High Temperature Moderator - ANL

Sumit Bhattacharya, Yinbin Miao, Abdellatif Yacout

Argonne National Laboratory

Milestones

- **Title:** Develop advanced coating solutions for high-temperature moderator applications with optimization and demonstration
  - **Level:** M3 **Due:** 3/31/2023
  - **Description:** Develop advanced functional coatings to enhance the performance of microreactor moderators at elevated temperatures where the coatings will be applied to a TZM substrate which is the enclosure solution material for hydride moderators. The coating parameters will be optimized based on the substrate and designed operating conditions.

- **Title:** Develop advanced design for yttrium hydride moderator encapsulation
  - **Level:** M3 **Due:** 9/30/2023
  - **Description:** Fabricate and test miniature advanced moderation modules (AMMs) with all essential components (i.e., hydride pellet, refractory metal liner, advanced coating, and SiC/SiC cladding) and endcaps appropriately joined.

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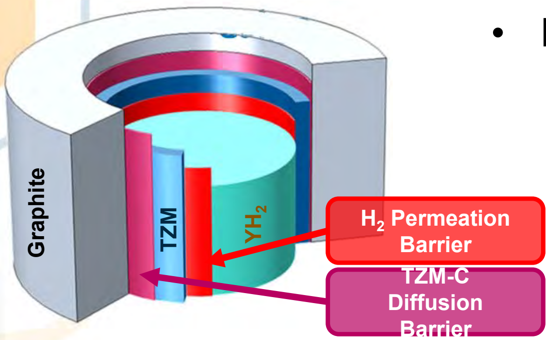
Milestones Status:

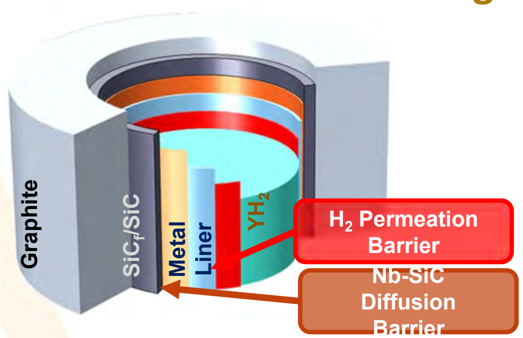
Current Moderator



Containment: TZM alloy

- Design of H_2 permeation barrier for TZM
  - Selection of **compatible materials (optimized)**
  - Permeation barrier **architecture (optimized)**
  - Resistant to H.T. **thermal cycling**
  - Resistant to **radiation damages**

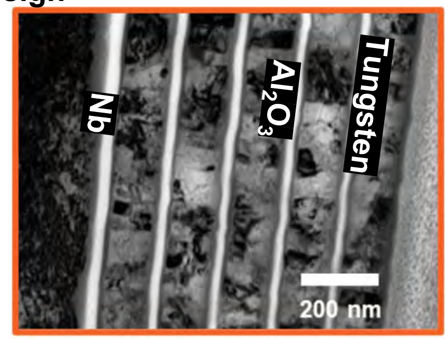
Advanced Moderator Design



Containment: Nb liner + SiC

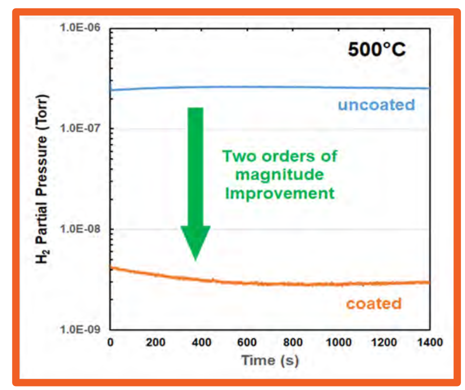
- Design & Development of tube coating technologies (*Primarily Internal tube surface*)
  - **Identification of parameters** to implement metal coating internally with plasma sputtering technique.
  - Verification of developed **film quality**

Based on our previous Barrier Design



PVD/ALD technique

Significant reduction in H_2 Permeation



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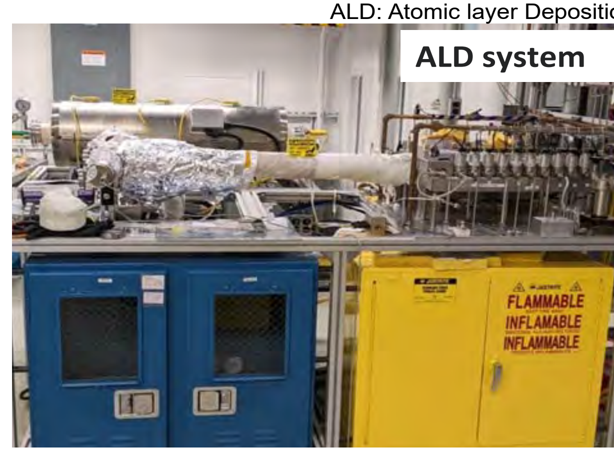
Functional Coating Implementation Infrastructure at ANL

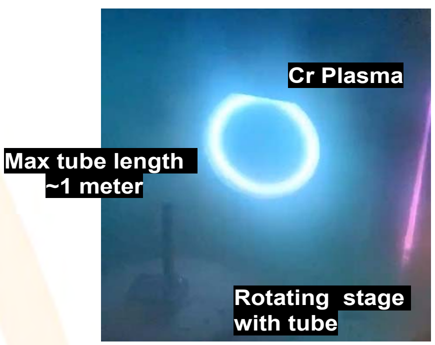
PVD: Physical Vapor Deposition
ALD: Atomic layer Deposition

External surface coating facility (metal/alloy layer)

Internal surface coating facility (metal/alloy layer)

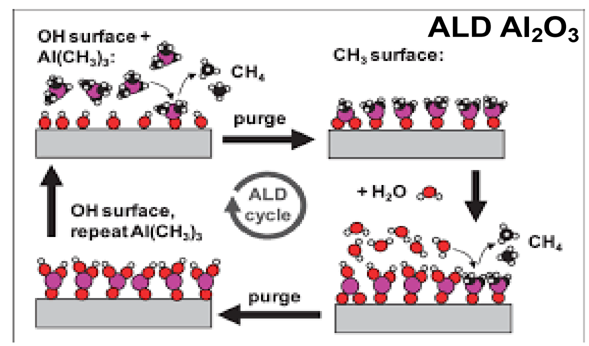


Internal/External surface coating facility (Ceramic layer)



Capabilities

- Can deposit both metal & ceramic materials.
- Minimum Tube diameter ~5 mm, and max length ~ 12 feet.



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Material Selection for H_2 Permeation Barrier & Thermal Performance

Barrier coating considerations:

- Low H_2 permeability,
- Stable at High temperature,
- Low neutron penalty.

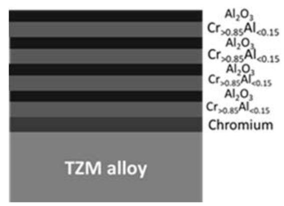
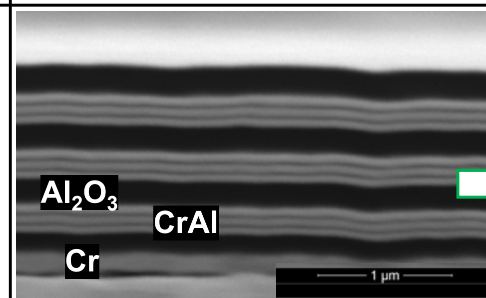
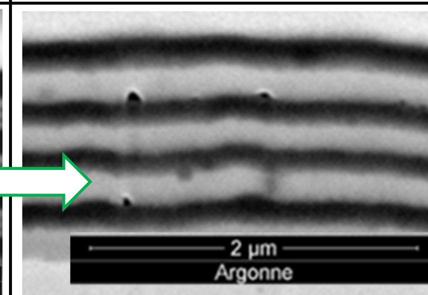
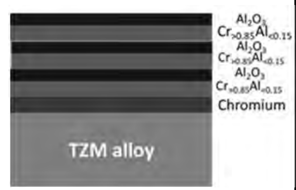
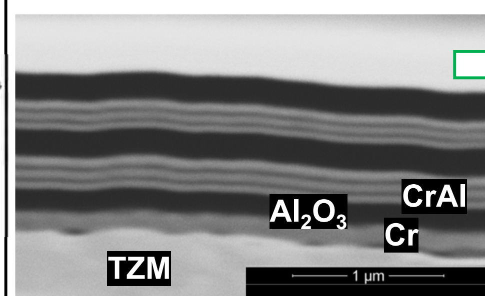
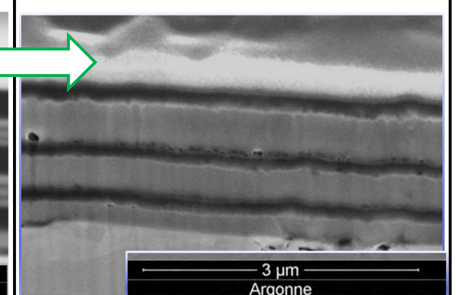
Selected materials:

- H_2 permeation Barrier: **Al_2O_3**
- Intermediate layer with TZM: **Cr**
- Alternate metal layer: **BCC phase CrAl**

Observations:

- No surface cracks
- No separation at the interfaces.
- No interaction between the metal/ceramic layers.
- Small pore formation in the metal layers (expected).

High Temperature Performance of the Functional Barrier

	Design Architecture	As-Prepared	After 10 Thermal cycles (900°C)
H			
I			

Carried out under 2.5% H_2 (Ar gas))

Conclusion:

CrAl-Al_2O_3 multilayer design performance is satisfactory

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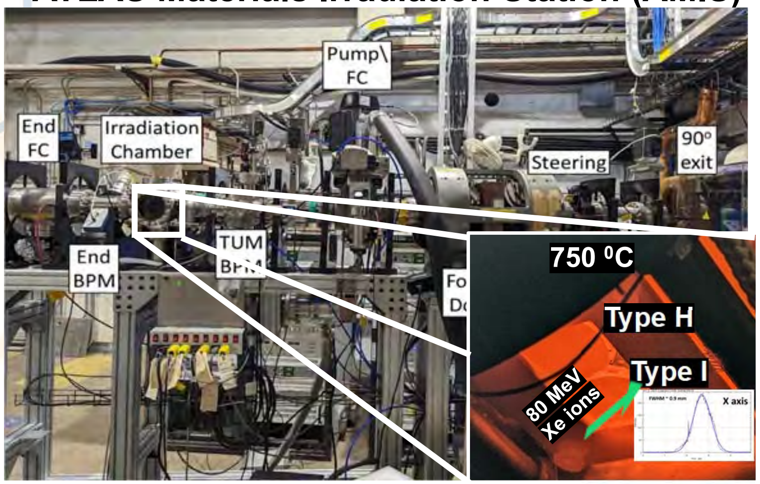
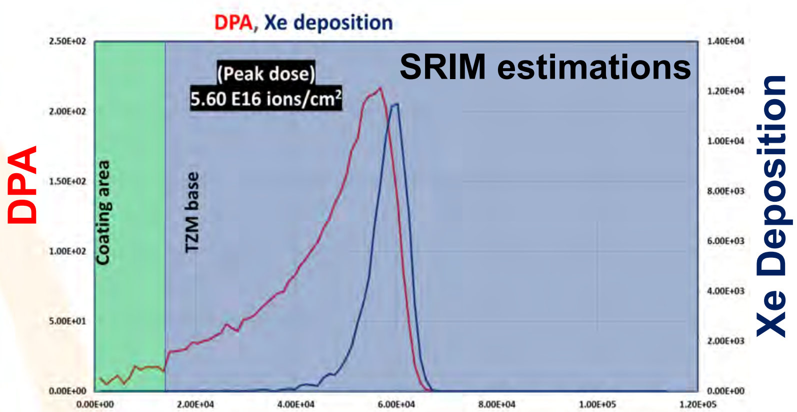
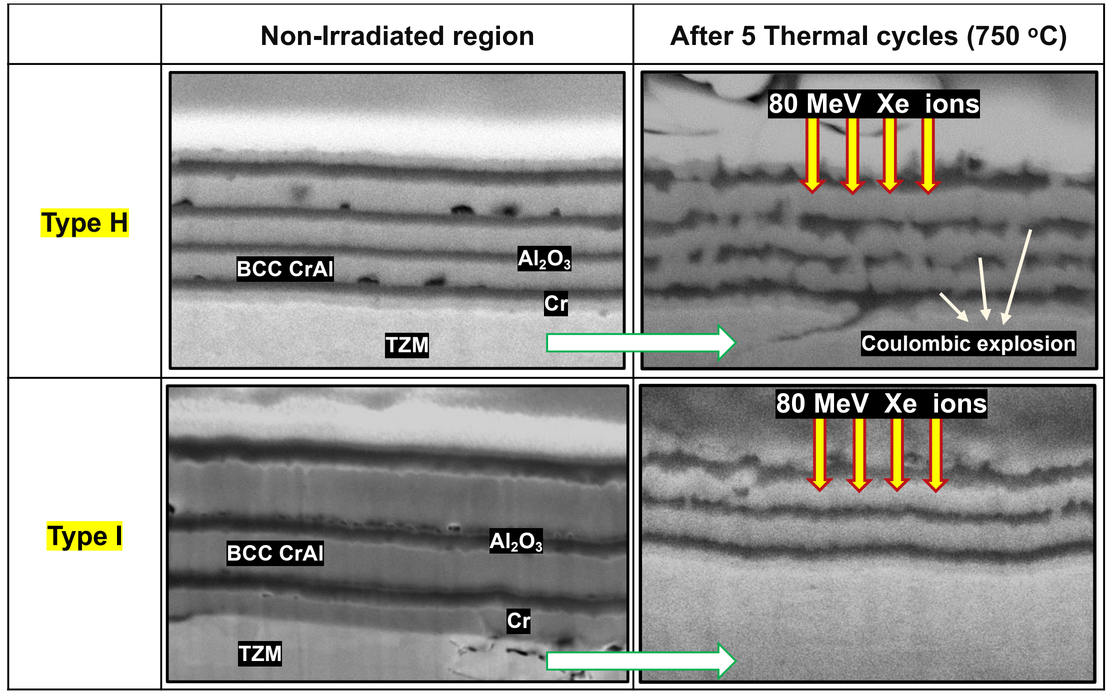
Radiation Tolerance of Developed Permeation Barrier (High Energy Ions)

ATLAS Materials Irradiation Station (AMIS)







- Coating designs survived 750 C heavy ion irradiation with 80 MeV Xe ions. (No spalling or cracking observed)
- Coulomb effect (Type H) most likely due to use of high beam current and energy

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Radiation Tolerance of Developed Permeation Barrier (Low Energy Ions)

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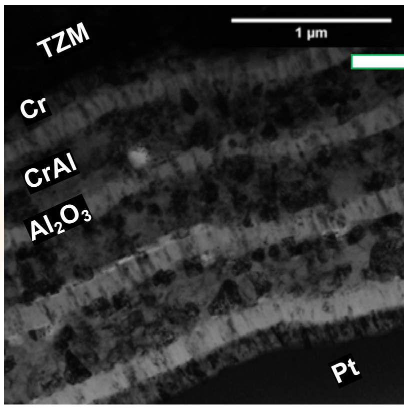
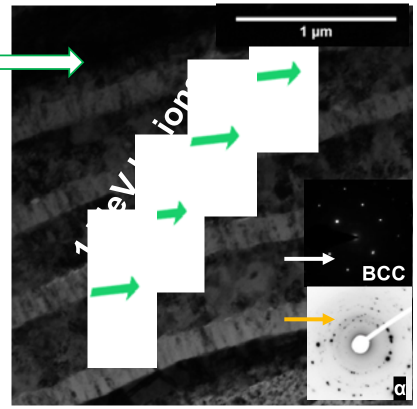
<tr><th></th><th>Film at 800 °C (In-situ)</th><th>After completion of 4 TC</th></tr>
<tr><td>H</td><td>
</td><td>
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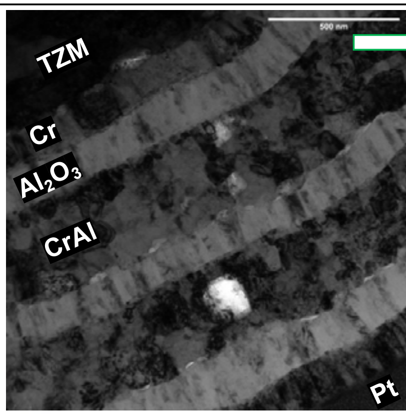
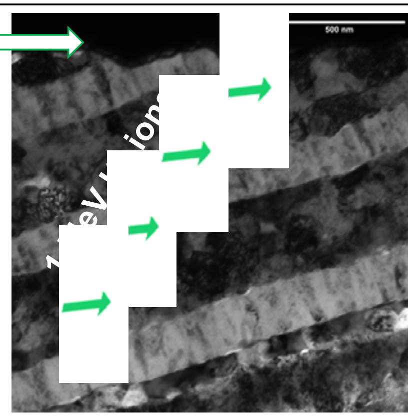
<tr><td>I</td><td>
</td><td>
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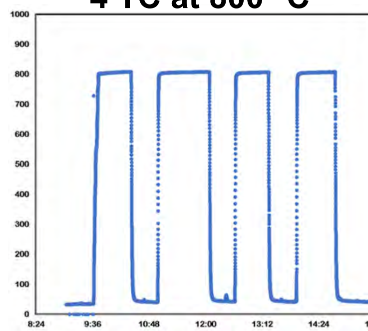
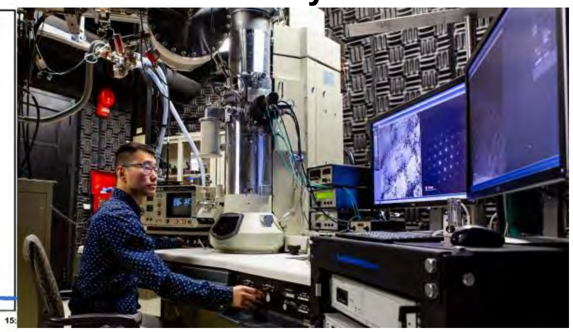
4 TC at 800 °C



IVEM facility at ANL



- While undergoing **irradiated with 1 MeV Kr ions**.
- Total dose reached **4E15 ions/cm²** to achieve **~ 5 dpa** damage

Observations:

- **Negligible change** in the microstructure.
- **No observable diffusion** between multilayers
- **No bubble formation** observed within/interfaces
- BCC CrAl and Al_2O_3 **phases remain intact**

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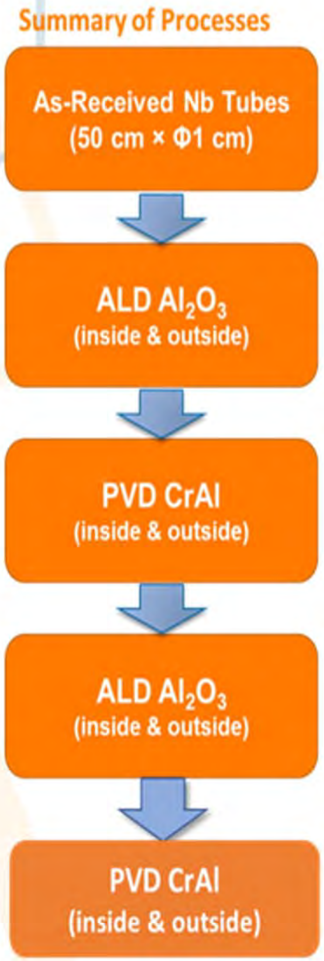
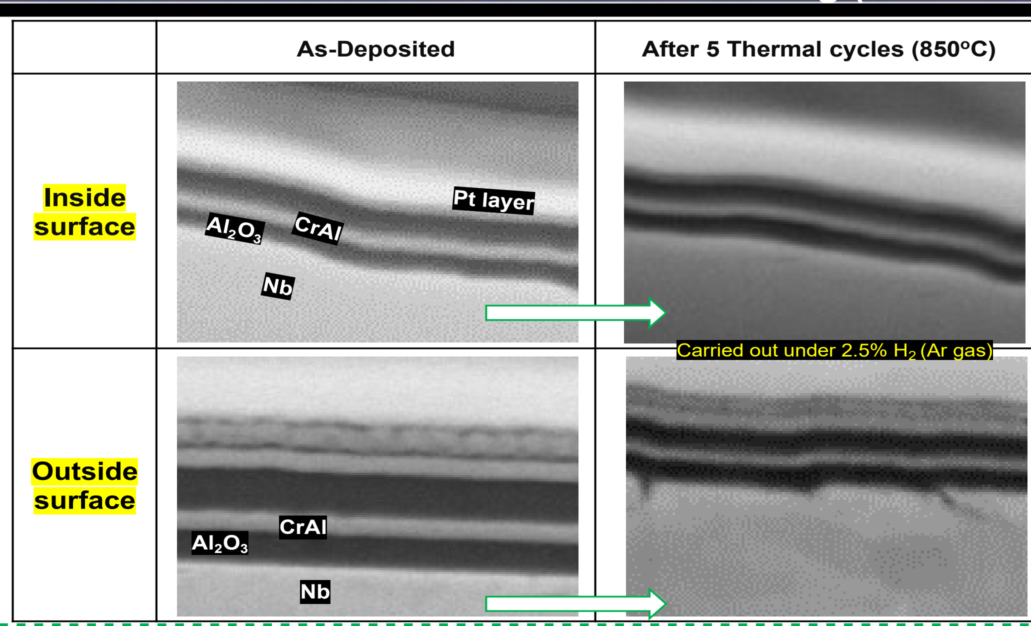
IMPLEMENTING THE COATING WITHIN A TUBULAR STRUCTURE





Conclusions

- Uniform & Conformal.
- Dense
- No spallation, cracks.
- Interfaces intact

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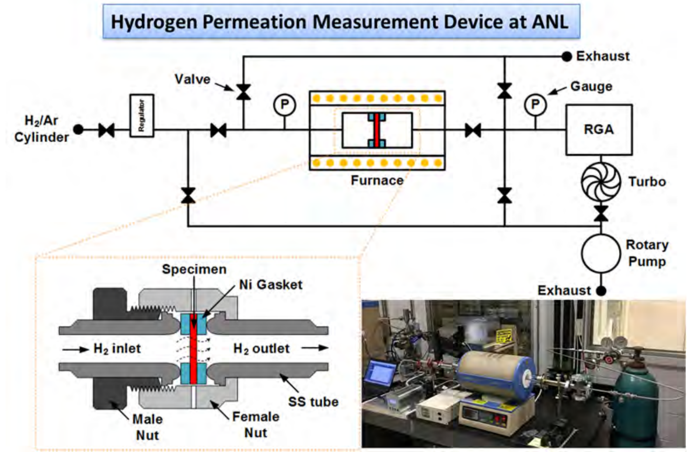
Next Steps and Ongoing work

- **H_2 permeation barrier development**
  - Perform H_2 permeation study with the identified coating designs (H, I, G) implemented over TZM discs. Using 2.5 to 3.5% diluted H_2 gas at 700 – 750 ^{o}C.
    - Use current H2 permeation setup at ANL
    - Coated TZM discs prepared for LANL/INL for further testing
  - Upgrade the H_2 permeation measurement capability, to allow long term 800 ^{o}C +, operation with almost pure H_2 gas.
- **TZM-Graphite barrier development**
  - Diffusion studies with graphite in contact with TZM (with and without barrier coating) at 900 ^{0}C.
  - We want to implement similar coating designs to reduce complicacies.
- **Continue to implementation of the final coating design over tubes.**
- **Manufacturing of ANL Advanced Moderator Module sample.**



Advanced Moderation Module