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# Critical Decision 3

## for the

## National Compact Stellarator Experiment

## Princeton Plasma Physics Laboratory
## Oak Ridge National Laboratory


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DOE Federal Project Director

Princeton Area Office


September, 2004

# Presentation Outline

- Background and recent project history
- Status and performance metrics
- Recent project challenges with Modular Coil Winding Forms (MCWF) and Vacuum Vessel Sub Assembly (V VSA)
- ISM & ISSM considerations
- Project subsystems and site related issues
- Readiness to proceed with NCSX fabrication

# Compact Stellarator Vision

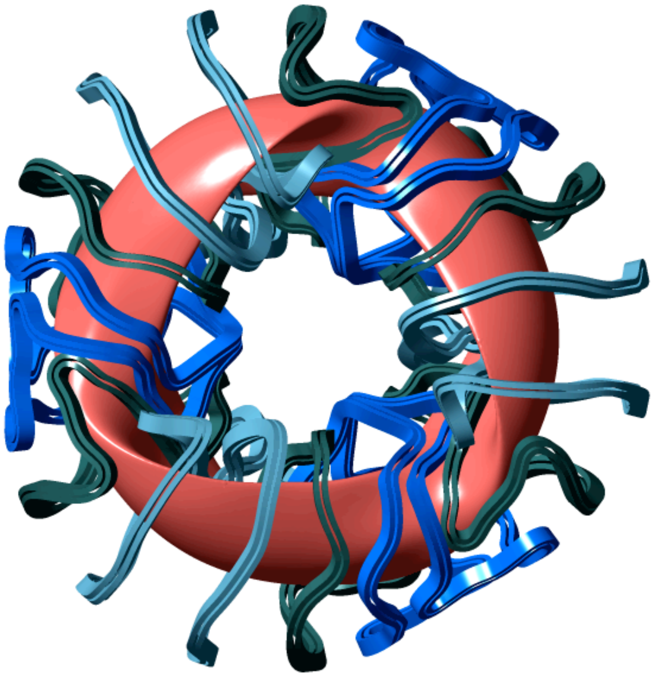
**Stellarators solve critical problems for magnetic fusion.**

- Steady state without current drive.
- Stable without feedback control or rotation drive. No disruptions.
- Advances 3D plasma physics understanding.

**Compact Stellarators improve on previous designs.**

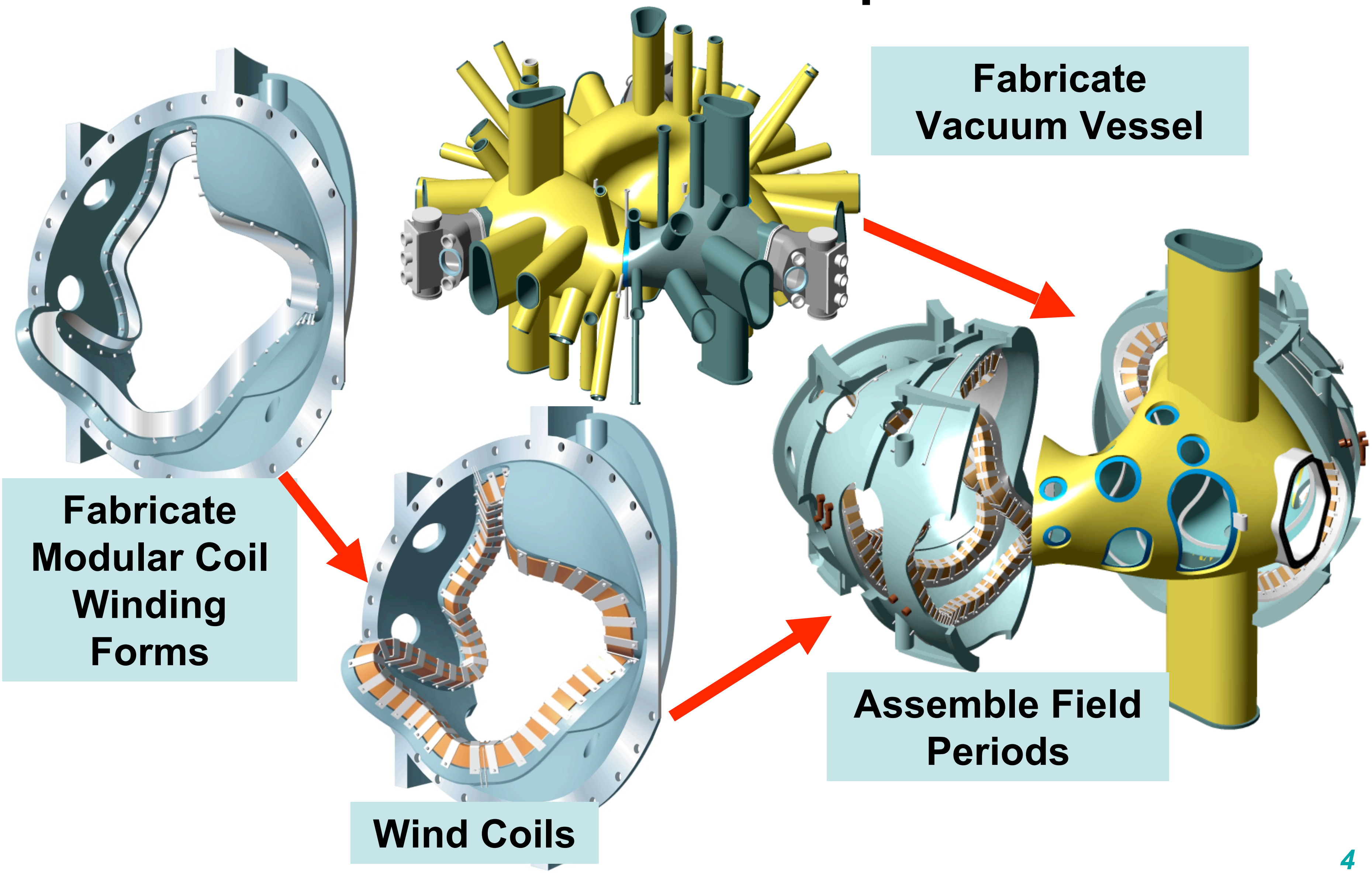
- Magnetic quasi-symmetry:
  - good energetic particle confinement.
  - link to tokamak physics.
- Lower aspect ratio.

**3D geometry produces benefits & costs Need to assess risk & manage both.**



**3-Period NCSX Plasma and Coil Design**

# The Basic NCSX Device Concept is Robust



# The Baseline Scope is Defined for CD3

**NCSX Major Item of Equipment (MIE) scope includes…**

- Equipment required to achieve First Plasma, begin research program.
- Systems to support operation w/ coils at cryogenic temperature.
- Examination and testing of 1.5-MW NBI equipment.
- Integrated system testing, including flux surface mapping and startup.
- Design effort to ensure facility can accommodate required upgrades when needed by the program.

**Not in MIE scope…**

- Research program planning and preparation of long-lead equipment upgrades.

# Recent NCSX Project History

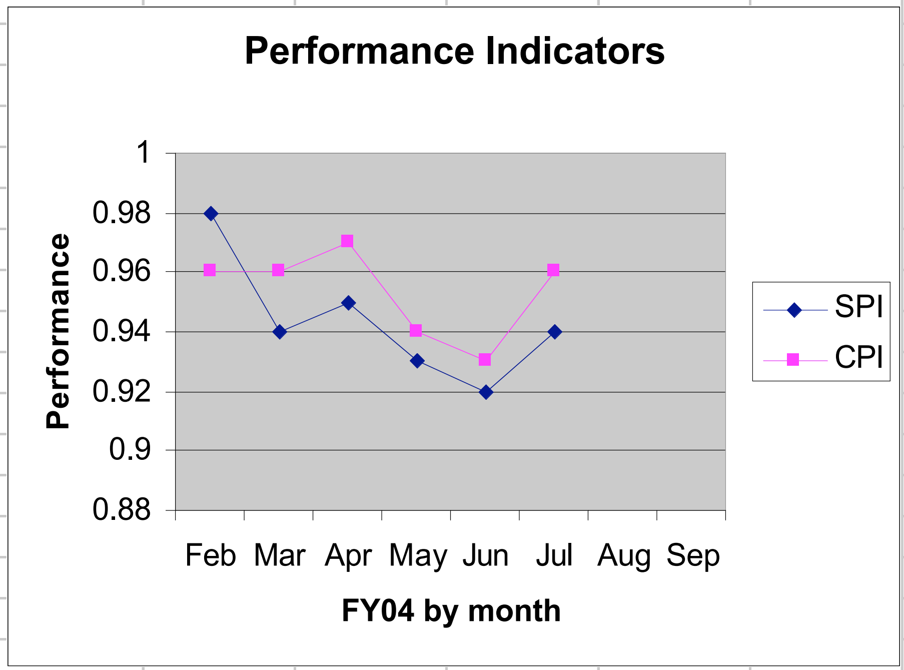
- ✓ CD-0 (Mission Need) – approved June, 2001.
- ✓ CD-1 (Acquisition Plan, Cost Range) – approved November, 2002.
- ✓ Fabrication Project Started – April, 2003
- ✓ Preliminary Design Review – October, 2003
- ✓ EIR & Performance Baseline (SC) Review – November, 2003
- ✓ CD-2 Establish Performance Baseline – approved February, 2004
- ✓ **Final Design Review – completed May, 2004**
- ✓ **Independent Project Review (Execution Readiness) – June, 2004**
- ✓ **Receipt of vendor proposals (V VSA & MCWF) – July, 2004**
- ✓ **Independent Project Review Update – September, 2004**
- ➢ CD-3 Start of Fabrication – September 2004

# The Project Status is Sound

- The project is progressing and baseline established at CD2 is valid.
- The project organization and management systems are working well.
- Requirements, scope, and objectives are well established and stable.
- Estimates have a sound technical basis. (Successful Reviews **and fixed-price agreements for major procurements**)
- Risks have been assessed and mitigation plans developed.
  - Adequate cost and schedule contingencies maintained.
  - Risk assessment is a continual process in the NCSX culture. Critical issues list identifies coil winding (40%) & assembly (32%).
- Resource-loaded schedule has been developed and maintained.
- Earned-value performance measurement system has been validated and implemented.
- PARS EVMS reporting started March, 2004 – NCSX is *Green !!*

# Performance Metrics Thru August 1

| | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|
| SPI | 0.98 | 0.94 | 0.95 | 0.93 | 0.92 | 0.94 | | |
| CPI | 0.96 | 0.96 | 0.97 | 0.94 | 0.93 | 0.96 | | |



# Project Control Systems are In Place

Engineering Changes and Contingency Calls Since CD2

| ECP # | Title | Date | Contingency out |
|---|---|---|---|
| 04-004 | Est. Performance Baseline(CD2) | 3/04 | $630k |
| 04-005 | VV & Field period assembly mods | 3/04 | $560k |
| 04-006 | Add VV ports and Coil test mods | 4/04 | $630k |
| 04-007 | Twisted racetrack VPI mods | 4/04 | $ 0k |
| 04-008 | Production costs of 5&6 above | 6/04 | $540k |
| 04-009 | Project replanning WBS 1 | 7/04 | $ 0k |
| 04-010 | Twisted racetrack design change | 7/04 | $ 0k |
| 04-011 | MCWF design costs & variances | 7/04 | $1485k |
| *04-XXX* | *Replan to accommodate proposals* | *9/04* | *($700k)* |
| | Remaining Contingency through ECP 04-XXX (~24% of remaining work) | | $13400K |

# High Risk Areas and Challenges as We Approach CD3

- Technical – Tolerances…..always tolerances
  Complex geometries
  Modular coil cooling scheme & components

- Cost - VVSA & MCWF prices *received and evaluated.*
  Proposed costs were higher than expected.
  Close attention to contingency usage and contract changes.

- Schedule – Level 2 milestones to date have been met.
  MCWF production time exceeds plans.

- Management – Resource availability bears watching.
  Some non-critical work may move to FY05/06 due to
  BA limitations.

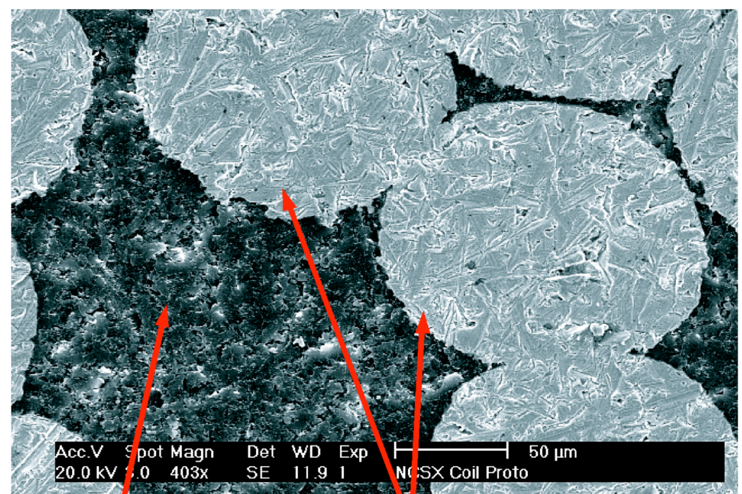
# Modular Coil Technical Risks Addressed Through R&D

## Many Issues Have Already Been Resolved

- Conductor handling, placement, and clamping on a 3-D winding surface (top photo).
- Conductor and insulation system design to minimize keystoning.
- Epoxy impregnation methods (bottom photo).
- Construction, cooldown, and energizing of a racetrack-shape demonstration coils.
- Conductor mechanical properties tests.

## Twisted racetrack demonstration coil will be manufactured and tested prior to production.

## Winding facility has been established in the former TFTR test cell.



# Vendor Proposals Higher Than Estimated

- Cost estimate for critical components increased **$4.4M** (from $8.1M to $12.5M)
    - MCWF actual $8.0M vs. $5.1M (+57%)
    - VVSA actual $4.5M vs. $3.0M (+50%)
- Agreements on fixed prices retires $2.0M of risk.
    - Contingency assessment reduced from $3.25M (40% of previous estimate) to $1.25M (10% of negotiated fixed price).

- **This increase was offset by $5.1M of reductions in other work, in order to improve the project's contingency position and respond to concerns of SC reviews.**
- 10% on MCWF and VVSA to cover risk of project-directed changes.
- 28% average contingency on all other work, consistent with job-level risk assessments developed and reviewed prior to CD-3.

# Vendor Proposals Required Revisions to Project Planning

- We challenged the project team to develop a sound plan for completing all NCSX CD-4 scope and performance requirements within the approved performance baseline:

  **TEC = $86.3M, CD-4 in May, 2008.**

- Plans were modified to offset cost and schedule challenges in the VVSA and MCWF procurements.
  - Some of the changes were under consideration at the June review.
  - Additional savings/reductions identified during planning exercise

- We have selected very capable suppliers for the Vacuum Vessel Sub-Assemblies (VVSA) and Modular Coil Winding Forms (MCWF).
  - Negotiated prices and schedules are in place between Princeton and suppliers as the basis for fixed-price and -schedule subcontracts to be awarded in mid-September.
  - A major project risk is now much better defined.

# Cost Offsets Overview

**Planning changes were made to achieve the needed $5.1M savings.**

- C-Site power supplies instead of D-site, -$1.63M.
- Diagnostic interface goals satisfied, -$0.83M
- NBI testing goals satisfied, -$0.83M
- Basic I&C system, -$0.4M
- Simpler cryogenic supply system, -$0.3M
- Reduced metrology tool set, -$0.13M
- Induction bakeout system, -$0.5M
- Proportional reduction in Mgmt & Integration, -$0.5M
- **New Plan satisfies all project requirements.**
- No risk to safety or research mission.
- Meets, but does not exceed, all CD-4 scope and performance requirements.
- At CD-4, the facility is ready to start research operations.

# New Plan Offsets 5-Month Delay in Delivery of Last MCWF

- Schedule for completing field period and machine assembly (>1 year) was optimized by paralleling activities and some use of second shift. (-1.5 mos.)

- Construction-to-ops transition tasks are taken off critical path and completed in parallel with final assembly tasks including cryostat installation. (-2.0 mos.)
  - Last-minute construction items (“punch list”).
  - Sub-system pre-ops. tests (incl. CD-4 vacuum tests) and configure for operation.
  - Safety reviews and approvals, preliminary readiness assessment.
  - Compares favorably with actual experience on NSTX.

- E-beam mapping is limited to only CD-4 requirements: confirmation that basic magnet system produces magnetic surfaces. (-1.0 mos.)

**5 months schedule contingency is maintained**

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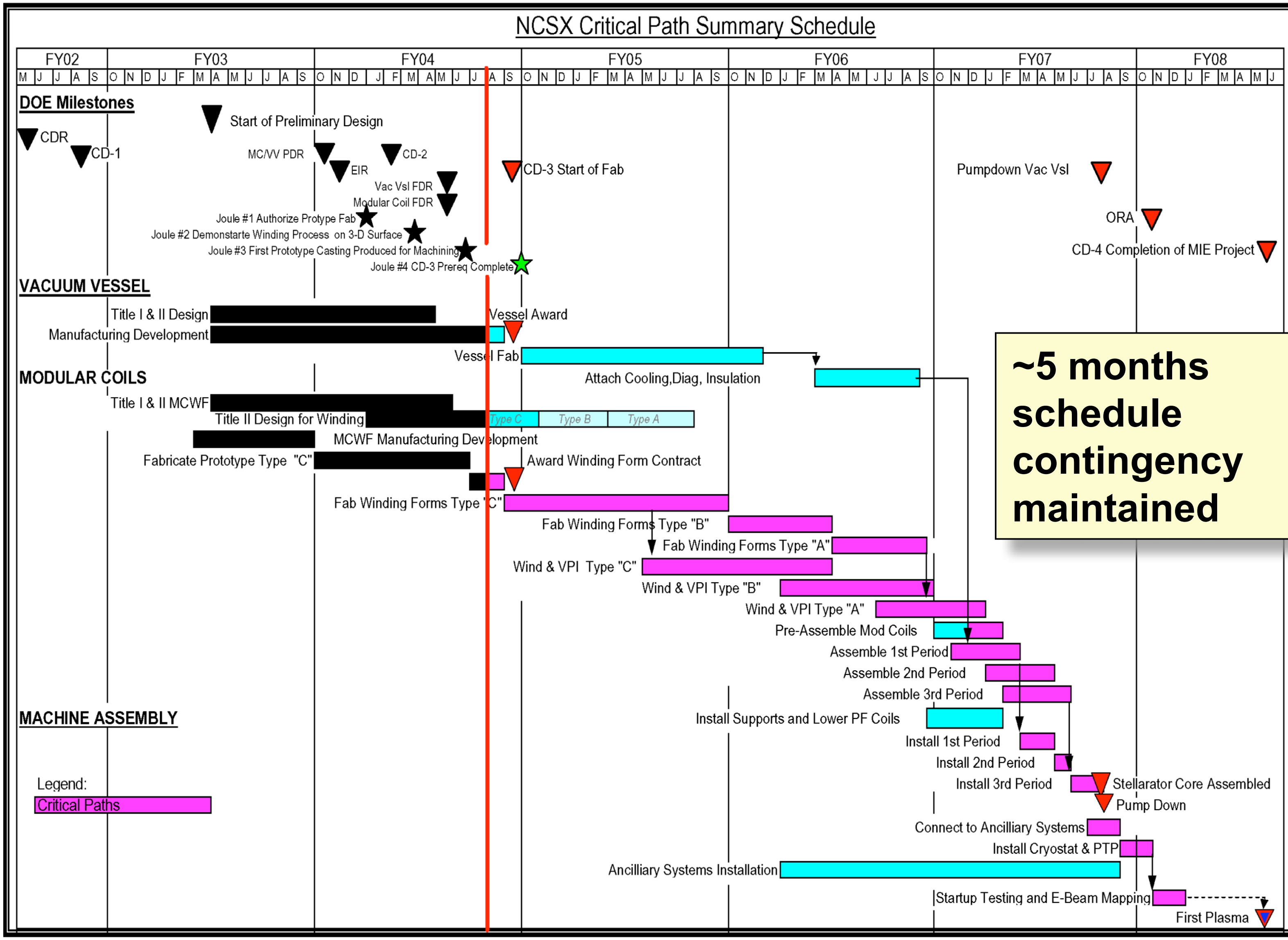
# Estimated Cost is $86.3M w/ 24% Contingency

| WBS | Description | |
|---|---|---|
| **1** | **Stellarator Core Systems** | **49.4** |
| | 11 - In-Vessel Components | 0.1 |
| | 12 - Vacuum Vessel | 8.5 |
| | 13 - Conventional Coils | 4.2 |
| | 14 - Modular Coils | 25.2 |
| | 15 - Structures | 1.4 |
| | 16 - Coil Services | 1.0 |
| | 17 - Cryostat and Base Support Structure | 1.3 |
| | 18 - Field Period Assembly | 5.0 |
| | 19 - Stellarator Core Management and Integration | 2.7 |
| **2** | **Heating, Fueling, and Vacuum Systems** | **0.8** |
| **3** | **Diagnostic Systems** | **1.2** |
| **4** | **Power Systems** | **3.7** |
| **5** | **Central I&C / Data Acquisition Systems** | **2.2** |
| **6** | **Facility Systems** | **1.1** |
| **7** | **Test Cell Prep & Machine Assembly** | **4.3** |
| **8** | **Project Management & Integration** | **10.2** |
| | **Subtotal** | **72.9** |
| | **Contingency (24% of remaining work from 8/1/04)** | **13.4** |
| | **Total Estimated Cost** | **86.3** |

Contingency estimate is supported by WBS managers' assessments of subsystem technical, cost, and schedule risks.

Risk management is a continuing Integrated Project Team focus.

# NCSX Critical Path Summary Schedule




**~5 months schedule contingency maintained**

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# Project Performance Baseline Remains Valid

- We are able to maintain cost baseline and accommodate higher component costs, *but near term contingency is tight.*

- We are able to maintain schedule baseline with longer delivery schedule on MCWF's, *but schedule is success oriented.*

- *Funding profile constrains progress and results in delaying start of some non-critical path work.*

- *We have addressed the above concerns & will continue to look for ways to optimize as we proceed with fabrication and assembly activities.*

# ISM & ISSM for NCSX

- Integrated Safety Management
  - NCSX is governed by lab-wide ISM standards
  - Line management accountability
  - Project specific engineering & administrative controls implemented as required to enhance safety of workers, the public, & the environment
- Integrated Safeguards & Security Management
  - NCSX governed by lab-wide security standards based on threat risk assessment
  - Line management accountability
  - Systems include sitewide physical access controls (ACAMS), Operational interlock systems, Cyber security controls, Foreign visits & assignments procedures, and Centralized material control.

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# The Stellarator Device is the Heart of the System

**Device Threshold Ratings at CD-4:**

Major radius: 1.4 m

Magnetic Field Strength (B):
1.6 T (0.2 s pulse) / 1.2 T (1.2 s)

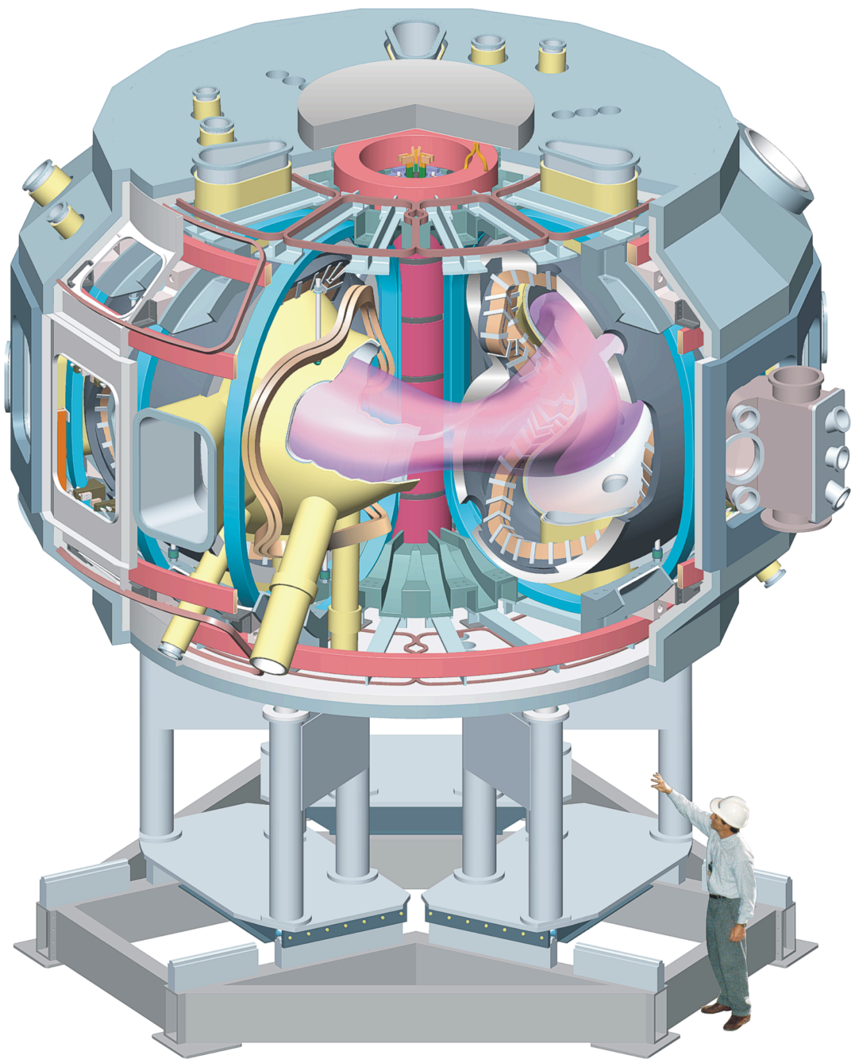
Vacuum base pressure (p):
$8 \times 10^{-8}$ torr

Flexible

Good Access

**Design targets aim at higher performance for additional physics value and margin:**

B = 2.0 T (0.2 s pulse)
p = $5 \times 10^{-8}$ torr



# Baseline Scope: Stellarator Device

## WBS 1. Stellarator Core Systems

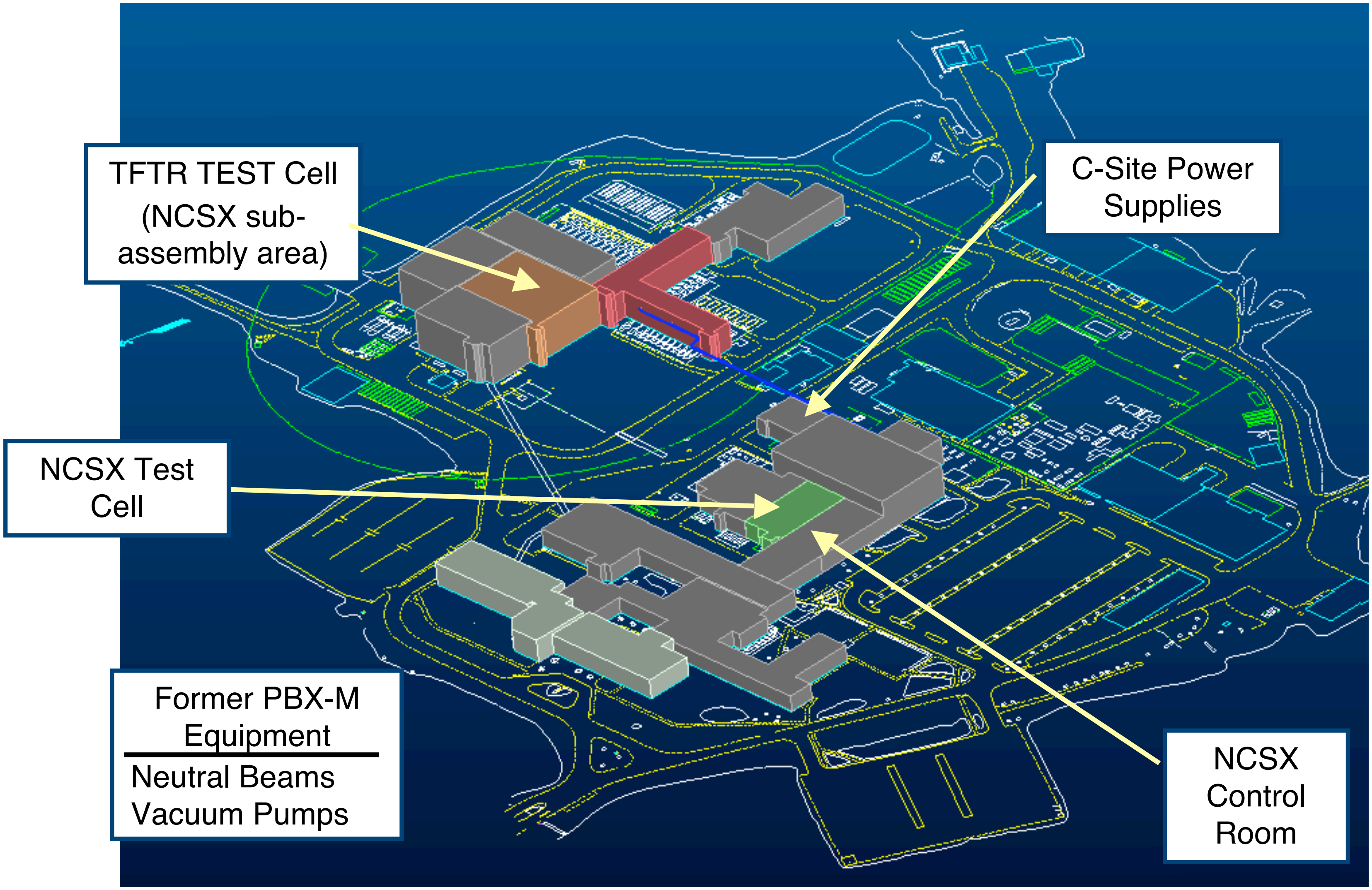
- Vacuum Vessel.**
- Modular Coils**, Conventional Coils, Coil Structures & Services.
- Field Period Subassembly.
  - TF and modular coils, trapped magnetic sensors, vacuum vessel.
- Cryostat and machine base.

## WBS 74-76. Machine Assembly

- Construction management and support
- Final Stellarator Core Assembly.

*****The Recent Final Design Review focused on these items***

# NCSX Uses Many PPPL Site Assets




*Project scope includes refurbishment and reconfiguration of existing equipment and facilities.*

# Baseline Scope: Ancillary Systems

## WBS 21-22. Fueling & Vacuum Pumping

- H/D/He gas injection, turbomolecular pumping system.

## WBS 25. Neutral Beam Injection (NBI) Heating

- Equipment for one 1.5-MW beam, refurbished and tested.

## WBS 3. Diagnostics

- Ex-vessel magnetic sensors, fast camera, field mapping system, design integration for upgrade diagnostics.

## WBS 4. Power Systems

- Coil power, AC power, monitored ground system.

## WBS 5. Central I&C

- Facility control, timing, computing, data acquisition, control room, safety interlocks.

## WBS 6. Facility Systems and 71-73. Test Cell Prep

- Water, cryogen system, 150 C bakeout, utilities, machine platform, control room refurbishment.

# Project Management and Integration Scope

**WBS 8:**

- Project Management/Risk Management
- Project Control
- Engineering Management
- System Engineering
- Design Integration
- Technical Assurance
- Safety and Environment*
- Quality Assurance*
- Procurement*
- Project Physics
- Integrated System Testing ⇒ First Plasma (CD-4)

* Project support costs indirectly charged.

# CD-4 Performance Metrics Are Fixed

**First Plasma**

- $B = 0.5$ T, $I_P = 25$ kA, $\iota_{ext}/\iota_{tot} \geq 0.5$, Ohmically heated.

**Coils and Power Supplies**

- Coils tested to specified currents at cryogenic temperature.
- e-beam mapping at room temp. to confirm vacuum magnetic surfaces.

**Vacuum, Pumping, and Bakeout**

- Base pressure $\leq 4\times10^{-7}$ torr achieved.

**Controls**

- Interlocks, timing, power supply control, data acq. tested.

**Neutral Beams**

- Base vacuum achieved, cryopanels & source leak-checked.

# Project Estimates Have a Sound Basis

**Modular Coils, Vacuum Vessel, Stellarator Assembly**

- Design and work breakdown developed to a detailed level.
- Analysis and R&D results underpin design and fabrication processes.
- Firm proposals from industry, based on detailed manufacturing plans and prototyping, now define the costs for major procurements.

**Power Systems, Vacuum Pumping, Neutral Beams, Fueling**

- Modifications of well-maintained legacy equipment.
- Condition known based on testing or being in active service.
- Estimates based on well defined scope, experience from past projects.

**Conventional Coils, Cryostat, Diagnostics, I&C, Facility Systems.**

- Conventional, low-risk designs proven on past projects.
- Estimates based on well defined scope, experience, catalog prices, vendor quotes.

**All Have Undergone Extensive Internal and External Review.**

# We Are Ready To Proceed to CD-3

**Project needs are well understood.**

- Design and R&D have improved understanding of cost of meeting NCSX requirements. (Drivers are complex geometry, field errors.)
- NCSX's and other stellarator projects' experiences have improved understanding of risks and mitigation costs.
- **Fixed-price agreements with excellent suppliers reduces uncertainties in the two major procurements.**

**The suppliers' strong technical and management capabilities are important assets for the project going forward.**

- Qualified through NCSX R&D and prototype fabrication activity.
- Selected through a competitive, best-value procurement process.
- Demonstrated commitment to the success of the NCSX program.

**WBS managers are responsible for cost and contingency estimates.**

- Are responsible for executing work scope within cost and schedule.
- Have good understanding of the technologies, work scope, and risks.
- Manufacturers fixed price proposals provide additional confidence.

# Major Tool Will Provide NCSX Vacuum Vessel

**Excellent performance on NCSX prototype.**

- Product met all requirements: tight tolerance, vacuum, surface finish.

**Excellent performance on other SC projects.**

- SNS target vessel, HFIR monochrometer.
- UT-Battelle small business contractor of the year, 2003.

**Ample heavy fabrication capabilities: meets NCSX needs with margin and flexibility to manage risks.**

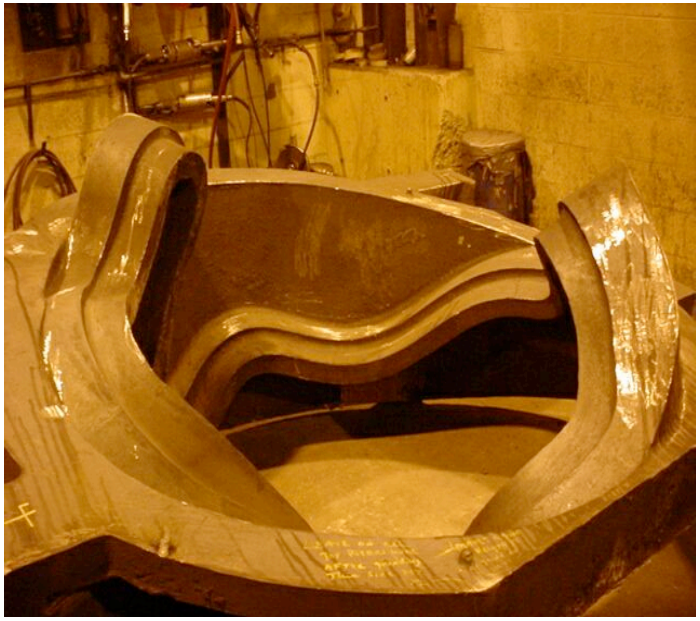
- Multiple centers for forming, welding, 5-axis machining.
- All major operations are under one senior manager at Indianapolis facility.

- **Price: $4.5M. Delivery: 14 mos.**
- **Original baseline: $3.0M, 14 mos.**

# Energy Industries of Ohio Will Provide Winding Forms

**•EIO provides the management capabilities this contract requires.**

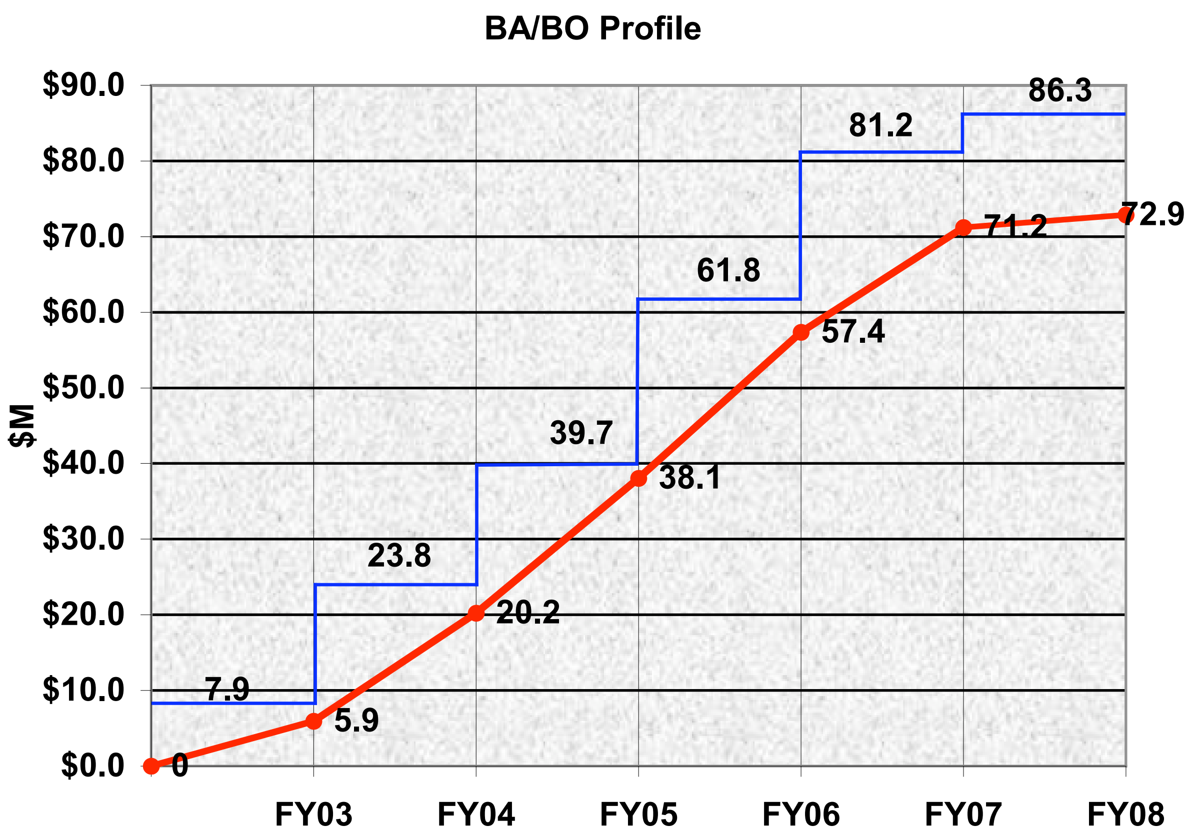
•Assembled a professional team with relevant experience in gov't. contracting (DOE, NASA), industry teams, technical management, QA.
•Produced winding form for NCSX "twisted racetrack" subscale demo coil.



**•EIO re-structured its team to correct weaknesses they recognized during the prototype program.**
•Major Tool and Machine was brought in to capitalize on their capabilities and depth in machining, excellent reputation, familiarity with NCSX.
•EIO moved to a more centralized management model to improve lines of authority and communication.

**Price: $8.0M. MCWF Delivery– First: May, 2005. Last: Sept. 2006.**
**Original baseline: $5.1M, First: Jan., 2005. Last: Apr., 2006.**

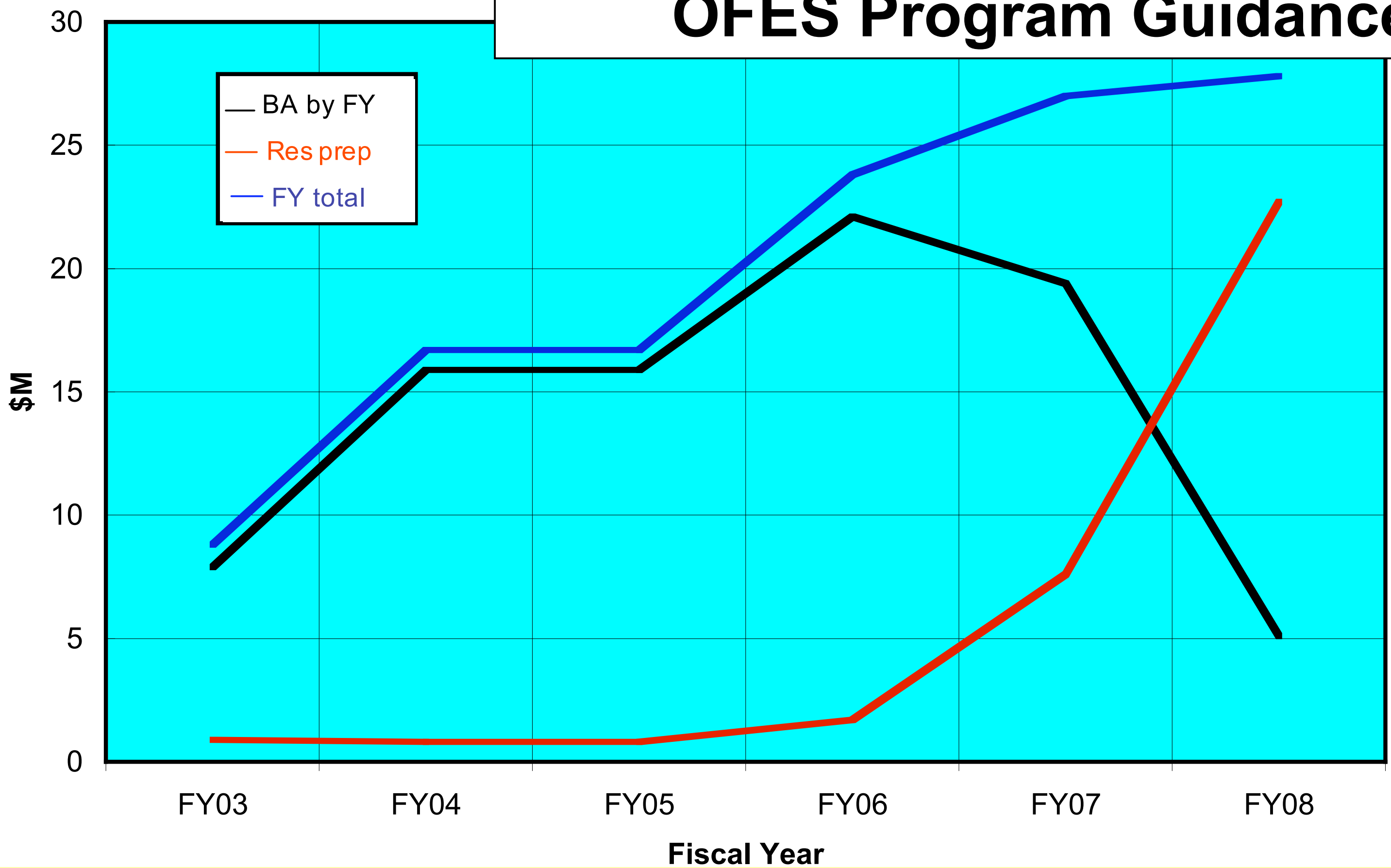
# BA/BO Profile Supports Project Plan




| | FY03 | FY04 | FY05 | FY06 | FY07 | FY08 | Total |
|---|---|---|---|---|---|---|---|
| BA Funding | 7.9 | 15.9 | 15.9 | 22.1 | 19.4 | 5.1 | 86.3 |
| BO Plan wo/ cont | 5.9 | 14.3 | 17.8 | 19.3 | 13.8 | 1.7 | 72.9 |
| Contingency | | | 1.6* | 2.8 | 5.6 | 3.4 | 13.5 |
| BO Plan with cont | 5.9 | 14.3 | 19.5 | 22.1 | 19.4 | 5.1 | 86.3 |

* $1.7 M additional held in PPPL reserve for FY05

# Program Funding Profiles Match OFES Program Guidance




| NCSX Program Funding ($M) | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | Total |
|---|---|---|---|---|---|---|---|
| MIE Fabrication Project (BA) | 7.9 | 15.9 | 15.9 | 22.1 | 19.4 | 5.1 | 86.3 |
| Research Preparation (+Ops in 08) | 0.9 | 0.8 | 0.8 | 1.7 | 7.6 | 22.7 | |
| NCSX Program Total | 8.8 | 16.7 | 16.7 | 23.8 | 27.0 | 27.8 | |

# All CD-3 Pre-requisites Have Been Addressed

- ✓ Integrated Project Team.
- ✓ Project Execution Plan.
- ✓ Work Breakdown Structure.
- ✓ Resource Loaded Schedule.
- ✓ Total Estimated Cost and Project Schedule.
- ✓ Acquisition Strategy.
- ✓ Risk Management Plan.
- ✓ Critical Subsystems Final Design and Final Design Review.
- ✓ External Independent Review and Performance Baseline Review.
- ✓ System Functions and Requirements.
- ✓ NEPA Documentation and Hazards Analysis.
- ✓ Integrated Safety Management.
- ✓ Integrated Safeguards & Security Management
- ✓ Value Management / Engineering.
- ✓ Project Controls, Earned Value Management System, PARS reporting.
- ✓ Start-up Test Plan.

**Documentation for all items is posted on project web site.**
**http://ncsx.pppl.gov//Meetings/CD_3/CD_3_Docs.html**

# NCSX Is Ready to Begin Fabrication

**Project has a solid foundation based on a robust machine concept.**

- Stable requirements, scope, organization, acquisition and mgt. plans.

**Firm pricing for critical components.**

- Mature designs, manufacturer input, R&D, legacy equipment tests.
- Identified risks, documented mitigation plans, adequate contingencies.
- Rigorous change management will be employed throughout the project.

**Resource loaded schedule provides a reliable roadmap.**

- Estimates have been carefully developed and reviewed.
- Updated to accommodate review recommendations, current funding guidance, and recent fixed pricing.

**All CD-3 scope items have been addressed.**

- Project documentation is complete. Systems are in place.

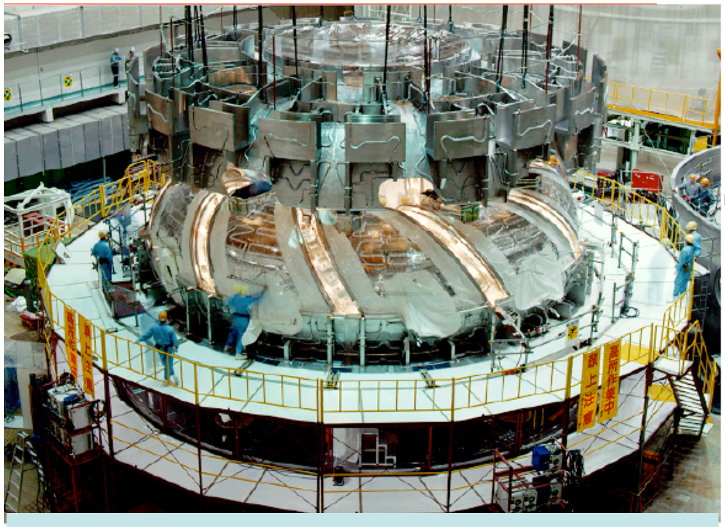
*The NCSX Team requests your endorsement and approval of CD-3 !*

# Extra Slides

# Project Level I & Level II Milestones

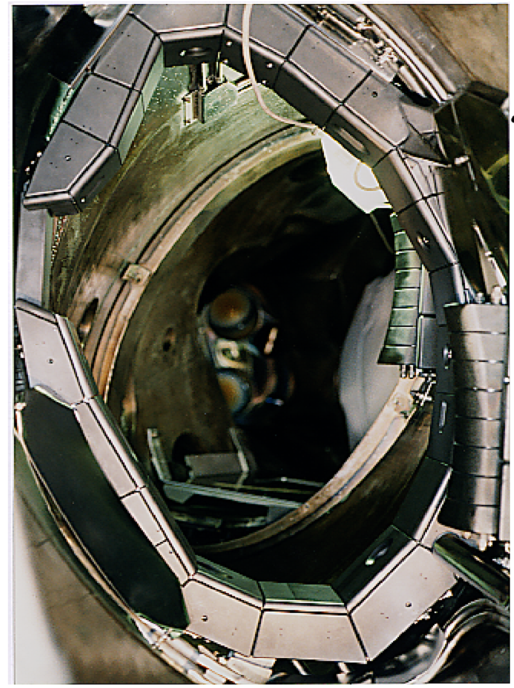
| | | CD-2 Baseline | CD-3 Baseline | *Forecast* | *Actual* |
|---|---|---|---|---|---|
| **Level I** | CD-1 | May-2003 | May-2003 | | ***May-2003*** |
| | CD-2 | Feb-2004 | Feb-2004 | | ***Feb-2004*** |
| | CD-3 | Sep-2004 | Sep-2004 | ***Sep-2004*** | |
| | CD-4 | May-2008 | May-2008 | ***Jan-2008*** | |
| **Level II** | Vacuum Vessel & Modular Coil Prel Dsn Rvw | Oct-2003 | Oct-2003 | | ***Oct-2003*** |
| | Performance Baseline Review | Nov-2003 | Nov-2003 | | ***Nov-2003*** |
| | Conduct VVSA FDR | Jul-2004 | Jul-2004 | | ***May-2004*** |
| | Mod Coil Winding Form Final Design Review | Jul-2004 | Jul-2004 | | ***May-2004*** |
| | Award VV Production Vendor | Dec-2004 | Oct-2004 | ***Sep-2004*** | |
| | Award MCWF Mfg Contract | Nov-2004 | Oct-2004 | ***Sep-2004*** | |
| | First MCWF Delivered | Mar-2005 | Jul-2005 | ***May-2005*** | |
| | TF Coils Awarded | Apr-2005 | Jul-2005 | ***May-2005*** | |
| | Complete First Mod Coil Fabrication | Aug-2005 | Feb-2006 | ***Nov-2005*** | |
| | Vacuum Vessel Delivered | Feb-2006 | Feb-2006 | ***Nov-2005*** | |
| | PF Coils Awarded | Jun-2006 | Jan-2007 | ***Sep-2006*** | |
| | Last MCWF Delivered | Aug-2006 | Dec-2006 | ***Sep-2006*** | |
| | Begin Assembly of First Field Period | Sep-2006 | Mar-2007 | ***Nov-2006*** | |
| | All TF Coils Delivered | Jan-2007 | May-2007 | ***Jan-2007*** | |
| | Last Field Period Assembled | Jun-2007 | Sep-2007 | ***May-2007*** | |
| | Begin Vac Vsl Pumpdown | Sep-2007 | Nov-2007 | ***Jul-2007*** | |
| | Begin Cryostat Installation | Nov-2007 | Jan-2008 | ***Sep-2007*** | |
| | Operational Readiness | Nov-2007 | Mar-2008 | ***Oct-2007*** | |
| | Begin Start-up Testing | Mar-2008 | Mar-2008 | ***Nov-2007*** | |

# Stellarators Are Making Excellent Progress



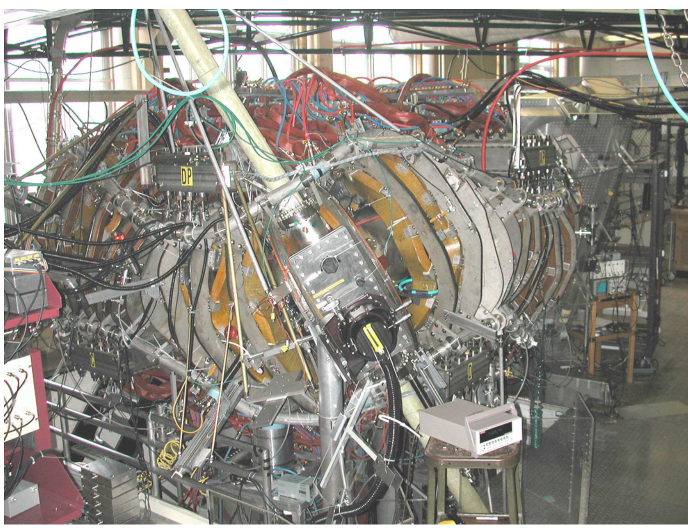
**Large Helical Device (S/C magnets - Japan)**

- high beta
- high plasma temperatures
- enhanced confinement
- long pulses



**Wendelstein 7-AS (Germany)**

- high beta
- enhanced confinement
- divertors



**Helically Symmetric Experiment (U. Wisc.)**

- Successful test of quasi-symmetry

**Wendelstein 7-X (Germany)**

**Optimized Design - S/C magnets**

**Under construction - Ops. In 2010**

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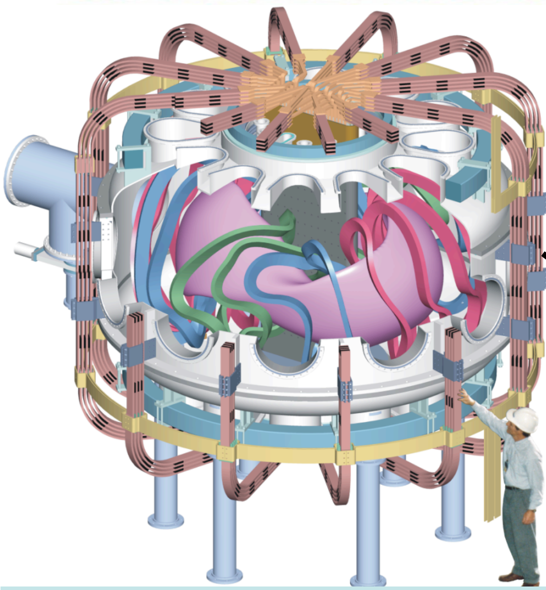
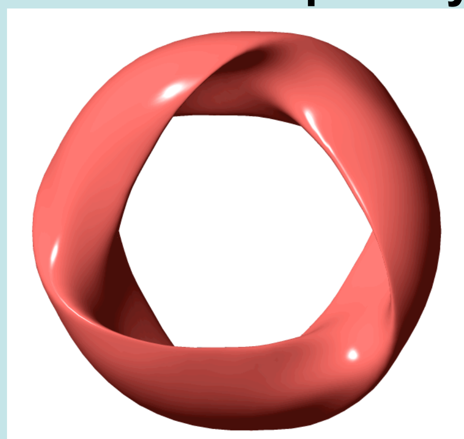
# U.S. Program Develops Physics Basis for Assessing CS Attractiveness



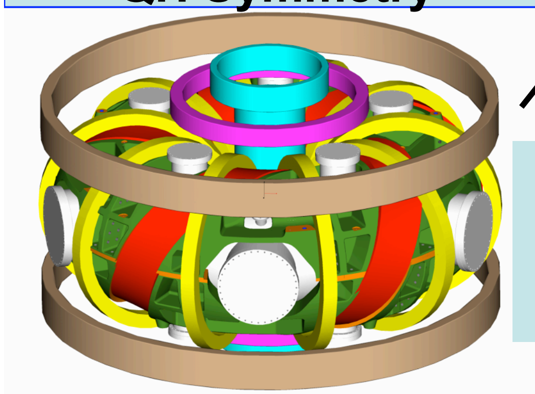
**QPS (ORNL)** - CDR 2003
QP symmetry, R/⟨a⟩ < 3.

**HSX (operating @U. Wisconsin)**
QH Symmetry

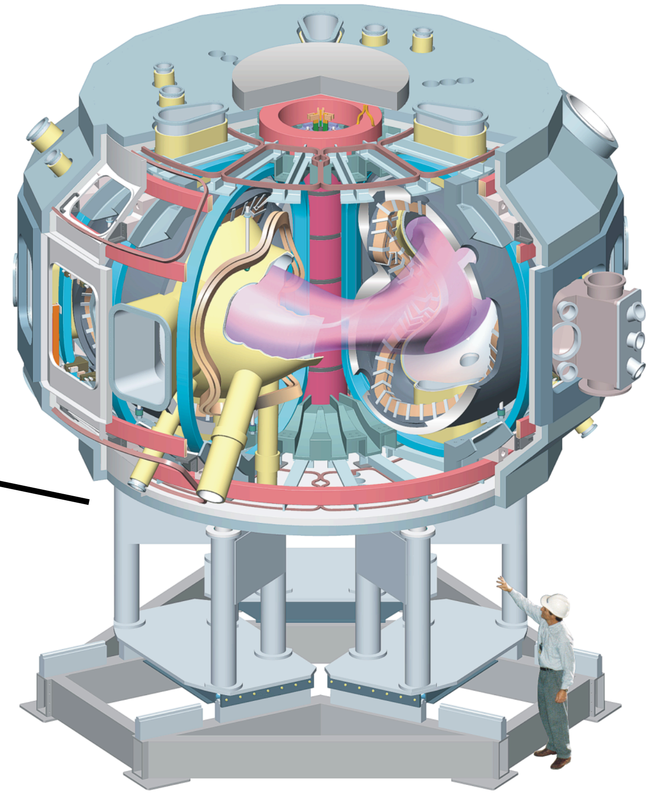
**Theory & Computation**
Computational Tools
Predictive Capability



**ARIES System Study**
Update CS Power Plant Designs



**CTH (Auburn U.)**
Stability Physics
Ops. in 2004



**NCSX (PPPL-ORNL)**
Integrated PoP test of CS physics w/ $\beta \geq 4\%$,
QA symmetry.
First Plasma - 2008