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# Critical Decision 2

## Establish Performance Baseline

## for the

## National Compact Stellarator Experiment

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

Greg Pitonak
DOE Federal Project Director
Princeton Area Office

*…for the NCSX Team*

February, 2004

# Outline: Introduction to the NCSX Project

## Background

- Project team, purpose, and history

## NCSX Performance Baseline

- Baseline parameters.

  *scope, performance, cost, and schedule*

- Technical basis.

## All prerequisite reviews completed

- PDR, EIR, & Office of Science reviews

## Summary: NCSX is Ready to Proceed to CD-2

# NCSX Integrated Project Team

| | |
|---|---|
| Gregory Pitonak, DOE-PAO, Chair | NCSX Federal Project Director |
| Gene Nardella, DOE-OFES | NCSX Program Manager |
| Chuck Finfgeld, DOE-OFES | NCSX Physics Program Mgr. |
| Hutch Neilson, PPPL | NCSX Laboratory Project Manager |
| James Lyon, ORNL | NCSX Deputy Project Manager |
| Wayne Reiersen, PPPL | NCSX Engineering Manager |
| Ron Strykowsky, PPPL | NCSX Project Control Manager |
| Judy Malsbury, PPPL | PPPL QA Division Head |
| Rodney Templon, PPPL | PPPL Procurement Director |
| Jerry Levine, PPPL | PPPL ES&H Division Head |

All key disciplines and organizations are represented.

**Frequent IPT meetings have been effective in managing risks and guiding project through critical steps.**

# Compact Stellarator Vision

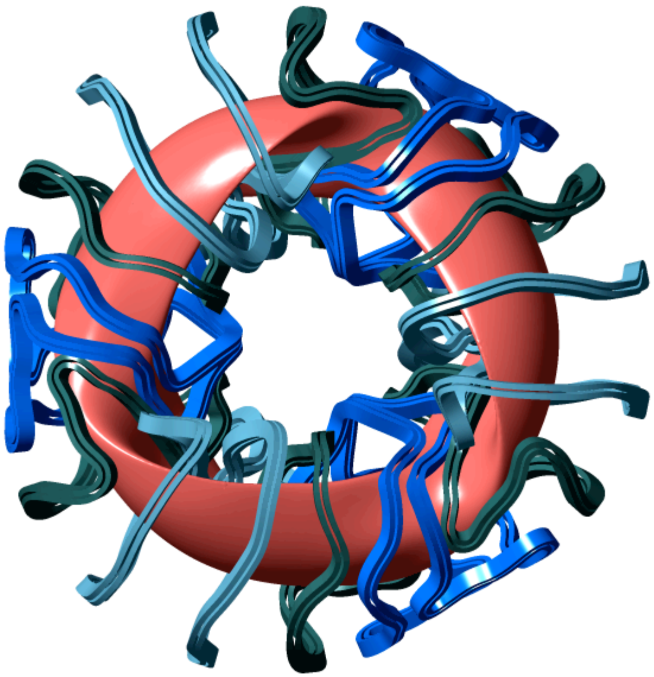
**Stellarators solve critical problems for magnetic fusion.**

- 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 and costs. Need to quantify both.**



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

# NCSX Mission Supports OFES Program Goals: Configuration Optimization and Science

**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 quasi-axisymmetric 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.

# Recent NCSX Project History

- ✓ Physics Validation Review – March, 2001
- ✓ CD-0 (Mission Need) – approved June, 2001.
- ✓ DOE Conceptual Design Review (CDR) - May, 2002.
- ✓ CD-1 (Acquisition Plan, Cost Range) – approved November, 2002.
- ✓ Fabrication Project Started – April, 2003
- ✓ Site Preliminary Design Review – October, 2003
- ✓ EIR & Performance Baseline (SC) Review – November, 2003
- ➢ **CD-2 Establish Performance Baseline – February, 2004**

# Reviews Unanimously Concluded: NCSX is Ready for CD-2

- All reviewed the "PDR Baseline" presented by project.
- PDR found:

**"NCSX design is technically sound, the management plans and budget are adequate, and the project is ready for CD-2."**

- Office of Science Review and External Independent Review were strongly positive.
- The IPT has developed disposition plans for all review recommendations and updated the baseline accordingly.

# Key Changes in the CD-2 Baseline

- **Changes recommended by reviews will reduce risks:**
  - Second winding line provides additional schedule flexibility.
  - All modular coils will be cryogenically tested before assembly.
  - Vacuum vessel bakeable to 350C reduces future PFC costs and risks.

- **Additional testing is included to meet expanded CD-4 criteria:**
  - e-beam mapping campaign to verify coils produce magnetic surfaces.
  - Cryogenic operation of magnets at first plasma.

- **Budget profile was modified due to reduced FY-05 funding guidance.**
  - Work was stretched out to fit new funding constraints.
  - Even so, contingency profile was advanced in time, in response to PBR concerns. Schedule contingency was held at 5.5 months.

# Summary of Cost and Schedule Changes in the CD-2 Baseline

| | Cost ($M) | Schedule |
|---|---|---|
| PDR Baseline (presented at reviews) | 81.0 | Sept., 2007 |
| PDR Recommendations | +1.4 | +2 mos. |
| Expanded CD -4 criteria and scope | +1.9 | +4 mos. |
| Other PBR Recommendations | +1.3 | 0 |
| EIR Recommendations | 0.0 | 0 |
| Budget profile changes | +0.7 | +2 mos. |
| Total of changes | +5.3 | +8 mos. |
| **CD-2 Performance Baseline** | **86.3** | **May, 2008** |

- Also, updated estimates of tasks in progress since Oct. 1 are incorporated to align performance baseline with current estimates.
- Budget contingency is 26% on remaining work.

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## Better understanding of requirements, costs, and funding limits have caused estimate changes since CD-1.

## But Value Engineering improvements and scope adjustments have partially offset the increases.

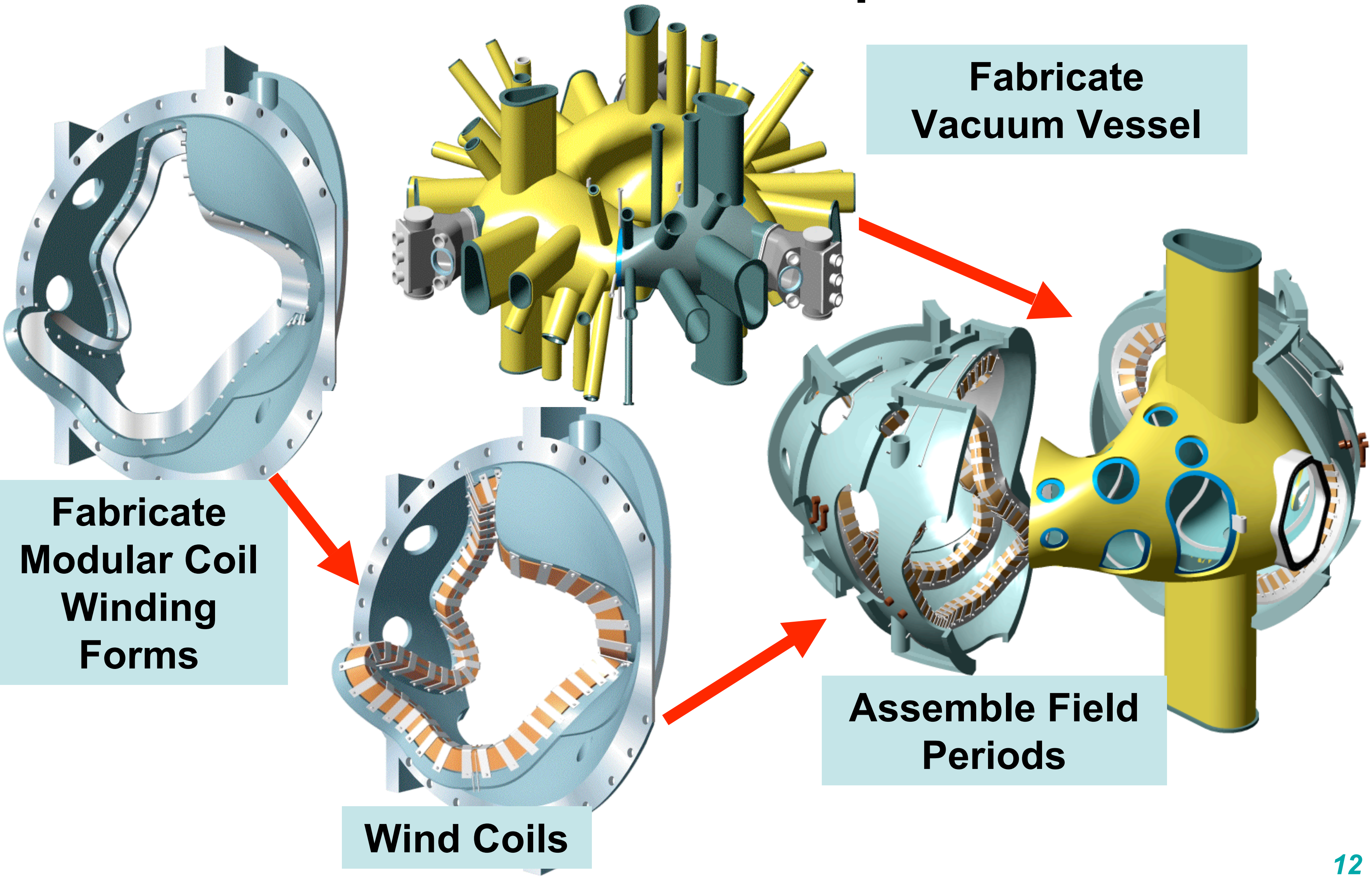
| Event (date) | TEC ($M) | CD-4 Date | |
|---|---|---|---|
| CD-0 (May, 2001) | 65.0 | 9/06 | |
| • Funding stretchout (reduced FY2003-04 BA guidance)<br>• Component cost increased based on manufacturer input. | | | |
| CD-1 (May, 2002) | 73.5 | 6/07 | |
| • Stellarator core increased due to better understanding, manufacturer input.<br>• Ancillary systems reduced via value improvements and some scope deferral.<br>• Management and system engineering increased due to better understanding of risk mitigation requirements.<br>• Delayed start due to CR, partially recovered via schedule optimization. | | | |
| PDR (Oct., 2003) | 81.0 | 9/07 | |
| • Expanded CD-4, review recommendations, funding stretchout. | | | |
| CD-2 (Feb, 2004) | 86.3 | 5/08 | |

# The CD-2 Baseline is Sound

- Requirements, scope, and objectives are well established and stable.
- Estimates have a sound technical basis. (Successful Reviews)
- Risks have been assessed and mitigation plans developed.
  - Adequate cost and schedule contingencies included.
  - Risk assessment is a continual process in the NCSX culture.
- Resource-loaded schedule has been developed.
- Earned-value performance measurement system has been validated and implemented.
- PARS EVMS reporting begins after CD2 approval.

**We Are Ready to Establish Baselines !**

# The Basic NCSX Device Concept is Robust



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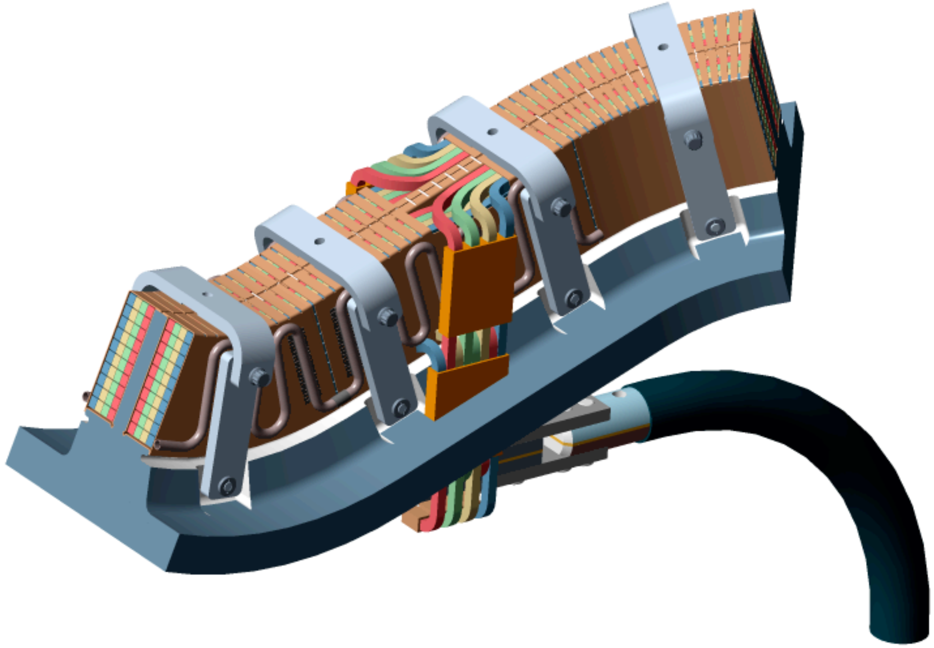
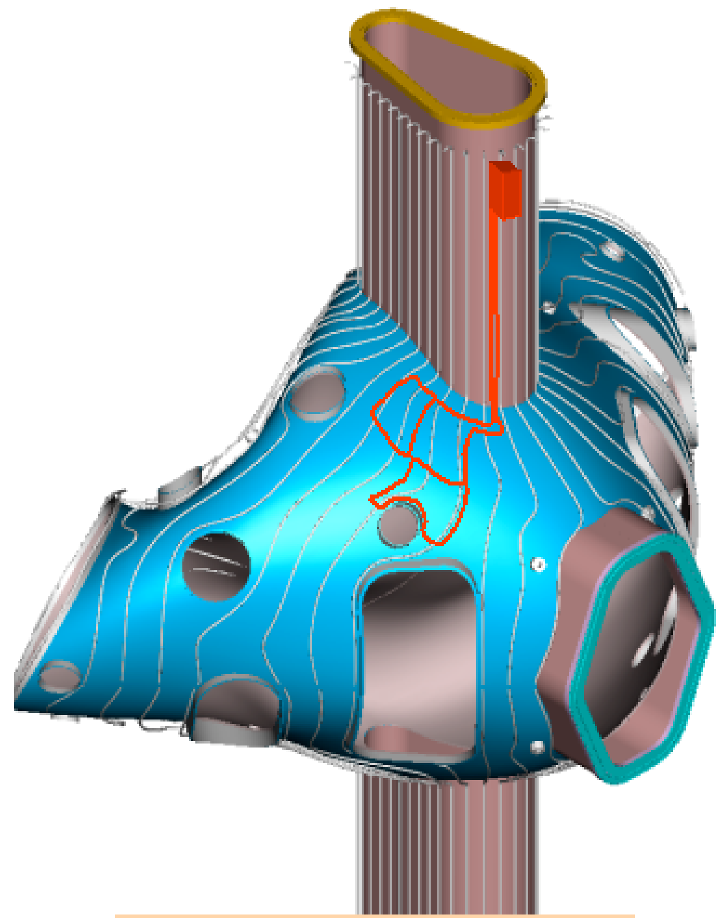
# Component and Interface Details Are Defined





**Details of Modular Coil Clamps and Leads**

**Cooling Tubes and Magnetic Sensors Installed on Vessel**

# The Baseline Scope is Clearly Defined

**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.
- Refurbishment 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.

# The Stellarator Device is the Heart of the System

**Device 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)

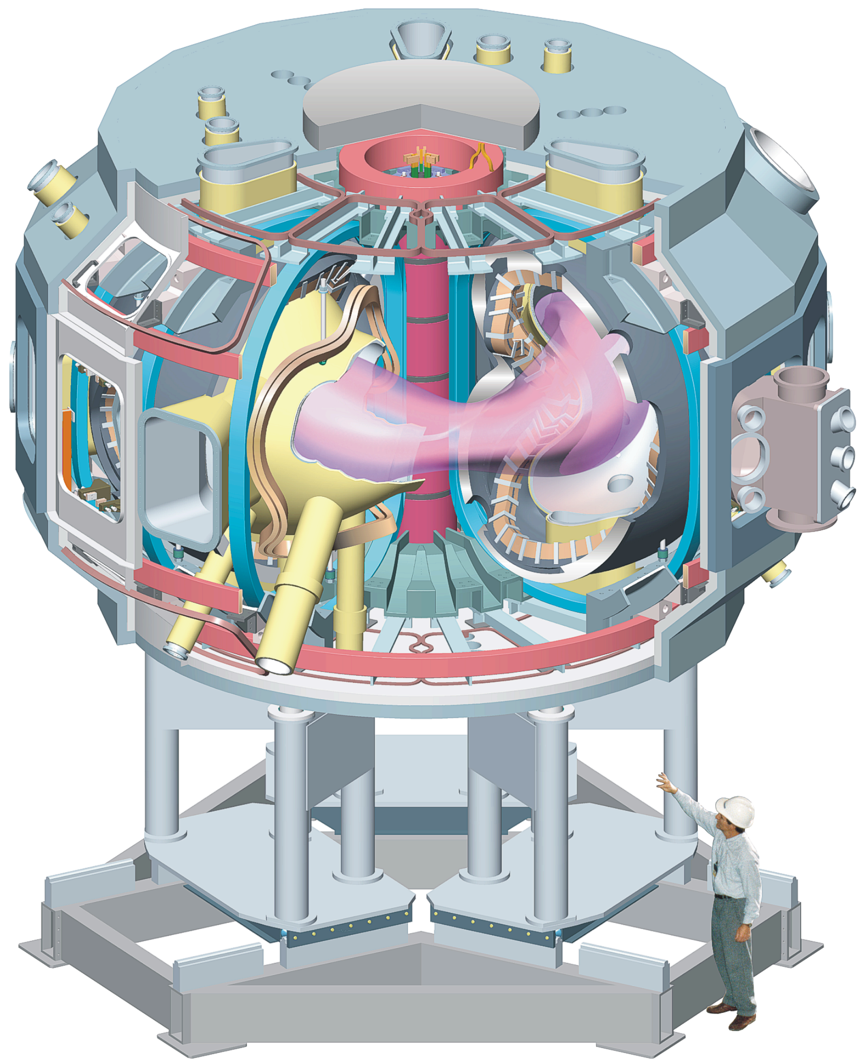
Vacuum base pressure (p):
$8 \times 10^{-8}$ torr

Flexible

Good Access

**Design aims 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

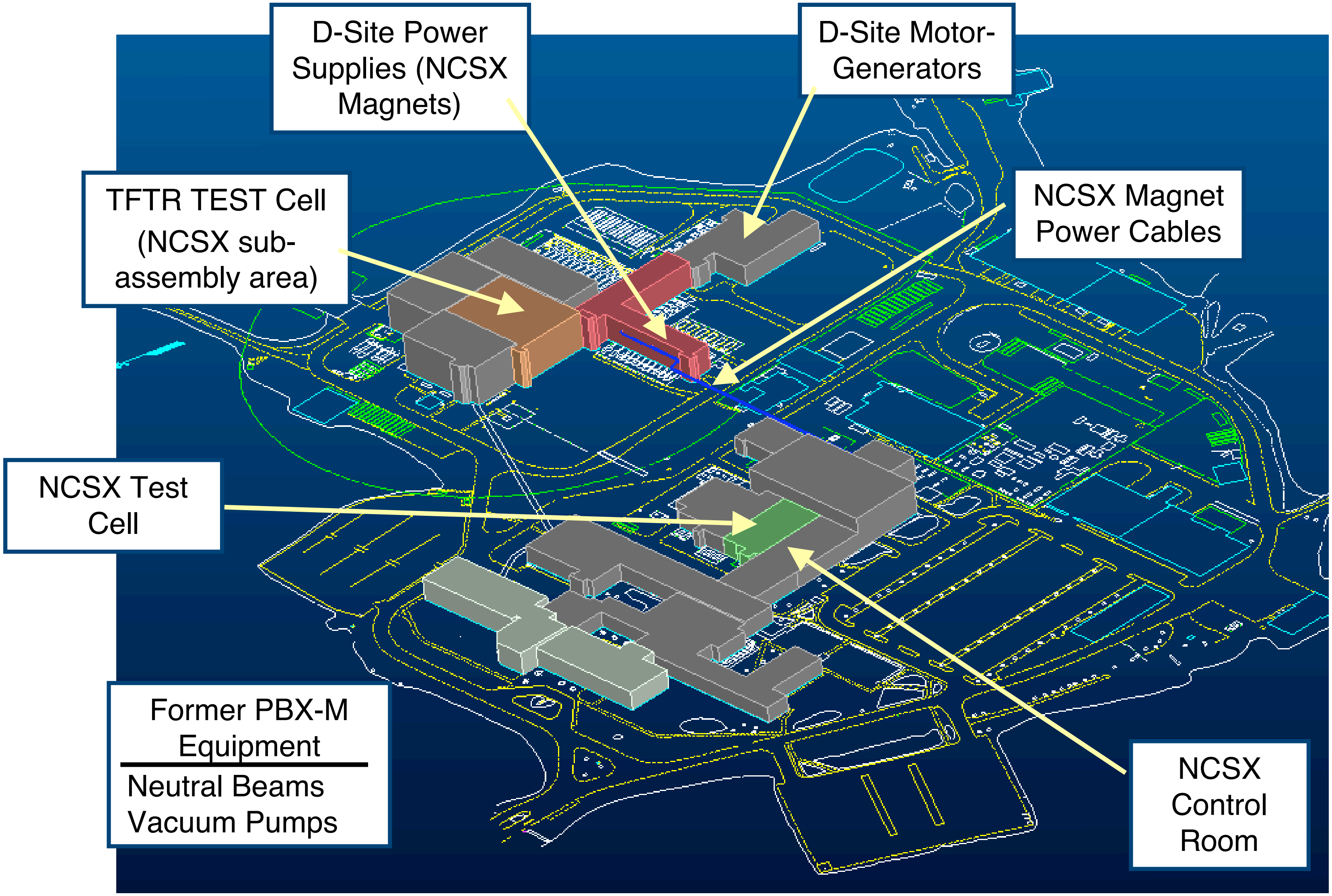
## WBS 1. Stellarator Core Systems

- Vacuum Vessel.
- Modular & 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.

# 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 Defined.

**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. *(new scope)*

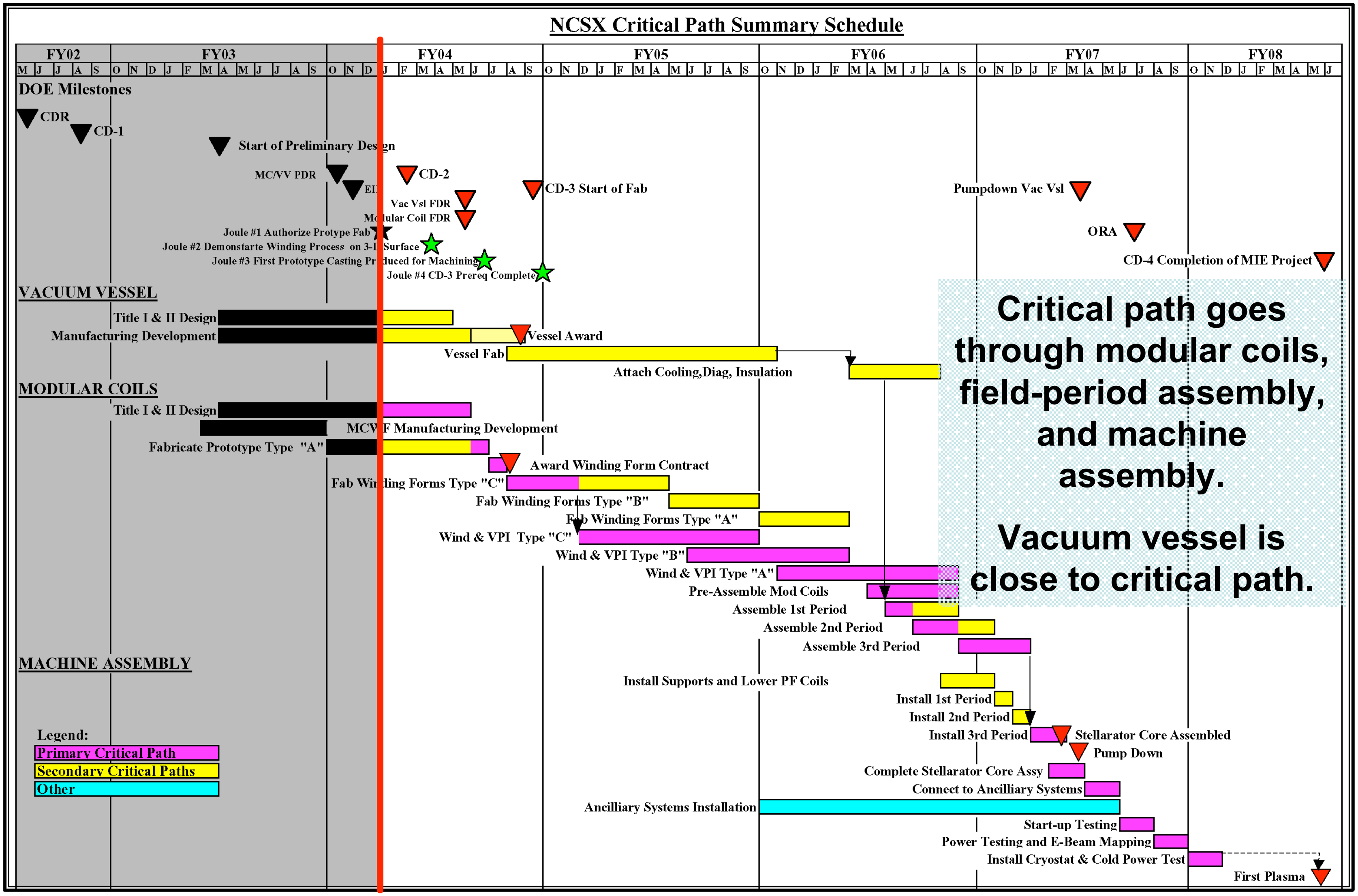
**Vacuum, Pumping, and Bakeout**
- Base pressure $\leq 4 \times 10^{-7}$ torr achieved.

**Controls**
- Interlocks, timing, power supply control, data aq. tested.

**Neutral Beams**
- Base vacuum achieved, cryopanels & source leak-checked.

# The Work Is Scheduled

## (Summary of resource-loaded master schedule)




***First Plasma: May, 2008. Schedule contingency: 5.5 months.***

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# Baseline Milestones Are Defined

## Selected Level I and II Milestones

| Accomplishment | Milestone |
|---|---|
| Project Start (Title I) | Apr, 2003(A) |
| Award MCWF/VV Prototype contracts | Apr, 2003(A) |
| Authorize Prototype Fab. | Dec, 2003(A) |
| **CD-2** | **Feb, 2004** |
| Initiate Winding Process on 3D Surface | Mar, 2004 |
| MCWF Prototype Casting Ready for Machining | Jun, 2004 |
| Modular Coil Winding Form FDR | Jul, 2004 |
| Vacuum Vessel FDR | Jul, 2004 |
| Award Conductor Contract | Sep, 2004 |
| CD-3 prerequisites satisfied | Sep, 2004 |
| **CD-3** | **Oct, 2004** |
| Award MCWF Contract | Nov, 2004 |
| Award VV Contract | Dec, 2004 |
| First MCWF Delivered | Mar, 2005 |
| Award TF Contract | Apr, 2005 |
| First Modular Coil Fabrication Completed | Aug, 2005 |
| Award PF Contract | Jun, 2006 |
| Last MCWF Delivered | Aug, 2006 |
| Begin Assembly of First Field Period | Sep, 2006 |
| Last Field Period Assembled | Jun, 2007 |
| Pump Down of Vacuum Vessel | Sep, 2007 |
| Operational Readiness Assessment | Nov, 2007 |
| Begin Cryostat Installation | Mar, 2008 |
| **CD-4 (First Plasma)** | **May, 2008** |

**There is float between "early completion" schedule and most milestones.**

# Cost 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.
- Budgetary estimates from industry, based on detailed manufacturing plans, support the estimates 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 Have Confidence in the Estimate

**Estimates were developed over several years and updated for all major reviews since 2001.**

- Have received substantial effort, de-bugging, and scrutiny.

**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.
- Manufacturer input builds additional confidence.

**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 projects' experiences have improved understanding of risks and mitigation costs.

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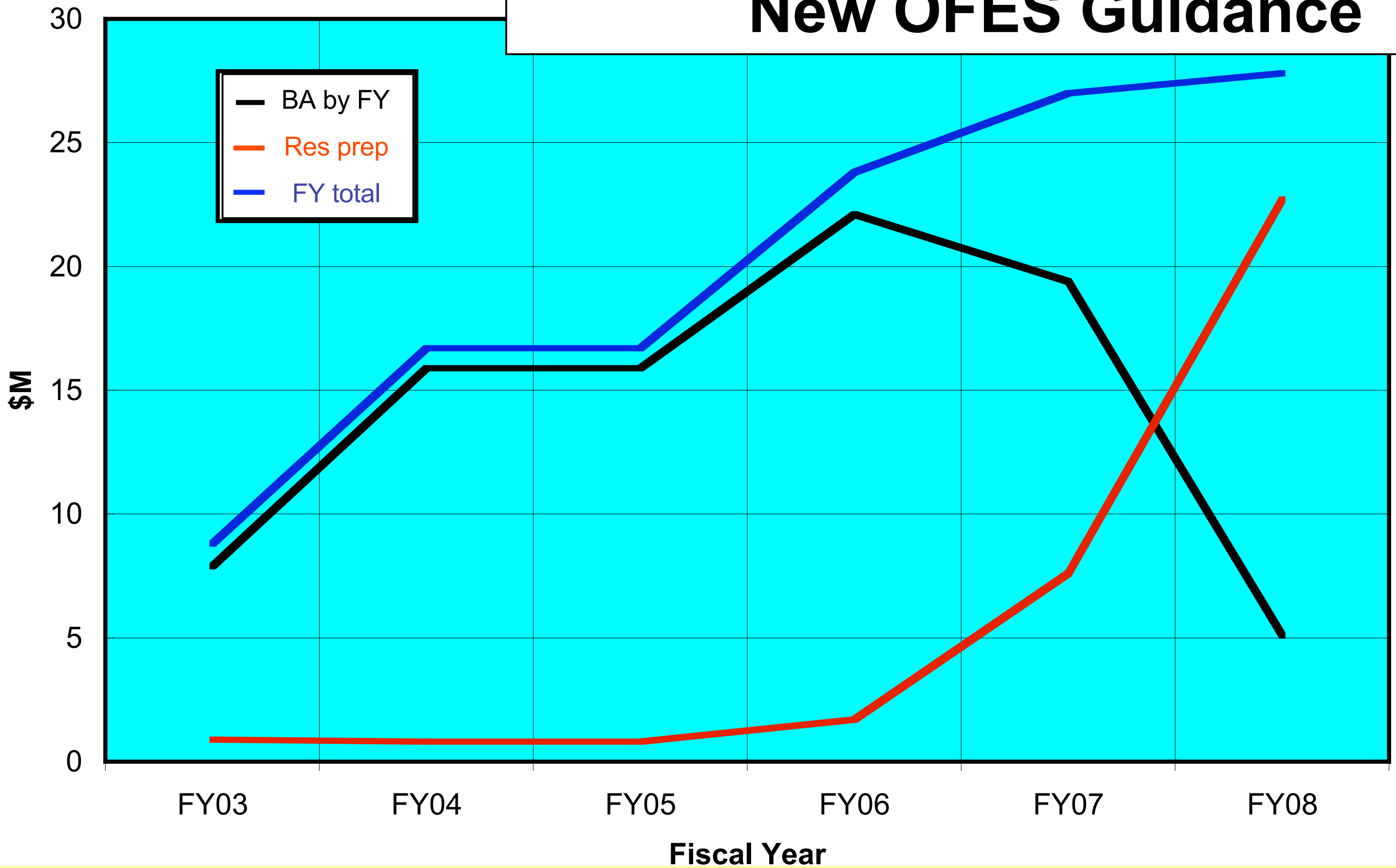
# Estimated Cost is $86.3M w/ 26% Contingency

| WBS | Description | Budget ($M) |
|---|---|---|
| 1 | **Stellarator Core Systems** | **42.3** |
| | 11 - In-Vessel Components | 0.1 |
| | 12 - Vacuum Vessel | 6.0 |
| | 13 - Conventional Coils | 4.2 |
| | 14 - Modular Coils | 20.4 |
| | 15 - Structures | 1.5 |
| | 16 - Coil Services | 1.0 |
| | 17 - Cryostat and Base Support Structure | 1.3 |
| | 18 - Field Period Assembly | 5.1 |
| | 19 - Stellarator Core Management and Integration | 2.7 |
| 2 | **Heating, Fueling, and Vacuum Systems** | **1.6** |
| 3 | **Diagnostic Systems** | **1.7** |
| 4 | **Power Systems** | **5.3** |
| 5 | **Central I&C / Data Acquisition Systems** | **2.6** |
| 6 | **Facility Systems** | **2.0** |
| 7 | **Test Cell Prep & Machine Assembly** | **4.3** |
| 8 | **Project Management & Integration** | **10.6** |
| | **Subtotal** | **70.4** |
| | **Contingency (26% of work to go from 1/1/04)** | **15.9** |
| | **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.

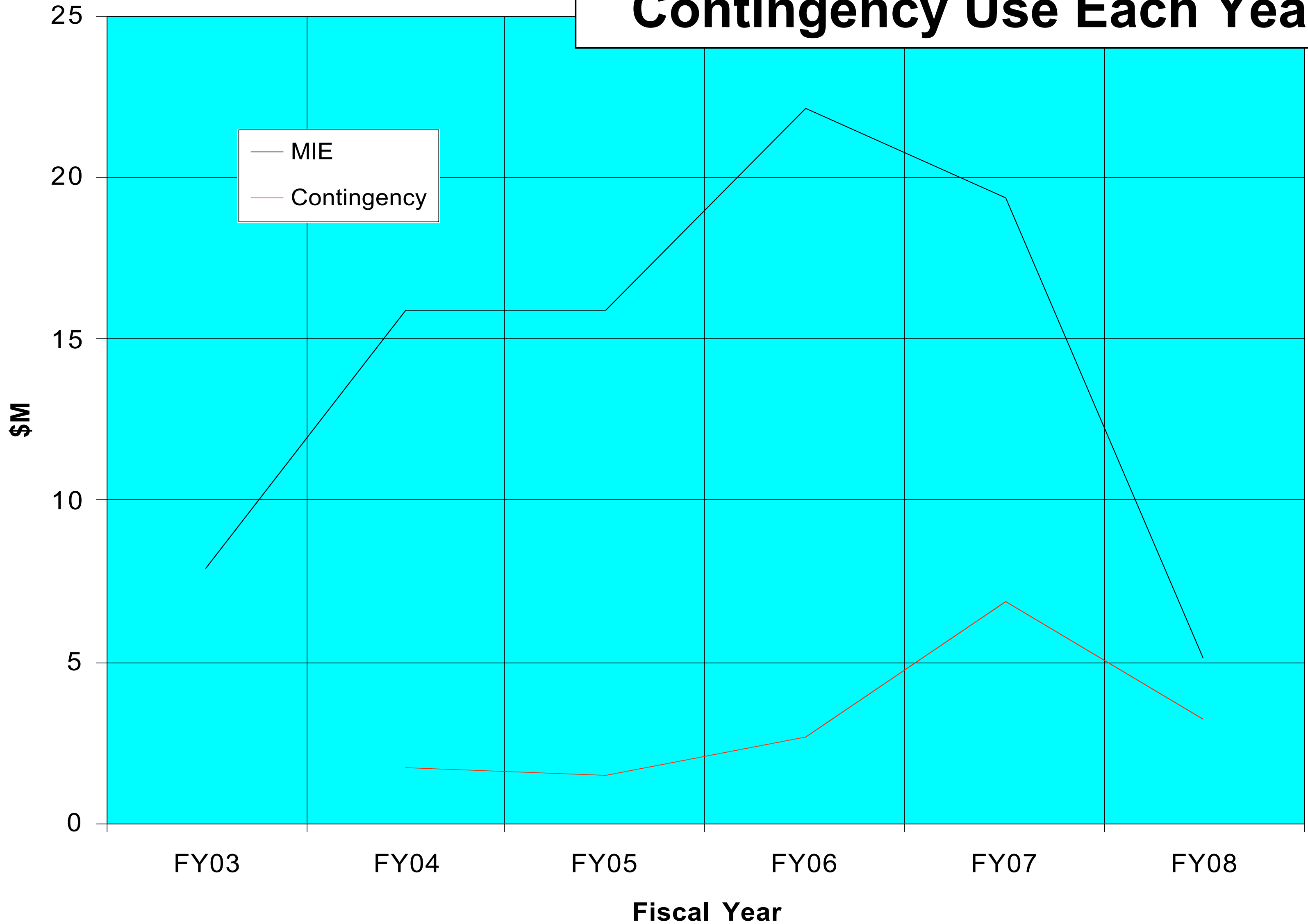
# Program Funding Profiles Match New OFES Guidance




| 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 | |

- Research preparation priorities: diagnostics, plasma-facing components.

# Plan Assumes Some Contingency Use Each Year




- FY-05 Contingency was kept at $1.5M, despite $4.5M BA reduction.

# All CD-2 Scope Items Have Been Addressed

- ✓ Integrated Project Team.
- ✓ Work Breakdown Structure.
- ✓ Resource Loaded Schedule.
- ✓ Total Estimated Cost and Project Schedule.
- ✓ Acquisition Strategy.
- ✓ Risk Management Plan.
- ✓ Preliminary Design and Design Review.
- ✓ External Independent Review and Performance Baseline Review.
- ✓ System Functions and Requirements.
- ✓ NEPA Documentation and Hazards Analysis.
- ✓ Integrated Safety Management.
- ✓ Value Management / Engineering.
- ✓ Project Controls, Earned Value Management System, PARS reporting.
- ✓ Project Execution Plan (ready for signature).
- ✓ Start-up Test Plan.

**Documentation for all items is posted on project web site.**
**http://ncsx.pppl.gov//Meetings/PDR/CD2.html**

# NCSX Is Ready to Be Baselined

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

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

**Estimates have a sound basis.**

- Mature designs, manufacturer input, R&D, legacy equipment tests.
- Identified risks, documented mitigation plans, adequate contingencies.

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

- Estimates have been carefully developed and reviewed.
- Updated to accommodate review recommendations and funding guidance.

**All CD-2 scope items have been addressed.**

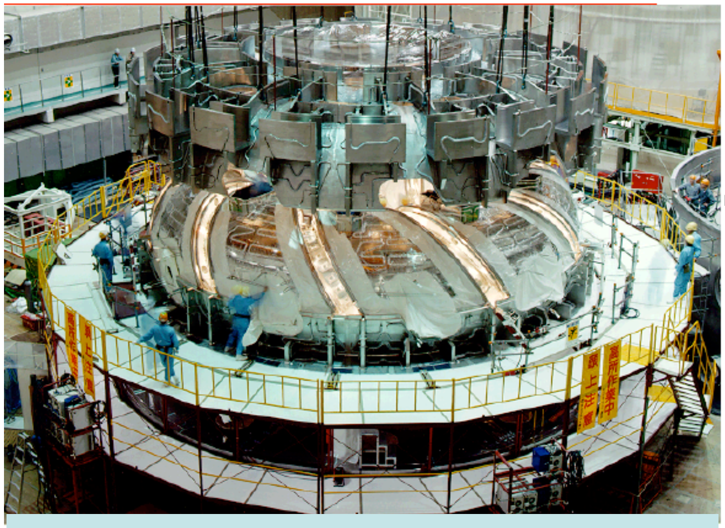
- Project documentation is complete.

**PDR, EIR, & Lehman panels unanimously agreed that "…the NCSX project is ready to proceed to CD-2".**

*The NCSX Team requests your approval of Critical Decision 2*

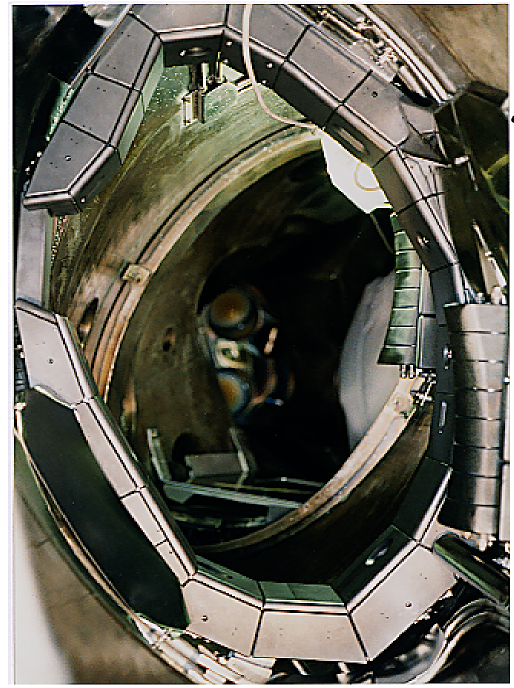
# Extra Slides

# Stellarators Are Making Excellent Progress



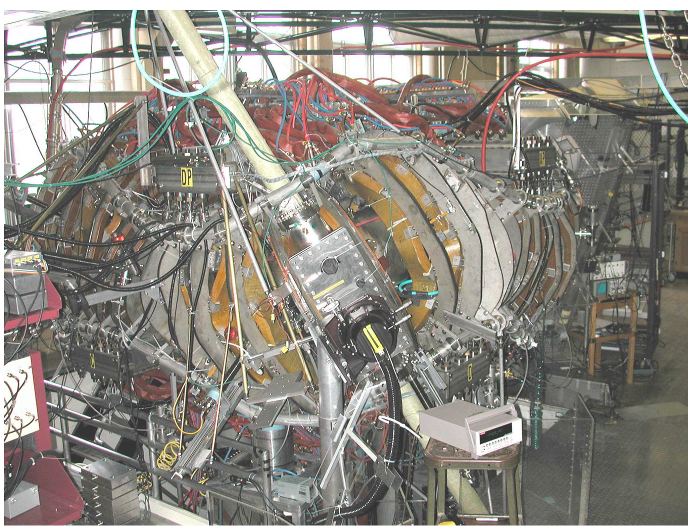
**Large Helical Device (S/C magnets - Japan)**

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



**Wendelstein 7-AS (Germany)**

- high beta
- enhanced confinement
- divertors



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

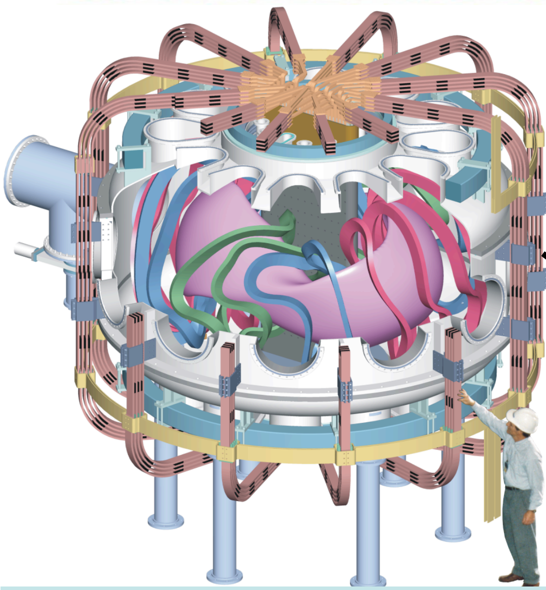
- Successful test of quasi-symmetry

**Wendelstein 7-X (Germany)**

**Optimized Design - S/C magnets**

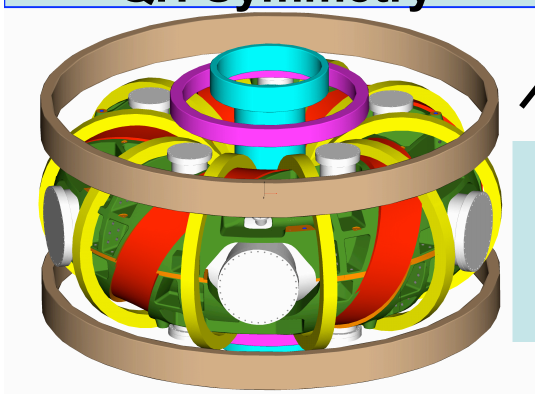
**Under construction - Ops. In 2010**

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



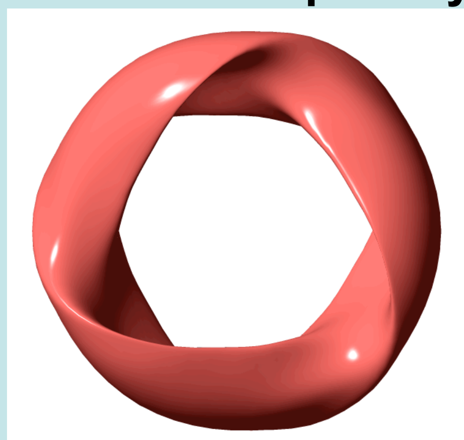
**QPS (ORNL) - CDR 2003**
QP symmetry, $R/\langle a \rangle < 3$.

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

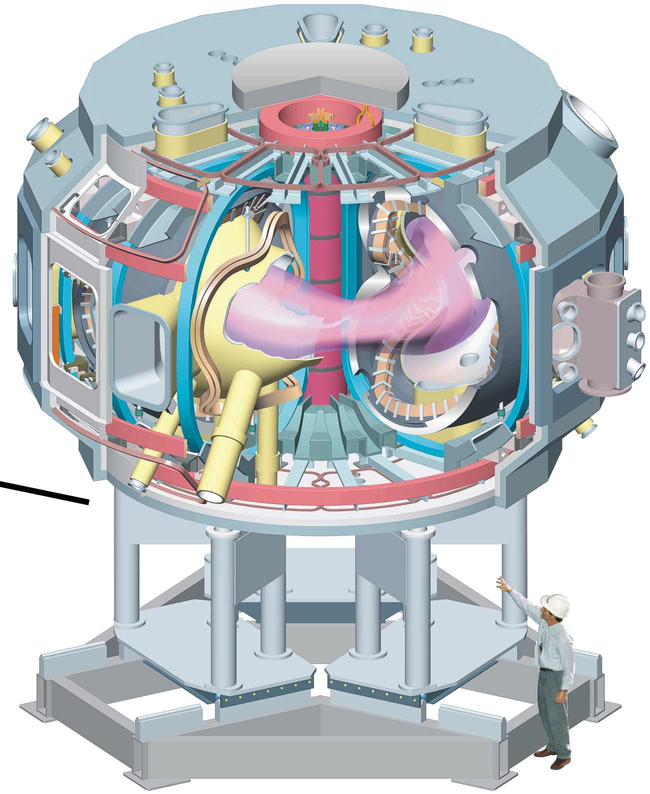


**CTH (Auburn U.)**
Stability Physics
Ops. in 2004

**Theory & Computation**
Computational Tools
Predictive Capability



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



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