

Technology Strategic Planning for Plasma Interacting Technologies

Presented to

DIII-D Plasma Interacting Technology Research Group

DIII-D National User Facility

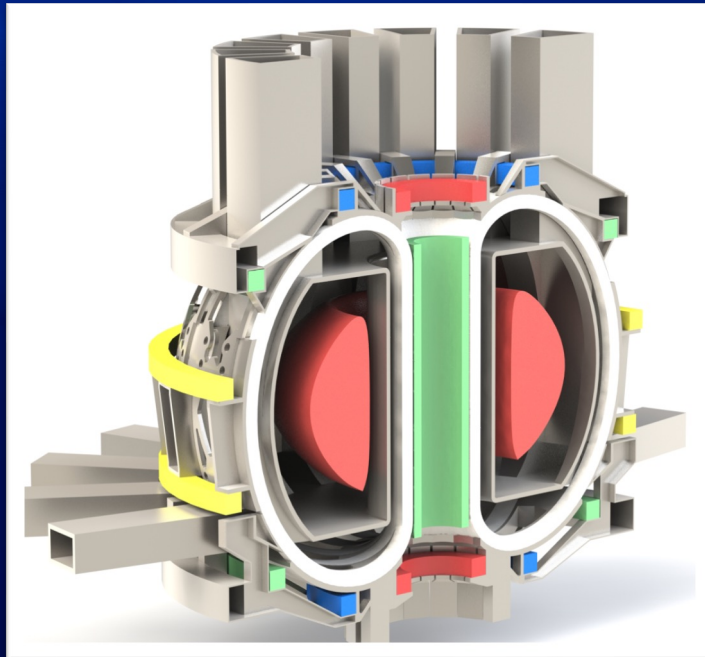
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Fusion Pilot Plant Design

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Concept Maturation and Down-Selection is Critically Linked to Closing Gaps on Technology Roadmap

Concept Highlights



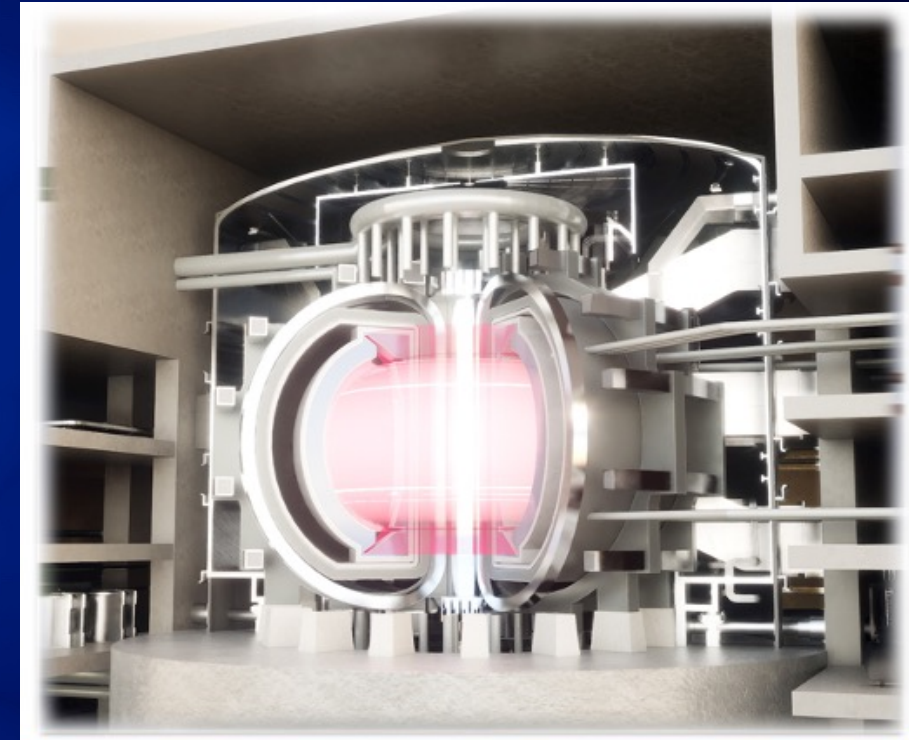
Technology



*Technology Readiness Level

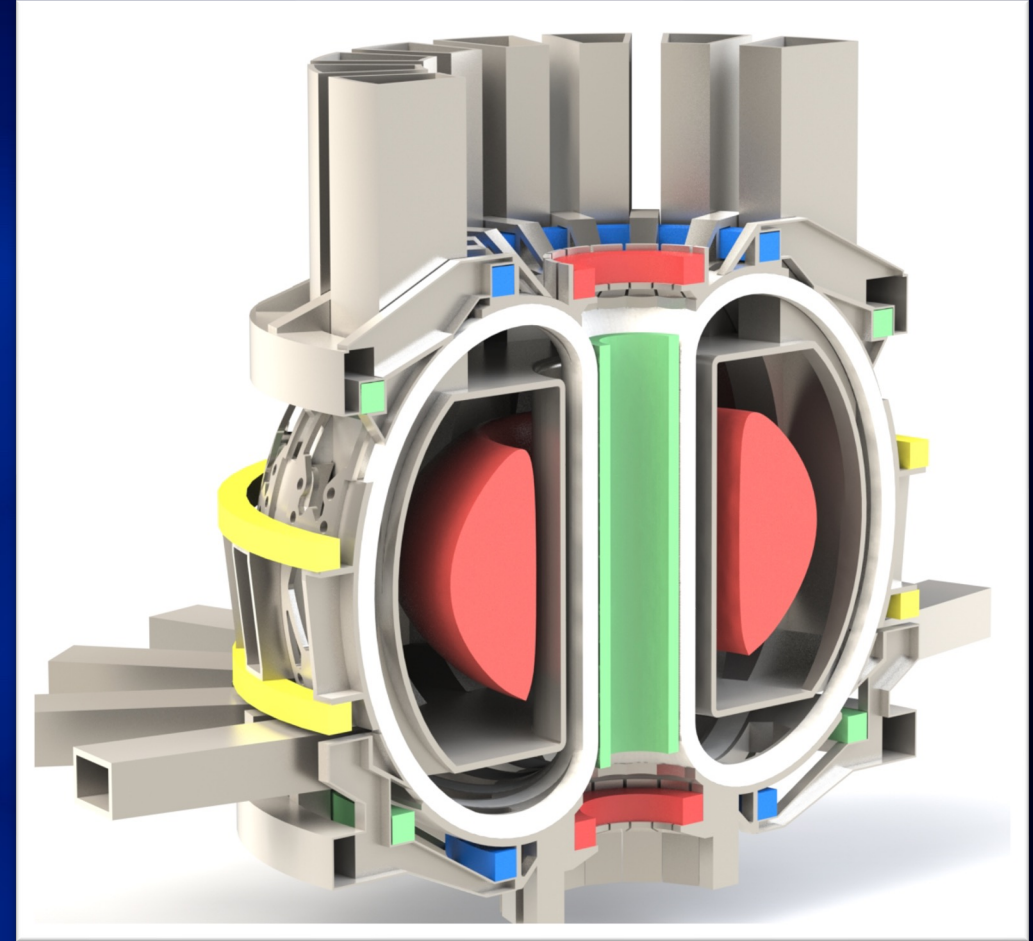
Steady-State Advanced Tokamak

- **Cost effective by maximizing fusion performance**
 - Power density $\sim p^2$ highly leveraging 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



High Level Concept Selection

- **Strong AT shaping: near double-null**
 - Inboard & outboard breeder maximizes TBR
 - 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
 - Online composition control
 - Drain for maintenance



High Priority Technology Gaps to Resolve for FPP

- **Divertor and first wall power & particle handling solutions with active cooling**
 - Water-cooled W+CuCrZr is high TRL but desire to avoid use of water in FPP
 - Need to develop de(re-a)tachment control sufficient for He coolant
- **Management of material erosion, migration and hydrogen retention**
 - Large (kg-level) W erosion expected and irradiation effects trap hydrogen
 - Need to develop heated div. and first wall solutions for erosion, avoid H retention
- **Control solutions with FPP-relevant diagnostics & actuators**
 - Limited wall area (TBR) and technology (rad.) available
 - Need to develop proxy measurements and model/ML-augmented sensors
- **Efficient H&CD compatible with harsh nuclear environment**
 - Limited wall area for H&CD (TBR), high irradiation, high recirculating power
 - Need to develop improved efficiency in-vessel actively cooled systems that survive full duration between maintenance periods

Change in Environment Produces Gaps in Science and Technology

Overall DIII-D Technology Program is Pursuing Valuable Directions



Consultation on the
5-Year Research Plan
2024 - 2029



Modular Divertor #1	Demonstrate Plasma Exhaust Solution Compatible with High-performance Core	Modular Divertor Research Program Executes a staged divertor implementation to address issues of exhaust power handling as a function of divertor geometry. Provides for comprehensive diagnostic coverage to accelerate experimental program.
Modular Divertor #2		
Modular Divertor #3		

- **Sufficient power & particle handling while maintaining confinement targets two key levers for economic fusion**
 - Develop transient-resilient divertor using liquid-metals, or other innovations that close the reattachment gap
 - Develop detachment control with FPP-relevant diagnostics
 - Develop solutions for handling large (~kg) W erosion

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WITS Preparation		Wall Interaction Tile Station (WITS) System
WITS	Demonstrate Plasma-facing Material Compatibility	Establishes capability to expose novel materials to controllable levels of plasma heat flux. Material extraction is performed through an airlock that allows for in-situ measurements prior to exposing samples to atmosphere.

- **Lifetime of plasma facing materials determines replacement frequency and maintenance**
 - Measurements of first-wall particle flux & impact energy
 - Reduced hydrogen retention in radiation damaged W
 - PFC component technology with active cooling systems
 - Wall conditioning compatible with long pulse operation

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Disruption Mitigation Upgrade	Address Fusion Pilot Plant and ITER Needs	Disruption Mitigation Research Program Two-stage capability upgrade demonstrating viability of pellet injection and alternative disruption mitigation technologies in serving requirements for FPP and ITER.
REMC Prototype	Address Fusion Pilot Plant Needs	Runaway Electron Mitigation Coil (REMC) Demonstrates ability to mitigate growth of runaway electron population following a disruption. Passive coil is charged by the current of the seed runaways, generating a magnetic field distortion that leads to their deconfinement.
REMC		

- **Disruption avoidance and prevention maximizes uptime**
 - Demonstrate matter injection performance sufficient to house technology outside of bioshield (high velocity)
 - Qualify new disruption mitigation technologies

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- **Efficient and task-specific heating & current drive**
 - Minimizing recirculating power needed for high $P_{e,net}$
 - FPP-relevant measurements actuators for targeted & steerable instability control
- **Approaches that extrapolate to nuclear environment**
 - High heat and particle flux plasma facing materials
 - Structural and functional materials that survive & do not produce high level or long lived radioactive waste
 - Consideration of neutron streaming paths and/or considering shielding requirements

DIII-D Capabilities are Synergistics with Needs for Plasma Interacting Technology Development

- Fusion Pilot Plant environment requires development across all technologies
 - Control
 - Diagnostics & Actuators
 - Fueling & Disruption mitigation
 - Heating & Current drive
 - Materials & Nuclear science
- Raising TRL of critical technologies key to maturing *integrated* design

Many opportunities for innovation!

