Overview of General Atomics Steady-State Advanced Tokamak Fusion Pilot Plant

Presented at

Fusion Power Associates
44th Annual Meeting and Symposium:
Pilot Plants for Fusion Power

By

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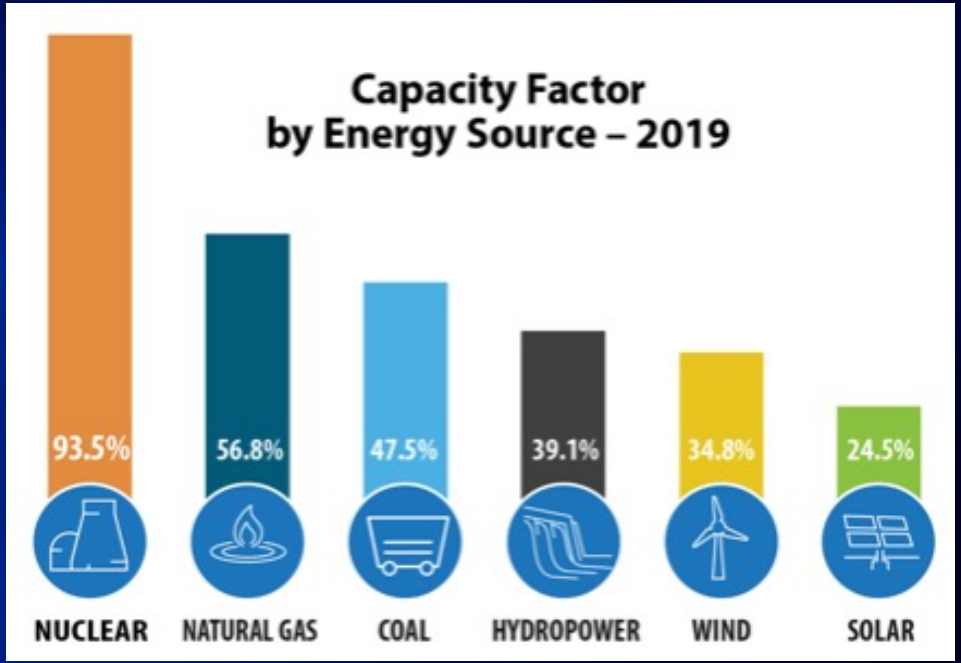
High Capacity Factor Operation Required

ANS, *Nuclear News*



- **Fusion is capital intensive**
  - Dominated by upfront capital and O&M costs
  - Long facility lifetime to recover investment
    - 80 year lifetime, 40 year license period
- **When fuel costs dominate, reducing power or pausing operation makes financial sense**
  - Not true for fusion, only lose revenue
  - Ramping power fatigues system (O&M)
- **Additional challenge to breed fuel for operation and *subsequent* plants**
  - Reduced/paused operation slows doubling time
  - Limits expansion of fusion into the market

Target markets and concepts for continuous operation

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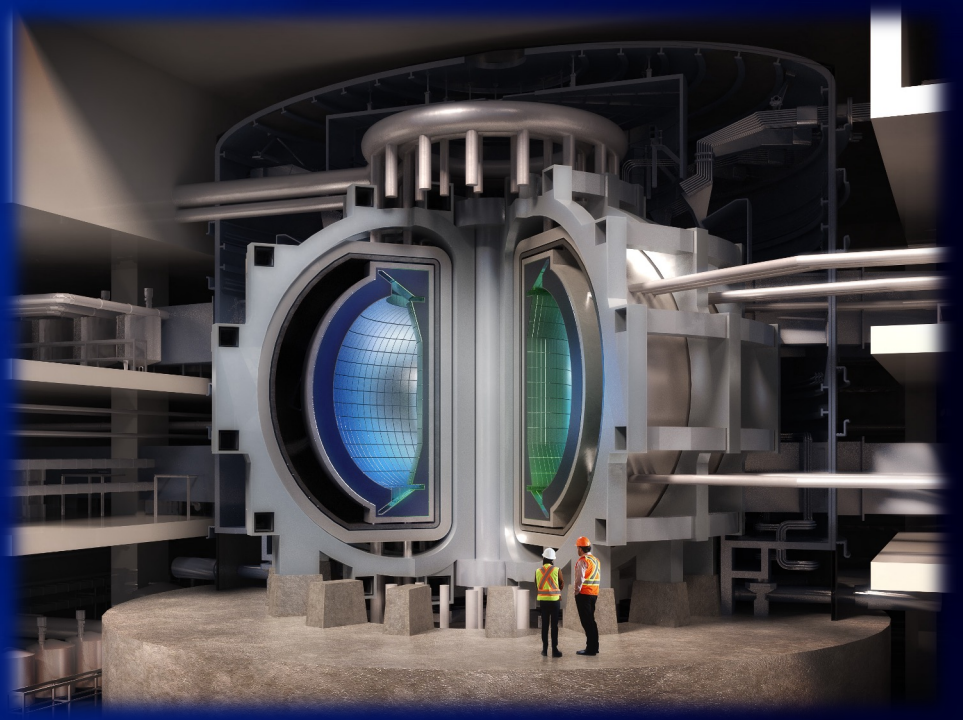
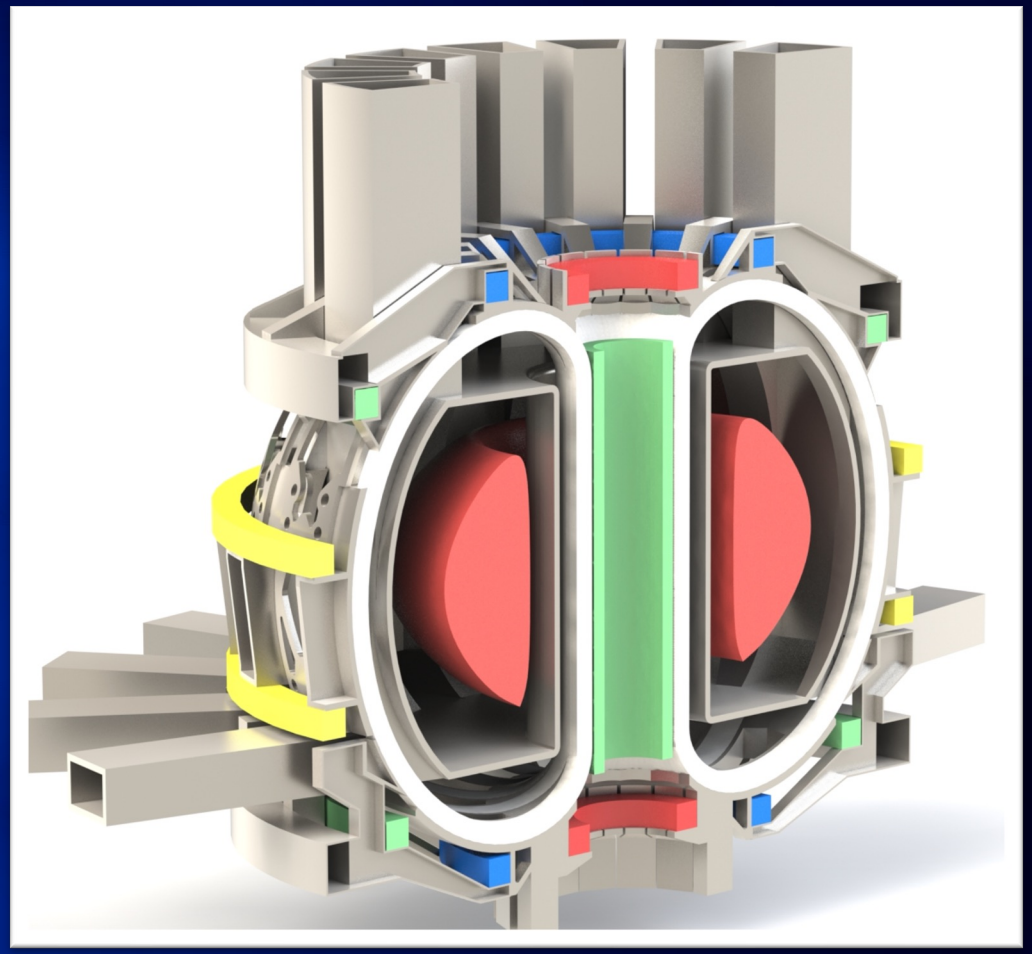
Steady-State Advanced Tokamak: Clean Energy 24/7

- **Cost effective by maximizing fusion performance**
  - Power density ~ p^2 highly levering for given field
  - High fraction of self-driven current at high pressure
  - Efficient current drive minimizes recirculating power
- **Robustness against operational transients**
  - High plasma pressure at reduced current avoids instabilities that could interrupt facility operation
- **Avoidance of cyclic stresses & fatigue**
  - High availability, minimized maintenance costs, long facility lifetime



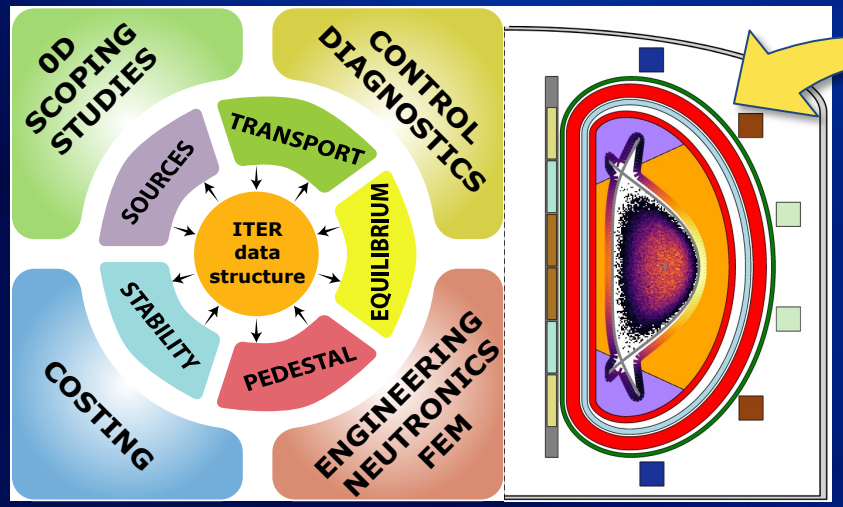
Concept Selection Accelerates Design and Technology Roadmap

- **Strong AT shaping: near double-null**
  - Inboard & outboard breeder
  - Building on ITER divertor design
- **Avoid large midplane ports**
  - Maximize tritium breeding & MHD stability
  - Use ECH and ITER-like gyrotrons
- **Vertical maintenance**
  - Most free access is above machine
- **Breeder made of lead-lithium**
  - Low melting point
  - Chemically compatible with materials
  - Dynamic composition control
  - Drain for maintenance

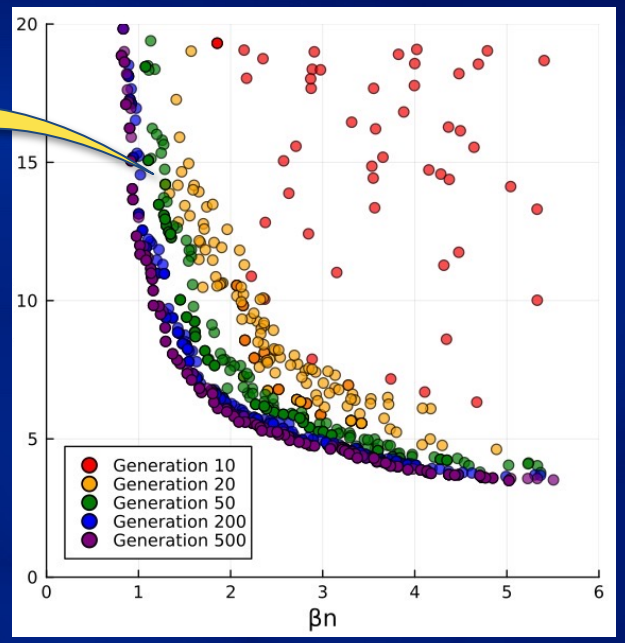


GA Has Developed the Most Complete and Fastest Whole Facility Design Tool

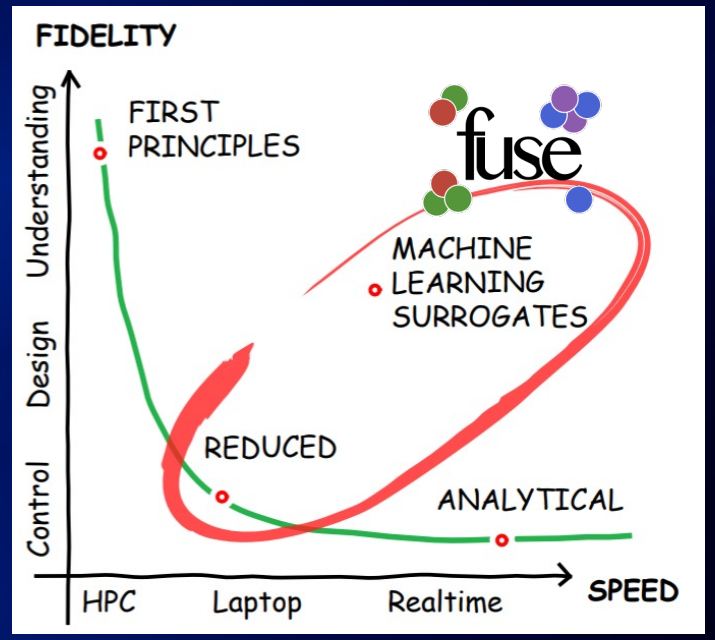
Each point is entire facility



Minimum Cost Optimization ($Bn)



Breaking Speed/Fidelity Tradeoff



FUSE breakthroughs

- Whole facility at increased fidelity
- Machine learning (10^{10} speedup)
- Genetic algorithm optimization
- First principle HPC and reduced models
- Time dependent evolution

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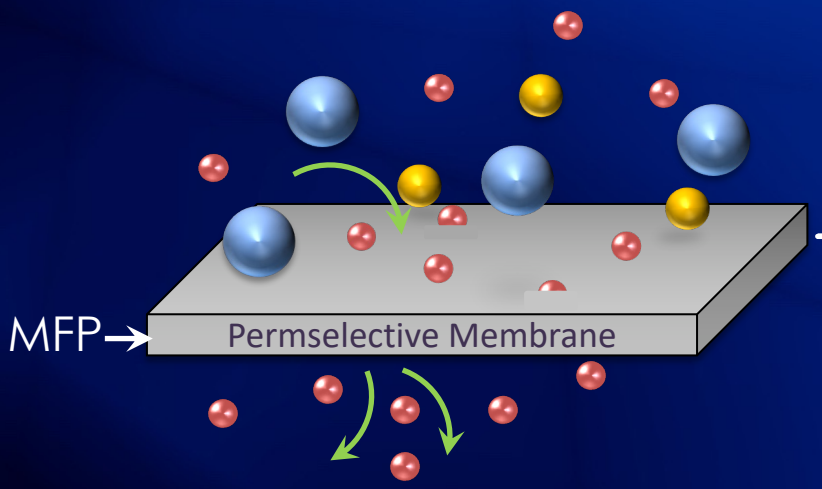
GA Self-Supported Thin Films Are an Innovative Fuel Cycle Technology

Plasma exhaust:
Deuterium & Tritium
+
He, Ne, Ar, Kr, Xe

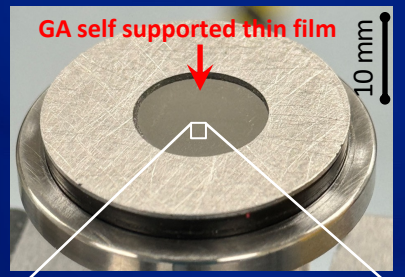


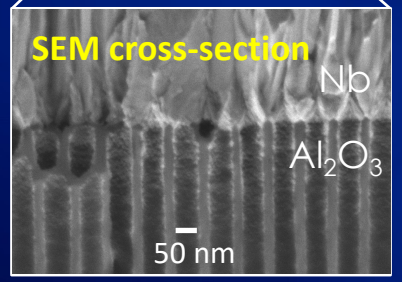
Tritium recovery

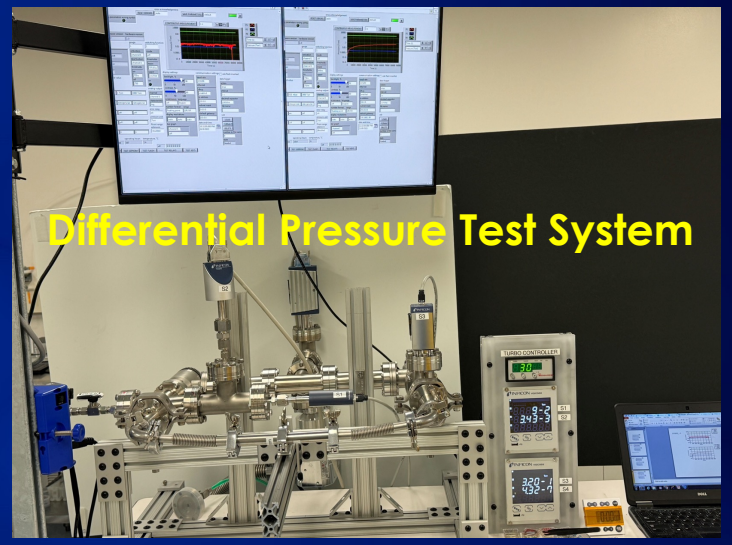
Cost $$$ ↓ **Complexity** ↓ **Safety** ↑

Potential to reduce size & cost of tritium system by an order of magnitude

Feature	Foils	Thin Film	GA Thin Film
Mechanical Strength	✓	✗	✓
Manufacture and Handling	✓	✗	✓
Integration into Device	✓	✗	✓
Temp. and Pressure Resistance	✓	✗	✓
Hydrogen Diffusion Speed	✗	✓	✓
Material Tunability	✗	✓	✓
Scalability	✓	✗	✓







- ✓ **Higher permeation rates than foils**
- ✓ **Pursuing permeators & barriers**

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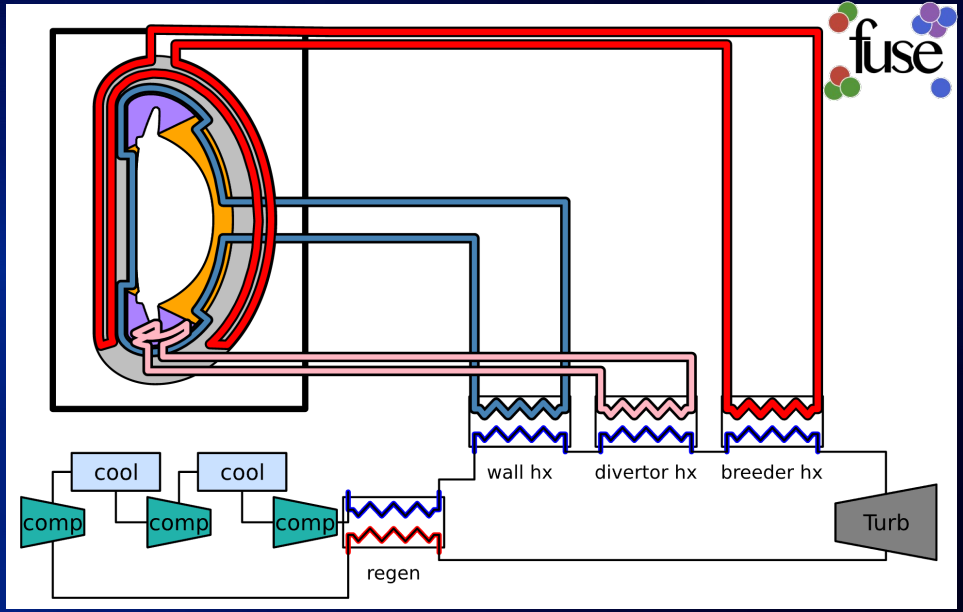
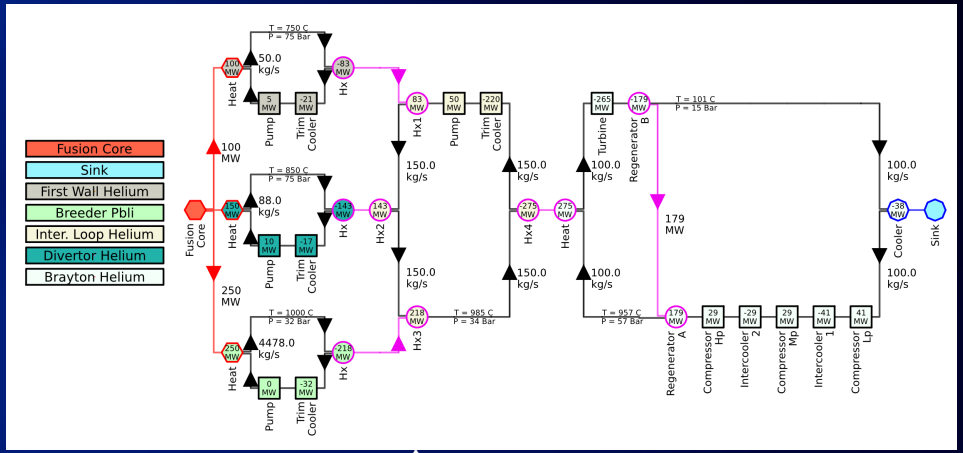
Balance of Plant Integrated into Design Optimization Reinforces the Benefit of High Temperature Operation

- **Fusion power core and power conversion system intimately connected**
  - Must be designed together
  - Multiple coolant streams & temperatures
- **Cycle analysis with state-of-the-art tools validating simplified models**
  - Simple models sufficient for optimization
  - Cycle efficiency >50%

Self-consistent use of high grade heat for electricity and cogeneration





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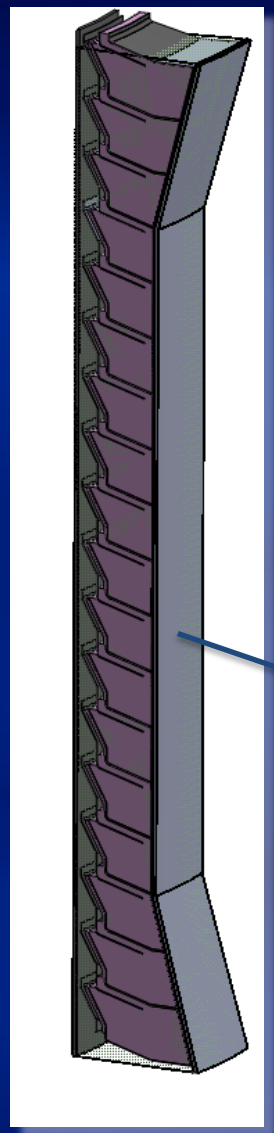
GA Modular Blanket (GAMBL) Developed as High Temperature Dual-Cooled Blanket Using SiC-based Structures

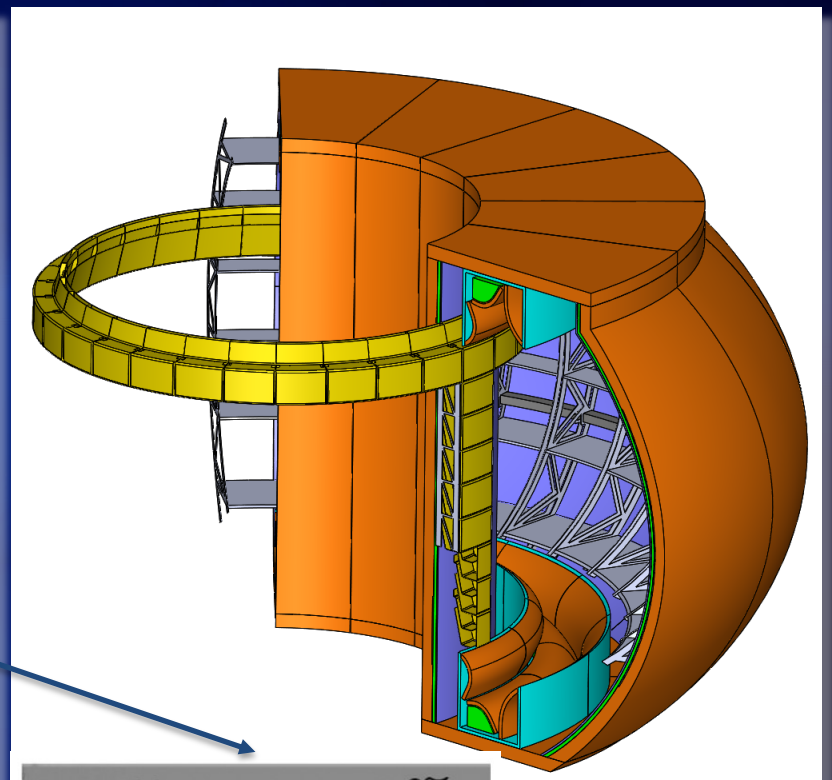
- **SiC opens high thermal efficiency and industrial heat markets**

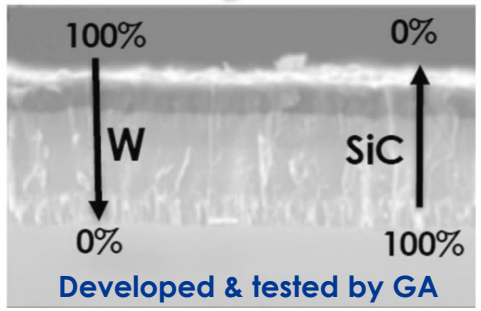
- **GAMBL simplifying design features**
  - Relieves hydrostatic pressure between containers by cascading PbLi from top to bottom
  - Minimizes/eliminates complex cooling channels in structures using radiatively-cooled thin "scaffolding"

GAMBL concept improved, mocked-up

Waterfall demonstrated pressure relief







Developed & tested by GA

M. Tillack, *et. al.*, Fus. Eng. and Design **180**, 113155 (2022)
C.P. Deck, *et. al.* J. Nuclear Materials **466** 667-681(2015)

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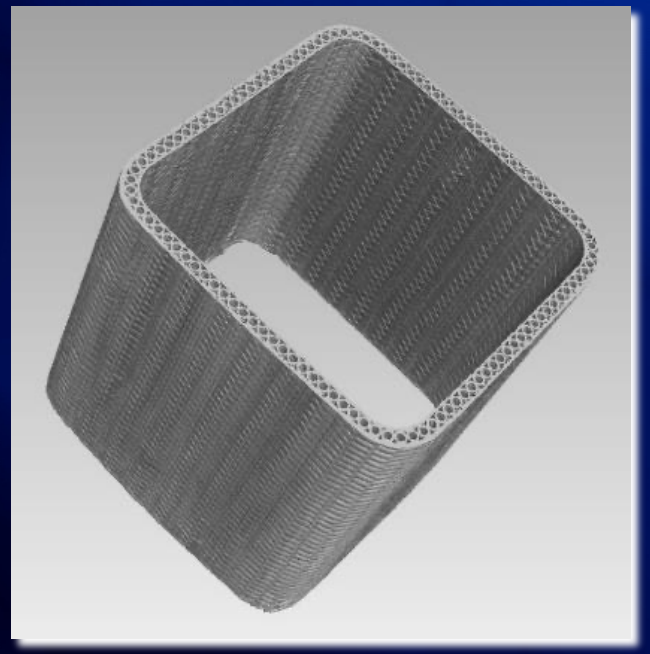
SiGA® Nuclear Grade Fiber Overcomes Perceived Challenges with Advanced Composites

- Complex shapes
- Joints and bonds
- Low impurities
- Efficiency & cost for scalability

Flow Channel Insert



Joints

Engineered Shapes

Leveraging existing bridges to GA's broader capabilities in manufacturing, nuclear technologies, and industrial supply chains

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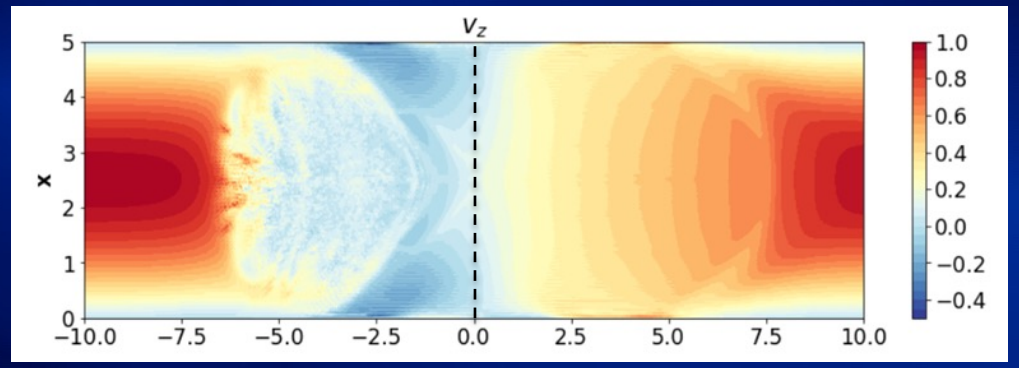
GA's ALMA Code Has Been Extended to Enable Study of Liquid Metal MHD Applicable to a Blanket in a Strong Magnetic Field

Turbulent flow into magnetic barrier



Fundamental science

\+ Validation of key physics

\+ Engineering excellence

\+ Existing site credits at MTC

→ opportunity to realize a US blanket facility

Laboratory-scale apparatus for liquid metal MHD science and validation

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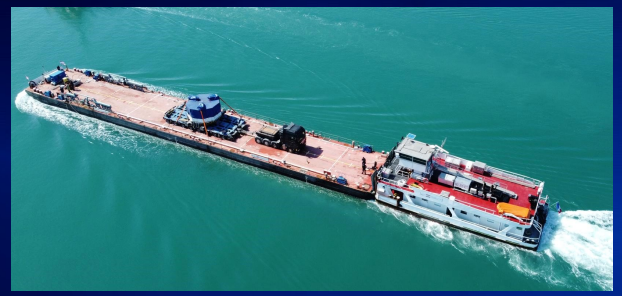
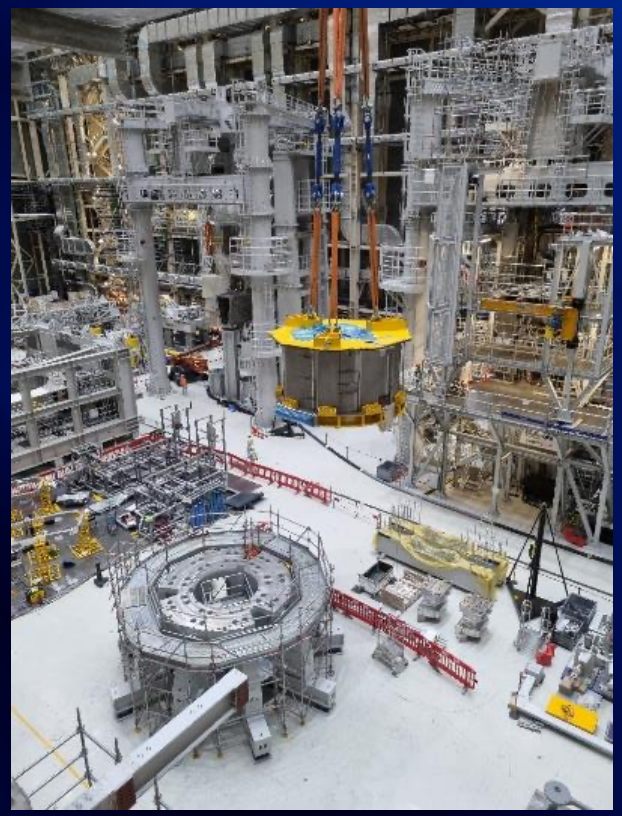
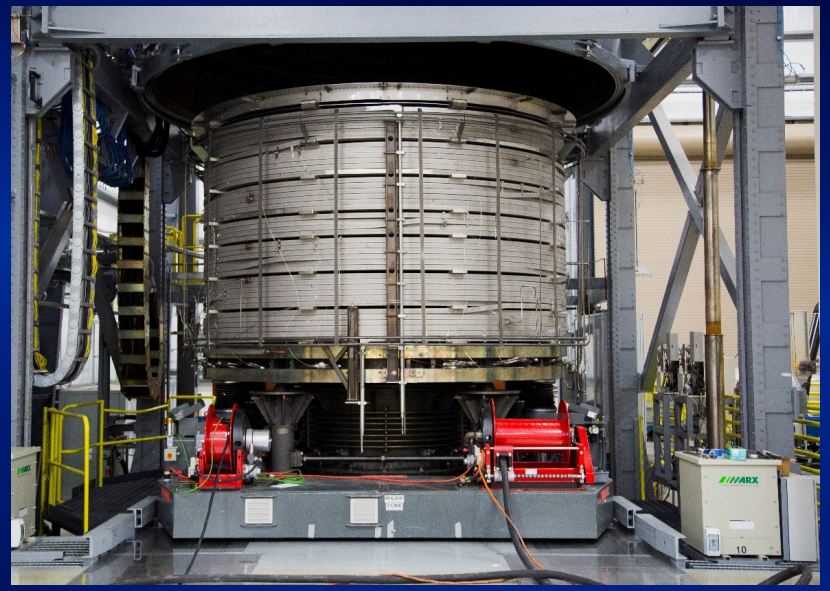
ITER Knowledge and Experience in Manufacturing and Testing Superconducting Magnets Leveraged to Innovate

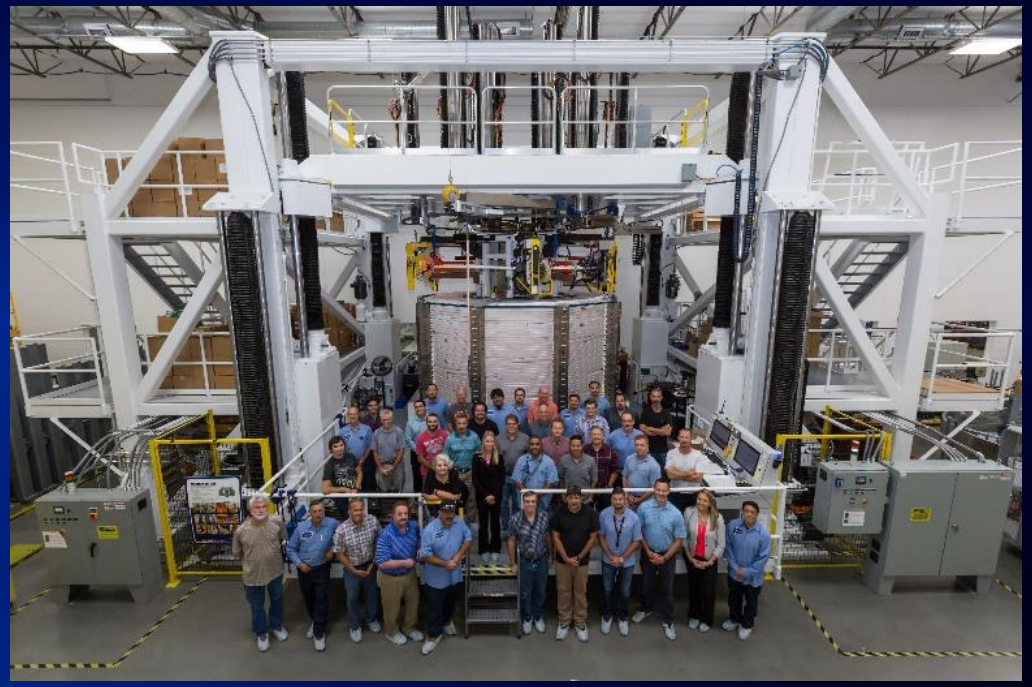






Module #1 in furnace

Turn Over Tool after VPI



Experienced team

- Developing manufacturing processes, tools
- Qualifying manufacturing methods
- Power testing of magnets at current (40kA)
- Paschen Testing

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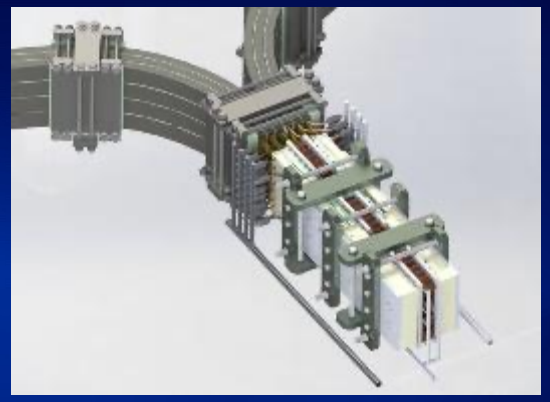
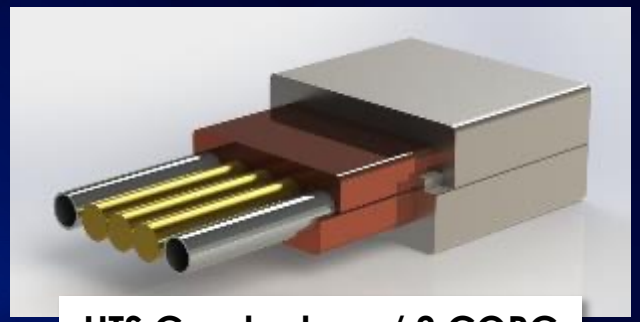
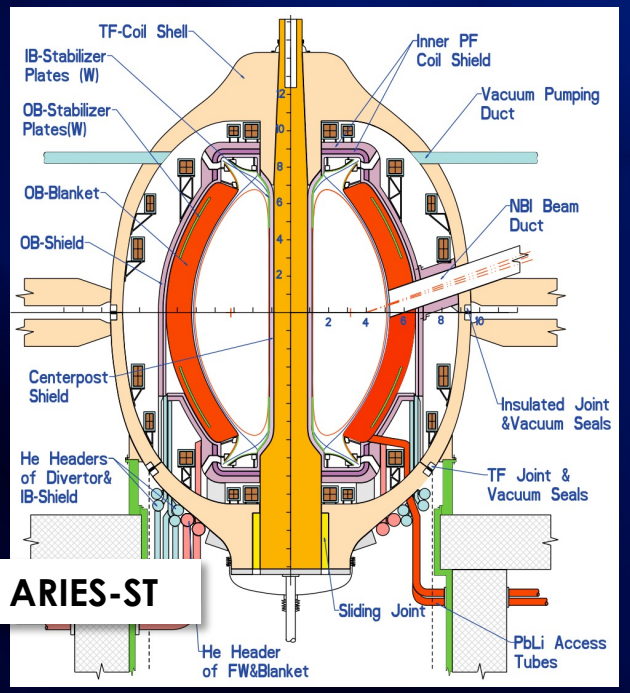
Maintainability and Remote Handling Schemes Are Required: Demountable HTS Magnet May Be One Enabling Technology for FPP

- Improves availability by rapid change-out of non-lifetime components
- Potential for overhead cranes and vertical maintenance schemes





HTS Conductor w/ 3 CORC Cables in SS Jacket



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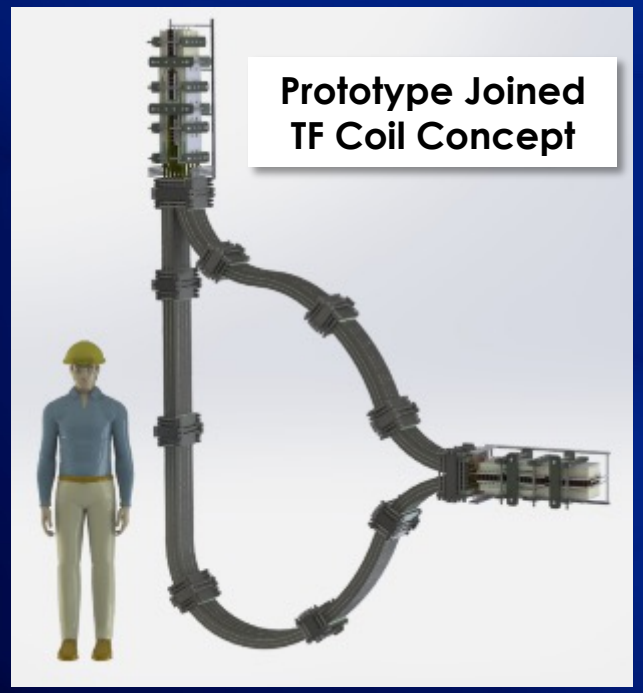
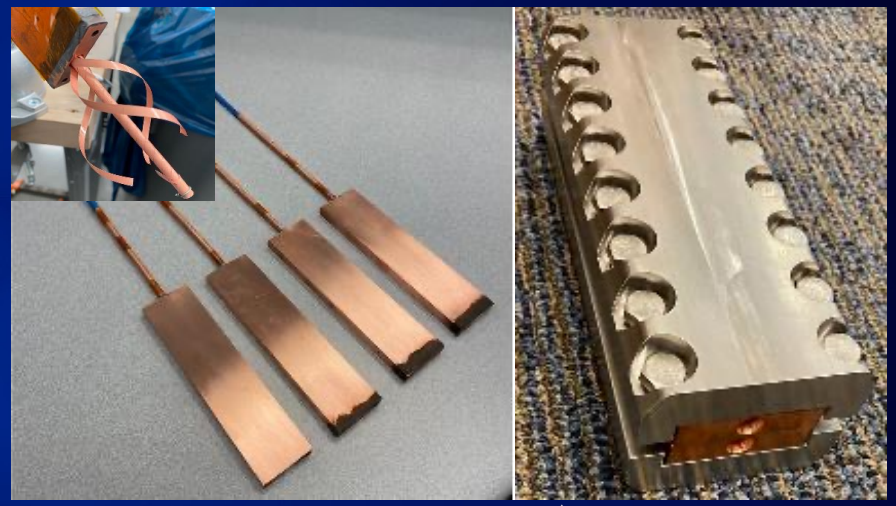


Prototype Joined TF Coil Concept

GA Working with National Labs
LBNL - HTS Joint Tests
BNL - CICC



INFUSE

Brookhaven National Laboratory

BERKELEY LAB

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General Atomics and Tokamak Energy Working Together on HTS Magnets

General Atomics and Tokamak Energy Announce Collaboration Regarding High Temperature Superconducting Magnet Technologies

"Tokamak Energy is a leader in HTS magnet modelling, design and prototyping and GA has expertise in developing and fabricating large-scale superconducting magnets for fusion applications."

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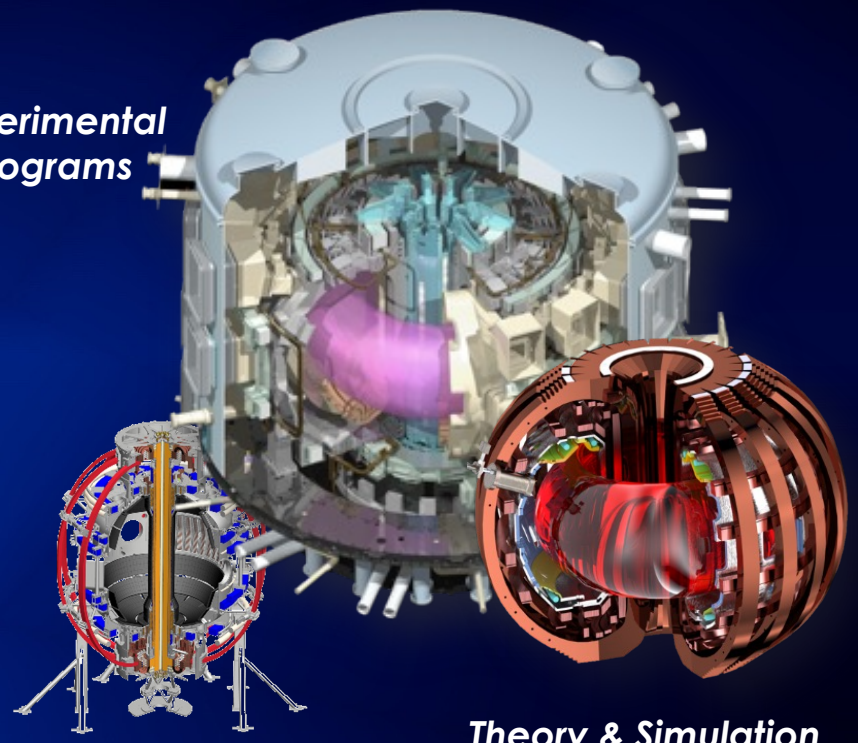
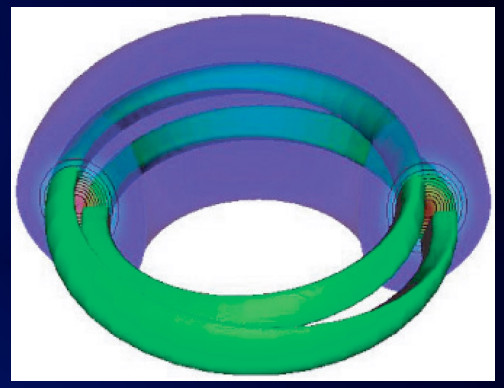
Realization of Fusion Depends on Enhanced Public-Funded Research and Ready Access to Results from Decades of Progress

- **Upgrade key facility capabilities to address gaps**
- **Provide continuity and leverages extensive lab resources**
- **Facilitate opportunities for testing and qualification of private sector solutions**
- **Enable private efforts to effectively build on progress**
  - Acceleration of advances in both private and public sector

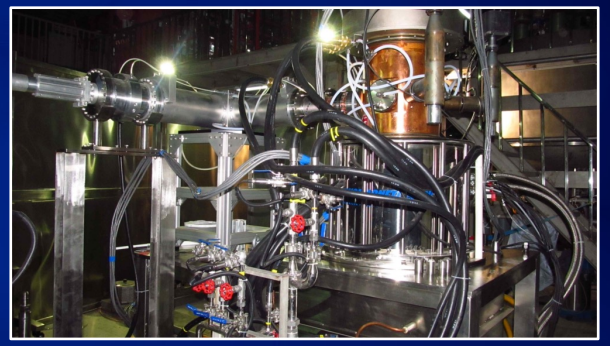
Experimental Programs



Theory & Simulation

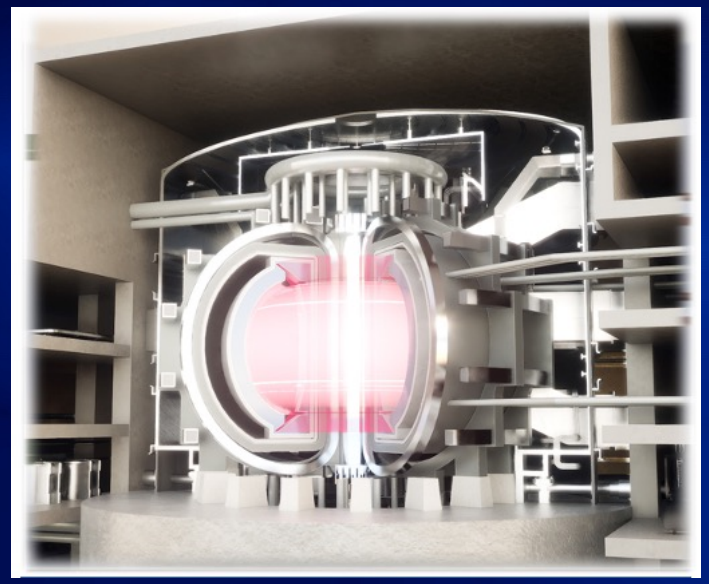


Test Facilities



HPC resources

Steady-state Advanced Tokamak for Robust and Economical Fusion



- **Attractive fusion energy requires innovative solutions** ***Building on knowledge and experience from ITER and decades of public research***

Come join us!

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