Preliminary Design Review Report

of the

NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX) PROJECT

October 7-9, 2003

NCSX Preliminary Design Review
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Panel Report

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Appendices

Summary and Response to Charge

A review of the preliminary design of the National Compact Stellarator Experiment (NCSX) was held at the Princeton Plasma Physics Laboratory (PPPL) from October 7-9, 2003, at the request of the PPPL Director. This was a key technical review of the NCSX design prior to the approval of Critical Decision 2 (CD-2), Department of Energy (DOE) approval of the performance baseline.

The NCSX project is an innovative magnetic fusion plasma configuration consisting of a stellarator core with three field periods surrounded by eighteen modular coils (six per field period.) A vacuum vessel fills the internal volume of the modular coils to provide maximum space for plasma shape flexibility. The modular coils are supplemented by toroidal and poloidal field coils. A diagnostic system provides the detailed measurement of the plasma parameters that are critical to the research goals of NCSX. The project's preliminary Total Estimated Cost (TEC) is $81M and scheduled completion is September 2007.

The Preliminary Design Review (PDR) committee found that the NCSX design is technically sound, the management plans and budget are adequate, and the project is ready for CD-2. Twenty-four recommendations for improvements to the design were suggested. Recommendations and issues identified during the Conceptual Design Review (CDR) have been adequately addressed.

The modular coils and vacuum vessel comprise the most technically challenging subsystems and embody the most risk. The present state of the modular coil design is very well developed and the technical basis is sound. Proposed budgets to develop and fabricate the modular and conventional coils are sufficient, although the schedule is tight. Recommendations were made to evaluate stress, fatigue and assembly tolerances of the modular coil systems composite material. The vacuum vessel design is also very well advanced, has incorporated lessons-learned from previous projects and meets the NCSX performance parameters. The fabrication approach is well founded and budgets appear adequate. Several recommendations were made to improve the configuration and fabrication processes, including rapid delivery of a full-scale prototype of a complete, 120-degree sector of the vessel. For other major subsystems, key recommendations included development of a full-size mockup to demonstrate assembly of the modular coil pairs around the vacuum vessel segment, resolution of bolting access between field period assemblies, inclusion of a ground fault monitor, and a review of diagnostic integration studies with emphasis on critical diagnostics prior to the Final Design Review. The use of legacy equipment in the design has been investigated thoroughly.

Management staff, systems, processes and controls are in place and adequate to proceed to CD-2. The NCSX collaboration with ORNL is effective. Value engineering, risk management and systems integration efforts have been effectively employed at this stage of the design. Recommendations were made to develop an on-going plan for value engineering during the life of the project, and to include scheduled, annual “bottom-up” estimates of cost-to-complete. The TEC of $81M (including approximately $16.5M in contingency) and scheduled completion in September 2007 (including 5.5 months of schedule float) appear reasonable.

Technical Findings, Comments, and Recommendations

1. Introduction

The NCSX is a fusion research facility included in the DOE FY 2003 budget for fabrication at the 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 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.

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, heating, 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 ORNL 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, with minimal civil construction, DOE designated the project as a Major Item of Equipment (MIE) and included it as such in the FY 2003 budget. The preliminary total estimated cost prepared at the end of pre-conceptual design and proposed in the FY 2003 budget was $69 million with completion in March 2007. Upon completion of the conceptual design, the preliminary total estimated cost increased to $72 million with completion in March 2007. The increase is the result of a detailed “bottom-up” estimate for the first time including additional proposed contingency for the highest risk components.

The NCSX Project completed a DOE conceptual design review (CDR) in May 2002. Following the CDR, the DOE approved an acquisition plan for NCSX based on a preliminary cost estimate of $73.5M and an execution period of October 2002 through June 2007. In November 2002, the Department approved Critical Decision 1 (CD-1), authorizing the start of preliminary design. At CD-1 approval, a baseline TEC range of $69M-$83M for the MIE fabrication project was established. Because of the delay in the Congressional budget appropriation in early FY-03, the NCSX advanced conceptual design phase was extended through March 2003, during which time the project continued to resolve design issues and initiated R&D activities. The NCSX project execution phase, beginning with preliminary design, started on April 1, 2003.

2. Magnets and Coils

The review committee viewed detailed presentations on the present state of the design and ongoing R&D for the modular and the conventional coil systems.

Technical Findings

- The present state of the design for the modular coils is very well developed. The technical basis for the modular coils systems is sound.

The technical complexity of NCSX and W7-AS is nearly of the same level. The major difference exists in the supporting structure of the modular coil system and the number of coils and coil types. W7-AS used “self-supporting” winding packs with an overall structure shell and lateral support elements inside, transferring the net coil forces to the shell. Therefore the coils were wound up into stiff moulds, capable to withstand 10 manufacturing processes. The winding packs then could be adjusted during the assembly relatively to the structure and to each other applying tolerance gaps in the structure. The final fixation for force transmission was produced by resin filled cushions after the adjustment.

NCSX will use shell elements with machined connecting surfaces and interfaces to the winding packs. Each winding pack has to be wound with final precision into these elements. The elements can be adjusted by shims in the overall assembly. Both methods do have the potential to fulfill the conditions for stellarator symmetry with tight enough tolerances. NCSX engineering provides sufficient attention to these problems.

- The budgets developed are sufficient to fabricate the modular coils along with the attendant research and development.

The NCSX team has developed a detailed costing based upon expected work with input from industry on purchased components. These estimates appear reasonable. Comparisons with the previous modular coil stellarators, HSX and W7-AS support these levels. The actual cost for the core system of W7-AS was 32 M DM for capital expenditure to industry (1988 price basis). The estimate for today would be 42 M DM based on development of industrial prices in Europe. Another 40% have been generated in the institute (staff and shop floor performance). The total of roughly $35M corresponds well with the estimate of $39M for NCSX. Including the foreseen contingency, the costing for NCSX looks sound and sufficient.

- The schedule is tight.

- Issues raised by the Conceptual Design Review are being addressed.

- Toroidal, poloidal and trim coil designs are of a more conventional nature and appear sound and reasonably costed. They will be fabricated externally.

- The project is ready to be baselined and proceed toward final design

The state of the design quality for NCSX at the Preliminary Design Review is more developed than at the beginning of the procurement phase of W7-AS. Three-dimensional design and manufacturing tools, prototype work and early involvement of industry have positioned the project well. Attention has been given to elements critical at this phase of the project and budgets and schedule have been well developed.

Comments

Thermal and electromagnetic load cycles may lead to de-lamination of the copper-epoxy composite due to low shear strength. The conduction cooling of the coil could then be adversely effected. Efforts should be undertaken to examine the expected fatigue properties of the modular coil system.

Concern exists over the short time between prototype delivery and release of production contracts for minor modifications of winding forms. Close interaction with vendors can help accelerate the feedback into the production design.

For final design and fabrication, verification of the prototype coil should be completed and tested as soon as possible.

For Final Design Review significant work remains to be completed on current feed design. Prototyping and testing needs to be performed to assure quality of these elements. If possible, access through the shell at the current feed locations should be available. Care should be exercised to maintain stellarator symmetry in bus systems for conventional coils as well as the modular coil system.

Coil services, such as liquid nitrogen distribution systems need to be laid out with respect to the overall structure.

The tolerance budget should be re-examined with regard to assembly to guarantee stellarator symmetry.

It should be confirmed that the cable is compacted without any lubricant which would degrade the epoxy/copper bonding and lower the shear strength.

As prototyping and R&D continue, efforts should continue to identify areas where the schedule contingencies could be increased.

Recommendations

2-1. Develop and implement a plan to evaluate shear stress quality of the composite used and fatigue properties of the modular coil system.

2-2. Determine motions from machining in the "tee" section and investigate potential processes to minimize this motion. Significant motion could have a large impact on cost and delivery time. The sample twisted casting could be useful in this regard.

2-3. Continue winding and potting coil sections with multiple curvatures to gain experience in conductor placement and clamping and epoxy flow in complex geometries.

3. Vacuum Vessel

Technical Findings

The Subpanel was impressed by the progress that the project team has made in developing the reference vacuum vessel design. The design configuration meets the established NCSX performance requirements and the fabrication approach seems to be well founded. Furthermore, the level of design detail that was presented clearly has taken into account lessons learned plus best practices established on the NSTX project and is well beyond the minimum required for the Preliminary Design Review stage of the project in the critical vacuum vessel area.

The project team has initiated prototype vessel sub-component (two 20-deg sectors) fabrication contracts with two suppliers that will demonstrate critical aspects of the vessel design and tolerance control prior to the final design review. These contracts will provide essential information concerning the feasibility of achieving the reference vessel configuration within the established cost and schedule. The panel strongly endorses completion of these demo contracts and recommends that all reasonable actions be taken to ensure that parts from these two competing vendors are successfully delivered and evaluated prior to the FDR milestone.

Comments

The NCSX vessel is a complex three-dimensional assembly that depends upon model-based design definition and close coordination with suppliers to achieve the challenging fabrication and assembly tolerances. It utilizes Inconel 625, a high strength alloy, that will require well-controlled fabrication processes and established quality assurance procedures to achieve the desired end result.

Other aspects of the in-vessel component and auxiliary system design are perceived to be well in-hand by the panel. They are adequately defined for the PDR stage of the project and they address the proposed NCSX baseline operation and upgrade needs. The power, water, bakeout and gaseous supply systems build on recent design concepts implemented successfully on NSTX and they utilize legacy on-site hardware from prior PPPL experiments wherever possible to reduce cost. A thorough review of legacy subsystems has been completed to determine their current operational status and costs have been included in the baseline cost estimate to refurbish and upgrade these systems to the state required for successful NCSX operation.

Recommendations

The vessel panel has no concerns about the readiness of the project to proceed towards the FDR. However, the panel has the following recommendations to the project team concerning aspects of the design that could potentially benefit from the proposed configuration and/or process changes:

3-1. *Port Extensions*: Transition to stainless steel as soon as possible in the port extensions. If possible this should be done at the short stub weld location. The current design, which extends Inconel to the primary flange location on these ports, introduces added machining and preparation costs on these large vacuum seal surfaces. The selection of vacuum vessel and port material may benefit from a graded approach to technical requirements. Inconel 625 is clearly appropriate for the vacuum vessel due to its high strength, low electrical conductivity and low magnetic permeability, although its cost and difficulty of fabrication are high. As distance from the plasma increases, Inconel's properties are less important. Review of cost and fabrication issues may support the selection of stainless steel for ports and the neutral beam port box. Inconel flanges should be avoided if possible. The panel also recommends that the vessel weld joint be changed on these parts to provide a final internal vacuum integrity pass. The external weld should be a skip weld providing only the area required to react to mechanical loads. After the port openings are cut, an internal weld pass should be made to assure vacuum integrity.

3-2. *Vessel Welds*: Evaluate feasibility of automating the final vessel assembly welds at the three spool insert locations. The flanges on these welds should provide a convenient means of tracking the weld joint and supporting a fixture for the weld head. This would eliminate the need for manual welding operations in this restricted area during assembly and should produce more reliable root and fill pass weld joints. The project should also evaluate use of Penetration Enhancing Compounds (PEC) to increase root pass penetration depth and reduce the number of fill passes on all vessel welds. This could significantly reduce weld distortion and residual stress. On the ITER project, PEC's were used to increase root pass depth from 2 to 6-mm in an extensive length of 1000 psi water channel close-out welds on a large SS-316 structure without any weld quality, vacuum integrity, or magnetic permeability side effects.

3-3. *Bakeout Temperature*: Assess viability of increasing the vessel bakeout temperature to 350 C. This temperature is presently used on the D-III device and it enables conditioning to be accomplished in a few hours. More importantly, it would also eliminate the need for installation of a separate in-vessel PFC heating loop during future upgrades. The PFCs could instead be passively mounted to the wall with simple electrical isolation breaks. This would eliminate costs associated with the 200 psi in-vessel helium system and potential leaks that could develop in this system during operation.

3-4. *Insulation*: Alternatives should be assessed to the proposed use of Microtherm blankets for the vessel insulation. While efficient, this insulator will be difficult to conform to the compound curvatures associated with the NCSX vessel. On Wendelstein 7, this insulator needed to be made in 10x10-cm tiles that were stitched together to form a blanket. Newer high-performance, flexible insulating blankets are available using silica aerogel technology that should be applicable to the NCSX environments. Aerogel materials are ultra low conductivity, low density insulations that offer market-leading thermal insulation, acoustic protection, and infrared suppression performance.

3-5. *Prototype Sector*: Due to the significant amount of welding used in vessel fabrication, the panel is concerned about possible effects of residual weld stress on the vessel dimensional stability. We therefore recommend that a 400 C thermal stress anneal cycle be performed on one of the prototype vessel sectors to evaluate possible benefits of this added fabrication step on the dimensional stability of the vessel after fabrication. This anneal cycle should be performed before the port extensions are removed so that the extended port structure is in-place to help maintain the wall stub geometry until weld stresses are relieved. In addition, the panel recommends that fabrication of a complete, 120-deg sector of the vessel be initiated as soon as possible once supplier down-select is completed. The contract should allow for staged delivery of the full-scale prototype sectors so that the first one is available early to assess tolerance build-up and dimensional stability of a full sector of the vessel to determine if any final design or manufacturing process adjustments are needed prior to exercising the option for the remaining sectors. This will provide incentive for the supplier to achieve first-time quality and full confidence to proceed with the remaining vessel sector fabrication.

3-6. *Port Bakeout*: The panel recommends that additional measures be taken to assure that the large wall surface areas associated with the neutral beam boxes and other port extensions be raised to above 100 C to assure good wall conditioning prior to operation. This could be done using external heating blankets and insulation blankets where appropriate, but a plan for heating these volumes should be presented at the FDR.

3-7. *Auxiliary Utility Lines*: The panel is concerned that costs associated with electrical breaks, single point grounding, and other installation details associated with the auxiliary LN2 and high pressure helium lines that must penetrate the cryostat are not properly accounted for in the PDR cost assessment. Due to the large number of these lines, more typical installation detail is needed prior to the FDR to assure that these costs are properly budgeted for in the estimate.

4. Field Period Assembly

Technical Findings

The committee finds that the engineering design has advanced since the conceptual design review and is well developed for this stage of the project. The sequence of steps in the assembly process has been documented and crew sizes have been estimated.

The dimensional requirements have been developed, and the position tolerance on the coil current center of +/-0.020 in. is thought to be aggressive but achievable.

Required metrology tools have been identified and include a FARO Arm, Laser Tracker, and an Arcsecond Constellation 3DI system.

A temperature-controlled area has been identified for field period assembly with adequate space and crane coverage (TFTR Test Cell).

The assembly of the three field periods is on the critical path but the schedule duration for this activity appears to be adequate.

Cost estimates based on crew sizes and durations are reasonable and 40% contingency appears to be adequate at this point in design development.

There is no legacy equipment required for the field period assembly (except for cranes, etc., in the TFTR Test Cell)

This element of the project is ready for CD-2.

Comments

Although the metrology tools have been identified for measuring locations of critical points, the software for resolving these points into the NCSX coordinate system has not been developed/procured. This is a critical element of the assembly process and should be obtained as early as possible.

The surfaces of the modular coil castings will be contour machined only where the coil winding pack will be placed and there is high reliance on CAD models to assure the castings will provide adequate clearance during assembly – although a worst case condition of clearances approaching ¼ inch is envisioned. Time should be allowed in the schedule to pre-assemble castings for each type of joint: A-A, A-B, B-C, C-C, to assure the planned clearance exists.

The alignment of coils utilizing custom shims can become complex. Guidelines should be established to utilize standard shims unless some acceptable threshold misalignment is exceeded.

The integration of the modular coil pair subassemblies around the vacuum vessel segment is a critical operation. At the earliest possible time, a full scale mockup should be developed that allows this operation to be practiced. This same mockup, if so constructed, could be used to demonstrate adequate clearance for making all the in board connections between subassemblies at final assembly. Experience could also be gained with the metrology tools and software using the mockup.

Welding of port extensions may prove to be more challenging than presently envisioned. There is a need to document flange locations and tolerances so a short development effort can be conducted to demonstrate that these requirements can be met during the assembly process.

Recommendations

4-1. Obtain metrology software to allow testing and debugging before critical needs arise.

4-2. Plan time in the schedule to pre-assemble each type of modular casting assembly joint to assure adequate clearance exists between mating parts.

4-3. Develop a full-size mockup to be used to demonstrate the assembly of the modular coil pairs around the vacuum vessel segment.

4-4. Develop misalignment threshold for installation of customized shims.

5. Cryostat and Cryogenic System

Technical Findings

The design of the cryostat was well thought out and should provide the needed insulation and protection from condensation required for proper cooling of the NCSX coils and structure. The estimates of LN2 use seem reasonable and indicate a cryostat is being planned at least as capable as that in use on C-Mod. Most of the materials chosen for construction of the cryostat have been proven on C-Mod as has the boot concept planned to seal around ports. The concept of a standardized sub-frame with customized port is a very good one.

Comments

No details were presented on how the LN2 was to be supplied to the coils. What types of tubing and electrical breaks are being used? How do the feed and exhaust lines run to the various coils? How is the LN2 controlled? Is it planned to purge the coils of LN2 before running current through the coils? These issues were not reviewed; however, informal talks with the engineer in charge indicated that these systems are being given serious consideration.

The cost and schedule for the cryostat and cryogenic systems described were reasonable.

Recommendations

5-1. More consideration should be given to providing an external vaporizer to provide initial room temperature GN2 pressurization of the cryostat. Initial removal of moisture from the cryostat and machine surfaces should be done without introducing LN2 into the system since control of the low temperature vapor from such a system would be difficult. On the scale of NCSX, this is a minor cost with large benefits for the facility.

5-2. The addition of humidity sensors inside the cryostat is strongly encouraged. Otherwise it will not be known for certain how well sealed the system is or when introduction of cool gas and liquid into the system should be made.

6. Machine Assembly

Technical Findings

For a preliminary design review, the challenging machine assembly task was well developed and presented with one notable exception. The feasibility of bolt installation and tightening of fasteners between the inboard area of the field period assemblies is not apparent. Any resolution of this issue was not presented with a satisfactory level of confidence.

The machine assembly does not utilize legacy equipment.

Comments

The issue of the lack of access for bolt installation and tightening of fasteners between field period assemblies in the inboard area needs to be addressed. These equivalent bolts are accessible during build up of the Field Period Assemblies since the TF coils are installed last into these assemblies. The presence of the wedged TF coils during the machine assembly task forms a barrier to the access required for these bolts.

Vacuum vessel and port welds, particularly field welds that may be made with limited access, may develop leaks anytime throughout the life of the machine. This process of leak locating should be identified during the design of the machine. This may require the permanent installation of helium injection tubes to the area of the weld on the outside of the vessel.

Space allocation inside the cryostat is limited. Before the final design review, space allocations should be well defined. The following is a short list of equipment to be packaged within this volume:

1. Electric power feeds to all coil systems
2. Turn to turn electrical connection for the TF coils
3. Insulated bake out helium supply and return manifolds, lines and electrical breaks
4. Instrumentation lines
5. Nitrogen supply lines
6. Grounding cables

Sufficient design work should be done to assure a reasonable arrangement could be developed within the space allocated.

Recommendations

6-1. Resolution of the bolting between field period assemblies is required. The preload requirement for this joint is uncertain. Can the bolt requirement be met by additional accessible bolts at the top and bottom or by spacers compressed between the field period assemblies? A cure-in-place shim the full height of the joint might be feasible. This could be made from an inflatable shim bag filled with pressurized epoxy. Would this be beneficial?

7. Power Systems

Technical Findings

The plan to use the existing D-site power supplies is a cost effective approach. In addition, since these supplies are numerous and highly modularized, they provide significant flexibility and redundancy. The four quadrant capability as demonstrated on NSTX provides significant operational advantages. The nature of the system facilitates gradual upgrading from 1st plasma to future scenarios in a seamless manner. Ample power and power supplies are available.

During the operational phase, maintenance and operating cost savings may be realized since the equipment is being shared between the two machines. Although the power supplies will be shared with NSTX, the four hour turnaround time to switch back and forth between machines will not impose a significant restriction. However, careful planning will be needed to ensure that the modifications needed for NCSX are coordinated with the NSTX operating schedule.

The plan is technically sound. The use of the thyristor rectifier power supplies, even with 6-pulse harmonics, has been judged acceptable because of the circuit inductance and the filtering effect of the vacuum vessel. Current measurement, regulation, and control response typical of this equipment has been judged acceptable.

The scope of work to be performed is conventional, and similar to prior work on NSTX, so the cost, schedule, and technical risk should be moderate as reflected in the assigned contingency.

Comments

It appears that the deployment of a ground fault monitor to sense the status of the many insulating breaks in the machine structure has not been included in the Project scope. Although the system is not needed during construction, it would save time and reduce risk beginning with the first energization of the magnets.

Recommendations

7-1. It is recommended that the wiring of these elements to a single point ground, along with a ground fault monitor, be included in the project scope.

8. Vacuum, Fueling, and Heating

Technical Findings

- There are no significant technical, cost or schedule issues for the pumping and fueling systems planned for the MIE, and the specified future upgrades can be accommodated.
- There is adequate expertise, resources and schedule to achieve the project goal of installing and testing one NBI system.
- Upgrades for future heating systems and extended pulse length can be accommodated.

Comments

The Auxiliary Systems scope of the NCSX MIE project includes fueling, torus vacuum pumping, and heating subsystems.

Pumping System (WBS 22) The NCSX project team provided good responses to the CDR recommendations for the pumping system. The legacy turbo and roughing pump systems planned for use on NCSX have been checked out and found to be in good condition. The pumping system conductance has been increased where possible and it appears to be adequate to achieve the desired pumping speed of at least 2600 l/s at the torus. Good options exist for increasing the pumping capability if it is required later in the NCSX program.

Upgrades including glow discharge cleaning, boronization, and lithiumization can be accommodated.

Fueling Systems (WBS 21) NCSX will re-use the existing Gas Fueling System from PBX-M and there appear to be no issues with this plan.

NCSX can accommodate a pellet injector and inboard pellet launch guide tubes as a future upgrade.

Heating Systems (WBS 25) A single neutral beam system will be installed and tested as part of the NCSX MIE Project. This NBI system (and three others) was used on the PBX-M project. The project team has made a good start on checkout and refurbishment of these systems. The beamline boxes and components appear to be in very good shape. New turbo and cryo pumps will be required and they have been included in the cost estimates. The power supply systems will require further checkout and modernization. There appears to be adequate expertise, resources and schedule to achieve the project goal of installing and testing one beamline.

Additional neutral beam systems (up to 3 more) are planned for and can be accommodated in the later operational phases. Upgrades including radio frequency wave and electron cyclotron wave heating systems can be accommodated. The facility can accommodate the requirement for the extended heating pulse duration of 1.2 sec. There is space available to accommodate future plasma facing component upgrades that could handle a total heating power of 12 MW.

Legacy systems for the Vacuum, Fueling and Heating systems have been evaluated/tested and where required further testing and/or replacements have been included in the cost estimates.

Recommendations

None

9. Water, Bakeout, Utilities, Test Cell Prep

Technical Findings

The systems considered here will provide water for vacuum, neutral beam, and diagnostic systems. The pressurized helium system for vacuum chamber and PFC bakeout is also considered here as are systems to provide GN2 and air to the cell.

Much of the hardware used for these systems will be legacy hardware or hardware that has already been proven on other machines. All the water systems seem to be well planned with capability well beyond what will be required, at least early on in the project. The same can be said of the air and GN2 systems (particularly if recommendation 5-1 is followed). Cost and schedules seem very reasonable, and since there has been recent experience on NSTX, the panel has good reason to think the numbers are solid.

Comments

The pressurized helium system is a reproduction of a system used on NSTX which has been working extremely well. One issue that was raised was whether or not the system should be planned from the start to allow a 350 C bake of the vessel.

Recommendations

9-1. If graphite is to be used it would be much preferred to bake the vessel and the PFCs to 350 C and eliminate the complications of invessel helium lines, shields, and complicated support structure. On the other hand, using hi-Z PFCs and no carbon should also be considered.

9-2. Bakeout on C-Mod requires 5 to 10 days at 130C. This long bake period is primarily the result of water evolution from cabling and conduits. DIII-D at 350 C bakes for 10 hours or so. So this tradeoff should also be considered.

10. Central I&C and Data Acquisition

Technical Findings

A comprehensive package of network infrastructure, centralized I & C, data acquisition, and facility timing has been developed for the NCSX experiment. The design of these elements is largely based on experience from NSTX. NCSX plans to not use legacy CAMAC equipment from the TFTR era (and presumably earlier), but will implement either PCI-based acquisition cards or the presently less well-developed Compact-PCI architecture. The team will make its selection not long before first plasma in order to take advantage of continuing development of commercial hardware.

NCSX will make use of a real-time plasma and power supply control system, also modeled from NSTX experience. The necessary signals for control of the stellarator equilibrium, while not known at this time, are expected to be treatable by the same system used on NSTX with appropriate adaptation.

Comments

The action plan makes good use of NSTX experience, and is well-planned. The cost estimates for labor and M&S have been thought out, and require relatively low contingency levels. The decisions to relinquish the CAMAC hardware in favor of PCI or cPCI, as well as deferring the selection of the latter are appropriate.

The CDR recommendation to incorporate a faster clock (10 MHz) was followed.

Recommendations

None

11. Diagnostics

Technical Findings

The NCSX team has proposed to implement a minimal set diagnostics to verify that the project has achieved its goal of generating a plasma with a modest level of ohmic plasma current. Furthermore, the team will install a set of magnetic field diagnostic loops between the outside of the vacuum vessel and the modular coil frames – these external diagnostics will never be accessible again once the field period assembly is completed, and therefore must be installed prior to assembly if they are to be implemented at all. The diagnostics described by the team consist of flux loops lying directly on the outer surface of the surface of the vacuum vessel, and loops parallel to each modular coil embedded within the epoxy potting of the coil. In addition, flux loops will be attached to the PF ands TF coils, and a pair each of Rogowski coils and diamagnetic loops will be mounted on the vacuum vessel. The total number of coils was not specified at this time, but is on the order of 300. Only a Rogowski coil and a fast camera will be used during initial phase of operation to commission NCSX.

Project costs also include e-beam field-mapping equipment, although this is not intended for use until after commissioning. Finally, the project also supports design studies for implementing future diagnostics on NCSX.

Following the completion of the project, the research plan calls for several months of electron beam mapping, and then initial plasma experiments with 1.5 MW of neutral beam power, followed a year later by operation with 3 MW of neutral beam power. Appropriate diagnostics will be implemented at each stage of the research plan.

Comments

Because the diagnostic needs for project completion are minimal, there are no substantive cost and schedule issues in this area. The allocated budget of $1.504M should readily accomplish the above tasks. The average contingency of 30% is above the project average, and results from uncertainties in the number of loops required for the magnetic diagnostics and the budgets being derived from top-down estimates in the remainder.

Diagnostic issues are minor at this stage relative to construction needs. Looking to the future, there is some uncertainty in the plan for field mapping experiments to be carried out following project completion. While field mapping equipment is provided for in the project budget (but will not be used), there is no provision in the budget to check out and hook up the existing power supplies for the trim coils that should be included in the field mapping experiments. Furthermore, the Initial Operation period calls for wall conditioning, but installation of glow discharge cleaning has been postponed until after this period.

Present diagnostic integration studies i.e., how to implement profile diagnostics in 3-D plasma geometry through long port extensions have begun, and have been responsible for improving the port design. Nonetheless, many of the studies appear to be mainly conceptual at this stage, and not yet inclusive of all appropriate diagnostics.

The new research plan making initial use of a single neutral beam is scientifically interesting. It should be feasible to carry out with the diagnostics listed for this phase of operation.

No significant issues raised in the CDR remain outstanding.

Recommendations

11-1. Develop more specific goals for the field mapping experiments following MIE that take into account that NCSX has a highly variable magnetic configuration.

11-2. One can defer purchase of e-beam equipment until completion of project; consider implementing funds for GDC earlier.

11-3. Review diagnostic integration studies, and strengthen emphasis on critical diagnostics. After April 2004 (scheduled FDR for the vacuum vessel), it will be too late for further accommodations

12. Management

Technical Findings

The management tools and processes seem appropriate for the Project at this stage of development. The Management Subcommittee reviewed a number of documents such as the Risk Management Plan, the CDR Report on the Project Controls System and the Hazards Analysis document. Additionally, there was a half-day breakout session on Management and Long-Range Planning with six specific papers presented. Based on the information gathered at this review the Subcommittee concludes that the NCSX management team has prepared the correct documents and cost estimates and has implemented processes and controls that are adequate for the Project to proceed to CD-2. Specific details are discussed and presented below.

The collaboration between PPPL and ORNL seems effective and as seamless as is possible. It was impossible for the Management Subcommittee to determine, without some additional information, whether any specific speaker was a member of the PPPL staff or the ORNL staff. This seamless interaction seems to permeate the manner in which the Project approaches their work. This is seen as a very positive sign that the collaboration between the two organizations can lead to a successful completion of the Project. The Project has implemented a very detailed Project Control System (PCS) and uses this system to produce monthly reports using an Earned Value Measurement System including cost and schedule indices, cost to complete and plotting earned value. The PCS is based on a system PPPL has been using for several years and has provided similar data for several projects at PPPL. The staff continues to make minor improvements in the system, but it has a demonstrated record of providing the data required by Project managers. The subcommittee inquired about Project plans to conduct an annual “bottom-up” estimation of cost to complete. Laboratory (as opposed to NCSX) management stated that this has been done with past projects and would be done for NCSX.

The NCSX Project has used a risk-based analysis system for estimating the required contingency on the “to-go” work. This contingency estimate is based on the WBS manager’s assessment of technical, cost and schedule risk, with weighting factors applied, and seems to be an appropriate process. Each WBS element manager thus calculates the contingency requirements for the work to go in that element. The estimates from all WBS elements are summed giving a Project total. There is a continuing assessment of these data by Project managers and there has undoubtedly been some management discretion applied. These contingency estimates summed to $16,541, equaling 28% of to-go costs. These measures of contingency seem reasonable at this stage of the project.

The Risk Management plan was reviewed and appears to be a well planned, reasonable assessment of project risk. It was obvious from the presentations that the engineers and scientists working on NCSX are aware of and sensitive to the many technical, cost and schedule risks this

Project must deal with. Many of the speakers devoted considerable time to risk identification and assessment and to mitigation techniques for dealing with these risks. The Risk Management Plan not only identifies these risks but also captures mitigation and “what if” scenarios for dealing with the risks.

A Value Engineering Task Force was formed during the Preliminary Design period. This Task Force performed a study of ways to reduce cost and risk to the Project. A number of areas were identified as having potential for some cost savings. Project management reviewed these data carefully, accepting some of the Task Forces suggestions and rejecting others as not being appropriate for inclusion. This activity proved to be successful and resulted in savings of some $3.4M to the estimated cost of the Project. These savings are reflected in the cost numbers presented to the Committee. The Project does not seem to have a crisp, forward-looking plan for how to continue the value engineering activity.

The key elements of system engineering – design integration and verification, work planning, and configuration management and control – are in place and well documented. Utilization of a common model and drawing database should minimize miscommunications between PPPL, ORNL, and their respective vendors. The committee reviewed a list of approximately $3.6M in scope that has been removed since the CDR. It is important that the rationale for these reductions be documented for potential upgrades.

The procurement and the QA approaches are designed to reduce overall risk to the Project. For example, the plan to pre-qualify two vendors each for the vacuum vessel and modular assembly coil winding form in their prototype development program illustrate the commitment of both procurement and QA to this project early in its inception.

Comments

The annual “bottom-up” cost estimate provides a valuable management tool to Project leaders/managers and the Subcommittee strongly recommends that NCSX management commit to this activity. This activity will be a major impact on Project activities and progress each year, therefore, this activity needs to be included in the Project’s master schedule, with milestones associated with this continuing activity.

The Project management stated their intention of keeping the Risk Management Plan current throughout the life of the Project. This is essential and Project Management must commit to this idea. Many of the identified risks will be managed and handled successfully, but as the Project proceeds new risks will be identified and earlier identified risks will indeed become reality and must be dealt with.

Project management acknowledged the value of continuing a value engineering activity but was not clear on what form this should take. The Subcommittee strongly urges the Project Management to make and document this decision and implement a continuing value engineering activity for NCSX.

The Project should document the items removed from the scope baseline between the CDR and the PDR. The rationale for these changes should be included in this documentation. This will provide a documented history for removal of these components and justification for their consideration as upgrades during operations.

Recommendations

12-1. The project should clearly identify and document how value engineering will be applied and used during the life of the project.

12-2. The project needs to document the plan to do an annual "bottom-up" estimation of cost to complete. This activity should be included in the project schedule.

Appendix 1.

NCSX Preliminary Design Review Charge

Background and Context

The NCSX Project passed a DOE conceptual design review (CDR) in May 2002. Following the CDR, the DOE approved an acquisition plan for NCSX based on a preliminary cost estimate of $73.5M and an execution period of October 2002 through June 2007. In November 2002, the Department approved Critical Decision 1 (CD-1), authorizing the start of preliminary design. Because of the delay in the Congressional budget appropriation in early FY-03, the NCSX advanced conceptual design phase was extended through March 2003, during which time the project continued to resolve design issues and initiated R&D activities. The NCSX project execution phase, beginning with preliminary design, started on April 1, 2003.

In the DOE project management system, the performance baseline is not established until the design reaches a level of maturity well beyond conceptual design. The performance baseline defines the performance, scope, cost, and schedule commitment to which the Department will execute the project and marks the beginning of performance tracking by the Department. This Preliminary Design Review is the key technical review in a series of reviews leading up to Critical Decision 2 (CD-2), DOE approval of the performance baseline. It will be followed in November by a DOE Performance Baseline Review conducted jointly by the Office of Science (D. Lehman's organization) and the DOE's Office of Engineering and Construction Management (OECM). The OECM will use a team of outside consultants with expertise in engineering and project management but not specifically in fusion. The OECM review will satisfy the DOE requirement for an External Independent Review (EIR) for a project of this size. The conclusions of this PDR will be made available as input to the November DOE review.

PPPL's Objectives for the Preliminary Design Review

At the preliminary design review, the project is presenting its proposed performance baseline, that is, the self-consistent performance, scope, cost, and schedule baselines for the project. The primary objectives of the review are to establish the technical soundness of the performance baseline and to obtain feedback and recommendations from experts on how the design, plans, and cost and schedule estimates could be improved. The modular coils and the vacuum vessel are the critical NCSX subsystems, i.e., the ones that are the most technically challenging and contain the greatest risk. All other subsystems have much lower risk– they are either adaptations of existing equipment or new equipment based on proven designs. Therefore, this review covers all NCSX subsystems but places special emphasis on the modular coils and vacuum vessel. An additional objective is to review the adequacy of the management plans and budget for completing the project.

Charge to Committee

The committee is asked to review the performance baseline for the NCSX fabrication project, and respond to the following:

1. Does the performance baseline have a sound technical basis? Does it clearly establish the capability being acquired?
2. Are the estimated cost and schedule adequate to acquire that capability?
3. Does the performance baseline account for risks and mitigation strategies in the cost and schedule and provide a realistic, achievable plan that includes adequate contingency?
4. Does the (a) modular coil and (b) vacuum vessel design work address all requirements including interfaces with other systems? Are there sound plans to complete their design and implementation? Are issues of manufacturability and constructability adequately addressed?
5. For the other subsystems, have all issues (e.g., testing of legacy equipment) been adequately addressed for purposes of establishing the performance baseline?
6. Are the risk management and value engineering approaches adequately addressed?
7. Are the CDR recommendations adequately addressed?
8. Are the management plans and costs adequate?
9. Is the project ready to proceed to Critical Decision–2, Establish Performance Baseline?
10. Please provide recommendations for improving the project's designs, plans, and estimates.

Schedule

Sept. 23	Project documentation to be issued. Project will post it on their web site and notify committee that it is available for review.
Oct. 1	Committee questions due to project.
Oct. 7-9	Preliminary Design Review at PPPL. The committee is asked to present its conclusions at the closeout briefing on October 9.
Oct. 24	Final Report due. The committee is requested to submit a final report addressing their findings, comments, recommendations, and responses to the charge.

Appendix 2.

NCSX Preliminary Design Review Panel Members

David T. Anderson, Deputy Chair	U. Wisconsin	dtanders@facstaff.wisc.edu
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Peter Wanderer	BNL	wanderer@bnl.gov

Appendix 3

Agenda for Preliminary Design Review

NCSX Preliminary Design Review Agenda
Princeton Plasma Physics Laboratory, Princeton, NJ
October 7-9, 2003

Tuesday, October 7, 2003

Morning, Room LSB-318

7:45 **Continental Breakfast (LSB 318)**

Committee Executive Session

8:00 NCSX Federal Project Director Perspective, G. Pitonak

8:10 OFES Perspective, G. Nardella, J. Willis

8:20 Committee discussion, C. Strawbridge

Project Overviews (Plenary Session) Facilitator: R. Hawryluk

9:00 PPPL Welcome, R. Goldston

9:15 NCSX Overview, H. Neilson

10:15 Break **(Coffee refresh in LSB 318)**

Late Morning, Room A-104 (Display Wall Room) Facilitator: H. Neilson

10:30 Stellarator Device Overview (WBS 1), B. Nelson

11:30 Discussion

12:00 **Working Lunch for Committee (Conference room A118)**

Afternoon, Room A-104 (Display Wall Room) Facilitator: H. Neilson

1:00 Field Period Assembly and Metrology (WBS 18), M. Cole

2:00 Test Cell Preparations and Machine Assembly (WBS 7), E. Perry

2:45 Break **(Coffee conference room A118)**

3:00 Discussion

Committee Executive Session, Room LSB-318

4:00 Committee discussion, formulation of questions for NCSX team.

5:30 Meeting with NCSX team.

6:00 Adjourn

NCSX Preliminary Design Review Agenda
Princeton Plasma Physics Laboratory, Princeton, NJ
October 7-9, 2003

Wednesday, October 8, 2003 Morning

Committee Executive Session, Room LSB-318

7:45 Continental **Breakfast for Committee (LSB 318)**
7:45 Committee discussion, C. Strawbridge

Breakout Session A-1, Room A-104 (Display Wall Rm) **Modular Coils (WBS 14) Facilitator: W. Reiersen**	**Breakout Session B-1, Room LSB-331** **Vacuum Vessel (WBS 12) Facilitator: H. Neilson**
D. Anderson (chair), R. Johnson, C. Neumeyer, J. Sapper, C. Strawbridge, P. Wanderer	D. Driemeyer (chair), J. Anderson, P. Anderson, J. Irby, S. Knowlton, T. Nicol, D. Rasmussen
8:15 Modular Coil Design and Analysis, D. Williamson 9:15 MC Winding Form Fab. and R&D, P. Heitzenroeder 10:00 Break **(Coffee in A118)** 11:00 Modular Coil Fab. and R&D, J. Chrzanowski 11:45 Modular Coil Summary, D. Williamson 12:00 Adjourn	8:15 Vacuum Vessel Design and Analysis, P. Goranson 9:00 Vacuum Vessel Interfaces, M. Cole 9:30 Vacuum Vessel Fab. and R&D, M. Viola 10:00 Break **(Coffee outside LSB 331)** 10:30 PFC Upgrade Design and Analysis, P. Goranson 10:50 Vacuum Vessel/PFC Summary, P. Goranson 11:10 Discussion 12:00 Adjourn

12:00 Working Lunch for Committee (outside Director's Conference room - LSB 331)

NCSX Preliminary Design Review Agenda
Princeton Plasma Physics Laboratory, Princeton, NJ
October 7-9, 2003

Wednesday October 8, 2003 Afternoon		
Breakout Session A-2, A-104 **Magnet Systems** **Facilitator: W. Reiersen**	**Breakout Session B-2, LSB-331** **Ancillary Systems** **Facilitator: L. Dudek**	**Breakout Session C-2, LSB-233** **Management & Long-Term Plans** **Facilitator: J. Lyon**
D. Anderson (chair), R. Johnson, C. Neumeyer, J. Sapper, P. Wanderer	D. Driemeyer (chair), P. Anderson, J. Irby, S. Knowlton, D. Rasmussen	J. Anderson (chair), T. Nicol, C. Strawbridge
Conv. Coils/Structures (WBS 13/15) 1:00 Design, M. Viola 1:30 Analysis, L. Myatt Electrical Power Systems (WBS 4) 1:50 Electrical Power Systems, S. Ramakrishnan 2:10 Discussion (coffee @LSB-331)	1:00 Vacuum and Fueling Systems (WBS 21/22), W. Blanchard 1:20 NB Injection (WBS 25), T. Stevenson 1:45 Cryostat, Base, & Cryo. System. (WBS 17/62), G. Gettelfinger 2:10 Diagnostics (WBS 3), D. Johnson 2:30 Discussion **(coffee @ LSB-331)** 2:50 Central I&C / Data Acq. (WBS 5), G. Oliaro 3:10 Facility Systems (WBS 6), L. Dudek 3:30 Adjourn	1:00 Project Management, H. Neilson 1:30 System Engineering, W. Reiersen 1:50 Cost & Schedule Methodology, R. Strykowsky 2:10 QA/QC, J. Malsbury 2:25 Procurement, R. Templon 2:40 Break **(coffee @LSB-331)** 3:00 Integrated System Testing and First Plasma, C. Gentile 3:15 Research Program, M. Zarnstorff, J. Lyon and M. Williams 3:45 Adjourn
2:30 Executive Session A 3:00 **Break (coffee outside LSB 331)** **4:30 Adjourn Exec. Session**	**3:30 Executive Session B** **4:30 Adjourn Exec. Session**	**3:45 Executive Session C** **4:30 Adjourn Exec. Session**

Committee Executive Session, LSB-318

4:45 NCSX team responses to questions.
5:15 Committee discussion, C. Strawbridge
6:00 Adjourn

NCSX Preliminary Design Review Agenda
Princeton Plasma Physics Laboratory, Princeton, NJ
October 7-9, 2003

Thursday, October 9, 2003
Room LSB-318

7:45 Continental Breakfast **(LSB 318)**

Project Summary (Plenary Session)

8:15 Summary, H. Neilson

8:45 Discussion

Committee Executive Session

9:00 Committee drafts report and conducts dry run of closeout briefing.

12:00 **Working Lunch for Committee (LSB 331)**

1:30 Closeout Briefing

3:00 Adjourn

Appendix 4.

Proposed NCSX Baseline Performance Objectives

The milestone marking the transition from a fabrication project to an operating facility is the DOE Critical Decision 4 (CD-4) milestone, also known as “First Plasma”. The Operations phase will begin upon completion of the First Plasma milestone. The First Plasma milestone will demonstrate a level of system performance sufficient for the start of research operations.

The NCSX facility will initially support operation with room-temperature coils, including: First Plasma operation with a magnetic field strength of 0.5T and a plasma current of 25 kA, and field-line mapping operation with a magnetic field strength of 0.1 T and no plasma. Fabrication of systems needed to support coil operation at cryogenic temperatures, and refurbishment and installation of equipment for 1.5 MW of Neutral Beam Injection (NBI) heating, will be done as part of the NCSX MIE project. These systems are needed in the first year of the research program.

Performance projections for NCSX have some uncertainty because of the developmental nature of the design. It is prudent to set a lower level of acceptable performance as a threshold in case the cost of meeting the objective performance proves to be prohibitive. At the threshold level of performance the scope of the physics mission that could be accomplished would be reduced to a degree, but the core mission to resolve issues bearing on the attractiveness of the compact stellarator concept would not be compromised. The performance objectives and performance thresholds at Project Completion are tabulated below.

Proposed NCSX Baseline Performance Objectives

NCSX Performance Objectives and Thresholds at Project Completion

	Objective Performance	**Threshold Performance**
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 room 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).	
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 coils is rated for operation at cryogenic temperatures to support plasma conditions with: • high beta (4%) • magnetic field up to 2 T (0.2) or 1.2 T (1.7s) • Ohmic current drive up to 320 kA • full flexibility, per the GRD.	Magnet system rating reduced to: • magnetic field up to 1.6 T (0.2 s) or 1.2 T (1 s) • Ohmic current drive up to 250 kA • reduced flexibility

Proposed NCSX Baseline Performance Objectives

	Objective Performance	**Threshold Performance**
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 2×10^{-8} torr @293K • global leak rate less than or equal to 2×10^{-5} torr-l/s @293K. • bakeable at 150 C	Vacuum vessel system rating reduced to: • 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 • operable at room temperature.
Vacuum Pumping	A pumping speed of 1,300 l/s at the torus will be achieved.	
Vacuum Vessel Base Pressure	4×10^{-7} torr	
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.	

Appendix 5.

Proposed NCSX Baseline Scope Objectives

The NCSX fabrication project scope includes all the equipment required at the start of operations (First Plasma and initial field mapping), plus systems needed to support coil operation at cryogenic temperatures, and refurbishment and installation of equipment for 1.5 MW of neutral beam heating power. The scope spans Title I through Title III engineering, physics analyses in support of the design, manufacturing development for certain components, fabrication, assembly and installation, integrated systems testing, and project management associated with producing the in-scope equipment. It includes achievement of First Plasma.

The NCSX Performance Baseline Scope objectives are listed, by WBS, in the first column of the table below. The second column lists the upgrades that the system is designed to accommodate, without regard to their implementation schedule

Objective Scope (Performance Baseline)	**Future Upgrades Accommodated By Design**
WBS 1. Stellarator Core	
• Vacuum vessel system including all ports and port covers. • Stellarator magnet system, consisting of modular coils, toroidal field coils, and poloidal field coils. • External trim coils. • Coil services (electrical and coolant feeds) • Support base and structures. • Cryostat (partially assembled)	• Plasma-facing component upgrades for: - power handling up to 12 MW - pumped diverter - alternate materials (e.g., C, Li, W). • Internal trim coils • Completion of cryostat assembly.
WBS 21, 22, 23. Fueling, Vacuum Pumping and Wall Conditioning Systems	
• Torus vacuum pumping system based on two of the PBX-M turbomolecular pumps mounted on a single duct. Pumping speed approx. 1,300 l/s. • Residual gas analyzer. • Gas injection system based on 3 injectors @50 torr-l/s each for H, D, and He.	• Two additional turbomolecular pumps on a second duct, bringing the total pumping speed to 2,600 l/s. • Wall conditioning systems: - GDC, boronization, lithiumization. • Pellet injector.
WBS 25 Neutral Beam Injection Systems	
• Refurbishment and installation of equipment for up to 1.5 MW of neutral beam heating based on PBX-M neutral beam legacy equipment.	• Additional 4.5 MW of NBI based on PBX-M legacy equipment. • 6 MW of ICRF heating • 3 MW of ECH.
WBS 3. Diagnostics	
• Ex-vessel magnetic sensors installed; eight fully operational. • Fast visible camera on simple mount. • Electron-beam field mapping apparatus	• In-vessel magnetic sensors. • All magnetic diagnostics fully operational. • Permanent installation of fast visible camera. • Physics diagnostic system, per GRD.

Objective Scope (Performance Baseline)	**Future Upgrades Accommodated By Design**
WBS 4. Power Systems	
• Coil power systems for First Plasma and initial field mapping operation with room temperature coils, consisting of 6 circuits. • Associated AC, DC, control, and protection systems.	• Coil power upgrades of the PPPL D-Site equipment for high-beta plasma operation up to 2 T (short pulse), 1.2 T (long pulse), Ohmic current drive up to 320 kA, and full flexibility with coils cooled to cryogenic temperatures, consisting of 10 circuits (total). • Trim coil power supplies. • Associated AC, DC, control, and protection systems.
WBS 5. Central I&C and Data Acquisition System	
Computer system consistent with control and data acquisition requirements of in-scope equipment: • Computer network infrastructure. • Central instrumentation and control system • Data acquisition and facility computing. • Facility timing and synchronization. • Real-time power supply control. • Central safety interlocks. • Control room facility.	Expansions consistent with requirements of upgrades in other systems.
WBS 6. Facility Systems	
• Water cooling system for vacuum pumps and neutral beams. • Cryogenic supply and transfer systems. • 150 C Vacuum Vessel Bakeout system. • Utility systems (venting, GN2, compressed air) • C-Site water system re-commissioning.	• Water cooling for diagnostics • 350 C PFC Bakeout system.
WBS 7. Test Cell Preparation and Machine Assembly	
• Control Room Refurbishment • Access Platform. • Machine assembly.	N/A

Objective Scope (Performance Baseline)	**Future Upgrades Accommodated By Design**
WBS 8 Project Management and Integration	
• Project Management • Project Control • System Engineering Management • System analysis • Design integration. • Environment, Safety, and Health • Project physics • Integrated System Tests	N/A

Appendix 6.

Proposed NCSX Baseline Cost Objectives

The NCSX Project is designated as a Major Item of Equipment (MIE) by the DOE and will be built using Capital Equipment Funds. At CD-1 approval, a baseline total estimated cost (TEC) range of \$69M - \$83M for the MIE fabrication project was established. As part of the CD-2 approval process, a baseline Total Estimated Cost objective will be established. The proposed objective is \$81.0M, including \$16.5M of contingency, or 28% of the estimated cost to complete the project from October 1, 2003.

The cost objective is supported by detailed “bottom-up” cost estimates to complete the scope and “bottom-up” estimates of the contingency needed to mitigate the risks.

Cost Breakdown by System

	MIE	Contingency (applied to balance of project)		Total
	Estimate	**%**	**\$**	**w/conting**
1 - Stellarator Core Systems	**39,042**	**35%**	**12,246**	**51,287**
11 - In-Vessel Components	8			*8*
12 - Vacuum Vessel Systems	5,570	*39%*	*1,948*	*7,519*
13 - Conventional Coils	3,697	*26%*	*922*	*4,618*
14 - Modular Coils	18,357	*39%*	*6,234*	*24,591*
15 - Structures	1,783	*32%*	*567*	*2,350*
16 - Coil Services	921	*24%*	*223*	*1,144*
17 - Cryostat and Base Support Structure	1,298	*29%*	*376*	*1,674*
18 - Field Period Assembly	5,036	*32%*	*1,592*	6,628
19 - Stellarator Core Management and Integration	2,373	*17%*	*383*	2,755
2 - Plasma Heating Fueling & Vac Systems	**1,607**	**15%**	**213**	**1,820**
21 & 22 - Vacuum Pumping & Fueling Systems	512	*14%*	63	575
25 - Neutral Beam Injection System	1,095	*16%*	149	1,244
3 - Diagnostics	**1,504**	**33%**	**454**	**1,958**
4 - Electrical Power Systems	**5,094**	**20%**	**1,015**	**6,109**
5 - Central I&C Systems	**2,545**	**10%**	**249**	**2,795**
6 - Facility Systems	**2,063**	**20%**	**411**	**2,474**
7 - Test Cell Preparation and Machine Assy	**3,549**	**21%**	**692**	**4,242**
71,72,73 Conventional Facility	270	*11%*	*18*	*288*
74,75,76 Machine Assembly	3,279	*22%*	674	3,953
8 - Project Oversight and Support	**9,008**	**16%**	**1,262**	**10,270**
	64,413	***28.0%***	***16,541***	**80,954**
	Contingency (applied to balance of project)			

Appendix 7.

Proposed NCSX Baseline Schedule Objectives

The project's proposed baseline schedule objective is to complete the project with the achievement of First Plasma by September 2007. The project's master schedule supports this objective, with 5.5 months of schedule contingency.

A summary graph of the master schedule follows.

NCSX Project Milestones

Table 2.2-1

	Milestone	Schedule	DOE Acquisition Executive (Level I)	DOE Project Manager (Level II)	Joule Milestone
1	Complete Physics Validation Review	**Mar 2001 A**		X	
2	Complete CD-0 Milestone	**May 2001A**	X		
3	Select Conceptual Design Configuration	**Dec 2001 A**		X	
4	Submit NEPA Preliminary Hazards Analyses	**Apr 2002 A**		X	
5	Complete Conceptual Design Review	**May 2002A**		X	
6	Complete CD-1 Milestone		X		
7	Start Preliminary Design (Title I)	**Apr 2003 A**		X	
8	Award Prototype Contract(s) for Modular Coils Winding Forms	**Mar 2003 A**		X	
9	Award Prototype Contract(s) for Vacuum Vessel	**Apr 2003 A**		X	
10	Authorize Prototype Fabrication for MCC and VV	Dec-03			04-1
11	Complete External Independent Review and Preliminary Design Review	Nov-03		X	
12	Complete CD-2 Milestone	Jan-04	X		
13	Initiate winding process on 3-D surface	Mar-04			04-2
14	First Prototype Modular Coil Winding Form Casting Produced for Machining	Jun-04			04-3
15	Complete Final Design Review for Modular Coils Winding Forms	Jul-04		X	
16	Complete Final Design Review for Vacuum Vessel	Jul-04		X	
17	Complete Prerequisites for CD-3 Milestone for Procurement and Fabrication of Components	Sep-04	X		04-4
18	Award Production Contract for Modular Coils Winding Forms	Nov-04		X	
19	Award Production Contract for Vacuum Vessel	Sep-04		X	
20	Award Conductor Contract	Sep-04			
21	Award Production Contract for TF Coils	Dec-04		X	
22	Award Production Contract for PF Coils	Dec-05		X	
23	First Modular Coil Winding Forms Delivered	Feb-05			
24	Complete First Modular Coil Fabrication	Jul-05		X	
25	Complete Delivery of TF Coils	Oct-06		X	
26	Vacuum Vessel Delivered	Jan-06		X	
27	Begin Assembly of First Field Period	Jul-06		X	
28	Last Modular Coil Winding Form Delivered	Jun-06		X	
29	Last Field Period Assembled	Apr-07		X	
30	Pump Down of Vacuum Vessel	Jun-07		X	
31	Complete Operational Readiness Assessment	Aug-07		X	
32	Complete CD-4 Milestone (First Plasma and Completion of MIE Project)	Sep-07	X		

NCSX Critical Path Summary Schedule