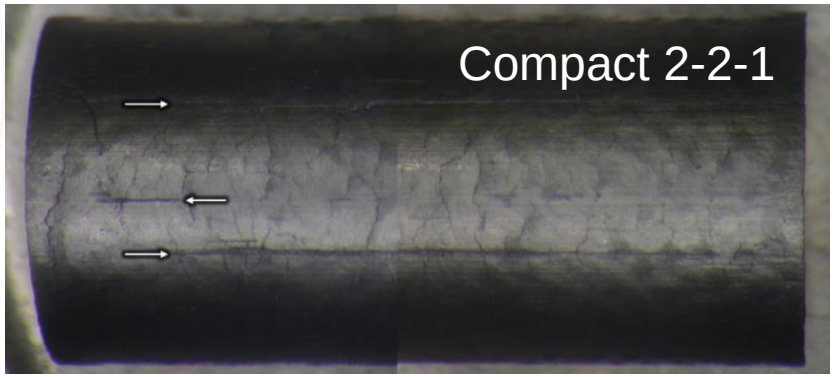


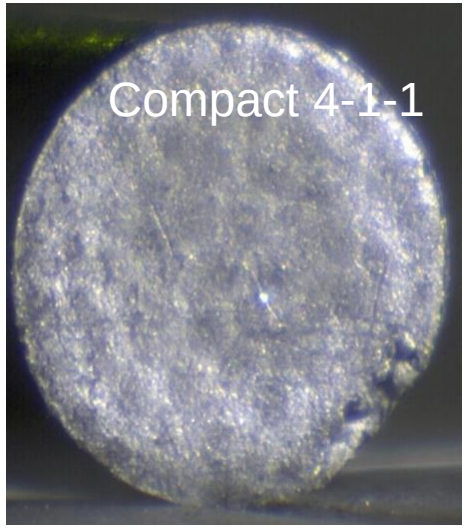
Compact 5-6-2



Compact 4-6-4

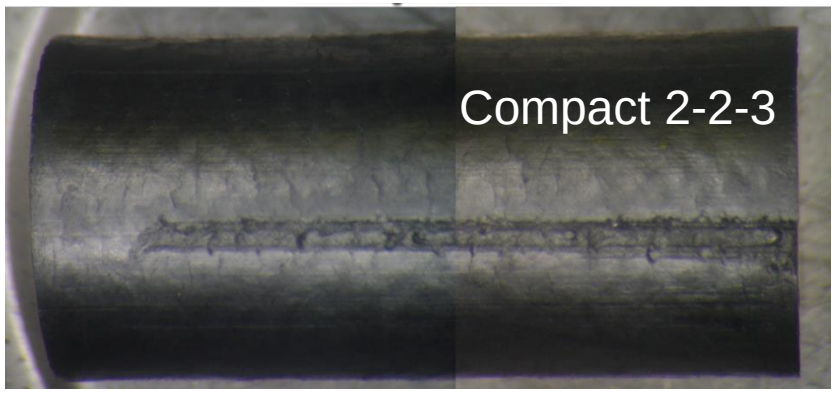
# Unusual Compact Appearance and Damage



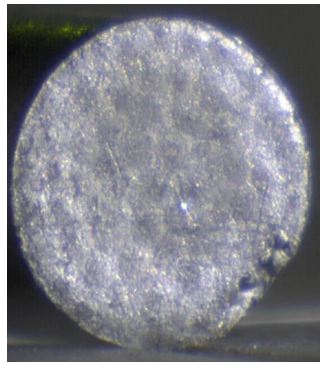






# Complete In-cell Visual Examinations, Assess Frequency of Compact Damage, Determine Severity of Damage

- Compacts not already sent to ORNL or used in DLBL will be examined via in-cell camera
- Compacts with damage could be screened in NRAD plus simplified furnace or possibly FACS for damage
- Compacts could also face DLBL to assess damage
- The point is to distinguish in-pile damage from disassembly/handling damage and potentially allow some compacts to be salvaged for fuel performance exams

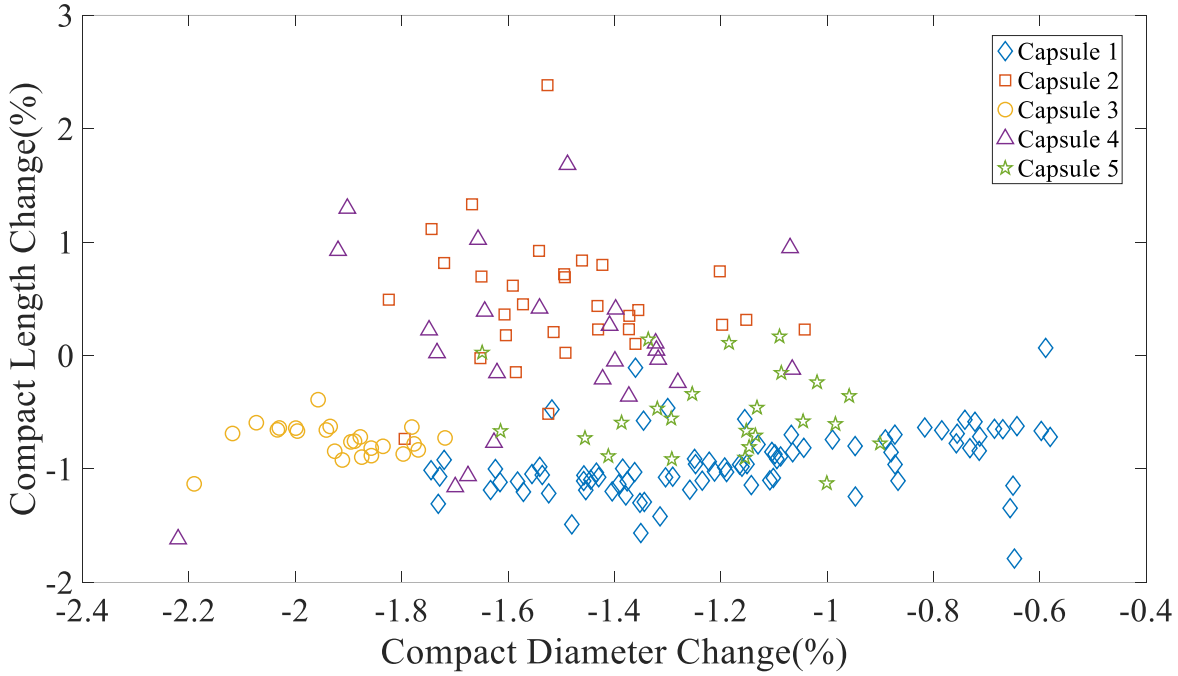


# AGR-5/6/7 Metrology

Collaborators:

John D. Stempien
Philip Winston
Cad Christensen
Cassie Anderson-Thueson
Skyler James

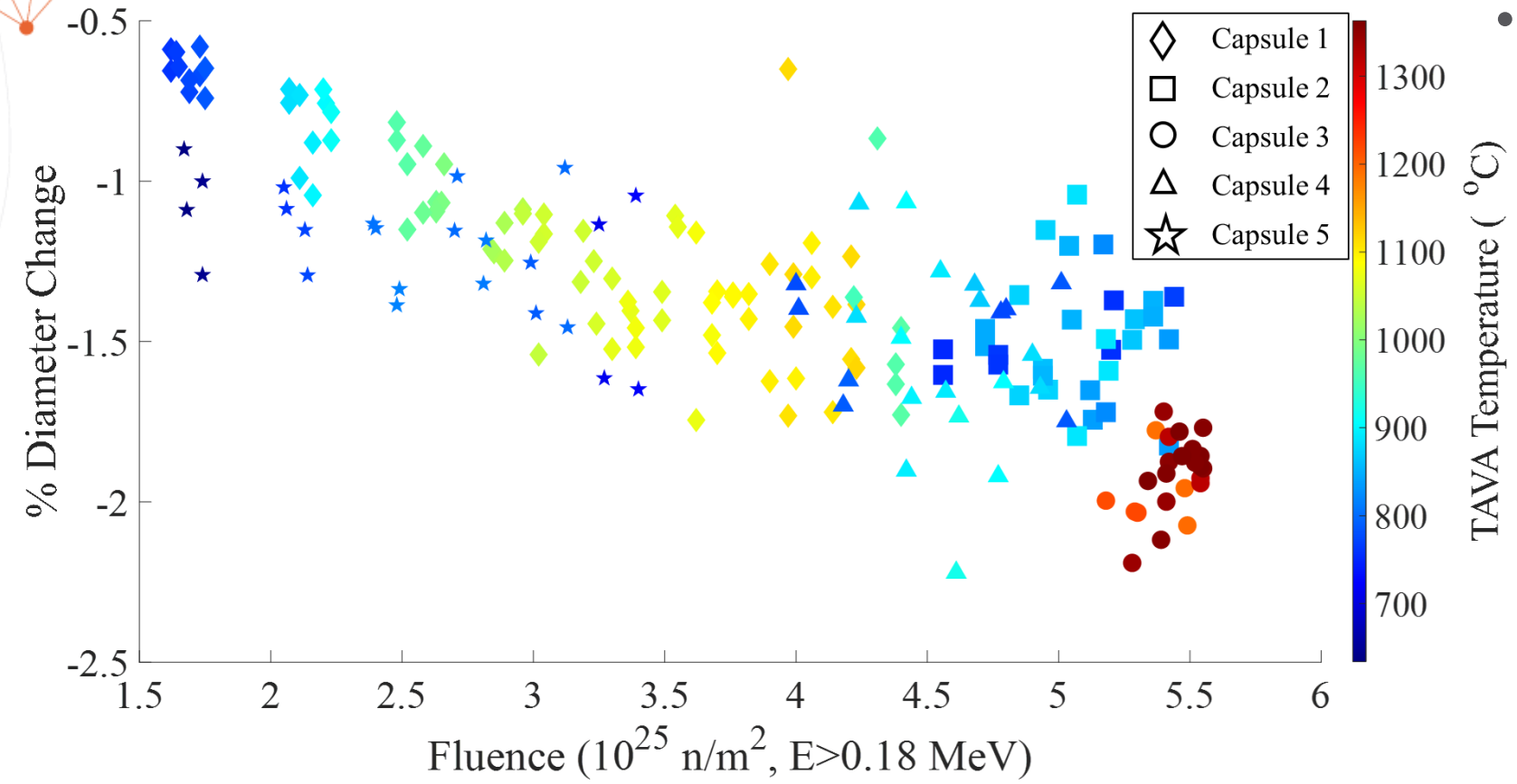
# AGR – 5/6/7 - Fuel Compacts Overall




Nominal Packing Factor (PF):
25% - Capsules 1 and 5
40% - Capsules 2, 3, and 4

- The PIE dimensions of 188 compacts were compared with as-fabricated dimensions.
- For PF~40%, the fuel compacts from Capsules 2 and 4 had similar irradiation conditions, and their length changes vs. diameter changes (ΔL vs. ΔD) are similar. The Capsule 3 compacts exhibited length reduction instead of the length increase seen in Capsules 2 and 4, probably due to higher irradiation temperature at Capsule 3.
- For PF~25%, the fuel compacts from Capsules 1 and 5 show different trends in ΔL vs. ΔD despite having similar neutron fluence ranges, likely due to different irradiation temperature.

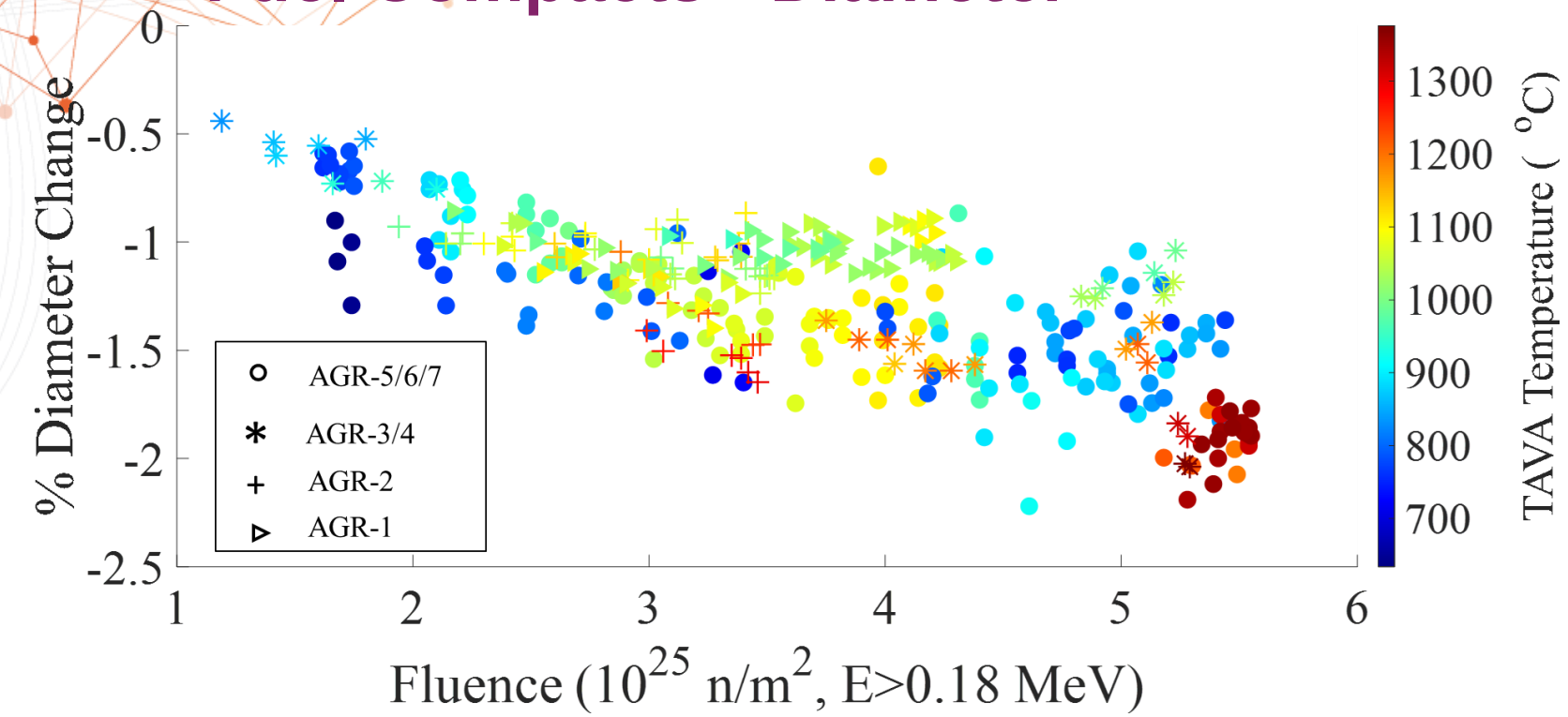
# Fuel Compacts - Diameter




- The diameters decrease with increasing fast neutron fluence until about $4.5\times10^{25}$ n/m$^2$ (E>0.18 MeV). Above this fluence, the diameter reduction of compacts with TAVA temperatures <1000°C becomes less pronounced.

- The hotter Capsule 3 compacts (TAVA>1190°C) have generally greater diameter reduction than the cooler Capsule 2 compacts (TAVA≤890°C).

# Fuel Compacts - Diameter

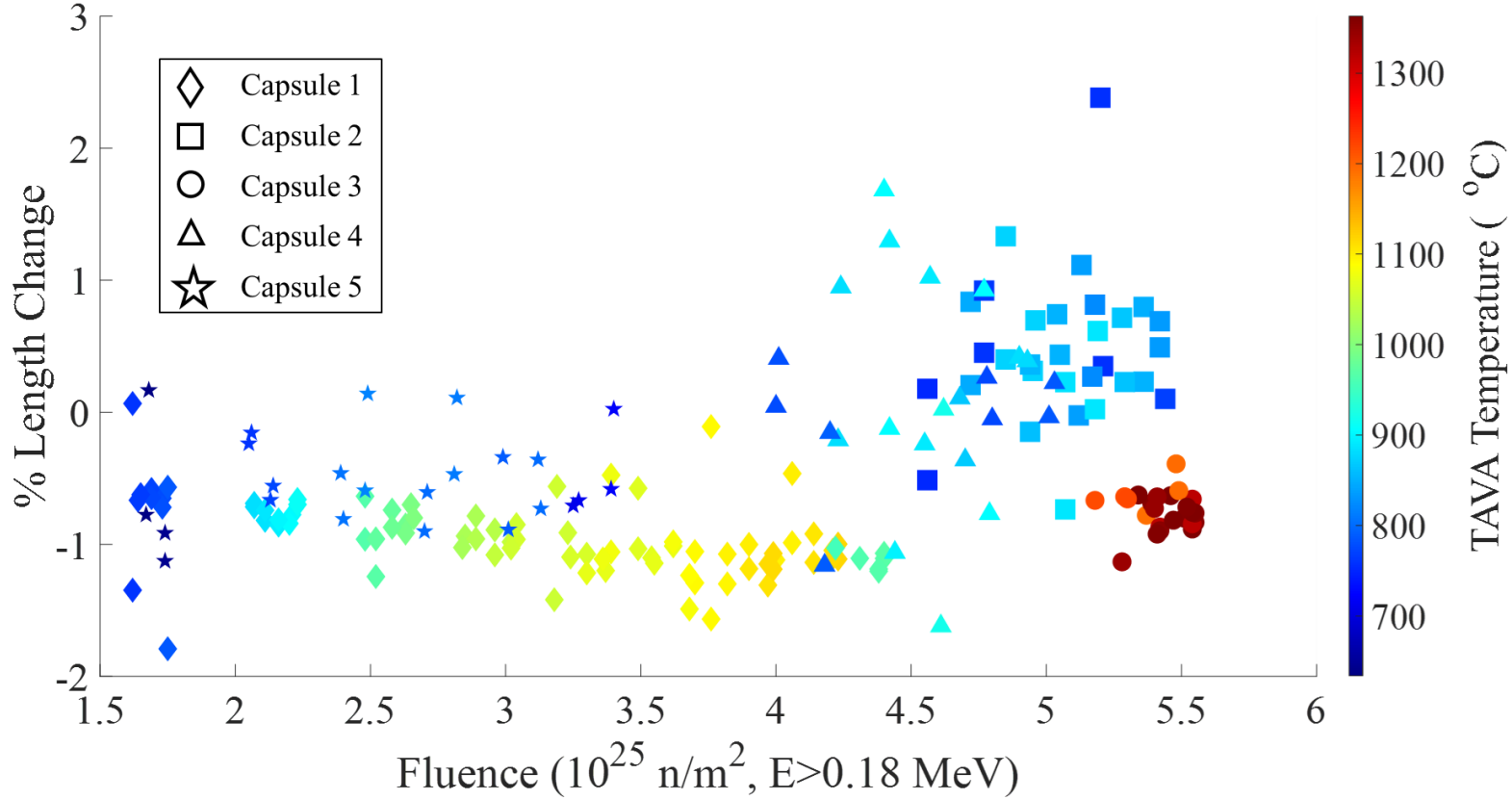



- A similar trend is observed for all AGR campaigns.

| | Packing Fraction (%) | Mean Matrix Density (g/cm³) | Matrix Formulation* |
|---|---|---|---|
| **AGR-1** | 36-37.5 | 1.22-1.34 | A3-3 |
| **AGR-2** | 36.8 (UCO kernel)<br>23.5 ($UO_2$ kernel) | 1.59 (UCO kernel)<br>1.68 ($UO_2$ kernel) | A3-3 |
| **AGR-3/4** | 37 | 1.60 | A3-3 |
| **AGR-5/6/7** | 25 or 40 | 1.75 or 1.76 | A3-27 |

* - this is an identifier, not a grade.

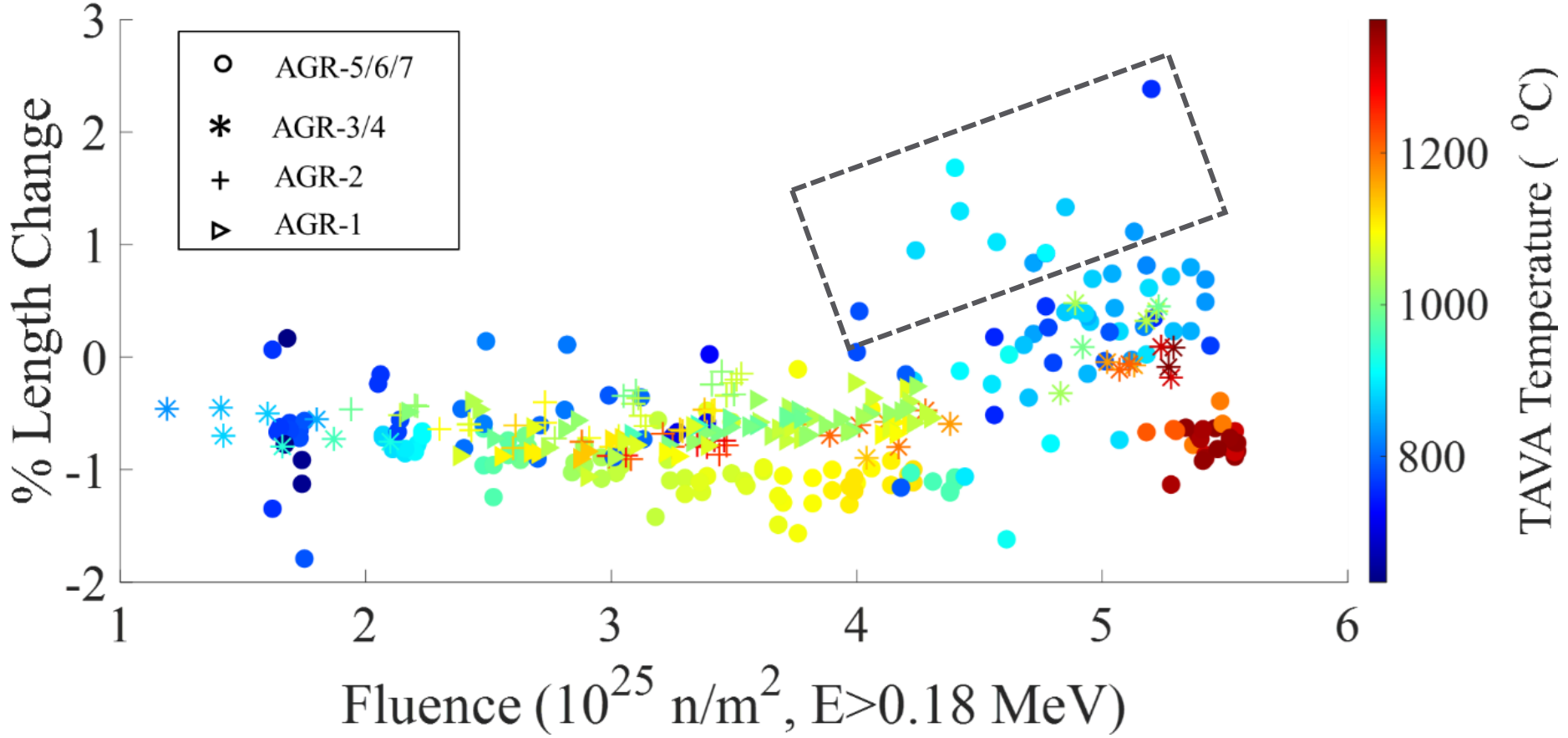
# Fuel Compacts - Length




- The compact length changes scatter between -2% and 0% until about $4.5\times10^{25}$ n/m$^2$ (E>0.18 MeV), above which the length changes for compacts with TAVA temperatures less than about 950°C in AGR-5/6/7 increase with increasing fluence.

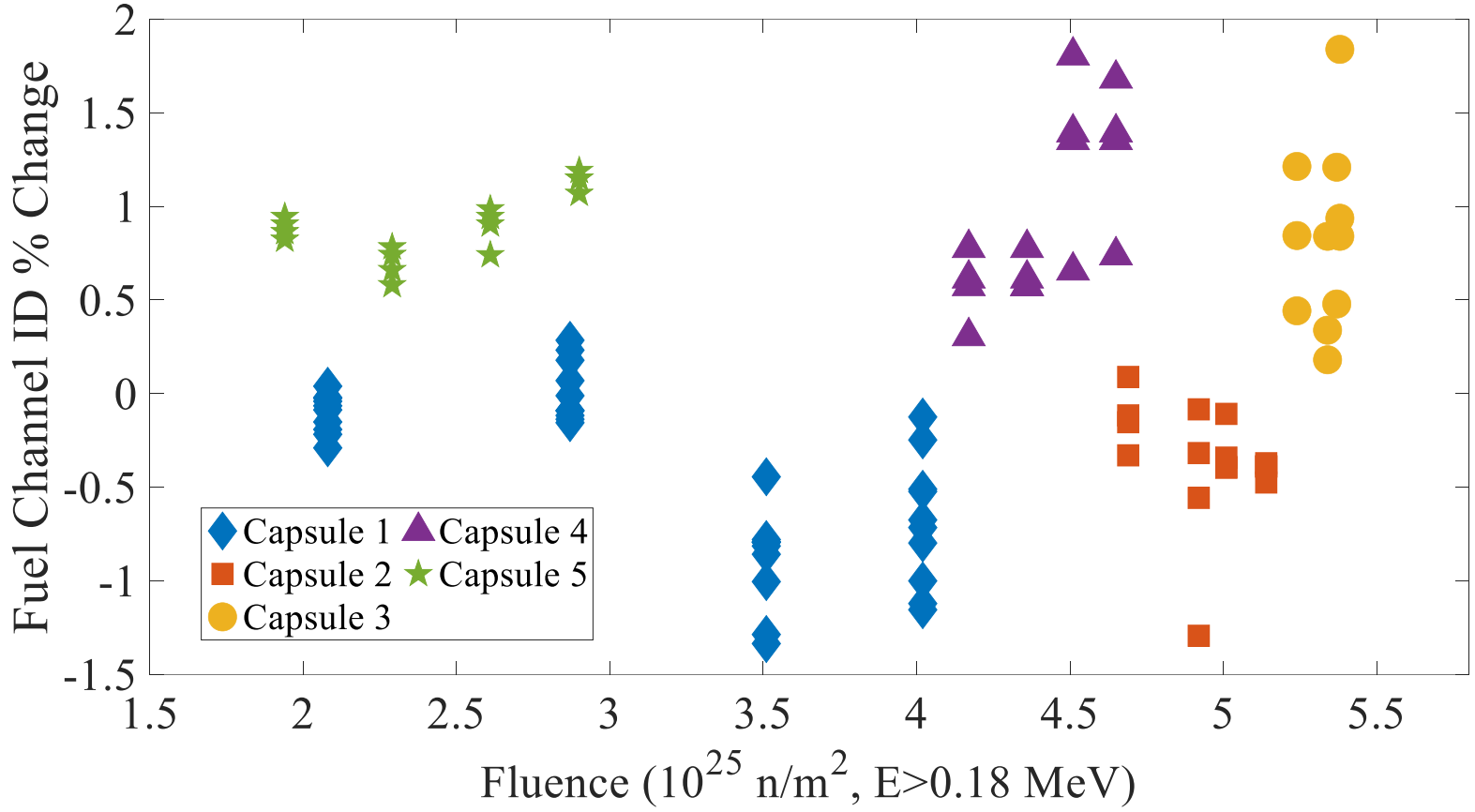
- At the similar fluence, the hotter compacts from Capsule 3 have length shrinkage while the cooler compacts from Capsule 2 have length expansion.

# Fuel Compacts - Length




- Trends are generally consistent among all AGR campaigns.
- The high fluence low temperature realm covered by AGR-5/6/7 Capsules 2 and 4 is different than in prior experiments

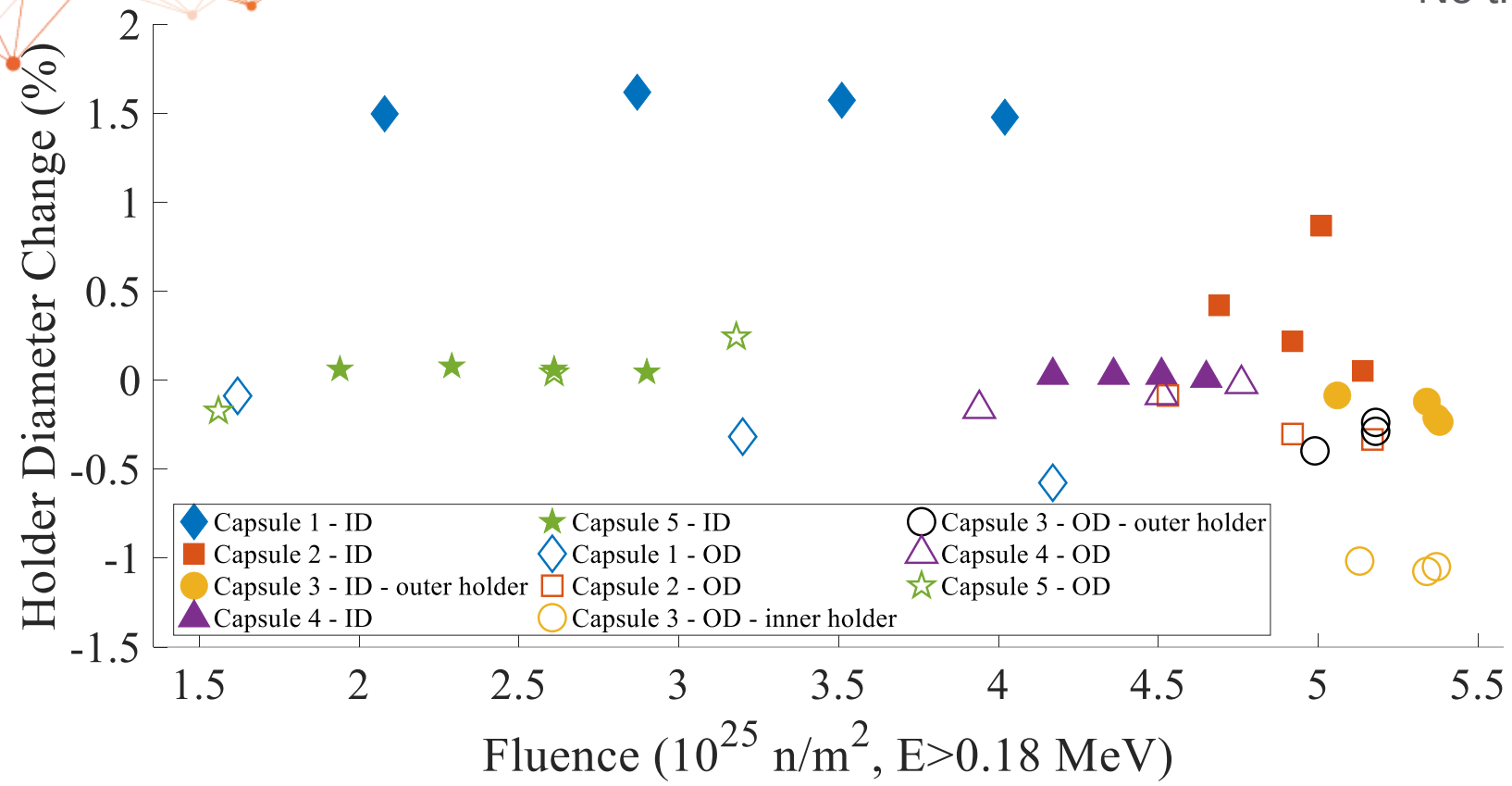
# Graphite Holder - Fuel Channel ID



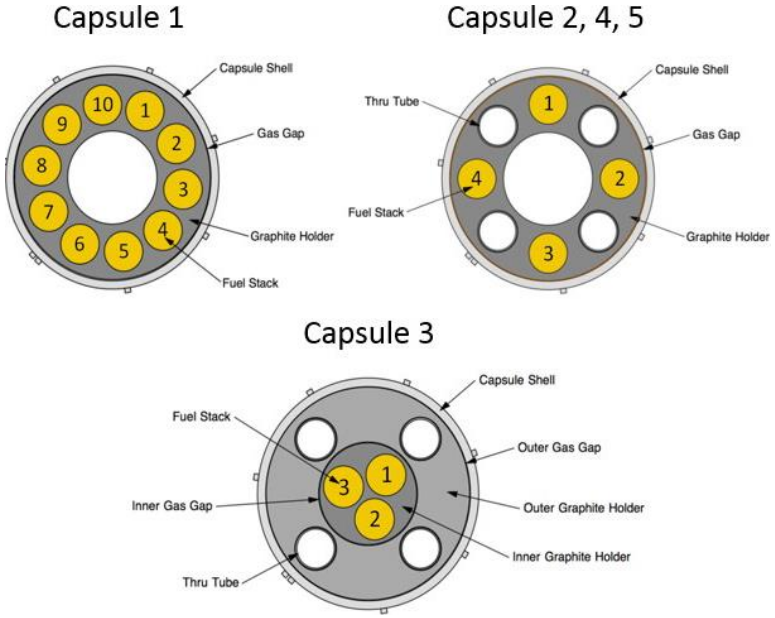

- The fuel hole diameter in Capsules 1 and 2 exhibit reductions. The largest compact diameter is less than the smallest measured fuel hole diameter, so there is no hard contact between fuel compacts and graphite holder .

- There is no clear dependence of fuel hole diameter changes as a function of dpa, irradiation temperature, or fluence.

# Graphite Holder - Diameter




No through tubes




Inner holder: no through tubes and annulus

- The ID and OD changes are not strongly related with the irradiation temperature and fluence.
- The differences in structure and geometry of graphite holders likely have some effect on the dimensional change.

# Summary

- The disassembly and metrology work for AGR-5/6/7 is complete.  Initial analysis of deposits on the graphite holder of Capsule 1 confirmed the existence of nickel, which was mostly likely from overheated thermocouples.
- The fuel compact dimensional changes are related to both fast neutron fluence and TAVA temperatures.
- For the graphite holders, the fuel channel diameter change, ID change, and OD change did not seem to be strongly correlated with the irradiation temperature and fluence. The differences in structure and geometry of graphite holders likely have some effect on the dimensional change.
- These dimensional changes are generally consistent with what has been observed in prior AGR campaigns.
- These dimensions will be fed back into the thermal model to refine the calculations.


Idaho National Laboratory