Moving Fusion Energy Forward

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Fusion Power Associates Annual Meeting
Washington, DC
7 December 2022

MIT Plasma Science and Fusion Center: Pushing the Boundaries Toward Fusion and Clean Energy

- Contributing across physics and technology
  - Magnetic confinement: the high magnetic field approach to tokamaks and stellarators
  - First at-scale demonstration of high field superconducting magnet (TFMC)
  - Physics basis and diagnostics for SPARC, expected to be the first net energy producing tokamak
  - Molten salt blanket development, tritium breeding (the LIBRA project)
  - Efficient/robust current drive for steady-state tokamak reactors(HFS-LHCD on DIII-D)
  - Fusion spin-off technology for deep-drilling geothermal
  - High energy-density physics, state-of-the art measurements
- Teaming with Private Industry (a growing portfolio of companies)
- Core MIT mission to educate the next generation of fusion scientists and engineers

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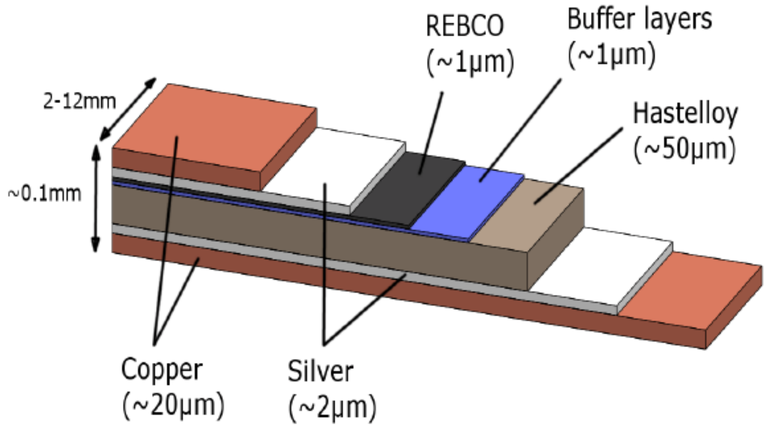
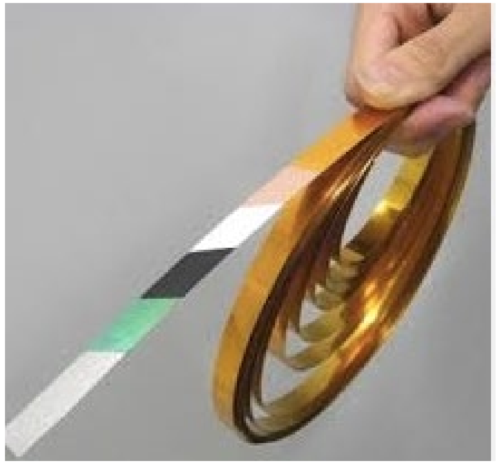
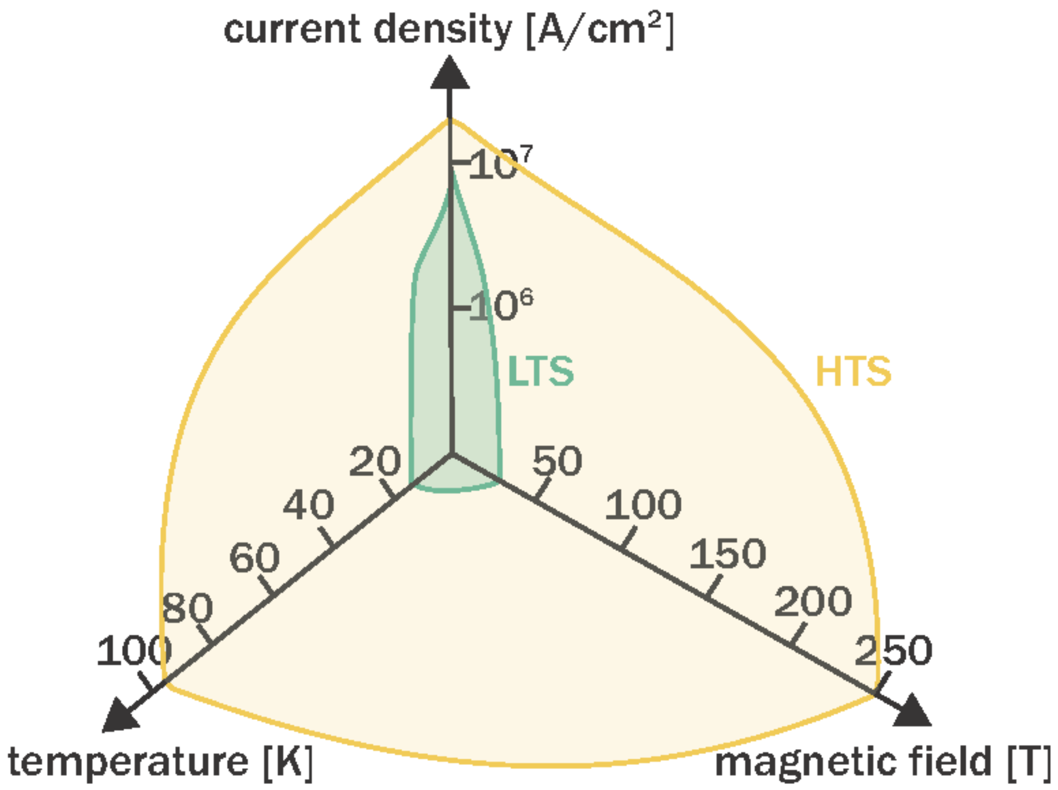
High Temperature/High Field Superconductors:

Commercialized superconductor tapes could DOUBLE the practical magnetic field for Magnetic Fusion Energy







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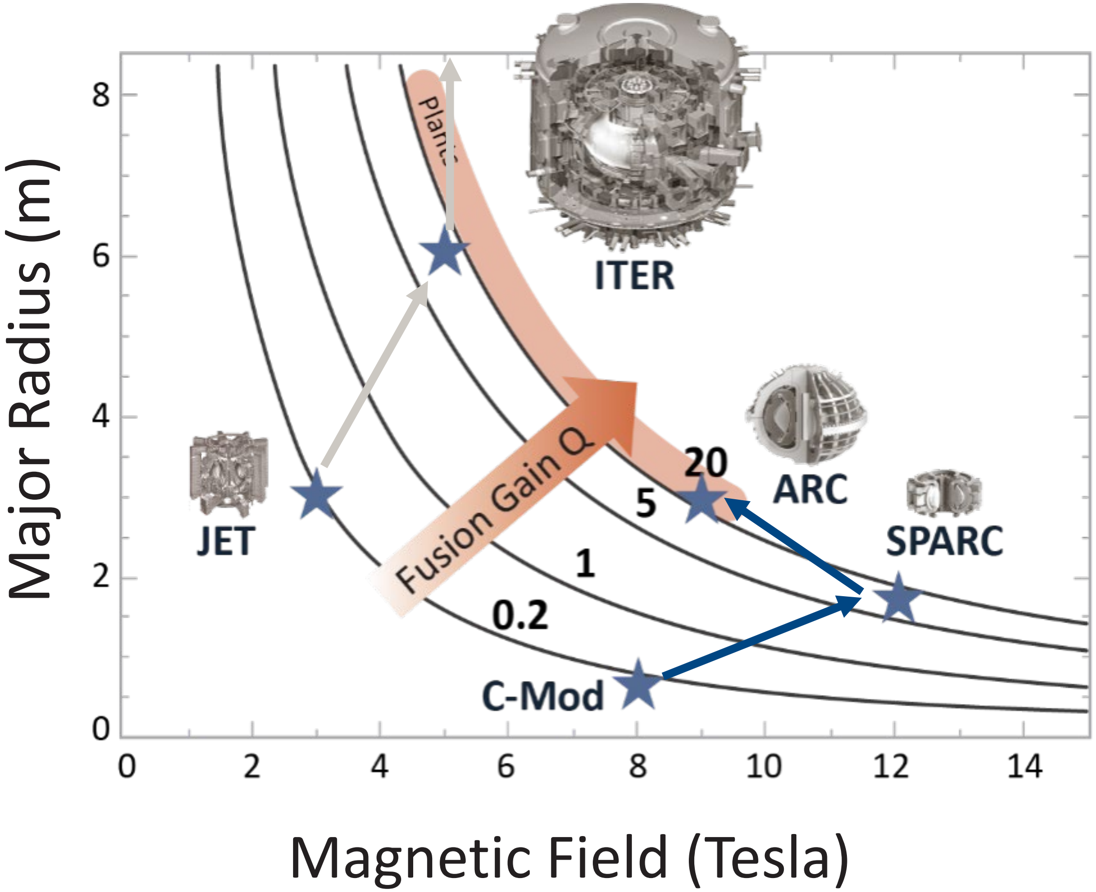
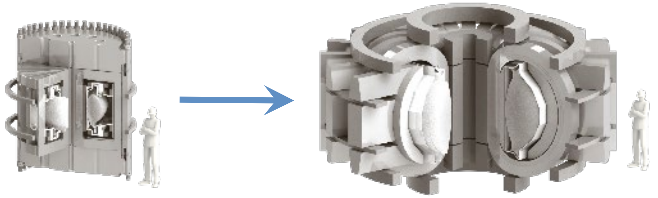
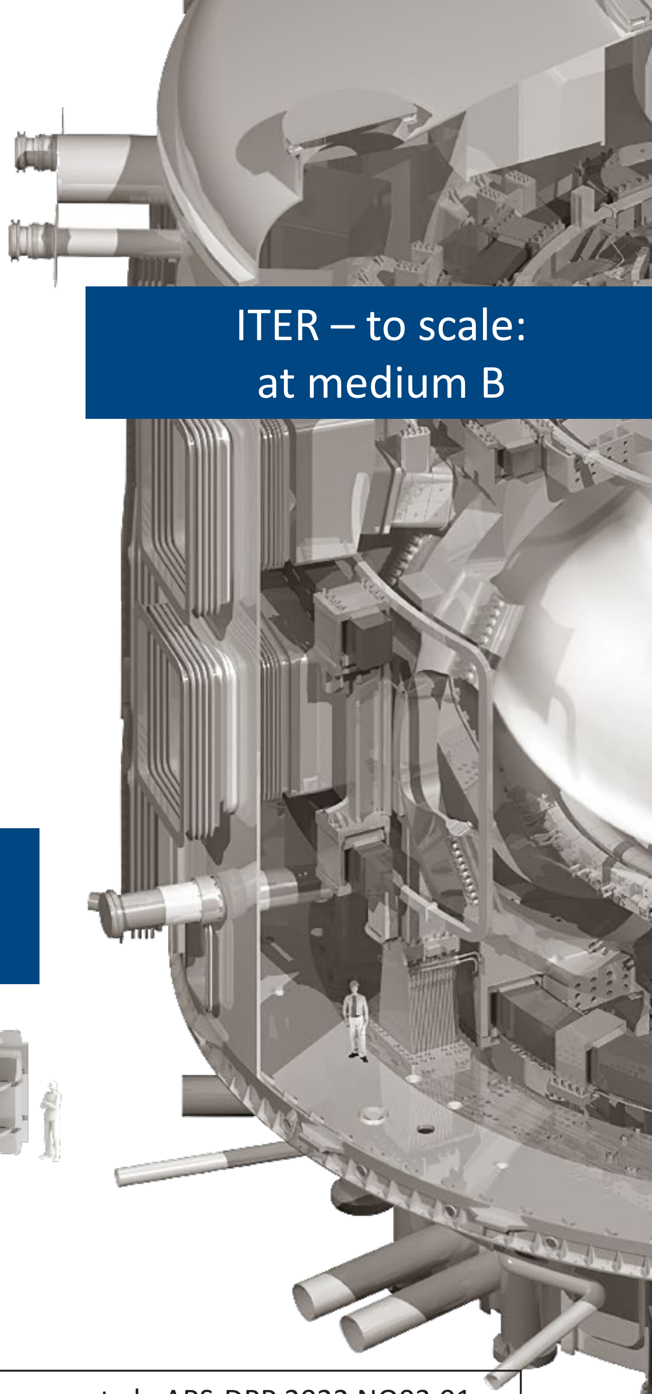
High-field magnets open a new pathway to fusion



C-Mod and SPARC:
at high B



ITER – to scale:
at medium B



D. Brunner, et al., APS-DPP 2022 NO03.01

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High-Magnetic-Field path to fusion energy

COMPLETED:
Alcator C-Mod
Record-setting tokamak
(MIT+Collaborations, Gov't funded)

COMPLETED:
Demonstrate groundbreaking HTS magnets
(Joint MIT/CFS, CFS funded)

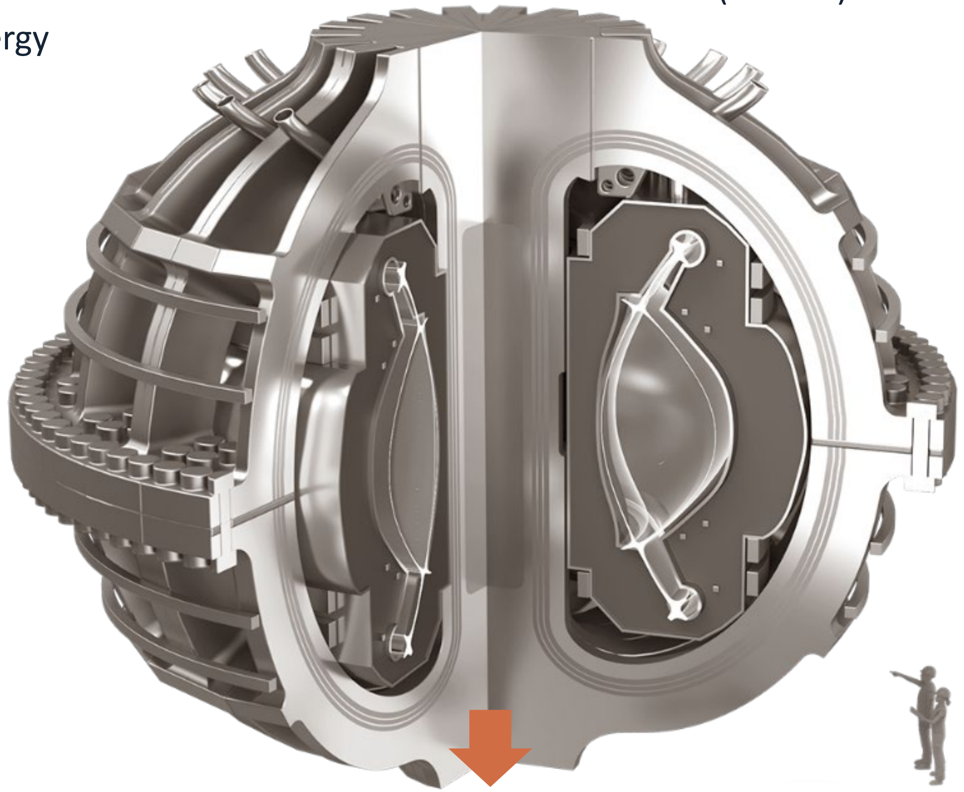
CONSTRUCTION UNDERWAY for 2025 LAUNCH:
SPARC Q>1
Achieve net fusion energy
(CFS funded)

EARLY 2030s:
ARC deployed
>200 MW (CFS led)

+ knowledge from world fusion program

Early revenue from magnet platform

Commercially-relevant net fusion energy for the first time



Carbon-free commercial power on the grid

D. Brunner, et al., APS-DPP 2022 NO03.01

Pivoting largest experimental spaces and teams at MIT

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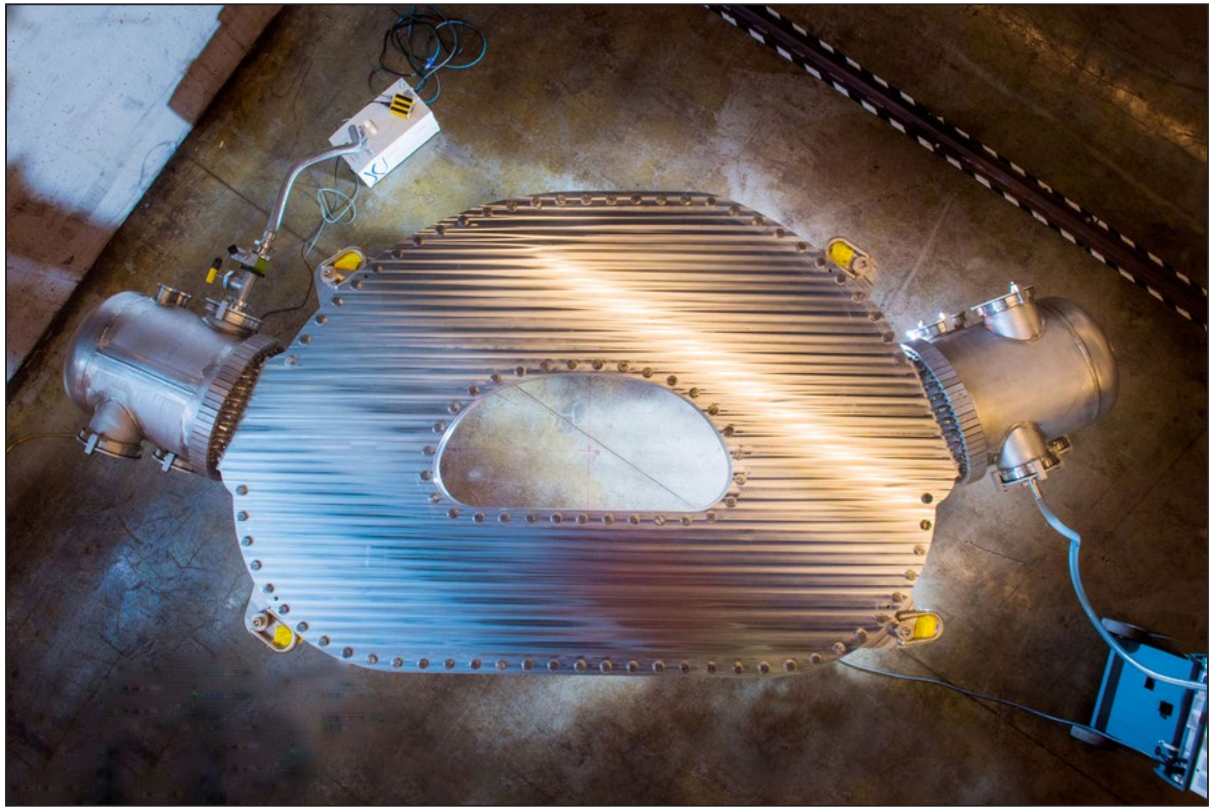
Sept. 2021: Completed Toroidal Field Model Coil (TFMC) B=20.3 T on the HTS

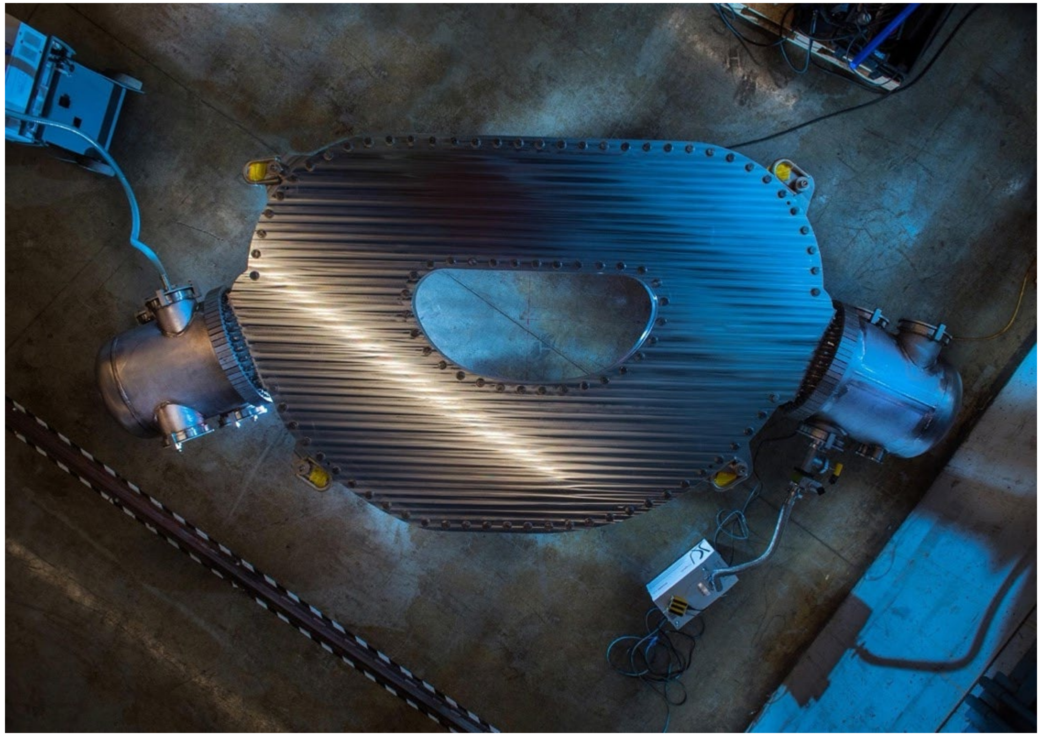
Close MIT/CFS collaboration

Leveraged PSFC facilities



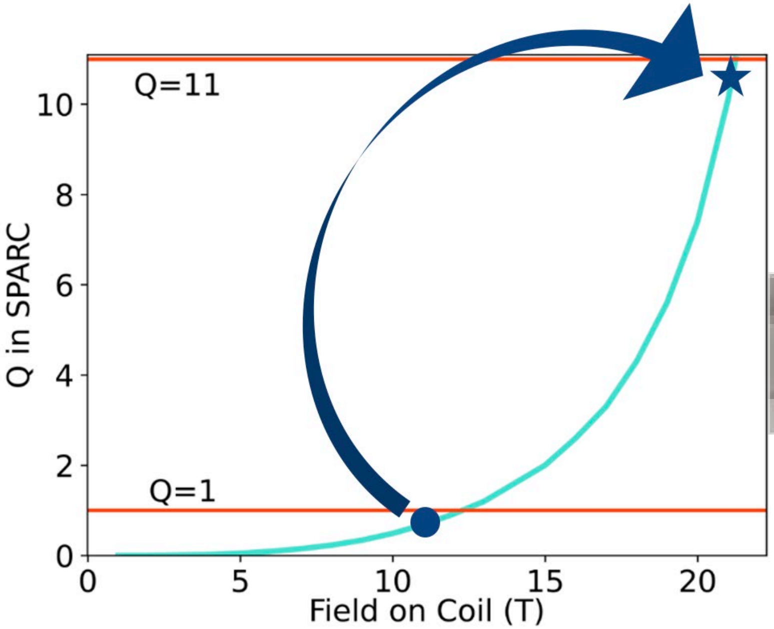
The teams delivered the technology and project readiness in record time to accelerate fusion’s development

20 Tesla coil demonstrated at scale and performance needed for SPARC at PSFC using joint MIT-CFS teams



SPARC physics basis published

- Peer-reviewed literature
- Most downloaded papers of the year



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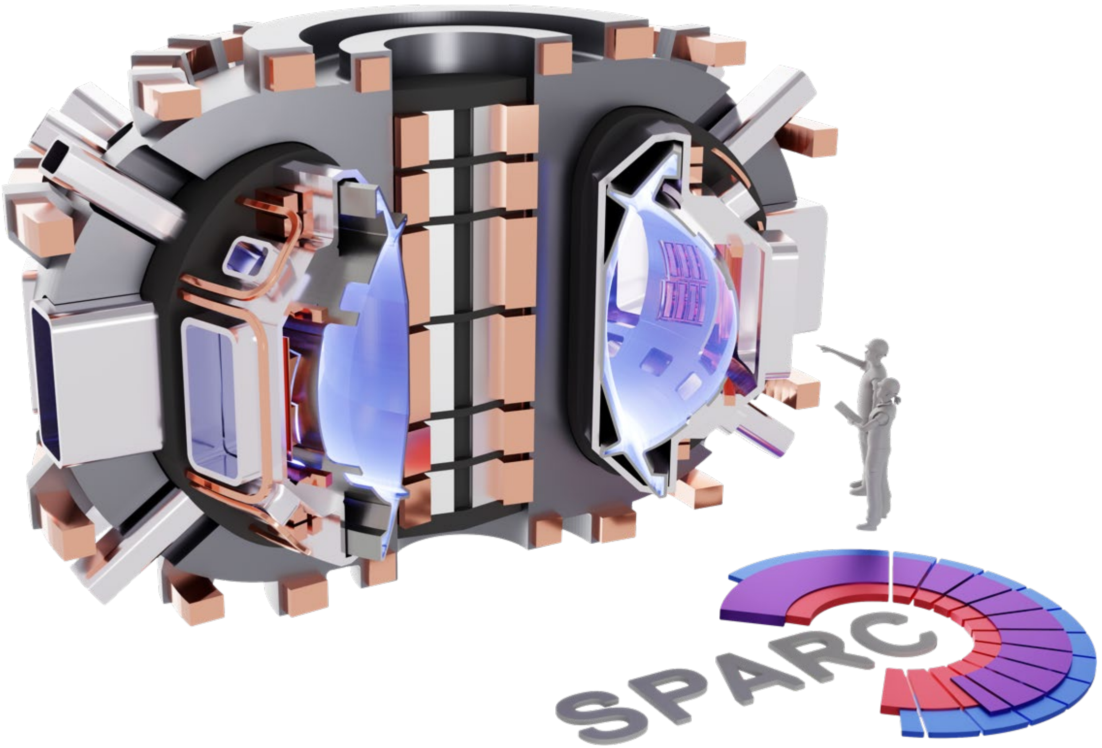
June 2021: Completed “ready-to-construct” design review

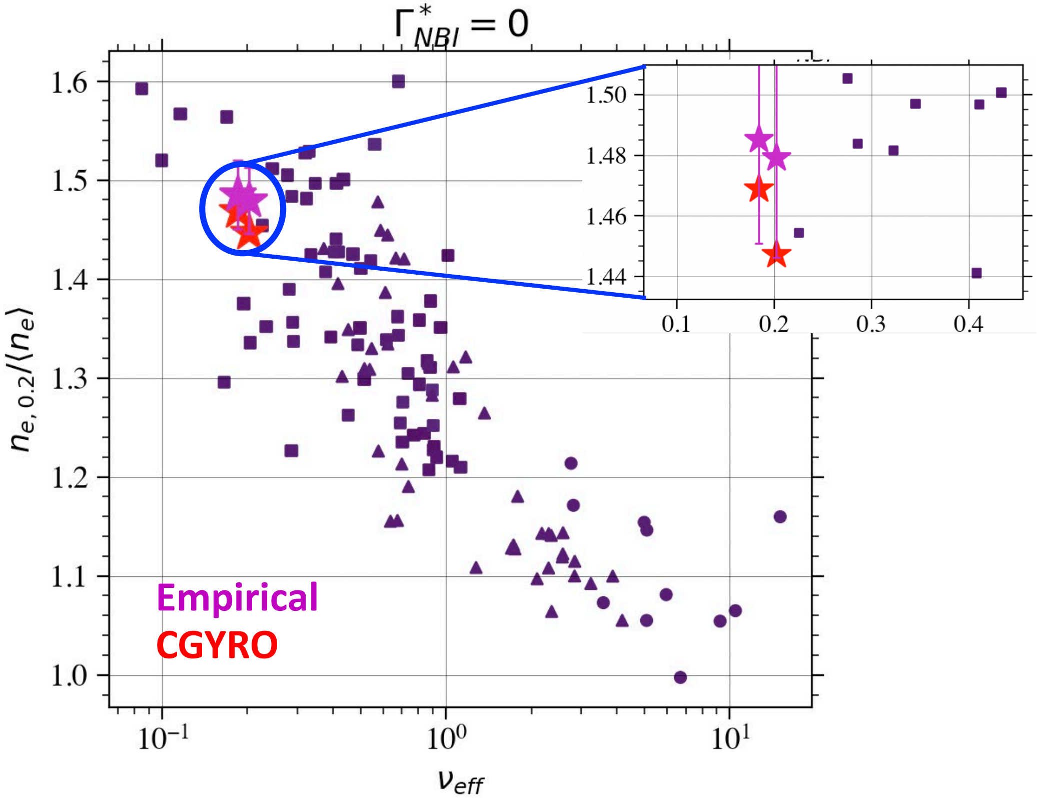
Toroidal magnetic field on axis	B_0	12.2	T
Major radius	R_0	1.85	m
Minor radius	a	0.57	m
Inverse aspect ratio	ϵ	0.31	
Elongation (separatrix)	κ_{sep}	1.97	
Triangularity (separatrix)	δ_{sep}	0.54	
Plasma current	I_p	8.70	MA
Safety Factor at 95% Flux Surface	q_{95}	3.4	
Pulse flattop length	$t_{flattop}$	10	s
Available coupled RF power	$P_{rf,coupled}$	25.0	MW



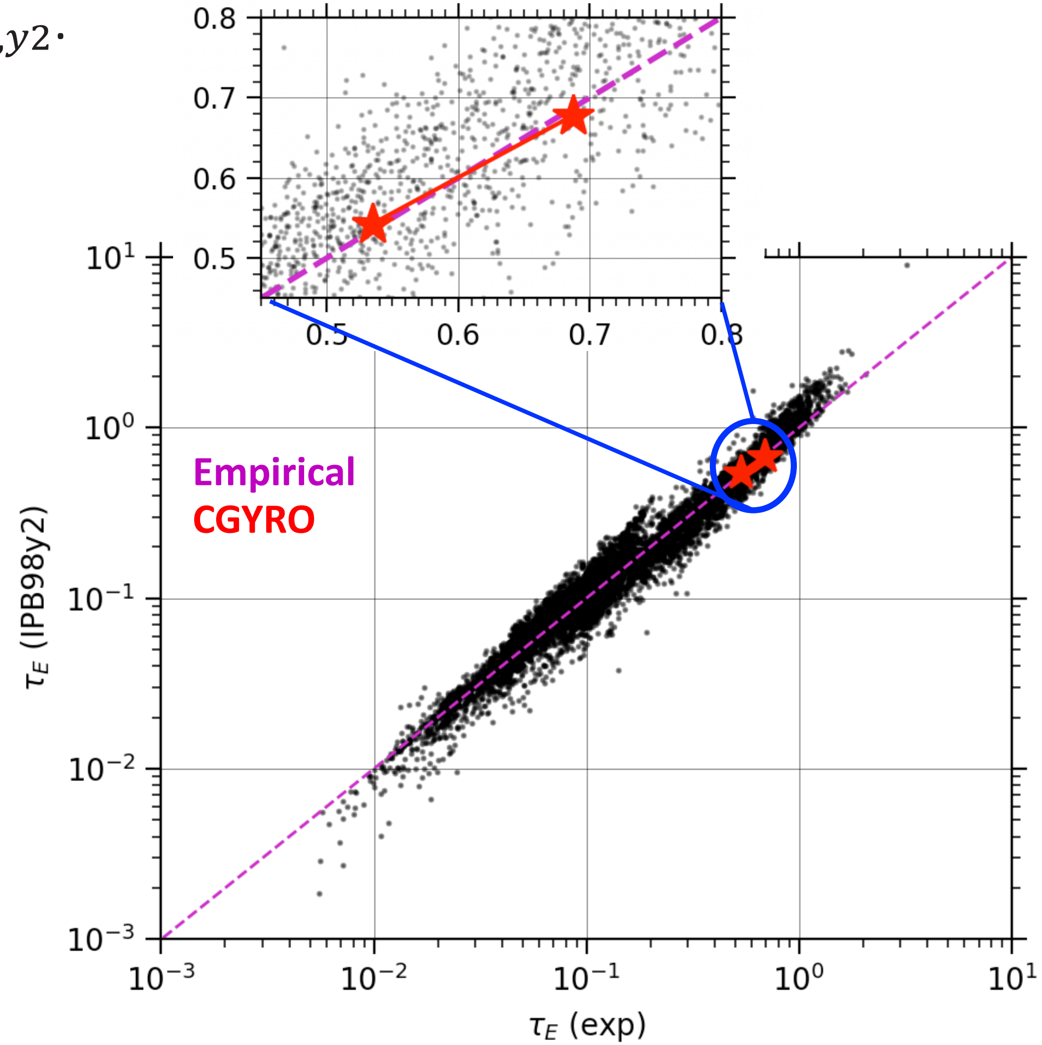
D. Brunner, et al., APS-DPP 2022 NO03.01

Global, empirical estimates and first-principles simulations agree

- Density peaking in **agreement** with scaling law for source-free plasma cores (*Angioni PoP 2007*). Trend with ν_{eff} captured.
- EPED + CGYRO yields confinement time in agreement with $\tau_{98,y2}$. Trend with P_{TOT} captured.



Experimental data from
Angioni PoP 2007, Greenwald NF 2007



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SPARC: First Plasma in 2025, Net Energy Soon After

SPARC site at Devens 45 minutes NW of Boston

- Large electrical power
- 40 acre site
- Licensed by MA as agreement state

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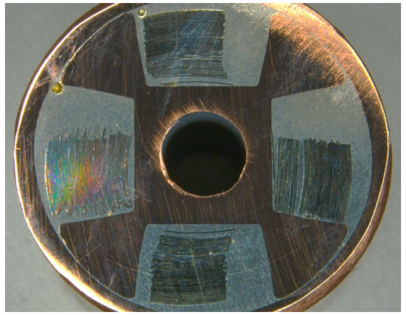
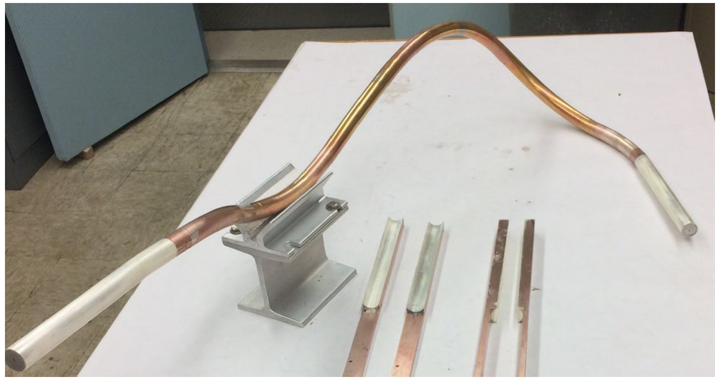
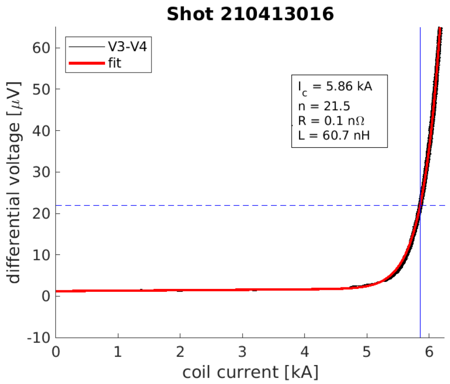
MIT PSFC

MIT PSFC, Univ. of Wisconsin, and Type One Energy have an ARPA-E grant to build a prototype stellarator coil using high temperature superconductor (HTS) and 3D metal printing.

- HTS allows for higher magnetic fields, should benefit stellarator performance just as much as in tokamaks
- HTS VIPER cable technology has been modified to successfully build non-planar coils with tight bend radii that are prototypical of optimized stellarators







This technology could be used by a private startup to build high-field optimized stellarators.

arpa·e awardee MIT PSFC WISCONSIN UNIVERSITY OF WISCONSIN-MADISON TYPE ONE ENERGY

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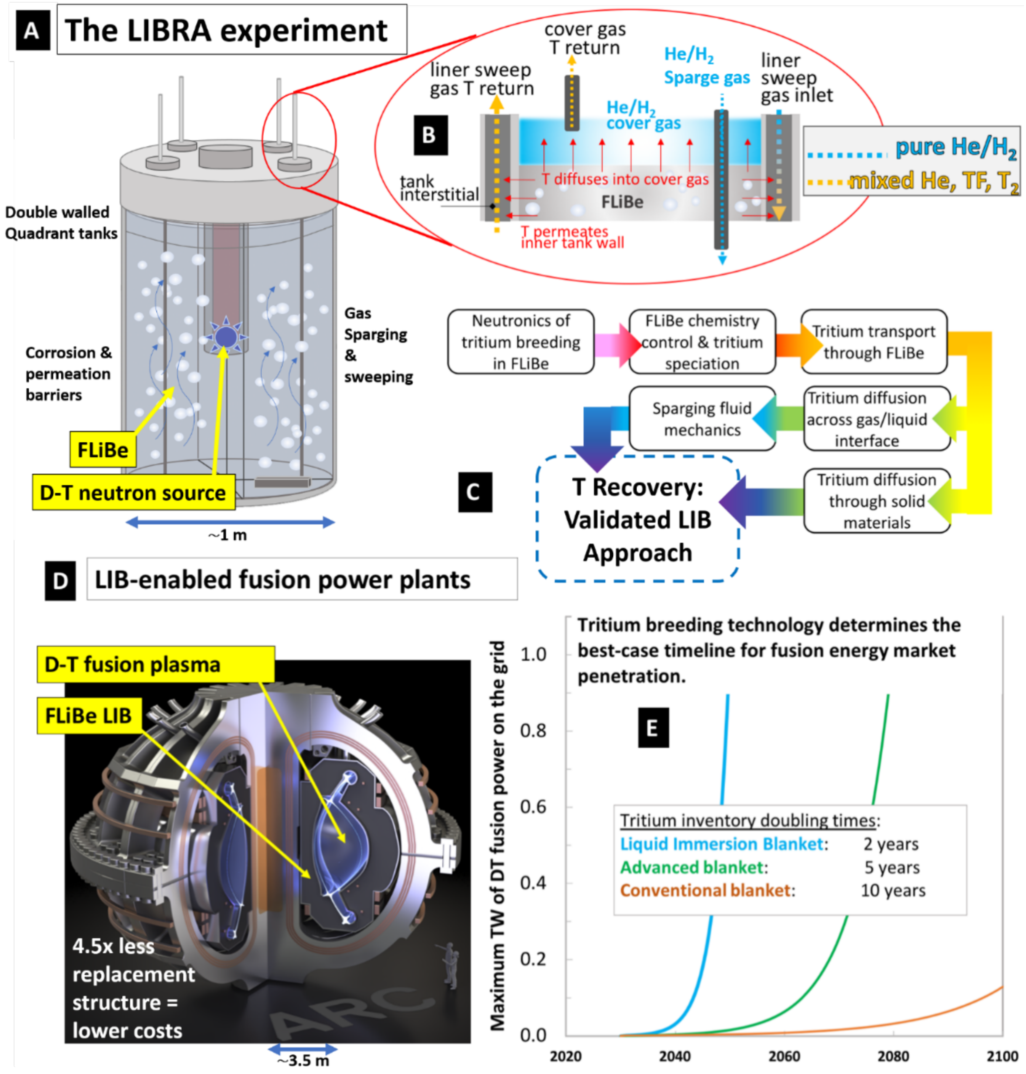
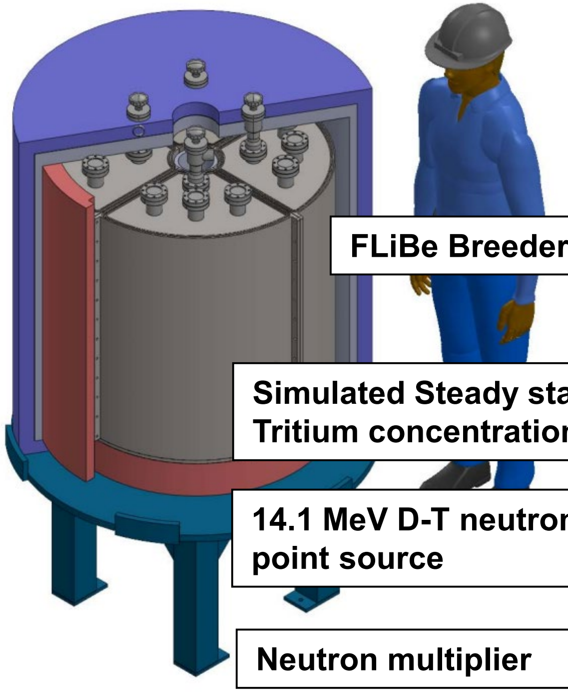
Liquid Immersion Blanket: Robust Accountancy (LIBRA)

Funded by DoE ARPA-E

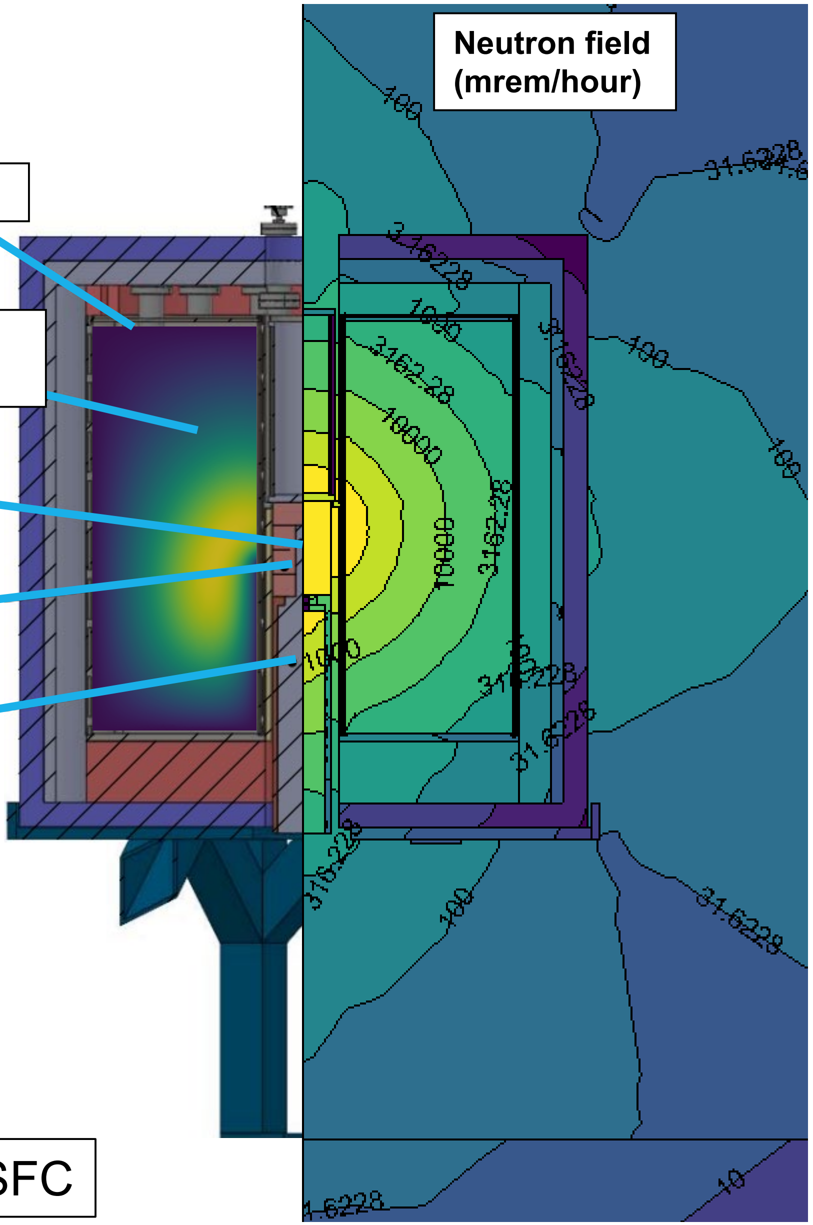


(A) Sectored LIBRA experiment validates T breeding and transport with 14 MeV D-T neutrons in FLiBe breeder for rapid analysis of radiochemical effects. **(B)** Insoluble and permeated T are extracted and collected by gas sparging and sweeping. **(C)** LIBRA integrates key physical/chemical phenomena relevant to T transport in the Liquid Immersion Blanket. **(D)** Tokamak example of Liquid Immersion Blanket lowers power plant costs due to increased lifetime components **(E)** High T breeding ratio (TBR) with short T doubling time enables global fusion power capacity for decarbonization.

Engineering CAD of FLiBe breeding experiment



Neutronics and tritium modeling of current LIBRA design



Technical Specifications

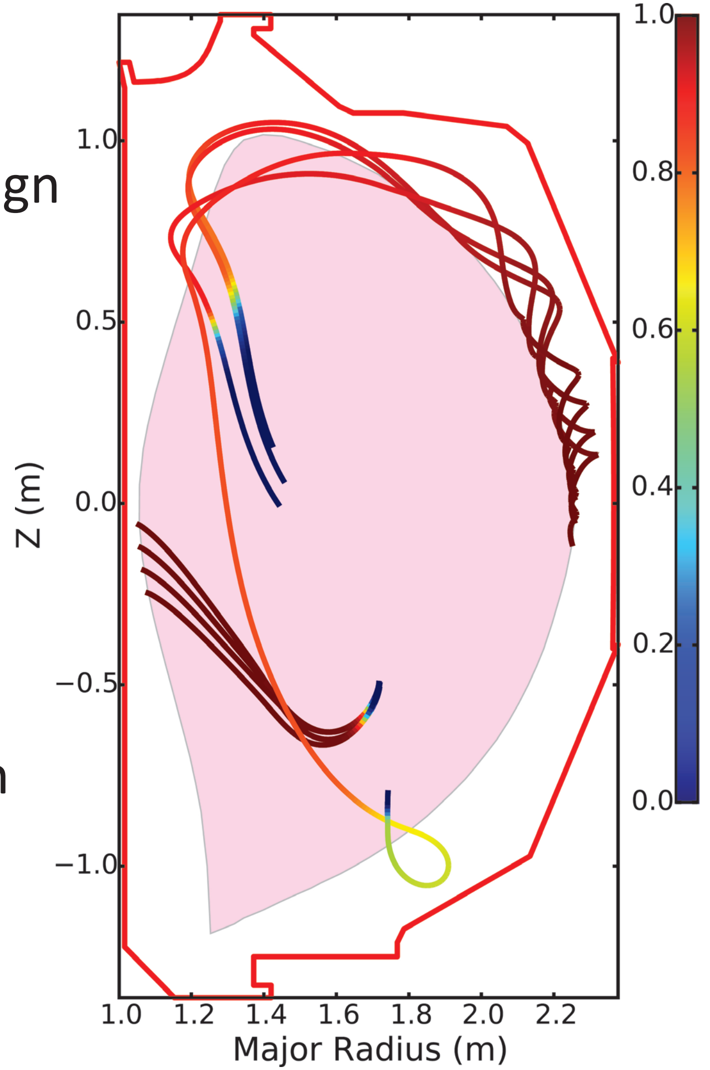
500-750 C
500 L of FLiBe
1E9-1E11 n/s
60 cm radius
1.7E5-1.5E7 Bq/day

Kevin Woller, MIT PSFC

Plasma Sustainment Challenge: Balance Physics Goals with Engineering Constraints

- **Efficient, robust current drive: key enabling technology for economical steady state tokamak**
  - Plug-to-plasma efficiency a major consideration for plant design (higher efficiency → smaller device).
  - Seek high efficiency, off axis-current drive that augments bootstrap current
  - Broad current profile simultaneously improves confinement and MHD stability
- **High Field Side Launch Lower Hybrid Current Drive**
  - Expect quiescent SOL without ELMs and weaker plasma material interaction that translates to improved coupling with longer coupler lifetime
  - High local B improves accessibility, penetration, I_p drive.
  - For reactors: minimize impact on tritium breeding.

Wave propagation in DIII-D AT discharge with $n_{||}$=2.8



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Scientific goals of this initiative: Retire HFS LHCD Physics Risks

MIT PSFC

- Demonstrate launcher and system technology with high system efficiency
  - Development of RF couplers with high directivity, high power density, and reliable coupling
  - CD/heating technologies with high system efficiency (~70%), high system availability and reliability, and continuous operation
- HFS LHCD experiments will begin on DIII-D in 2024
  - Investigate CD efficiency and location dependence on plasma and RF parameters
  - Validate LHCD simulations through comparison with measurements

Additive manufacturing enabled compact launcher with internal RF elements to improve coupling and meet stringent thermal and disruption requirements

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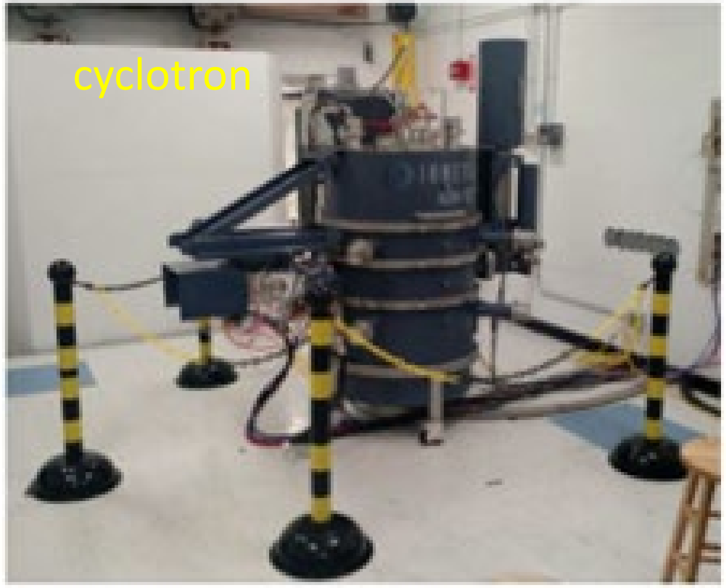
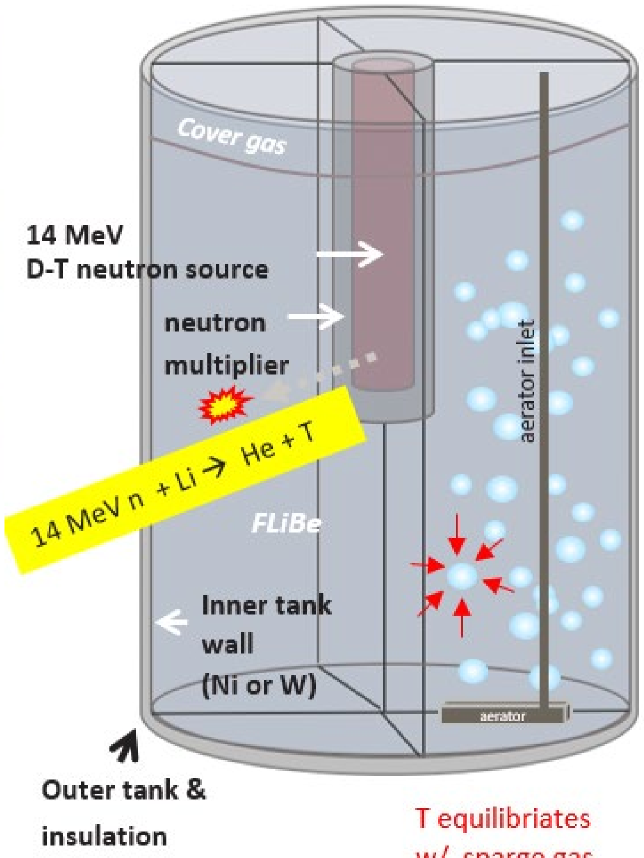
MIT PSFC plays vital role in growing the fusion eco-system

MIT



The MIT LIBRA experiment



Helping to educate the next generation of fusion scientists and engineers

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