

Introduction to Fusion Energy and Applications for Computational Methods






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EPRI Fusion Energy Strategic Program

Guest lecture for UNC Charlotte AEEE 5274, Applied Computational Methods
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Agenda

-  Introduction to Fusion Energy & Industry Overview
-  R&D Opportunities and Challenges for Commercialization & EPRI Research to Accelerate Fusion Energy
-  Applications for Computational Methods



Introduction to Fusion Energy & Industry Overview

Fusion Role and Benefits



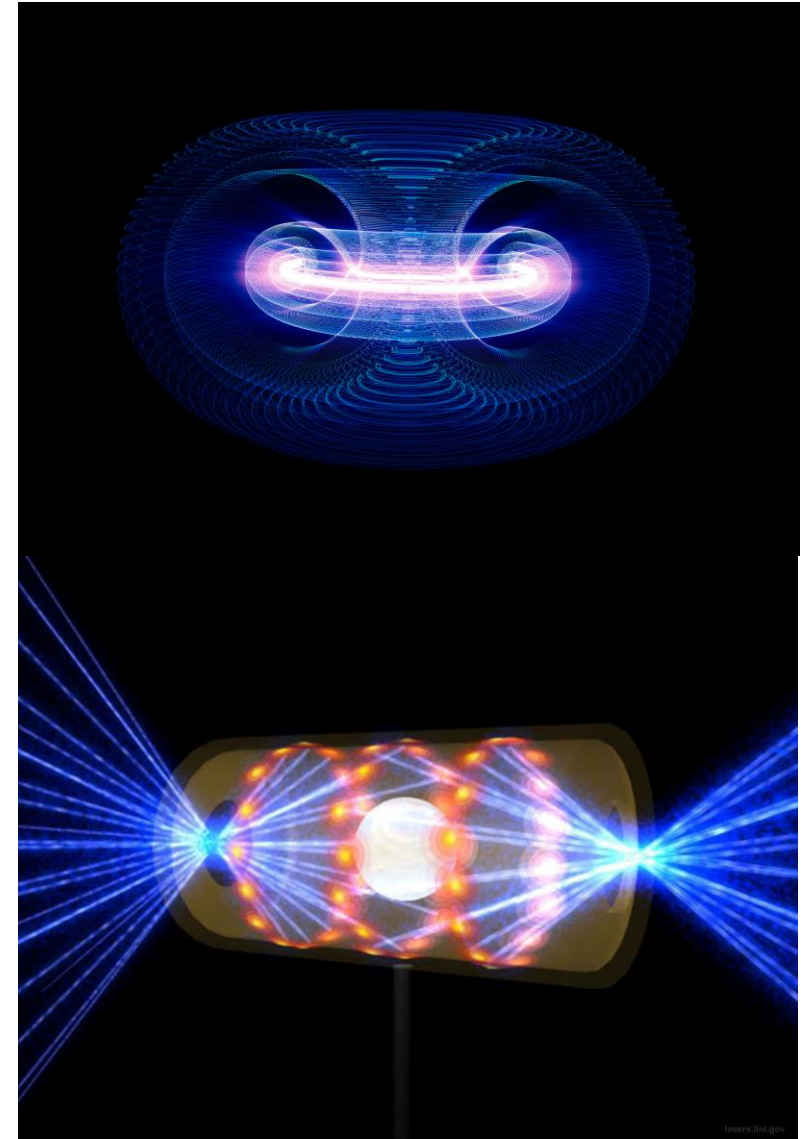
Fusion has a role in a resilient, net-zero energy system as a firm, non-emitting energy generation option



Most concepts are thermal sources and are compatible with existing balance-of-plant technologies



Compelling safety benefits. Driven reactions require external energy + replenished fuel source. Fusion is hard to initiate and likes to shut down.

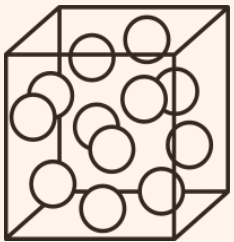


The Fusion Reaction

Fusion requires keeping a fuel bearing plasma:



Hot enough
(plasma temperature)

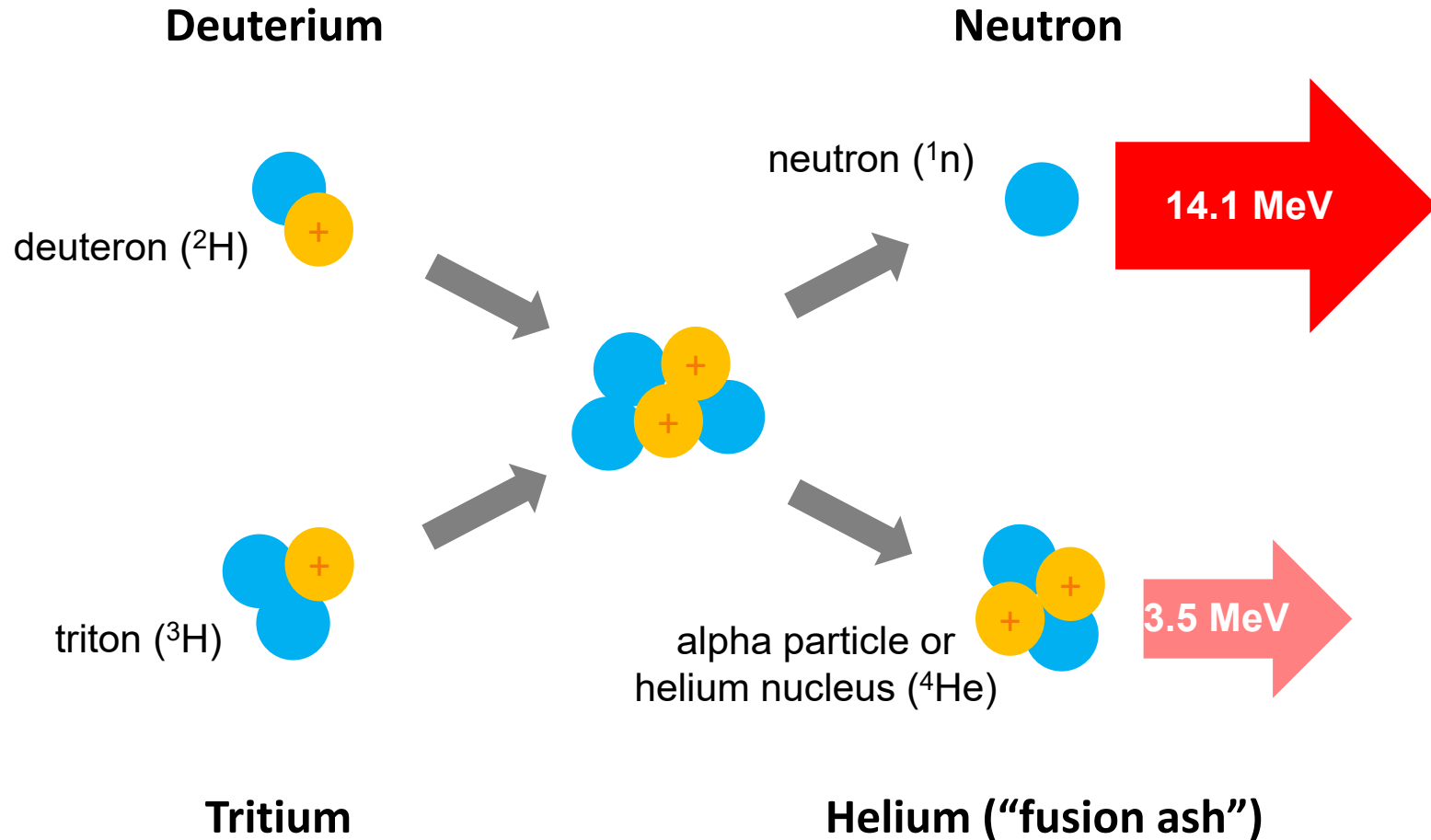


Dense enough
(plasma density)



For long enough
(plasma confinement time)

Light nuclei combine to form heavier nuclei



[Technology Insights Brief: A Review of Fusion Confinement Types, EPRI, Palo Alto, CA: 2023. 3002026585.](#)

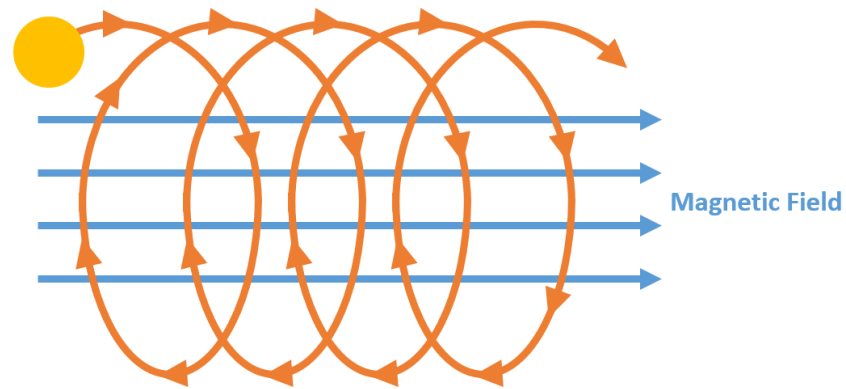
Difference in mass before and after is released as energy ($E = \Delta mc^2$)

Plasma Confinement Approaches: Magnetic vs Inertial

Magnetic Confinement

Strong magnetic and electric fields contain the plasma fuel until fusion occurs.

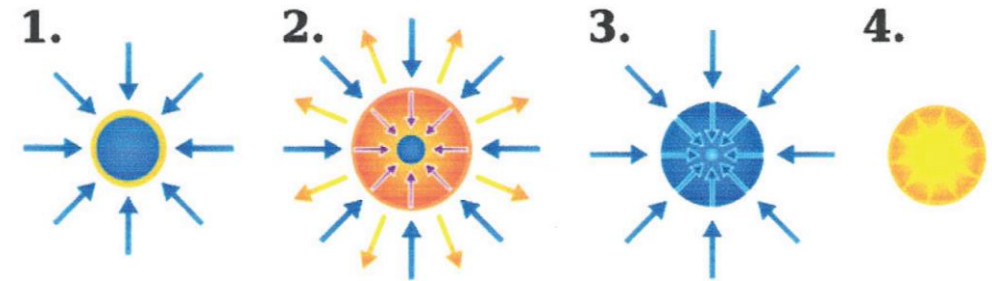
Motion of Charged Particle (e.g., positive ion or electron)



- Examples Devices: tokamak, stellarator, magnetic mirror
- Example Organizations: ITER, UKAEA, Commonwealth Fusion Systems, Tokamak Energy, Type One Energy Group

Inertial Confinement

Compression forces targeted at fuel create favorable temperature and pressure conditions for fusion.



- Example Devices: Laser-Driven Confinement, Shock-Driven Confinement
- Example Organizations: National Ignition Facility, Xcimer Energy, Marvel Fusion

Image credit: National Research Council. 2013. *An Assessment of the Prospects for Inertial Fusion Energy*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18289>.

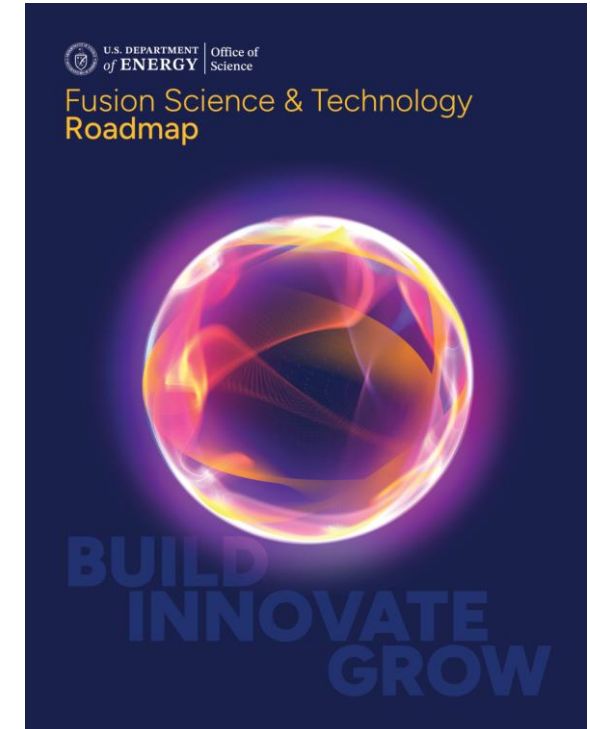
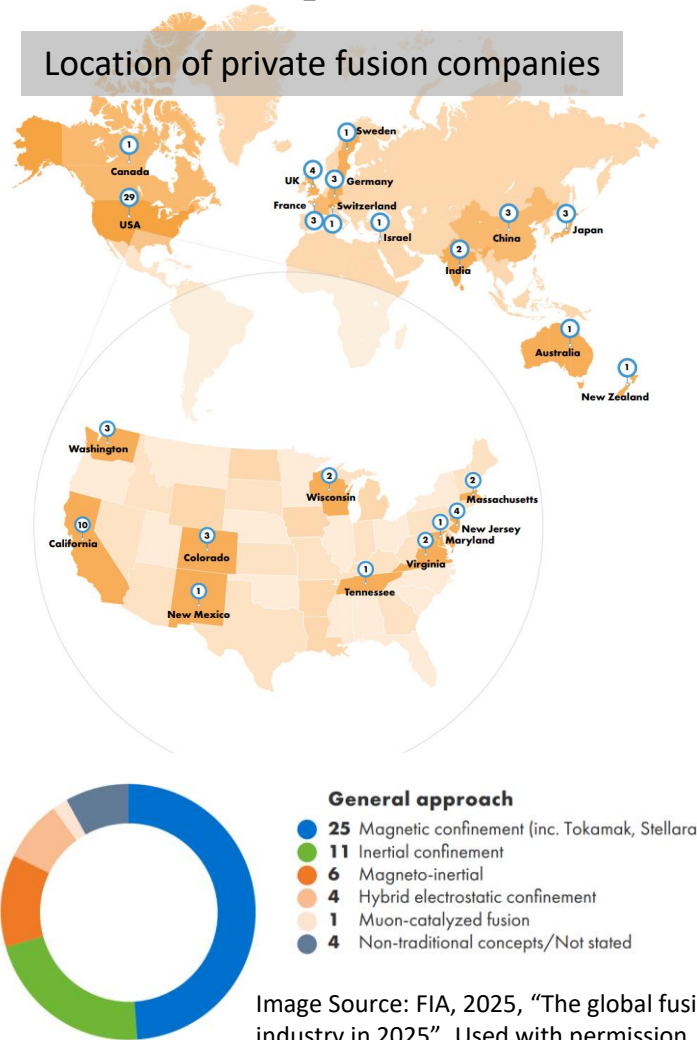
State of the Fusion Energy Industry

Private sector:

- 53+ companies, diversity of technology approaches
- >\$8.9 billion in private investment
- multiple private fusion developers with \$1 billion+
- Many companies planning pilot plants in the 2030s
- Acceleration and accumulation of technical milestones
 - magnets, confinement temperatures, new experiments, major construction projects, AI enabling technology

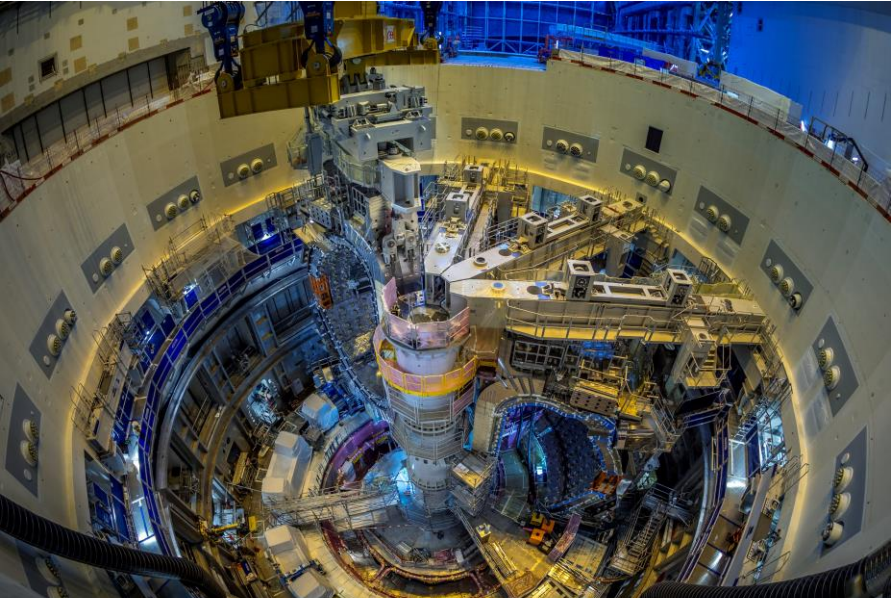
Public sector:

- U.S.
 - Aligning on R&D priorities and roadmap
 - Launched Fusion Innovation Research Engines
 - Desire to align public program with private industry needs
- International
 - Aligning on regulatory schemes
 - Acceleration of research funding opportunities

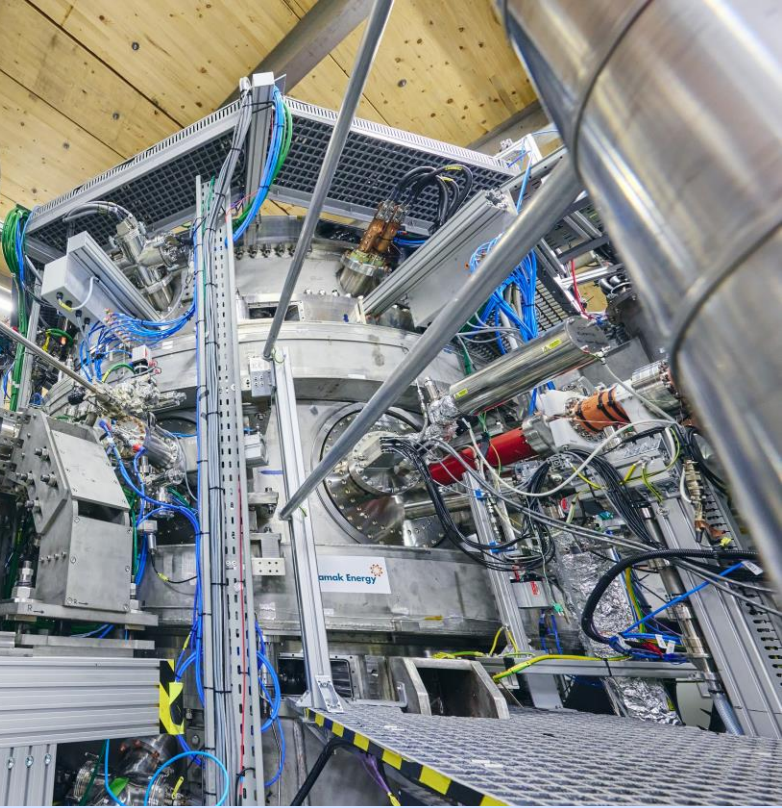
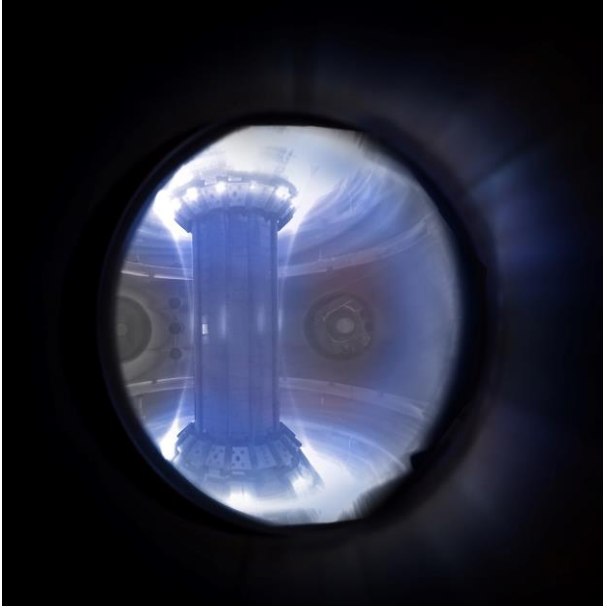


Transition occurring to accelerate development of materials, blanket, fuel cycle, and power plant concepts (R&D beyond plasma physics)

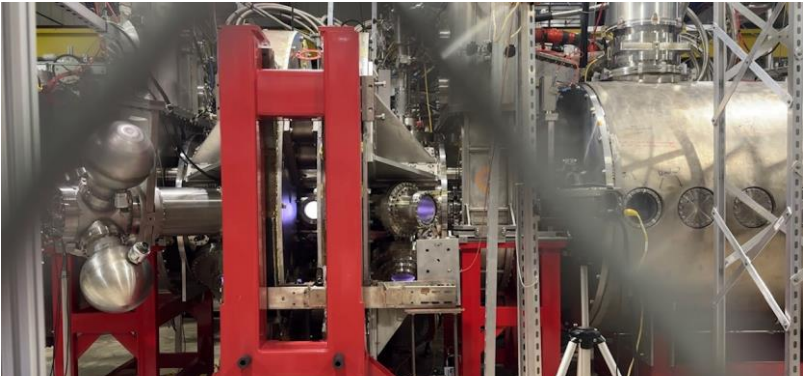
Fusion experiments and demonstration are happening...



ITER tokamak pit, with four sector modules installed. Credit © ITER Organization, <http://www.iter.org/>



Tokamak Energy ST-40 Spherical Tokamak with plasma (inset). Used with permission.



Realta Fusion, plasma pulse on WHAM magnetic mirror device. Photo taken & used with permission



**R&D Opportunities and Challenges for Commercialization &
EPRI Research to Accelerate Fusion Energy**

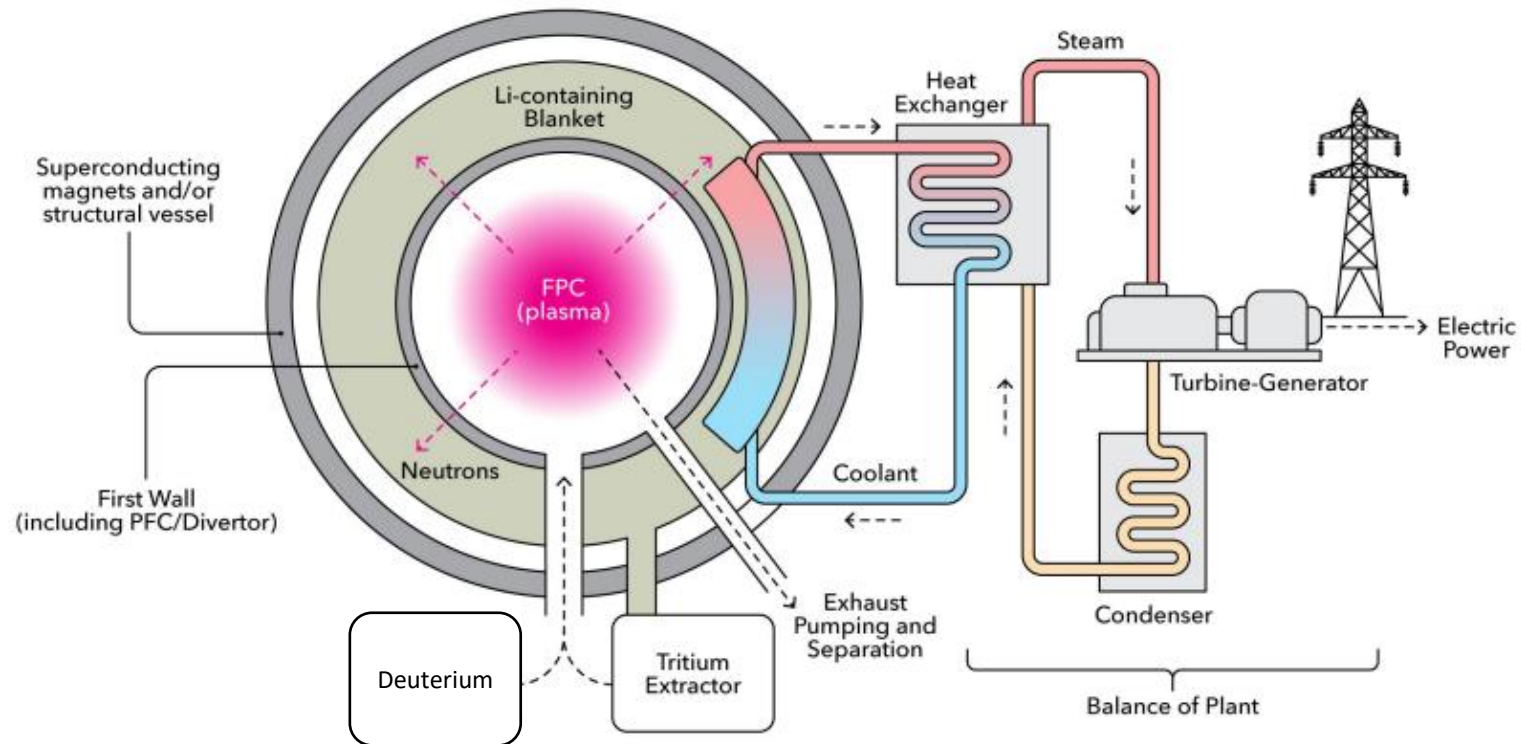
Net energy gain was achieved at the National Ignition Facility. So is fusion here?

Scientific net energy gain (Q_s) is a necessary but not sufficient milestone.

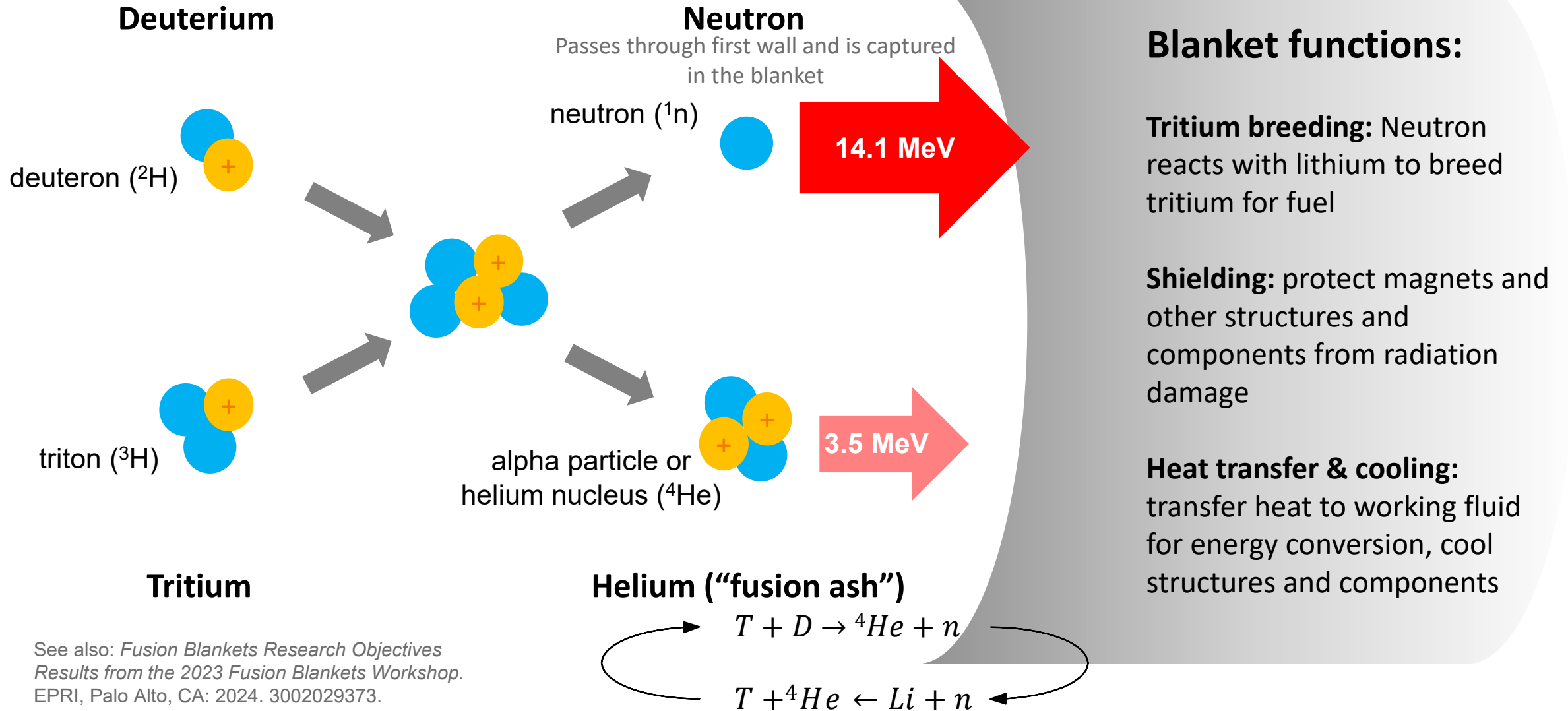
Significant science, technology, and engineering gaps remain on path to a fusion pilot plant:

- Fuel Cycle (tritium extraction and processing)
- Fusion Blanket Development (tritium breeding, shielding, heat transfer)
- Novel Materials

... in addition to plasma physics challenges



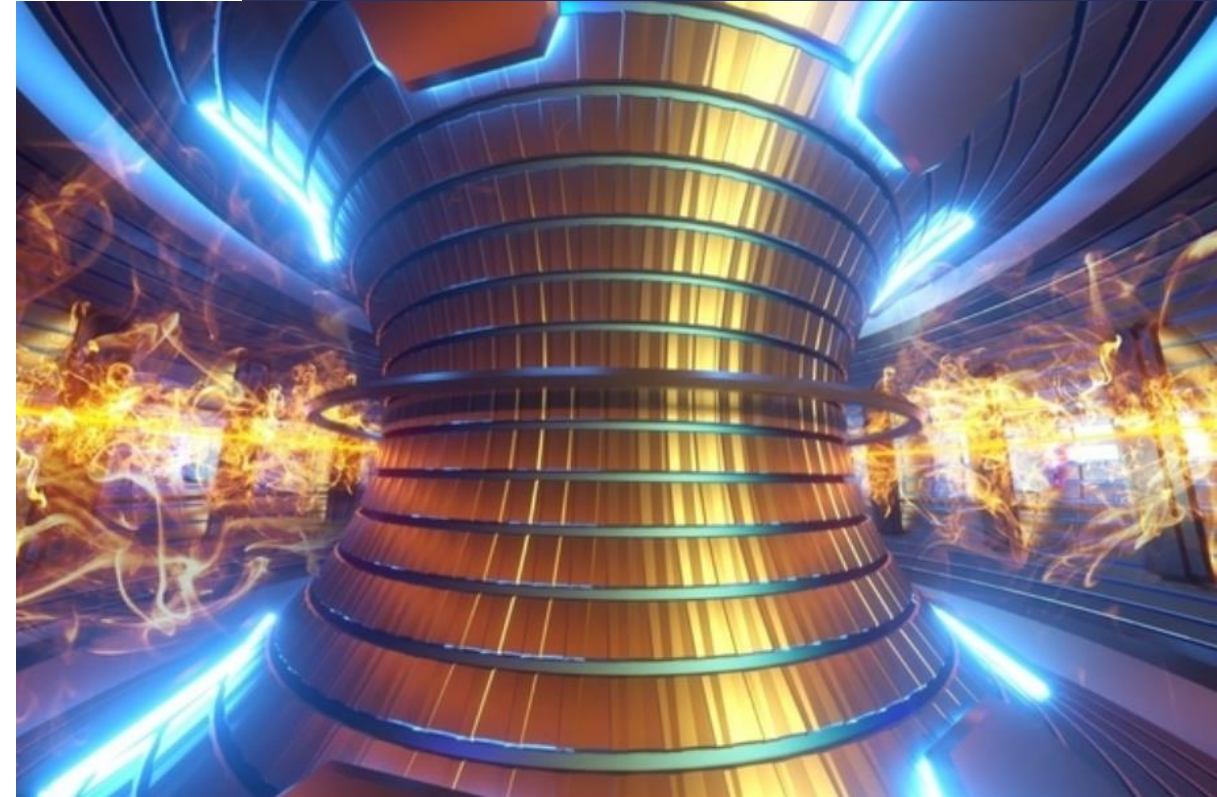
Fusion blankets: In D-T fusion, most energy is transferred by high-energy neutrons



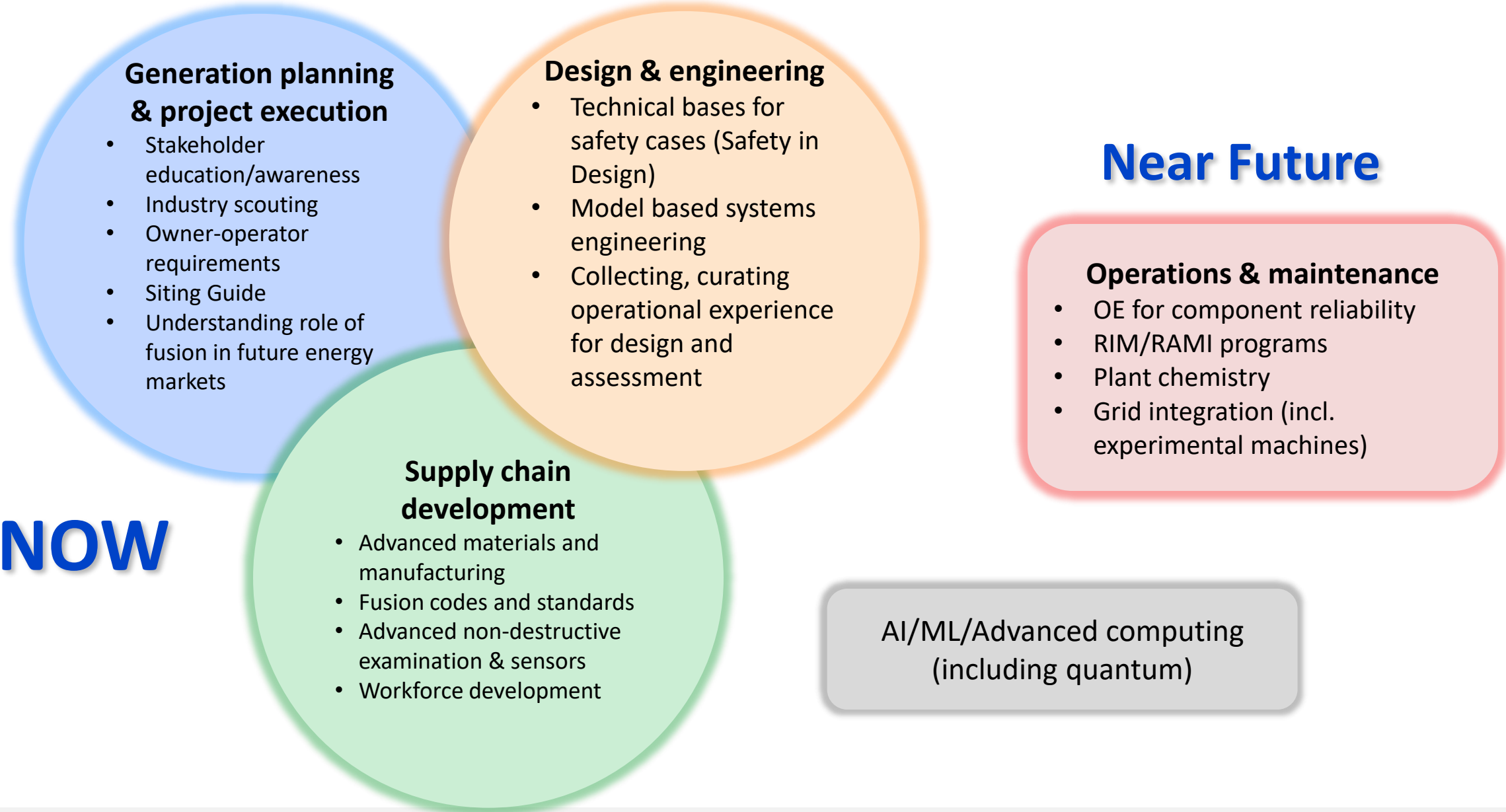
See also: *Fusion Blankets Research Objectives Results from the 2023 Fusion Blankets Workshop*. EPRI, Palo Alto, CA: 2024. 3002029373.

EPRI Fusion Energy Strategic Program: Objectives

- Inform EPRI and its members on technology, challenges, opportunities
- Provide value to fusion stakeholders through R&D products and resources
- Target broadest benefit for the public interest: safe, reliable, affordable, and sustainable energy generation and delivery



EPRI Fusion R&D Priorities



EPRI Fusion Forum

- Since 2021, EPRI has hosted representatives from fusion and EPRI communities to share updates on technology milestones and perspectives on commercialization.
- **Join us! The Fusion Forum is open to all who are interested!**



Fusion Forum Goals:

- 1 Introduce EPRI and its members to the fusion community**
Private fusion technology development companies, national laboratories, and fusion trade organizations.
- 2 Introduce fusion community (and technology) to EPRI and its members**
EPRI members exploring emerging technologies and EPRI staff researching common needs for driving innovations towards commercialization.

Fusion Forum materials can be found at <https://www.epri.com/fusion>

To join, contact Diana Grandas (dgrandas@epri.com) or Andrew Sowder (asowder@epri.com)

2024 DOE FES INFUSE Award (with Savannah River National Lab)

Documenting Tritium Operating Experience

Tritium management is an established practice across many industries with many decades of collective operating experience (OE) and lessons learned.

Project Objective: Curate existing information on tritium handling experience to develop a resource for private-sector fusion energy technology developers and regulators. Understand the extent to which tritium may be a hazard and how to appropriately manage risk.

Strategy: Leverage information from existing industrial-scale tritium use-cases to inform practices for fusion facilities.

- Nuclear fission applications/byproducts
- Exit sign/lighting manufacturers
- Defense applications



Image generated using MS Copilot

Current scope comprises:

- Engagement with tritium facilities in the US and Canada (initially) as a starting point for a Tritium OE Body of Knowledge
- Development of a common template for document OE
- Atmospheric modeling to assess impacts and site boundaries of potential fusion-relevant tritium releases
- Communication with fusion industry and other key stakeholders

This work is supported in part by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences under INFUSE 2024 Award “Building a Tritium Facility Operating Experience Body of Knowledge to Support Commercial Fusion Power Plant Safety Case Development and Licensing” (CR-24-005)

Example fusion energy applications for computational tools

Codes and simulations for:

- Plasma physics modeling
- Neutronics modeling (e.g., Monte Carlo neutron transport codes)
- Magnetohydrodynamic modeling
- Heating and current drive modeling
- Tritium transport:
 - Along desired breeding and fueling pathways
 - Understanding undesired permeation into or damage to components
 - Dispersion in atmosphere
- Materials behavior:
 - Plasma material interactions
 - Behavior and damage under neutron irradiation and thermal loads
 - Finite element analysis for predicting failure and deformation of components
- Integrated power plant systems modeling

Additional application examples:

- Instrumentation and controls (e.g., mitigating plasma instabilities)
- Model based systems engineering tools
- Economic optimization tools
- Environmental review and siting tools

Computational tools are useful for all aspects of fusion energy development



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