



# Tritium fueling, processing and handling

Heena K. Mutha, PhD

June 2021

Commonwealth Fusion Systems

# My journey to fusion starts with wind turbines, micro-nanoengineering, and electrochemical systems



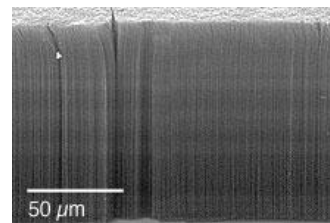
B.S.  
Mechanical  
Engineering



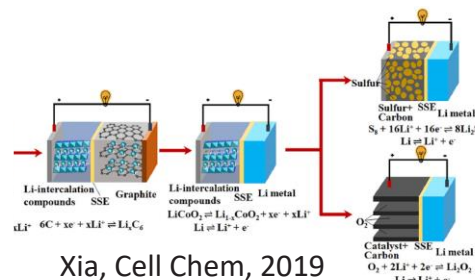
SULI



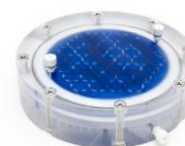
Stuart Darsch, MITEI News



M.S., PhD  
Mechanical  
Engineering  
minor in  
electrochemistry



Xia, Cell Chem, 2019



**DRAPER**  
Senior Member of  
Technical Staff  
Materials and Devices



# Transitioning my experience to CFS as the Fueling and Tritium System Responsible Officer

## Experience:

- Worked on fluidic, biologic, chemical, and lithium metal-based systems
- Comfortable designing, analyzing, storing, and automating experiments and test data
- Coordinating multiple levels of staff and engineers to execute and drive projects
- Set up equipment, testing apparatus, systems, labs from scratch
- Comfortable moving between modeling, design, test, validation



## Fueling and Tritium SRO

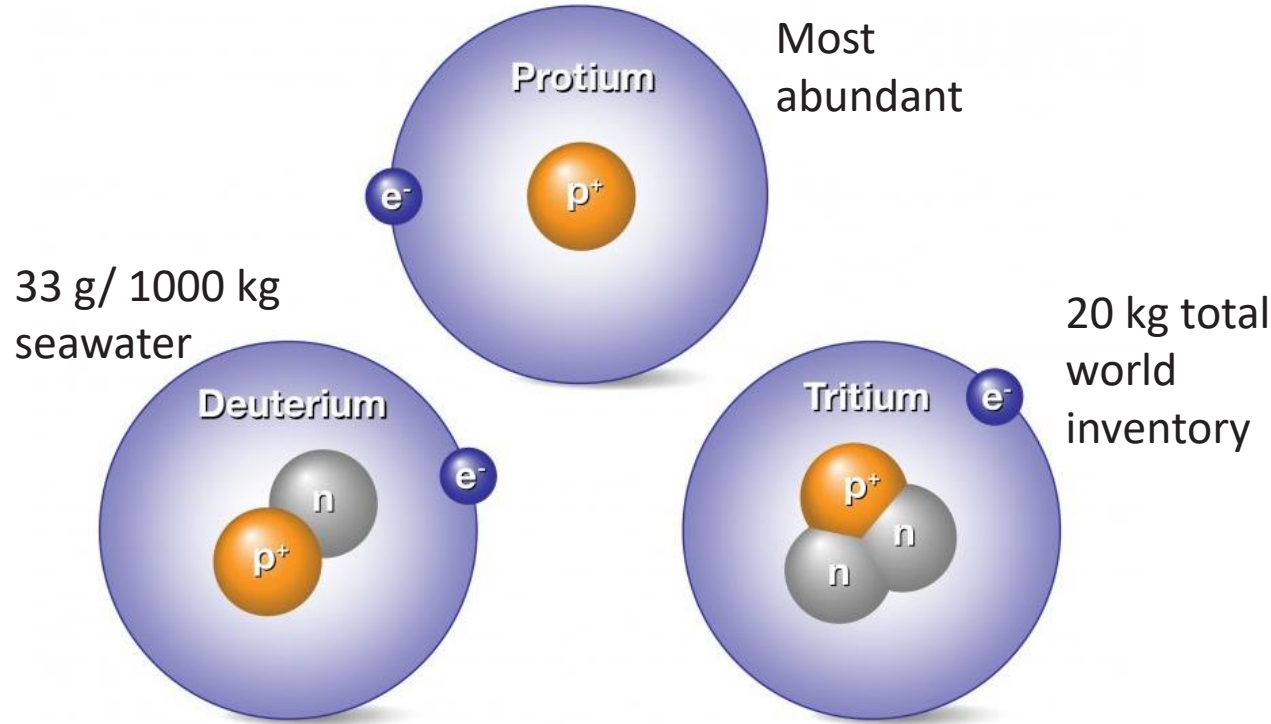
- Excited and able to learn about tritium systems and transition existing know-how in-house to design, build, and test the tritium system
- Identify unknowns, required storage and flow specifications, operating pressures and temperatures
- Build a tritium team comprised of engineers, staff, co-ops
- Comfortable presenting and debating concepts with experts and engineering teams
- Able to develop schedules, budget, identify engineering challenges and maintain critical path

Fun fact: I pulled this from my CFS interview slide deck

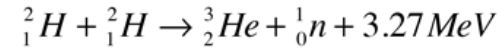


# Hydrogen isotopes: deuterium and tritium have been used to generate fusion energy

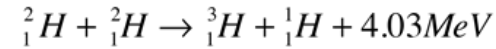
## ISOTOPES OF HYDROGEN



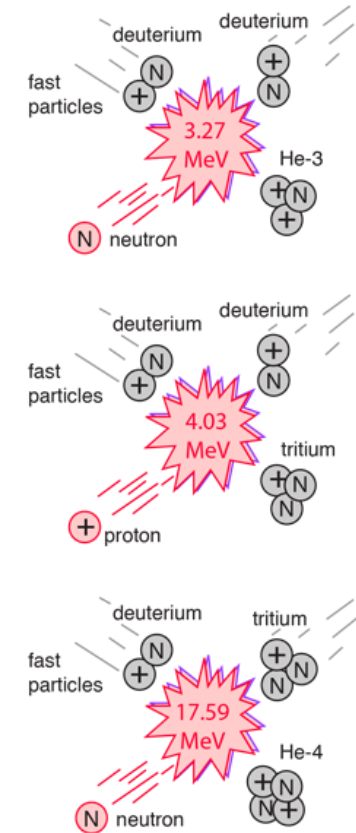
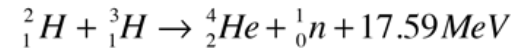
There is only one proton in the nucleus of all isotopes of hydrogen, but the number of neutrons varies.



Deuterium-deuterium Fusion



Deuterium-tritium Fusion



DT fusion generates more than **4x** more heat than DD fusion

### Fusion is > 4 million times more energy dense than coal-fired power plants



# DD fusion has allowed us to study many plasma properties, but moving fusion back towards DT enables high power fusion ( $Q > 1$ )

## DD fusion



General Atomics  
DIII-D



National Spherical  
Torus Experiment  
(NSTX-U), PPPL



Alcator C-mod, MIT  
(1991-2016)

## DT fusion



National Ignition  
Facility (LLNL)



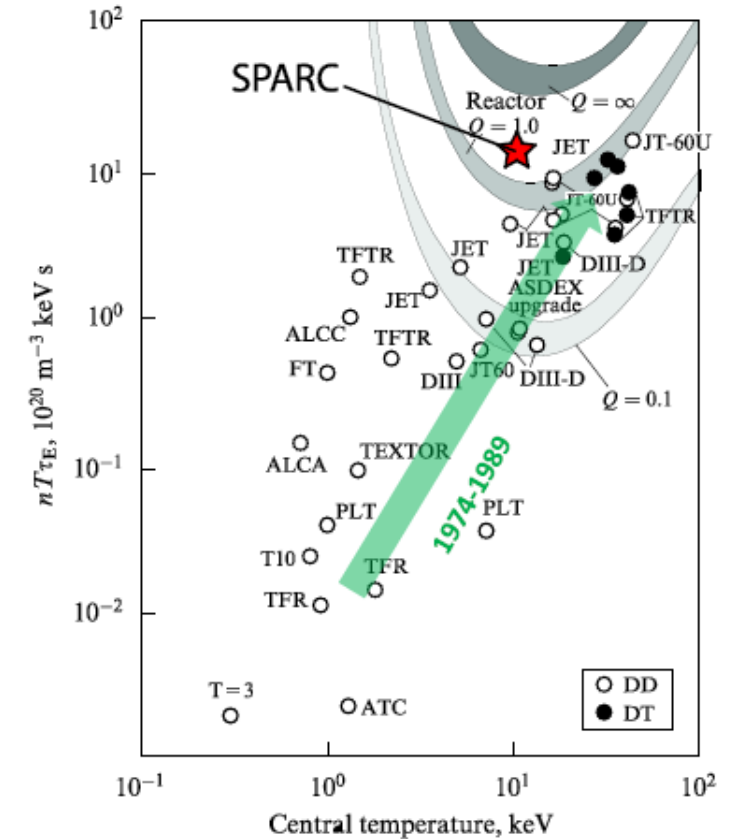
University of  
Rochester, LLE



Joint European  
Torus (JET), UKAEA

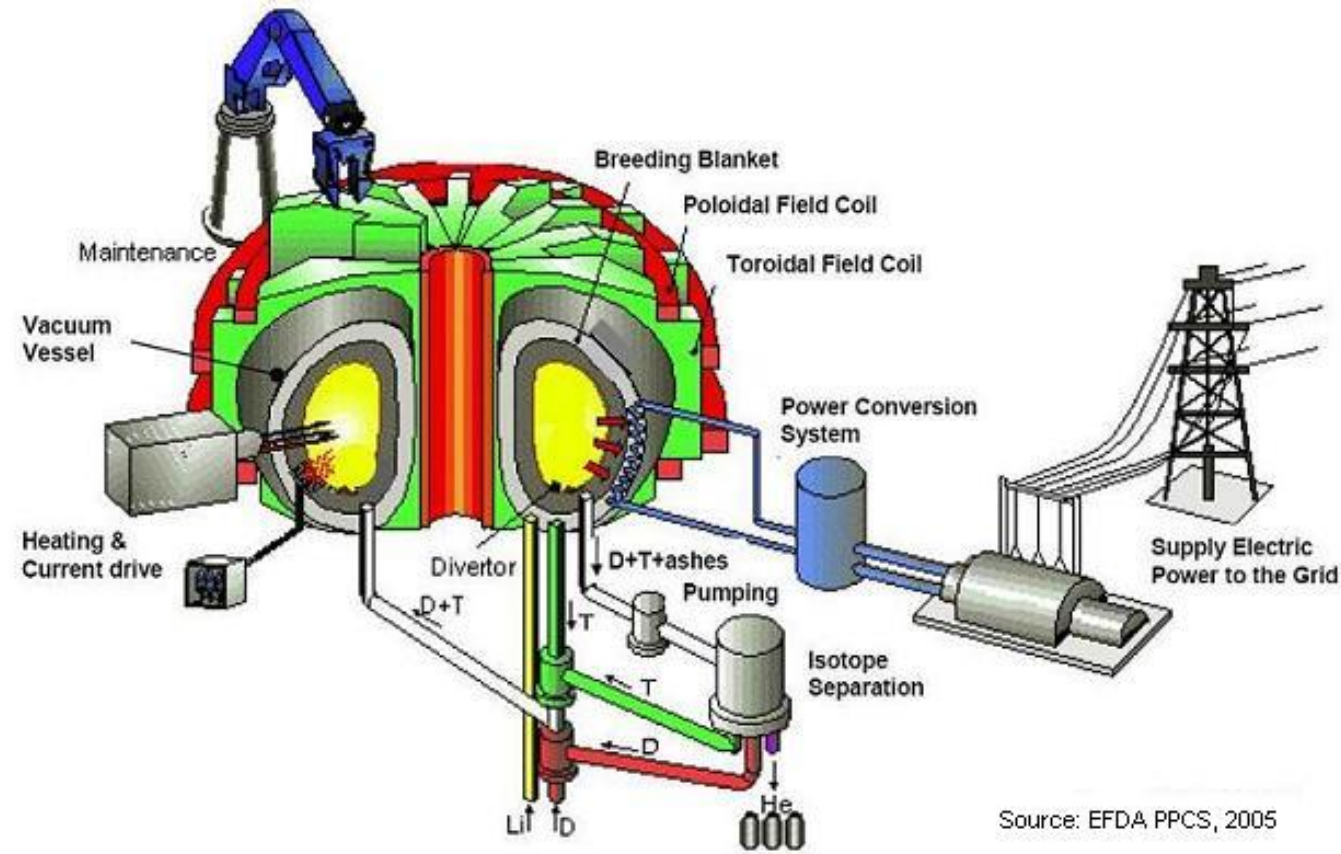


Tokamak Fusion  
Test Reactor (TFTR)  
(1989-1997)





# The Deuterium-Tritium fusion gas cycle is designed for tritium recycling and reuse of fuel



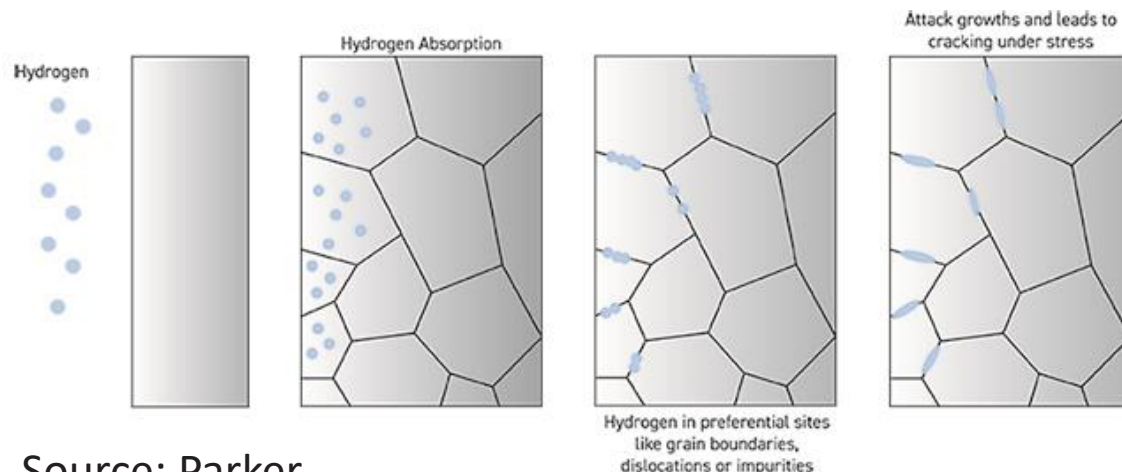
In a fusion power plant, neutrons will react with a lithium breeder blanket to generate tritium fuel which will be purified and recirculated into the fuel stream



Hydrogen systems are designed to prevent explosions (4% in air), while tritium systems are designed to minimize inventory and losses

- Hydrogen systems can use high concentration hydrogen, at high pressures, and are designed to prevent explosions
- Tritium systems are ~gram scale –never an explosion risk, and designed for vacuum operation
- Tritium is a weak beta emitter: decays to helium by releasing an energetic electron
  - Beta particles can only penetrate through 6 mm in air
  - Goal: keep concentrations as low as possible (1 ppm is a very high concentration)

**Tritium systems are designed to minimize inventory, limit diffusion, reduce tritiation of compounds**



Source: Parker

**Useful conversion factors:**

1 cc T<sub>2</sub> (STP)      2.588 Ci

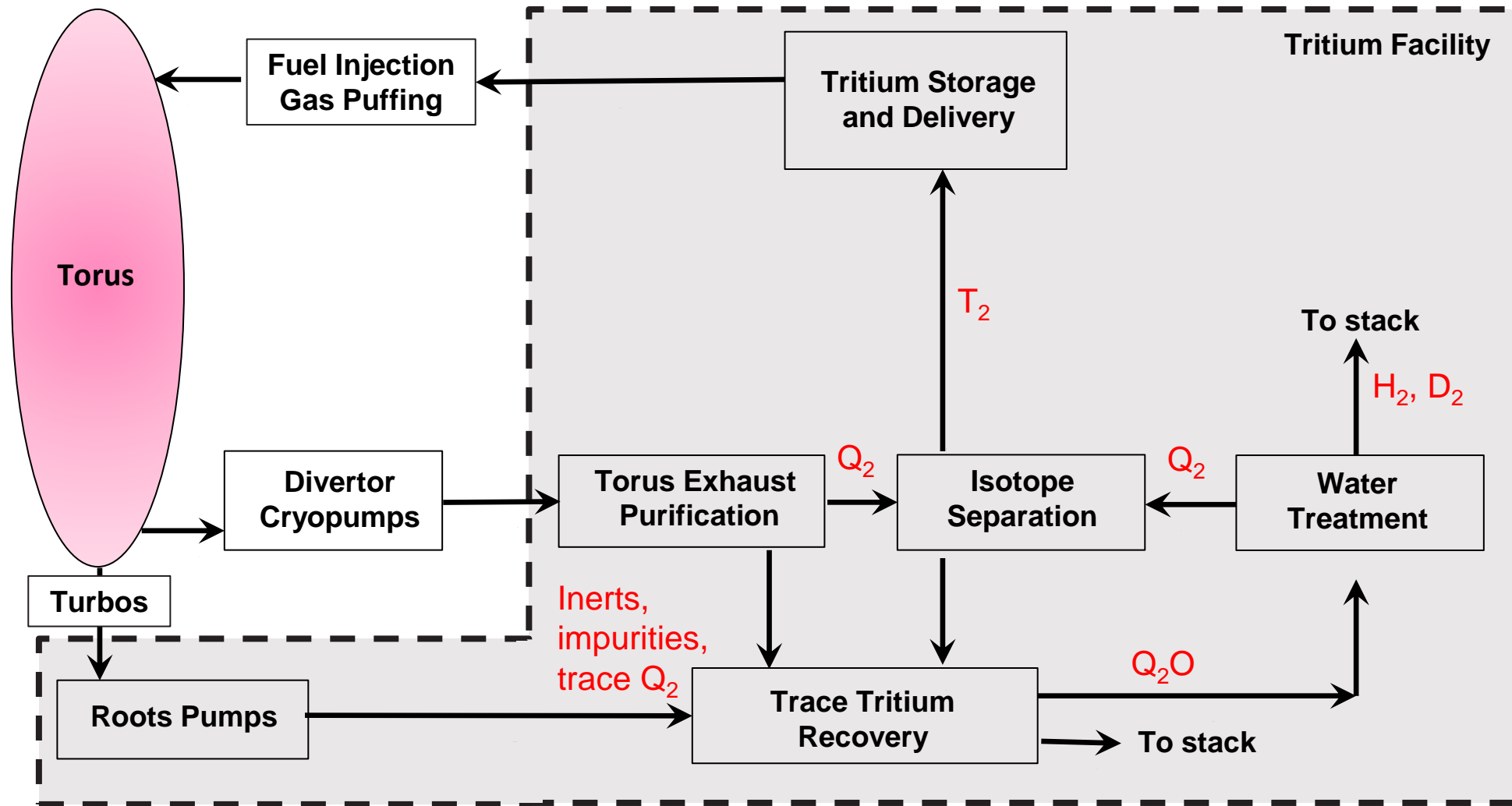
**1 ppm**                      **2.588 Ci/m<sup>3</sup>**

1 gram of T<sub>2</sub>            9615 Ci



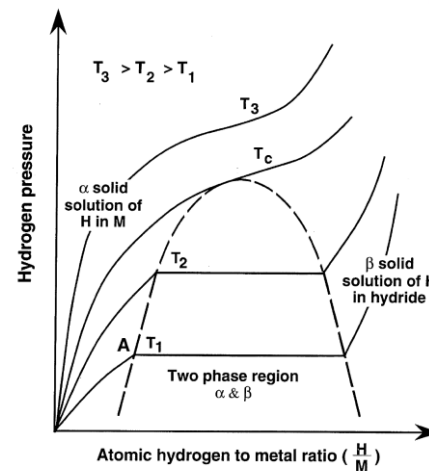
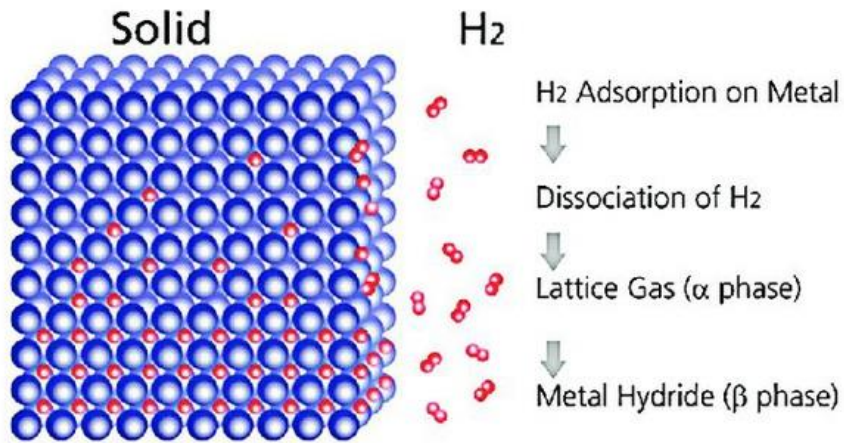
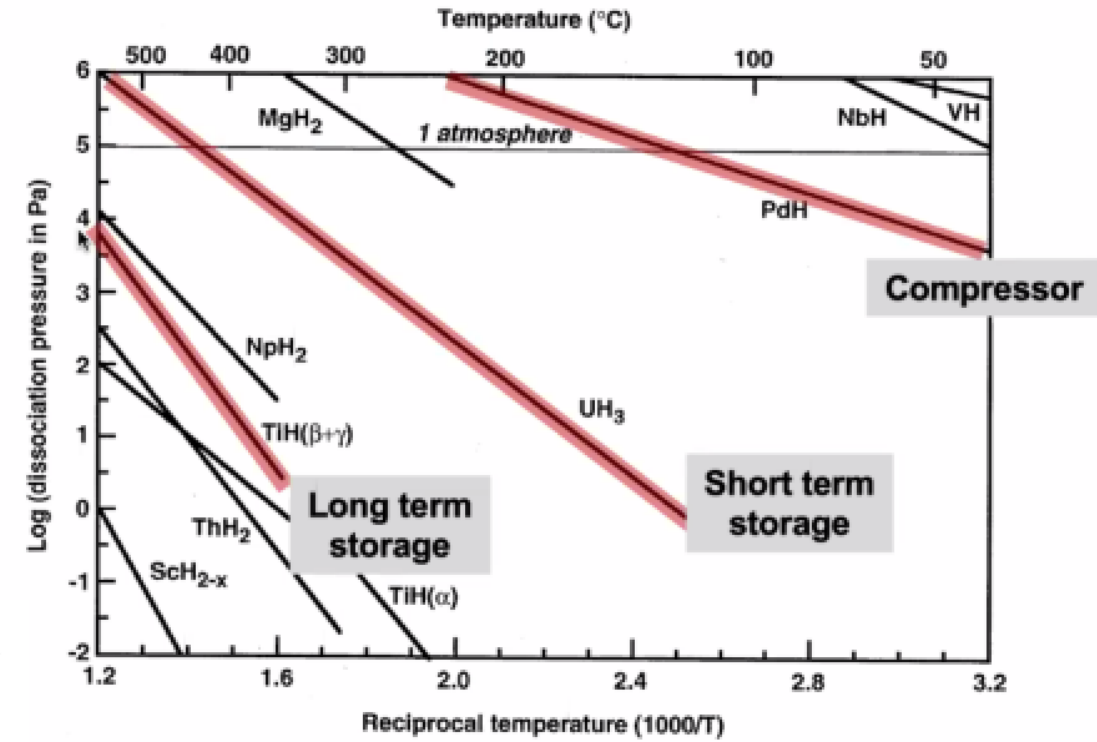


# The SPARC fuel cycle is designed for short pulse DT fusion for $Q > 1$



The tritium plant is designed to take tritiated process gas mixtures, separate and purify tritium, and minimize tritium emissions to trace quantities.

# Tritium Storage: tritium is stored as a metal tritide (hydride)



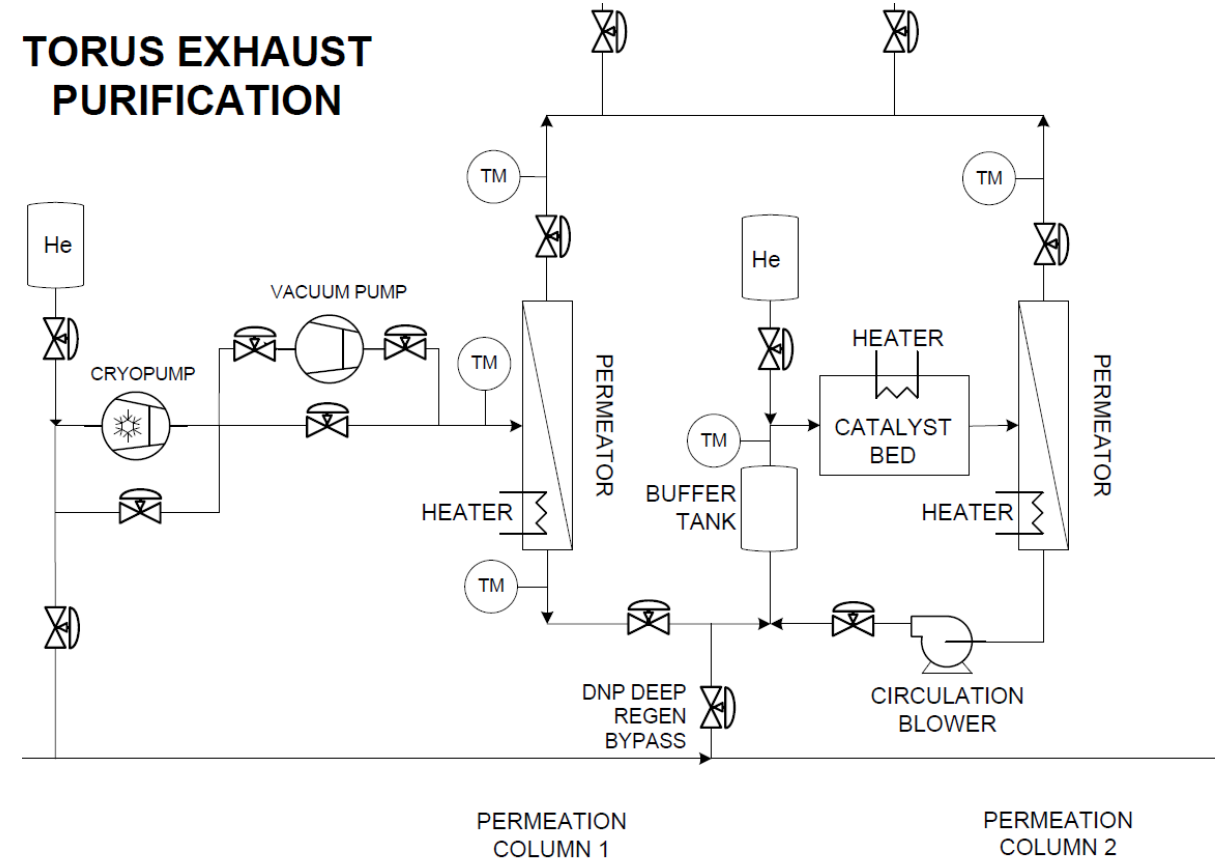
Shmayda, TRANSAT workshop 2021



Torus Exhaust Purification collects high tritium concentration streams and uses a catalytic permeator to separate hydrogenics from other gas species



**TORUS EXHAUST  
PURIFICATION**

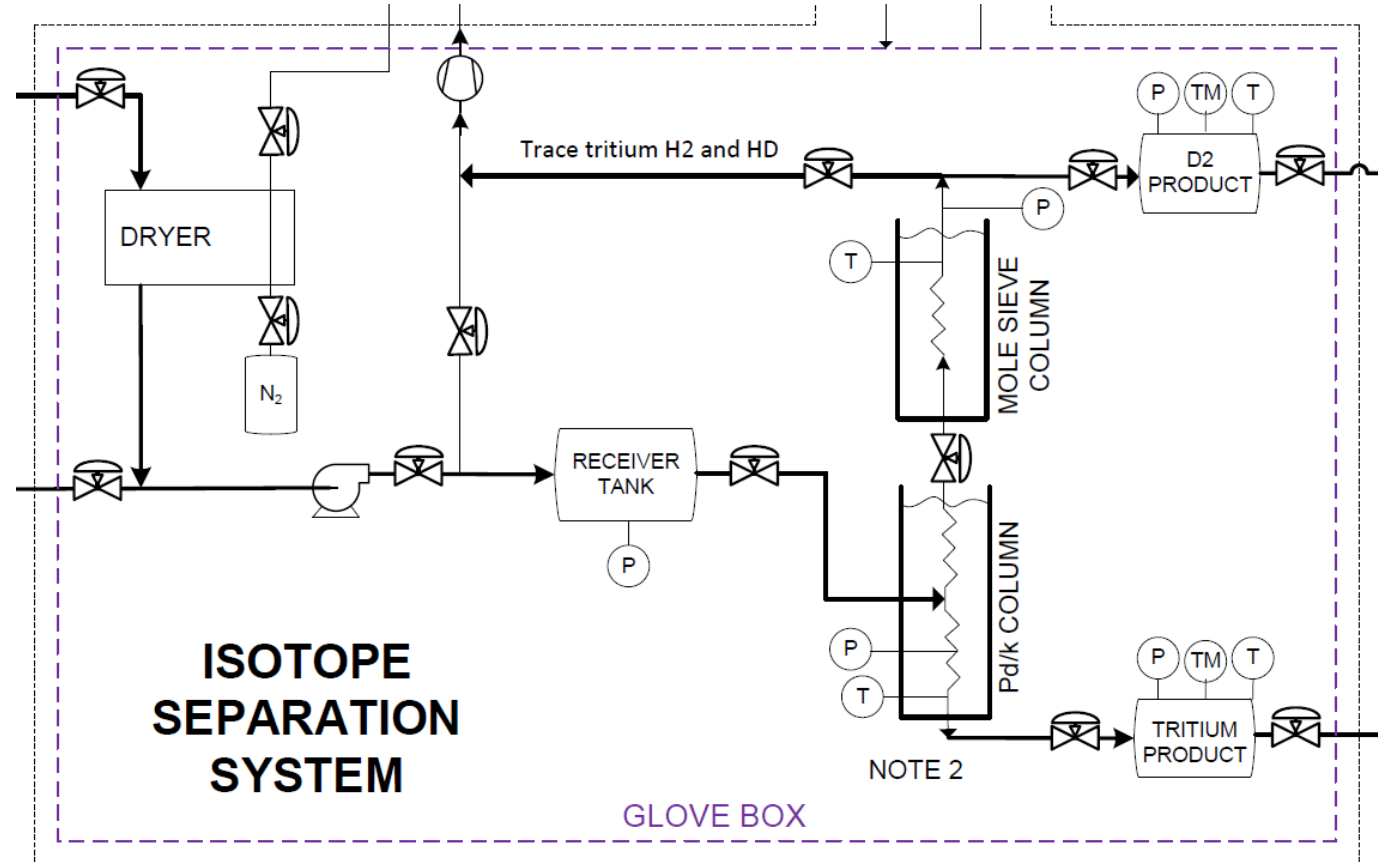




# Isotope Separation Systems uses a combination of Pd/k and mole sieve columns to separate T from D and H

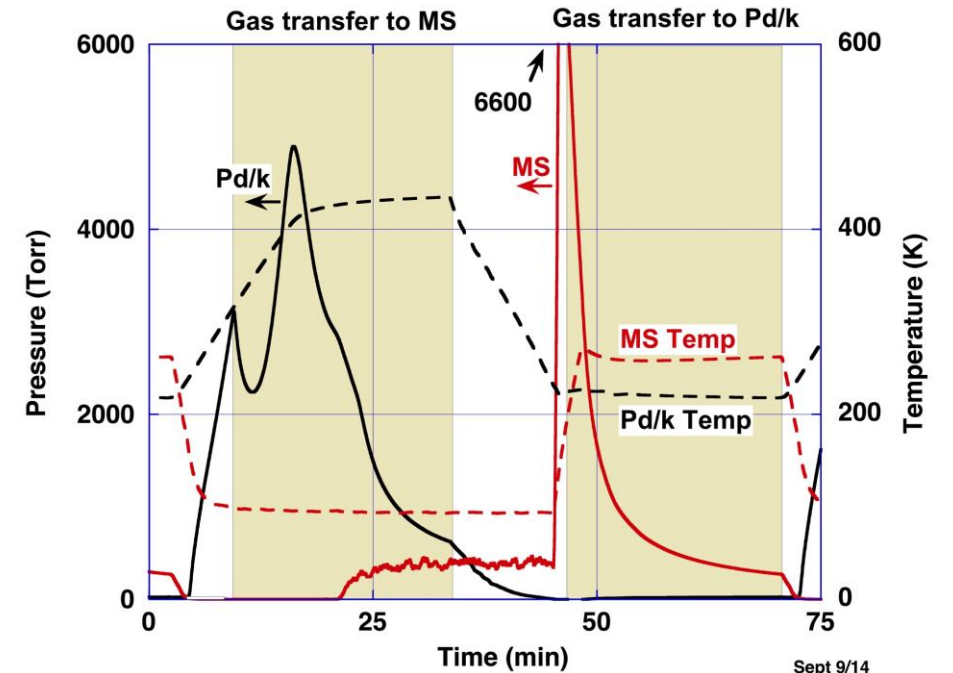
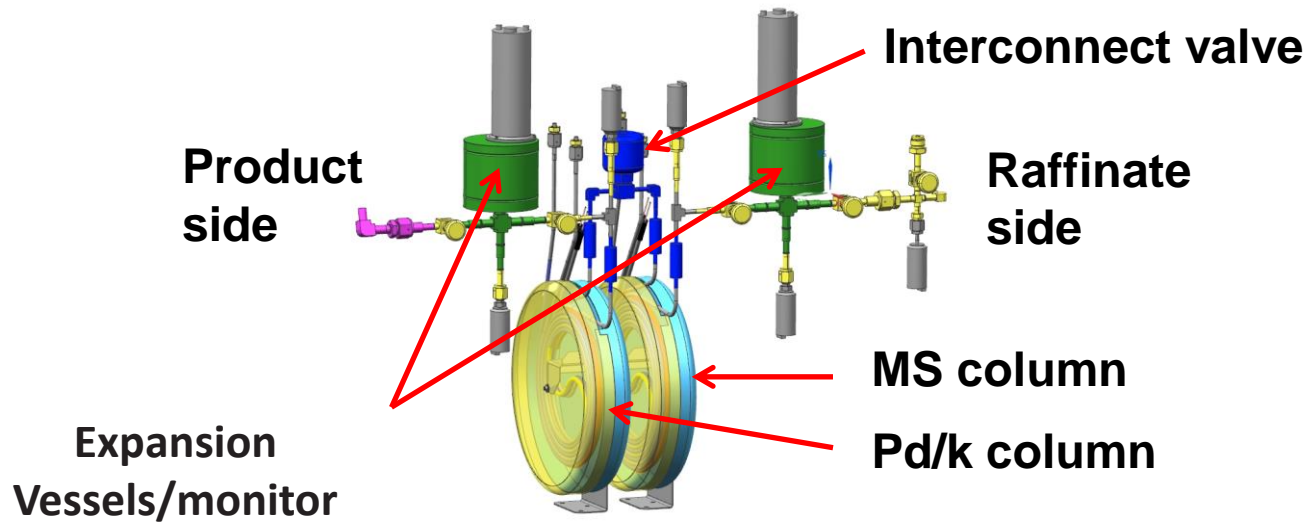


Credit: W. Shmayda





# Isotope separation is based on shuffling elemental hydrogen between Pd/k and molecular sieve (MS) coils

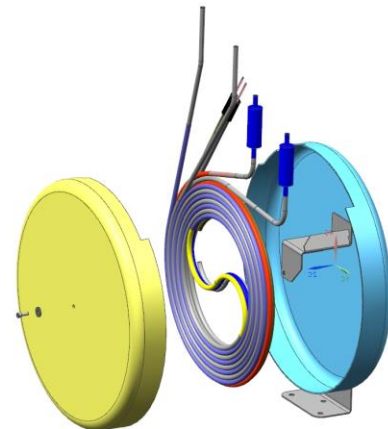


Sept 9/14  
Inventory: 5.8 sL



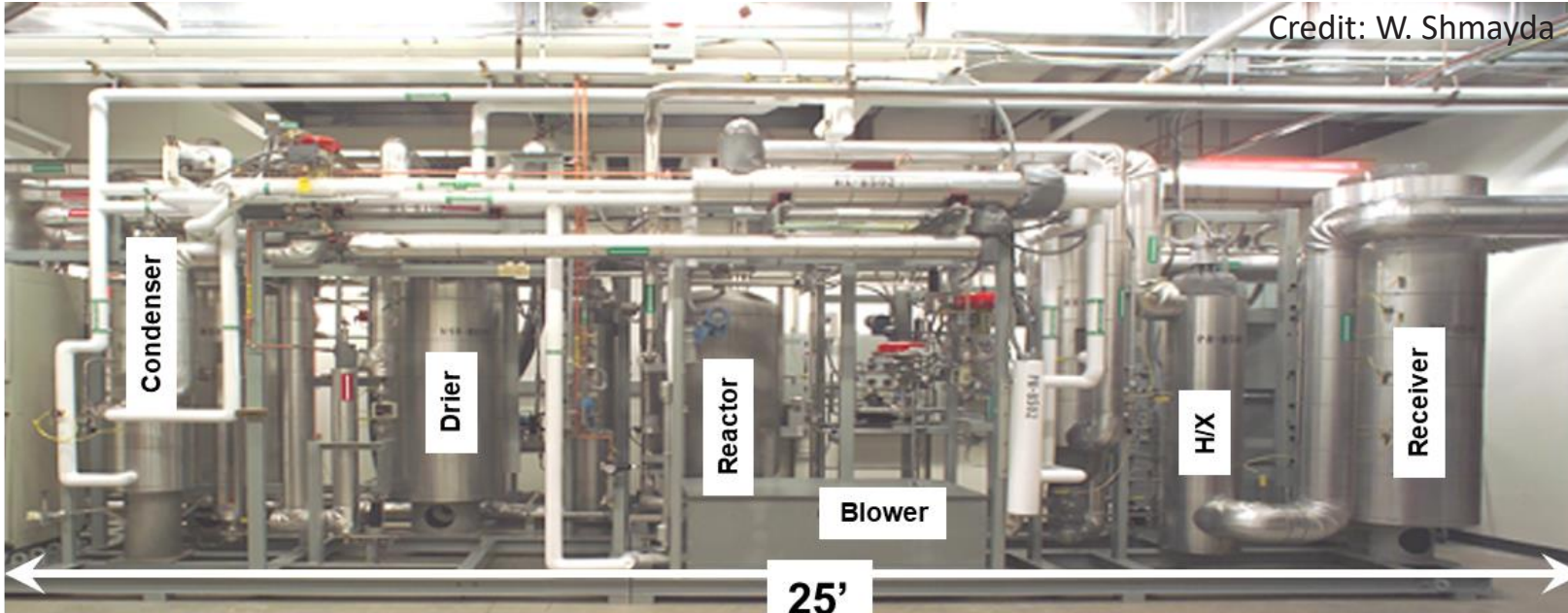
Credit: W. Shmayda

6/23/2021



- The Pd/k coil sorts atomic hydrogen
- The MS coil sorts molecular hydrogen isotopologues
- Coil capacity 6.5 sL

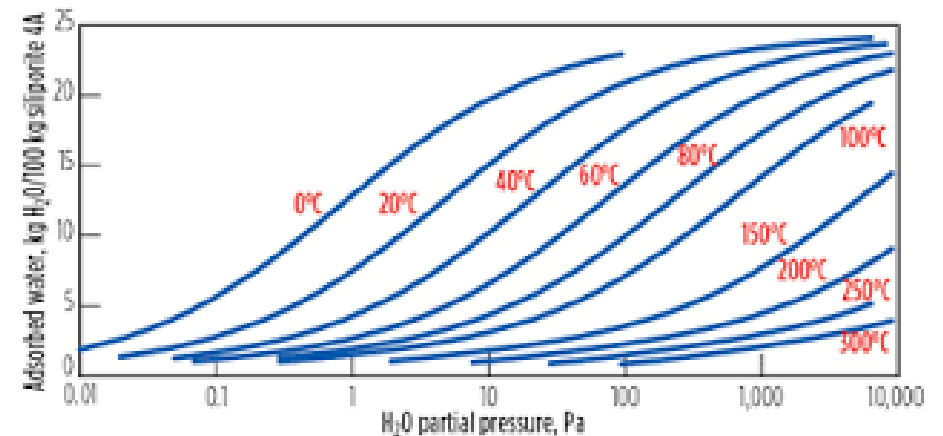
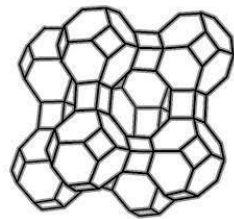
# Detritiation for further collection: combustion and water generation



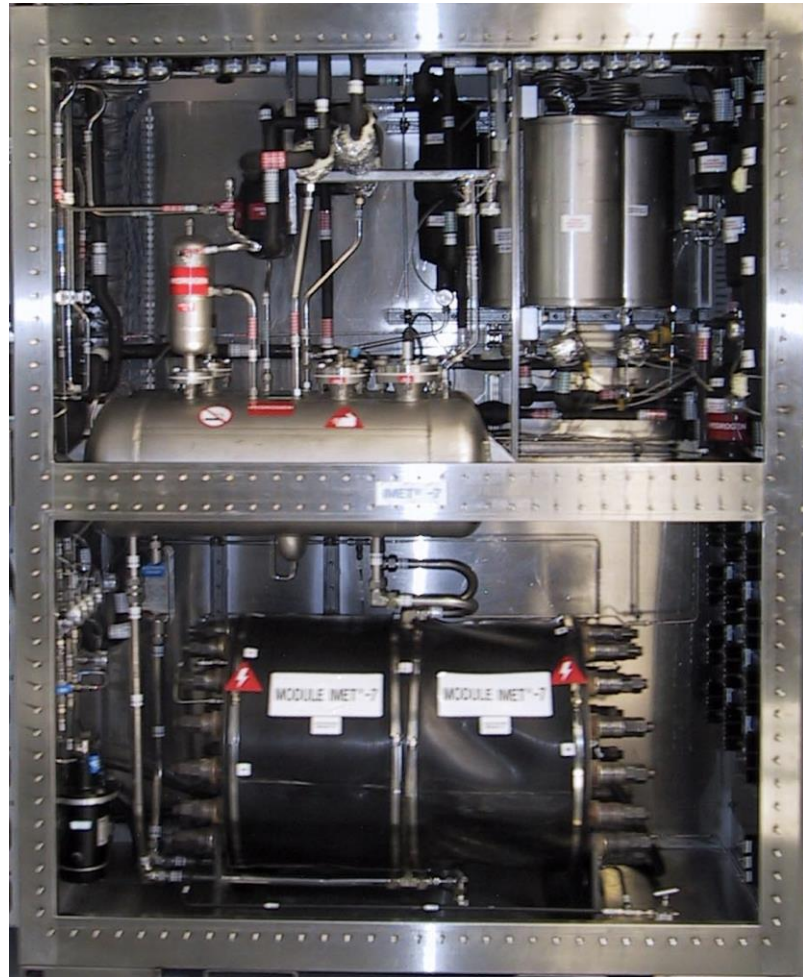
Combustion:  
Tritiated organics + air  
→ CO<sub>2</sub> + Q<sub>2</sub>O

Drier (molecular sieve adsorbent):

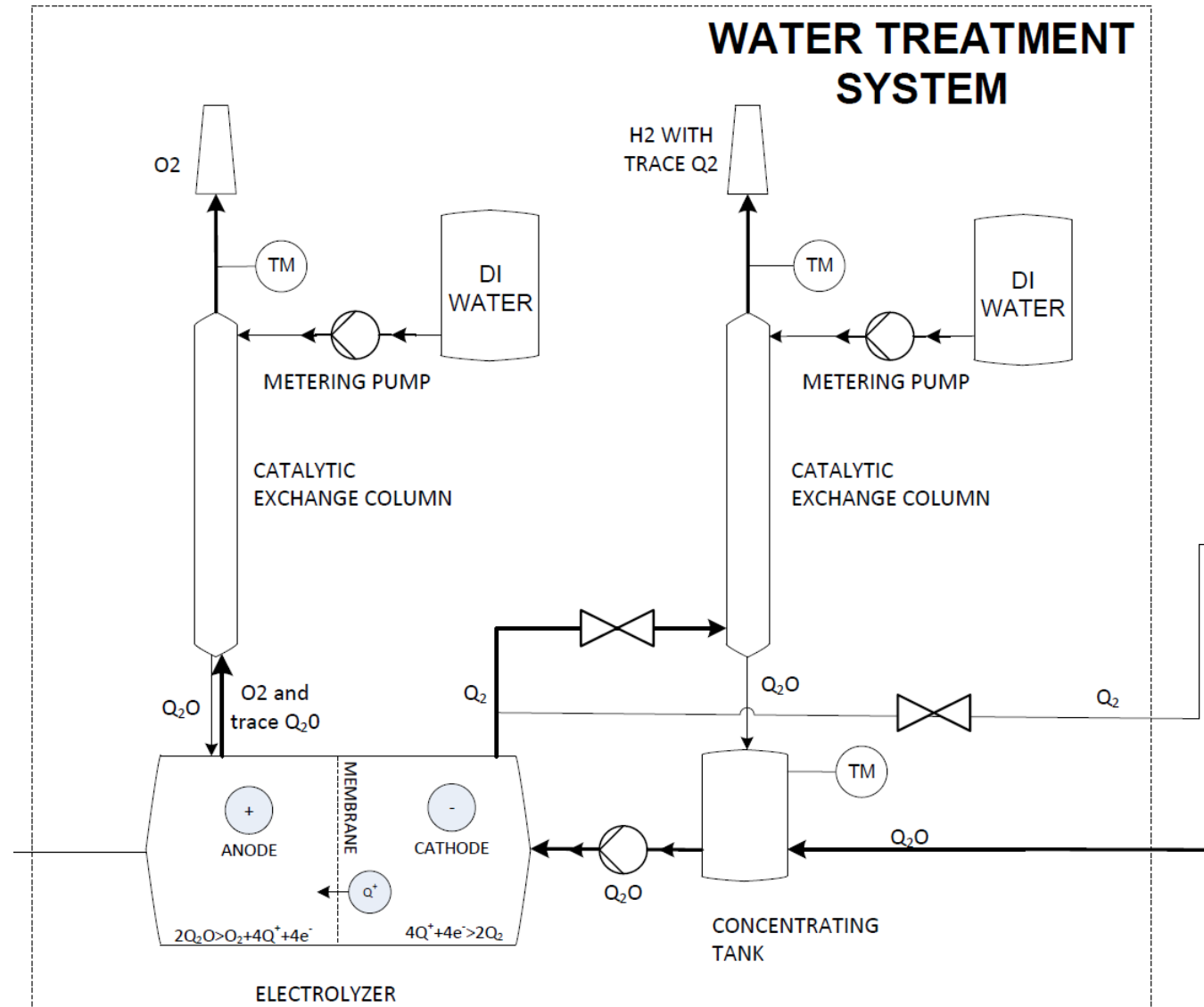
Crystal structure size selective for trapping water



# Detritiation for further collection: electrolysis to collect tritiated gas



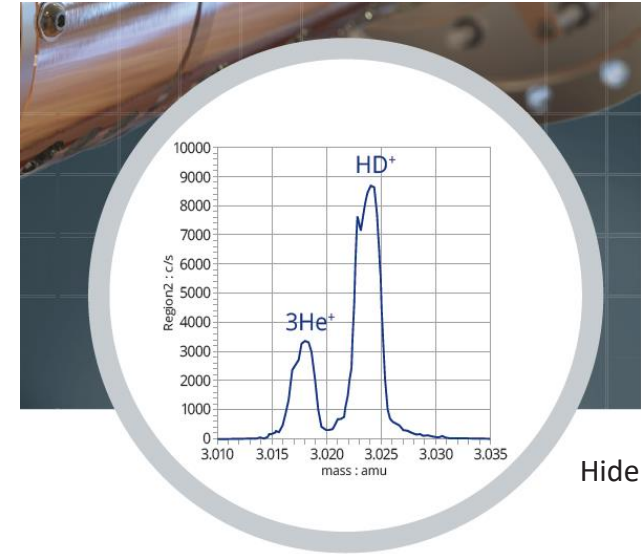
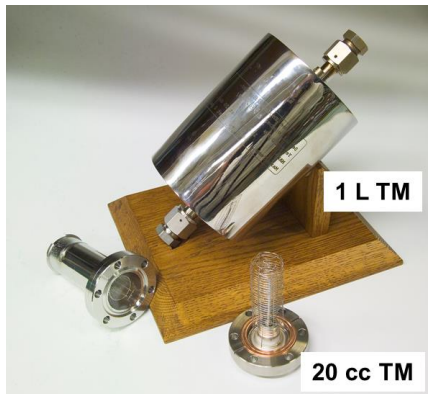
Credit: W. Shmayda



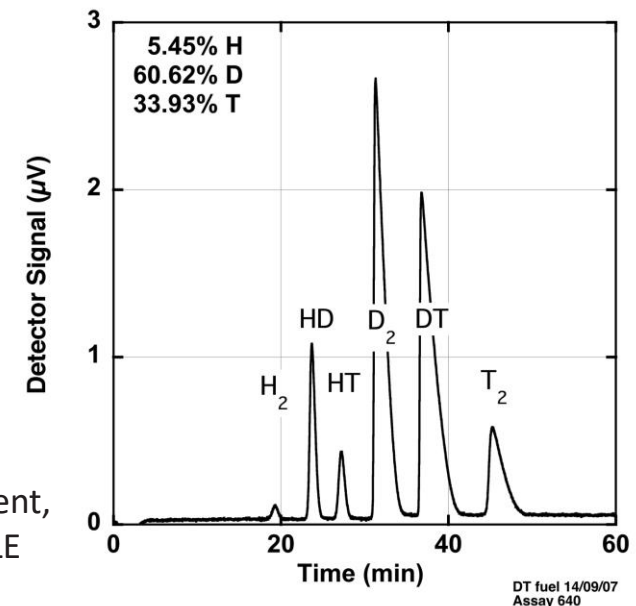


# Tritium measurements and accounting

- Traditional gas techniques: mass, charge, gas laws
  - Mass spectrometry (AMU) (Residual gas analyzers)
  - Gas chromatography
  - Laser Raman Spectroscopy
  - PVT measurements
- Measurements from tritium's beta decay:
  - Calorimetry: measure tritium decay heat
  - Ionization Chambers



Hidden Analytical



GC measurement,  
W. Shmayda LLE



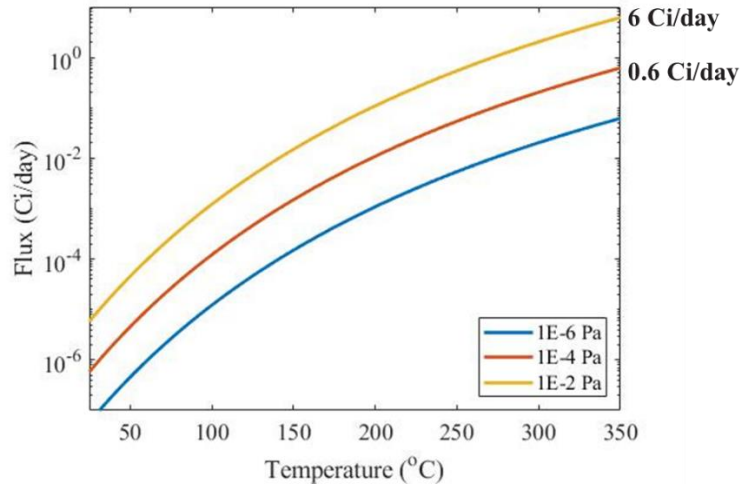


# Open research for the design of systems for tritium compatibility

- Studies on tritium diffusion through metals
- Tritium uptake and retention in plasma facing components
- Technology development:
  - Fueling valves and vacuum pumps for tritium operation
  - Tritium pellet injection
  - Processing tritiated ammonia for plasmas using nitrogen
- Corrosion at high tritium activities
  - 10s of % starts to react (liquids/compounds)

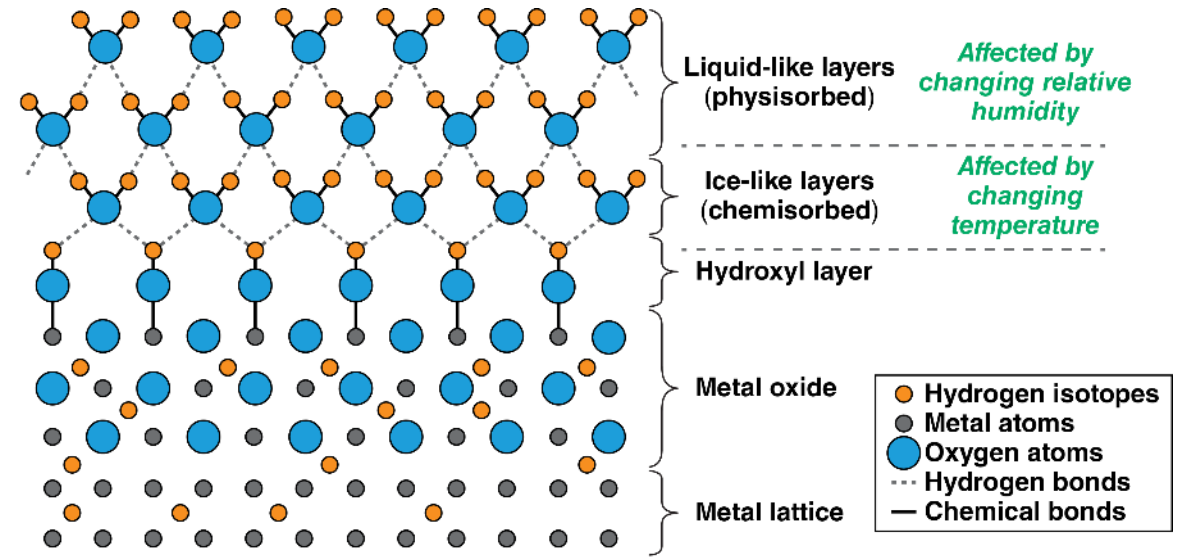


# Diffusion through metals and surface water formation leads to outgassing of T<sub>2</sub>



Flux through SS for varying P(T<sub>2</sub>)

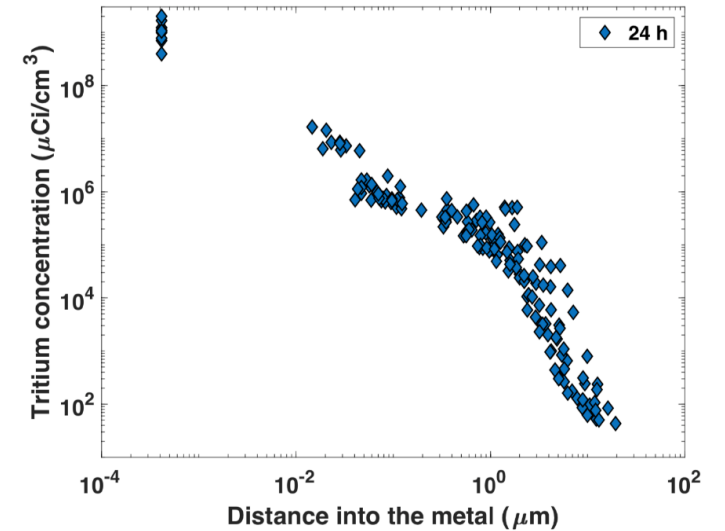
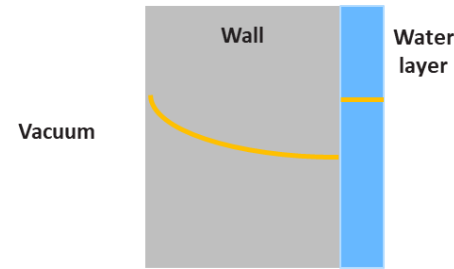
## Surface water layer: Isotopic exchange to form HTO



E26748b

Flux = diffusivity \* concentration gradient

Ongoing studies for permeation through metals, surface chemistry, and metallic structure





# Tritium retention and recovery from plasma-facing components

- Significant tritium inventory has been adsorbed by carbon PFCs in previous tokamaks
- As tokamaks move to metal walls (tungsten, beryllium) the retention is likely reduced but very limited studies
- Mechanisms for uptake, mitigations, and recovery are all of interest

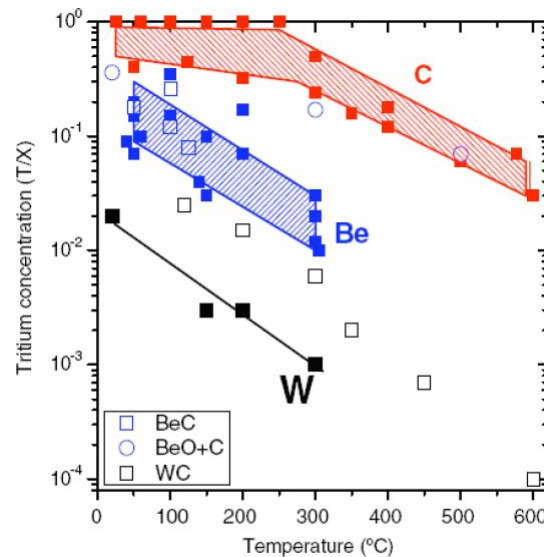
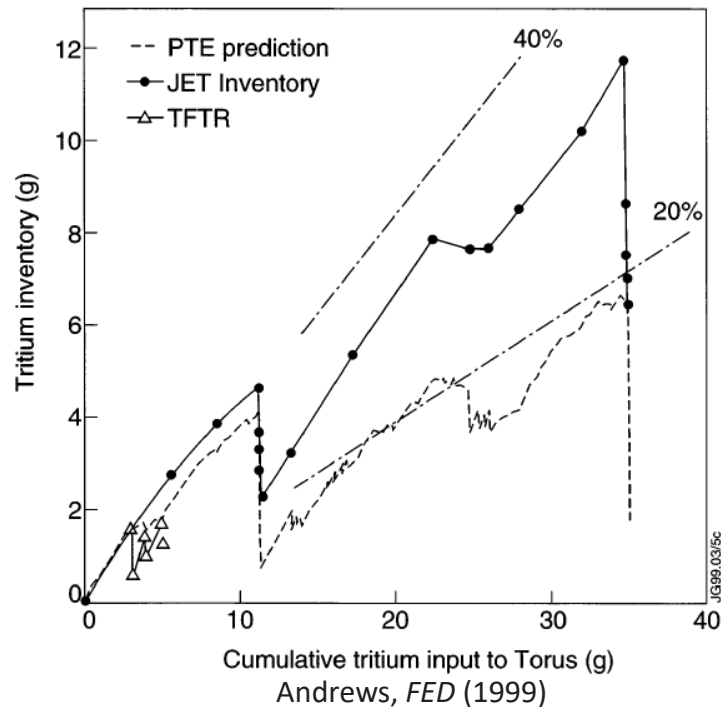


Figure 3.4.1: Data for retention of D co-deposited with C, Be and W.

Lipschultz, B., et al. "An assessment of the current data affecting tritium retention and its use to project towards T retention in ITER." (2010).

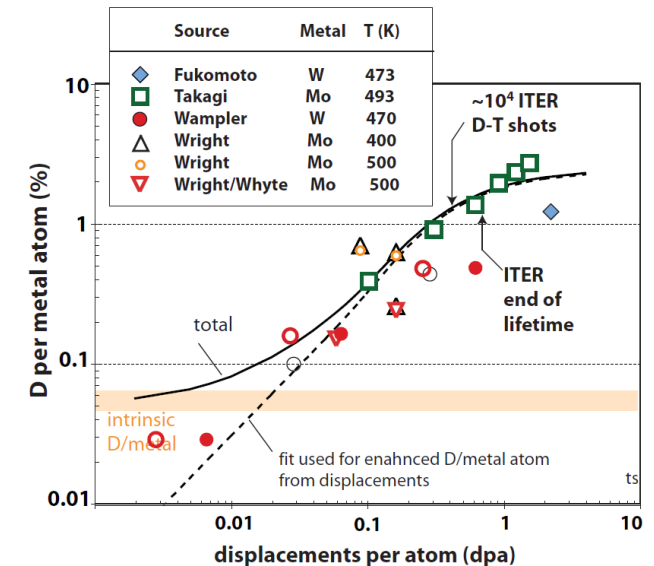


Figure 4.1.1. The increase in deuterium concentration due to damage from ion irradiation in tungsten [48-49] and molybdenum [29, 50-51].

# Tritium fueling: modules, valves, and pellet injectors

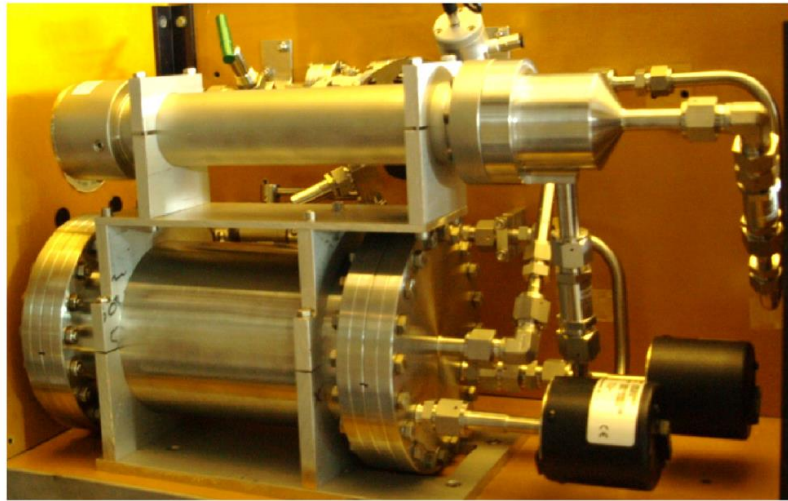


Fig. 5. GIM3 as installed on the machine. 5L reservoir on bottom and piezoelectric valve on top.

Carvalho, Fus. Engr Des. 2017

JET Tritium Injection Modules are 0.8 bar pressure vessels with ~2g 10L systems

High inventory and pressure systems

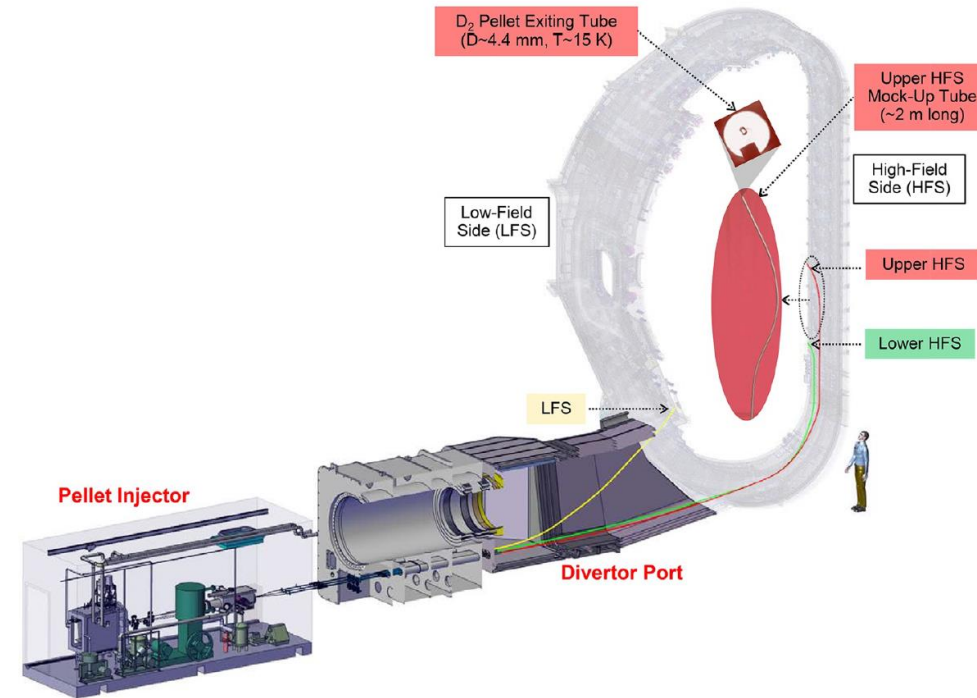


Fig. 12. Design schematic of the ITER pellet injection system; three curved guide tubes are used to transport pellets for injection at three wall locations.

Combs and Baylor, OSTI, 2018

Minimize tritium inventory, recirculate gas, eliminate failure points, confined system



# Processing tritiated ammonia to allow for nitrogen seeding of plasmas

- Impurity seeding is typically used to manage heat fluxes in divertor region and reduce sputtering of wall material into plasma,  $N_2$  is one candidate gas
- Previous works shows nitrogen adsorbs on tungsten wall
- This adsorbed nitrogen can exchange with tritium to form tritiated ammonia compounds
- Tritiated ammonia can poison getter beds and many components in the tritium facility
- Pre-processing to crack ammonia needed
  - Hydrogen fuels industry looking at cracking but technology needs to be adapted for tritium

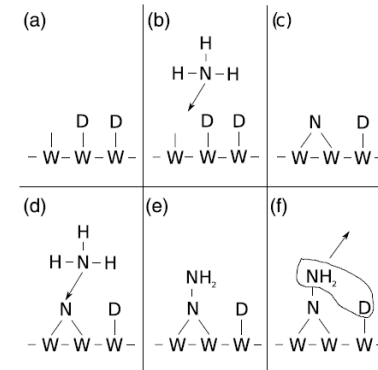
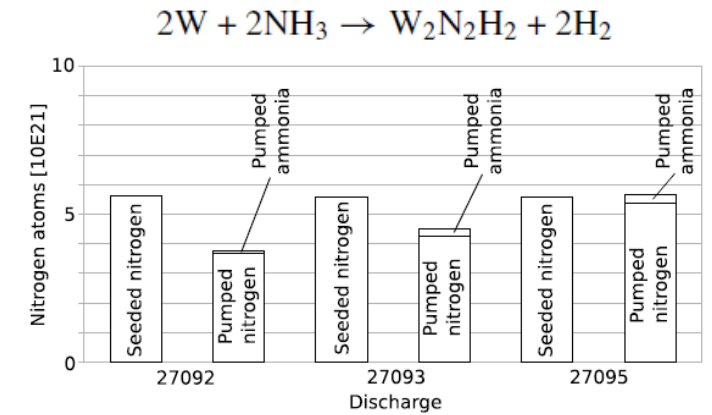
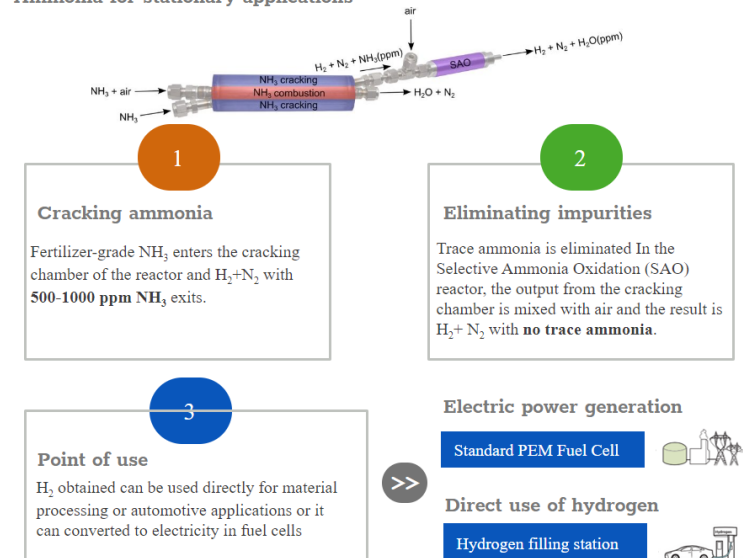


Figure 3. Six-step model of the interaction of ammonia with the tungsten surface of the AUG plasma vessel.



D Neuwirth *et al* 2012 *Plasma Phys. Control. Fusion* **54** 085008

## Ammonia for stationary applications



<https://rencat.net/>

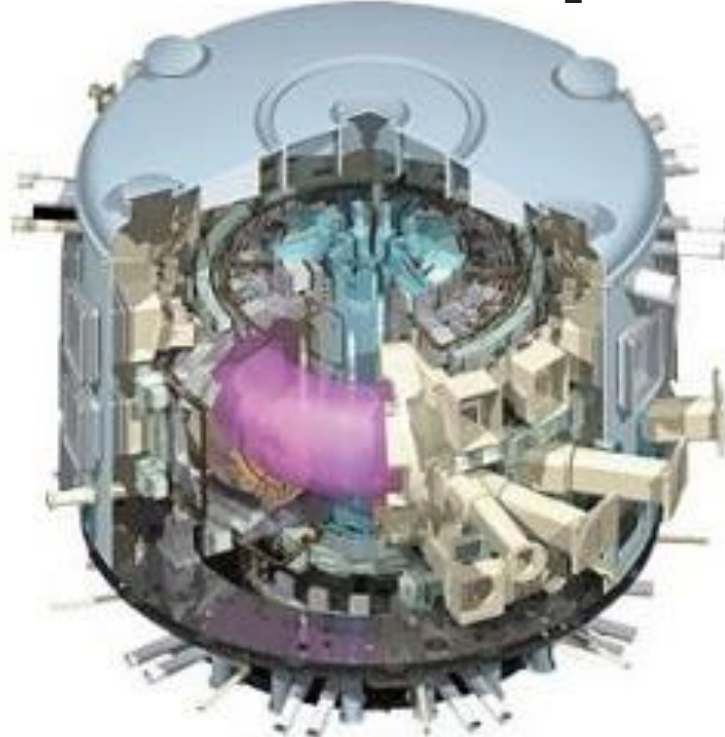
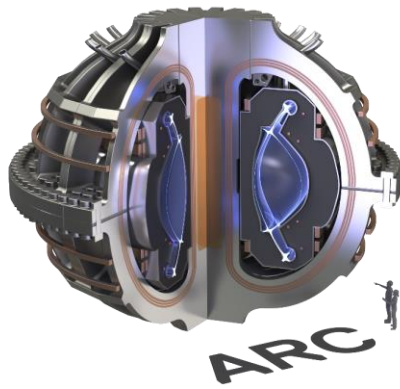


# Tritium inventories: CFS scaling compared to ITER

- SPARC is 1/40<sup>th</sup> the size of ITER
- ARC is planned to be 1/15<sup>th</sup> the size of DEMO
- Tritium inventory required for fueling scales with plasma volume

2000-3000 g T<sub>2</sub>

10 g T<sub>2</sub>



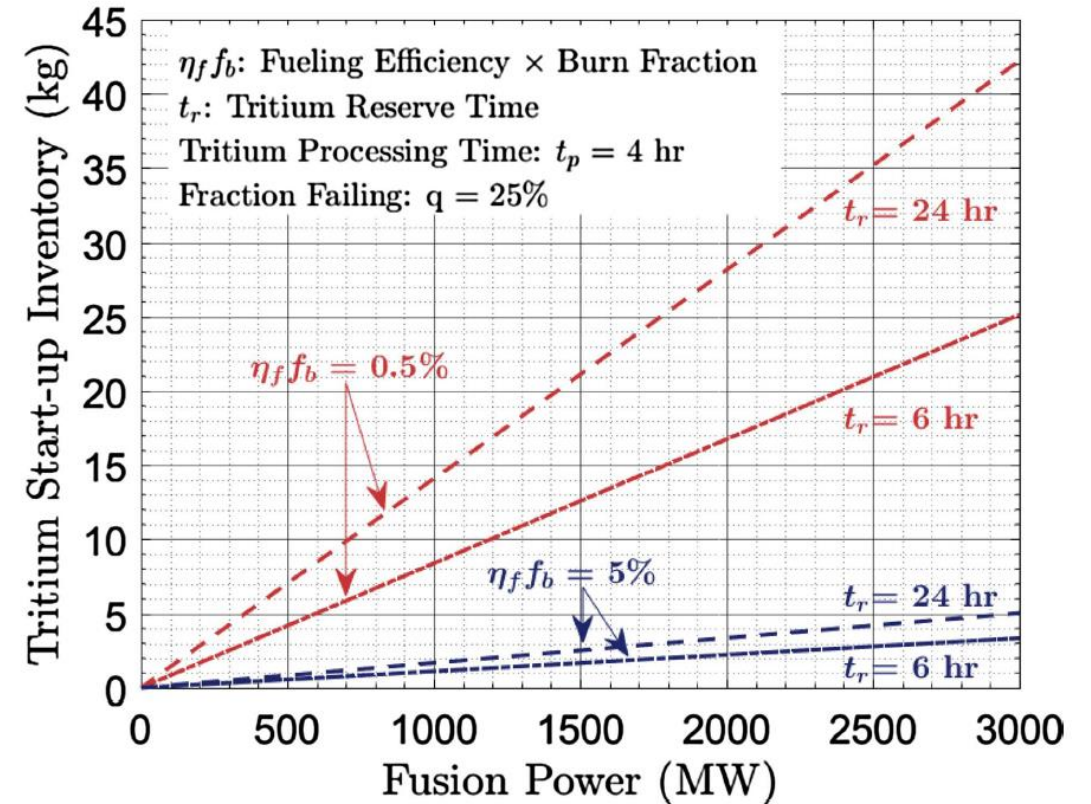
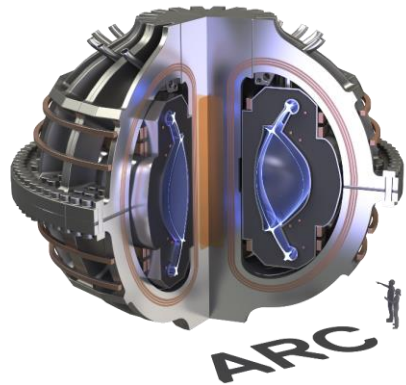
**ITER**



**DEMO**



DEMO fuel cycle could require up to 40 kg of tritium inventory, greater than the world's tritium stores today.

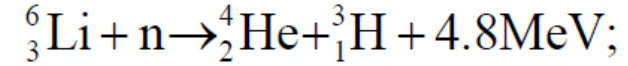


Abdou et al. *Nucl. Fus.* 2021

The CFS ARC team is developing breeding blankets to reduce inventory. Combined with an efficient tritium fuel processing loop, ARC should be well below what ITER and DEMO require



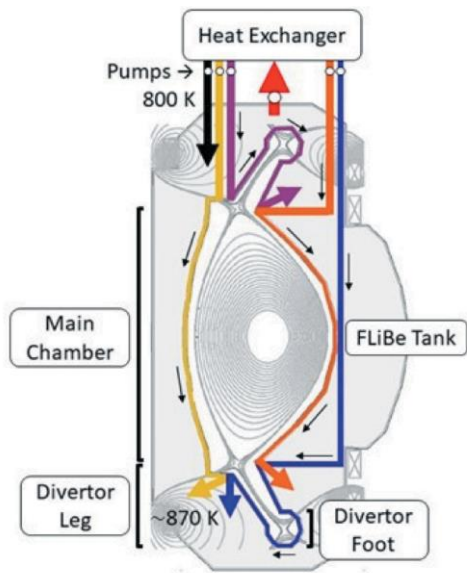
For continuous operation of a DT fusion power plant, tritium can be generated from lithium breeder blankets



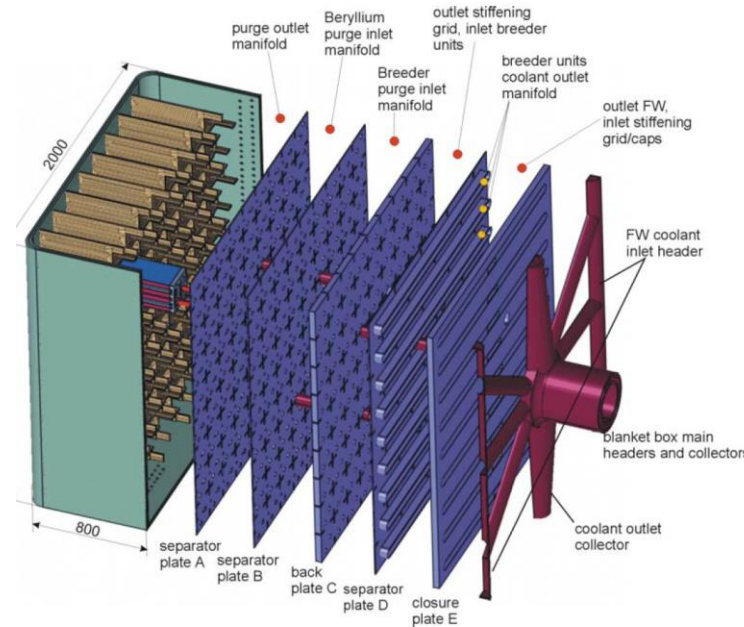
Self-cooled:  
FLiBe

Separately-cooled:  
Pb-Li/He coolant

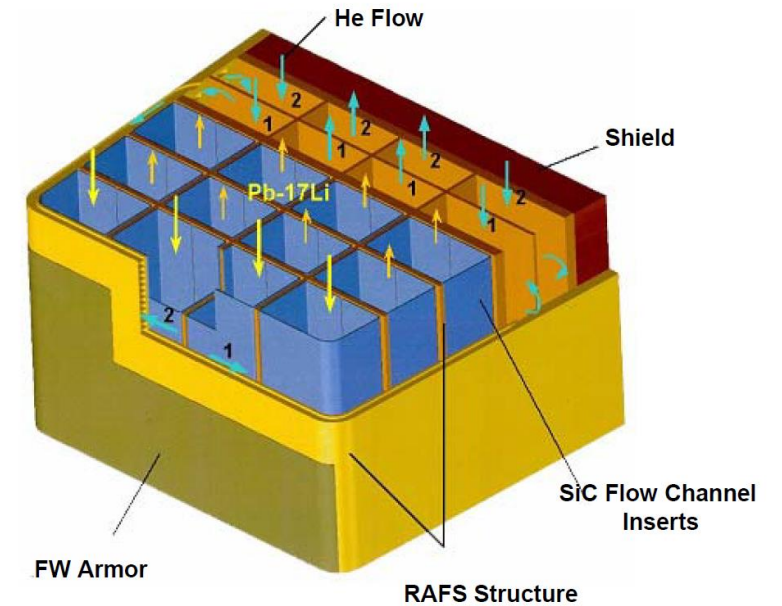
Dual-cooled:  
Pb-Li/He coolant



C Forsburg, Nuclear Fusion 2019



EU-PPCS B







# Research areas for breeder blankets

- Efficient breeding of tritium from blanket materials
- Developing channels and pumps for efficient circulation of FLiBe coolant
- Handling of tritiated fluorides and separation of tritium from TF
- Corrosion resistance materials for coolant loop

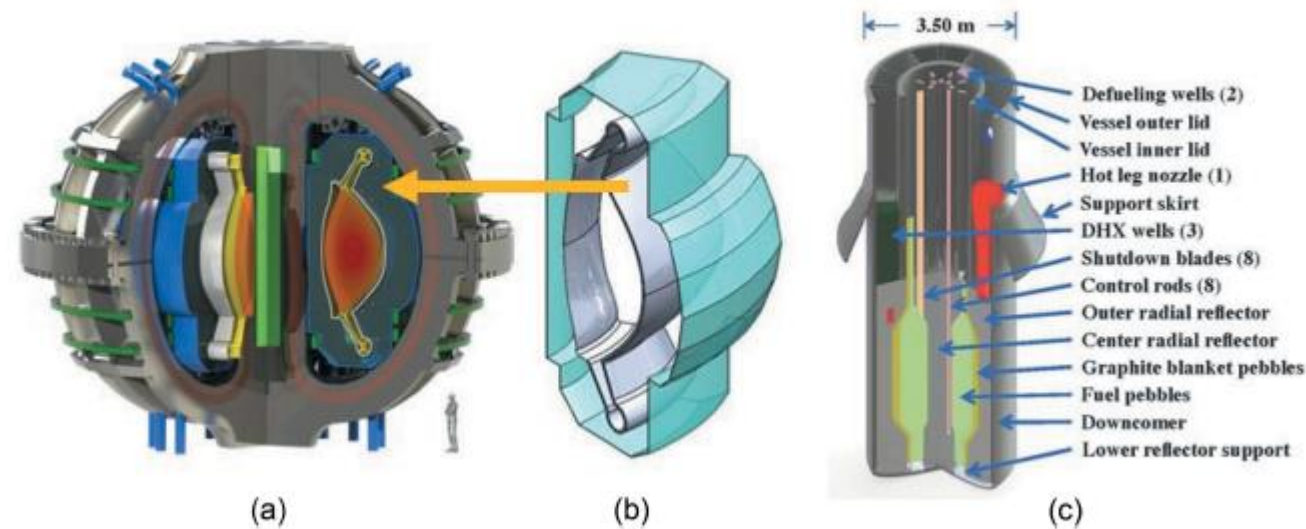


Fig. 1. (a) ARC fusion system, (b) flibe fusion blanket for ARC, and (c) FHR fission system.

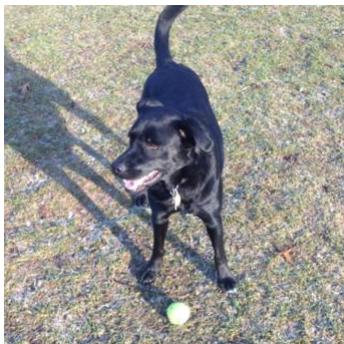
C Forsburg, Nuclear Fusion 2019

# The SPARC FUEL team is comprised of many scientists and engineers with collaborations among fusion facilities



Corinne Mitchell,  
Corporate Radiation  
Protection Manager

Dr. Walter Shmayda  
University of Rochester, LLE  
Faculty and RSO



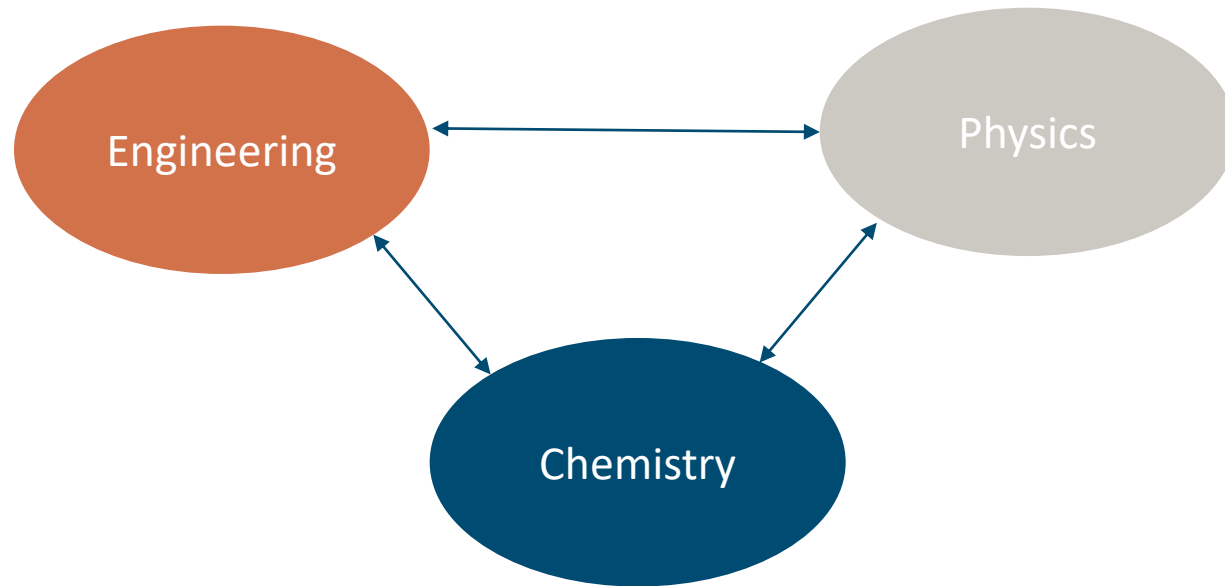
Dr. Valeria Riccardo  
Head of Mechanical  
Engineering

ChemE, MechE,  
Vacuum systems,  
tokamak physicists,  
lab scientists,  
postdoctoral  
researchers,  
tritium experts



# Tritium engineering builds from skills in many fields and there are many opportunities along the full R&D spectra

- Skills: labwork, attention to detail, modeling, programming, data analysis
- Attitude: push to enable fusion, contribute to a culture of trust, transparency, and safety, and always strive to design systems to minimize fuel needs outside the fuel cycle



- Plasma physics
- Vacuum systems
- Semiconductors
- Micro-nano phenomena
- Fuel cells and electrochemistry

# Overview of ongoing tritium projects at UofR LLE



- Tritium extraction from air using a platinized molecular sieve
- Evaluation of flow through palladium permeators
- Process torus exhaust using asymmetric permeation
- Tritium beta induced isotopic exchange with protons on 316 SS surfaces



Walter Shmayda

[wshm@lle.Rochester.edu](mailto:wshm@lle.Rochester.edu)

SULI on-site lab opportunity  
Graduate research opportunities

# Questions?

Contact: [hmutha@cfs.energy](mailto:hmutha@cfs.energy)

Subject: SULI PPPL 21