Compact Stellarator Program

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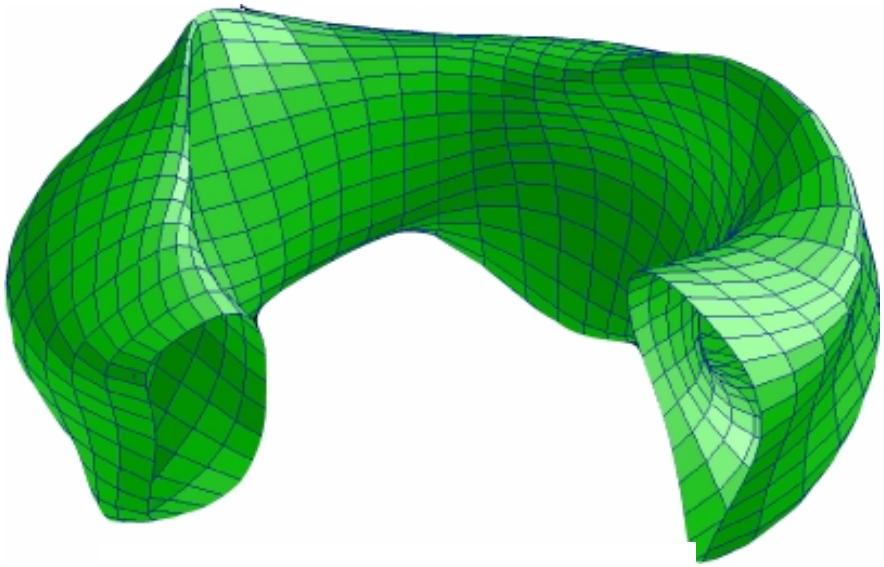
Overview

- Compact Stellarators (CS) are needed to meet our goal of developing an attractive toroidal configuration for MFE.

- The program is on schedule for FY-2001 programmatic and design reviews.

- To stay on track, we need to:
  - Expedite reviews in FY-2001.
  - Increase budgets in FY-2001 and FY-2002.
  - Start construction in FY-2003.



CS Plasma Configuration

Compact Stellarators Offer Innovative Solutions for MFE

A **steady-state** configuration with **tokamak-like power density**–
disruption-free **without elaborate controls or high recirculating power**.

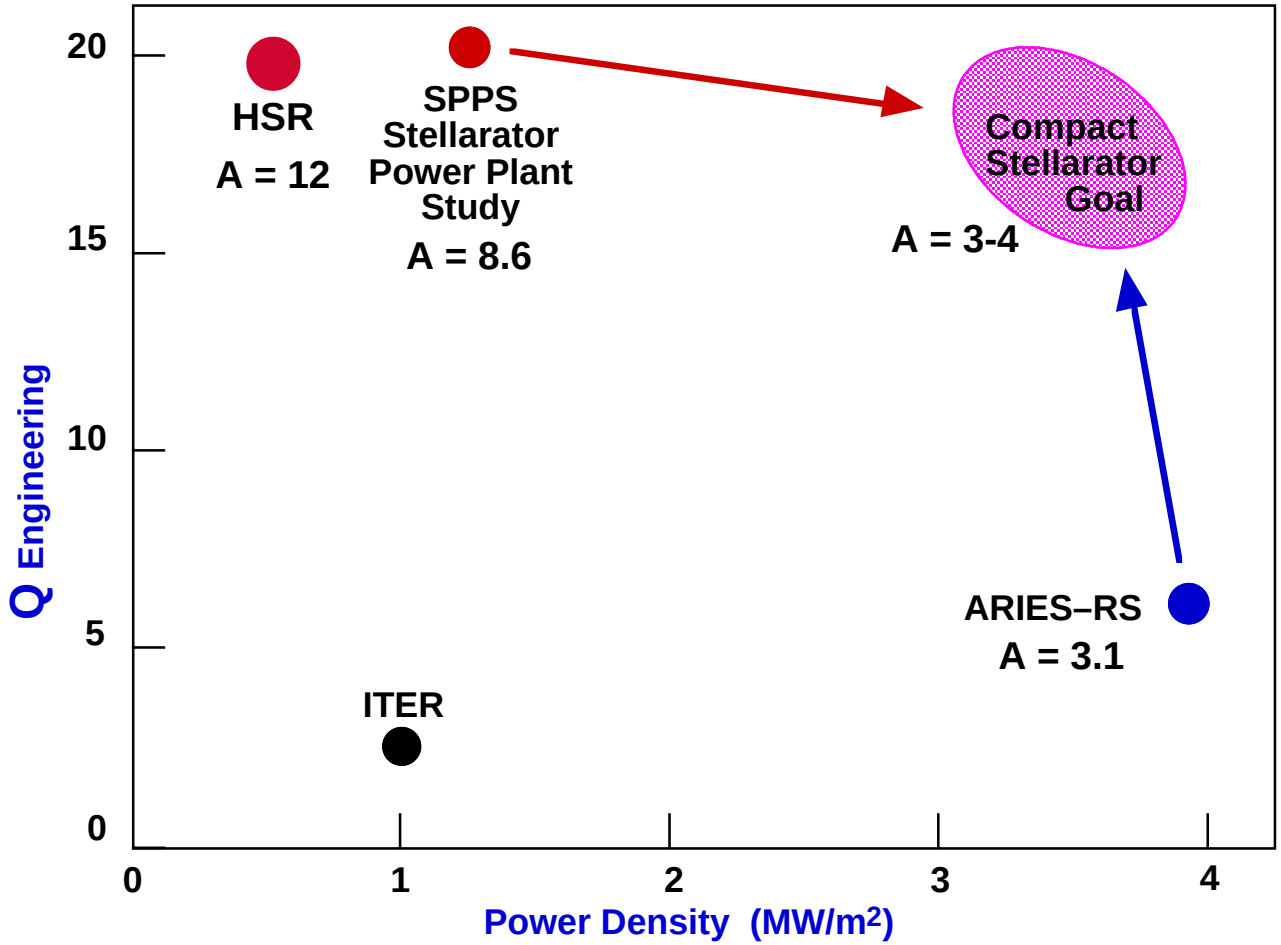
- Challenge for MFE: Finding an attractive plasma configuration.
  Strategy: Pursue complementary solutions in parallel.

- **Advanced tokamaks**
  Bootstrap current, current profile control, MHD mode control.

- **High-aspect-ratio stellarators**
  Externally-generated helical fields, 3D shaping, low power density

- **Compact Stellarators, a hybrid concept**
  Bootstrap current + helical fields / 3D shaping.
  $\Rightarrow$ Low-aspect-ratio (≤ 4), high-β ($\geq 5\%$) toroidal configuration.
  $\Rightarrow$ **Low recirculating power, high power density.**

A Compact Stellarator Could Combine the Best Features of Tokamaks and Stellarators!



Large Reactor ⟷ Compact Reactor

Compact Stellarator Program Targets U.S. Fusion Goals

FESAC 10-Year Goals

- "Determine the attractiveness of a compact stellarator…"
  NCSX (new PoP experiment): disruption-free operation, stability, transport.

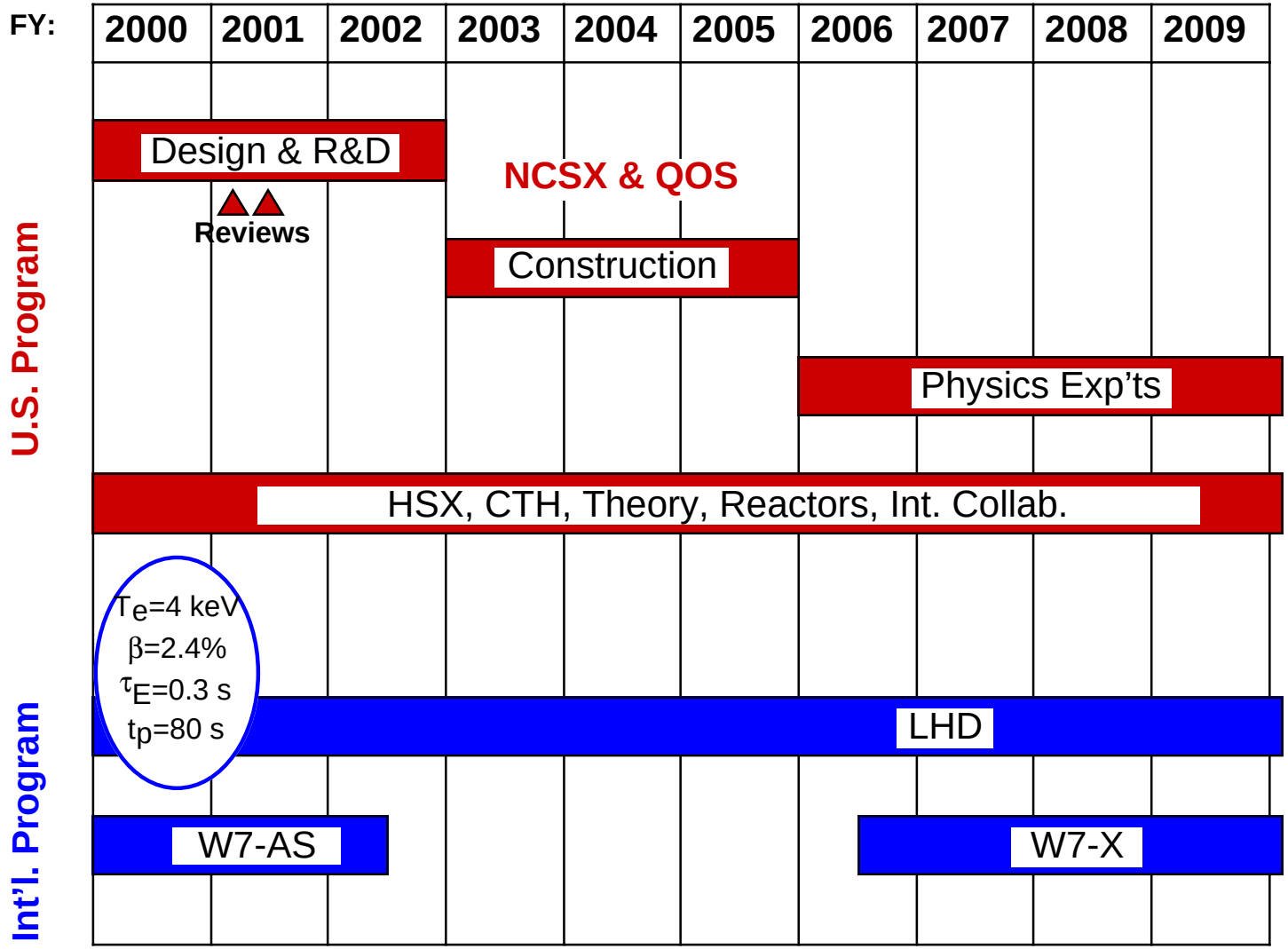
- "Resolve key issues for an extended spectrum of configurations at the exploratory level."
  QOS (new CE experiment): test quasi-omnigeneity at low aspect ratio.

- "Predict performance of externally-controlled systems."
  Use of 3D stellarator fields to control macrostability, turbulent transport.

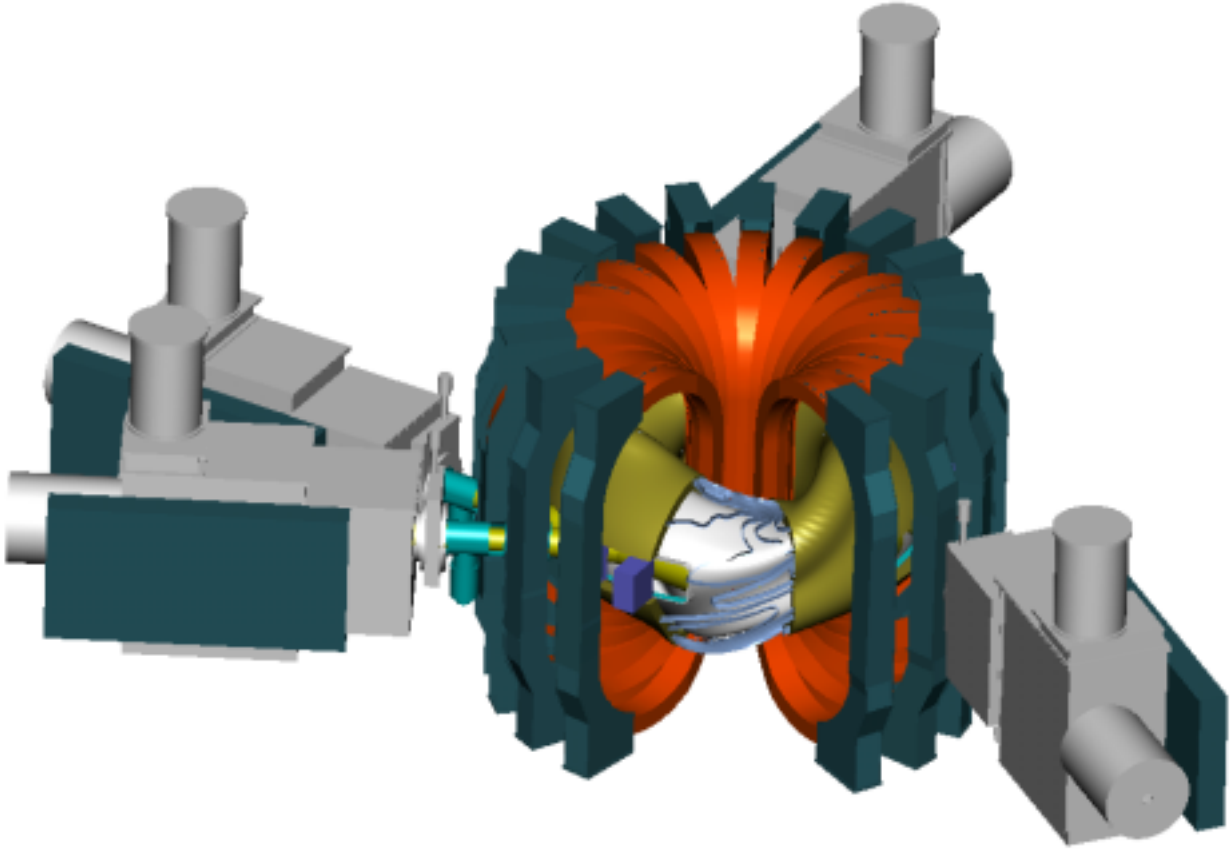
5-Year Goals:

- "Advance fundamental understanding of plasma"
  HSX: first test of quasi-symmetry.
  CTH: MHD studies with plasma current.
  Theory: macrostability, transport in 3D.

Timely Construction of New U.S. Experiments is Needed To Support 10-Year Goals, Impact World Program



NCSX Initial Design (1999) Demonstrates Realizable Machine Concept Satisfying Stability Requirements



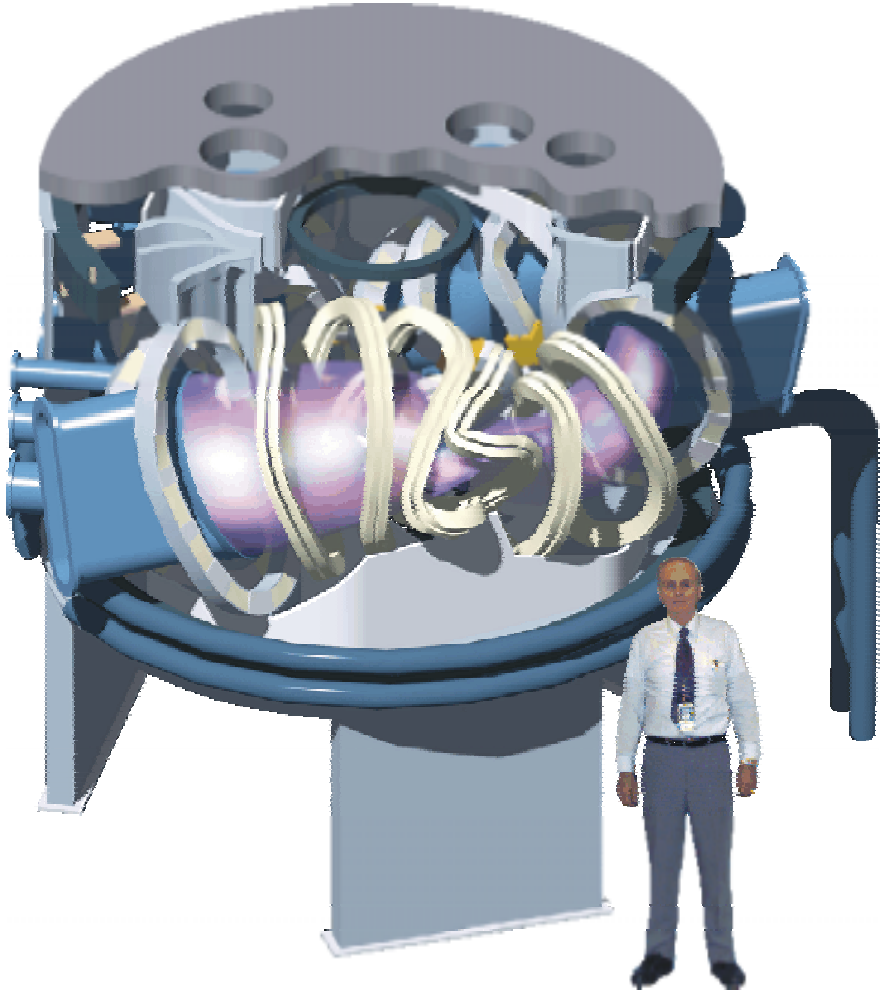
R=1.4 m

⟨a⟩=0.4 m

B=2 T

- Quasi-axisymmetric (QA) plasma stable to external kink, vertical, ballooning, neoclassical tearing, and Mercier modes at β=4% with no conducting wall.
- Re-uses PBX-M coils and neutral beams.

Initial Low-Aspect-Ratio QOS Design (1999) Has Good Confinement and Stability at Low Bootstrap Current



Scoping Study Parameters

R=1 m

⟨a⟩=0.3 m

B=1 T

- Quasi-omnigeneous (QO) plasma robust to changes in plasma beta.

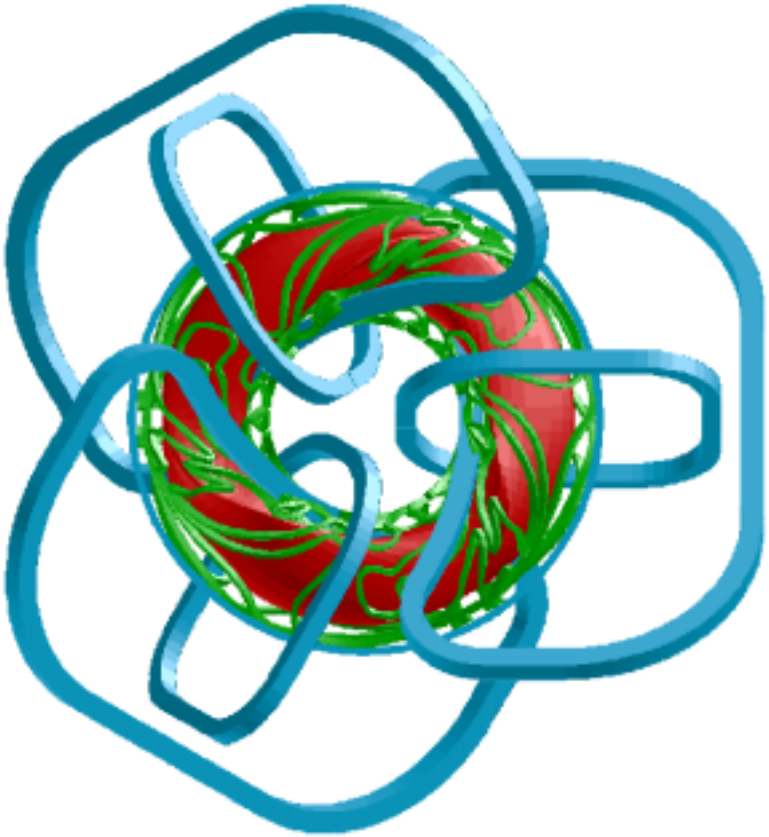
FY-2000: Completing the Concept Developments Needed to Start Conceptual Design

Tools Have Been Improved, Options Expanded.

- QA plasma design: *improved optimizer physics, 3D equilibrium codes.*
- QOS plasma design: *extended physics optimization, explored new high-beta, high-bootstrap reactor option.*
- NCSX coil design: *defined non-PBX topology options, improved tools for optimization and flexibility, determined conductor engineering limits.*
- NCSX heating, diagnostics, and pumping access: *developed concepts to accommodate requirements.*
- CS Reactors: *defined initial reference configuration, improved tools for reactor scoping: parameters, coils, sensitivity to assumptions.*

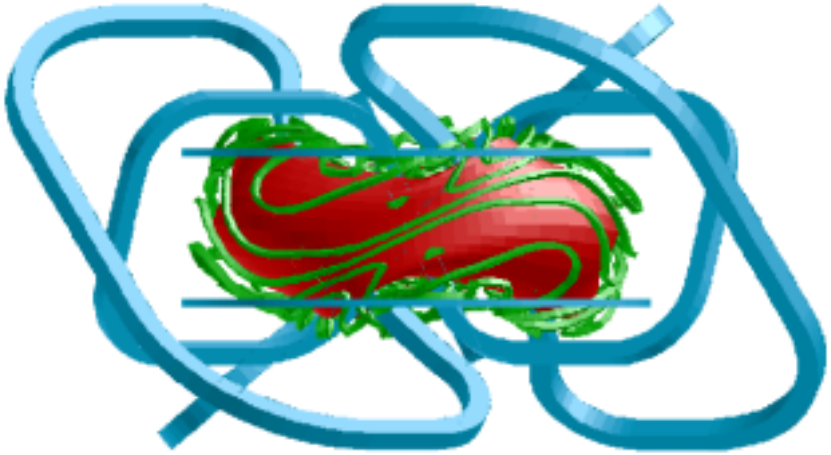
Science and technology innovations by U.S. national team have already advanced the frontier of stellarator research.

NCSX New-Coil Option Reduces Coil Requirements and Improves Access Compared to PBX Option



50% reduction in current density

70% increase in min. conductor spacing



- Benefits and costs are being compared with PBX option to select the best.

Program is on schedule for updating NCSX configuration to meet all physics requirements by end of FY-2000.

FY2001-02: Complete Design, R&D, and Key Reviews to Prepare for Timely Construction Start

(requires incremental budgets)

NCSX Physics Validation Review, Dec., 2000

NCSX Conceptual Design Review/Project Validation, Mar.-May, 2001

- Establish project baseline for FY-2003 construction funding request.

QOS Proposal Review, May, 2001

FY2001-02:

- Physics development: flexibility, operating scenarios, heating, diagnostics.
- Engineering design of all subsystems.
- R&D: industrial capabilities, manufacturing approaches, reduce costs & risk.

Goal: ready to start construction in early FY-2003.

Vacuum Vessel R&D

Issue:

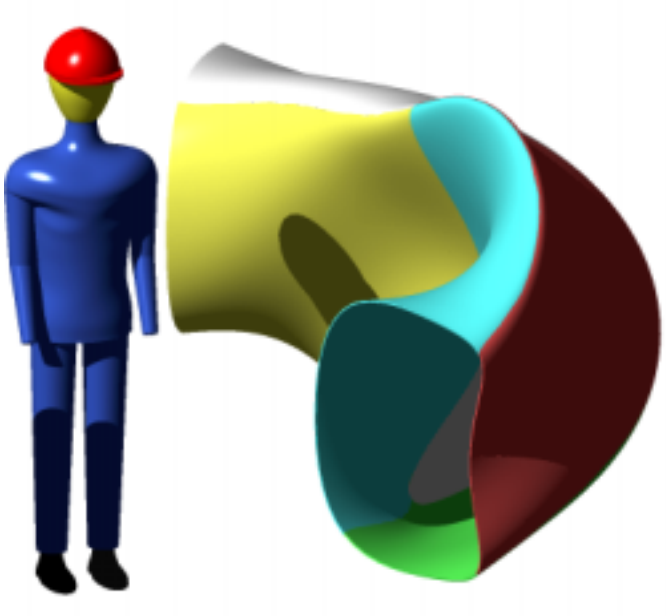
Vessel on critical path for machine assembly

Goal:

Avoid costly production delays

Plan:

- Select best fabrication technique e.g., formed vs bent, considering quality / cost / risk (FY00)
- Fabricate one-half field period (one-sixth) of vessel (FY01-02)
- Adjust design and tooling for final production parts (FY02)

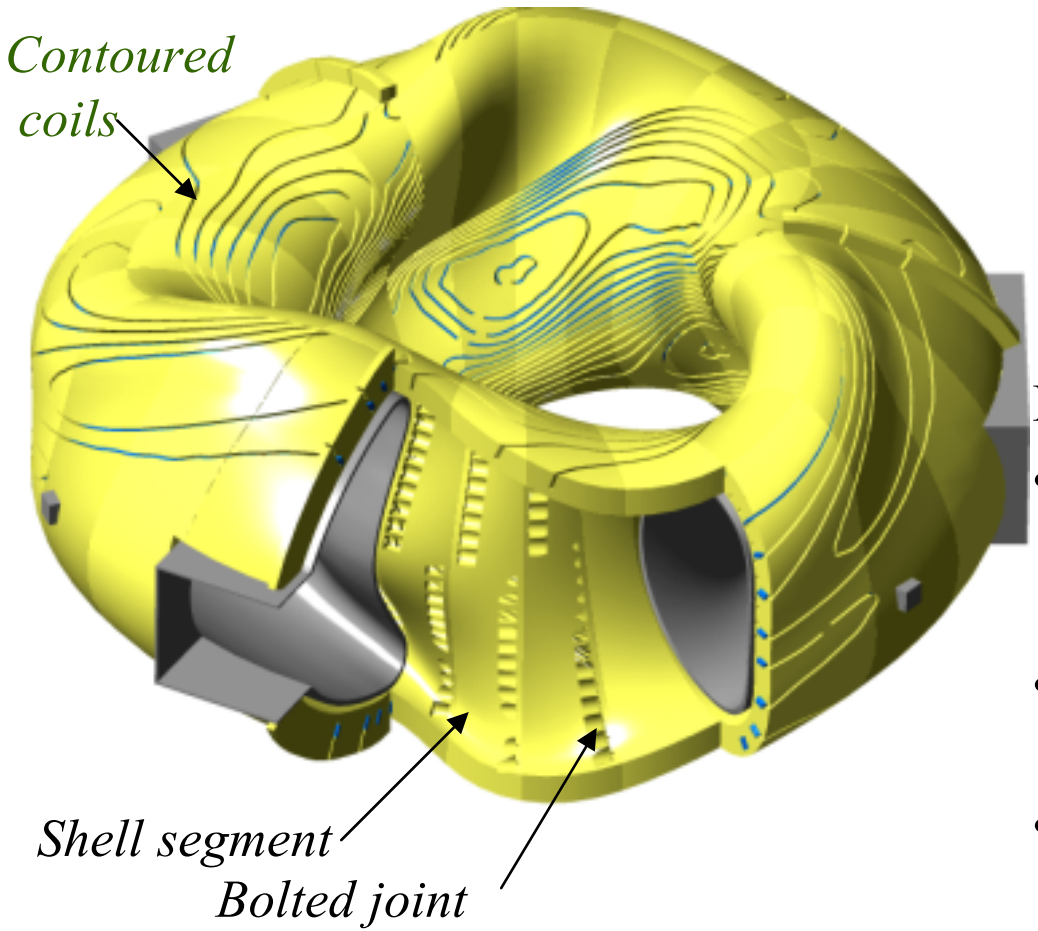


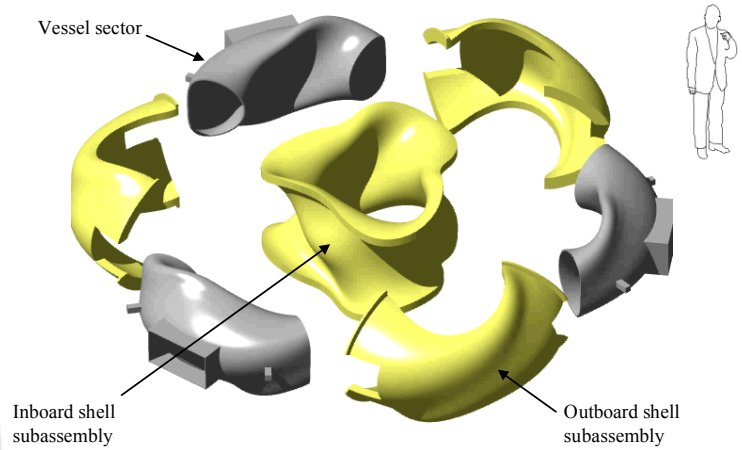
One field period
of vacuum vessel

Conformal coils wound on segmented shell

Issues:

- Engineering limits of cable conductor
- Fabrication and assembly of shell





Plan:

- Cast and machine representative shell segments, assemble with bolts (FY 01-02)
- Wind prototype, contoured coil (FY 02)
- Test prototype coil (FY 02)

Modular Coil R&D (QOS)

Issue:

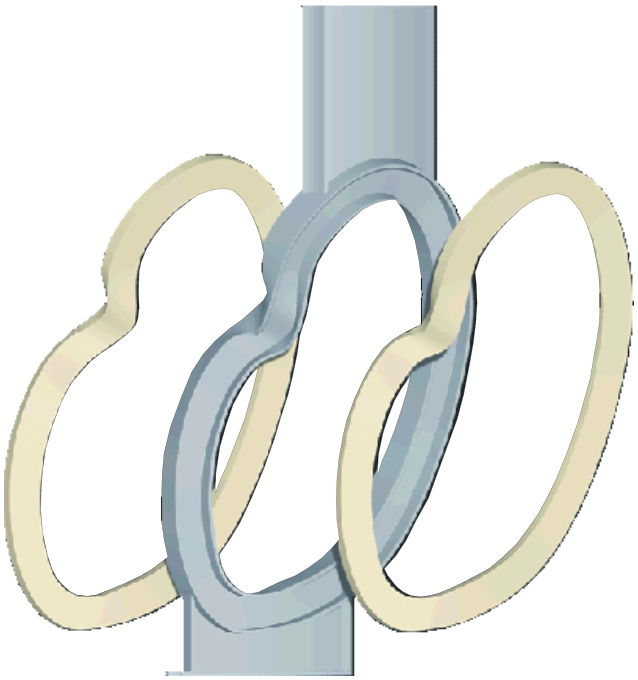
- Can we avoid expensive contour machining by using advanced fabrication techniques?

Goal:

- Verify fabrication techniques, performance (structure, cooling)

Plan:

- Fabricate and machine one coil form (FY02)
- Wind prototype, modular coil (FY02)
- Test prototype coil with self field (FY02)
- Modify design as required



Exploded view of modular coil and structure

Budget Increases Are Needed to Prepare for Timely Construction Start

(K$)	Initial Funding 2000	Baseline Budget 2001	Baseline Budget 2002	Base+Incremental Budget 2001	Base+Incremental Budget 2002
PPPL	3,576	3,380	3,380	3,880	7,500
ORNL	1,531	1,600	1,600	1,700	3,000
Program Total	5,107	4,980	4,980	5,580	10,500

- $600k increment in FY-2001 to maintain CDR schedule. Restores ~$100k cut and increases by ~$500k over FY-2000, as FESAC recommended.
- $5.5M increment in FY-2002 for engineering design and R&D will permit early-FY2003 construction start.
- QOS spending will remain at ~10% of program budget throughout this period.
- Includes university collaborators (~$300k in FY-2000).

Impact of Baseline Budget:
Delay Start of Construction and Achievement of Goals

~1-month delay in Conceptual Design Review, to Apr., 2001.

- Compresses CDR/Validation process (must complete by end of May).
- Reduced benefit from the review process.

~8-month delay in design and R&D by end of FY2002.

- Poorly positioned to start construction in FY-2003.
- Likely ~1-year delay in first plasma and experimental results.

Summary

- The program has made excellent progress:
  - Advanced stellarator science and technology.
  - Developed initial designs.

  On schedule to complete FY-2000 goals.

- To stay on course, we need to:
  - Expedite programmatic and design reviews in FY-2001.
  - Increase FY-2001 budget by $500k over FY-2000, as recommended by FESAC.
  - Increase FY-2002 budget to prepare for timely construction start (early FY-2003).