NCSX Baseline Change Summary

August 2, 2007

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1. Introduction

Over the last six months, the NCSX Project has completed a bottoms-up estimate-to-complete (ETC) the remaining work. This exercise was directed by DOE, following a recommendation from the last Office of Science review of NCSX on December 19, 2006. A change in the performance baseline is proposed based on this estimate, so the project can be completed successfully. This document summarizes the impact of the new estimate on the performance baseline parameters. The Project Execution Plan will be updated to reflect these changes.

The NCSX project started on April 1, 2003 and CD-2 was approved in February, 2004. The current baseline was approved in July, 2005 following a directed change due to a stretchout of the funding profile. In the four years since it started, the project has made good technical progress and accomplished all but one of its milestones on schedule. Manufacture of the vacuum vessel and of the modular coil winding forms, the project's two largest procurements, have been completed. A fixed-price contract for the eighteen toroidal field coils is in place and the first coil is nearly completed. Thirteen of the eighteen modular coils have been completed through winding and epoxy impregnation. Field period assembly activities have started.

The project is technically challenging because of the required complex geometries and tight tolerances. As a result, the cost of the work performed to date has exceeded CD-2 estimates. The technical experience gained in the first four years of the project has also provided a better understanding of the challenges and costs expected in the remaining work than existed at CD-2. The new job estimates have taken advantage of this improved understanding, for example the metrology and engineering support required to achieve NCSX assembly tolerances, and have made allowances for problems that the job managers expect to encounter. Job estimates were internally reviewed by the PPPL Engineering Dept. to ensure completeness and a common standard of realism. Contingencies were determined based on a probabilistic (Monte Carlo) analysis of the estimating uncertainties and risks in the remaining work. The process was further strengthened by two external reviews, sponsored by Princeton University, which examined the job-level and project-level estimates and analyses.

2. Summary of Cost, Schedule and Funding Changes

Item	**Current ECP-53**	**Proposed ECP-54**	**Comment**
Cost ($M)			
Cost through April 30, 2007	67.2		
ETC from May 1, 2007 (w/o contingency)	21.6	50.8	
EAC (w/o contingency)	88.8	118.0	
Contingency free balance at May 1, 2007	3.6	14.4	28.3% of ETC
Total Estimated Cost	**92.4**	**132.4**	**$40.0M increase**
Schedule			
ETC from May 1, 2007 (w/o contingency)	22	45	
Early Finish	Feb. 2009	Jan. 2011	
Contingency (months)	5	11	
Project Completion (CD-4)	**Jul. 2009**	**Dec. 2011**	**29 months delay**

Item	Current ECP-53	Proposed ECP-54	Comment
Funding Profile ($M)			
2003	7.9	7.9	
2004	15.9	15.9	
2005	17.5	17.5	
2006	17.0	17.0	
2007	15.9	15.9	
2008	15.9	15.9	Cong. budget
2009	2.3	18.6	OFES guidance
2010		17.0	
2011		6.7	
Total	**92.40**	**132.4**	

3. Level 1 and 2 Milestones

Of the 36 Level 1 and 2 milestones documented in the current Project Execution Plan, only 7 remain to be accomplished. We propose additional milestones to increase that number to 32, consistent with the longer estimated time to completion from May 1, 2007.

Milestone	Level	Approved	Proposed √=complete
Complete Physics Validation Review	2	Mar. 01	√
Complete CD-0 Milestone	1	May 01	√
Select Conceptual Design Configuration	2	Dec. 01	√
Submit NEPA Preliminary Hazards Analyses	2	Apr. 02	√
Complete Conceptual Design Review	2	May 02	√
Receive FONSI	2	Oct. 02	√
Complete CD-1 Milestone	1	Nov. 02	√
Award Prototype Contracts for Modular Coils Winding (MCC) Forms	2	Mar. 03	√
Award Prototype Contracts for Vacuum Vessel	2	Apr. 03	√
Start Preliminary Design (Title I)	2	Apr. 03	√
Complete Project Preliminary Design Review for Vacuum Vessel and Modular Coils	2	Oct. 03	√

Milestone	Level	Approved	Proposed √=complete
Complete External Independent Review and DOE Performance Baseline Review	2	Nov. 03	√
Authorize Prototype Fabrication of MCC and Vacuum Vessel	2	Dec. 03	√
Complete CD-2 Milestones	1	Feb. 04	√
Initiate Modular Coils Winding Process on a 3D Surface	2	Mar. 04	√
Produce First Prototype Modular Coil Winding Form Casting for Machining	2	June 04	√
Complete Final Design Review for Modular Coils Winding Forms	2	Jul. 04	√
Complete Final Design Review for the Vacuum Vessel	2	Jul. 04	√
Complete Prerequisites for the CD-3 Milestone for Procurement and Fabrication of Components	2	Sep. 04	√
Award Conductor Contract	2	Dec. 04	√
Complete CD-3 Milestone	1	Sep. 04	√
Award Production Contract for Modular Coils Winding Forms	2	Oct. 04	√
Award Production Contract for Vacuum Vessel	2	Oct. 04	√
First Modular Coil Winding Forms Delivered	2	Jul. 05	√
Begin fabrication activities for TF Coils	2	Jul. 05	√
Complete First Modular Coil Fabrication	2	Mar. 06	√
Vacuum Vessel Sectors Delivered	2	Sep. 06	√
Last Modular Coil Winding Form Delivered	2	Sep. 07	√
Begin Assembly of First Field Period	2	Jul. 07	√
MC Interface Overall FDR (excl C-C)	2		Nov. 07
Deliver TF Coils for FPA #1 assy (4)	2	Aug. 08	Dec. 07
Shims required for 1st MCHP Assy. (Sta. 2) available	2		Jan. 08
PF Coil PDR	2		Mar. 08
FDR Base Support Structure	2		May. 08
Complete 1st MCHP Assy. (Sta. 2)	2		Sep. 08
Award PF Coils Contract	2	Mar. 08	Sep. 08
Award Coil Support Structure	2		Oct. 08

Milestone	Level	Approved	Proposed √=complete
Complete VPI of 18th Mod. Coil	2		Nov. 08
Complete Modular Coil Fabrication	2		Feb. 09
Station 6 Assy. Specification & Drawings Complete	2		Mar. 09
Complete 1st MC-VV Assy. (Sta. 3)	2		Apr. 09
Power Systems PDR	2		June 09
Complete Base Support Structure Assembly	2		Jul. 09
Complete 2nd MC-VV Assy. (Sta. 3)	2		Sep. 09
Complete 1st Field Period Assy. (Sta. 5)	2		Nov. 09
Complete 3rd MC-VV Assy. (Sta. 3)	2		Dec. 09
Complete Fab. TF/MCWF Coil Structures Hardware	2		Dec. 09
Power Systems C-Site Cabling FDR	2		Feb. 10
Complete 2nd Field Period Assy. (Sta. 5)	2		May. 10
Install 3rd Field Period on Assy. Sleds (Sta. 6)	2		Jul. 10
Move FPA's & Spacers together & check fitup	2		Oct. 10
E-Beam Mapping Apparatus Assembled and Ready for Installation	2		Dec. 10
Complete Cryo Systems Pre-Ops Tests	2		Feb. 11
Pump Down of Vacuum Vessel	2	Feb. 09	Mar. 11
Complete Central Safety & Interlock System Pre-Ops Tests	2		May 11
Begin Cryostat Installation	2	Apr. 09	Jul. 11
Complete Power System Pre-Ops Tests	2		Aug. 11
Complete Operational Readiness Assessment	2	Jun. 09	Sep. 11
Begin Start-Up Testing	2	Jun. 09	Oct. 11
Cooldown of machine	2		Nov. 11
Complete CD-4 Milestone (First Plasma and Completion of MIE Project)	1	Jul. 09	Dec. 11

4. Reconciliation of New Baseline with Original $92.4M Baseline

The new proposed baseline for the NCSX (ECP-054) would supersede the current performance baseline (ECP-031), which was approved by the Deputy Secretary in July, 2005. The new EAC is compared, by WBS, with that of ECP-031 in the following table (costs in $k).

	EAC ECP-031 8/11/05	EAC New Baseline ECP-054 8/1/07	EAC Change from ECP-031	per cent Complete 4/30/07
1 Stellarator Core	**54,507**	**78,047**	**23,540**	69%
12. Vacuum vessel	9,531	9,909	378	98%
13. Conventional Coils	4,790	6,688	1,898	48%
14. Modular Coils	28,092	40,443	12,351	85%
15. Coil Structures	1,412	1,597	185	21%
16. Coil Services	1,140	864	(276)	0%
17. Cryostat & Base Structure	1,360	1,215	(145)	35%
18. Field Period Assembly	5,430	13,583	8,153	26%
19. Stellarator Core Mgt. & Int.	2,752	3,748	996	57%
2 Auxiliary Systems	**784**	**589**	**(195)**	59%
3 Diagnostics	**1,143**	**1,671**	**528**	57%
4 Electrical Power Systems	**3,301**	**3,145**	**(156)**	23%
5 Central I&C/Data Aq.	**2,050**	**1,169**	**(881)**	3%
6 Facility Systems	**691**	**1,403**	**712**	2%
7 Test Cell Prep & Machine Assy.	**4,412**	**8,914**	**4,502**	11%
8 Project Mgt. & Integration	**12,704**	**23,019**	**10,315**	46%
81. Project management	4,584	7,718	3,134	44%
82. Engineering Mgt. & Integration	4,884	11,197	6,313	47%
84. Project Physics	470	470	0	100%
85. Integrated System Testing	1,189	765	(424)	0%
89. Allocations	1,577	2,869	1,292	49%
Total Work	**79,592**	**117,957**	**38,365**	**57%**
DCMA	-	75	75	100%
Contingency	**12,804**	**14,380**	**1,576**	
Total	**92,401**	**132,412**	**40,016**	

It can be seen that most of the increase (92% of the work) is in a few packages: modular coils, field period and machine assembly, engineering management and integration, and project management:

	Increase	
Modular coils	12,351	
Field Period Assy.	8,153	
Machine Assy.	4,502	
Eng. Mgt. & Integration	7,309	(WBS 82 plus 19)
Project management	3,134	
All other work	2,990	
Total work	38,440	
Contingency	1,576	
Total	40,016	

The modular coils are nearly complete, with most of the remaining cost being in completing fabrication of the last few coils. The modular coil winding form contract is complete, and the in-house fabrication work is now proceeding in a routine production mode. Thus, while substantial cost growth has been realized in modular coils, the risks in that area are now substantially reduced.

On the other hand, field period assembly is at a relatively early stage and machine assembly operations have not started, so the growth in those packages reflects increases in the estimates for remaining work. The new estimates are based on an understanding of the design and assembly sequence that has advanced far beyond what was understood in 2005, and on an understanding of the work requirements, especially metrology and dimensional control, that has been informed by lessons learned from modular coil and vacuum vessel fabrication in the last two years. The growth in engineering is closely related, reflecting the design integration, analysis, and dimensional control efforts required to plan and support field metrology and fabrication operations. These requirements, and their costs, are now better understood as a result of the fabrication experience gained since 2005.

Project management estimates have grown as a result of decisions to improve management by adding a construction manager and increasing project control staff. The expanded project office will provide more disciplined risk management, tighter control over construction activities, semi-annual ETC updates, and more rigorous cost and schedule control. The longer period of performance due to project stretchout is also a factor in the cost growth.

Following is a detailed reconciliation of the estimate growth, by WBS.

12. Vacuum Vessel +$378K

The heating and cooling system was re-designed after a 2005 procurement solicitation for hard tubing unexpectedly resulted in no bids. Additional design and R&D were required

to change to flexible tubing, and the cost of system hardware (e.g., heating and cooling tubes, as well as thermocouples, heater tapes, thermal insulation, supports) also increased.
Design: +$195k Fabrication: +$183k

13. Conventional Coils +$1,898K

TF coils: +$1,500k. The project changed its acquisition plan from in-house fabrication to procurement in late 2005 with the aim of reducing cost risks. A firm fixed price contract was subsequently placed with an industrial supplier. Nonetheless the contract price, plus cost of design changes and sunk costs of in-house preparations resulted in a net increase.
PF coils, trim coils, and I&C: +$398k. The PF coil estimate increased based on vendor quotes for coils and structures. An October, 2005 change to using existing NSTX PF1a coils instead of building new coils for the central solenoid, and simplifying the trim coil system, provided some partially offsetting savings.

14. Modular Coils +$12,351k

At the time of ECP-031, a contract was in place for the modular coil winding forms but the supplier's manufacturing process was then still being developed and deliveries had not yet started. The twisted racetrack R&D coil was being fabricated. Now, the MCWF contract is finished and coil production is proceeding smoothly with 12 of the 18 coils having been wound and epoxy impregnated.
Design and R&D: +$3,311k. Design and R&D costs for the modular coil winding pack assemblies and the modular coil interface hardware grew due to greater than expected complexity and difficult requirements.
Modular coil winding forms (MCWF): +$1,546k. The fabrication contract took 8 months longer than planned. Costs grew because of a contract price increase that was negotiated to obtain a better delivery sequence and provide incentives to improve schedule performance. The difficulties experienced in developing the process and the longer performance period resulted in increased Title III design and engineering oversight costs.
Modular Coil Fabrication: +$6,511k. The manufacturing complexity was not fully appreciated until the twisted racetrack R&D coil and the first production coil were completed. Although unit costs improved after the first coil, there was significant net cost growth. MC interface hardware estimates grew after the design concept was developed and it was realized that the combination of requirements (tight tolerances, structural performance, and fabricability) were more complex than expected.
Cold Testing: +$984k. Problems encountered in constructing and operating the test facility and testing two coils (the twisted racetrack and one production coil) were greater than expected.

15. Coil Structures +$185k

At the time of ECP-031, the coil structures were envisioned as castings. Subsequent increases in estimates for the TF wedge support castings (in WBS 13) prompted a re-thinking of the coil structure concept, resulting in a change to simpler structures and cheaper materials (aluminum) to minimize the cost growth.

Design: +$296k Fabrication: -$111k.

16. Coil Services -$276k

The coil services estimate has been updated based on current understanding of the work requirements. The costs have come down slightly due to simplifications in the electrical and coolant circuit configurations required for CD-4.

17. Cryostat and Base Support Structure -$145k

Design concepts for both the cryostat and base support structure have been simplified since ECP-031. The base support structure no longer has to support the moving together of the field periods during final assembly; that function is now provided by separate tooling in another work package. A simpler cryostat construction, based on the concept successfully developed for the coil test facility cryostat, has been adopted.

18. Field Period Assembly +$8,153k

At the time of ECP-031, tooling design and area preparation were in early stages. An R&D test of a simplified approach to assembling the coils over the vacuum vessel led to significant cost avoidance. However, understanding of assembly requirements and costs has matured as the component designs and work requirements have matured, leading to substantial net cost growth. Significantly, the experience in coil winding operations and vacuum vessel fabrication since ECP-031 has led to a much better appreciation of the metrology and dimensional control efforts required to meet NCSX assembly tolerances. Estimates have been updated to incorporate the best current understanding.

Design, Constructability, and Tooling:+$995k Operations: +$7,158k

19. Stellarator Core Management & Integration +$996k

Experience with coil winding and initial stages of field period assembly have shown that there will be an ongoing demand for ORNL stellarator core design activities, including Title III support of assembly, and CAD modeling and engineering analysis of the stellarator core as a system. These demands are expected to continue at a high level until the machine is assembled then drop to a lower level until CD-4, a longer overall period than originally estimated. Estimates for ORNL engineering management and integration have increased based on these considerations.

2. **Auxiliary Systems -$195k**

   The fueling and vacuum pumping system designs were simplified to the minimum required to meet CD-4 objectives.

   Fueling: -$19k Torus vacuum pumping: -$176k.

3. **Diagnostics +$528k**

   Fabrication of magnetic diagnostic loops has proven to be more difficult than expected due to requirements for insulation and component protection. First plasma imaging and electron-beam mapping costs have been reduced as a result of equipment loan and collaboration arrangements.

   Magnetic Diagnostics: +$590k Imaging and e-beam mapping: -$62k

4. **Electrical Power Systems, -$156k**

   Since ECP-031, there has been cost growth as the detailed planning has advanced, offset by reductions in requirements (controls, number of circuits) to the minimum required for CD-4 objectives. Result is a slight net reduction.

5. **Central I&C and Data Acquisition, -$881k**

   Since ECP-031, requirements have been reduced to the minimum needed to satisfy CD-4 objectives.

6. **Facility Systems, +$712k**

   Since ECP-031, estimates for the cryogenic system have increased based on actual experience with the coil test facility. A vacuum vessel bakeout system has been budgeted to reduce the risks in meeting CD-4 requirements for 150 C bakeout and achieving adequate vacuum conditions for first plasma.

   Cryogenic Systems: +$192k

   Vacuum Vessel Bakeout System: +$573k

   Other: -$53k

7. **Test Cell Prep & Machine Assembly, +$4,502k**

   Since ECP-031, understanding of final assembly requirements and costs has matured as the sub-assembly designs and work requirements have matured, leading to substantial net cost growth. Significantly, the experience in coil winding and initial field period assembly operations since ECP-031 has led to a better appreciation of the metrology and dimensional control efforts required to meet NCSX assembly tolerances. Estimates have been updated to incorporate the best current understanding.

   Design, Area Preparation, and Tooling: +$242k Operations: +$4,260k

81. Project Management, +$3,134k

Project management estimates have increased based on the realization that project management needs to be strengthened with the addition of a construction manager and more project control staff. The expanded project office will provide more disciplined risk management, tighter control over construction activities, semi-annual ETC updates, and more rigorous cost and schedule control. The longer period of performance due to project stretchout is also a factor in the cost growth.

82. Engineering Management and System Integration, +$6,313k

Since ECP-031, understanding of NCSX engineering requirements and costs has matured as the component designs and work requirements have matured, leading to substantial net cost growth. Significantly, the experience in coil winding and initial field period assembly operations since ECP-031 has led to a much better appreciation of the engineering efforts, including dimensional control planning and “back office” support of metrology operations, required to meet NCSX assembly tolerances. Experience also points to an ongoing demand for CAD modeling and engineering analysis of the system. These demands are expected to continue for a longer period than originally estimated because of the forecast stretchout of the project. Estimates for engineering management and system integration have increased based on these considerations.

Engineering Management & System Eng. Support: +$2,460k

System Engineering: +$3,852k

85. Integrated System Testing, -$424k

Since ECP-031, integrated system testing plans have been streamlined, consistent with minimum CD-4 objectives and the experience on NSTX.

89. PPPL Allocations, +$1,292k

The estimate for PPPL indirect cost allocations to the NCSX project has increased due to the forecast extended duration of the project.

Contingency, +$1,576k

The contingency needs for the remaining work have been estimated based on current understanding of the outstanding risks and uncertainties, and found to be $1,576k more than the balance at ECP-031.

5. CD-4 Project Objectives

In this section we address the Project Objectives that are documented in the NCSX Project Execution Plan. The performance objectives have not changed and no scope changes are proposed with this baseline change. However, changes in scope that have previously been approved through the project's change control process have in some cases affected the *manner* in which the performance objectives will be satisfied. Here we document the project's plans for meeting the CD-4 objectives.

a. First Plasma

PEP Table 2-1:
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.

Plan:
We will produce the specified plasma. The geometry will be documented with a visible TV camera. The plasma current will be measured with a Rogowski coil.

b. Coils and Power Supply Performance

PEP Table 2-1:
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
- PF1 & PF2 Coils: 12 kA
- PF3-4 Coils: 3 kA
- PF5-6 Coils: 2 kA
- External Trim Coils: 1 kA. (w/ temp. power supplies).

Plan:
The coils will be operated at cryogenic temperature for first plasma. The baseline power supplies will be a subset of the existing C-Site rectifiers. The First Plasma scenario has been optimized to minimize power supply cost and risk, resulting in lower coil currents and fewer units and circuits than originally thought necessary. The coil test current requirements are not meant to drive

power supply requirements and costs beyond what is necessary for the program. Coil performance requirements will be satisfied as follows:

- Modular coils: Energize to 9 kA as part of the First Plasma scenario. Energize to 12 kA independently using a temporary re-connection of one of the baseline power supplies.
- TF coils: Not included in the First Plasma scenario. Energize to 2 kA independently using a temporary re-connection of one of the baseline power supplies.
- PF 1&2 Coils: Energize the two central solenoid coils (originally the NSTX PF1a coils) to 17 kA as part of the First Plasma scenario.
- PF 3 Coils: Previously removed from the baseline.
- PF 4 Coils: Energize to 2.8 kA as part of the First Plasma scenario.
- PF 5 Coils: Not included in the First Plasma scenario. Energize to 2 kA independently using a temporary re-connection of one of the baseline power supplies.
- PF 6 Coils: Only requires 0.2 kA as part of the First Plasma scenario. Energize to 2 kA independently using its assigned power supply.
- External trim coils: Not included in the First Plasma scenario. Energize to 1 kA independently using a temporary connection of one of the power supplies.

c. Magnet System Rating

PEP Table 2-1:
It will be demonstrated on the basis of component design verification data that the stellarator magnet system of modular coils, TF coils, and PF coils is 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

Plan:
The coils will be operated at cryogenic temperature for First Plasma. The coils are designed to satisfy reference operating scenario requirements that are specified in the GRD and that meet or exceed the PEP objectives. Conformance of the coil design to the GRD requirements will be verified by analyses appropriately documented. The coils were fabricated according to product specifications and manufacturing procedures that were developed based on the design. Conformance of the components to the design was verified by in-process tests and inspections, including cooldown of a modular coil to cryogenic temperature and full-current pulsing of that coil at cryogenic temperature. Testing of the C1 coil is documented in NCSX-TEST-14-01.

d. Magnet System Accuracy

PEP Table 2-1:
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.

Plan:
The physics requirement for good magnetic surfaces was translated into a design requirement, documented in the GRD, that limits the allowable island size due to fabrication errors, magnetic materials, and eddy currents. That requirement translated into design choices, particularly tolerances, material choices, and lead arrangements that are documented in lower-tier component specifications and procedures. Analyses verified that the designs conformed to the GRD requirement. Conformance of the fabricated components and sub-assemblies was verified by in-process tests and inspections, including dimensional measurements with metrology equipment and magnetic permeability measurements. Inspection and test results are documented in the run-copy manufacturing procedures and travelers for each coil. An electron-beam mapping test will be performed to confirm that the final assembly produces vacuum magnetic surfaces. While a room temperature e-beam test is allowed, it will most likely be done with the coils at cryogenic temperature, a more stringent and more relevant condition.

e. Vacuum Vessel System Rating

PEP Table 2-1:
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.

Plan:
Vacuum test data from the manufacturer will be used to document the vacuum vessel base pressure and leak rate. The device will be baked to 150 C for first plasma.

f. Vacuum Pressure and Pumping

PEP Table 2-1:
A base pressure of 4x10-7 torr will be achieved.
A pumping speed of 1,300 l/s at the torus will be achieved.

Plan:
The specified base pressure will be achieved with a high-vacuum pumping system having much less than the specified pumping speed. The requirements in the PEP are over-specified. For CD-4, we will focus on the more fundamental requirement, namely the base pressure.

g. Controls

PEP Table 2-1:
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.

Plan:
These systems will be operational during the integrated system test program (ISTP) and First Plasma. Specifically:

- Safety interlocks. NCSX will incorporate a Central Safety Interlock System which will provide centralized control and monitoring of high energy subsystems and hazardous areas. For first plasma this system will be implemented in a hardwired manner resembling the TFTR and NSTX Hardwired Interlock System (HIS).
- Timing and synchronization. The Facility Timing and Synchronization System, based on a single master clock encoder and a fiber optic broadcast transmission system, will provide a sufficient number of events triggers for first plasma.
- Power supply real time control. The power supply real time control system will provide the control signals to drive the power supply rectifier triggers. The hardware and software will be patterned after NSTX.
- Data acquisition. The data acquisition system, using hardware and software patterned after NSTX, will be implemented to a degree sufficient for First Plasma.

h. Neutral Beams

PEP Table 2-1:
For one neutral beam injector:

- Beamline operating vacuum shall have been achieved.
- Beamline cryopanels shall be leak-checked.
- A source shall be leak-checked

Plan:
These tests were completed in 2004.

i. Readiness for Research

PEP Section 2.2:
"The NCSX will provide the initial set of equipment necessary to achieve the CD-4 First Plasma milestone defined herein and to begin the research program."
"The First Plasma milestone will demonstrate a level of system performance sufficient for the start of research operations."

Plan:
The MIE will provide the minimum configuration needed for first plasma and e-beam mapping. We will have 5 power supply circuits connected to the machine at the time of first plasma. They are connected to MA, MB+MC, PF1A, PF4, and PF6. The TF and PF5 are not powered in the first plasma scenario, but will be used in the first research campaign following CD-4, magnetic configuration studies. Since PF1A is not required for magnetic configuration studies, it frees up one power supply circuit. Another circuit can be freed up, if necessary by connecting all the modular coils series. The first research campaign, including studies with the TF and PF5, can thus proceed with the equipment provided by the MIE project.

j. Scope

PEP Section 2.2.3:
"The NCSX fabrication project scope includes all the equipment required at the start of operations (First Plasma and initial field mapping) with coil operation at cryogenic temperatures, and refurbishment and testing of equipment for 1.5 MW of neutral beam heating power."
"See Annex I for detailed scope by WBS."

Plan:

We will meet the fundamental scope requirement, as summarized in the first sentence. Annex I has not been updated to be consistent with approved scope changes since the PEP was approved. The differences are minor, specifically,

- A portable turbomolecular pumping (TMP) system is sufficient for First Plasma; the two PBX-M TMPs on a duct are not needed.
- One (not 3) gas injector is sufficient for First Plasma.
- One (not 8) fully operational magnetic sensor, namely the Rogowski loop, is sufficient for First Plasma.
- We will have 5 magnet coil circuits, not 6, for First Plasma, but all circuits can be tested by reconnecting the baseline power supplies in various ways.