Department of Energy
Review Committee

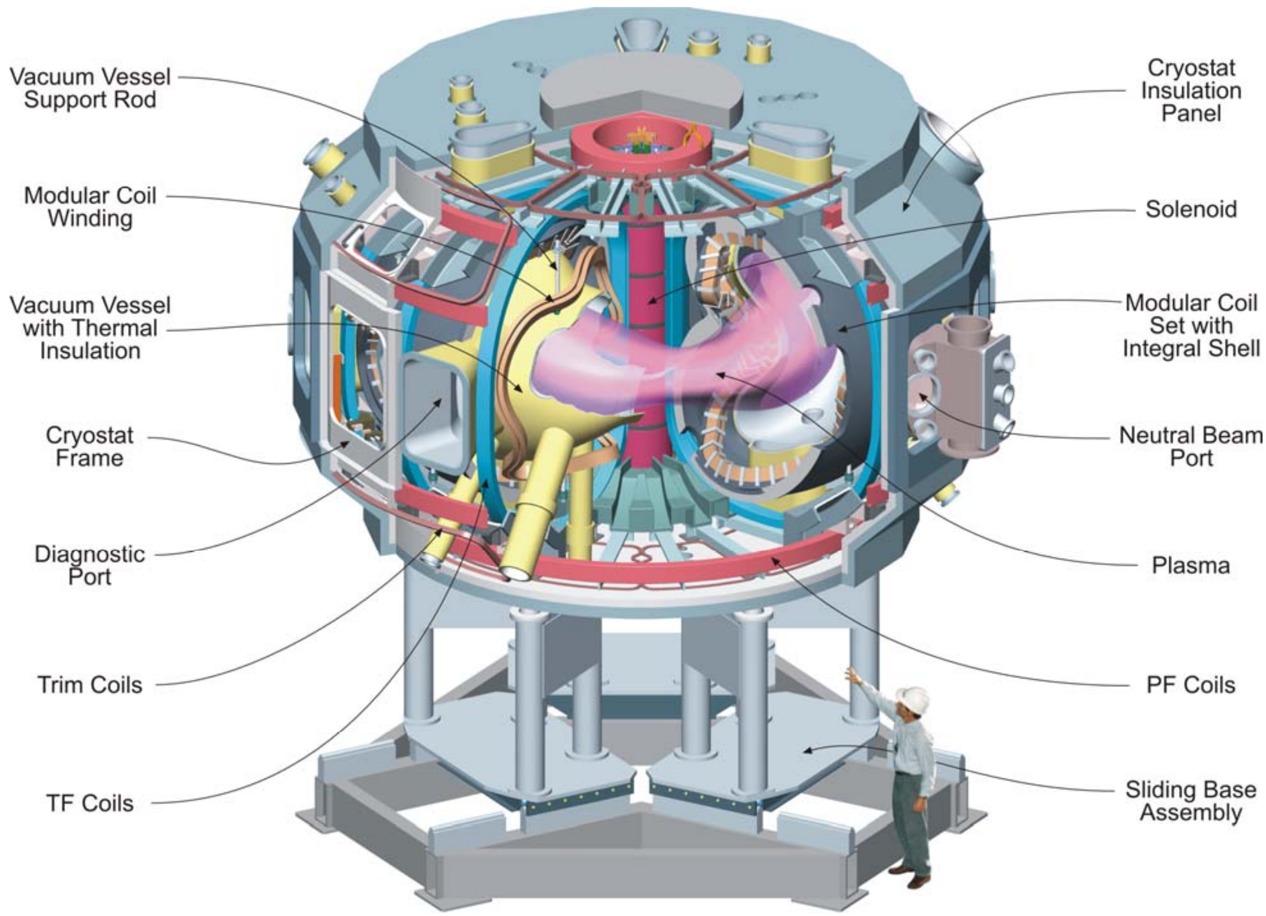
for the

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

of the

NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX) PROJECT

April 2008



NATIONAL COMPACT STELLARATOR EXPERIMENT (NCSX) PROJECT

EXECUTIVE SUMMARY

As requested by Dr. Raymond Fonck, the Associate Director for Fusion Energy Sciences, Office of Science, a Department of Energy (DOE) Independent Project Review of the National Compact Stellarator Experiment (NCSX) Major Item of Equipment was performed at Princeton Plasma Physics Laboratory (PPPL) from April 8-10, 2008. The purpose of the review was to evaluate the credibility and reasonableness of the project's latest cost and schedule estimates, and assess the likelihood of project success.

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

The NCSX project presented a proposed baseline to increase the Total Project Cost (TPC) by $68 million (from $102 to $170 million) and extends the schedule completion date by 49 months (from July 2009 to August 2013). The new estimates include $22.4 million or approximately 36 percent of cost contingency and 19 months or approximately 30 percent schedule contingency. Since the August 2007 DOE review, the Estimate to Completion increase of $29 million is due to an increase in contingency of $8 million and $21 million in baseline costs, with some additional scope items. The current estimate is based on the bottoms-up estimate developed in August 2007, which has been re-assessed and revised. The proposed estimate is also based on the assumed constrained funding profile.

There continues to be strong management support for the NCSX project from the Princeton University, PPPL, Oak Ridge National Laboratory (ORNL), and DOE Princeton Site Office (PSO). Additionally, a new, experienced project manager was brought on board approximately two months ago and is having a positive impact, particularly in the areas of project management discipline. There has been continued substantial technical progress in building the machine, and the integration of design and project engineering has been strengthened.

The fabrication of previous high risk items such as the Vacuum Vessel sub-assembly and Modular Coils are mostly complete along with the procurements of most of the technical components. The project proposed inclusion of additional Trim Coils that will allow some relief or compensation if the specified tolerances cannot be met after final machine assembly. However, Field Period Assembly and final Machine Assembly are just being initiated. High risks due to complexity of the machine and the tight tolerance requirements still remains for the project.

Considering that the project received Critical Decision 2 over four years ago (since February 2004), the amount of design remaining is unusually high (e.g., designs for test cell preparation are in the very early conceptual states, while the design is minimal for machine assembly, and cryostat and base support structure) for a project at this stage. However, it should be noted that budgetary constraints and cost overruns caused the project to focus efforts on critical path activities, often at the expense of completing designs on ancillary systems. Nevertheless, the Committee judged that completing design earlier would be beneficial in terms of reducing risks. As a summary, the NCSX project has not yet met normal DOE expectations for a rebaselining action in certain areas.

Based on the information the NCSX project presented, the Committee's major recommendations to the project include the following:

- Accelerate the design of remaining stellarator core components to better understand and evaluate the risks of future work.

- Include coil services and cryogenic systems in overall system integration and evaluate as part of a comprehensive review of cryostat and core region.

- Institute quality assurance measures to preclude component and system failures that could further delay and increase the cost of the project.

- Perform a peer review ("Red Team") of the proposed baseline resubmittal by an independent panel to enhance the quality of the cost and schedule estimate.

- Submit to DOE by May 1, 2008, a plan for resolving the issues identified by the Committee and resubmit the rebaseline package.

There were no action items resulting from the review.

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1. INTRODUCTION

The National Compact Stellarator Experiment (NCSX) is a fusion research project (located at the Princeton Plasma Physics Laboratory (PPPL) that was initiated by the Department of Energy (DOE). 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 benefits of this fusion concept, and advancing the state-of-the-art, three-dimensional analysis of fusion plasmas. In 2001, a panel of plasma physicists and engineers conducted a Physics Validation Review of the NCSX design. The panel concluded that the physics approach to the NCSX design was appropriate and that the concept was ready for the next stage of development, namely proof-of-principle. The Fusion Energy Sciences Advisory Committee endorsed the panel view. NCSX Critical Decision (CD) 0, Approve Mission Need, was approved in May 2001. A May 2002 DOE Conceptual Design Review panel found that the NCSX design concept and project plans provided a sound basis for engineering development. Approval of CD-1, Approve Alternative Selection and Cost Range, was obtained in November 2002.

The NCSX project involves the design, fabrication, installation, and integrated system tests of a compact stellarator core device consisting of a highly shaped vacuum vessel; surrounding coil systems; enclosing cryostat and various auxiliary power; cooling, vacuum, cryogenic, and control systems; as well as a set of startup diagnostics. All of this equipment plus a control room will be located in existing buildings at PPPL that were previously used for other fusion experiments. Further, many of the NCSX auxiliary systems will be made available to the project from equipment used on the previous experiments. The project is being 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). The initial cost range of NCSX, based on the pre-conceptual design, was between $69-83 million. The Total Estimated Cost (TEC) of the device based on the conceptual design was $73.5 million with a completion date in June 2007. Due to the continuing resolution at the beginning of FY 2003 that was not resolved until February 2003, the project activities were delayed until April 2003 instead of the planned October 2002 date. With this later start and additional design and cost information, PPPL estimated the TEC of the device to be $81 million with a completion in September 2007. PPPL assembled an outside committee to perform a preliminary design review in October 2003. Upon completion of the review and after analyzing the impacts from recommendations of that committee, the project team estimated the NCSX TEC to be $82 million with a completion date of November 2007. In addition, the preliminary design review committee concluded that the project was ready to proceed to CD-2, Approve Performance Baseline (signed in February 2004 with a baseline TEC of $86.3 million and a completion date in May 2008 after incorporating recommendations from the November 2003 Performance Baseline Review and updated DOE funding profile).

After various reviews, CD-3, Approve Start of Construction, was obtained in September 2004, with a TEC of $86.3 million and a completion date in May 2008. In 2005, the NCSX funding profile was modified by OFES in response to budgetary constraints. A new baseline was developed and approved by the Deputy Secretary in July 2005. This new baseline established a TEC of $92.4 million and a July 2009 completion date.

2. REMAINING TECHNICAL SCOPE

2.1 Stellarator Core

The stellarator core includes all components and systems out to the cryostat and base support structure and comprises: the vacuum vessel, modular coils (MC), conventional coils (toroidal field (TF), poloidal field (PF), and trim), coil structures, coil services, and cryostat and base support structure. The project made good progress in fabricating the more complex components, notably the modular coils and vacuum vessel sections. Subassembly and final machine assembly of the fabricated components are discussed in Section 2.3.

2.1.1 Findings

Vacuum Vessel

The three vacuum vessel sections, connecting spools, and port extensions have been delivered. Addition of magnetic diagnostics and vessel bake-out tubes are well in hand. Design is progressing well on the neutral beam extension ducts.

Modular Coils

Sixteen of the eighteen modular coils are completed with the last two in the winding process. The majority of the risk in modular coil fabrication has been retired (assembly is now key). The remaining budget for this WBS appears satisfactory.

Conventional Coils

The TFs are well into production with approximately 50 percent delivered all within specification; production is proceeding at an acceptable pace. The PF coils, which are conventional circular coils, have received acceptable bids that are within the stated budget. Bid evaluation for the PF coils is in progress.

The project included a set of 48 trim coils in response to the August 2007 DOE review. Analysis has shown that these can be used to mitigate effects of resonant errors from some level of misalignment in assembly, leading to higher confidence in operation.

The trim coil design is straightforward and has undergone a preliminary design review; and the budget appears to be adequate and the fabrication seems to impose minimal risk.

Coil Structures and Base Support Structure

The coil structures provide support for the conventional coil systems referenced to the modular coil set. The design seems straightforward and the components are presented in detail in the relevant work authorization form (WAF); and the preliminary design review has been completed. The components are of low technical complexity and cost estimates for the components as detailed should be achievable. A final design review is planned for June 2008.

The base support structure interfaces with the test cell floor, and TF support brackets. It also provides mounting pads for the three field period assembly (FPA) fixtures. The preliminary design review was completed and a final design review is planned for April/May 2008. Due to time limitations, there were no presentations that covered detailed assembly of the base and coil support structures.

Coil Services

This element provides for the current feeds and liquid nitrogen cooling to the varied coil sets within the cryostat. This design is at the conceptual level. Significant engineering remains in coil lead and cooling tube routing and flow control.

Cryostat

The cryostat design presented was pre-conceptual and no system requirements list was presented.

2.1.2 Comments

Vacuum Vessel

The estimate for completion of these subassemblies appears credible.

Major risk/work in the vacuum vessel resides in assembly operations. Several of the bake-out tubes have been determined to have leaks. The project needs to understand the origin of these leaks and what mitigation will occur prior to further assembly. Similar tubes may be used for coil services. The project should institute quality assurance measures to minimize risk of further leaks.

The project should ensure that viable leak checking including procedures is available at appropriate times during assembly and in operation. American Vacuum Society Standard 4.1 is suggested.

Modular Coils

Limitations on thermal gradients in coil operation and cool-down from modular coil stress analysis should be clarified and incorporated into coil services and cryostat design and a document produced on cool-down requirements and procedures.

Conventional Coils

The Committee judged that conventional coil procurement is well in hand and the budget is adequate. The project is to be commended for the inclusion of the trim coil set.

Coil Structures and Base Support Structure

Care in alignment with the modular coil set is necessary to ensure successful operation of the machine and these structures need to accommodate this. Major risk in this item is deferred to assembly.

Coil Services

The design of the cryogenic distribution systems are not well enough defined for a credible cost estimate to be made or for a realistic assessment of contingency or schedule.

Current feeds are a common failure point. Therefore, careful attention to the coil lead connections must be considered, especially given the lead extensions required by inaccessibility of the actual coil terminations after assembly.

With 48 trim coils, 18 modular coils and the PF and TF sets, significant interfaces and potential interferences exist within the cryostat; detailed design is needed to accommodate available space runs. Flow control requirements need to be assessed with respect to the allowed thermal variations in cool down and operation in the modular coils. Additionally, coil services need a high degree of integration with the cryostat and cryostat cooling.

The project has a good start on this element and the Committee encouraged support of this effort to the fullest extent possible.

Cryostat

The design of the cryostat is not well enough defined for a credible cost estimate to be made or for a realistic assessment of contingency or schedule. The cryostat base support is at a conceptual design phase. Details should ensure controlled positioning in all six degrees of freedom of the FPAs when assembling into the full torus.

The design needs to address potential hazards or operational problems associated with oxygen enrichment of the cryostat atmosphere, condensation and freezing of moisture in the cooling and vacuum vessel bake-out tubes, fire retardancy of insulating materials, etc.

A full-time engineer was assigned to address these designs. This is a good start and the Committee encouraged support of this effort to the fullest extent possible. The Committee also encouraged the use of outside consultants, and personnel from other national laboratories and universities to support this activity.

The cryostat sets the envelope for all coil services and needs to account for activities in this WBS.

Efforts should be undertaken to understand any potential risks associated with oxygen deficiency hazards (ODH) that might be created in the experimental hall, especially at the basement level.

The Committee encouraged the project to address applicable DOE, ASME, and PPPL codes as they relate to pressure piping, and pressure and vacuum vessels required to operate the stellarator at PPPL.

2.1.2 Recommendations

1. The engineering staff needs to be increased such that “just in time” prints and procedures are minimized. In addition, while modern CAD systems are very helpful, the output needs significant human review to assess hidden faults and assumptions, especially with regard to engineering integration. It was the Committee’s impression that parts and components were optimized, but system integration was less than perfect.

2. In all of the site walk-through exercises the Committee did not see shop travelers that included specific assembly procedures and quality assurance steps. This will be very important now that the project is moving to an assembly phase.

3. Coil Structures and Base Support Structure—ensure that adequate alignment capabilities exist within the supporting system and that metrology needs are accounted for to simplify assembly.

4. Coil Services—complete detailed engineering as soon as possible and ensure design is integrated with the balance of the stellarator core.

5. Cryostat—include failure modes and required safety measures in the engineering package.

6. Cryostat—leverage cryogenic support in DOE laboratories and supported universities to accelerate development of requirements document and the detailed design.

2.2 Ancillary/Auxiliary Systems

2.2.1 Findings

The total Estimate to Complete (ETC) for the Ancillary/Auxiliary systems was $9,069K with a contingency of $1,941K. The design maturity for most of these systems is very low because the design effort is not scheduled to start until FY 2009 or later. Most of these ancillary systems require designs that are very similar to other experimental facilities installed at PPPL and rely heavily on components and experience from the National Spherical Torus Experiment (NSTX) experiment. The basis for estimate for most systems is credible primarily due to these similarities. The cryogenic system represents the exception to this conclusion.

The cryogenic system is at preconceptual design level and requires further development to obtain a reliable cost and schedule estimate. Significant detail development is needed for the liquid nitrogen circulation system in order to ensure proper control during cool down and steady state operation of the system. The cold nitrogen gas circulation system planned for the annular space between the Aerogel®-insulated vacuum vessel and the cryostat wall is also in the preconceptual design phase, in part due to the rejection of two previous conceptual designs by the NCSX managers.

The NCSX Diagnostics Team has an interface document under development at this time. This document is crucial in order to ensure the proper installation—the team is commended for taking the initiative to develop this document.

The E-beam mapping system development assumes collaboration with ORNL, Auburn University, and the University of Wisconsin; however, no Memorandum of Understanding (MOU) is in place with these institutions.

2.2.2 Comments

Overall the Committee detected no major “show stoppers” in the Ancillary Systems. The Committee was concerned regarding the low maturity of detailed design of the Liquid Nitrogen (LN2) and Gaseous Nitrogen (GN2) cooling system within the cryostat due to the potential impact these subsystems may have with other systems in proximity to the cryogenic systems components within the cryostat. Careful integration/interfacing of all of the systems within the cryostat volume is essential, but may be difficult until the cryogenic system design has matured. The Committee judged that particular attention should be paid to the cryogenic system controls and in overall safety associated with the operation of the cryogenic/cryostat system, thus the Committee suggested the responsible engineer should:

- Evaluate the potential for flow imbalances and the need for additional control valves in order to ensure the proper level of control during NCSX cool down and steady state operation.

- Develop Safety and Failure modes and effects analyses for the cryogenic system.

With respect to diagnostic integration, the Committee judged that this effort may require significantly more than ten percent of one physicist in order to facilitate installation in a timely manner. Close consultation, early-on, with systems integration engineering staff is encouraged.

2.2.3 Recommendations

1. The detailed design of the cryogenic system should be advanced to identify any required changes to core components in time to prevent schedule delays. In order to accomplish this in a timely manner, the Committee recommended:

   - The addition of more engineering resources with cryogenic experience,
   - Inclusion of at least one independent external reviewer with relevant experience on the CDR and other design reviews, and
   - Inclusion of the Cryogenic system in overall system integration and evaluation as part of a comprehensive review of cryostat and core region.

2. MOUs should be established with the Universities who will collaborate on the E-beam mapping system. These documents should clearly define the scope of work (including deliverables), establish who is responsible for each deliverable, establish a cost (including a basis of estimate) for the deliverables, and state a schedule for the delivery of the items described in the scope of work.

2.3 Final Assembly

2.3.1 Findings

WBS 18, Field Period Assembly, is 28 percent complete and has an Estimate at Completion (EAC) of $20.0 million, which represents an increase of $6.4 million compared to the EAC presented at the August 2007 DOE review. Progress includes fit-up of the first two MCs—A1 and B1—into a mated pair with initial shim welds just completed.

Approximately 60 percent of the $6.4 million increase is due to extra steps identified in developing the Station 2 assembly process after the August 2007 review, with the remainder due to improved understanding of resource needs, especially metrology and Title III support.

Primarily because of these extra steps in the assembly process, the planned completion date for FPA has been extended by nine months compared to that presented at the August 2007 DOE review.

WBS 7, Test Cell Prep and Machine Assembly, is eight percent complete and has an

EAC of $9.4 million, which represents an increase of $0.4 million, based on additional scope, e.g. trim coil installation.

Seventeen of the eighteen MCs have completed winding operations, with sixteen completed through the Vacuum Pressure Impregnation (VPI) step. The remaining coils are in various stages of fabrication.

Assembly space and technicians from the MC fabrication effort have begun the transition to the FPA effort. The risk of increased project cost and schedule from problems associated with the MC fabrication is minimal.

Photogrammetry is being investigated as a tool for assessing weld distortion of the FPA with the prospect of decreasing measurement times for the critical “nose” welding steps.

An increased effort has been applied to the Systems Engineering and Systems Integration tasks during the past eight months.

Ten of eighteen TF coils are complete. The PF coil design is complete and multiple qualified vendors have responded within the estimated cost.

NCSX has incurred additional scope as the number of Trim Coils has increased to 48. The trim coil windings are low risk items since they consist of two relatively simple shapes and can be fabricated using standard techniques from common insulated solid wire stock.

Leaks were found in the helium gas lines on one Vacuum Vessel section. NCSX will leak test 100 percent of these gas lines at a pressure in excess of the operating level. Failures that are not related to joint flaws will be investigated to determine the source of the failure.

2.3.2 Comments

Coil Services

The manifold system for LN distribution to the actively cooled coils incorporates a G10 electrical break that will be tested at operating temperature (77 K). An allowable leak rate should be established for these tests since a hermetically sealed system may be difficult to achieve and unnecessary given that the manifolds will be immersed in nitrogen gas.

While the engineering and materials for the LN distribution system are well established, the system is not mature from a design standpoint and may require several iterations to resolve space and assembly conflicts and therefore the rating of a “low” complexity does not seem warranted.

Project Integration

Integration of all “services” (power, signal, LN) should be incorporated into the system design since manifolds, bus bars, cables, and hoses may need several iterations to satisfy space and machine assembly limitations.

The possibility of high stresses and/or distortions to the components supported by the Modular Coil Winding Forms (MCWF) as a result of thermal gradients during cooldown has not been adequately addressed.

The design of the nitrogen gas delivery system for cooling of the machine annulus is not mature and the requirements on allowable temperature variation through the affected volume have not been established. These temperature differentials have an impact on the stress and distortion of the MCWF, and all magnet structures supported by the MCWF.

Given that the cryostat design has not begun, design and engineering estimates for subsystems that interface with this system are suspect. Physical limitations of the cryostat may necessitate design changes to these associated subsystems.

The efforts to strengthen Project Integration appear to be working. The addition of the roles of Project Integration Manager (G.H. Neilson) and Engineering Support Head (P.J. Heitzenroeder) are helping to shape a more formal approach to design integration between systems and across interfaces. Integration requirements have been added to design and system review requirements, and weekly meetings ensure adequate communication takes place. However, there is still room for improvement as some reviewers noted occasional confusion between parties concerning interface responsibilities. As more and more of the workflow passes through the new, more formal, interface/integration process, these problems are expected to be reduced.

Other

An upper limit on the acceptable leak rate for the Vacuum Vessel helium lines should be established prior to any rework.

Escalations in WBS 18 cost and schedule from the August 2007 Baseline Change

Proposal (BCP) to the present BCP are largely due to the problems and remedies associated with the FPA "nose" region. The new remedy of welding shims in an interleaved fashion and holding spacing with "puck" spacers is promising but is still being validated. The Committee was less than 50 percent confident that the new remedy will satisfy the original tolerance requirements fully on all FPA joints. However, the addition of Trim Coils appears to relieve the tolerance requirements to a reasonable level. This results in a more favorable confidence level of 85-90 percent that the new welding plan will achieve "acceptable" distortions.

Uncertainties due to still maturing procedures exist since the actual work has outpaced the detailed design and R&D efforts. This is not something that can be easily remedied at this point. The best approach is to look ahead to identify problems already inherent in the existing individual component designs and address these "just in time" process. To accommodate this approach, work plans must be flexible enough to allow for "in the field" engineering judgments and changes. Such iterations appear to be incorporated into the current work plans as presented by the WBS 18 and seven job managers.

Several large risks (aside from the "nose" welding) remain in the "to go" assembly work such as damage to FPA's during transport. These risks are hard to assess due to the wide range of severity possible (small damage versus complete dis-assembly and re-work). Some of these risks have mitigation plans. However, the plans lacked sufficient detail to make the Committee comfortable.

Consider thermal cycling of the Vacuum Vessel segments and helium pressure/leak test prior to Station 3 assembly.

Filling the annular space between the vacuum vessel and the MCs with Aerogel® insulation restricts further work on vacuum vessel systems (such as leak detection, instrumentation repair, etc.). Consider delaying this step until as far into the Machine Assembly process as is reasonable.

WBS 7 shows a contingency of 59 percent of the ETC. This high contingency (according to the project) is a result of relatively long schedule delays incurred by risk event remediation. Consider reviewing risk event probabilities and remediation to reduce contingency requirements where reasonable. For instance Vacuum Vessel Welding has a critical path schedule impact of four months. Reduction of this impact through pre-engineering or mitigating down the probability of risk occurrence should reduce contingency requirements.

The Stellarator Core Systems (WBS 1) includes Stellarator Core Management and

Integration activities (WBS 19). These activities proved very helpful to the FPA (WBS 18) efforts by identifying key risks/decision points and embarking upon engineering and technical analyses and trials to provide worthwhile alternatives and retiring risks early. The project is using this same team to provide like services for Test Cell Prep and Machine Assembly (WBS 7). The Committee encouraged this plan and would like NCSX to consider formalizing the arrangement by creating a similar Level 3 WBS element under WBS 7 or through Project Integration management directives.

The Basis of Estimate for most of the assembly tasks is predominantly dependant upon past experience. However, few links to documents that show the applicability of past experience or estimating worksheets are given. Any information pertaining to such estimation basis should be referenced in the WAFs.

2.3.3 Recommendations

1. Evaluate the risk of possible future failure of the Vacuum Vessel helium lines and develop mitigation plans as appropriate.

2. Evaluate the risk of unsatisfactory vertical welds of half period assemblies in Station 3 and develop mitigation plans as appropriate.

3. Verify that all critical items (diagnostic loops, thermocouples, gas lines, etc.) are in working order after transport of the FPA to the experimental hall prior to final machine assembly. Evaluate the risk of failure of a critical item at this point in the assembly process and develop mitigation plans as appropriate.

4. Complete validation tests for the new “nose” welding technique and incorporate any resulting changes to the assembly plan before re-baselining. In addition the new proposal should take advantage of retiring risks during this time interval to reduce contingency requirements.

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3. COST ESTIMATE

3.1 Findings

The NCSX project team presented the new Total Project Cost (TPC) as $170.2 million, an increase of approximately $29 million from the August 2007 DOE review. The higher cost is due to an increase in contingency of $8 million and $21 million in baseline costs, with some additional scope items.

The baseline presented to the Committee was based upon the bottoms-up estimate developed in August 2007 and has been reassessed and revised. As of February 1, 2008, the project has spent approximately $86 million in TPC and is approximately 54 percent complete (based on the new TPC of $170.2 million).

The proposed contingency for the project is $22.4 million or approximately 36 percent of the ETC. The project's contingency estimate was based on detailed, probabilistic risk, and uncertainty analyses. The risk analysis and thus the cost estimate assumes exclusion of bounding conditions related to off-normal execution such as funding availability, no changes to CD-4 criteria, or no extraordinary incidents, stand downs, or laboratory shutdown. The cost estimate also excluded risk events that have a very low likelihood of occurrence but high impact consequences such as major technical events requiring disassembly or reassembly of the machine or a field period, failure of a key component or system during integrated system testing, or detection of large islands during e-beam mapping requiring extensive troubleshooting and remediation.

3.2 Comments

Implementation of a quantitative risk assessment and cost estimating process is commendable. A detailed, independent review of the baseline has yet to be performed by the project. The bottoms-up estimate is yet to achieve acceptable credibility due to design maturity, integration complexity, evolving experience base, and risk events excluded from analysis. Risk analysis and contingency calculation are yet to mature to a level that supports a rebaseline request.

Because of the lack of maturity of some of the systems, the committee could not assess the adequacy of the remaining contingency and the resulting cost to complete estimate. (See Appendix D for the committee's assessment of the project costs).

3.3 Recommendation

1. Perform a peer review ("Red Team") of the proposed baseline by an independent panel to enhance the quality of the cost and schedule estimate.

4. SCHEDULE and FUNDING

4.1 Findings

The NCSX project presented a proposed project completion date of August 2013, which includes 19 months (approximately 30 percent) schedule contingency until the project completion date. The proposed CD-4 date extends the existing schedule by 49 months. The resource-loaded schedule was developed using a bottoms-up approach at the execution ("Job") level with estimates from Job Managers for resource requirements; activity duration; and sequencing, risk identification and mitigation planning, and overall execution uncertainties. The integrated resource-loaded schedule clearly identifies the critical path through Stations 2, 3, 5, and 6 assembly and commissioning. (See Appendix E, the summary project schedule).

The schedule contingency is based on detailed, probabilistic risk, and uncertainty analyses. The schedule was developed with an assumption that several key design activities yet to be completed will be done on schedule, and excludes risk events that have a very low likelihood of occurrence but high impact consequences such as major technical events requiring disassembly or reassembly of the machine or a field period, failure of a key component or system during integrated system testing, or detection of large islands during E-beam mapping requiring extensive troubleshooting and remediation.

The proposed funding profile presented by the project is shown in Table 4-1.

Table 4-1. NCSX Proposed Funding Profile ($M)

	Prior FY ($M)	FY2008 ($M)	FY2009 ($M)	FY2010 ($M)	FY2011 ($M)	FY2012 ($M)	FY2013 ($M)	Total ($M)
TPC	$83.8	$15.9	$19.6	$20.1	$22.1	$8.6		**$170.2**

4.2 Comments

The funding profile presented is yet to provide an optimal balance between planned activities and funding resources held to support risk events and contingency requirements. The project might consider resequencing the activity schedule to complete the outstanding design activities earlier. Prompt completion of the design will support resolution of open items related to design uncertainty in the risk register and mitigate the commensurate cost and schedule risk.

A detailed, independent review of the baseline has yet to be performed by the project. The bottoms-up estimate is yet to achieve acceptable credibility due to design maturity, integration complexity, evolving experience base, and risk events excluded from analysis. Risk analysis and contingency calculation are yet to mature to a level that supports a rebaseline request.

Because of the lack of maturity of some of the systems, the committee could not assess the adequacy of the remaining schedule contingency and the schedule estimate.

4.3 Recommendation

1. Perform peer review (“Red Team”) of the proposed baseline by an independent panel to enhance the quality of the cost and schedule estimate.

5. MANAGEMENT

5.1 Findings

There continues to be strong management support for the NCSX project from the Princeton University, PPPL, ORNL, and DOE/PSO. Management recognizes the important role that NCSX will play not only for their institution, but the fusion program overall. NCSX has top priority at PPPL.

A new project manager, Don Rej, was brought on board approximately two months prior to the review. Don has extensive project management experience and demonstrated good understanding of the management challenges facing NCSX. (See Management Chart in Appendix F.)

The Committee was presented with a proposed baseline of $170.2 million TPC with $22.4 million contingency, which is approximately 36 percent of the ETC. The proposed completion date of August 2013 includes 19 months of schedule contingency. This proposal represents a substantial increase to the cost and schedule of NCSX.

The project believes the staffing requirements for the remaining NCSX work in the proposed baseline are within the resources available at PPPL and ORNL.

Overall, in the proposed rebaseline, a substantial amount of design work remains, 32 percent or $6 million. In addition to machine assembly, incomplete design and engineering are major factors in the proposed contingency.

PPPL developed a comprehensive risk management approach. The project manager uses this methodology in the monthly project meetings to deal with ongoing and emerging issues.

5.2 Comments

Relationships among all parties seem healthy with open communications. The new project manager has made transparency one of his overarching goals. The Federal Project Director and the DOE/PSO are fully engaged, informed, and supportive of project activities.

While on board only a short time, the new project manager has already had a positive impact, particularly in the areas of project management discipline.

Since becoming more engaged, the University has made positive contributions to NCSX, such as bringing techniques for metrology and assembly of large complex scientific equipment from the particle physics/ large detector community. The University has also supported reviews of project plans that have added substantial value to the quality of those plans.

As noted in other portions of this report, there has been substantial and impressive progress in building the NCSX machine. This progress was particularly evident during the tour of fabrication and assembly areas.

The project is to be commended for actions to strengthen systems integration in the engineering area. This effort should be continued. Along with the continued strong physics and technical integration function already in place, this will serve the project well.

While it is recognized that some independent review of the proposed rebaseline was conducted, the Committee judged that the quality of the cost estimate would have been enhanced by more detailed, external independent review.

The amount of design remaining is unusually high for a project at this stage, four years since CD-2 in February 2004. However, it should be noted that budgetary constraints and cost overruns caused the project to focus efforts on critical path activities, often at the expense of completing designs on ancillary systems. These decisions were addressed in prior reviews and documented in baseline change control systems where applicable. Nevertheless, the Committee judged that completing design earlier would be beneficial in terms of reducing risks. In this regard, it is noted that the project did not respond adequately to the previous recommendation to develop an alternate baseline for consideration based on “optimum” funding. The result of this was that insight was not gained regarding the potential benefit of advancing the design and retiring risks earlier.

As a summary comment reflecting the Committee’s review, the NCSX project has not yet met normal DOE expectations for a rebaselining action in certain areas.

5.3 Recommendations

1. Proceed with the project rebaselining process when the key engineering issues identified by the Committee have been resolved.

2. Submit to DOE a plan for resolving those issues and resubmitting a rebaseline package by May 1, 2008.

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APPENDIX A

CHARGE MEMORANDUM

Department of Energy
Washington, D.C. 20585

February 12, 2008

MEMORANDUM FOR Daniel R. Lehman, Director
Construction Management Support Division

FROM: Raymond Fonck
Associate Director for Fusion Energy Sciences

SUBJECT: Cost and Schedule Review of the Revised Baseline for the National Compact Stellarator Experiment (NCSX) at the Princeton Plasma Physics Laboratory (PPPL)

I would like to request that your office organize and lead an Office of Science (SC) review of the NCSX project.

The purpose of this review is to evaluate the project's proposed cost and schedule re-baseline, and the project's path forward.

The review is planned to be held on April 8-10th, 2008, at PPPL. In carrying out its charge, the review committee should evaluate the following:

1. Is the project's bottoms-up-estimate to complete credible? Is there an adequately mature design available on complex activities, such as machine assembly, to support the estimate?

2. Is the contingency supported by and consistent with an appropriate project-wide risk analysis based on the use of a comprehensive Risk Registry? Is there adequate cost and schedule contingency in the proposed baseline to achieve a high level of confidence in completing the project successfully?

3. Has the project adequately incorporated developmental, fabrication, and component assembly experiences in the bottoms-up estimate to increase the success of final machine assembly and improve reliability during research operations?

4. Is the project being properly managed and organized at this point, and are future staffing plans at both PPPL and ORNL adequate? What is the level of confidence that the NCSX project team can complete the project within the proposed baseline? Is there adequate support from PPPL and ORNL management?

5. Ensure that the Critical Decision 4 workscope definition, as defined in the July 2005 baseline, will be met.

Barry Sullivan, the NCSX Program Manager, will work closely with you as necessary to plan and carry out this review. I would appreciate receiving your Committee's report within 15 days of the conclusion of the review. This review will play an important role in ensuring that the NCSX project can be completed within the proposed cost and schedule.

Thank you for your help in this matter. If you have any questions or need additional information, please contact Barry at (301) 903-8438.

cc:
P. Dehmer, SC-2
R. Fonck, SC 24
G. Nardella, SC-24.2
St. Eckstrand, SC-24.2
B. Sullivan, SC-24.2
S. Barish, SC-24.2
J. Faul, SC-PSO
J. Makiel, SC-PSO
R. Goldston, PPPL

APPENDIX B

REVIEW PARTICIPANTS

Department of Energy Review of the
National Compact Stellarator Experiment (NCSX)

REVIEW COMMITTEE PARTICIPANTS

Department of Energy

Daniel R. Lehman, DOE/SC, Chairperson

Consultants

Subcommittee 1
Dave Anderson, U. of Wisconsin
Bruce Strauss, DOE/SC
Thomas Nicol, Fermilab

Subcommittee 2
Thomas McManamy, ORNL
Harry Carter, Fermilab

Subcommittee 3
Patrick Hurh, Fermilab
John Haines, ORNL
Russell Wells, LBNL
Harry Carter, Fermilab

Subcommittee 4 and 5
John Post, LLNL
Kin Chao, DOE/SC
Frank Crescenzo, DOE/BSO

Subcommittee 6
Les Price, consultant
Frank Crescenzo, DOE/BHSO

Observers

Ray Fonck, DOE/SC
Barry Sullivan, DOE/SC
Jeff Makiel, DOE/PAO
Greg Pitonak, DOE/PAO
Naomi Hake, DOE/BHSO

APPENDIX C

REVIEW AGENDA

Department of Energy Review of the
National Compact Stellarator Experiment (NCSX)

AGENDA

Tuesday, April 8, 2008—CONF ROOM LSB318

8:00 am	DOE Executive Summary
9:00 am	Plenary Session: Welcome/Overview.........................A.J.S. Smith, D. Christensen
9:10 am	Project Overview .... D. Rej
9:45 am	Engineering Design and Integration ....P. Heitzenroeder
10:30 am	Break
10:45 am	Mechanical Construction and Assembly .... L. Dudek
11:15 am	**Laboratory Tours**
	Vacuum Vessel Preparation and Field Period Assembly .... M. Viola
	Modular Coil Fabrication...J. Chrzanowski
	NCSX Site Preparation .... E. Perry
12:30 pm	Lunch
1:30 pm	**Breakout Session I: Stellarator Core Systems (SC 1)—<u>LSB331</u>**
	Vacuum Vessel Systems...P. Goranson
	Modular Coils ....J. Chrzanowski, M. Cole, L. Dudek
	Conventional Coils ....M. Kalish, J. Chrzanowski, F. Dahlgren, M. Cole
	Cryostat and Cryosystem..S. Raftopoulos
	Coil Services ....P. Goranson
	Support Structures... F. Dahlgren
	Breakout Session II: Assembly, Test Cell Prep, Start-up (SC 2/3)—<u>LSB318</u>
	Field Period Assembly...M. Viola, T. Brown, L. Dudek
	Test Cell Preparation & Machine Assembly .... E. Perry
	Integrated Systems Testing..A. von Halle
	CD-4 Objectives .... H. Neilson
	Breakout Session III: Management (SC 4/5/6)—<u>DOE Conf Rm, 2nd floor</u>
	Cost, Schedule, Milestones..R. Strykowsky
	Risk Based Contingency Analysis...C. Gruber
	Staffing .... D. Rej, J. Harris
	Procurement .... R. Templon
	ES&H ....J. Levine
	QA ....J. Malsbury
	Management Initiatives .... D. Rej
5:00 pm	DOE Executive Session
6:30 pm	Adjourn

Wednesday, April 9, 2008

8:00 am **Breakout Session I: Ancillary Systems (SC 2)—LSB318**

Vacuum Pumping and Gas Fueling .... W. Blanchard
Diagnostics... B. Stratton
Electrical Power Systems ....R. Ramakrishnan
Central Controls and Computing .... P. Sichta
Facility Systems:
Cooling and Utilities... L. Dudek
Bakeout .... L. Dudek

Breakout Session II: Integration & Systems Engineering (SC 1/3)—LSB331

Project Integration Overview...................................... H. Neilson, P. Heitzenroeder
Design Integration... T. Brown
Plant Design .... E. Perry
System Analysis/Technical Assurance .... A. Brooks
Dimensional Control Coordination.. R. Ellis
Stellarator Core Management and Integration... M. Cole
System Engineering ....R. Simmons

12:00 pm Lunch
1:00 pm Subcommittee Working Sessions
3:00 pm DOE Executive Session
6:00 pm Adjourn

Thursday, April 10, 2008

8:00 am DOE Executive Session
9:30 am DOE Closeout Dry Run
11:30 am Lunch
12:30 pm Closeout Presentation to PPPL, ORNL, Princeton University Management
1:30 pm Adjourn

APPENDIX D

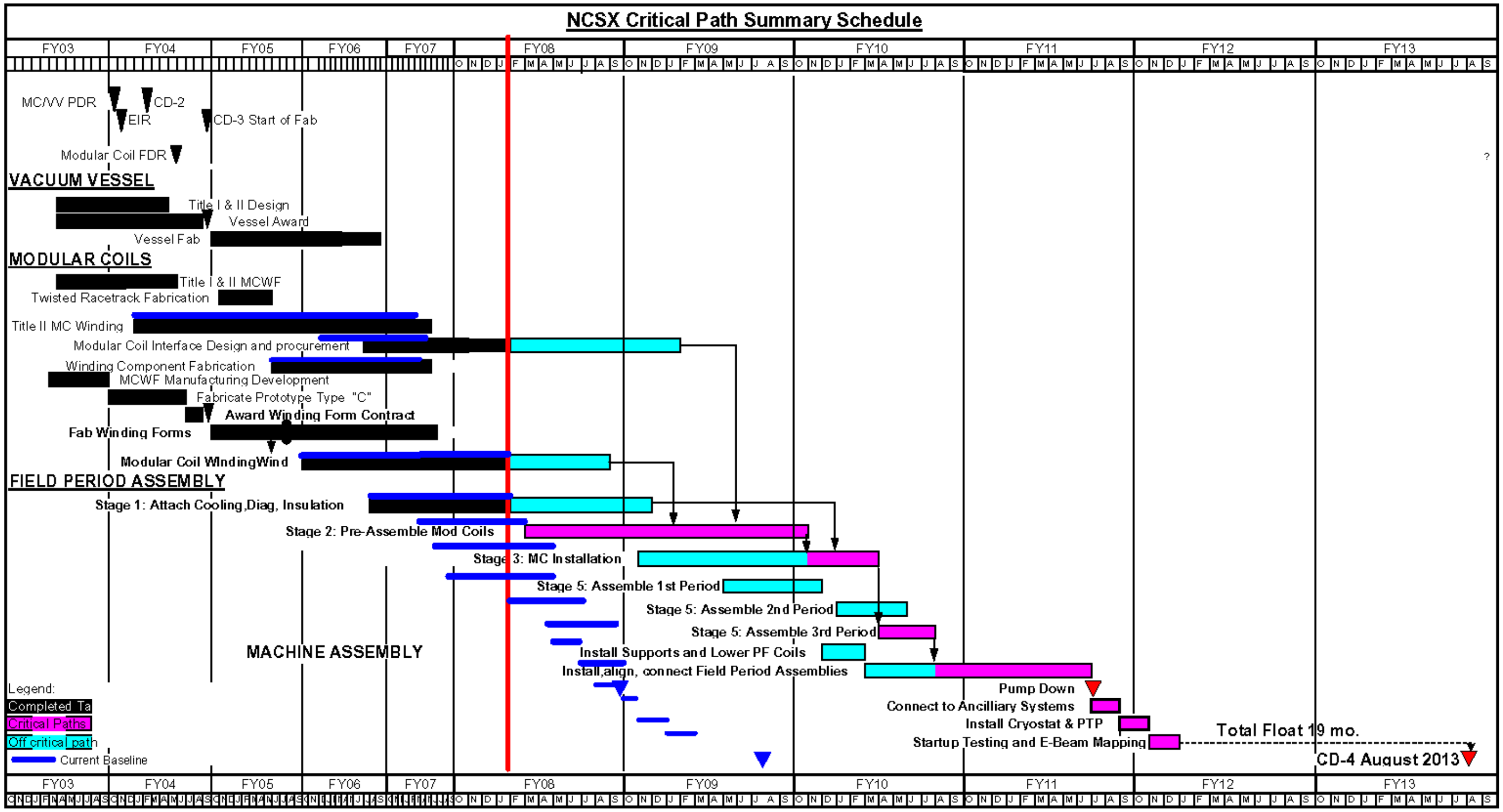
COST TABLE

				PROJECT ESTIMATE (Cost in $K)					DOE REVIEW ESTIMATE (Cost in $K)				
					Contingency					Contingency			
	WBS	Baseline (4/05)	ACWP (through 1/31/08)	ETC	$	% of ETC	%Complete (as spent)	TOTAL EAC with contingency	ETC	$	% of ETC	TOTAL EAC	Comments
12	Vacuum Vessel	$9,531	$9,743	$1,429	$222	16%	87%	$11,394	$1,429	$222	16%	$11,394	
13	Conventional Coils	$4,790	$3,830	$4,256	$725	17%	47%	$8,811	$4,256	$725	17%	$8,811	
14	Modular Coils	$28,091	$38,172	$2,563	$398	16%	94%	$41,133	$2,563	$398	16%	$41,133	
15	Structures	$1,413	$550	$1,528	$749	49%	26%	$2,827	$1,528	$749	49%	$2,827	Need more design.
16	Coil Services	$1,140	$3	$1,085	$196	18%	0%	$1,284	$1,085	$400	37%	$1,488	Double the contingency.
17	Cryostat & Base Support Structure	$1,361	$489	$1,497	$564	38%	25%	$2,550	$1,497	$564	38%	$2,550	Design minimal--can't assess adequacy.
18	Field Period Assembly	$5,430	$5,540	$14,412	$5,262	37%	28%	$25,213	$14,412	$5,262	37%	$25,213	60% of the $6.4 M increase is due to extra steps identified in developing the Station 2 assembly process after the August review, with the remainder due to improved understanding resource needs, especially metrology and Title III support.
19	Stellarator Core Mgmt & Integration	$2,752	$2,317	$2,255	$894	40%	51%	$5,466	$2,255	$894	40%	$5,466	
2	Auxiliary Systems	$783	$348	$1,018	$235	23%	25%	$1,601	$1,018	$235	23%	$1,601	Accepted---Based on NSTX experience.
3	Diagnostics	$1,143	$1,131	$811	$98	12%	58%	$2,040	$811	$243	30%	$2,185	Concerned that contingency is insufficient---suggest 30%---primarily due to uncertainties associated with the e-beam field mapping system.
4	Electrical Power Systems	$3,301	$615	$2,718	$356	13%	18%	$3,690	$2,718	$356	13%	$3,690	Accepted---Based on NSTX experience by chief EE.
5	I&C Systems	$2,050	$33	$2,099	$267	13%	2%	$2,399	$2,099	$267	13%	$2,399	Accepted---Based on NSTX experience.
6	Facility Systems	$691	$24	$2,423	$985	41%	1%	$3,432	$2,423	$985	41%	$3,432	Accepted---Based on NSTX experience.
7	Test Cell Preparation & Machine Assembly	$4,413	$708	$8,577	$5,100	59%	8%	$14,384	$8,577	$5,100	59%	$14,384	Designs are in very early conceptual stages. This high contingency (according to the Project) is a result of relatively long schedule delays incurred by risk event remediation.
81	Project Management	$4,509	$4,025	$4,814	$2,100	44%	46%	$10,939	$4,814	$2,100	44%	$10,939	
82	Project Engineering	$4,885	$6,500	$7,608	$3,500	46%	46%	$17,607	$7,608	$3,500	46%	$17,607	
84	Project Physics	$470	$470		$0		100%	$470	$0	$0		$470	
85	Start-up	$1,189	$0	$795	$150	19%	0%	$945	$795	$150	19%	$945	
89	Allocations	$1,577	$1,792	$1,928	$610	32%	48%	$4,330	$1,928	$610	32%	$4,330	
	DCMA	$75	$75				100%	$75	$0	$0		$75	
	Contingency	$12,804											
	Total	**$92,401**	**$76,365**	**$61,814**	**$22,410**	**36.3%**	**55%**	**$160,589**	**$61,814**	**$22,759**	**37%**	**$160,938**	

APPENDIX E

SCHEDULE CHART

NCSX Summary Schedule

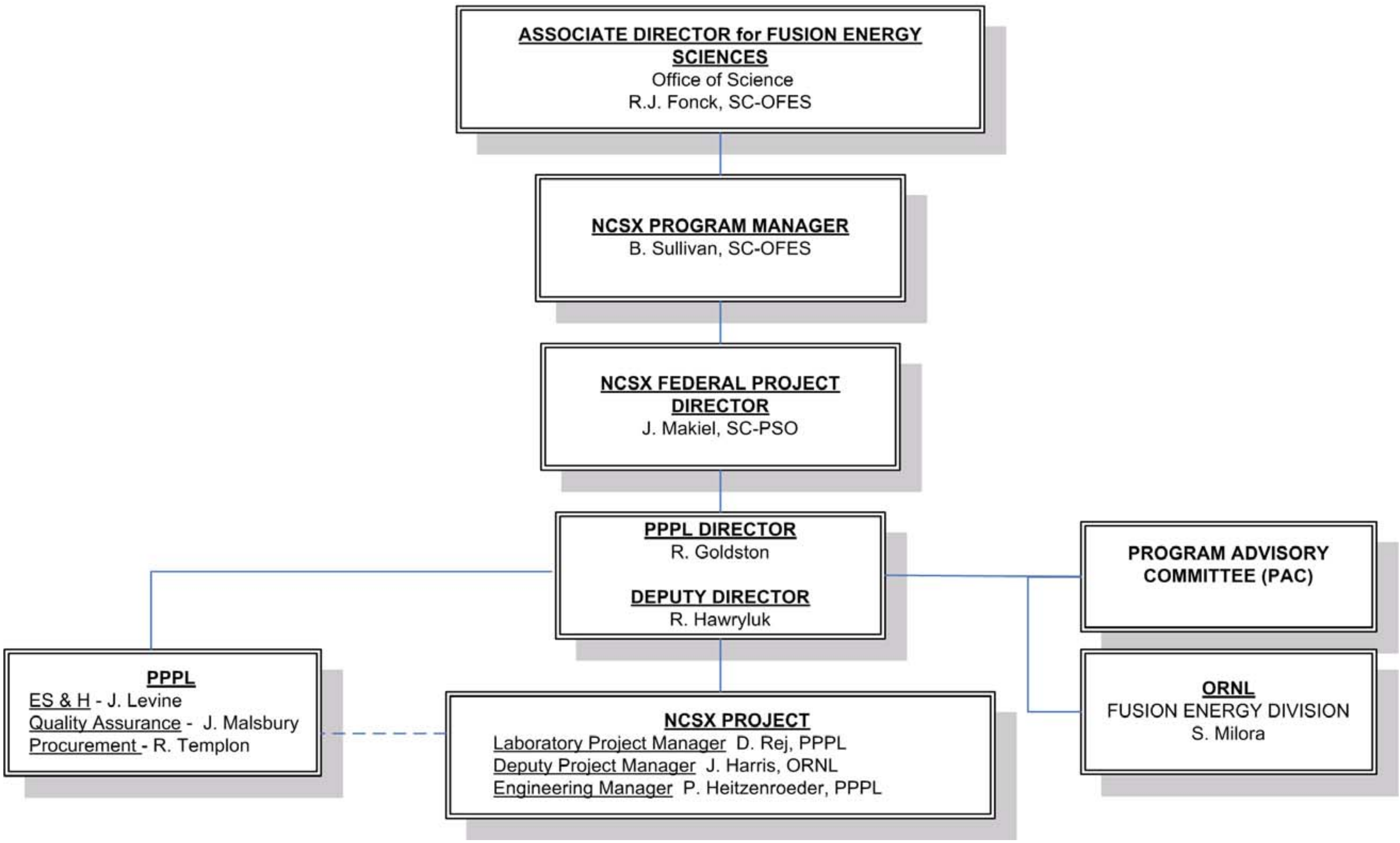


APPENDIX F

MANAGEMENT CHART

NCSX National Organization

March 2008



NCSX Project

April 2008