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Advances in Design of the Next Generation Hydride Bed

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(Presented by Dave Babineau)

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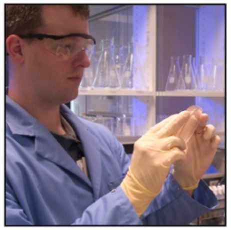

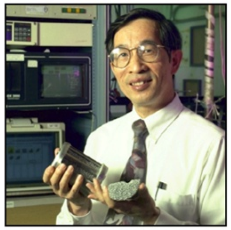


Tritium Focus Group Meeting

Germantown, MD - April 23-25, 2013

SRNL-STI-2013-00210

Outline

I. History of Hydride Bed Development at SRNL

- 1^{st}, 2^{nd}, and 3^{rd} generation hydride storage beds

II. Current Hydride Bed Research

- TECH Mod hydride bed development
- Full-scale hydride bed test system

III. Conclusions and Future Research

- Validation of key design features
- FISH bed development plan
- Other applications

IV. Acknowledgements

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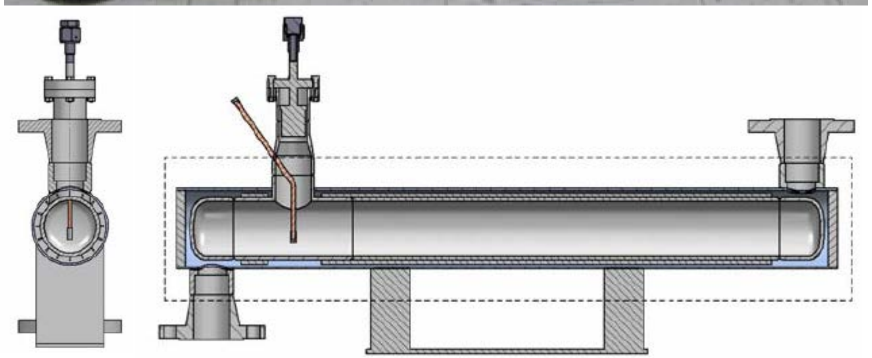
I. Hydride Bed Development at SRNL – 1st Generation



Gen 1 Hydride Storage Bed

- Due for replacement in 2014

Specifications:

- 3” pipe, 3 ft. long
- Absorbs/desorbs hydrogen isotopes by inducing thermal swings using a hot/cold nitrogen system
- No heater wells, no lateral fins
- 12.6 kg LANA.75 (70% fill)
- Requires manual hydride leveling

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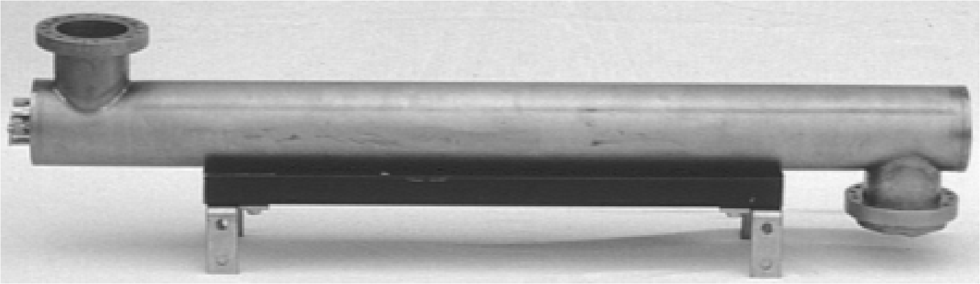
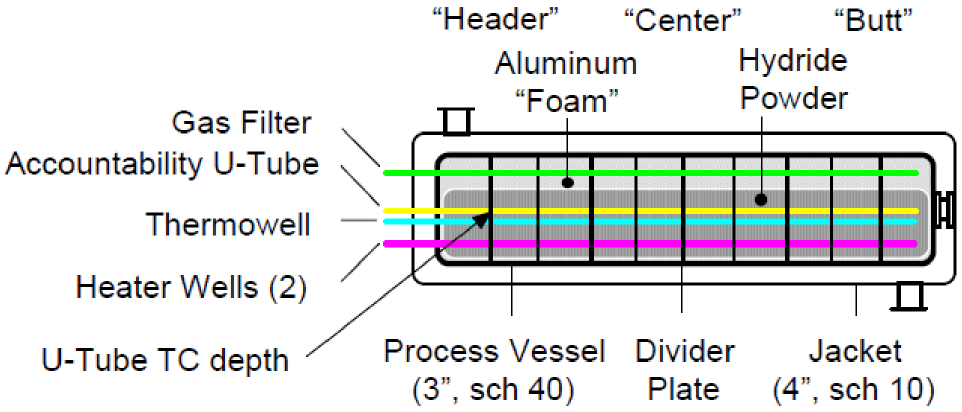
Hydride Bed Development at SRNL – 2nd Generation

Gen 2 – <u>F</u>orced-<u>A</u>tmosphere <u>C</u>ooled, <u>E</u>lectrically Heated (<u>FACE</u>) Bed

- Designed for Tritium Facilities Consolidation Project (TCON)
- Required faster absorption/cooling rates





Specifications:

- 3" pipe, 4 ft. long
- Thermowell, heater wells (2), gas filter tube
- In-Bed Accountability (IBA) U-tube
- Al foam, divider plates
- Electric cartridge heaters
- Forced atmosphere cooling (glovebox air)
- 12.6 kg LANA.75 (70% fill)

Advantages:

❖ No hot/cold nitrogen system
❖ No manual hydride leveling
❖ Faster heating/cooling times

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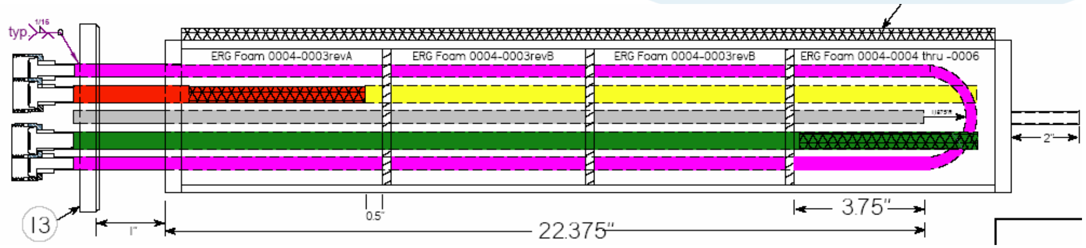
Hydride Bed Development at SRNL – 3rd Generation

Gen 3 – Four-Inch Short Hydride (FISH) Bed

- Designed for direct replacement of Gen 3 (FACE) beds



Specifications:

- 4" pipe, 2 ft. long
- Thermowell, heater wells (2)
- Gas filter tubes (2) to test flow-through performance
- IBA U-tube
- Al foam, divider plates
- External fins to match heat transfer area of FACE bed
- Lower pressure LANA.85 (70% fill)

Advantages:

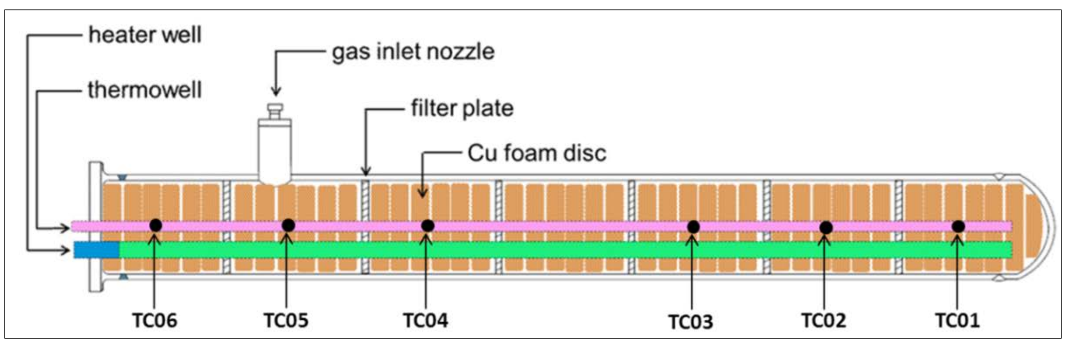
- ❖ No hot/cold nitrogen or manual leveling
- ❖ Half the length of FACE bed with same storage capacity
- ❖ Allows for heater replacement (4 ft. pull space instead of 8 ft. for FACE beds)
- ❖ Lower pressure LANA will reduce gas loss during inert evacuation

*FISH bed development will not be completed in time for 2014 hydride bed replacement in Tritium Facilities

II. Current Hydride Bed Research – TECH Mod

Thermal Enhancement Cartridge Heater Modified (TECH Mod) Hydride Bed

- Key modifications made to existing Gen 1 bed design



Specifications:

- 3” pipe, 3 ft. long (identical dimensions as Gen 1 bed)
- 12.6 kg LANA.75 (70% fill)

Added Features:

- Thermowell with custom 6-channel thermocouple
- Heater wells (2) for 400W cartridge heaters
- Porous divider (filter) plates
- Copper foam discs

Advantages:

❖ All of the potential advantages of the FACE and FISH beds but easily retrofitted into current Gen 1 process configuration

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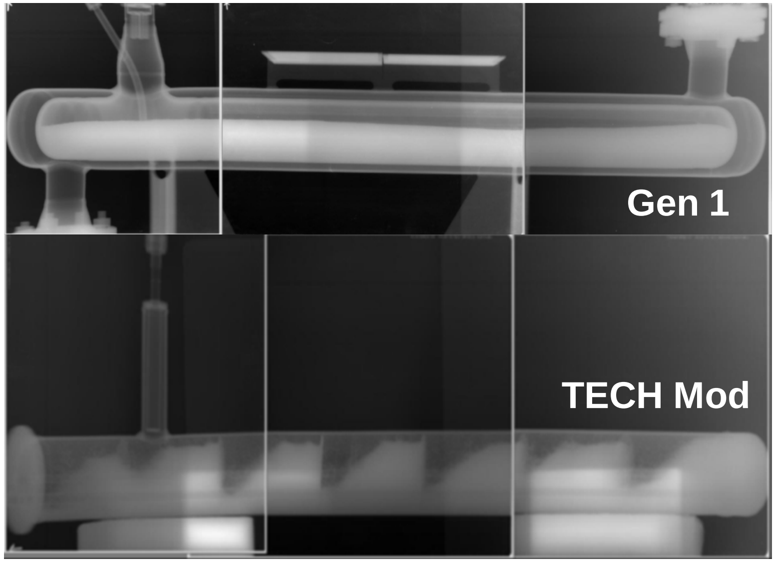
Design Modifications and Advantages

- **TECH Mod (electric cartridge heaters)**
  - Achieve higher bed temperature than hot nitrogen system for improved desorption and end-of-life bakeout
  - Lower gas residuals requiring fewer isotopic exchanges for safe disposal
  - Electric heat (vs. tritium gas) to simulate tritium decay for IBA calibrations
  - Facilitate partial He-3 release at end-of-life and potentially allow full He-3 recovery (higher temperature materials/design)



Radiographs of filled hydride beds prior to activation

- **Porous divider plates and copper foam**
  - Compartmentalize hydride material for more uniform distribution
  - Reduce risk of vessel damage/rupture upon hydride material expansion (absorption)
  - Immobilize hydride material without hindering gas flow
  - Eliminate need for manual leveling
  - Improve heat transfer rates

- **Remote activation**
  - Combination of internal heating element and immobilization of hydride material allows for remote activation of bed prior to installation in the Tritium Facilities, leading to significant time and cost savings

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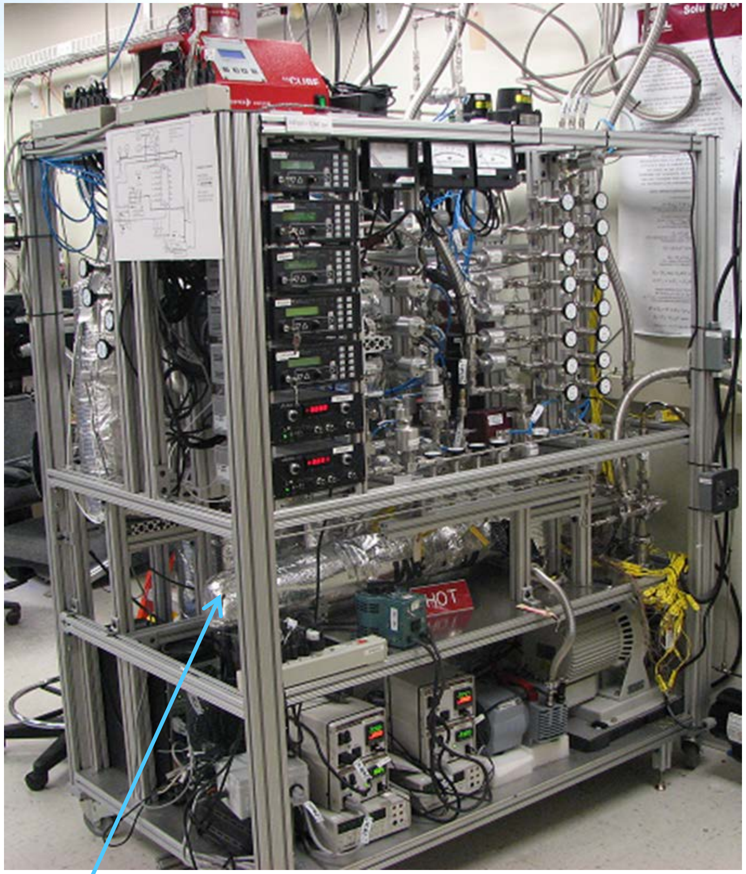
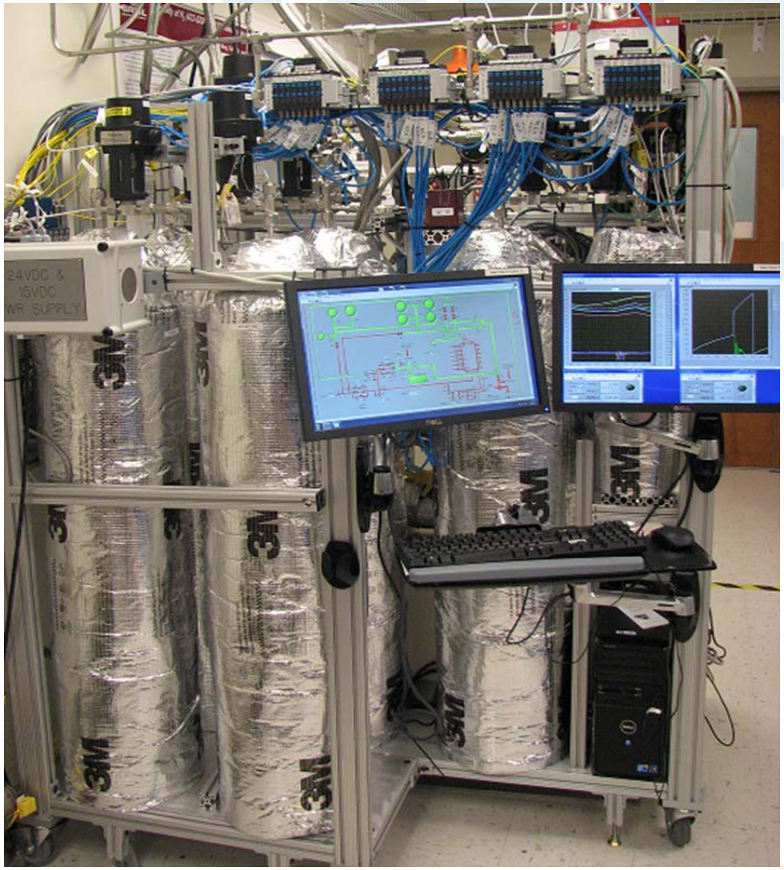
Full-Scale Hydride Bed Test System – PDRD FY11





Insulated TECH Mod Hydride Bed

- Pressure transducers: (4) 0-10,000 torr and (1) 0-100 torr
- Calibrated volumes: (5) ~44 L, (1) ~10 L, (1) ~1 L
- Flow controllers and back pressure regulators for absorptions and desorptions
- Residual Gas Analyzer (RGA)
- Total volume ~243 STP-L
- Capable of taking hydride bed to full hydrogen storage capacity (~1500 L)

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TECH Mod Flow Characterization – PDRD FY12

Verify that the TECH Mod design changes…

- ❖ Have no adverse effects on hydride bed performance compared to the existing Gen 1 bed
- ❖ Do not impede gas flow even after repeated hydrogen absorption/desorption cycles, high flow rates, and material decrepitation

1) Baseline Flow Characterization

- Gen 1 and TECH Mod beds prior to activation
- Series of inert gas (argon) expansions to and from hydride bed
- Baseline comparison for post-hydriding studies

2) Hydrogen Flow Characterization

- Bed activation with hydrogen
- Controlled absorptions and desorptions with hydrogen (full bed capacity)
- Various loading pressures, flow rates, and initial bed temperatures

3) Post-Hydriding Inert Gas Flow

- Repeat argon expansions at several points during hydrogen flow testing
- Compare to baseline data

* Radiographs of TECH Mod bed before and after hydriding

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TECH Mod Flow Characterization – Baseline Flow

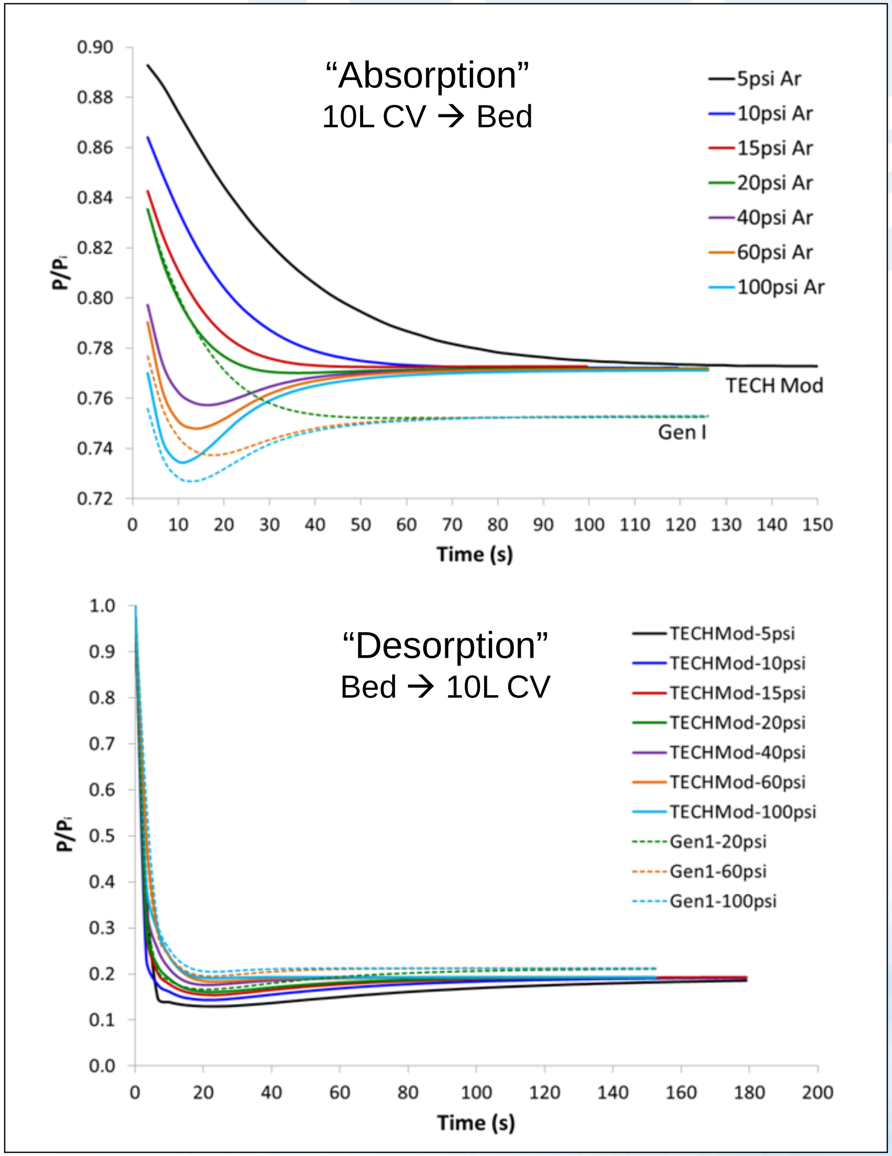
Baseline Argon Expansions:

"Absorption" = CV → Bed
"Desorption" = Bed → CV

- 10 and 1L CVs
- 20, 60, 100 psi Ar (Gen 1 and TECH Mod)
- 5, 10, 15, 40 psi Ar (TECH Mod only)
- Both beds filled with ~12kg LANA.75 (unactivated)

❖ No difference in inert gas flow between TECH Mod and Gen 1 beds

❖ Deviation in "absorptions" due to slightly larger void volume of the Gen 1 bed



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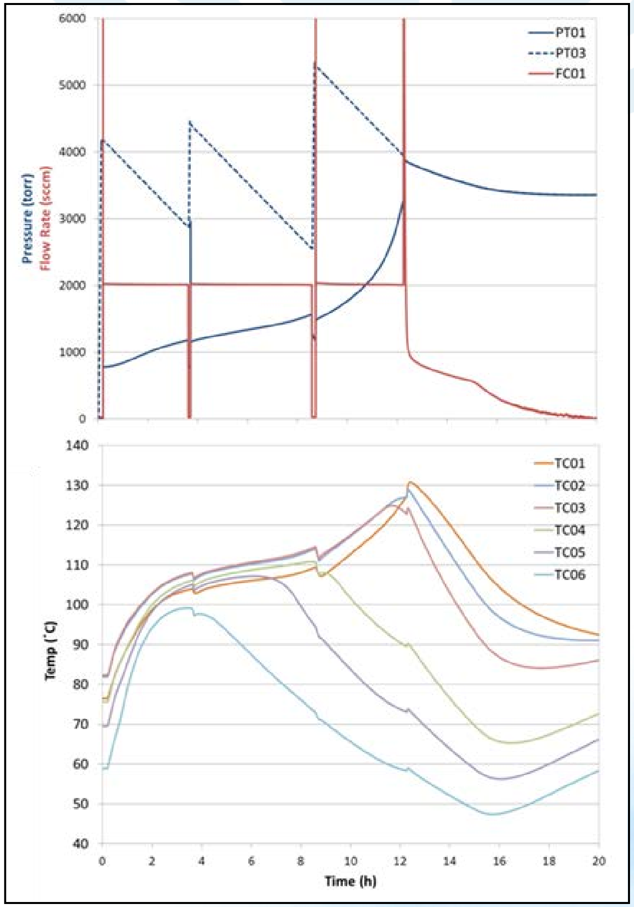
TECH Mod Flow Characterization – H_2 Absorption

Controlled Hydrogen Absorptions:

- Initial bed temperature: RT (~23°C), 80°C, 120°
- Loading Pressure: 2000, 5500, 7000 torr
- Flow Rate: Max, 2 L/min

Hydrogen Absorptions	7000 torr			5500 torr			2000 torr	
	RT	*80 C*	*120 C*	*RT*	*80 C*	*120 C*	*RT*	*80 C*
Total H_2 in System (STP-L)	1989	2012	1987	1564	1570	1563	1070	1279
H_2 Absorbed in 12h (STP-L)	1514	1504	1304	1336	1321	998	930	1031
Max Abs Rate (SLPM)	**189**	**136**	**120**	**110**	**83**	**74**	**13**	**11**
Max Bed Temp (C)	150	162	167	138	151	162	80	108

2 L/min H_2 absorption
80˚C initial bed temp



* 2 L/min absorptions at each bed temperature were also performed. CVs were recharged 2-3 times to maintain flow rate (~8-12 h) and reach storage capacity.

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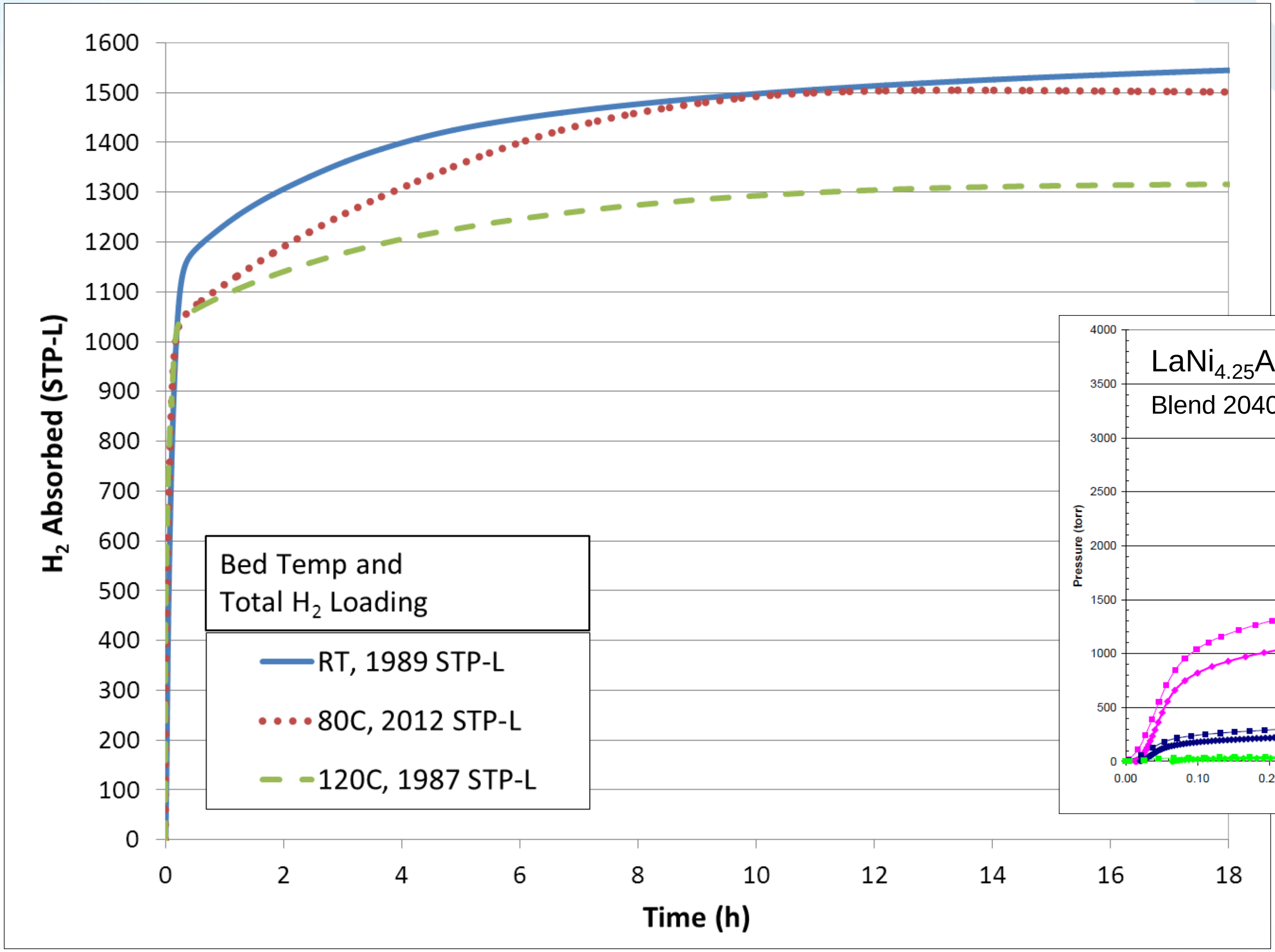
TECH Mod Flow Characterization – H_2 Absorption

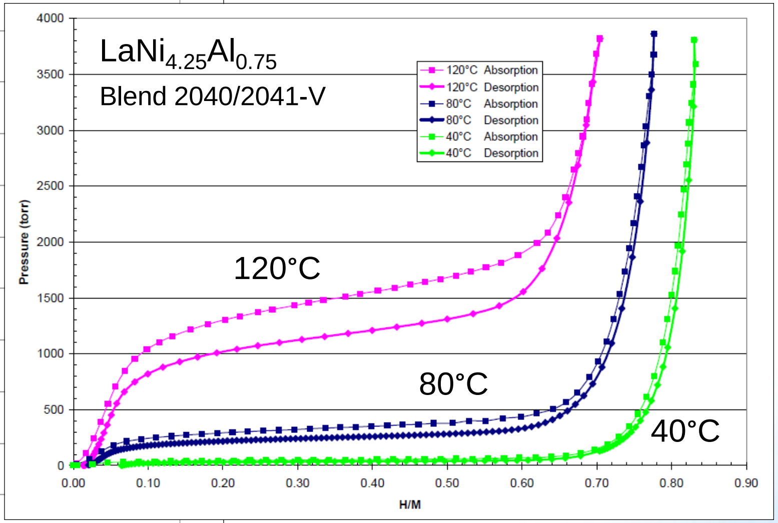
H_2 Absorptions in TECH Mod Bed
7000 torr Loading Pressure



Final H/M

RT	**0.75**
80°C	**0.72**
120°C	**0.63**

LANA.75
Isotherms with H_2



G. A. Morgan, SRNL-L2100-2008-00014

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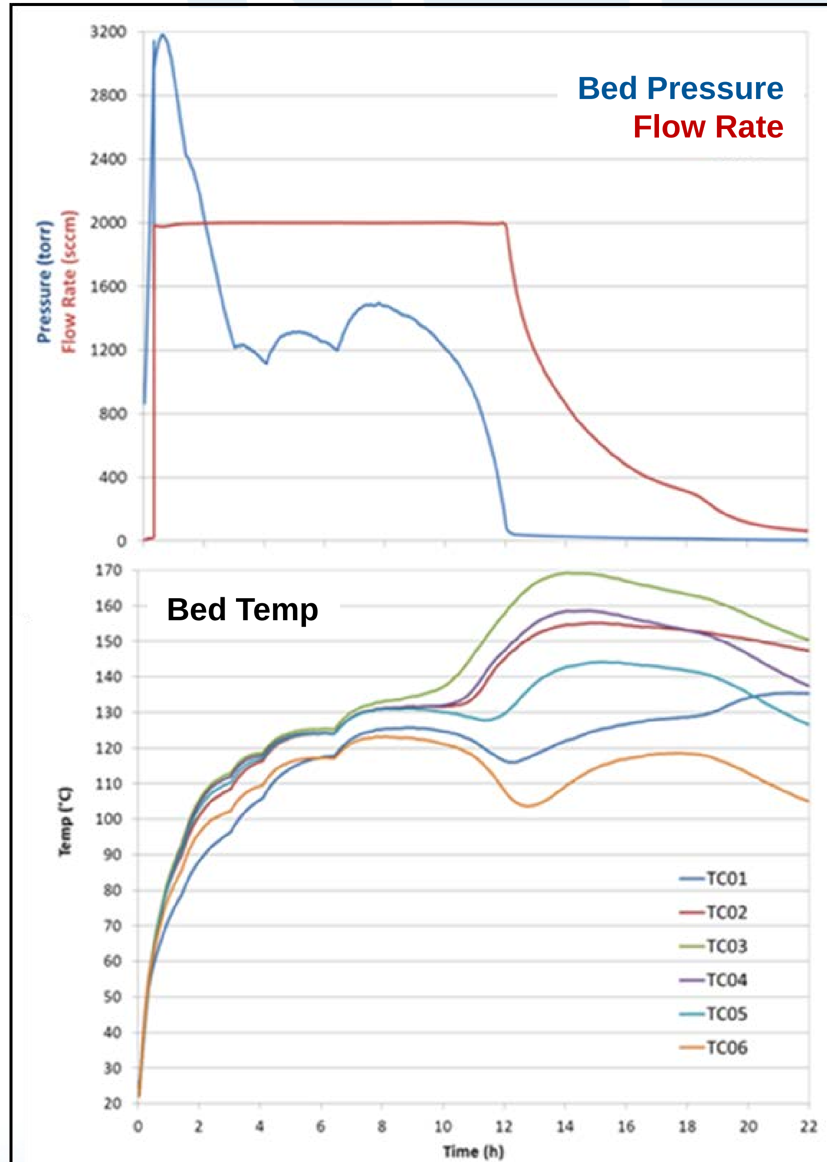
TECH Mod Flow Characterization – H_2 Desorption

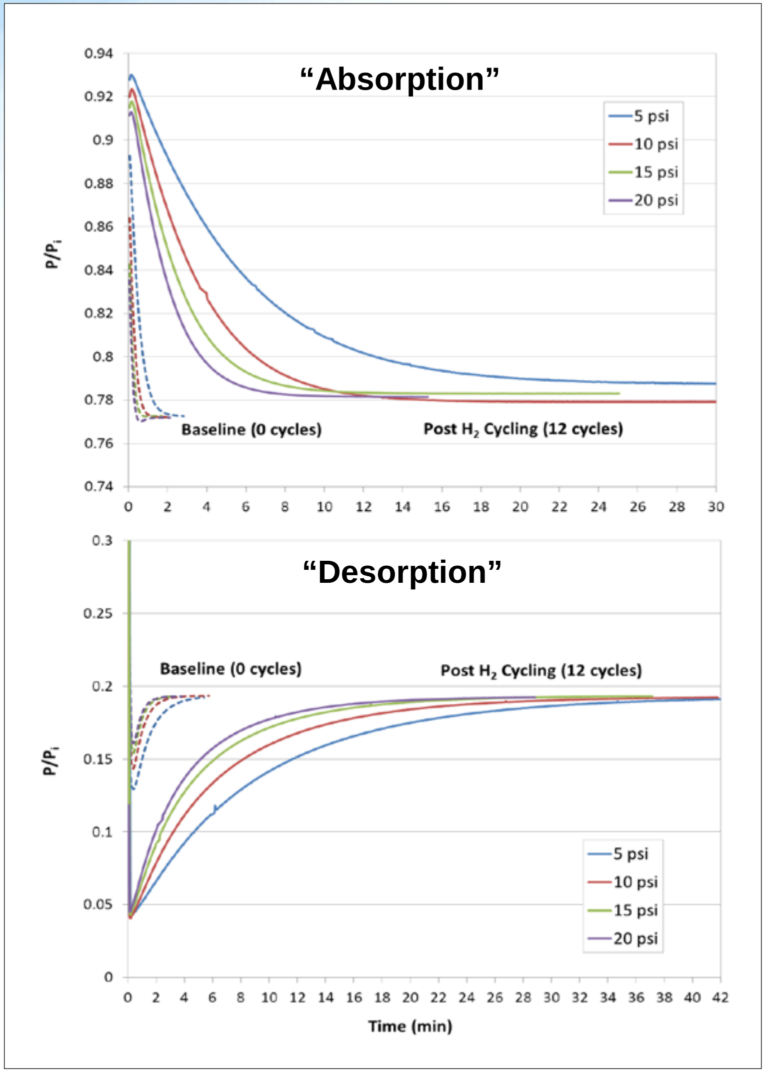
Controlled Hydrogen Desorptions:

- Initial bed loading at or near capacity
- Initial bed temperature: RT (~23°C), 80°C, 120°
- Flow Rate: Max, 2, 4, 6 L/min

Hydrogen Desorptions		Desorption Time at Constant Rate	Average Bed Temp
2 L/min	***RT***	12 h	120 C
	80 C	10 h	120 C
	120 C	5 h	120 C
4 L/min	***RT***	4 h	120 C
	80 C	5 h	125-135 C
	120 C	5 h	135 C
6 L/min	***80 C***	2.5 h	135 C
	120 C	2.5 h	135 C
Max Flow	***80 C***	2-4 L/min, 7 h	80-120 C
	120 C	1-7 L/min, 4 h	120-150 C

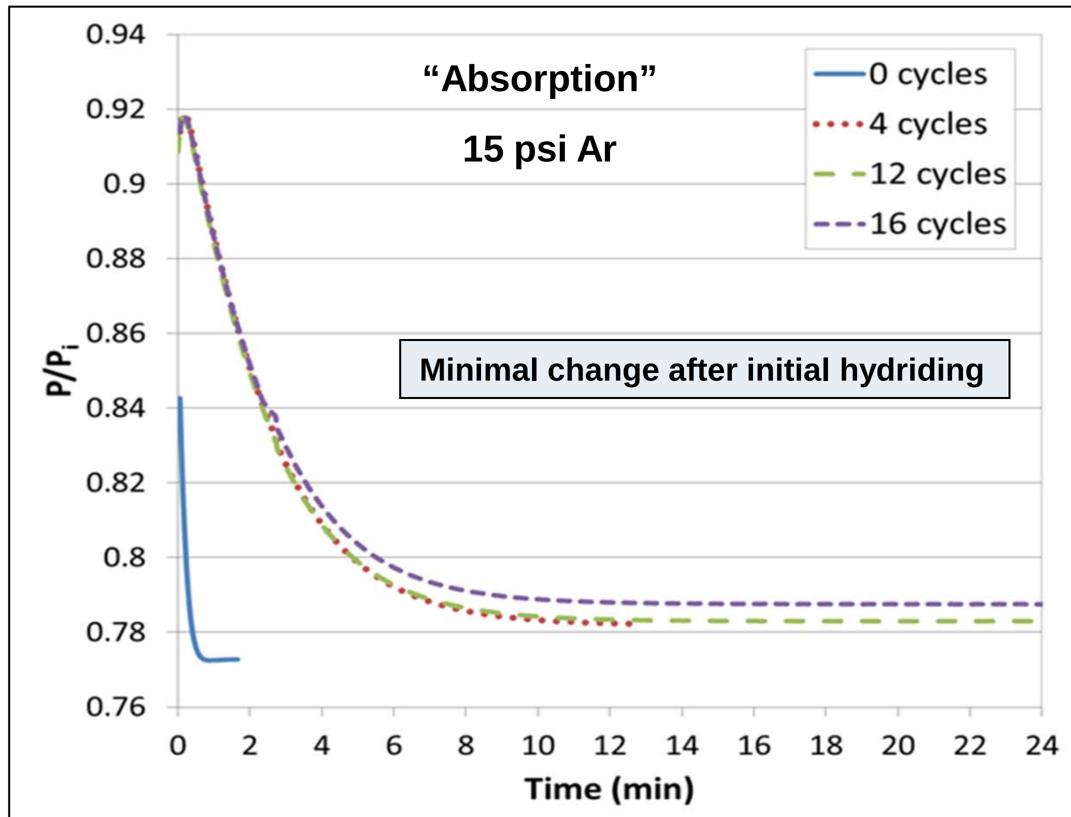


TECH Mod Flow Characterization – Post-Hydriding Flow



Post-Hydriding Ar Expansions:

- Repeat baseline flow measurements on TECH Mod bed at various points during testing (~every 4 hydride cycles)
- Bed at RT for comparison to baseline
- 5, 10, 15, 20 psi Ar
- 10L CV only



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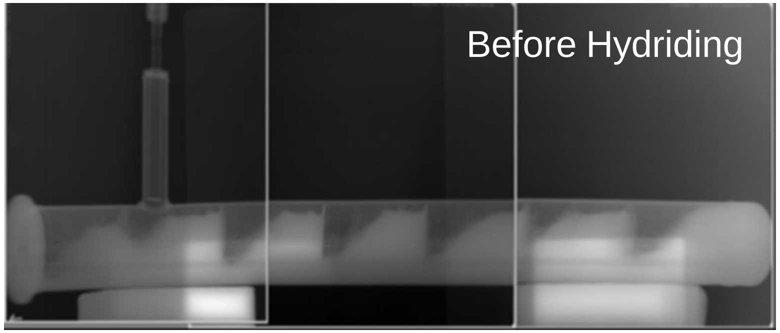
III. Conclusions and Future Research – TECH Mod

TECH Mod Flow Characterization:

- Complete flow characterization of the prototype TECH Mod hydride bed confirmed that the design modifications had no adverse effects on bed performance, further validating these features for next generation hydride beds
- Ar expansions before and after repeated abs/des cycles showed minimal change in flow rate after initial hydriding, suggesting slight decrepitation of the LANA.75 material as opposed to blockage of the filter plates
- Post-hydriding radiographs of the TECH Mod bed confirmed that the hydride material was sufficiently immobilized during testing despite high gas flow rates



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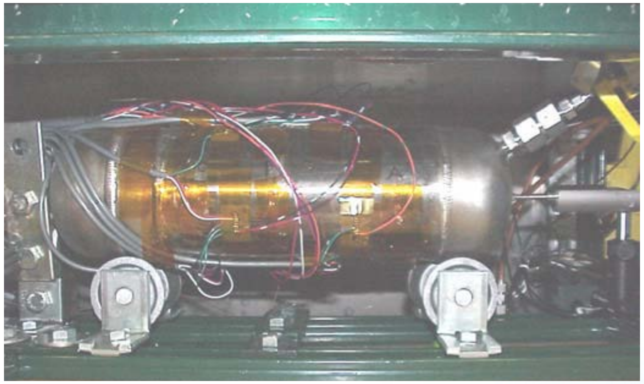
Conclusions and Future Research – FISH Bed

FISH Bed Development Plan:

1. **Confirm 4” hydriding wall stresses on the prototype FISH bed**
   - Wall stresses on standard 4” pipe determined to be within ASME allowable limits in 2004 (see image below)
   - Ensure that added design features in prototype bed (foam, divider plates, U-tube, etc.) do not induce additional strain on vessel walls

2. **Verify that the FISH bed performs as well as the existing PACE/FACE beds**
   - Complete flow characterization testing including inert gas flow measurements, hydrogen absorption/desorption rates, heat transfer effects, etc.

3. **Determine In-Bed Accountability (IBA) errors**



- Strain gauge measurements on standard 4” pipe for FISH bed development
- Hydriding wall stresses verified at two different LANA fill levels

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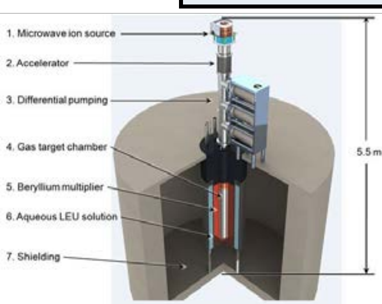
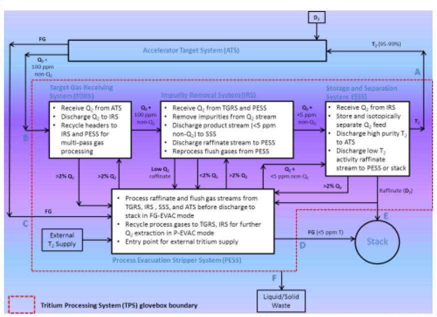
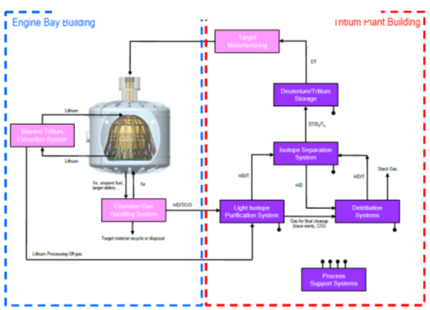
Conclusions and Future Research – Other Applications

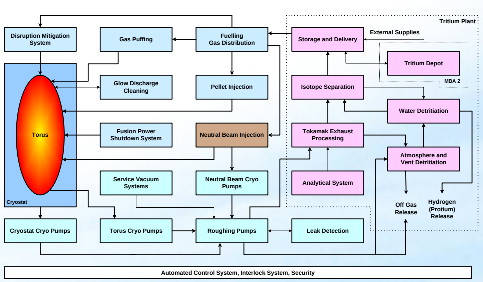
Rapid Cycling Storage Bed :

- ❖ **Future commercial applications will require much smaller (1 – 100) gram storage beds with rapid cycling capability.**
  - ➢ **Minimize inventory**
  - ➢ **Considering Safety and Cost**
- ❖ **Technology development plans include this approach for ITER, LIFE, SHINE;**
  - ➢ **Consulting with ITER to analyze KO-DA Storage and Delivery System (SDS) Bed Design**
  - ➢ **Currently working with LLNL on pre-conceptual design of Laser Inertial Fusion Energy (LIFE) tritium facility**
  - ➢ **Completed pre-conceptual and currently working on conceptual design of tritium purification system for SHINE Medical Technologies (Moly 99 Production)**









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