"I want some fusion soon"

FIRE

Creating and Controlling a Burning Plasma

in the Laboratory

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for the National FIRE Study Team

AES, ANL, Boeing, Columbia U., CTD, GA, GIT, LLNL, INEEL, MIT, ORNL, PPPL, SNL, SRS, UCLA, UCSD, UIIC, UWisc

PPPL

May 21, 2003

http://fire.pppl.gov

FIRE *Lighting the Way to Fusion*

Outline

- Burning Plasma Issues, Metrics and Status
- Status of Burning Plasma Reviews and Governmental Actions
- Status and progress on FIRE
- Plans for Burning Plasma Activities

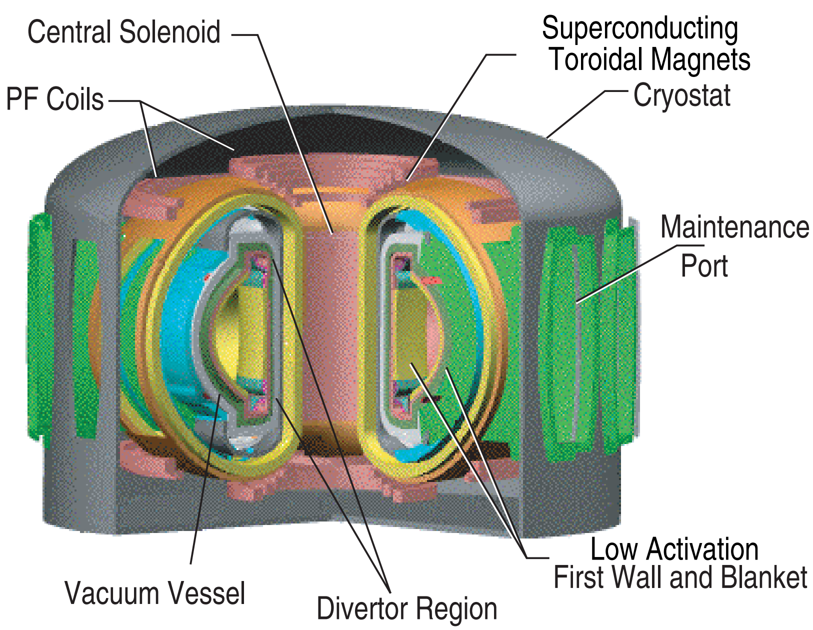
From the President's Science Advisor's Office

Questions

- Do we know what scientific questions need to be addressed for fusion to be viewed as a viable (practical) energy source? How will we know we are there?
- Do we have a definition of the most critical scientific questions that need to be addressed over the coming decade? (is there a relative priority?)
- How does ‘time-to-market’ development plan map onto a risk-weighted portfolio? Can we see a risk-weighted portfolio with stage-gates (milestones, deliverables, check points) within the ‘time-to-market’ plan?
- Example: Do we understand how the existing and planned (e.g. ITER) suite of facilities help to address critical scientific questions? Are there obvious gaps?

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

The U.S. ARIES — AT system study



Economically Competitive - COE ~ 5¢/kWhr

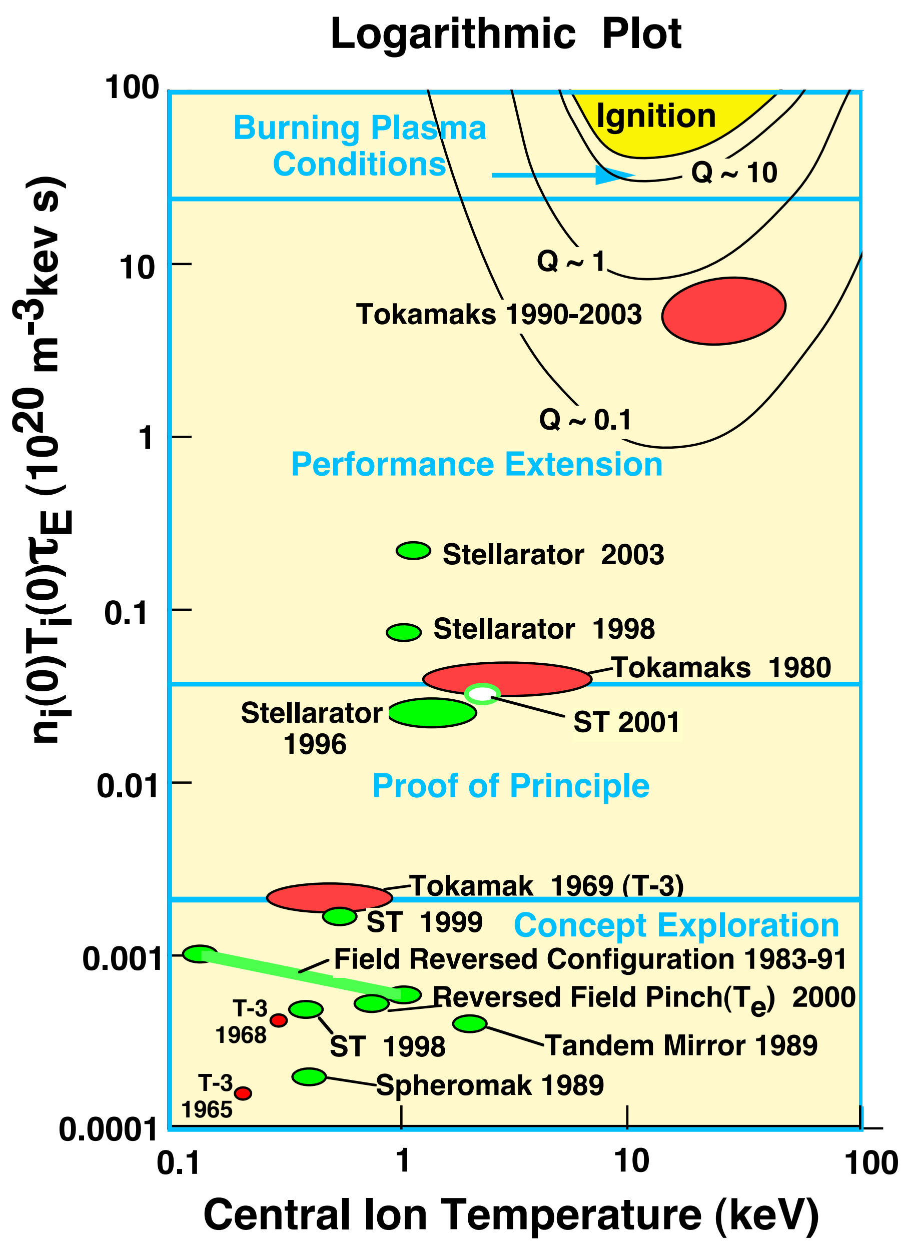
Enviromentally Benign - Low Level Waste

Safety - No evacuation

- **Fusion Power Gain** Q ~ 25
- **Advanced Tokamak Features**
  - High Power density ~5 MW/m^3
  - Steady-State f_{BS} ~ 90%
  - Exhaust Power P/R ~ 80 MW/m
- **Advanced Technology Features**
  - Hi Tc Superconductors
  - Neutron Resistant >150 dpa
  - Low Activation materials
- **High Availability** > 80%

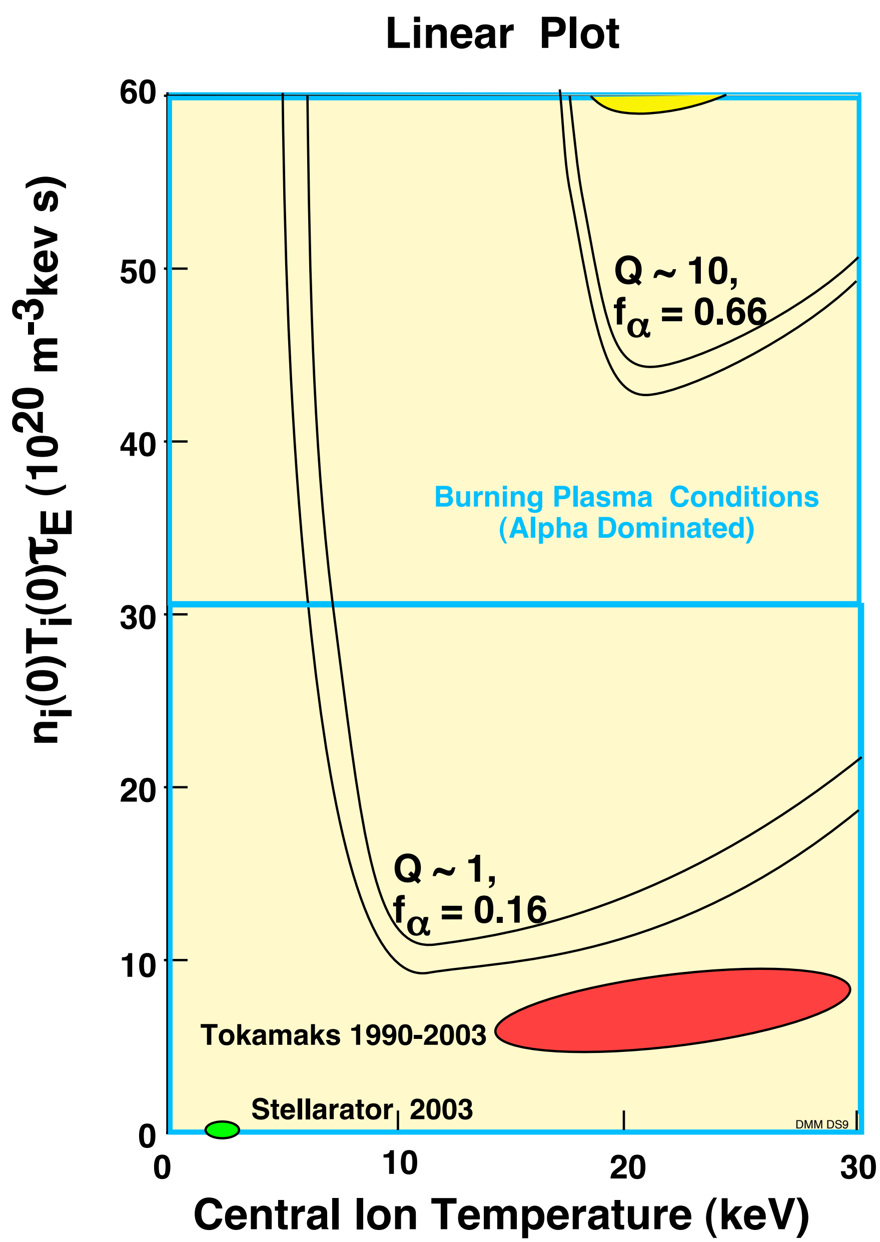
Major Advances in Physics and Technolgy are needed to achieve this goal.

Lawson Diagram - Contour Map for Magnetic Fusion Confinement



- Steady Progress with each new generation of confinement devices.
- Fusion Temperatures have been achieved
- The log-log plot gives the impression that confinement has only a small step left. However, funding agencies use linear plots.

The Step to Burning Plasmas is the Most Challenging Yet.



- In reality, the step to burning plasmas is the largest, most technically challenging step and expensive step so far.
- Burning plasma conditions must be sustained for many characteristic plasma times, much longer than present exp'ts.
- Community and external reviews have concluded that now is the time to initiate steps leading to the construction of a burning plasma experiment.

High Power Density Needed for Compact Reactors

- The fusion power density is given by:

$$P_f / V_p \sim n^2 \langle \sigma v \rangle = n^2 T^2 \langle \sigma v \rangle / T^2$$

Note: $\langle \sigma v \rangle / T^2 \approx$ constant from 10 to 20 keV

Define $\beta = \langle p \rangle / B^2$

Then

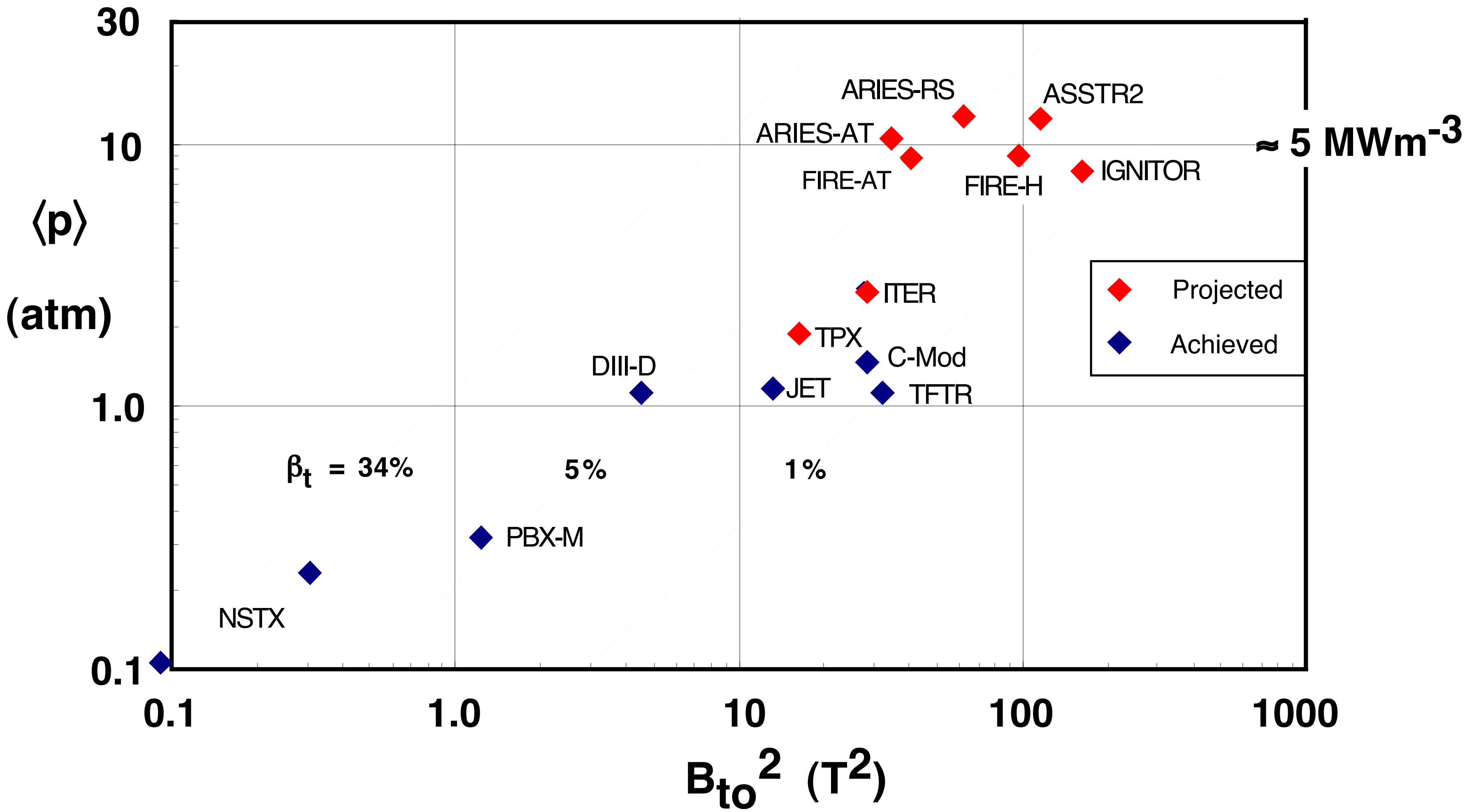
$$P_f / V_p \sim \beta^2 B^4$$

or (a) $P_f / V_p \sim \boldsymbol{\beta_t^2 B_{to}^4}$ where $\mathbf{B_{to}}$ is the field at the magnetic axis

or (b) $P_f / V_p \sim \boldsymbol{\beta_t^2 (B_{to} / B_{coil})^4 B_{coil}^4}$

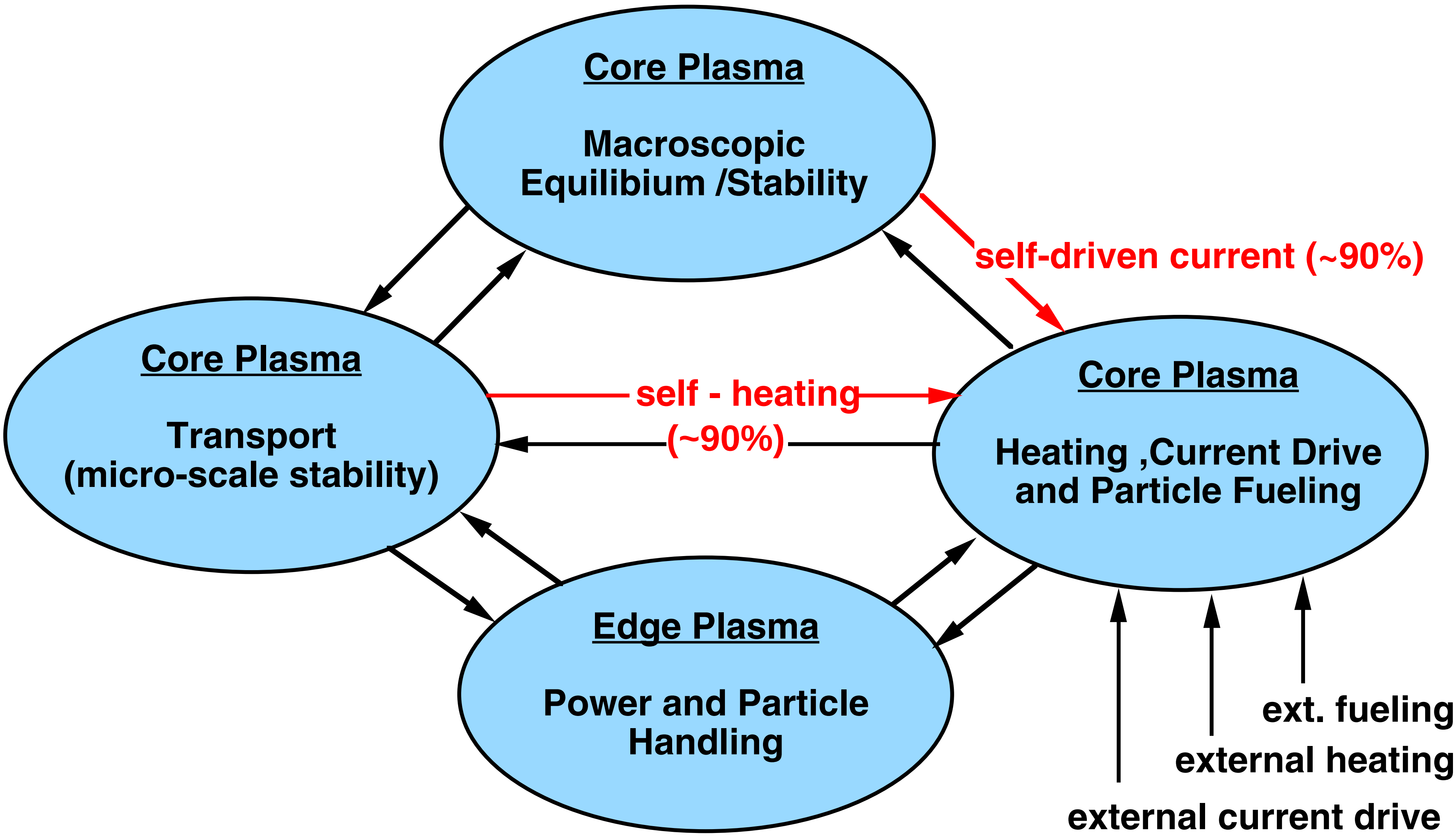
Physics limit Geometry Engineering limit

Fusion Will Require Plasma Pressures of 10 to 15 Atm.



- "Compact" fusion systems require power densities of ~ 5 MWm^{-3}
- Plasma pressure must be increased by a factor of 10 while maintaining $\beta \sim 5\%$

Fusion Plasmas are Strongly-Coupled Self-Driven Systems



Can a fusion dominated plasma be created and controlled in the laboratory?

FESAC has Recommended a Dual Path Strategy for Burning Plasmas

Based on the Snowmass Assessment, FESAC found that:

"ITER and FIRE are each attractive options for the study of burning plasma science. Each could serve as the primary burning plasma facility, although they lead to different fusion energy development paths.

Because additional steps are needed for the approval of construction of ITER or FIRE, a strategy that allows for the possibility of either burning plasma option is appropriate."

FESAC recommended a dual path strategy:

1. that the US should seek to join ITER negotiations as a full participant
   - US should do analysis of cost to join ITER and ITER project cost.
   - negotiations and construction decision are to be concluded by July 2004.

2. that the FIRE activities continue toward a Physics Validation as planned and be prepared to start Conceptual Design at the time of the ITER Decision.

3. If ITER does not move forward, then FIRE should be advanced as a U.S.-based burning plasma experiment.

Energy Policy Bills are Under Discussion in Congress

- Authorizing bills (HR 6 and S 14) layout requirements for participation in ITER negotiations including budget allotments for FY 2004 -2008 are consistent with the Administration's proposal of ~$500 M for ITER over ~ 10 years plus an increased base program.

- Both bills also layout requirements for a domestic burning plasma (FIRE) if ITER does not go forward.

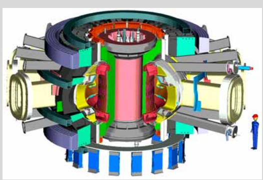
  HR 6 – If at any time during the negotiations on ITER, the Secretary determines that construction and operation of ITER is unlikely or infeasible, the Secretary shall send to Congress, as part of the budget request for the following year, a plan for implementing the domestic burning plasma experiment known as FIRE, including costs and schedules for such a plan. The Secretary shall refine such plan in full consultation with the Fusion Energy Sciences Advisory Committee and shall also transmit such plan to the National Academy of Sciences for review.

  S 14 – In the event that ITER fails to go forward within a reasonable period of time, the Secretary shall send to Congress a plan, including costs and schedules, for implementing the domestic burning plasma experiment known as the Fusion Ignition Research Experiment. Such a plan shall be developed with full consultation with the Fusion Energy Sciences Advisory Committee and be reviewed by the National Research Council.

- Appropriation bills for FY 2004 are under discussion.

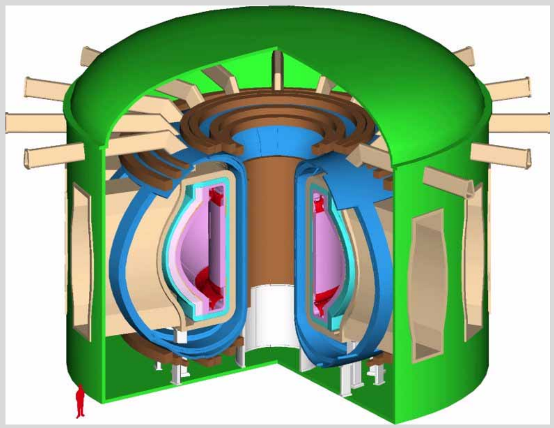
FIRE and ITER are Complementary Options

FIRE



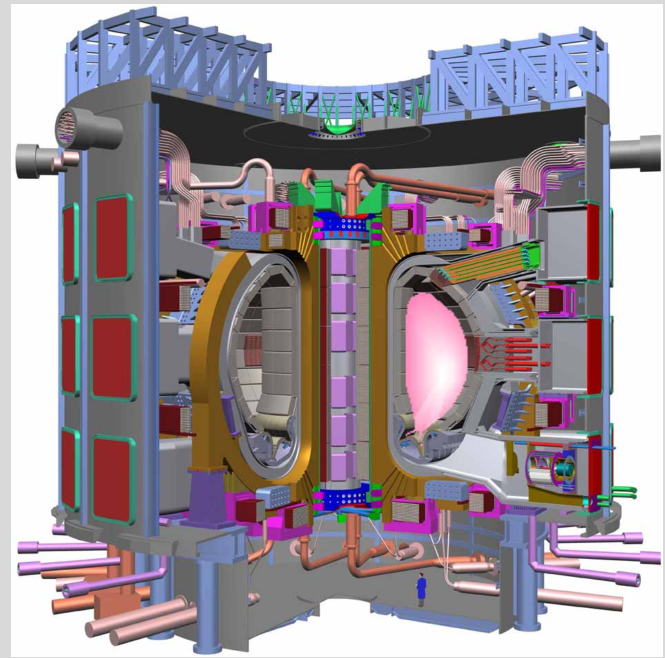
150 MW
27 m^3
1.4 ktonne

Fusion Power Plant
ARIES-AT



1,800 MW
350 m^3
13 ktonne

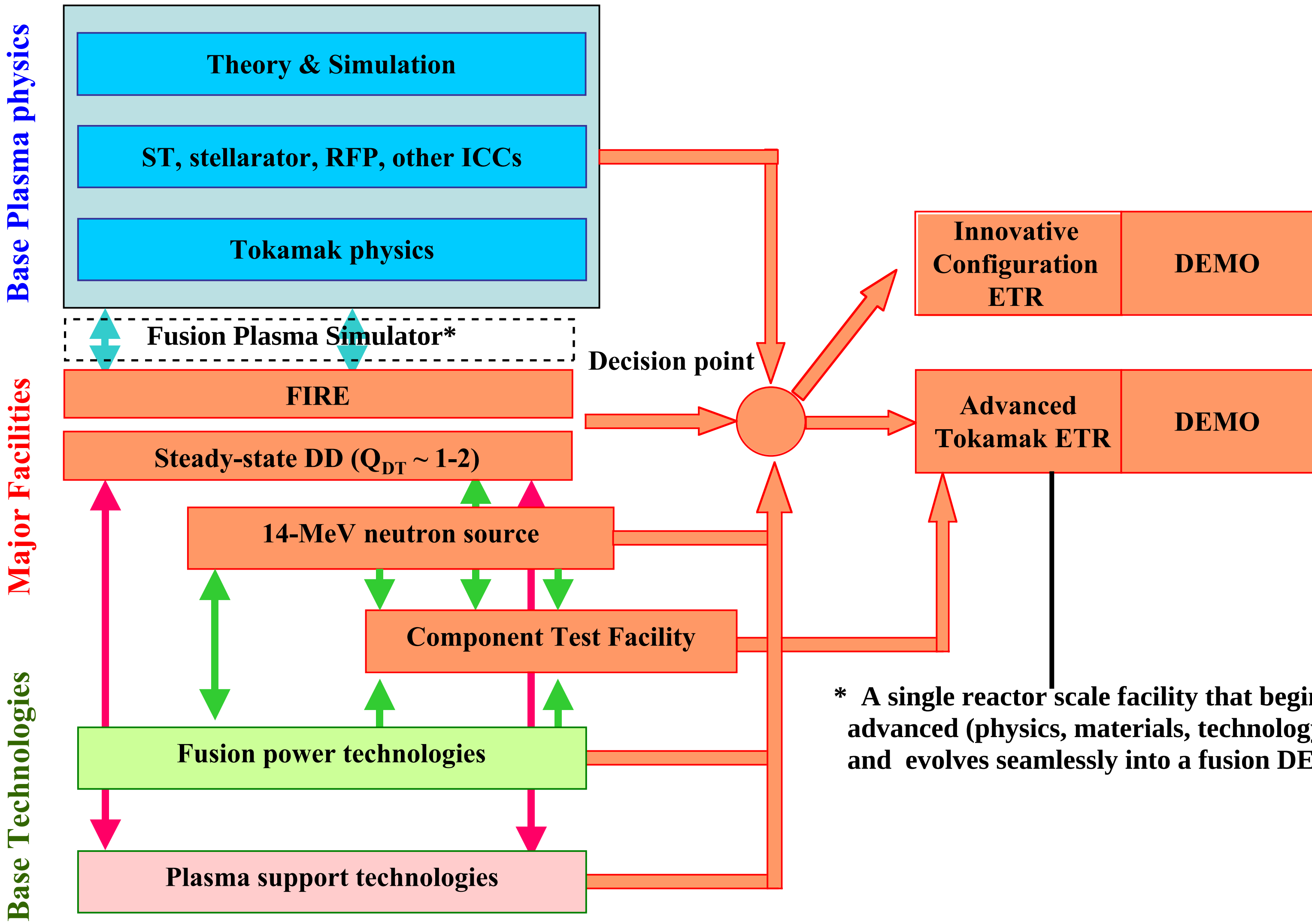
ITER



500 MW
840 m^3
19 ktonne

- FIRE is focused on exploring advanced physics and high power density plasmas.
- ITER is focused on conventional physics and long pulse fusion technologies.

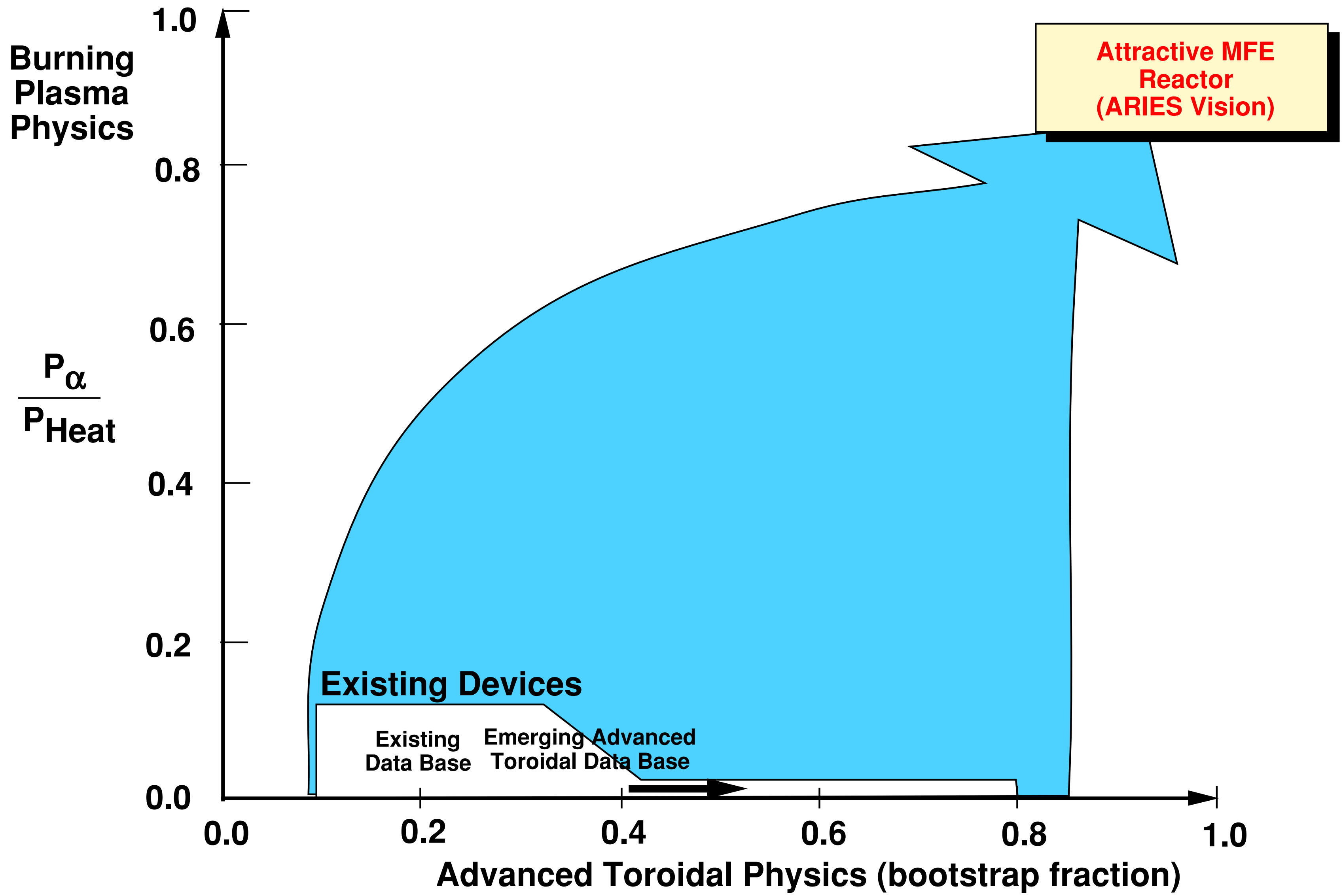
FIRE- is Part of a Multi-Machine Int'l Program



* A single reactor scale facility that begins as an advanced (physics, materials, technology) Engineering Test Reactor and evolves seamlessly into a fusion DEMO.

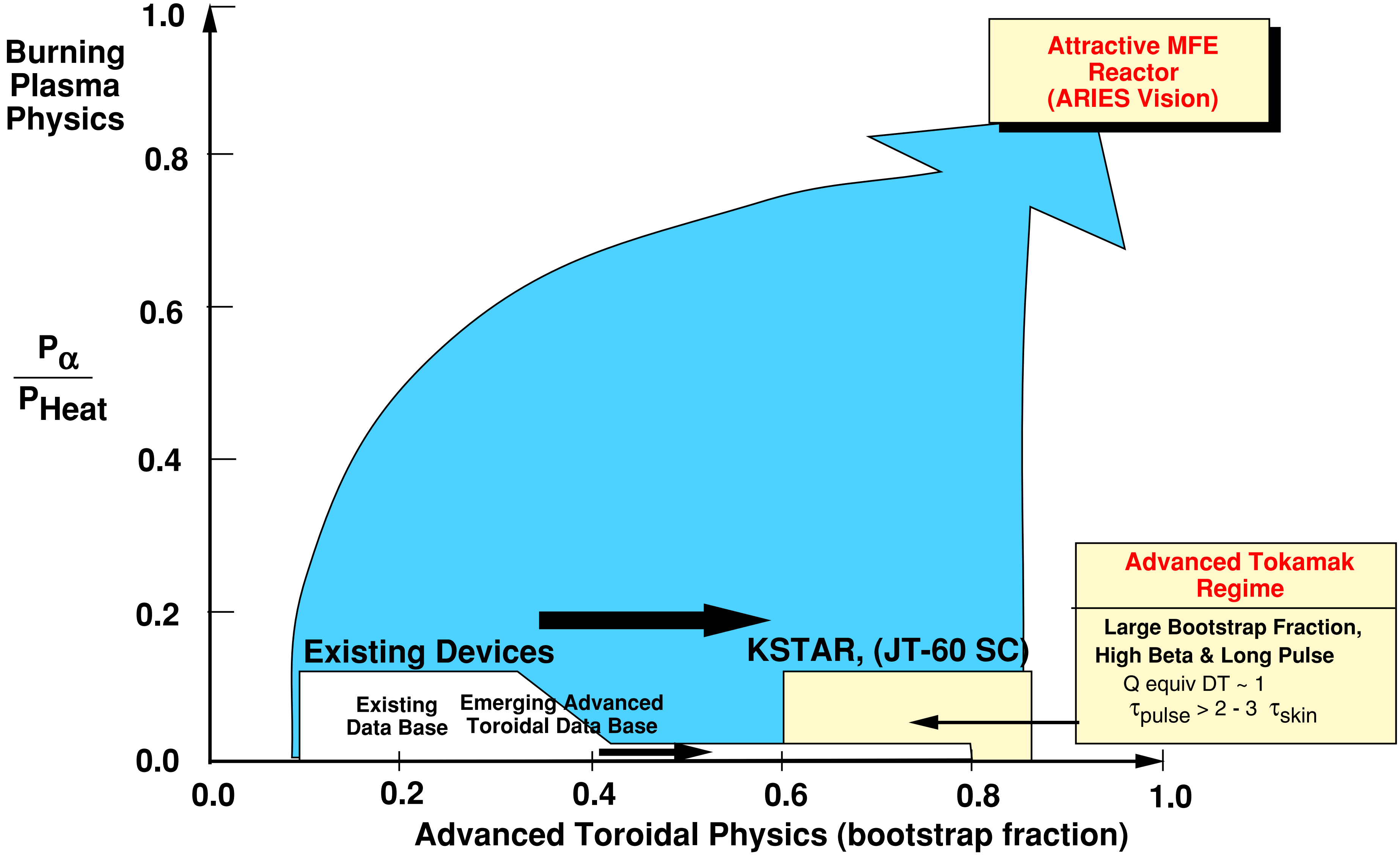
Develop and Test Advanced Physics and Technology before Reactor Scale Integration

Portfolio Approach to Address the Critical Burning Plasma Science Issues for an Attractive MFE Reactor.



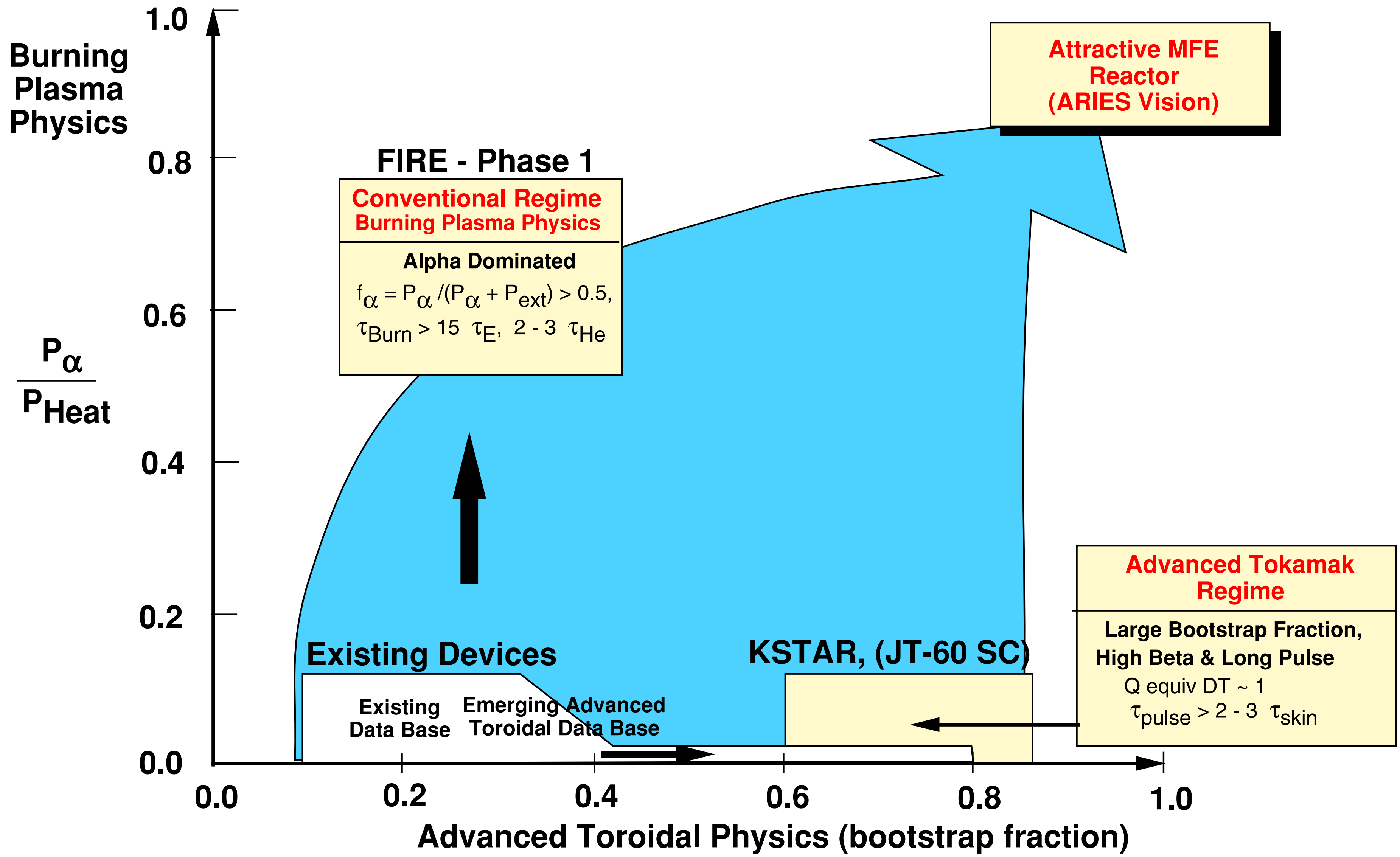
There is a very large gap between the capability of existing advanced tokamaks and the requirements for an attractive reactor.

Portfolio Approach to Address the Critical Burning Plasma Science Issues for an Attractive MFE Reactor.



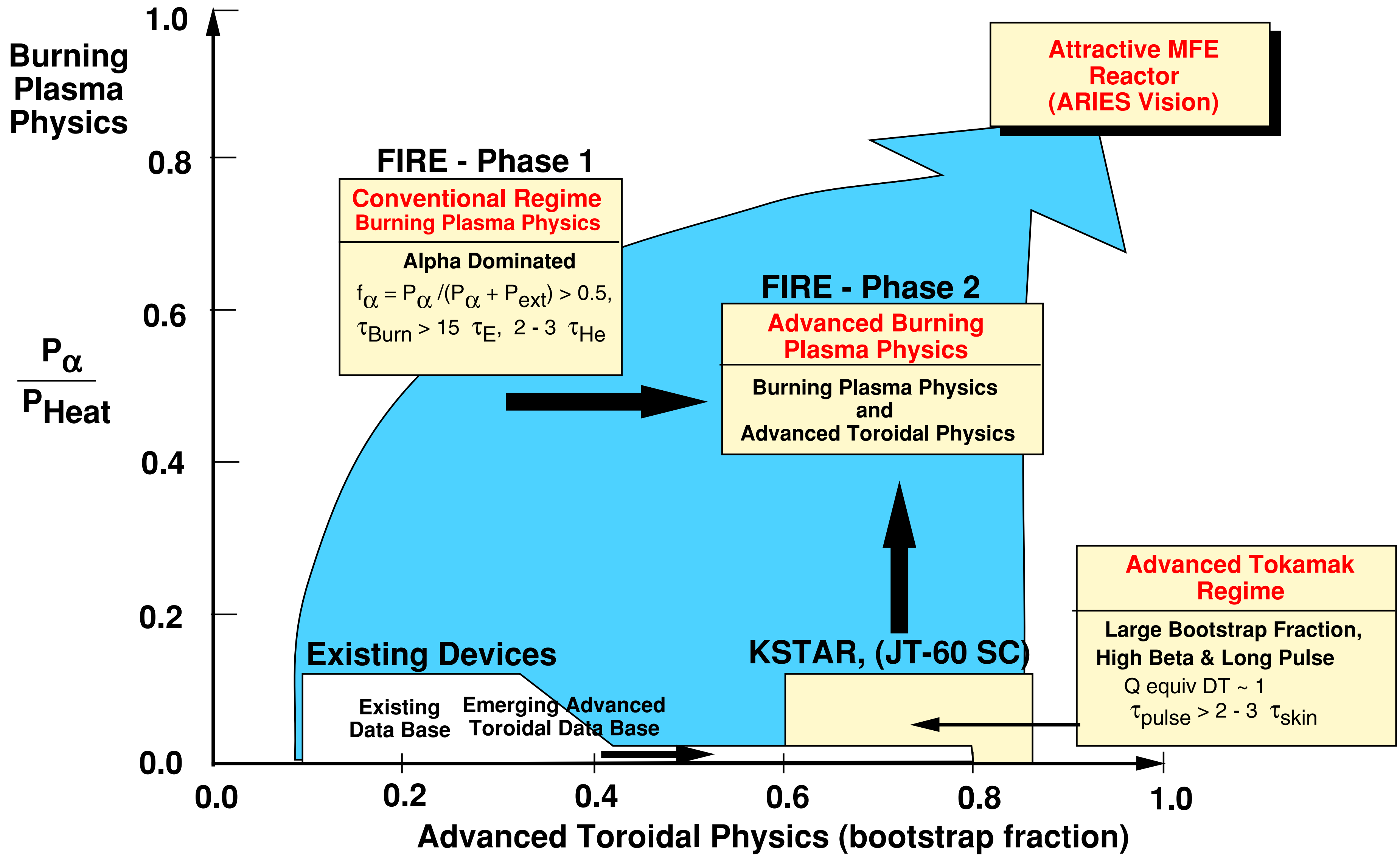
New high-beta "steady-state" tokamaks are needed to the develop and test AT physics in non burning plasmas.

Portfolio Approach to Address the Critical Burning Plasma Science Issues for an Attractive MFE Reactor.



FIRE-Phase 1 would build on the results of existing tokamaks and begin burning plasma studies in the convential regime.

Portfolio Approach to Address the Critical Burning Plasma Science Issues for an Attractive MFE Reactor.



FIRE-Phase 2 would integrate results of Non-burning ATs and Conventional burning plasmas to test the compatibility and control of high bootstrap (~ 80%) and high gain (Q = 5 to 10) burning plasmas.

FIRE Aims to Explore Coupling of BP and AT

Burning Plasma Physics

Q	~ 10 as target, ignition not precluded
$f_\alpha = P_\alpha / P_{heat}$	~ 66% as target, up to 83% at Q = 25
TAE/EPM	stable at nominal point, able to access unstable

Advanced Toroidal Physics

$f_{bs} = I_{bs}/I_p$	~ 80% (goal)
β_N	~ 4.0, n = 1 wall stabilized

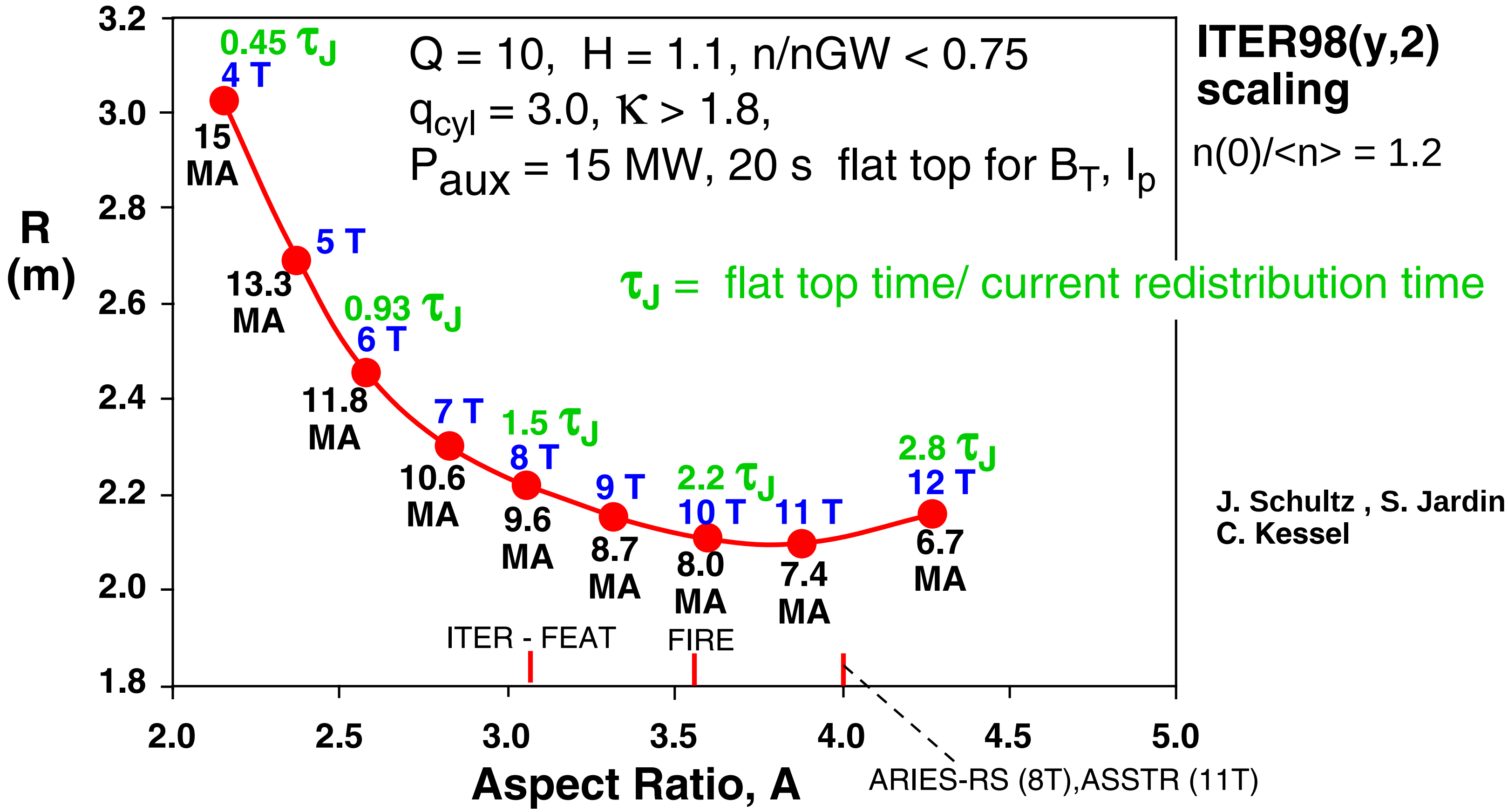
Quasi-stationary Burn Duration (use plasma time scales)

Pressure profile evolution and burn control	> 10 τ_E
Alpha ash accumulation/pumping	> several τ_{He}
Plasma current profile evolution	2 to 5 τ_{skin}
Divertor pumping and heat removal	several $\tau_{divertor}$

Optimization of a Conventional Regime Burning Plasma Experiment

- Consider an inductively driven tokamak with copper alloy TF and PF coils precooled to LN temperature that warm up adiabatically during the pulse.

- Seek minimum R while varying A and space allocation for TF/PF coils for a specified plasma performance - Q and pulse length with physics and eng. limits.



What is the optimum for an Advanced Regime burning plasma experiment?

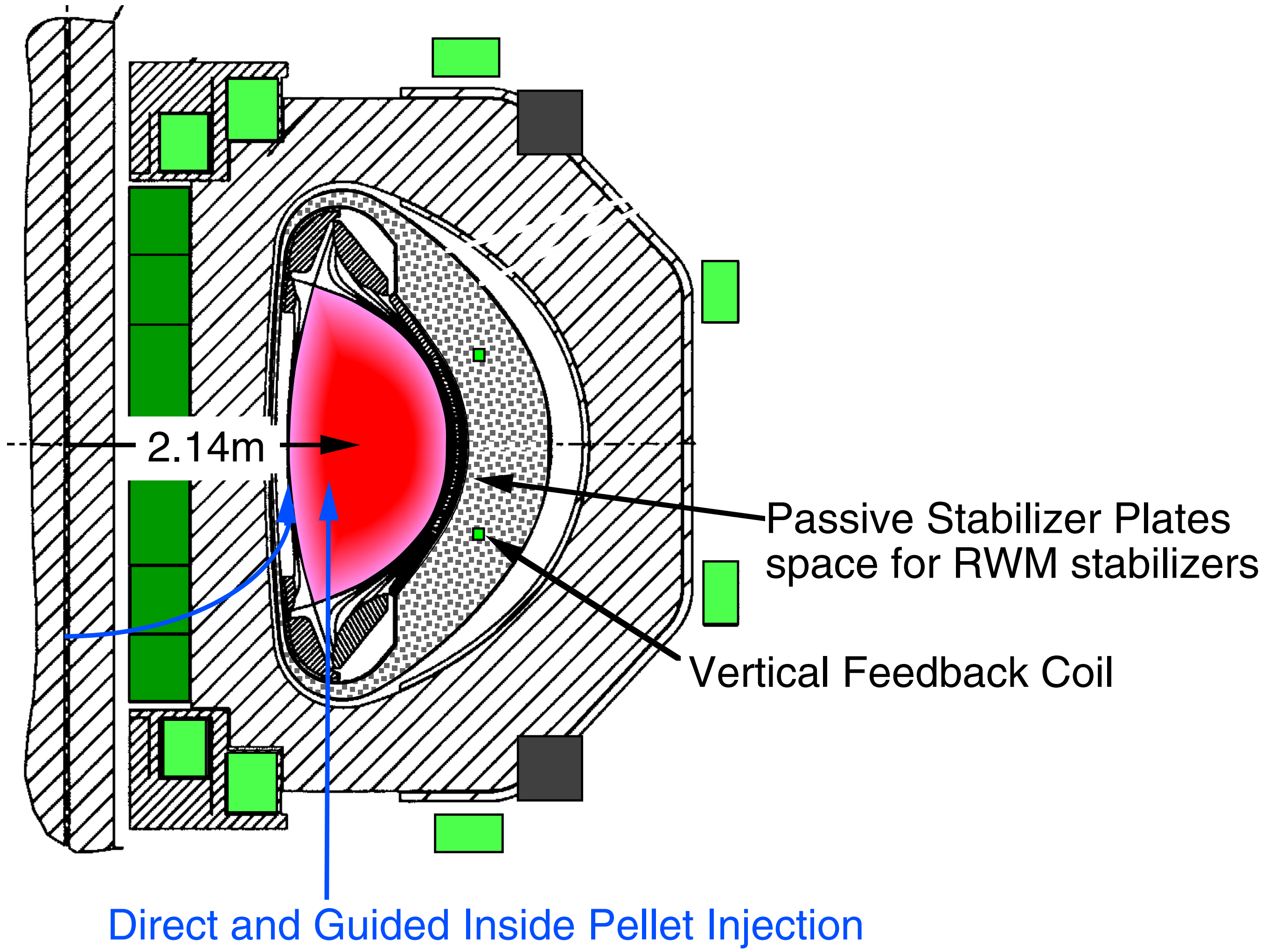
FIRE has Adopted the Advanced Tokamak Physics Features Identified by ARIES Studies

- Similar magnetic field
- Double null
- Strong shaping
  - $\kappa = 2.0$, $\delta = 0.7$
- Internal vertical position control coils
- Cu wall stabilizers for vertical and kink instabilities
- Very low ripple (0.3%)
- ICRF/FW on-axis CD
- LH off-axis CD
- LHCD stabilization of NTMs
- Tungsten divertor targets
- Feedback coil stabilization for Resistive Wall Modes (RWM)
- Burn times exceeding current diffusion times
- Pumped divertor/pellet fueling/impurity control to optimize plasma edge

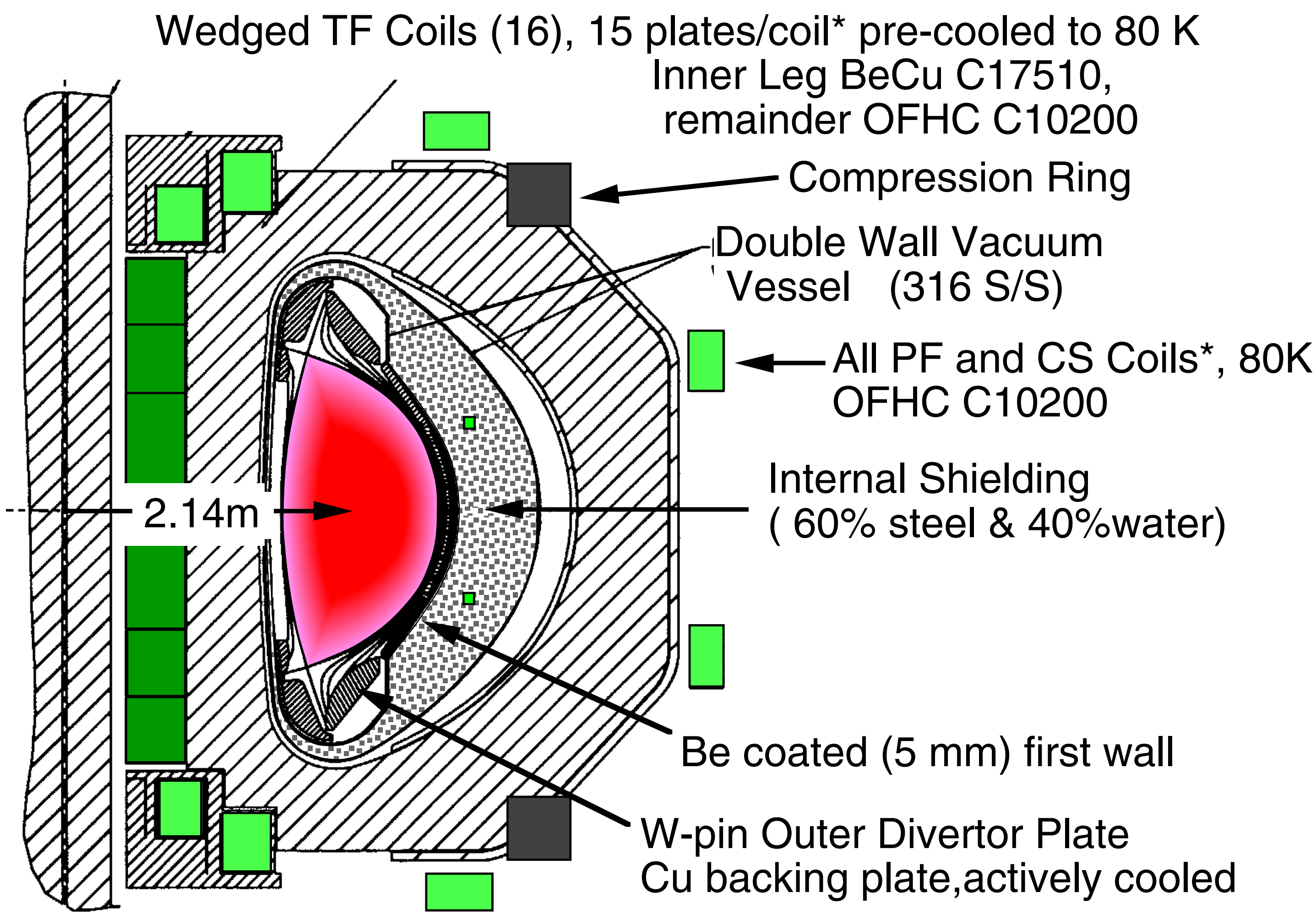
FIRE has Adopted the ARIES-RS Plasma Cross-section

AT Features

- strong shaping
  κ_x, κ_a = 2.0, 1.85
  δ_x, δ_{95} = 0.7, 0.55
- segmented central solenoid
- double null double divertor pumped
- low ripple (<0.3%)
- internal control coils
- space for RWM stabilizers
- inside pellet injection



FIRE Engineering Features



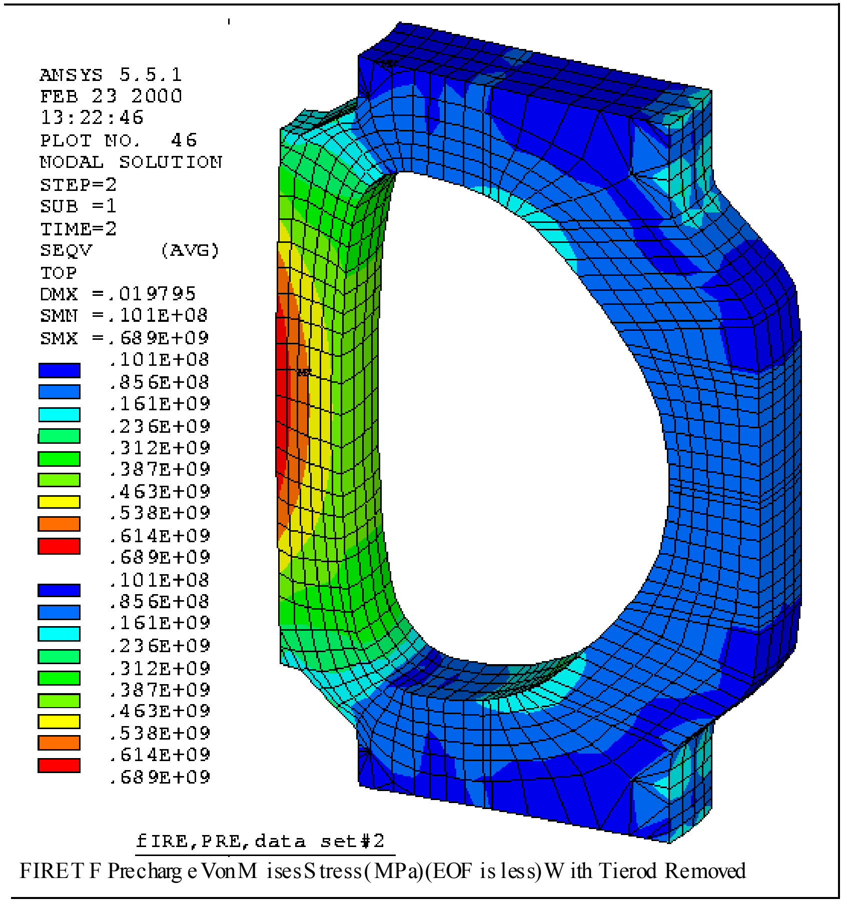
FIRE will push plasma facing components for the wall and divertor toward reactor power densities.

FIRE TF coils are simple and have added margin.

- **FIRE Baseline**
  R = 2.14 m, a = 0.595 m
  B = 10 T, Ip = 7.7 MA,
  20 s flat top, Pfus = 150
- **Wedged TF/compression ring**
  BeCu (C17510) inner leg
- **The peak conductor VM Stress of 529 MPa for 10 T (7.7 MA) is within the static allowable stress of 724 MPa**

(Allowable/Calculated = 1.3)*

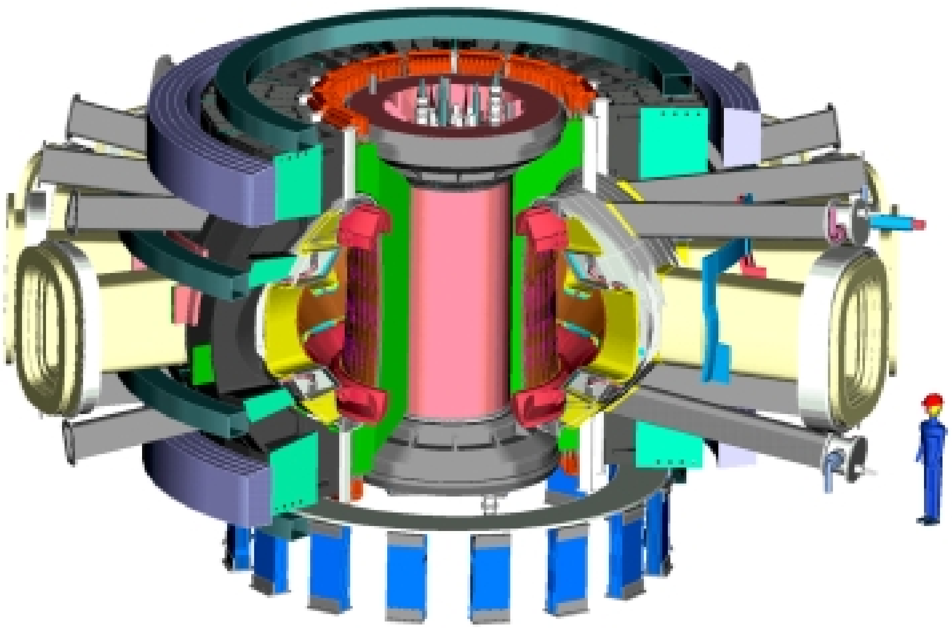
*** Now 1.18 after cooling tube added to triple rep rate.**



TF Coil Von Mises Stress Contours at 12 T

Fusion Ignition Research Experiment
(FIRE)

http://fire.pppl.gov



1,400 tonne

Design Features

- R = 2.14 m, a = 0.595 m
- B = 10 T (~6.5 T AT)
- W_{mag}= 5.2 GJ
- I_p = 7.7 MA (~5 MA AT)
- $P_{aux} \leq$ 20 MW
- Q ≈ 10, P_{fusion} ~ 150 MW
- Burn Time ≈ 20 s (~ 40 s AT)
- Tokamak Cost ≈ \$350M (FY02)
- Total Project Cost ≈ \$1.2B (FY02) at Green Field site.

Mission: Attain, explore, understand and optimize magnetically-confined fusion-dominated plasmas.

FIRE Auxiliary Systems

Plasma Heating.

ICRF Heating: 20 MW, 80 – 120 MHz
Four mid-plane launchers (two strap)

Current Drive

Fast Wave
Lower Hybrid Upgrade: 20 - 30 MW, 4.6 - 5.6 GHz, n = 1.8- 2.2
Electron Cyclotron Upgrade: 170 GHz @ r/a ≈ 0.33 for Adv Tok at 6.6T.

Plasma Fueling and Pumping

HFS launch: guided slow pellets, high speed vertical inside mag axis
Various impurity seeding injectors for distributing power
Cryopumps (>100 Pa m^3 s^{-1}) in the divertor for exhaust and He pumping

Tritium Inventory (similar to TFTR)

~0.3 g-T/pulse, site inventory
< 30 g-T, Low Hazard Nuclear Facility, Category 3 like TFTR

Operating Sequences

3,000 full field and power, 30,000 pulses at 2/3 field (AT) like BPX
1 hr rep time at full power and pulse length, ~**20** min for AT 10 s pulses
Insulator R&D and improved cooling design to increase pulse and rep rate

Guidelines for Estimating H-Mode Performance (0-D)

Confinement (Elmy H-mode) - ITER98(y,2) based on today's data base

$$\tau_E = 0.144\, I^{0.93}\, R^{1.39} a^{0.58}\, n_{20}^{0.41} B^{0.15} A_i^{0.19} \kappa^{0.78}\, P_{heat}^{-0.69}\ \ H(y,2)$$

Density Limit - Based on today's tokamak data base

$$n_{20} \leq 0.8\, n_{GW} = 0.8\, I_p/\pi a^2,$$

Beta Limit - theory and tokamak data base

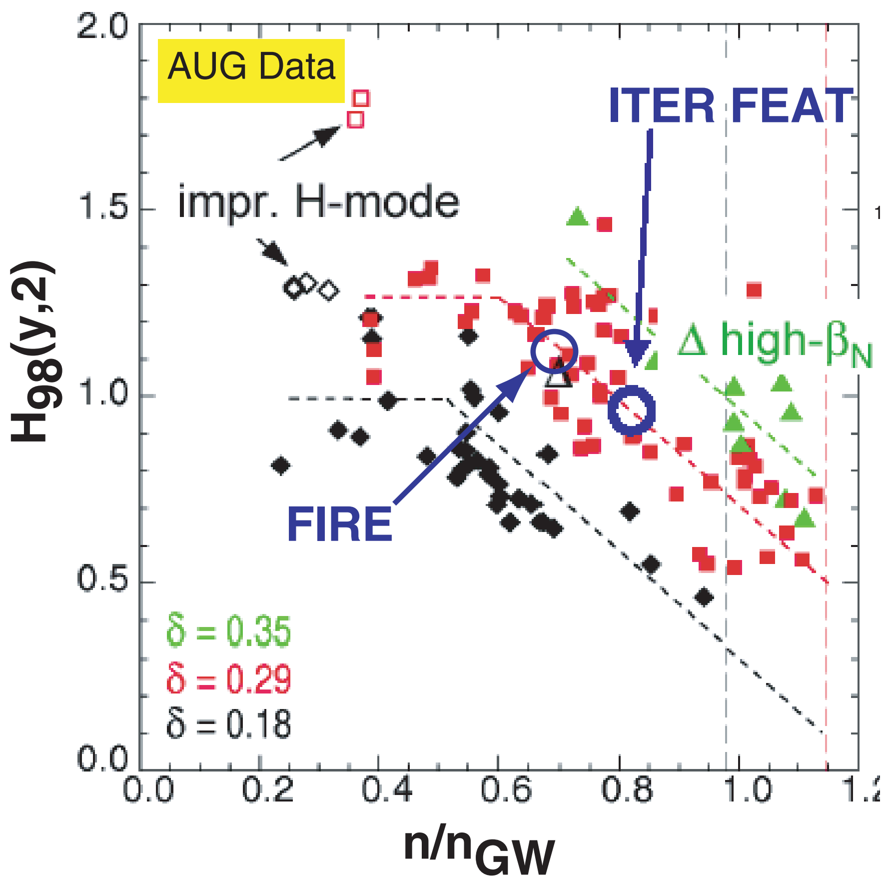
$$\beta \leq \beta_N (I_p/aB), \quad \beta_N < 2.5 \text{ conventional}, \ \beta_N \sim 4 \text{ advanced}$$

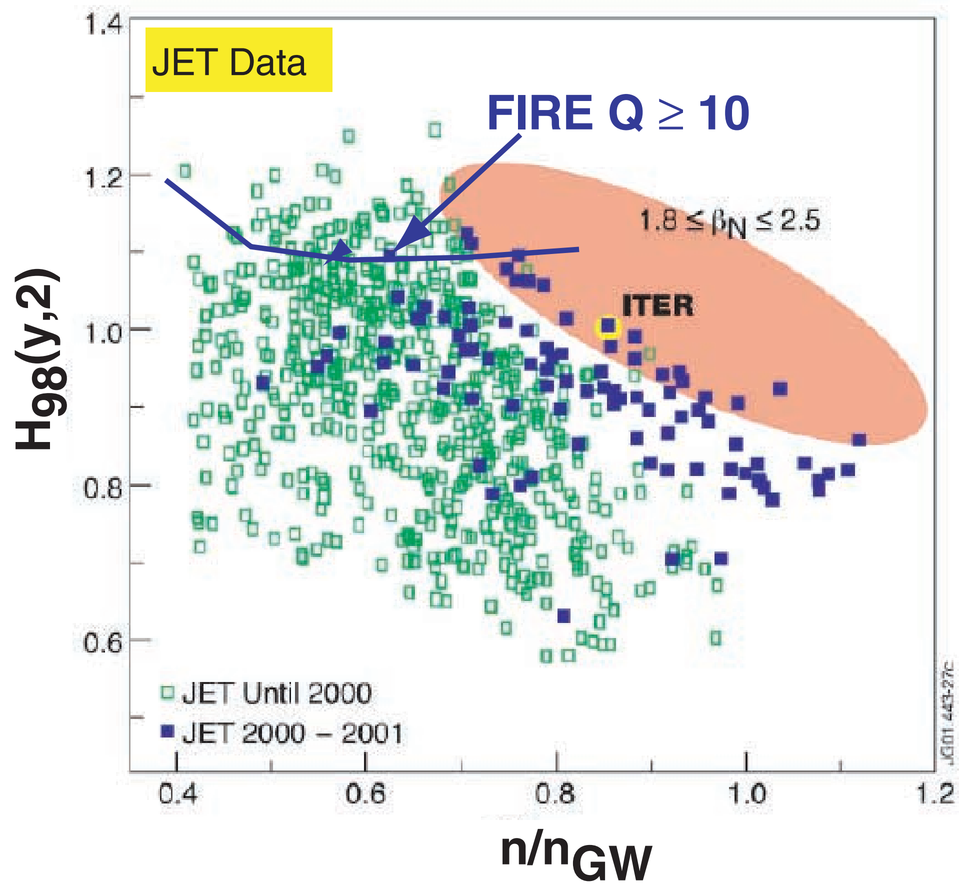
H-Mode Power Threshold - Based on today's tokamak data base

$$Pth \geq (2.84/Ai)\, n_{20}^{0.58} B^{0.82} Ra^{0.81}$$ **, same as ITER-FEAT**

Helium Ash Confinement $\tau_{He} = 5\,\tau_E$, impurities = 3% Be, 0% W

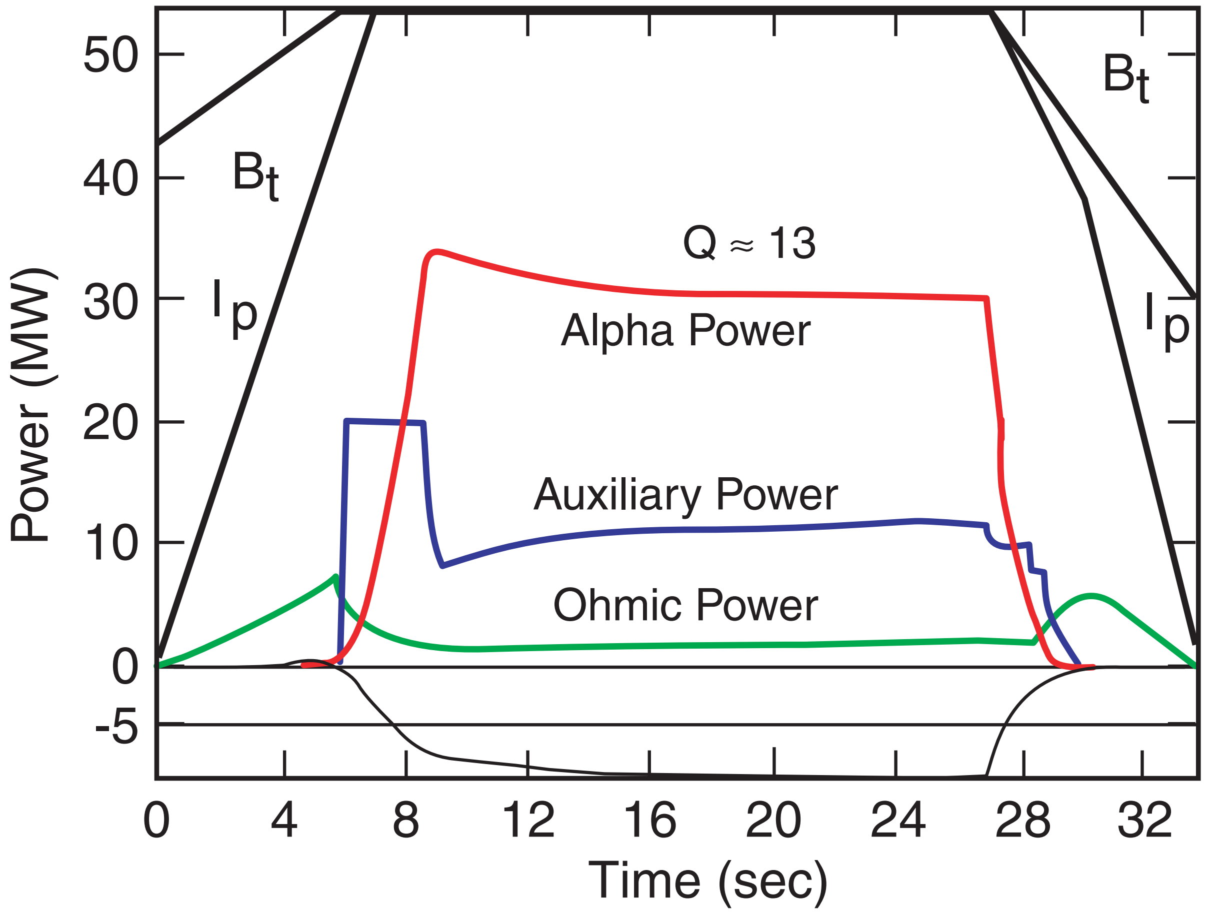
High Triangularity and Modest Density Relative to Greenwald Facilitate H-Mode Operation





- Need predictive transport models that can replicate the trends with trianglarity, DN vs SN and n/nGW.
- Experiments proposed at DIII-D and C-Mod to study effects of high triangularity and DN on transport, MHD

1.5D Simulation of Quasi-Stationary H-Mode in FIRE



B = 10 T

I_p = 7.7 MA

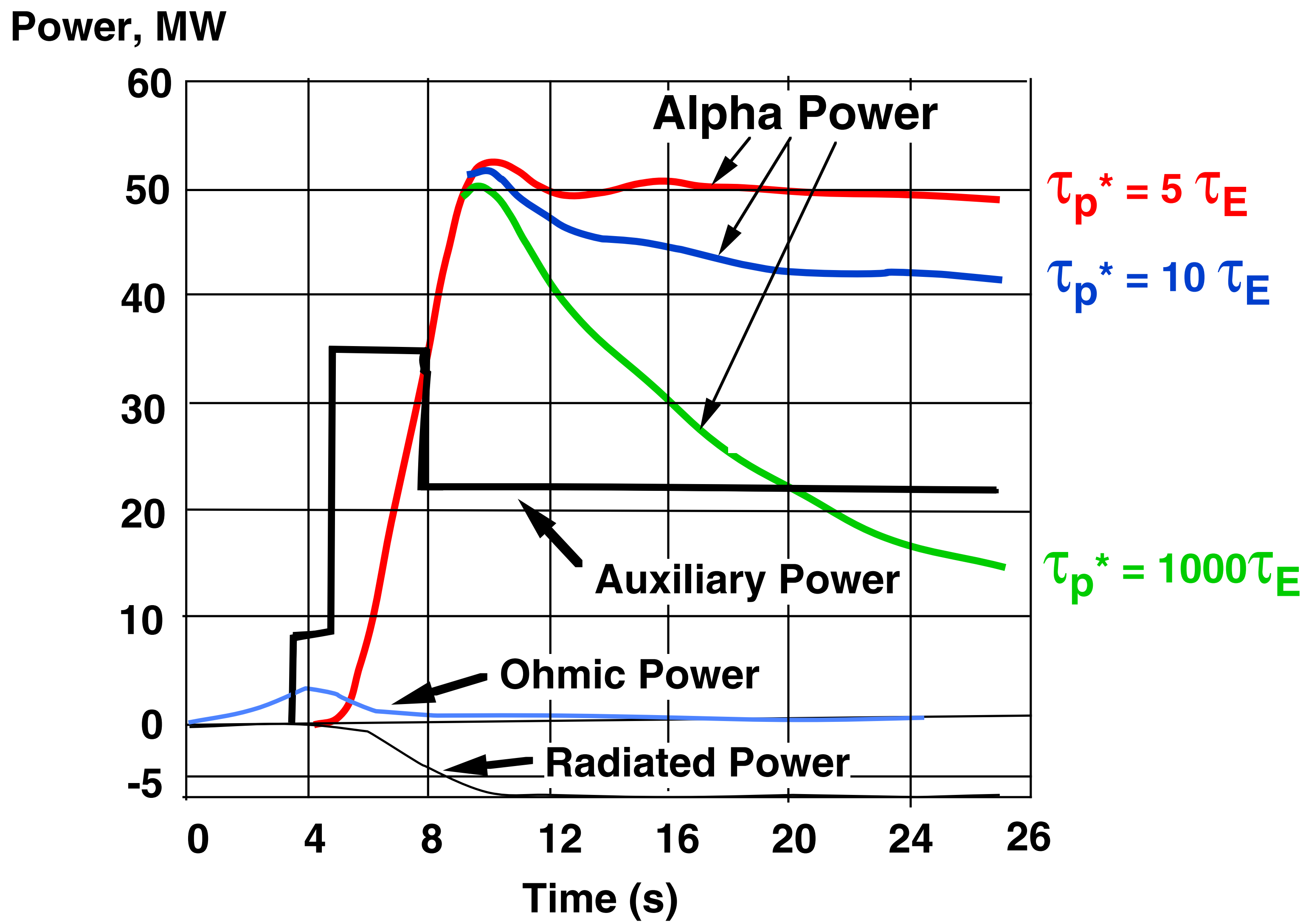
R = 2.14 m

A = 3.6

- ITER98(y, 2) with H(y, 2) = 1.1, n(0)/⟨n⟩ = 1.2, and n/ n_{GW} = 0.67
- Burn Time ≈ 20 s ≈ $21\tau_E \approx 4\tau_{He} \approx 2\tau_{CR}$

Q = Pfusion/(Paux + Poh)

Helium Ash Removal Techniques Required for a Reactor can be Studied on FIRE



Fusion power can not be sustained without helium ash punping.

TSC/Kessel/21-q.ps

FIRE Simulation Project

- realistic geometry
- 2-D magnetics
- 1-D transport
- time evolution

Conventional Mode

~ 70% self heating

~20% self generated confining magnetic field

5.5 MW/m3
Fusion Power density
(reactor level)

Snowmass Conclusions on Confinement Projections for FIRE

• Based on 0D and 1.5D modeling, all three devices (ITER, FIRE and IGNITOR) have baseline scenarios which appear capable of reaching Q = 5 – 15 with the advocates' assumptions. ITER and FIRE scenarios are based on standard ELMing H–mode and are reasonable extrapolations from the existing database.

• More accurate prediction of fusion performance of the three devices is not currently possible due to known uncertainties in the transport models. An ongoing effort within the base fusion science program is underway to improve the projections through increased understanding of transport.

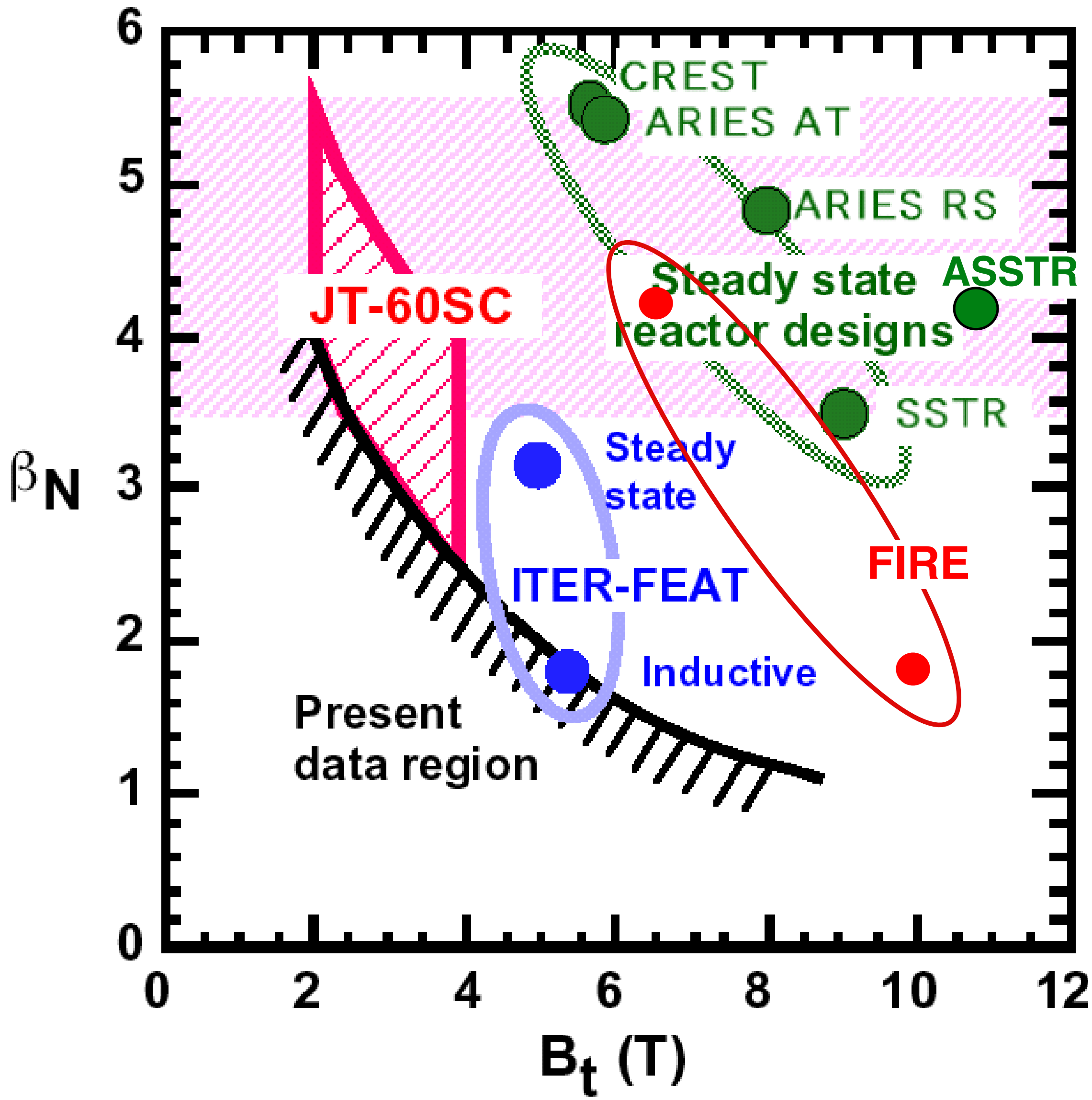
Note: part of the purpose of a next step burning plasma experiment is to extend our understanding of confinement into the burning plasma regime

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(6.5)	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

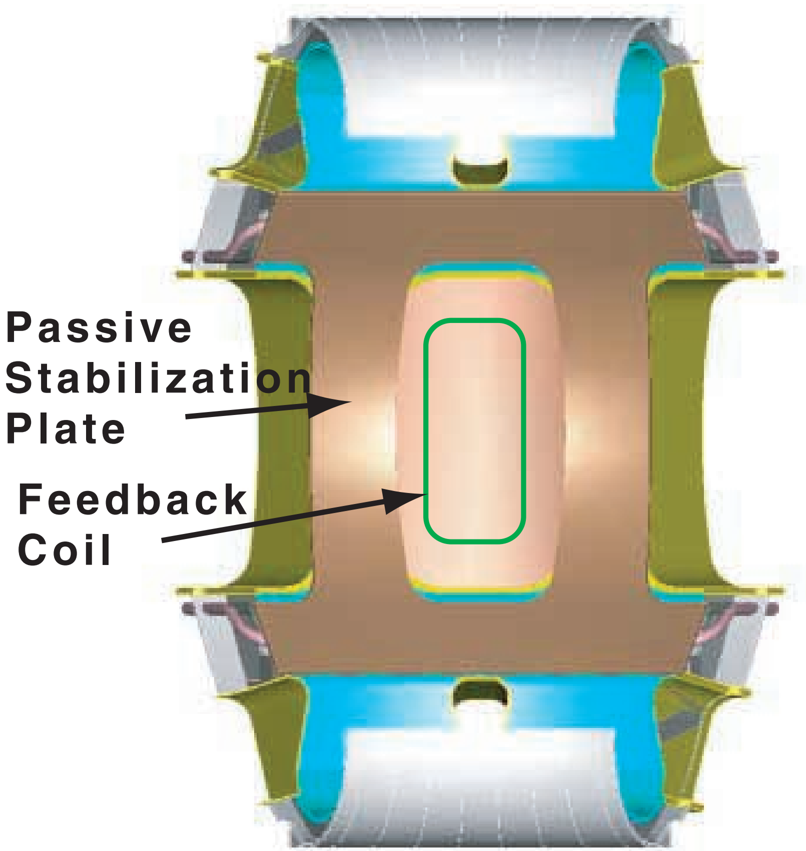
FIRE can Access Regimes of Interest to Advanced Reactors

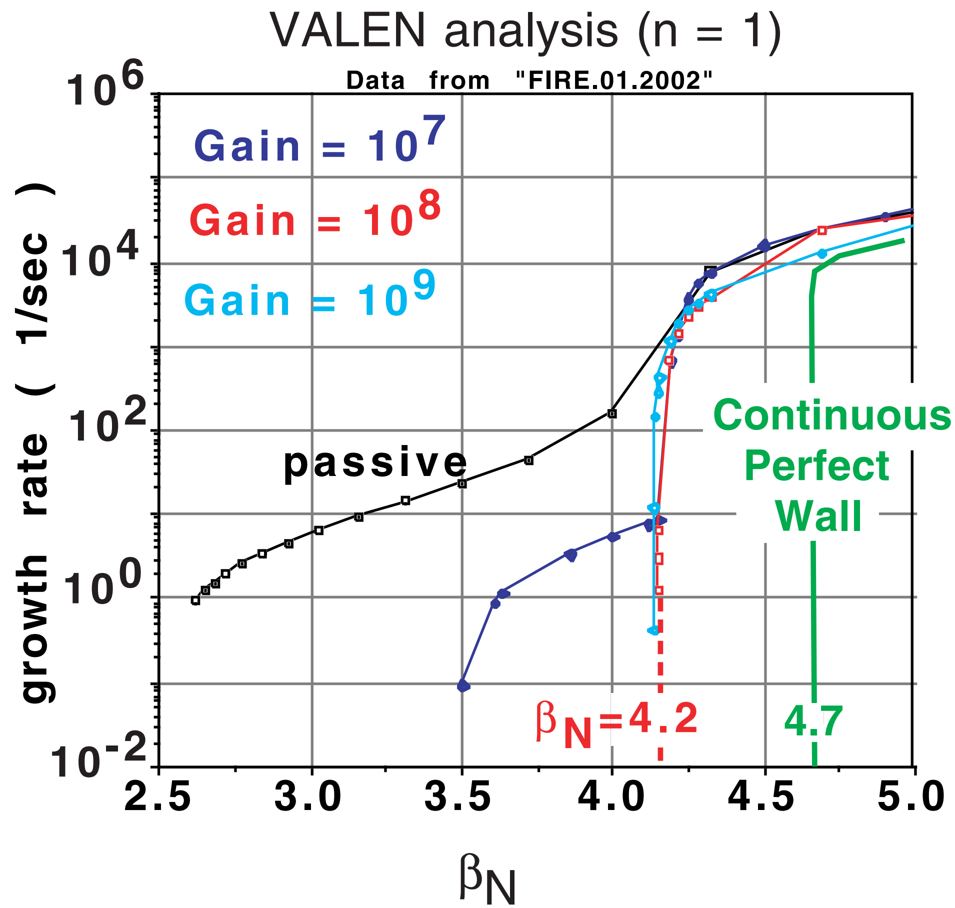
- Reactor studies ARIES in the US and CREST/SSTR in Japan have determined the requirements for an attractive fusion reactor.
- Present tokamak results are far from the attractive reactor regime.
- The present ITER-FEAT design **does not** access the attractive reactor regime.
- The present FIRE design **does** access the attractive reactor regime.



FIRE_JT60SC_at_range

FIRE Accesses β_N ~ 4 with RWM Control





- **Control Coils Located in 8 of 16 ports (4 n=1 coil pairs).**
- **Stable β_N for n = 1 reaches 4.2, 90% of continuous wall limit.**
- **Effects of n = 2 are being examined.**

Feasibility of First Wall RWM coils is being studied.

Columbia University

The Range of Energetically Accessible Non-Inductive AT Modes has been Determined using a 0-D Systems Analysis.

- Plasma Heating and Current Drive provided by LHCD and FWCD with $\eta \approx$ 0.24 A/W-m^2 and bootstrap $f_{BS} \approx \beta_N\, q_{cly}\, (R/a)^{1/2}\, C_{bs}\, n(0)/\langle n \rangle$
- Confinement assumed to scale as a multiplier on ITER98(y,2)
- Exhaust power distribution optimized by adding impurities in both the core (Be, Ar) plasma and divertor (Ne) subject to:

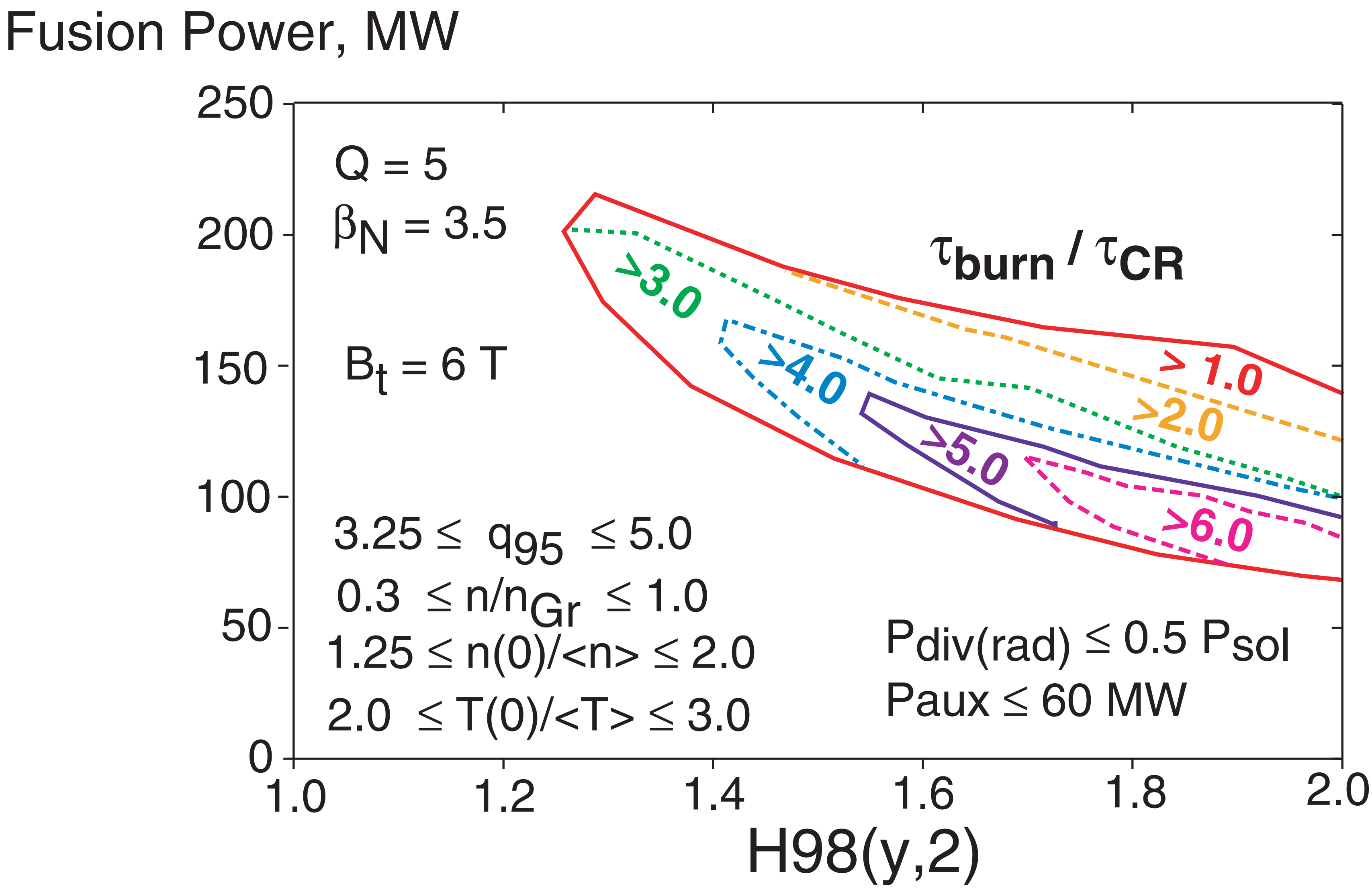
  P_{FW} (rad) $\leq$ 1 MWm^{-2}, including a peaking factor of 2
  P_{div}(part) < 28 MW, P_{div} (rad) < 0.5-0.7 P_{sol}, P_{div} (rad) < 8MWm^2

- Resistive and Nuclear Heating of the TF coils/Nuclear heat of Vac Vess limit

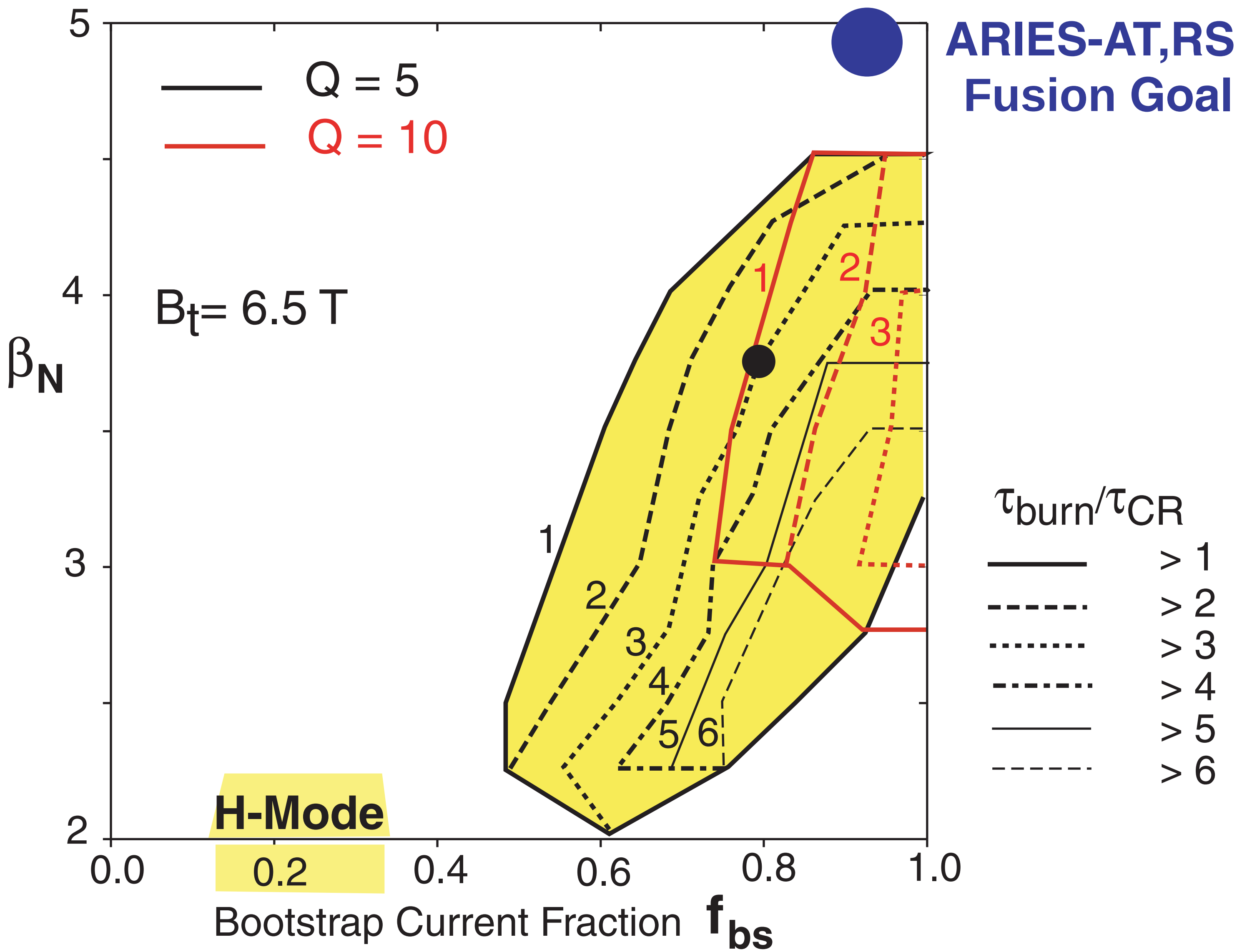
  P_{fusion} x Burn duration $\leq$ 4 GJ/pulse

- Parameter space scanned for power balance over:
  $3.5 \leq q_{95} \leq 5$, $0.3 \leq n/n_{Gr} \leq 1.0$, $1.25 \leq n(0)/\langle n \rangle \leq 2.0$, $2.0 \leq T(0)/\langle T \rangle \leq 3$
  $1\% \leq f_{Be} \leq 3\%$, $0\% \leq f_{Ar} < 0.4\%$, $2.5 \leq \beta_N < 4.5$, for Q = 5, 10
  to determine the required H(y,2) and allowed τ_{burn}/τ_{CR}

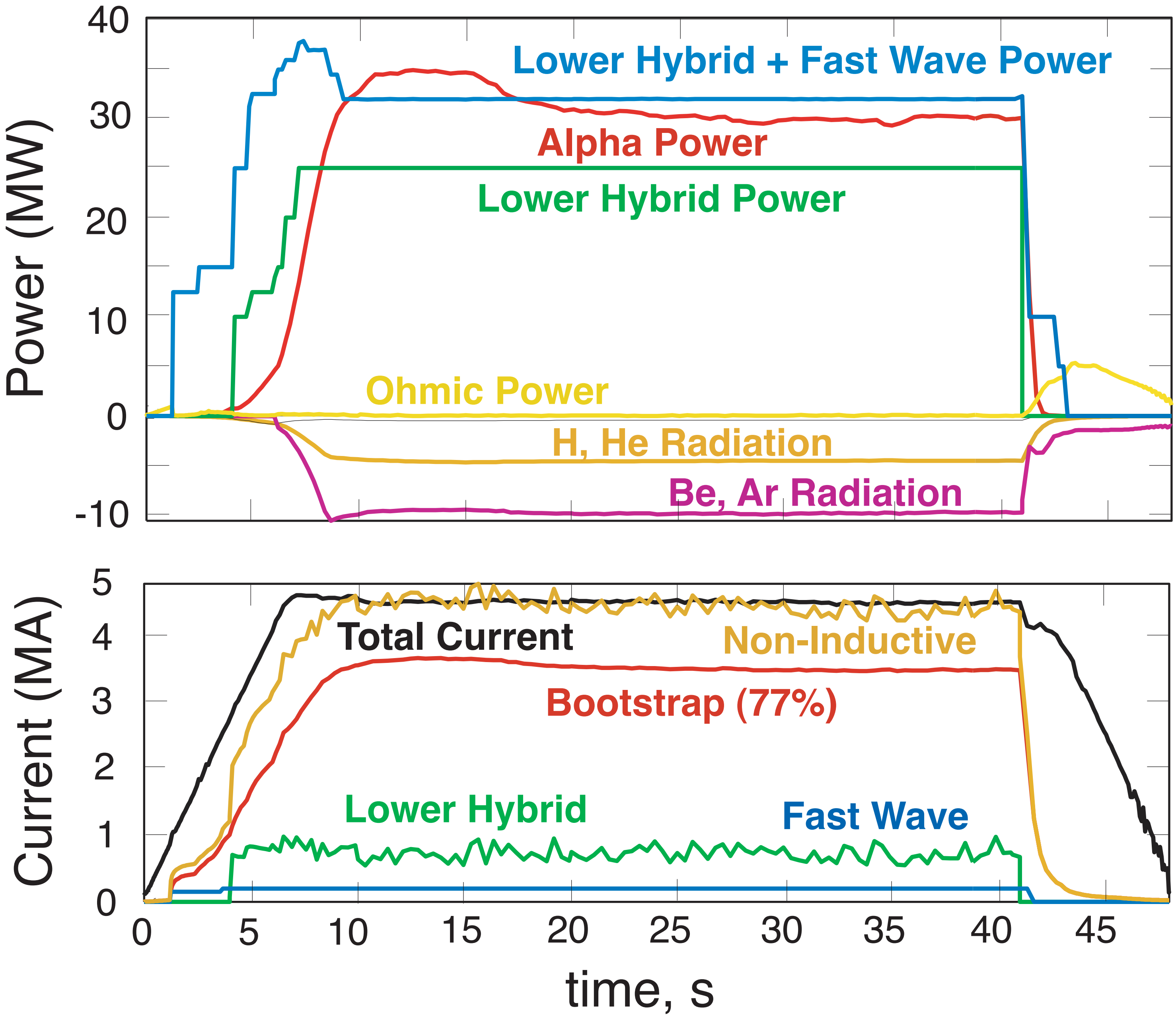
FIRE can Access High-β AT Modes under Quasi-Steady-State Conditions



AT Modes with $\beta_N \approx 4$, $f_{bs} \approx 85\%$ Sustained for 2 - 4 τ_{CR} are Energetically Accessible in FIRE



"Steady-State" High-β Advanced Tokamak Discharge on FIRE



$Q \sim 5$

$B = 6.5$ T

$\beta_N = 4.1$

$f_{bs} = 77\%$

$H_{98} = 1.7$

$n/n_G = 0.85$

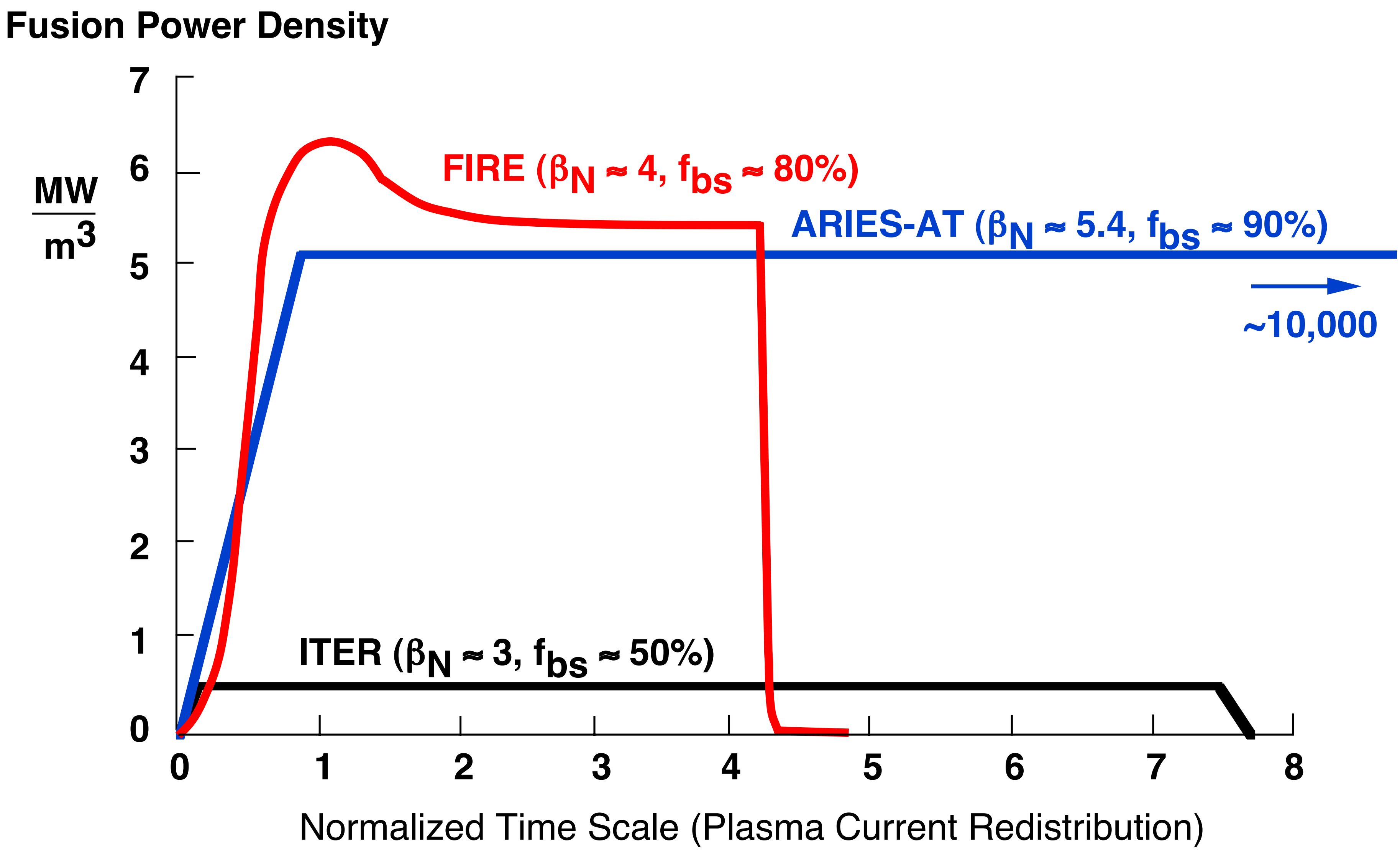
$\tau_E = 0.7$s

$\tau_{He} = 3.5$ s

$\tau_{CR} = 9$ s

fireAT_031003_48s

FIRE Could Explore Advanced Tokamak Regimes Close to ARIES-AT Parameters



Edge Physics and PFC Technology: Critical Issue for Fusion

Plasma Power and particle Handling under relevant conditions

Normal Operation / Off Normal events

Tritium Inventory Control

must maintain low T inventory in the vessel ⇒ all metal PFCs

Efficient particle Fueling

pellet injection needed for deep and tritium efficient fueling

Helium Ash Removal

need close coupled He pumping

Non-linear Coupling with Core plasma Performance

nearly every advancement in confinement can be traced to the edge

Edge Pedestal models first introduced in ~ 1992 first step in understanding

Core plasma (low n_{edge}) and divertor (high n_{edge}) requirements conflict

Solutions to these issues would be a major output from a next step experiment.

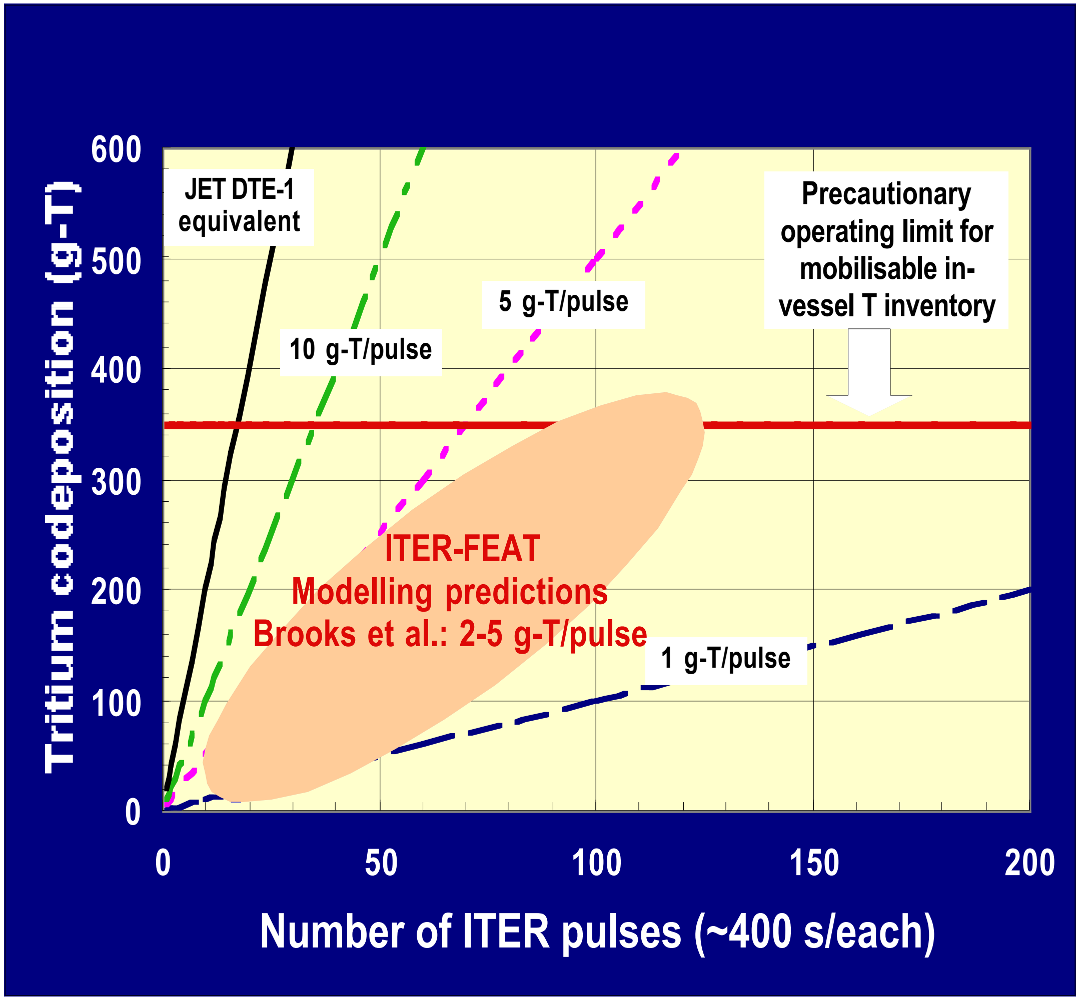
Tritium retention with CFC divertor

ITER

ITER plans to install CFC divertor with option to switch to more reactor relevant all-W armoured targets prior to D-T operation.

Change depends on:

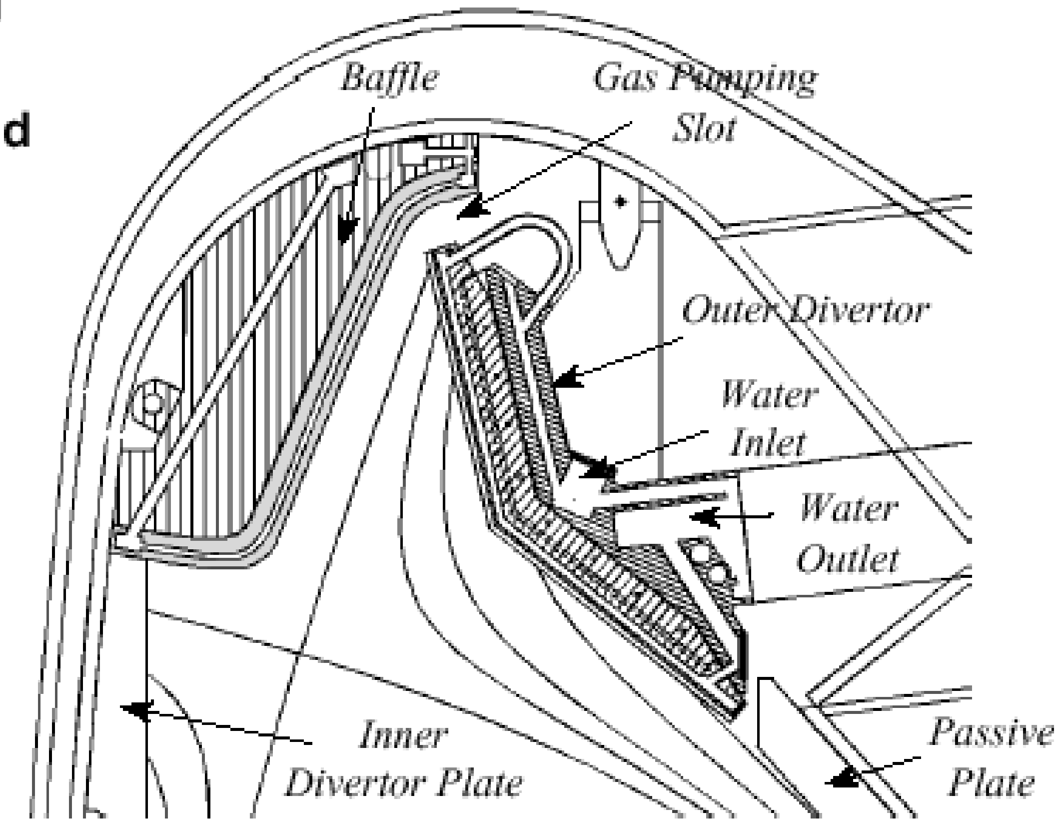
- frequency and severity of disruptions,
- success achieved in mitigating the effects of T co-deposition.



FIRE's Divertor Must Handle Attached(25 MW/m2) and Detached(5 MW/m2) Operation

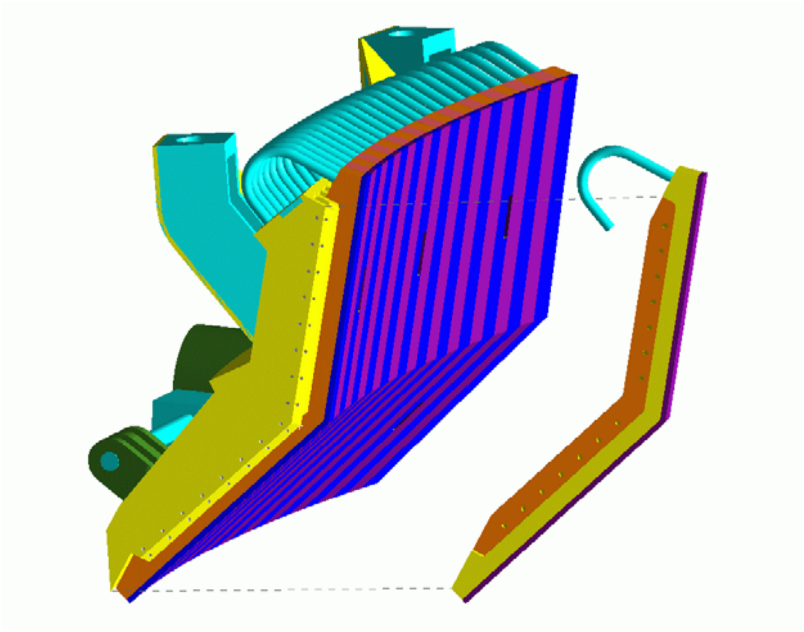
- Build on design/fabrication approaches developed during ITER-EDA
- W-brush armor for divertor and plasma-sprayed Be for first wall tiles
- Cu-alloy finger elements for high heat flux outer target
- Swirl tape or helical wire inserts for CHF enhancement
- Dome-like construction for lower heat flux baffle
- Passively-cooled W-Cu tiles for low heat flux inner target
- Modular units for remote maintenance during operation

D. Dreimeyer, M. Ulrickson



Divertor Module Components for FIRE

Sandia

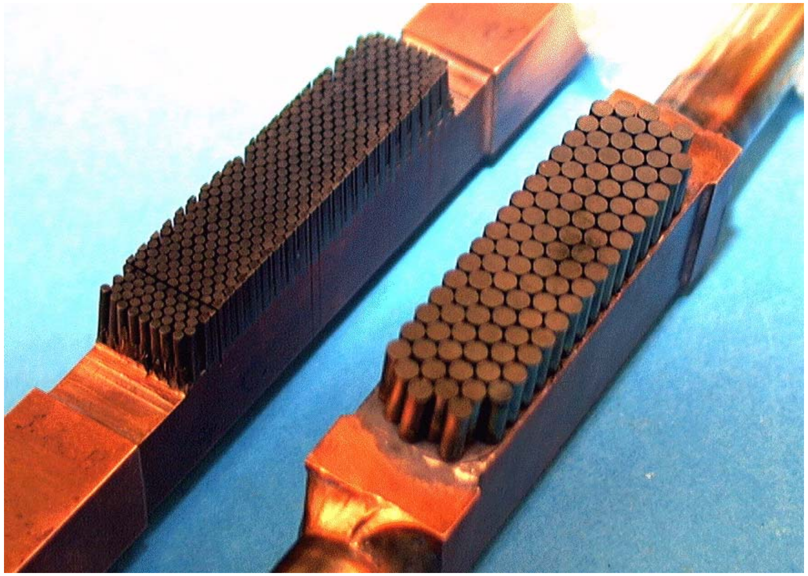


Finger Plate for

Outer Divertor Module

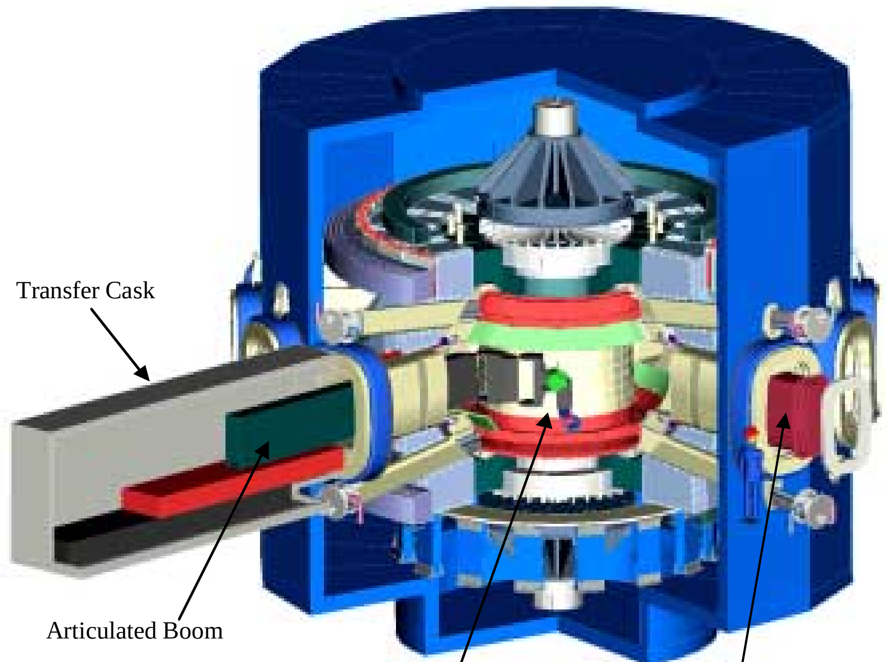
Two W Brush Armor Configurations

Tested at 25 MW/m^2



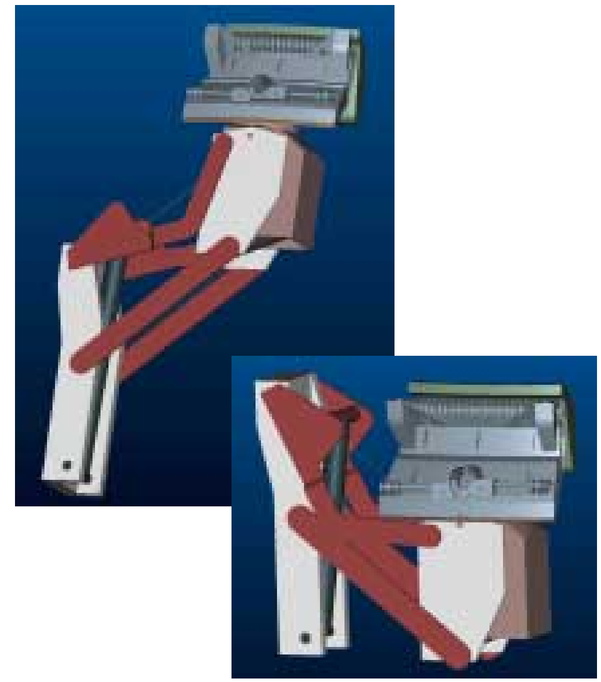
Carbon targets used in most experiments today are not compatible with tritium inventory requirements of fusion reactors.

FIRE In-Vessel Remote Handling System



In-vessel transporter

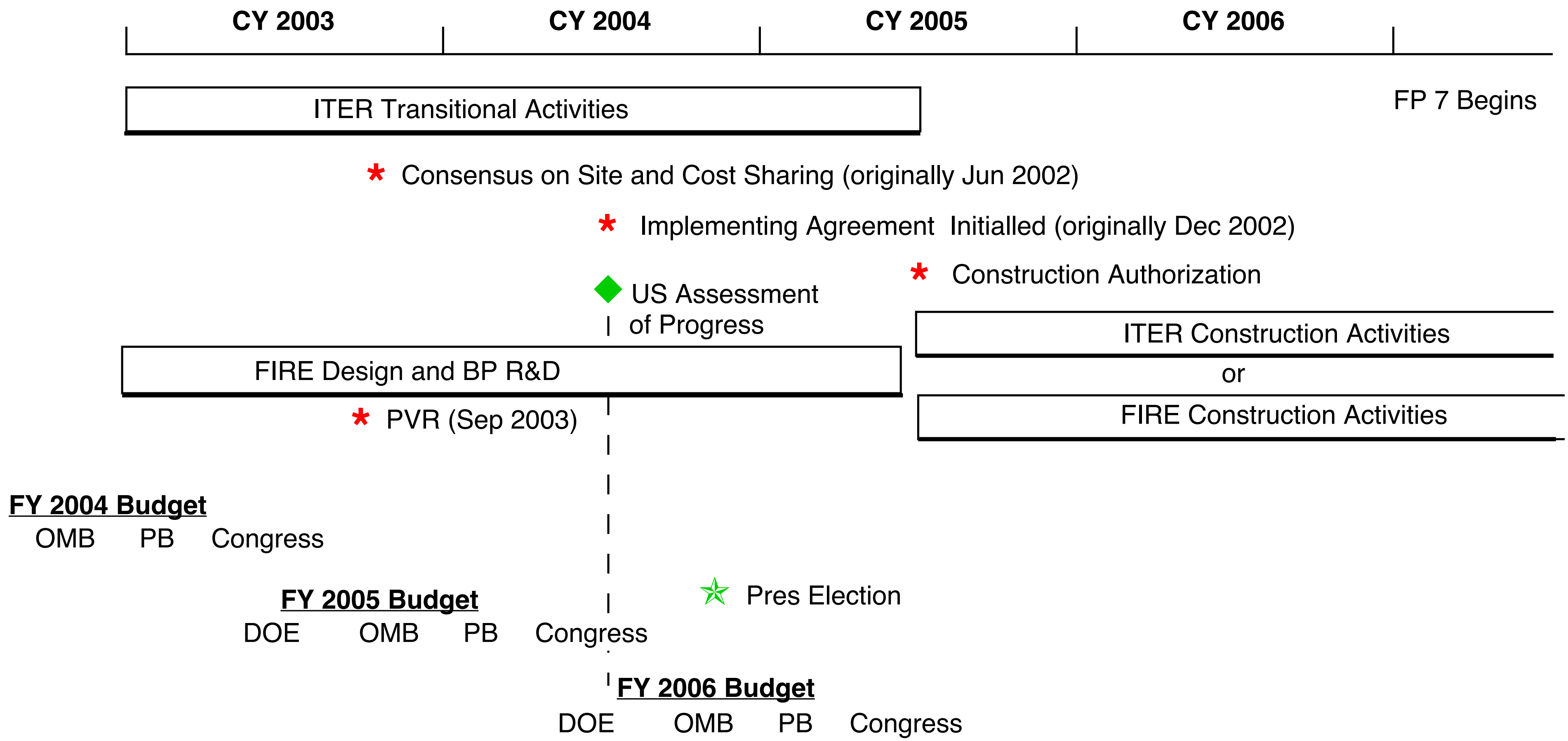
- Articulated boom deployed from sealed cask
- Complete in-vessel coverage from 4 midplane ports
- Fitted with different end-effector depending on component to be handled
- First wall module end-effector shown



Divertor end-effector

- High capacity (module wt. ~ 800 kg)
- Four positioning degrees of freedom
- Positioning accuracy of millimeters required

Overall Schedule of Burning Plasma Activities



HR 6	**FY 2004**	**FY 2005**	**FY 2006**	**FY 2007**
Base	$ 276M	$ 300M	$ 340M	$ 350M
BP Prog	$ 12M	$ 20M	$ 50M	$ 75M
Total	$ 388M	$ 320M	$ 390M	$ 425M

S 14	**FY 2004**	**FY 2005**	**FY 2006**	**FY 2007**
Base	$335M	$ 349M	$ 362M	$ 377M
BP Const.	0	0	$ 55M	$ 95M
Total	$335M	$ 349M	$ 417M	$ 472M

FY 2003 Progress on FIRE

Response to Snowmass and NSP-PAC Critiques

- readjusted radial build of the center stack and the configuration to increase major radius to 2.14 and respond to Snowmass
- tripled pulse repetition rate by cooling both sides of TF inner leg
- SBIR on magnet insulation looks promising for increasing lifetime shots
- vacuum vessel/divertor support stresses now OK for disruptions in the 2m machine, need to scale up to 2.14m machine
- development of “steady-state” ARIES-like mode ($\beta_N \sim 4$, $f_{bs} \sim 80\%$)
- > doubled the pulse length of AT mode up to 5 τ_{CR}

Work in Progress

- scaling disruptions and disruption stresses to the 2.14m machine
- modeling of edge and divertor plasma power handling for 2.14 m and to extend power handling capability for AT modes
- feasibility study of resistive wall mode coil integrated with first wall
- study of a generic diagnostic integrated with shield and first wall
- evaluation of new proposal for FWCD launcher, and LHCD launcher.
- extending TSC simulations to latest versions of GLF23 transport model
- participating in ITPA and have an oral talk at EPS

FIRE PVR

- Fusion Community assessment of FIRE's capability to accomplish program
- Respond to previous reviews of FIRE
  - Engineering Review June 2001
  - Snowmass Technical assessment
  - NSO-PAC Recommendations
- Since resources are limited,
  - Propose to carry this out in mid September 2003.
  - Use NSO-PAC (plus additional experts) for review panel

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.

    - Respond to PVR chits and recommendations

    - Extend “advanced capability” – physics and technology

- 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)

FY 2004 Activities

Proposed Budget: $1.9M (Note: President's budget = 0)

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

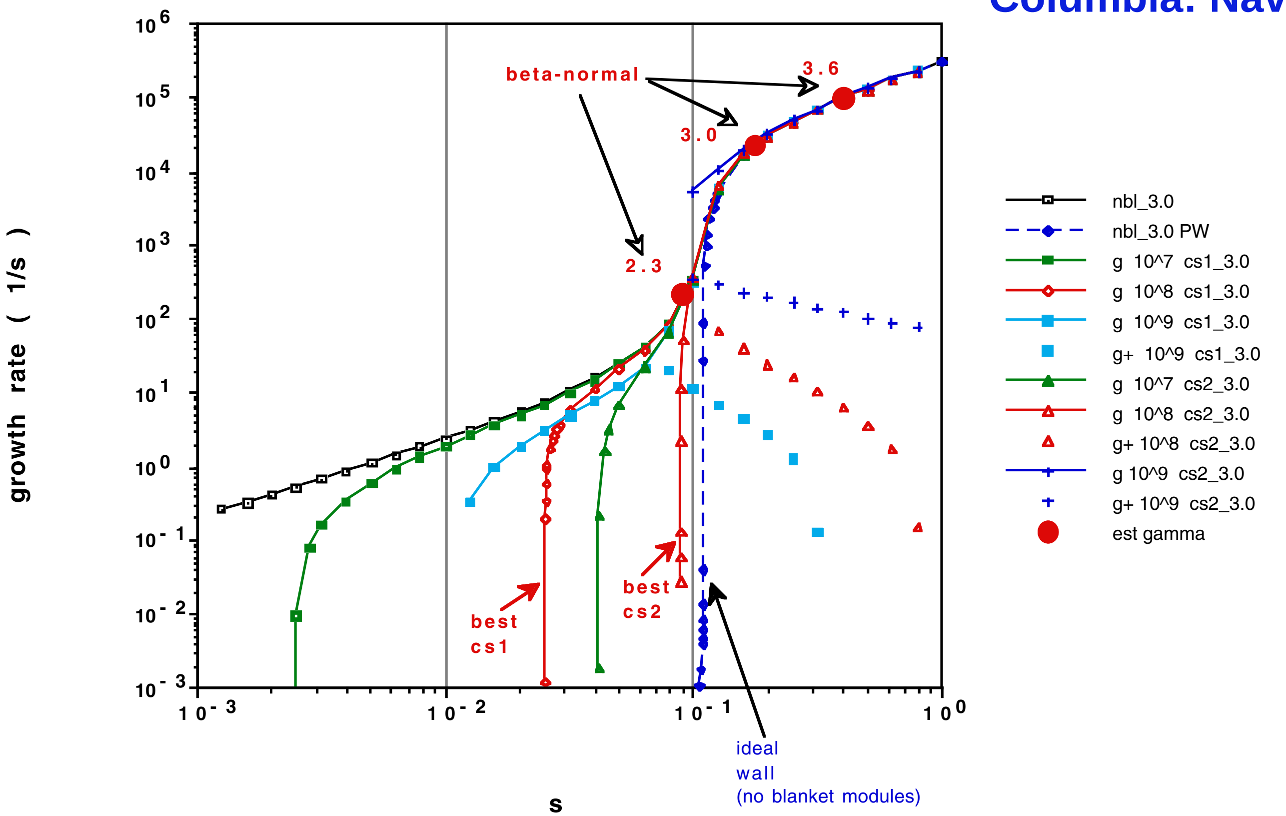
- Optimize PFCs to extend performance of FIRE and ITER $\Rightarrow$ ARIES
- Develop RWM technology (insulation, feedback control,..) for FIRE and ITER $\Rightarrow$ ARIES
- Disruption Mitigation Development for FIRE and ITER $\Rightarrow$ ARIES
- Plasma Engineering (ICRF, LHCD, Pellets, ..) with aim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

Example of a Joint FIRE-ITER Activity

Installation of FIRE-like Midplane Port Control Coils in ITER would Allow Significantly Higher Stable Beta Approaching the Ideal Limit

Data from "ITER.10.2002"

Columbia: Navratil, Bialek



- Base ITER feedback coils outside the TF Coils (cs1) stabilize only ~ 20% above the no-wall beta limit.
- Feedback coils in 9 of the 18 mid-plane ports (cs2) can approach the ideal wall beta limit.

of beta_N = 3.6 for n = 1 (Note: n = 2 limit at beta_N = 3.5 for ITER)

Burning Plasma Initiatives or Task Forces

- Advanced Tokamak (U. S. Plan to achieve required capability-ARIES as guide) (κ, δ, A, SN/DN, β_N, f_{bs}, ……)
  - PFCs (high heat flux, tritium retention)
  - RWM Stabilization What is required and what is feasible?
  - Integrated Divertor and AT
- Plasma Control (heating, current-drive, fueling, fast position control)
- Integrated Simulation of Burning Plasmas
- Diagnostic Development, a long term program is needed.
- Plasma Facing Components for BPs and reactor.

Concluding Remarks

- The Administration has shown an interest in fusion and has approved joining the ITER negotiations. Congress has also shown interest with Authorization bills that support ITER if it goes ahead, and support FIRE if ITER does not go ahead. This is consistent with the consensus in the fusion community.

- The step to a burning plasma experiment – either ITER or FIRE – is large and technically challenging. Success with either would provide a strong signal that magnetic fusion could be a practical energy source.

- However, budgets will be very tight in the coming years, and the fusion community will have to make a compelling case that fusion is an important part of Energy Independence.

- Near term progress would be enhanced by the formation of Burning Plasma Task Forces to address technical issues for ITER/FIRE. We must continue to make progress in critical areas even if construction is delayed.