Preliminary Design Review (PDR) Committee Report

for the

National Spherical Torus Experiment (NSTX) Upgrade Project

Princeton Plasma Physics Laboratory
Princeton, NJ

June 23-24, 2010

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1. Introduction

A Preliminary Design Review was held at the Princeton Plasma Physics Laboratory (PPPL) for the NSTX Upgrade Project on June 23-24, 2010 at the request of Dr. Michael D. Williams, Associate Laboratory Director, Engineering and Infrastructure. The purpose of the review was to assess the project's technical, cost, schedule, and ES&H status in preparation for the CD-2 milestone review to be held in July 2010. The committee was asked to review the NSTX center stack upgrade and the addition of a second neutral beam for plasma heating to assess whether:

- the general requirements have been addressed
- the risks have been appropriately identified and adequately addressed by the project plans
- there are any "show stoppers"
- the ES&H issues have been properly addressed
- the cost range is adequate and the proposed schedule realistic for this stage of the project
- the project organization and staffing is appropriate
- if the project is ready for CD-2.

The NSTX is the world's highest performance Spherical Torus (ST) research facility and is the centerpiece of the U.S. ST research program. Since starting operation in 1999, NSTX has established the attractiveness of the low-aspect-ratio tokamak ST concept characterized by strong intrinsic plasma shaping and enhanced stabilizing magnetic field line curvature. The purpose of the NSTX Center Stack Upgrade project is to expand the NSTX operational space and thereby the physics basis for next-step ST facilities.

The plasma aspect ratio (ratio of plasma major to minor radius) of the upgrade is increased to 1.5 from the original value of 1.26, which increases the cross sectional area of the center stack by a factor of ~ 3 and makes possible higher levels of performance and pulse duration. The project intends to replace the NSTX "center stack" in order to effectively double the magnetic field and plasma current (from 0.5T to l.0 T, and l.0 MA to 2.0 MA, respectively), increase the plasma pulse length (from nominally 1 second to 5 seconds), and add an additional neutral beam injector to effectively double the neutral beam heating power.

The NSTX Upgrade Project team presented to the review committee technical details of the center stack and magnet systems upgrade task including, TF, OH, PF coils, and structure modifications. They also presented detailed progress for the task of adding the second neutral beam, as well as an overview of ES&H issues. The project cost and schedule was presented and how it indicates their readiness for Critical Decision-2 (CD-2) as described in DOE order 413.3A. All presentations were very comprehensive in content, well organized, and professional in presentation, which allowed the committee to understand the complexity of the upgrade project and the supporting programmatic and administrative requirements. The presentations were supported by extensive project documentation provided to the committee including Work Approval Forms (WAFS), costs, and project schedule broken down by WBS, etc.

The committee was very impressed with the level of effort and comprehensiveness of the design effort to date, and commends the project management and team for their dedication to making this project a success. The committee appreciates the support given to the committee and the responsiveness of the project team during this review.

2. Summary of Response to the Charge

A summary of the review committee response to the charge is given below. Further details of committee report are given in the following sections.

1. Are ES&H issues properly addressed?

Yes, based on self-assessment (below). Committee didn't review thoroughly but is not aware of any information contrary to this conclusion. PPPL Health Physics Division will support compliance with occupational radiation exposure regulation (10CFR835) and DOE-approved PPPL Radiation Protection Program. Non-radiological hazards will be comparable to present NSTX operations. NSTX Failure Modes & Effects Analysis (FMEA) has been updated to include the Upgrades. Current radiation worker controls will be maintained post upgrade. The existing NSTX Safety Assessment Document (SAD) will be revised.

2. Have the requirements for the NSTX Upgrade Project, delineated in the General Requirements Documents (attached), been addressed? Is the scope of the project adequately and clearly described?

The GRD requirements have been specifically detailed in design point data spreadsheets. The project WBS has been updated. The project CD-4 performance baseline scope and demonstrated performance at completion are documented in the PEP, and approved by DOE.

3. Does the Preliminary Design Review satisfy the objectives of PPPL Procedure ENG□033, "Design Verification", Attachments 4 and 6, "Design Review Objectives and Input Documentation" and "Human Performance Improvement/Factors Considerations in Design Reviews"?

Many of the objectives of this Procedure for PDR were reviewed and are addressed in the other charge questions (e.g., requirements, supporting analyses, disposition of action items from previous reviews, FMEA, manufacturability, cost and schedule. Once consideration and disposition of this committee's recommendations are complete, The NSTX-U Project will have satisfied these objectives.

4. Have previous recommendations from prior reviews (CDR and Lehman) been adequately addressed?

Recommendations from previous design reviews are being tracked and dispositioned, but not all are complete as of the time of this review.

5. Have risks been appropriately identified? Yes Are project plans adequate to address/retire the identified risks? **Partially** *Are there any "show stoppers?"* **No**

A Risk Registry has been prepared and implemented for tracking all identified risks. Since CD-0, 10 risks have been retired and about 50 new ones have been added. A project review recommendation log tracks all open chits & recommendations from formal reviews. Risk mitigation plans appear to be reactionary after the risk event has occurred. Risk mitigation plans should be modified, where appropriate, to avoid or mitigate risk by proper prior R&D and/or analysis. Furthermore, consider adding "opportunities" to the registry, where cost reduction and schedule acceleration options can be encouraged, identified, considered, and implemented as appropriate. There are no apparent "show stoppers" at this stage.

6. Are the proposed cost and schedule estimates sufficiently defined to establish a performance baseline for CD-2? Are the proposed cost and schedule contingencies adequate for this stage (CD-2) of the project?

Yes. The proposed cost and schedule estimates are based on detailed analysis and management review conducted as a routine activity in the preparation and approval of the Work Authorization Form, WAF. These include contingency estimates that are included in the WAF. The engineers are requested to prepare cost and schedule estimates that are "center of the error bar". PPPL Standard estimating methodology provides format and process for capturing work scope, task, estimates, contingency, risks and uncertainties. These estimates are then subjected to review by Project Management, up to and including the Associate Director for Engineering and Infrastructure. Discussions with the Associate Director and the NSTX Upgrade Project Manager demonstrated that these estimates are indeed carefully prepared and extensively reviewed before they are signed and accepted as a *"contract*" between the engineer and the Project Office. The Team has identified four long lead-time items where the early placement of large procurements results in some significant savings. These require early program funding and, therefore, will require acceptance by DOE and PPPL to place these early contracts.

7. Given the current stage of the project, is the project's management structure and team appropriate, and are the plans to support the next phase of the project sufficient?

Yes. The NSTX Upgrade project organization has been established and key management positions are filled with experienced staff members, most of whom have demonstrated records of success in managing high-tech, first-of and one-of-a kind projects. The project is staffed with the necessary talents that will be needed for the next phase of the project. The organization brings together individuals with proven project leadership coupled with experienced technical experts in the fields of analysis, design, magnets, power systems, NB systems, I&C, and construction.

Staffing levels requirements for the entire project have been identified by staff category and compared with present staffing levels. For most job categories there are sufficient manpower resources, but job assignments will require close planning and monitoring by project management to assure availability and to avoid conflict with other laboratory programs.

8. Is the project ready for CD-2 per DOE Order 413.3A? Is the required documentation for this phase in order?

Yes, the project is ready for CD-2 with comments as noted in the Findings Section for CD-2 Requirements under Management, Cost and Schedule.

3. Technical Systems Evaluations

The following sections provide the findings, comments, and recommendations broken down for the major program elements of Center Stack Upgrade, Second Neutral Beam, and Management, Cost, and Schedule.

3.1 Center Stack Upgrade

Findings

A comprehensive amount of detailed design and technical analysis was presented for a PDR level review. It was clear that a significant amount of progress in the design has been achieved since the previous CD-1 review in October 2009. The major design issues are being addressed and design solutions are being pursued.

The Center Stack upgrade scope includes the following items:

- Inner TF bundle (centerstack)
- TF Flex bus
- OH coil
- Inner PF coils
- Enhance outer TF supports
- Enhance PF supports
- Reinforce umbrella structure
- New umbrella lids

The project team plans to fabricate the new TF inner leg bundle in-house and then wind the OH coil onto the TF legs via a removable slip plane which provides strain isolation between the two coils. The use of Aquapour^{TM} is a creative solution to isolating the two coil systems during fabrication and the review panel looks forward to the results of the R&D tests. The new TF coil flexible joint appears to be greatly improved from the previous version and has been developed since the CDR with a more comprehensive and consistent set of analysis. Brazing trials and tensile strength tests have commenced with more planned. The outer TF cage and PF supports have been developed further and greatly simplified in many areas. There is a location on the inner TF near the TF flags

where the temperature exceeds 100°C. The plan is to use conventional epoxy resin with a new undeveloped/untested primer for the TF.

The new vessel protective tiles are now radiatively cooled with no Grafoil ™ in the design with many proposed to be manufactured from 2 and 3-D CFC. The mechanical fastening scheme is still being developed.

The DPS is further developed with an algorithm-based scheme and the components needed to assemble have been identified. Many of the necessary algorithms are being developed as part of the stress analysis of the components.

The critical path now runs through the procurement of the tile material for the center stack, closely followed by the copper for the inner TF legs and its fabrication processes. Due to the new critical path, the project is planning to request early procurement of the material for both the tiles and TF legs.

The design of the tile system that commits the project to nearly $1M of CFC material needs further development prior to the procurement. The design of the inner TF also needs further development before early procurement of the material can proceed. However, further studies on the TF Flex are warranted to demonstrate the design meets the requirements.

Comments

There appear to be no show-stoppers in the chits. In-line braze joints in central solenoid conductor may be eliminated using the CONFORM™ continuous extrusion process presently being used by Luvata in Finland. If joints are kept, then careful NDT of the joints is needed.

The use of epoxy resin at 100°C requires appropriate testing of a primer system as few, if any, fusion magnets have ever been proposed using VPI epoxy resin operating at this temperature. If the primer is developed by CTD it needs to be tested in static and fatigue to demonstrate the shear bond strength between the insulation and the copper.

Friction stir welding seems a good solution for joining the flags to the wedges and the test results are needed for the CuCrZr bond joint.

The procurement of 2x plus 8 TF wedge material should be re-evaluated as a potential cost saving as weighed against the risk reduction to the project.

While we accept the proposal to accommodate the cycles of existing components using inspection of these components, the inspection plan needs to be clearly documented and placed in a PM program.

Heat loads in the divertor area develop high temperatures and a radiatively cooled scheme is proposed. The impact on operational scenarios needs to be examined more thoroughly to demonstrate the GRD is met.

The design of the tile and the attachment scheme needs additional development to reach a level sufficient to commit the project to a $1M early procurement. The requirements for design are not clearly defined (heat load profile, peaking factors on edges, allowable temperatures, dimensional tolerances, halo currents - both global and local). There is a potential cost savings opportunity available if graphite is considered for the bulk of the center stack tiles.

The machine cannot meet the design criteria under static-only loading cases. The current analysis only considers the fastest disruption case. The DLF may change with slower disruptions and these other load cases should be considered.

Error fields from the eddy current loop created by vacuum vessel patch for the new NB port were not been presented.

The two fixed point support clamps for PF4 and PF5 could create an n=2 perturbation and an evaluation assessing the effect should be performed

Develop a Manufacturing and Inspection Plan (MIP) that identifies the tests and hold points during manufacturing and assembly to ensure a successful completion.

Recommendations

Slip plane

Add a radial position restraint between the CS and TF to prevent excessive lateral motion during operation

Solenoid conductor braze joints

Finalize the manufacturing process for the CS conductor.

Design and manufacture of centre rod wedge conductors and flags

Ask Kabelmetal at Osnabruck, Germany, to quote for the extrusion of the wedges. They have previously made the wedges for MAST centre rod, which included the cooling channel inside the wedge, which reduces machining and soldering.

Add additional material to the copper alloy flag to reduce maximum temperatures and stresses. Re-assess the tensile hoop stress produced by thermal gradients in the wedges in this region.

Centre stack and solenoid insulation

Demonstrate the shear bond strength between the insulation and the copper by testing at 100°C and at room temperature.

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Structural Design

Define R&D goals, document, and carryout a supporting R&D program for all components and processes to support the design and its requirements and to reduce program risk

Tile Design
Define the requirements for the tile design. Continue development of the tile design to meet the requirements. Examine attachment schemes and experiences on other fusion devices.

3.2 Second Neutral Beam

Findings
The second neutral beam scope includes:

- Disassemble and evaluate a TFTR beamline
- Decontaminate the beamline and internal components
- Refurbish for reuse
- Relocate numerous diagnostic systems, work platforms, etc., to make room for beamline in the NSTX Test Cell
- Replace bay K, J ports with new design to accommodate beamline
- Move NB2 to the NSTX Test Cell
- Run services (power, water, cryo and controls)
- Improve armor for higher power induced by simultaneous beam operation

Decontamination efforts have made considerable progress, reducing radiation levels by one or two orders of magnitude in the last year. Safety was a top priority during the process, both in handling the radioactive by-products and assuring personnel safety. Having reached lower radiation levels and a point of diminishing returns, it is proposed that most beamline components can now be handled safely enough to allow disassembly and refurbishment efforts to commence. A Decon peer review concluded that the decontamination efforts are largely completed and the beamline can be used on NSTX with minimal impact.

Plans for supplying the additional beamline with necessary services are comprehensive, with installation routes identified, access platforms proposed, and test cell rearrangement included.

A plan for the movement of the decontaminated beamline into the NSTX test cell has been formulated and appears to be achievable without major modification of the test cell walls.

The beamline armor protection system monitoring has been improved, with the addition of two plasma current interlocks and post-shot monitoring of the armor thermocouples, although a real-time pyrometer system has not been added.

The proposed NB port modification is a significant alteration of the vacuum vessel structure, and has been improved to increase strength. Port modifications have grown to include the modification of Bay L, in order to accommodate a required modification of the MPTS line of sight.

Comments

The use of an existing old TFTR beamline and all the support systems it needs allows a significant upgrade of the NSTX device to double the power without introducing much of an element of risk.

Procedures for working on or in the NSTX vessel, beamlines, ion sources, and auxiliary equipment must continue to account for the possibility of tritium-contaminated components, as they do now. These procedures should remain in use indefinitely, as a risk of contamination is always present.

All chits from previous design reviews have not yet been completed, although they are being addressed.

The beam armor could possibly take a large influx of power in an off-normal event. A suggestion was made in one of the presentations that visual inspection of the armor may be necessary, and therefore a viewport might be desired. Such a port could also be used by a real-time monitor such as a pyrometer and thus would provide a real-time interlock capability for the beam system.

It was noted that more testing is needed to fully analyze the effects of a high power dump of beam energy onto the armor, and whether the cooling system can adequately reduce the temperature of the tiles before the next shot. The committee agrees.

Recommendations

It is understood why the second beamline controls and acquisition system will initially use CAMAC as one of its elements, but we strongly encourage the incorporation of replacement technology as soon as possible.

3.3 Management, Cost, and Schedule

Findings

Project Management

Excellent progress has been achieved since the CDR. It is evident that there is a strong project management team in place. A detailed resource-loaded schedule has been developed. It includes:

- 1950 tasks, 2631 links, 2631 individual resource loadings.
- Disciplined and uniform approach for all work through the use of Work Authorization Forms (WAFs).
    - the WAFS include scope, costs, basis of estimates, staffing, risk identification and uncertainty estimates for each work task.
    - a top-down review of each WAF has been performed by the Project Manager, PPPL Assoc. Director, and Dept Heads
    - This information forms the basis of the resource-loaded schedule

A detailed, near-term staffing plan has implemented through May 2010. The project and lab management relationship and communication with DOE continues to be very good. The Site Office is satisfied with Project performance at this stage. Communications with HQ are enabled by monthly IPT meetings and weekly PSO/PPPL Director's calls.

Risk Management

82 risk events have been identified, and several have been retired. Risk mitigation and acceptance has become part of the baseline plan. We note, however, that the risk mitigation plan tends to be passive rather then proactive. Mitigation in many cases is to deal with the issues after a risk event has occurred. The Risk Registry has minimal "opportunities" listed to reduce cost and/or accelerate schedule.

Cost Estimates

The Total Project Cost (TPC) is $89.3M for the unconstrained case, and $90.3M for the DOE budget profile guidance case specified at CD-1.

- $10.9M has been spent on engineering design to date
- The Estimate to Complete is $58.9M.
- Approximately 30 major procurements, totaling ~ $8M, have been identified with a quantitative basis of estimate.

A contingency estimate of $16.1M is based upon uncertainty estimates for each task, risk events, and schedule risk impacts.

The TPC estimate is nearing the CD-1 upper range

- This is consistent with needed 27% contingency
- There has been a $2.2M net increase since CD-1, principally from design maturity (e.g., CS design and installation, diagnostic relocation requirements, and PFC tile quotes).

•The funding guidance constrained schedule adds $1M to the TPC.

Schedule

Bottoms-up staffing estimates have been loaded into the Project schedule. The project finish (CD-4) for unconstrained funding profile (assuming CD-2/3a approval in Sep-2010) is Jan-2015, including 8 months schedule contingency. There exist 36 Level-2 milestones. The unconstrained schedule critical path would benefit from $1.7M of advanced program funding for long lead procurements (CD-3a). The constrained schedule would add 5 months.

Comments

The unconstrained budget profile will save money and time, and is close to the CD-1 guidance from DOE. The Dec-2009 Lehman Review Executive Summary recommendation to establish an NSTX-U project management advisory committee that meets regularly and reports to the PPPL Director, is somewhat similar to our

recommendation of a PU Advisory Committee.

The Job Managers are "owning" their Project assignments, as evidenced by the completed WAF. Their ability to communicate WAF content in a consistent manner will instill confidence at future project reviews.

Some risk mitigation strategies appear to be acceptance strategies, e.g., adding 2x into baseline cost/schedule, or planning to repair when risk materializes. Can one be more proactive, e.g., R&D, additional design/analysis, hold points?

Level-2 milestones are measurable and at about the right frequency to keep the project on track. Staffing levels appear to be at the appropriate level, and are being managed well. DOE Approval of critical procurements is vital to meeting the proposed schedule, to mitigate vendor delivery uncertainties, and to posture the project to the accelerate schedule.

Recommendations

The following recommendations should be completed before the upcoming Lehman Review.

1) As soon as possible ,but no later than 4 weeks before Lehman review, finalize the budget profile with DOE, and incorporate that profile into the project baseline.
2) Consider forming a single project management advisory committee that fulfills both recommendations from the Lehman review and the PU Advisory Board.
3) Assure that all Job Managers show ownership of their scope, cost, and schedule by communicating their WAF content and obligations at the next Lehman review.
4) Consider rolling up the basis of estimates at Lehman review, to help communicate project maturity and confidence level of the estimates.
5) Evaluate the current risk registry and attempt to take more pro-active mitigation strategies.
6) Consider changing the name "Risk Management" to a "Risk and Opportunity" Management, to encourage cost reduction ideas, integrated into the WAFs and registry.
7) Continue implementing the detailed forward-looking (3-6 months out) staffing plan at all times.
8) Continue to regularly communicate the benefits of executing an advance procurement plan associated with the proposed CD-3a. This will save money and reduce risks.

Findings for CD-2 Requirements

1) Establish Performance Baseline – Ready.
2) Update Project Execution Plan – Ready.
3) Employ Compliant Earned Value Management System – Ready for Validation.
4) Perform External Independent Cost Review – Aug Lehman Review.
5) Determine that QA Program is Acceptable & Being Applied – Not Reviewed.

6) Update Project Data Sheet – Not Reviewed.
7) Prepare Preliminary Design & Conduct Design Review – This Meeting.
8) Prepare Hazard Analysis Report – Not Reviewed.
9) Update Preliminary Security Vulnerability Assessment Report – Not Reviewed.
10) Acquisition Strategy – Approved by DOE and Not Reviewed.
11) Complete or Obtain Approval of Final NEPA Determination – Approved by DOE and Not Reviewed.

4. Appendices

3.4 Charge Letter

PRINCETON UNIVERSITY

Plasma Physics Laboratory
James Forrestal Campus
P.O. Box 451
Princeton, New Jersey 08543

April 16, 2010

Dr. Joseph Minervini
Massachusetts Institute of Technology
Plasma Fusion Center
Room NW22-129
77 Massachusetts Avenue, NW16
Cambridge, MA 02139

Dear Dr. Minervini,

The Princeton Plasma Physics Laboratory (PPPL) is planning a Preliminary Design Review for the NSTX Upgrade Project on June 23-24, 2010. We would be honored and grateful if you could agree to serve, again, as the Chairman of the Review Committee. Mr. Al von Halle of PPPL will be available to help you with the administrative aspects of this responsibility.

The Laboratory recently received CD-1 approval from DOE for this project signifying their approval of the selected design approach as well as the cost and schedule range. This approval allows us to perform the design work, which will result in a firm cost and schedule baseline. The next major milestone, CD-2, will establish a scope, cost, and schedule baseline from which the project will be measured against. The Preliminary Design Review will prepare us for this stage. Additional pertinent information will be provided prior to the review.

If you have any questions, please contact me (at 609-243-2866 or Williams@pppl.gov) or Ron Strykowsky (at 609-243-2674 or rstrykow@pppl.gov). Please let me know of your intentions by April 30, 2010.

Sincerely,

Michael D. Williams
Associate Laboratory Director
Engineering and Infrastructure

cc: A. Cohen
S. Prager
S. Smith (PU)
R. Strykowsky

3.5 PDR Charge

1. Are ES&H issues properly addressed?

2. Have the requirements for the NSTX Upgrade Project, delineated in the General Requirements Documents (attached), been addressed? Is the scope of the project adequately and clearly described?

3. Does the Preliminary Design Review satisfy the objectives of PPPL Procedure ENG-033, "Design Verification", Attachments 4 and 6, "Design Review Objectives and Input Documentation" and "Human Performance Improvement/Factors Considerations in Design Reviews" (attached)?

4. Have previous recommendations from prior reviews (CDR and Lehman) been adequately addressed?

5. Have risks been appropriately identified? Are project plans adequate to address/retire the identified risks? Are there any "show stoppers?"

6. Are the proposed cost and schedule estimates sufficiently defined to establish a performance baseline for CD-2? Are the proposed cost and schedule contingencies adequate for this stage (CD-2) of the project?

7. Given the current stage of the project, is the project's management structure and team appropriate, and are the plans to support the next phase of the project sufficient?

8. Is the project ready for CD-2 per DOE Order 413.3A? Is the required documentation for this phase in order?

3.6 Review Participants

PDR Committee:		
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3.7 Review Agenda

NSTX Upgrade Project
Preliminary Design Review
Agenda

Wednesday June 23

Time	Topic	Speaker	
8:00 AM	EXECUTIVE SESSION		0:30
8:30 AM	Welcoming Remarks and Introductions	Mike Williams	0:05
8:35 AM	Project Overview	Ron Strykowsky	0:20
8:55 AM	Center Stack Upgrade Overview and progress summary	Larry Dudek	0:20
9:15 AM	TF, OH and Inner PF Coils	Jim Chrzanowski	0:45
10:00 AM	TF Flex Joint and TF Bundle Stub	Tom Willard	0:20
10:20 AM	Vacuum Vessel & Supports structures	Mark Smith	0:15
10:35 AM	BREAK		0:15
10:50 AM	CS Plasma Facing Components	Kelsey Tresemer	0:10
11:00 AM	Center Stack Analysis Summary	Peter Titus	1:10
12:10 PM	Center Stack Upgrade Power and Controls	Raki Ramakrishnan	0:20
12:30 PM	LUNCH		1:00
1:30 PM	Coil Protection System	Neumeyer	0:15
1:45 PM	Neutral Beam Overview and progress summary (incl decon status)	Tim Stevenson	0:30
2:15 PM	Beamline Power and Controls	Tim Stevenson	0:20
2:35 PM	Beamline Duct and Vacuum Vessel Modifications	Tim Stevenson	0:30
3:05 PM	In-vessel Armor	Kelsey Tresemer	0:15
3:20 PM	Beamline Relocation and Services	Martin Denault	0:20
3:40 PM	Cost and Schedule & CD-2 Readiness	Ron Strykowsky	0:45
4:25 PM	EXECUTIVE SESSION		1:30
5:55 PM	Project debrief, questions and request for data & add'l materials		0:35
6:30 PM	Dinner		

Thursday June 24

8:00 AM	EXECUTIVE SESSION
8:30 AM	Breakout sessions & followup
11:30 AM	PREPARATION OF CLOSEOUT PRESENTATION BY REVIEWERS
2:30 PM	CLOSEOUT MEETING