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CLOSEOUT REPORT

Department of Energy review of the

National Compact Stellarator Experiment (NCSX)

Princeton Plasma Physics Laboratory (PPPL)

Daniel Lehman, Chair
DOE/SC Review Committee
April 10, 2008
http://www.science.doe.gov/opa/

Charge Memorandum

1. Is the project's bottoms-up-estimate 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 as 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?

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Review Committee Participants

Daniel R. Lehman, Chairperson, DOE/SC

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

Report Outline/Writing Assignments

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Executive Summary .... Chao

1. Introduction .... Sullivan
2. Accomplishments to Date .... Sullivan
3. Remaining Technical Scope
    - 3.1 Stellarator Core (CQ 1, 2, and 5) .... Anderson*/Strauss/Nicol
        - 3.1.1 Findings
        - 3.2.1 Comments
        - 3.3.3 Recommendations
    - 3.2 Ancilliary/Auxiliary (CQ 1, 2, 3, and 5) .... McManamy*/Carter
    - 3.3 Final Assembly (CQ 1, 2, 3, and 5) .... Hurh*/Haines/Wells/Carter
4. Cost Estimate (CQ 1, 2, 3, and 5) .... Post*/Chao/Crescenzo
5. Schedule and Funding (CQ 1, 2, 3,and 5) .... Post*/Chao/Crescenzo
6. Management (CQ 4 and 5) .... Price*/ Meador/Crescenzo

*Lead

CQ-Charge Question

3.1 Stellarator Core (CQ 1,2, and 5)

Subcommittee Members:
David Anderson, Tom Nicol, Bruce Strauss

This subcommittee was tasked with evaluating the elements of the stellarator core comprising the vacuum vessel, modular coils, conventional coils (toroidal, poloidal, and trim), coil structures, coil services, and cryostat and base support structure. Subassembly and final machine assembly are discussed in Section 3.3

Vacuum Vessel

Findings:

•The three vacuum vessel sections, connecting spools and port extensions have been delivered.

•Addition of magnetic diagnostics and vessel bake-out tubes is well in hand

•Design is progressing well on the neutral beam extension ducts

•The estimate for completion of these subassemblies appears credible

Comments:
•Several of the bake-out tubes have been determined to have leaks. The project needs to understand the origin of these leaks and implications/mitigation during operations should these continue to develop

•Similar tubes may be used for coil services. The project should institute QA measures to preclude this failure

•Major risk/work in the vacuum vessel resides in assembly operations

•The project should ensure that viable leak checking is available at appropriate times during assembly and in operation

Recommendations: None

Modular Coils

Findings:

•16 of the 18 modular coils have been completed with the last two in process
•The majority of the risk in modular coil fabrication has been retired (assembly now key)
•The remaining budget for this WBS appears satisfactory

Comments:

•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

Recommendations: None

Conventional Coils

Findings:

•The toroidal field coils are well into production with ~50% delivered all within specification; production is proceeding at an acceptable pace

•The poloidal field coils are conventional circular coils. Acceptable bids have been received within the stated budget. Bidder evaluation in progress

•The project has included a set of 48 trim coils in response to the last 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; the budget appears adequate and their fabrication seems to impose minimal risk

•The committee feels that conventional coil procurement is well in hand and budget is adequate

Comments:

•The project is to be commended for the inclusion of the trim coil set

Recommendations: None

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Coil Structures

Findings:

•This element provides 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 WAF; 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

Comments:

•There were no presentations that covered detailed assembly of the base and coil support structures.

•In particular, 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

Recommendations:

•Ensure that adequate alignment capabilities exist within the supporting system and that metrology needs are accounted for to simplify assembly

Coil Services

Findings:

•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.

•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.

Comments:

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

•With 48 trim coils, 18 modular coils and the poloidal and toroidal field coil sets, significant interfaces and potential interferences exist within the cryostat; detail design is needed before space runs out.

•Flow control requirements need to be assessed with respect to allowed thermal variations in cool down and operation in the modular coils; not minimal cost

•Coil services needs high degree of integration with the cryostat and cryostat cooling

•The project has a good start on this element and we encourage support of this effort to the fullest extent possible.

Recommendations:

•Complete detailed engineering as soon as possible and ensure design is integrated with the balance of the stellarator core.

Cryostat and Base Support Structure

Findings:

•The cryostat design presented was ***preconceptual***
•No requirements list was presented
•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 base support is at a conceptual design phase. Details should ensure controlled positioning in all six degrees of freedom

Comments:
•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.
•An engineer has been assigned to address these designs full time. This is a good start and we encourage support of this effort to the fullest extent possible.
• We also encourage the use of outside consultants, personnel from other national labs, 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.

•We encourage looking at and addressing applicable DOE, ASME, and PPPL codes as they relate to pressure piping, and pressure and vacuum vessels required to operate the stellarator at PPPL.

Recommendations:

•Include failure modes and required safety measures in the engineering package

•Leverage cryogenic support in DoE laboratories and supported universities to accelerate development of requirements document and the detailed design.

General Recommendations:

- More engineering
- Integration issues (parts not whole)
- QA

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3.2 Ancillary/Auxiliary Systems

T. McManamy

H. Carter

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Systems Evaluated

- Auxiliary Systems
  - Torus Vacuum Pumping
  - Gas Fueling
- Diagnostics
- Electrical Power Systems
- I&C Systems
- Facility Systems
  - Vacuum Pump Water cooling
  - LN2/GN2 Cryogenic Supply systems
  - Utility Systems
  - VV heating/cooling systems

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Findings

- Total ETC for these elements –
  - $9069
  - $1941 contingency
- Detail Design for most of these systems is not scheduled to start until FY09 or later
- Most Ancillary systems require designs which are very similar to other experimental facilities installed at PPPL and rely heavily on components and experience from NSTX

Findings (2)

- There is a good basis for the estimate for most systems based on this experience despite the early design stage
  - Vacuum Systems
  - Gas injection fueling systems
  - Diagnostics (except for e-beam mapping)
  - Electrical Power Systems
  - Central I&C systems
  - Vessel bake-out system
  - Water utilities
- Cryogenic system is at pre-conceptual design level and requires further development to obtain a reliable cost and schedule estimate
- Diagnostics
  - Interface Document is under development
  - E-beam mapping development assumes collaboration with ORNL, Auburn University and the University of Wisconsin.

Comments

- Overall – no major "show stoppers"
- The detail design of the LN2 and GN2 cooling within the cryostat has the potential to impact the design of interfacing systems (addition of cooling plates, fans, etc)
  - The design needs to evaluate the potential for flow imbalances and the need for additional control valves
  - Safety and Failure modes and effects analyses need to be developed
- Diagnostic integration effort may require more than 10% of one physicist in order to facilitate installation

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Recommendations

- The detailed design of the cryogenic system should be advanced to identify any required changes to core components in time to prevent schedule delays
  - Add additional engineering resources with cryogenic experience
  - The CDR and other design reviews should include at least one independent external reviewer with relevant experience
  - The Cryogenic system should be included in overall system integration and evaluated as part of a comprehensive review of cryostat and core region

Recommendations (2)

- MOUs should be established with the Universities who will collaborate on the e-beam mapping system

Sub-Committee Members:
P. Hurh (FNAL)
J. Haines (ORNL)
H. Carter (FNAL)
R. Wells (LBNL)

Highlights of Findings/Comments

- 14 Findings *(will show 6)*
- 16 Comments *(will show 8)*
- 4 Recommendations *(will show 4)*

Findings

- WBS 18, Field Period Assembly, is 28% complete and has an EAC of $20.0 M, which represents an increase of $6.4 M compared to the EAC presented at the August 2007 review. Progress includes fit-up of the first two MC's (A1 & B1) into a mated pair with initial shim welds just completed.
- Approximately 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.

Findings

- Primarily because of these extra steps in the assembly process, the planned completion date for Field Period Assembly has been extended by 9 months compared to that presented at the August 2007 review.
- WBS 7, Test Cell Prep and Machine Assembly, is 8% complete and has an EAC of $9.4 M, which represents an increase of $0.4 M, based on additional scope, e.g. trim coil installation.

Findings

- Assembly space and technicians from the Modular Coil fabrication effort have begun the transition to the Field Period Assembly (FPA) effort.
- Leaks have been found in the helium gas lines on one Vacuum Vessel section. The Project will leak test 100% 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.

Comments

- The new remedy of welding shims in an interleaved fashion and holding spacing with "puck" spacers is promising but is still being validated. The sub-committee is less than 50% confident that the new remedy will satisfy the original tolerance requirements 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% that the new welding plan will achieve "acceptable" distortions.

Comments

- 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. Look ahead to identify problems already inherent in the existing individual component designs and address these “just in time”. 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 7 job managers

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Comments

- 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 tolerable damage versus complete dis-assembly and re-work). Some of these risks have mitigation plans that lack sufficient detail to make the sub-committee comfortable.

Comments

- WBS 7 shows a contingency of 59% 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 as reasonable. For instance Vacuum Vessel Welding (Stat6-16) has a critical path schedule impact of 4 months. Reduction of this impact through pre-engineering or mitigating down the probability of risk occurrence should reduce contingency requirements.

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Comments

- *(Comment applies to Project Integration)* The efforts to strengthen Project Integration appear to be working. 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.

Comments

- 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 WAF’s.

Comments

- *(Comment applies to Project Integration)* The possibility of high stresses and/or distortions to the components supported by the MCWF as a result of thermal gradients during cool down has not been adequately addressed.
- Filling the annular space between the vacuum vessel and the Modular Coils 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.

Recommendations

- Evaluate the risk of possible future failure of the Vacuum Vessel helium lines and develop mitigation plans as appropriate.
- Evaluate the risk of unsatisfactory vertical welds of half period assemblies in Station 3 and develop mitigation plans as appropriate.
- 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.

Recommendations

- Complete qualification 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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4.0 Cost

John Post--LLNL/NIF

Frank Crescenzo--DOE/BHSO

Kin Chao--DOE/SC

Findings - Cost

- Total Project Cost has grown from ~$142M in August to ~$171M in April.
- ETC increase of $29M is due to an increase in contingency of $8M and $21M in baseline costs, with some additional scope identification.
- Bottom-up estimate to complete presented at August 2007 Lehman review has been re-assessed and revised.

Comments - Cost

- Bottom-up estimate is yet to achieve acceptable credibility due to
  - Design maturity
  - Integration complexity
  - Evolving experience base
  - Risk events excluded from analysis

Findings - Risk Analysis

- Bounding conditions related to off-normal execution are excluded from the analysis
  - Funding Availability
  - Currently planned/projected state of PPPL operations/overheads (no significant change)
  - No extraordinary incidents, stand downs or lab shutdown
  - No change to CD-4 Completion Criteria
  - Specific risks with very low likelihood of occurrence but high impacts/consequences excluded

Findings - Risk Analysis (cont)

- Specific Risk items excluded:
  - Major technical events requiring disassembly of the machine or a field period.
  - Damage requiring re-fabrication of a coil. (But damage requiring re-work in accessible areas, e.g. cooling tubes and leads, is covered.)
  - Damage requiring major disassembly and reassembly of a field period. (But disassembly / reassembly of individual joints during assembly is covered.)
  - Failure of a key component or system during integrated system testing.
  - Large islands detected during e-beam mapping requiring extensive troubleshooting and remediation.
  - A quantitative risk assessment methodology has been implemented

Comments - Risk analysis

- Risk analysis and contingency calculation are yet to mature to a level that supports a rebaseline request
- Analysis assumes risk events are detected prior to impact
  - Cost and schedule associated with significant rework are precluded by base assumptions
- Implementation of a quantitative risk assessment is commendable

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5.0 Schedule

John Post--LLNL/NIF

Frank Crescenzo--DOE/BHSO

Kin Chao--DOE/SC

Findings - Schedule

- Proposed CD-4 date is August 2013
  - 4 year and 1 month slip over current baseline
  - Includes 19 months float from early finish date
- Critical path is through Stations 2,3,5, and 6 assembly and commissioning
- Several key design activities are yet to be completed

Comments - Schedule

- Funding profile is not optimal
- Consider prioritizing design completion over assembly and installation to close out risk register

Recommendations

- Peer review ("Red Team") of the proposed baseline by an independent panel

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6.0 Management

Frank Crescenzo, DOE-BHSO

Les Price, Consultant

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Findings

- There continues to be strong management support for the NCSX Project from the University, PPPL, ORNL and PSO.
- A new, experienced project manager was brought on board approximately 2 months ago.
- The committee was presented with a proposed baseline of **$170.2M TPC** with $22.4M contingency (36% of ETC) and 19 months of float within the **August 2013** completion date.
- The project believes the staff requirements for the remaining NCSX work in the proposed baseline is within the resources available at PPPL and ORNL.
- Overall, a substantial amount of design work remains, 32% or $6M.
- In addition to machine assembly, incomplete design and engineering are major factors in the proposed contingency.
- PPPL has developed a comprehensive risk management approach that is being used as a management tool.

Comments

- Relationships among all parties seem healthy with open communications.
- The new project manager is having positive impact, particularly in the areas of project management discipline.
- The University has made a positive impact on NCSX by bringing to bear experience from the particle physics/ large detector community.
- There has been continued good technical progress in building the machine.
- The project did not respond adequately to the previous recommendation to develop an alternate baseline for consideration based on "optimum" funding.

Comments, continued

- The amount of design remaining is unusually high for a project at this stage (4 years since CD-2 in February 04).
- The committee believes that completing design earlier would be beneficial in terms of reducing risks.
- The quality of the cost estimate would have been enhanced by a detailed, external independent review.
- Actions to strengthen systems integration should be continued.
- The project has not yet met the normal DOE expectations for a rebaselining action.

Recommendations

- Proceed with the project rebaselining process when the key engineering issues identified by the committee have been resolved.
- Submit to DOE by May 1, 2008, a plan for resolving those issues and resubmitting a rebaseline package.

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