National Compact Stellarator Experiment

Status and Plans

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Topics

- Mission and Design
- Completing Construction.
- Starting Experimental Research.

Community Planning of NCSX Experimental Campaigns Begins Now

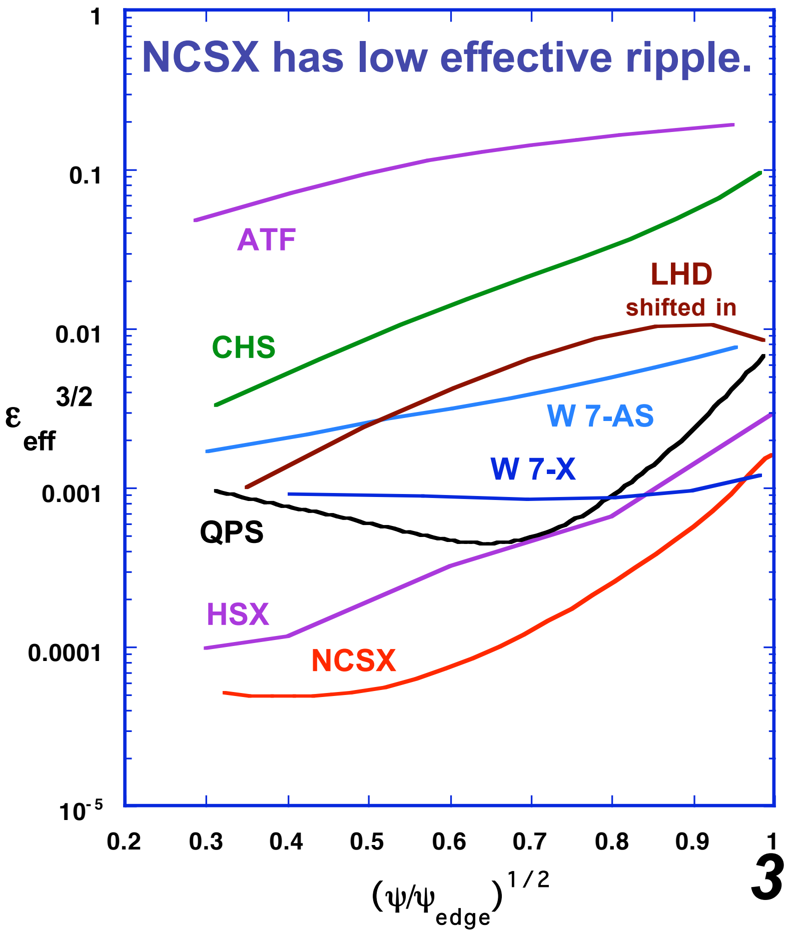
Compact Stellarator Benefits for Magnetic Fusion

Stellarators solve critical problems.

- Steady state without current drive.
- No disruptions: stable without feedback control or rotation drive.
- Unique flexibility to resolve 3D plasma physics issues.

Compact Stellarators have additional benefits

- Magnetic quasi-symmetry. In NCSX:
  - Quasi-*axi*symmetric configuration with effective ripple <1.5%.
  - Low flow damping, tokamak-like orbits ⇒ enhanced confinement
  - Makes full use of tokamak advances, allowing rapid and economical development.
- Lower aspect ratio than typical stellarators.
  - 4.4 in NCSX *vs.* ~11 in W7-X.

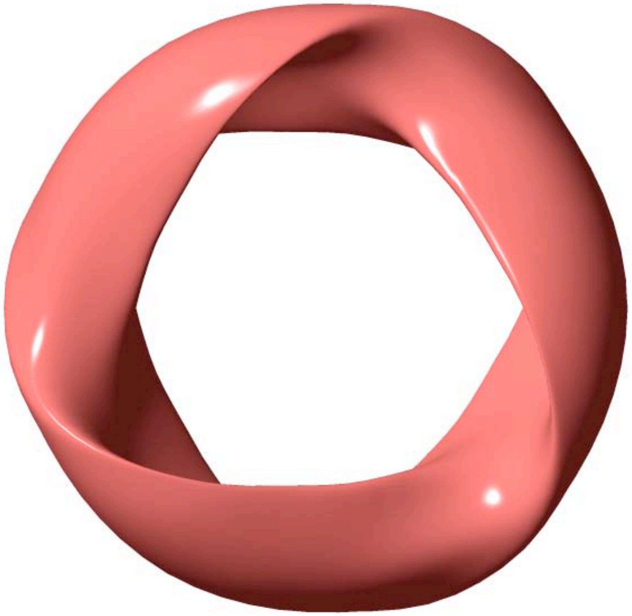


NCSX has low effective ripple.

Stellarator Benefits Are Due to its 3D Geometry

- Stellarators create confining magnetic configuration with magnets alone.
  - Robust mode of operation, simple control.
- Compact stellarators take advantage of 3D shaping flexibility to design for additional attractive properties.
  - Compactness, good confinement, high-β stability, etc.
- The shape can be varied.
  - Provides flexibility for physics tests..

3D geometry produces benefits and costs. We need to quantify both.



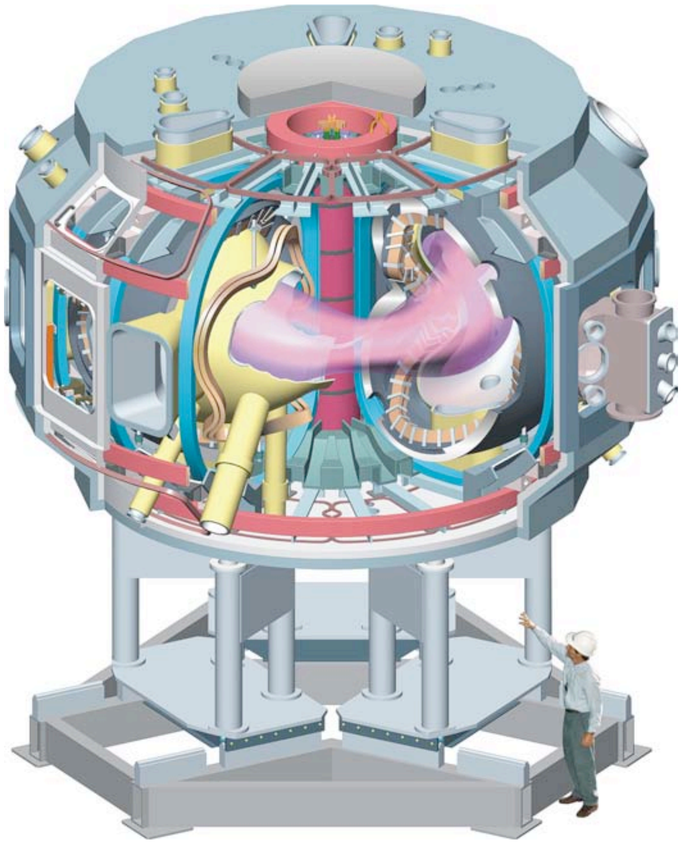
NCSX Plasma

NCSX Mission: Physics of Compact Stellarators

Acquire the physics data needed to assess the attractiveness of compact stellarators; advance understanding of 3D fusion science.

Understand…

- Beta limits and limiting mechanisms.
- Effect of 3D magnetic fields on disruptions
- Reduction of neoclassical transport by QA design.
- Confinement scaling; reduction of anomalous transport.
- Equilibrium islands and neoclassical tearing-mode stabilization.
- Power and particle exhaust compatibility w/good core performance.
- Alfvénic mode stability in reversed shear compact stellarator.



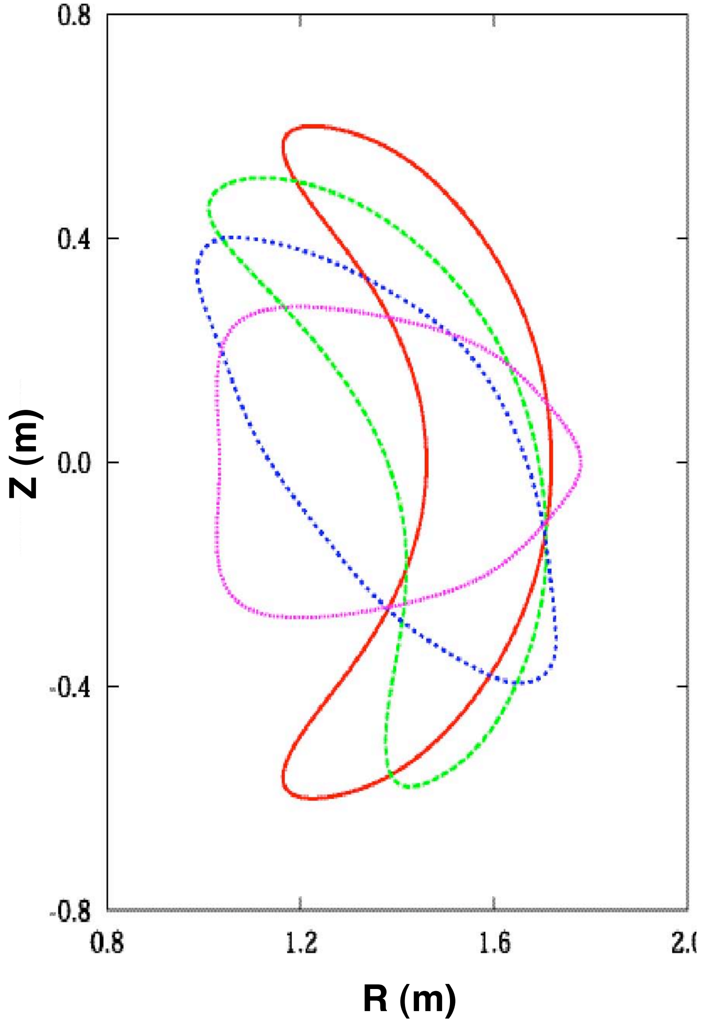
Demonstrate…

- Conditions for high-beta, disruption-free operation.

NCSX Physics Design

Configuration was optimized to realize target physics properties.

Plasma Cross Sections

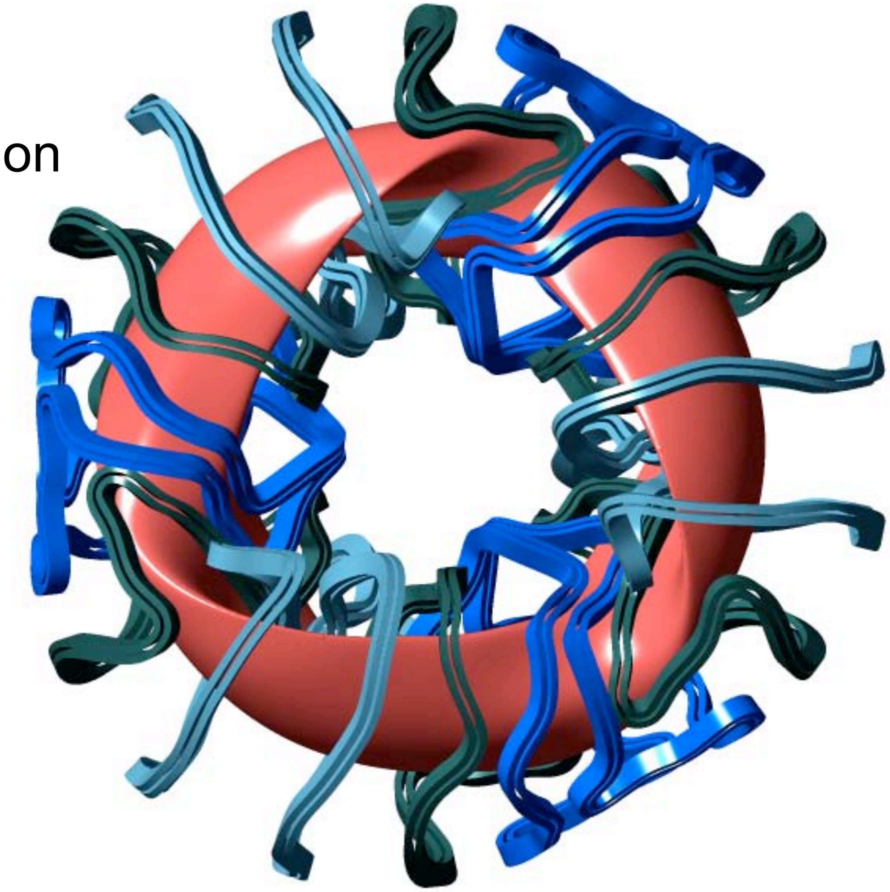


Configuration Properties

- Low R/⟨a⟩ (4.4); 3 periods.
- Quasi-axisymmetric w/ low ripple.
- Stable at β=4.1% to specific MHD instabilities.
- Reverse shear q-profile.
- 25% of transform from bootstrap.
- Good magnetic surfaces at high β.
- Constrained by engineering feasibility metrics.
  - coil-coil spacing
  - min. bend radius
  - tangential NBI access
  - coil-plasma spacing.

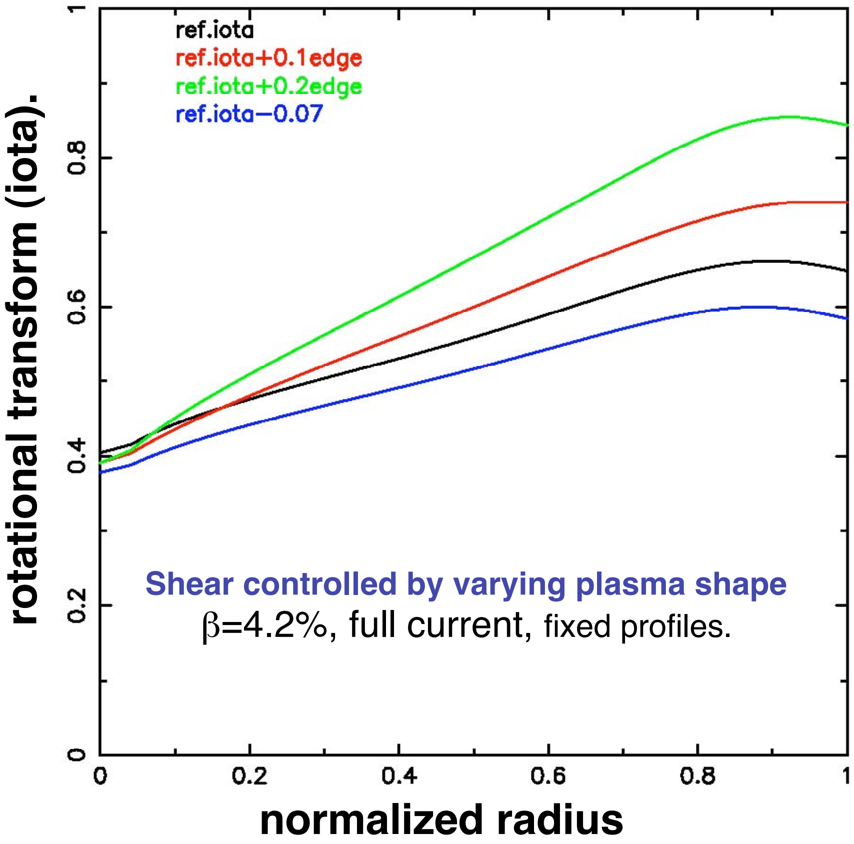
NCSX Design Satisfies Physics & Engineering Criteria

- 18 modular coils (3 shapes)
  - Also TF, PF, and helical trim coils.
- Massively parallel computer optimization used to target required properties.
  - Over 500,000 designs analyzed.
- Provides required physics properties:
  - Low aspect ratio.
  - Stable at high beta.
  - Quasi-axisymmetric.
  - Flexible.
- Satisfies feasibility metrics :
  - Coil-coil spacing & NBI access
  - Coil bend radius
  - Coil-plasma spacing.



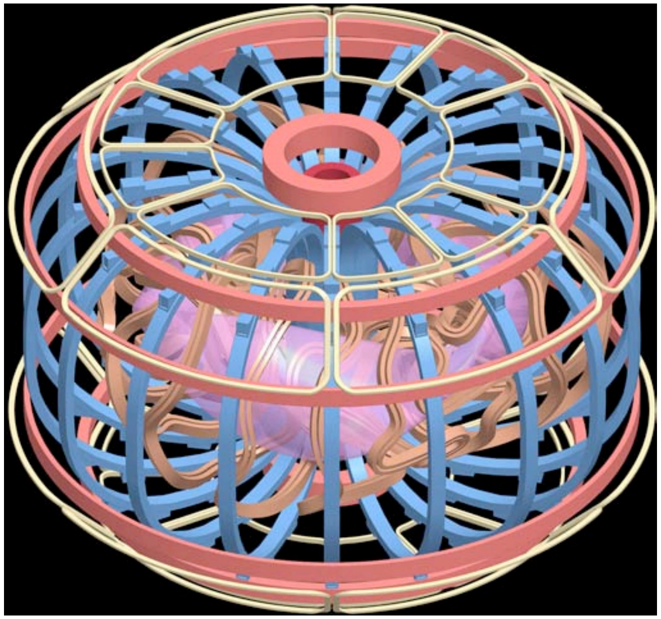
NCSX Plasma and Modular Coils

NCSX Coils: Flexibility to Vary Physics Properties



Shear controlled by varying plasma shape

β=4.2%, full current, fixed profiles.



- Magnet system has 4 coil sets
    - Modular, TF, PF, trim.

Also

- Can externally control iota.
- Can increase ripple by ~10x, preserving stability.
- Can lower theoretical β-limit to 1%.
- Can cover wide operating space in β (to at least 6%), I_P, profile shapes.

NCSX Parameters and Machine Design

Stellarator

Major radius: 1.4 m

Performance:

Magnetic Field Strength (B)
@ 0.2 s pulse: 2.0 T
@ 1.7 s pulse: 1.2 T

Vac. base pressure: 2×10^{-8} torr

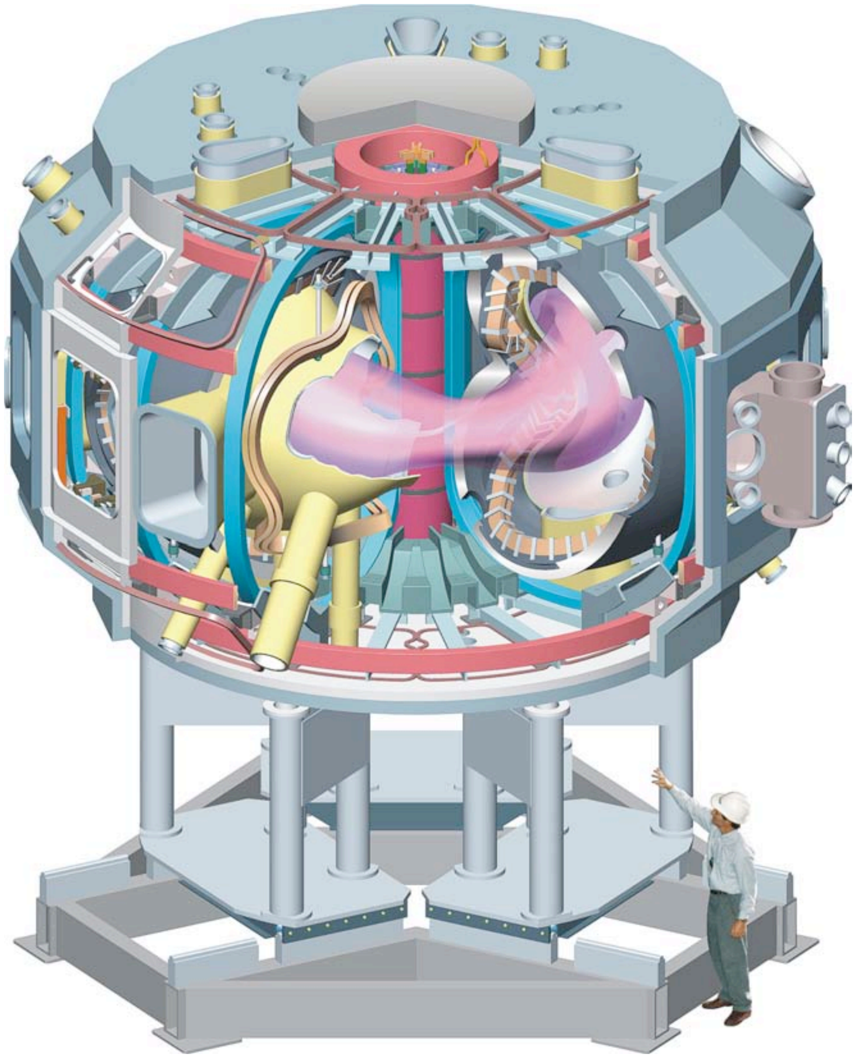
Vessel bakeable to 350 C.

Plasma Heating planned

NBI: 6 MW (tangential)

ICH: 6 MW (high-field launch)

ECH: 3 MW

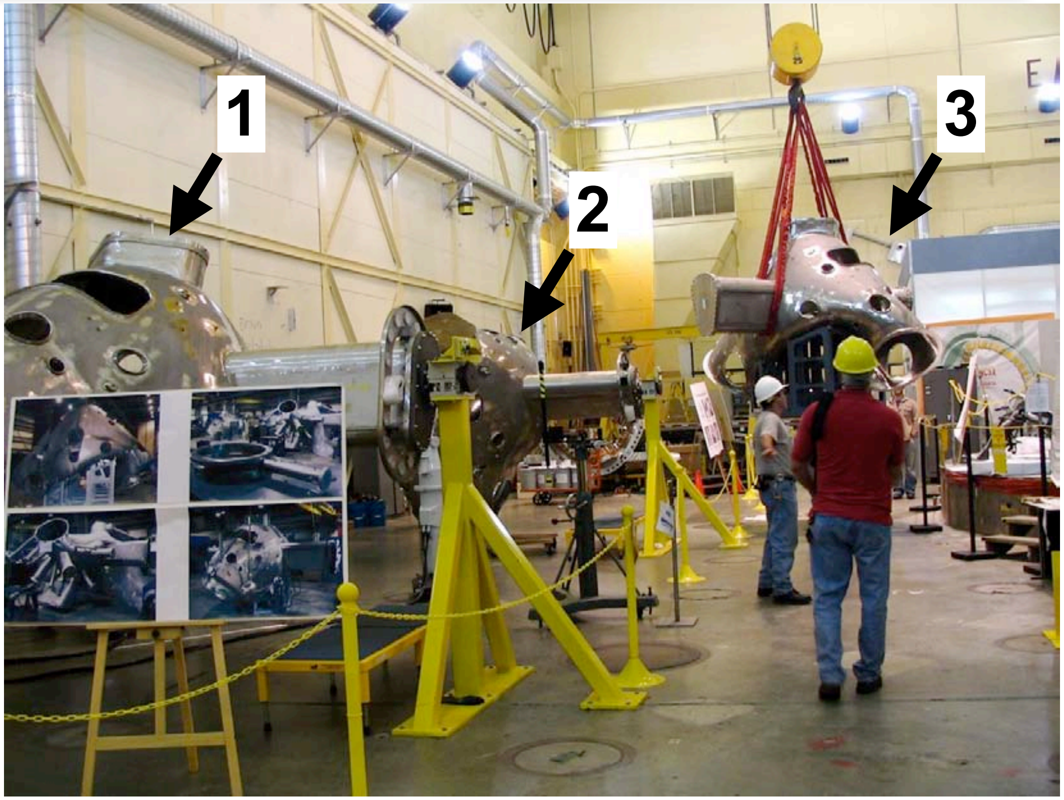


coils cooled to cryogenic temperatures, vacuum vessel at room temperature.

Vacuum Vessel Manufacture is Complete!

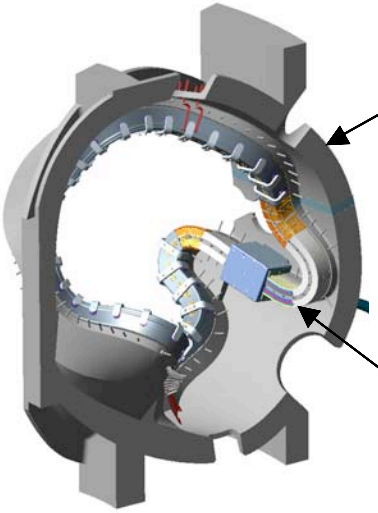
Major Tool and Machine, Inc.

- Good access (99 ports).
- Space inside for first wall & divertor.
- Inconel for low field errors.
- Bakeable to 350 C.



All 3 Segments at PPPL

Modular Coils Are in Production



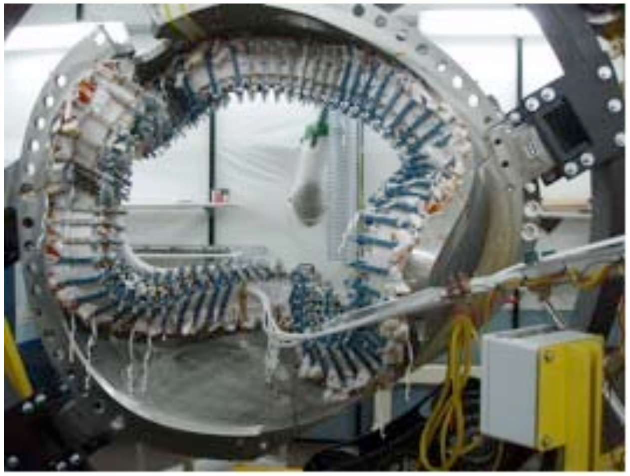
Winding form (one per coil).

Winding

Winding Forms

Energy Industries of Ohio, Inc.

- All 18 have completed foundry ops.
- 8 have completed machining and shipped



Coil Winding (PPPL)

6 have been wound

Completed Coil

4 completed.

NCSX Construction Summary

Status

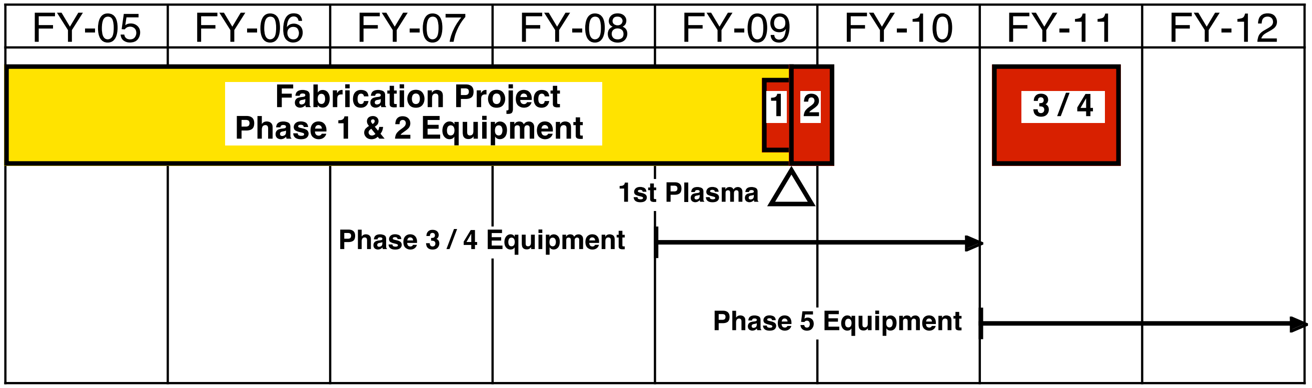
- Vacuum vessel manufacture: complete.
- Modular coils(18): 8 MCWF delivered, 4 coils complete.
- TF coils (18): contractor preparing tooling to wind coils.

Schedule Highlights

- FY-07: component fabrication, sub-assembly activities.
- FY-08: Assembly of field-periods (3), test cell preparations
- FY-09: Final assembly, testing, First Plasma.

Construction project is over 60% complete and on schedule for First Plasma in July, 2009.

First Experimental Campaigns Will Be in FY09 & 11



Phase / Research Goals

1. **Stellarator Acceptance Testing**
   - Verify construction accuracy
   - First Plasma
2. **Magnetic Configuration Studies**
   - Vacuum flux surface documentation.
   - Magnetic configuration control w/ coils.

3./4. Initial Heating Experiments
   - Explore plasma operating space
   - Global confinement, stability, & operating limits; dependence on 3D shape
   - Confinement *vs.* 3D shape
   - Stability at moderate β *vs.* 3D shape
   - Local transport, effects of quasi-symmetry
   - SOL characterization
   - Transport barriers & enhanced confinement.

NCSX & NSTX will operate in alternate years starting in FY10.

Community Planning for NCSX Experimental Campaigns Begins Now

- Research program will be a national / international collaboration.
  - Led by PPPL-ORNL partnership.
- Program Advisory Committee meets Nov. 9-10.
  - Advise on priorities and preparation plans.
- First NCSX Research Forum, Dec. 7-8 at PPPL (immediately after NSTX forum).
  - All invited. Remote participation will be available.
  - Learn about NCSX and collaboration opportunities.
  - Community input on priorities and planning.
- First call for diagnostic collaborations- FY-08
  - For funding in FY-09.

Stellarators Provide Unique Opportunities for Fusion Science

Understanding 3D plasma physics important to all of MFE science

- Rotational transform sources (int., ext.): effect on stability, disruptions?
- 3D plasma shaping: stabilize without conducting walls or feedback?
- Magnetic quasi-symmetry: tokamak-like fundamental transport properties?
- Effects of 3-D fast ion resonant modes & Alfvénic modes in 3-D?
- 3D divertors: effects on boundary plasma, plasma-material interactions?

Answering critical fusion science questions, e.g.

- How does magnetic field structure impact plasma confinement?
  - plasma shaping? internal structure? self-generated currents?
- How much external control *vs.* self-organization will a fusion plasma require?

Role in burning plasma research

- Provide tools, database, strategies for understanding 3D effects
- Contribute to ITER experimental planning.

Summary

- The NCSX project is implementing an optimized 3D system to test compact stellarator benefits.
  - Low-R/⟨a⟩, high-beta, quasi-axisymmetric stellarator plasma.
  - Flexible coil set and vacuum vessel
  - Component geometries determined by physics optimization.

- Construction is on schedule for July, 2009 completion.
  - Vacuum vessel and 4 modular coils completed.
  - Assembly activities have started.

- FY09-11 experimental campaigns are being planned.
  - First NCSX Research Forum will be Dec. 7-8. All invited.