Post Irradiation Examination of Yttrium Hydride Moderator

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INL Idaho National Laboratory | Oak Ridge National Laboratory | MRP Microreactor Program | Los Alamos National Laboratory | Argonne National Laboratory

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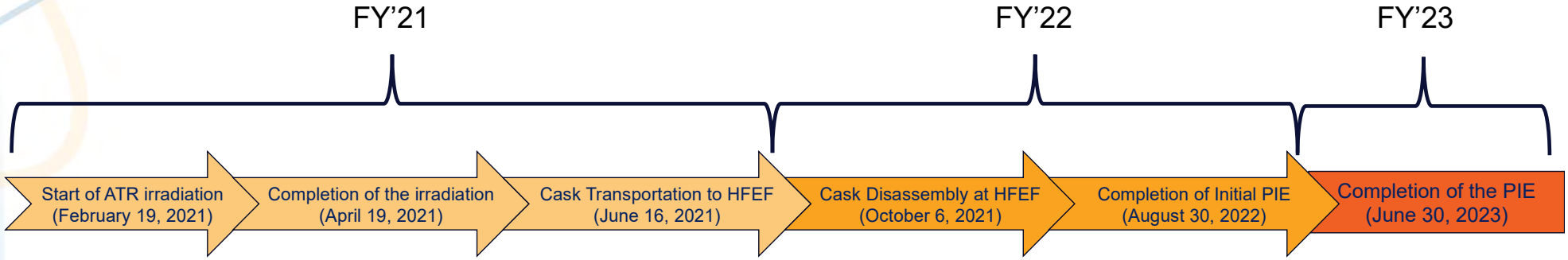
Schedule | We Are On Track! | 60% of Planned PIE for FY'23 Is Complete



- M2AT-23IN0804021: Complete integration of ATR irradiated sample PIE into advanced moderator handbook
- M3AT-23IN0804022: Complete hydrogen measurements on irradiated YH samples

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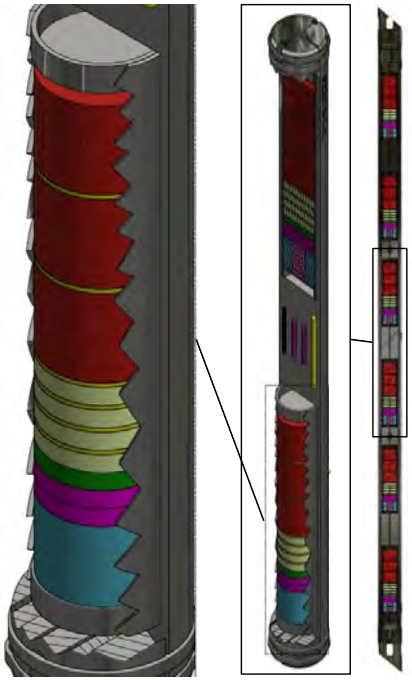
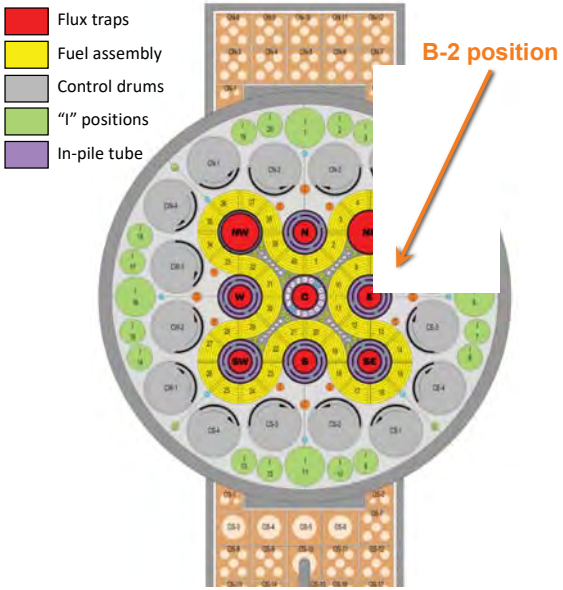
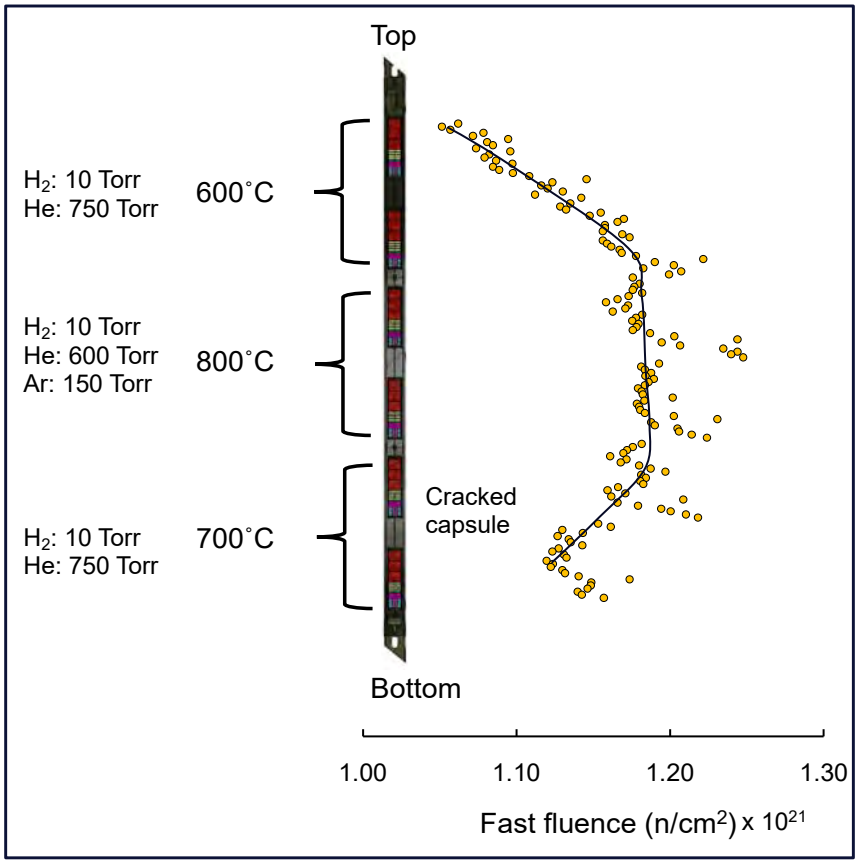
Advanced Test Reactor Irradiation (ATR) (FY'21)

- ***Samples | 102 yttrium hydride specimens | 36 TZM foils***
- ***Two fabrication paths | Direct hydride and Powder metallurgy***
- ***Target temperatures | 600, 700, and 800˚C***
- ***Irradiation conditions | 60 full power days***







PIE focuses on the structural stability and predictable behavior of moderator

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Status of the Post-Irradiation Examination Activities

1- Geometrical and structural stability

Neutron radiography (FY'22) ✓
Visual examination of assemblies, capsules, and samples (FY'22) ✓
Metallography and electron microscopy of yttrium hydrides (FY'23) → 60% is complete

2- Predictable behavior

Assessment of hydrogen behavior/content

Yttrium hydride mass, volume, and density measurements (FY'22) ✓
Hydrogen content measurement to assess hydrogen content (FY'23) → 60% is complete
X-ray diffraction measurements to assess hydride and metal phases (FY'23) → 60% is complete

Thermal properties

Thermal diffusivity and heat capacity investigations (FY'23) → 60% is complete

Post-Irradiation Examination activities is complete by 60%

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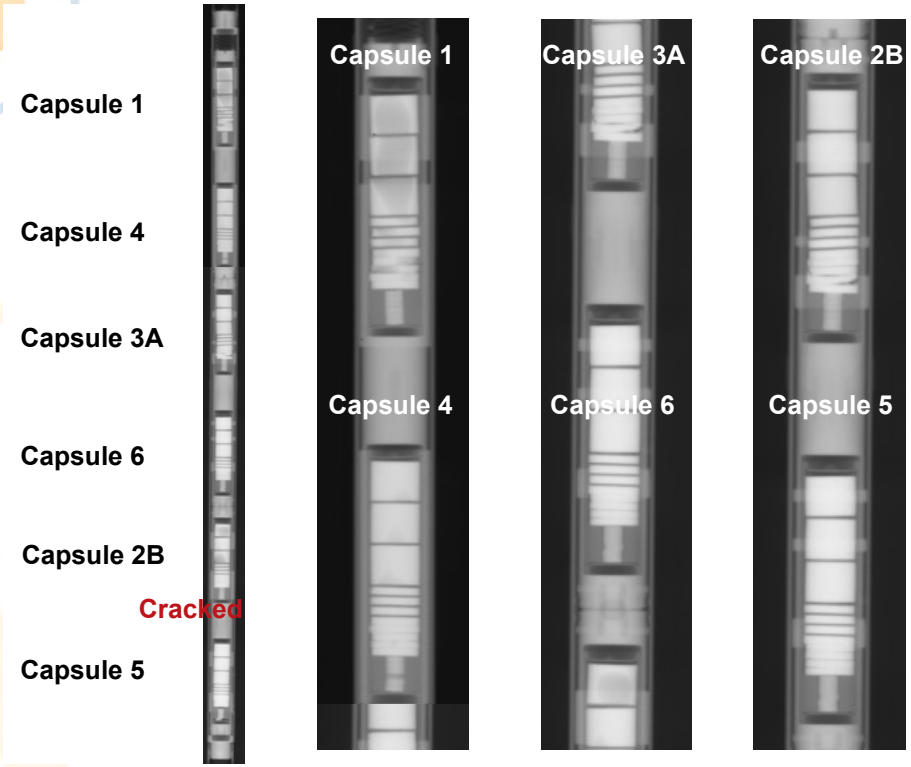
Geometrical and Structural Stability: Neutron Radiography & Visual Examinations (FY'22) | Completed



After capsule opening

Specimen name	Capsule identifications					
	600-1	700-2B	800-3A	600-4	700-5	800-6
RUS1	Intact	Intact	Intact	Intact	Intact	Intact
RUS2	Intact	Intact	Intact	Intact	Intact	Intact
RUS3	Intact	Intact	Intact	Intact	Intact	Intact
GDOES1	Intact	Intact	Intact	Powdered	Intact	Intact
GDOES2	Intact	Intact	Intact	Powdered	Intact	Intact
GDOES3	Intact	Intact	Intact	Powdered	Bonded to TZM	Intact
GDOES4	Intact	Intact	Intact	Powdered	Intact	Intact
GDOES5	Intact	Intact	Broken	Powdered	Intact	Intact
TEM1	Intact	Intact	Intact	Intact	Intact	Intact
LFA1	Intact	Intact	Broken	Intact	Intact	Intact
LFA2	Intact	Intact	Intact	Intact	Intact	Intact
DSC1	Intact	Intact	Bonded together	Intact	Intact	Intact
DSC2	Intact	Intact		Intact	Intact	Intact
DSC3	Intact	Intact		Intact	Intact	Intact
DSC4	Intact	Intact	Bonded together	Intact	Intact	Intact
DSC5	Intact	Intact		Intact	Broken	Intact
DSC6	Intact	Intact	Intact	Intact	Intact	Intact

Neutron radiography provides an essential information on the geometrical and structural stability

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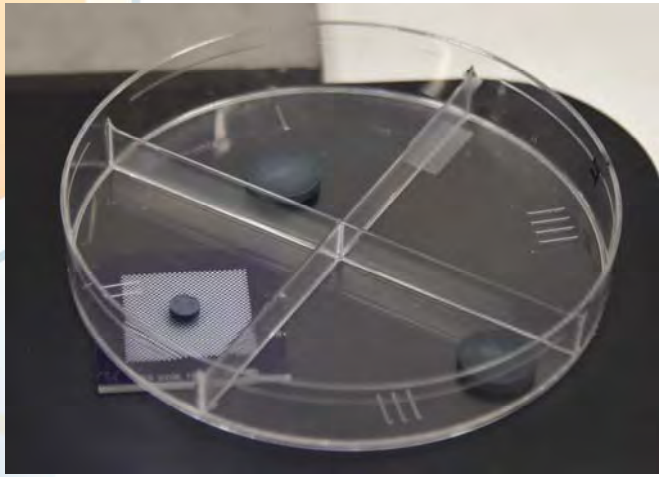
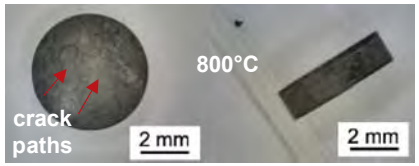
Geometrical and Structural Stability: Optical Examinations of Samples (FY'22) | Completed

TZM: Titanium-zirconium-molybdenum alloy

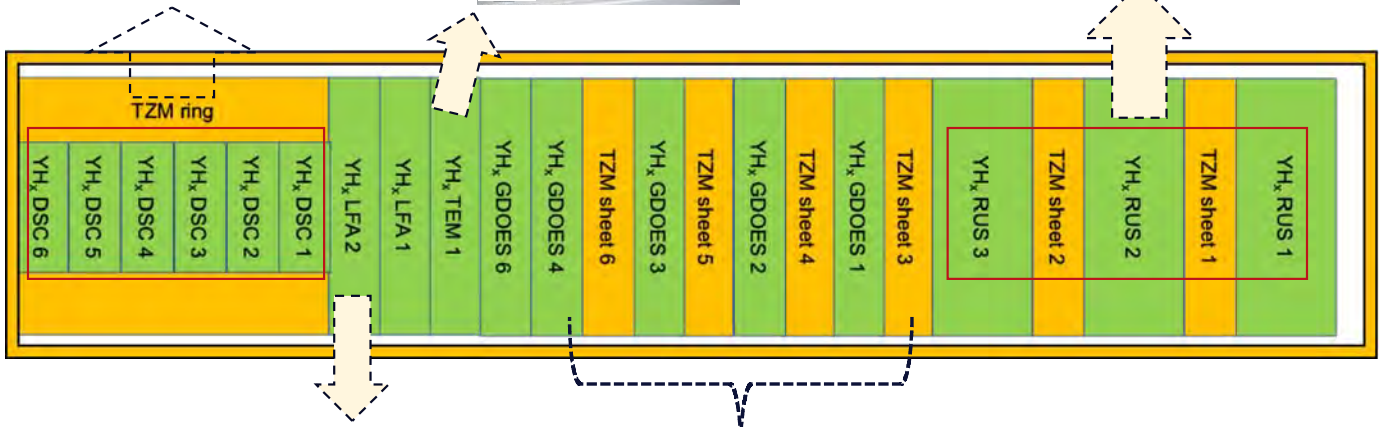


No significant interaction with TZM on the lateral surface

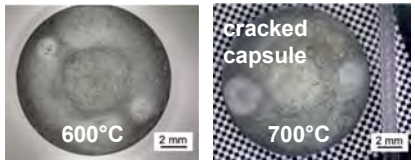


Some sample had bulk discoloration, likely caused by the initial fabrication or some hydrogen loss, No bulk molybdenum diffusion determined

These samples are still at main hotcell due to dose limitations of the PIE facilit



Only shadow interactions limited to specimen surface



No significant TZM/YHx interactions are observed for most of the samples, All surface limited

No critical TZM/YHx interaction was determined, most of the interaction was limited to the surface

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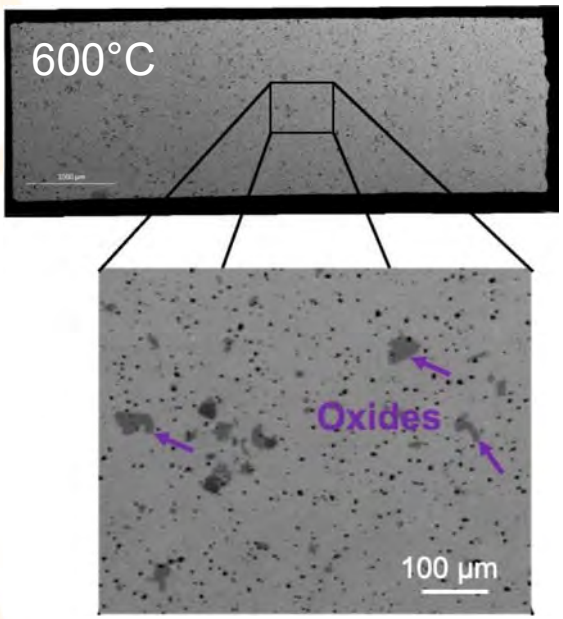
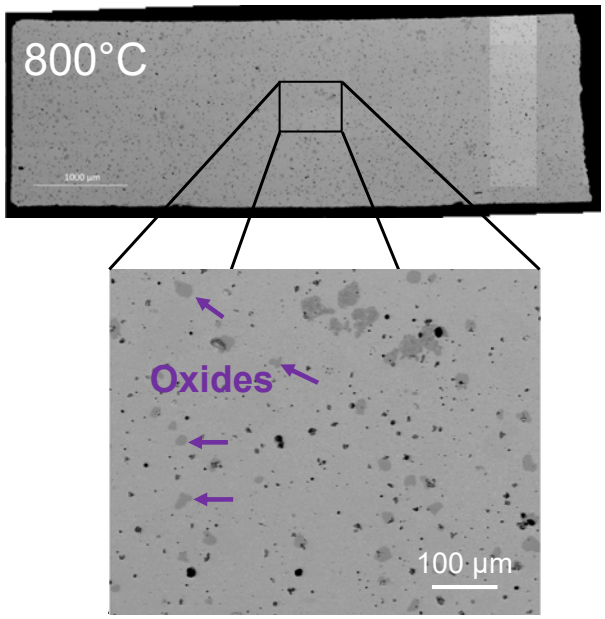
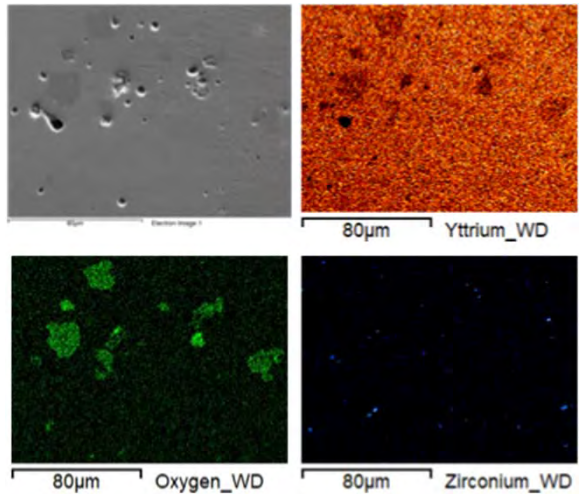
Geometrical and Structural Stability: Metallography of Samples (FY'23) | 70% is complete





Elemental distribution in an oxide



Closed porosity formed as a result of manufacturing (or void formation due to irradiation) improves hydrogen retention

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Predictable Behavior: Thermal Properties (FY'23) | 60% Complete | We Are On Track

$$k = \alpha \rho c_p$$

Heat capacity
(Differential scanning calorimetry)

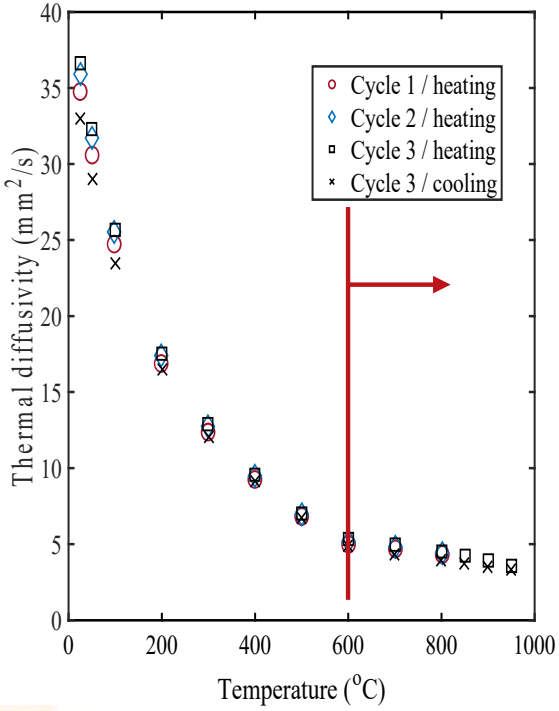
$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T$$

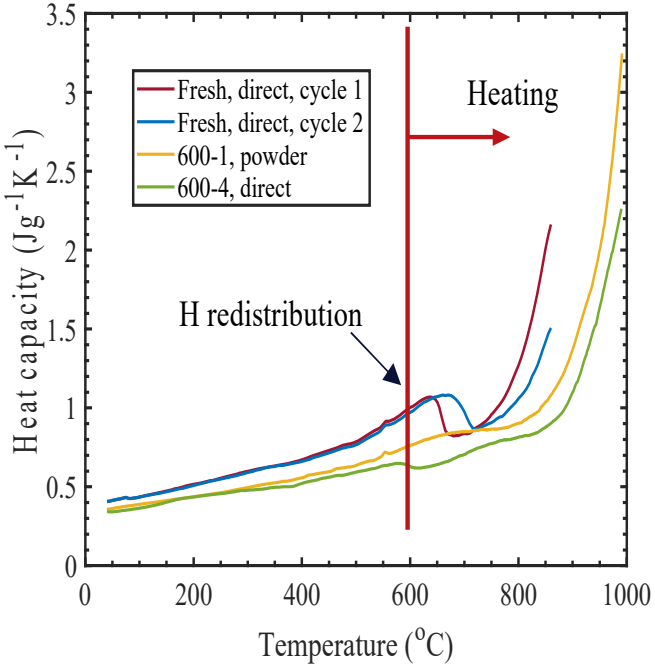
Thermal diffusivity
(Laser flash analysis)

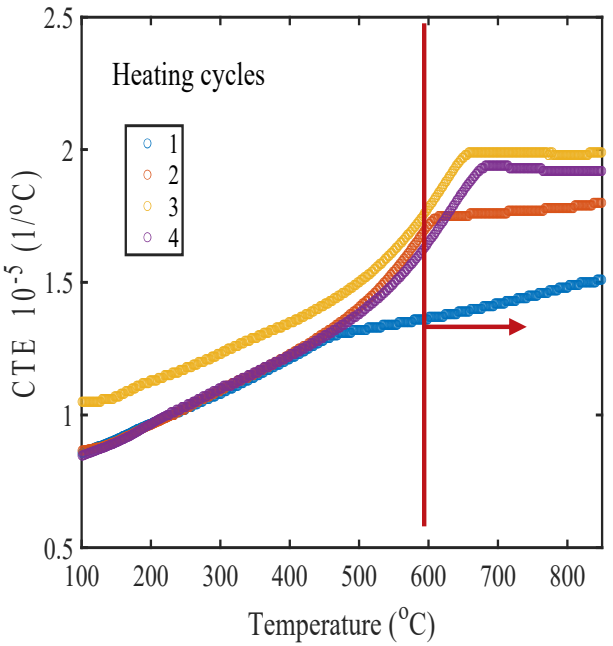
$$\rho(T) = \rho_o(1 + \alpha_T(T - 25))$$

Density @ 25˚C
(Gas pycnometer)

Linear thermal expansion coefficient
(Dilatometry)







FY'23 focus is LFA and DSC; dilatometry samples are not included in the current PIE due to dose levels

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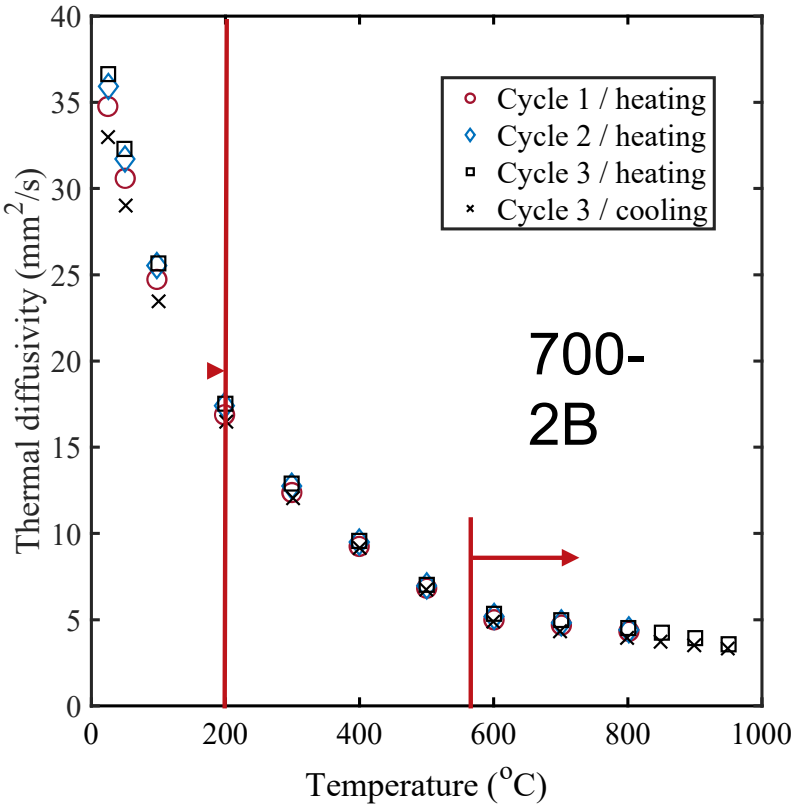
Predictable Behavior: Thermal Properties (FY'23) | Quick Takeaways Are:

Laser Flash Analysis (LFA) is used to determine thermal diffusivity

Above 600°C, thermal diffusivity can be treated as linear or constant

Below 200°C, impact of hydrogen and/or irradiation damage is detectable



High temperature thermal diffusivity is not a strong function of irradiation (based on diffusivity data of all irradiated specimen)

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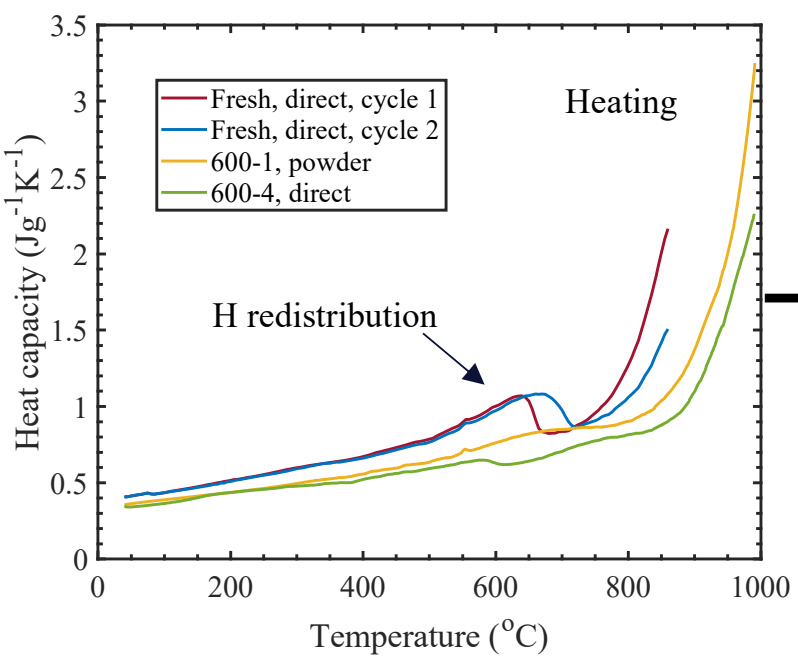
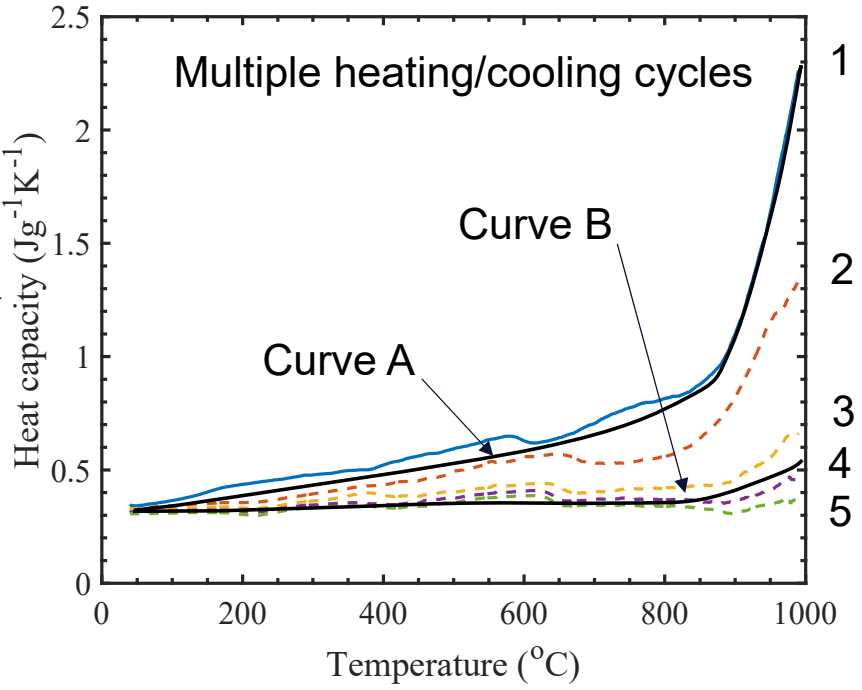
Predictable Behavior: Thermal Properties (FY'23) | Quick Takeaways Are:

Hydrogen redistribution/mobility in the yttrium hydride moderator needs to be addressed

Multiple heating/cooling to see hydrogen loss at 1000°C





Solving heating equation require careful numerical treatments for heat capacity and thermal expansion coefficient

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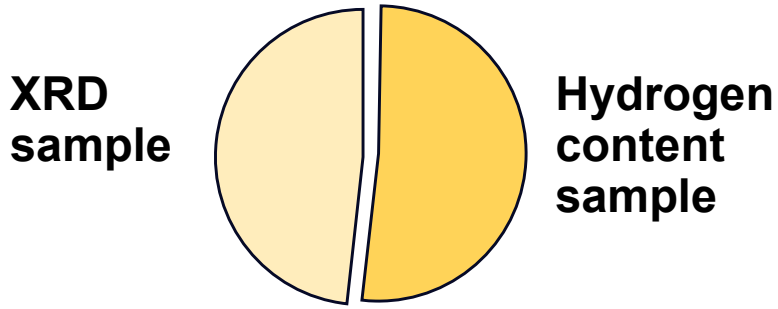
Hydrogen Content and X-ray Diffraction (XRD) Measurements | 60% is complete

Hydrogen content measurements and XRD will be performed on the same specimen

XRD measures the volume fraction of phases which is good indicator for hydride phase stability

All specimens were sectioned into two for hydrogen measurements and XRD, we are collecting data to provide comparison



We are on track for the completion of the hydrogen content measurement milestone

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Main Takeaways Are:

- ***Up-to-date PIE indicates yttrium hydride have good irradiation performance***

- ***We are on track for completion of planned PIE activities,***
- ***Milestone data collection is 60% complete***
- ***Milestone report writing has been initiated***

- ***Hydrogen redistribution needs to be accounted by fuel performance codes with proper numerical techniques***

Cladding technologies | hydrogen permeation barriers to ensure the moderator performance for long operation durations

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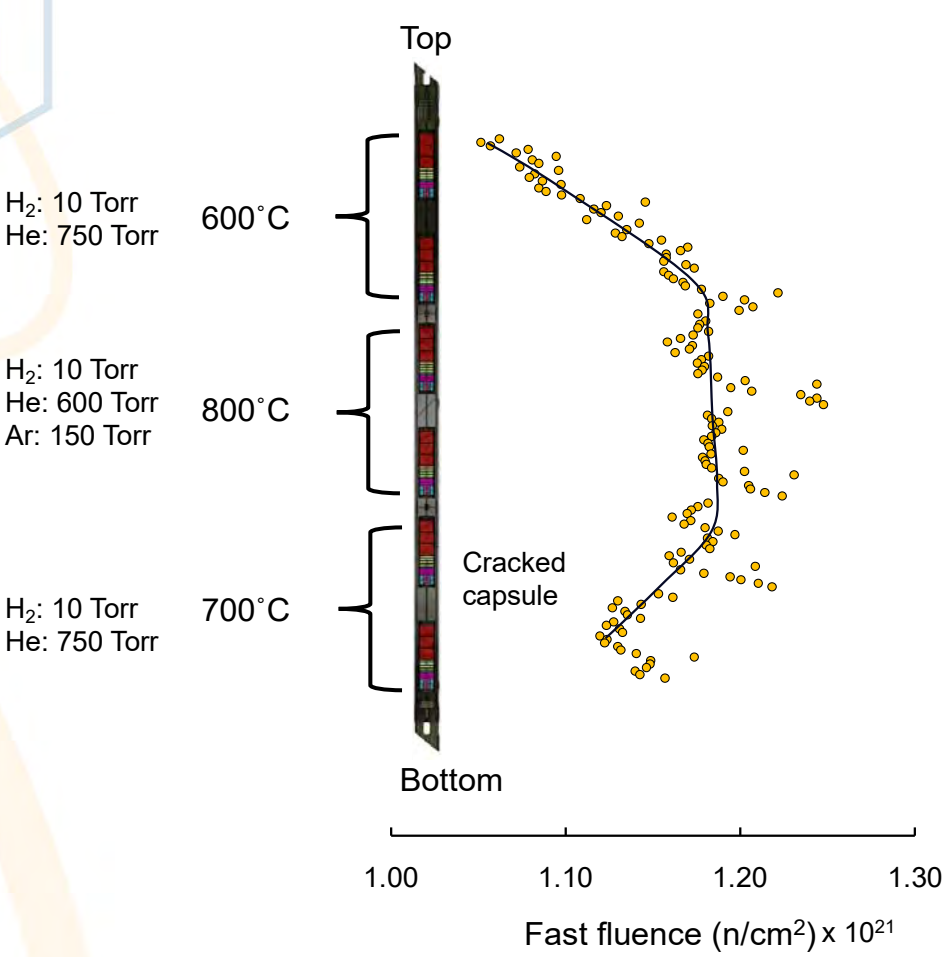
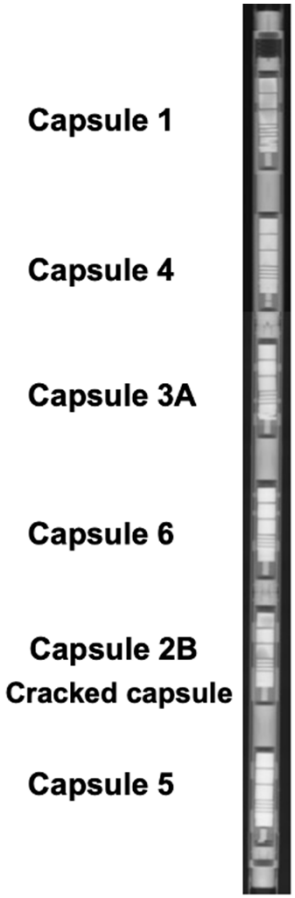
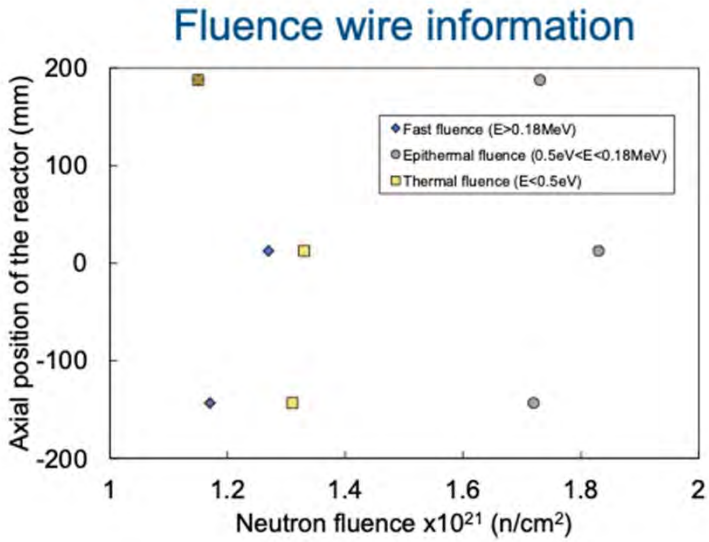
Reminder | Irradiation Design







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