PROJECT CLOSEOUT REPORT
NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX)

March 2009

Prepared for the U.S. Department of Energy
Office of Science

Princeton Plasma Physics Laboratory
Oak Ridge National Laboratory

PROJECT CLOSEOUT REPORT
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May 2009

Submitted by …… Title Princeton Plasma Physics Laboratory	Date
Approved by Jeffrey Makiel DOE Federal Project Director for the National Compact Stellarator Experiment	Date

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ACRONYMS

ACC	activity certification committee
BCP	baseline change proposal
CAD	Computer-Aided Design
CCD	charged-coupled device
CD	DOE Critical Decision
CDR	Conceptual Design Report
CERN	European Organization for Nuclear Research, Geneva
DOE	U.S. Department of Energy
ECN	engineering change notices
ECR	engineering change proposal
ESAAB	DOE Energy Systems Acquisition Advisory Board
ES&H	environment, safety, and health
ES&H/EB	PPPL ES&H Executive Board
EPICS	experimental physics and industrial control system
FESAC	DOE Fusion Energy Science Advisory Committee
FDR	Final Design Report
GPP	general plant project
GRD	general requirements document
I&C	instruments and controls
ISM	integrated safety management
ITER	International Thermonuclear Experimental Reactor
LHC	Large Hadron Collider
LN2	Liquid Nitrogen
MCWF	modular coil winding form
MIE	major item of equipment
MHD	magnetohydrodynamic
NCR	nonconformance report
NCSX	National Compact Stellarator Experiment
NEPA	National Environmental Policy Act
NSTX	PPPL National Spherical Torus Experiment
OECM	DOE Office of Engineering & Construction Management
OFES	DOE Office of Fusion Energy Research
ORNL	Oak Ridge National Laboratory
PDR	Preliminary Design Report

PEP	project execution plan
PF	poloidal field
PPPL	Princeton Plasma Physics Laboratory
PU	Princeton University
QA	quality assurance
QC	quality control
RFD	requests for deviations
RLM	responsible line manager
SC	DOE Office of Science
SRD	systems requirements document
TEC	total estimated cost
TF	toroidal field
TPC	total project cost
W7-X	Wendelstein 7X Stellarator, Max Planck Inst., Greifswald
WAF	work authorization form
WBS	work breakdown structure
VVSA	vacuum vessel sub-assemblies

EXECUTIVE SUMMARY

1. INTRODUCTION

The compact stellarator is one of several innovative magnetic fusion plasma configurations being investigated by the U.S. Department of Energy (DOE) Office of Science (SC), Office of Fusion Energy Sciences (OFES). The promise of the compact stellarator as a practical fusion concept lies in its potential to eliminate disruptions and operate steady-state with minimal recirculating power. Due to its geometry, a compact stellarator can generate significant rotational transform by currents in external magnet coils and can stabilize limiting magnetohydrodynamic (MHD) instabilities by plasma shaping instead of relying on active feedback control. Compact stellarators have aspect ratios much lower than previously optimized stellarator designs. Though three-dimensional in their physical geometry, they can be designed with an approximate symmetry direction in the magnetic field, which gives them important physics similarities with tokamaks and allows them to make use of tokamak scientific and technical advances, *e.g.,* burning plasma research and development on the International Thermonuclear Experimental Reactor (ITER). When extrapolated to a fusion power plant, the compact stellarator is projected to require low operating power compared with that produced by the power plant. In order to evaluate these benefits as well as the cost associated with three-dimensional geometry, a national compact stellarator program consisting of theory, experiment, international collaboration, and design was established. The National Compact Stellarator Experiment (NCSX), an experimental research facility under construction at the DOE Princeton Plasma Physics Laboratory (PPPL), was to have been a centerpiece of the U.S. stellarator program.

2. PROJECT PURPOSE & SCOPE

The mission of the NCSX was to acquire the physics knowledge needed to evaluate compact stellarators as a fusion concept, and to advance the understanding of three-dimensional plasma physics for fusion and basic science. Specific objectives were to:

- Demonstrate conditions for high-beta disruption-free operation, compatible with bootstrap current and external transform in a compact stellarator configuration.
- Understand beta limits and limiting mechanisms in a low-aspect-ratio current-carrying stellarator.
- Understand reduction of neoclassical transport by quasi-axisymmetric design.
- Understand confinement scaling and reduction of anomalous transport by flow-shear control.
- Understand equilibrium islands and stabilization of neoclassical tearing-

modes by choice of magnetic shear.

- Understand compatibility between power and particle exhaust methods and good core performance in a compact stellarator.

The key technical objective involved the design, fabrication, installation, and integrated system tests of the NCSX experimental facility, consisting of a highly-shaped vacuum vessel; surrounding magnet coil systems; enclosing cryostat and various auxiliary power; cooling, vacuum, cryogenic, and control systems; as well as a set of startup diagnostics. Figure 1 shows a cutaway view of the stellarator core assembly.

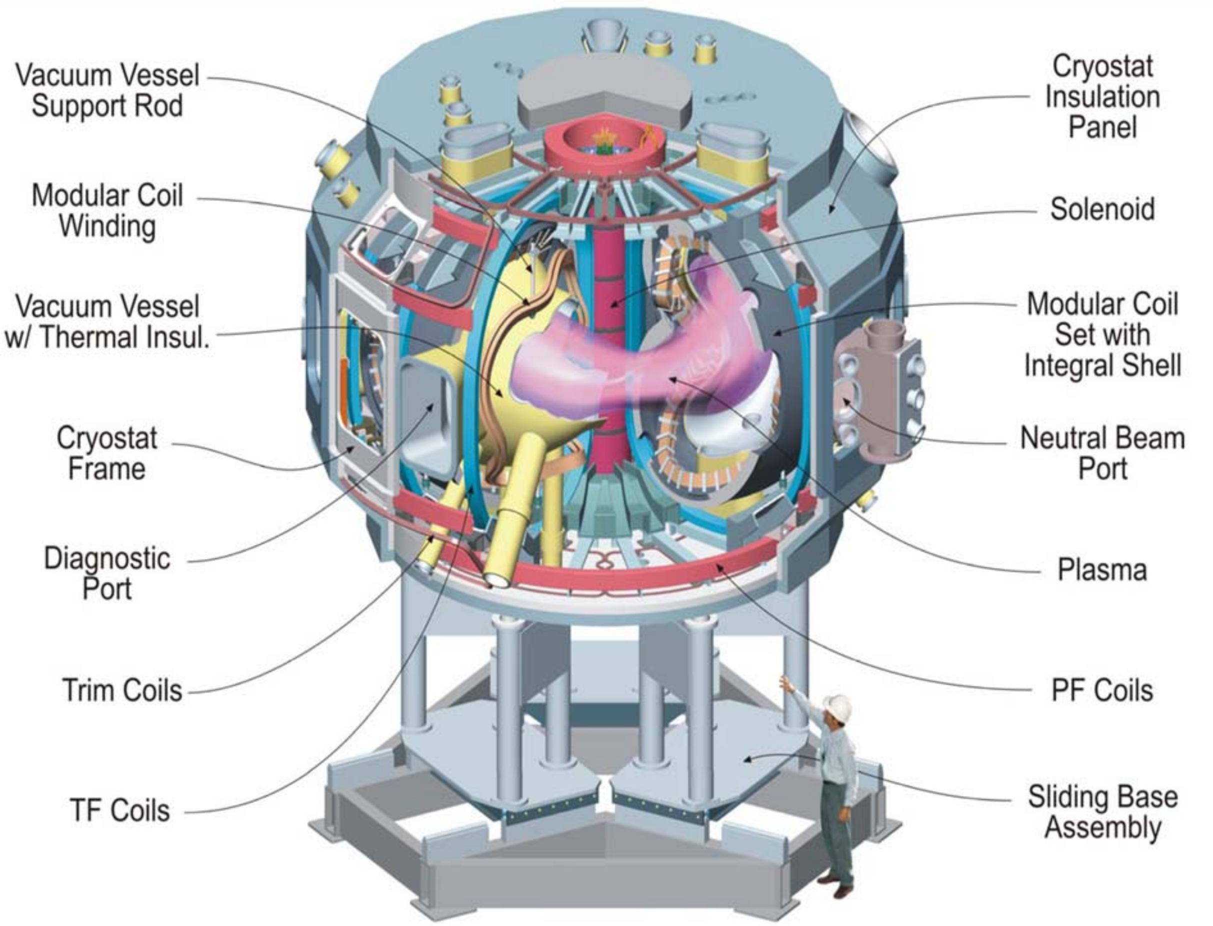


Figure 1: NCSX Stellarator core assembly

Because the project involved the fabrication of new equipment and considerable re-use of existing facilities and hardware systems and minimal civil construction, DOE designated the project as a Major Item of Equipment (MIE). The project was led by the PPPL with the Oak Ridge National Laboratory (ORNL) providing major leadership and support as a partner. PPPL had overall responsibility for the project. The plasmas to be studied were three-dimensional toroids, that is, doughnut-shaped plasmas whose cross sectional shape varies depending on where it is sliced (Figure 2). The magnetic field coils, which control the plasma shape, must be accurately constructed to precise shape specifications.

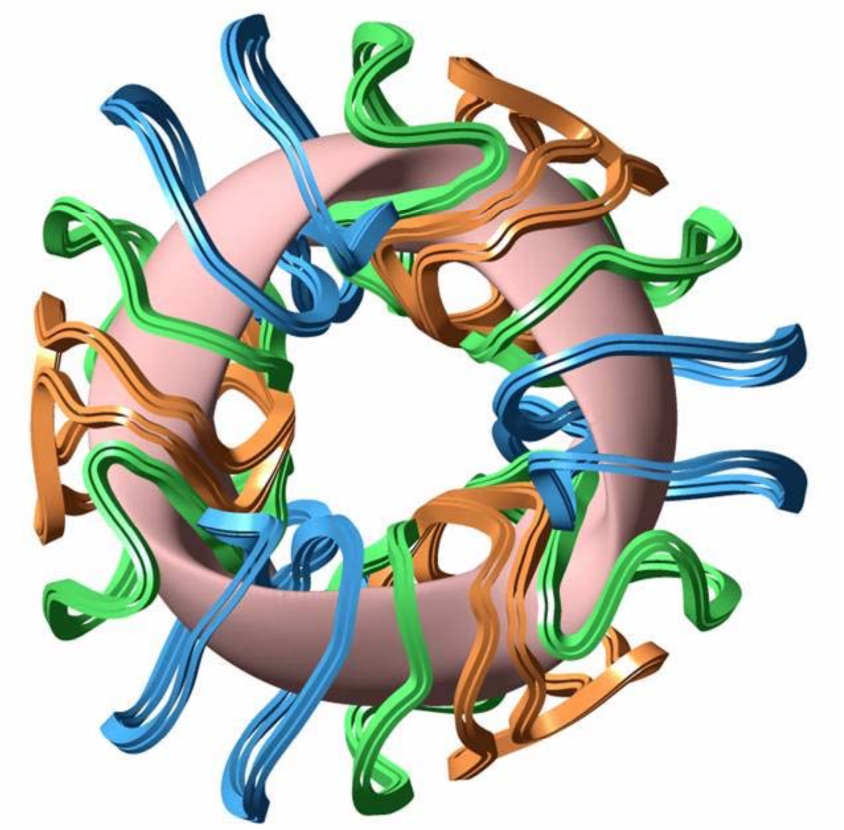


Figure 2: Illustration of the NCSX quasi-axisymmetric plasma confined with the 18 modular coils.

3. PROJECT HISTORY

In 2001, a panel of plasma physicists and engineers conducted a Physics Validation Review of the NCSX design. The panel concluded that the physics approach to the NCSX design was appropriate and that the concept was ready for the next stage of development, namely proof-of-principle. The DOE Fusion Energy Sciences Advisory Committee endorsed the panel view. NCSX Critical Decision (CD) 0, Approve Mission Need, was approved in May 2001. A May 2002 DOE Conceptual Design Review panel found that the NCSX design concept and project plans provided a sound basis for engineering development. Approval of CD-1, Approve Alternative Selection and Cost Range, was obtained in November 2002. All equipment plus a control room were to be located in existing buildings at PPPL that were previously used for other fusion experiments. Further, many of the NCSX auxiliary systems would have been made available to the project from equipment used on the previous experiments. The initial cost range of NCSX, based on the preconceptual design, was between $69-83 million. The Total Estimated Cost (TEC) of the device based on the conceptual design was $73.5 million with a completion date in June 2007. Due to the continuing resolution at the beginning of FY 2003 that was not resolved until February 2003, the project activities were delayed until April 2003 instead of the planned October 2002 date. With this later start and additional design and cost information, the Project estimated the TEC of the device to be $81 million with a completion in September 2007. PPPL assembled an outside committee to perform a preliminary design review in October 2003. The preliminary design review committee concluded that the project was ready to proceed to CD-2, Approve Performance Baseline, and recommended design improvements which the project largely adopted. Approval of CD-2 was signed in February 2004 with a baseline TEC of $86.3 million and a completion date in May 2008 after incorporating recommendations from the aforementioned reviews and an updated DOE funding profile. After various reviews, CD-3, Approve Start of Construction, was obtained in September 2004, with a TEC of $86.3 million and a completion date in May 2008. In 2005, the NCSX funding profile was modified by OFES in response to budgetary constraints. A new baseline was developed and approved by the DOE Deputy Secretary in July 2005. This new baseline established a TEC of $92.4 million and a July 2009 completion date.

By 2007 it became clear that the baseline cost and schedule objectives could not be met. In early 2008, following reviews of the project's scientific mission, engineering feasibility, and cost and schedule, the DOE directed the Project to prepare a baseline change proposal (BCP) a draft of which was submitted to SC in March 2008. That proposal, based upon a bottoms-up cost estimate with risk-based cost and schedule contingency analyses, recommended a performance baseline with a TEC of $160.6M and a completion date of August 2013. Following several internal and external reviews in 2007 and 2008, the DOE concluded that the budget increases, schedule delays and continuing uncertainties of the NCSX construction project necessitated its closure. DOE announced its decision to terminate the NCSX project in May 2008. The Project proposed a closeout plan in June 2008 that was accepted by the DOE in July 2008. Closure of the construction effort was managed to capture many benefits of the project, *e.g.*, completion of the modular and toroidal field coils, safekeeping of materiel, and thorough documentation of designs, R&D achievements, retired and residual risks, and lesson learned, to allow revisiting this particular design if future developments in the fusion program warrant it. A chronology of key Project events is listed in appendix A. Baseline performance objectives are listed in Appendix B.

4. PROJECT DESCRIPTION & STATUS AT CLOSEOUT

4.1 Stellarator Core

Vacuum Vessel System (WBS 12)

The vacuum vessel was to have provided the vacuum boundary around the plasma suitable for high vacuum conditions; structural support for all internal hardware and access for auxiliary systems such as neutral beam injection and plasma diagnostics. The vacuum vessel was highly shaped, three-period inconnel structure which approximately conforms to the plasma (Figures 3-5). Work included engineering design, R&D in support of design and fabrication, component procurement, and fabrication. [add learning curve data for VVSA fab?] Project scope and construction status at the end of the project are listed in Table 1.

Figure 3: NCSX vacuum vessel design.

Figure 4: One of three NCSX vacuum vessel sectors fabricated by industry and delivered to PPPL.

Figure 5: Vacuum vessel sub-assembly with cooling hoses and diagnostic instrumentation installed.

Table 1: Vacuum Vessel System Scope **[Larry/Paul/Mike V to finalize]**

MIE Project Scope	Status at Closeout
Three vacuum vessel sub-assemblies, each consisting of a 120-degree shell sector, spacer, and associated ports	**Complete**
Heating and cooling hoses, with attachment hardware	**Complete**
Heating and cooling manifolds	**Complete**
Cryostat interface flanges	**Complete**
Heater tapes	**Complete**
Supports	**Design 100?% complete** **50?% of parts delivered** **Not installed**
Thermocouples and other instrumentation	**Complete?**
Thermal insulation	**Title-I & II design complete** **xx?% of materials delivered** **Some further design changes likely needed**

Conventional Coils (WBS 13)

The conventional coil systems scope included the fabrication of eighteen toroidal field (TF) coils (Figure 6), six poloidal field (PF) coils (Figure 7), forty-eight trim coils (Figure 8) for control of low-order helical field harmonics, local instrumentation, and certain support structures. The TF coils are identical, and were to be installed equally spaced, providing flexibility in the magnetic configuration. TF coils were wound from copper conductor, assembled to steel support wedges, and vacuum impregnated with epoxy. They were designed to operate at the liquid nitrogen (LN2) cryogenic temperatures. The PF magnets produce the poloidal magnetic field within the NCSX device. These coils were to provide inductive current drive and plasma shape and position control. The coils were to be wound from copper conductor and vacuum impregnated with epoxy, and also designed to operate at the LN2 temperatures. Existing PF solenoids from the National Spherical Torus Experiment (NSTX) were to be utilized as the initial central solenoid for NCSX. Project scope and construction status at the end of the project are listed in Table 2.

Figure 6: One of the 18 NCSX toroidal field coils fabricated by industry and delivered to PPPL.

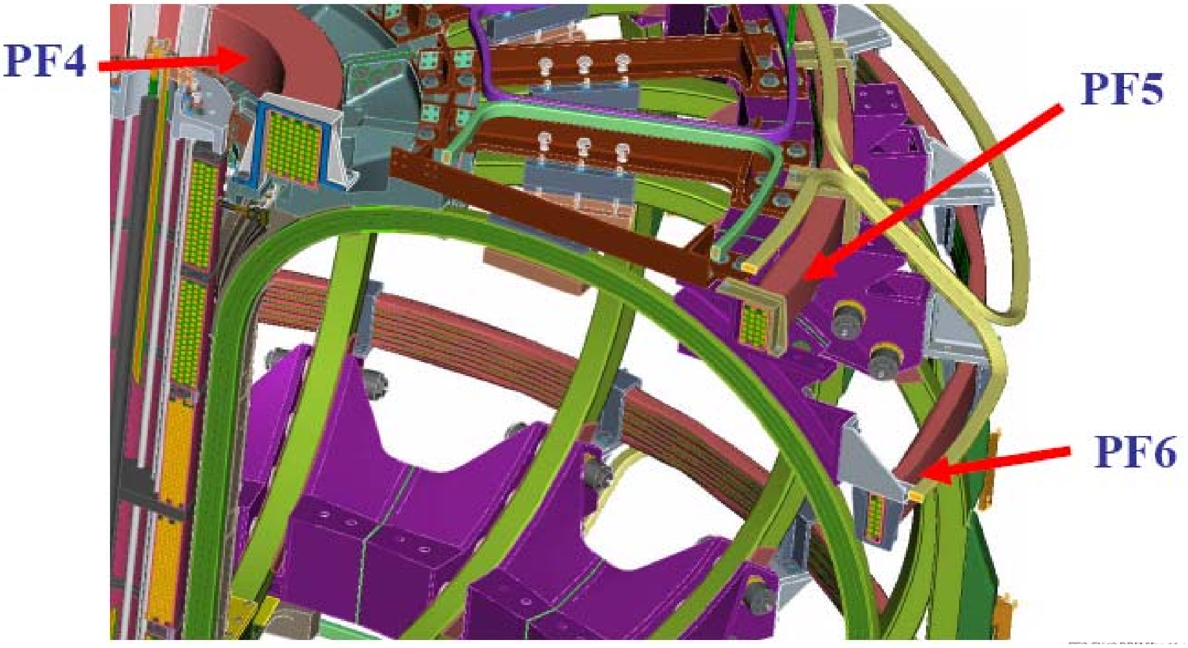


Figure 7: Poloidal field coils design

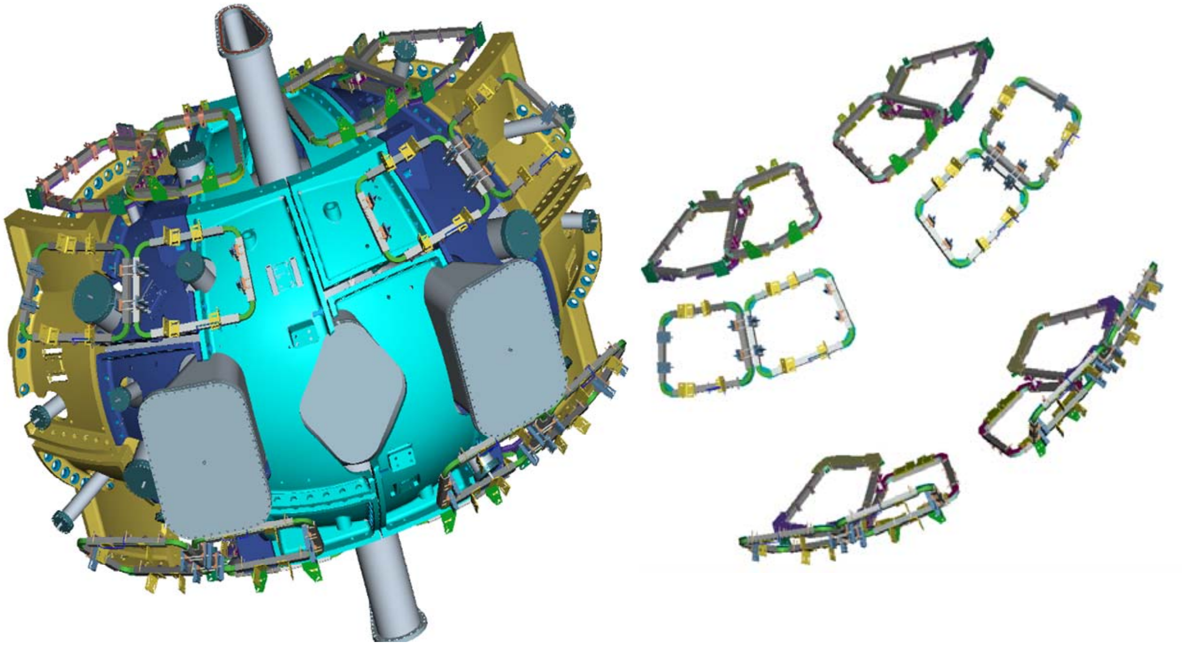


Figure 8: Trim coils design

Table 2: Conventional Coils Scope

MIE Project Scope	Status at Closeout
Design and fabrication of eighteen TF coil assemblies consisting of D-shaped coils assembled to wedge support pieces	**Complete.**
Design and fabrication of three pairs of PF ring coils. Central Solenoid will utilize existing PF-1a solenoid from NSTX	**Final design complete; fabrication contract award was pending at time of Project cancellation.**
Design and fabrication or procurement of trim coils required for MIE project.	**Final design complete.**
Fabrication and installation of local instrumentation for the conventional coils, e.g., thermocouples, strain gauges, RTDs, and voltage taps	**Not started.**
Fabrication and installation of the support structure for existing central solenoid coils, and procurement and installation of I&C for those coils	**Final design complete.**

Modular Coils (WBS 14)

The modular coils consisted of eighteen complex-shaped coils supported on the interior surface of a toroidal shell structure (Figures 9-12). The coils were fabricated on 2700 kg castings made from a specially developed CF8M alloy named Stellalloy. There were three types of coils differing primarily in their shapes. The coils were wound from flexible copper cable conductor which is installed on the inner diameter of a support structure called a modular coil winding form (MCWF), and vacuum impregnated with epoxy. In the finished assembly, the modular coils were arranged in three identical field periods, each containing six coils, two of each type. The coils were bolted together at mating flanges on the MCWF (which forms the shell when completed), using complex assembly hardware to provide structure support, insulation, and accurate coil positioning. Coils were designed to operate at LN2 cryogenic temperatures. Work included engineering design, R&D in support of design and fabrication, component procurement, tooling and fixtures, fabrication, and sub-assembly. During the winding and epoxy impregnation process refinements were continually made which reduced coil assembly time from 7000 man-hours down to approximately 1000 man-hours (Fig 13). Project scope and construction status at the end of the project are listed in Table 3. There were many challenges that were overcome during the coil winding process, one of the most significant was the metrology. In order to minimize islands in the toroidal flux to less than 10%, a tolerance in the positioning of the modular coil winding pack ± < 1.5 mm was required. Through careful assembly and after-winding shaping techniques the tolerance was achieved on almost all points on the winding path.

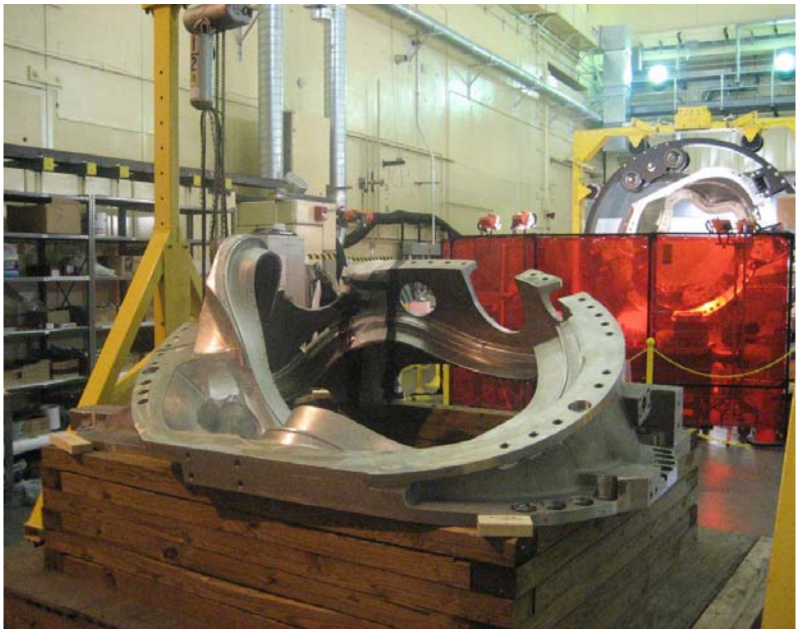


Figure 9: Modular coil winding form fabricated by industry and delivered to PPPL.

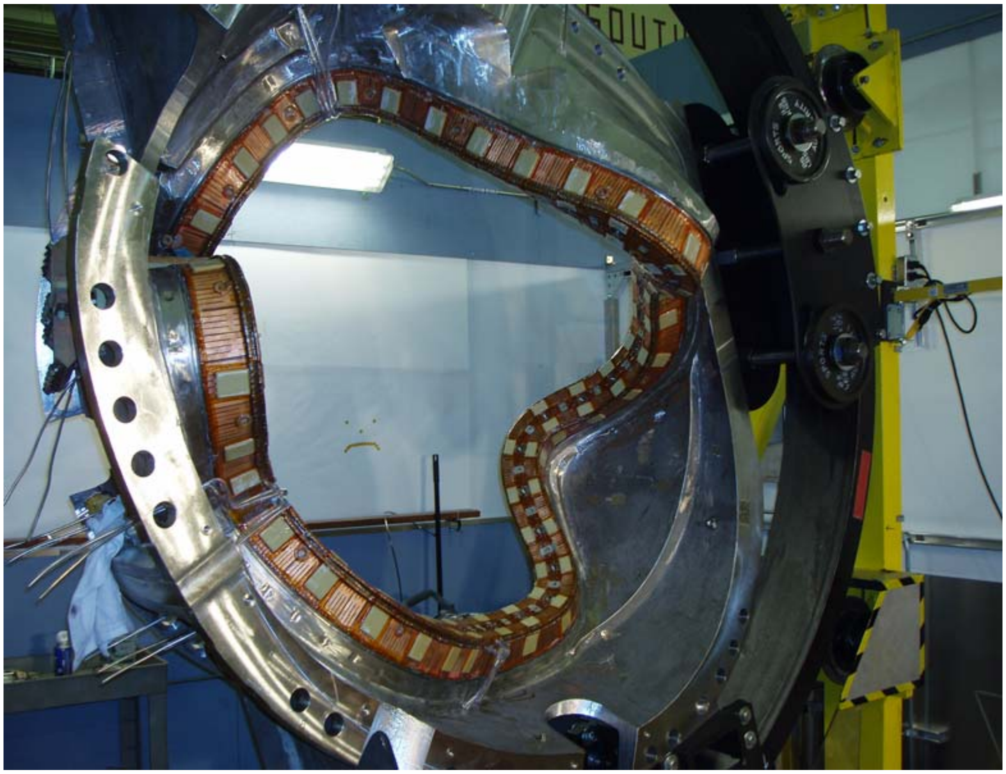


Figure 10: Modular coil winding stand

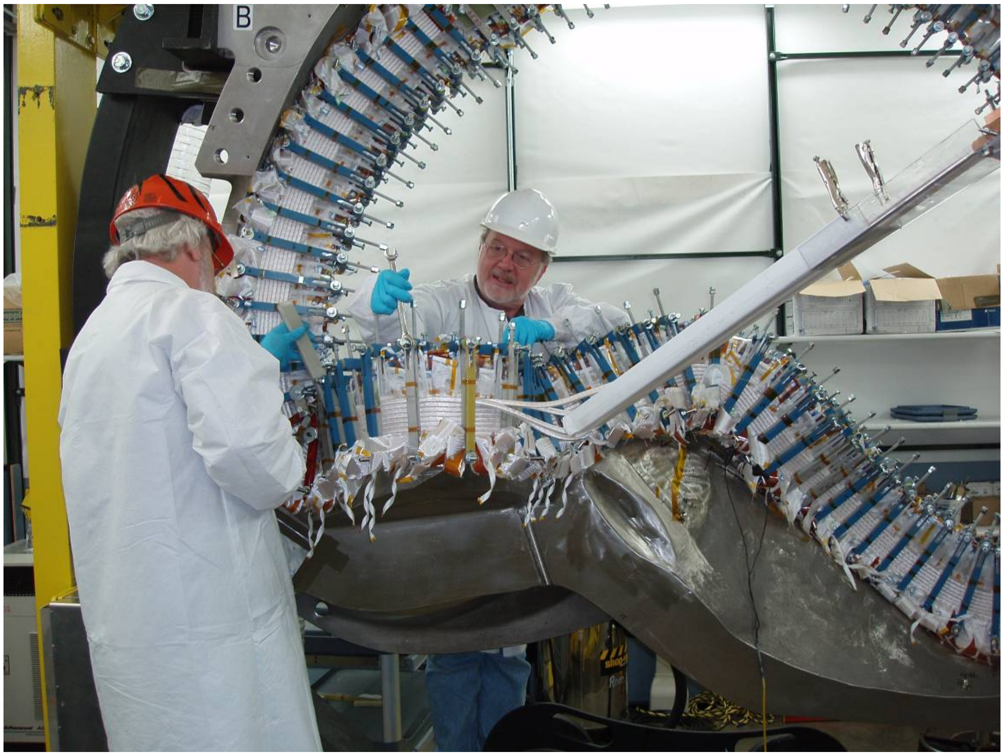


Figure 11: Modular coil winding operations at PPPL

Figure 12: Modular coil after vacuum impregnation at PPPL.

Table 3: Modular Coils Scope [Jim/Mike C/Larry/David W to finalize]

MIE Project Scope	Status at Closeout
Delivery of eighteen winding forms to modular coil fabrication operations	Completed
Delivery of eighteen instrumented coils and assembly hardware to assembly operations	Coils complete? Status instrumentation?
Delivery of drawings, specifications, and models to fabrication and assembly operations; and documentation of coil protection limits.	Document Status: xx% Complete
Delivery and installation (as appropriate) of tooling for the modular coil fabrication facility.	Complete
Delivery of modular coil interface parts to assembly operations	Document Status xx% Complete?

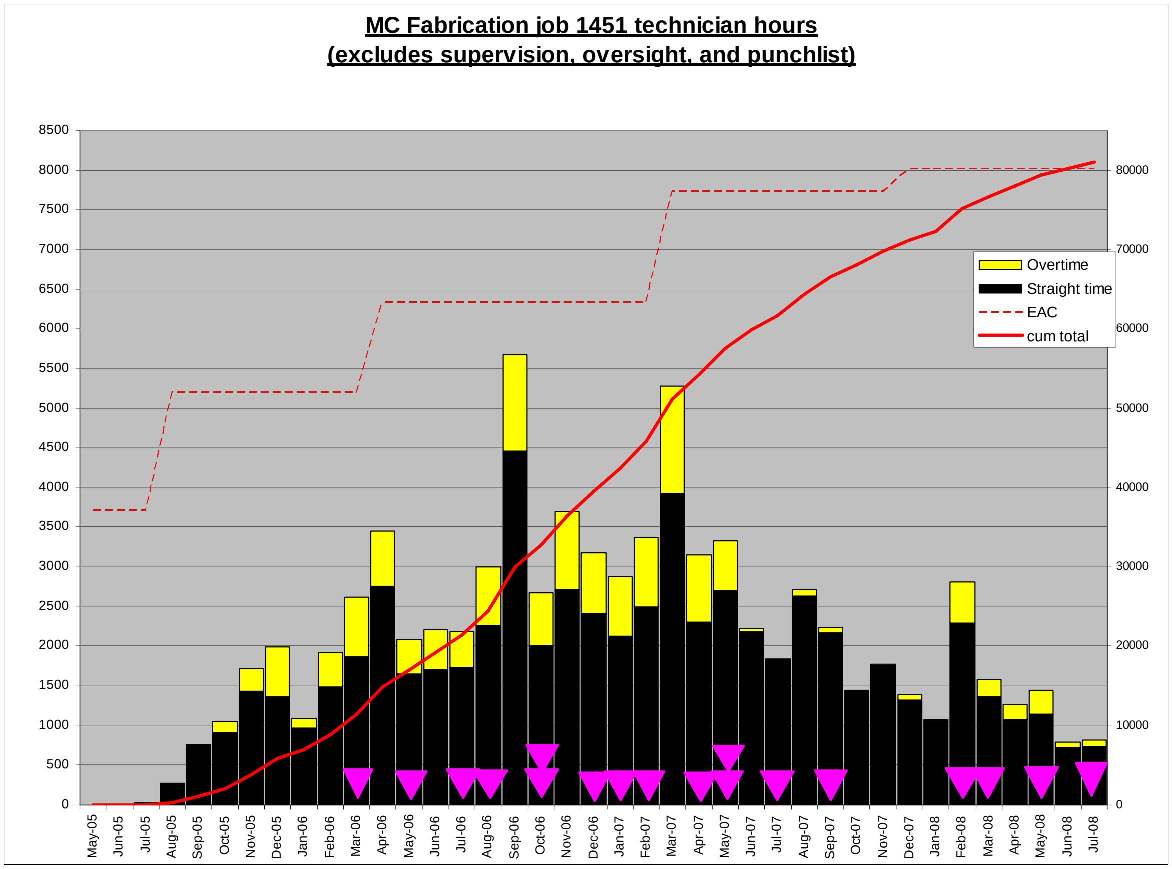


Figure 13: Curve for manufacture of modular coils [need better representation of these data & modified caption showing man-hours vs coil; also add other learning curves, e.g., MCWF, ED&I?]

Conventional Coil Structures (WBS 15)

The coil support structures were to have provided the mechanical supports connecting TF, PF ring coils (PF 4, 5, and 6) to the modular coil toroidal shell and the base support structure. Work included engineering design, procurement, and fabrication of structures and associated instruments and controls. The coil supports interfaced with the MCWF shell which provided the load path to react all coil electromagnetic and gravity loads. It also interfaced with mounting hardware for supporting coil buswork, cryogen lines & cryostat (Fig 14). Project scope and construction status at the end of the project are listed in Table 4.

Coil Services (WBS 16)

The coil services consisted of the LN2 distribution system (Fig 15) and electrical leads (Fig 16) inside the cryostat, serving all of the coils. It also included the specification of requirements for the coil protection system. Project scope and construction status at the end of the project are listed in Table 5.

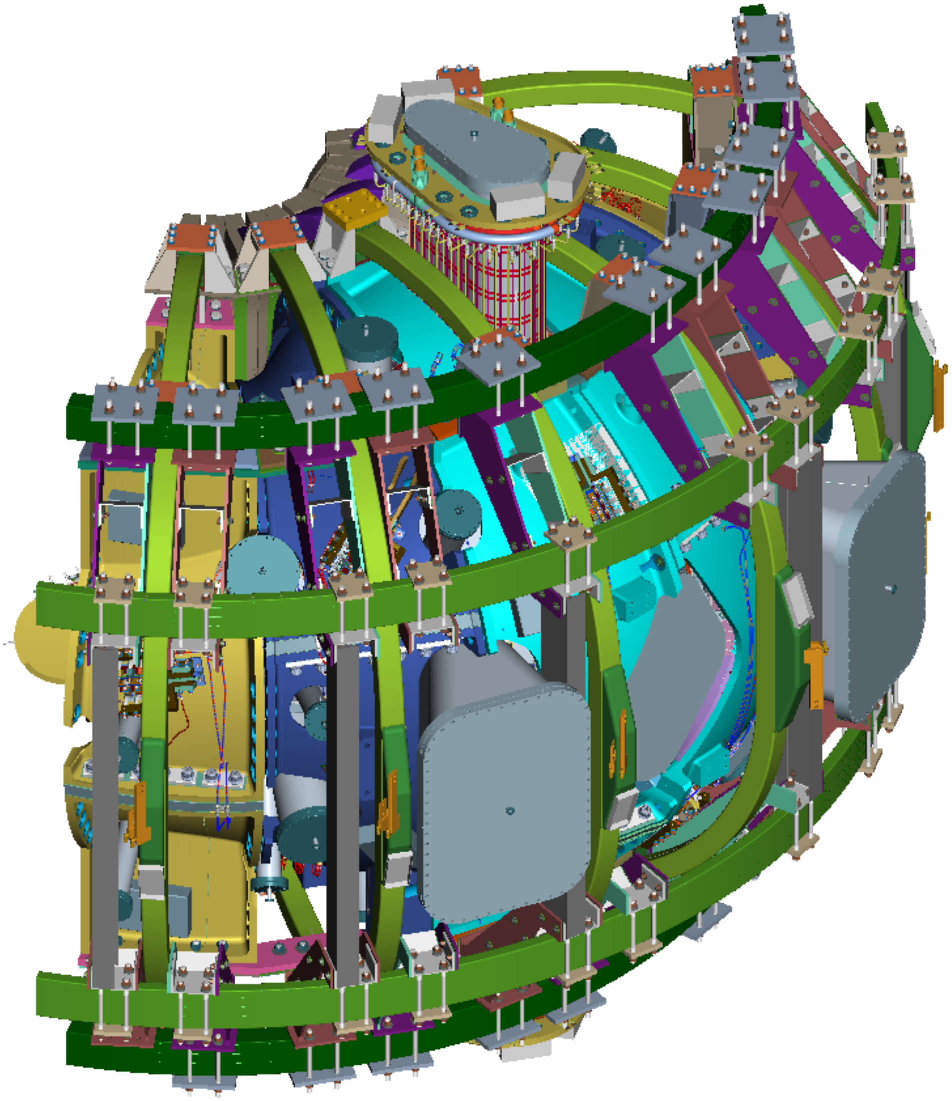


Figure 14: Conventional Coil Structures

Table 4: Conventional Coil Structures Scope

MIE Project Scope	Status at Closeout
Design, fabrication, and delivery of coil support structure components to machine assembly operations.	**Final design complete. Final design review judged successful pending resolution of open chits. 2 chits from the FDR and 4 remaining from PDR will be left open, pending re-start of NCSX since their resolution is dependent on work stopped due to NCSX closeout.**

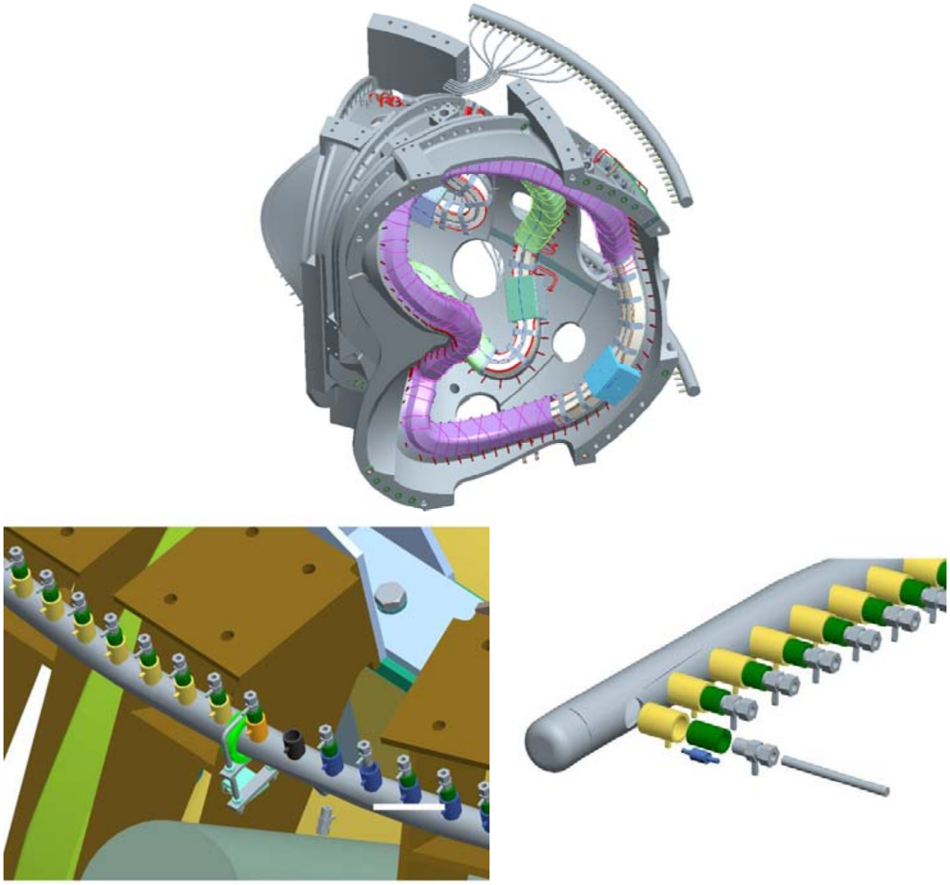


Figure 15: Schematics illustrating LN2 distribution

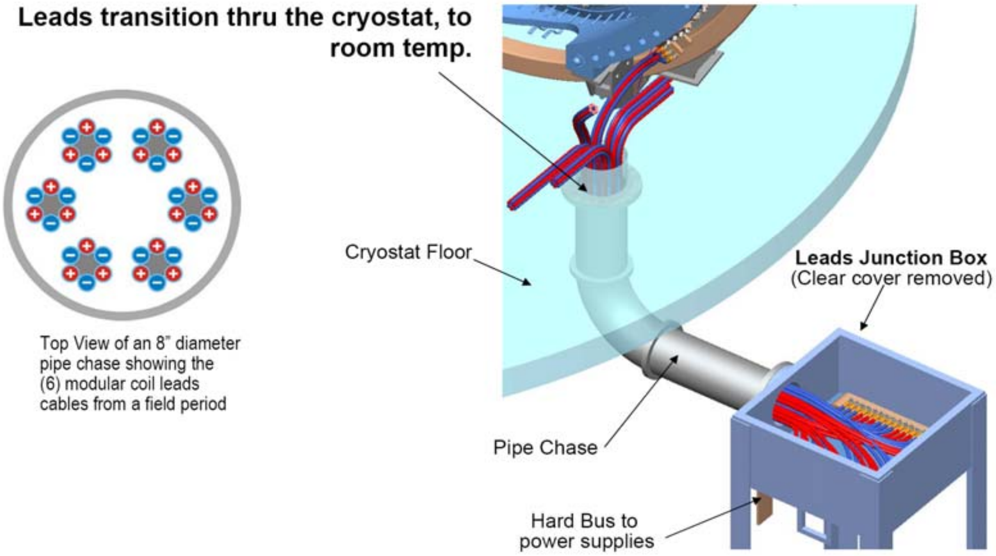


Figure 16: Schematic illustrating coil electric power distribution

Table 5: Coil Services Scope[Paul/Mike C/Jeff to finalize]

MIE Project Scope	Status at Closeout
Engineering design, procurement, and fabrication of manifolds, cooling pipes, and associated supports and I&C, and delivery of components to machine assembly operations.	**Preliminary design complete**
Engineering design, procurement, and fabrication of leads and associated supports, and delivery of components to machine assembly operations.	**Preliminary design xx% complete??**
Design, fabrication, and delivery of delivery of coil protection requirements to the coil protection system design activity	**Document Status**

Cryostat & Base Structure (WBS 17)

A cryostat (Figure 17) was to have enclosed the NCSX device to provide a suitable thermal environment for the magnets, and provides thermal insulation and a tight seal to isolate the cold gaseous nitrogen atmosphere surrounding the coils and cold structure from the ambient atmosphere. It would also provide a means for circulating dry nitrogen inside the cold volume to cool down and maintain the temperature of the interior structures. The base support system (Figure 18) would have provided the gravity support for the core device (vacuum vessel and coils) and also thermal isolation of the cold structure from the floor. Project scope and construction status at the end of the project are listed in Table 6.

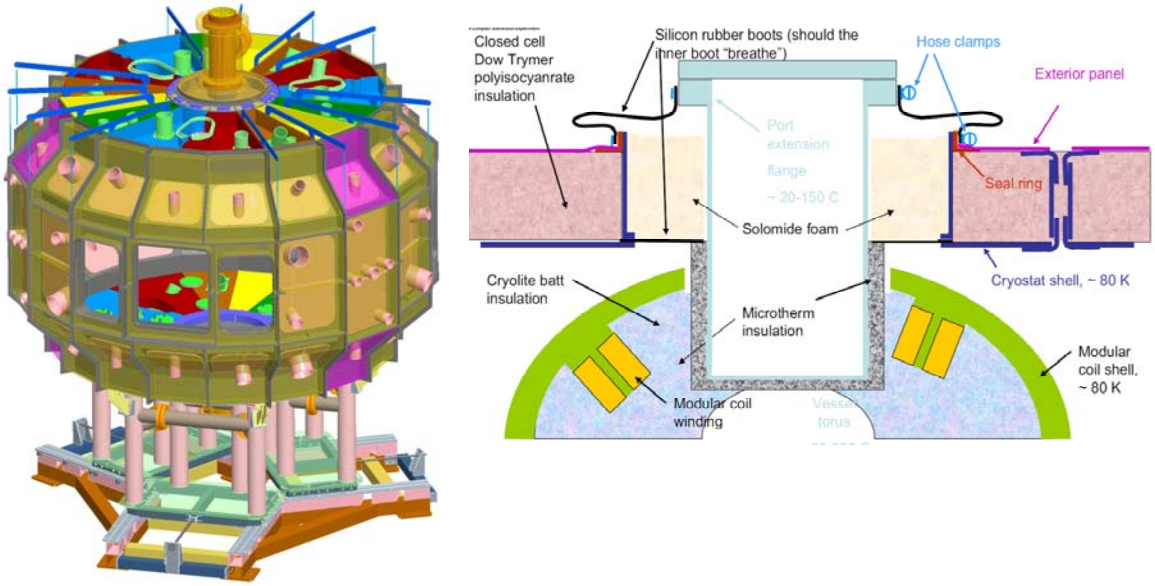


Figure 17 Conceptual schematic of cryostat and port penetration design

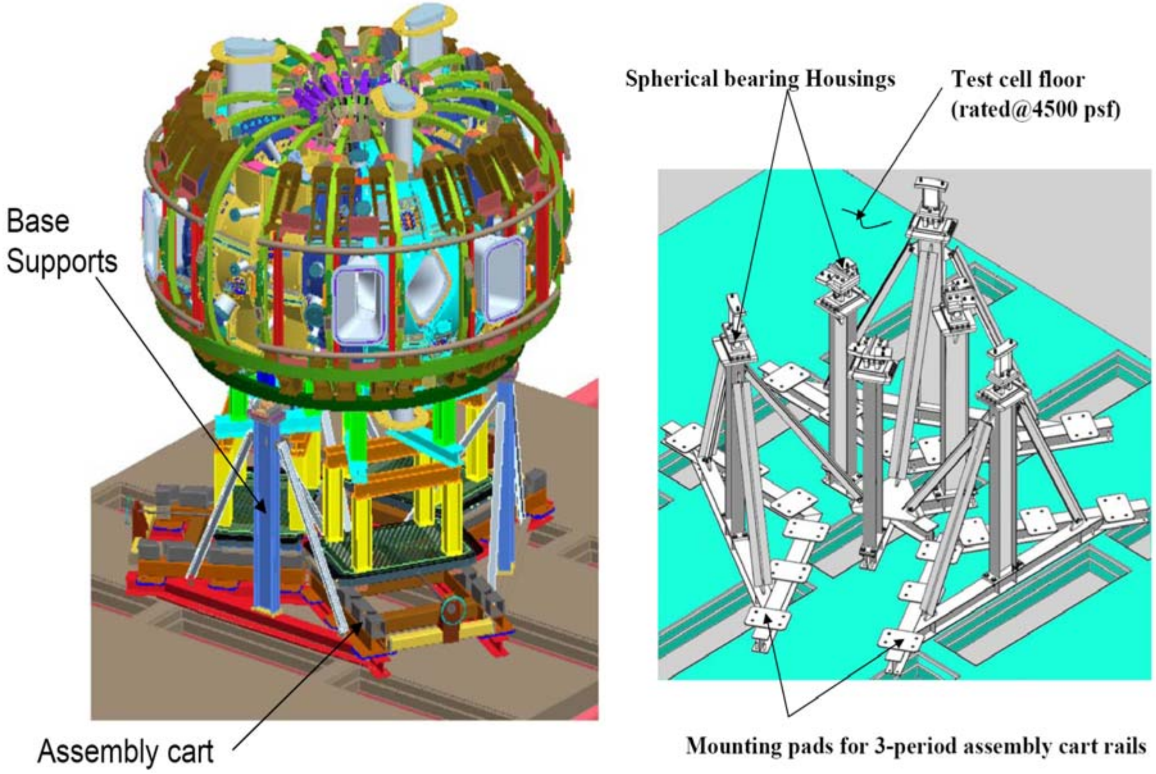


Figure 18: Base supports design

Table 6: Cryostat & Base Structure Scope

MIE Project Scope	Status at Closeout
Engineering design, procurement, and fabrication of the cryostat shell and structure components, insulation, attachments for the structural support of internal components, and penetrations for electrical, cooling, and mechanical support services. Delivery of components to machine assembly operations.	**A Peer Review of the cryostat involving experts from other laboratories and industry was held on April 23, 2008. A cryostat and cryosystem development plan was formulated based on input from the review. The targeted completion dates for Final Designs were in the 2nd quarter of CY 09. At the time of closeout, a cryostat shell design compatible with the structures, internal components, and penetrations was well underway. A subcontract that was being negotiated for expert support to guide the completion of the shell design, insulation, and integration was terminated.**
Engineering design, procurement, and fabrication of the permanent base support structure for the machine. Delivery of components to machine assembly operations.	**Final design complete.**

Field Period Assembly (WBS 18)

This activity included the assembly of the vacuum vessel, modular coils, and toroidal field coils and trim coils into three identical modules known as field periods (Figures 19-21). Each field period would contain one vacuum vessel sub-assembly (120-degree shell sector, toroidal spacer, and ports), six modular coils (two each of the three types), six toroidal field coils, sixteen trim coils, and associated coil support structures. Work included engineering design, R&D in support of design and fabrication, component procurement, tooling and fixtures, and assembly. The three different modular coils were aligned, bolted and welded together to form a half period assembly. Alignments were measured to a precision of 0.08 mm and maintained to position requirements of 0.50 mm or less. Project scope and construction status at the end of the project are listed in Table 7.

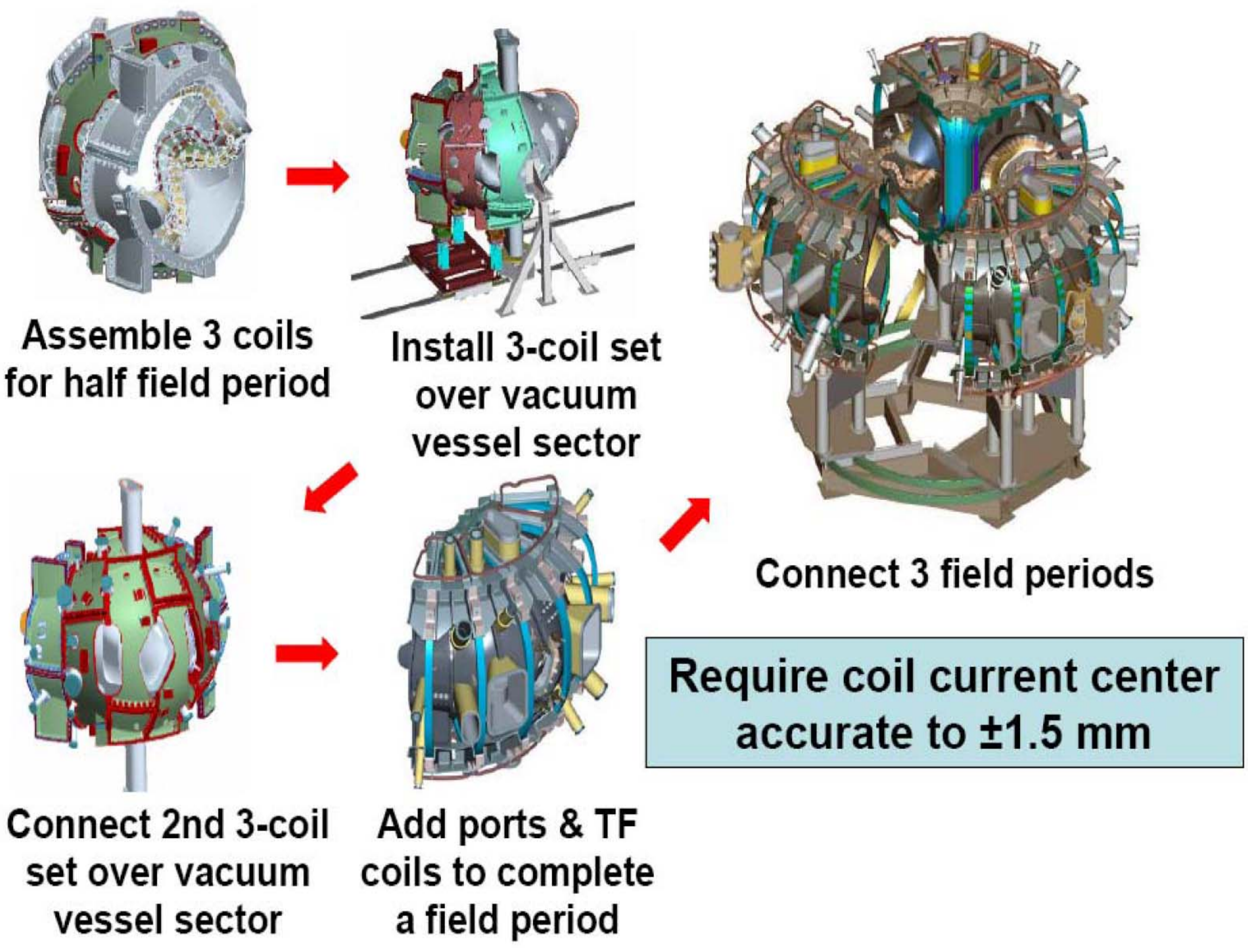


Figure 19: Assembly sequence schematic

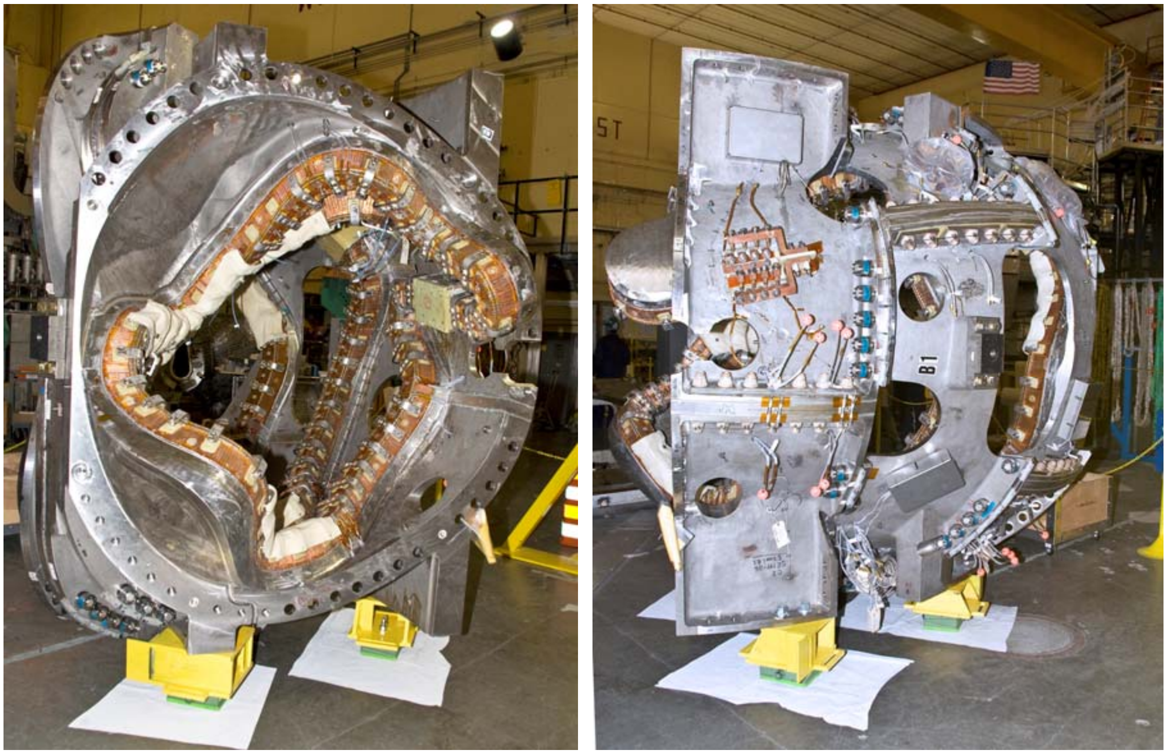


Figure 20: Assembled half field period

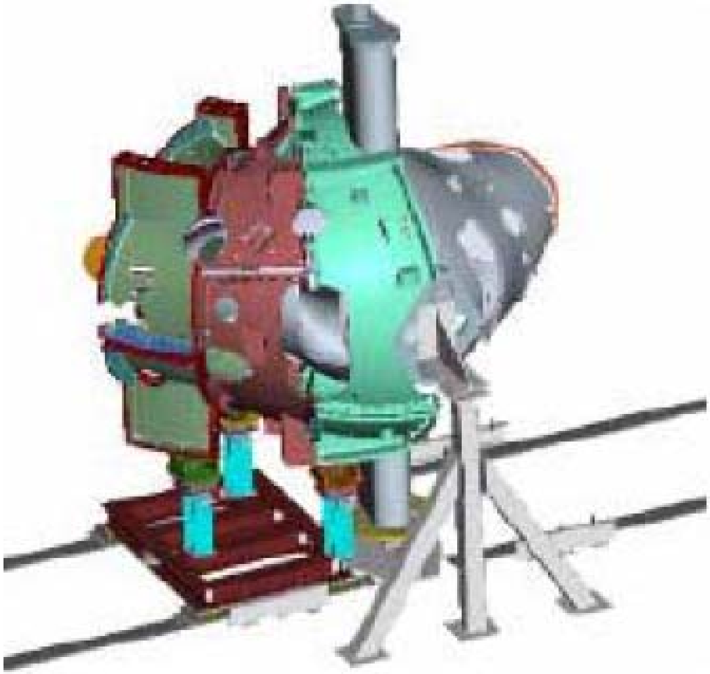


Figure 21: Half-field period assembly installed over vacuum vessel sub assembly

[REPLACE CARTOON WITH PHOTO FROM ACTUAL FIT-UP TESTS]

Table 7: Field Period Assembly Scope[Mike V & Mike C to finalize]

MIE Project Scope	Status at Closeout
Delivery of drawings, specifications, and models to field period assembly and machine operations.	**Station 2: xx% complete Station 3: xx% complete Station 5: xx% complete Station 6: xx % complete**
Delivery and receiving inspections of 3 vacuum vessel assemblies (plus port extensions), to Station 1	**Complete**
Delivery of three field period modules to machine assembly operations.	**Two half periods were (hopefully!) assembled**
Delivery and installation (as appropriate) of tooling for field period assembly	**Station 1: 100?% complete Station 2: 100?% complete Station 3: xx% complete Station 5: xx% complete Station 6: xx % complete**
Design, procure and fabricate additional metrology equipment needed for field period assembly.	**xx% competed**

4.2 Auxiliary Systems (WBS 2)

MIE Project scope included gas fueling, vacuum pumping, and an evaluation of an existing PPPL neutral beam system for potential future use after the planned completion of the Project. Work includes design, R&D to support the design effort, component fabrication, assembly, installation, system level commissioning and testing. Project scope and construction status at the end of the project are listed in Table 8.

Table 8: Vacuum Vessel System Scope

MIE Project Scope	Status at Closeout
Design, fabrication, refurbishment, installation, and system testing of gas fueling equipment capable of injecting H_2, D_2, or He gas into the plasma. Components include a gas delivery line, and pulse valve control.	**Design ~25% complete. No parts were procured, fabricated or refurbished. Neither installation nor testing of the system had been started.**
Design, fabrication, installation, and system testing of turbomolecular pumps backed by existing mechanical/booster vacuum pump systems.	**Design ~30% complete. No parts were procured, or fabricated. Installation of the system had not been started. System testing ~30% complete (offline tests of legacy TMPs and mechanical pumps).**

Evaluate, for future use, a neutral beam injection including one beamline, power systems, ac power, & controls system, based on existing C-site NBI system.	**Complete**

4.3 Diagnostics (WBS 3)

Diagnostic systems would have provided measurements of first plasma parameters. The NCSX MIE Project included the following diagnostics: (1) magnetic field probes and flux loops; (2) an existing fast visible TV camera to measure edge and divertor plasma; (3) an electron beam mapping apparatus to measure properties of the magnetic surfaces including shape and topology. Project scope and construction status at the end of the project are listed in Table 9.

Table 9: Diagnostics Scope[Brent/Jeff to finalize]

MIE Project Scope	Status at Closeout
Co-wound magnetic flux loops installed on the modular coils, TF coils, and PF coils. Saddle loops installed on the vacuum vessel. Rogowski loops. Integrator, digitizer, and data acquisition for one Rogowski loop.	**Design xx?% complete xx?% of parts delivered xx% installed**
Delivery of one Fast visible TV camera system (based on existing equipment).	**Design xx?% complete No components delivered**
Installation of electron-beam mapping equipment including probe drive with an electron gun at its tip, fluorescent detector which intercepts the electron beam, and a high-resolution CCD camera to detect the light from the detector. Existing components will be used to the extent possible	**Design xx?% complete No components delivered or installed**

4.4 Electrical Power Systems (WBS 4)

This system consisted of the supply and delivery of all AC and DC electrical power to NCSX equipment, and equipment control and protection systems. The MIE scope dealt with all electrical power system capabilities required for initial operation, including design, component fabrication, assembly, and installation activities, system level commissioning, and testing. General Plant Project (GPP) funds were authorized for refurbishment of AC systems. Project scope and construction status at the end of the project are listed in Table 10.

4.5 Central Instrumentation, Controls, & Data Acquisition (WBS 5)

This system consisted of equipment and software that would have provided central computing, control, and synchronization for NCSX. Components interfaced with the subsystem's local instrumentation and controls (I&C) systems and allowed for control and monitoring of NCSX experiments from the control room and includes analysis and display of the data. Subsystems included: network & fiber infrastructure; central I&C; data acquisition and facility computing; facility timing and synchronization; real time control; central safety & interlocks; and control room. Project scope and construction status at the end of the project are listed in Table 11.

Table 10: Electric Power System Scope

MIE Project & GPP Scope	Status at Closeout
Provide auxiliary AC power systems and experimental AC Power Systems.	**Design 80% complete Fabrication 45% complete (GPP work) Installation 45% complete (GPP work)**
Provide refurbished AC/DC Convertors required for initial operation.	**Design 70% complete Procurement 0% complete Refurbishment 0% complete**
Provide, refurbishing as needed, cabling and other DC components required to feed the NCSX machine from the existing C-Site rectifiers.	**Design 35% complete Fabrication 0% complete Installation 0% complete**
Provide control and protection systems including electrical interlocks, Kirk key interlocks; real time Control systems, instrumentation systems, and coil protection systems	**Design 15% complete Fabrication 0% complete Installation 0% complete**
Perform systems testing	**Not Started**

Table 11 Central Instrumentation, Controls, and Data Acquisition Scope [Paul S to finalize]

MIE Project Scope	Status at Closeout
Provide and install network & fiber infrastructure systems with common backbone for all data acquisition, and I&C communications.	**Design xx% complete Fabrication xx% complete Installation xx% complete**
Provide and install integrated control of NCSX through supervisory control and a common user interface to selected engineering subsystems and diagnostics instruments. It will provide process control and monitoring functions, inter-process synchronization, operator displays, alarm management, and historical trending. It will be designed using the Experimental Physics and Industrial Control System (EPICS).	**Design xx% complete Fabrication xx% complete Installation xx% complete**
Provide and install a software structure to collect, catalog, and manage experimental results for analysis and subsequent retrieval. The design will use the MIT-	**Design xx% complete Fabrication xx% complete Installation xx% complete**

developed MDSplus software for data acquisition, data archiving and display.	
Provide and install a timing & synchronization system sufficient to synchronize the equipment and computers used for achieving the MIE Project requirements.	**Design xx% complete** **Fabrication xx% complete** **Installation xx% complete**
Provide and install a PC-oriented, LabVIEW-like system to produce synchronized, open-loop power supply commands and gas injection commands. The system will also control a few gas delivery valves.	**Design xx% complete** **Fabrication xx% complete** **Installation xx% complete**
Provide and install a central safety and interlock system Provide a limited CSIS, sufficient to achieve safe operation of the NCSX device.	**Design xx% complete** **Fabrication xx% complete** **Installation xx% complete**

4.6 Facility Systems (WBS 6)

Facility Systems consisted of the following subsystems which support operation: water cooling; cryogens; air system utilities; vacuum vessel heating and cooling. Project scope and construction status at the end of the project are listed in Table 12.

Table 12: Facility Systems Scope **[Larry/Steve to finalize]**

MIE Project Scope	Status at Closeout
Provide required cooling water for vacuum pumping system	**Design xx% complete** **Fabrication xx% complete**
Provide liquid nitrogen supply for coil and cryostat cooling consistent with CD-4 requirements	**Design xx% complete** **Fabrication xx% complete**
Establish requirements and system architecture for entire LN2 feed system including in-cryostat LN2 distribution system (WBS 161).	**Design xx% complete** **Fabrication xx% complete**
Provide LN2 cooling system based on that constructed for the coil test facility (CTF).	**Design xx% complete** **Fabrication xx% complete**
Provide a vent for the vacuum vessel pumping system.	**Design xx% complete** **Fabrication xx% complete**
Provide a system to force 150-deg-C heated air through the vacuum vessel heating and cooling tubes.	**Design xx% complete** **Fabrication xx% complete**

4.7 Test Cell Preparation & Machine Assembly (WBS 7)

This work consisted of engineering and field labor to prepare the test cell and install the stellarator core systems, including trial machine assembly in which the three field period assemblies would be joined together to form the torus, followed by installation of PF coils, remaining trim coils, coil services, and cryostat. Design and fabrication of special machine assembly tools and equipment were included in this work. Project scope and construction status at the end of the project are listed in Table 13.

Table 13: Test Cell Preparation and Machine Assembly Scope **[Erik/Tom to finalize]**

MIE Project Scope	Status at Closeout
Design and fabricate a platform around the NCSX device, in support of various diagnostics and systems required for operation.	**Design xx% complete**
Perform final assembly of the stellarator core, specifically: installation and leveling of machine base plate; installation and leveling of the machine support columns; installation of the machine platform; installation of lighting and fire detection/suppression systems under the platform; installation of the lower cryostat floor; installation of the lower PF-3 & 4 coils in preliminary positions; installation of the three field periods; support pump down and vacuum leak testing; placement of the lower PF-3 & 4 into their final position; installation of the upper PF-3 & 4 coils; installation of the PF-1 & PF-2 solenoid; installation of external cryostat walls and ceiling; and cold power test PTP.	**Not started?**
Design and fabricate tooling and fixtures for machine assembly including the base support structure used during assembly and constructability analyses.	**Design xx% complete** **Fabrication not started?**

4.8 Technical Management & Support

Project Physics

This work included the definition of the project physics requirements and documenting them in the NCSX Project General Requirements Document (GRD)**.**

Project Engineering

This work included risk management, project planning, including implementing the PPPL work planning program, safety, including implementing the PPPL Integrated Safety

Management (ISM) program. Responsible Line Managers (RLMs) were responsible for managing on-site fabrication and assembly work and the design, fabrication, and assembly of ancillary, facility, and electrical systems.

System Engineering

This work included requirements management, design verification, including a program for systematic design reviews, configuration management and change control, including processing of Requests for Deviations (RFDs), Engineering Change Proposals (ECPs), and Engineering Change Notices (ECNs), and interface control, document control, and training project personnel in project plans, procedures, and practices.

Design Integration

This work included configuration development and integration support for all design and construction activities, design reviews, the computer aided design (CAD) database of project models and drawings, reviewing and promoting CAD models and drawings, establishing Intralink procedures and privileges, and providing support to the metrology and dimensional control efforts by analyzing metrology data in conjunction with CAD models of the parts and assemblies.

System analysis / Technical Assurance

This work included establishing structural and cryogenic design criteria, establishing dimensional accuracy requirements for coil systems based on field error considerations, analyzing field errors and managing field error budgets for as-designed conditions, out-of-tolerance conditions, eddy currents, and magnetic materials. It also included the disposition of nonconformance reports (NCRs), providing analysis support to the metrology and dimensional control efforts for troubleshooting problems as well as production activities, analyzing options for optimally aligning modular coils based on physical and magnetic measurements, performing global analyses which are outside the scope of individual subsystems, and independently assessing design adequacy and risks for critical systems and design feature. Analyses included electromagnetic analyses to determine coil inductances, fields, forces; global structural modeling to determine overall structural behavior, mechanical interface loads, and operating limits.

Dimensional Control Coordination

This work included support of design and construction activities in the realization of dimensional accuracy requirements by developing strategies and procedures for dimensional control and supporting their implementation.

Plant Design

This work included allocating space within the NCSX Test Cell and adjacent areas, and developing models and drawings to define the routing and location of equipment in the Test Cell.

Integrated System Testing

This work covered the planning, document preparation, and execution of the NCSX integrated system testing and startup activities, through the generation of the first plasma. Program was documented in a draft *NCSX Safe Startup & Control Plan.* Costs for the development and completion of the sub-system preoperational tests procedures were the responsibility of the individual (sub-system) WBS managers and were detailed in the specific WBS work elements.

5. PROJECT MANAGEMENT

The NCSX Project was executed in compliance with DOE Order 413.3, *Program and Project Management for the Acquisition of Capital Assets.* An Integrated Project Team (IPT) was formed and led by the NCSX Federal Project Director to implement and achieve the overall project objectives and goals. The NCSX IPT consisted of the Federal Project Director, OFES NCSX Program Manager, OFES Stellarator Program Manager, Professional from the SC Office of Project Assessment, Laboratory Project Manager and Deputy Project Manager, Project Quality Assurance Engineer, Project Controls Manager, PPPL ES&H Manager, and PPPL Procurement Manager. Tasks were organized around a work breakdown structure (WBS, Table 14). A WBS dictionary has been archived at http://ncsx.pppl.gov/SystemsEngineering/WBS/WBS_index.htm. The WBS was further subdivided into jobs, each assigned to specific Job Manager who was responsible and accountable for accomplishing the scope of the work, as defined, with established schedule and cost targets. There were sixty-four active jobs at the time of the Project cancellation. The vehicle for documenting and authorizing work was the Work Approval Form (WAF). Each WAF formally documented the approval and acceptance of the statement of work, deliverables and milestones, cost, schedule, design, fabrication and assembly labor, materials and supplies, a standardized basis for the cost estimate, identification of risks, and designation of the design maturity and complexity of the work at a given time. The complete project organization, along with individual roles, responsibilities, authorities, and accountability were documented in a Project Execution Plan (http://ncsx.pppl.gov//Management/Documents/PEP_03_Signed.pdf). The project followed a methodical process for quantifying cost and schedule contingency through the use of probabilistic calculations accounting for identified risks, and WBS design maturity and complexity. Increased emphasis on the use of a complete and up-to-date project risk registry occurred as the project evolved (Appendix F).

A resource-loaded, integrated, baseline project schedule was developed and implemented using Primavera project management software. The schedule was based on deliverables and/or tasks identified by the job managers in their WAFs, with labor resources assigned to each tasks, with Institutional overhead and labor rates. The integrated project schedule was optimized focusing on the critical path (*e.g.,* use of 2 shift operations, floor space for assembly tasks, crane utilization studies), maximizing free float of non-critical path activities, front end loading system designs, fitting within OFES budget guidance, and mitigating the highest risks. When needed, contingency budget authority was to be created by delaying low-risk/large float activities. Task durations were based on realistic resource loadings & crew sizes, and were logically linked (2,170 tasks, 2700 links, 2900 individual resource loadings).

Progress relative to the performance baseline was assessed with an earned value management system. Progress was reported in: (1) weekly meetings with the Federal Project Director; (2) weekly meetings with the PPPL Director; (3) weekly teleconferences with the OFES Program Manager; (4) monthly reviews by the PPPL Director and PU Dean for Research; (5) monthly cost and schedule reports to DOE; (6) semi-annual cost and schedule reviews by SC Office of Project Assessment; (7) three separate project reviews by an external independent review committee established by PU in 2007. A chronology of major external project reviews is provided in Appendix J.

Quality assurance was achieved by executing a plan that included procedures, policies, inspections, design reviews, support of procurements. Compliance-based and performance-based audits of the project and its associated plans and procedures were performed to assure that the requirements of the DOE Order on Quality Assurance, 414.1A were met. The Defense Management Contract Agency (DCMA) augmented PPPL QA organization by providing written audit reports.

6. COST & SCHEDULE PERFORMANCE

Unsatisfactory cost and schedule performance relative to the approved baseline was reported to OFES beginning with the 3QFY07 quarterly report. Bottoms-up cost estimates were performed in June 2007 through March 2008 which were part of the draft baseline change proposal that was prepared by the Project and reviewed by DOE in April 2008.

Table 14: NCSX Work Breakdown Structure

WBS-1	**Stellarator Core Systems**
WBS-2	**Auxiliary Systems**
WBS-3	**Diagnostics Systems**
WBS-4	**Electrical Power Systems**
WBS-5	**Central Controls & Computing Systems**
WBS-6	**Facility Systems**
WBS-7	**Test Cell Preparation & Machine Assembly**
WBS-8	**Project Oversight & Support**

6.1 Cost & Schedule of Work Accomplished

MIE construction work ended in September 2008. Percentages of completion are listed in Tables 15-16. Status of the project work elements at the time of closeout is may be accessed at http://ncsx.pppl.gov/NCSX_Engineering/CloseOut_Documentation/CloseoutDoc_index.htm.

Table 15: Percentages of budget spent (actual costs/approved TEC) and work completed (BCWP/BCWS) at the time of Project termination [UPDATE!]

Spent Capital Budget	**97%**
Overall Project	**62%**
R&D	**98%**
Design	**75%**
Procurements	**70%**
Fabrication & Assembly	**51%**

Table 16: Breakdown of project completion status at the time of Project termination [UPDATE!]

Project Completion Analysis

			Design	R&D	Procure	Fab & Assy	Mgt & Oversight	TOTAL
12	Vacuum Vessel	Spent $k)	$1,641	$1,787	$6,315	$0		**$9,743**
		Total ($k)	$1,864	$1,787	$7,305	$216		**$11,172**
13	Conventional Coils	Spent $k)	$1,278	$0	$2,016	$536		**$3,830**
		Total ($k)	$1,665	$0	$5,670	$751		**$8,086**
14	Modular Coils	Spent $k)	$6,297	$5,454	$12,938	$13,483		**$38,172**
		Total ($k)	$6,461	$5,456	$13,963	$14,855		**$40,735**
15	Structures	Spent $k)	$550	$0	$0	$0		**$550**
		Total ($k)	$639	$0	$1,427	$12		**$2,078**
16	Coil Services	Spent $k)	$3	$0	$0	$0		**$3**
		Total ($k)	$392	$24	$493	$179		**$1,088**
17	Cryostat & Base Support Structure	Spent $k)	$489	$0	$0	$0		**$489**
		Total ($k)	$1,206	$0	$780	$0		**$1,986**
18	Field Period Assembly	Spent $k)	$1,439	$0	$7	$4,094		**$5,540**
		Total ($k)	$2,520	$0	$362	$17,070		**$19,952**
1	**Stellarator Core**	**Spent $k)**	**$11,697**	**$7,241**	**$21,276**	**$18,113**		**$58,327**
		Total ($k)	**$14,747**	**$7,267**	**$30,000**	**$33,083**		**$85,097**
			79%	*100%*	*71%*	*55%*		*69%*
2	**Auxiliary Systems**	**Spent $k)**	**$348**	**$0**	**$0**	**$0**		**$348**
		Total ($k)	**$784**	**$0**	**$215**	**$367**		**$1,366**
			44%	-	*0%*	*0%*		*25%*
3	**Diagnostics**	**Spent $k)**	**$565**	**$0**	**$0**	**$566**		**$1,131**
		Total ($k)	**$938**	**$0**	**$68**	**$936**		**$1,942**
			60%	-	*0%*	*60%*		*58%*
4	**Electrical Power Systems**	**Spent $k)**	**$615**	**$0**	**$0**	**$0**		**$615**
		Total ($k)	**$1,369**	**$0**	**$216**	**$1,749**		**$3,334**
			45%	-	*0%*	*0%*		*18%*
5	**I&C Systems**	**Spent $k)**	**$33**	**$0**	**$0**	**$0**		**$33**
		Total ($k)	**$818**	**$0**	**$624**	**$690**		**$2,132**
			4%	-	*0%*	*0%*		*2%*
6	**Facility Systems**	**Spent $k)**	**$24**	**$0**	**$0**	**$0**		**$24**
		Total ($k)	**$896**	**$104**	**$722**	**$725**		**$2,447**
			3%	*0%*	*0%*	*0%*		*1%*
7	**Test Cell Prep & Machine Assy**	**Spent $k)**	**$0**	**$0**	**$0**	**$708**		**$708**
		Total ($k)	**$0**	**$0**	**$367**	**$8,918**		**$9,285**
			-	-	-	*8%*		*8%*
	Sub-TOTAL	**Spent $k)**	**$13,282**	**$7,241**	**$21,276**	**$19,387**		**$61,186**
		Total ($k)	**$19,552**	**$7,371**	**$32,212**	**$46,468**		**$105,603**
		% complete	**68%**	**98%**	**66%**	**42%**		**58%**
19 & 8	**Stellarator Core Mgnt/Integration & Project management & Engr**	Spent $k)	$0	$0	$0	$0	$15,179	**$15,179**
		Total ($k)	$0	$0	$0	$0	$32,578	**$32,578**
	Grand Total	Spent $k)	$13,282	$7,241	$21,276	$19,387	$15,179	$76,365
		Total ($k)	$19,552	$7,371	$32,212	$46,468	$32,578	$138,179
		% complete	**68%**	**98%**	**66%**	**42%**		**55%**

6.2 Cost & Schedule Estimates to Complete for Remaining Work

A bottoms-up estimate for the remaining work was performed from June 2007 through March 2008 and submitted to DOE in March 2008 as part of a draft baseline change proposal (http://ncsx.pppl.gov/Reviews/FY08/BCP_2008/BCP_08_index.html), reviewed by DOE in April 2008. Cost estimates were performed with a formal and consistent basis of estimate (Fig. 22), and independently reviewed by the PPPL Engineering Directorate and by Princeton University (PU). For much of the first-of-a-kind subsystems associated with the stellarator core, the basis of estimate evolved over the course of the project from engineering judgment to actual NCSX experience.

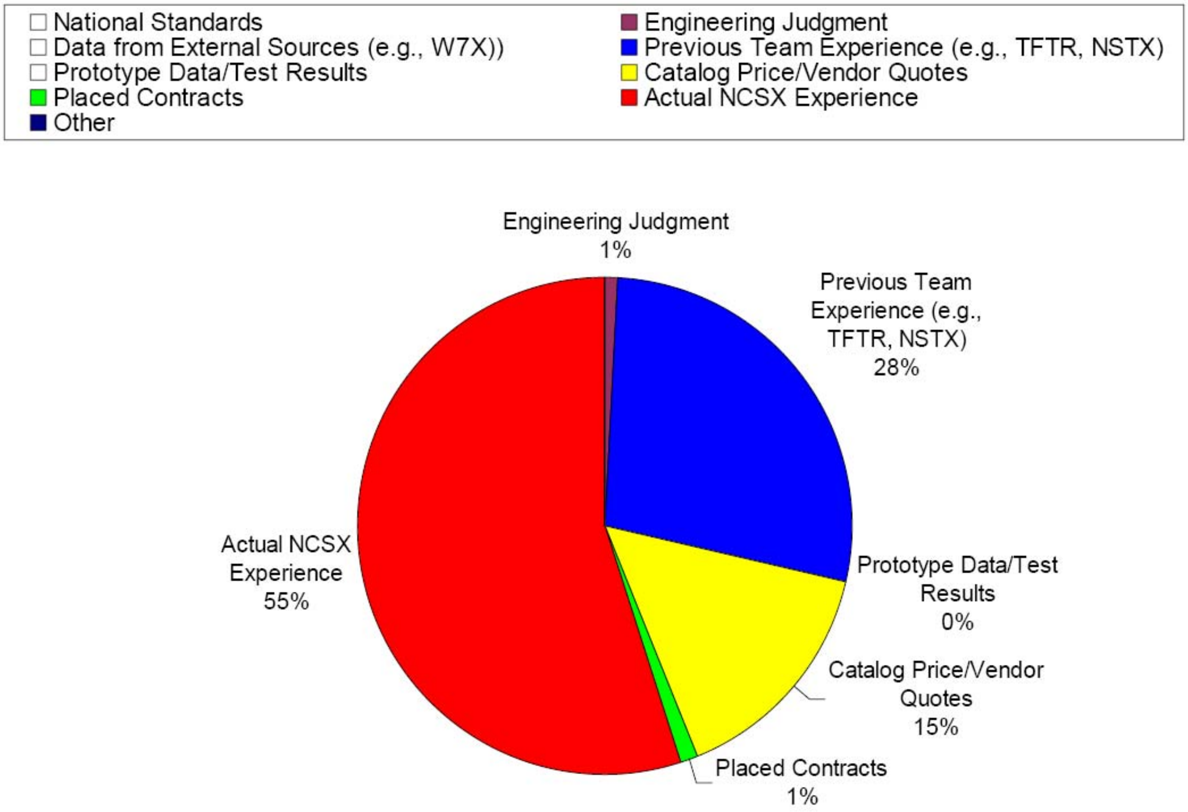


Figure 22: Basis of cost estimate in March 2008

In this section, a “best & final” estimate to complete (ETC) is presented. This ETC is based upon the March 2008 draft BCP modified after: (1) accounting for all subsequent earned value and actual costs incurred by the project for non-closeout activities; (2) including modest corrections for ETC omissions and errors that were communicated to OFES on May 1, 2008; (3) revising the bottoms-up ETC for field period assembly, accounting for actual experience since April 2008; and (4) performing a final, risk-based contingency estimate, accounting for risks that were retired since April. Summary and more detailed ETCs are provided in Tables 17-18. Costs are based upon escalated 2008 dollars, while closeout specific tasks that were not part of the 2005 MIE project baseline, such as additional documentation and materiel disposition, are not included. Estimated schedule was consistent with OFES budget guidance prior to termination of the project. The critical path (Fig 23) passed through field period assembly, final machine assembly and start-up operations. Major procurement of components as well as ancillary system had ample schedule margin (months off critical path). Contingency was calculated using the NCSX risk-based probabilistic model, taking into account changes in risk reduction and design maturity since the March 2008 draft BCP.

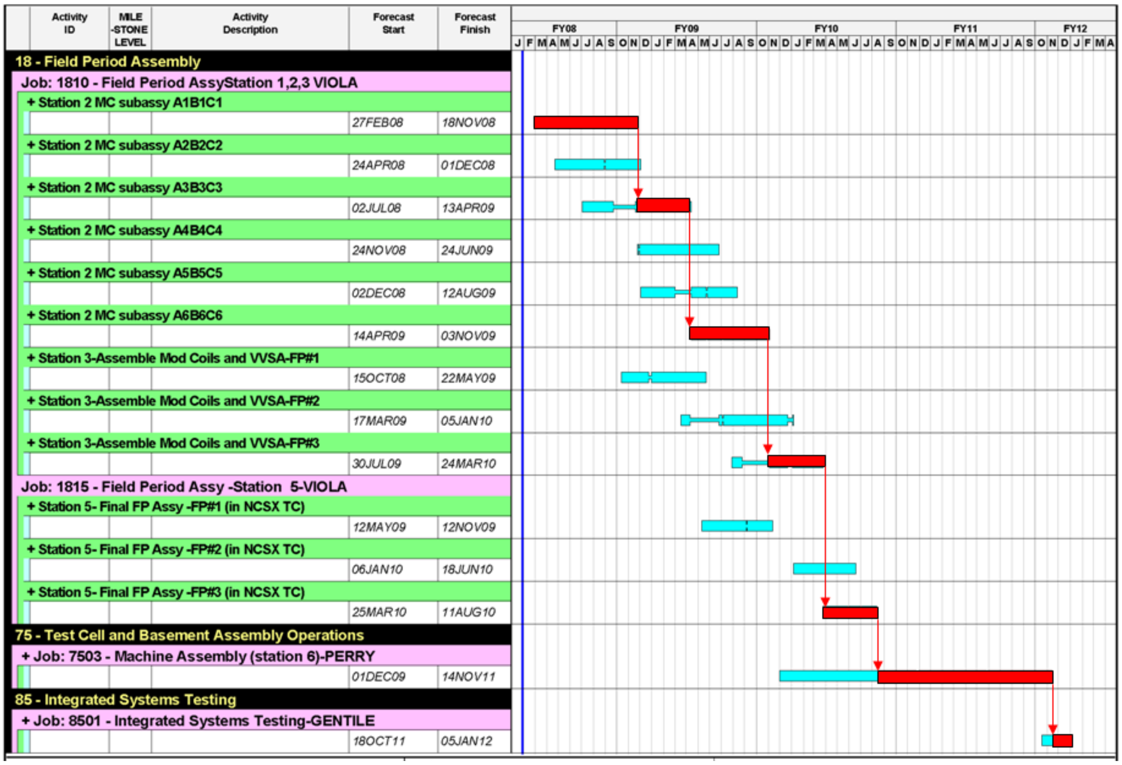
Table 17: Summary of the estimate to complete (ETC) for remaining work [UPDATE!]

Actual costs at project closeout	**$89.7M**
Cost estimate to complete	**$??.?M**
Estimate at Complete	**$??.?M**
Schedule estimate to complete	**?? mo**
Cost Contingency	**$??.?M**
Schedule Contingency	**??-mo**

Table 18: Details of the estimate to complete (ETC) for remaining work

[update ETCs from 10/1/08 and add a middle column describing "status at Closeout" from http://ncsx.pppl.gov/NCSX_Engineering/CloseOut_Documentation/CloseoutDoc_index.htm]

JOB	ETC (bottoms-up) from 2/1/08		JOB	ETC (bottoms-up) from 2/1/08
Job: 1204 - VV Sys Procurements (nonVVSA)-DUDEK	221		Job: 2101 - Fueling Systems-BLANCHARD	338
Job: 1260 NB Transition Ducts- GORANSON	567		Job: 2201 - Vacuum Pumping Systems-BLANCHARD	679
Job: 1270 - Heater Control System-GORANSON	642		Job: 3101 - Magnetic Diagnostics-STRATTON	411
Job: 1302 - PF Design -KALISH	91		Job: 3601 - Edge Divertor Diagnostics-STRATTON	30
Job: 1352 - PF Coil Procurement-CHRZANOWSKI	1,638		Job: 3801 - Electron Beam Mapping-STRATTON	258
Job: 1353 - CS Structure Procurement-DAHLGREN	357		Job: 3901 - Diagnostics sys Integration-STRATTON	112
Job: 1354 - Trim Coil Design &Procurement-KALISH	1,433		Job: 4101 - AC Power-RAMAKRISHNAN	154
Job: 1355 - WBS 13 I&C Proc and Coil Assy-KALISH	110		Job: 4301 - DC Systems-RAMAKRISHNAN	579
Job: 1361 - TF Fabrication-KALISH	628		Job: 4401 - Control & Protection-RAMAKRISHNAN	1,080
Job: 1408 - MC Winding Supplies-CHRZANOWSKI	124		Job: 4501 - Power Sys Dsn & Integr-RAMAKRISHNAN	905
Job: 1416 - Mod Coil Type AB Fnl Dsn-WILLIAMSON	140		Job: 5101 - Network and Fiber-SICHTA	221
Job: 1421 - Mod Coil Interface Design-WILLIAMSON	28		Job: 5201 - I&C Systems-SICHTA	412
Job: 1429 - MC Interface R&D-DUDEK	4		Job: 5301 - Data Acquisition-SICHTA	166
Job: 1431 - Mod. Coil Interface Hardware-DUDEK	1,074		Job: 5401 - Facility Timing -SICHTA	358
Job: 1451 - Mod Coil Winding-CHRZANOWSKI	909		Job: 5501 - Real Time Control -SICHTA	502
Job: 1459 - Mod Coil Fabr.Punch List-CHRZANOWSKI	283		Job: 5601 - Central Safety &Interlock Sys-SICHTA	372
Job: 1501 - Coil Structures Design-DAHLGREN	89		Job: 5801 - Central I&C Integr& Oversight-SICHTA	67
Job: 1550 - Coil Struct. Procurement -DAHLGREN	1,439		Job: 6101 - Water Systems-DUDEK	112
Job: 1601 - Coil Services Design-GORANSON	1,085		Job: 6201 - Cryogenic Syst-RAFTOPOLOUS	1,568
Job: 1701 - Cryostat Design-RAFTOPOLOUS	578		Job: 6301 - Utility Systems-DUDEK	109
Job: 1751 - Cryostat Procurement-RAFTOPOLOUS	550		Job: 6401 - PFC/VV Htng/Cooling(bakeout)- KALISH	634
Job: 1702 - Base Support Struct Design-DAHLGREN	139		Job: 7301 - Platform Design -PERRY	213
Job: 1752 - Base Support Proc-DAHLGREN	230		Job: 7401 - TC Prep & Mach Assy Planning-PERRY	2,323
Job: 1802 - FP Assy Oversight&Support-VIOLA	3,826		Job: 7501 - Construction Support Crew-PERRY	1,325
Job: 1803/1805- FPA Tooling/Constr-BROWN/DUDEK	994		Job: 7503 - Machine Assembly (station 6)-PERRY	4,317
Job: 1806 - FP Assembly specs-COLE	360		Job: 7601 - Tooling Design & Fabrication-PERRY	399
Job:1810-Field Period Assy -Station 1 2 3 VIOLA	7,343		Job: 8101 - Project Management &Control-REJ	4,160
Job: 1815 - Field Period Assy Station 5	1,888		Job: 8102 - NCSX MIE Management ORNL-HARRIS	654
Job: 1901 - Stellarator Core Mngtt&Integr-COLE	2,255		Job: 8202 - Engr Mgmt & Sys Eng Support-HEITZENROEDER	3,254
			Job: 8203 - Design Integration-BROWN	2,581
			Job: 8204 - Systems Analysis-BROOKS	1,032
			Job: 8205 - Dimensional Control Coordin-ELLIS	542
			Job: 8215 Plant Design-PERRY	200
			Job: 8501 - Integrated Systems Testing-GENTILE	795
			Job: 8998 - Allocations-STRYKOWSKY	1,928



Activity ID	MILE-STONE LEVEL	Activity Description	Forecast Start	Forecast Finish
18 - Field Period Assembly				
Job: 1810 - Field Period AssyStation 1,2,3 VIOLA				
+ Station 2 MC subassy A1B1C1				
			27FEB08	18NOV08
+ Station 2 MC subassy A2B2C2				
			24APR08	01DEC08
+ Station 2 MC subassy A3B3C3				
			02JUL08	13APR09
+ Station 2 MC subassy A4B4C4				
			24NOV08	24JUN09
+ Station 2 MC subassy A5B5C5				
			02DEC08	12AUG09
+ Station 2 MC subassy A6B6C6				
			14APR09	03NOV09
+ Station 3-Assemble Mod Coils and VVSA-FP#1				
			15OCT08	22MAY09
+ Station 3-Assemble Mod Coils and VVSA-FP#2				
			17MAR09	05JAN10
+ Station 3-Assemble Mod Coils and VVSA-FP#3				
			30JUL09	24MAR10
Job: 1815 - Field Period Assy -Station 5-VIOLA				
+ Station 5- Final FP Assy -FP#1 (in NCSX TC)				
			12MAY09	12NOV09
+ Station 5- Final FP Assy -FP#2 (in NCSX TC)				
			06JAN10	18JUN10
+ Station 5- Final FP Assy -FP#3 (in NCSX TC)				
			25MAR10	11AUG10
75 - Test Cell and Basement Assembly Operations				
+ Job: 7503 - Machine Assembly (station 6)-PERRY				
			01DEC09	14NOV11
85 - Integrated Systems Testing				
+ Job: 8501 - Integrated Systems Testing-GENTILE				
			18OCT11	05JAN12

Figure 23: Schedule critical path associated with the estimate to complete [update!]

7. ENVIRONMENT, SAFETY, & HEALTH

The NCSX Project pro-actively strove for a zero incident safety record. Work was performed in accordance with PPPL Engineering and ES&H Procedures and Directives and best safety practices, which included: Integrated Safety Management (ISM), the National Environmental Policy Act (NEPA), job hazard analyses, work planning, installation and, safety procedures, pre-job and post-job briefings, and training. All PPPL supervisors were trained in the DuPont Safety Training and Observation Program (STOP). The Project regularly used the PPPL Safety Certification System which provided a formalized, standardized means of assuring independent review and authorization of high hazard operations. The PPPL ES&H Executive Board (ES&H/EB) appointed an Activity Certification Committee (ACC) for NCSX that conducted safety reviews, recommend issuance or denial of Safety Certificates, recommended to the ES&H/EB any necessary special conditions or constraints on which the issuance of Safety Certificates should be based. ACC reviews were conducted for modular coil winding, casting, electrical and cryogenic testing, welding, and assembly operations. In addition to formal review, the PPPL ISM system was reinforced with regular toolbox meetings involving management, supervisors, and staff to discuss relevant safety topics such as working hazard analysis, personal protective equipment, electrical systems, welding, hoisting and rigging, ladders, ergonomics, and emergency management. Further details of NCSX ES&H program are at http://ncsx.pppl.gov/NCSX_Engineering/ES&H/index_ESH.htm.

DOE conducted a re-evaluation of PPPL ISM in 2006 with particular emphasis on services and activities that supported NCSX. In their outbrief, reviewers noted that NCSX: post-job briefings were effective; management actively solicited input from workers to improve safety and improve operations; management and support staff maintained a day-to-day awareness of activities by walkthroughs, observations of work, interactions with employees, as well as leading pre-and post-job briefings. An Environmental Assessment (EA) was completed for NCSX in 2002, and following an independent external review, DOE issued a Finding of No Significant Impact in October 2002.

Overall ES&H performance on NCSX was excellent. From the beginning of the MIE Project in April 2003 through June 30, 2008, PPPL. PPPL personnel worked a total of 454,000 on the project without a single away from work injury or Days Away/Restricted Work/Job Transfer (DART) incident, and with one OSHA recordable incident. [update with final data] This performance was recognized for three [?] consecutive years by the State of New Jersey with their Commissioner of Labor & Workforce Development Award to the NCSX Project. [add sentence re ORNL safety record].

8. KEY LESSONS LEARNED

8.1 DOE Perspective

[to be written by Jeff M.]

8.2 Contractor Perspective

Underlying Issues

A lessons learned study was conducted by PPPL and PU to better understand issues that led to cost and schedule variances and to establish corrective actions to prevent reoccurrence of similar problems in future projects. The following issues were identified with the NCSX Project:

1. Premature definition of the project cost and schedule when the project baseline was established at CD-2, due to the design, analysis, and R&D being insufficiently mature.
2. Underestimate of the implications of meeting the tolerance requirements of a complex three-dimensional structure.

3. Lack of appreciation of the high risks associated with the application of cutting edge technologies.
4. Inadequate engineering staffing early in the project, leading to the need to develop "just in time" engineering solutions to technical problems that arose.
5. Lack of independent internal review of cost and schedule.
6. Loss of key experienced technical personnel to a higher-priority project.
7. Insufficient management for a project of this size and complexity.
8. Inadequate PPPL and PU oversight.
9. Inadequate communication with DOE.

Lessons learned

1. Complete requisite R&D and designs prior to establishing a baseline.

The complex geometry and tight fabrication tolerances of NCSX created unique engineering and assembly challenges. R&D and design needs to be sufficiently completed to establish a sound technical basis for the cost and schedule estimates. To the extent that such tasks are still outstanding at the time a baseline is established, it poses a risk which must be recognized, quantified, and managed with risk acceptance/mitigation/transfer plans and with contingency management. The NCSX was a highly developmental project, which distinguished itself from most other DOE construction projects. The design was not at a PDR level and assembly process for many critical components, and more importantly, critical prototyping tasks were still outstanding when the project was baselined in 2003. At the time of project termination, not all of the design and prototyping had been completed, resulting in considerable residual risks. These risks were eventually identified and the management of these risks was addressed in the draft BCP reviewed by DOE in April 2008.

2. Implement rigorous, disciplined cost estimating techniques.

The formality of job estimates needed to be increased as the project evolved. A standardized basis of estimate (Fig 22) was included in each WAF. It is important to realistically assess the uncertainties, their sources, and the prospects for reducing them. Subjective characterizations of "confidence" should be avoided. Comparison with previous similar experience can be misleading if it does not adequately take into account the special circumstances of a complex project like NCSX. For first-of-a-kind hardware, estimates need to realistically account for "learning experience curves" associated with the initial fabrication, installation, and integration activities (for example, see Fig. 13). From 2007, the job manager, the Responsible Line Manager, Project Manager and the PPPL Associate Director for Engineering and Infrastructure reviewed and approved all cost and schedule changes, thus documenting their commitment to meeting the proposed estimate. They also identified risks and opportunities associated with the job estimate as input to the risk registry. Lower level milestones at approximately monthly intervals were identified for each job and tracked and statused by the engineering managers such that off-critical path tasks were given greater visibility. Such rigor was lacking in the original estimates.

3. Conduct regular bottoms-up estimates to complete to identify and address cost and schedule issues.

After the approval of CD-3, the Project did not perform thorough ETC updates on a regular basis. Thus, while attention was given to cost and schedule problems occurring in ongoing work, the ramifications for future work, especially assembly, were not adequately analyzed. The project was remiss in characterizing its December 2006 estimate as a "high-confidence" estimate, given its basis. Rather, a bottom-up analysis should have first been conducted for all remaining work, risks, and uncertainties. Subsequently, all NCSX job estimates were extensively revised by all the job managers in 2007-08, incorporating new analyses and lessons learned. In particular, metrology and Title-III engineering experience in the fabrication of the modular coils and vacuum vessel were applied to assembly estimates. This resulted in a new, uniform format for developing NCSX cost estimates, designed to decrease the likelihood of missing sub-tasks in a cost estimate, and of elements being missed at the interface between jobs.

4. Develop and execute an effective risk management plan.

The use of formal risk and opportunity assessment techniques, based on a risk register and analysis of the tasks at the job level, is required to establish the need for cost and schedule contingency. In support of the 2008 NCSX rebaselining effort, an external expert was brought in to augment PPPL capabilities and apply more quantitative approaches such as Monte Carlo analysis to transform the risks identified in the risk registry into contingency requirements, and to help distinguish cost estimation uncertainty from risk. An up-to-date risk registry including risk mitigation actions became a key project management tool. Most importantly, the Project Team became more skilled at recognizing the risks in the remaining work, quantifying them, and developing mitigation plans (Appendix F). In this regard, the experiences in component fabrication provided a much better understanding of the project risks than existed at the time of CD-2.

5. Develop, maintain, and execute a staffing plan.

The NCSX benefitted from the many high-qualified, experienced staff assigned to the project. However, staffing levels were often inadequate to successfully execute the project due to several interconnected factors including: the underestimate of time and effort needed to complete a job; over-commitments of personnel, exacerbated by an incomplete or incorrect staffing plan; preferential commitment of resources to critical path scope, cost overruns, and schedule delays; and the premature (relative to job completion) loss of critical personnel to the ITER Project, which was the highest facility construction priority of the DOE SC and OFES. This understaffing caused engineering efforts to fall behind, leading to the much-derided "just-in-time" engineering as an unintended consequence. Ultimately, the Project was held up for almost one year waiting for a critical design task to be completed. The Project eventually developed a staffing level that accounted for monthly assignments of specific individuals (*i.e.*, no near-term tasks performed by "TBDs") for each WBS level-4 task, self-consistent with the resource-loaded schedule.

6. Exercise care when using high technology tools at or near their upper limits.

NCSX benefitted from several state-of-the-art tools and techniques, such as three-dimensional computer-aided design modeling, metrology, and low-distortion welding. Capabilities selected for a project must be confirmed prior to establishing the cost and schedule baseline. Training and qualification certification standards also need to be included. To improve implementation times and usage estimates, other more experienced users of the technology should be consulted and/or recruited. All tools need to be validated before their use is required.

7. Develop strong ties with other laboratories, including those outside of your area of expertise.

Several of the NCSX key technical issues were faced and resolved by others, often working in other scientific areas such as particle physics. The NCSX project consulted with CERN LHC and the Max Planck W7-X projects tapping their considerable expertise in metrology and low-distortion welding. Accessing and listening to experts in early stages, (*e.g.*, during design reviews) would have avoided crises that protracted the NCSX critical path during assembly.

8. Utilize external peer review

A rigorous independent design review procedure developed by PPPL was adopted by the project for peer, conceptual, preliminary, and final designs. As the project evolved, there also was a concerted effort to bring in external reviewers from the fusion as well as from other disciplines (*e.g.*, particle accelerators, neutron spallation, cryogenic engineering, and high-magnetic fields) which brought healthy fresh evaluation and constructive criticism.

9. Build a strong, effective project management organization early

PU has been strengthening project management at PPPL. Starting in 2007, PU and PPPL brought in experienced project managers from the outside to make immediate changes and improvements on NCSX such as cost estimating, risk management, staffing, instilling a culture of personal accountability, increasing focus on driving schedule without compromising safety and quality. Unfortunately, these investments did not prevent the decision to cancel the Project. In the wake of NCSX, a concerted effort is underway to develop and modify Lab-wide project management policies, procedures and plans, based on these lessons-learned. The formal cost estimating process used to develop the bottoms-up ETC is being incorporated into PPPL policies and procedures. The current training budget for engineering is being augmented.

10. Communicate!

Throughout the Project, PPPL senior management was engaged. They proactively reviewed Project earned value reports in detail, drove value engineering and scope reductions to try to maintain contingency, and were heavily involved in preparations for reviews. There were frequent briefings for PSO and OFES. There were regular updates to SC, especially after the Project was placed on the SC Deputy Director's Watch List in 2006 when modular coil winding form delays and overruns were recognized. The Federal Project Director did draw attention to a looming cost and schedule crisis at that time. Unless such fundamental problems are promptly confronted, there is no real communication. PU senior management became actively involved beginning in 2007 and was a strong advocate of getting the "bad news" out fast, and insuring that it is not only communicated, but also dealt with.

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APPENDICES:

A. NCSX MIE PROJECT CHRONOLOGY

5/98	U.S. Stellarator Proof-of-Principle Program Plan Issued.
6/98	Compact Stellarator Program Approved Following DOE Peer Review; Pre-Conceptual Design of a Proof-of-Principle Experiment Initiated.
3/01	Report From FESAC Proof of Principle Sub-Panel Recommends Further Optimization Studies.
3/01	Physics Validation Review of Physics Requirements & Pre-Conceptual Design Successful.
5/01	Mission Need (CD-0) Approved by DOE.
6/01	FESAC Letter Endorsing Stellarator Proof-of-Principle Experiment Issued.
5/02	DOE-SC Review of Conceptual Design Report Finds Project Ready for CD-1 After Some Revision.
11/02	Preliminary Baseline Range (CD-1) Approved by DOE.
4/03	NCSX MIE Project Begins
11/03	SC Review of Preliminary Design Report Finds Project Ready for CD-2 After Appropriate Consideration to Committee’s Comments & Recommendations. Also, External Independent Review (EIR) by the DOE Office of Engineering & Construction Management (OECM) Endorses Proposed Baseline.
2/04	Performance Baseline (CD-2) Approved by DOE.
6/04	SC Review of Readiness to Start Construction Finds Project Ready for CD-3 Pending Successful Outcome of VVSA and MCWF Procurement Process.
8/04	OFES Notifies PPPL Acknowledging ~ $5M Increase in MCWF & VVSA Fabrication Costs Proposals with Warning of Possible Project Cancellation.
9/04	SC Mini-Review of Project Plan to Absorb the MCWF & VVSA Cost Increase; 22% Contingency Found Low; 5-mo Fabrication Delay Recognized.

9/04	Start of Construction (CD-3) Approved by DOE.
12/04	DOE_SC Mini-Review; Continued Concern Expressed About Technical Complexities & Adequacy of Cost & Schedule Contingency Amounts.
1/05	OFES Alters Funding Profile; Directed Project to Prepare Baseline Change Proposal.
4/05	SC Mini-Review of BCP; Only Changes Attributed to Funding Stretch-out Allowed.
7/05	Baseline Change Approved by DOE Deputy Secretary.
11/05	SC Review Notes Satisfactory Cost & Schedule, but that Critical Work Remains in Early Stages (e.g., Winding Learning Curves); Predict Next 6 mo Would or Would Not Validate Project Cost & Schedule Assumptions.
1/06	Serious MCWF Delivery Delays Cast Doubts on Vendor's Ability to Successfully Perform - Contract Re-Negotiated, & Acceptable Delivery Schedule Established.
??/06	Project Placed on SC Deputy Director's Watch List
5/06	SC Review Notes a Well-Functioning & Appropriately Staffed Project Team; Procurement Risks (e.g., MCWF) Found to be Substantially Reduced While Significant Risks Remained With In-House Assembly.
6/06	PSO Sends PPPL Director Letter Expressing Concerns About Rate of Contingency Drawdown and Requests "Unconstrained Bottoms-Up ETC.
7/06	PPPL Replies to PSO Stating Project Will Have to Manage Within Established Baseline.
11/06	PSO & OFES Meet with SC Director, Resulting in Revised Charge for 12/06 SC Review Asking How Much Additional Contingency Would Be Needed to Successfully Complete Project with "high confidence."
12/06	SC Review of Top-Down ETC that With $12.4M Added to Contingency; Probability for Successfully Completing Project Within 2005 Baseline Found to Be Low; Committee Rejects ETC & Calls for Bottom-Up Estimate to Substantiate Proposed Cost & Schedule Contingency.

2/07	Project Informs PPPL Director that Cost will Significantly Exceed 12/06 Estimate. PPPL Director informs PU.
5/07	PU Establishes EIR. Committee Finds Need for Realistic Cost Estimates, Formal Risk Management, Continued Senior Management Attention.
6/07	PU EIR Recognize Improvements and Work in Progress.
6/07	New Interim Project Manager Appointed by PPPL.
8/07	SC Review of New Bottoms- Up ETC, with $132M TEC & Dec 2011 CD-4 Date, Judged to be Achievable.
9/07	FESAC Science Review of Compact Stellarator Program and NCSX Results in Re-Affirmation of Science Case for NCSX, Even With Delayed Start-Up.
10/07	PU Review of Construction Feasibility Concludes that Team Can Succeed in Building & Maintaining NCSX.
1/08	OFES Directs Project to Prepare "Final" Bottoms-Up ETC and Prepare for SC Review and OECM EIR.
2/08	New Project Manager Appointed by PPPL
3/08	PU Review Finds Final Bottoms-Up ETC Estimates with Contingency to be Credible.
4/08	SC Review Judges Final Bottoms-Up ETC to be Non-Credible Due to Inadequate Design Maturity, Integration Complexity, Evolving Experience Base, Excluded Risk Events, and an Immature Risk Analysis And Contingency Calculation.
5/08	Project Submits Recovery Plan Addressing 4/08 SC EIR Recommendations.
5/08	SC Director Informs PU of Decision to Cancel NCSX Project.
6/08	Project Closeout Proposal Submitted to DOE.
7/08	OFES Concurs With Project Closeout Proposal.
8/08?	Closeout Baseline Change Approved by DOE SC Director.
7/09	Project Closeout Complete.

B. 2005 BASELINE PROJECT PERFORMANCE OBJECTIVES

Parameter	Completion Objective at CD-4
First Plasma	An Ohmically heated stellarator discharge will be produced with: • major radius 1.4 m. • magnetic field of ≥ 0.5 T • plasma current of ≥25kA • at least 50% of the rotational transform provided by stellarator fields. The three-dimensional stellarator geometry will be confirmed by taking video images of the plasma.
Coils and Power Supply Performance.	The coils will be operated at cryogenic temperature and energized with the baseline power supplies (except as noted) to the following currents: • Modular coils: 12 kA • TF Coils: 2 kA • Central Solenoid Coils: 12 kA • PF4 Coils: 3 kA • PF5-6 Coils: 2 kA • Trim Coils: 1 kA. (w/ temp. power supplies).
Magnet System Rating	It will be demonstrated on the basis of component design verification data that the stellarator magnet system of modular coils, TF coils, and PF Ring coils are rated for operation at cryogenic temperatures to support plasma conditions with: • high beta (4%) • magnetic field up to 1.6 T (0.2 s) or 1.2 T (1 s) • Ohmic current drive up to 250 kA • flexibility per the General Requirements Document
Magnet System Accuracy	It will be demonstrated on the basis of design verification data, including electron-beam flux-surface mapping with the coils at room temperature, that the stellarator magnet system of modular coils, TF coils, and PF coils produces vacuum magnetic surfaces.
Vacuum Vessel System Rating	It will be demonstrated on the basis of component design verification data that the vacuum vessel system is rated for high-vacuum performance with: • base pressure less than or equal to 8×10^{-8} torr @293K • global leak rate less than or equal to 5×10^{-5} torr-l/s @293K • bakeable at 150 C.
Vacuum Pressure	A base pressure of $4x10^{-7}$ torr will be achieved.
Vacuum Pumping	A pumping speed of 1,300 l/s at the torus will be achieved.

Parameter	**Completion Objective at CD-4**
Controls	Integrated subsystem tests, to the level required for First Plasma, will be completed for the following systems: • Safety interlocks. • Timing and synchronization. • Power supply real time control. • Data acquisition.
Neutral beams	For one neutral beam injector: • Beamline operating vacuum shall have been achieved. • Beamline cryopanels shall be leak-checked. • A source shall be leak-checked

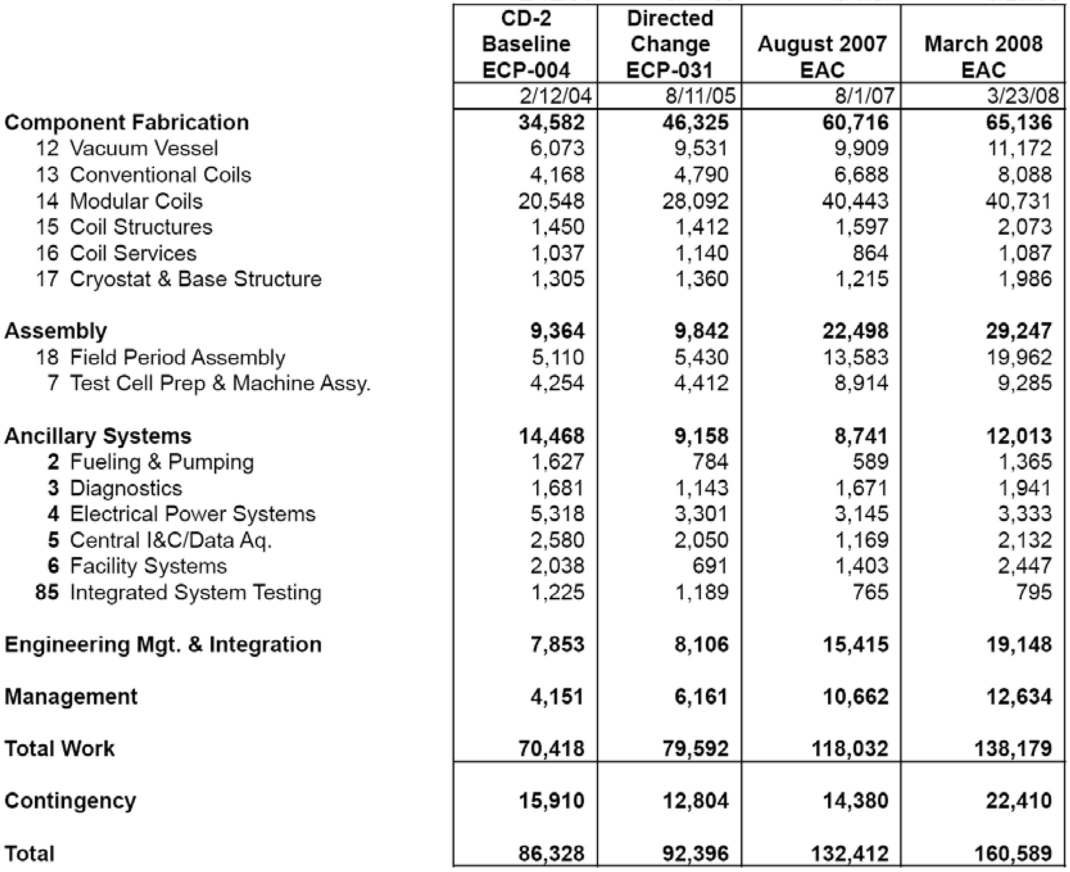
C. FINAL COSTS BY WBS LEVEL 4

[Ron to provide Job-level version of Table 17]:

D. COST ESTIMATE HISTORY

[Update with best & final ETC]

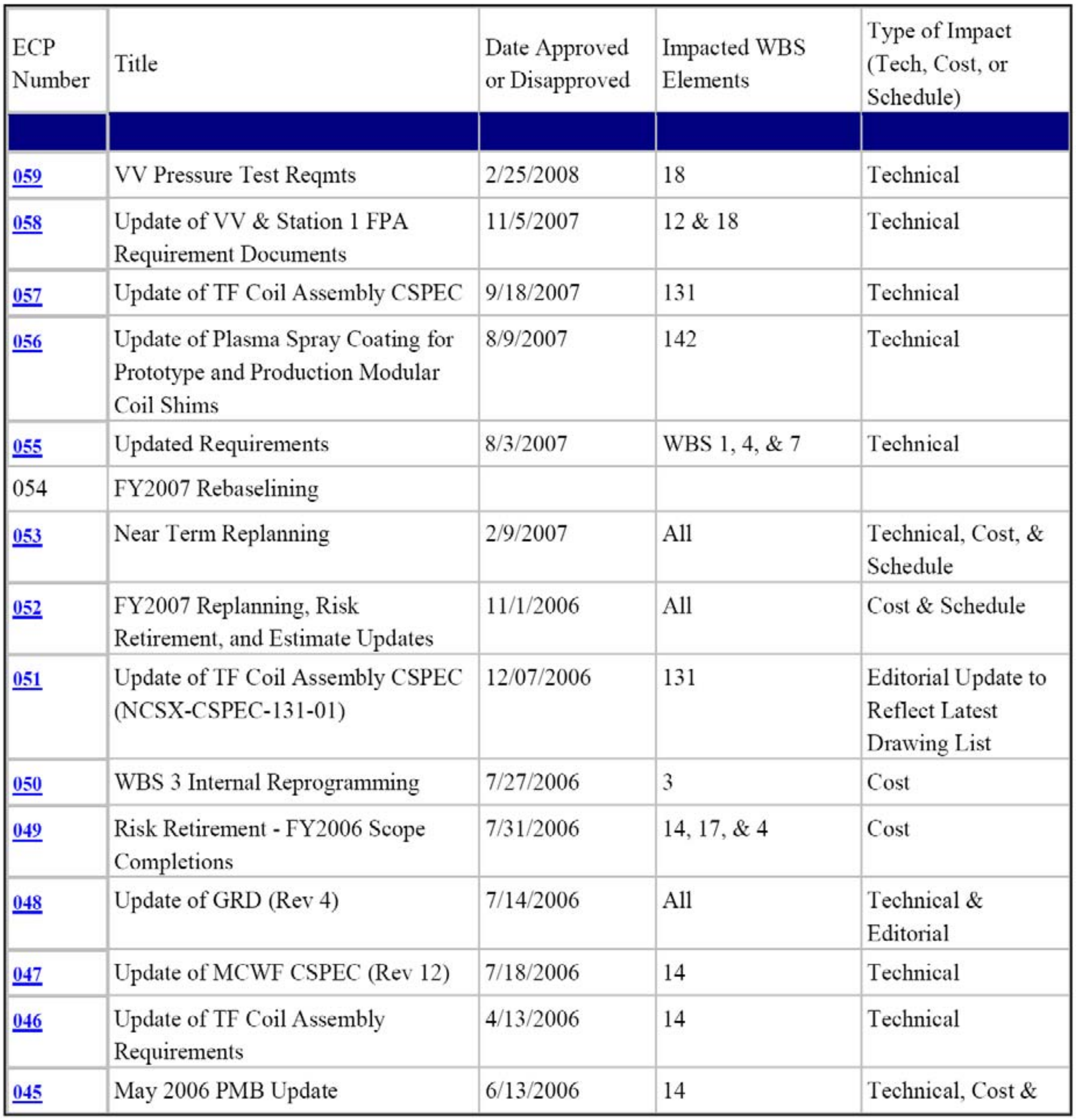
CD-2 Baseline ECP-004 2/12/04 | Directed Change ECP-031 8/11/05 | August 2007 EAC 8/1/07 | March 2008 EAC 3/23/08



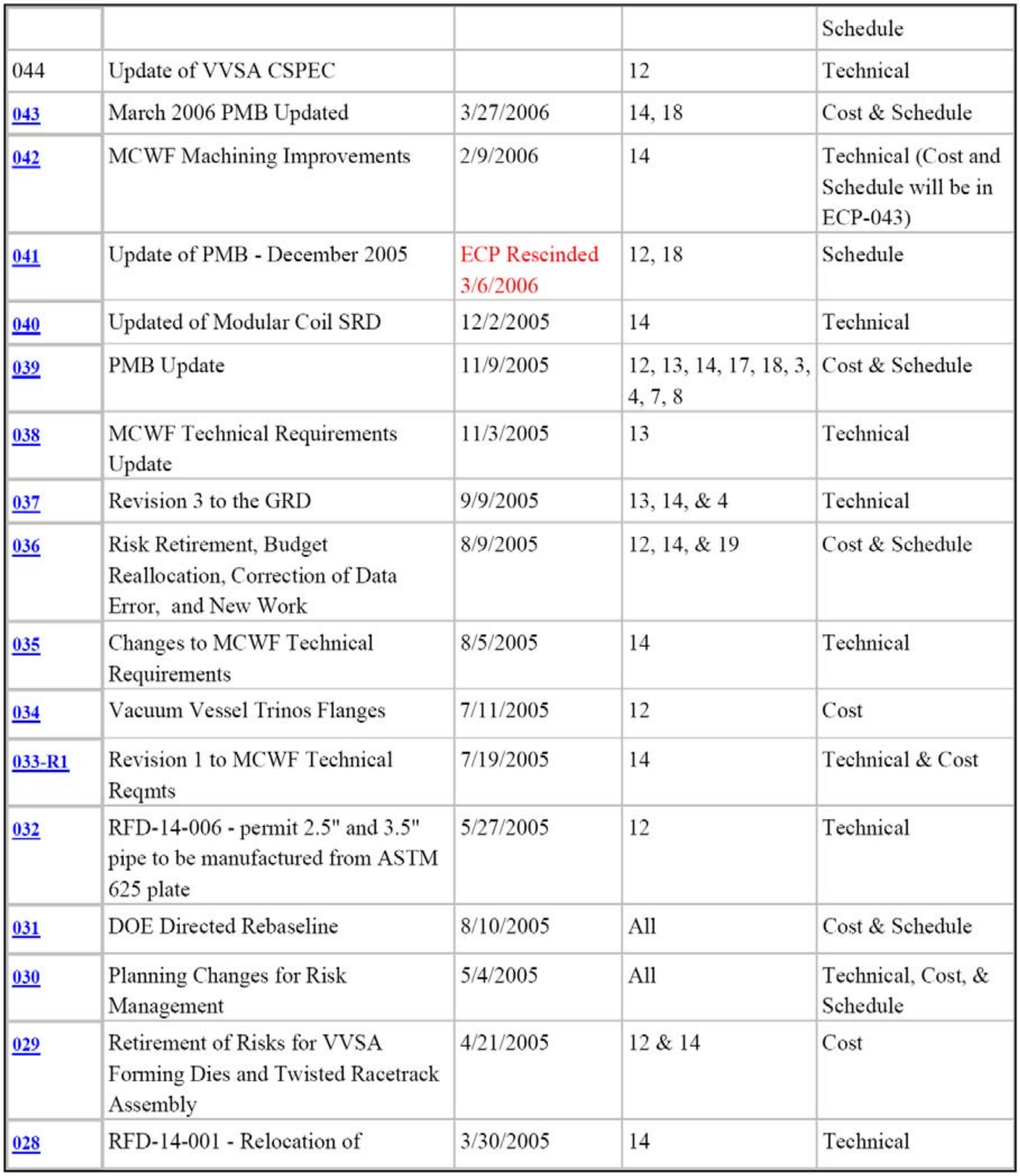
	CD-2 Baseline ECP-004	Directed Change ECP-031	August 2007 EAC	March 2008 EAC
	2/12/04	8/11/05	8/1/07	3/23/08
Component Fabrication	**34,582**	**46,325**	**60,716**	**65,136**
12 Vacuum Vessel	6,073	9,531	9,909	11,172
13 Conventional Coils	4,168	4,790	6,688	8,088
14 Modular Coils	20,548	28,092	40,443	40,731
15 Coil Structures	1,450	1,412	1,597	2,073
16 Coil Services	1,037	1,140	864	1,087
17 Cryostat & Base Structure	1,305	1,360	1,215	1,986
Assembly	**9,364**	**9,842**	**22,498**	**29,247**
18 Field Period Assembly	5,110	5,430	13,583	19,962
7 Test Cell Prep & Machine Assy.	4,254	4,412	8,914	9,285
Ancillary Systems	**14,468**	**9,158**	**8,741**	**12,013**
2 Fueling & Pumping	1,627	784	589	1,365
3 Diagnostics	1,681	1,143	1,671	1,941
4 Electrical Power Systems	5,318	3,301	3,145	3,333
5 Central I&C/Data Aq.	2,580	2,050	1,169	2,132
6 Facility Systems	2,038	691	1,403	2,447
85 Integrated System Testing	1,225	1,189	765	795
Engineering Mgt. & Integration	**7,853**	**8,106**	**15,415**	**19,148**
Management	**4,151**	**6,161**	**10,662**	**12,634**
Total Work	**70,418**	**79,592**	**118,032**	**138,179**
Contingency	**15,910**	**12,804**	**14,380**	**22,410**
Total	**86,328**	**92,396**	**132,412**	**160,589**

		CD-2 Baseline ECP-004	Directed Change ECP-031	August 2007 EAC	March 2008 EAC
		2/12/04	8/11/05	8/1/07	3/23/08
1	**Stellarator Core**	**42,355**	**54,507**	**78,047**	**89,670**
12	Vacuum vessel	6,073	9,531	9,909	11,172
	Design	*2,218*	*3,233*	*3,428*	*3,428*
	Fabrication	*3,856*	*6,298*	*6,481*	*7,744*
13	Conventional Coils	4,168	4,790	6,688	8,088
	TF Coils	*1,690*	*2,555*	*4,055*	*4,151*
	PF & Trim Coils	*2,479*	*2,235*	*2,633*	*3,937*
14	Modular Coils	20,548	28,092	40,443	40,731
	Design & R&D	*2,342*	*4,658*	*7,969*	*7,870*
	Modular Coil Winding Forms	*7,853*	*10,886*	*12,432*	*12,448*
	Modular Coil Fabrication	*9,923*	*12,060*	*18,571*	*18,941*
	Modular Coil Testing	*430*	*488*	*1,472*	*1,472*
15	Coil Structures	1,450	1,412	1,597	2,073
	Design	*310*	*221*	*517*	*629*
	Fabrication	*1,140*	*1,191*	*1,080*	*1,443*
16	Coil Services	1,037	1,140	864	1,087
	Design & Fabrication	*1,037*	*1,140*	*864*	*1,087*
17	Cryostat & Base Structure	1,305	1,360	1,215	1,986
	Cryostat & Base Structure	*1,305*	*1,360*	*1,215*	*1,986*
18	Field Period Assembly	5,110	5,430	13,583	19,962
	Design, Constructability, & Tooling	*1,427*	*1,281*	*2,276*	*2,884*
	Assembly Operations	*3,684*	*4,149*	*11,307*	*17,078*
19	Stellarator Core Mgt. & Int.	2,663	2,752	3,748	4,572
	Stellarator Core Mgt. & Int.	*2,663*	*2,752*	*3,748*	*4,572*
2	**Auxiliary Systems**	**1,627**	**784**	**589**	**1,365**
	Fueling	*140*	*151*	*132*	*401*
	Torus Vacuum Pump	*384*	*349*	*172*	*679*
	Neutral Beams	*1,103*	*284*	*285*	*285*
3	**Diagnostics**	**1,681**	**1,143**	**1,671**	**1,941**
	Magnetic Diagnostics	*1,290*	*787*	*1,377*	*1,653*
	Imaging & e-beam mapping	*391*	*356*	*294*	*288*
4	**Electrical Power Systems**	**5,318**	**3,301**	**3,145**	**3,333**
	Electrical Power Systems	*5,318*	*3,301*	*3,145*	*3,333*
5	**Central I&C/Data Aq.**	**2,580**	**2,050**	**1,169**	**2,132**
	Central I&C/Data Aq.	*2,580*	*2,050*	*1,169*	*2,132*
6	**Facility Systems**	**2,038**	**691**	**1,403**	**2,447**
	Cryogenic Systems	*747*	*463*	*655*	*1,568*
	Vacuum Vessel Bakeout System	*629*	*-*	*573*	*634*
	Other	*661*	*228*	*175*	*246*
7	**Test Cell Prep & Machine Assy.**	**4,254**	**4,412**	**8,914**	**9,285**
	Design, Area Prep, & Tooling	*492*	*482*	*724*	*720*
	Assembly Operations	*3,762*	*3,930*	*8,190*	*8,565*
8	**Project Mgt. & Integration**	**10,566**	**12,704**	**23,019**	**27,930**
81	Project management	3,195	4,584	7,718	8,843
82	Engineering Mgt. & Integration	4,689	4,884	11,197	14,105
	Eng. Mgt. / System Integ. Support	*288*	*2,835*	*5,295*	*6,437*
	System Engineering	*4,401*	*2,049*	*5,901*	*7,668*
84	Project Physics	501	470	470	*470*
85	Integrated System Testing	1,225	1,189	765	*795*
89	Allocations	956	1,577	2,869	*3,716*
	Total Work	**70,418**	**79,592**	**117,957**	**138,104**
	DCMA			75	*75*
	Contingency	**15,910**	**12,804**	**14,380**	**22,410**
	Total	**86,333**	**92,401**	**132,412**	**160,589**

E. BASELINE CHANGE CONTROL LOG

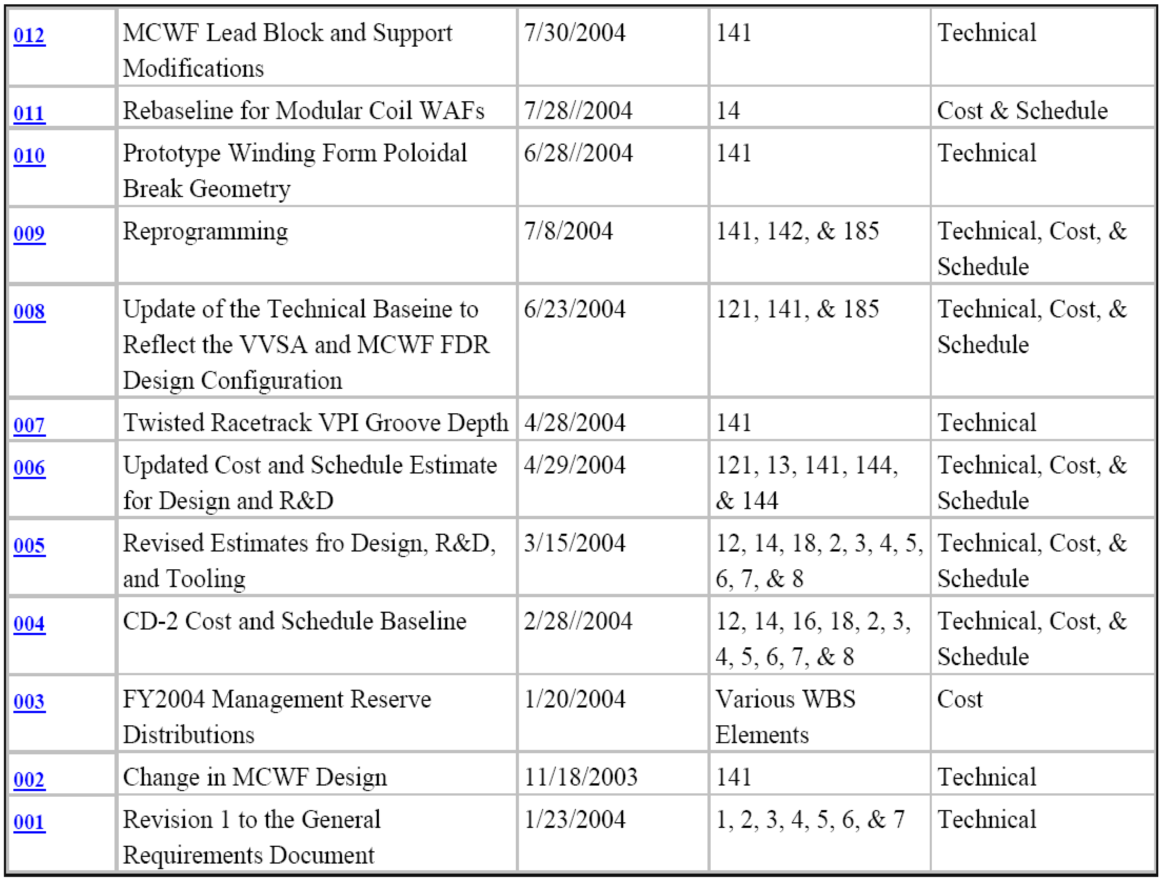


ECP Number	Title	Date Approved or Disapproved	Impacted WBS Elements	Type of Impact (Tech, Cost, or Schedule)
059	VV Pressure Test Reqmts	2/25/2008	18	Technical
058	Update of VV & Station 1 FPA Requirement Documents	11/5/2007	12 & 18	Technical
057	Update of TF Coil Assembly CSPEC	9/18/2007	131	Technical
056	Update of Plasma Spray Coating for Prototype and Production Modular Coil Shims	8/9/2007	142	Technical
055	Updated Requirements	8/3/2007	WBS 1, 4, & 7	Technical
054	FY2007 Rebaselining			
053	Near Term Replanning	2/9/2007	All	Technical, Cost, & Schedule
052	FY2007 Replanning, Risk Retirement, and Estimate Updates	11/1/2006	All	Cost & Schedule
051	Update of TF Coil Assembly CSPEC (NCSX-CSPEC-131-01)	12/07/2006	131	Editorial Update to Reflect Latest Drawing List
050	WBS 3 Internal Reprogramming	7/27/2006	3	Cost
049	Risk Retirement - FY2006 Scope Completions	7/31/2006	14, 17, & 4	Cost
048	Update of GRD (Rev 4)	7/14/2006	All	Technical & Editorial
047	Update of MCWF CSPEC (Rev 12)	7/18/2006	14	Technical
046	Update of TF Coil Assembly Requirements	4/13/2006	14	Technical
045	May 2006 PMB Update	6/13/2006	14	Technical, Cost &



				Schedule
044	Update of VVSA CSPEC		12	Technical
043	March 2006 PMB Updated	3/27/2006	14, 18	Cost & Schedule
042	MCWF Machining Improvements	2/9/2006	14	Technical (Cost and Schedule will be in ECP-043)
041	Update of PMB - December 2005	ECP Rescinded 3/6/2006	12, 18	Schedule
040	Updated of Modular Coil SRD	12/2/2005	14	Technical
039	PMB Update	11/9/2005	12, 13, 14, 17, 18, 3, 4, 7, 8	Cost & Schedule
038	MCWF Technical Requirements Update	11/3/2005	13	Technical
037	Revision 3 to the GRD	9/9/2005	13, 14, & 4	Technical
036	Risk Retirement, Budget Reallocation, Correction of Data Error, and New Work	8/9/2005	12, 14, & 19	Cost & Schedule
035	Changes to MCWF Technical Requirements	8/5/2005	14	Technical
034	Vacuum Vessel Trinos Flanges	7/11/2005	12	Cost
033-R1	Revision 1 to MCWF Technical Reqmts	7/19/2005	14	Technical & Cost
032	RFD-14-006 - permit 2.5" and 3.5" pipe to be manufactured from ASTM 625 plate	5/27/2005	12	Technical
031	DOE Directed Rebaseline	8/10/2005	All	Cost & Schedule
030	Planning Changes for Risk Management	5/4/2005	All	Technical, Cost, & Schedule
029	Retirement of Risks for VVSA Forming Dies and Twisted Racetrack Assembly	4/21/2005	12 & 14	Cost
028	RFD-14-001 - Relocation of	3/30/2005	14	Technical

	Pattern/Casting ID Number			
027	RFD-12-002R1 - Substitution of Sch10 Pipe for Sch40 Pipe for the 2.5" Pipe	3/24/2005	12	Technical
026	MCWF Fast Response	3/14/2005	141	Technical
025	RFD-12-001 - Manufacture of the 6", 8" and 10" Pipe from ASTM 625 Plate	3/10/2005	12	Technical
024	Miscellaneous Rescheduling and Contingency Draw for Added and Re-Estimated Scope	3/7/2005	12, 13, 81 & 82	Technical, Cost, & Schedule
023	MCWF Minimum Mechanical Properties	2/17/2005	141	Technical
022 R1	TRC Design Updates	R1 - 2/3/2005	142	Technical, Cost, & Schedule
021	Job Close-Out & Contingency Drawdown	1/31/2005	12, 141, 142, & 84	Cost & Schedule
020	Resolution of MCWF Questions (Dec-2004)	1/14/2005	141	Technical
019	VVSA Contract Addenda 3-1 though 3-3	1/25/2005	121	Technical
018	FY005 Replanning Baseline	11/19/2004	12, 14, 15, 18, 19, 3, 4, 5, & 7	Technical, Cost, & Schedule
017R1	VVSA Inner Support Bosses	11/9/2004	121	Technical
016R1	Reprogramming for FY2004 Closeout	11/9/2004	121, 133, 141, 142, 144, 19, 21, 432, 612, 614, & 82	Technical, Cost, & Schedule
015	Final Technical Scope of MCWF	9/17/2004	141	Technical
014	CD-3 Replanning	9/20/2004	12, 14, 187, 25, 3, 4, 5, 62, 64, 81, 82, 84, & 85	Technical, Cost, & Schedule
013	Modifications to VV Joint R&D Seals and End Pieces	7/30/2004	121	Technical & Cost

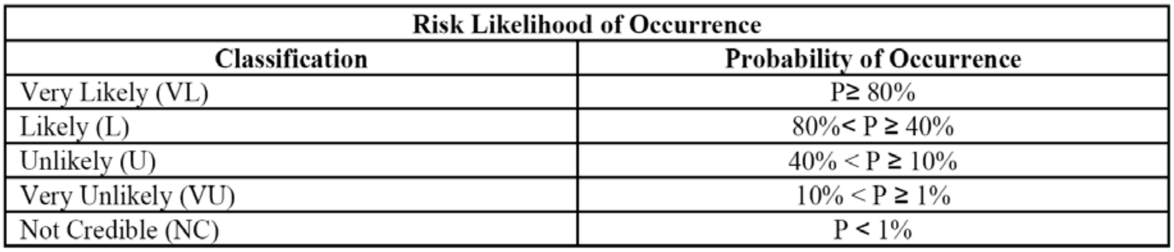


012	MCWF Lead Block and Support Modifications	7/30/2004	141	Technical
011	Rebaseline for Modular Coil WAFs	7/28//2004	14	Cost & Schedule
010	Prototype Winding Form Poloidal Break Geometry	6/28//2004	141	Technical
009	Reprogramming	7/8/2004	141, 142, & 185	Technical, Cost, & Schedule
008	Update of the Technical Baseine to Reflect the VVSA and MCWF FDR Design Configuration	6/23/2004	121, 141, & 185	Technical, Cost, & Schedule
007	Twisted Racetrack VPI Groove Depth	4/28/2004	141	Technical
006	Updated Cost and Schedule Estimate for Design and R&D	4/29/2004	121, 13, 141, 144, & 144	Technical, Cost, & Schedule
005	Revised Estimates fro Design, R&D, and Tooling	3/15/2004	12, 14, 18, 2, 3, 4, 5, 6, 7, & 8	Technical, Cost, & Schedule
004	CD-2 Cost and Schedule Baseline	2/28//2004	12, 14, 16, 18, 2, 3, 4, 5, 6, 7, & 8	Technical, Cost, & Schedule
003	FY2004 Management Reserve Distributions	1/20/2004	Various WBS Elements	Cost
002	Change in MCWF Design	11/18/2003	141	Technical
001	Revision 1 to the General Requirements Document	1/23/2004	1, 2, 3, 4, 5, 6, & 7	Technical

F. RISK MANAGEMENT

The NCSX Risk Management Plan (NCSX-PLAN-RMP-01) was substantially revised in 2008, considering factors within the Project's control that both threatened and provided opportunities to improve project cost and schedule performance and the achievement of project technical objectives. Risk analysis involved a systematic evaluation of identified risk events by determining the probability of occurrence and consequences, assigning a risk rating based on established criteria, and prioritizing the risks. The first step in the risk analysis process was to determine for each risk event the probability that the risk item will actually occur. Table 19 provides guidelines for classifying risks in terms of likelihood that they will occur.

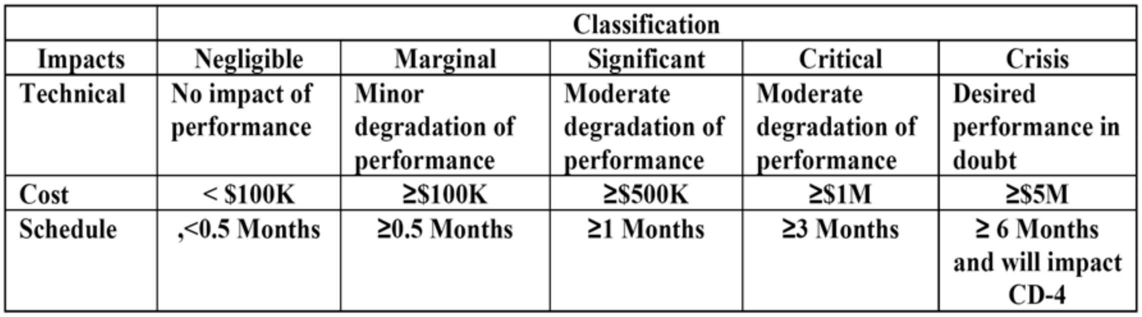
Table 19



Risk Likelihood of Occurrence	
Classification	**Probability of Occurrence**
Very Likely (VL)	P≥ 80%
Likely (L)	80%< P ≥ 40%
Unlikely (U)	40% < P ≥ 10%
Very Unlikely (VU)	10% < P ≥ 1%
Not Credible (NC)	P < 1%

The next step was to determine for each risk item the magnitude of the consequences should the event occur. For NCSX, consequences were assessed in terms of cost and schedule impacts, and classified in accordance with Table 20.

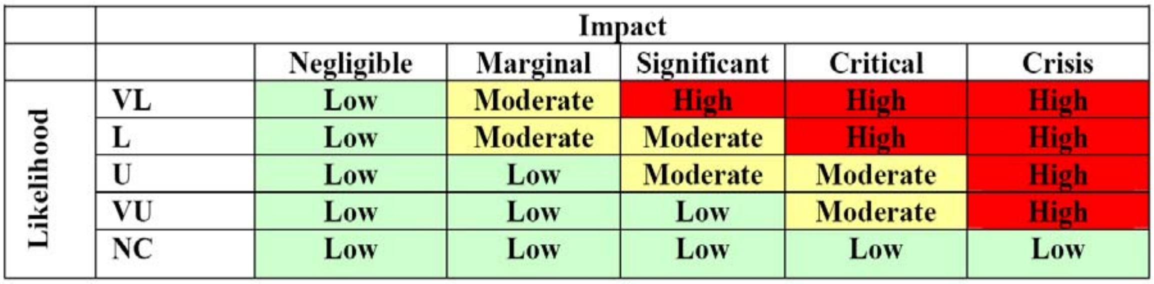
Table 20: Risk Consequences



	Classification				
Impacts	**Negligible**	**Marginal**	**Significant**	**Critical**	**Crisis**
Technical	**No impact of performance**	**Minor degradation of performance**	**Moderate degradation of performance**	**Moderate degradation of performance**	**Desired performance in doubt**
Cost	**< $100K**	**≥$100K**	**≥$500K**	**≥$1M**	**≥$5M**
Schedule	**,<0.5 Months**	**≥0.5 Months**	**≥1 Months**	**≥3 Months**	**≥ 6 Months and will impact CD-4**

Once the risk likelihood and consequences were established, a risk ranking was assigned to each risk item. This rating was a qualitative measure of the severity of the risk item and provides a starting point for development of risk management priorities. The risk ranking was assessed based on likelihood and consequences, and classified as high, medium, or low in accordance with Table 21.

Table 21: Risk-Ranking Matrix

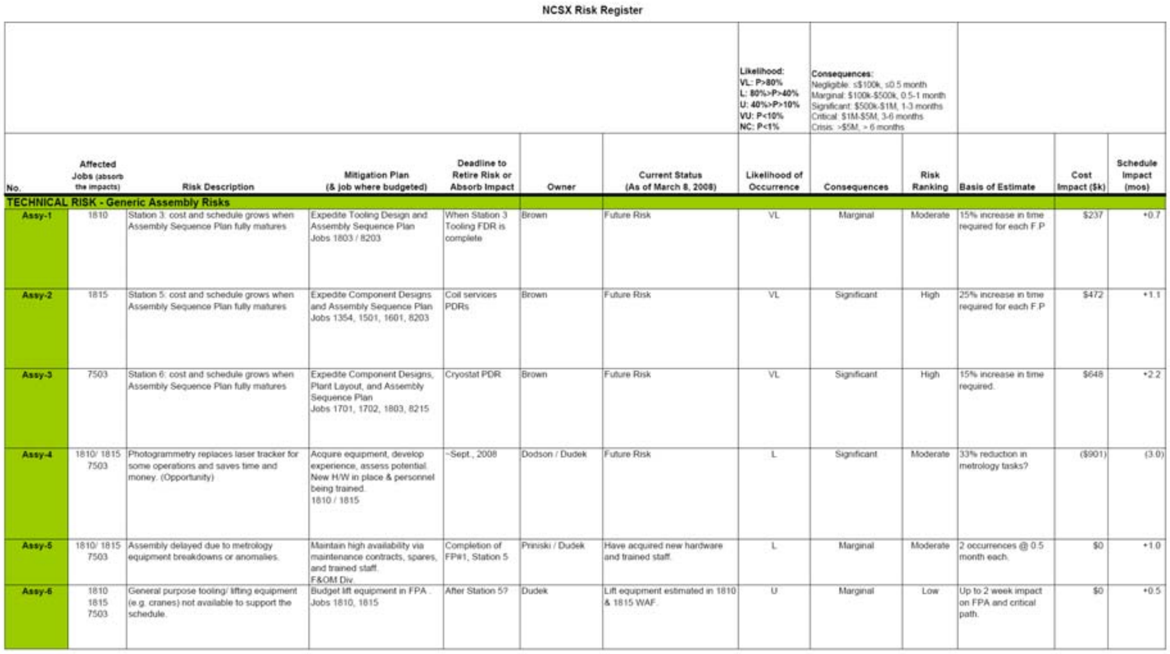


		Impact				
		Negligible	Marginal	Significant	Critical	Crisis
Likelihood	VL	Low	Moderate	High	High	High
	L	Low	Moderate	Moderate	High	High
	U	Low	Low	Moderate	Moderate	High
	VU	Low	Low	Low	Moderate	High
	NC	Low	Low	Low	Low	Low

There were four approaches to handling risk: avoidance, transfer, mitigation, and acceptance. Risk avoidance represented change in the concept, requirements, specifications, and/or practices that reduce risk to an acceptable level. Risk transfer represented an allocation of risk to other activities outside the NCSX MIE project, thereby reducing the overall project risk. Risk mitigation represented the implementation of activities to reduce the consequences (likelihood and/or impact) of a risk event. The goal of mitigation was to retire risks so that their consequences did not affect the project or to minimize those consequences to the project. Mitigation activities were typically budgeted and scheduled in the project baseline unless those activities were on hold pending further project development or the occurrence of certain risk triggers. Risk acceptance was an acknowledgment of the existence of a particular risk situation and a conscious decision to accept the impact on the project's baseline. Acceptance could entail a decision not to mitigate a risk, or a decision to accept a residual risk after mitigation activities were completed. The impacts of an accepted risk were to be budgeted and scheduled in the project baseline.

Priority was placed on identifying and mitigating risks. The NCSX risk registry was the vehicle for documenting identified risks, risk mitigation activities, affected jobs, ownership responsibilities, retirement deadlines, likelihood, consequences, estimated impacts and their bases, and the risk level classification. In 2008, the risk registry key input grew from 36 to 88 items that were statused and updated monthly. A snapshot of one page from the NCSX risk registry is illustrated in Fig. 24.

Each Job Manager was responsible for developing a detailed and thorough estimate of the resources in their WAFs. Both cost estimates and schedule durations had inherent levels of uncertainty that was a result of the degree of design maturity and complexity of the elements involved – in effect, how much definition exists to provide a basis for the estimate. As means to measure this uncertainty, the NCSX Project developed standard definitions for both design maturity complexity categorizations as shown in Tables 22 and Table 23.



NCSX Risk Register

							Likelihood: **VL: P>80%** **L: 80%>P>40%** **U: 40%>P>10%** **VU: P<10%** **NC: P<1%**	**Consequences:** Negligible: ≤$100k, ≤0.5 month Marginal: $100k-$500k, 0.5-1 month Significant: $500k-$1M, 1-3 months Critical: $1M-$5M, 3-6 months Crisis: >$5M, > 6 months				
No.	**Affected Jobs (absorb the impacts)**	**Risk Description**	**Mitigation Plan (& job where budgeted)**	**Deadline to Retire Risk or Absorb Impact**	**Owner**	**Current Status (As of March 8, 2008)**	**Likelihood of Occurrence**	**Consequences**	**Risk Ranking**	**Basis of Estimate**	**Cost Impact ($k)**	**Schedule Impact (mos)**
TECHNICAL RISK - Generic Assembly Risks												
Assy-1	1810	Station 3: cost and schedule grows when Assembly Sequence Plan fully matures	Expedite Tooling Design and Assembly Sequence Plan Jobs 1803 / 8203	When Station 3 Tooling FDR is complete	Brown	Future Risk	VL	Marginal	Moderate	15% increase in time required for each F.P	$237	+0.7
Assy-2	1815	Station 5: cost and schedule grows when Assembly Sequence Plan fully matures	Expedite Component Designs and Assembly Sequence Plan Jobs 1354, 1501, 1601, 8203	Coil services PDRs	Brown	Future Risk	VL	Significant	High	25% increase in time required for each F.P	$472	+1.1
Assy-3	7503	Station 6: cost and schedule grows when Assembly Sequence Plan fully matures	Expedite Component Designs, Plant Layout, and Assembly Sequence Plan Jobs 1701, 1702, 1803, 8215	Cryostat PDR	Brown	Future Risk	VL	Significant	High	15% increase in time required.	$648	+2.2
Assy-4	1810/ 1815 7503	Photogrammetry replaces laser tracker for some operations and saves time and money. (Opportunity)	Acquire equipment, develop experience, assess potential. New H/W in place & personnel being trained. 1810 / 1815	~Sept., 2008	Dodson / Dudek	Future Risk	L	Significant	Moderate	33% reduction in metrology tasks?	($901)	(3.0)
Assy-5	1810/ 1815 7503	Assembly delayed due to metrology equipment breakdowns or anomalies.	Maintain high availability via maintenance contracts, spares, and trained staff. F&OM Div.	Completion of FP#1, Station 5	Priniski / Dudek	Have acquired new hardware and trained staff.	L	Marginal	Moderate	2 occurrences @ 0.5 month each.	$0	+1.0
Assy-6	1810 1815 7503	General purpose tooling/ lifting equipment (e.g. cranes) not available to support the schedule.	Budget lift equipment in FPA. Jobs 1810, 1815	After Station 5?	Dudek	Lift equipment estimated in 1810 & 1815 WAF.	U	Marginal	Low	Up to 2 week impact on FPA and critical path.	$0	+0.5

Figure 24: Snapshot page from the NCSX MIE Risk Registry

Table 22: Design maturity definitions

Design Maturity	Definition
High	Final design available. All design features/requirements are well known. No further significant design development or evolution is expected that will impact the estimate => relatively low probability of change..
Medium	Preliminary design is available. Some additional design evolution is likely. Further developments can be anticipate and will impact the estimate => relatively moderate probability of change..
Low	At the conceptual design level. Design details still need much development and evolution of requirements beyond the current estimate basis is anticipated and very likely => relatively high probability of change.

Table 23: Design complexity definitions

Design Maturity	Definition
Low	Work is fairly well understood – either standard construction or repetition of activities performed in the past. Little likelihood of estimate not being well understood and requirements not being well defined
Medium	More complex work requirements that have potential to impact cost and schedule estimates. Relatively limited experience performing similar tasks, so ability to estimate accurately is somewhat limited.
High	Extremely challenging tasks and/or requirements. Unique or first-of-a-kind assembly or work tasks. Very limited basis for estimating this work exists, so there is a high degree of uncertainty.

Table 24 translates the combination of design maturity and design complexity into uncertainty ranges that were used in NCSX contingency analysis. These ranges were based on standard industry and DOE estimate classifications (*e.g.,* ASCEI Recommended Practice 18R-97, *Cost Estimate Classification System*).

Table 24: NCSX Estimate Uncertainty Ranges

	Design Complexity			
		Low	**Medium**	**High**
Design Maturity	**Low**	**- 15% to +25%**	**-20% to +40%**	**-30% to +60%**
	Medium	**-10% to +15%**	**-15% to +25%**	**-20% to +40%**
	High	**-5% to +10%**	**-10% to +15%**	**-15% to +25%**

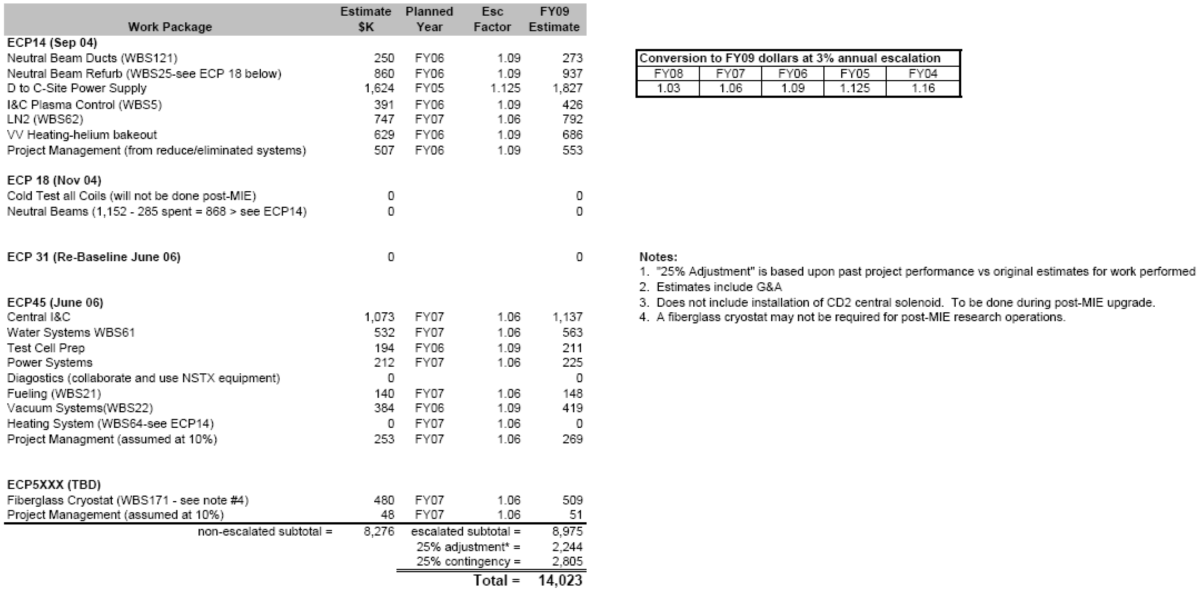
The NCSX Project employed a structured process to assess and analyze all areas of risk and uncertainty that might affect the cost and schedule estimates on the projects. Probabilistic risk assessment techniques with Monte Carlo analyses were used. Inputs to this analysis were the uncertainty ranges for each job and the likelihood and impacts for each risk. The result was an estimate of the cost and schedule contingency allowances required to cover the estimated uncertainties and risks in the project for a given level of confidence that the proposed baseline estimates would not exceed. Further details may be found in the report *NCSX Project Contingency*.

G. CONTINGNECY USE

[Ron, Hutch, & Don to fill in]

ECP No.	Date	Description	Contingency Allocation ($K)	Scope Change ($K)

[Considerations for Scope Reduction ECPs:]



Work Package	Estimate $K	Planned Year	Esc Factor	FY09 Estimate
ECP14 (Sep 04)				
Neutral Beam Ducts (WBS121)	250	FY06	1.09	273
Neutral Beam Refurb (WBS25-see ECP 18 below)	860	FY06	1.09	937
D to C-Site Power Supply	1,624	FY05	1.125	1,827
I&C Plasma Control (WBS5)	391	FY06	1.09	426
LN2 (WBS62)	747	FY07	1.06	792
VV Heating-helium bakeout	629	FY06	1.09	686
Project Management (from reduce/eliminated systems)	507	FY06	1.09	553
ECP 18 (Nov 04)				
Cold Test all Coils (will not be done post-MIE)	0			0
Neutral Beams (1,152 - 285 spent = 868 > see ECP14)	0			0
ECP 31 (Re-Baseline June 06)	0			0
ECP45 (June 06)				
Central I&C	1,073	FY07	1.06	1,137
Water Systems WBS61	532	FY07	1.06	563
Test Cell Prep	194	FY06	1.09	211
Power Systems	212	FY07	1.06	225
Diagostics (collaborate and use NSTX equipment)	0			0
Fueling (WBS21)	140	FY07	1.06	148
Vacuum Systems(WBS22)	384	FY06	1.09	419
Heating System (WBS64-see ECP14)	0	FY07	1.06	0
Project Managment (assumed at 10%)	253	FY07	1.06	269
ECP5XXX (TBD)				
Fiberglass Cryostat (WBS171 - see note #4)	480	FY07	1.06	509
Project Management (assumed at 10%)	48	FY07	1.06	51
non-escalated subtotal =	8,276	escalated subtotal =		8,975
		25% adjustment* =		2,244
		25% contingency =		2,805
		Total =		**14,023**

Conversion to FY09 dollars at 3% annual escalation				
FY08	FY07	FY06	FY05	FY04
1.03	1.06	1.09	1.125	1.16

Notes:

1. "25% Adjustment" is based upon past project performance vs original estimates for work performed
2. Estimates include G&A
3. Does not include installation of CD2 central solenoid. To be done during post-MIE upgrade.
4. A fiberglass cryostat may not be required for post-MIE research operations.

H. ACQUISITION CONTRACT STATUS

[Rod & Ron to determine format & content]

I. STAFFING

Two Charts:

- **A. Total FTEs per year at PPPL & ORNL (stacked bar)**
- **B. Total FTEs per year per WBS (stacked bar)**

J. MAJOR EXTERNAL NCSX PROJECT REVIEWS

Review materials & reports archived at:
http://ncsx.pppl.gov/Management/Mgmnt.html

No	Date	Sponsor	Review Topic/Report	Purpose
1	3/01	DOE-OFES	Physics Validation Review	Pre-CDR Validation
2	5/02	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	CDR Approval
3	2/03	DOE-PSO	Project Control Systems Review	Compliance Audit
4	10/03	PPPL Director	Preliminary Design Review	PDR Validation
5	11/03	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	CD-2 Readiness
6	11/03	DOE-OECM	External Independent Review of Acquisition Performance Baseline	CD-2 Readiness
7	2/04	ESAAB	Establishing Performance Baseline	CD-2 Approval
8	5/04	PPPL Director	Final Design Review	CD-3 Readiness
9	6/04	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	CD-3 Readiness
10	9/04	DOE-SC	Technical, Cost, Schedule, , and Management Mini-Review of NCSX	CD-3 Readiness
11	9/04	ESAAB	Starting Construction	CD-3 Approval
12	12/04	DOE-SC	Technical, Cost, Schedule, , and Management Mini-Review of NCSX	Status Review
13	4/05	DOE-SC	Mini-Review of Proposed BCP	BCP Concurrence
14	7/05	ESAAB	OFES directed baseline change due	Approval ECP #031

			to funding profile changes	
15	11/05	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	Status Review
16	5/06	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	Status Review
17	9/06	DOE-SC	Technical, Cost, Schedule, , and Management Mini-Review of NCSX	Status Review
18	12/06	DOE-PSO	Cost, Schedule, and Management Review of NCSX	Status Review
19	6/07	PU	Review of NCSX Cost & Schedule	Status Review
20	8/07	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	Status Review
21	9/07	DOE-OFES	FESAC Scientific and Programmatic Review	Re-validation of mission need
22	11/07	PU	NCSX Construction Feasibility Review	Validation of construction and assembly plans
23	3/08	PU	Review of the NCSX Project	BCP assist visit
24	4/08	DOE-SC	Technical, Cost, Schedule, ES&H, and Management Review of NCSX	Status Review

K. PROJECT TERMINATION & CLOSEOUT COMPLETION DOCUMENTATION

Statement by Dr. Raymond L. Orbach
Under Secretary for Science and Director, Office of Science
U.S. Department of Energy
May 22, 2008

Future of the Princeton Plasma Physics Laboratory (PPPL)

In late 2006, it became clear that National Compact Stellarator Experiment (NCSX) construction project would not be able to meet its approved baseline total project cost of $102M or its completion date of July 2009. Since then, DOE, Princeton University, and PPPL have worked extensively together to understand the issues and plot a course of action that maximizes the benefits for the scientific community and the taxpayers, and ensures an exciting path for PPPL research well into the future. Following several internal and external reviews over the past 18 months, it has been concluded that the budget increases, schedule delays and continuing uncertainties of the NCSX construction project necessitate its closure, and that PPPL's future as a world-leading center of fusion energy and plasma sciences is more assured by a renewed focus on the successful Spherical Torus confinement concept.

The Office of Science always weighs the scientific benefits to be obtained from facilities against the cost to the taxpayer – in this case the escalating costs and remaining uncertainties make continuation of the construction project untenable. The latest cost estimate is $170M with an August 2013 scheduled completion. An Office of Science review (April 2008) concluded that the project has not yet met the requirements needed to approve a new baseline cost and schedule. This puts the future of research at PPPL in unnecessary peril, and increases the burden on the DOE fusion energy sciences program. It would require the premature closure of the Spherical Torus experiment (NSTX), a proven, productive, world-leading scientific facility, while creating an uncertain gap in research capabilities at PPPL. This would result in a loss of opportunities for a large number of collaborators in the research community and constrain the ability to start new initiatives during the ITER era.

The highest priority of the U.S. fusion program is participation in the international ITER burning plasma experiment, which is based on the tokamak concept. The Spherical Torus is closely related to the tokamak, and experiments planned for the next several years in the NSTX facility promise many exciting discoveries that should directly impact our ability to understand the new plasma regimes expected in ITER. The Spherical Torus may also prove to be a prototype for the next step for the U.S. domestic fusion program. Proposed upgrades for the Spherical Torus experiment at PPPL can keep this facility at the forefront of fusion science research in the world well into the future. As such, a concentration on the Spherical Torus better positions PPPL to remain a center of excellence for fusion energy and plasma sciences, and thereby compete for new areas of leadership in the future fusion program.

Closure of the Compact Stellarator construction effort will be managed to capture many benefits of the project. PPPL will complete the special modular and toroidal field coils in FY 2008. A modest engineering effort will document the R&D achievements to date, and continue to retire remaining risks of the Compact Stellarator design to allow revisiting this particular design if future developments in the fusion program warrant it. In addition, the U.S. fusion program will increase its investments in theory and smaller focused experiments on stellarator concepts to maintain its interest in future development of these exciting plasma confinement concepts.

We believe this decision is in the best interests of the American fusion program PPPL and Princeton University. Our decision reflects our strong commitment to the future of PPPL as a center of scientific excellence, including the prospect that it will compete successfully for opportunities to extend its work in plasma and fusion science in a number of important and promising new directions.

Record of Decision Memo

Questions/to do:

1. learning curve charts (Ron + JMs)
2. Table 14 original (Bob)
3. ORNL Safety Stats (Jeff)
4. Contingency use table (Ron)
5. Acquisition Contracts Status (Rod & Ron)
6. Staffing
    a. PPPL (Ron)
    b. ORNL (Jeff/Mike M)