

*Department of Energy
Review Committee*

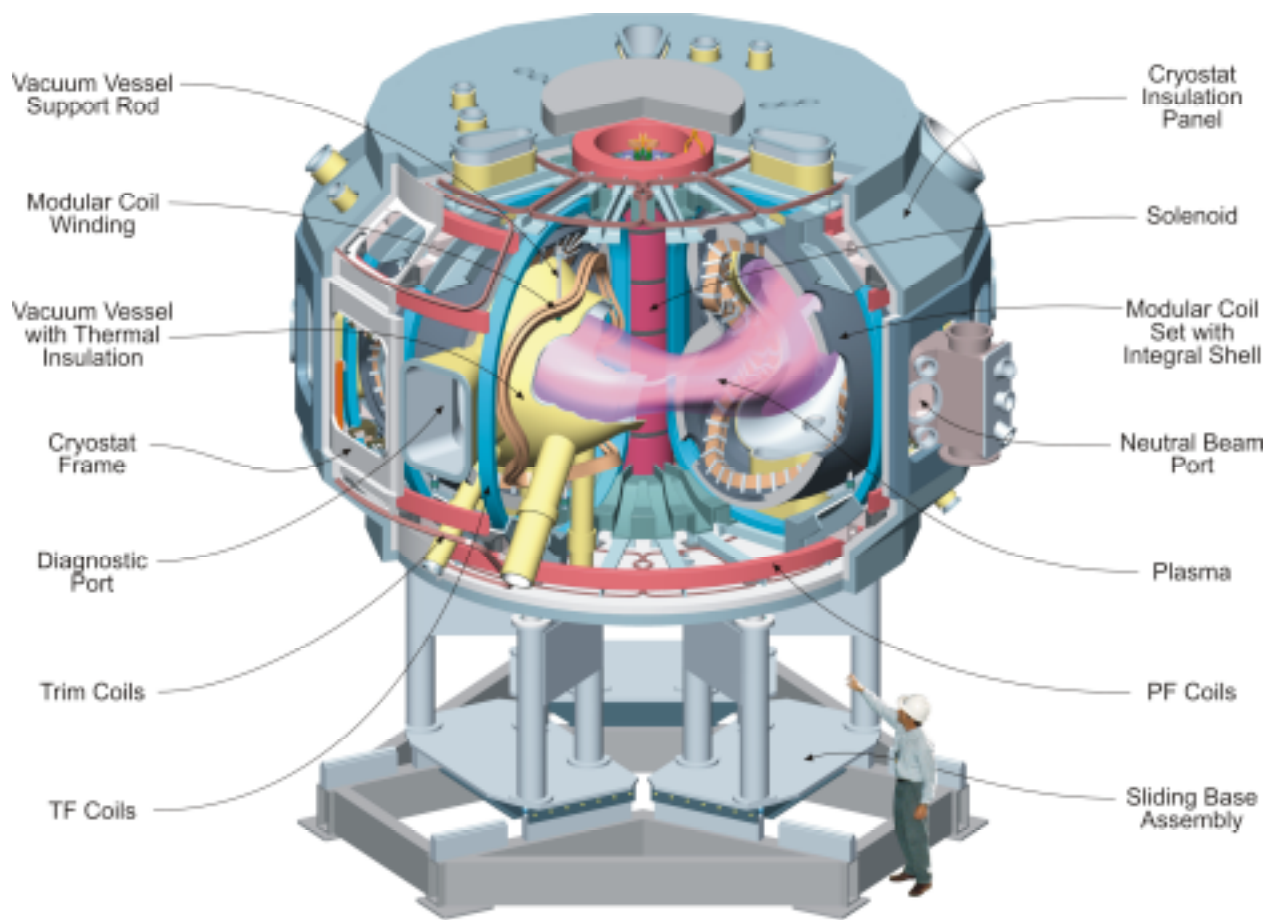
for the

Technical, Cost, Schedule,
ES&H, and Management Review

of the

**NATIONAL COMPACT
STELLARATOR
EXPERIMENT (NCSX)
PROJECT**

November 2003



NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX) PROJECT

EXECUTIVE SUMMARY

At the request of Dr. N. Anne Davies, Associate Director for Fusion Energy Sciences (OFES) in the Office of Science, a Department of Energy (DOE) project review of the National Compact Stellarator Experiment (NCSX) Major Item of Equipment was performed. The purpose of the review was to evaluate the project's readiness for setting the performance baseline and proceeding to final design. This assessment will also aid the OFES in their evaluation of the readiness of NCSX for Critical Decision 2 (CD-2), Approve Performance Baseline. The review was conducted at Princeton Plasma Physics Laboratory (PPPL) on November 18-20, 2003.

Overall, the Committee found that the NCSX project was ready for CD-2, after appropriate consideration and response to the Committee's comments and recommendations. The Committee found the Preliminary Design, technical approach, and project planning to be sound and likely to meet the functional and operations performance requirements. The proposed staff at DOE, PPPL, and the Oak Ridge National Laboratory is experienced and well qualified to execute the NCSX project. The cost and schedule, including the contingencies are reasonable. The design and R&D status is good, and the overall management organization demonstrated a strong commitment to the successful completion of the NCSX project.

The NCSX project is an innovative magnetic fusion plasma configuration consisting of a stellarator core that has three field periods and is surrounded by eighteen modular coils (six per field period). A vacuum vessel fills the internal volume of the modular coils to provide the maximum space for plasma shape flexibility. The modular coils are supplemented by toroidal field (TF), poloidal field (PF), and trim coils. Diagnostic systems provide the detailed measurement of the plasma parameters that are critical to the research goals of NCSX.

The Total Estimated Cost for the NCSX project reported to the Committee is \$81 million including escalation and contingency. The project has expended approximately \$5.9 million for activities leading up to this review. Contingency, as a percentage of remaining project costs, is 28 percent. A detailed, resource-loaded schedule has been prepared that identifies the project's critical path. The project is scheduled for completion in September 2007 and includes five-and-a-half months of schedule contingency.

The Committee's major recommendations included:

- Performing cold testing of all the Modular Coils during the construction project;
- Assuring that senior DOE management and fusion physics community clearly understand the limitations on the physics productivity of early NCSX operations that derive from the existing definition of Critical Decision 4, Approve Start of Operations;
- Reevaluating adequacy of contingency amount and funding level for FY 2005 and proposed total project funding profile in concert with OFES;
- Considering the changes to proposed changes to project base costs or contingency; and
- Evaluating alternative technical options proposed by the Committee.

The Total Estimated Cost of \$81 million and project completion (CD-4, Approve Start of Operation) scheduled for September 2007 appears to be reasonable. There were no action items resulting from the review.

CONTENTS

Executive Summary.....	i
1. Introduction.....	1
2. Technical Systems Evaluations.....	3
2.1 Stellarator Core (WBS 1).....	3
2.2 Plasma Heating, Fueling, and Vacuum System (WBS 2).....	8
2.3 Diagnostics (WBS 3).....	10
2.4 Power Systems (WBS 4).....	11
2.5 Central Instrumentation and Controls (WBS 5).....	12
2.6 Facilities Systems, Site, and Utilities (WBS 6).....	14
2.7 Test Cell Preparation and Machine Assembly (WBS 7).....	14
3. Cost Estimate.....	17
4. Schedule and Funding.....	19
5. Management.....	21

Appendices

- A. Charge Memorandum
- B. Review Participants
- C. Review Agenda
- D. Cost Table
- E. Schedule Table
- F. Management Chart

1. INTRODUCTION

The National Compact Stellarator Experiment (NCSX) is a fusion research project initiated in the Department of Energy (DOE) FY 2003 budget for fabrication at the Princeton Plasma Physics Laboratory (PPPL). The compact stellarator is one of several innovative magnetic fusion plasma configurations supported by the DOE Office of Fusion Energy Sciences (OFES) and has the attractive potential of operating continuously and without plasma disruptions. Also, 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.

The mission of NCSX is to acquire the scientific and technological knowledge needed for understanding the behavior of a compact-stellarator plasma, evaluating the attractiveness of this fusion concept, and advancing the state-of-the-art, three-dimensional analysis of fusion plasmas. The NCSX mission need (Critical Decision 0) was approved by OFES in May 2001. Earlier that year, a panel of plasma physicists and engineers conducted a Physics Validation Review (PVR) 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 Fusion Energy Sciences Advisory Committee endorsed the panel view. 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 the Alternative Selection and Cost Range (Critical Decision 1) by OFES occurred in November 2002.

The NCSX project involves the design, fabrication, installation, and integrated system tests of a compact stellarator core device consisting of a highly shaped vacuum vessel, surrounding coil systems, enclosing cryostat and various auxiliary power, cooling, vacuum, cryogenic, and control systems, as well as a set of startup diagnostics. All of this equipment plus a control room will be located in existing buildings at PPPL that were previously used for other fusion experiments. Further, many of the NCSX auxiliary systems will be made available to the project from equipment used on the previous experiments. The project will be led by PPPL with Oak Ridge National Laboratory providing major leadership and support as a partner.

Because the project involves 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 and included it as such in the FY 2003 budget. The cost range of NCSX based on the preconceptual design was between \$69-83 million. The total estimated cost of the device based on the conceptual design was \$73.5 million with a completion in June 2007. Due to the continuing resolution at the beginning of FY 2003 that was not resolved till February 2003, the project did not start until April 2003 instead of the planned October 2002 start. With this later start and with additional design and cost information, PPPL estimated the cost 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. Upon the completion of the review and after analyzing the impacts from the recommendations of that committee, the project team has now estimated the total cost of the NCSX project to be \$82 million with a completion date of November 2007. In addition, the preliminary design review committee concluded that the project was ready to proceed to Critical Decision 2 (CD-2), Approve Performance Baseline.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Stellarator Core (WBS 1)

2.1.1 Findings

The Work Breakdown Structure (WBS) 1 scope is composed of the major components of the machine core including the Vacuum Vessel (VV), the Modular Coils (MC), the Conventional Coils (TF, PF, and External Trim Coils), the coil support structures, coil services, the cryostat, the base support structure, the subassembly of the three field periods and the stellarator core management and integration. The cost of this large portfolio of components is estimated at \$39 million, which is approximately 60 percent of the project total base cost. The Committee noted that tasks under this WBS were completed very effectively by an integrated team of engineers from both PPPL and Oak Ridge National Laboratory (ORNL).

Independent control of the MC and PF coils, as well as variable background TF field is required to meet the performance and flexibility requirements in the specified operating scenarios. The MC windings must be located with sufficient accuracy to limit magnetic islands less than ten percent of the toroidal flux. The most technically risky components of the stellarator are the MC and the VV because of their unique, non-regular, non-planar shapes. The MC fabrication and assembly are on the critical path with the VV not far behind.

All coils are operated cryoresistively and are cooled by liquid nitrogen. Coil operation requires the use of a cryostat and thus imposes special design requirements on the magnet system.

Significant progress has been made in the development of the design and analysis of many of the most critical components (field errors, thermal-hydraulic, forces, stresses, eddy currents, etc.). Further design work on some of the lower-priority tasks is delayed until later in the project as is appropriate.

The MC are particularly difficult to fabricate because of very tight tolerances required to insure the specified field quality. Early project efforts have been directed to determining the most cost effective method to manufacture the coils and coil forms to achieve these tolerances.

Contracts have been placed with several industrial firms to determine the best manufacturing methods and to develop manufacturing, inspection, and testing methods for the coil forms and

the VV sectors. Before down selection is made between vendors each will deliver prototype components for detailed evaluation of the manufacturing process and for further use in the R&D program.

Laboratory R&D has been focused on developing methods to wind the MC, and to develop winding support, cooling, and Vacuum-Pressure-Impregnation methods. This has included conductor cabling optimization and winding characterization through the use of small coil mock-ups. A 3-D coil (twisted racetrack) with prototypical features will be developed early in 2004.

The VV will be supplied as three symmetric sector assemblies with port stubs attached. The modular coil sectors will be assembled around the VV sectors and port extensions attached and welded from the inside. The 3 VV sectors will be joined together by internal welding at final assembly using spool pieces supplied by the VV vendor.

All core components have been designed in Pro-E, which significantly increases the effectiveness of design exchange with industrial vendors. Solid models are useful for analyzing tolerances and clearances, and especially useful for studying assembly sequences and interferences.

The project has invested in three different metrology systems for core component, dimensioning, and assembly. These different methods will be applied throughout the manufacturing and assembly processes with early efforts focused on determining the most effective use of the equipment during the R&D and prototyping stages.

The stellarator core will be assembled in three sectors in the Tokamak Fusion Test Reactor (TFTR) hall as part of WBS 1. The base support structure is also within the scope of WBS 1. The three-sector subassemblies will be transported by truck to the NCSX Hall, and then joined together there on the base support under WBS 7.

The cryostat will be constructed around the machine core after assembly of the entire machine. The cryostat will be fabricated from standardized fiberglass subframes and inserts, and custom boss segments for port extension interfaces. Insulation will be a sprayed-on closed-cell, rigid polyurethane foam. Silicone rubber impregnated fabric will seal around penetrations and butyl rubber will be applied to form vapor barriers inside and outside the cryostat shell. The cryostat will be filled with slightly pressurized nitrogen gas.

The Committee believes that the NCSX has made a credible estimate of the base costs for the stellarator core and applied an appropriate level of contingency made on the basis of technical and schedule risk. Cost estimates for some critical components (MC forms, VV) have been based on industry budgetary estimates developed through manufacturing study contracts. Costs of the conventional coils have been based on PPPL experience with similar coil systems for other recent projects like NSTX. R&D, coil winding, and core assembly costs have been made on the basis of a resource-loaded project schedule developed from at least preliminary definition of fabrication steps, and relying on laboratory experience from other projects.

The schedule seems credible, especially for fabrication and assembly of some of the more conventional components for which there is similar experience. Since there is no relevant experience for some components best engineering judgment has been applied. In the case of the MC winding task, conservatism has been built in by assuming no time shortening for sequential coil winding through learning curve improvements.

The Committee stated that schedule contingency could be increased by adding a second winding line and running two teams in parallel, instead of two shifts in series. Further increases can be gained by adding overtime for the two teams, if needed. The use of triple shifts is not recommended.

The Committee noted that the project and DOE have agreed that the CD-4 milestone is considered complete with first plasma generated by energization of the coils at room temperature with a relatively low current level. At this time, delivery of the cryostat components is within the scope of the Major Item of Equipment (MIE) project, but assembly is not within scope.

2.1.2 Comments

The vacuum vessel has the highest contingency, 44 percent of cost-to-go, of any component in the core but at this time there have been no full-size models and tests of the assembly procedures.

The modular coils have the second highest contingency at 40 percent of cost-to-go, yet at this time no models have been made for winding the coils onto a coil form. While the coil models that have been constructed have yielded information regarding the cryogenic properties of the

coils they have not indicated potential fabrication challenges. The R&D plan shows a winding task into a twisted racetrack and this should be done as soon as possible.

The stress in the modular coil form insulating break due to mechanical and electromagnetic loads needs to be evaluated.

Magnetic field in the modular coils will depend upon the placement of the gross coil block and not individual conductors. In addition, the highly stranded conductor has little, if any, dimensional stiffness. The shape and position of the coil block will be determined by the clamping arrangement at the vacuum impregnation stage. Consideration should be given to resolving coil positioning at that time rather than on a turn-by-turn basis.

The project should consider two winding lines for the modular coils. Tooling is relatively inexpensive. Supervision will be more efficient. The same crew of people will be working on each coil. If there is a manufacturing challenge on one line, the second line will still be operable. Schedule contingency can be restored with overtime.

The Committee did not understand the placement of the trim coils in the two small and one large set, symmetric top and bottom. This seems to violate stellarator symmetry. Four small coils could increase flexibility in tuning out errors.

Pro-E model verifications are very important including checks such as magnetic field requirements to Pro-E model and back to magnetic field distribution, modular magnet support Pro-E model to vendor models and back to Pro-E; VV Pro-E model to vendor model to Pro-E (points); and modular magnet support/VV Pro-E models to stereo lithography.

Metrology, both at the vendor and during assembly, is key and needs more emphasis. Project personnel must be able to easily and quickly relate metrology data to Pro-E models.

Evaluating the stack-up of tolerances in a 3-D Pro model can be difficult. It may be useful to use a software package designed to work with Pro-E to do this evaluation.

Practice moving large assemblies in a complicated motion would be very useful, i.e., the motion of the MC assembly over the VV. This should be performed early to determine if the supporting and motion tools are adequate or need changing.

The Committee saw no technical challenge on the TF coils. However, the number of firms that can take on fabrication of these coils appears to be shrinking yearly. Attention should be given early to insure that delivery of these coils does not affect the machine assembly schedule. The TF coils must be ready in time to assemble around the field sectors, and the lower PF coils must be installed in the machine base before the field sectors are mounted.

Fabrication of the VV will be a challenge. The project has worked closely with two experienced vendors and prototype sectors are presently being built. It will be important to understand the effects of welding on the mechanical tolerances of the vacuum shell and what procedures can be utilized to minimize these deviations. It is not clear at this time what stress relieving anneals needs to be programmed into the fabrication process.

Additional VV issues that need further evaluation include: establishment of the allowable mechanical loads on the ports for interfaces; the seismic loads including port loading from attached equipment, if applicable; and the need for a pressure relief device if a Plasmas Facing Components cooling system fails.

The Committee suggested that the engineering of the field joint with the spool piece be revisited. Weld shrinkage, weld deformation, weld repair, and joint efficiency and inspection need to be given more consideration in the R&D program. For example, a sleeve inside the spool piece may be much easier than trying to align the four mating surfaces at each spool piece site.

A relatively short delay of the VV task will put it on the critical path. The effect of such a delay should be explored with project scheduling software to determine the impact on overall project schedule and cost.

Although the base support is not a major technical problem, it is on the core critical path. The base design and interfaces to other components comes late in the project because it is tied into the overall funding profile. It would reduce schedule risk if this design task can be moved up earlier in the schedule.

The cryostat procurement is a multi-stage procurement and fabrication. In the MIE phase of the project, the Committee suggested that all of the fiberglass frames be procured and

that a significant number be installed prior to the core assembly completion since access will be better at this time. Foaming should be deferred to the commissioning stage. At present, it appears the foaming cost is included in the MIE cost, but the work cannot be completed until after CD-4 milestone is reached.

The NCSX will only produce significant physics results when operated as a cryogenic machine. A large amount of assembly and engineering work will remain to be done after CD-4 to put the machine in condition to start-up under cryogenic operation and to determine if the cooldown and cold operating performance meets the minimum acceptable engineering performance.

In view of the lack of any cryogenic operation within the present scope of the MIE project, the Committee believes that all of the MC should be tested cryogenically. This can be achieved by testing them in the autoclave. Heat transfer parameters can be verified at that time. A few thermal cycles will give an indication of any problems with possible delamination of the insulation system. Proper instrumentation of the coils during the cooldown cycle can easily determine if dimensional changes affect magnetic field tolerances.

2.1.3 Recommendations

1. Include performing cold testing of all the Modular Coils during the construction project. Determine the cost and schedule impact of these tests before CD-2.
2. Investigate alternative designs for the Vacuum Vessel spool pieces to optimize the final assembly and closeout welding.
3. Evaluate the use of tolerance stack-up software for performing 3-D assembly in Pro-E.
4. Evaluate the use of fixators for base adjustments.
5. Evaluate the option of determining the position of the Modular Coils winding packs by tooling and fixturing during winding and prior to impregnation.
6. Evaluate the effect on the overall project schedule and cost of a Vacuum Vessel delay sufficient to cause it to become a critical path item.

2.2 Plasma Heating, Fueling, and Vacuum Systems (WBS 2)

2.2.1 Findings

The function of the NCSX heating system is to provide sources of auxiliary plasma heating power. The initial system, included in the NCSX MIE project, is a single neutral beam source and beamline capable of delivering 1.5 MW to the plasma for at least 0.3 seconds. This is part of the legacy neutral beam system previously used on the Princeton Beta eXperiment (PBX) experiment and mothballed in 1993. The PBX system, consisting of four beam sources for a total of 6 MW, was carefully preserved in anticipation of a restart of PBX, and so the sources are in excellent condition. The MIE scope includes refurbishing and assembling a single beamline with one source. Some testing of vacuum integrity has been completed. However, the integrated testing is deferred until after the start of operations and after the completion of Ohmic plasma testing and e-beam field mapping. The NCSX design also includes provision of space and access for additional heating systems, beams and/or RF, up to a total of 12 MW. Refurbishment of the beamline starts in FY 2004. Installation and system connections are scheduled to start in the second quarter of FY 2006.

The function of the fueling system is to provide H₂, D₂, He, or other plasma fuel gasses to the vacuum chamber. The MIE scope consists of a single-gas feed line with a fast piezo-electric valve for control of the gas flow. The purpose of the vacuum system is to provide the base vacuum for the vessel, and to remove injected fuel and gasses evolved from the walls. Legacy equipment is being used to provide pumping, including four turbomolecular pumps that were used on PBX. Currently, one pump is presently in use on another experiment, but, the three other pumps have been bench tested and appear in good condition. Two of these pumps will provide the requisite pumping speed for the MIE scope. There are also mechanical pumps in place which have been tested and are in working condition. All pumps will be refurbished prior to use on NCSX. Refurbishment and installation of the fueling and pumping hardware is scheduled to be done entirely within FY 2006, in time for First Plasma in FY 2007.

2.2.2 Comments

The use of legacy equipment in the areas of heating, fueling, and vacuum is commended. This allows timely performance of these necessary functions at minimal cost. The MIE WBS 2 budget of \$1,820K, including 13 percent contingency, appears appropriate and adequate. Most of this budget (\$1,245K including contingency) is devoted to neutral beam refurbishment and assembly. The schedule for fueling and pumping systems is reasonable as these use standard equipment, much of it existing and in working condition. It also makes sense to start

refurbishment of the beamline early, so that it will be ready for timely installation. PPPL and its staff have extensive experience in these areas and the people assigned to these jobs are highly qualified and skilled.

2.3 Diagnostics (WBS 3)

2.3.1 Findings and Comments

The Diagnostics WBS element has a baseline budget estimate of \$1,504K included in the MIE scope of the NCSX construction project, which will deliver the minimum compliment of plasma diagnostics needed for the CD-4 (first plasma) milestone. This initial set of diagnostics includes: 1) a dual set of Rogowski coils to measure the plasma current; 2) installation of the magnetic flux loops onto the vacuum vessel surface that will be buried during the NCSX installation process; 3) a fast camera system for plasma viewing; and 4) an electron beam system for mapping the magnetic fields within the vacuum vessel volume. The scope for this WBS element also includes the planning needed to define the complete set of plasma diagnostics for the presently envisioned research program. The design, procurement strategy, scheduled tasks, installation plan, and estimated cost for the defined set of diagnostics required for first plasma appears valid. The WBS 3 managers and PPPL as an institution, have decades of relevant experience in the design, fabrication, and operation of plasma diagnostic systems. The task of planning a complete diagnostic set is absolutely essential for completion early in the initial phase of the NCSX construction project when the vacuum vessel port layout is still in the design stage. Significant progress has already been accomplished on this task. The Committee was presented with a mapping of the current vacuum vessel port layout with an initial assignment of diagnostics that was clearly done in concert with best estimates of plasma viewing angles and other spatial constraints.

Although outside of the scope of the MIE construction project, a budgetary estimate (\$16 million) has been developed for the complete set of diagnostics that will be included in the NCSX research program budget. The WBS 3 managers have begun the process of identifying where diagnostic systems and diagnostics physicists can be provided or cost-shared with systems currently in use on Princeton's National Spherical Torus eXperiment (NSTX) device, and/or provided by external collaborators from universities and other national laboratories involved in the national and international fusion sciences program. Since the largest advanced stellarator system in the world wide fusion program, the Wendelstein 7X at IPP/Greifswald, Germany, is currently under construction and is not slated for operation until 2010, a mutually beneficial collaboration involving the sharing of diagnostic systems and diagnostic physicists should be explored between PPPL and the IPP.

2.3.2 Recommendation

1. Consider negotiating an agreement between PPPL and IPP/Greifswald, Germany that would allow sharing of plasma physicists (and possibly plasma diagnostics systems) during the current construction phase and the first two to three years of NCSX operations.

2.4 Power Systems (WBS 4)

2.4.1 Findings

The NCSX Electrical Power Systems (WBS 4.1-4.6) is comprised of all required AC power distribution, DC power for the Modular, TF, and PF circuits, and equipment grounding.

The existing NSTX AD-DC power supplies exceed all of the power requirements of the NCSX field coils. PPPL recognized that sharing the power supplies between NSTX and NCSX would provide a significant cost savings to the project. The plan calls for connecting the NCSX magnets into six strings. The strings will be connected to the NCSX power supplies with cables in an aerial tray running between the C site and D site buildings. The power supplies can only be used by one experiment at a time, so the two experiments will have to coordinate running times. The switchover between experiments is expected to be less than four hours.

The cost (\$5,029K) presented seemed appropriate for the required task. The cost estimates are based on the recent experience with NSTX and industry feedback.

The schedule appears fully adequate for the required task. This work does not require any new system development. The funding levels for FY 2004 and FY 2005 provide sufficient time for the procurement of long lead time equipment.

2.4.2 Comments

The work required for the NCSX power systems is straightforward and has no major technical risks. The hardware and control software are currently in use at NSTX. The engineers responsible for the NCSX are highly experienced and familiar with these systems.

The technical and safety issues of shared remote power supply operation have been adequately addressed. There will be overload protection provided for the field coils and distribution cables. The power supplies will be equipped with a isolation/grounding switch near the load. This provides a high level of safety for personnel working on or around the magnet coils.

The current scope of the power system is the minimum required for first plasma. The initial system does not include power supplies for the trim coils which are expected to be added after operation starts (CD-4).

Future upgrades of the modular coil supplies will allow the experiment to reach its full potential. The magnets are expected to be split into a total of ten strings requiring 26 additional NSTX AC-DC power supplies.

The complex grounding of the electrically isolated modular magnet forms does not include a ground monitor circuit. This function was added to NSTX and will be added to NCSX in the future.

2.4.3 Recommendation

-
- 1. Review the decision to exclude trim winding power supplies and ground monitor circuit in the scope of baseline work prior to CD-2.

2.5 Central Instrumentation and Controls (WBS 5)

2.5.1 Findings

The material presented to the Committee provided a general description of seven components required to implement a controls and data acquisition system for the MIE. These included central instrumentation and controls (I&C), data acquisition, timing and networking infrastructure, safety and interlock systems, and control room facilities. Additions to this system will be required to support diagnostics and heating systems for physics operations. The design effort is minimal since the systems to be employed are mostly replications of NSTX systems. The majority of the design work is for the NCSX-specific facilities requirements, a new control room, the networking and interlocks for the experimental cell, and the EPICS-based controls for selected subsystems.

The major non-commercial software to be used, MDSplus and EPICS, are community supported and already in use on NSTX. Software connections have been developed for and in use on NSTX. EPICS provides the overall subsystem control and experimental shot cycle with MDSplus providing the diagnostic data file system. Local instrument control, at least in part, is also provided by the commercial software package LabView. Software connection between LabView and both MDSplus and EPICS has also been developed for and in use on NSTX. The only new direction for data acquisition is the total reliance on a network of PCs with PCI-based data acquisition architecture. This completely eliminates the use of CAMAC-based legacy hardware that is now essentially obsolete and has become expensive to maintain but does introduce total reliance on systems that are fairly new.

The cost estimates appear reasonable and well founded since they are mostly based on NSTX actual experience, as do the relatively low contingencies. There is some concern for the relatively late start on design efforts for these systems.

2.5.2 Comments

The decision to not use CAMAC in favor of PCs/PCI seems appropriate.

In the material presented to the Committee, the interaction between the new LabView-based local controls, e.g., the neutral beam installation as part of the MIE, and the central I&C was not clearly defined. This leads to some concern as to how well this interface has been specified.

The design and implementation of all WBS 5 systems is scheduled very late in the project—the last 16 months. From a cost-performance point of view, it is generally prudent to delay purchase of computer-related hardware to as late as possible in the project. While the time estimates for implementation appear reasonable, this delayed approach leaves very little room for error in the schedule. Since the staff is shared between the NSTX and NCSX facilities, this could result in difficulties meeting the schedule should NSTX require the same staff for operations or unanticipated development needs. In addition, this leaves no provision for interaction between the central I&C team and those developing local sub-system control.

2.5.3 Recommendation

1. Consider moving preliminary and some detailed design of Central I&C components into the FY 2005 schedule and establish dialog between the Central I&C team and local control system developers to insure that these systems are compatible. Clearly define the role and use of LabView (and any others) versus EPICS in the overall I&C system implementation.

2.6 Facilities Systems, Site, and Utilities (WBS 6)

2.6.1 Findings and Comments

This WBS element contains four elements: the water cooling systems, the cryogenic system, utility systems (gas manifolds and vent), and vessel bakeout systems. In general the systems are very similar in scope to what has been done on previous experiments including recent experience with NSTX. The water system will make use of the existing C-site water system that includes 16-inch manifolds under the test cell. Some maintenance and repair will be needed and piping/manifolds within the test cell added. The cryogenic system will make use of the 9,200 gallon LN₂ tank that has been recently refurbished. The vessel helium bakeout system design is based on the existing NSTX bakeout system that has been operated successfully. All four systems should have low technical risk since the PPPL staff has had extensive and recent experience designing and installing similar systems.

Good cost data from experience exists to support the base estimate of \$2,063K. A 20 percent contingency has been applied to all systems. This is reasonable since design requirements may change as the detail design for the core systems develops.

Preliminary design has intentionally proceeded slowly to allow development of the requirements for the core systems. Most activities occur between mid-FY 2006 and mid-FY 2007. These systems are not on the project critical path and are not a schedule driver.

The management of these activities is to be performed by personnel with good experience. Overall these are low risk elements with a well established cost basis. The cost and schedule estimates are reasonable and credible.

2.7 Test Cell Preparation and Machine Assembly (WBS 7)

2.7.1 Findings

Test cell preparation activities (WBS 71, 72, 73, & 74) were presented. These activities are straightforward and well understood, and the cost and schedule estimates are reasonable.

The overall machine assembly plan (WBS 75) was presented. This plan lacks detail at this time, but the basic assembly plans are defined well enough to illustrate feasibility for this activity that will not begin until FY 2006. The plans are sound and should result in accurately aligned magnets and a leak-tight vessel.

The two most complicated aspects of the machine assembly are: 1) the positioning and assembly of the three Field Period, and 2) the positioning and welding of the VV sections. In both cases, very accurate metrology systems must be used to position these components before bolting or welding them in place. Shimming of the magnet housing and machining of the spool piece at the interface is likely to achieve the desired tolerances. Shimming, machining, and the require metrology will be very time consuming. The cost estimate appears low in these areas. Schedule risk is lower since the activity is done on one shift and overtime and additional shifts can be used to alleviate schedule problems.

Metrology is critical during fabrication and assembly of many components, but particularly important during the positioning and assembly of the modular magnets (part of the Field Periods) and the VV sections/spool pieces. More detail metrology planning in the near term is appropriate.

A Preliminary Design Review comment regarding the feasibility of installation and tightening of the fasteners on the inboard side of the field period assemblies is being addressed by the design team.

2.7.2 Comments

The design described in this WBS element is sound and likely to meet requirements. The plans currently in place (particularly the field joint and spool piece R&D activity) should reduce

the main technical issues associated with VV assembly. The cost of assembling and shimming the modular magnets (part of the Field Periods) and the VV sections and spool pieces is likely greater than the value in the current baseline. A shortfall of approximately \$89K is estimated for WBS 75. Even with this cost increase, the cost risk in WBS 75 and 76 is still higher than suggested by the 24 percent in the current baseline. A 30 percent contingency is more consistent with the risk in these WBS elements.

The schedule estimates in the current baseline are credible, however overtime and occasional double shifts are likely needed to maintain the schedule during the assembly of the three Field Periods. These activities are more complex and will take longer than currently planned.

Positioning the spool pieces (field joints) between vessel sections will be complicated and time consuming. Multiple fit-ups and adjustments of the spool piece may be required. In addition, the three vessel sections may need to be positioned simultaneously (with spool pieces), tack welded, and then seal welded in a way that minimizes deformations. This may require a special sequence that will also slow progress. These factors have not been fully considered in the current plan.

Spool piece and field joint R&D (included in WBS 1) is very critical and must answer questions such as: field joint design; weld shrinkage; weld deformation; weld repair methods; joint efficiency and inspection; and vacuum leak testing after the root pass.

Metrology is critical during fabrication and assembly of many components, but particularly important during the positioning and assembly of the modular magnets (part of the Field Periods) and the VV sections/spool pieces. More detail metrology planning in the near-term is appropriate. The overall metrology effort will be more efficient and results more accurate if both vendors and in-house systems are the same. This should be considered. To get accurate results, the metrology system must have a good stable base (floor) and a good view of the component being positioned. A plan for positioning the device for key measurements should be developed. To get accurate results requires trained (experienced) personnel. Training costs should be included.

2.7.3 Recommendations

1. Review and consider an increase in the current baseline cost of WBS 75 associated with assembling and shimming the modular magnets (during Field Period assembly) and the positioning and welding of the Vacuum Vessel sections and spool pieces. This should be done before CD-2, Approve Performance Baseline.
2. Review and consider an increase in the current contingency for WBS 75 and 76 to accommodate the higher risk associated with these activities. This should be done before CD-2, Approve Performance Baseline.
3. Develop a plan to efficiently compare metrology data, taken during fabrication and assembly, with the Pro-E models. This should be done before the completion of the final design.

3. COST ESTIMATE

3.1 Findings

The Total Estimated Cost (TEC) for the NCSX MIE reported to the Committee is \$81 million. Included in this amount is escalation (based on locally established PPPL and ORNL escalation rates) and contingency. The project has expended approximately \$5.9 million for activities leading up to the NCSX Performance Baseline Review. Contingency as a percentage of remaining project cost is 28 percent.

The cost estimate presented to the Committee is an update of the estimates used to support the Conceptual Design Report and the Preliminary Design Review held the first week of October 2003. The NCSX Project Controls Manager provided the NCSX WBS managers with written guidelines for documenting the scope, resources, risk factors, and contingency for each WBS element. The current TEC estimate was compiled using the bottoms-up scope and resources identified by the WBS managers. The individual WBS cost estimates were reviewed by a group that included the NCSX Project Manager, the PPPL Project Controls Manager, the NCSX Project Engineer, the PPPL Department of Engineering Head, and other invited reviewers based on the nature of the work associated with the WBS element being reviewed.

The NCSX basis of estimate incorporates vendor estimates, experience from completed projects and detailed work planning by the responsible WBS managers. Some scope not needed for first plasma and field mapping was deferred. A Value Engineering team examined all project systems and identified \$3.4 million in savings. A contingency drawdown plan developed by the project was illustrated by a contingency profile contained in the presentations provided to the Committee.

3.2 Comments

The cost estimating methodology used by the NCSX project team appears to have been rigorously applied. Consequently the quality of the bottoms-up estimates developed by the WBS managers is consistent. A large fraction of the total estimate is underpinned using cost information from vendors (approximately 40 percent). The remainder of the estimate is based on

experience from completed projects and the detailed planning by the WBS managers using the bottoms-up estimating methodology.

The quality of the cost estimate documentation could have been enhanced by requiring the WBS managers to more fully document their requirements, assumptions, cost drivers, and references (this is especially important to facilitate independent cost evaluations by external groups).

The process used to review the estimate required the WBS managers to justify and defend their scope, approach, assumptions, and risk factors. This two-way feedback is very valuable to not only develop a shared understanding of the current estimate basis, but also to improve communications within the project organization regarding future changes or updates to the existing estimate.

The risk assessment methodology is reasonable and appropriate for the nature and size of the project. The Value Engineering efforts are valuable not only to create savings for the project, but also to provide additional confidence in the cost estimate.

The project may benefit from developing some summary analyses of project cost information, such as Engineering, Design, Inspection and Administration (EDIA), to serve as an independent reasonableness test for certain categories of project costs.

The Committee is concerned that the contingency profile presented allocates contingency in such a way that the majority of the contingency is available in the last half of the project life (about 50 percent of contingency is allocated to tasks in the last year).

The Committee independently assessed the project costs and contingency at WBS Level 2 and either agreed with the estimated costs or suggested revisions to project costs or contingency amounts. A summary of the Committee's assessment is presented in Appendix D.

3.3 Recommendations

1. Reevaluate the planned contingency profile and coordinate any revisions to the profile with the DOE Princeton Area Office before CD-2, Approve Performance Baseline.
2. Evaluate the Committee's comments and recommendations and consider any proposed changes to project base costs or contingency before CD-2, Approve

Performance Baseline.

4. SCHEDULE and FUNDING

4.1 Findings

A detailed, resource-loaded schedule was prepared to show the project's critical path. The schedule was developed using inputs from the WBS managers, who identified durations for their activities and resources required. Input from the WBS managers was then used to develop the master integrated schedule for the project. The project is scheduled for completion in September 2007, which includes five-and-a-half-months schedule contingency. The funding profile and contingency availability is shown in Table 4-1.

Table 4.1—Funding and Contingency Usage (\$M)

	FY 03	FY 04	FY 05	FY 06	FY 07	Totals
Scope	7.9	13.6	18.9	16.5	7.6	64.5
Contingency		2.3	1.5	4.0	8.7	16.5
Total	7.9	15.9	20.4	20.5	16.3	81.0

4.2 Comments

Unlike the cost estimate, where there were guidelines to determine the cost risk and contingency, there was no analogous guidance for the WBS managers to develop schedule risks and contingency. As a result, the confidence in the durations and resources needed may vary from one WBS manager to another.

Table 4.1 shows the planned contingency amount in FY 2005 is only \$1.5 million. Most of the work during this fiscal year consists of modular coil winding form fabrication and the winding of the coils. These activities are not only on the critical path, but the risks associated with these activities are also high. It is possible that contingency and funding levels for that year may result in work scope being pushed into FY 2006 thus extending the project schedule. In FY 2007, the amount of planned contingency is more than the cost of work to be performed.

Overall, the Committee is concerned by the proposed funding profile. The concern with the contingency amount in FY 2005, and the relatively large amount of funding in the last year warrant a reexamination of the funding profile by the project team and DOE sponsor.

4.3 Recommendations

1. Reevaluate adequacy of contingency amount and funding level for FY 2005 prior to CD-2, Approve Performance Baseline.
2. Reexamine the proposed total project funding profile in concert with OFES prior to CD-2, Approve Performance Baseline.

5. MANAGEMENT

5.1 Findings

The project is organized under the overall leadership of PPPL, in partnership with ORNL. The initial steps of active collaboration with a number of other laboratory and academic institutions for participation in the research program have been taken.

An Integrated Project Team that meets the requirements of DOE Order 413.3 is in place and functioning. A preliminary Project Execution Plan (PEP) that defines the roles and authorities of the participants is in place. The PEP identifies key milestones for DOE management tracking and control.

A Risk Management plan has been completed and provides the basis for the initial estimate of contingency provided within the overall TEC.

The project scope is defined such that at CD-4, the machine is ready to operate at room temperature and very basic plasma conditions. However, other system components, mainly the cryostat, will not be installed at that point in order to allow for important subsystems evaluation to take place.

A procurement plan for the near term exists. PPPL procurement staff will be augmented with an additional hire to reflect the increased workload.

5.2 Comments

The proposed staff, DOE, PPPL, and ORNL is experienced and well qualified to execute the NCSX project.

The PPPL Laboratory Director and Deputy Director took an active part in the review and demonstrated strong commitment to the NCSX project. The Deputy Director practice of detailed weekly reviews of project status and issues is particularly constructive.

The cost estimate of \$6.8 million for project management and project engineering is about

ten percent of the total base estimate, which is reasonable for a project of this nature. This includes the systems engineering function, which appears to be appropriately planned.

The NCSX Project Manager and PPPL Deputy Director expressed strong commitment to conducting a bottoms-up estimate-to-complete on at least an annual basis and rigorously maintaining the Estimate at Completion (EAC) to reflect management's best judgment of final costs—this is commended.

There are a few metrics in addition to the formal Project Measurement System that the project management staff should consider using on periodic basis. Among them are: EDIA; percent complete ratios for design, fabrication, installation, etc; and ratios of source information that form the basis for the baseline estimate such as vendor data, engineering estimates, firm bids and/or actual cost.

ES&H and quality assurance planning are performed under the overall PPPL programs in this area—this is appropriate.

The current fiscal year procurement plan is rudimentary, containing only the award date and estimated price. It is suggested that the project team consolidate existing information from the scheduling system into a Procurement Plan. This would provide more complete information in one document, such as type of procurement, and beginning of the procurement process itself.

As pointed out in other sections, the plan to define the project scope such that installation of the cryostat and machine cool down occur after CD-4 could lead to unrealistic expectations for results from early operations.

Confidence in the overall project schedule would be significantly enhanced if the funding profile provided higher budget authorization in FY 2005, on the order of \$2-4 million, with corresponding reduction in FY 2006 and/or FY 2007. DOE and PPPL management should consider this matter.

There are a number of issues that relate to the operations planning. The suite of planned scientific diagnostics is quite extensive. Bringing up the facility to full performance capability is a big task. An early review of the post CD-4 operations budget would be quite beneficial in making sure that there is adequate funding for the successful execution of the scientific program.

5.3 Recommendations

1. Assure that senior DOE management and the fusion physics community clearly understand the limitations on the physics productivity of early NCSX operations that derive from the existing definition of CD-4.
2. Based on the overall assessment of status against requirements for this stage of the project, NCSX is ready to proceed with CD-2, after appropriate response to this committee's recommendations

Intentionally Blank