NCSX Project Overview

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NCSX Project Manager

NCSX Program Advisory Committee Meeting #5

Princeton Plasma Physics Laboratory

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UCSD, Columbia U., LLNL, ORNL, PPPL, SNL-A, U. Texas

in collaboration with

Auburn, NYU, Wisconsin

Australia, Austria, Germany, Japan , Russia, Spain, Switzerland, Ukraine

NCSX Is On Track for an FY-2003 Project Start

- Progress made since PAC-4 (Aug., 2000) is commensurate with the goal of an FY-03 start:
  - Design, issue resolution, decisions.
- We have a good plan for completing the next critical milestone: a Conceptual Design Review (CDR), in April, 2002.
  - Sound technical basis, work plans targeting CDR issues.

⇒ ***Charge from Rob: Advise on the project's plans for addressing issues as it prepares for the CDR.***

- This talk:
  - Goals for a CDR.
  - Progress since PAC-4.
  - Recommendations from PAC-4 and Physics Validation Review (PVR).
  - Current status and plans for the CDR.

Goals for a Conceptual Design Review

Assure that:

- Requirements are identified.
- Requirements can be satisfied within acceptable envelopes.
- Cost and schedule targets can be met.
- Issues from past reviews are satisfactorily resolved. [PVR, PAC]
- Plans for completing the design and development, and hardware acquisition, are sound.
- Risks and hazards are identified; have plans for managing them.
- Project organization and management plans (including Integrated Safety Management) are appropriately developed and implemented.

Obtain:

- Recommendations for improving designs or plans.

Emphasize novel or unusual aspects of the design.
(NCSX: modular coils, vacuum vessel)

Progress Since PAC-4 Is Commensurate with FY03 Start

PAC-4 (Aug., 2000). Highlights of committee report:

- "Project needs to complete a design proposal"
- 2 major recommendations: 1) emphasize physics in design choices, 2) pursue magnetic surface studies with high priority.
- Numerous findings and observations.

Completion of the preconceptual design (Aug., 2000-Mar., 2001).

- Key design decisions were made: reference plasma, coil topology, size.
- Proposal (>300 pgs.) documenting design and physics basis was written.

PVR (Mar., 2001). Highlights:

- **Review was very positive!**
- QAS choice and overall physics design approach affirmed.
- FESAC PoP sub-panel: "We conclude that the CS is ready for PoP designation."
- 29 recommendations.

Key Programmatic Decisions Were Made Based on the PVR.

- FESAC endorsement of PoP designation for the compact stellarator.
  - “The NCSX program offers an exciting opportunity in fusion research.”
  - May resolve reactor issues: disruptions, steady state.
  - Complements advanced tokamak, foreign stellarator research.
  - Advances physics of 3D magnetized plasmas.
  - “These gains earn for the compact stellarator an important place in the portfolio of confinement concepts being pursued by the US Fusion Energy Sciences program.”
- DOE approval of “Mission Need” for NCSX.
- Start of conceptual design

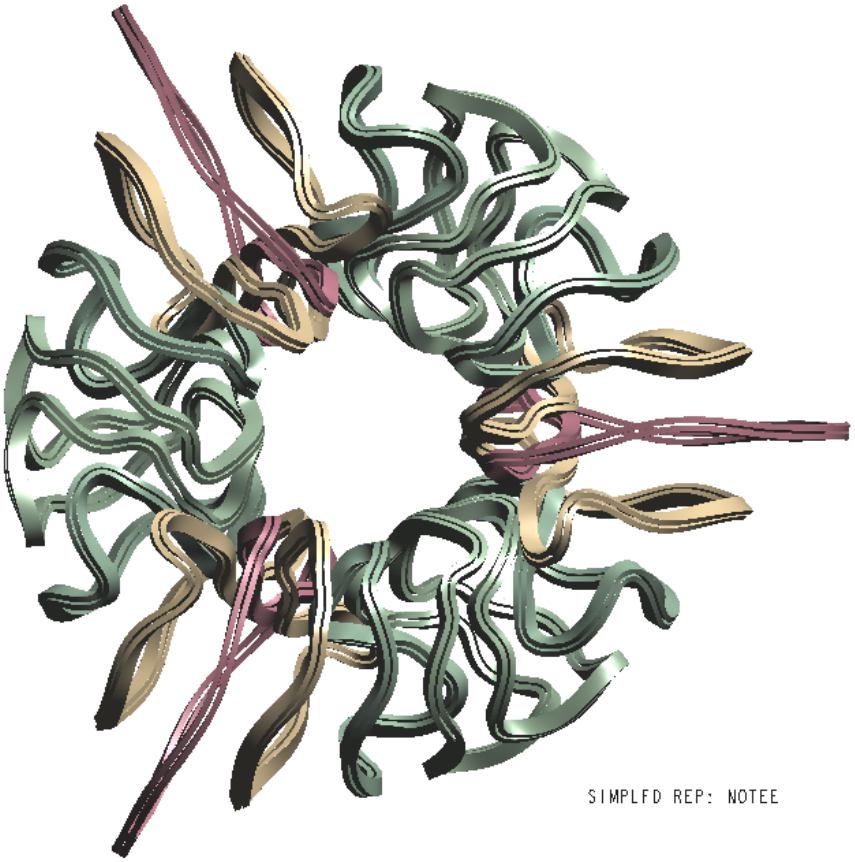
Design Has Improved Considerably Since the PVR.

- New configuration.
  - 18 modular and TF coils (reduced from 21); 5 pairs of PF coils.
  - Have a coil design that provides required physics properties and flexibility. (M. Zarnstorff, N. Pomphrey)
  - Coils were optimized targeting engineering objectives as well as physics.
  - Better heating and diagnostic access: no coils on symmetry planes.
  - Enlarged vacuum vessel: more volume for plasma, divertor hardware, RF launcher; smoother surfaces.

- A coil design for engineering studies has been selected.
  - Local coil perturbations needed to provide adequate coil-to-coil separation.

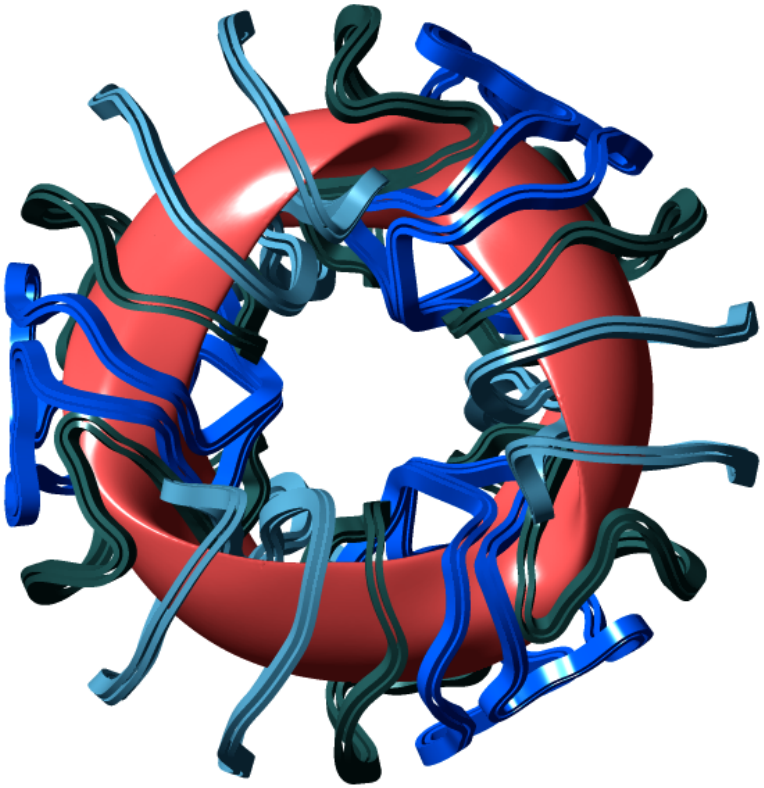
- Coil design improvements will continue.
  - Optimization tools targeting physics and engineering objectives.
  - Results of design improvments, manufacturing studies will be folded in to future updates.

18 Modular-Coil Design is Better for Access and Cost



21 coil design (PVR)

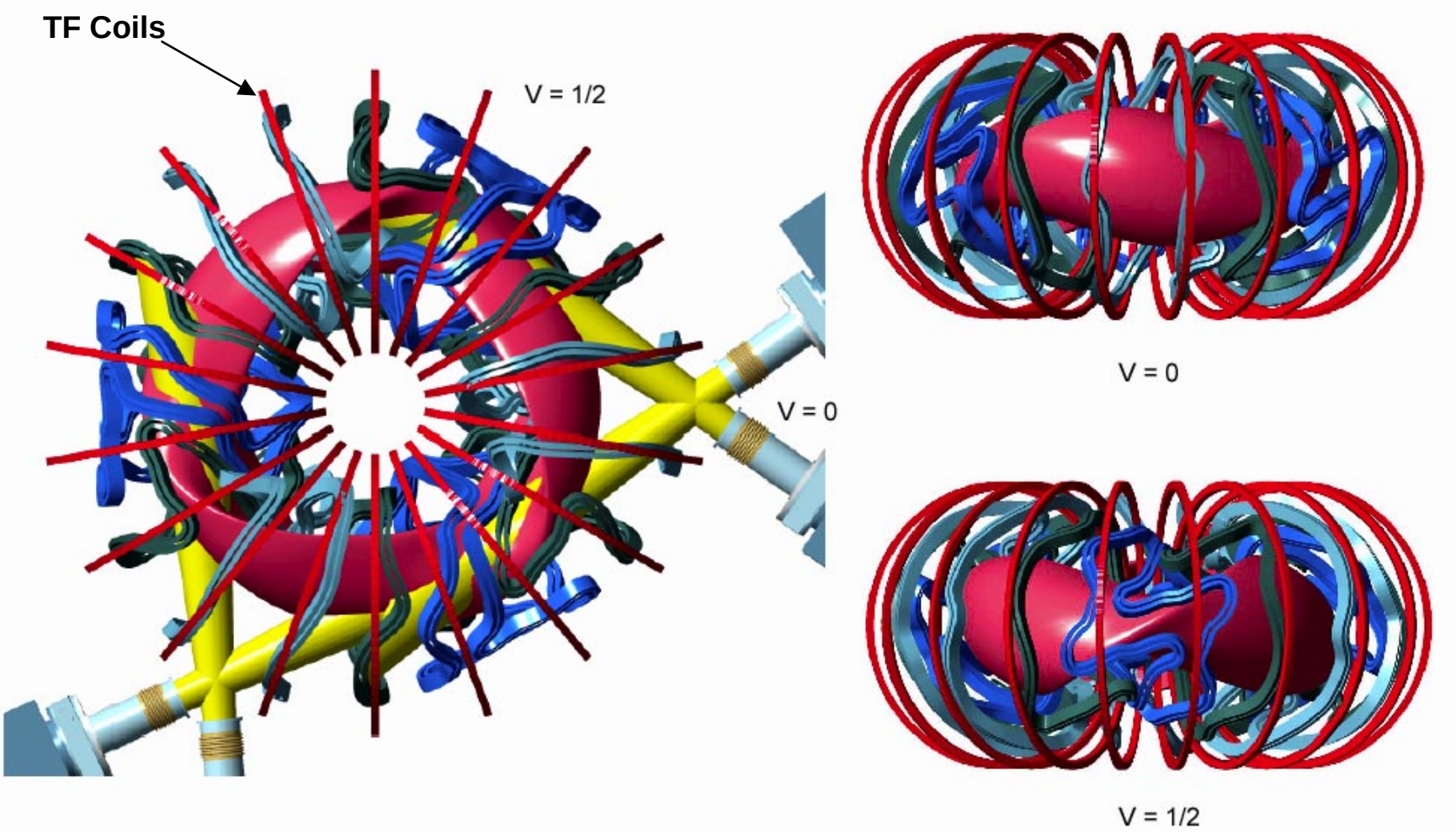
- 4 coil shapes
- v=0 symmetry plane coils extended for NBI access.



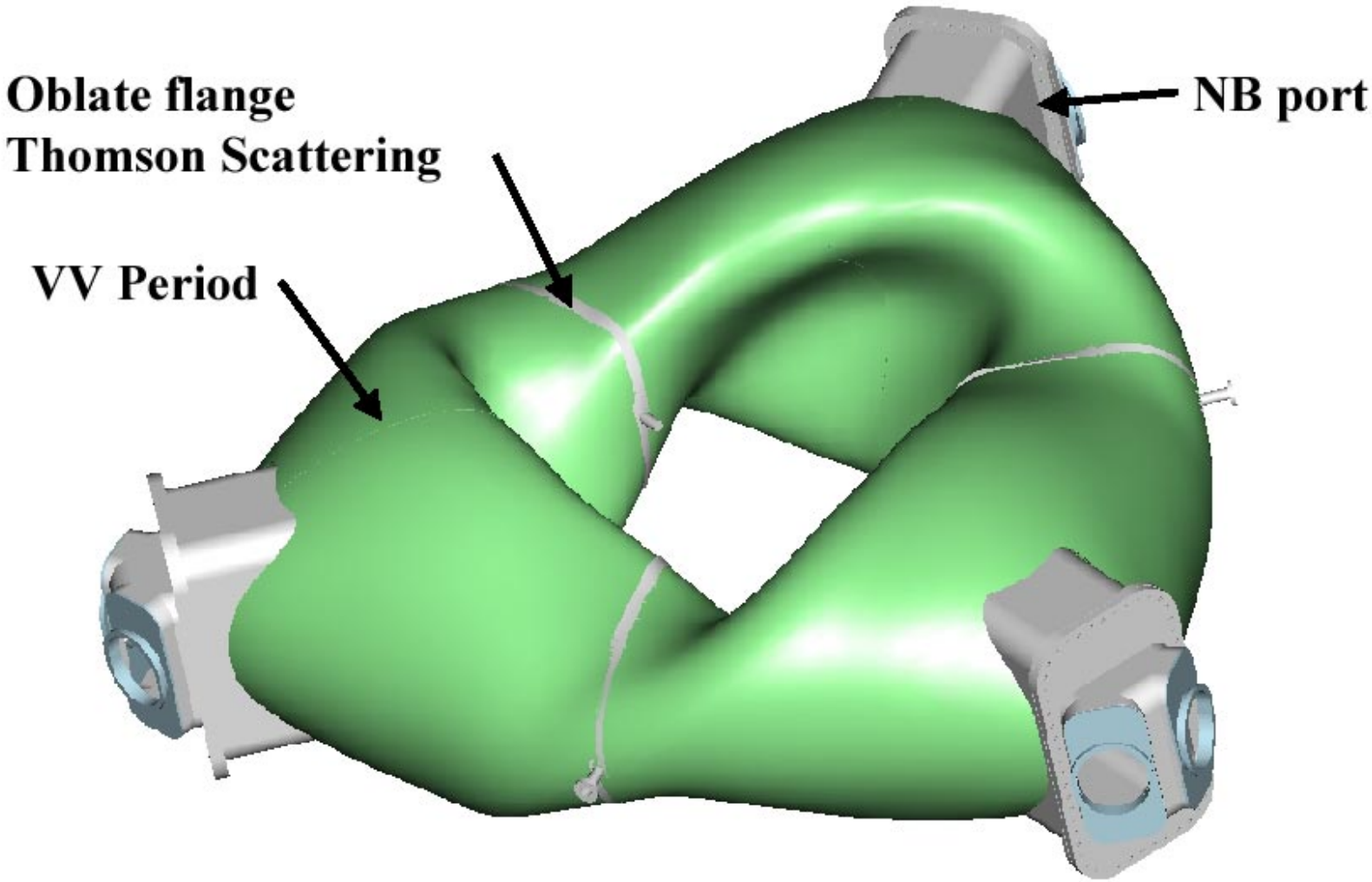
18 coil design (PAC-5)

- 3 coil shapes
- no symmetry plane coils.
- provides NBI access.

TF Coils Are Centered on Modulars to Provide Best Access

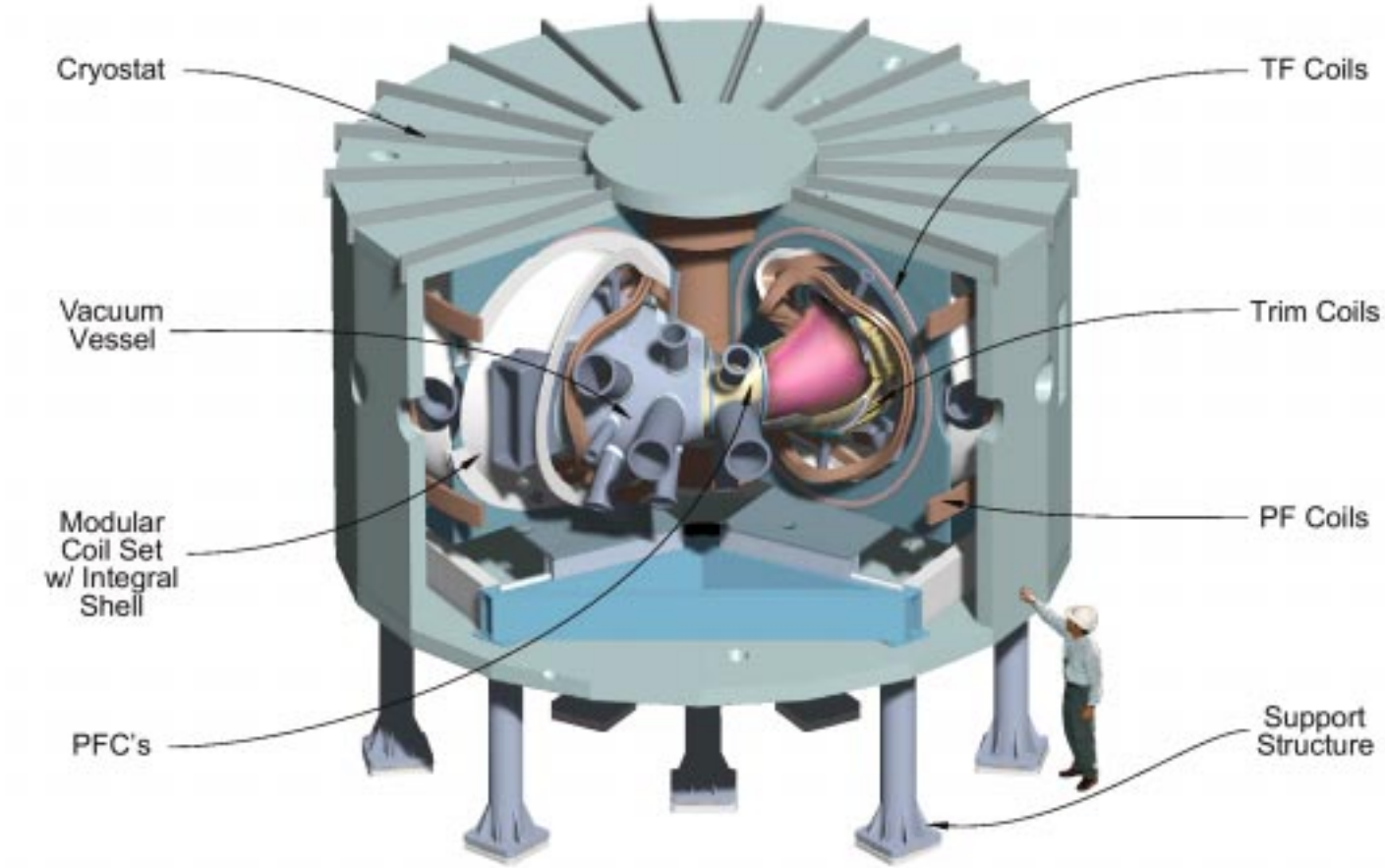


Vacuum Vessel Configuration



- **New shape provides more plasma-first wall clearance and space for PFCs.** (B. Nelson, P. Mioduszewski)

NCSX Stellarator Core Concept



- Sited in PLT/PBX test cell
- Re-uses existing neutral beams, power supplies, infrastructure.
- Project cost ~$69M (Oct., 2002 - March, 2007).

Size and Baseline NBI Power Are Unchanged From PVR

Is the PVR design point (R=1.4 m, P_{NB}=3 MW) "too small"? (PVR issue)

- Concerns: marginal in…
  - NBI power, NBI losses, confinement needed to reach design beta.
  - Plasma-to-PFC spacing, neutral penetration
  - Access.
- Recommendation II-2: size to be carefully considered, well justified for CDR.

Project position: (details to follow)

- Requirements can be satisfied at PVR design point.
- Design improvements have led to increased margins.
- There are physics benefits to larger size and more power, but it would raise project cost and delay program.
- PVR size provides the appropriate balance between cost and risk considerations.

⇒ No change needed.

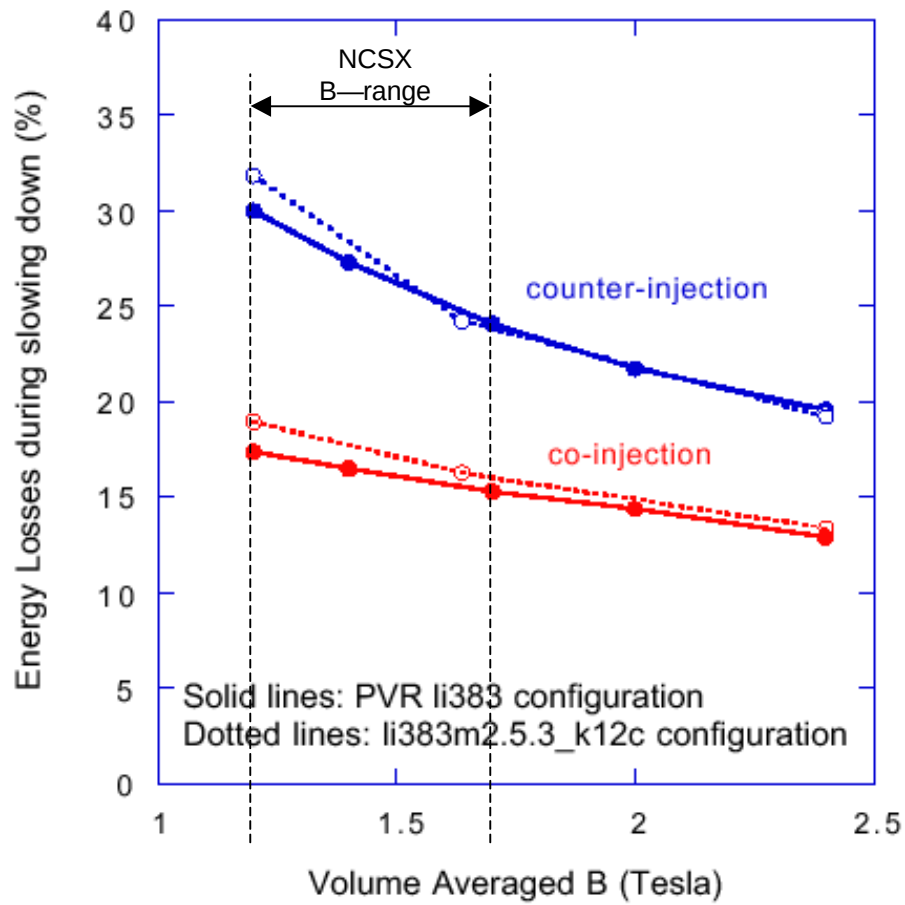
Beam Loss Sets Minimum $B_0 \times R$ at 1.2 T × 1.4 m

- Balanced injection orbit loss of 24% at $(B_0R)_{min}$ is included in confinement predictions.

- Options exist, if losses are a problem:
  - Increase power.
  - Rely more on RF.

- Larger machine ⇒ higher maximum B_0.
  - higher plasma performance, access to lower collisionality.

Monte Carlo calculations for E_{inj} = 40 keV and fixed-bdy / free-bdy (solid / dashed) NCSX equilibria at R = 1.4 m.



Adequacy of Heating

- Baseline project scope provides 3 MW of NBI and includes…
  - Core machine designed for 6 MW of NBI using the 4 PBX-M beams.
  - Core machine designed to also accommodate future RF launchers (in-vessel, high-field side) for 6 MW of mode conversion heating using existing RF system. (Recent design improvement- B. Nelson)
  - NBI system design work for full 6 MW.
  - Hardware modifications, installation, and testing for the first 3 MW of NBI. (needed for initial heating experiments, ~1 year after 1st plasma)

- Next 3 MW will be added as an upgrade.

- Heating can be increased up to 12 MW via upgrades, if needed.

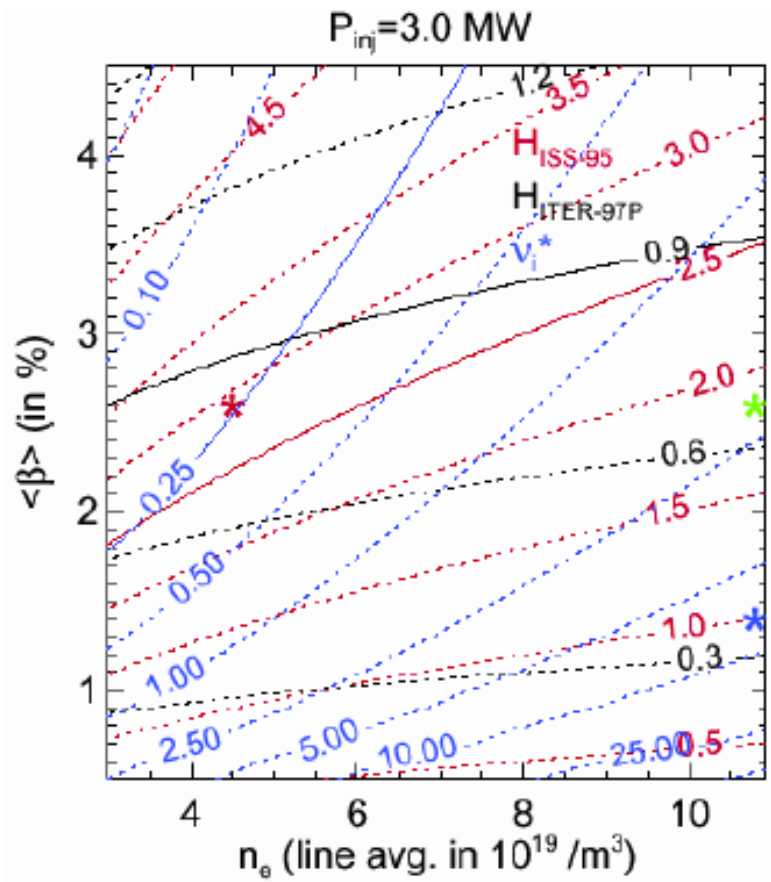
Plan is well matched to program needs.

Beta Limit Physics is Testable With P = 3 MW

With P = 3 MW, can reach…

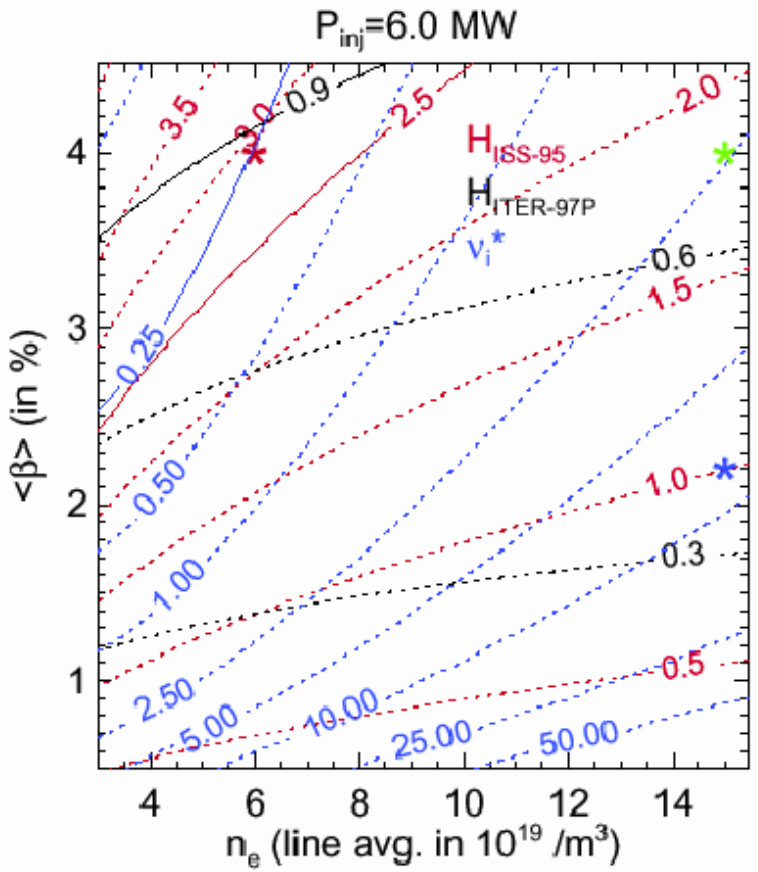
- $\langle\beta\rangle$ = 2.6% at ν_i^* = 0.25 with H_{ISS95} = 2.9, $H_{ITER97P}$ = 0.8.
- $\langle\beta\rangle$ = 2.6% with H_{ISS95} = 1.9, but large ν_i^*.
- $\langle\beta\rangle$ = 1.4% with H_{ISS95} = 1.
- MHD stability predictions can be tested at these betas with de-optimized shapes. (N. Pomphrey)

Projected Operating Space at B_0 = 1.2 T, R = 1.4 m



Higher Power ⇒ Wider Operating Range

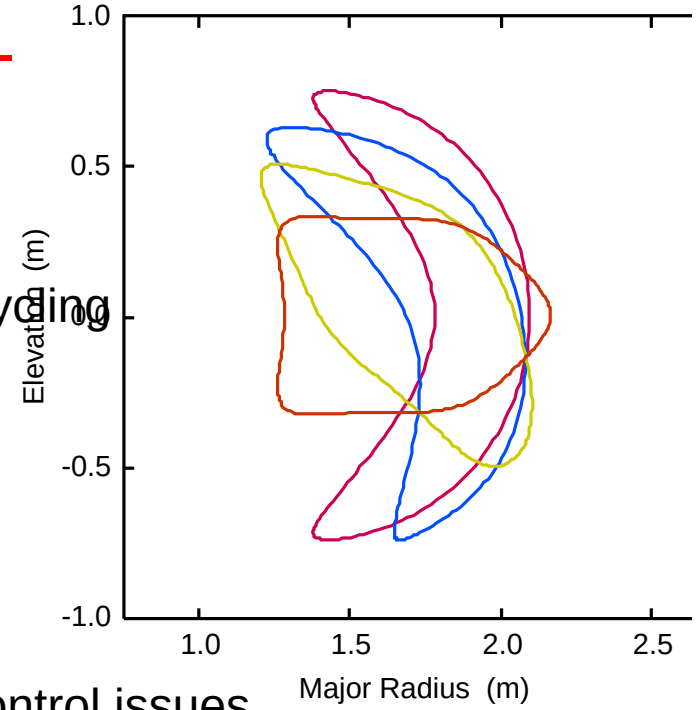
Projected Operating Space at B_0 = 1.2 T, R = 1.4 m



With P = 6 MW, can reach…

- $\langle\beta\rangle$ = 4% at ν_i^* = 0.25 with H_{ISS95} = 2.9, $H_{ITER97P}$ = 0.9.
- $\langle\beta\rangle$ = 4% with H_{ISS95} = 1.8, but large ν_i^*.
- $\langle\beta\rangle$ = 2.2% with H_{ISS95} = 1.

Neutral Penetration



PVR status…

- Calculations showed importance of controlling recycling source location.
- Further investigation recommended (IV-7).

Since the PVR…

- Increased NCSX design emphasis on boundary control issues.
  - Provision for adequate plasma-PFC spacing (connection lengths)
  - Vacuum vessel geometry modified to accommodate pumped divertor upgrade.
  - Further plasma and neutrals modeling.

  P. Mioduszewski will discuss.

Neutral penetration concerns can be allayed without increasing size.

Access is Adequate

Beams

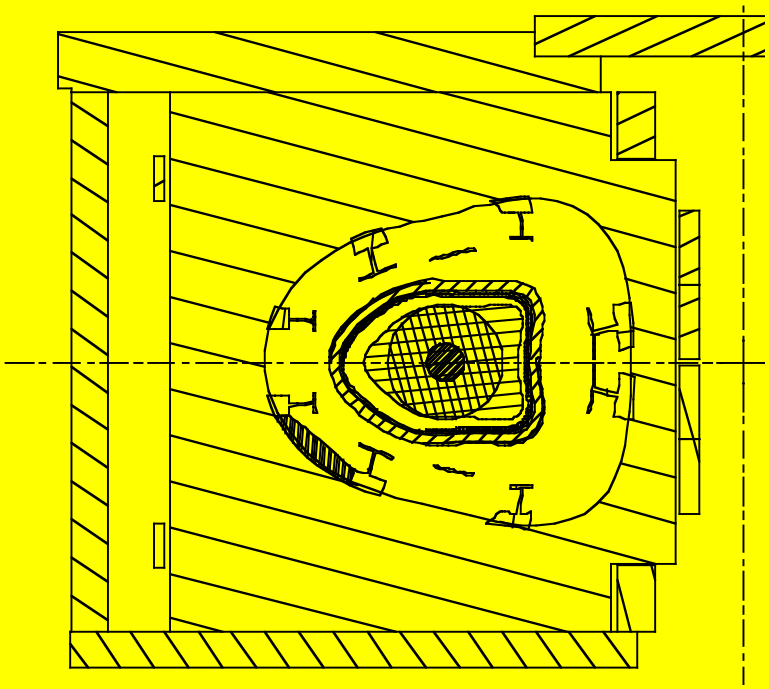
- Design provides adequate tangential access for PBX-M beams.
- Larger size would allow some aiming flexibility.

Diagnostics

- Challenges stem from complexity of geometry; size is not the major issue.
- Since PVR, access has been improved via design modifications.

Personnel

- Design provides adequate in-vessel entry access, though larger size might make it easier.

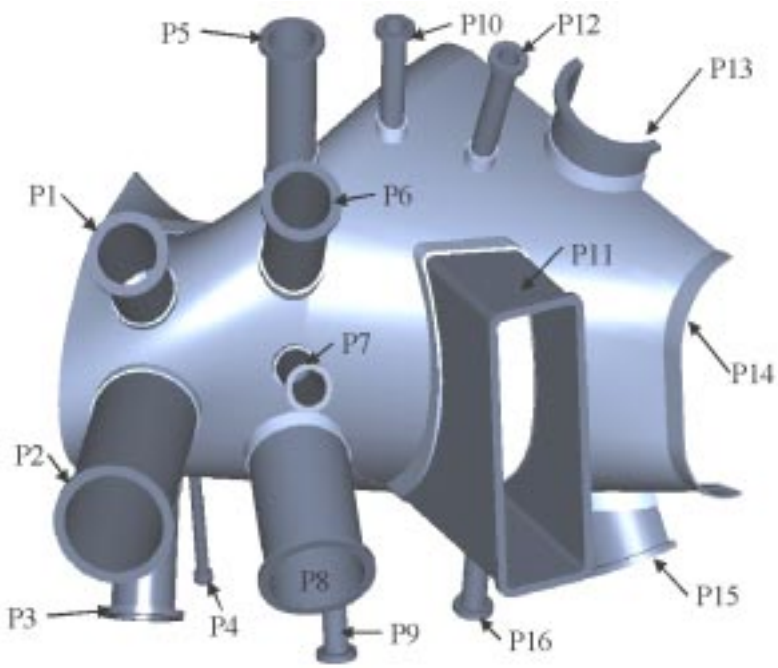


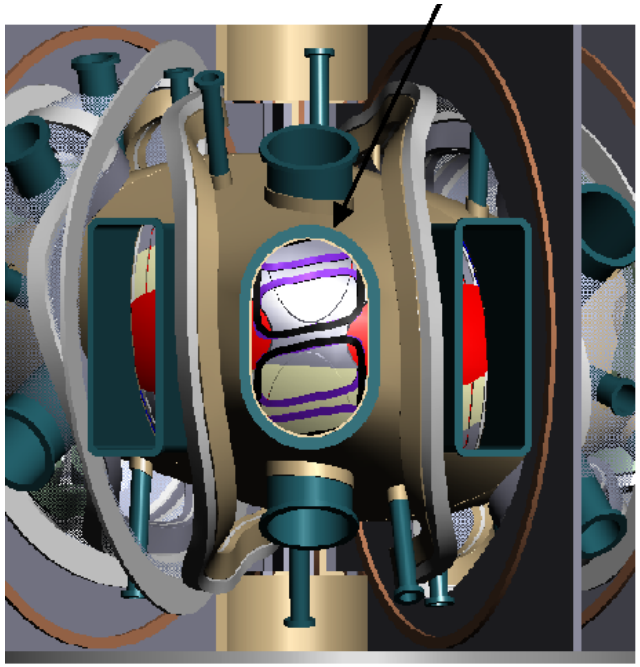
Beam footprint at oblate cross section.

- **Larger circle encloses 96% of injected power.**
- **Smaller circle encloses 47%.**

Diagnostic and Personnel Access

- 87 separate ports for ~100 different diagnostics
  - The number and sizes of ports matched to diagnostic needs.
  - Geometric requirements for specific diagnostics will be addressed in more detail during conceptual design
- Personnel access available through NBI or adjacent large ports





Size and Baseline NBI Power: Summary

- Requirements can be satisfied, physics goals can be accomplished at PVR design point.
- A larger machine would indeed provide some physics benefits…
  - Higher B_{max} ⇒ access to lower ν^* regimes.
  - Improved access for NBI and personnel.
- But, cost would be higher.
  - Ex.: ~$90M for an earlier R = 1.7 m version (incomplete study) vs $69M for current R = 1.4 m design. Likely program delay of ~1.5 year.
- Margins can be increased more cost-effectively via design improvements.

⇒ PVR size provides the appropriate balance between cost and risk considerations.

Project Response on Major PAC-4 Recommendations

PAC-4 #1: Emphasize physics capabilities in design choices. Flexibility is key to NCSX value.

Progress to date (examples):

- Modular coils (3 circuits) with PF and TF coils provide flexibility to control physics, e.g., internal and external iota, beta limits, ripple. (N. Pomphrey)
- Post-PVR design changes for improved diagnostic access, in-vessel space for divertors and launchers $\Rightarrow$ more flexibility. (B. Nelson)

Future plans (examples):

- Continue to optimize PFC design for flexibility, boundary control $\Rightarrow$ good performance. (P. Mioduszewski)
- Integrate diagnostics with configuration design, based on system-by-system analysis of access needs derived from program goals. (D. Johnson)

Project Response on Major PAC-4 Recommendations

PAC-4 #2: Pursue magnetic surface quality studies with high priority. Run free-boundary PIES for actual coils and variety of plasma states. Island healing important.

Progress and plans:

- Free-boundary PIES equilibria for island-healed coils and multiple states were presented at PVR.
- PVR report urged continued attention to flux surface quality and PIES.
- Since PVR, PIES group has emphasized code improvements for island healing in coil design.
- Improved code will be used to heal new coil design, analyze a variety of states for CDR.

A. Reiman will discuss.

Project Response on PVR Recommendations

General approach:

- Project and DOE developed a disposition plan for all 29 recommendations following the PVR.
- Priorities and schedules for issue resolution are set according to the needs of the design process.
- Many are scheduled to be closed out by CDR; others are longer-term.
- Progress tracking log has been maintained on web; 6-month report was issued in September.

Recommendations on Equilibrium Reconstruction

- Develop real-time reconstruction of LCMS from magnetics for control (III-6).
- Develop full 3D equilibrium reconstruction like EFIT (III-7).
- Identify measurements needed for reconstruction and integrate with design (III-7, IV-10).

By CDR

- Identify types of sensors, space envelopes, and interfaces for key diagnostics. Develop plans for completing the design and construction of in-scope diagnostics, including magnetics. *D. Johnson.*

Longer term

- New 3D reconstruction code is needed for experimental program. NCSX magnetics design could also benefit.
- A proposal to develop code has been submitted to DOE by E. Lazarus et al.

Preparations for the CDR

- Document requirements.
- Analyze performance.
- Manufacturing studies for modular coils and vacuum vessel.
- Continued design improvements.
- Update cost and schedule estimates.
- Document physics (update) and design.
- Conceptual Design Review. April 16-18.

Summary

- The design has improved dramatically since the PVR.
- The 1.4 m size provides the appropriate balance between cost and risk considerations, and has therefore been preserved.
- Resolution of PAC-4 and PVR issues is progressing, commensurate with CDR needs.
- Good CDR preparation plans are in place.