Department of Energy
Review Committee Report

on the

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

of the

NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX) PROJECT

May 2002

EXECUTIVE SUMMARY

A Department of Energy (DOE) Office of Science project review of the National Compact Stellerator Experiment (NCSX) Conceptual Design Report (needed for Critical Decision 1, Approve Preliminary Baseline Range) was conducted at Princeton Plasma Physics Laboratory on May 21-23, 2002. The review was conducted at the request of Dr. N. Anne Davies, Associate Director for Fusion Energy Sciences in the Office of Science

The Committee found that the NCSX project was ready for Critical Decision 1 with some revision. Overall, the Committee found the Conceptual Design Report sound and likely to meet the functional and operations performance requirements, the costs including contingency are reasonable, the schedule estimate is tight but achievable, the required Environment, Safety and Health aspects are being properly addressed, most of the comments from the Physics Validation Review have been resolved, the design and R&D status is good, the commissioning plans are good but need work, and the overall management organization was found to be excellent.

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 module 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 and poloidal field coils. A diagnostic systems provides the detailed measurement of the plasma parameters that are critical to the research goals of NCSX. The project's preliminary Total Estimated Cost is $72 million.

The Committee made 31 recommendations including: develop start-up scenarios with 3 Megawatt neutral beam power, expedite R&D efforts, accelerate production/delivery of the coil winding forms, identify and test critical components in the legacy (existing) systems, increase the speed of the real-time plasma control system, develop an integrated testing and commissioning plan, revise the Acquisition Execution Plan and Preliminary Project Execution Plan, and define a new project completion milestone.

The total estimated cost of $72 million and project completion scheduled for March 2007 appear to be reasonable. There was one action item: resolve the annual BA funding levels for FY 2004 and beyond with the Office of Fusion Energy Sciences and adjust project cost and schedule if warranted, prior to Critical Decision 1.

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1. INTRODUCTION

The National Compact Stellarator Experiment (NCSX) is a fusion research project proposed 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.

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 Oak Ridge National Laboratory (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 and 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, which was presented at this review, the preliminary total estimated cost increased to $72 million with completion in March 2007. The increase is the result of a detailed bottoms-up estimate for the first time including additional proposed contingency for the highest risk components.

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2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Physics

2.1.1 Findings

The NCSX team proposal describes a facility and program that should be able to address the major issues it is intended to examine. It should be possible to examine the effects of three dimensional plasma shaping and quasisymmetry on plasma confinement.

The quality of the flux surfaces in a wide range of plasma states has been effectively studied by means of the Princeton Iterative Equilibrium Solver (PIES) code.

Plasma start-up scenarios were presented which describe the transition from vacuum magnetic fields to plasma equilibrium over four percent beta. Neutral beam heating 4.5 Megawatt was assumed.

The proposed magnetic field coils have been shown to admit a wide range of acceptable, stable plasma configurations with differing rotational transform, shear, pressure and curved profiles, shape, and critical values of beta.

As part of the development of a research program, plasma edge, particle, and energy handling scenerios have been outlined and explored. The phased approach involves transitions from limiter to open divertor, to baffled divertor with or without pumping.

Stability and transport analyses have been successfully integrated into the preceeding activities. A diagnostic development plan matched to the physics plans has been completed. Work has started on three-dimensional equilibrium reconstruction from experimental observations.

2.1.2 Comments

The PVR raised a large number of programmatic and technical issues. Many, but not all, are closely connected to the physics presentations at this review. Many have been fully accepted by the NCSX team. Each of the findings above relates directly to one or more of the PVR recommendations. It is credible that NCSX will achieve its goals even though it has not accepted all of the PVR recommendations. The size and design point, as well as the initial neutral beam power have been reasonably justified, and there appears to be sensible upgrade options if the NCSX performance falls short of what is desired. Certain of the topics, such as flow drive and damping the development V3FIT, and critical measurements for equilibrium reconstruction are in an appropriately preliminary stage of development. On balance, the NCSX Team has heeded the PVR recommendations to strengthen the proposal and has accepted the bulk of them.

2.1.3 Recommendations

1. Develop start-up scenarios with 3 Megawatt neutral beam power.

2. Determine the physics impact of magnetic field errors likely to occur from coil imperfections.

3. Continue V3FIT code development and associated necessary diagnostic development (a PVR recommendation).

4. Extend the use of the PIES code to additional flexibility studies.

2.2 Engineering

2.2.1 Findings

The Committee finds that the engineering design presented at the Conceptual Design Review is well-developed for this stage of the process. Critical elements have been examined and show that the device has a credible minimal performance level satisfactory to achieve the physics goals of the program. The critical path items have been correctly identified as the modular coils and vacuum vessel. Confidence in their design and cost estimates is increased through manufacturing studies, experience of the design team, and consultation with programs with previous experience in these areas (W7-X and HSX). Some R&D efforts are now in progress to more-fully develop design data and validate proposed concepts and analysis. Contingencies on costs have been assigned based on perceived risk factors and appear reasonable. The Committee is primarily concerned that the proposed schedule is very tight and back-loaded and that efforts need to focus on ways to ensure that the device can be completed so that operations can begin on schedule.

2.2.2 Comments

Many of the stellarator core components are straightforward in design such as the PF coils, TF coils, cryostat, and OH solenoid. These designs seem well prepared. The primary challenge in the engineering design of NCSX is the modular coils, with concerns for the vacuum vessel.

From the physics analysis and input from potential vendors, the required tolerance of 1.5 mm on the modular coils seems achievable. This is commensurate with the levels achieved in other modular coils. A tolerance budget needs to be developed to ensure that the finished product meets these goals. Adjustment of individual coil packs to accommodate random build-up of errors during fabrication is not seen as a viable method to advance these goals.

The fabrication of the coil winding forms determines to a large part the critical path. Ways need to be examined to speed up the delivery of these forms through choice of manufacturing technique or sequence. R&D needed to develop the winding forms should proceed as rapidly as possible. The design of the winding forms needs to include any necessary provisions for alignment/assembly; it may be beneficial to include features for the winding and clamping as well. At the earliest possible time the NCSX should manufacture and operate a demo coil for thorough testing to validate the completed design and manufacturing techniques and provide input into the process.

It may be that development of each type (for production) needs to proceed sequentially, in which case production of the various types sequentially (or until the next type is fully developed) may provide the most rapid delivery. There could be some advantage to moving from simplest (BA coil) to most complex (BU coil) in providing experience for the next level of complexity. This sequence could allow start of period assemblies at an earlier time, as the BA coils must be the first to be installed.

The NCSX team has decided to do the coil winding and potting in-house. The Committee agrees with this decision as the best way to keep the schedule and quality under control. While NCSX personnel have significant experience in coil winding and potting, this is all with planar coils wound in tension. Significant experience needs to be gained in these new types of coils before production runs can begin. There is a benefit to having the same winding team fabricate all of the coils of a given type, so that the coils are as similar as possible. This may even require the set up of three winding lines. NSCX should carefully examine potential improvements to schedule for various fabrication scenarios. Efforts should be put into the development of accompanying documentation (traveler) to go with each coil as the fabrication process is developed.

Preparations for next design review need to include the development of a testing plan for the assembled coil set, instrumentation needed to monitor the performance and sense abnormal or coil fault conditions, and safety systems to mitigate any potential damage to the coil set in event of improper performance.

The allowable field and pulse length for NCSX are set by the thermal and mechanical stresses in the coil and supporting elements. The device goals can be achieved with an allowable delta-T of 40 K. Mechanical tests of the conductor, including cycling, should be executed as early as possible in the design to ascertain whether an allowable delta-T of the conductor of over 40 K is feasible. For increases in the magnetic field and pulse length attainable, this has implications (perhaps minimal) for the coil casing and support structure from electro-magnetic stresses as well. Efforts should look at the maximum parameters that can be attained in the machine based on design knowledge obtained in the R&D.

Manufacturing studies on the vacuum vessel demonstrated that there are several potential methods to handle this system. Tolerances of 3.8 mm on the inboard side and much larger on the outboard side are achievable, although this will require prototyping and evaluation. It is possible that there will be variations between the sections; the most likely source of problems comes at assembly as the torus must follow the tolerance envelope and maintain vacuum integrity. Landmarks need to be incorporated into the vessel sections to provide references as the assembly is developed. During the fabrication of the sections, landmarks should also be included on the inside of the vessel for future installation and location of in-vessel components. Rib profiles, for mounting of the Plasma Facing Components, should also be taken at this time, as there is likely to be some variation in their shape as well. More on the vacuum vessel is discussed in Section 2.8, Assembly and Commissioning. Care needs to be taken that the vacuum vessel does not move onto the critical path, as the vacuum vessel is needed before assembly operations can begin.

2.2.3 Recommendations

1. R&D efforts need to be pushed earlier and expediently accomplished. These include tests of the epoxy-potted flexible conductor with respect to mechanical and thermal properties for incorporation into stress, thermal analysis, and tests of the chill plate cooling method on the planar test coil to evaluate conduction as a function of required preloads and contact area, and obtain the necessary keystoning data for incorporation into the design of the winding forms.

2. The NCSX project should start R&D on coil winding and potting techniques at the earliest possible time to develop expertise in the forming and required clamping of the conductor into twisted, non-planar forms, tooling required to set up the winding lines, and in the epoxy impregnation techniques required to ensure a good fill with the complex geometry.

3. The NCSX team should examine ways to speed up production and delivery of the coil winding forms.

4. A demo coil should be fabricated and operated at cryogenic temperatures early in the procurement process to provide input into unforeseen problems with the design and/or manufacturing. This coil needs to be highly instrumented with regard to stress and strain in critical areas, temperature measurement, and subject to repeated thermal and mechanical cycling.

5. Develop alternatives for manufacturing and assembly planning to accommodate the most rapid delivery schedule that can be achieved by the form vendors.

6. Quality assurance measures must be planned very carefully in all steps of manufacturing and assembly.

2.3 Heating, Fueling, and Pumping Systems

2.3.1 Findings

The presentation and documentation for the Conceptual Design Report are complete and adequate. Issues are well understood and being addressed.

The use of old Princeton Beta Experiment-Modification (PBX-M) equipment should be a cost effective solution and seems to be an adequate way to proceed.

The hardware has not been in operation since 1993 and many parts will be more than 25-years-old at the start of NCSX. The status of many components is not known and may need extensive repair.

Within the scope of the project, the Neutral Beam Injection (NBI) system will be installed but will not be ready for operation. The computer control needs to be installed in addition during operation of NCSX.

Provisions are made for the future upgrade of the heating systems with additional NBI and Ion Cyclotron Resonant Heating (ICRH).

The use of Electron Cyclotron Resonant Heating (ECRH) as an upgrade is not being considered due to budgetary reasons.

Fueling and conditioning are adequate. The Turbomolecular pumps will be installed rather far away from the torus, due to the magnetic fringe field.

2.3.2 Comments

The time schedule is a success-oriented plan. Any difficulties getting old equipment operating to specification will cause significant delays in the operating schedule.

The cost estimate depends to a large extent on the needs for maintenance and repair of legacy systems, which are not really known at present.

Should the initial two beamlines require parts, these can be taken from the remaining beamlines, but at expense of future upgrades.

2.3.3 Recommendations

1. Responsible engineers should identify critical, one-of-a-kind components (particularly components that may not be repairable or replaceable) in legacy systems, and develop a test plan that checks these components before assembly and installation of the complete system.

2. The future upgrade for ECRH may be considered since most stellarators rely on this heating method.

3. The location of the Turbomolecular pumps may need to be reconsidered in order to increase effective pumping speed.

2.4 Diagnostics

2.4.1 Findings

In response to a PVR recommendation, the NCSX team has developed a credible plan for implementing key plasma diagnostics on the device. This reflects their extensive experience in plasma diagnostics of fusion confinement devices. The plans discussed include both the base set of diagnostics to be installed as part of the fabrication project—magnetic measurements, flux surface mapping, interferometer, and visual cameras, as well as the preparations for implementation of the more advanced diagnostic set for the operational research program. In the course of developing these plans, the NCSX team may need to adjust the details of the relative budgets among the diagnostic items needed for commissioning in view of the importance of the flux surface and other magnetic configuration measurements.

2.4.2 Comments

The diagnostics included in the NCSX project comprise those essential for commission and early stage operation of the device and are well chosen for executing the planned physics program. The largest individual budget items are devoted to magnetics (approximately $900 K), flux-surface mapping (approximately $500 K), and integration ($550 K).

The project envisions an array of soft X-ray cameras to be used for tomographic imaging of the NCSX plasma. These would be developed using the operating budget. This diagnostic promises to be valuable for studying magnetic islands in finite pressure plasmas, and should be pursued vigorously.

Substantial provision for diagnostics for the detailed physics program is made in the planned operational budget for FY 2006-2009, with annual allocations of $1-1.7 million. These seem reasonable, but in this event, will also need to be coherent with the operating budgets and available staff resources.

2.4.3 Recommendation

1. Review, as project matures, allocations of funding and effort between diagnostics needed for commissioning in order to ensure that key measurements of magnetic surfaces and configuration properties are carried out effectively.

2.5 Power Systems

2.5.1 Findings

The NCSX experiment requires a complement of 30 power supply modules for initial operation of the toroidal, poloidal, and modular coils. The Volt-Ampere requirement for the individual coils varies, but the capability of the existing power modules formerly used by the Tokamak Fusion Test Reactor (TFTR), 24 kA at 1 kV, is sufficient to power each of them. The energy and peak power requirements are easily met by one of the two Motor Generator (MG) sets used to provide prime power to TFTR. The National Spherical Torus Experiment (NSTX) also uses a TFTR MG set for prime power together with approximately 50 of the approximate 74 existing rectifier units. A single MG set has sufficient energy storage to power both experiments in parallel operation, however this would require purchase of additional supplies, four in the initial stage of NCSX operation and as many as 28 for later phases. The project has concluded that the cost of making the operation of the two experiments independent is prohibitive and therefore foresees operating the two experiments in alternating time periods. A side benefit to this approach is that power supply operating costs will be somewhat lower for each experiment than would be the case if each had its own dedicated supply. This situation is not without precedence at PPPL, and elsewhere, and experience has shown that such shared operation is workable and need not significantly reduce experimental productivity.

Although external trim coils will be installed within the Project Scope, installation of trim coil power supplies is deferred until the operating phase. The plan is to use for this purpose up to six power supplies originally manufactured by Robicon for the Poloidal Divertor Experiment (PDX)/PBX. Two of these power supplies are presently used by the CDX experiment and the condition of the others is uncertain.

2.5.2 Comments

The Committee endorses the project's decision to make the most efficient use of the existing TFTR power supply by alternating operation with NSTX. The penalty from such shared operation is minimal (present machines find that approximately 26 weeks per year operation is close to the maximum practicable) and the cost savings to the project is substantial (approximately $15 million). The general approach to the design of the power systems required for NCSX is solid, both for the initial operating phase, as well as for upgrades required for later phases.

The Committee also believes that the costs estimated for making the TFTR power supply available for NCSX operation, as well as other estimated costs for installing C-site auxiliary power, are realistic and are based on a level of detail that is appropriate at this stage of the project.

2.5.3 Recommendation

1. Install the six Robicon power supplies for operation of the trim coils within the Project Scope, with a cost implication of approximately $0.5 million. Mapping stellarator flux surfaces is traditionally one of the first studies undertaken after the main power, coil and vacuum systems have been commissioned. A follow-on task is to eliminate or reduce the size of any significant islands that might appear as a result of field errors. In order to carry out this task efficiently, the external trim coils should be made available essentially from the beginning of the operating phase.

2.6 Central Installation and Commissioning and Data Acquisition

2.6.1 Findings

The NCSX project has a good understanding of the issues involved in instrumentation, data acquisition, and control for the proposed facility. The PPPL staff is highly experienced and is presently involved in installation and commissioning for an experiment of similar size and scale—NSTX.

Detailed specifications and acquisition of components is scheduled for late in the project period, primarily in FY 2006.

Most of the systems and components to be used on NCSX will be installed, tested, and used on the NSTX first. The exceptions are the safety/interlock system and the timing system for the NCSX facility.

2.6.2 Comments

This is a good plan, well thought out for the present stage and development. It will be of significant advantage to the NCSX project to have the experience with very similar systems on NSTX occur first. Deferring detailed specifications and hardware acquisition to late in the project will allow NCSX to benefit from the very rapid improvements in capabilities and cost measures for information technology systems.

In light of the rapid improvements expected in digital systems, and considering the increasing sophistication of fusion science experiments, some of the present specifications should be more aggressive.

2.6.3 Recommendations

1. The timing system and the real term plasma control system should be as fast as possible (at the time of acquisition). The present specifications should be increased by a factor of ten in speed. A synchronized clock rate of 0.1 microseconds should be both possible and affordable. The real time control system will be asked to do complicated analyses and plasma reconstruction in order to maintain the desired plasma configuration.

2.7 Site and Utilities

2.7.1 Findings

The PPPL site is fundamentally well suited for NCSX based on its existing facilities, equipment and past use.

Most utilities use existing equipment (i.e., water pumps, cooling towers, vacuum pumps) or are copies of similar existing systems such as the helium bakeout system. Capacities appear adequate. Existing installed systems have adequate capacities for planned operations. The water, vacuum, and helium bakeout systems are similar in size and performance to those systems currently used on NSTX.

The liquid nitrogen system is a new system with its closed loop recirculation and boiling pool heat exchanger. It is unclear that the proposed nitrogen cryogenic system is similar to existing, proven systems.

2.7.2 Comments

Liquid nitrogen costs for .8 trucks per day for six months per year is nearly $500 K per year. Most of this nitrogen is disposed of as gas at around 80 degrees K. During operations, nitrogen gas boiloff is released to the atmosphere through an electrical heater. Since the electrical power supplied to the NCSX device is all removed by the heat of vaporization of the liquid nitrogen, it is likely that the electrical heater power requirement may exceed the power used by the NCSX device in order to heat the nitrogen to near room temperature.

The closed loop recirculation liquid nitrogen system with boiling heat exchanger should work, but may be a rather unique system. A pressure relief valve on the close loop system should be installed to handle pressure increases due to unexpected heating conditions. This relief valve would likely be needed if nitrogen circulation failed due to a common mode failure of the recirculation pumps.

The many parallel nitrogen circuits for separate coil systems will have different thermal performance based on system mass, heat load, heat transfer rate, etc. This is frequently addressed with flow control valves on individual circuits.

2.7.3 Recommendations

1. Develop a cost comparison for a nitrogen reliquification system and the proposed once-through system.

2. Perform analysis of transient cooldown from room temperature and thermal recovery after a shot to demonstrate single-phase flow in the parallel cryogenic cooling circuits. The concern is stable flow of liquid nitrogen and the design approach used for cooldown of parallel flow paths. Is there a requirement for a flow control valve on

each parallel line?

2.8 Assembly and Commissioning

2.8.1 Findings and Comments

The NCSX Team has addressed many issues needed for the assembly of the device. The Committee feels that there is a credible process for assembly, although many details need to be worked out as the engineering design develops. The NCSX project has identified risk elements in assembly and assigned contingencies accordingly. Rapid prototyping through stereolithography has been employed to confirm that the modular coils can be installed over the vacuum vessel. The Committee finds the most uncertainty in the ability to adhere to the presented schedule given uncertainties in delivery of vendor components, the modular coil winding process, and some of the custom fitting required. No integrated testing/commisioning plan was presented in the documentation provided, and this needs to be developed as the design becomes finalized.

Assembly of the field period sections cannot proceed until the vacuum vessel sections are completed. The project realizes that coil positioning fixtures will be required to manipulate the coils over the vessel. At assembly (or at manufacture) fiducials need to be incorporated both inside and outside of the vessel. The fitup of the vessel into a torus with vacuum integrity requires shim plates between the sections. Given no flexible connections, it is prudent to envision a complete test assembly of the vessel to custom fit these plates, unless extremely high precision in fabrication is achieved. Shimming of the coil/shell modules does not present this situation. Thought should be given to work most cost-effectively accomplished at this stage where access to the vessel interior and reference marks is high. Delivery of the coils may require modification to the assembly sequence as proposed to maintain schedule. This might require parallel assembly of the three field periods. The three completed field periods can be moved and lifted into place on the machine base at the NCSX site. The radial motion needed to move the three periods into a torus is in the design. Significant testing of the coil leads, both coaxial and “no-kick” cables, needs to be performed and their design checked for magnetic perturbations. It is advisable to significantly test the device (vacuum and coil connections) prior to installation of the cryostat.

2.8.2 Recommendations

1. Consider potential alternative assembly plans to interface with vendor delivery and coil winding.

2. Develop detailed assembly techniques and requirements and the necessary tooling as designs of the shell and vessel sections mature.

3. Develop an integrated testing and commissioning plan.

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3. MANAGEMENT

3.1 Findings

The project is organized as a collaborative effort between PPPL and ORNL. PPPL has overall responsibility and authority for project execution through the PPPL Director, reporting to DOE.

The project organization follows a conventional Work Breakdown Structure (WBS) format with clear lines of responsibility. As shown in Appendix D, the top level WBS managers report to a Project Engineer who reports in turn to the Project Manager assisted by two deputies. The key management positions down to the first WBS level have been filled with experienced and highly competent individuals. Notable is the fact that the most critical WBS area—the Stellarator Core, which comprises approximately 50 percent of the project cost, is headed by an individual from ORNL. The project is supported by an experienced PPPL infrastructure in the areas of Project Control, Environment, Safety and Health (ES&H), quality assurance and procurement. While legal authority for procurement rests with PPPL, technical authority is delegated to the relevant WBS manager regardless of institutional affiliation.

A draft Project Execution Plan (PEP) that describes the management approach and controls has been prepared. The PEP identifies the Project Scope; in essence, it is that which is necessary to obtain first plasma, a traditional integrated milestone for a project of this type.

The drafts of the NCSX Acquisition Execution Plan (AEP) and Preliminary PEP that were provided to the Committee were both thoroughly reviewed. They are generally well written and complete, but certain aspects will need more work prior to their approval by DOE at Critical Decision 1, Approve Preliminary Baseline Range. In the case of the AEP, which must be approved by the DOE Under Secretary, recent Office of Science experience indicates that more brevity and simplicity would reduce the potential of future changes that would require re-approval at the Under Secretary level. As for the Preliminary PEP, it will require a few changes to bring it into compliance with DOE Order 413.3. In addition to the Preliminary PEP, there is a Memorandum of Understanding between PPPL and ORNL that allocates responsibilities within the project. It dates back to the beginning of pre-conceptual design (1998).

3.2 Comments

The management structure is appropriate for the project, has been filled out with top quality personnel and is functioning smoothly as evidenced by the high quality of the Conceptual Design Report presentations. While the potential for conflict exists due to conflicting institutional allegiances, absolutely no indication of this was detected and excellent working relationships have been established between the two institutions. The physical separation does not appear to present a problem thanks in large measure to good will and modern electronic means of communication.

The Committee suggests that the next level of management of WBS 1 (the Stellarator Core) be specified explicitly by Critical Decision 1.

The Committee was not satisfied with the definition of project completion in the PEP since quantitative performance measures were not specified. It is important for both the project and the sponsor to agree to the scope at an early stage. The integrated end-of-project milestone suggested at the Conceptual Design Review, namely producing an Ohmic plasma with 25 kA of current at 0.5 T field, is not appropriate since this target could be achieved without the field of the modular coils, i.e., by operating NCSX in a tokamak mode.

The Committee provided detailed comments to the project on the AEP and Preliminary PEP, and discussed these with the DOE Project Manager and Program Manager, as well as with the NCSX Project Controls Manager. It is suggested that the Memorandum of Understanding be incorporated into the Preliminary PEP as an appendix so that it can be periodically reviewed and updated with that document as necessary. Key areas of the PEP that should receive careful attention include defining the criteria for project completion at Critical Decision 4, Approve Start of Operations (as well as other major milestones), and specifying appropriate change control thresholds for scope, schedule, and cost.

3.3 Recommendations

1. Define an integrated end-of-project milestone reflecting the unique stellarator character of NCSX.

2. Develop quantitative metrics defining Project Completion (Critical Decision 4) prior to Critical Decision 1, Approve Preliminary Baseline Range.

3. Revise and finalize the AEP and Preliminary PEP in concert with the DOE Project and Program Managers as necessary to secure the approval of these documents by Critical Decision 1, Approve Preliminary Baseline Range.

4. Develop a preliminary commissioning and test plan. This documentation should be prepared for Critical Decision 2, Approve Performance Baseline.

5. Incorporate the PPPL-ORNL Memorandum of Understanding into the Preliminary PEP as an appendix.

6. Specify Level 3 management of WBS 1 (the Stellarator Core) by Critical Decision 1, Approve Preliminary Baseline Range.

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4. ENVIRONMENT, SAFETY and HEALTH

4.1 Findings

ES&H aspects of the NCSX project are being properly addressed at this stage of the project development. Documentation for Critical Decision 1, Approve Preliminary Baseline Range is in place.

Line management responsibility and accountability for ES&H are in place and are assigned to the NCSX Project Manager for project design and component fabrication.

A National Environment Protection Act (NEPA) determination to prepare an Environmental Assessment for construction and operation of the NCSX was made on May 21, 2002, by the Manager of the DOE Chicago Operations Office (CH). Preparation of the Draft Environmental Assessment will be managed by the Princeton Area Office (PAO).

There is an established Integrated Safety Management infrastructure and culture that should provide an excellent basis for ensuring the protection of the environment, and the safety and health of workers and the public, during execution of the NCSX project.

4.2 Comments

A Preliminary Hazards Assessment has been prepared and accounts for hazards known and anticipated for this Project. Also, the Chicago Operations Office Environmental Evaluation Notification Form was prepared to support the NEPA determination to prepare the Environmental Assessment. This Environmental Evaluation Notification Form also examines hazards and also should be useful in evaluating their mitigation.

The Preliminary PEP shows that line management roles, responsibility and accountability for ES&H are in place for project design and fabrication, and have been delegated from the PPPL Director to the NCSX Project Manager. Project support for ES&H is being provided by the PPPL ES&H staff. To assist line management with implementing ES&H and monitoring safety during project fabrication, the NCSX project should evaluate the need for a full time construction safety engineer. The DOE NCSX Federal Project Manager will be responsible for oversight of the NCSX project and its implementation of ES&H.

The project has stated, informally, that when the NCSX project transitions to an operational scientific research facility, there will be a continuity of key personnel and there will be an NCSX project head who will be the line manager responsible for ES&H. This will be an important contribution to the continuity of safety and should be formalized in the project documentation at the earliest appropriate time.

The NCSX project's milestone for Critical Decision 2, Approve Performance Baseline is June 2003. The project also has an earlier March 2003 milestone of pre-Critical Decision 2 for beginning detailed design of the modular coils. In compliance with the DOE NEPA regulations, the Environmental Assessment must be completed prior to initiation of detailed design that will be supported by Critical Decision 2 for NCSX. The current schedule is for the Environmental Assessment process to be completed in February 2003. In order to assure that the NEPA schedule does not impact the March 2003 pre-Critical Decision 2 milestone, the project should consider ways to accelerate the Environmental Assessment schedule, without sacrificing quality, adequacy, and completeness. A discussion among the review committee, PPPL, PAO, and CH identified some possible efficiencies that might be found by involving PAO and CH in early reviews of the Preliminary Draft Environmental Assessment, and by concurrent reviews of the Draft Environmental Assessment prior to its approval for state coordination. There is a reasonable expectation that the Environmental Assessment process will result in a Finding of No Significant Impact (FONSI). Assuming this, completion of the NEPA process for the NCSX project should be achievable by both the pre-Critical Decision 2 and Critical Decision 2 milestones.

The Draft Environmental Assessment will be coordinated with several of the Federal, state, and local regulatory agencies, and the local public, once the Environmental Assessment is ready for state coordination under DOE's NEPA procedures. The early involvement of the appropriate regulatory agencies and the public, using existing means (e.g., the Plainsboro Environmental Council), will help to ensure effective communications and a smooth and timely regulatory approval process. While the ES&H risks of the project appear to be minimal, any delay in the Environmental Assessment process due to regulatory or public concerns has the potential to affect the project schedule.

For those R&D activities, in support of the NCSX project, that will occur at the ORNL facility in Oak Ridge, Tennessee, PAO should assure that the appropriate NEPA documentation is in place for that work, in order to fully consider associated environmental consequences and to protect the project.

The NCSX MIE Project Cost Estimate Summary shows the costs for ES&H and quality assurance to be zero. This is because the ES&H costs for the project are coming from PPPL site-wide services overhead and other general and administrative cost categories, as per the standard PPPL process. This is acceptable to the review committee.

4.3 Recommendation

1. Consider ways to accelerate the Environmental Assessment process and complete it as expeditiously as possible.

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5. COST, SCHEDULE, and FUNDING

5.1 Findings

Using a sound methodology, the project has developed a credible bottoms-up cost estimate for a total estimated cost of $72.0 million (Appendix E), which includes 27.8 percent ($15.66 million) of contingency. For a conceptual design, the estimate is itemized in considerable detail (generally at WBS Level 4). Laboratory overhead rates and escalation appear to have been properly applied. In order to hold down costs, there is considerable reliance on re-use of existing PPPL facility infrastructure and equipment valued by the project at roughly $70-75 million. Much of the equipment to be reused is in excess of 15-years-old and may not have been used recently.

The Stellarator Core (WBS 1) is the most technically challenging part of the project, and its cost comprises about half of the total estimated cost (neglecting contingency). Within WBS 1, the project has obtained costing information from manufacturing studies by several potential vendors for the most critical components—the modular coils and the vacuum vessel. This information has been selectively incorporated into the WBS 1 cost estimate and this, coupled with a fairly generous contingency (40 percent), gave the Committee an added degree of confidence that the amount budgeted will be adequate.

Contingency was estimated by using a risk-based approach starting at the lower level tasks, and then aggregating the percentages progressively up the WBS. It was spread across the years of the Budget Authority funding profile in a realistic manner (i.e., not back-loaded). The Committee judged the contingency amounts at Level 2 to be appropriate given the current stage of the project and found no reason for significant changes to be made. No estimate was provided for the annual costs to operate the NCSX facility after project completion.

A detailed, resource-loaded schedule has been prepared that indicates a critical path running through the prototyping, procurement, fabrication, and assembly of the stellarator's modular coils, followed by integrated systems testing (i.e., commissioning). Vacuum vessel production and assembly is near critical path, and there are a number of interdependent assembly activities that occur in parallel late in the project that could also be on the critical path given slight delays in predecessor activities. NEPA approval is also within a month of the critical path to Critical Decision 2, Approve Performance Baseline. The schedule uses the appropriate durations and logic dependency links and contains four months of schedule contingency at the end. Its overall duration, which calls for project completion (Critical Decision 4, Approve Start of Operation) in March 2007, appears feasible, but there are significant risks in the production and assembly sequence for the above components that could easily consume the four months of contingency. The project team has identified potential methods of accelerating the modular coil production and vessel assembly areas if necessary. These factors provide reasonable assurance that the schedule can be achieved.

The project presented an annual funding profile for completing NCSX by March 2007 that calls for \$11.0 million in FY 2003, \$18.3 million in FY 2004, \$19.5 million in FY 2005, \$16.4 million in FY 2006, and \$6.8 million in FY 2007. In the two middle years of the schedule, these amounts collectively exceed the current DOE/OFES funding guidance by almost \$5 million.

5.2 Comments

The level of cost estimate development exceeds that typically found at the conceptual design stage of a project and provides additional confidence that the scope identified for each WBS is reasonably well defined and can be achieved within the stated budget. The project team has done a commendable job of identifying major risk areas early in the project life cycle and has performed significant engineering and manufacturing studies that mitigate the technical, cost and schedule risk to the project. This is most notable in the Vacuum Vessel and Modular Coil WBS areas.

Although there are some activities where the Committee had differing opinions as to the level of effort required, there were no collective recommendations for adjustments to the project's cost estimate. In each of these areas, the project provided reasonable justification for the basis of their estimate.

The Committee was concerned that the condition of the existing PPPL equipment to be re-used poses a risk to the project cost and schedule if expensive or long lead components are found to be unusable late in the project.

The cost estimate includes a category called "PPPL Allocations" that covers the costs for things like computing services. For the sake of clarity to external reviewers, it would be best to incorporate this into the overhead burden.

The Project Summary Schedule (Appendix F) proposes that the Critical Decision 2, Approve Performance Baseline, milestone be split into two phases, however, this appears to be unnecessary. A more efficient approach would be to request Critical Decision 2 for the whole project in June 2003 (well after NEPA is to be completed), and also request Critical Decision 3a, Start Fabrication of Long-Lead Hardware to allow awarding the modular coil and vacuum vessel fabrication contracts. Critical Decision 3b, Start Fabrication of Remaining Systems, would remain in August FY 2004.

The project should make every effort to shorten the period between the end of manufacturing development of the modular coils and vacuum vessel, and awarding the production contracts for those components. Any time gained in the schedule at this relatively early stage will then become available for use later during fabrication and assembly when it is most likely to be needed to deal with problems.

Because the project's proposed cost and schedule estimates are predicated on a funding profile that is somewhat above the DOE/OFES guidance, it is important that this issue be resolved so that the FY 2004 DOE Budget Request contains accurate project cost and schedule data. For the sake of outyear OFES program budget planning, a preliminary estimate of NCSX annual operating costs (including upgrades) should be developed.

5.3 Recommendations

1. Prepare a preliminary annual NCSX facility operating cost estimate, based on the envisioned research program, that includes costs for planned diagnostics and upgrades, by Critical Decision 2, Approve Performance Baseline.

2. Identify by Critical Decision 2, Approve Performance Baseline, reused equipment

that could have significant impact on cost and schedule if it is not functional when required by the project. This equipment should be tested as early as possible to identify cost and schedule impacts.

3. Implement measures by Critical Decision 2, Approve Performance Baseline, to enable acceleration of the critical and near-critical path activities (primarily modular coil production and vacuum vessel production) to reduce schedule risk. Also implement recommendations of Section 4 that accelerate completion of the NEPA (Environmental Assessment) process.

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6. RESEARCH PROGRAM PLANS

6.1 Findings

The NCSX team has developed a reasonable phased set of program plans leading from initial start-up and shakedown, through field line and flux surfaces mapping, a limited period of ohmic operation and then a substantial period with auxiliary heating. High performance and longer pulse operations are in the later phases.

The diagnostic necessary for the first phases are included in the project costs and plans, while the diagnostics for auxiliary heating phase and beyond are clearly identified and included in operation costs.

The ability to carry out vacuum field line and flux surface mapping is essential in all phases of operation, even after the start of plasma operations.

6.2 Comments

The NCSX's effort in this subject area successfully addresses the related PVR concerns. As is fully appropriate, the research plans in the early phases are far more specific than those of the later phases.

6.3 Recommendation

1. Keep deployable field mapping apparatus within the NCSX machine, so that measurement may be done, as needed, without having to open the machine to vacuum.

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