SPARC and the high-field path to commercial fusion energy

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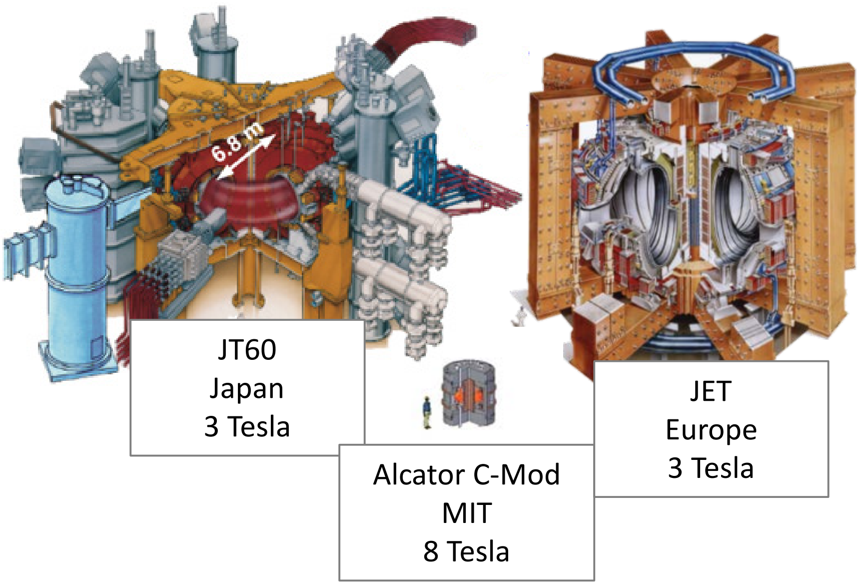
Feedback from the energy world:

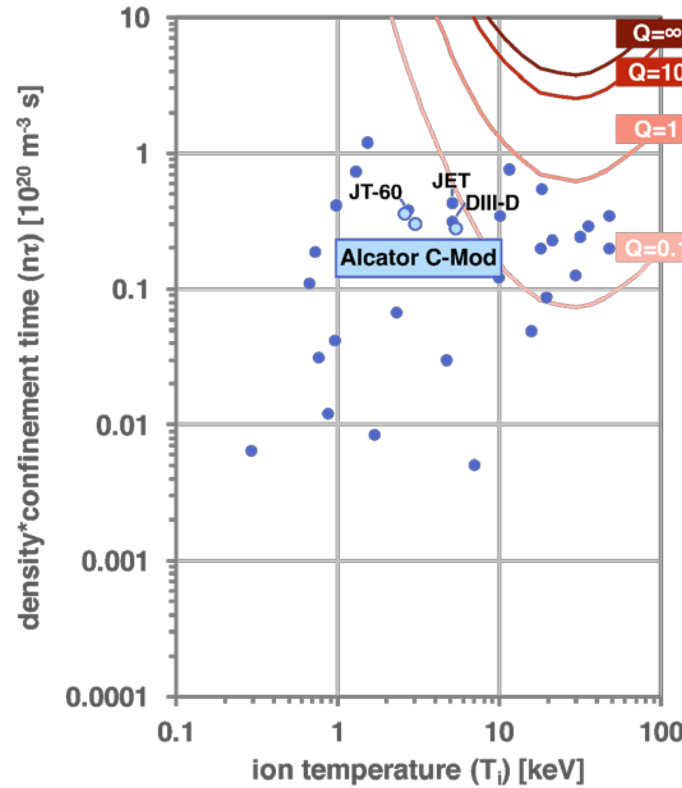
We have worked extensively with utilities, investors, energy companies, manufacturers around fusion. They are excited to participate in a commercialization effort.

What needs to be done:

- Show net-energy high power production ASAP
- In a package that scales to an economical and market-relevant power plant
- In a relevant timeframe
- With concrete risk retirement milestones

Compact high-performance tokamaks: Demonstrated high absolute performance in small package

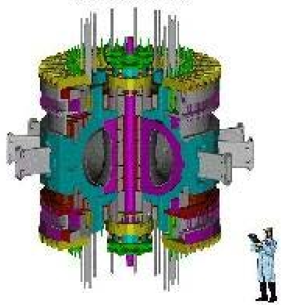




- C-Mod finished a successful 23 year career
- Extended physics basis for tokamak operation at high-field
- Data is still providing insights

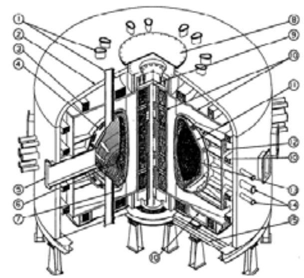
The road not taken: Compact, High-field, Copper

Ignitor



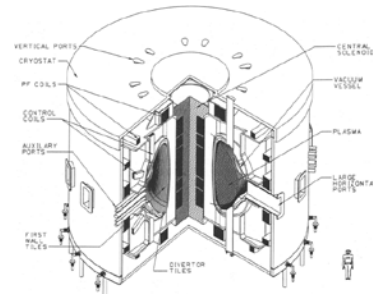
International study
~1985- present

CIT



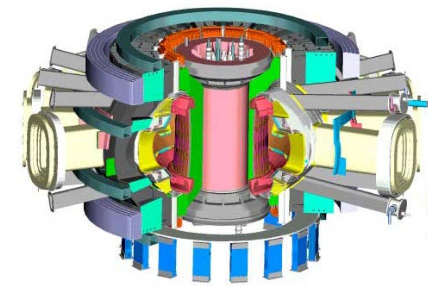
US study (MIT, Oak Ridge, PPPL)
~1985-1990
Alcator C-Mod was a prototype

BPX



US study (PPPL)
~1990- 1995
[Special issue, FST 21 3P1]

FIRE



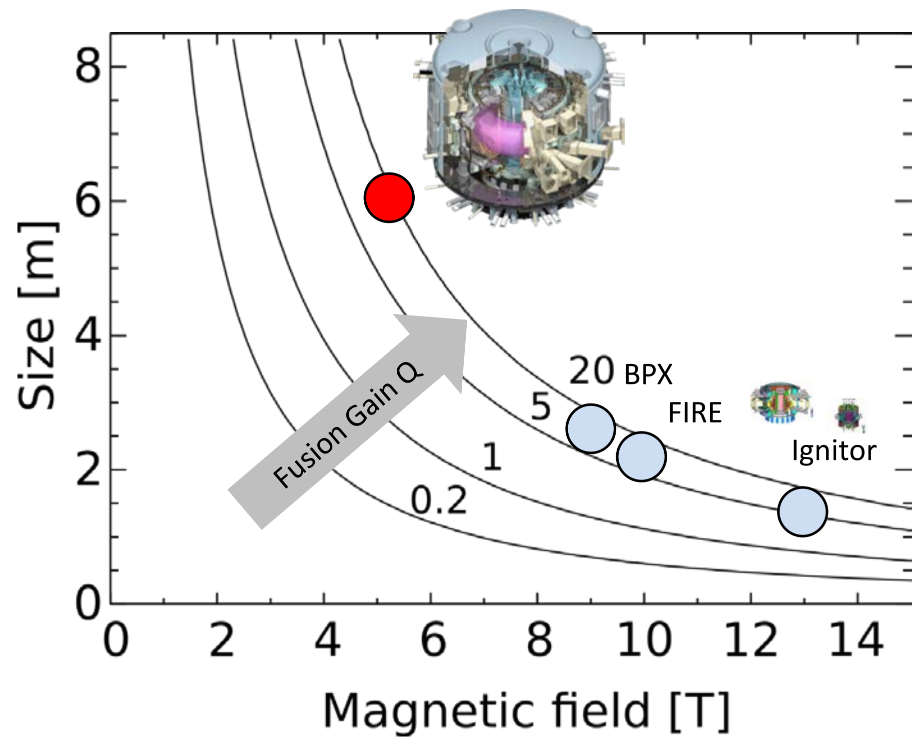
US study (MIT, PPPL)
~1998-2005
[Meade, D. "FIRE" Fusion engineering and design 63-64 (2002): 531-540.]

Device	B	R	a	Ip	Q	Pfus	Pulse	Pext
Ignitor	13T	1.3 m	0.4 m	11 MA	??		5 s	
CIT	10.4T	1.2 m	0.46 m	10 MA	5	530MW	3.8 s	
BPX	9T	2.6 m	0.8 m	11.8MA	5-25	100-500MW	10 s	20MW
FIRE	10T	2.14 m	0.595 m	7.7MA	10	100-200MW	20 s	20MW

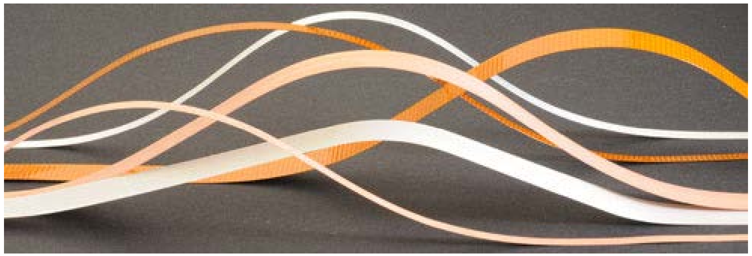
These high-field tokamaks were the main thrust of the U.S. Next Step Options

Had they been built: They would have burned

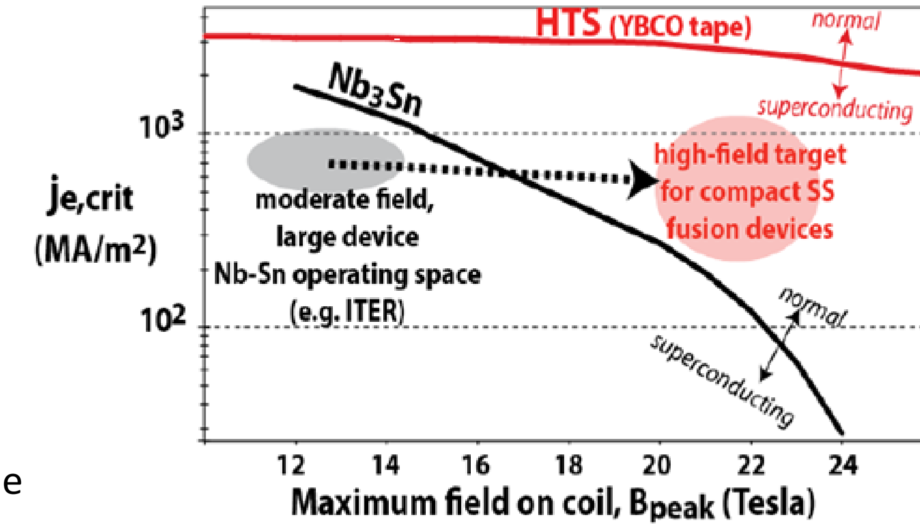
- Concepts validated by extensive review by FESAC, NAS, workshops.
- ITER was chosen and the U.S. program was down-selected.
- There were compelling reasons to go with ITER over FIRE and vice-versa.
- These copper machines would never scale to a power plant due to the magnet power consumption.



What has changed: High-field superconducting with HTS

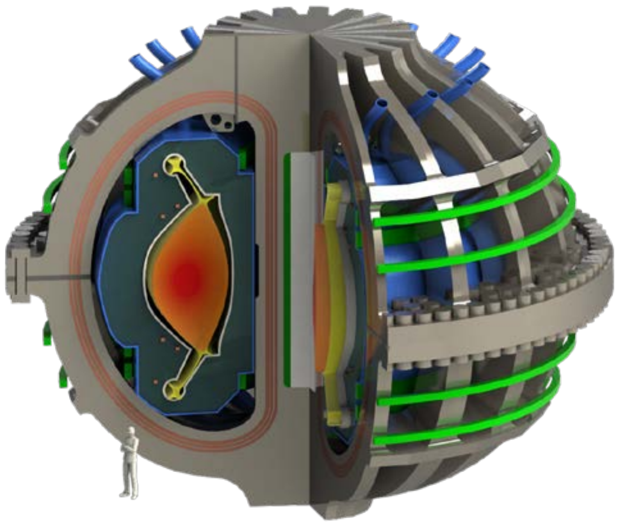


- High-temperature superconductors (HTS) are transformative [FESAC TEC report 2018]
  - Enable much higher magnetic fields
  - Higher current densities
- Only recently commercialized on a relevant scale
- Opens new options for power plants
- Commercially interesting on their own

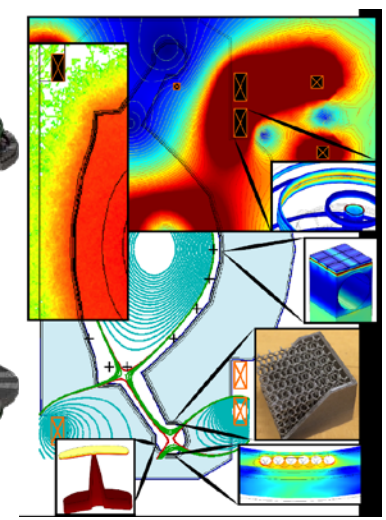


This is ambitious. A high-field large-bore HTS coil has not been demonstrated. Yet.

ARC: An innovative high-field power plant



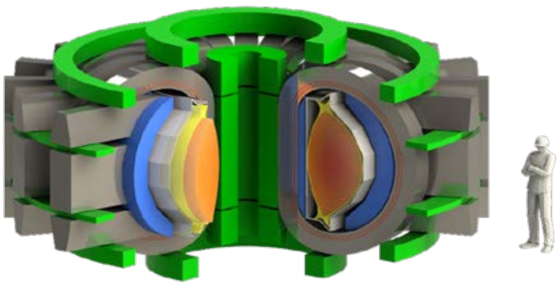
	ITER	ARC
R [m]	6.2	3.2
Magnet	LTS	HTS
B [T]	5.3	9.2
P_{fusion} [MW]	500	500
$P_{electric}$ [MW]	0	200



Recent publication explores heat exhaust and other issues [Kuang, FED 137 221-242, 2018] [Wigram Poster, Thurs PM]

This is at a scale and cost that is commercially interesting

SPARC: A fast-track HTS-based net-energy machine

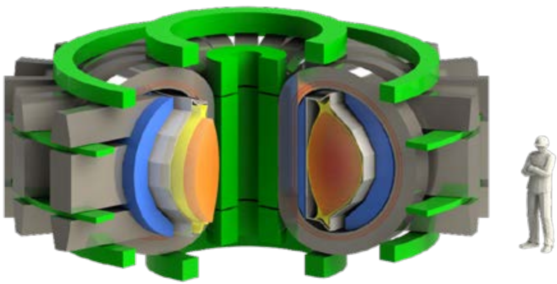


A net-energy device at the scale of DIII-D

Principles of program:

- Go fast
- Use established plasma physics
- Require no breakthroughs beyond magnet
- Leverage private experience in delivering programs
- Avoid mission scope creep

SPARC: A fast-track HTS-based net-energy machine



A net-energy device at the scale of DIII-D

R_0	1.65	m
a	0.5	m
ε	0.33	
κ	1.8	
B_0	12	T
I_P	7.5	MA
B_{max}	20.9	T
P_{fus}	50-100	MW
P_{ext}	30	MW

SPARC programmatic requirements:

- Demonstrate break-even fusion energy production
  - Should Q be higher?
- Demonstrate fusion-relevant HTS magnets at scale
- Demonstrate high-field fusion plasma scenarios for an ARC scale device

SPARC V0 technical requirements:

- Burn D-T fuel
- Q > 2 (with headroom)
- P_{fusion} > 50MW up to 100MW
- Pulsed with 10s flattop burn
- ~1,000 D-T pulses, >10,000 D-D pulses

A smaller, sooner machine offers physics advantages

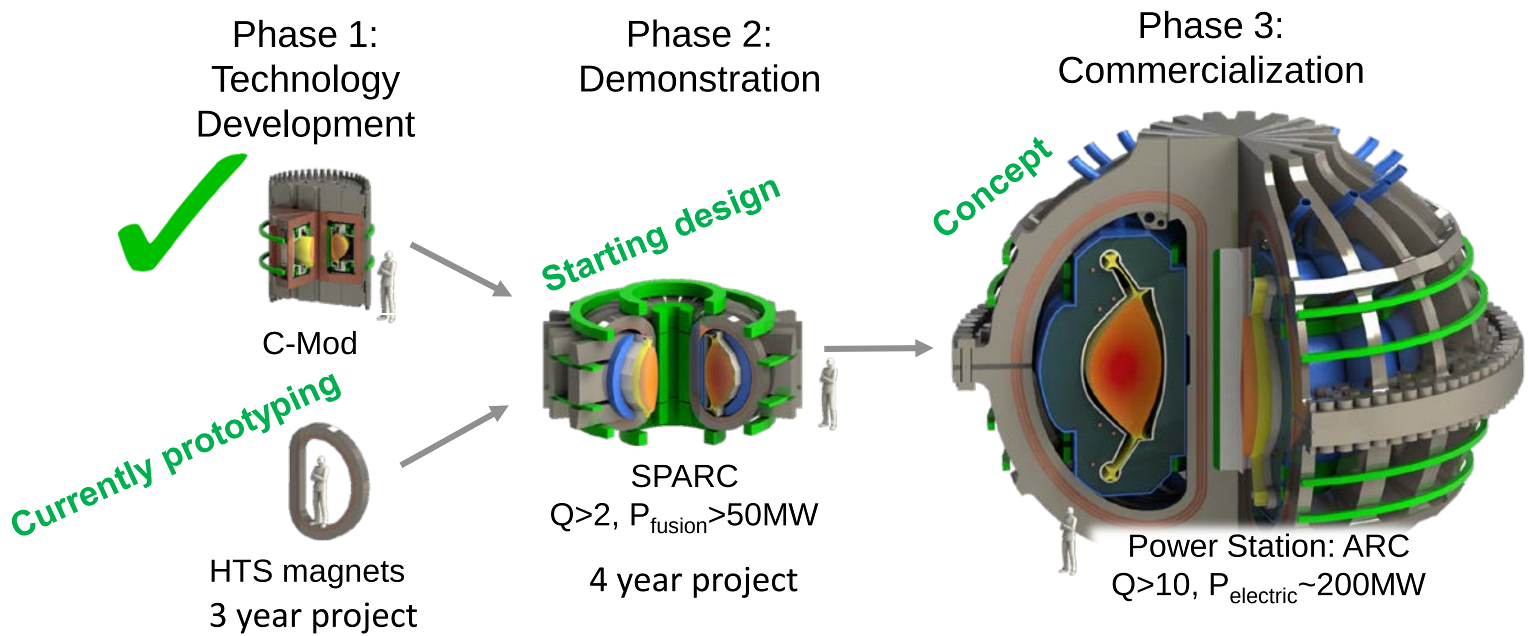
Design:	ITER: 5.3T, 6.2m	12T, 1.65m
Pulse length	400 s	10 s
Fusion power	500 MW	100 MW
Physics learning:		
Pulse length/Plasma equilibrium time	2	1.7
Pulse length/Energy confinement time	133	17
Pulse length/Helium confinement time	25	3
Engineering systems:		
Pulse length/Wall thermal equilibration time	40	0.5
Energy in/pulse	20 GJ	0.3 GJ
Energy out/pulse	220 GJ	1.3 GJ
Plasma thermal energy/surface area	0.5 MJ m^{-2}	0.4 MJ m^{-2}
Nuclear systems:		
Tritium burned/pulse	350 mg	1.8 mg
Gas throughput/pulse	1,500 Atm-l	2.7 Atm-l
10^{20} neutrons produced/pulse	730	3.5
10^{20} neutrons fluence/pulse	1 m^{-2}	0.08 m^{-2}

Access to similar physics

With orders of magnitude smaller engineering systems

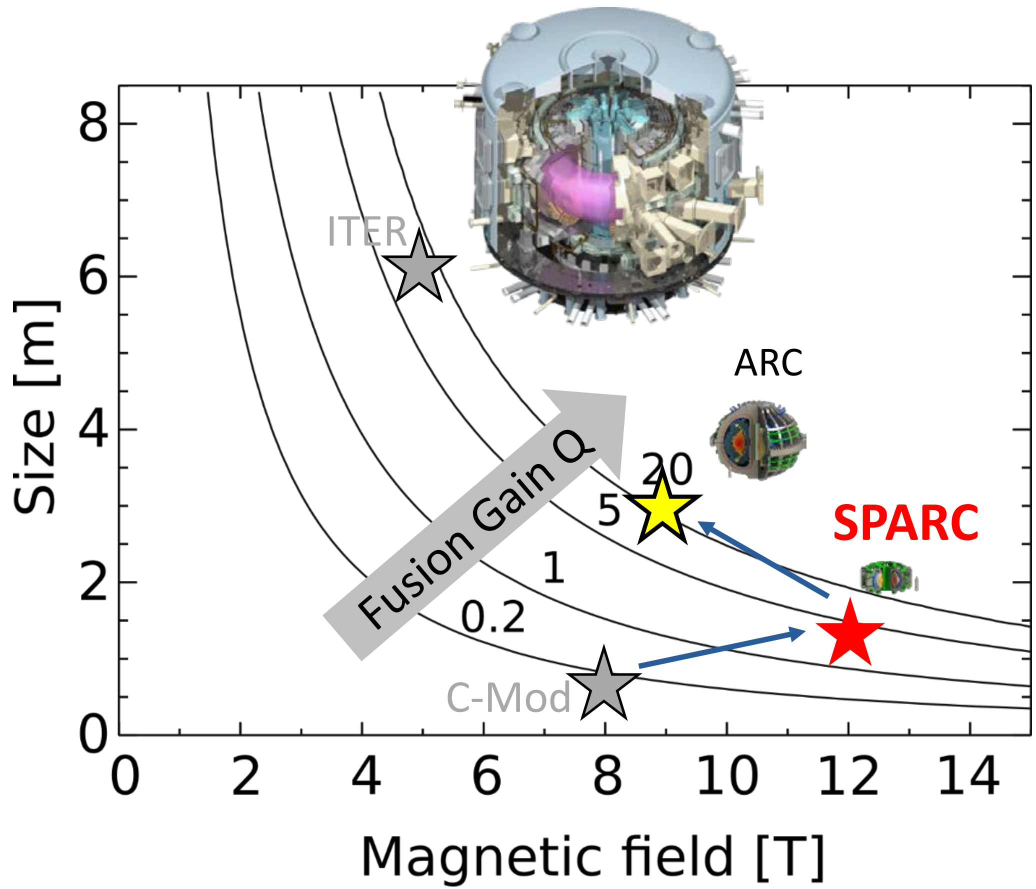
At orders of magnitude smaller nuclear impacts

The high-field approach to fusion energy



This path is backed by our investors. We are executing now.
More details: Marmar Poster Thurs pm

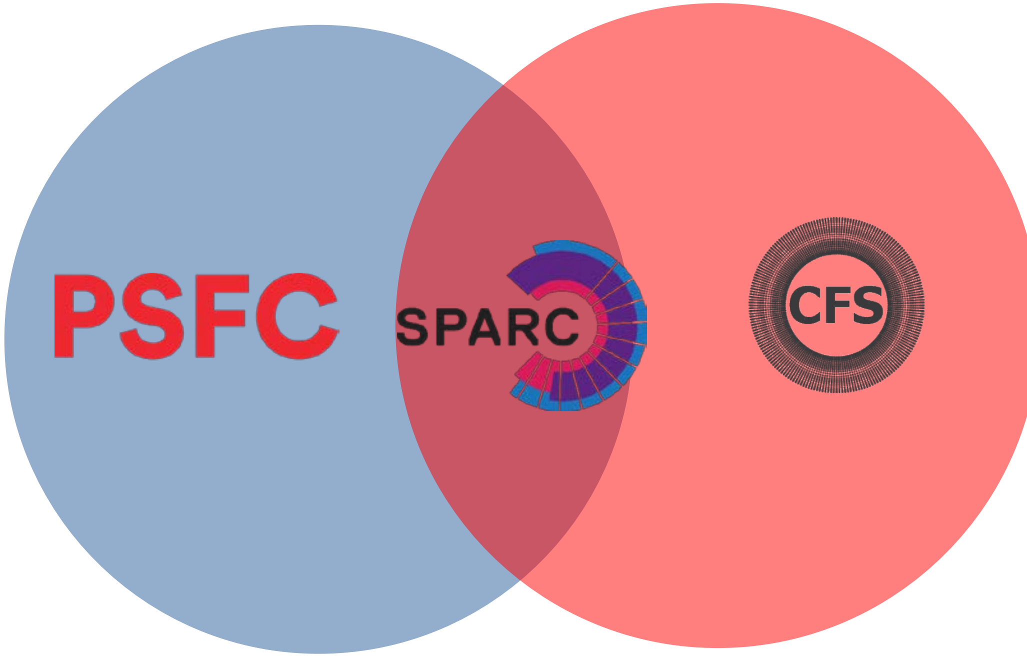
Opening a path to fusion risk-retirement



A new model for fusion commercialization

MIT PSFC remains an independent research establishment

Providing scientific and R&D to the joint project



CFS is a private company

Investor-backed with the aim of commercializing the high-field pathway

Investors are in it for the long haul with capital to see it through

Bringing the best of both worlds together:
The scientific underpinnings from tokamak research and the speed, capital and drive of the private sector

Our timeline motivates increased science efforts

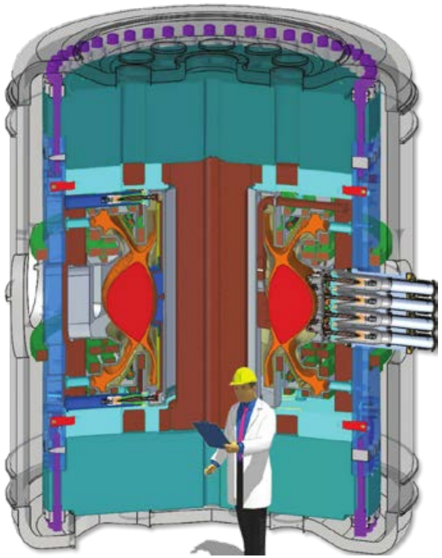
Not necessary for SPARC– but helpful for ARC:

- Advanced divertors for higher power handling
- First wall plasma material interactions
- Radiation tolerant materials
- Blankets and power conversion
- Tritium processing

These have long been identified as important

The U.S. program should do them

…. sooner rather than later



- A divertor test tokamak is desired, ADX is an example.
- Must be at relevant heat flux, geometry, and field.
- An opportunity for US leadership.

SPARC design underway– but more work to do

Open questions where help is desired to make SPARC successful

- Confinement predictions *[Greenwald, 2nd talk in session]*
- Heat exhaust – should SPARC do an advanced divertor? *[Whyte, 3rd talk]*
- ICRF heating *[Lin, 4th talk]*
- Neutronics *[Sorbom, 5th talk]*
- Alpha physics *[Tolman, 6th talk]*
- Pedestal *[Hughes, 7th talk]*
- Diagnostics *[White, Poster Thurs PM]*
- Disruptions *[Granetz, Poster Thurs PM]*

We're taking a collaborative approach

- Engaging with fusion community on SPARC physics
- SPARC physics basis will be published and available
- An opportunity to test our blind prediction capabilities
- Operating machine intended to be long-term science asset
- DOE FES establishing framework for broader community participation in program

Discussion at 5pm today in room C123 for those interested in collaborating

Questions?

More information:

Next 4 talks specifically on SPARC physics basis

Rest of this session on the high-field approach

Poster session on Thurs afternoon

Collaborators meeting Today at 5pm in Room C123

www.cfs.energy

www.psfc.mit.edu/research/topics/sparc

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