Commonwealth Fusion Systems' High-Field Path to Fusion Energy

Commonwealth Fusion Systems

CFS is on a path to deliver commercial fusion energy

- Commonwealth Fusion Systems was founded in 2018
- Spun out of MIT with the goal of commercializing fusion energy to combat climate change
- Raised more than $2 billion
- Built a high caliber, diverse team from startups, industry, and academia
- >600 employees and >100 contractors

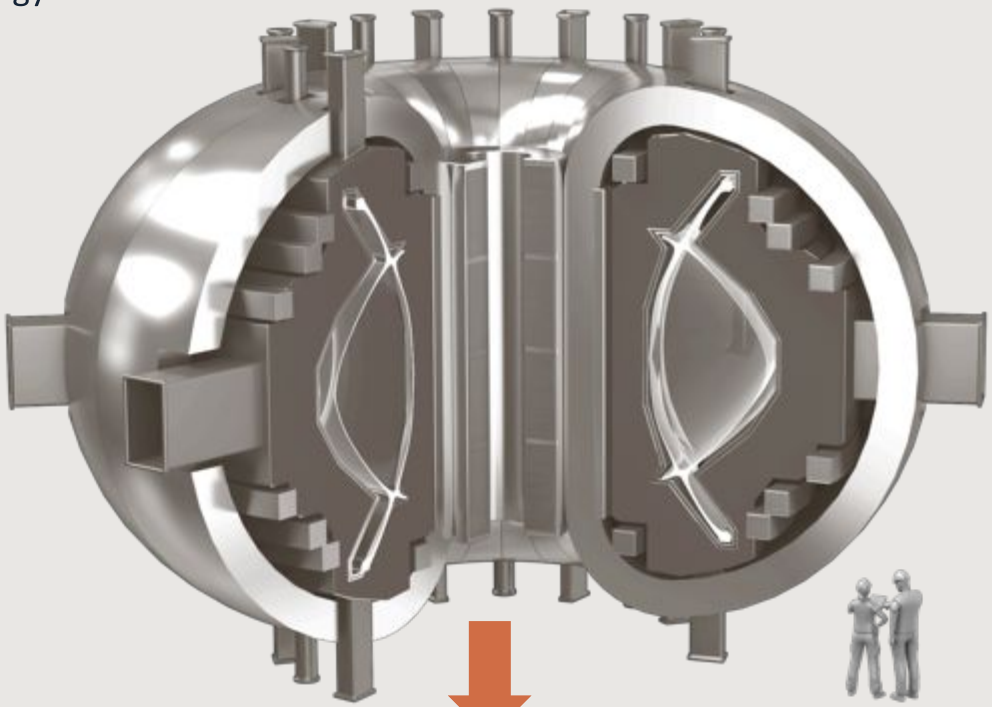
High-field tokamak path to fusion energy

Building on tokamak physics demonstrated in machines around the world

COMPLETED:
Demonstrate groundbreaking HTS magnets

CONSTRUCTION UNDERWAY for 2025 LAUNCH:
SPARC Q>1
Achieve net fusion energy

EARLY 2030s:
ARC deployed
~400 MWe



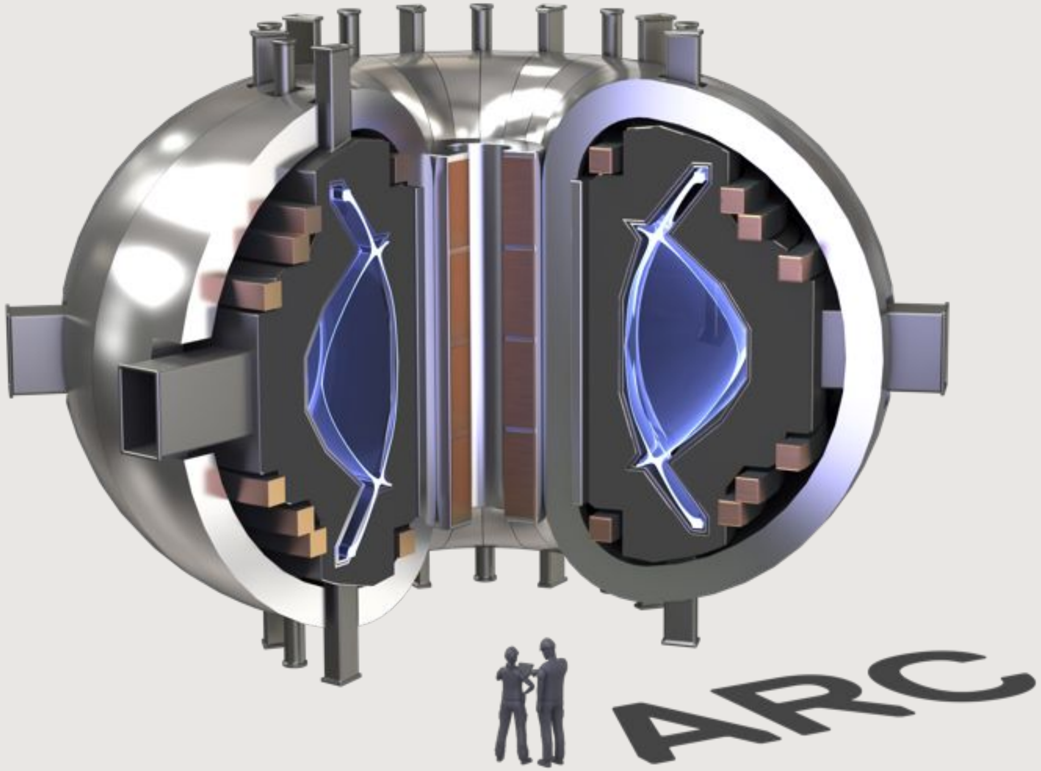
Commercially-relevant net fusion energy for the first time

Carbon-free commercial power on the grid

CFS' fusion pilot plant: ARC

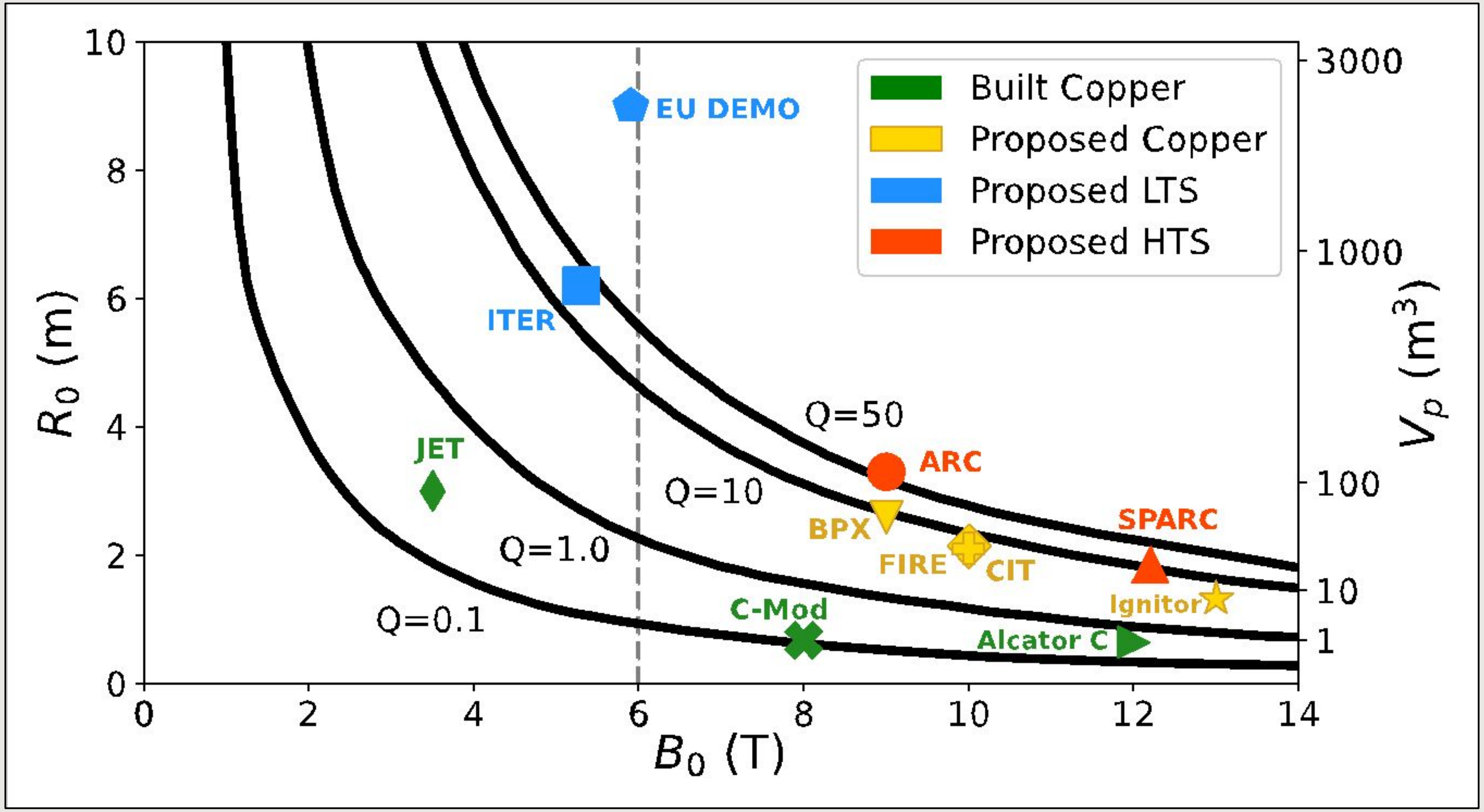
ARC is a high-field, standard aspect ratio tokamak

- High-field: B_0=11.5 T, I_p=10.1 MA
- Compact size: R_0=4.08 m, a=1.06 m
- Standard aspect ratio: R_0/a=3.85
- ICRF heated: <25 MW
- CS-pulsed: 15-minute flattop
- Conservative physics: $H_{98,y2}$=1.0, β_N=1.7, f_G=0.85
- High-power: Q=50, P_{fus}=1 GW, P_e=0.4 GW
- Tungsten first-wall
- Demountable HTS magnets
- Liquid immersion FLiBe molten salt blanket



High magnetic field enables smaller machines

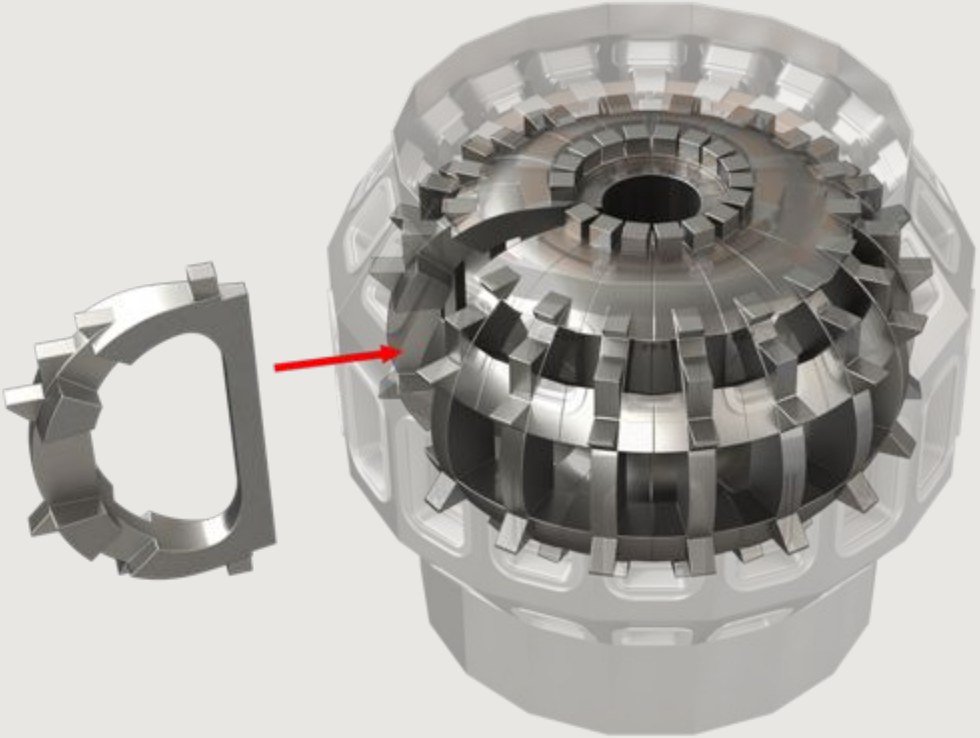
- 170+ tokamaks gives solid physics foundation for prediction of machine performance
- Field and size are major design levers for increasing Q
- Low-temperature superconductors were limited in magnetic field, result in large machines
- Copper was the only option to go to high field, with many high-Q machines designed, until now…



Other device data from [Parker et al. 1985, 1988; Hutchinson 1989; Neilson 1992; Coppi et al. 1999, 2001; Keilhacker et al. 2001; Meade 2002b; Shimada et al. 2007; Sorbom et al. 2015; Federici et al. 2018]

Fusion relevant high field magnets demonstrated

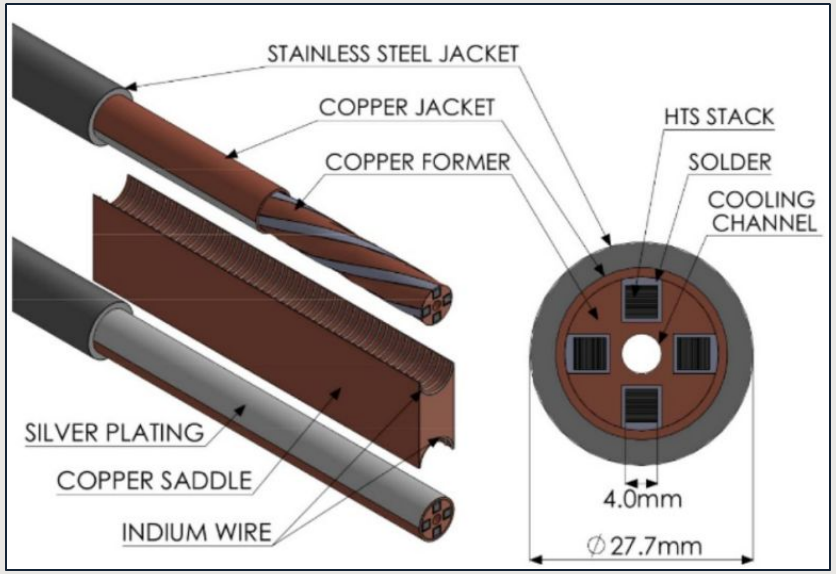
- In September 2021, CFS and MIT built and tested a full-performance, nearly full-scale, HTS fusion magnet
- It was designed and built it in 3 years, demonstrated 20.1 Tesla on coil
- Retired DC operational risks of “no-insulation” HTS magnets (manufacturing, stresses, E&M, cooling, etc.)
- **Destructively quenched to validate models, learned a lot, incorporating into SPARC TFs and Quench Model Coils**
- **Papers on tests publishing March 2024, IP protection in process on quench learnings**



See Z. Hartwig’s talk earlier this week.

Also developing high-field insulated HTS magnets

- Based on VIPER cable published in 2020 in Superconducting Science and Technology
- HTS monolithically soldered into copper former for improved thermal, electrical, and structural performance
- Tested in SULTAN to meet SPARC requirements
- 0.3% axial strain and >1,000 cyclic loads at 382 kN/m with <5% stable degradation after 30 cycles
- Novel use of insulation reduces AC heating losses by more than 20x
- **Testing qualification coils for full-scale Central Solenoid Model Coil, successful layer test this past summer, including quench detection (3% false positive, 0% false negative)**



Magnets enable SPARC: a compact, high-field tokamak designed to achieve net energy gain in DT plasmas

- Designed based on the same physics basis as ITER, but high field reduces size
- Initial operation aims for Q>1, but designed to achieve Q=11 and P_{fusion} = 140 MW
- Physics basis published in 2020 in the Journal of Plasma Physics
- SPARC is under construction now in Devens, MA

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Overview of the SPARC tokamak

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The SPARC tokamak is a critical next step towards commercial fusion energy. SPARC is designed as a high-field ($B_0 = 12.2$ T), compact ($R_0 = 1.85$ m, $a = 0.57$ m), superconducting, D-T tokamak with the goal of producing fusion gain $Q > 2$ from a magnetically confined fusion plasma for the first time. Currently under design, SPARC will continue the high-field path of the Alcator series of tokamaks, utilizing new magnets based on rare earth barium copper oxide high-temperature superconductors to achieve high performance in a compact device. The goal of $Q > 2$ is achievable with conservative physics assumptions ($H_{98,y2} = 0.7$) and, with the nominal assumption of $H_{98,y2} = 1$, SPARC is projected to attain $Q \approx 11$ and $P_{fusion} \approx 140$ MW. SPARC will therefore constitute a unique platform for burning plasma physics research with high density ($\langle n_e \rangle \approx 3 \times 10^{20}$ m^{-3}), high temperature ($\langle T_e \rangle \approx 7$ keV) and high power density

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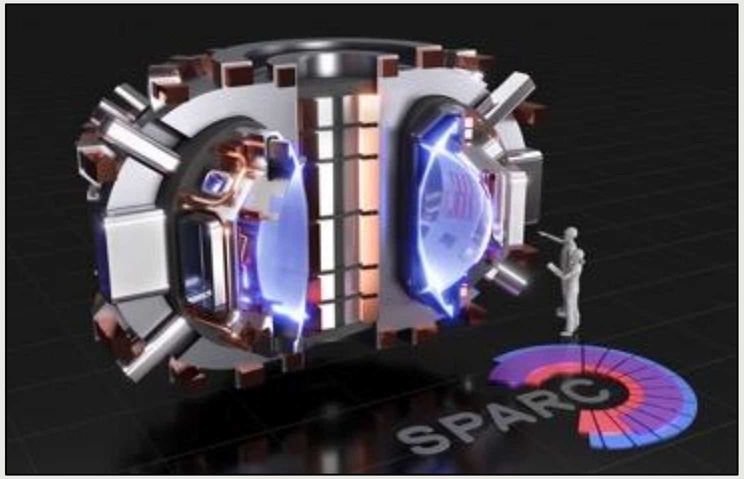
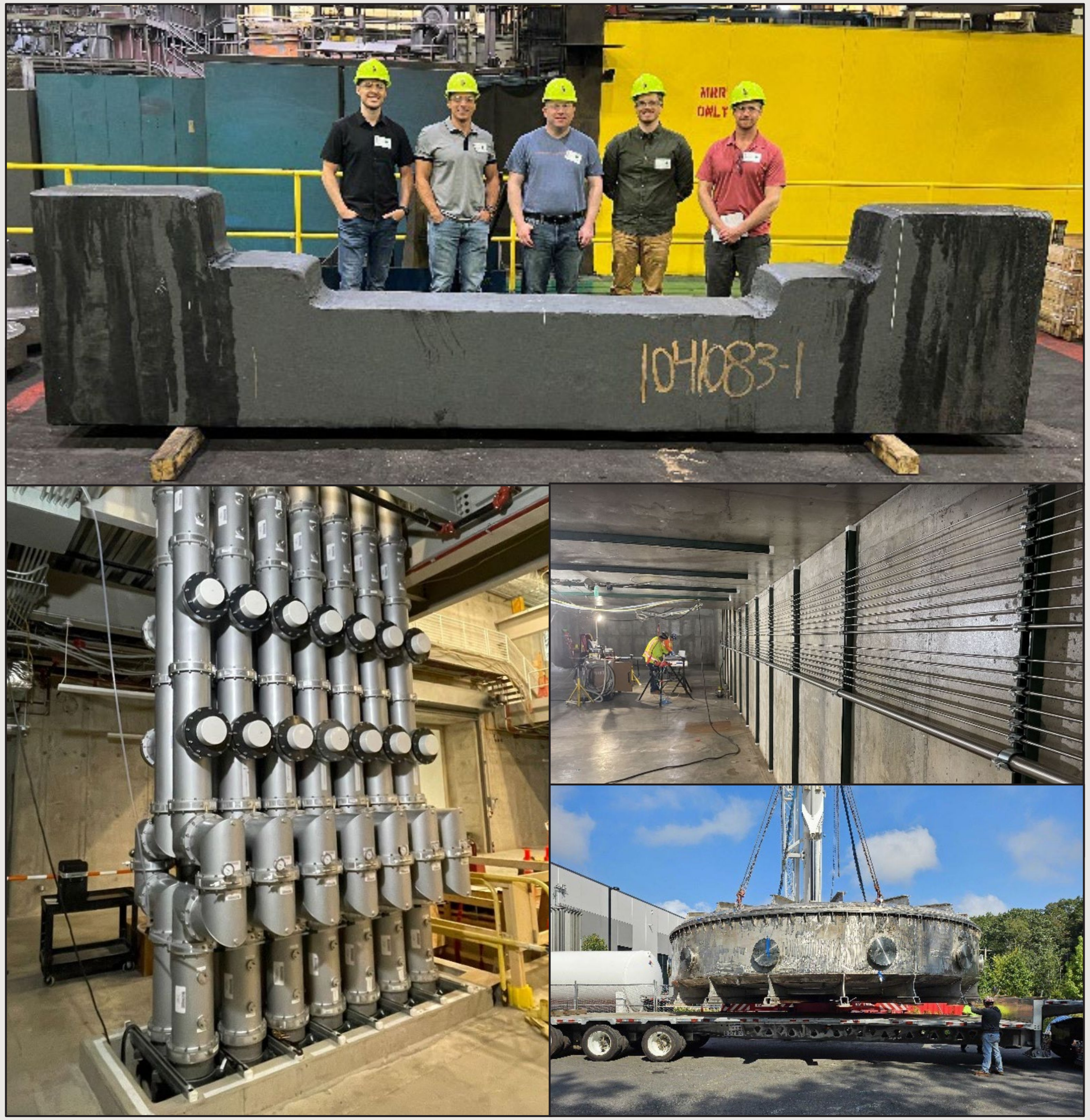


SPARC construction proceeding at a rapid pace from greenfield in 2.5 years ago to today:

SPARC manufacturing and procurement are in progress

- In house magnet production
  - All HTS is ordered, >40% on site now
  - First TF in production
  - HTS cabling line in final commissioning
  - All magnets are tested at temperature and current before SPARC installation

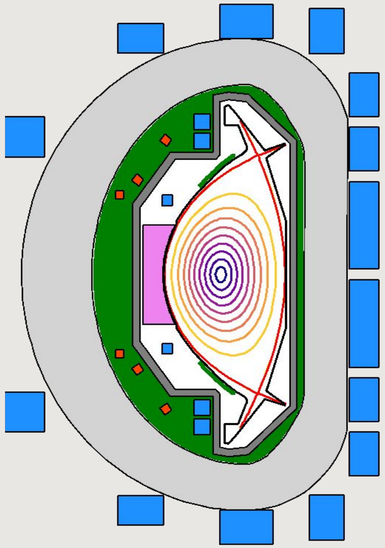
- Long lead procurements from vendors
  - >60% of all orders placed
  - Vacuum vessel, cryoplant, power supplies, plasma facing components, etc.
  - First systems arriving at SPARC now



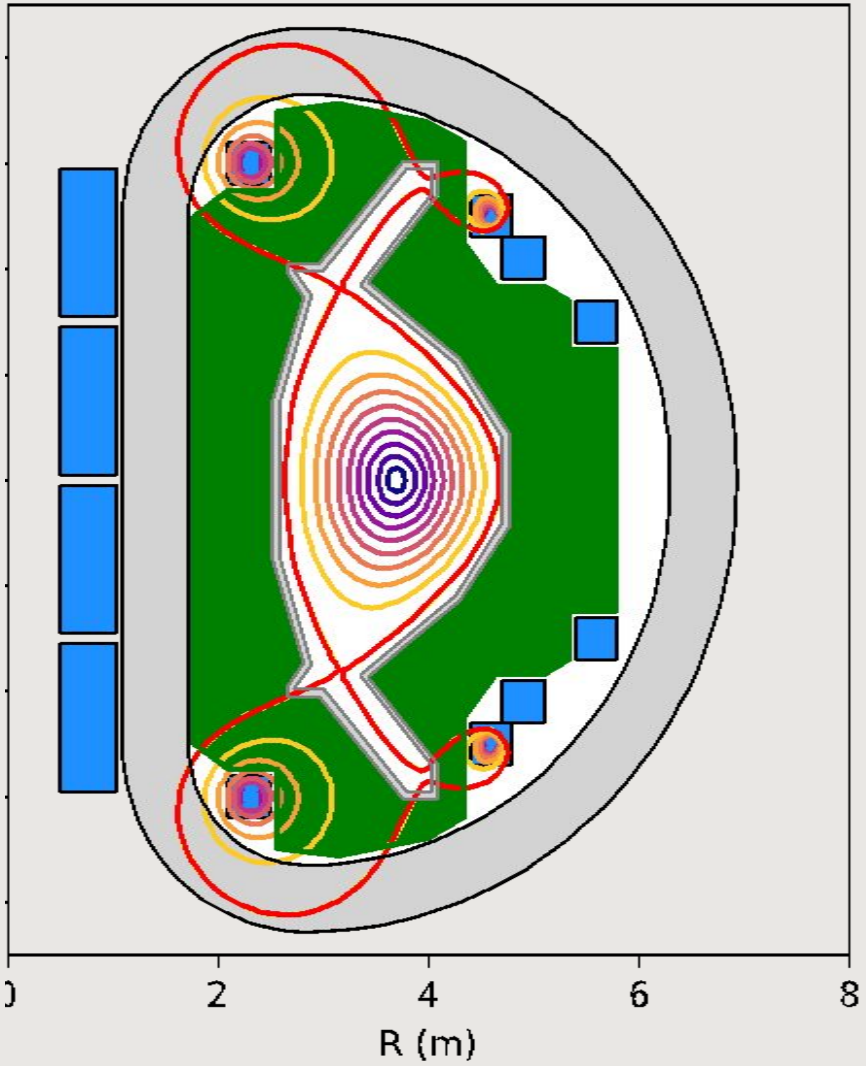
SPARC operation directly informs ARC design

- Molten salt blanket and demountable magnets enables ARC to be a flexible platform
- Try different vacuum vessel and plasma-facing component shapes and materials
- Design of ARC vacuum vessel and plasma-facing components can be held open until late in the process, wait on results from SPARC
- Input from core performance, core-edge-boundary integration, disruptions, and diagnostics/control

SPARC



ARC

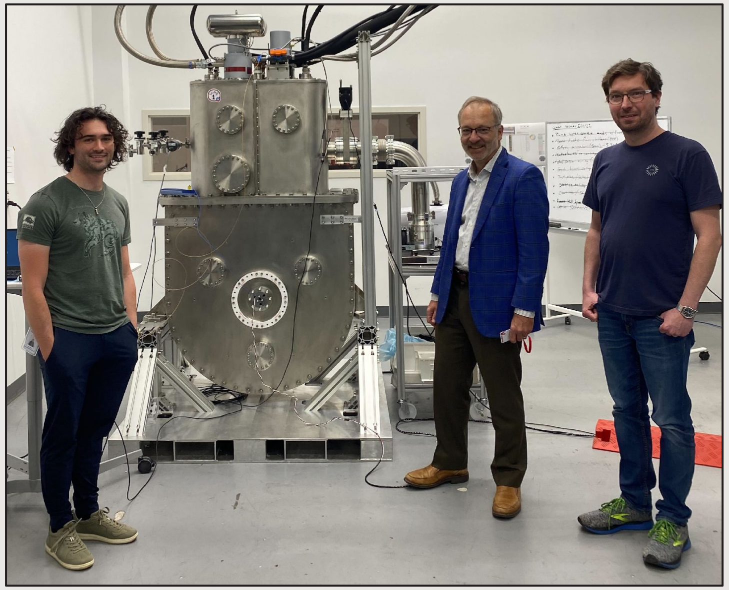


Ramping up design and R&D for ARC

- Much of the design of ARC is similar to SPARC, "hit the ground running" using the same team and tools developed on SPARC for ARC
- ARC magnets are being designed to the same rules as the magnets we're building for SPARC
  - HTS joints at the cable level demonstrated, need to scale to whole magnets
- Other major R&D areas
  - Fusion nuclear materials
  - FLiBe molten salt blanket
  - Tritium processing
  - Maintenance: Apply best-practices from other industries (aerospace, fission, etc.)
  - Diagnostics: Find solution space between what can be fielded in a fusion environment and what's needed for control

CFS is working with public programs on it's path to ARC

- Working on basic R&D goals to help inform CFS designs:
  - Plasma physics: disruptions, core-edge, energetic particles, divertor Diagnostics: neutron cameras, lifetime and survivability
  - Fusion nuclear materials: High-strength alloys
  - Tritium and blanket science and technologies: Breeding, separation
- CFS supports growing public-private partnerships
  - Grantee in existing and new US DOE public private partnerships, including Milestone program
  - Framework agreements with public institutions in UK and Europe, deepening relationships across entire development cycle
  - Advocate of commercially relevant (~10-year) timelines
- Providing direct R&D support with unique capabilities
  - CFS is designing, manufacturing HTS magnets for public-funded programs
  - Finding ways to support public research on SPARC



Magnetic mirror HTS coil designed, built by CFS for Realta Fusion under ARPA-E funding

Non-planar stellarator HTS coil prototype from Type One, MIT, CFS collaboration

Join CFS in our pursuit of fusion energy

Contact CFS’ Open Innovation team <oi@cfs.energy> to see how we can collaborate together

Or, with >60 open roles, apply to directly join our team: www.cfs.energy/careers