Transforming Microreactor Economics Through Hydride Moderator Enabled Neutron Economy

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Project goals and objectives

Goals

- Demonstrate significantly reduced fuel costs through novel microreactor designs enabled by the technical advancement of engineered hydride ceramic composite moderators.

Objectives

1. Fabricate stabilized entrained hydride moderators for continuous operation at 800 °C through neutronics informed optimization
2. Enhance the performance of an annular, spherically-shaped, and reflected core through these moderators and integrated design optimization
3. Produce entrained hydride composites up to 10 cm in diameter via DCS and map the spatial distribution of microstructure and properties,
4. Measure H desorption from the entrained hydride composites with a migration model developed for hydrogen transport in MgO
5. Quantify the trade-off cost with savings realized through reduced uranium loading and other factors pertinent to microreactors.

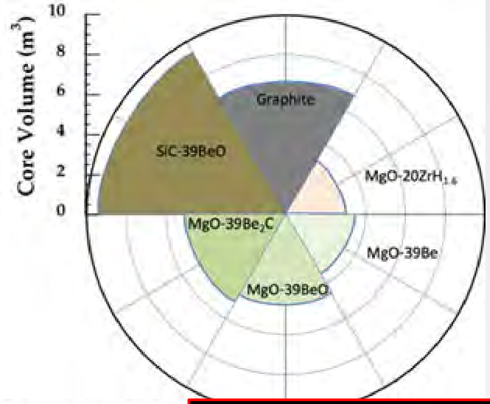
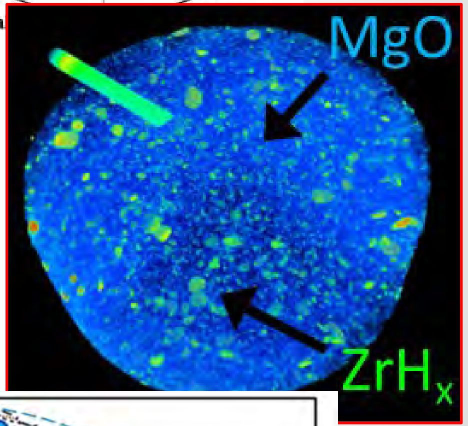
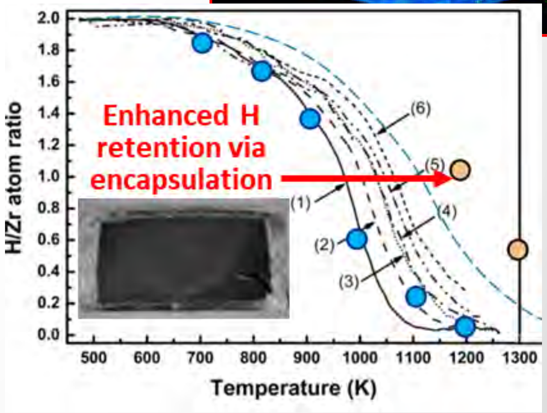


Figure 4: Core Critica





Project leadership

Jason Trelewicz, Associate Professor, Stony Brook University

- Project lead with a focus on fabrication and scaling of the entrained hydride moderator and reflector composites optimized for hydride loading, stability, and scalability to increase the technology readiness level (TRL).
- Model development for BISON on parameterizing the diffusivity models based on the experimental results for H/D transport and stability.

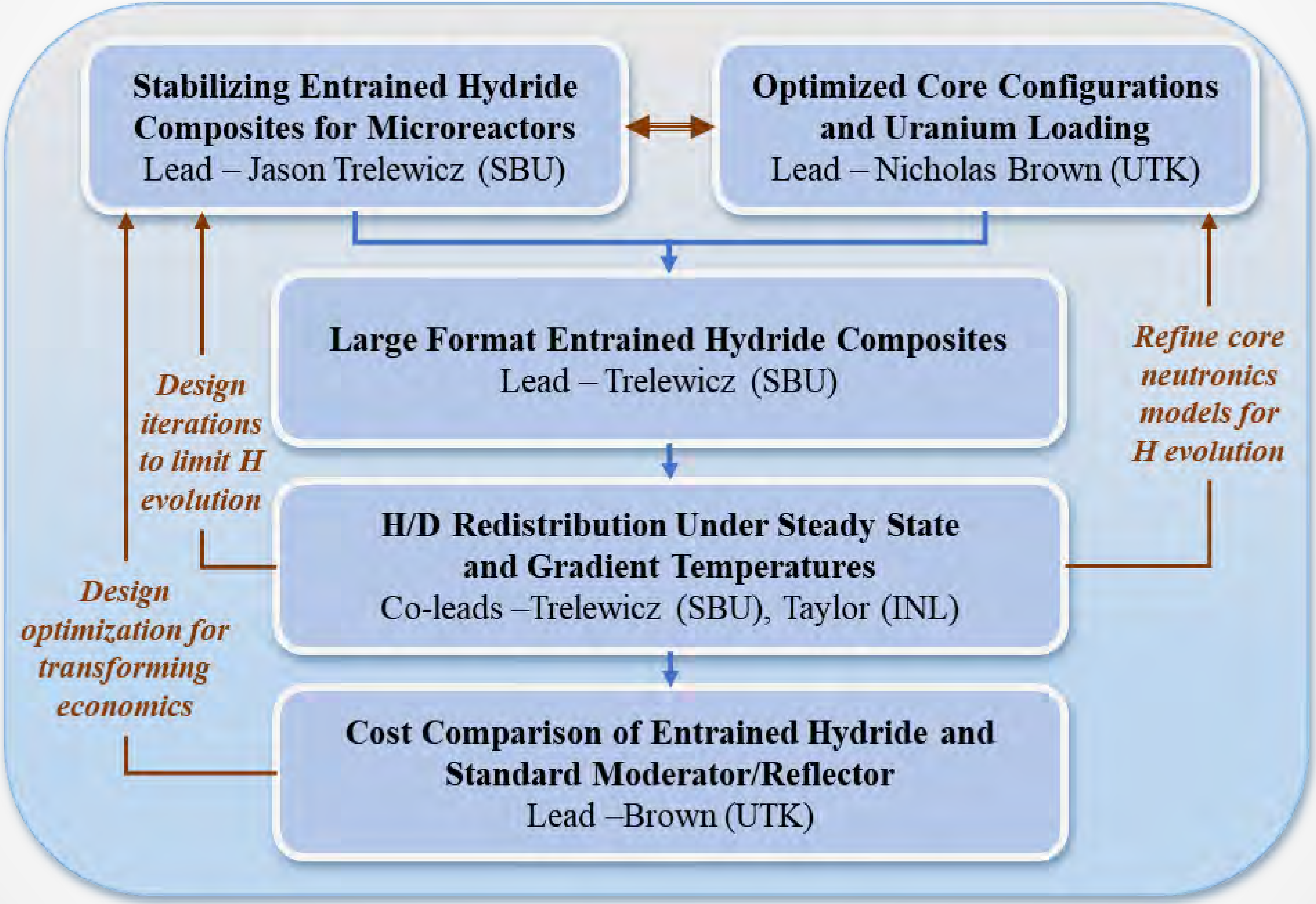
Nicholas Brown, Associate Professor, University of Tennessee Knoxville

- Reactor physics calculations to quantify the performance of the entrained hydride composites.
  - → *Represents a critical component to inform material development with the goal of defining an optimized a core configuration specific to these materials*

Chase Taylor, Senior Staff Scientist, Idaho National Laboratory

- Thermal desorption spectroscopy experiments to determine H/D transport in MgO and stability of various hydrides/deuterides entrained in MgO.
  - → *Represents important input for the H/D transport model and mapping overall stability of the hydride entrained compositions.*

Structure and task integration



Project schedule and milestones

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WBS	Task/Milestone Title	Start	End
Task 1a	**Microreactor-specific Entrained Hydride Development**	1	8
M1.1	Fabricate crack-free (ZrHx/YHx)-MgO composites	4	4
M1.2	Demonstrate stability at 800°C through an encapsulation barrier	8	8
Task 1b	**Optimized Microreactor Core Configurations and U Loading**	1	10
M1.3	Annular spherical core designs with composite moderators	5	5
M1.4	Technical report on fuel cycle performance with composites	10	10
Task 2	**Large Format Entrained Hydride Composites**	7	10
M2.1	Technical report on scaling of the entrained hydride composites	10	10
Task 3	H redistribution under steady state and gradient temperatures	3	11
M2.1	Hydrogen migration model for MgO within BISON	7	7
M2.2	Technical report on hydrogen desorption and transport properties	11	11
Task 4	**Cost Comparison of Hydride and Standard Technologies**	9	12
M4.1	Economic impacts report on entrained hydride composites	12	12

Restructured Milestones

1. Report on the fabrication of stabilized entrained hydride ceramic composites with hydride loading optimized based on the annular spherical core models and stability up to 800°C
2. Report on fuel cycle performance of the spherical cores optimized to exploit the enhanced neutron economy enabled by the hydride-entrained composite moderators and reflectors.
3. Report on hydrogen transport in the entrained hydride composites coupled with a hydrogen migration model for MgO and its impact on fuel cycle performance under transients.
4. Technical Report on Large Format Production of Entrained Hydride Composites

Technical approach – reactor physics calculations

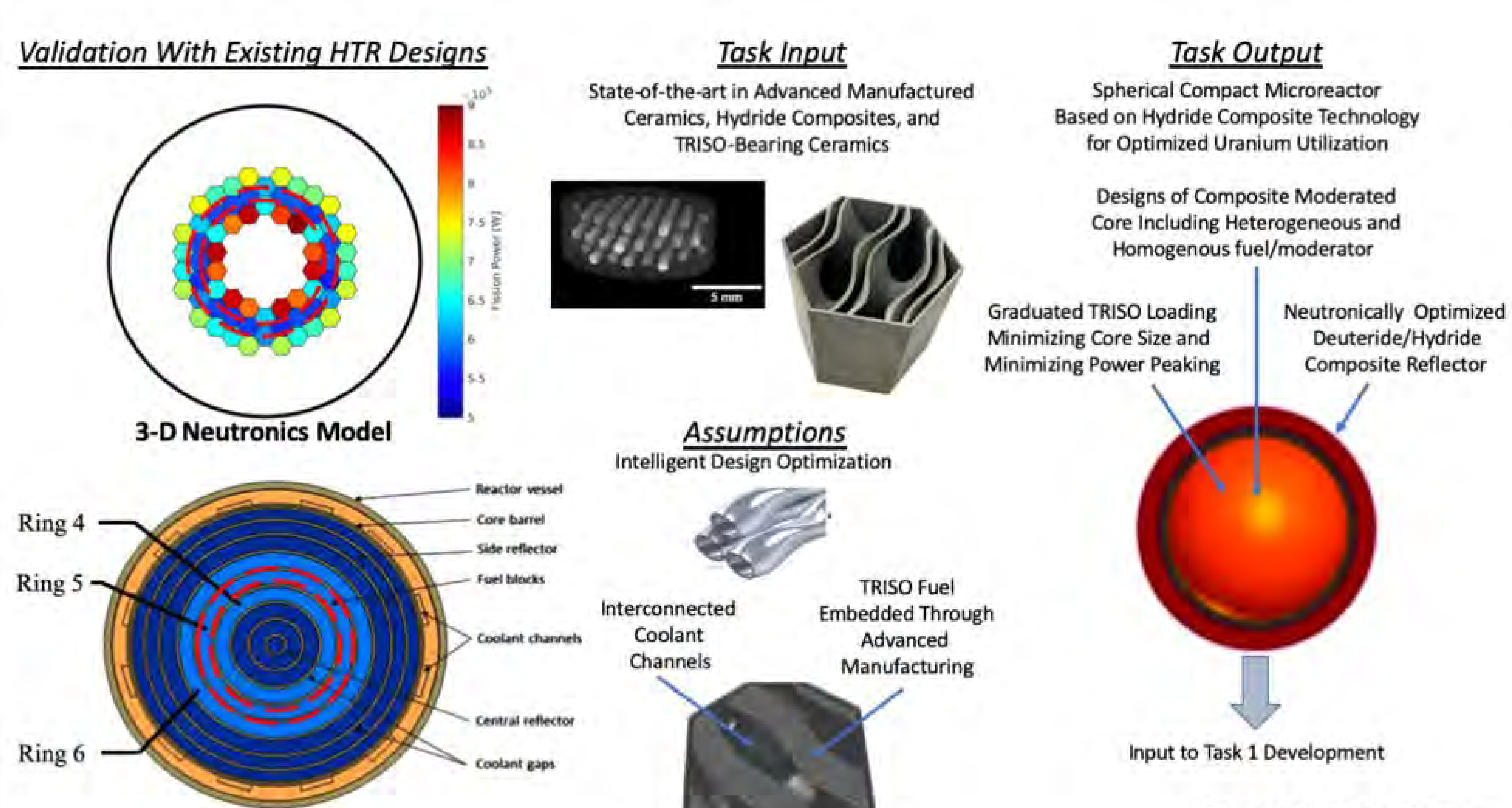
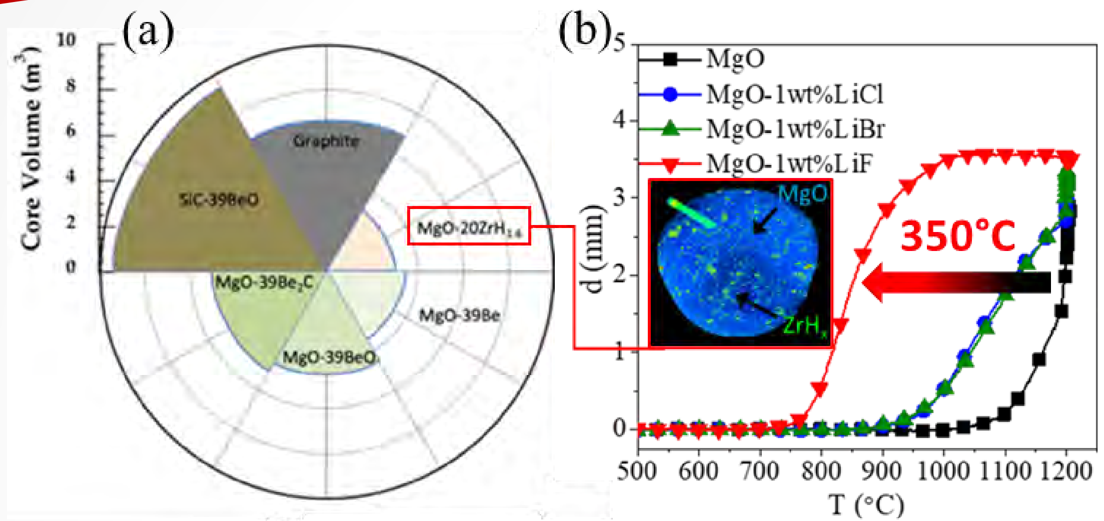


Figure 5: Task 2 Flow

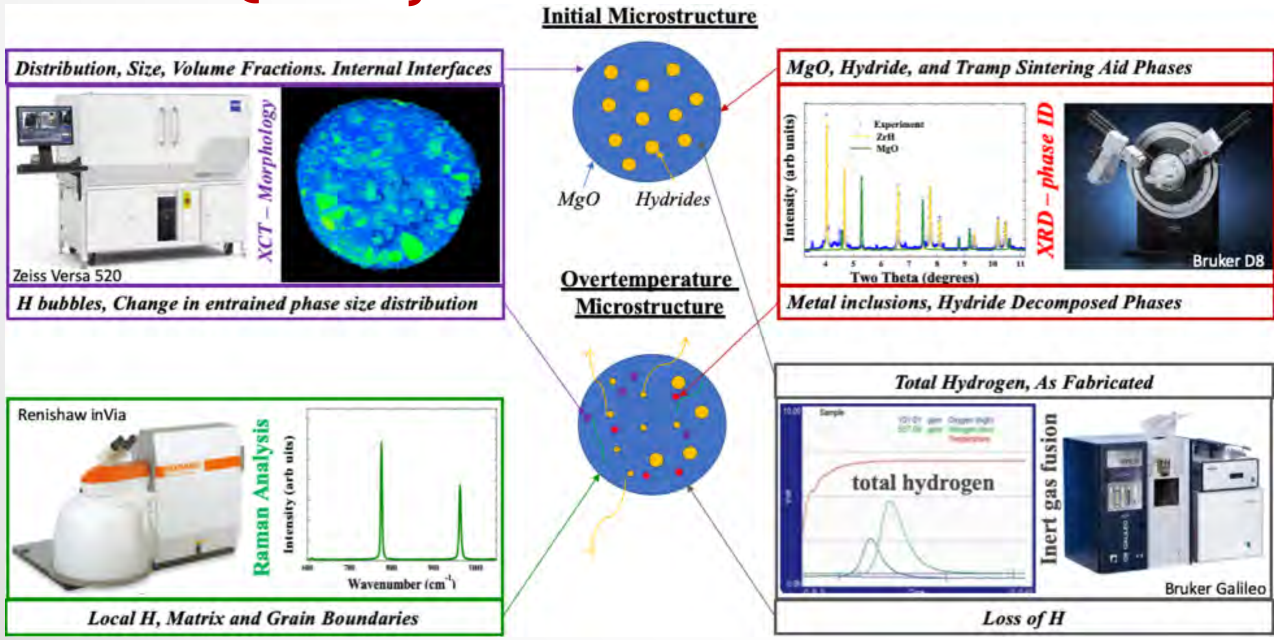
Technical approach – composite moderator development

Modeling informed composite fabrication



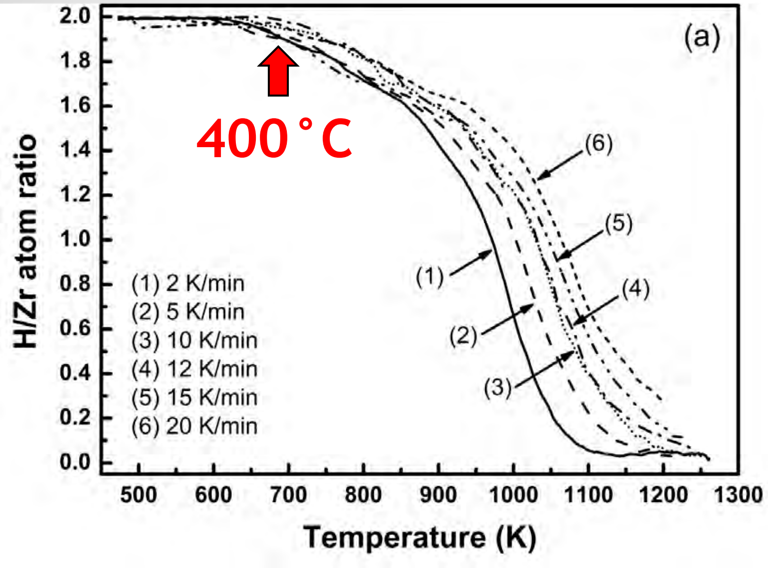
Cladding implementation

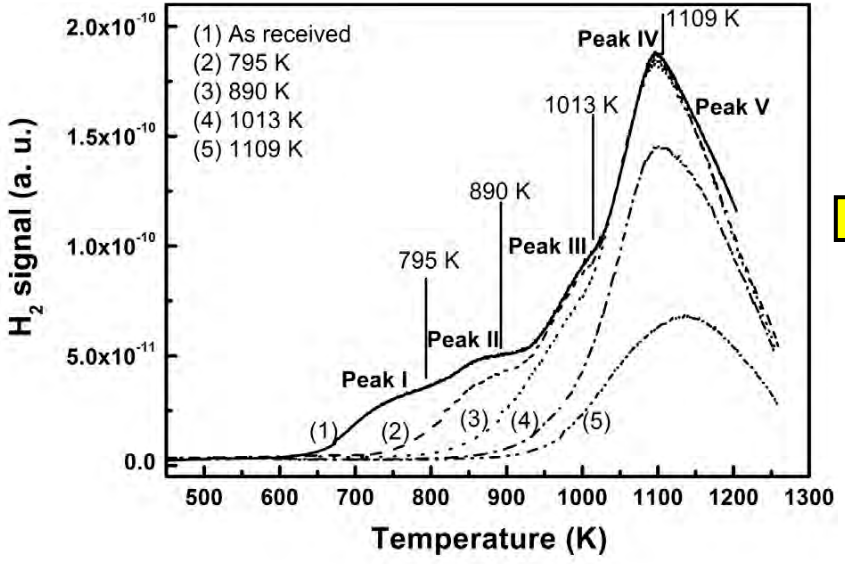
Quantify structural characteristics → Thermal stability

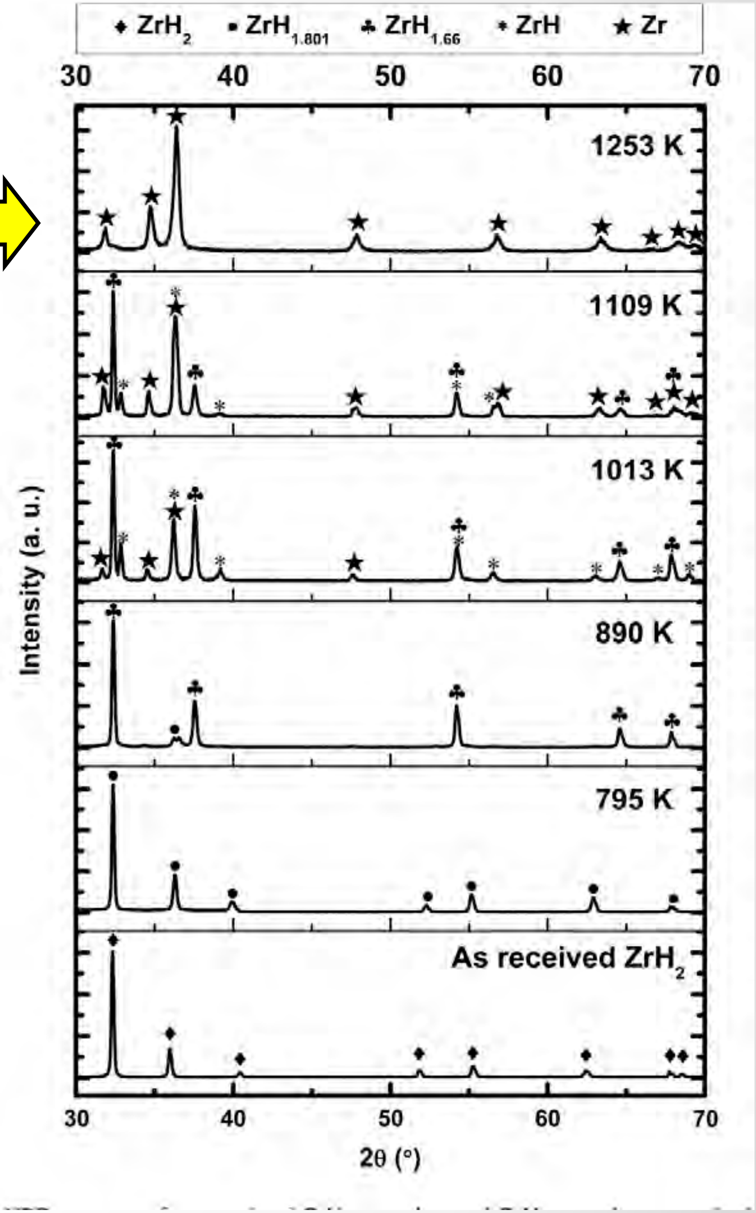


Hydride stability and retention

Background: thermodynamic limitations of ZrH_x







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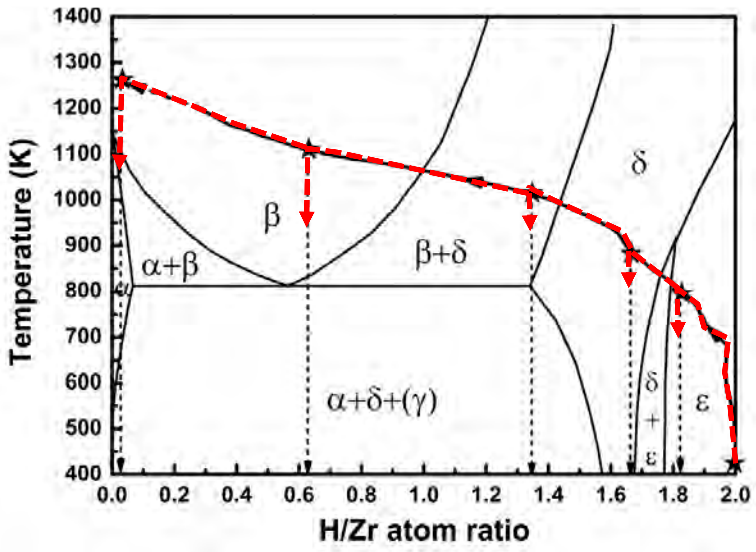

Hydride stability is intrinsically limited by thermodynamics, but what if we can suppress the desorption of hydrogen?

Ma et al. JAC 2015

Ceramic composites as engineered moderator/reflector materials

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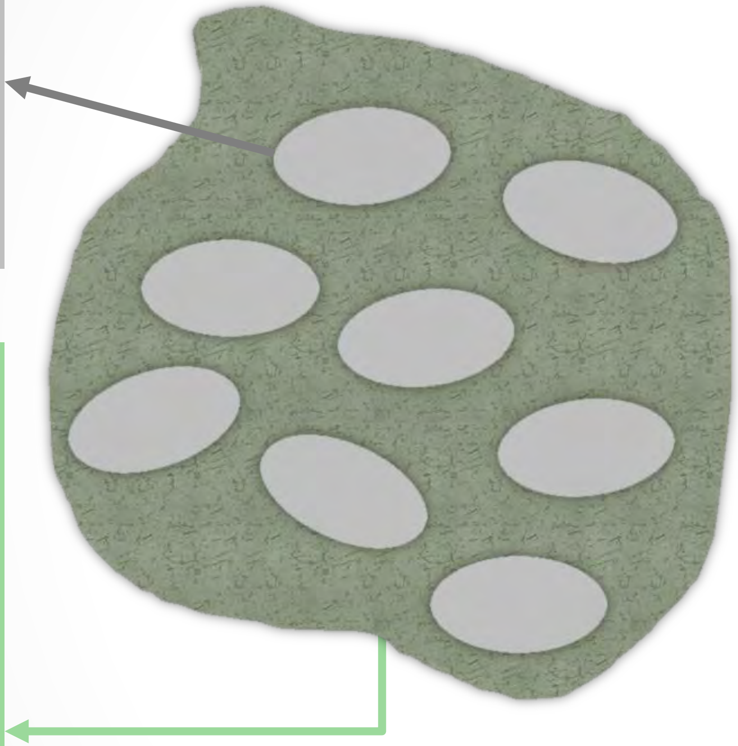
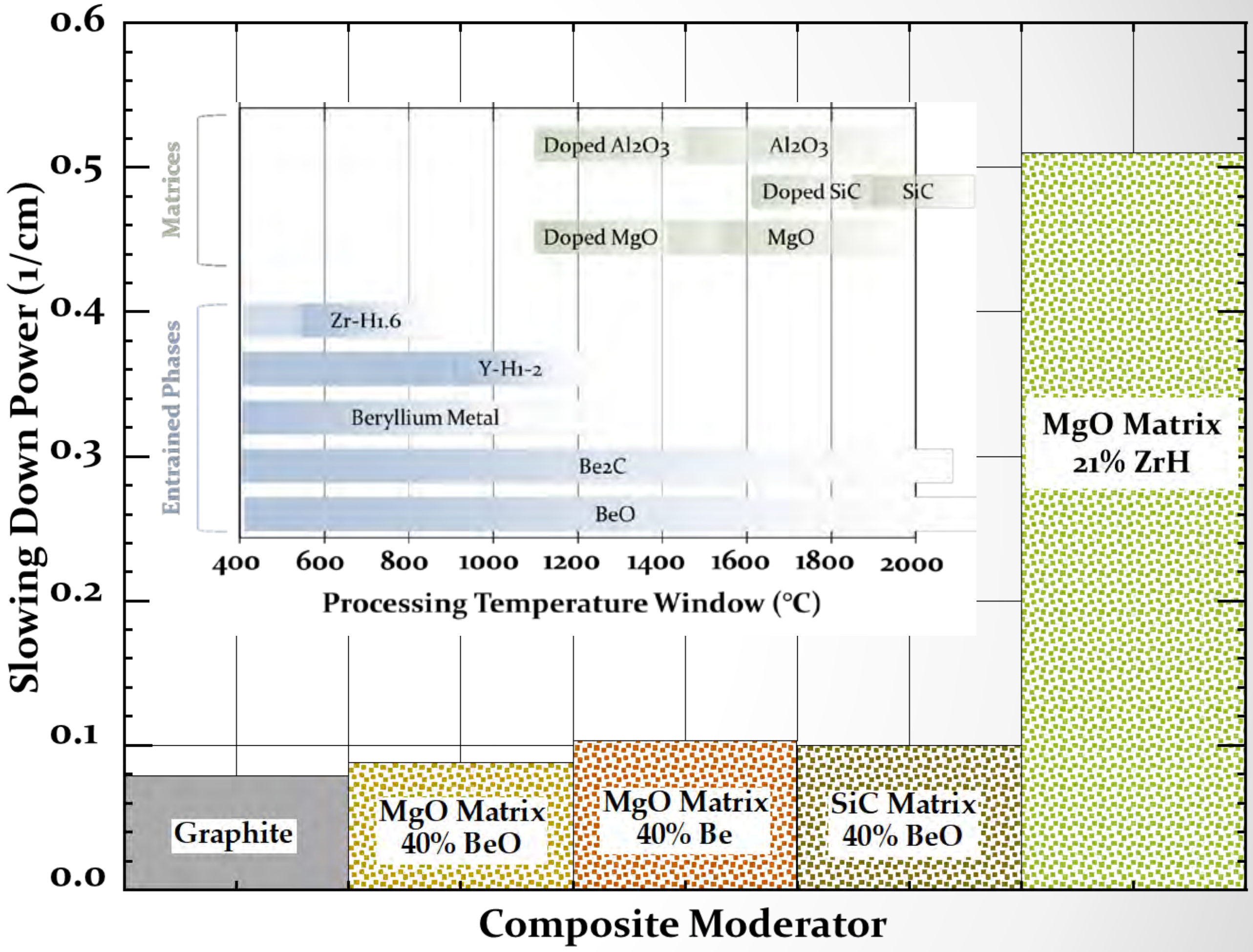
Entrained Phase

- High Moderation
- Low Neutron Absorption
- Fair Radiation Stability
- Low Transmutation



Matrix Phase

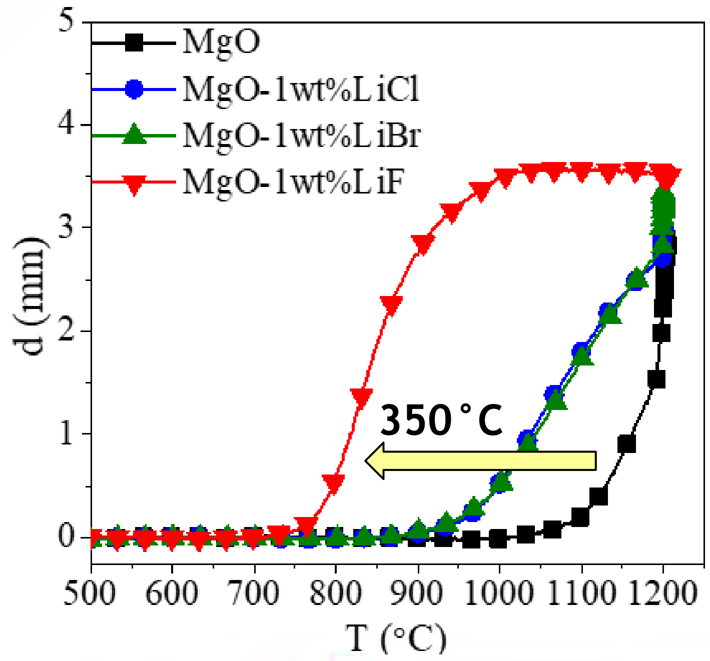
- Fair Moderation
- Low Absorption
- Good Radiation Stability
- Good Thermal Conductivity
- Good Compressive Strength
- Low Permeability

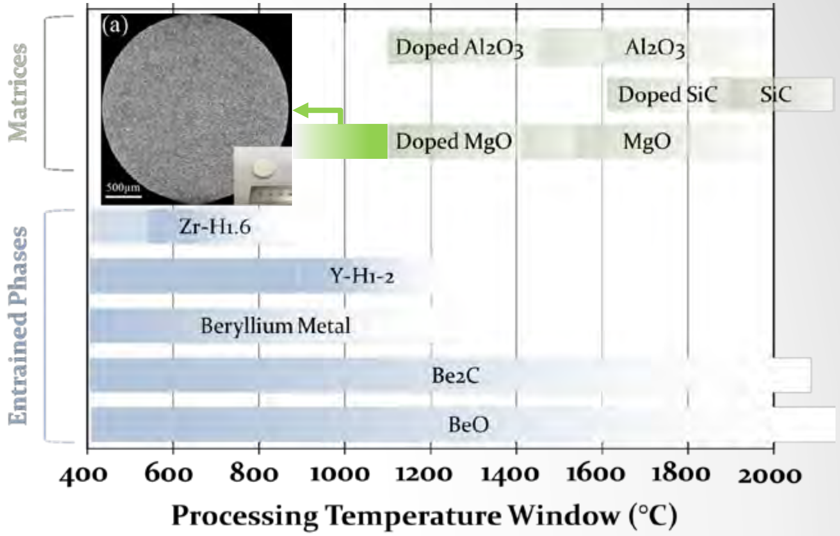


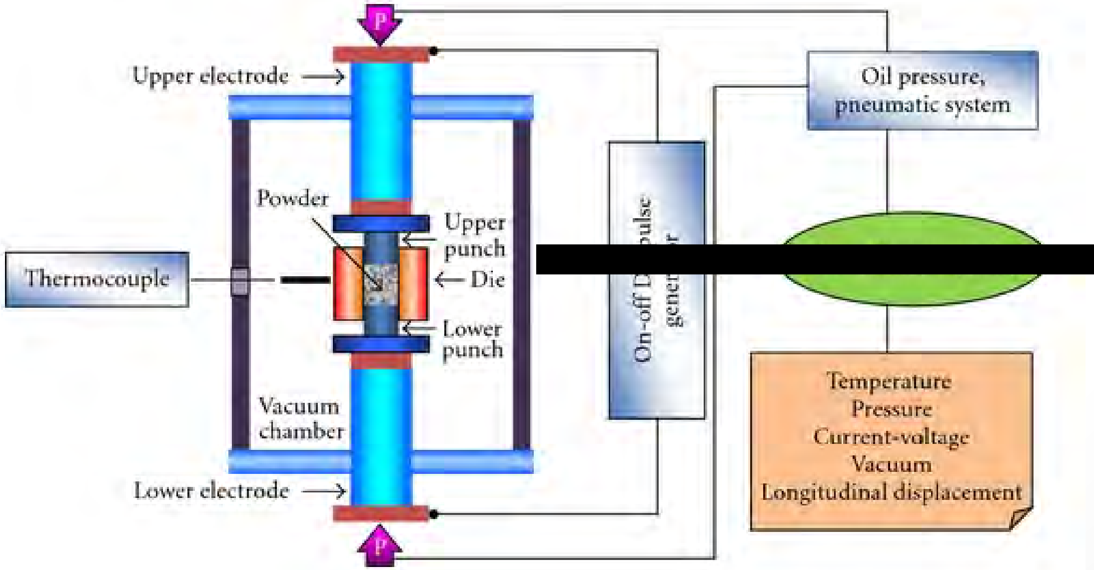
Manufacturing: ideally no chemical reactivity between the two phases with processing temperatures that do not decompose either phase and offer a pathway to economy of scale.

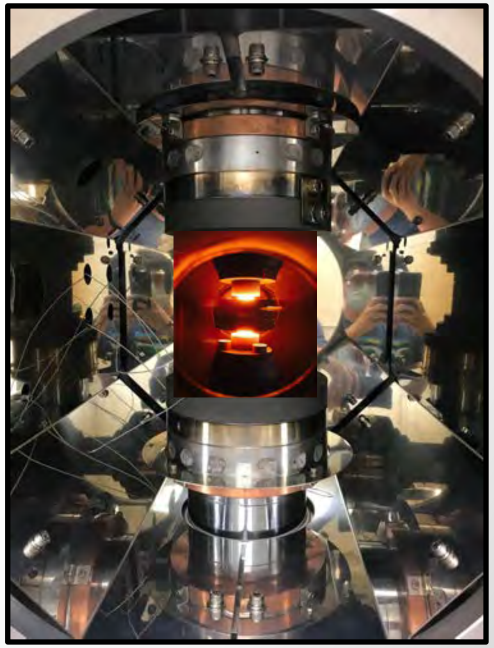
Tuning the sintering temperature of MgO

- MgO Feedstock
- Calcined at 500°C
- Calcined MgO Powder
- Li Salt
- Moderating Particles
- Mixed and Blended
- Homogenized Powder
- Cold-pressed under 100MPa
- Green Body
- DCS Sintering at 1100 °C
- Densified Body
- Purification Anneal at 1000 °C
- Nuclear Grade Composite Moderator





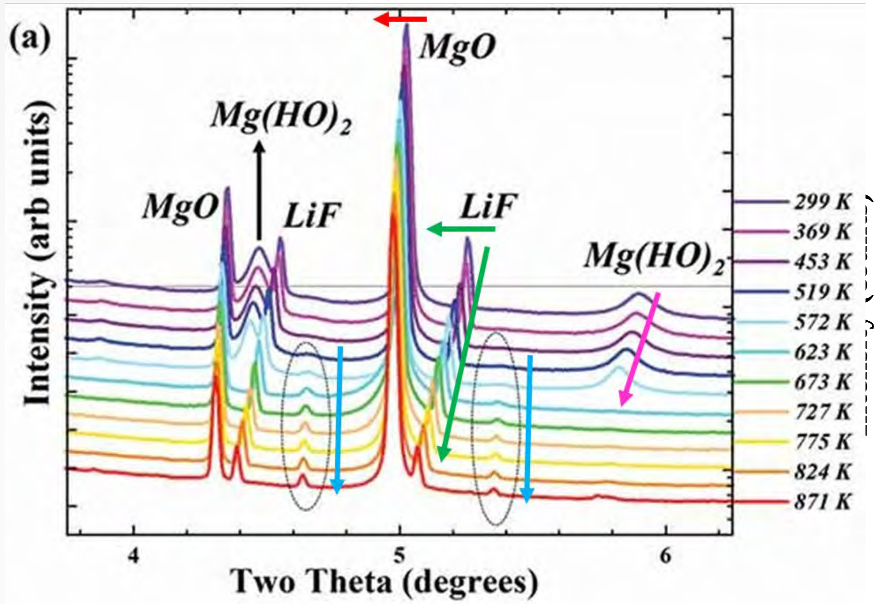


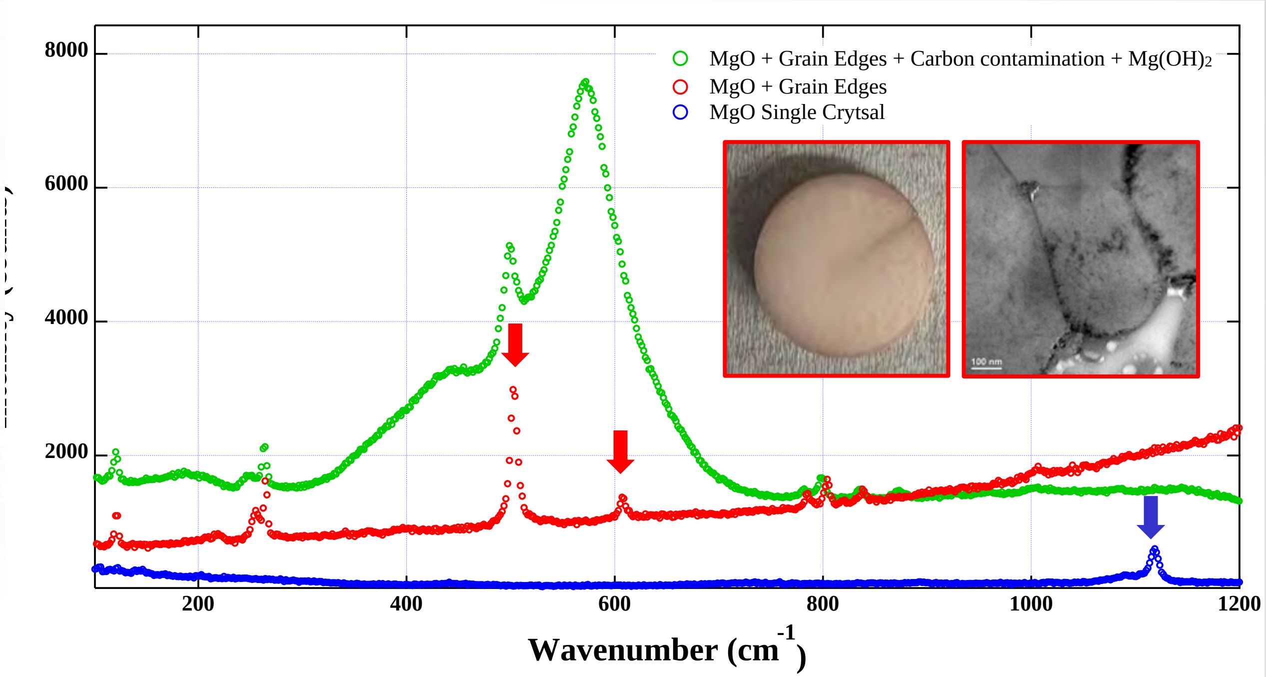


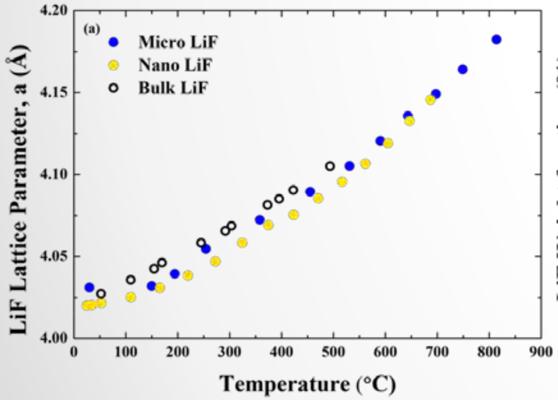
Understanding the reduction in the sintering temperature

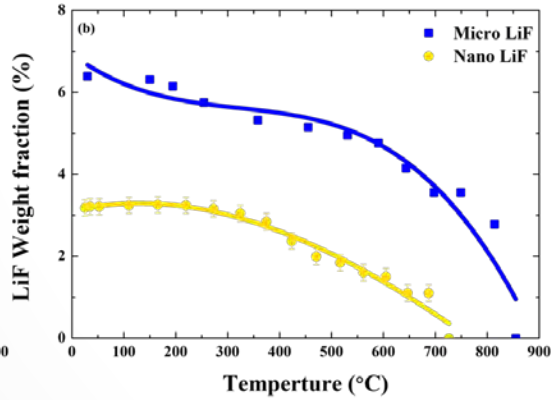
NSLS-II

XPD Beamline

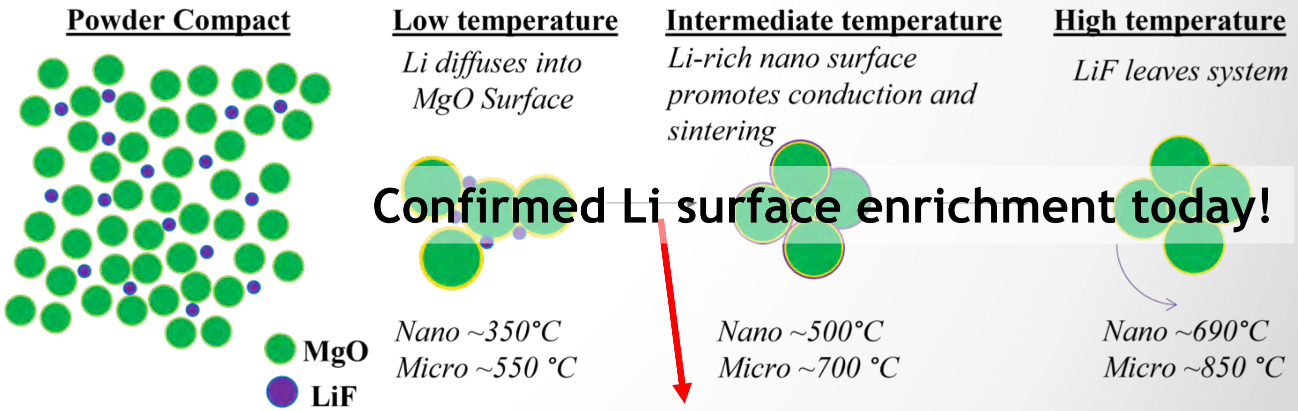








Decomposition of LiF and $Mg(OH)_2$ above 500 °C with no additional phase formation

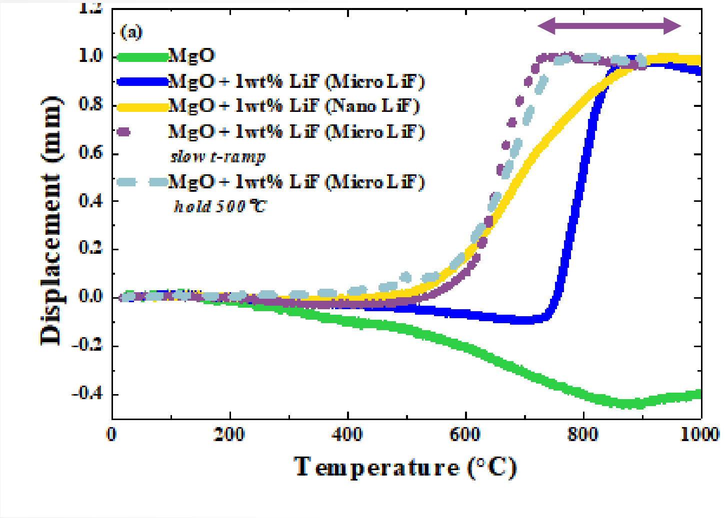


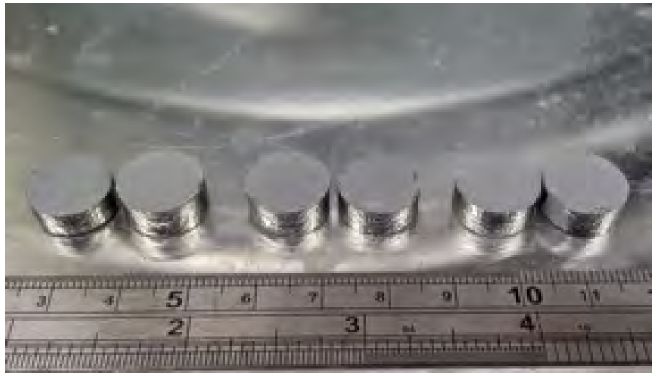
Confirmed Li surface enrichment today!

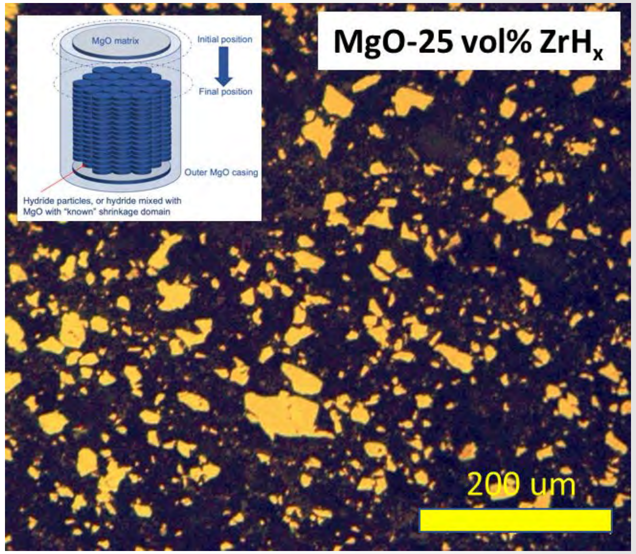
Mg^{2+} vs. Li^{1+} => charge balance necessitates the formation of oxygen vacancies

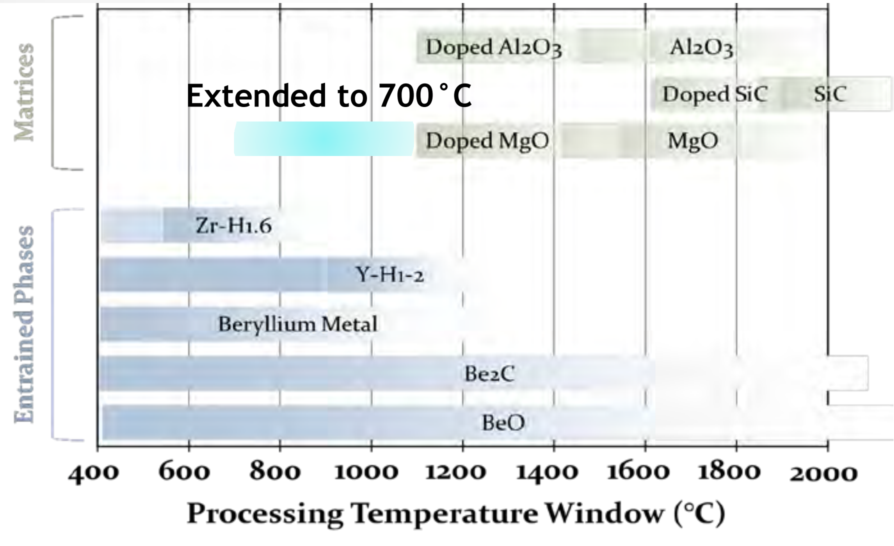
Exploiting the Li enhanced sintering kinetics

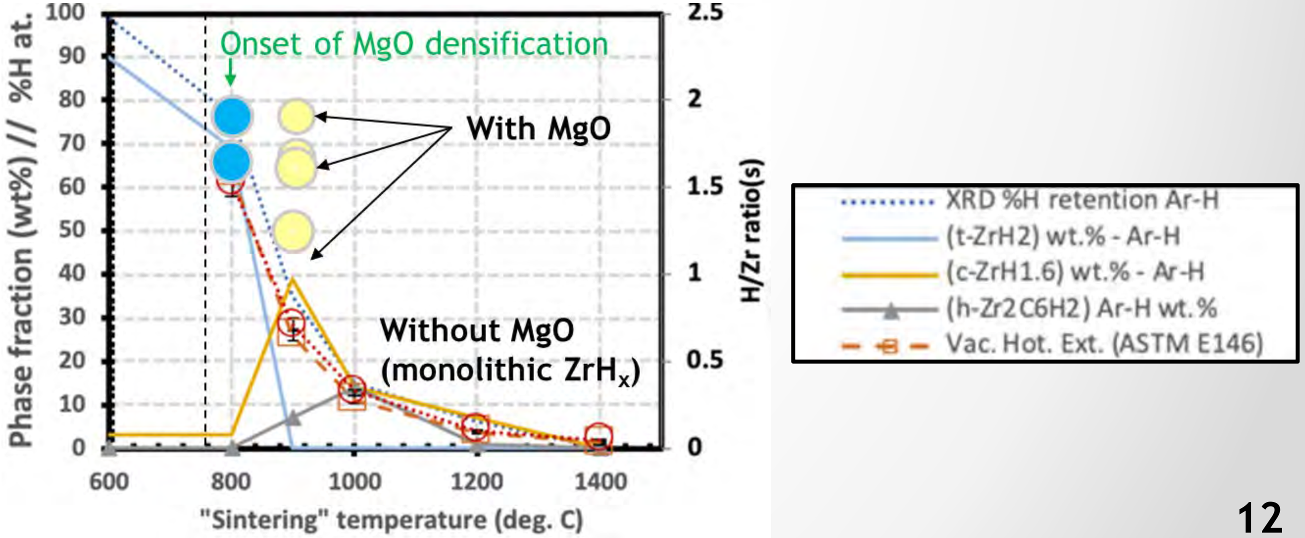
Controlled heating profiles to allow for Li to enrich particle surfaces → Reduced sintering temperature of MgO enables a fine, homogenously distributed δ-$ZrH_{1.6}$ phase.











Next steps

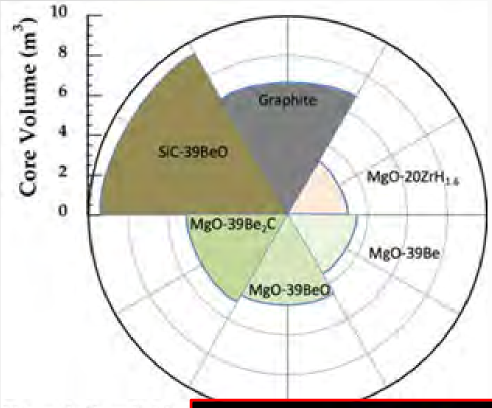
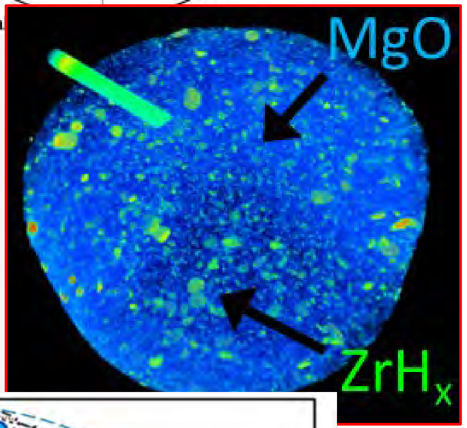
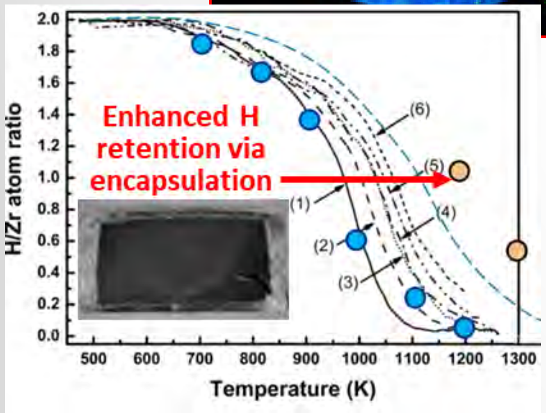


Figure 4: Core Critica





- Optimize sintering conditions to entrain ZrH with minimal hydrogen loss as quantified through XRD phase analysis and hydrogen quantification with the demonstration of varying hydride volume fractions.
- Initial thermal stability experiments to map decomposition temperatures without encapsulation. (INL)
- Optimize hydride loading based on the reactor physics calculations, which have been initiated via the definition of an initial spherical compact microreactor core point design and code-set verification

- *Quarterly report to be submitted by April 30, 2024*
- *Preparing a publication on the sintering mechanism*