Savannah River National Laboratory

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Fusion Perspectives and Related R&D at SRNL

Fusion Power Associates 42nd Annual Meeting

Dave Babineau and Brenda Garcia-Diaz

Savannah River National Lab

SRNL-STI-2021-00662

12/16/2021

U.S. DEPARTMENT OF ENERGY

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BSRA Battelle Savannah River Alliance, LLC

SRNL Contract Transition, Tritium Technology Division, and Fusion Energy

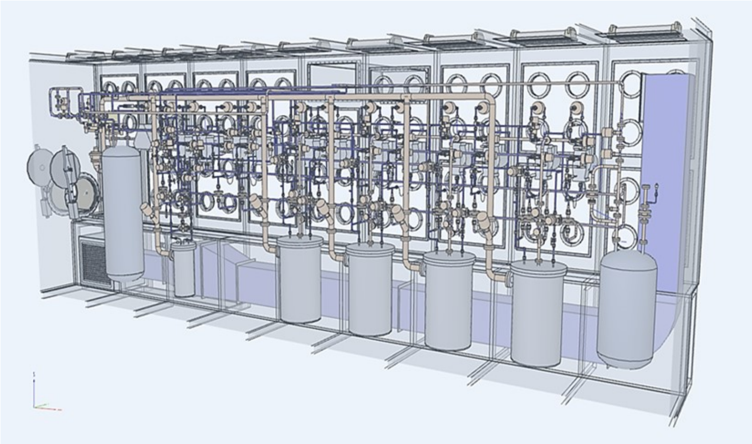
- **SRNL Transition –**
  - The SRNL management contract separated from the SRS site M&O contract at the end of Jun 2021
  - SRNL now managed by Battelle Savannah River Alliance (BSRA)
  - BSRA also includes strategic partnerships with 5 regional universities:
    - *Georgia Tech*
    - *University of Georgia*
    - *Clemson University*
    - *University of South Carolina*
    - *SC State University*
  - Fusion Technologies is an area of emphasis for SRNL in the new contract and is under the Tritium Technology Division

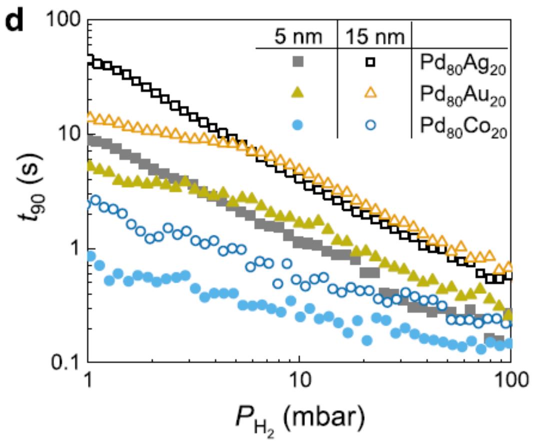
BSRA
Battelle Savannah River Alliance, LLC

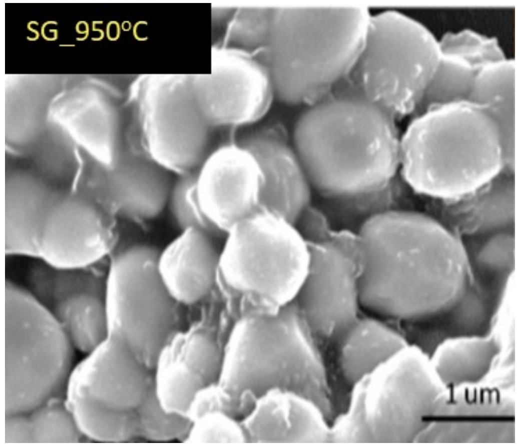
SRNL®

SRNL Fusion Energy Organizational Structure

- Dave Babineau – Tritium Technology
  - Robbie Allgood – ITER TEP Lead
    - Jeff Coughlin – Design Engineering
    - Anita Poore – Tritium Support
  - Brenda Garcia-Diaz – Fusion Research
    - George Larsen / Lucas Angelette – Fusion Fuel Cycle
    - Tim Krentz / Dale Hitchcock – Fusion Materials
    - Holly Flynn / Adrian Mistreanu – Fusion Modeling

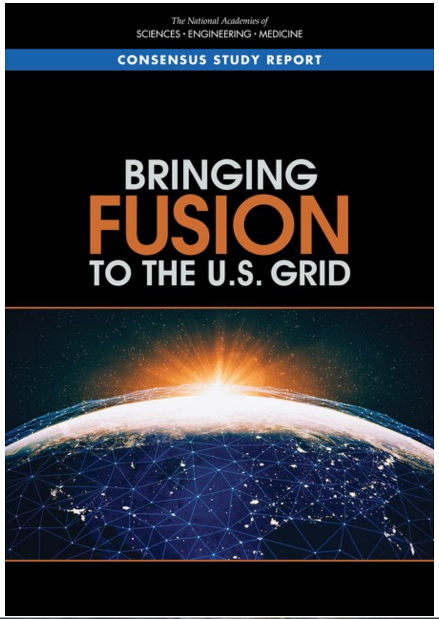






Fusion Pilot Plant Perspectives

- <u>**DOE Perspective**</u> **–**
  - Different scenarios laid out in FESAC report for getting to a Fusion Pilot Plant (FPP).
  - **Only the "unconstrained" scenario** that envisions a significant increase in DOE FES budget **gets to fusion pilot plant operation in the 2040's**. Low / moderate growth scenarios result in longer times to an FPP.
- <u>**Industry Perspective**</u> **–**
  - **71% of fusion companies see grid connection in 2030's as achievable** (2021 FIA Industry Report)
  - Example: Commonwealth Fusion Systems plans for SPARC facility constructed and demonstration started by 2025 with a pilot scale ARC facility by 2030 to 2035
- <u>**NAS Study Perspective –**</u>
  - Utility executives see **market** opportunities **for firm, non-carbon emitting fusion power in the 2050's**. If 2050 window is missed, then there will not be many opportunities for market penetration until 2100.
  - **Tritium supply** needed for FPP startup is anticipated to come from CANDU reactors that is **in doubt past 2040** due to the need for refurbishments and commitments for tritium to ITER and China
  - Significant **Public-Private Partnerships** will be **needed** with increased DOE or other government funding **to meet all pilot plant goals in the 2035 – 2040 timeframe** that can lead to a **first-of-a-kind system by the early 2050's**



SRNL Thoughts on Fusion Pilot Plant Perspectives

- **<u>DOE</u> – 2020 FESAC Report**
  - FESAC report ties FPP construction primarily to DOE funding in the report scenarios
  - FESAC report came prior to much recent private investment and does not account for current ~50:1 private-to-public funding ratio
  - Due to limited funding, reserving main research portfolio funding for technologies that are associated with MFE and ITER. Not strongly considering alternatives. (note: this could change in latest funding scenarios if enacted)

- **<u>Industry</u>– 2021 Fusion Industry Association Market Study**
  - Private investment in a fusion pilot plant gives the timeline to an FPP much more independence from DOE or other government funding
  - Industry making significant technology decisions quickly and that may not follow ITER or traditional technologies because of aggressive timelines
  - Aggressive tactics may drive private industry to *<u>consider abandoning proven</u>* principles (e.g., tritium secondary confinement) that would force components to be **safety relevant** or run into other known technology problems because lack of experienced personnel who are unfamiliar with field

- **<u>NAS Study</u>– 2021 NASEM Report**
  - NASA success in the COTS program came from embracing fixed-price milestones and allowing liberal technology approaches
  - Market will put significant pressures on companies requiring them to meet tight deadlines
  - Aggressive approaches can be tried by companies, but everyone should be prepared some may fail and plan extra time
  - Public-Private Partnerships needed to leverage existing expertise while betting on approaches that can get to market on time
  - DOE and industry need to invest heavily in the PPP approach and start an FPP focused approach now
  - To stay on timelines, designs are needed in the **next 6 years** along with technology demonstrations up to ~TRL 7

Timeline Comparison to get to Pilot

2021 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050

NASEM

- Conceptual and Preliminary Design: Define Fuel Cycle Reqs. & Demo.; Fuel Cycle TRL 5-6
- Final Design and Construction: Fuel Cycle TRL 7
- Start of Operation: Fuel Cycle TRL 9
- First Operating Phase: Q_e>1; 50 MW & >3hr
- Second Operating Phase: TBR > 1; 50 MW & Env. Cycle
- Third Operating Phase: Materials Durability Testing

B&FC Framework

- Tritium Multi-Function Fuel Cycle Facility Constructed
- Integrated Testing in Tritium Multi-Function Facility
- Extended Testing in Tritium Multi-Function Facility
- FPP Design & Construction
- FPP Operations

FESAC (Unconstrained)

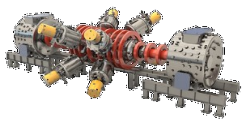
- Conceptual FPP Design & Facility Planning
- Pre-FPP Testing Facilities
- Fusion Pilot Plant (No Stages Specified)

ITER

- First Plasma
- TEP Delivery
- D-T Ops Start
- Long Burn
- Q=10

DEMO

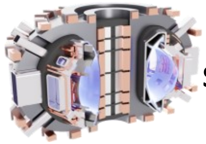
- DEMO Conceptual Design
- DEMO Engineering Design
- DEMO Construction



TAE Copernicus

Q_e>1

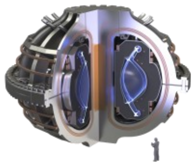
D-T Ops



CFS SPARC

Q_e>2

D-T Ops



CFS ARC

Commercial companies seem to prefer constructing multiple, smaller facilities faster to progressively prove out more of the process instead of a long design time to a large facility with more technical uncertainty. Could be due to investor milestones? PPPs might take similar approaches?

Tritium Processing & Fusion Materials Research in Latest NAS & FESAC Reports

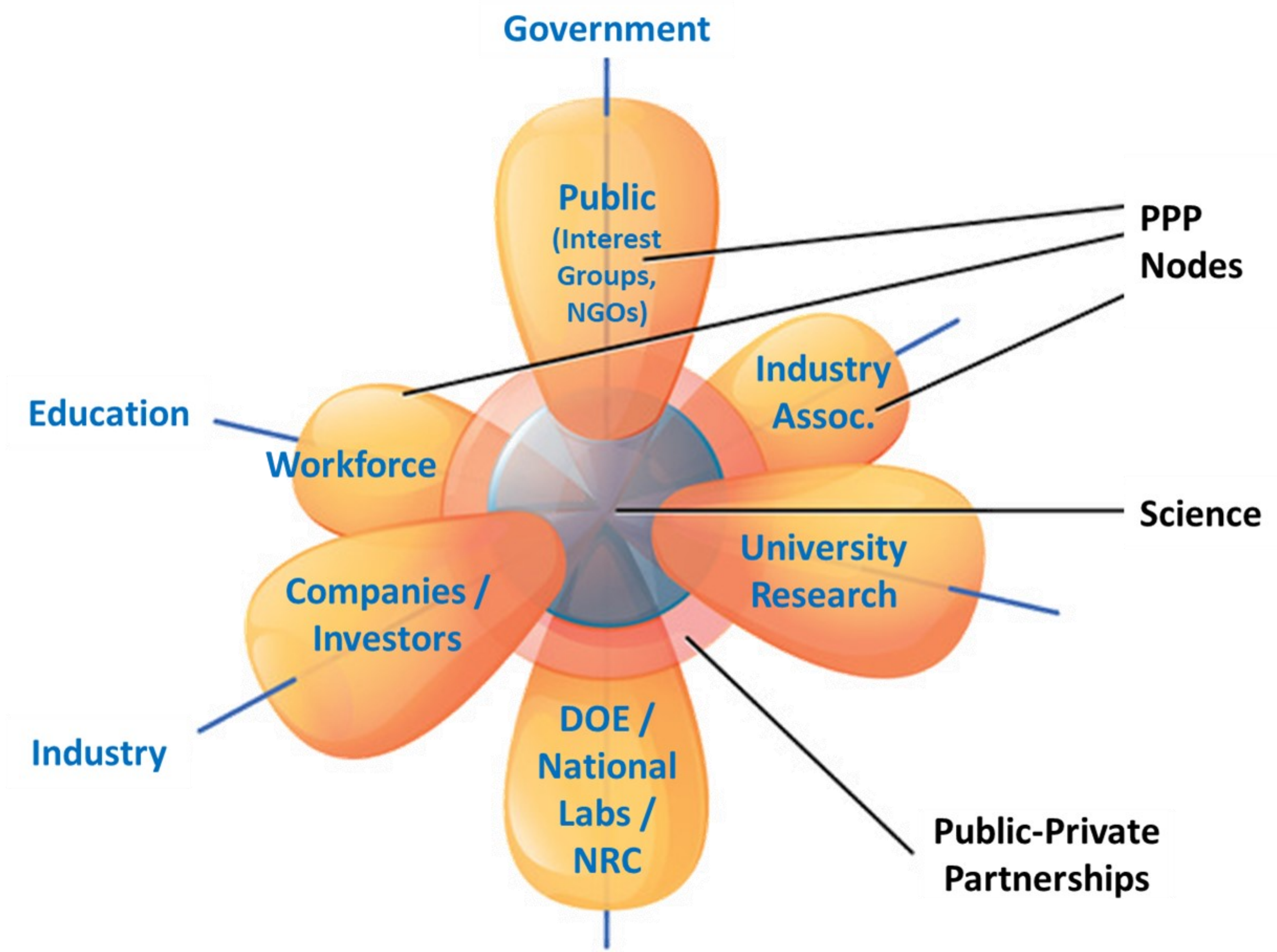
Dec 2020 FESAC Report – "Powering the Future Fusion & Plasmas"

- The **fusion pilot plant goal requires** a pivot toward research and **development of fusion materials** and **other needed technology**. Emphasis is needed on **fusion materials science**, plasma facing components, tritium-breeding blanket technology and the **tritium fuel cycle**.
- …Critical enabling technologies such as plasma facing components, structural and functional materials, and breeding blanket and **tritium handling systems are currently not advanced enough for an FPP**. The time required to develop these technologies at present levels of support is **incompatible with the goal of a fusion pilot plant by the 2040s.**
- **…**The program should **involve tritium experts in the US ITER team so as to maximally benefit from this technology demonstration.**
- **…**It should also support additional research and development of technologies that would **minimize the size, cost, and tritium inventory of the plant required to perform these functions.**
- **Recommendation: Significantly expand blanket and tritium research and development programs**

Mar 2021 NASEM Report – "Bringing Fusion to the US Grid"

- The **uncertain tritium production/recovery of the next 20 years**, coupled to 12.3-year half-life of the tritium, **motivates proceeding with the construction and operation of a pilot plant as soon as practical**.
- **Finding**: Innovations in boundary plasma science**, fueling technologies, and gas processing will be important for a pilot plant to decrease the cost and scale of tritium processing equipment.**
- The need to demonstrate **continuous operation** of these systems in a D-T fusion pilot plant will also likely **require continual operation of the tritium processing system, which has not yet been demonstrated.**
- **Finding**: A fusion pilot's integrated tritium processing rate will be 10-100x faster per day than present experience in heavy-water moderated fission.
- **Recommendation: The Department of Energy should establish and demonstrate efficient tritium processing technologies at relevant rates and processing conditions before operation of a pilot plant.**
- **Finding**: The requirements for tritium accountability in a fusion pilot plant must be clearly defined along with analytical methods that can satisfy accountability requirements.

SRNL Focused on Enabling Successful Public-Private Partnerships for Fusion



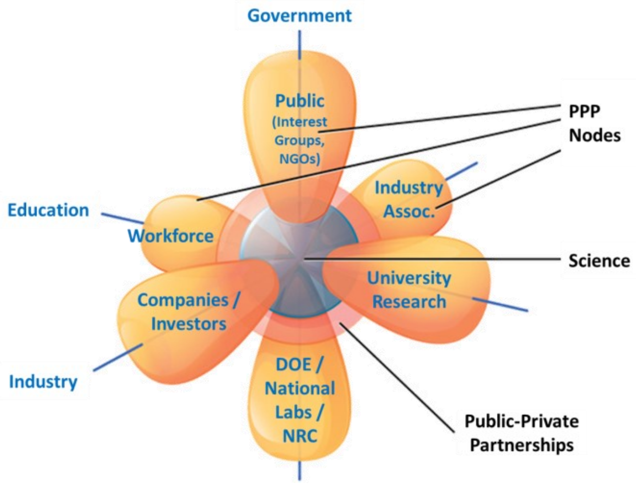
<u>SRNL Fusion Program Efforts</u>

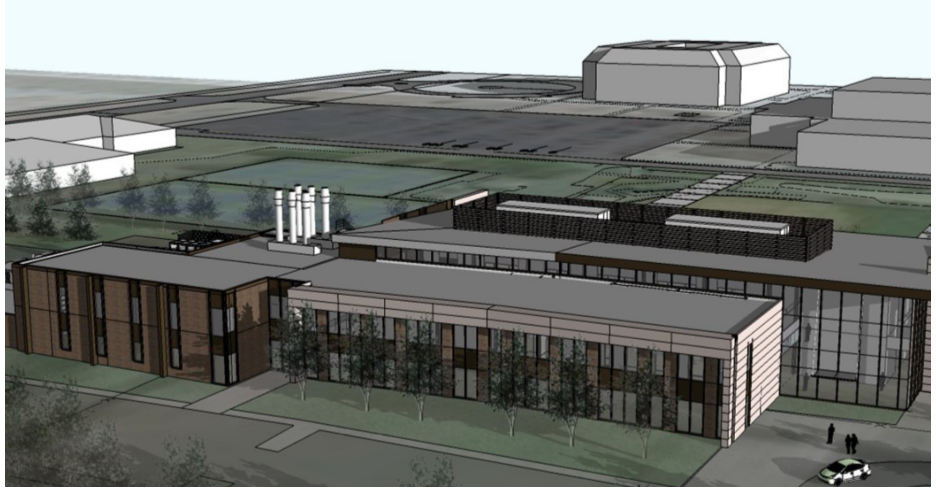
- Leveraging expertise gained from NNSA, ITER, and programs to help industry
- Licensing of fusion-relevant technologies to industry and supporting commercialization
- Public-Private Partnership Projects
  - DOE FES INFUSE Program
  - Fixed-price Milestone Programs –Like NASA COTS (Enabled by HR-133 Sec. 2008)
- DOE FES Efforts to Define/Support an FPP
  - Blanket & Fuel Cycle Working Group Mtg
  - Fusion Energy System Studies
  - Future FPP Related Efforts
- ARPA-e GAMOW Technology Development
  - HyPOR Loop Development
  - Direct LiT Electrolysis
- DOE FES Technology Development

SRNL Facilities in Development that can Assist Fusion

Proposed Tritium Research and Development Facility

Advanced Manufacturing Collaborative (AMC)

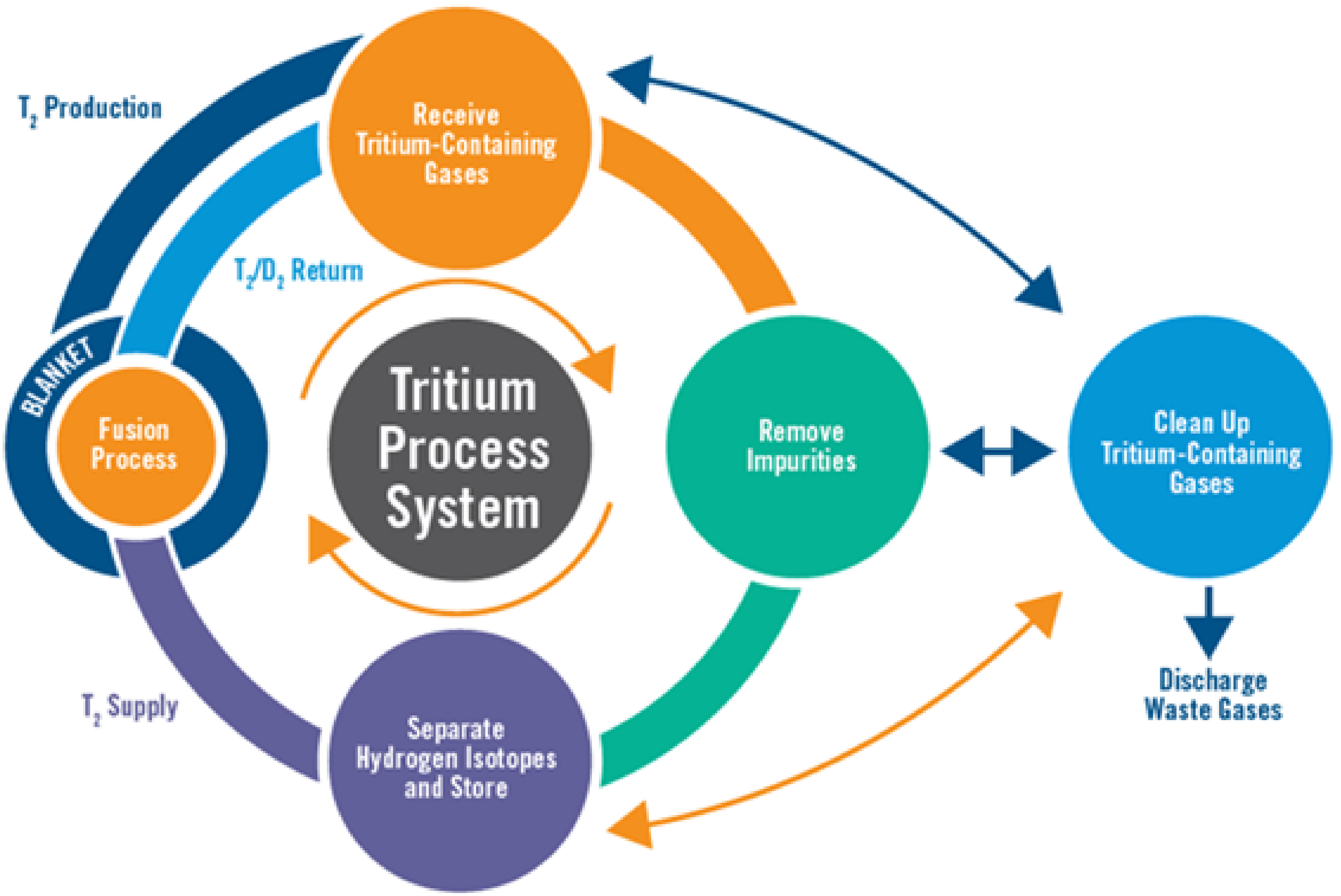




- 33,000 ft^2 Category 2 Nuclear Facility
- Never Operated, Original Mission cancelled
- < $50M to upfit for basic tritium capability
- Evaluating having up to **1 - 2 kg tritium inventory**
- NNSA exploring upfit/operation and participation by other DOE programs
- **30% (~8000 sq. ft.)** potentially available for **fusion fuel cycle demo**
- SRNL would like facility **operational by 2026**

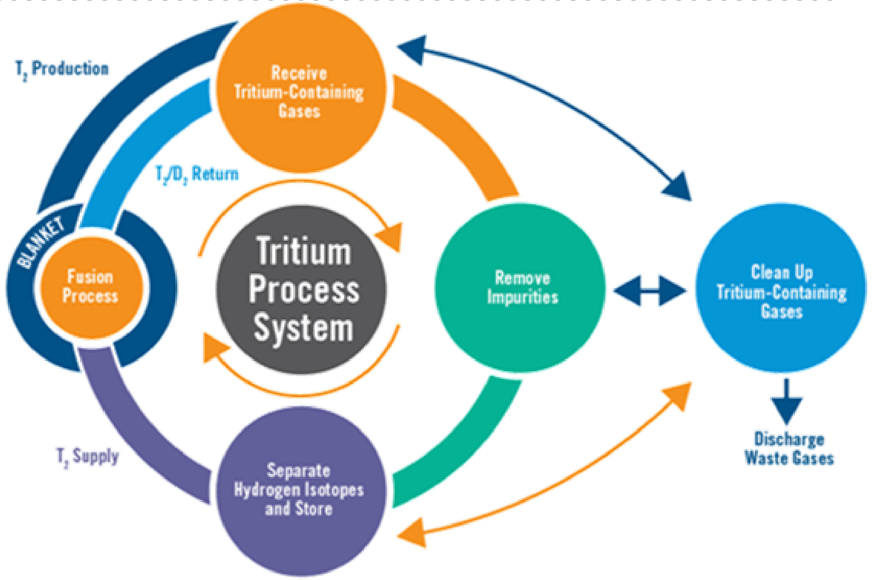
- DOE research center planned on the campus of the **UofSC – Aiken**
- Fusion and H_2 Processing Lab for **TRL 3-6** fuel cycle & materials research
- Fusion Lab is **~2200 sq. ft**. with more space in high bay as needed
- Facility operational somewhere in the **2023 – 2024** timeframe
- Location for **collaborative research** with industry and university partners
- **Non-radiological pilot preparation** research performed at AMC and will **transition to proposed R&D facility** when ready for tritium studies

Tritium Fuel Cycle: Similar Core for All Applications with Blanket Integration for Fusion



- **Main Fusion Processes are Similar to Other D/T Cycles**
  - Separate hydrogen isotopes from helium isotopes
  - Remove impurities that enter process (e.g. HTO, nitrogen, etc.)
  - Store and account for isotopes
  - Clean exhaust gas and ensure suitable for release
- **Blanket Tritium Extraction & DIR Unique to Fusion**
  - Blanket technologies are significantly varied, but vacuum extraction or helium extraction similar to current approaches
  - Need caution with SF_6 used for high voltage electronics and extra nitrogen gas used in divertor

Five Tritium Research Areas to Enable Fusion Energy



- **<u>Tritium Inventory Reduction</u> –** Improve tritium processing to reduce the inventory needed and lower the radioactive source term. This would also help to minimize releases.
- **<u>Tritium Process Technology Development</u> –** Develop technologies and materials that assist with process intensification / scale-up of impurity removal, isotope separation, and storage and resolve process issues
- **<u>Tritium Breeding and Extraction</u>** – Understand tritium breeding for fusion energy systems as well as methods to extract and recycle tritium back into the process are critical for self-sufficiency
- **<u>Environmental Confinement of Tritium</u> –** Reduce releases of tritium by at least 2 orders of magnitude over state-of-the-art methods and current technologies
- **<u>Development of Improved Materials for Fusion Energy Systems</u> –** Develop materials with improved properties such as corrosion-resistance, tritium damage resistance, tritium permeation barriers, as well as maintenance of these material properties / function during radiation exposure

SRNL Leverages Tritium Expertise to Advance Commercial Fusion Energy Technologies

- **Tritium Processing at SRS**
  - Tritium Sustainment (NA-19)
    - » *Required Minimum Inventory (RMI), gas process modeling efforts, next generation tritium facility*
  - Facility Support (MR&R, RTBF), PDRD, LDRD
    - » *Bed life extension, hydride aging studies, tritium accountability, component testing, water splitting*
- **Fusion Energy Programs Support**
  - US ITER – Tokamak Exhaust Processing (TEP)
  - National Ignition Campaign (Rochester LLE, NIF – LLNL)
- **Mo-99 Medical Isotope Production**
  - SHINE® Medical Technologies (NA-231)
    - » *Tritium Purification System*
    - » *SHINE TCAP System (isotope separation)*
    - » *Accelerator-Target System Interface*
- **Other Programs**
  - Nuclear Safety R&D (NSR&D) - Highly Tritiated Water, Tritium Oxidation
  - Thomas Jefferson National Accelerator Facility (TJNAF)

NNSA National Nuclear Security Administration

NIF

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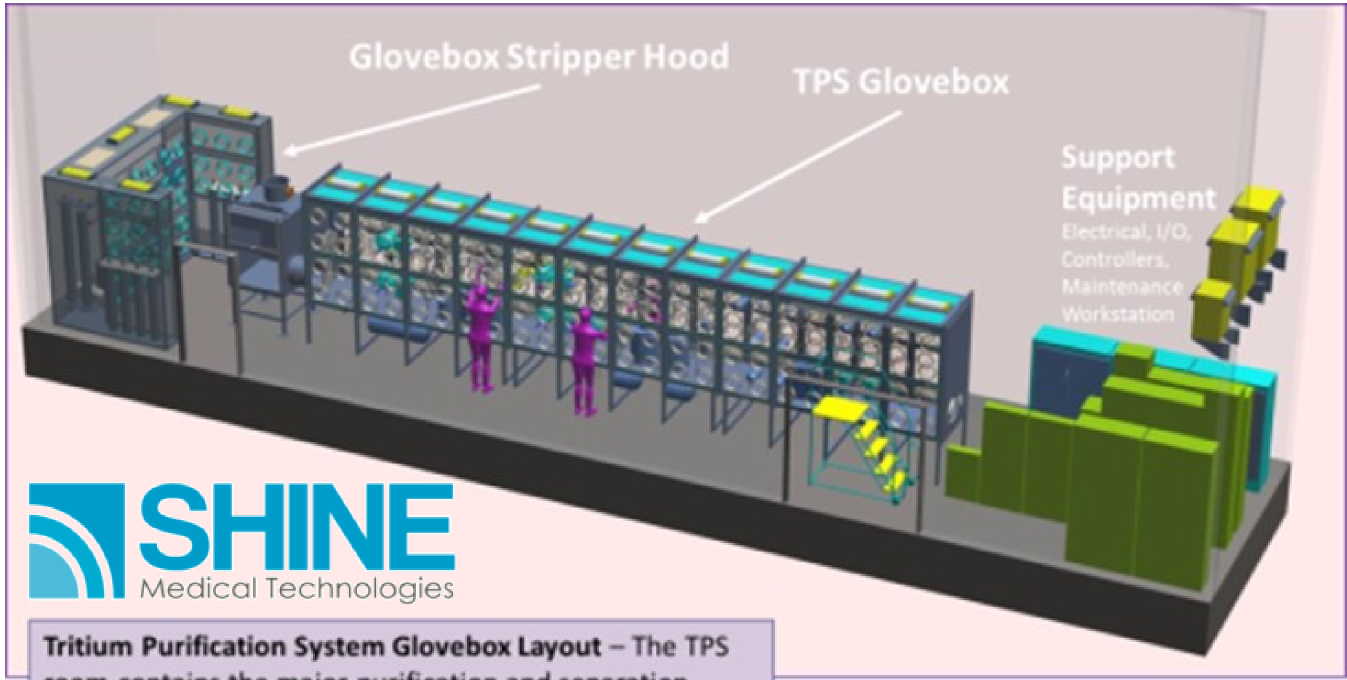
SRTE SAVANNAH RIVER TRITIUM ENTERPRISE

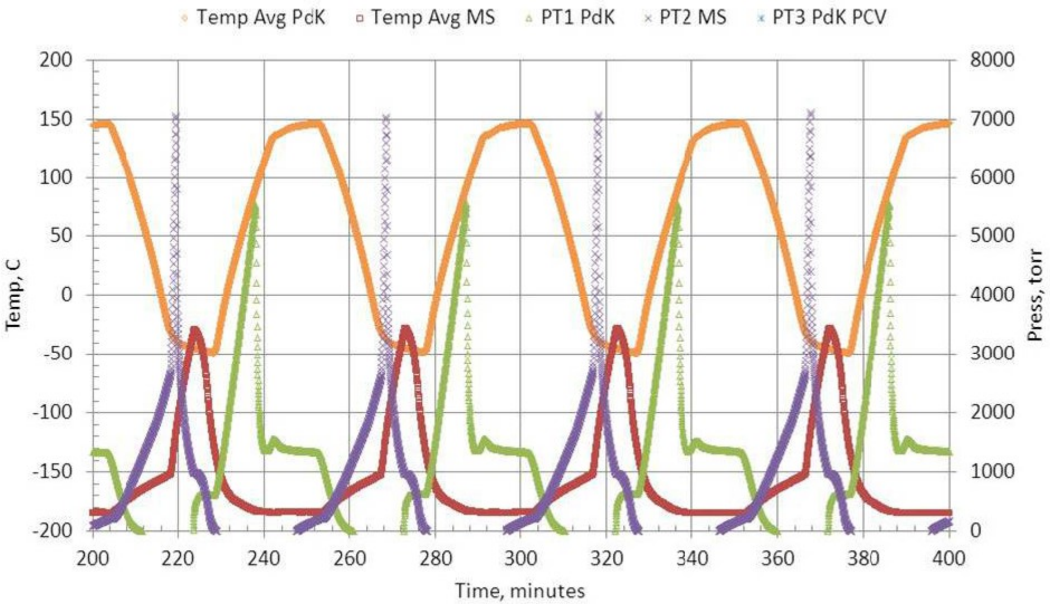
iter china eu india japan korea russia usa



Tritium Purification System Glovebox Layout – The TPS room contains the major purification and separation components, including a glovebox stripper system.

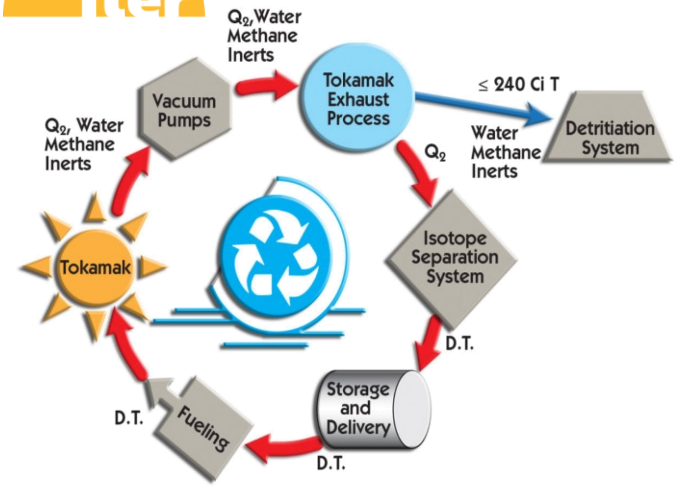
SRNL Focused on Supporting Commercialization of Fusion Energy Technologies

- **Licensing Technologies and Supporting Licensees**
  - Contracted to support manufacturing development of TCAP columns for a licensee
  - Helped them create first set of TCAP columns that was not fabricated by SRNL
  - Company developed design that:
    - *Increased purified tritium volume output **4x** over the SRNL reference design at their design conditions*
    - *Liquid nitrogen consumption by **<50%** of reference design*
    - *Achieved **<0.1 ppm** of deuterium (tritium surrogate) in the raffinate*
    - *Decreased cycle time by **15%***
- **Working to Improve Contracting for Industry Support**
  - Feedback from industrial partners is that CRADAs for public-private projects such as INFUSE can take too much time
  - Drafting agreements such as **umbrella CRADAs** that can be utilized to help companies get support for multiple projects
  - Exploring the ability to expand the agreements to include all types of public-private partnership programs including milestone-based PPPs



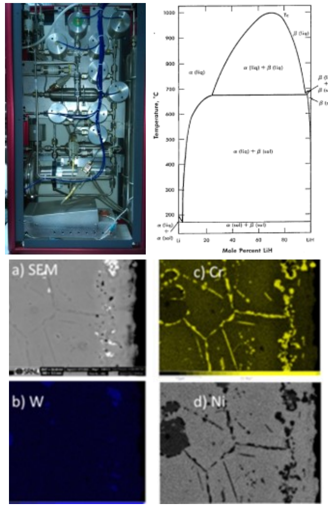
Current SRNL Fusion Project Portfolio

ITER Tokamak Exhaust Processing (TEP)



- SRNL is leading the design, procurement, and fabrication of the system that separates the hydrogen isotopes from torus exhaust and prepares them for processing
- Current Task (SP-1) scope is completion of final design of the US hardware for TEP

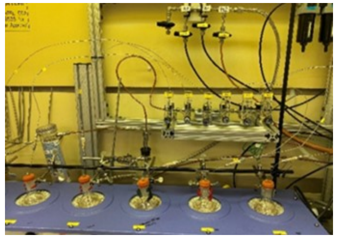
INFUSE Projects

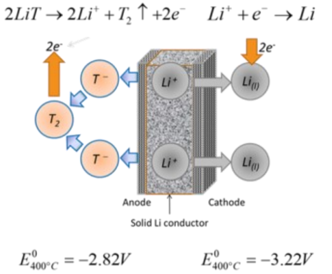


- Phase Diagram of Li-LiH,D,(T) Mixtures and Implications for Tritium Retention and Extraction – Measure phase diagrams for tritium extraction with LiH & LiD mixed with Li to allow extrapolation to LiT
- Active Redox Control of Molten Salts For Fusion Blankets – Demonstrate corrosion mitigation using redox control coupled with electrochemical potential measurements

RENAISSANCE FUSION   Commonwealth Fusion Systems

GAMOW Projects





- Hydrocarbon Pump Oil Recycling (HyPOR) Loop – Enable commercial vacuum pump use by selectively removing heavier H_2 isotopes from pump oil while also purifying the oil of radiation-induced damage
- Direct LiT Electrolysis Scale-up – Develop improved electrolytes, electrodes, and electrochemical cell designs to increase the LiT electrolysis rate from Pb-Li blanket materials

CLEMSON UNIVERSITY   UNIVERSITY OF SOUTH CAROLINA

FES Projects

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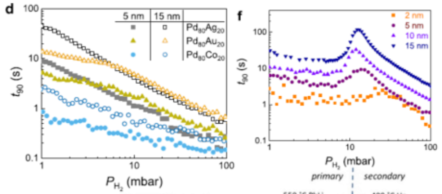

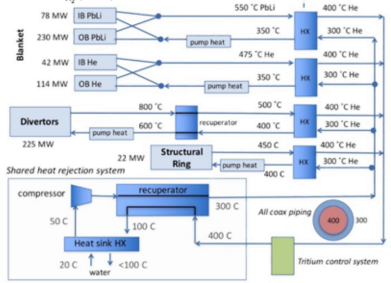

- Working to Reduce Tritium Inventory through Internal Recycle Technologies – Evaluating combinations of technologies that can both reduce tritium inventory and offer robust operation for realistic operating scenarios
- Identifying Concepts for Hydrogen Isotope Extraction from Helium – SRNL is investigating multiple system configurations to enable hydrogen isotope extraction

SRNL Fusion Energy Program Summary

- SRNL M&O contract transition & separation from SRS M&O Contract put greater emphasis on fusion energy technologies
- SRNL agrees with the conclusions of recent reports that significant tritium fuel cycle development is needed before an FPP and that support is needed quickly for an FPP in the 2030's
- Without a tritium research and development facility there is significant risk with a deuterium-tritium fuel cycle for an FPP
- SRNL working toward unique facilities for demonstration of tritium technologies to benefit both NNSA and the fusion industry
- SRNL increasing focus on technology licensing and PPP programs like INFUSE leading to an FPP
- Developing improved technologies for tritium applications through ITER, FES, and ARPA-e programs