FESAC Toroidal Alternates Panel

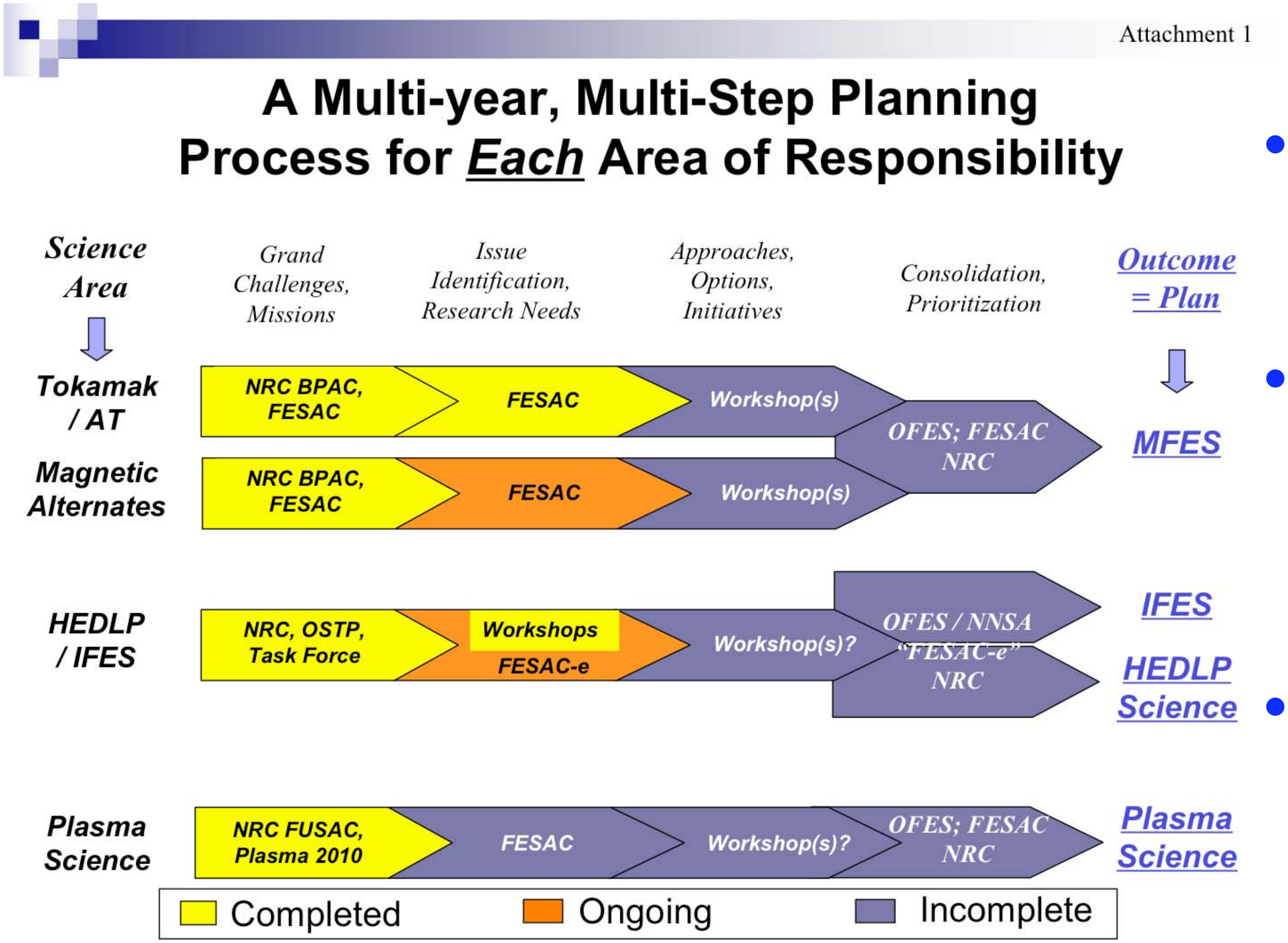
David N. Hill (Panel Chair)
Lawrence Livermore National Laboratory

<u>Outline</u>

- Charge from Ray Orbach
- Panel Process
- Concept Overview, Goals, and Issues
- Some General Issues Related to Alternates Research
- Website: http://fusion.gat.com/tap

Unofficial update on panel activities: final report yet to be approved by panel and by FESAC. Not speaking for panel yet.

Prioritization: OFES ReNeW Process



- Modeled after BES Research Needs Workshops
- MFE Process aims to produce long range strategic plan by January 2010.
- Workshop scheduled for June 2009

Charge to FESAC From Dr. Ray Orbach

- **Focus on Four Toroidal Confinement Concepts**
  - ST, Stellarator, RFP, CT(FRC and spheromak)

- **For those concepts that are seen to have promise for fusion energy, please identify and justify a long-term objective for each concept as a goal for the ITER era.**
  - ITER era: when ITER operates (~ next 15-20 years)
  - Panel addressing all four (some are closer than others to reaching fusion conditions)
  - Iterative process with community to identify ITER-era goal
  - Reasonably aggressive and focused goals

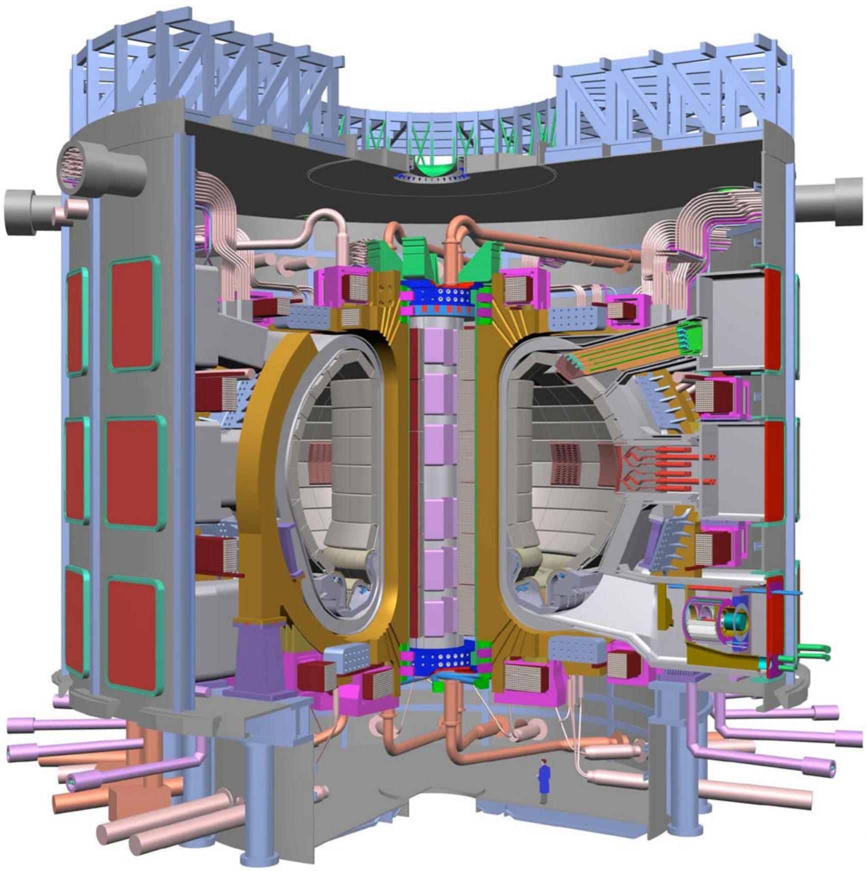
- **With that[goal] in mind, I ask that FESAC:**
  1 critically evaluate the goal chosen for each concept, and its merits for fusion development;
  2 identify and prioritize scientific and technical questions that need to be answered to achieve the specified goal;
  3 assess available means to address these questions; and
  4 identify research gaps and how they may be addressed through existing or new facilities, theory and modeling/computation.

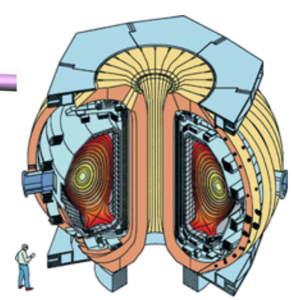
- **Identify and prioritize the unique toroidal fusion science and technology issues that an alternate concept can address, independent of its potential as a fusion energy concept.**

Promise For Fusion Energy Among Approaches

- Economically attractive fusion power remains a future goal, regardless of approach.
- Two major experiments to demonstrate fusion gain $Q > 1$ are under construction: ITER (tokamak, Int'l project, sited in France) and NIF (IFE, U.S. DOE at LLNL).

Alternates Research Exists Within the Context of the ITER Project





- Q=10 burning plasma experiment
- Updated and extensive physics basis document
- Extensive experimental database
- About “factor of 5-10 extrapolation” from existing tokamaks

Promise For Fusion Energy Among Approaches

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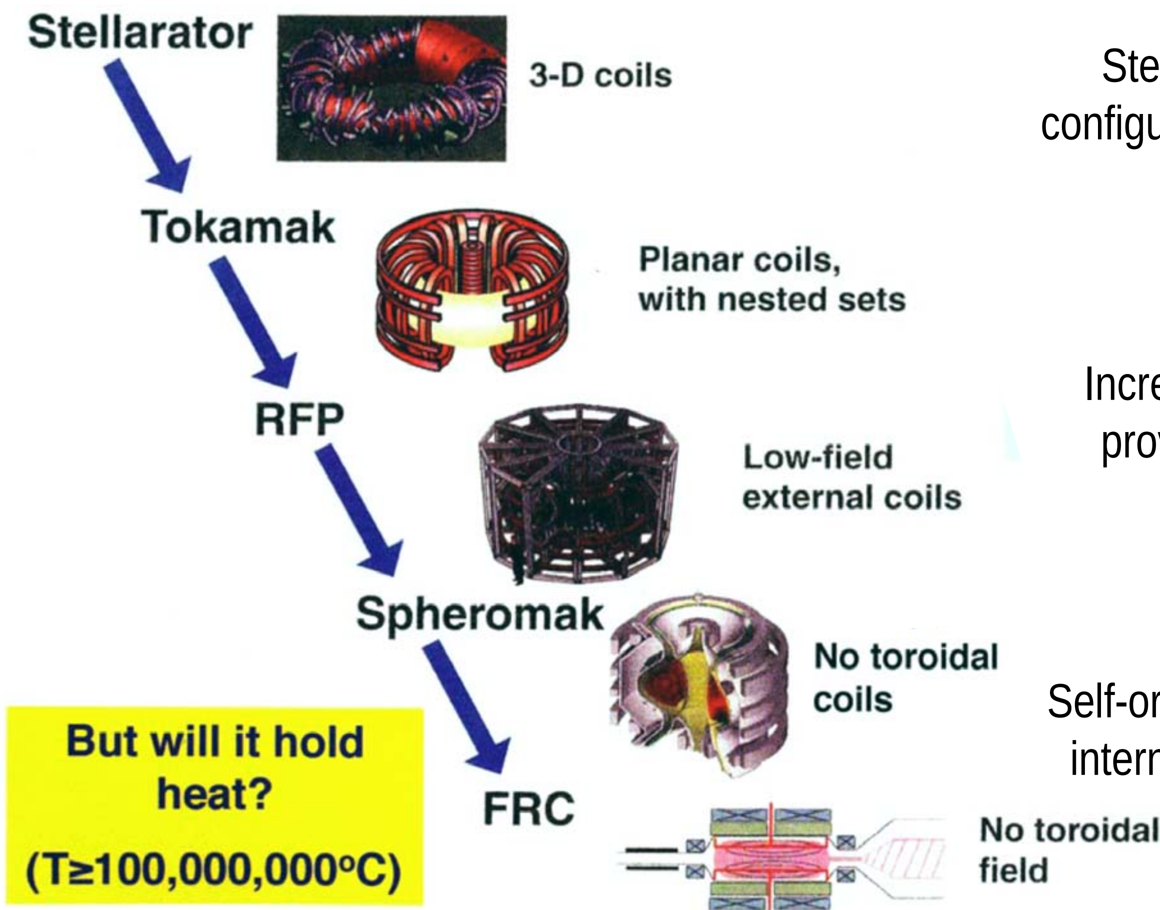
- Two major experiments to demonstrate fusion gain Q > 1 are under construction: ITER (tokamak, Int'l project, sited in France) and NIF (IFE, U.S. DOE at LLNL).
- The tokamak is the leading toroidal magnetic confinement concept due to its superior performance and due to significant long-term R&D investments (chicken and egg?). It is both the leader and the "target."
- Toroidal magnetic confinement fusion reactors have common elements:
  - Make and sustain a stable magnetic configuration
  - Reach fusion conditions for burn and remove helium ash
  - Control the burn, extract the power, breed tritium
  - Operate reliably over economic lifetime
- Advocates for alternate toroidal magnetic confinement concepts seek an attractive reactor by exploring ways to improve one or more of these common MFE elements.

Toroidal Alternates Seek to Reduce the Size, Cost and Complexity of the Fusion Power Core



Steady-state "current-free" plasma configuration maintained by external coils

↓

Increasing role of plasma currents in providing confining magnetic fields

↓

Self-organized plasma configuration with internal currents maintaining the fields

Simply-connected plasma chambers

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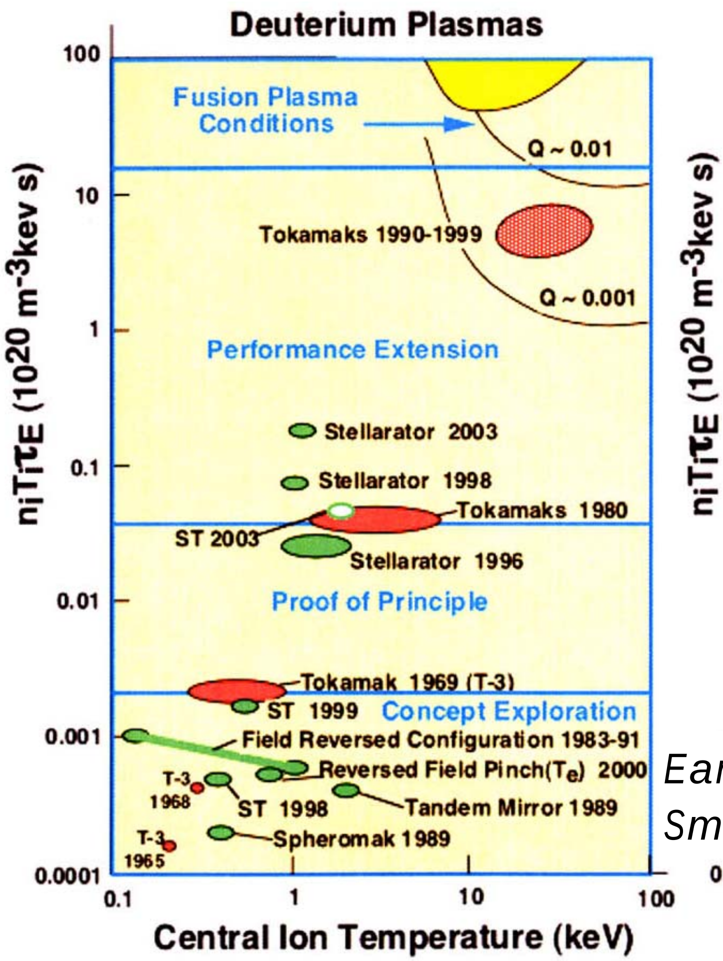
- Advocates for alternate toroidal magnetic confinement concepts seek an attractive reactor by exploring ways to improve one or more of these common MFE elements.
- Some concepts are closer to reaching fusion conditions than others. The science is not mature enough to unequivocally eliminate any of the four concepts considered.

All Approaches to Magnetic Confinement Must Satisfy Lawson Criteria: Some Are Closer Than Others



Must overcome transport and Bremsstrahlung losses for ignition

nkT τ_E > 8.3 atm-sec

Fusion power density $\propto \beta^2 B^4$

$$\beta = \frac{2\mu_0(nkT)}{B^2}$$

MHD stability limits β

Early experiments

Small experiments

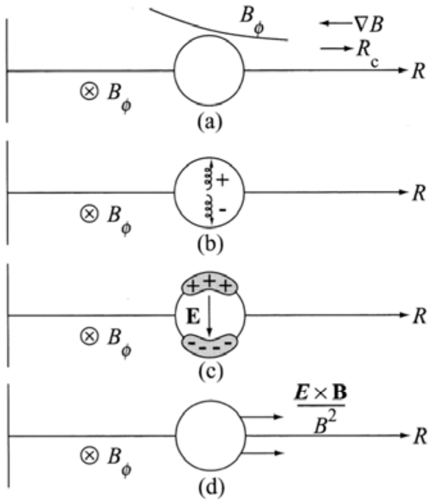
A Recent FESAC Panel Examined Common Issues For Magnetic Confinement Fusion Development Beyond ITER

- Some common issues are:
  - Plasma Energy confinement, transport, and overall energy balance
  - Configuration sustainment (e.g., current drive)
  - Operating limits (e.g., absolute plasma pressure for given coil limits)
  - Plasma thermal loads and PFC lifetimes (e.g. divertors)
  - Plasma exhaust particle control, overall tritium cycle
  - Wall neutron loading

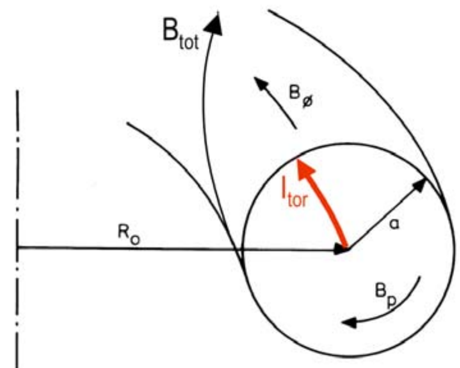
- Recent FESAC Strategetic Planning Panel Report (M. Greenwald, Panel Chair) identified a comprehensive set of 14 issues in addressing the charge:
  - What do we need to learn and what do we need to do, aside from ITER and other existing elements of the international program, to be **prepared** for DEMO?
  - Specific view of that panel was looking beyond success on ITER
  - Same issues will have to be addressed by alternates.
  - They are addressing some now, but at an earlier stage of maturity

Toroidal Confinement Requires Rotational Transform and MHD Stability

Toroidal field only: unconfined



Transform short-circuits drift



Internal or external currents can provide the transform:

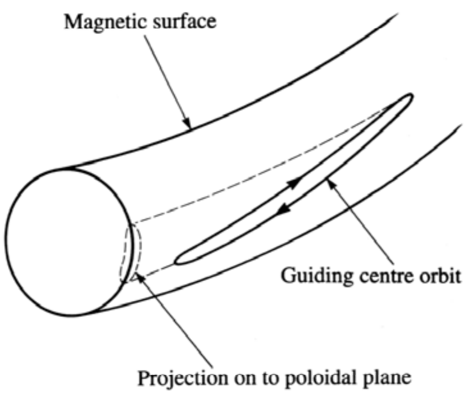
Safety factor $q = \frac{\Delta\phi}{2\pi} \cong \frac{rB_\phi}{R_0 B_\theta}$

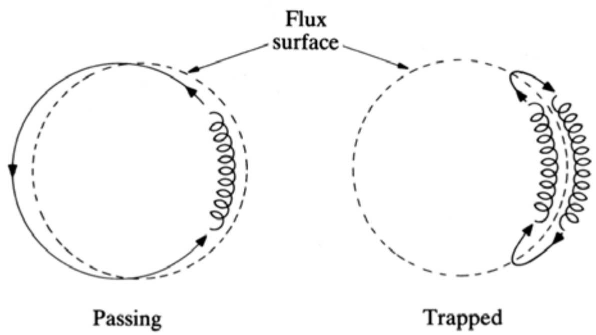
MHD stability affected by plasma pressure and q profiles.

Two classes of alternates:

q>1: ST, Stellarator

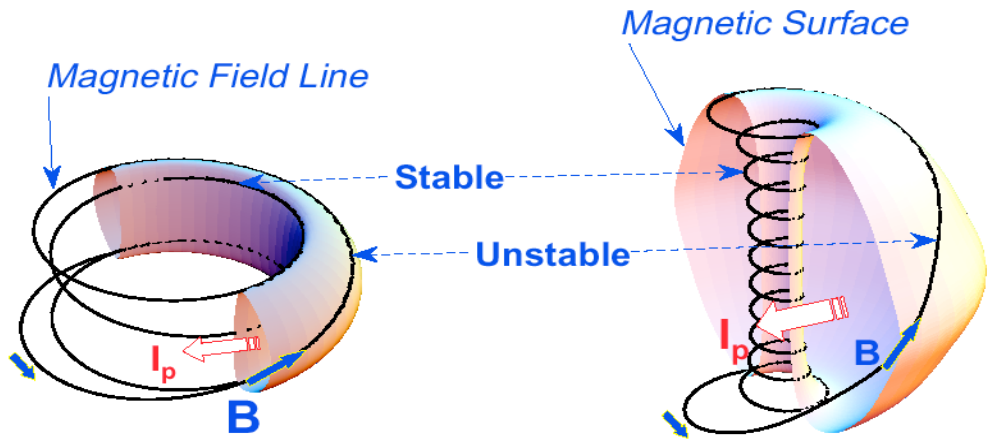
q<1: RFP, CTs





Toroidal geometry affects transport via particle drifts (neoclassical transport): depends on collisionality

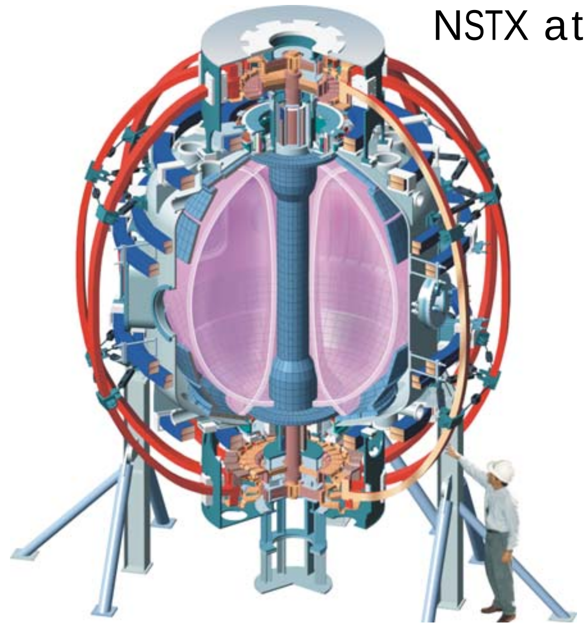
The Spherical Torus Pushes the Tokamak To Its Low-Aspect Ratio Limit: Higher Beta, Smaller Centerpost



R/a~4, κ=2, q_a=4

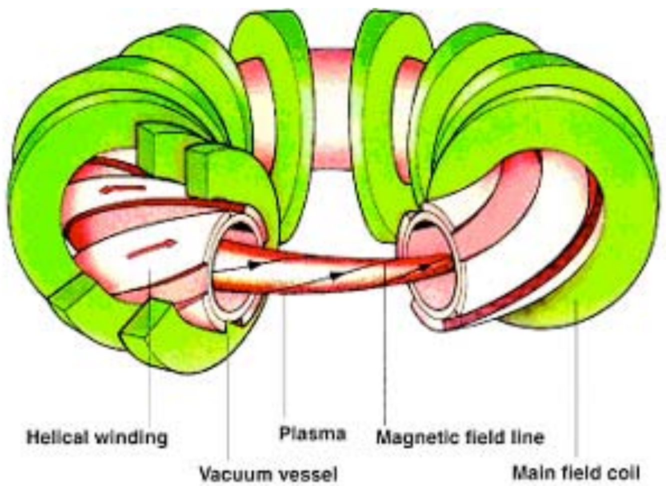
R/a~1.3, κ=2, q_a=12

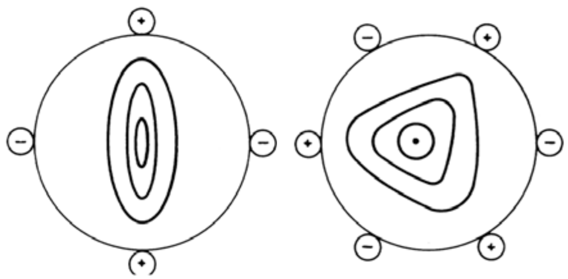
NSTX at PPPL



- Single-turn toroidal field coil and small ohmic transformer in centerpost. Unshielded.
- Strong radial variation in B_T, with high elongation and triangularity, give increased MHD stability, higher volume-averaged β; however low field in plasma compared to field at coil.
- Low surface-to-volume may enable a component test facility for fusion development.

The Stellarator Uses External coils to Generate the Confining Fields: Steady-state With Little or No Plasma Current



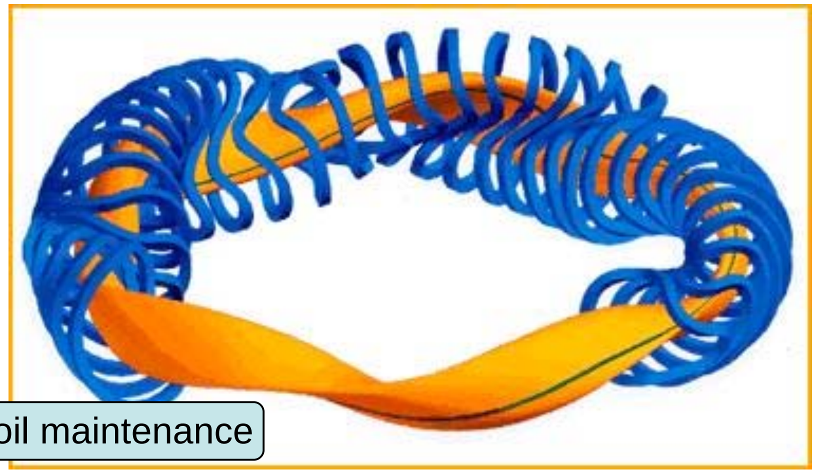


Cross section depends on windings

Iota $\iota = 2\pi/q$

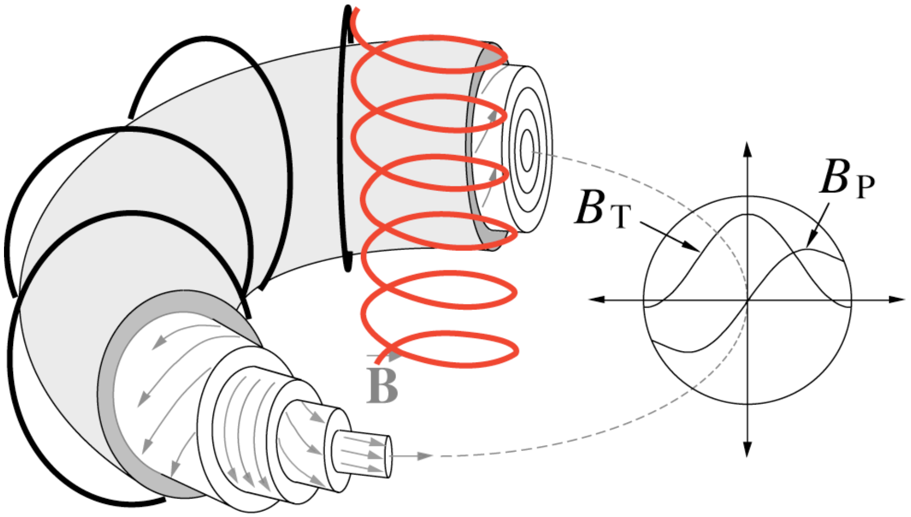
- Rotational transform provided by "helical" windings. No current - no transformer or auxiliary current drive - steady state - no disruptions
- Conventional stellarators have large neoclassical transpot due to variation in |B| and significant particle trapping.
- Complex coil geometry, 3D power handling

Modular coils: W7-X (Germany-under construction)



Improved coil maintenance

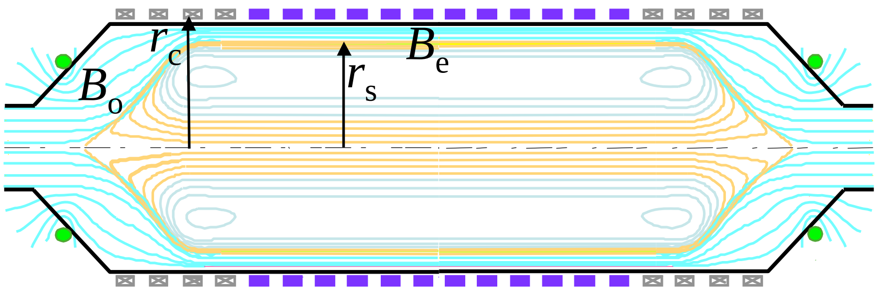
The Reversed-Field Pinch Uses Internal Currents to Produce Most of the Toroidal Magnetic Field



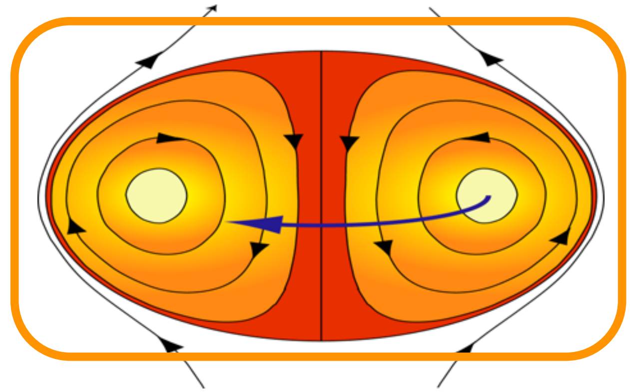
- Weak external TF field, with sufficient ohmic current to drive q below unity.
- Force-free plasma relaxation produces reversed Toroidal Field in core.
  Edge poloidal current effectively acts like a Toroidal Field coil.
- High field in plasma relative to field at the coils.
- Internal magnetic fluctuations or “Plasma dynamo” sustains current, but opens field lines via reconnection.
- Oscillating Field Current Drive might replace the ohmic transformer for steady state.

Compact Torus Configurations Use Self-organized Internal Plasma Currents to Produce the Confining Magnetic Field

Field Reversed Configuration (TCS-U @ U. Wash.)



Generic Spheromak



- Simply connected plasma chamber offers potential for smaller, cheaper reactors

- Very distinct geometry and physics
  - FRC: no toroidal field, diamagnetic currents only
  - FRC: β~1 stabilized by finite Larmor radius effects
  - FRC: Sustained by Rotating Magnetic Field current drive
  - Spheromak: toroidal and poloidal fields, force-free currents
  - Spheromak: wall stabilizes tilt instability, β ~0.1
  - Spheromak: sustainment by magnetic fluctuations (helicity transport)

Panel Members Represent a Broad Cross Section of Experts From the Fusion Community

FESAC Toroidal Alternates Panel

David Anderson	University of Wisconsin	dtanders@facstaff.wisc.edu
Jeff Freidberg	MIT	jpfreid@mit.edu
Martin Greenwald	MIT	g@psfc.mit.edu
Houyang Guo	RPPL @ U. Washington	guo@rppl.aa.washington.edu
Rich Hazeltine (VC)	U. Texas	rdh@physics.utexas.edu
Dave Hill (Chair)	LLNL	hilldn@fusion.gat.com
Bick Hooper	LLNL	hooper1@llnl.gov
Hantao Ji	PPPL	hji@pppl.gov
Tim Luce	General Atomics	luce@fusion.gat.com
Dale Meade	FIRE	dmeade@pppl.gov
Jon Menard	PPPL	jmenard@pppl.gov
Martin Peng	ORNL	pengym@ornl.gov
John Sarff	U. Wisconsin	jssarff@facstaff.wisc.edu
John Sheffield	ISSE @ U. Tennessee	jsheffi1@utk.edu
Xianzhu Tang	LANL	xtang@lanl.gov
Ed Thomas	Auburn U.	etjr@physics.auburn.edu
Mike Zarnstorff	PPPL	zarnstorff@pppl.gov

- Universities, Labs, and Industry
- Experiment and theory
- 8 Concept Experts
  9 At-large members
  6 FESAC members
- Panel members bring
  - Recognized contributions to fusion science
  - Program management experience
  - Experience on similar panels
- Neither shy nor stubborn

Panel Process and Community Input

- Panel discussions by email and teleconference to formulate overall process
- Panel organized into four Concept Working Groups to lead technical analysis: Stellarator, ST, RFP, and CT
- Panel sought advice from fusion community
  - Written input provided by concept advocates and researchers
  - Previous panel reports and program reviews provide perspective
  - Open solicitation for anyone to submit written input via website
  - Interactive process (not an exam)
  - Concept presentations to the Panel (6/30–7/2 @ DFW Wyndham)
    - 2 hr blocks for each concept (60min presentation, 60min discussion)
    - Invited speakers addressed questions from panel working groups
    - 1 hr for brief public comments each day by request
    - Presentations were open to the public

View all input at http://fusion.gat.com/tap/community

Working Groups Bring Requisite Focus To Each Concept

Panel Members	ST	Stellarator	RFP	CT	At Large
Dave Hill (C)					X
David Anderson		E(L)			
Jeff Freidberg				AL	X
Martin Greenwald	AL				X
Houyang Guo				E(L)	
Richard Hazeltine (VC)	Th	Th			X
Bick Hooper				E	
Hantao Ji			E(L)		
Tim Luce		AL			
Dale Meade			AL		X
Jon Menard	E				
Martin Peng	E(L)				
John Sarff			E		
John Sheffield	AL				X
Xianzhu Tang			Th	Th	X
Ed Thomas		AL			X
Mike Zarnstorff		E			
Totals	5	5	4	4	9

- Working groups consist of concept experts and at-large members
- Working group experts know the research community for their concept
- At-large members provide independent evaluation

General Report Structure and Emphasis

- Assessments are primarily concept by concept
  - Each concept will be evaluated relative to its ITER-era goals, rather than to its ultimate potential reactor advantages, which are well known but may be difficult to achieve in practice
  - Each concept faces significant scientific and technical challenges in meeting <u>its own</u> ITER-era goals
  - direct comparisons between concepts will be limited in scope

- The ITER-era goals motivate uniquely prioritized research
  - We used a common basis for evaluation where appropriate (e.g., definition of β, confinement time, and etc., see TAP website)
  - We are identifying contributions to fusion science for each concept

- We are focused on the scientific issues which must be resolved to make progress, and the types of facilities needed for the work, not the budget requirements for the program.

Charge to FESAC From Dr. Ray Orbach

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- **For those concepts that are seen to have promise for fusion energy, please identify and justify a long-term objective for each concept as a goal for the ITER era.**
  - ITER era: when ITER operates (~ next 15-20 years)
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- **With that[goal] in mind, I ask that FESAC:**
  1. critically evaluate the goal chosen for each concept, and its merits for fusion development;
  2. identify and prioritize scientific and technical questions that need to be answered to achieve the specified goal;
  3. assess available means to address these questions; and
  4. identify research gaps and how they may be addressed through existing or new facilities, theory and modeling/computation.

- **Identify and prioritize the unique toroidal fusion science and technology issues that an alternate concept can address, independent of its potential as a fusion energy concept.**

Evaluating ITER-era Goal

1. **Importance and relevance: Does the goal address critical scientific and technical issues to advance this concept and fusion science?**
   a. Will reaching the goal significantly change the outlook for the concept (i.e., address the major issues)?
   b. Will reaching the goal contribute to the improvement of other concepts?
   c. Will achieving the scientific goals for this concept significantly advance our knowledge of plasma science?
2. **Technical risk: Are the goals reasonably achievable based upon the current state of knowledge for this concept?**
   a. What degree of extrapolation in parameters or technical capability does the goal represent?
   b. Is there a sound scientific basis (theory and/or experiment) to anticipate success?
   c. To what extent will achieving the goal provide sufficient understanding to advance fusion science?
   d. Resource requirements: significant, not too big, almost free

How do we assess the relative priority of the issues which confront each of these 4 configurations?

- **Object is to provide analysis to help guide decisions**
  - Map a rational path forward
  - Resource requirements
- **Criteria include:**
  - Importance
  - Urgency
  - Generality
- **Proposed approach**
  a. Place each issue into one of 3 tiers (descriptions follow).
  b. (Any given issue will likely not match all of the bullets in a tier.)
  c. Compare results from members of panel, focus on discrepancies, and iterate to a consensus.

Issue Prioritization Criteria

Tier 1

- Issue is critical for reaching the agreed upon goal
- Issue contributes in an important way to the viability of the concept as a fusion energy source
- Resolution of this issue requires major extrapolation from current state of knowledge
- Scaling is untested and/or physics uncertain
- Progress on this issue is essential before other research areas can be adequately addressed.
- Progress would have the broadest impact on fusion and plasma science

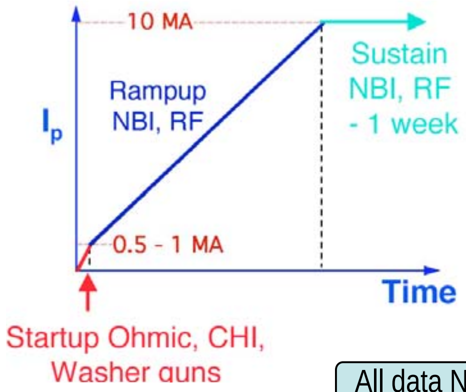
Tier 2

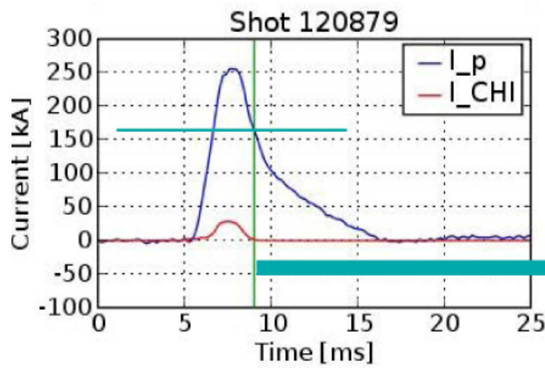
- Issue is important for reaching the goal and/or for the viability of the concept as a fusion energy source
- Resolution of this issue requires major extrapolation from current state of knowledge
- Only limited scaling data and physics basis exist.
- Progress on this issue would be helpful for research on other configurations
- Progress would have a moderate impact on fusion science

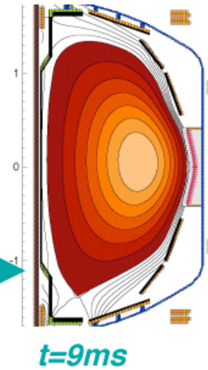
Tier 3

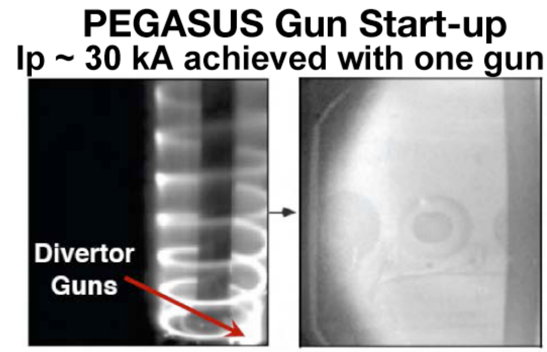
- Reaching the goal will require moderate extrapolation from current state of knowledge
- Some scaling data and/or a partially validated physics basis are available
- Information for resolving this issue may come from other parts of the FES program
- Present status does not hinder progress on other issues.
- Progress would have a narrow impact on fusion science

U.S. Spherical Torus Experiments Address A Wide Range Of Issues: Startup, Transport, Stability,and Power Handling









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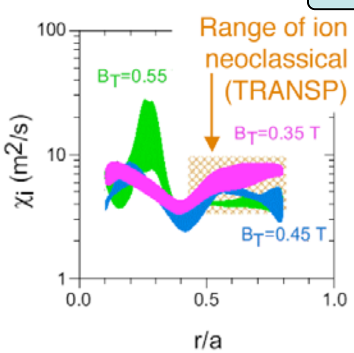
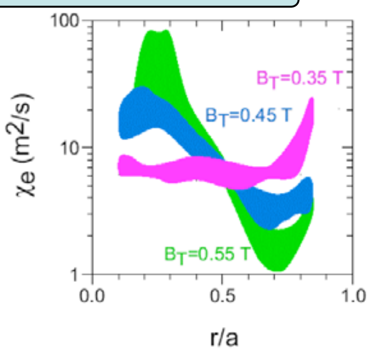
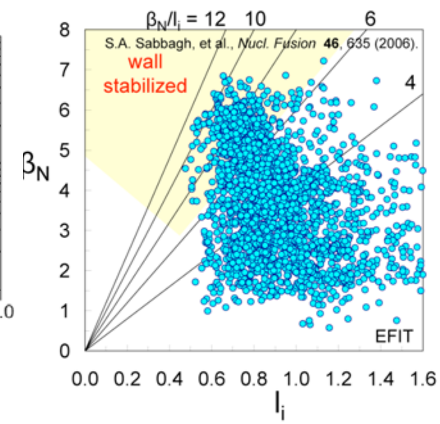
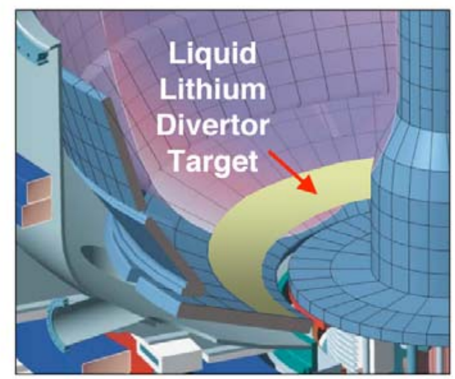








- Data over the last decade shows that essential physics is common with conventional aspect-ratio tokamak, (START, NSTX, MAST) but in different regimes. “Distinction is blurred” (Hill).

Draft ST Mission, ITER-era Goal, and Issues

- Mission: *To develop a compact, high beta, burning plasma capability for fusion energy.*

- ITER-era goal: *To establish ST knowledge base to construct a low aspect-ratio fusion componentt testing facility that provides high heat flux, neutron flux, and duty factor needed to inform the design of a demonstration fusion power plant.*

- Description of the goal: This goal aims to motivate ST R&D and design assessments, working jointly with the tokamak and other science and technology programs, to be ready to start design work on an ST-CFT.

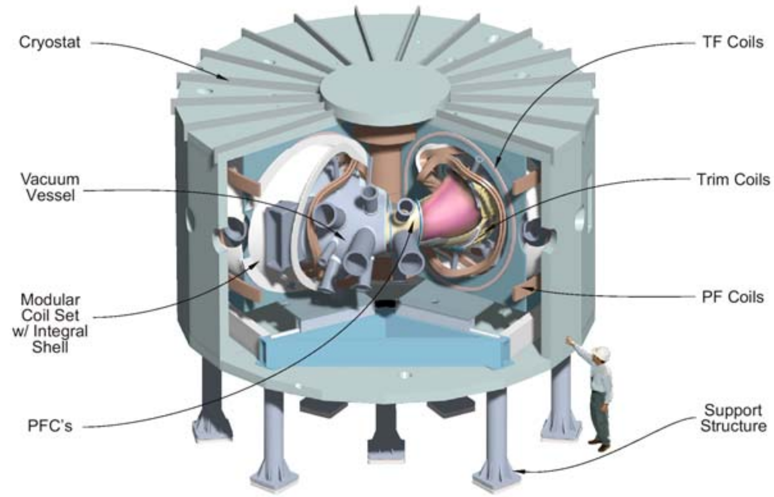
- High Priority Issues:
  1. Startup and ramp-up: *Is it possible to start-up and ramp-up the plasma current to multi-MA levels using non-inductive current drive with minimal or no central solenoid?*
  2. First-wall heat flux: *What strategies can be employed for handling normal and off-normal heat flux consistent with core and scrape-off-layer operating conditions?*
  3. Electron transport: *What governs electron transport at low-aspect ratio and low collisionality? Is it adequate to meet the goal?*
  4. Magnets: *Can we develop reliable center post magnets and current feeds to operate reliably under substantial fluence of fusion neutrons?*

US Stellarator Program Is Focused on Quasi-symmetric Configurations to Optimize Confinement

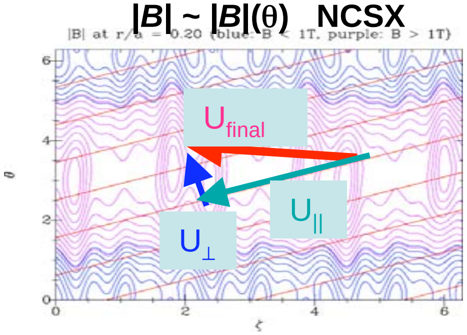
- Helical field variation from stellarator coils enhances neoclassical transport losses. Configuration optimization that minimizes the variation in |B| or “effective ripple” ε_{eff} along one coordinate produces “quasi-symmetric” configurations which can be built at low R/a: compact stellarators.

- US-developed configurations use:
  - quasi-axisymmetry with bootstrap current (NCSX);
  - quasi-helical symmetry (HSX);
  - Torsatron with Ohmic current (CTH).

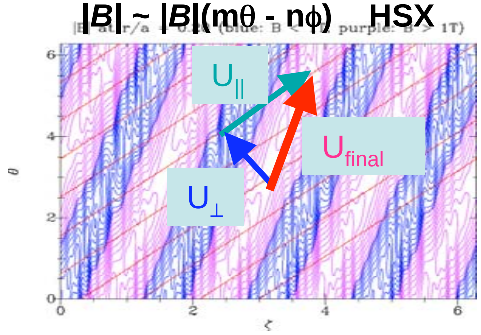
NCSX (PPPL-cancelled 2008)

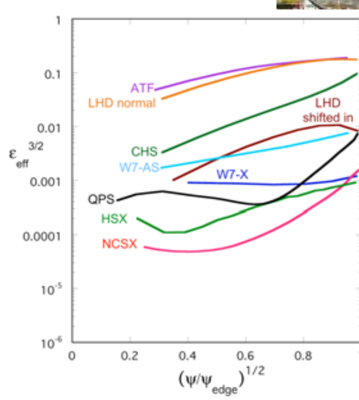


Quasi-toroidal symmetry
|*B*| ~ |*B*|(θ) NCSX

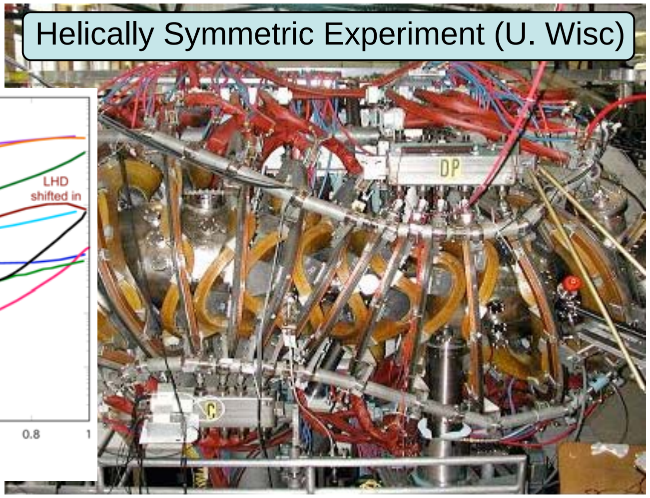


Quasi-helical symmetry
|*B*| ~ |*B*|(mθ - nϕ) HSX





Helically Symmetric Experiment (U. Wisc)



Draft Stellarator Mission, ITER-era Goal, and Issues

- Mission: *To achieve sufficient scientific understanding and plasma conditions to justify designing a fusion reactor based on a fully steady-state, passively stable stellarator.*

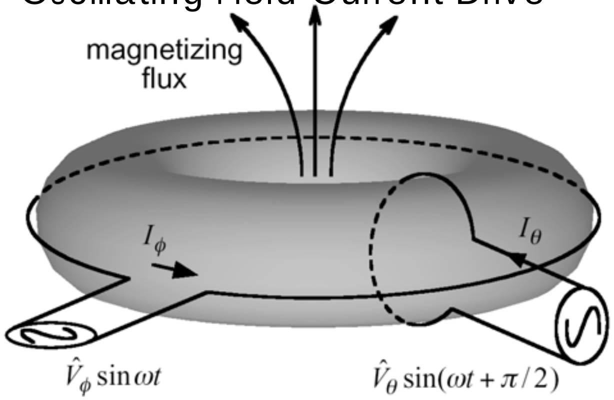
- US ITER-era Goal: *Develop and validate the scientific understanding necessary to assess the feasibility of a burning plasma experiment based on the quasi-symmetric (QS) stellarator.*

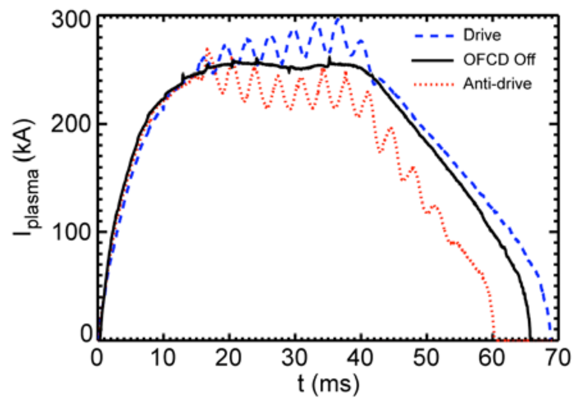
- Description of the goal: The U.S. stellarator program will use theory, modeling, experimental activities, international collaborations, and engineering studies to write the physics-basis document, similar to the ITER Physics Basis Document, that would be necessary to begin construction of a burning plasma experiment based on a quasi-symmetric stellarator.

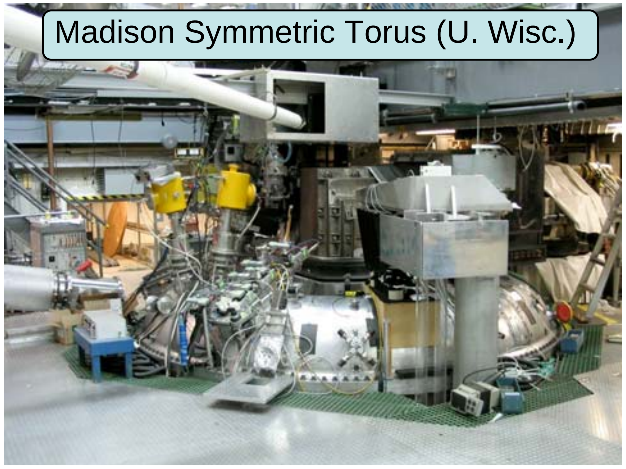
- High Priority Issues:
  1. Simpler coil systems: *Can we find ways to reduce the fabrication risk and cost of optimized high performance stellarator devices?*
  2. High performance integration: *Can improvements observed in smaller experiments be carried over to a high performance level device and what are its required attributes?*
  3. Predictive capability: *Can a predictive capability for quasisymmetric systems be developed by building upon the work in the tokamak program coupled with a smaller experimental database?*
  4. Power handling: *Can a divertor solutions be found for a 3D stellarator system compatible with quasisymmetric operation?*

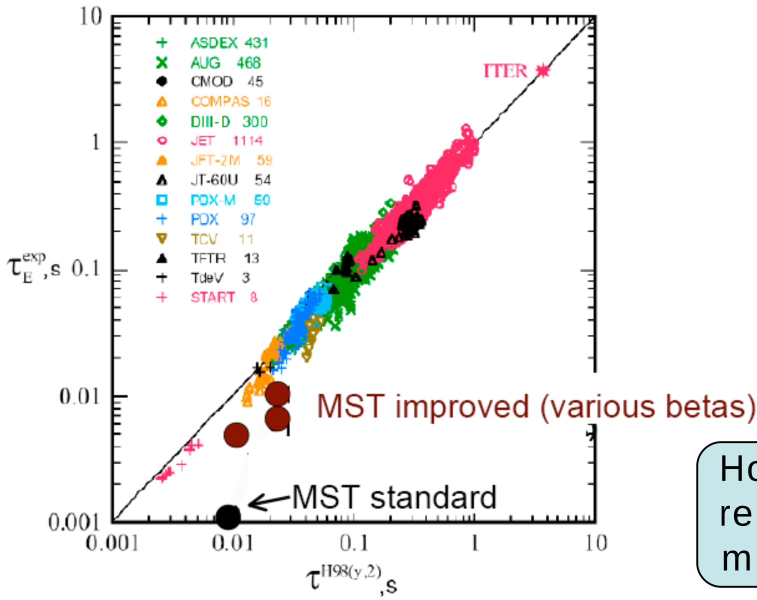
Reversed-Field Pinch Experiments Are Examining Current Drive, Confinement, and MHD Stability

Oscillating Field Current Drive





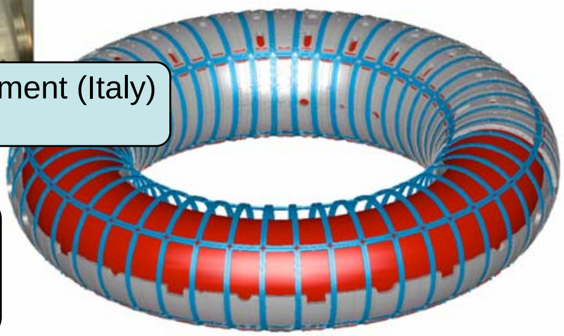




Total of 192 active coils.

100% coverage of the mechanical structure external surface.

Each saddle coil is fed with its own power supply.



Reversed Field Experiment (Italy)
RWM control

Hotter, higher field plasmas reduce CD requirements and may improve confinement

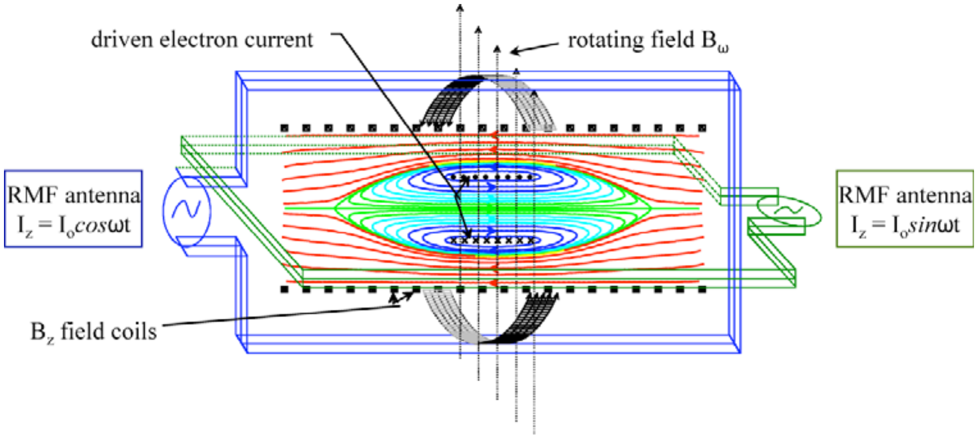
Draft RFP Mission, ITER-era Goal, and Issues

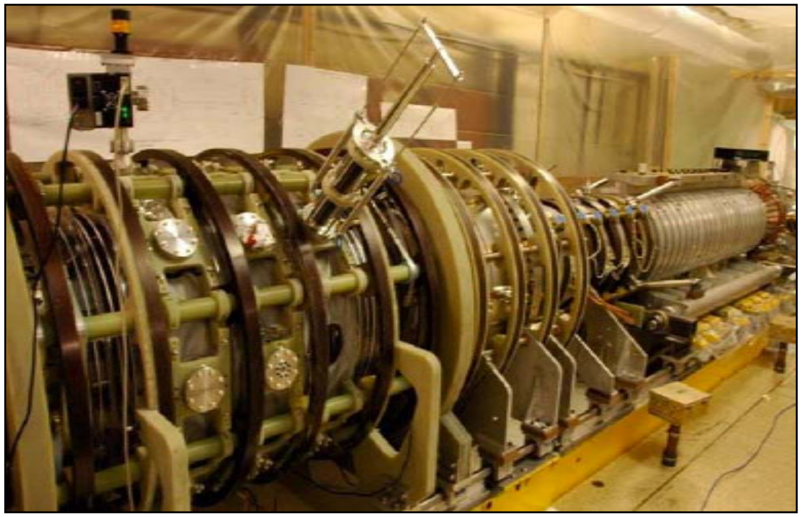
- Mission: *Develop the scientific and technical basis for a fusion power source that uses a small externally applied magnetic field.*
- ITER-era goal: *Establish the basis for a burning plasma experiment by developing an attractive self-consistent integrated scenario: favorable confinement in a sustained high beta plasma with resistive wall stabilization.*
- Summary description of the goal: Recent RFP research has demonstrated high beta plasmas with improved confinement in transient conditions. The next step for the ITER era is to maintain improved confinement at high Lundquist number using current drive methods that extrapolate to either steady-state or long-pulse high-gain fusion scenarios. Identification of important transport mechanisms and confinement scaling will be a major science objective.

- High Priority Issues:
  - Confinement and Transport: *What governs transport when magnetic fluctuations are reduced and how does energy confinement depend upon Lundquist number?*
  - Current sustainment: *Can Oscillating Field Current Drive sustain the RFP configuration with high efficiency as compared to long-pulse induction?*
  - Integration: *Is good confinement compatible with current sustainment at high Lundquist number?*
  - Plasma-boundary interactions: *What RFP boundary configurations for power handling and particle control are compatible with good confinement?*

State-of-the-art CT Experiments Are Not Large (Concept Exploration Class Devices)

Field Reversed Configuration (TCS-U @ U. Wash.)





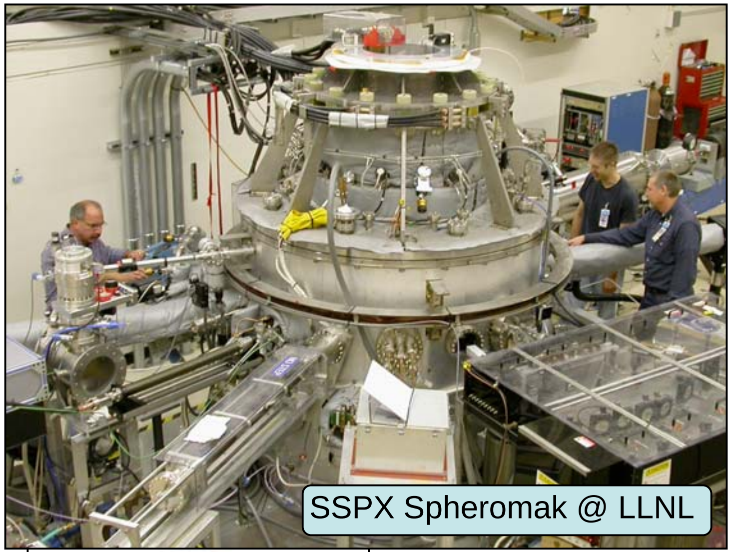
1m diameter

Te ~250eV

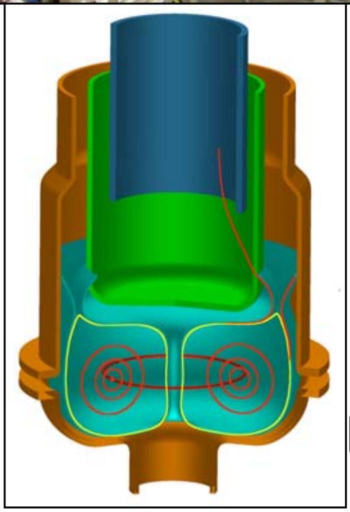
3msec pulse

0.03 Tesla

RMF drive



SSPX Spheromak @ LLNL



1m diameter

Te ~500eV

10msec pulse

0.8 Tesla

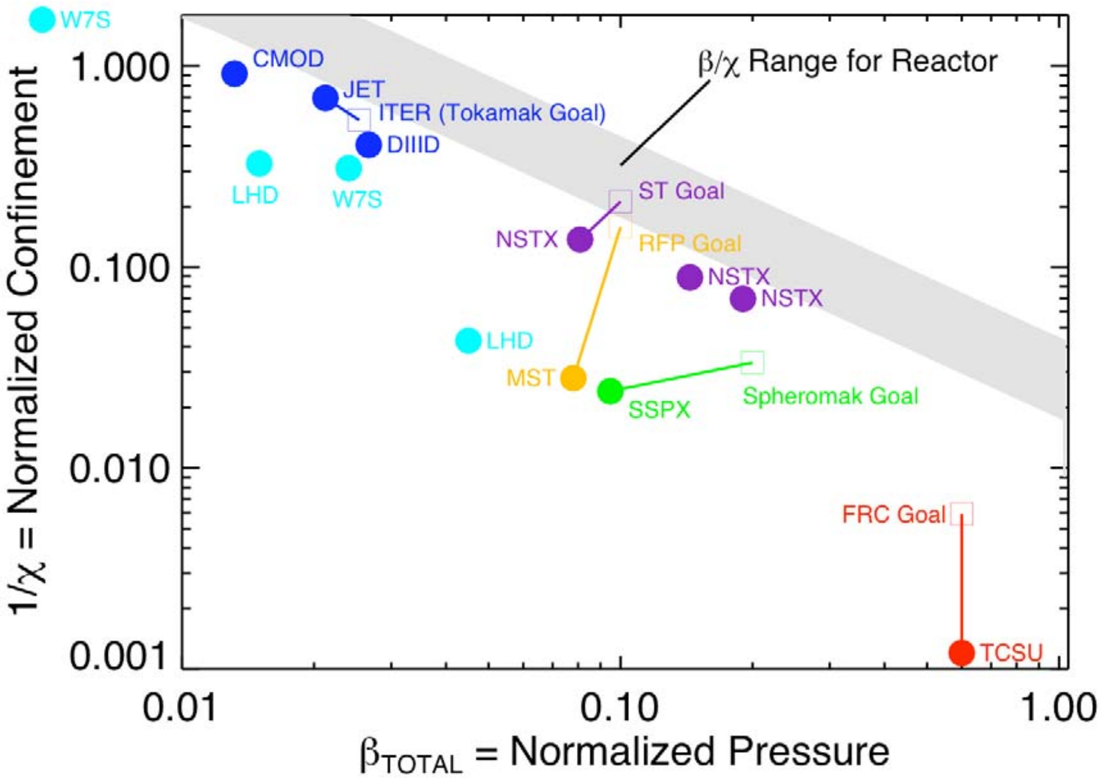
Coaxial Injection

LLNL closed SSPX in 2008

Draft CT Mission, ITER-era Goal, and Issues

- Mission: *Develop a compact magnetic fusion reactor without toroidal field coils or a central solenoid.*
- ITER-era goal: *To demonstrate that a compact toroid (CT) with simply connected vessel can achieve stable, sustained or long pulsed plasmas at kilovolt temperatures, with favorable confinement scaling to proceed to a pre-burning CT plasma experiment.*
- Summary description of the goal: The primary goals are to demonstrate MHD stability at large s (a/ρ_i) with sufficient confinement for the FRC, and to demonstrate efficient field generation and current sustainment with with good confinement in a spheromak.
- FRC Issues
  1. Stability: *Is global stability possible at large-s (a/ρ_i)in low collisionality FRCs?*
  2. Transport: *What governs energy transport and can it be reduced at high temperature?*
  3. Sustainment: *Is energy-efficient sustainment possible at large-s and is it compatible with good confinement?*
- Spheromak Issues
  1. Sustainment: *Can efficient time-averaged current drive be maintained simultaneously with good confinement?*
  2. Formation: *Can formation and buildup techniques be developed to achieve fusion relevant magnetic fields?*
  3. Transport: *What mechanisms govern transport mechanisms and confinement in low collisionality spheromak plasmas?*

Performance of Alternate Concepts Relative to Their ITER-era Goals



- Sheffield (NF 25 1733, 1985)considered general requirements for an attractive (COE) MFE reactor.
- Lawson ignition criteria, with 1D transport and neutron wall loading included, yields

$$\frac{\langle \beta \rangle}{\chi_E}$$

as a figure of merit.

- Takes out size, but possibly not B if χ_E is neoclassical or otherwise dropping with field.

A Couple of General Comments

- In general, we know the least about those concepts requiring the largest extrapolation to reach their ITER-era goal.
  - Low budgets mean comprehensive measurements are lacking: many inferences
  - Complex formation, short pulse-length, and resistive MHD effects represent serious theory and computational challenges to developing fundamental understanding
  - Limited variety of facilities (many are “one-of-a-kind”) and limited operating range for a given facility make it hard to identify trends or separate physics from hardware.
  - Highly specialized operating regimes and terminology require significant intellectual investment to become fully engaged in the research.

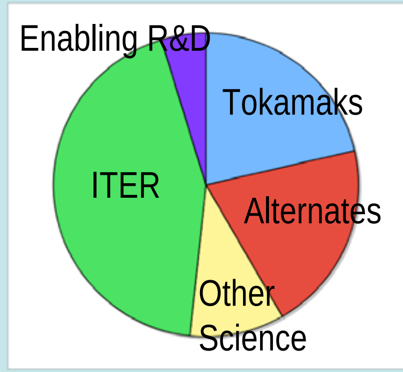
- Relatively speaking, next-step experiments are all expensive (that is, they would significantly impact their part of of the FES Portfolio).

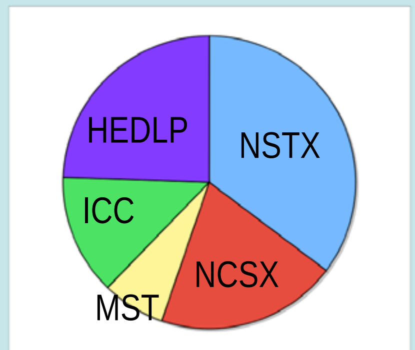
- Intra- and Inter-university collaborations could provide the means to increase effort and depth of research on some alternates.

Priorities Within the Fusion Energy Sciences and Among Innovative Confinement Concepts

FY07 ICC budgets($19M total). Does not include RFP exp.

"Strong External B field"		"Advanced Toroidal and Other"		
Tokamak innovation & physics	**Stellarator**	**Self-organized**	**HEDLP**	**Other**
HBT-EP Resistive-wall stab. Tokamak trans. phys. Divertor innovation Pegasus HIT-II LTX	HSX CTH QPS	Spheromak (SSPX, HIT-SI, CalTech) FRC (TCS-rotomak, Odd-parity RMF, SSX, Theory & Misc.)	Magneto-Inertial Fusion (FRX-L, Solid liner, theory, stand-off driver) Inverse Z-pinch Accelerated FRC Plasma jets	LDX Mary. Centr. Exp. IEC Flow Pinch (ZAP) CT Accel ICC Center
$3.6M	**$3.1M**	**$5.5 M**	**$3.5M**	**$3.3M**



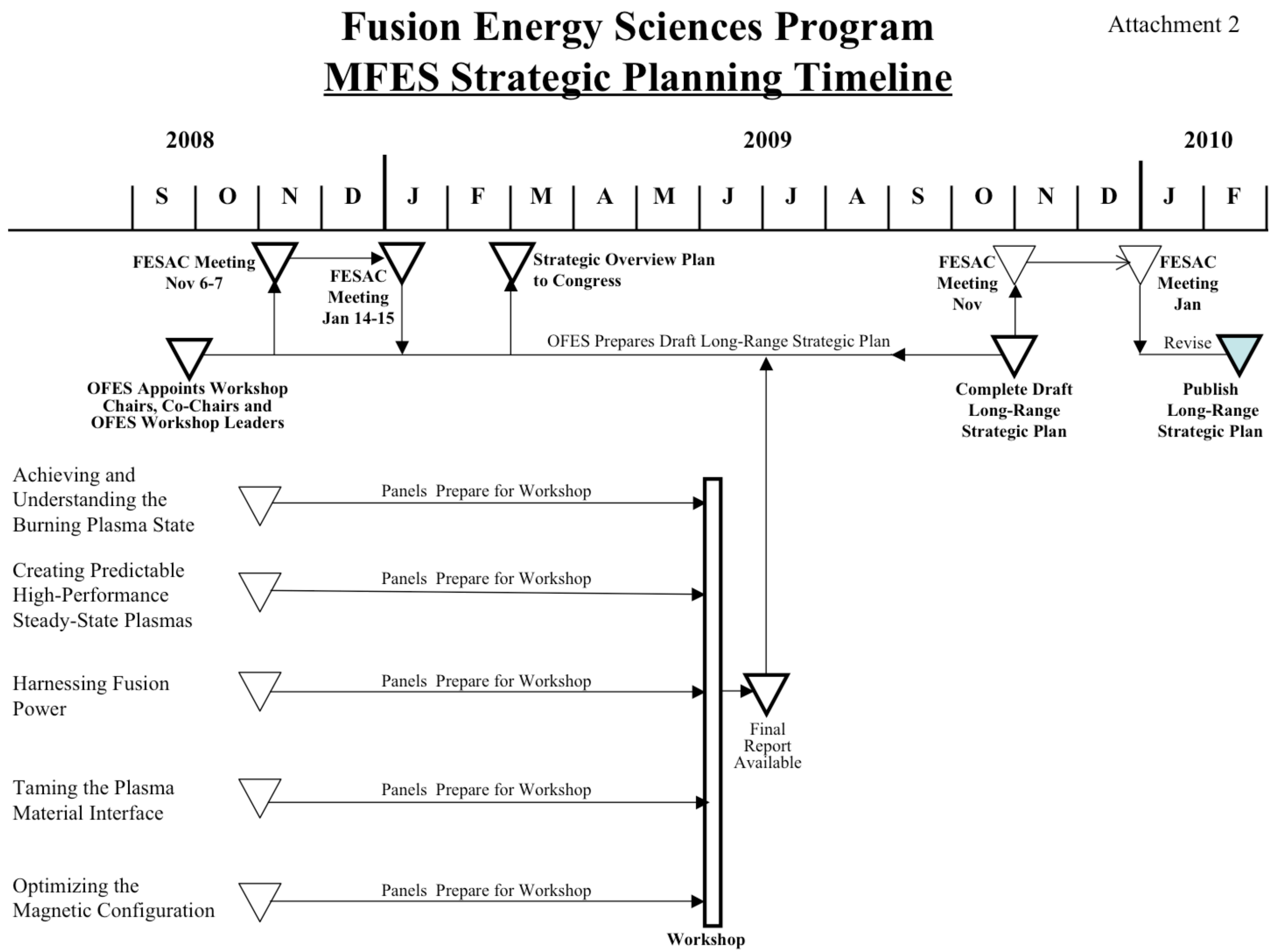


FY2009 Budget Rollout Numbers
Feb-08

Total Tokamaks*	**104389**
DIII-D	58060
C-Mod	23207
Int collab	4900
diagnostics	3912
other	7028
SBIR	7282
Total Alternates*	**100528**
NSTX	35437
MST-RFP	6915
NCSX-stellarator	20252
Exp Alternates (ICC)	13288
HEDLP	24636
Total Other Science	**48340**
Theory	24283
SciDAC	7212
FSP	1976
General Plasma Sci	14869
ITER (MIE+OPC)	**214500**
Enabling R&D	**22715**
MFE Plasma Tech	13351
Advanced MFE design	4573
MFE materials research	4791

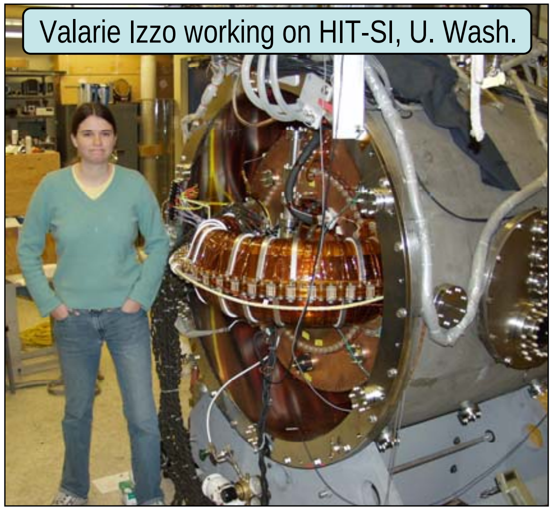
* includes operations+construction

Prioritization: Schedule for OFES ReNeW Process

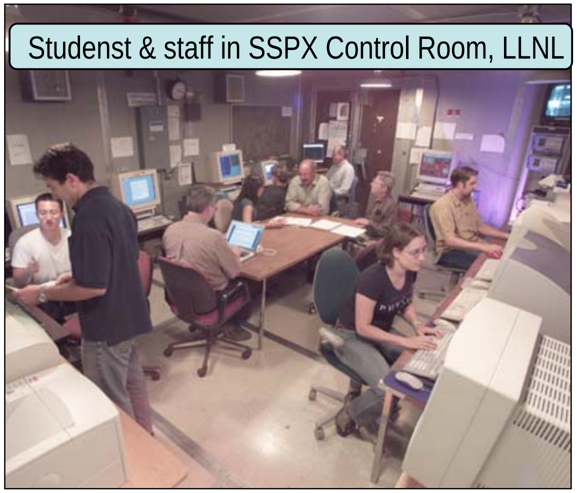


Small-Scale Experiments Located On or Near Campus Attract Students and Provide Unique Experience

- Strong link to fusion energy is a draw to students.
- Allure to the experimentalist is immediate, and theory students can touch the application.
- Limited budgets have both positives and negatives:
  - Positive: Students (graduate and undergraduate) do everything
  - Negative: Students do everything, less time for physics
- Small scale experiments usually have limited diagnostic capability, limited comparison with theory.



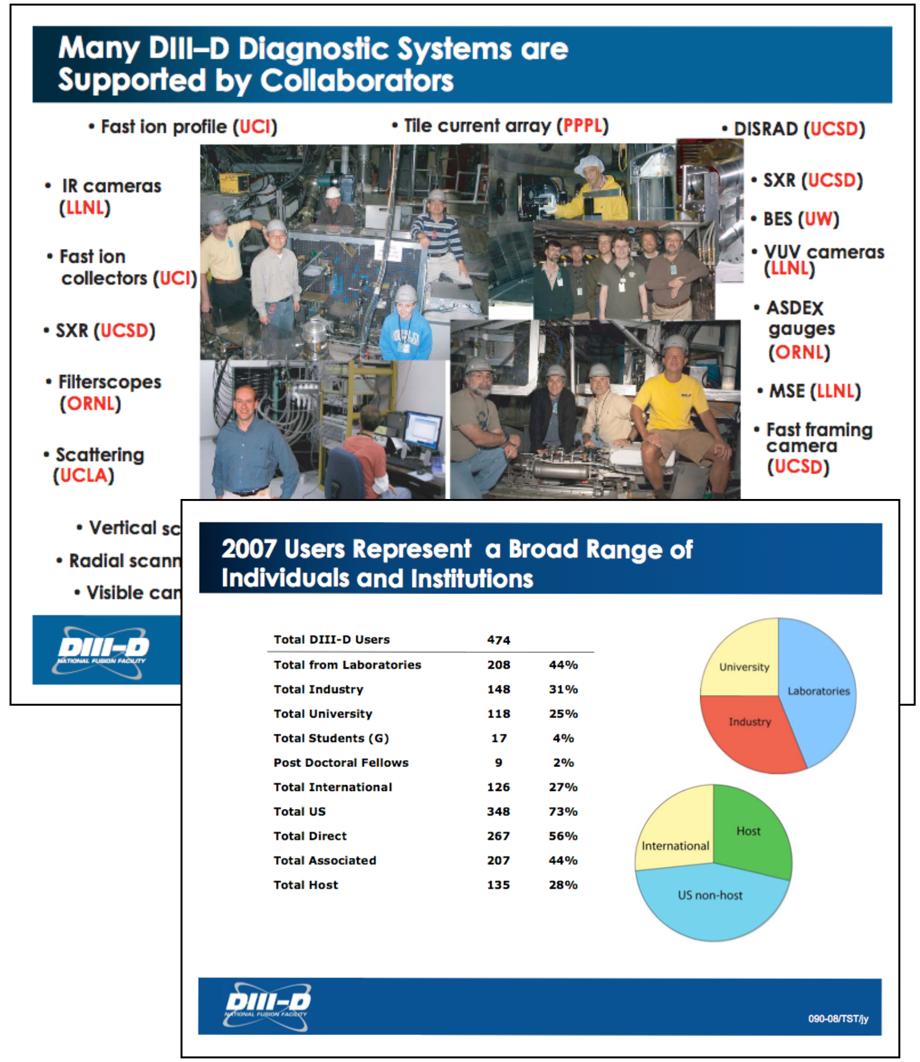
Valarie Izzo working on HIT-SI, U. Wash.



Studenst & staff in SSPX Control Room, LLNL

University Participation Can Grow and Is Welcome on Larger Tokamak Experiments

- Broaden scope of ICC program to invite participation on larger MFE (or IFE) experiments.
- Many opportunities and needs for “student sized” projects in theory, simulation, and experiment.
- Tremendous resources of the major facilities allow high quality, prize-winning science.
- Significance of the effort offers high national and international visibility.
- Easy path for integration into long-term fusion research



Total DIII-D Users	474	
Total from Laboratories	208	44%
Total Industry	148	31%
Total University	118	25%
Total Students (G)	17	4%
Post Doctoral Fellows	9	2%
Total International	126	27%
Total US	348	73%
Total Direct	267	56%
Total Associated	207	44%
Total Host	135	28%

Toroidal Alternates Panel Plans To Complete Its Report By End of October

- Final Panel meeting was in Austin, TX October 1-2, 2008.
- Findings and Recommendations have been completed
- Final editing of document now under way.
- Panel is planning to submit report to FESAC by end of October.
- Report is not official until approved by FESAC.

OFES will be scheduling workshops in FY09 to develop research plans to address high priority issues identified in the panel report