Diversified International Portfolio for Magnetic Fusion

and FIRE

Dale M. Meade

for the FIRE Study Team

Seminar at
Idaho National Engineering and Environmental Laboratory
Idaho Falls, ID

May 23, 2002

http://fire.pppl.gov

Outline

- Fusion Goals
- Critical Issues for Fusion
- Strategy for a Road Map
- FIRE
    - Goals
    - Characteristics
    - Issues/Challenges

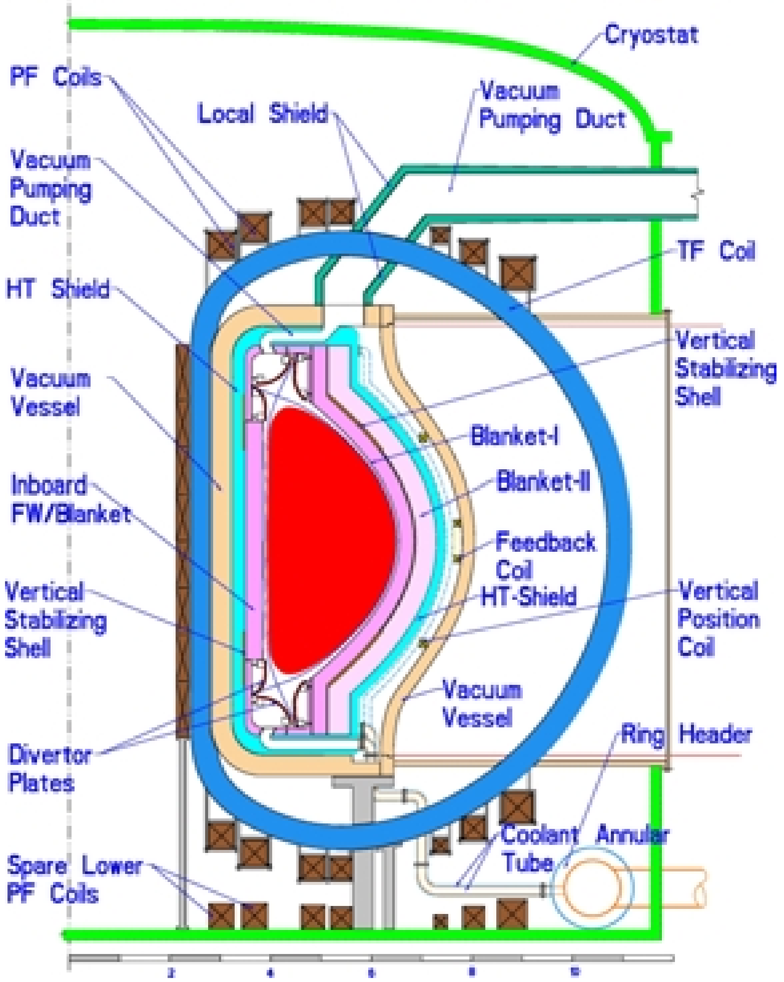
- Plans for the Future

The Key Features for an Attractive Fusion Power Plant have been Identified

Desired Characteristics

- Power gain $Q \geq 25$
  $n\tau_E T_i > 6 \times 10^{21}\ m^{-3}\ s\ keV$
- Power density $\geq 6\ MWm^{-3}$
  high beta $= p_{plasma}/p_{mag} > 5\%$
- Wall Loading $> 3\ MW\ m^{-2}$
- Steady state
  bootstrap current > 90%
- High availability
  First Wall Materials > 150 dpa
- Safety and Environment
  low activation materials
  no evacuation

Cross Section of ARIES-AT Power Core Configuration



Pfusion = 1.7GW, Pe = 1 GW

Critical Issues to be Addressed in the Next Stage of Fusion Research

- **Burning Plasma Physics**
  - strong nonlinear coupling inherent in a fusion dominated plasma
  - access, explore and understand fusion dominated plasmas

- **Advanced Toroidal Physics**
  - develop and test physics needed for an attractive MFE reactor
  - couple with burning plasma physics

- **Boundary Physics and Plasma Technology** (coupled with above)
  - high particle and heat flux
  - couple core and divertor
  - fusion plasma - tritium inventory and helium pumping

- **Neutron-Resistant Low-Activation Materials**
  - high fluence material testing facility using “point”neutron source

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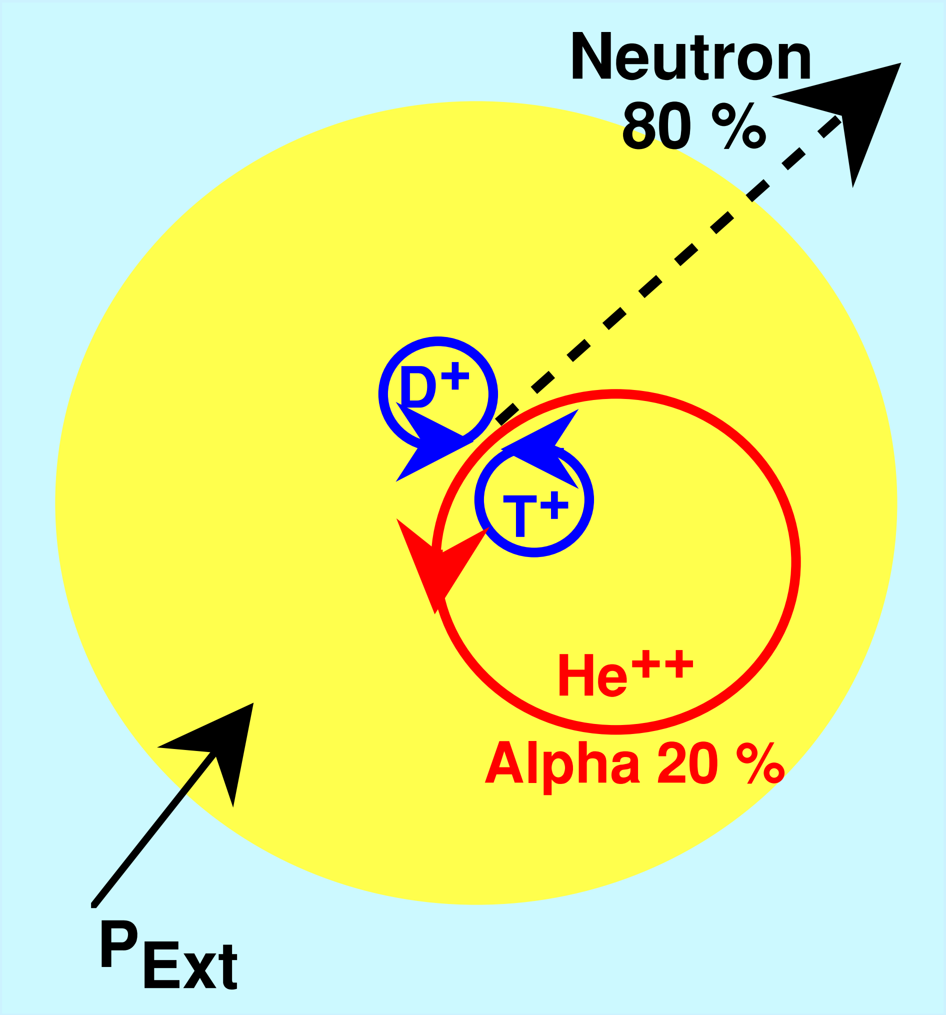
  - high fluence component testing facility using volume neutron source

- Superconducting Coil Technology does not have to be coupled to physics experiments - only if needed for physics objectives

Burning Plasma Physics in a D-T Fusion Reactor



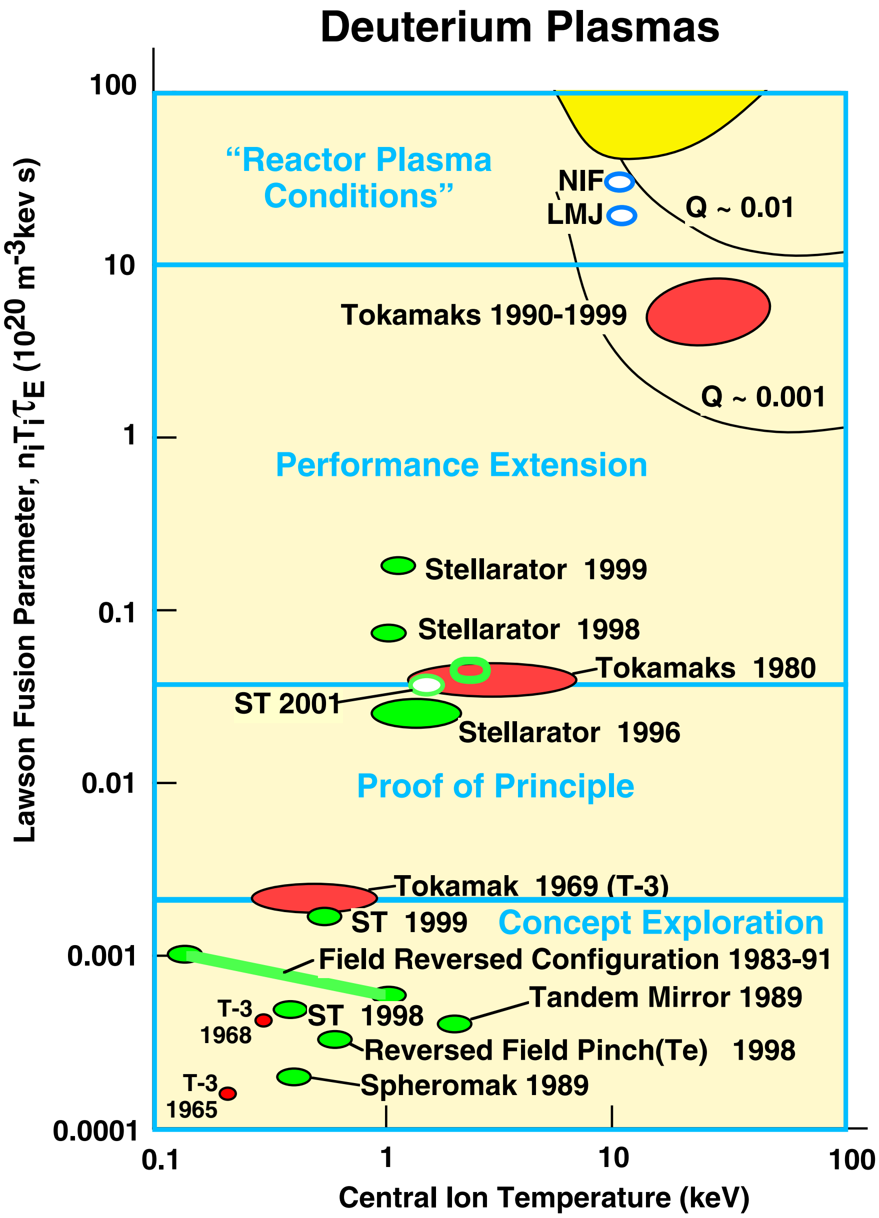
Alpha Physics Issues

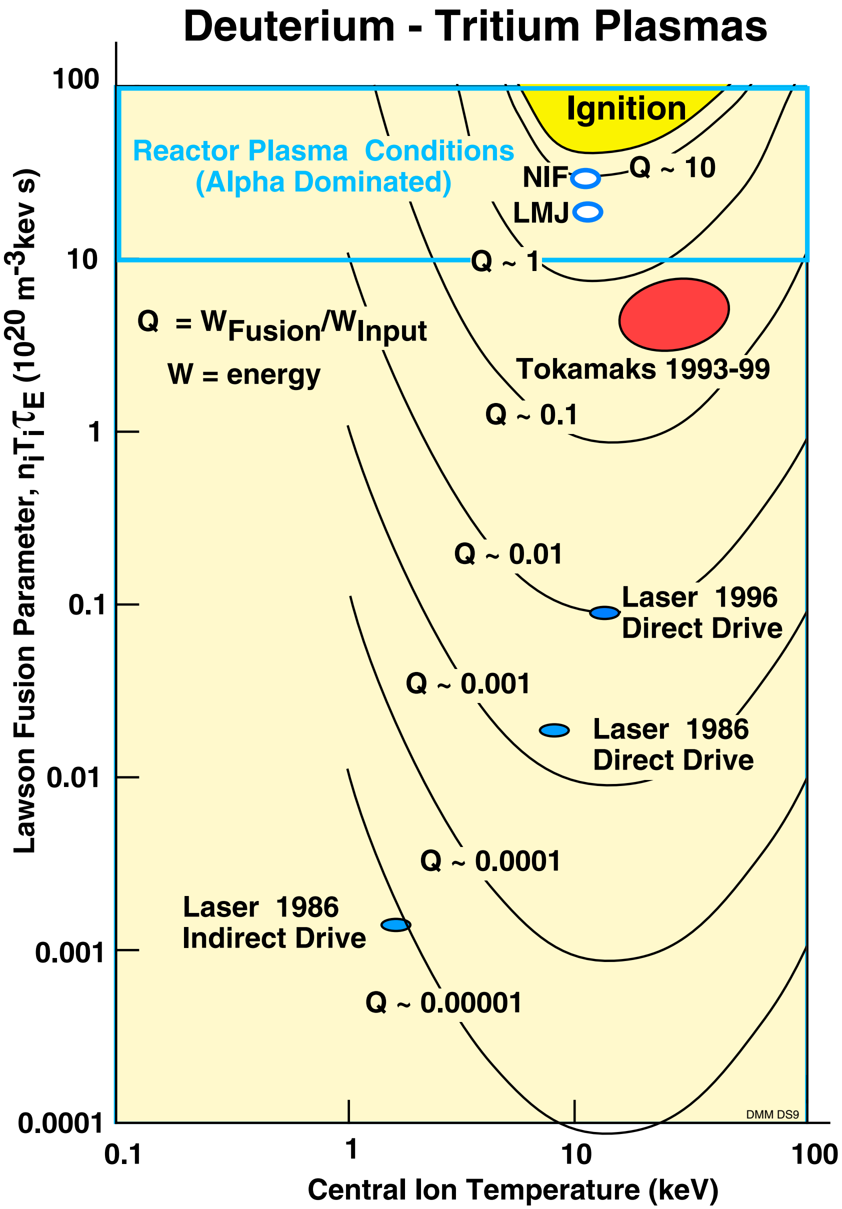
- Alpha confinement
- Alpha Energy to Plasma
  from alphas
  to plasma electrons
- Burn Control
- Alpha Ash Removal
- Alpha Driven Instabilities

$$Q = \frac{P_{Fusion}}{P_{Ext}}, \quad f_{\alpha} = \frac{P_{alpha}}{P_{Heat}} = \frac{Q}{Q+5}$$

The alpha particle, which has 20% of the fusion reaction energy, remains trapped in the plasma and heats the plasma.

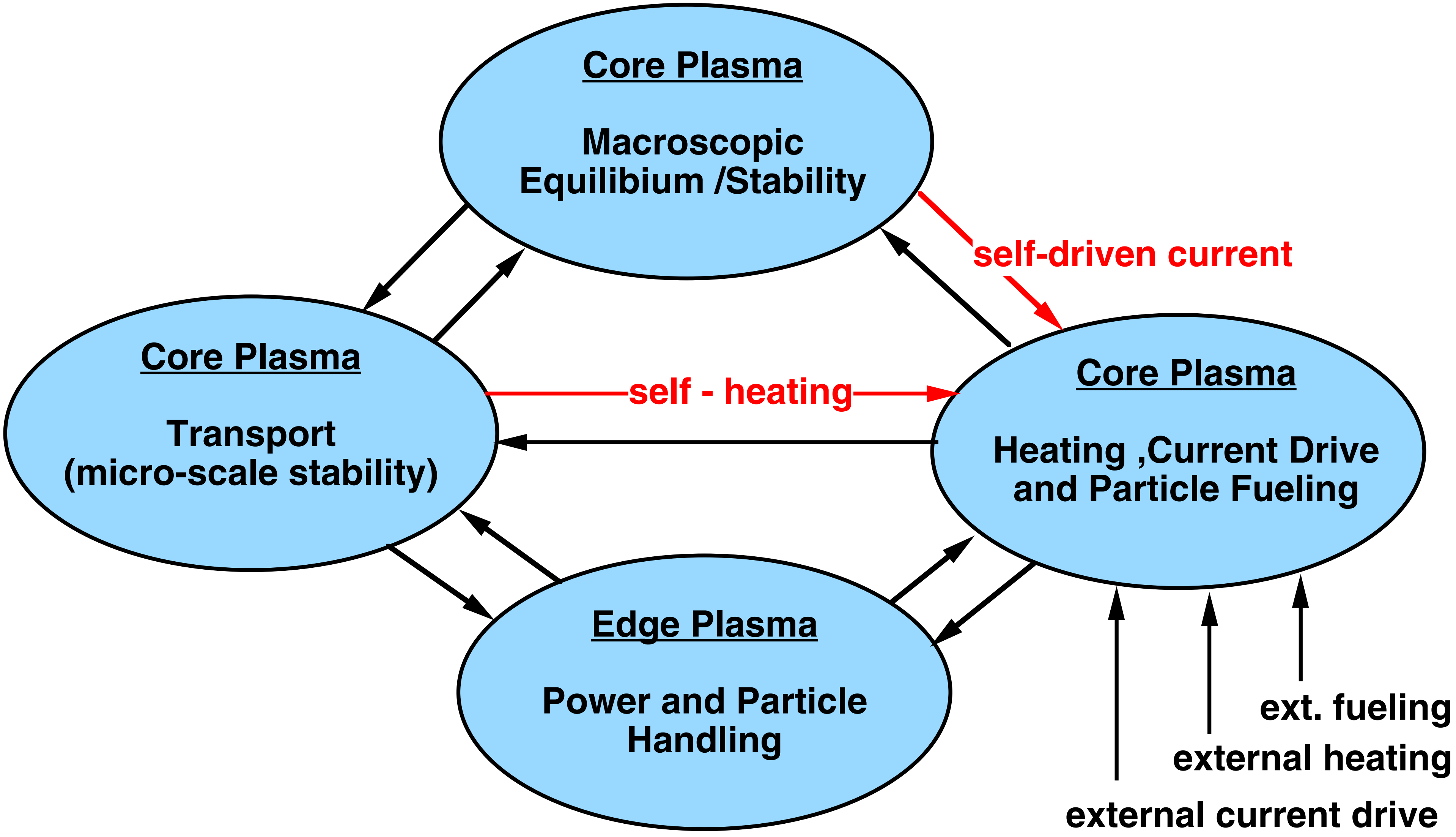
The Tokamak is Technically Ready for a High Gain Burning Exp't


Deuterium Plasmas


Deuterium - Tritium Plasmas

The tokamak is sufficiently advanced to permit the design, construction and initiation of a next step burning plasma experiment within the next decade that could address the fusion plasma and self-heating issues for magnetic fusion.

Fusion Plasmas are Complex Non-Linear Dynamic Systems



Core Plasma

Macroscopic
Equilibium /Stability

Core Plasma

Transport
(micro-scale stability)

Core Plasma

Heating ,Current Drive
and Particle Fueling

Edge Plasma

Power and Particle
Handling

self-driven current

self - heating

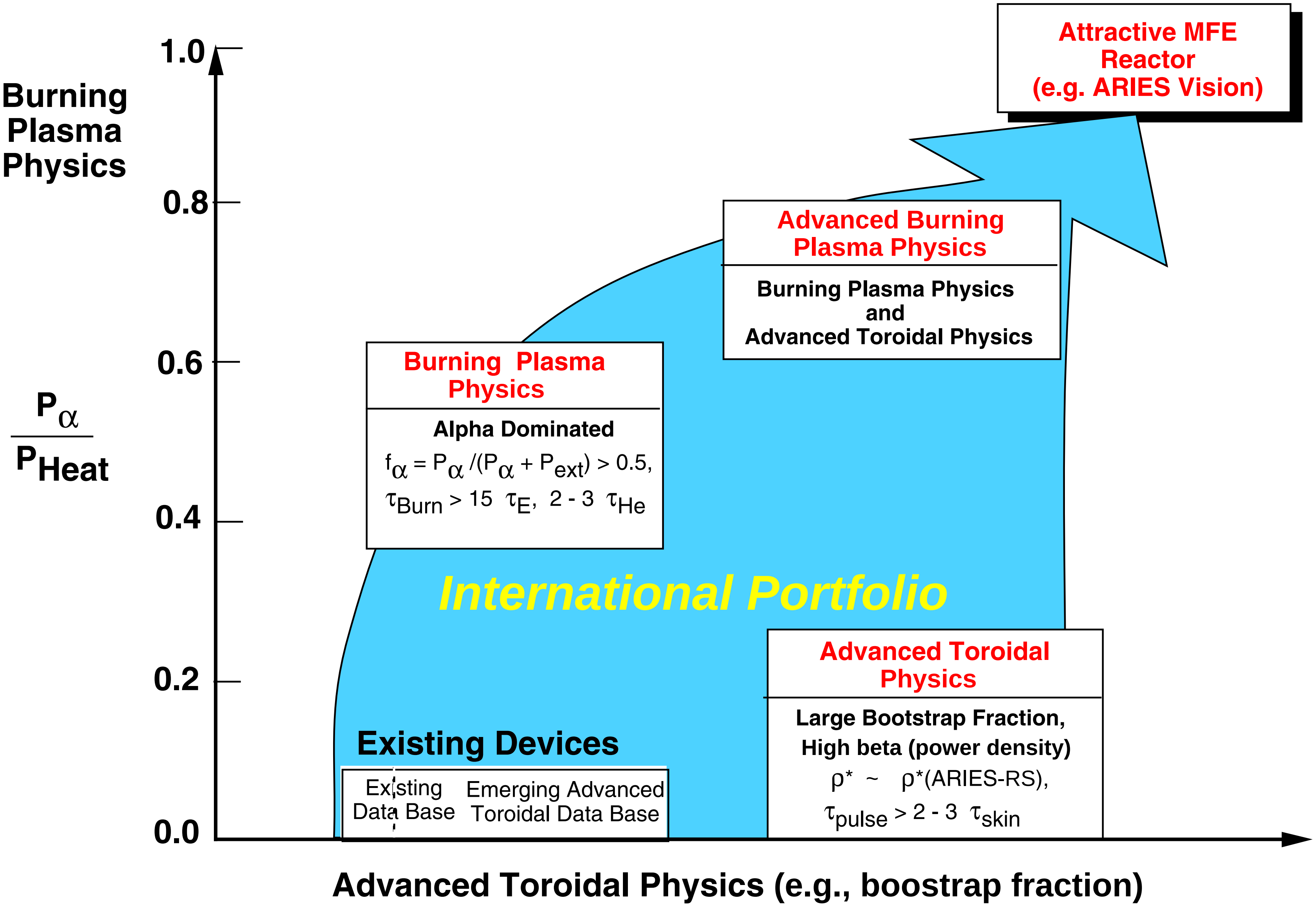
ext. fueling

external heating

external current drive

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

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



Attractive MFE Reactor (e.g. ARIES Vision)

Advanced Burning Plasma Physics

Burning Plasma Physics
and
Advanced Toroidal Physics

Burning Plasma Physics

Alpha Dominated

$f_\alpha = P_\alpha/(P_\alpha + P_{ext}) > 0.5$,

$\tau_{Burn} > 15\ \tau_E$, $2 - 3\ \tau_{He}$

Advanced Toroidal Physics

Large Bootstrap Fraction,
High beta (power density)

$\rho^* \sim \rho^*$(ARIES-RS),

$\tau_{pulse} > 2 - 3\ \tau_{skin}$

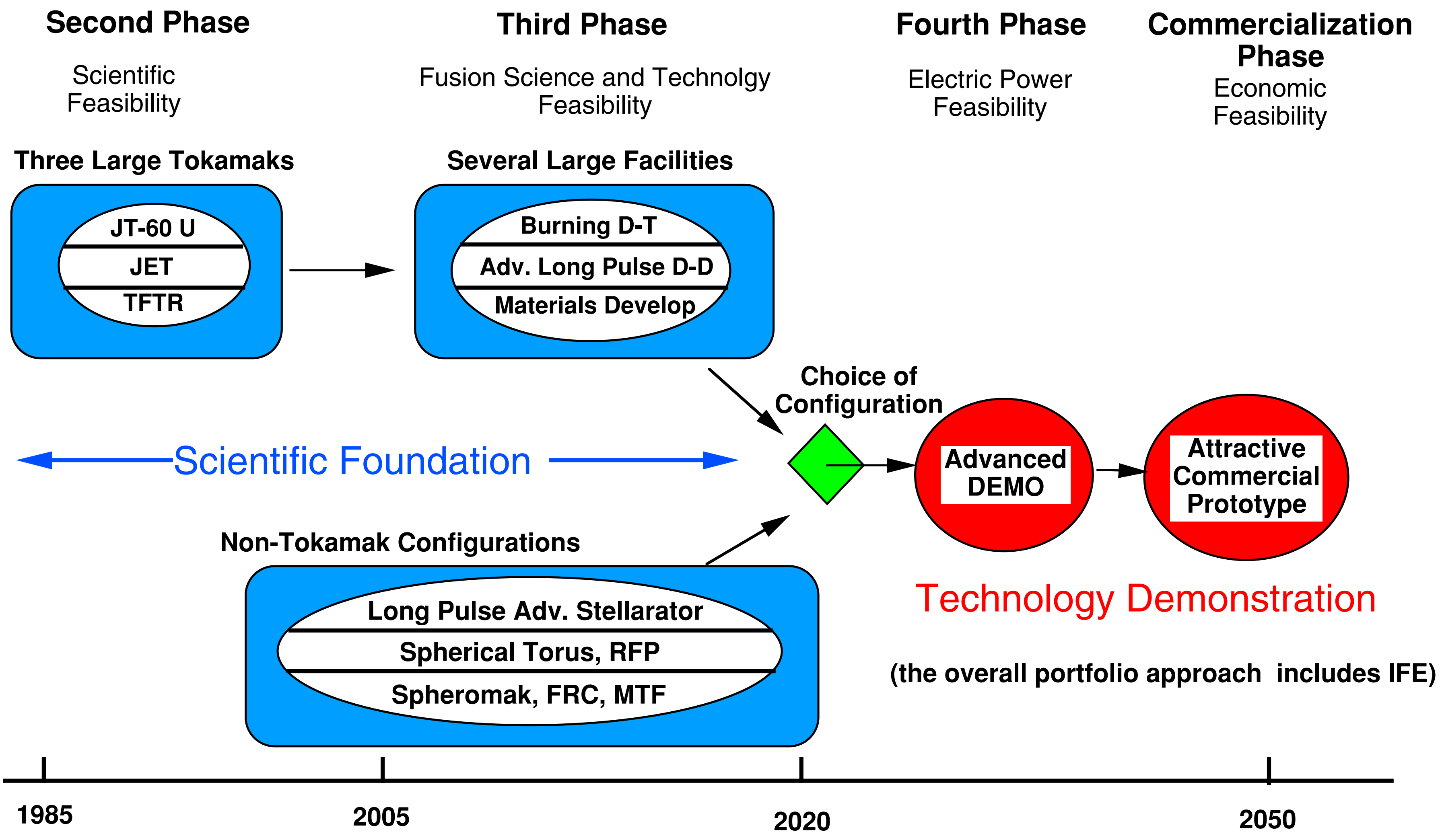
Existing Devices

Existing Data Base

Emerging Advanced Toroidal Data Base

Attain a burning plasma with confidence using “todays” physics, but allow the flexibility to explore tomorrow’s advanced physics.

Diversified International Portfolio for Magnetic Fusion



Second Phase

Scientific Feasibility

Third Phase

Fusion Science and Technolgy Feasibility

Fourth Phase

Electric Power Feasibility

Commercialization Phase

Economic Feasibility

Three Large Tokamaks

- JT-60 U
- JET
- TFTR

Several Large Facilities

- Burning D-T
- Adv. Long Pulse D-D
- Materials Develop

Choice of Configuration

Scientific Foundation

Non-Tokamak Configurations

- Long Pulse Adv. Stellarator
- Spherical Torus, RFP
- Spheromak, FRC, MTF

Advanced DEMO

Attractive Commercial Prototype

Technology Demonstration

(the overall portfolio approach includes IFE)

1985 **2005** **2020** **2050**

Reduced Technical Risk

Increased Technical Flexibility

Streamlined Management Structure

Faster Implementation

Better Product/Lower Overall Cost

Next Step Option (FIRE) Program Advisory Committee

- **Members:** Tony Taylor (Chair), Gerald Navratil, Ray Fonck, David Gates, Dave Hill, Wayne Houlberg, Tom Jarboe, Mitsuro Kikuchi, Earl Marmar, Raffi Nazikian, Craig Petty, Rene Raffray, Paul Thomas, James VanDam

- **Meetings**
  - July 20-21, 2000 at General Atomics, San Diego, CA.
  - January 17-18, 2001 at MIT, Cambridge, MA
  - July 10-11, 2001 at Univ. Wisc, Madison, WI
  - November 29-30 at LLNL, Livermore, CA
- **Charge for First and Second meetings**
  - Scientific value of a Burning Plasma experiment
  - Scientific readiness to proceed with such an experiment
  - Is the FIRE mission scientifically appropriate?
  - Is the initial FIRE design point optimal?

- Extensive PAC Reports provide detailed recommendations for the FIRE activity to address. NSO-PAC reports are on FIRE (http://fire.pppl.gov), will discuss in more detail under FY 2001-03 Plans.

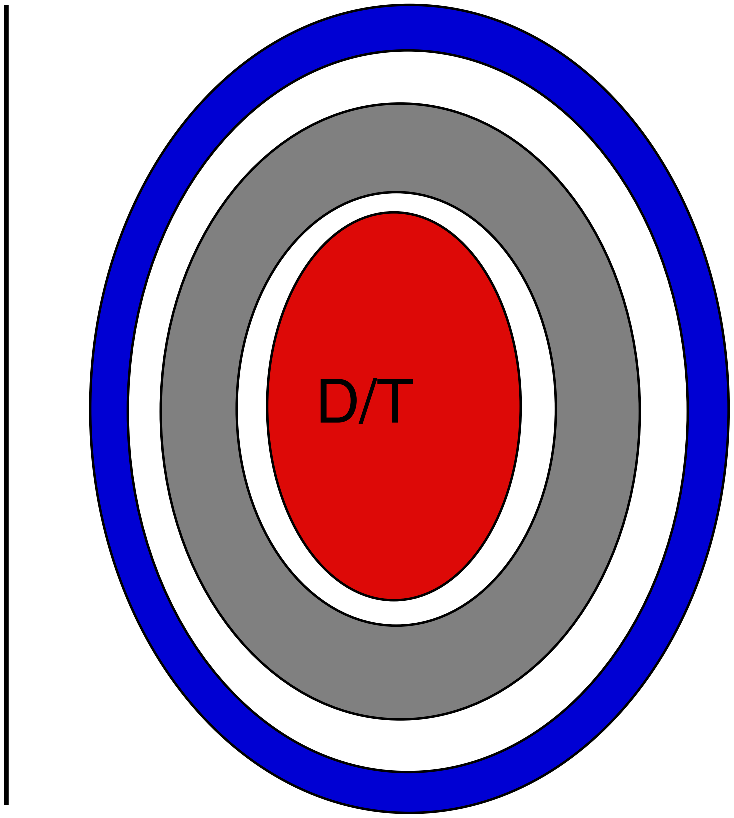
FIRE Study is a Pre-Conceptual design, integrated costs (1998-2002) <$12M.

Participants in the FIRE Engineering Design Study

FIRE is a design study for a major Next Step Option in magnetic fusion and is carried out through the Virtual Laboratory for Technology. FIRE has benefited from the prior design and R&D activities on BPX, TPX and ITER.

Advanced Energy Systems
Argonne National Laboratory
DAD Associates
General Atomics Technology
Georgia Institute of Technology
Idaho National Engineering Laboratory
Lawrence Livermore National Laboratory
Massachusetts Institute of Technology
Oak Ridge National Laboratory
Princeton Plasma Physics Laboratory
Sandia National Laboratory
Stone and Webster
The Boeing Company
University of Illinois
University of Wisconsin

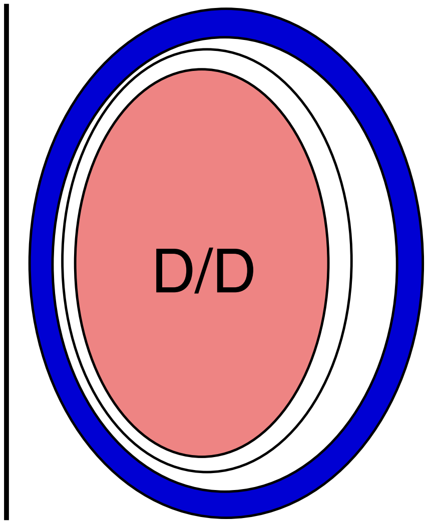
Evolution of Multi-Machine (International Portfolio) Strategy



ITER (400 MW)

- NbSn, LHe
- B = 5.3T, Ip = 15 MA
- Mag Energy = 50 GJ
- Vol p = 840 m3
- Surface pl = 600 m2

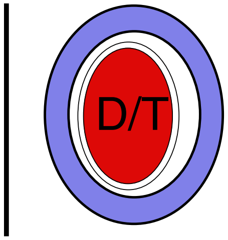
Cost ≥ $8B (US methodology)



KSTAR, (JT-60 SC)

- NbSn (NbAl), LHe
- B = 3.5T(4T), Ip = 1.8 MA(4 MA)
- Mag. Energy = 0.6 GJ

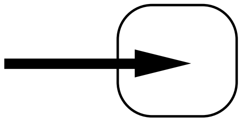
Cost = $0.3B + $0.5B < $1B



FIRE (150 MW)

- BeCu/CuCrZr/OFHC, LN
- B = 10 T, Ip = 7.7 MA
- Mag. Energy 6 GJ
- Vol pl = 27m3
- Surface pl = 60 m2

Cost ≈ $1.2B - Site Credits



IFMIF

- 2 MW/m2
- 10 liter

Cost ≈ $0.8B

Advanced Burning Plasma Exp't Requirements

Burning Plasma Physics

Q	≥ 5,	~ 10 as target,	ignition not precluded
$f_\alpha = P_\alpha/P_{heat}$	$\geq 50\%$, $\sim 66\%$ as target, up to 83% at $Q = 25$		
TAE/EPM	stable at nominal point, able to access unstable		

Advanced Toroidal Physics

$f_{bs} = I_{bs}/I_p$	$\geq 50\%$	up to 75%
β_N	~ 2.5, no wall	~ 3.6, $n = 1$ wall stabilized

Quasi-stationary Burn Duration

Pressure profile evolution and burn control	$> 10\ \tau_E$
Alpha ash accumulation/pumping	$>$ several τ_{He}
Plasma current profile evolution	1 to 3 τ_{skin}
Divertor pumping and heat removal	several $\tau_{divertor}$

FIRE has Adopted the Advanced Tokamak Features Identified by ARIES Studies

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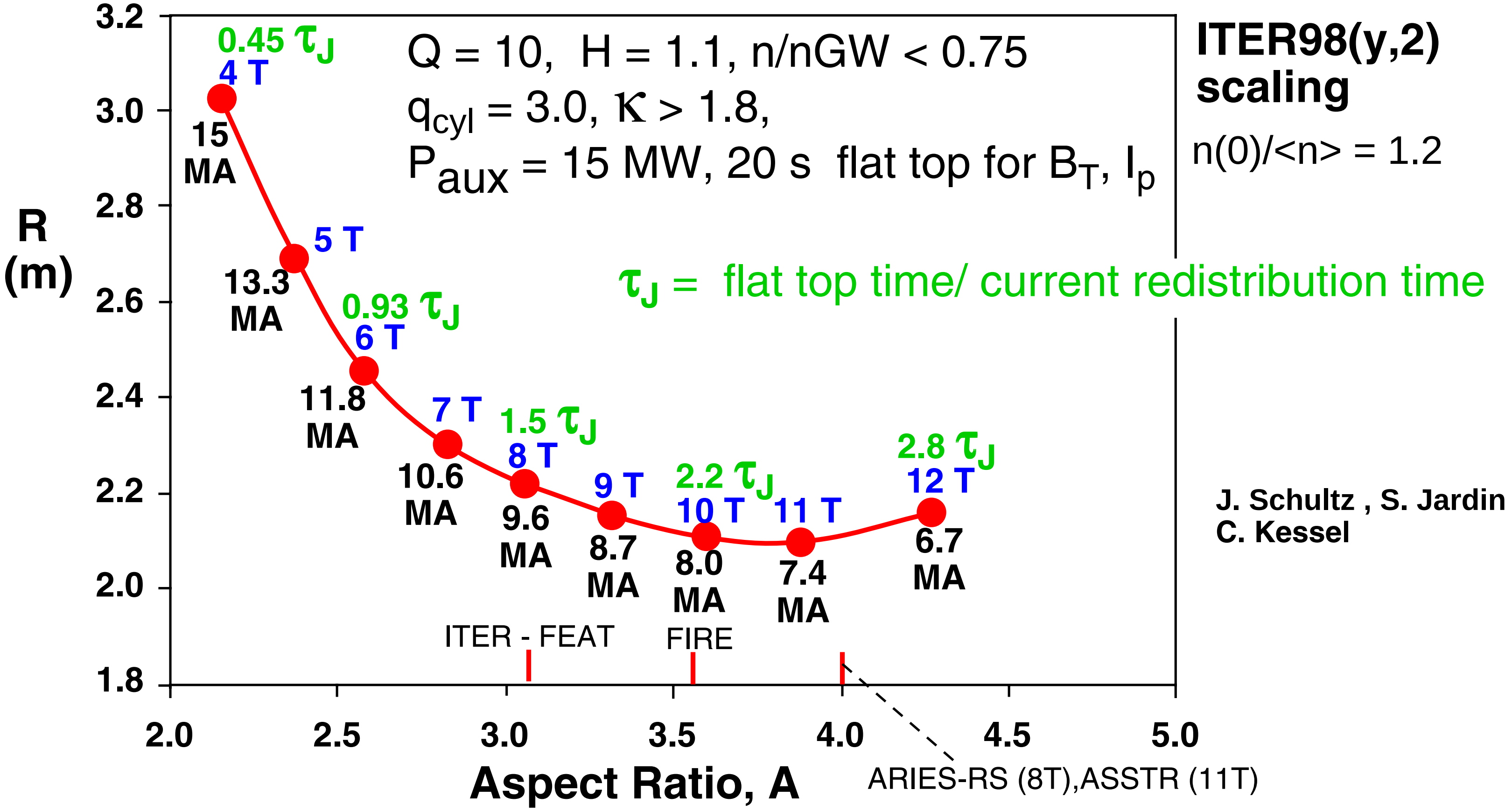
- High toroidal field
- Double null
- Strong shaping
  - $\kappa = 2.0$, $\delta = 0.7$
- Internal vertical position control coils
- Cu wall stabilizers for vertical and kink instabilities
- Very low ripple (0.3%)
- ICRF/FW on-axis CD
- LH off-axis CD
- LHCD stabilization of NTMs
- Tungsten divertor 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

Optimization of a Burning Plasma Experiment (H-Mode)

- 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.



$Q = 10$, $H = 1.1$, $n/n_{GW} < 0.75$
$q_{cyl} = 3.0$, $\kappa > 1.8$,
$P_{aux} = 15$ MW, 20 s flat top for B_T, I_p

τ_J = flat top time/ current redistribution time

ITER98(y,2) scaling

$n(0)/\langle n\rangle = 1.2$

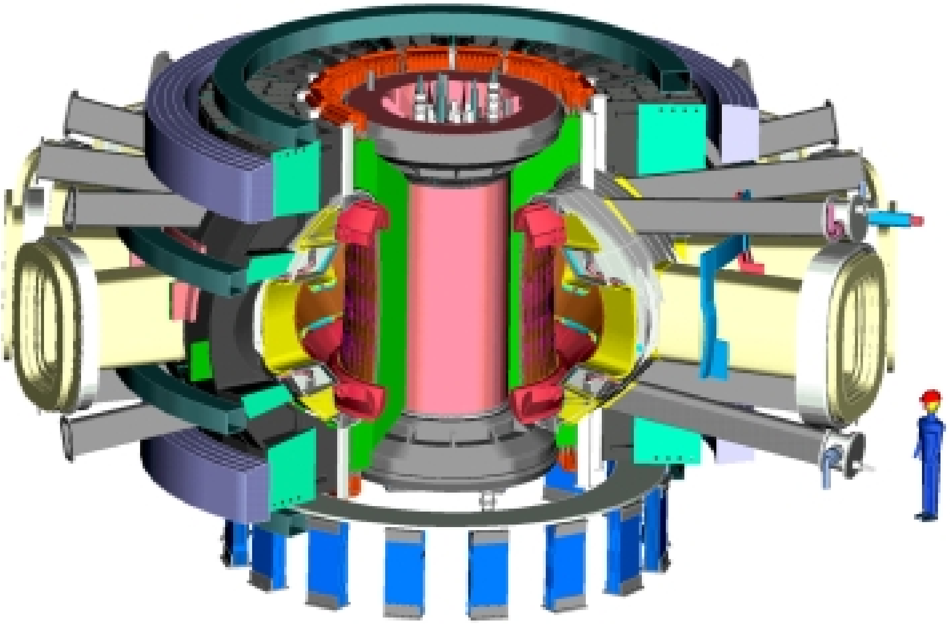
J. Schultz , S. Jardin
C. Kessel

What is the optimum for advanced steady-state modes?

Fusion Ignition Research Experiment

(FIRE)

http://fire.pppl.gov



Design Features

- R = 2.14 m, a = 0.595 m
- B = 10 T
- W_{mag}= 5.2 GJ
- I_p = 7.7 MA
- $P_{aux} \leq$ 20 MW
- Q ≈ 10, P_{fusion} ~ 150 MW
- Burn Time ≈ 20 s
- Tokamak Cost ≈ $375M (FY99)
- Total Project Cost ≈ $1.2B at Green Field site.

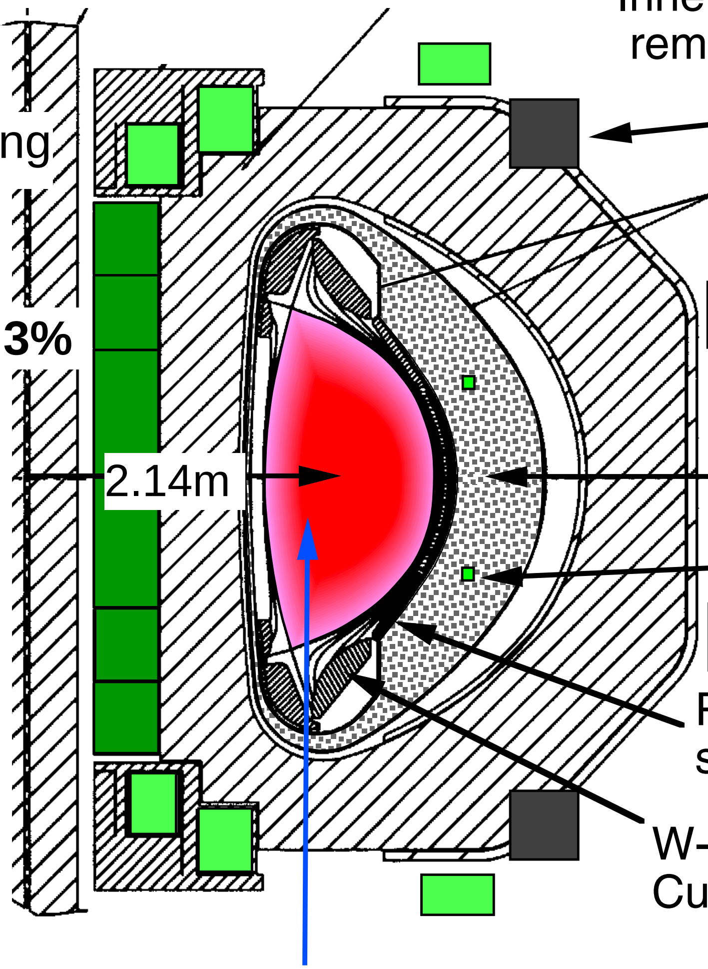
Mission: Attain, explore, understand and optimize magnetically-confined fusion-dominated plasmas.

CIT + TPX = FIRE leading to ARIES

High-Field Copper-Alloy Coils have Advantages for BP Expt's

AT Features

- DN divertor pumping
- strong shaping
- very low ripple **< 0.3%**
- internal coils
- space for wall stabilizers
- inside pellet injection
- large access ports



Wedged TF Coils (16), 15 plates/coil*
Inner Leg BeCu C17510,
remainder OFHC C10200

Compression Ring

Double Wall Vacuum Vessel (316 S/S)

All PF and CS Coils*
OFHC C10200

Internal Shielding
(60% steel & 40%water)

Vertical Feedback and Error Field Correction Coils

Passive Stabilizer Plates
space for wall mode stabilizers

W-pin Outer Divertor Plate
Cu backing plate, actively cooled

Direct and Guided Inside Pellet Injection

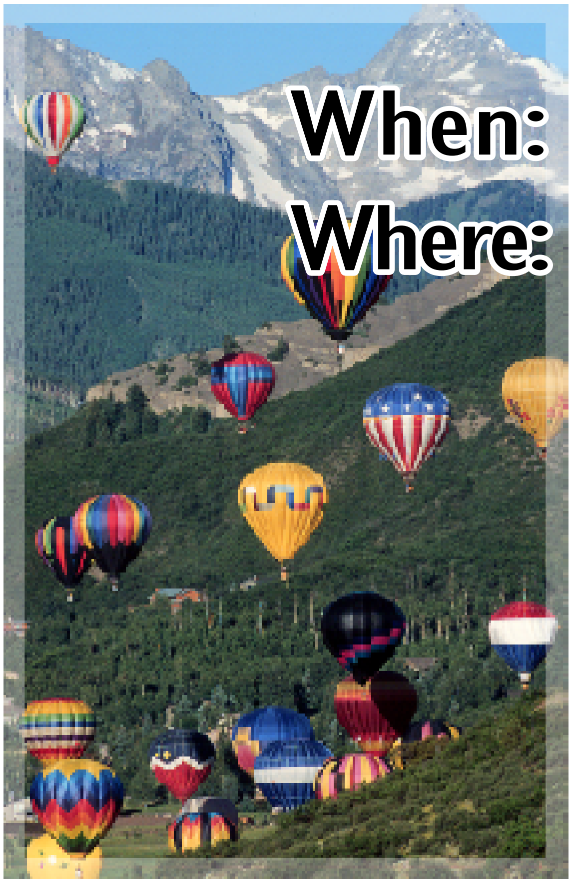
*Coil systems cooled to 77 °K prior to pulse, rising to 373 °K by end of pulse.

FIRE Cross/Persp- 5/25//DOE

Basic Parameters and Features of FIRE

R, major radius	2.14 m
a, minor radius	0.595 m
κx, κ95	2.0, 1.77
δx, δ95	0.7, 0.55(AT) - 0.4(OH)
q95, safety factor at 95% flux surface	>3
Bt, toroidal magnetic field	10 T with 16 coils, 0.3% ripple @ Outer MP
Toroidal magnet energy	5.8 GJ
Ip, plasma current	7.7 MA
Magnetic field flat top, burn time	28 s at 10 T in dd, 20s @ Pdt ~ 150 MW)
Pulse repetition time	~3hr @ full field and full pulse length
ICRF heating power, maximum	20 MW, 100MHz for 2ΩT, 4 mid-plane ports
Neutral beam heating	Upgrade for edge rotation, CD - 120 keV PNBI?
Lower Hybrid Current Drive	Upgrade for AT-CD phase, ~20 MW, 5.6 GHz
Plasma fueling	Pellet injection (≥2.5km/s vertical launch inside mag axis, guided slower speed pellets)
First wall materials	Be tiles, no carbon
First wall cooling	Conduction cooled to water cooled Cu plates
Divertor configuration	Double null, fixed X point, detached mode
Divertor plate	W rods on Cu backing plate (ITER R&D)
Divertor plate cooling	Inner plate-conduction, outer plate/baffle- water
Fusion Power/ Fusion Power Density	150 - 200 MW, ~6 -8 MW m-3 in plasma
Neutron wall loading	~ 2.3 MW m-2
Lifetime Fusion Production	5 TJ (BPX had 6.5 TJ)
Total pulses at full field/power	3,000 (same as BPX), 30,000 at 2/3 Bt and Ip
Tritium site inventory	Goal < 30 g, Category 3, Low Hazard Nuclear Facility

- A forum for the critical assessment of major next-steps in the fusion energy sciences.
- Provide crucial community input to the long range planning activities undertaken by the DOE and the FESAC.
- Assess benefits of a tokamak burning plasma.
- Evaluate the contributions of various MFE approaches.
- Examine initiatives in integrated research experiments in IFE.



When: **JULY 8-19, 2002**

Where: **SNOWMASS, CO**

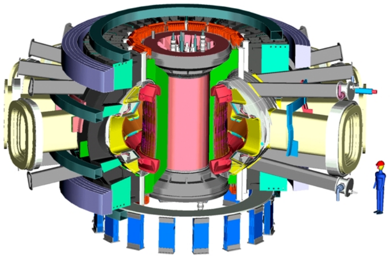
PROGRAM COMMITTEE CO-CHAIRS
ROGER BANGERTER, Lawrence Berkeley National Laboratory
GERALD NAVRATIL, Columbia University
NED SAUTHOFF, Princeton University

FOR MORE INFORMATION:
http://web.gat.com/snowmass/

ENDORSED BY: U.S. Department of Energy; and American Physical Society, Division of Plasma Physics and Division of Physics of Beams

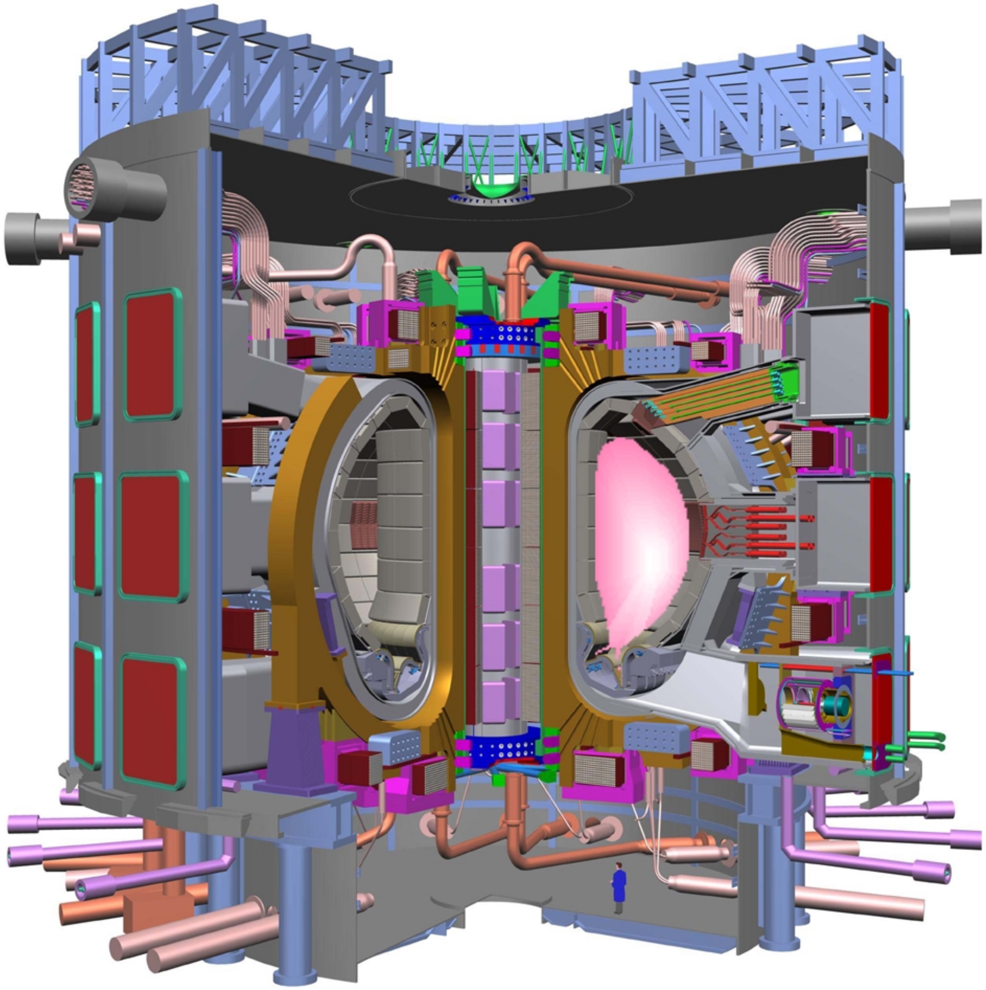
Burning Plasma Physics - The Next Frontier

Three Options
(same scale)



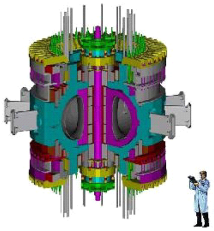
FIRE

US Based
Diversified International Portfolio



ITER-FEAT

JA, EU or CA Based
International Partnership



IGNITOR

Italian Based
International Collaboration

FIRE is a Modest Extrapolation in Plasma Confinement

Dimensionless Parameters

$\omega_c\tau = B\,\tau$

$\rho^* = \rho/a$

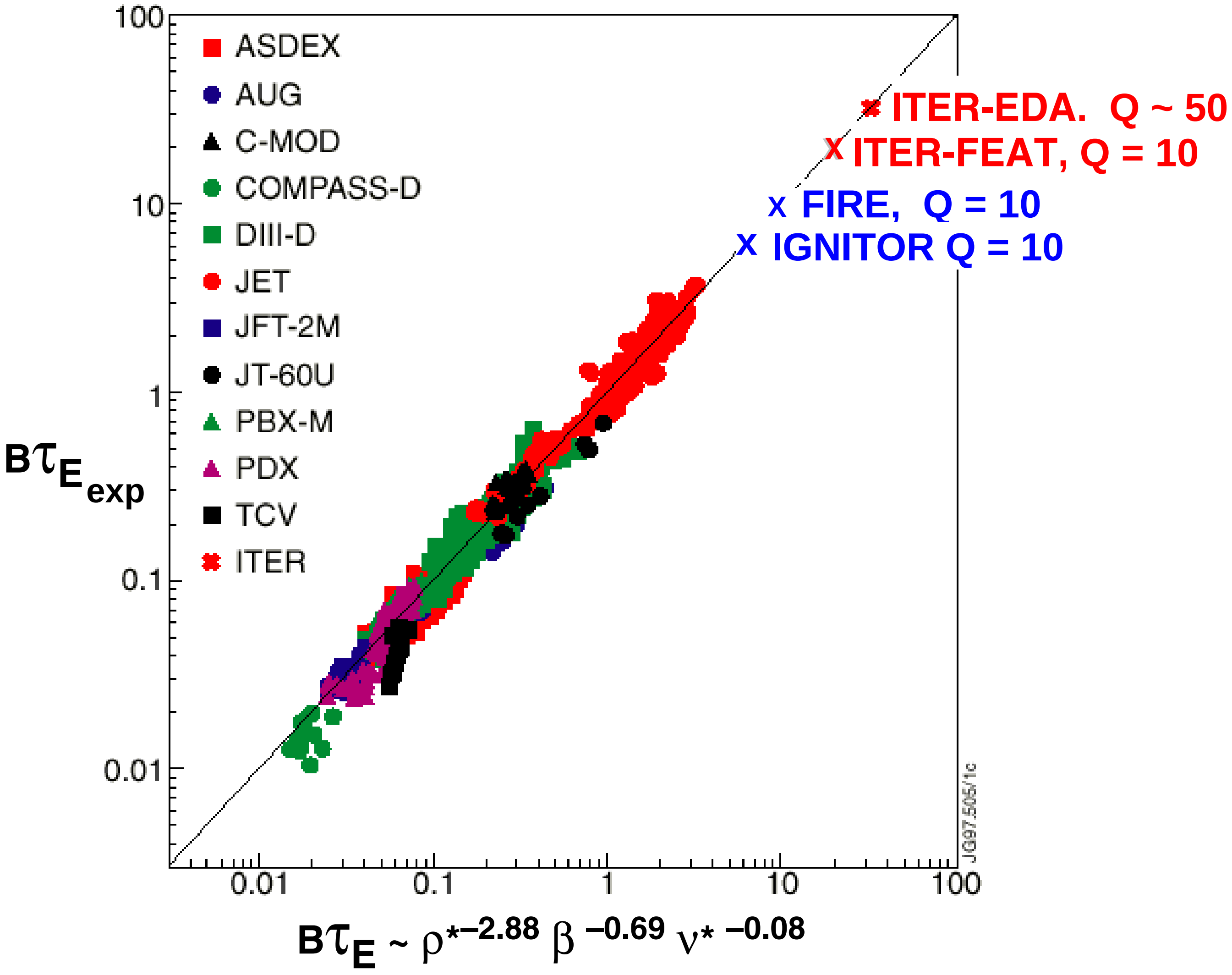
$\nu^* = \nu_c/\nu_b$

β

Similarity Parameter

$B\,R^{5/4}$

Kadomtsev, 1975



Guidelines for Estimating Plasma Performance

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

$\beta \leq \beta_N(I_p/aB)$, $\beta_N < 2.5$ **conventional,** $\beta_N \sim 4$ **advanced**

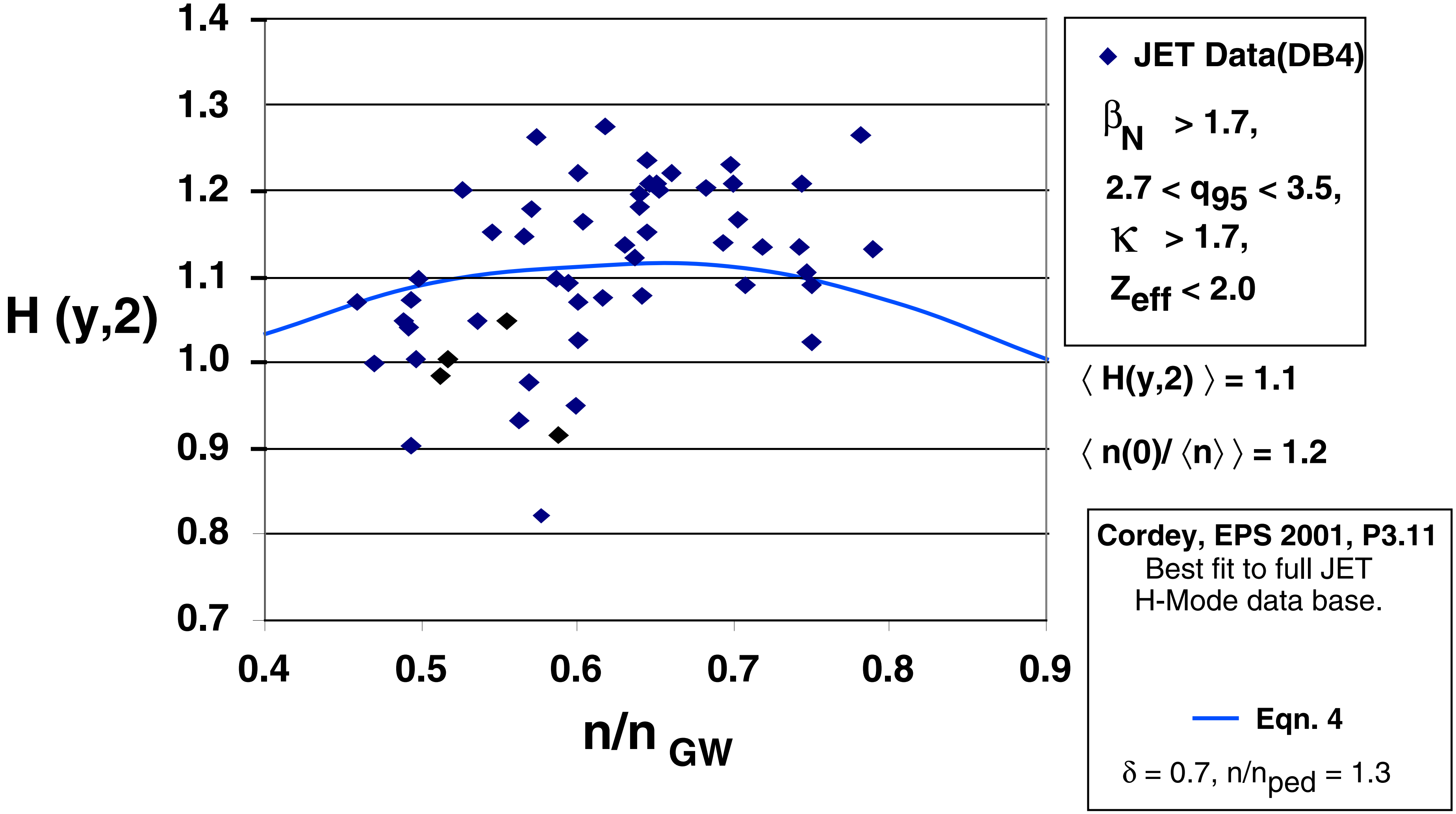
H-Mode Power Threshold - Based on today's tokamak data base

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

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

Understanding is mainly empirical. Better understanding is needed from existing experiments with improved simulations, and a benchmark in alpha-dominated fusion plasmas is needed to confirm and extend the science basis.

JET H-Mode Data Selected for FIRE-like Parameters



β_N > 1.7,

2.7 < q_{95} < 3.5,

κ > 1.7,

Z_{eff} < 2.0

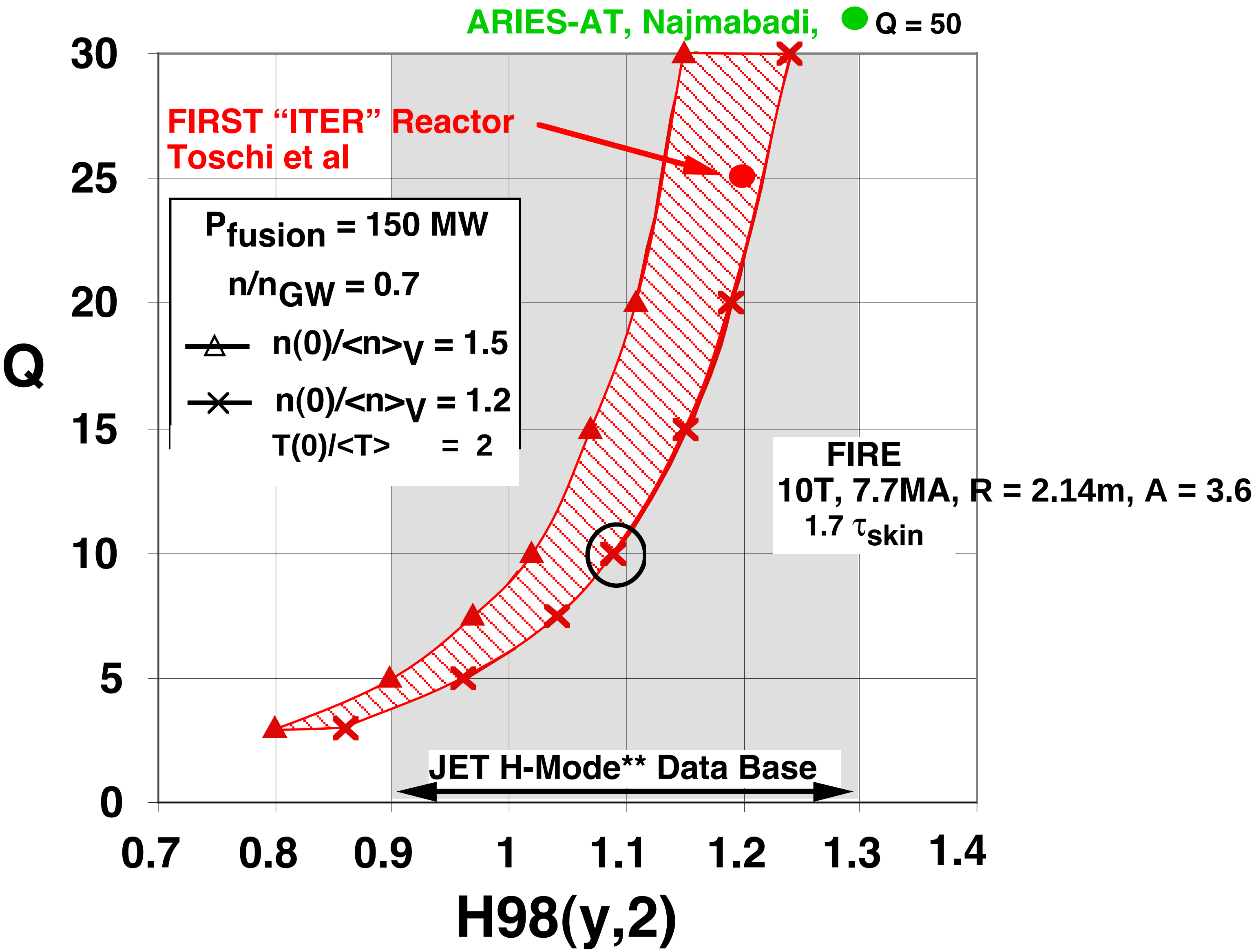
$\langle H(y,2) \rangle = 1.1$

$\langle n(0)/\langle n\rangle \rangle = 1.2$

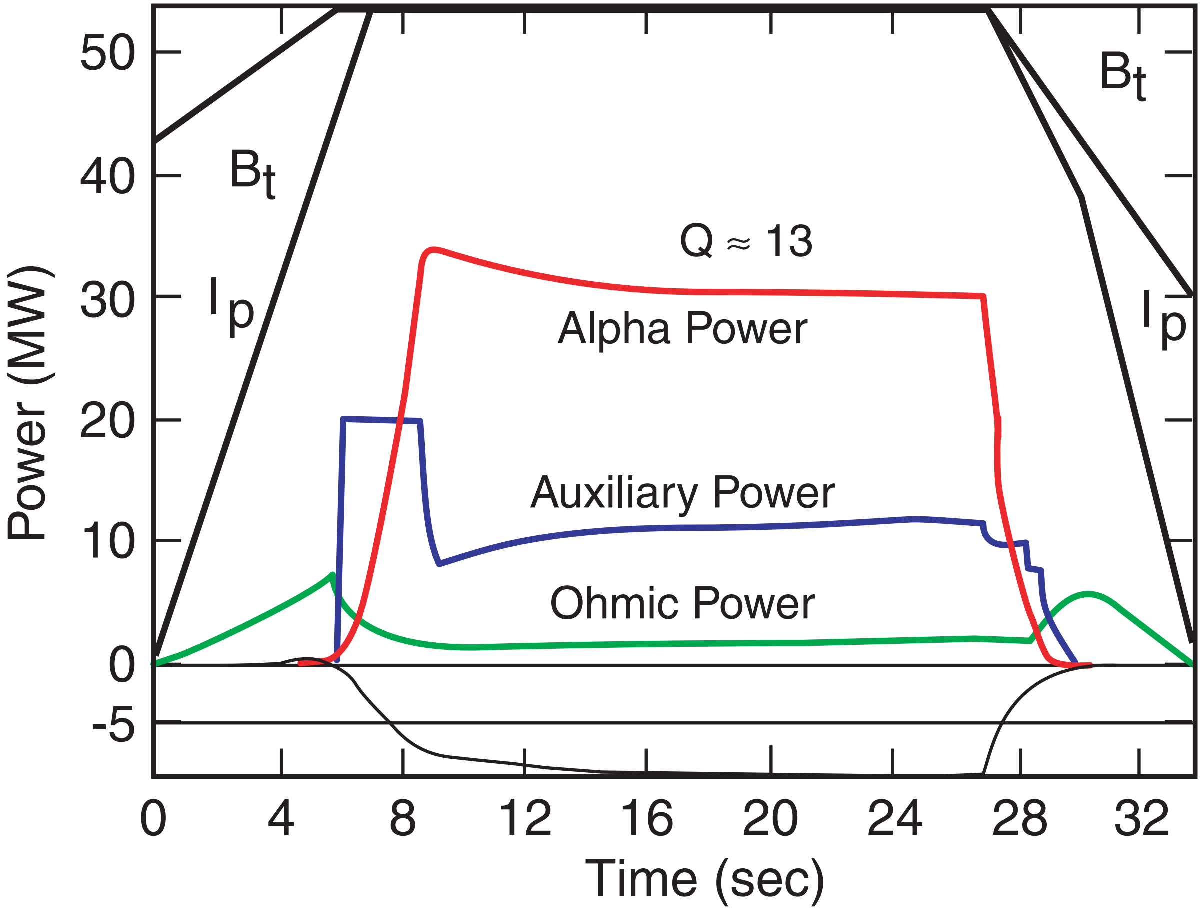
Cordey, EPS 2001, P3.11
Best fit to full JET
H-Mode data base.

$\delta = 0.7$, $n/n_{ped} = 1.3$

Projections to FIRE Compared to Envisioned Reactors



Simulation of Burning Plasma in FIRE



$B = 10\ T$

$I_p = 7.7\ MA$

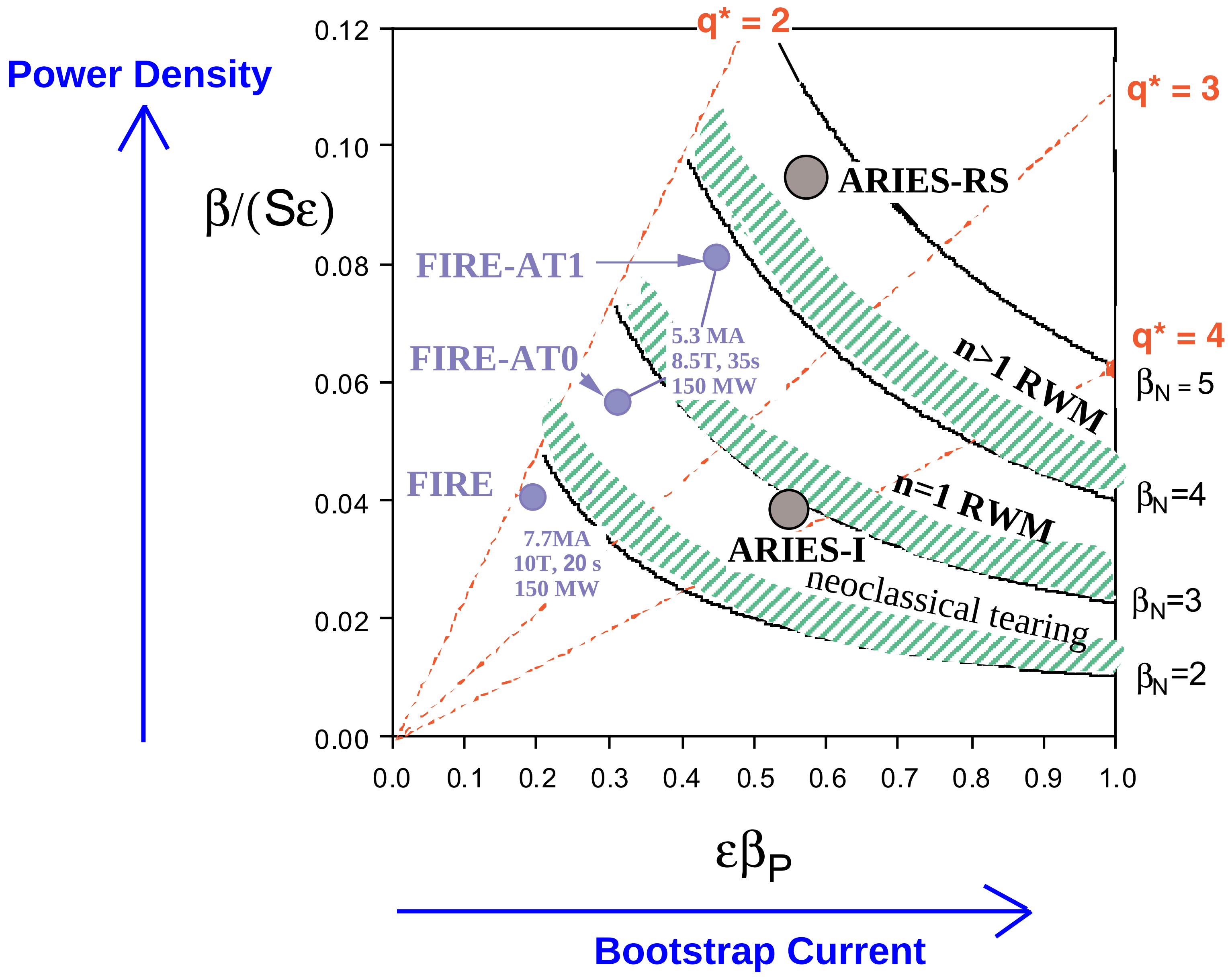
$R = 2.14\ m$

$A = 3.6$

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

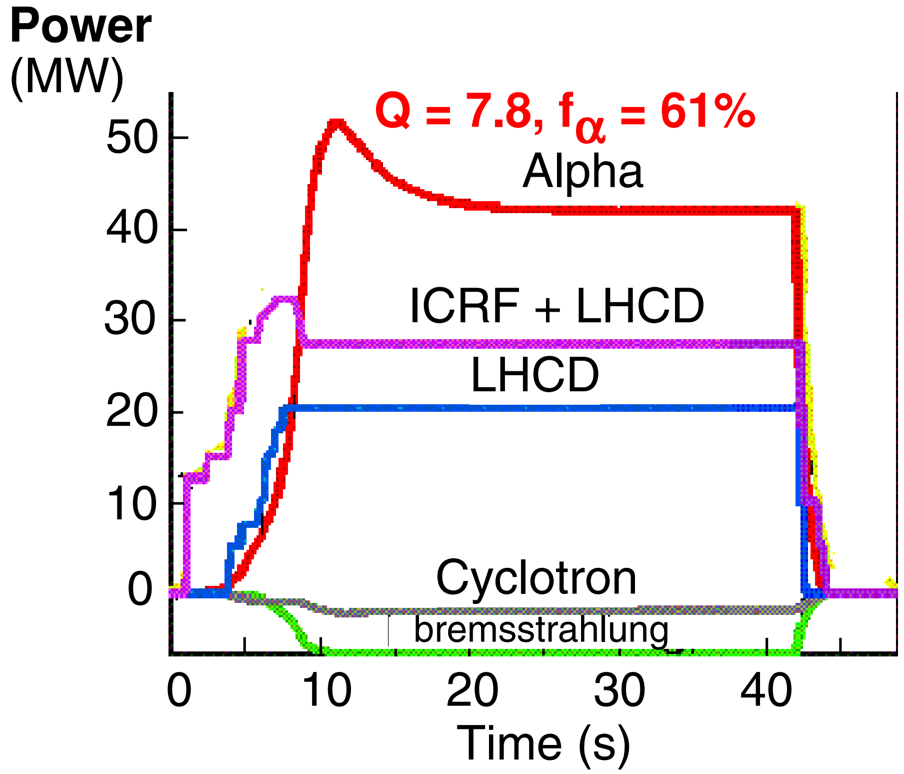
Q = Pfusion/(Paux + Poh)

FIRE would Test a Sequence of AT Modes



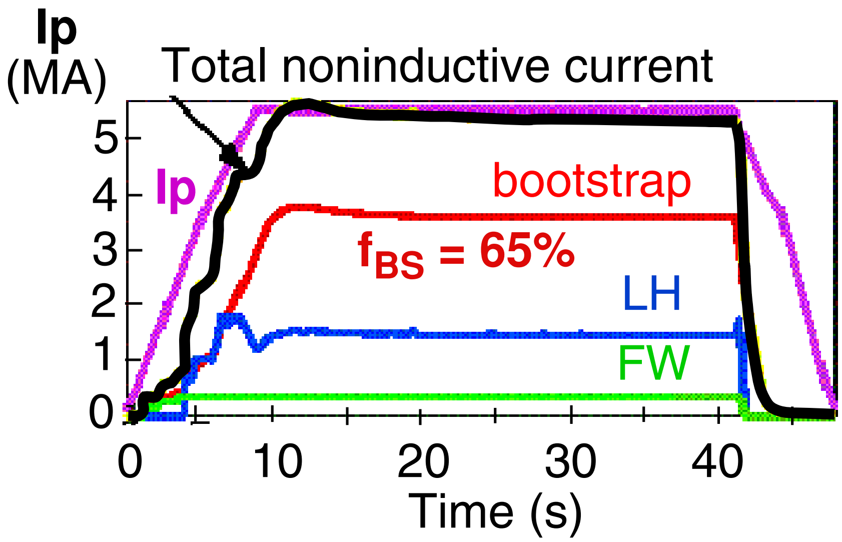
Advanced Burning Plasma Physics could be Explored in FIRE

Self-Heating Dominant



Self-Current Drive Dominant

Fully Non-Inductive for > 1 τ_{CR}



Tokamak simulation code results for H(y, 2) = 1.6, $\beta_N = 3.5$, would require RW mode stabilization. q(0) = 2.9, $q_{min} = 2.2$ @ r/a = 0.8, 8.5 T, 5.5 MA

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

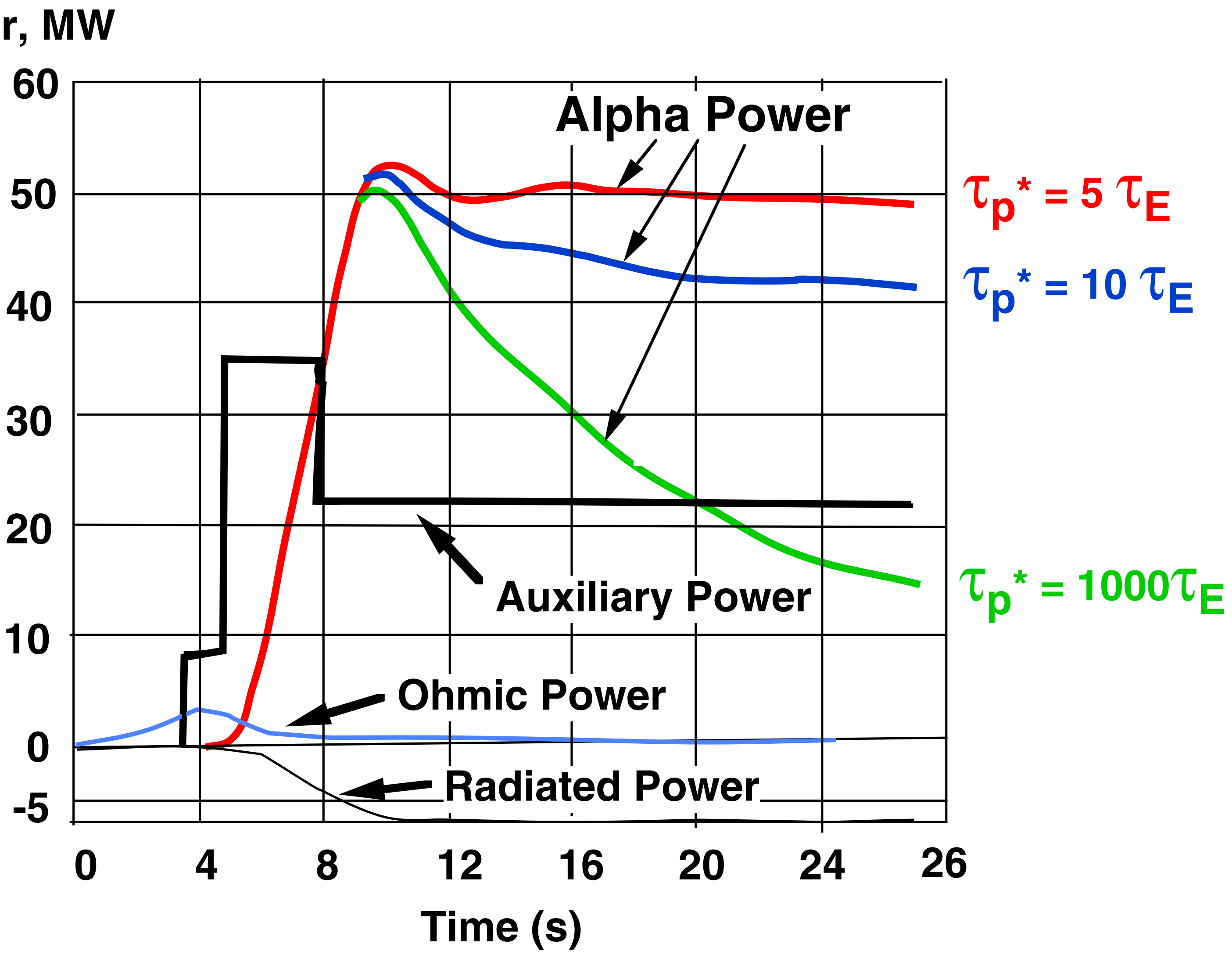
Efficient particle Fueling
  pellet injection needed for deep and tritium efficient fueling

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.

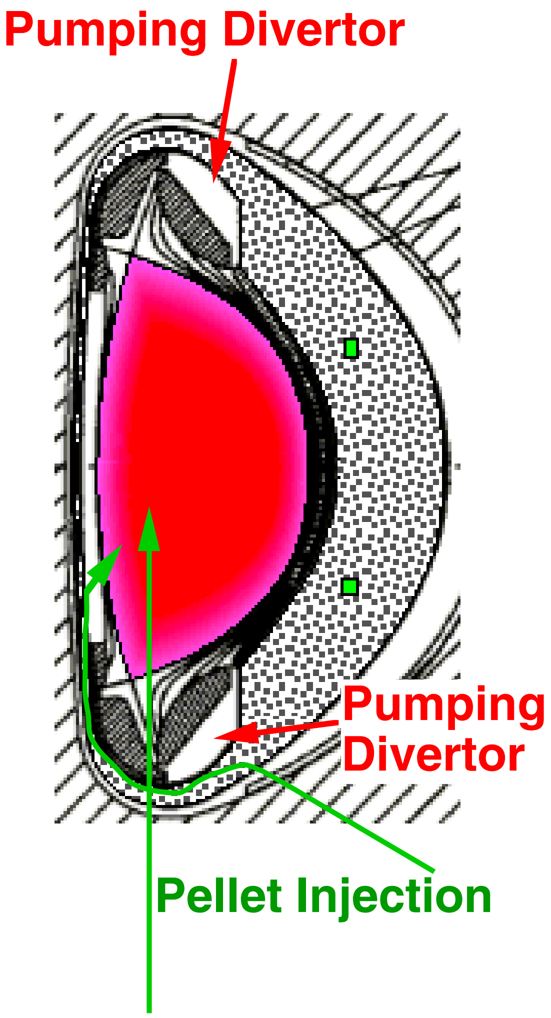
Helium Ash Removal Techniques Required for a Reactor can be Studied on FIRE

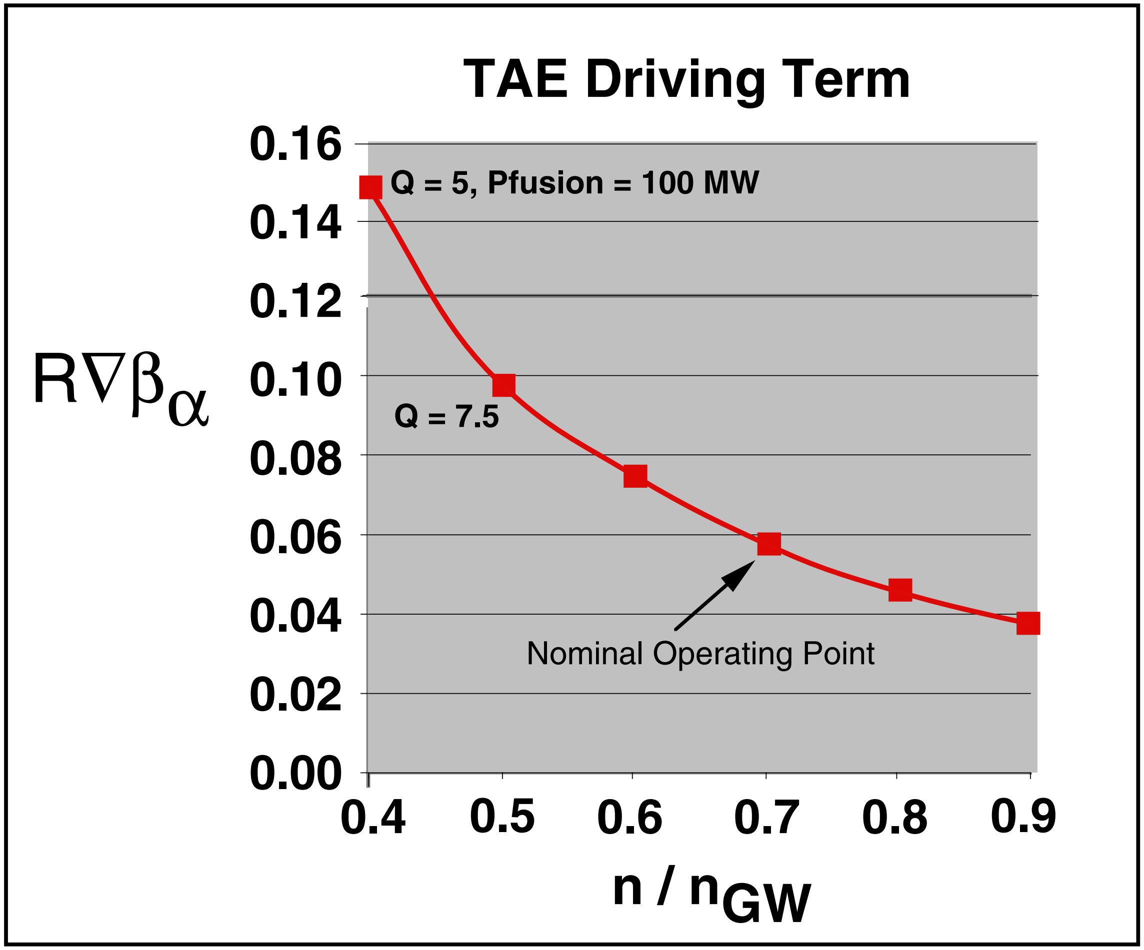


Fusion power can not be sustained without helium ash punping.

TSC/Kessel/21-q.ps

Energetic Particle Drive can be Varied in FIRE Using Divertor Pumping and Pellet Injection





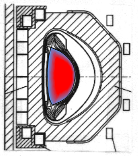
FIRE: $H(y,2) = 1.1$, $\alpha\_n = 0.2$, $\alpha\_T = 1.75$,
$Q = 10$, $P_{fusion} = 150$ MW except where noted

FIRE would Test the High Power Density In-Vessel Technologies Needed for ARIES-RS

Pfusion
= ~ 150 MW

Volume
= 27 m^3

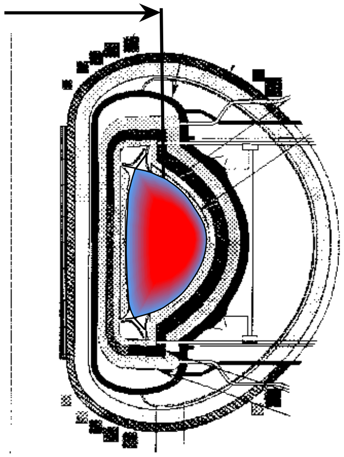
B = 10 T
R = 2.14 m
→



FIRE

~ 3X

B = 8 T
R = 5.5 m



ARIES-RS The “Goal”

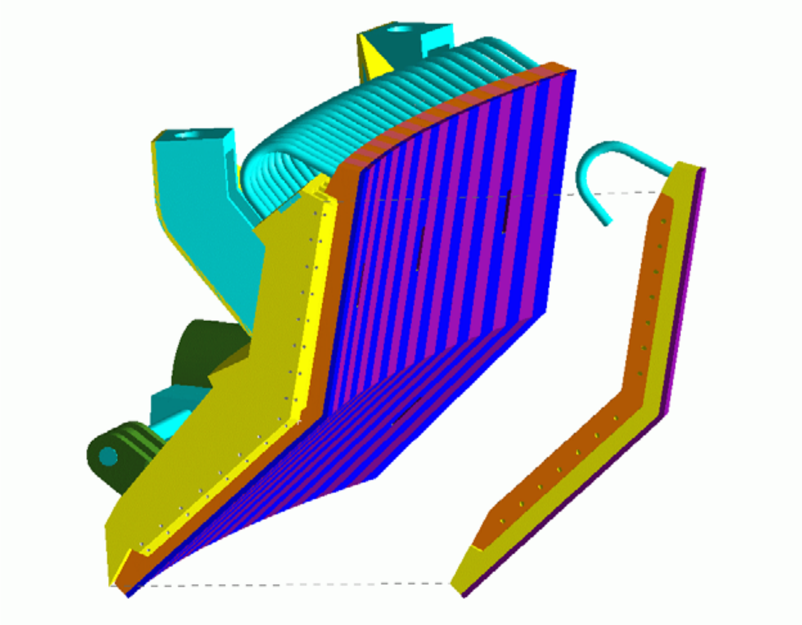
Pfusion
= 2170 MW

Volume
= 350 m^3

	JET	FIRE	ARIES-RS
Fusion Power Density (MW/m^3)	0.2	5.5	6
Neutron Wall Loading (MW/m^2)	0.2	2.3	4
Divertor Challenge (Pheat/NR)	~5	~10	~35
Power Density on Div Plate (MW/m^2)	3	~15-19 → 6	~5
Burn Duration (s)	4	20	steady

Divertor Module Components for FIRE

Sandia

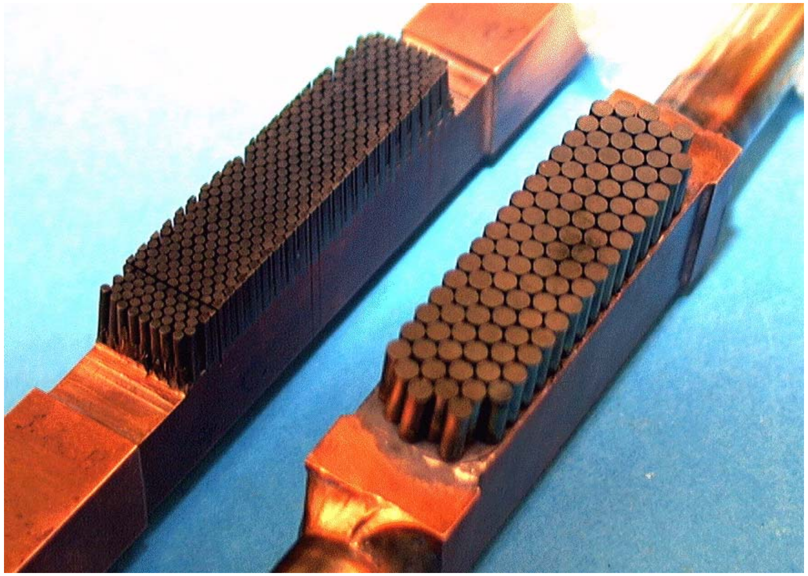


Finger Plate for

Outer Divertor Module

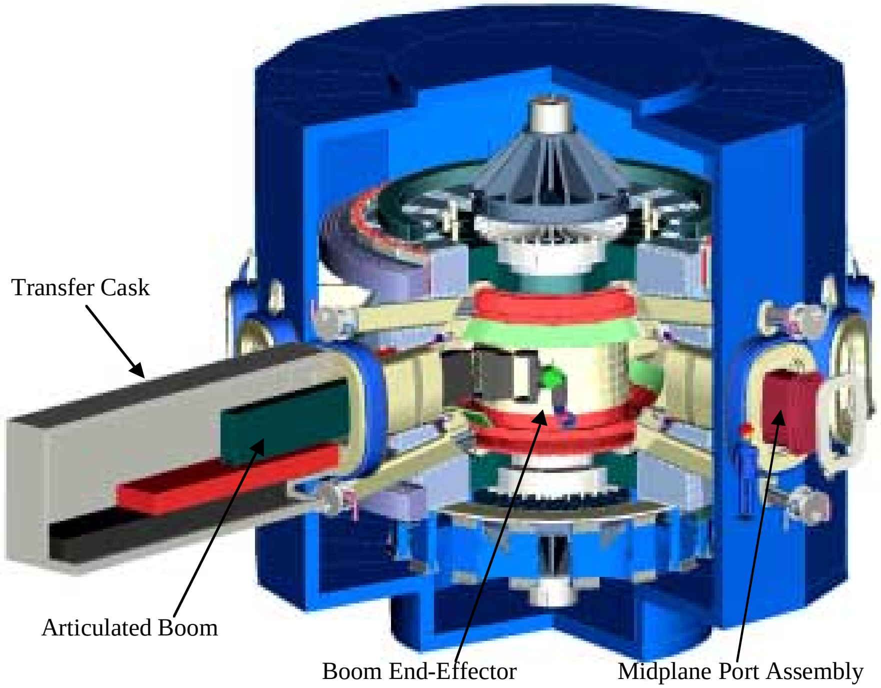
Two W Brush Armor Configurations

Tested at 25 MW/m^2



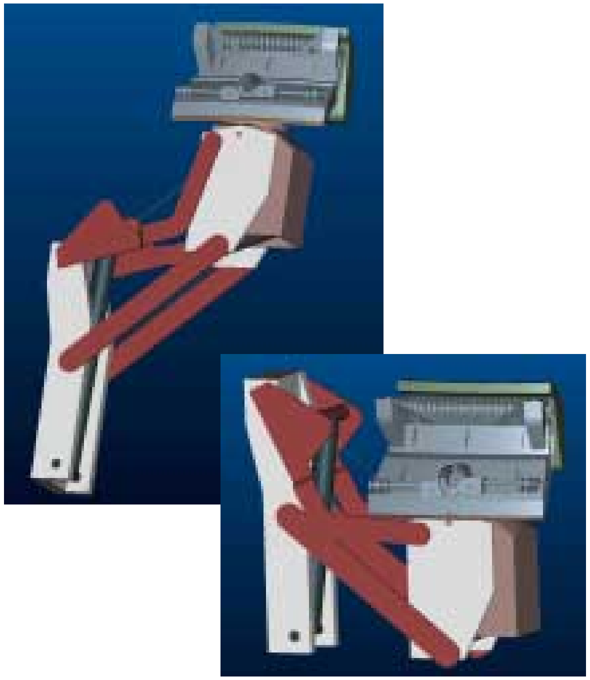
Carbon targets used in most experiments today are not compatible with tritiun inventory requirements of fusion reactors.

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

FIRE Parameters and Design Goals

	FIRE	ITER-FEAT	ARIES-RS
κ_x/κ_{95}	2.0/1.77	1.85/1.7	2/1.7
δ_x/δ_{95}	0.7/0.4-0.55	0.49/0.33	0.7/0.5
Divertor	DN	SN	DN
R (m)	2.14	6.2	5.5
A = R/a	3.6	3.1	4.0
B (T)	10	5.3	8
I_p (MA)	7.7	15	11.3
$Q = P_{fus}/(P_{oh} + P_{aux})$	10	10	27
Burn Time (inductive) (s)	20	400	steady
Current Redistributions	~2	~2	infinite
P_{fusion}(MW)	150	400	2170
P_{fusion}/Vol (MW/m^3)	5.6	0.5	6.2
Neutron Wall loading (MW/m^2)	2.3	0.5	4
First Wall Thermal Equilib.	no	yes	yes
Divertor Target material	W	C(W?)	W
$P_{fusion} - P_{bremm} /N2\pi R_x$ (MW/m)	1.5	1.4(0.7)	8.1
Div. Target Thermal Equilib.	yes	yes	yes

Cost Background for FIRE

- Three tokamaks physically larger but with lower field energy than FIRE have been built.

Water Cooled Coils	B(T)	R(m)	Coil Energy (GJ)	Const. Cost
TFTR (1983), US	5.2	2.5	1.5	$498M
JET (1984), Europe	3.4	2.96	1.4	~$600M
JT-60 (1984), Japan	4.4	3.2	2.9	~$1000M
FIRE*, US	10	2.14	5.0	(~ $1000M)

* FIRE would have liquid nitrogen cooled coils.

Cost estimates from previous design studies with similar technology.

Liquid N, Cu coils	B(T)	R(m)	Coil Energy (GJ)	Const. Cost
CIT (1989),	11	2.14	5	$680M (FY-89)
BPX (1991)	9.1	2.59	8.4	$1,500M (FY-92)
BPX-AT(1992)	10	2.0	4.2	$642M (FY-92)
FIRE Goal	10	2.14	5.0	(~$1,000M FY-99)
PCAST (120s)	7	5.0	40	~$5,815M (FY-95)

Preliminary FIRE Cost Estimate (FY99 US$M)

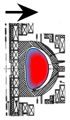
	Estimated Cost	Contingency	Total with Contingency
1.0 Tokamak Core	266.3	78.5	343.8
1.1 Plasma Facing Components	71.9	19.2	
1.2 Vacuum Vessel/In-Vessel Structures	35.4	11.6	
1.3 TF Magnets /Structure	117.9	38.0	
1.4 PF Magnets/Structure	29.2	7.2	
1.5 Cryostat	1.9	0.6	
1.6 Support Structure	9.0	1.8	
2.0 Auxiliary Systems	135.6	42.5	178.1
2.1 Gas and Pellet Injection	7.1	1.4	
2.2 Vacuum Pumping System	9.6	3.4	
2.3 Fuel Recovery/Processing	7.0	1.0	
2.4 ICRF Heating	111.9	36.6	
3.0 Diagnostics (Startup)	22.0	4.9	26.9
4.0 Power Systems	177.3	42.0	219.3
5.0 Instrumentation and Controls	18.9	2.5	21.4
6.0 Site and Facilities	151.4	33.8	185.2
7.0 Machine Assembly and Remote Maintenance	77.0	18.0	95.0
8.0 Project Support and Oversight	88.8	13.3	102.2
9.0 Preparation for Operations/Spares	16.2	2.4	18.6
Preconceptual Cost Estimate (FY99 US$M)	**953.6**	**237.8**	**1190.4**

Assumes a Green Field Site with **No** site credits or significant equipment reuse.

June 5, 2001

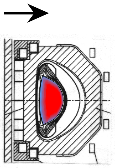
Comparison of Burning Plasma Device Parameters

B = 13 T
R = 1.3 m



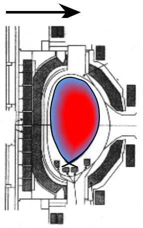
IGNITOR

B = 10 T
R = 2.14 m



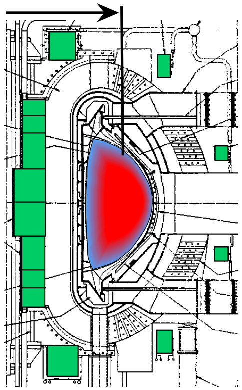
FIRE

B = 3.8 T
R = 2.9 m



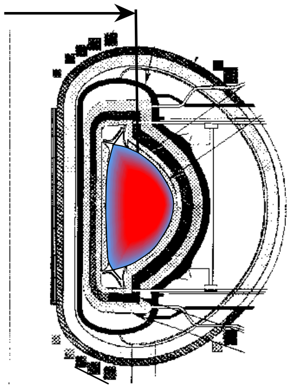
JET U

B = 7 T
R = 5 m



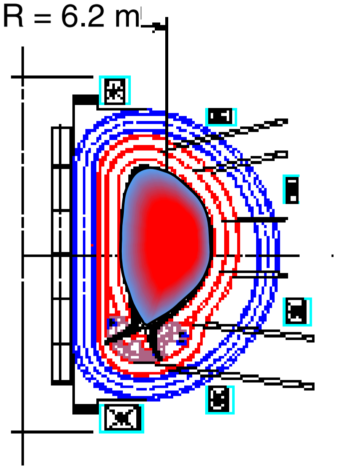
PCAST 5

B = 8 T
R = 5.5 m



ARIES-RS (1 GWe)

B = 5.5 T
R = 6.2 m



ITER-FEAT

Cost Drivers	IGNITOR	FIRE	JET U	PCAST	ARIES-RS	ITER-FEAT
Plasma Volume (m^3)	11	27	108	390	350	828
Plasma Surface (m^2)	36	67	160	420	420	610
Plasma Current (MA)	12	7.7	6	15	11.3	15
Magnet Energy (GJ)	5	5	1.6	40	85	50
Fusion Power (MW)	100	150	30	400	2170	400
Burn Duration (s), inductive	~1	20	10	120	steady	400
τ Burn/ τ CR		~2	0.6	1	steady	2
Cost Estimate ($B-2000$)		1.2	~0.6	6.7	10.6*	4.6?

* first , $5.3 B for 10th of a kind

AR RS/ITERs/PCAST/FIRE/IGN

Site Characteristics for FIRE

- **Land Area**

  ~ 20 acres

- **Buildings**

  Test cell ~ 30m x 45 m x 17 m (high)

  Auxiliary Buildings - power, material handling, cryo, support

- **Power**

  ~ 600 MW from grid for ~ 20 s pulse every 3 hours

  ~ 200 MW and ~ 4.5 GJ from on site MG

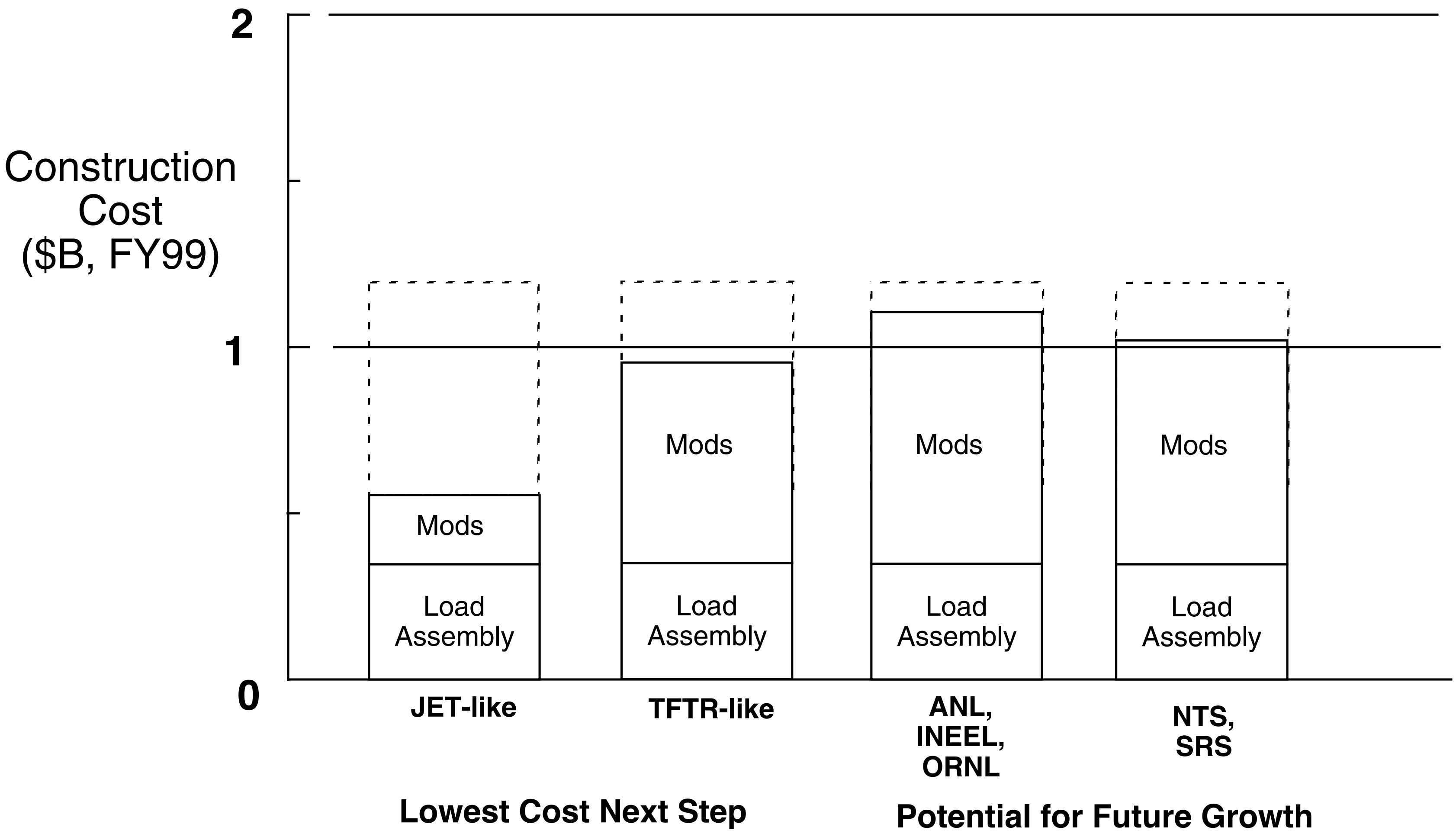
- **Tritium Inventory**

  5 g to 25g (in process inventory)

- **Cryogenic Plant**

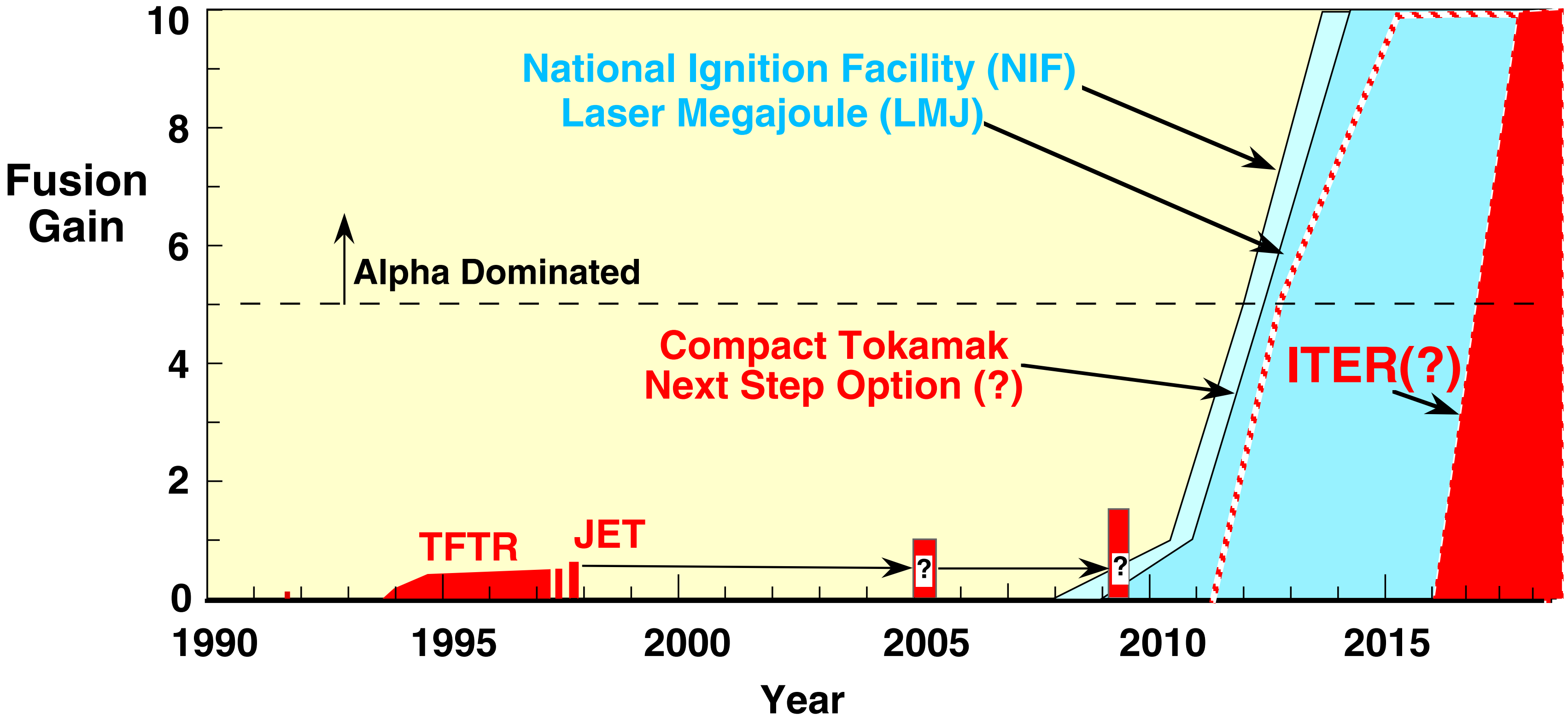
  2 kW refrigerator, 600 kgallon LN storage

Site Credits could be Significant and Need to be Evaluated



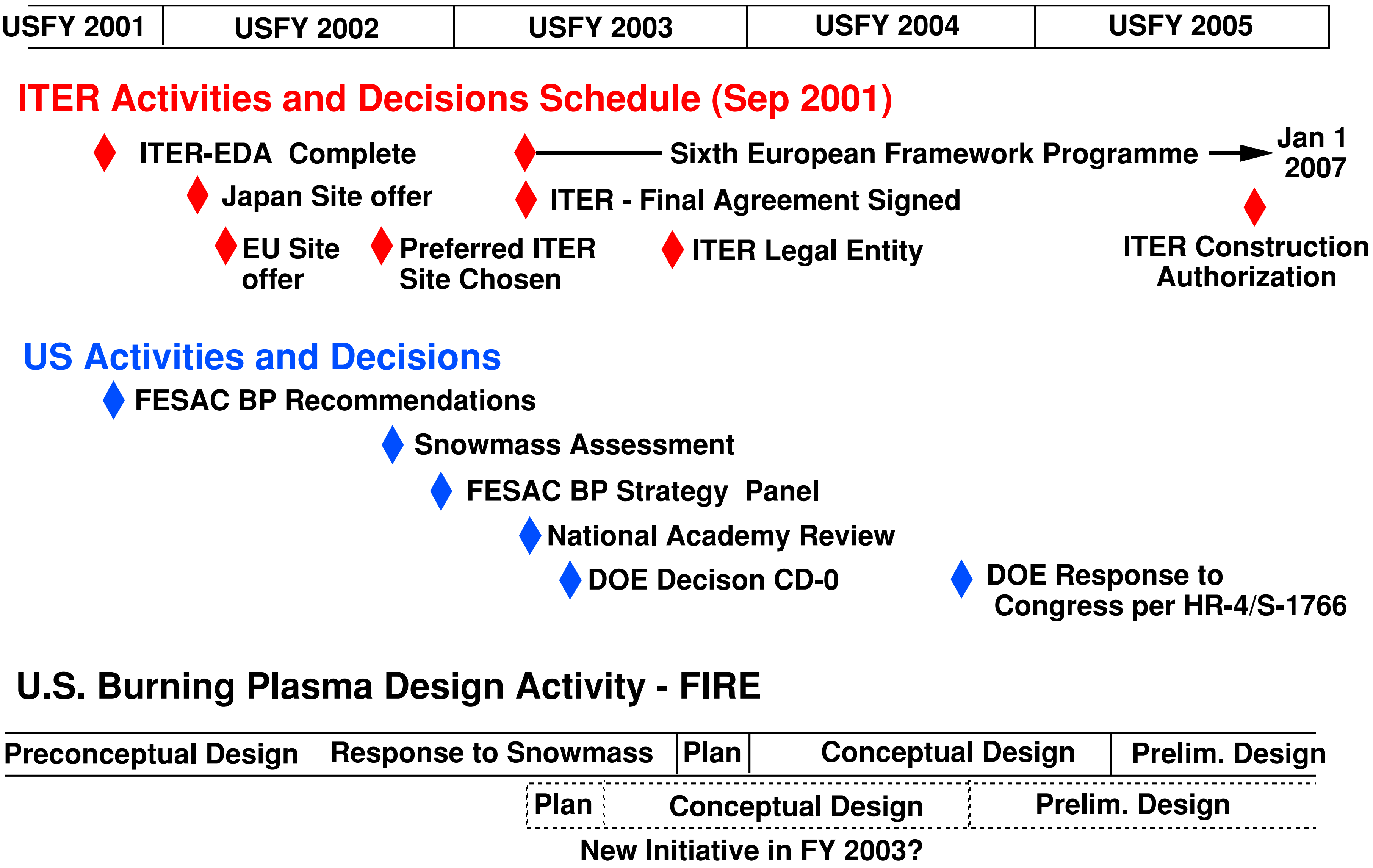
1. Could the TFTR site ever be used for tritium again? We need to determine this very soon.
2. Defense Program sites may be special opportunities.

Timetable for “Burn to Learn” Phase of Fusion



- Even with ITER, the MFE program will be unable to address the alpha-dominated burning plasma issues for ≥ 15 years.
- Compact High-Field Tokamak Burning Plasma Experiment(s) would be a natural extension of the ongoing “advanced” tokamak program and could begin alpha-dominated experiments by ~ 10 years.
- More than one high gain burning plasma facility is needed in the world program.
- The information “exists now” to make a technical assessment, and decision on MFE burning plasma experiments for the next decade.

Timetable for Investment Decisions in Magnetic Fusion



USFY 2001	USFY 2002	USFY 2003	USFY 2004	USFY 2005

ITER Activities and Decisions Schedule (Sep 2001)

◆ ITER-EDA Complete

◆ Japan Site offer

◆ EU Site offer

◆ Preferred ITER Site Chosen

◆ Sixth European Framework Programme → Jan 1 2007

◆ ITER - Final Agreement Signed

◆ ITER Legal Entity

◆ ITER Construction Authorization

US Activities and Decisions

◆ FESAC BP Recommendations

◆ Snowmass Assessment

◆ FESAC BP Strategy Panel

◆ National Academy Review

◆ DOE Decison CD-0

◆ DOE Response to Congress per HR-4/S-1766

U.S. Burning Plasma Design Activity - FIRE

Preconceptual Design	Response to Snowmass	Plan	Conceptual Design	Prelim. Design

Plan	Conceptual Design	Prelim. Design

New Initiative in FY 2003?

Burning_Plas_sched_3

Summary

- A Window of Opportunity may be opening for U.S. Energy R&D. We should be ready. The Diversified International Portfolio has advantages for addressing the science and technolgy issues of fusion.

- FIRE is being designed to :
  - address the important burning plasma issues, performance ~ ITER
  - investigate the strong non-linear coupling between BP and AT,
  - stimulate the development of reactor relevant PFC technology, and
  - provide generic BP science and possibly BP infrastructure for non-tokamak BP experiments in the U. S.

- Some areas that need additional work to realize this potential include:
  - Apply recent enhanced confinement and advanced modes to FIRE
  - Understand conditions for enhanced confinement regimes-triangularity
  - Compare DN relative to SN - confinement, stability, divertor, etc
  - Complete disruption analysis, develop better disruption control/mitigation.

- If a postive decision is made in this year, FIRE is ready to begin Conceptual Design in FY2003 with target of first plasmas ~ 2010.

http://fire.pppl.gov