Development of the FIRE Mission

Response to NSO-PAC1

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NSO-PAC1 Issues for FIRE (Short Form)

Mission:

Make the mission more exciting and compelling

What are the generic requirements to address the mission?

- balance between BP and AT
- keep it affordable, balanced program (MFAC XIV, PCAST 95)

Are we scientifically ready to embark on a next step in MFES?

FIRE:

Will FIRE attain to BP conditions?

- margin, flexibility and physics capability

What AT physics could FIRE explore?

- regimes, margin, flexibility,

What is optimum configuration, min cost and operating plan?

NSO-PAC Recommendations on FIRE Mission

Recommendation R1-1: The Committee recommends that the FIRE project review its mission statement with the goal of strengthening and communicating the excitement of the science of self-heated fusion-dominated plasmas. The project should review other mission statements from the Office of Science in order to understand better how to articulate the depth of the science and the excitement of the science to the broader scientific community and to the public.

Recommendation R1-2: Although this sentiment was clear, a number of Committee members felt quite strongly that the FIRE facility should be capable of addressing Advanced Tokamak (AT) physics issues—both in the context that improved physics would enhance the ability to pursue self-heated fusion dominated plasmas, and also in the context that FIRE should, as much as possible, be able to explore the regimes that lead to an attractive reactor. (**Jardin/Kessel talks)**

Recommendation R1-6: The Committee recommends that the project clearly show the logic for how the mission statement leads to the design point. The size of the machine, the aspect ratio, the toroidal field, and other design considerations should be better explained on the basis of meeting the objectives of the device. In particular, the choice of aspect ratio and the size of the device should be further examined with respect to accessibility of physics regimes and the cost of the device. The PAC requests that the choice of the design point be further discussed at a future meeting. (**also Schultz talk**)

Steps from the Vision to FIRE

Vision (the public inspiration)
HEP, NASA

Mission (statement for broad physics community)

Scientific Objectives (workscope for the fusion/plasma community)

Plasma Parameters (needed to address objectives)

Device Parameters (needed to produce plasma parameters)

Project Cost must be affordable (if not reduce the mission)

Vision and Mission for a Major Next Step in Magnetic Fusion (1)

Visions from other Fields

- Connecting Quarks with the Cosmos:
  Eleven Science Questions for the New Century (HEP)

- NASA is an investment in America's Future - to boldly explore the frontiers.

- **Interactions,** a glossy 30 page handout for HEP, (look at HEP Snowmass)

- Mars Explorers

- Fusion - securing an energy for the future of mankind

(First, we need a strong vision statement for fusion.)

Vision and Mission for a Major Next Step in Magnetic Fusion (2)

FIRE Vision Statement (some suggestions)

- **Lighting the Fusion Fire**
- Lighting the Way to the Future
- Exploring, Explaining and Expanding the frontiers of plasma science

FIRE Mission Statement

"Attain, explore, understand and optimize ~~alpha~~ fusion-dominated plasmas to provide knowledge for the design of attractive MFE systems."

Fusion Science Objectives for a Major Next Step Experiment (e.g., FIRE)

- Explore and understand the physics of fusion-dominated plasmas:
    - Energy and particle transport (extend confinement predictability)
    - Macroscopic stability (β-limit, wall stabilization, NTMs)
    - Wave-particle interactions (fast alpha driven effects)
    - Plasma boundary (density limit, power and particle flow)
- Strong nonlinear coupling of previous issues, and self-heating(self-organization?)
- Test techniques to control and optimize fusion-dominated plasmas.
- Sustain fusion-dominated plasmas - high-power-density exhaust of plasma particles and energy, alpha ash exhaust, study effects of profile evolution due to alpha heating on macro stability, transport barriers and energetic particle modes.
- Explore and understand various advanced operating modes and configurations in fusion dominated plasmas to provide generic knowledge for fusion plasma science, and to provide a foundation for attractive fusion applications.

Dimensionless Parameters Required for Fusion Plasma Physics Experiment

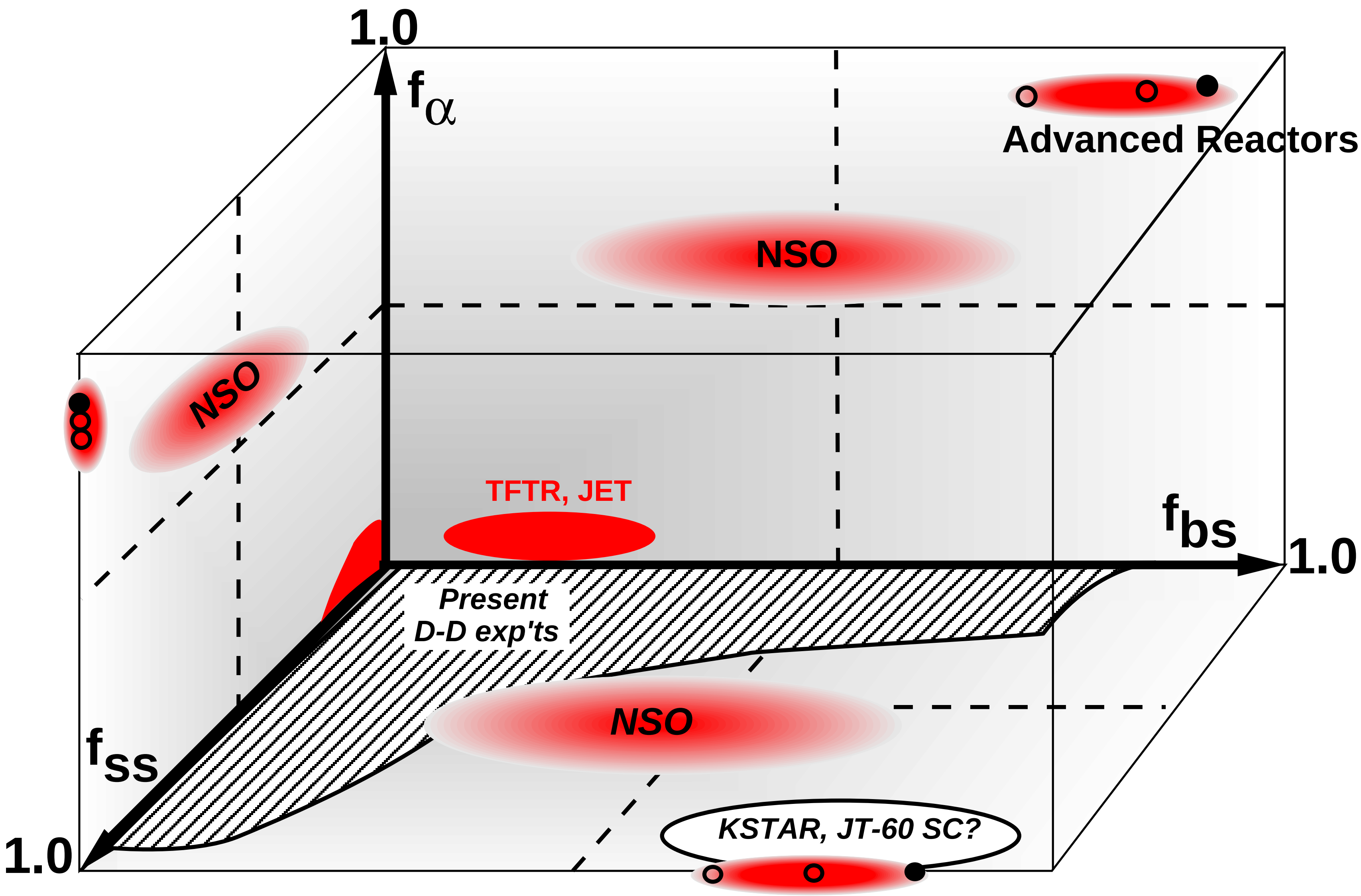
	Core*	Edge	Alpha	Duration			
	$BR^{5/4}$	?	P_α/P_{heat}	$\tau/\tau_{\alpha s}$	τ/τ_E	τ/τ_{He}	τ/τ_{CR}
Explore and Understand Fusion Plasmas	>0.5		>0.5	>3	>5	>3	>3
Energy and Particle Transport							
Macroscopic Stability							
Wave Particle (alpha heating, fast alpha)			β_α ~ ARIES				
Plasma Boundary		?					
Test Control and Optimization Techniques	>0.5		0.4 to 0.6		10	>3	1
Sustain Alpha Dominated Plasmas	>0.5				10		
Exhaust of power, particles and ash			0.4 to 0.6			3 to 5	
Profile evolution impact on τE, MHD			0.5 to 0.8				1.5 to 3
Explore and Understand Some AT Modes			0.5 to 0.8		>10	5	1.5 to 3
ARIES-AT	**1**		**0.9**	**>10**	**> 10**	**>10**	**> 10**
FIRE Goals	**0.6**		**0.5 to 0.8**	**>10**	**>10**	**>5**	**1.5 to 3**
JET/TFTR D-T Experiments	**0.3**		**0.04**	**~3**	**10**	**~2**	**<0.2**

* Core parameters are normalized to ARIES-AT $BR^{5/4}$

This is a start on this issue, a more detailed table is being developed for the meeting.

Requirements for a Next Step Burning Plasma Experiment

Note: these are the projections on to the 2-D planes.

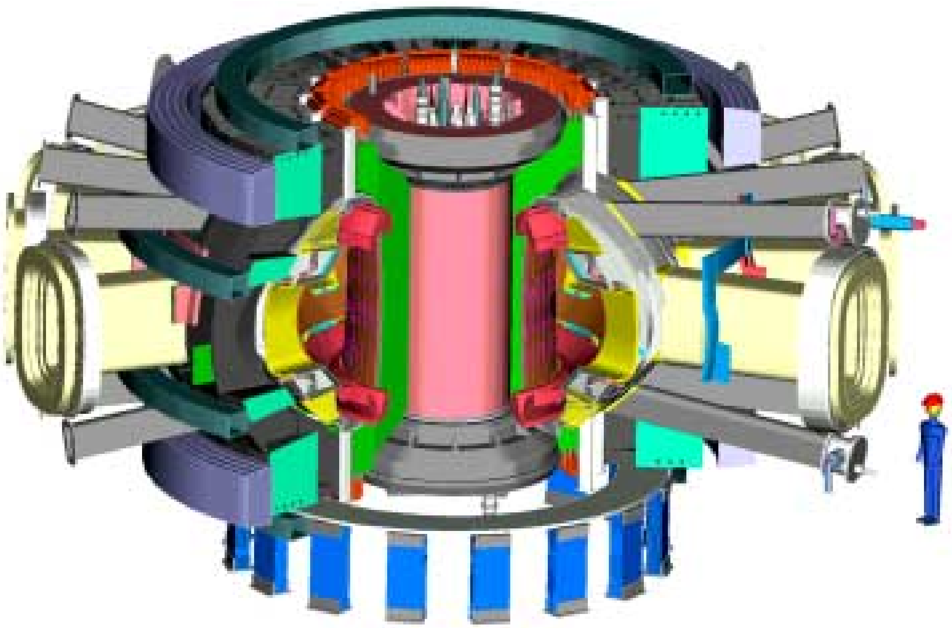


f_{ss} is the plasma current equilibration fraction

Fusion Ignition Research Experiment

(FIRE)

http://fire.pppl.gov



Cost goal drives one to the smallest size and constrained mission.

Design Goals

- **R = 2.0 m, a = 0.525 m**
- **B = 10 T, (12T)***
- **W_{mag}= 3.8 GJ, (5.5T)***
- **I_p = 6.5 MA, (7.7 MA)***
- **P_{alpha} > P_{aux}, P_{fusion} < 200 MW**
- **Burn Time ≈18.5s (≈12s)***
- **Tokamak Cost ≤ $0.3B**

  Base Project Cost ≤ $1B

* Higher Field Mode

Attain, explore, understand and optimize fusion-dominated plasmas that will provide knowledge for attractive MFE systems.

Plans (Ideas) for Vision and Mission Development

- Look for guidance from the UFA Burning Plasma Science Workshop Series
  - followup on action items
  - more active involvement of the community
- Respond to FESAC Burning Plasma Review
- Continue outreach activity ~ 30 talks in last 18 months, 1/3 non-fusion audiences
  - extend discussions and visits within the fusion community
  - actively participate/discuss with broader physical sciences community
    - Spring APS in Washington, DC, AAAS meetings, HEP Snowmass?
    - Accelerator laboratories - physics and enabling technology
    - High Field Magnet Community, NASA science and technology