NCSX Project Overview

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Informal NCSX Program Advisory Committee Meeting No. 4

Princeton Plasma Physics Laboratory

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NCSX Has Made Dramatic Progress Since PAC-3

Substantial Gains in Tools and Understanding

- Improved capabilities to optimize and evaluate critical metrics.
- Technical issues are being resolved.

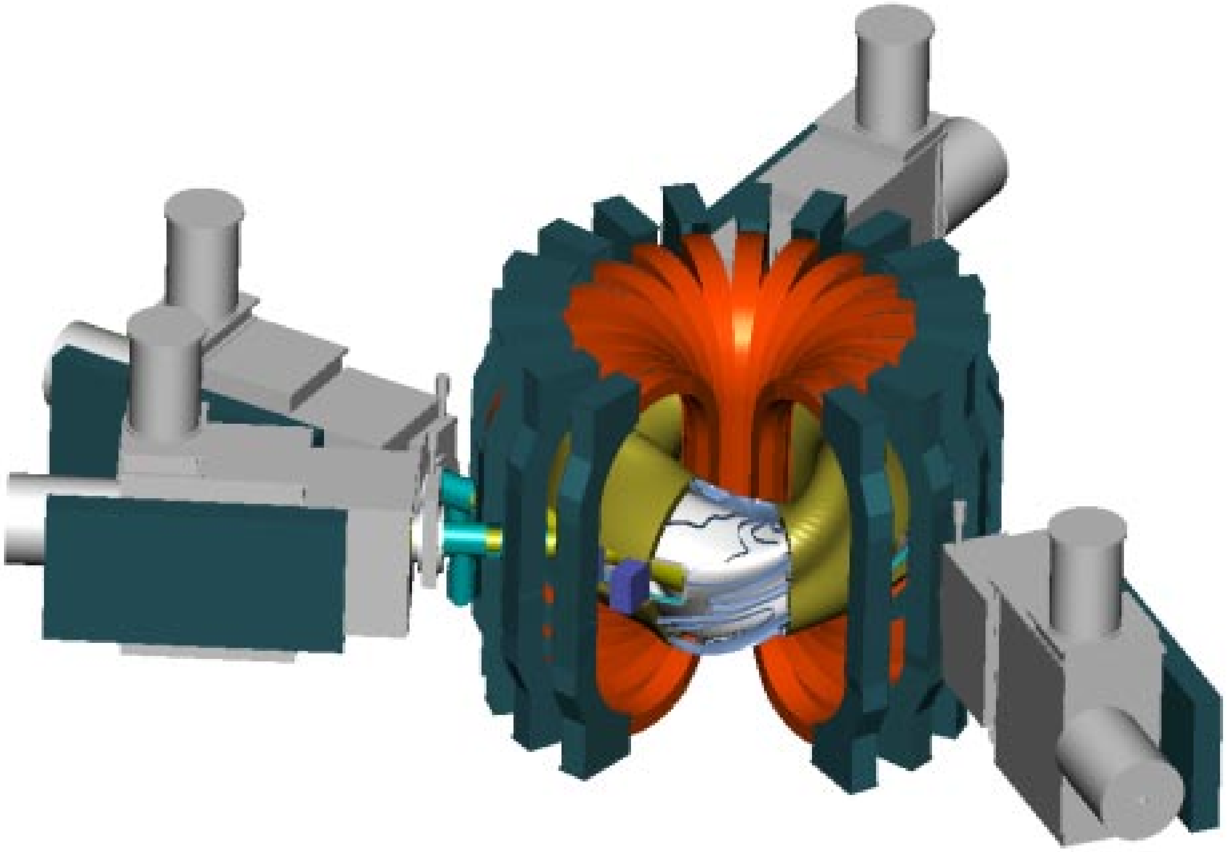
Substantial Improvements in Design

- Much better magnetic surfaces, confinement, coils.
- Have explored a broad range of attractive options from which to choose.
- Now: have narrowed down to 2 plasma and 2 coil options.

Compact Stellarators Included in U.S. Fusion Planning

- FESAC 10-year goal to determine compact stellarator attractiveness.

PAC-3 Design (June, 1999): A Machine Concept Satisfying Most Requirements



R=1.4 m

$\langle a \rangle$=0.4 m

B=2 T

P_{NB}=6 MW

- Reference QA plasma "C82" stable at β=4% without a conducting wall.
- Re-used PBX-M TF and PF coils and neutral beams.
- New conformal saddle coil system and vacuum vessel.

PAC-3 Assessment

PAC Found:

- An interesting plasma configuration and a set of coils that can produce it.

Issues Identified, Further Studies Recommended:

- Magnetic surfaces.
- Coil flexibility for startup and physics studies.
- Technical capabilities, access.
- Confinement, attainability of target beta.
- Coil current density reductions.
- High-beta plasma explorations.
- Bootstrap current uncertainties.
- Wave heating options exploration.
- Tool development.

PAC Expectation: Significant time and tool refinement needed.

FESAC Assessment, August, 1999

Regarding the Compact Stellarator Proof-of-Principle Program

- Ranked high in scientific benefit, energy vision, international integration.
- Expected to become an important PoP program.
- Not then approved for PoP, “because of an important technical issue that needs to be resolved; specifically, the conceptual design embodiment (NCSX) must exhibit robustness of the equilibrium configuration throughout the plasma evolution.”

Recommendations

- FESAC subpanel participation in NCSX review process to complete PoP readiness evaluation.
- Budget increases ($1M in FY-2000, $1.5M in FY-2001) to expedite design completion, issue resolution, successful reviews.

Program Responses to PAC & FESAC Reports

Agreed that NCSX design needed improvement. Steps taken:

- Improved tools, developed understanding.
- Broadened the range of options: plasma configurations, coil topologies.
- Shifted balance of effort: increased physics, reduced engineering.
- Delayed Physics Validation Review to Dec., 2000.

Program budget was increased by $0.9M (to $5.1M) for FY-2000, per FESAC recommendation. But flat budgets are planned for FY-2001-02.

FY-2000 Accomplishments- 1
Gains in Tools & Understanding

Issue	Tool improvements and Studies
Magnetic surfaces **(Reiman)**	• Major improvements in PIES and VMEC codes. • New island-reduction method being tested.
Flexibility **(Lazarus, Hirshman)**	• New free-boundary optimizer for coil flexibility analysis. • Startup simulations clarifying system requirements.
Plasma design **(Zarnstorff)**	• Improved targeting of physics and coil metrics. • Parameter-space explorations: ι, κ_{axi}, β, $R/\langle a\rangle$, $N_{periods}$
Coil design **(Hirsh-man, Nelson)**	• Improved optimization tools and explored various coil types. • Small-scale conductor tests to determine design allowables.
Confinement **(MZ)**	• New power-balance solver with improved self-consistency.
Wave heating **(MZ)**	• HHFW absorption, system study extended.
Access **(Nelson)**	• Heating, diagnostic access req'ments, solutions studied.

Physics and technology innovations by national stellarator team have dramatically advanced the stellarator knowledge base.

FY-2000 Accomplishments- 2
Major Improvements in Design

Metric	**PAC-3 Design**	**Current (PAC-4) Status**
Magnetic surfaces @high β	stochastic for r/a>0.75.	good surfaces out to r/a=1; ~15% internal islands.
Eff. helical ripple @r/a0.7	1.0%	0.6%
Fast ion loss	22.5%	19.0%
Coil current density (unopt.)	35.8 kA/cm^2	17.8 kA/cm^2
Coil complexity	3.11	2.05
Flexibility of coils	unexplored	startup states, alternate high-β profiles
Access	only NBI studied	NBI, RF, diagnostics, pumping

Desired improvements have been achieved.

Selection of Reference Plasma-Coil Configuration

Plasma Configurations Unconstrained by PBX-M (M. Zarnstorff)

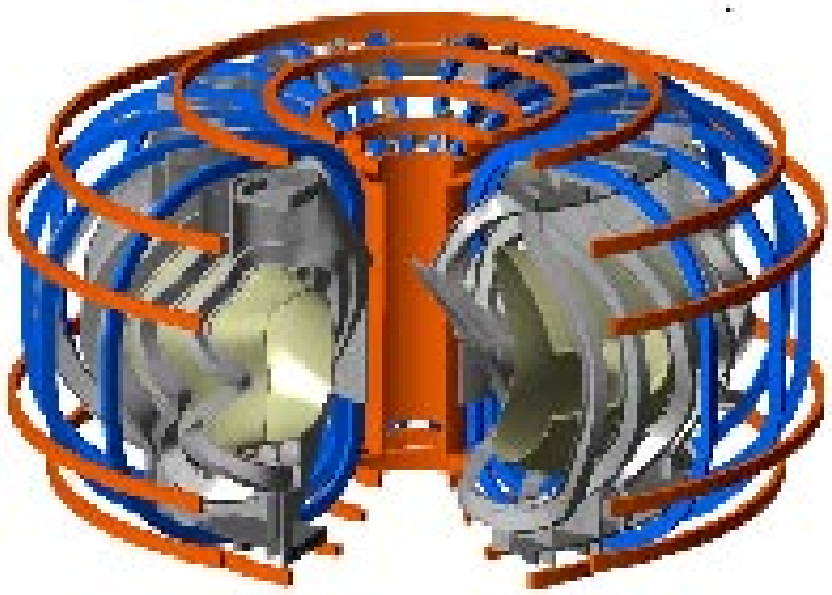
- Found many better than C82 from which to choose.
- Currently focussing on two:
  - 3-period, A≈4.4 (better developed).
  - 2-period, A≈3.3.

Coil Topologies (W. Reiersen, S. Hirshman)

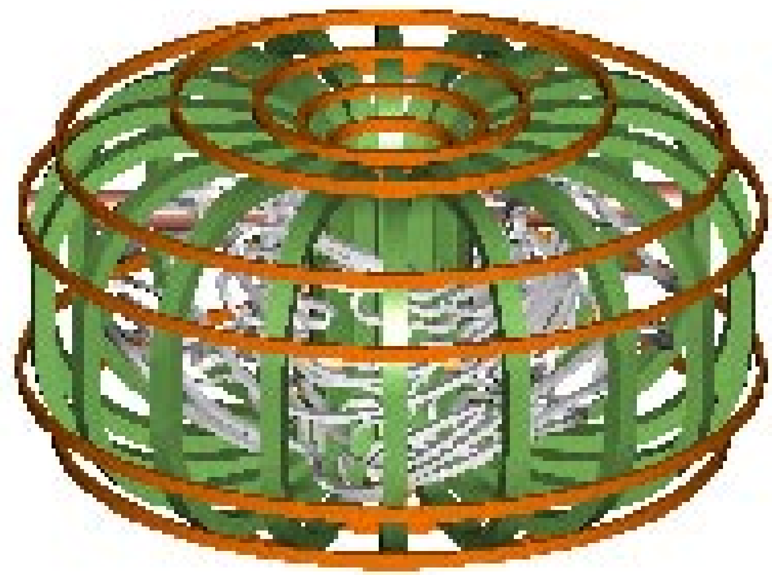
- Found multiple attractive alternatives.
- Currently focussing on two:
  - saddles + background TF coils
  - modulars with weak TF coils

Select reference plasma (next few days) and coil topology (Sept.) for FY-2001 design development and reviews.

Modular and Saddle Coil Designs Are Being Evaluated



Modular + Weak TF



Saddles + TF

Satisfy common compulsory physics requirements.

Likely differentiators: flexibility, access, risk, maintainability, cost,...

PAC-3 & FESAC Issues: Magnetic Surfaces

PAC-3: good surfaces in the primary plasma configurations; maintaining surfaces in other configurations.

FESAC: the conceptual design embodiment (NCSX) must exhibit robustness of the equilibrium configuration throughout the plasma evolution.

Current Status (A. Reiman)

- Greatly improved surfaces; ~15-20% internal islands in β=0 and full-β states.
- Promising method for shrinking internal islands being tested.
- Surface quality relatively insensitive to profile variations, in initial studies.

PAC-3 Issues: Flexibility

PAC-3: Coil-set flexibility: accommodate different profiles, plasma shape variations, start-up.

Current Status (S. Hirshman)

- Coil designs required to reproduce startup states.
- Coils compatible with high-beta equilibria over a range of profile shapes (initial studies).
- Coils provide fast current ramp rates (2 MA/s) for startup scenario.
  (E. Lazarus, W. Reiersen)

PAC-3 Issues: Confinement

PAC-3: Confinement enhancement, access to high beta with available power.

Current Status (M. Zarnstorff)

- New configurations have reduced ripple, better neoclassical and fast-ion confinement.
- Self-consistency of confinement projections improved.
- Power & particle handling scoping studies (J. Schmidt, P. Mioduszewski) has neutral control as key objective: wall conditioning, limiter placement, possible divertor upgrade.

PAC-3 Issues: Machine Capabilities and Design

PAC-3: Clarify technical capabilities, in particular pulse length, magnetic field strength, heating power, and diagnostic access.

Current Status (M. Zarnstorff, W. Reiersen, B. Nelson)

- Reference scenario (B-field/pulse length) satisfied by all designs.
- Heating (NB, RF) and diagnostic access requirements clarified and accommodated.

PAC-3: Explore current-density reductions, higher beta, wave heating; improve tools.

Current Status

- Progress on all of these.

Schedule Aims At Title I Design Starting in FY-2003

Preconceptual Design (complete in Dec., 2000)

- Update reference configuration (plasma + coils), Sept., 2000.
  $\Rightarrow$ basis for FY-2001 design development and reviews.
- Physics Validation Review (PVR), Dec., 2000
  - Physics basis; requirements; preconceptual design, cost, and schedule.
  - Resolution of FESAC technical issues for PoP readiness.

Conceptual Design (Jan. 2001 – Sept. 2002)

- Design, Cost, and Schedule Review ("DCSR"), April, 2001
  $\Rightarrow$establish baseline to support project validation (May, 2001) and FY-2003 budget request for start of engineering design.

Title I Design (start October, 2002)

The Project Can Meet These Milestones

Fusion Community Interest in Stellarators is Growing

News Items

- LHD getting good results: β=2.4%, enhanced confinement, high temperatures, 80-s pulses.
- Compact Toroidal Hybrid (Auburn University) proposal was successful!
  $\Rightarrow$ MHD studies with novel iota-profile diagnostics in current-carrying stellarator.
- Welcome to LLNL initiative to collaborate with ORNL & PPPL on power and particle handling for compact stellarators. (D. Hill, M. Fenstermacher)
- 1999 FESAC plan, draft integrated program plan include stellarator objectives:
  5-year: determine performance of a large stellarator through int'l collaboration.
  10-year: determine the attractiveness of a compact stellarator.

Outstanding Progress Has Been Made Since PAC-3

- Large gains in tools and understanding.
- Broad range of options studied.
- Major improvements in the design.
- Key design decisions are being made this summer.
  $\Rightarrow$Update reference machine configuration by end of September.
- On track for resolution of issues, favorable outcomes.

Goals for PAC-4:
An Interactive Meeting
Your Best Advice