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Savannah River National Laboratory®

Tritium Science and Technology for Fusion Energy Success

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FPA

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SRNL at a Glance

We protect our nation by applying science to international security, the environment and the energy economy

Core Competencies

- Tritium Processing, Storage and Gas Transfer Systems
- Environmental Remediation and Risk Reduction
- Nuclear Materials Processing and Disposition
- Nuclear Detection, Characterization and Assessments

Location: Aiken, SC
Type: Multiprogram
Year Founded: 1951
Director: Dr. Vahid Majidi
Contractor: Savannah River Nuclear Solutions

Multi-Program Laboratory
1,000 Staff

$365M

FY19 Lab Operating Budget

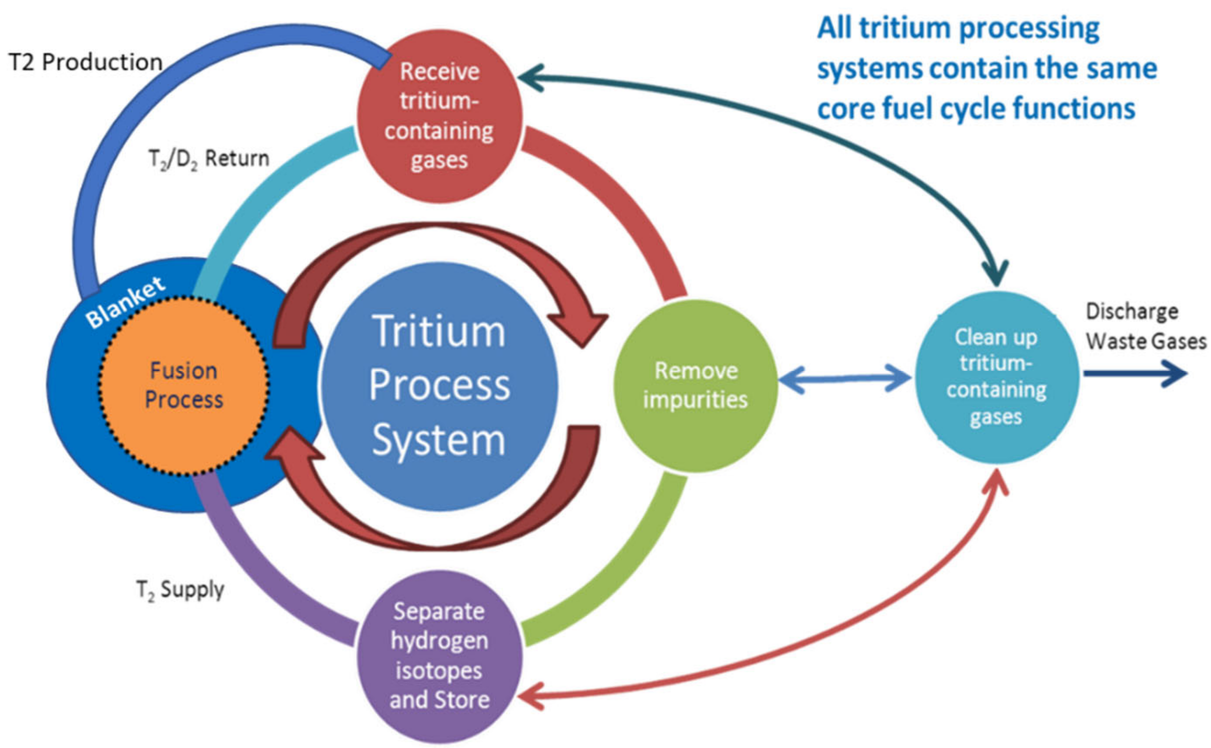
Program Areas

- National Security 41%
- Environmental Stewardship 37%
- Nuclear Materials Management 18%
- Secure Energy Manufacturing 4%

Fusion Challenges will Impact the Entire Fuel Cycle

Fusion Tritium Challenges:

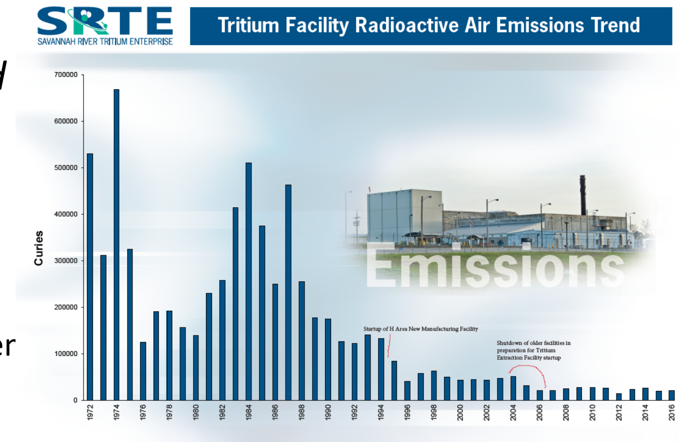
- Process tritium at rate 1 to 2 orders of magnitude higher that has been demonstrated to date.
- Reduce tritium emissions by 1 to 2 orders of magnitude lower than demonstrated performance.
- Demonstrate continuous operation (24/7 – 365) versus current semi-continuous and batch processing.
- Minimize in-process inventory of tritium.

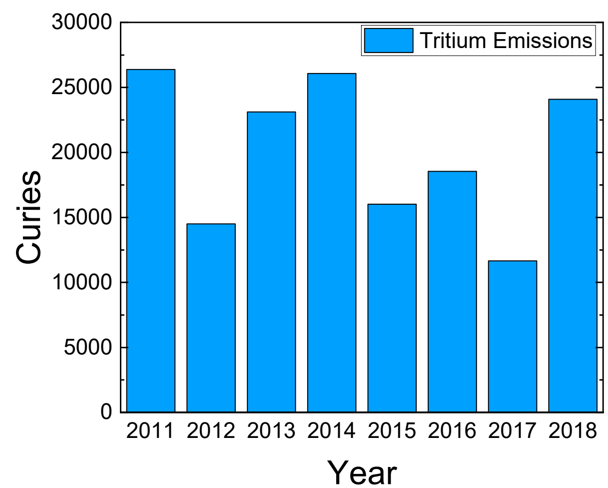


SRNL applies the full range of process development and materials science capabilities to address the key issues of blanket and fuel cycles for fusion science and technology.

Fuel Cycle Research Needs to Enable Commercialization of Fusion Energy

- Tritium Inventory Reduction
  - *More closely match tritium processing rates to tritium feed rate into the fusion machine*
    - Direct Internal Recirculation
  - *Improvement and Intensification of Tritium Process Technologies*
    - Improvement of tightly coupled heat and mass transfer limited syster such as TCAP for isotope separation
- Tritium Breeding and Extraction
  - *Ensure breeding ratio can be achieved and that tritium can be extracted from blanket at a rate that will sustain the fusion economy*
- Tritium Accountability and Tritium Analytical Capability
  - Improvement of Tritium Measurement Technology
  - Development of Rapid, High Accuracy/Precision Instruments
- Environmental Tritium Confinement
  - Reduce tritium emissions by improving facility-wide tritium confinement
  - *Development of Advanced Tritium Wetted Materials*
    - Develop tritium permeation barriers, tritium resistant materials, and corrosion-resistant materials / coatings





SRNL Priorities Align with Strategic Plan for U.S. Burning Plasma Research

NAS Finding: Innovations and promising new methods to separate and process tritium, will be essential to the development of a compact, lower cost fusion reactor.

- A fusion breeding blanket is an outstanding challenge for fusion because scientific gaps exist related to controlling tritium permeation and minimizing tritium inventory.
- The 2018 FESAC report recognizes this challenge and identifies (the opportunity) to develop…advanced tritium extraction technologies and new fuel recycling technologies that allow for minimization of tritium inventories.
- Novel tritium processing technology may reduce the cost and improve the reliability of fusion nuclear components and systems.
- Fusion nuclear components will need to safely and efficiently fuel, exhaust, breed, confine, extract, and separate unprecedented quantities of tritium.
- Tritium science, extraction technologies, and fuel processing are critical challenges for fusion energy systems, and significant challenges will need to be overcome including the need to develop effective tritium permeation barriers to prevent release of sizable quantifies of tritium.

Tokamak Exhaust Processing (TEP)

The US is responsible for the final design, fabrication, assembly, testing, and shipment of the tokamak exhaust processing (TEP) system.

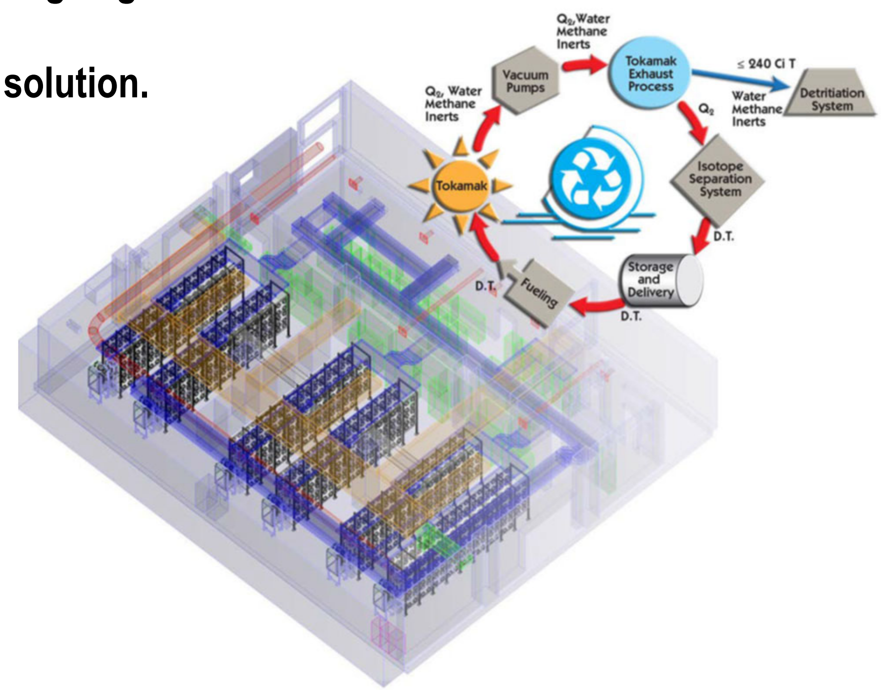
Overview:

ITER will require the processing of an unprecedented rate of hydrogen isotopes. To facilitate environmental responsibility and economic application of fusion technology, the re-use of the hydrogen isotopes is vital. The TEP system must separate the exhaust gases into a stream containing only hydrogen isotopes and a stream containing only non-hydrogen gases.

The implementation of the TEP system will provide a technically mature, robust, and cost-effective separation solution.

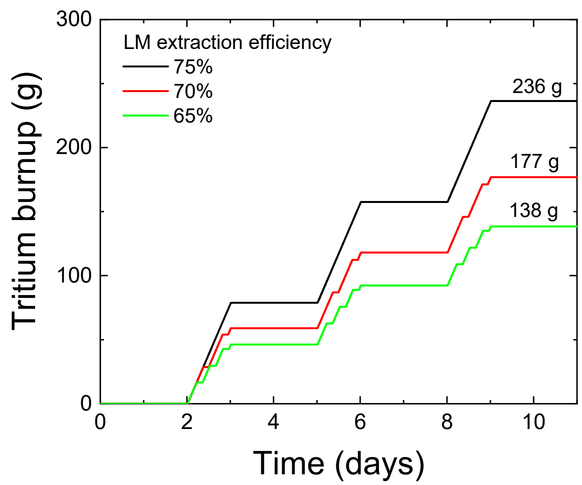
Technical Description

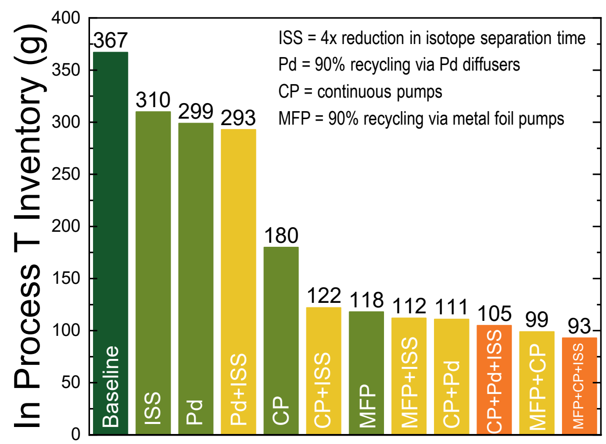
The TEP system consists of a series of filters, catalysts, and permeators to separate the hydrogen isotopes, which are then sent to an isotope separation system (furnished by the European Union) to deliver deuterium and tritium to the fuel storage and delivery system.

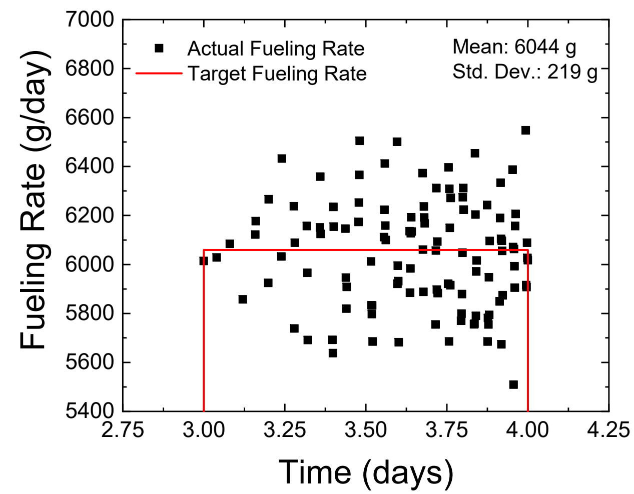


Support for FES Fusion Energy System Studies

- **Provide tritium plant subject matter expertise**
- **Simulation and process modeling analysis**







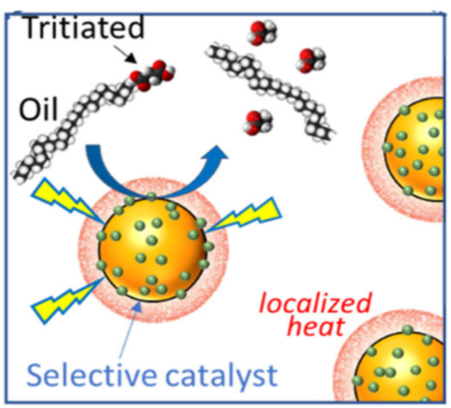
- **Investigate effects of liquid metal walls on tritium fuel cycle**
  - LM walls could benefit tritium fuel cycle IF:
    1. Metal is hydrogen selective (e.g., Li) **and**
    2. Tritium extraction is fast (e.g., LiT electrolysis)

- **Assess impacts of technology development**
  - Most important improvements to tritium fuel cycle are:
    1. Continuous pumping
    2. Direct recycling of hydrogen isotopes to fueling

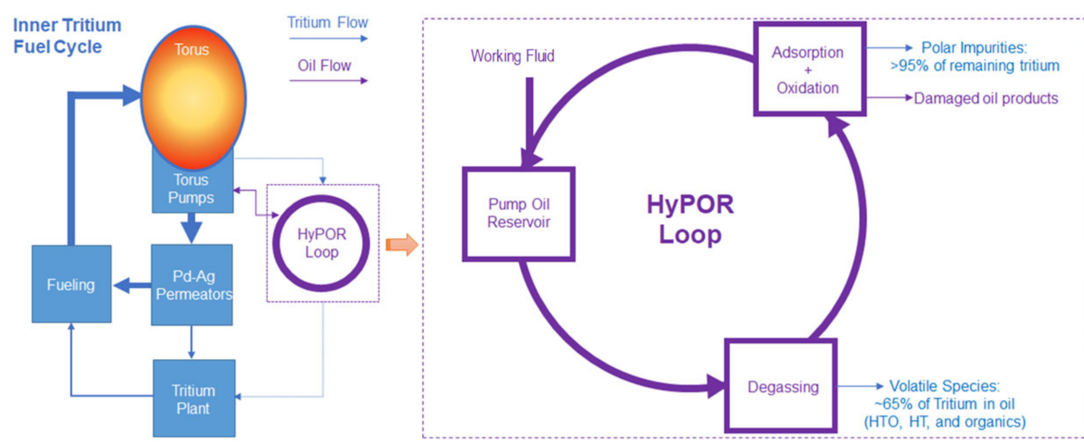
- **Incorporate sensor and process imprecision for tritium control & tracking**
  - Existing technology can control fueling for direct recycling
  - Working to understand tritium tracking throughout entire process

SRNL FES / ARPA-E GAMOW Projects

- **Upcoming ARPA-e Project: Hydrocarbon Pump Oil Recycling (HyPOR) Loop**
  - Vacuum technology for commercially relevant fusion power plant does not exist
    - *Cryo pumps are expensive, inefficient, and creates large tritium inventory*
  - Commercial technologies could be adapted but require oils
    - *Organics are typically avoided with tritium*
  - Proposed solution:
    - *Design a working fluid and recycling system together to achieve efficient pumping and oil detritiation*
  - Impact:
    - *4× reduction in tritium inventory, 10× reduction in pump electrical consumption, 50× reduction in costs*



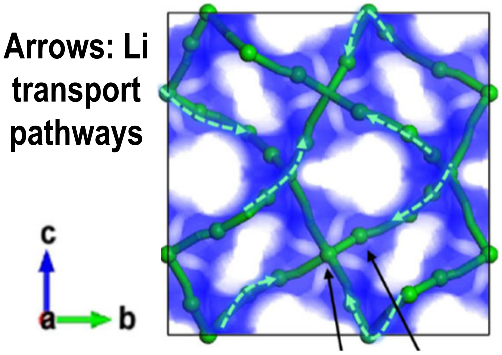
Targeted Tritium release



Direct LiT Electrolysis

- **$Li_7La_3Zr_2O_{12}$ (LLZO) has been extensively studied as solid-state electrolyte for Li ion conduction and is stable in molten**
  - High Li ion conductivity (~10^{-4} S/cm at RT)
  - Excellent chemical stability against molten Li
- **The SRNL Direct LiT Electrolysis concept utilizes a solid-state electrolyte like LLZO to move the LiT electrolysis reaction for tritium extraction into the buffer tank**

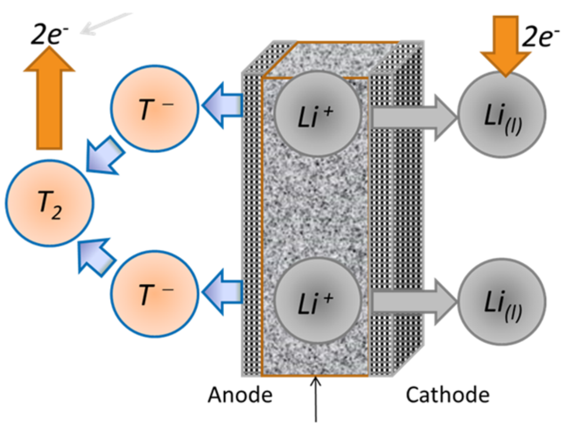
Li sub-lattice in LLZO



Shin et *al.*, *Sci. Reports*, **5**, p. 18053 (2015)

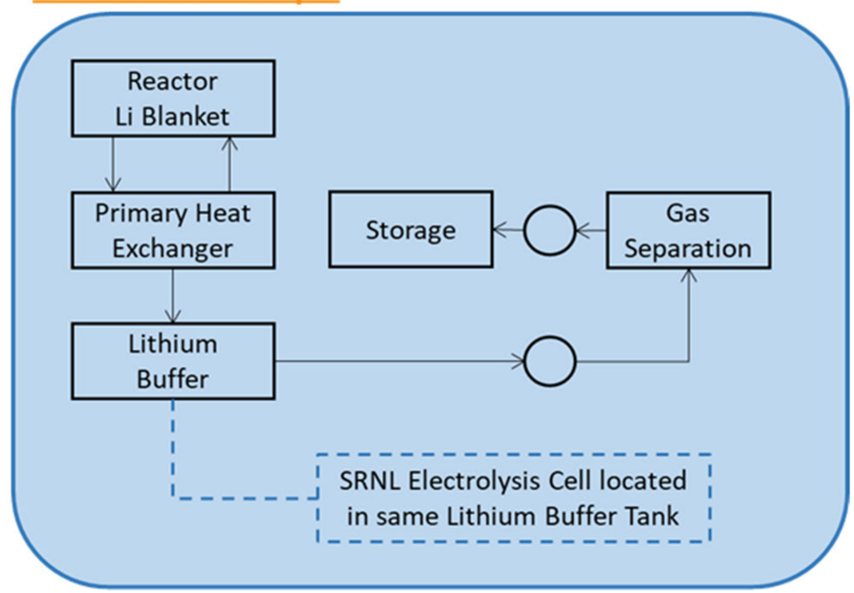
Lithium Conducting Electrolyte

$$2LiT \rightarrow 2Li^+ + T_2 \uparrow + 2e^- \qquad Li^+ + e^- \rightarrow Li$$



$$E^0_{400°C} = -2.82V \qquad E^0_{400°C} = -3.22V$$

SRNL Concept

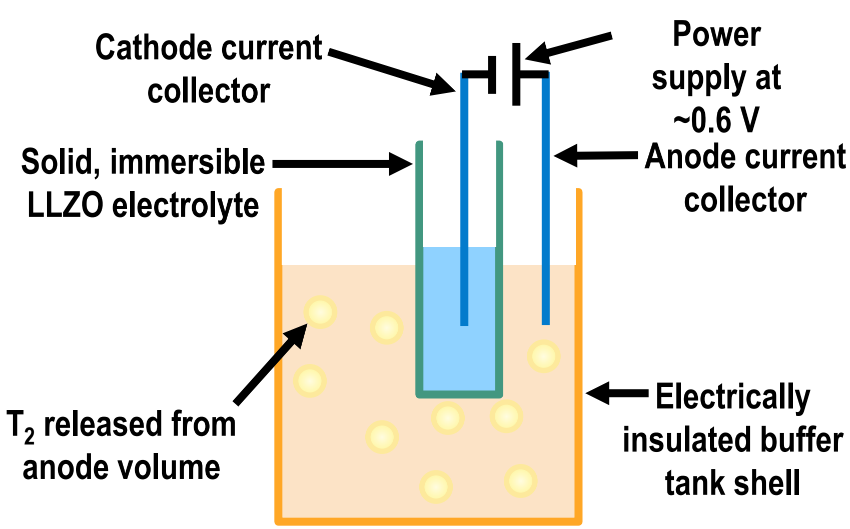


Teprovich et *al.*, *Fusion Engineering and Design*, **139**, pp. 1-6 (2019)

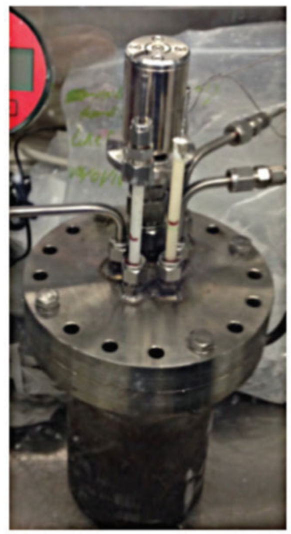
Direct LiT Electrolysis cont.

- **Initial electrolysis tests based on conceptual design were performed at SRNL; two primary issues were identified to improve performance in future research**
  1) Reduction in electrolysis cell volume: Allows for improved detection of H_2
  2) Fabrication of immersible, solid LLZO electrolyte with high aspect ratio: Prevents contact between BN paste and Li + LiT mixture
- **Improvements in cell design and synthesis of LLZO electrolyte will occur concurrently**

Immersion Cell Concept



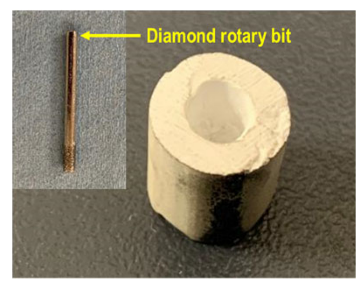
Initial Cell Design



Immersion Electrode Assembly

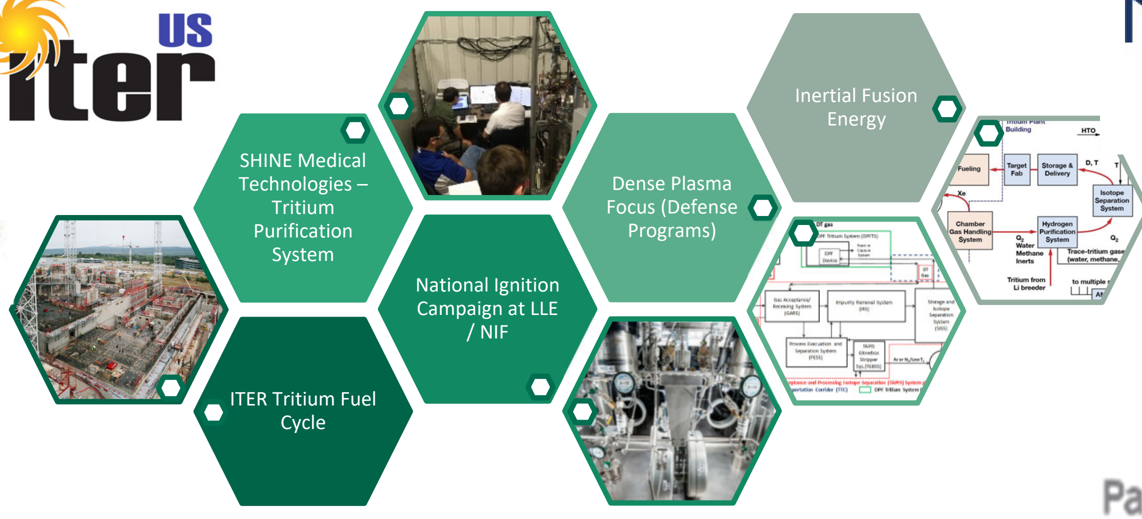
W wire is housed inside Al_2O_3 tube for contact with molten Li

LLZO electrode tip prototype



Ready to Partner for Fusion Success

AUBURN UNIVERSITY | Georgia Tech | VCU VIRGINIA COMMONWEALTH UNIVERSITY | US ITER | CLEMSON | NEVADA NATIONAL NNSS SECURITY SITE | Sandia National Laboratories | OAK RIDGE National Laboratory | Pacific Northwest NATIONAL LABORATORY | UNIVERSITY of ROCHESTER | SHINE Health. Illuminated.



• **Joint proposals**	• **Cooperative Research and Development Agreements**	• **Strategic Partnership Programs**

Contact: David *Babineau, Director of Defense Programs Technology, SRNL*

Email: *Dave.Babineau@srnl.doe.gov / phone:* 803-725-8936

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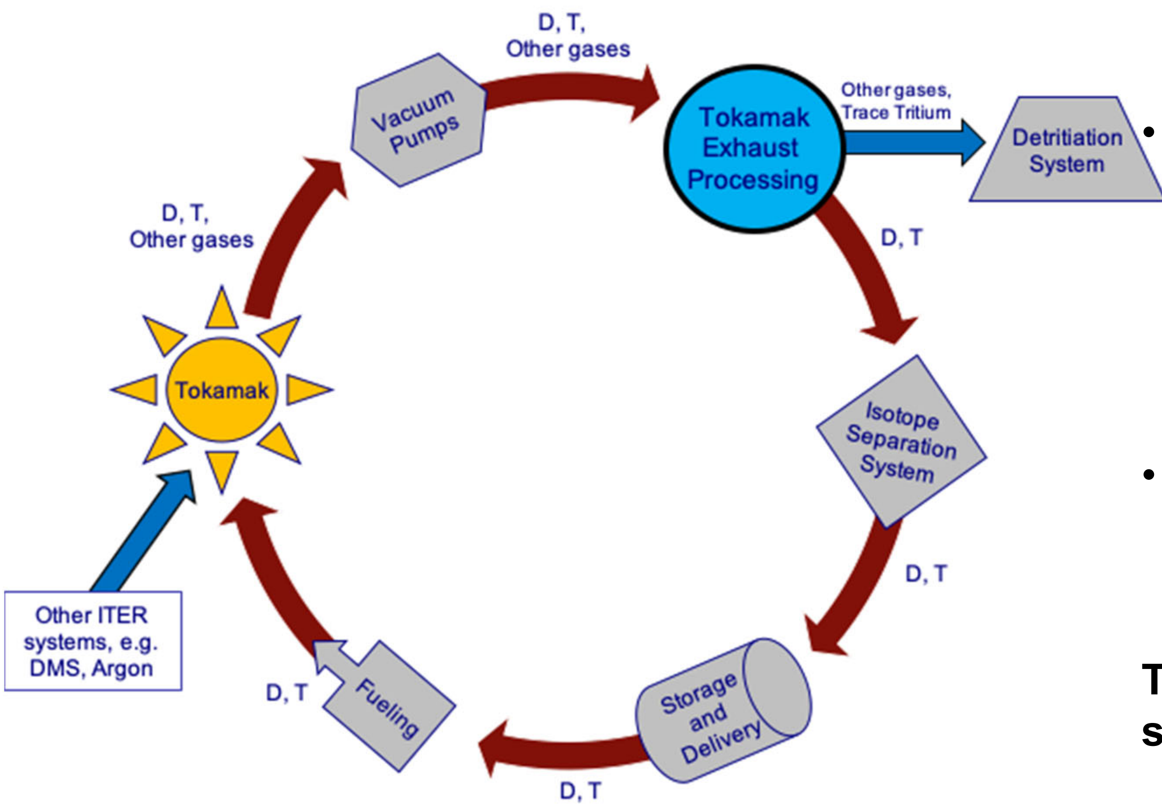
Backup

Tokamak Exhaust Processing (TEP)



Simplified ITER Fuel Cycle

The TEP system:

- **removes molecular hydrogen, including D/T, from process gas and gaseous tritiated compounds**
- **distributes the removed hydrogen isotopes and the remaining gases**
  - Hydrogen process gas (<1 ppm impurities) to Isotope Separation System
  - Remaining (impurity) gases with trace Tritium quantities (<240 Ci/day) to Detritiation System
- **stores Ar-41 (gamma emitting gas) to provide radiological decay time**

TEP technology established at smaller scale

- Scale-up required:10X flowrate
- TEP equipment is niche market

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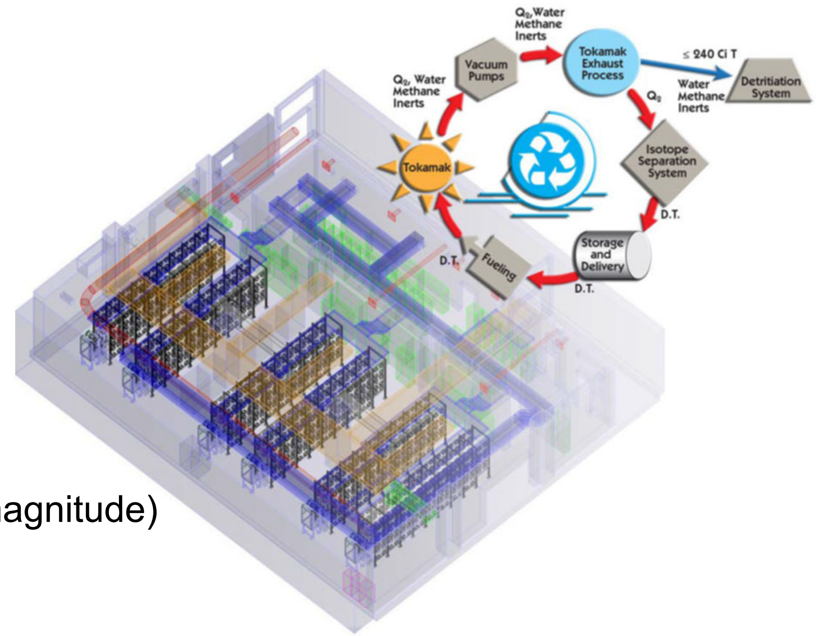


Technical Description

6 nitrogen inerted gloveboxes: 56 m3 each, totaling 340 m3

3 km of piping

5 tritium chemical processing technologies:

- Permeator
- Palladium membrane reactors
- Ambient temperature molecular sieve
- Cryogenic temperature molecular sieve
- Catalytic reactor

Throughput of 240 Pa*m3/sec (unprecedented by orders of magnitude)

Tritium recycled per year: ~100 kg

Output criteria:

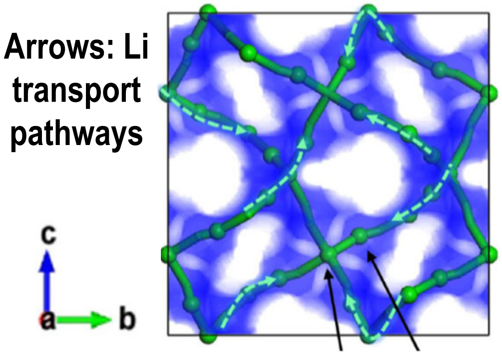
- Inert concentration to Isotope Separation System <1 PPM
- Tritium to Detritiation System less than 0.024 g per day

SRNL FES / ARPA-E GAMOW Projects cont.

Direct LiT Electrolysis

- **The SRNL Direct LiT Electrolysis concept utilizes a solid-state electrolyte like LLZO to move the LiT electrolysis reaction for tritium extraction into the Pb-Li blanket buffer tank**
- **Scale-up of the Direct LiT Electrolysis process is being funded through the ARPA-e GAMOW program by both ARPA-e and the Office of Science Fusion Energy Program**

Li sub-lattice in LLZO



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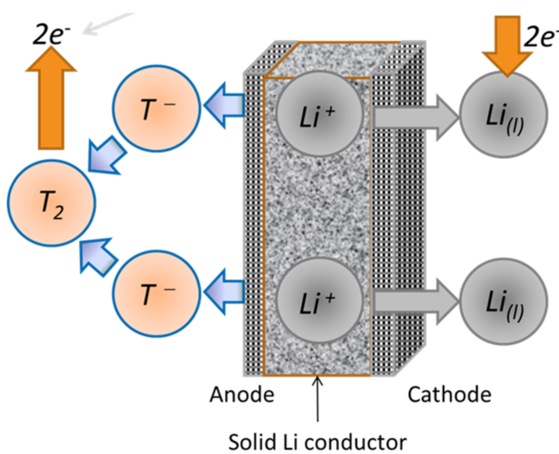

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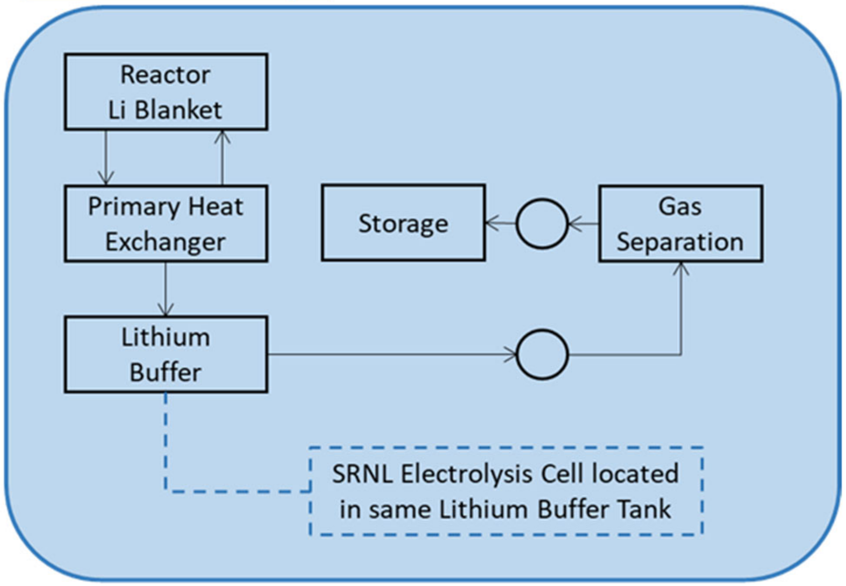

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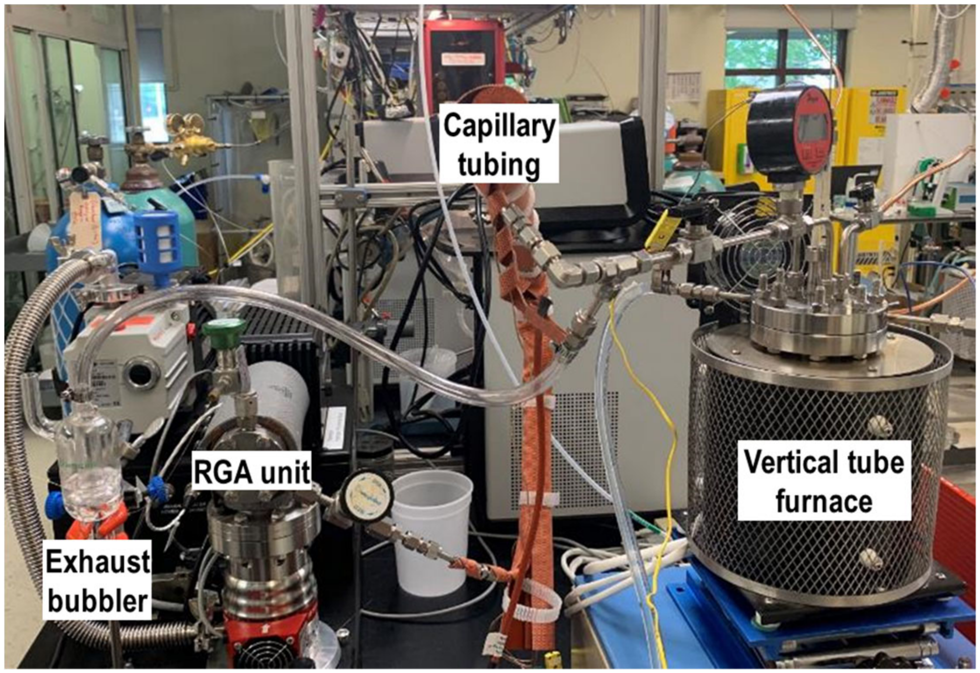

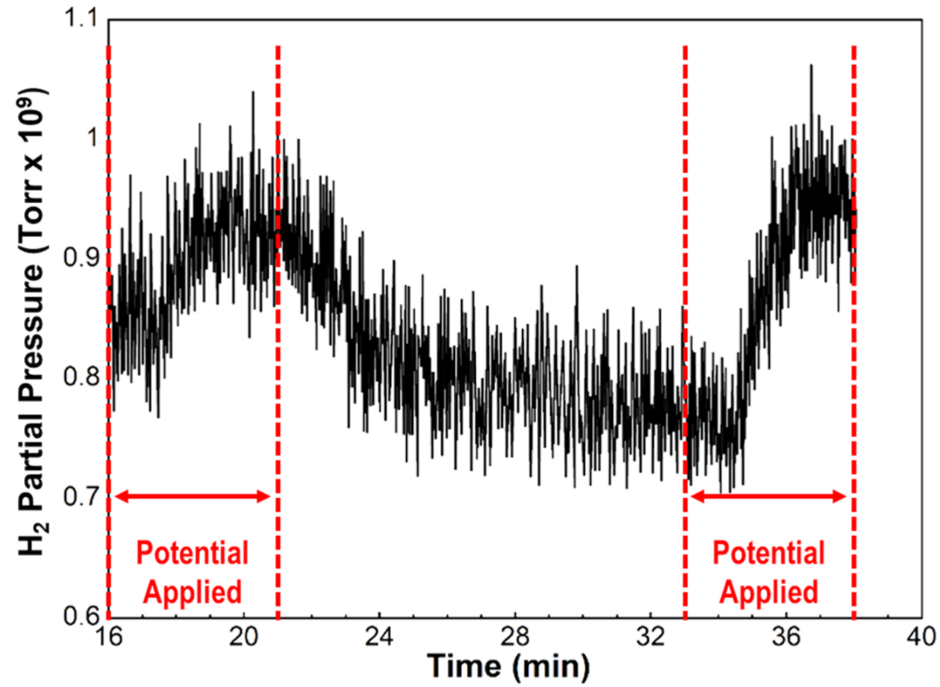

- **Initial full electrode experiment conducted at 300 °C with 5 mol% LiH**
  - Higher LiH content used to boost H_2 signal
- **Li-LiH mixture loaded into alumina crucible lined with Ta foil**
- **Crucible inserted into electrolysis cell under Ar ambient**
- **Potential of 3 V applied between working and counter electrodes**
- **No degradation of LLZO electrode or alumina paste evident at conclusion of electrolysis test**