Stellarator Program Update: Status of NCSX & QPS

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for the U.S. Stellarator Community

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Compact Stellarators Are Advancing U.S. Program Goals

Provide needed solutions for practical MFE systems.

- Steady state with no recirculating power for current or rotation drive.
- Passively stable without active feedback; no disruptions.
- Low aspect ratio (≤ 4.4) and high beta (≥4%) ⇒ high power density.

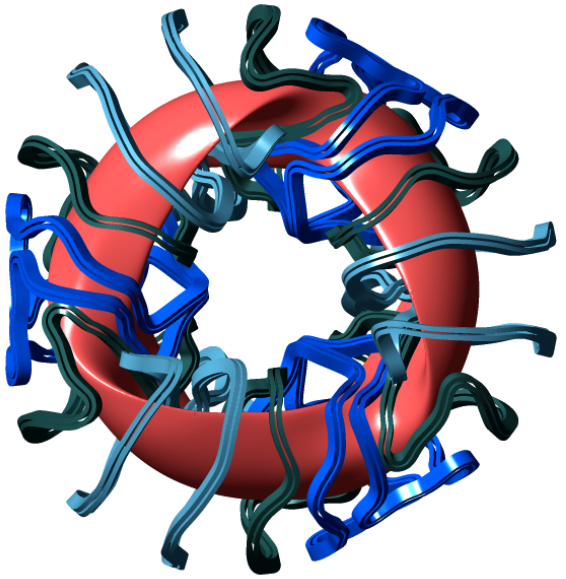
10-Yr. Goal: Determine attractiveness of compact stellarator.

Advance 3D plasma physics understanding important to MFE science generally.

Stellarator physics benefits derive from their 3D geometry.

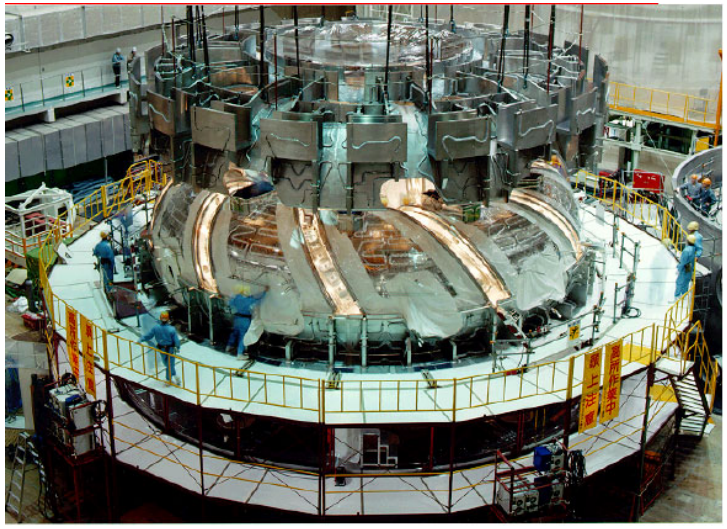
- More design freedom lets us design for desired plasma properties.
- Cost: more complex coil geometry.

Research: test and understand physics, quantify benefits *vs* costs, assess overall merit.



CS Plasma and Coils

Stellarators Are Making Impressive Progress



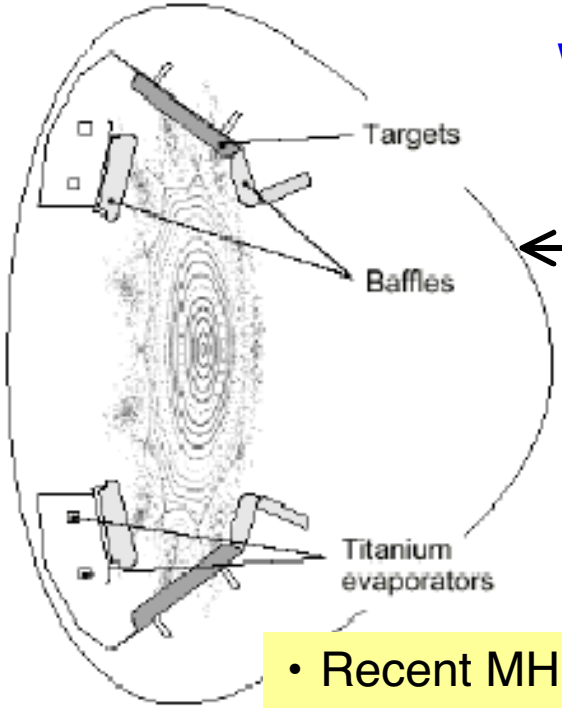
Large Helical Device
(PE w/ S/C magnets - Japan)

$\beta > 3\%$.

$T_e \approx 10$ kev, $T_i \approx 5$ keV.

enhanced confinement.

2-minute pulses.



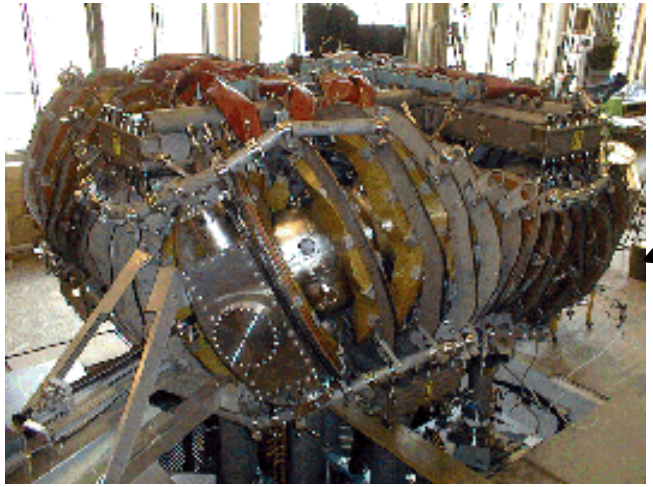
Wendelstein 7-AS
(PoP- Germany)

$\beta > 3\%$.

enhanced confinement.

density control & enhanced performance w/island divertor.

- Recent MHD stability results have favorable implications. – M. Zarnstorff talk.



Helically Symmetric Experiment
(CE- U. Wisc.)

- Successful test of quasi-symmetry.

New stellarators are coming!
NCSX, QPS (2007); W7-X (2009)

Stellarator Proof of Principle Program - 1

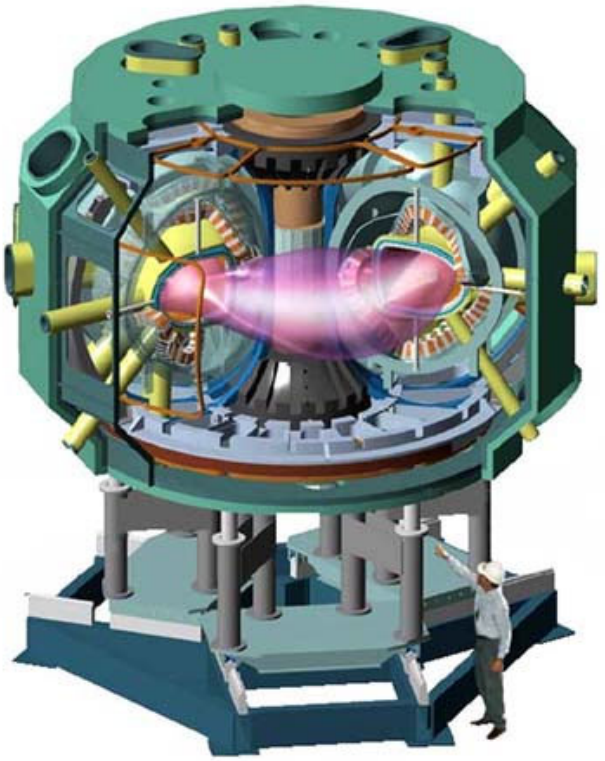
Goal is to develop the knowledge base needed to assess compact stellarator attractiveness and decide on next steps.

National program consists of several elements, integrating theory, experiment, and design.

1. NCSX PoP Experiment

- **R = 1.4 m, B = 1.2-2.0 T, P = 6 MW (NB) + 6 MW (RF)**
- **Based on stable QA plasma with R/a = 4.4, β = 4%.**
- **Flexible coils can test high β (up to ≥ 6%), and physics issues:**
  - beta limits and limiting mechanisms
  - confinement and flows with quasi-axisymmetry
  - transport reduction
  - NTM stabilization
  - Alfvén mode stability
  - divertor-core compatibility

What are the conditions for high-beta, disruption-free operation with no feedback stabilization, current drive, rotation drive, or profile control?

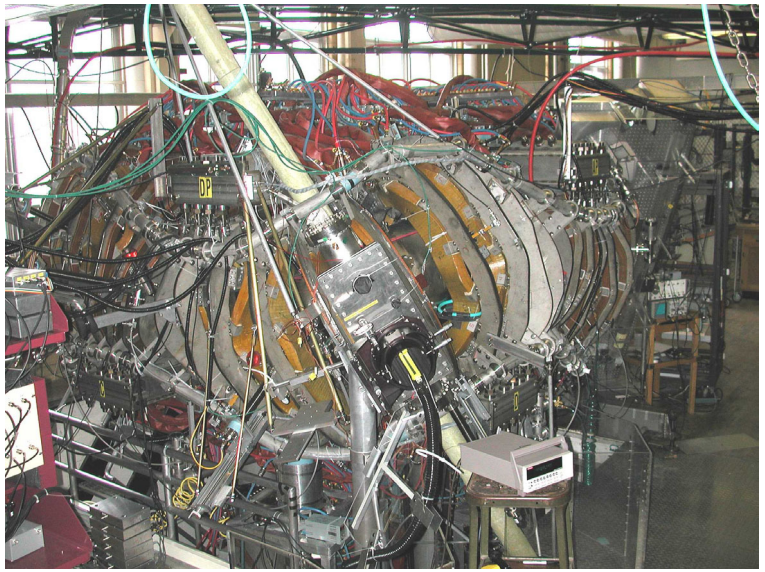


NCSX (PPPL-ORNL)

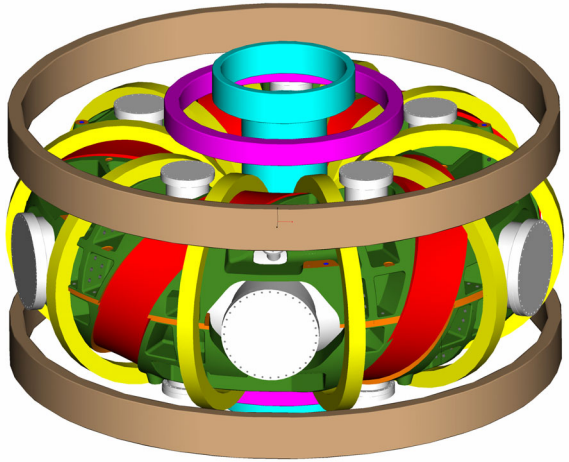
Stellarator Proof-of-Principle Program - 2

PoP Program Elements (cont'd.)

2. **QPS Compact Stellarator CE Exp't.**
   - Quasi-poloidal symmetry at very low R/a.
3. **Helically Symmetric Experiment (HSX)**
   - Quasi-helical symmetry.
   - Physics diagnostics coming on line.
4. **Compact Toroidal Hybrid (CTH)**
   - 3D equilibrium reconstruction, stability.
   - Under construction- complete late 2003.
5. **Stellarator Physics via Theory and International Collaboration**.
6. **CS Reactor Design Studies (ARIES)**
   - Reactor optimization, design for adequate alpha confinement, issue identification.



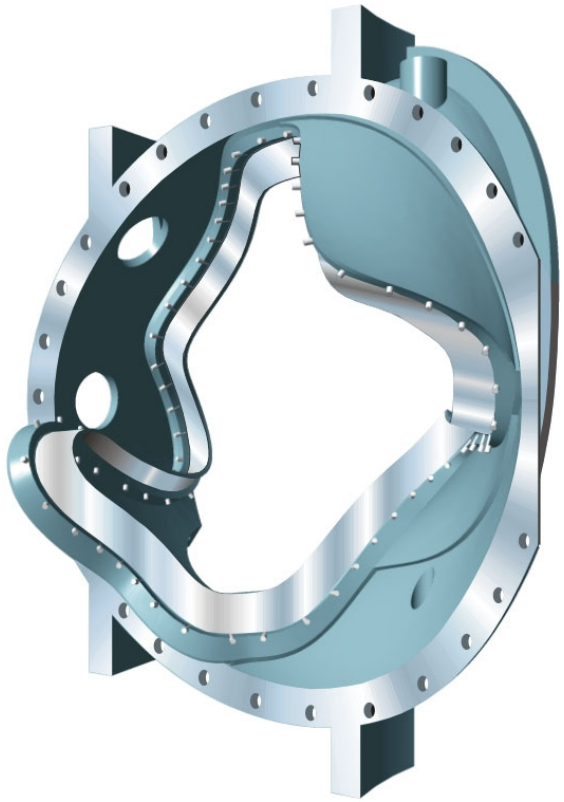
HSX (Univ. of Wisconsin)



CTH (Auburn U.)

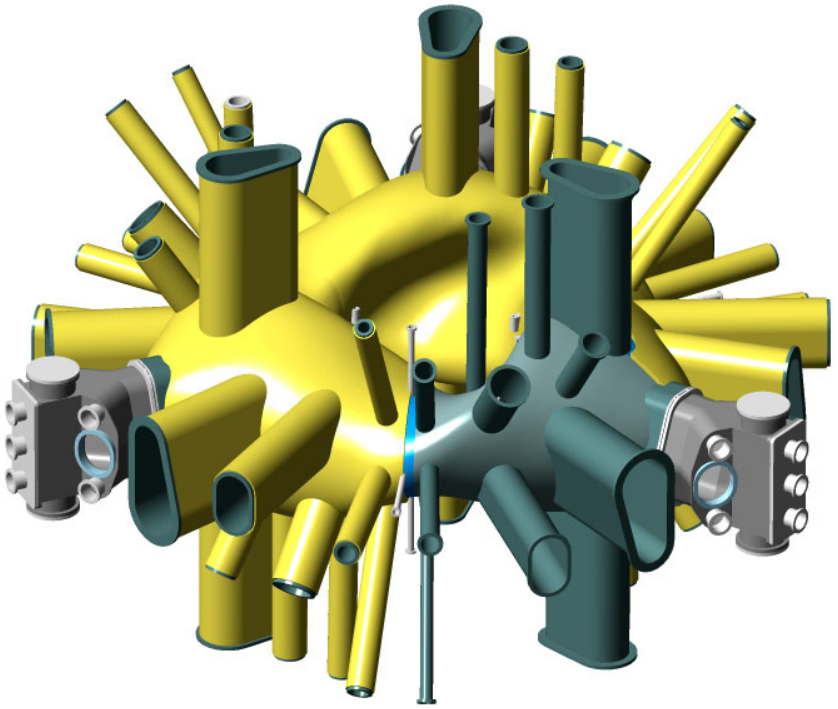
NCSX Fabrication Project Has Started

Industry performing manufacturing R&D for critical components



Modular Coil Winding Form

(Casting and Machining)

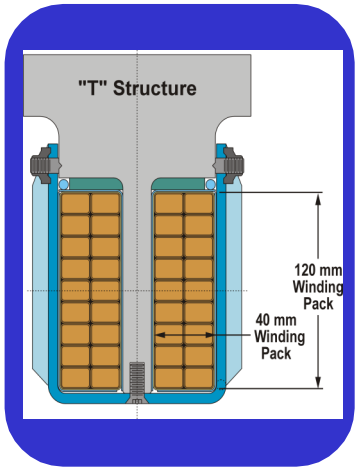


Vacuum Vessel

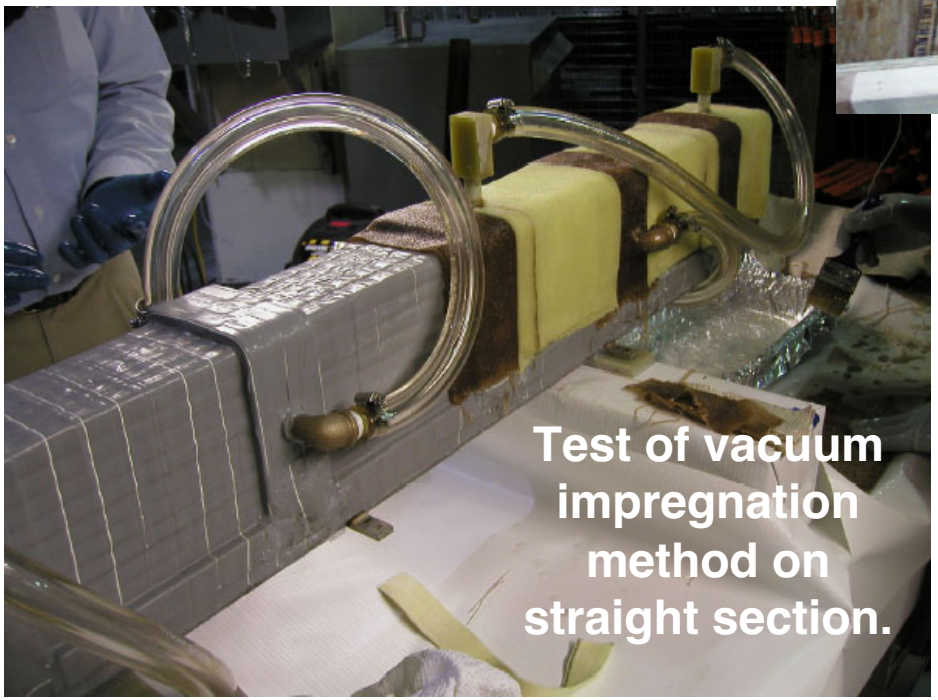
(Forming, Welding, Port Attachment)

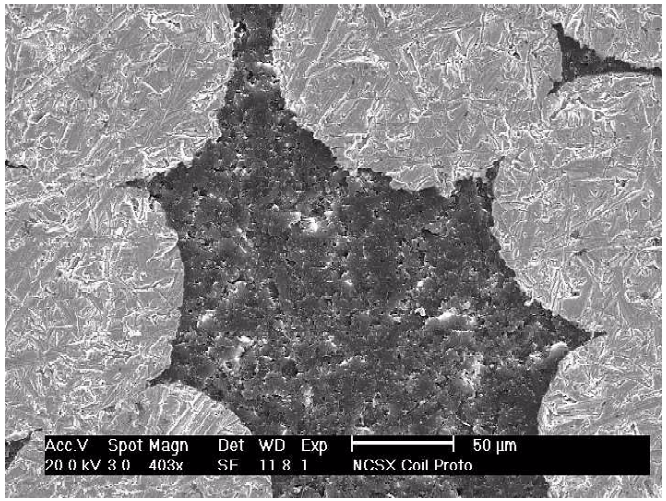
Processes will be developed and demonstrated via prototypes.

Coil Winding Methods Are Being Developed



NCSX Winding Cross Section

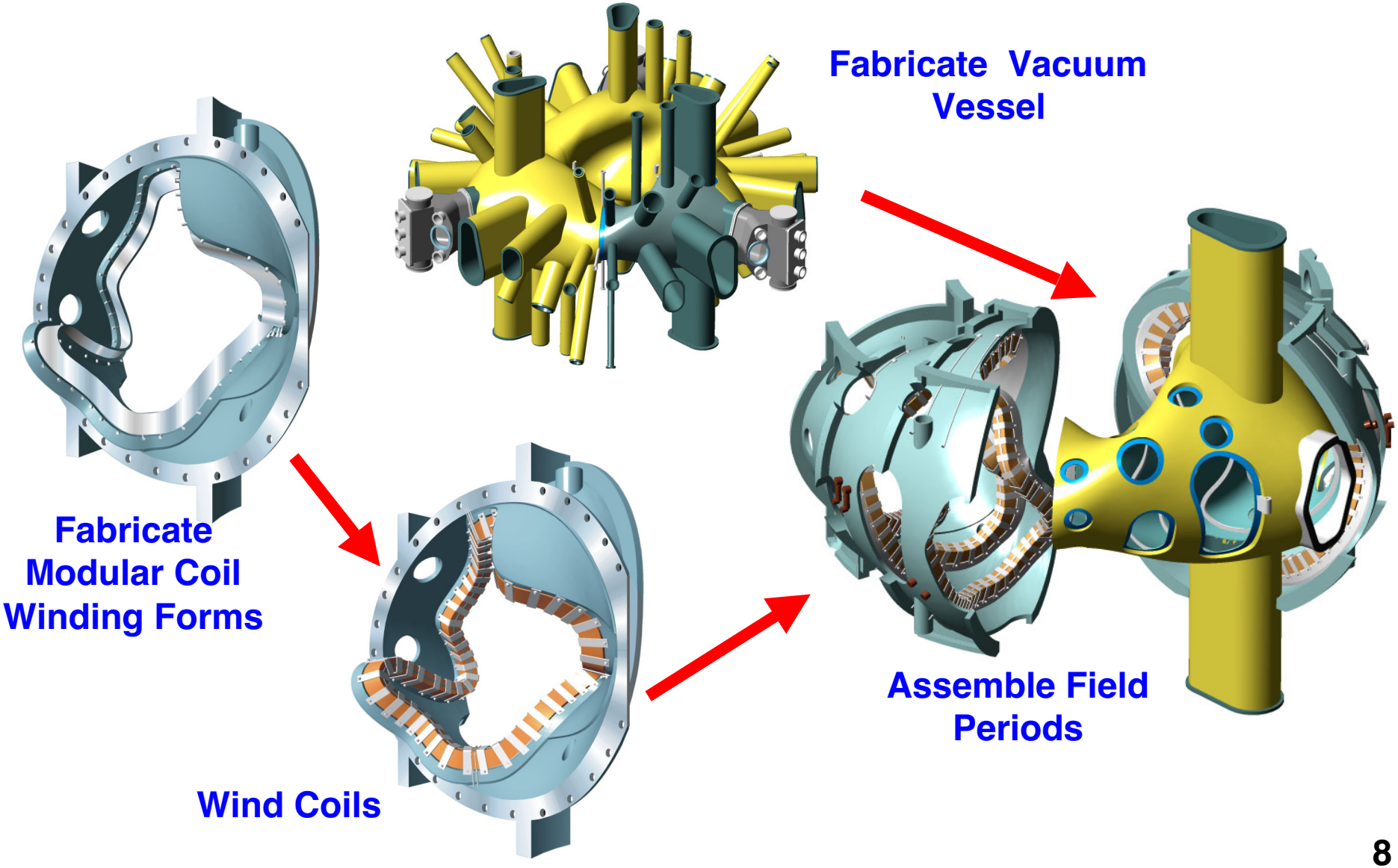




Scale 50 μm

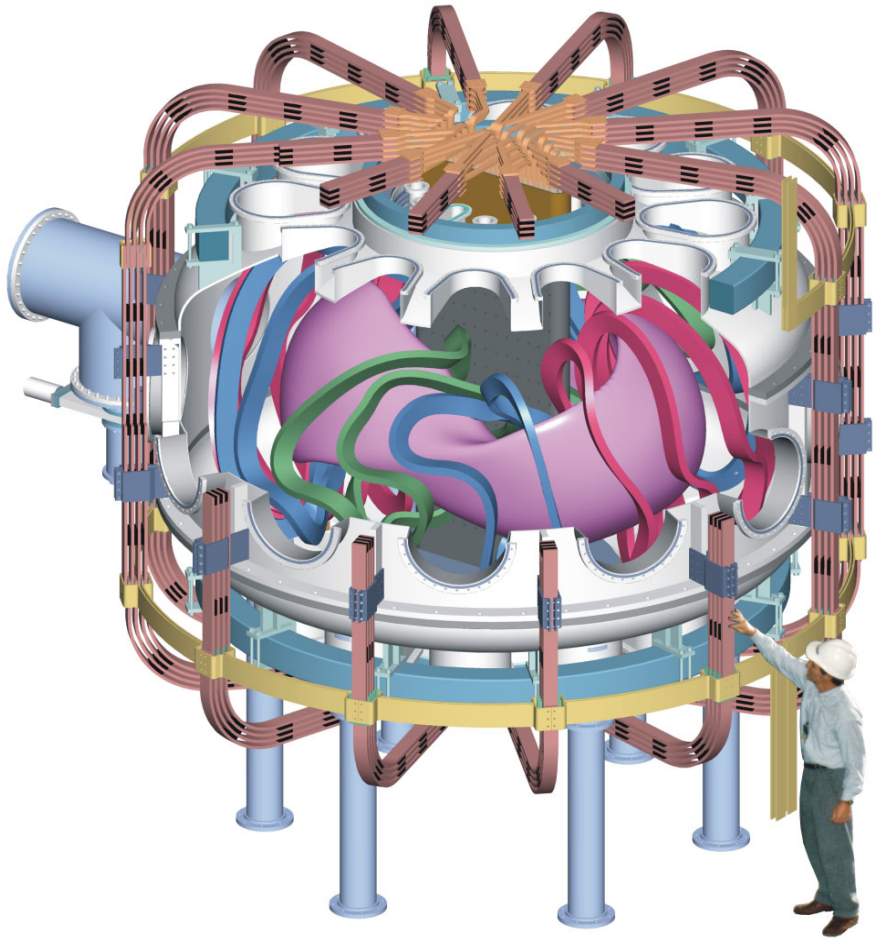
Good epoxy penetration into stranded copper conductor.

NCSX Plans for Next 2 Years: Fabricate Major Stellarator Components, Start Assembly



QPS Will Extend Physics Understanding to Very Low *R/a* and Quasi-Poloidal Symmetry

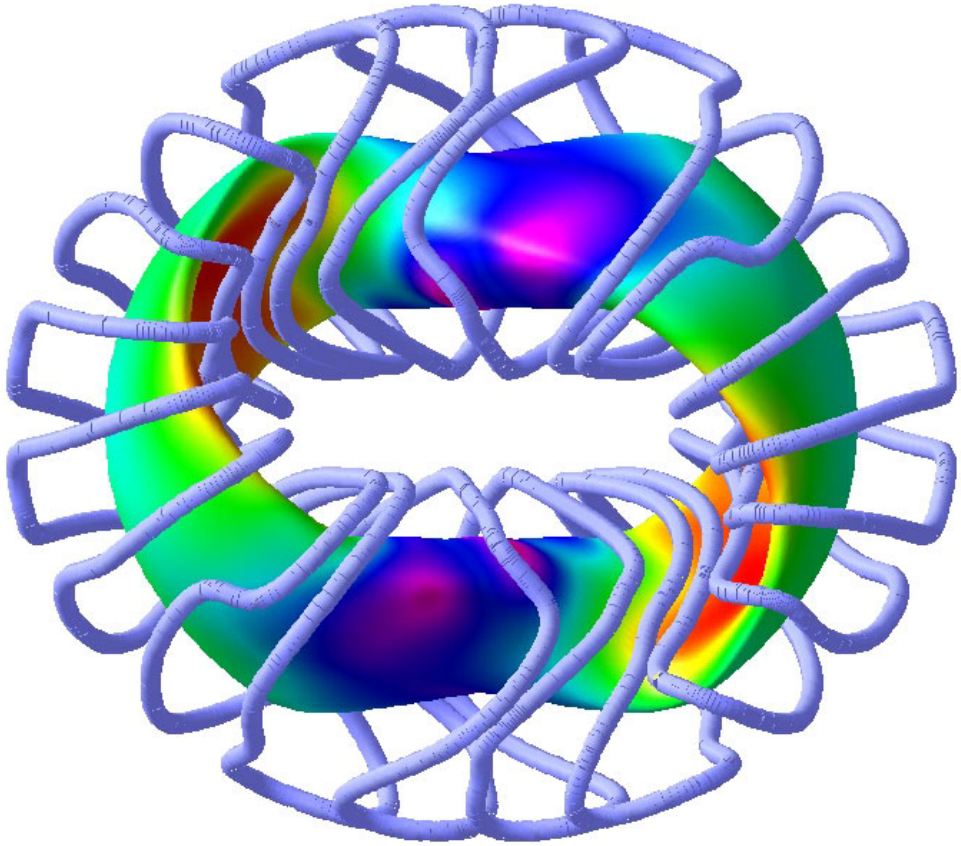
- **Focus on stellarator confinement improvement at very low *R/a***
  - **confinement scaling**
  - **flux surface robustness**
  - **reduction of neoclassical transport**
  - **reduction of anomalous transport**
  - **correlation of fluctuations with transport**



- **$\langle R_{pl} \rangle$ = 0.9-1 m, $\langle a_{pl} \rangle$ = 0.3-0.4 m**
- **V_{pl} = 2-3 m^3, Aspect ratio > 2.3**
- **B = 1 ± 0.2 T (1.5 s), P_{RF} = 2-4 MW**

QPS Configuration Has Considerable Flexibility

- Neoclassical transport losses can be changed by factor ~20-80
- Varying coil currents allows changing the degree of quasi-poloidal symmetry and poloidal flow damping over a wide range
- Vacuum magnetic configuration close to full-beta configuration



Project Status and Plans

NCSX

- Fabrication project started April 1.
- Preliminary Design Review planned for September in preparation for establishing project baseline.
- Major component manufacture starts in early 2004.
- First plasma in 2007

QPS

- Physics Validation Review completed, Mission Need approved.
- Conceptual Design Review planned for June 24-25, 2003.
- Complete design and begin modular coil R&D in 2004 in preparation for project start in October, 2005.
- First plasma in 2007.

Summary

Stellarators are advancing U.S. fusion program goals.

- Practical MFE configurations.
- Fundamental physics understanding.

Integrated national stellarator program is already making excellent progress.

- Physics understanding from HSX, theory, collaborations.
- New experiments moving from plans to reality.
- First steps in compact stellarator reactor explorations.