FIRE Status and Plans

What is the Appropriate Effort in FY 2004/2005?

Dale M. Meade

for the National FIRE Study Team

NSO PAC 5 Meeting
General Atomics
San Diego, CA

February 27, 2003

http://fire.pppl.gov

Situation Analysis

- After the disaster of 1996, the community worked hard over the next 6 years to develop a consensus on how to move the fusion program forward. The specifics of this consensus strategy were founded on the commitments and recommendations made by Community Leaders, FESAC and OFES as a result of the Leesburg, Knoxville, Snowmass and Austin meetings.

- We all knew the future was uncertain, and that getting increased funding to implement the strategy was going to be a challenge. That is why we had a broad, technically based plan that would be robust to small changes in the overall budget.

- The present problem is not the President's FY 2004 budget, it is that the FY 2004 plan abandons the community consensus and strategy and does unnecessary damage to the program.

Some Guiding Principles for “Balancing” the Plan

- The restructured program and community consensus strategy are still the appropriate foundation for moving fusion forward.

- Don’t abandon the community consensus.

- Adjust the pace, fine tune the balance, maintain the general direction.

- Everyone contributes and everyone will benefit.

  We have scarce resources and can’t afford to lose skills

- The community must be involved in Balancing the Plan

NSO PAC 5 Charge

1. Has the FIRE team addressed the critical technical issues identified by the NSO PAC and Snowmass?

2. What technical issues need increased attention in preparation for the PVR? Which issues should be lower priority?

3. Given the likelihood of very limited fusion funding in FY 2004, what is the best approach for following the FESAC recommendations for maintaining the viability of a FIRE option as the ITER negotiations are pursued?

4. Should the vision for FIRE focus more strongly on AT? If so what would be an attractive goal?

Snowmass Issues and Opportunities

- Baseline physics, engineering and cost were found to be likely to achieve goals, feasible to construct and reasonable estimate.

Issues that were raised and areas for improvement included:

- AT pulse length and range, would like > several τ_{CR}, higher Q, β_N, f_{bs}
- LHCD for stabilizing NTMs not developed, other techniques?
- Power handling for elms, disruptions, even normal ops near limit
- Pulse repetition rate satisfactory for mission but lots of requests for faster
- Number pulses and total fusion energy (neutron) production OK for base mission but limiting ability to explore AT regime fully – TF insulator issue
- Integration of diagnostics with first wall design, and AT diagnostics

U.S. Fusion Vision and FIRE

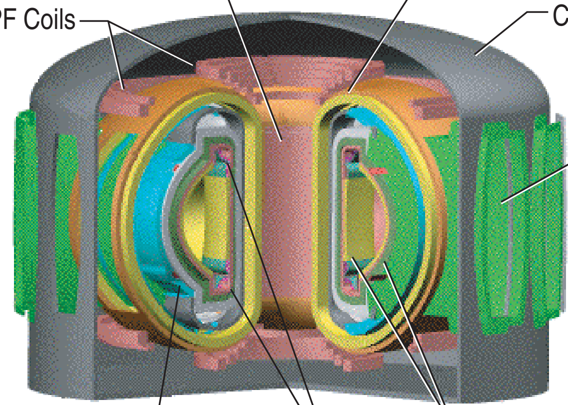
• The U.S. Fusion Community has a vision for the future –
  - it requires significant advances in physics and technology
  - the ARIES studies have identified the critical issues, and have quantified potential benefits
  - the U.S. fusion program (MFE, IFE) was aimed at resolving these issues to realize the potential of fusion

• The tokamak vision is exemplified by ARIES-RS/AT (ARIES figure)
  - The theme of FIRE (evolved from BPX-AT) has been to emphasize testing issues of relevance to the ARIES path
    – a stepping stone from today to ARIES-RS/AT.

• FIRE is needed as:
  -An attractive option for a next step burning plasma experiment
  As a driver to push ARIES advanced tokamak physics into BP regime
  As a vehicle to advance critical generic technology

A Decade of Power Plant Studies in the U.S. has led to an Attractive Vision for MFE

The U.S. ARIES — AT system study



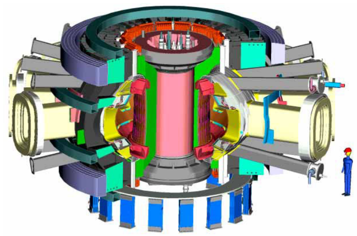
Economically Competitive - COE ~ 5¢/kWhr
Enviromentally Benign - Low Level Waste
Safety - No evacuation

- **Advanced Tokamak Physics Features**
  - High Power density $\beta_N \sim 5$
  - Steady-State $f_{BS} \sim 90\%$
  - Exhaust Power P/NR ~ 40 MW/m
- **Advanced Technology Features**
  - Hi Tc Superconductors
  - Neutron Resistant >150 dpa
  - Low Activation materials

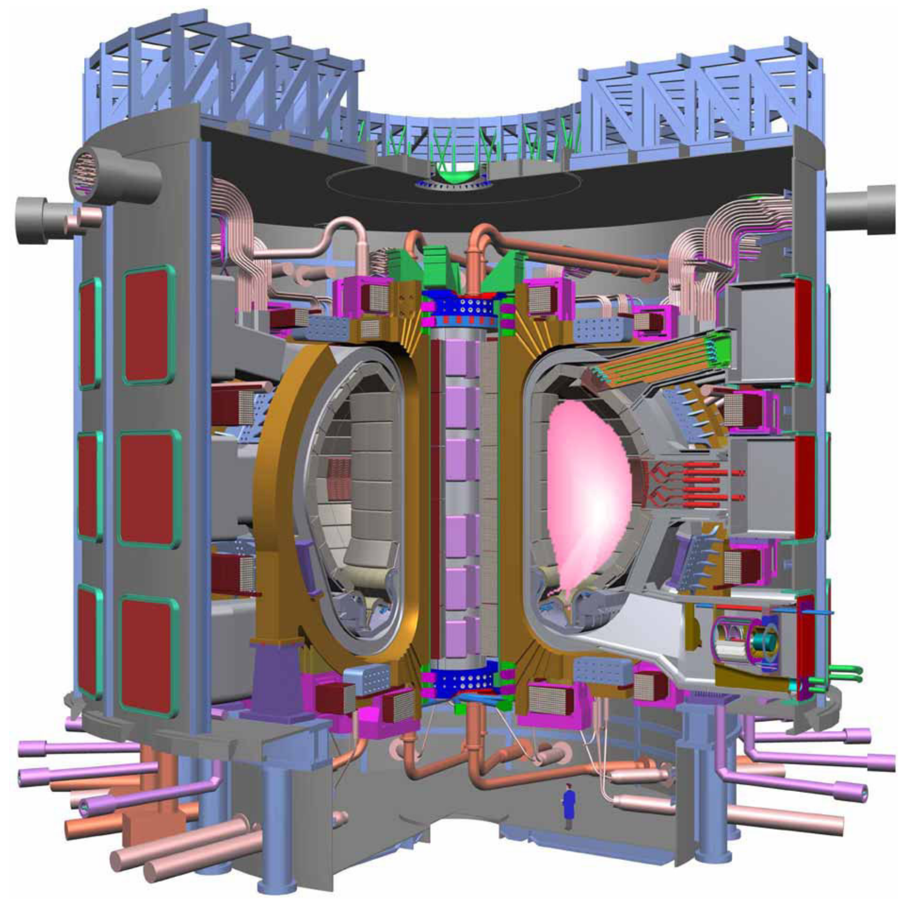
Major Advances in Physics and Technolgy are needed to achieve this goal.

ITER and FIRE are Each Attractive Options (FESAC)

Primary Burning Plasma Experiments (same scale)



FIRE ($ 1.2B - 1.4 ktonne)



ITER ($ 5B - 19 ktonne)

Conventional Operation

Q ~ 10 @ 86% J(r) equilibration
(FIRE and ITER)

Advanced Operation

Q ~ 5, f_{bs} ~ 80%, β_N ~ 4 @ 98% equil.
(FIRE)

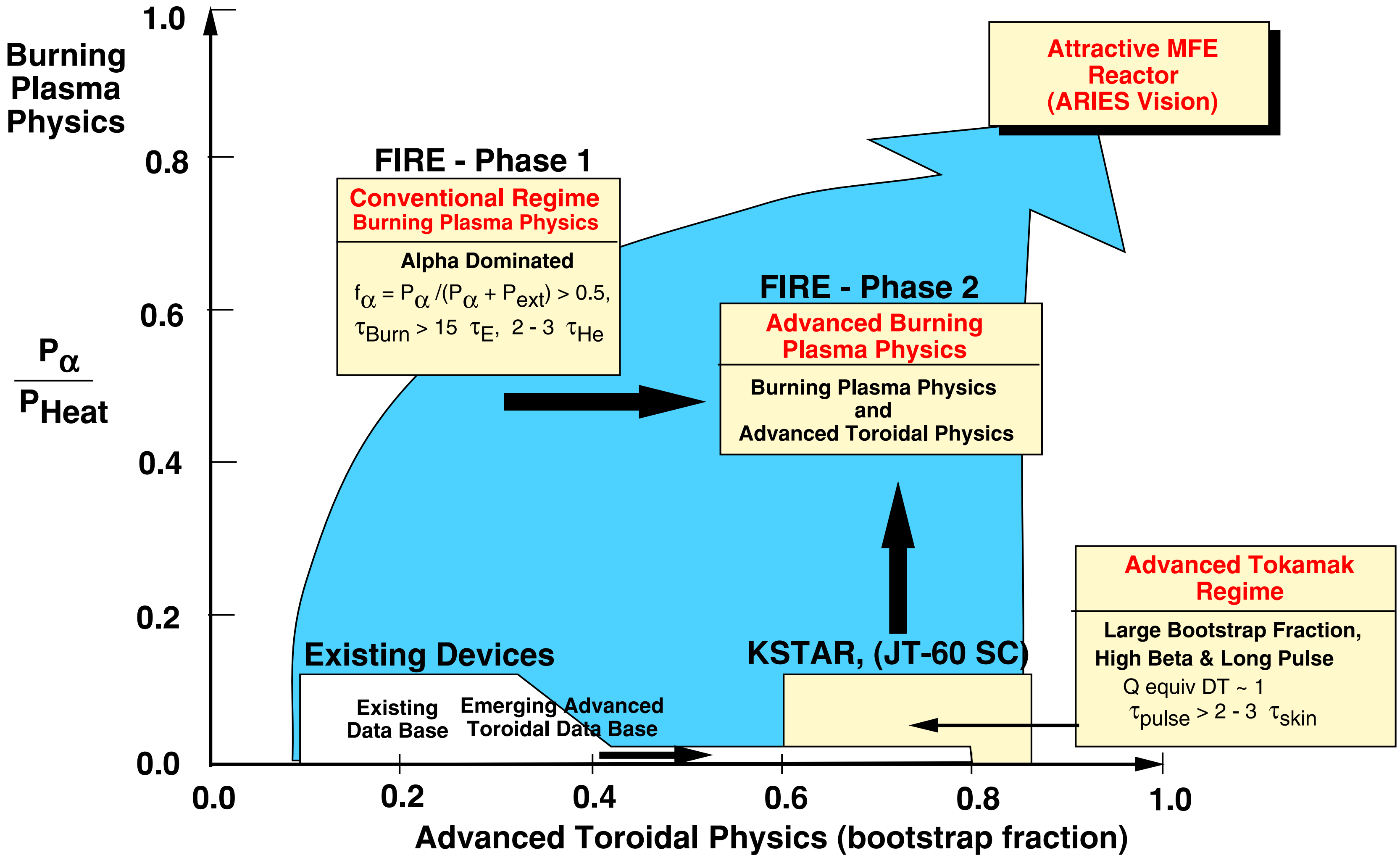
Q ~ 5, f_{bs} ~ 50%, β_N ~ 3 @ 99.9% equil.
(ITER)

A strategy that allows for the possibility of either burning plasma option is appropriate. (FESAC)

FIRE/ITER Would Test Advanced Physics for ARIES-RS

	ITER	FIRE	ARIES-RS
κ_x plasma elongation	1.85	2.0	2.0
δ_x plasma triangularity	0.49	0.7	0.7
Divertor Configuration	SN	DN	DN
β_N, normalized beta, AT	~3	~4	4.8
Bootstrap fraction, AT	50	80	88
B (T)	5.3	10	8
R (m)	6.2	2.14	5.5
Fusion Core Mass, tonne	19,000	1,400	13,000
Plasma Volume, m^2	840	27	350
P_{fusion}(MW)	400	150	2170
P_{fusion}/Vol (MW/m^3)	0.5	5.6	6.2
Neut Wall loading (MW/m^2)	0.57	2.7	4
P_{loss}/ R_x	20	20	100
Divertor Target material	C(W?)	W	W
$Q = P_{fus}/P_{ext}$ Conventional	10	10	n.a.
$Q = P_{fus}/P_{ext}$ Advanced Tok	5	5	27
Burn Time			
seconds	400 - 3,000	20 - 40	20,000,000
Current Profile Equilb,%	86 – 99.99	86 - 98	100

Staged Approach to Burning Plasma Operation
Conventional Mode then Advanced Mode.



- Should we optimize the FIRE Design for AT operation?
- Should we take credit for AT performance in the design?
- What would the impact be on the design?, When would we have data for design?

Should the FIRE Design be Based on the AT?

- H-Mode based reactor is unattractive, must use quite advanced AT

- An AT-Based FIRE at B= 6.5 T would have significant benefits.

  - TF coils could be OFHC- lower power, longer pulse, power supply cheaper

  - ECCD may now be feasible for NTM stabilization

  - ITER-like neutral beams could drive current at desired radius

- We should use anticipated delay in the decision process to make the FIRE design the best it be.

- What is a good target to shoot for? When will AT data be available?

Critical Items of Broad Interest (FIRE, ITER, ARIES)

- Plasma Facing Components (Divertor and First Wall)
  - high power density
  - long pulse capability
  - low tritium retention
  - elm erosion
  - disruption survivability
  - maintainability
- Vacuum Vessel (blanket modules and shielding port plugs)
  - low activation ?
  - nuclear heating ---- blanket module test assemblies
  - disruptions
  - integrate with closely coupled control and stabilization coils
  - integration with diagnostics
- Plasma Heating, Current Drive and Fueling
  - development/design of ICRF, LHCD systems for BP scenarios
  - interface with fusion environment (esp. launchers)
- Diagnostics Development and Design Integration
  - new diagnostics for J(r), E(r), fluctuations, alpha particles
  - integration with fusion environment(eg radiation induced conductivity)

FIRE Mission and Scope for FY 2004/2005

- Advance the design of FIRE as part of the FESAC Dual Path Strategy, and be prepared to initiate a conceptual design by the time of the U.S. decision on participation in ITER construction.

- Support both the ITER and FIRE paths of the FESAC Dual Path Strategy:

  - continue the development of advanced tokamak scenarios and advanced technologies needed for an attractive tokamak power plant in coordination with ARIES design activities.

  - address generic burning plasma R&D activities (e.g., PFC, disruption mitigation, plasma engineering, insulation development)

- Facilitate broad community involvement in the US burning plasma initiative

Preparation to Initiate a Conceptual Design

- Respond to technical input from: External Engineering Review, NSO-PAC and Snowmass Technical Assessment.
- Physics Validation Review (September 2003)
  - document followup to Snowmass Technical Assessment
  - identify R&D needed for a Conceptual Design
- Advance the PreConceptual design
  - Respond to PVR chits and recommendations
  - Extend “advanced capability” - physics and technology
  - address generic burning plasma R&D activities (e.g., PFC, disruption mitigation, plasma engineering, insulation development)

FY 2004 Activities

Proposed Budget: $1.91 M

Principal Milestone:

- Demonstrate feasibility of an ARIES-like AT Scenario for FIRE (and ITER)
  - RWM stability and feasibility analysis with compatible PFCs

September 2004

Other activities

- Optimize PFCs to extend performance of FIRE and ITER ⇒ ARIES
- Develop RWM technology (insulation, feedback control,..) for FIRE and ITER ⇒ ARIES
- Disruption Mitigation Development for FIRE and ITER ⇒ ARIES
- Plasma Engineering (ICRF, LHCD, Pellets, ..) with aim to FIRE and ITER ⇒ARIES
- Diagnostic Development for FIRE and ITER (AT Physics parameters)
- Collaborate with SCIDAC Fusion Plasma Simulator on BP simulations.

FY 2005 Activities

Proposed Budget: $1.91 M

Principal Milestone

- Join ITER Construction Projector or begin FIRE Conceptual design
- National Structure for US Burning Plasma Initiative in place

September 2005

(Note: ITER Construction Authorization scheduled for July 2005)

Other Activities

- Demonstrate a viable disruption mitigation technique suitable for FIRE or ITER ⇒ ARIES-RS
- Demonstrate a PFC configuration design with suitable heat loads and tritium inventory for FIRE or ITER ⇒ ARIES-RS
- Plasma Engineering (ICRF, LHCD, Pellets, ..) with aim to FIRE or ITER ⇒ ARIES
- Diagnostic Development for Burning Plasmas

Major ITER Milestones

Date of Schedule Presentation	Oct 2001	Feb 2002
Preferred ITER Site	Jul 02	May 03
Cost Sharing Agreement		May 03
Joint Implementing Agreement	Sep 02	Jul 03
ITER Legal Entity	Jul 03	Dec 03
ITER Construction Authorization	**Jul 05**	**Jul 05**
Construction License (EDA Report)		Jul 08
Start of ITER Operations (Cadarache site Proposal- Sep 2002)		Jan 2015
Start of DT Operations (after 3 years of H/D operation)		Jan 2018

Summary

- FIRE is responding to input from the community: NSO-PAC, Snowmass, etc.
- Good progress has been made in expanding the operating space for advanced tokamak operation, esp. normalized pulse length. Improvements in β_N and f_{BS} have also been made with potential for more. Key issue is feasibility of close coupled RWM coils which is high priority for PVR.
- Optimization of the configuration for the R = 2.14m case is in progress and is yielding benefits- 3x faster pulse rate, ~ 35% lower power densities due to nuclear heating and first wall than the previous standard case.
- The divertor configuration has been modified for R = 2.14 m. Power handling in the divertor is being reanalyzed for the new configuration. A full reanalysis of disruptions can't be done with present resources- previous results to be scaled. Working with existing experiments on elm behaviour etc for DN/SN.
- Our goal is to respond to the key questions by the time of the PVR.
- Future work proposes concentration on development of AT based design for FIRE with joint FIRE/ITER work on generic issues.