NSTX Upgrade External Independent Review October 7 & 8th, 2010

Princeton Plasma Physics Laboratory

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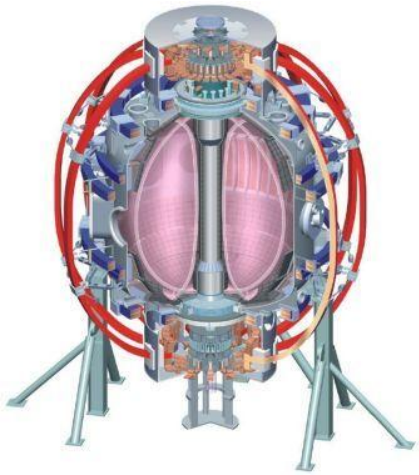

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Scope & Charge Questions

Scope

Center stack fabrication and assembly (WBS 1.1.3)
Field Installation and assembly (WBS 1.8)
CS Power Systems (WBS 1.5)
Neutral Beam (WBS 1.2.4)

Charge Questions

1) Have the scope and requirements been completely and clearly established?
2) Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?
3) Is the basis of contingency reasonable?
4) Have the appropriate technical, cost and schedule risks been identified?

Agenda

Thursday October 7th

8:00	Committee Caucus	Committee
8:30	Welcome/Project Overview	Ron Strykowsky
9:00	Center Stack Overview	Larry Dudek
9:45	Neutral Beam	Tim Stevenson
10:30	Break	
10:45 – 5:00	Breakout sessions	Committee & cogs
	Center stack fabrication (WBS1.1.3)	*Mike Cole & Jim Chrzanowski*
	Power Systems (WBS 1.5)	*Paul Bellomo & Raki Ramakrishnan*
	Field Installation (WBS 1.8)	*Michael Cowell & Mike Viola*
	Neutral Beam (WBS 1.2)	*Arnie Kellman, Joe Tooker & Tim Stevenson et al*
5:00	Tour	
5:30	Adjourn	

Friday October 8th

8:00	Breakout sessions
12:00	Committee Prepare Closeout Debrief
2:30	Debrief
3:00	Adjourn

External Independent Review– *Results*

	Center stack fabrication (WBS1.1.3)	Power Systems (WBS 1.5)	Field Installation (WBS 1.8)	Neutral Beam (WBS 1.2)
Targeted scope represents 70% of ETC →				
1. Have the scope and requirements been completely and clearly established?	*Yes*	*Yes*	*Yes*	*Yes*
2. Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?	*Yes*	*Yes*	*Yes*	*Yes*
3. Is the basis of contingency reasonable?	*Yes*	*Yes*	*Yes*	*Yes*
4. Have the appropriate technical, cost and schedule risks been identified?	*Yes*	*Yes*	*Yes*	*Yes*

External Independent Review– *Recommendations*

Date Ref	Review	Item	Concern/Recommendation	Responsibility / WBS or Job	Comment/Action
201010-01	October 2010 EIR	Rec-01	WBS 1.8-Maintain / advance design development so that down stream critical path activities (like WBS 1.8) can better define scope, activity detail and risks.	Strykowsky	Concur. Will factor in design maturation into the field ETC
201010-02	October 2010 EIR	Rec-02	WBS 1.8-EVMS Validation – start early	Strykowsky	Concur. Pre-Validation tasks begun. Procedures being updated, training scheduled for 10/27,EVMS statusing begun.
201010-03	October 2010 EIR	Rec-03	WBS 1.1.3-Review tooling cost for Center Stack assembly and revise if warranted.	Chrzanowski	Concur. WAF to be updated.
201010-04	October 2010 EIR	Rec-04	WBS 1.1.3-Consider having fewer reviews but longer durations	Strykowsky	Concur for the review under the project's control.. Future review will allocate sufficient time for more in-depth assessments.
201010-05	October 2010 EIR	Rec-05	WBS 1.5-Significantly more emphasis is needed in the design of a facility earth mesh (grounding) system. It is noted that the upgrade will increase power converter operating currents and magnetic fields. This is an opportunity to correct the observed deficiencies in the present system. The effort can be led by the Power Systems Job Manager, but must also include other disciplines as well.	Ramakrishnan	Disagree. Mesh grounding incompatible with Tokamak operation. . Tokamak grounding is a unique art/science, much different than accelerators. Single point grounding is essential. Separation of power and diagnostic grounds is the key feature to avoiding noise problems. On NSTX the complexity is compounded by the CHI requirement for biasing the inner and outer VV. Anyway it is true that we have multiple ground systems in the NSTX test cell but only the basic facility ground matters when people have access because all other sources are isolated prior to access. There is no safety issue. And, the rest of the facility, outside of the test cell, uses a highly meshed grid which is more per conventional practice and aligned with industrial standards. We are having a very safe facility with grounding installed as per IEEE standards - in operation for nearly three decades. Also in 1984 our grounding system was tested by an outside agency and declared to be in order. Single point grounding is a must. During the design of NCSX we had to remove the mesh to avoid loops - based on detailed analysis and calculations. How ever some changes to reduce noise is included in the

External Independent Review– *Recommendations (cont)*

Date Ref	Review	Item	Concern/Recommendation	Responsibility / WBS or Job	Comment/Action
201010-06	October 2010 EIR	Rec-06	WBS 1.5-Prior to (say one month before) the planned shutdown, as part of the ARR, all Job Managers must declare all materials are on hand, and account for them.	Ramakrishnan	Agree in principle. Will schedule within schedule priority and available funding. Sub-contract for installation will be awarded only after the receipt of all the materials
201010-07	October 2010 EIR	Rec-07	WBS 1.5-Because the installation is complex, prior to shutdown, identify an Installation Manager and imbue with full authority to manage the installation. During the installation phase all Job Managers report to the Installation Manager.	Ramakrishnan	Concur. The Upgrade project deputy project manager will be the construction coordinator. Work will be control daily via a work control center.
201010-08	October 2010 EIR	Rec-08	WBS 1.5-Include contingency quantities for components or equipment that are long lead, critical for the first plasma milestone, critical for subsequent operation on, and/or are one-of-a kind.	Ramakrishnan	The DC CLR for OH will be ordered giving sufficient time for delivery.
201010-09	October 2010 EIR	Rec-09	WBS 1.5-Permit Power System installation as soon as possible to minimize interferences, escalation of cost of materials, escalation of cost of labor.	Ramakrishnan	Agree in principle. Will schedule within schedule priority and available funding allowing ample free float. . Project Manager is requested to allow installation activities to begin six months earlier than currently planned.
201010-10	October 2010 EIR	Rec-10	WBS 1.5-Neutral Beam PS high voltage triaxial accel cable is special, long lead and has only one supplier. Suggest this be added to list of components to be purchased as soon as possible.	Ramakrishnan	Agree in principle. Will schedule within schedule priority and available funding allowing ample free float. Project Manager is requested to allow procurement of Triax to begin in January 2012
201010-11	October 2010 EIR	Rec-11	WBS 1.2.4-Beamline Services: review contingency applied to the installation tasks. Some runs are complicated routes that pass through congested areas which will impede access and likely increase time and effort to perform these tasks	Denault	Concur. Additional contingency will be added.
201010-12	October 2010 EIR	Rec-12	WBS 1.2.4-NBI Power Systems: review effort and contingency for reactivation of the power supplies. They have been mothballed for more than a decade and will not reawaken easily	Ramakrishnan	Concur. WAFs will be revised to reflect the comments
201010-13	October 2010 EIR	Rec-13	WBS 1.2.4-NBI Power Systems & Control: review and update the effort and durations for the subsystem testing and full system integration tests. First time that newly installed upgrades (those already in power supplies of NB1) plus reawakened subsystems have been fully restored to operation and likely to have issues	Ramakrishnan	Concur. WAFs will be revised to reflect the comments
201010-14	October 2010 EIR	Rec-14	WBS 1.2.4-NBI System: project is complete when 40 keV beam has been produced—effort to achieve this needs to be reviewed and likely updated; decision on where covered	Stevenson	Concur. a separate task will be added (probably in controls or in its own job) for commissioning, preoperational testing, and initial conditioning of 4ABC
201010-15	October 2010 EIR	Rec-15	WBS 1.2.4-NBI Duct & Vacuum Vessel Mods: procure rectangular bellows as early as possible to prevent this procurement from developing into a schedule issue	Priniski	Agree in principle. Will schedule within schedule priority and available funding allowing ample free float. The procurement schedule will be adjusted to allow for additional free float.

NSTX Upgrade Project
External Independent Review
Closeout report

Princeton Plasma Physics Laboratory
Director's Conference Room
October 7th & 8th, 2010

Mike Cole Oak Ridge National Lab

WBS 1.1.3 Center Stack Fabrication and Assembly

Charge Questions

1. **Have the scope and requirements been completely and clearly established?**

   yes

2. **Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?**

   yes

3. **Is the basis of contingency reasonable?**

   yes

4. **Have the appropriate technical, cost and schedule risks been identified?**

   yes

- **Findings**
  - Charging for Reviews is currently placed in the WBS 1.1.3. the reviewers understanding is that a specific number for charging for reviews is available.
  - The cost information for Center Stack tooling assembly appeared to be low. This should be reviewed to assure costing reflects the job scope.
  - The reviewer found that a 1 to 2 day review was challenging to learn the details of the project and comment on the cost and schedule. Detail information was provided early but interfacing with the design team was very informative. An additional day or 2 would have been very useful in drilling down deeper into the cost and schedule information.

- **Comments**

. Have the scope and requirements been completely and clearly established?

The General Requirements Document (GRD) is the basis for establishing the requirements. Additional engineering parameters were developed by Charlie Neumeyer. The COG and all those interviewed were knowledgeable and clear on the requirements.

Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?

Based on the information reviewed the cost and schedule information is credible and realistic.

Is the basis of contingency reasonable?

The contingency for the project is based on an approved process. This process was used to establish the contingency for WBS 1.1.3.

Have the appropriate technical, cost and schedule risks been identified?

The cost, schedule, and risk estimate seem reasonable based on the estimating process and a random check of the critical cost estimates appear reasonable at this stage of the project, however, a line by line detail analysis of 100's of task was not perfumed at this review. It is assumed that any anomaly could be covered under contingency.

- **Recommendations**
  - Review tooling cost for Center Stack assembly and revise if warranted.
  - Consider having fewer reviews but longer durations.

NSTX Upgrade Project
External Independent Review
Final Closeout Report

Princeton Plasma Physics Laboratory
Director's Conference Room
October 7th & 8th, 2010

Joe Tooker & Arnie Kellman
General Atomics

Neutral Beam WBS 1.2.4

Charge Questions

1. **Have the scope and requirements been completely and clearly established?**

2. **Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?**

3. **Is the basis of contingency reasonable?**

4. **Have the appropriate technical, cost and schedule risks been identified?**

Findings

- **NBI Sources: scope and effort for refurbishing three mores sources is well established and routinely performed for NSTX; level of contingency is reasonable**
- **NBI Relocation: scope and schedule of relocating beamline is well established; path and process is well thought through; cost & level of contingency is reasonable**
- **Beamline Decontamination: task is done (Beamline is "good to go"); few remaining items are well understood with a reasonable contingency**

Findings

- **NBI Beamline Refurbishment: scope and schedule of refurbishing the beamline are well established and should proceed well; cost & level of contingency is reasonable**
- **NBI Services: scope is well established; routing of services to relocated beamline are well developed; cost and level of contingency is reasonable for the most part; effort & contingency on installation needs to be reviewed**
- **NBI Armor: scope, cost, and schedule well established; level of contingency is reasonable**

Findings

- **NBI Power & Controls: scope, cost, schedule, & contingency of bringing three more power systems to the status of those for NB1 and the necessary upgrades are well established and should proceed well; reactivating the power systems and testing to be ready to resume source operations could likely require more effort than anticipated**

Findings

- **NBI Duct: scope and requirements are clearly established; design of vessel cap is well developed; testing of method to modify vacuum vessel yielding good results; cost and schedule are realistic to support baseline; level of contingencies are reasonable, especially on the few items that have higher percentages; procurement of rectangular bellows needs close attention**
- **Vacuum Pumping Systems: scope, cost, and schedule well established; level of contingency is reasonable**

Findings

- **NTC Equipment Removal/Relocation: scope and requirements are clearly established; procedures for removal & relocation of equipment are well developed and with proper care will proceed well; proposed baseline cost and schedule are realistic; balance of effort between removal and reinstallation seems appropriate; level of contingency is reasonable**

Comments

- **Reviewed a lot of detailed information in a short time—performed sanity check and looked for anything that stood out**
- **Discussion with NB personnel helped in gaining better understanding of scope of task and complication of working on a tritium contaminated system in comparison to similar tasks at DIII-D**
- **Installation of NB2 has more effort compared to that of NB1**
  - **NB1 was already in test cell and its location was only readjusted**
  - **NSTX was built with NB1 in place**
  - **NB1 never was operated with tritium**

Comments

- Working on, moving, and handling tritium contaminated beamline and sources has increased effort to perform tasks
- Installation of NB2 requires much more effort
  - Removal & relocation of equipment in NTC
  - Longer runs to extend services to NB2
  - Modification to vessel and new duct
  - Modifications to bring up to status of NB1
  - New work platforms

Comments

- **NBI staff is well experienced and has provided the input into the tasks – they've done the work before**
  - **Well defined scope of work**
  - **Credible estimates of cost and schedules**
  - **Overall low level of contingency**
  - **Higher level of contingency applied in appropriate areas**

Recommendations

- **Beamline Services: review contingency applied to the installation tasks**
  - **Some runs are complicated routes that pass through congested areas which will impede access and likely increase time and effort to perform these tasks**

Recommendations

- **NBI Power Systems: review effort and contingency for reactivation of the power supplies**
  - **They have been mothballed for more than a decade and will not reawaken easily**
- **NBI Power Systems & Control: review and update the effort and durations for the subsystem testing and full system integration tests**
  - **First time that newly installed upgrades (those already in power supplies of NB1) plus reawakened subsystems have been fully restored to operation and likely to have issues**

Recommendations

- **NBI System: project is complete when 40 keV beam has been produced—effort to achieve this needs to be reviewed and likely updated; decision on where covered**

Recommendations

- **NBI Duct & Vacuum Vessel Mods: procure rectangular bellows as early as possible to prevent this procurement from developing into a schedule issue**
  - **Vendor of bellows on NB1 (preferred choice) had a lot of problems fabricating it and is reluctant to do the second fabrication**
  - **Alternate vendors (both domestic and international) are being sought and will need to be qualified—this bellows is larger than their previous experience**
  - **In-house fabrication is being considered as a back-up—this will need effort to develop techniques and prove this capability**

NSTX Upgrade Project
External Independent Review
Closeout report

Princeton Plasma Physics Laboratory
Director's Conference Room
October 7th & 8th, 2010

Michael Cowell - BNL

WBS 1.8 – Field Installation and Assembly

Charge Questions

1. **Have the scope and requirements been completely and clearly established?**

   Yes

2. **Is the estimated cost and schedule basis credible and realistic to support establishment of a baseline?**

   Yes

3. **Is the basis of contingency reasonable?**

   Yes

4. **Have the appropriate technical, cost and schedule risks been identified?**

   Yes

- **Findings**
  - Staffing and Management of NSTX Upgrade Project is experienced, cohesive and qualified to execute the technical mission
  - Cost estimates, durations and risks are detailed and well documented as part of Work Approval Form (WAF) packages. They are credible and reasonable.
  - Although many activities within WBS 1.8 are not scheduled until FY2012-2013, durations are known based on historical and present maintenance durations that will be performed as baseline activities
  - Prove out/finalization of new designs are “real risks” to this and all WBS elements

- **Comments**

- Staffing and Management of NSTX Upgrade Project is experienced, cohesive and qualified to execute the technical mission
  - ✓ High level of experience demonstrated executing technical scope (i.e. not new technology or first-of-a-kind)
  - ✓ Good communication / relations with Site Office
  - ✓ Project Management 'best practices' demonstrated in Advance of EVMS Validation
    - o WBS is defined
    - o CAMs assigned (Job Managers)
    - o Resource loaded Schedule-basis of Budget at complete (BAC)
    - o Active risk management via risk registry (basis of contingency)
    - o Identified early risk mitigations/critical path accelerations (Advance procurements & fabrication activities)

- **Comments (cont)**
  - Maintaining CD Schedule will require close coordination
    - ✓ CD-2 (Nov 2010) – Based on EIR Findings
    - ✓ FDR (April 2011) – Design Complete
    - ✓ EVMS Validation – (June 2011)-new process (OPA not OECM) implementation of graded approach
    - ✓ CD-3 Approval – (July 2011)
    - ✓ Begin Outage- (April 2012)
  - Schedule is funding constrained- presents risks/opportunities
  - Cost estimates and risks are detailed and well documented as part of WAF package
    - ✓ (Assumption that rates and pricing are independently audited and certified)
    - ✓ Estimates and risks are owned by Job Managers – bottoms up estimating
    - ✓ Level of detail and Basis of estimate for WBS 1.8 is clear, easy to follow and based on previous PPPL experience

- **Comments (cont)**
  - Although many activities within WBS 1.8 are not scheduled until FY2012-2013, durations are known based on historical and present maintenance durations that will be performed as baseline activities
    - ✓ "Tail end" schedule risks being mitigated via coordination and input to design decisions
    - ✓ Some activities in WAF are contingent based on design/fit uncertainties
  - Prove out/finalization of new designs are "real risks" to WBS
    - ✓ Design- "details" being finalized, but comfortable with position relative to April FDR (per Neutral Beam Manager)
    - ✓ Design Maturity – rated "Low" (per WAF Job numbers 8200/8250)
    - ✓ Design Complexity – rated medium (Coil support system), high (Center stack) per WAF Job numbers 8200/8250

- **Recommendations**
  - ✓ Maintain / advance design development so that down stream critical path activities (like WBS 1.8) can better define scope, activity detail and risks.
  - ✓ EVMS Validation – start early

CLOSEOUT REPORT

NSTX UPGRADE REVIEW AT PPPL OCTOBER 7 - 8, 2010

WBS 1.5 POWER SYSTEMS

JOB MANAGER – MR. RAKI RAMAKRISHNAN

REVIEWER - PAUL BELLOMO

REVISION 0 – OCTOBER 14, 2010

NSTX UPGRADE REVIEW AT PPPL OCTOBER 7 - 8, 2010
WBS 1.5 POWER SYSTEMS CLOSEOUT REPORT, OCTOBER 14, 2010

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Appendices

1. REVIEW COMMITTEE CHARGE AND PPPL CONTACTS

1.1 Have Scope And Requirements Been Completely And Clearly Established?

1.1.1 Yes- the Power Systems Job Manager rigorously mapped the WBS 1.5 design scope and requirements from the General Requirements Document and other appropriate documents. Below is the Reviewer's interpretation of each Job.

Job 51, AC Power, involves the reinstatement of some experimental (not premises) AC circuits. The Job is relatively small in scope and the requirements are well defined.

Job 52, Reactivate Power Converters, involves the refurbishment of several existing, but currently non-operating, spare, power converters for deployment into the Toroidal Field system. This Job entails effort the Reviewer expects the maintenance staff presently and routinely perform. The Job is relatively small in scope and the requirements are well defined.

Job 53, TF DC Systems, involves changes to the Transition Area structure, terminating power cables, demolishing existing and erecting new enclosures for current limiting and smoothing reactors, and purchasing additional reactors. It also involves the removal of existing raceways and cable and the purchase and installation of new raceways and cables. This is a large and difficult Job, since the space needed for installation is extremely limited. However, the Job manager is well aware of the installation difficulties and risks associated with the reactor tasks, and the installation of very large and stiff 5kV insulated, 1000-kcmil cable, and containing raceways, in the severely constrained environment. The Reviewer identified some of the elements of this Job as risks in Section 1.4 of this Closeout Report.

Job 54, Control and Protection Systems, involves replacing the real-time power supply firing generators and feedback control with modern hardware (preferably using digital-based SCR gate firing generators), and replacing the existing power supply fault detectors with modern Programmable Logic Controllers (PLCs). Similarly, the existing 125VDC electrical interlock system, that mitigates the effects of inadvertent, accidental contact with exposed electrical conductors will be replaced with safer, low-voltage PLCs. The Job effort will augment and reconfigure the existing Kirk Key interlocks, needed to protect power system and other maintenance personnel when they actively and intimately work on machine electrical components or systems. The Job will upgrade or replace instrumentation associated with the power systems, in particular, the existing Rochester analog coil protection systems that serve as backups to the new Digital Coil Protection Systems.

Job 5008, Digital Coil Protection Systems, consists of a multivariate coil protection scheme. The system is new and ambitious, but does build, to a certain extent, on algorithms already employed on the current NTSX. The Job Manager has a good grasp of the Job scope and there is a plan for implementation that is already underway.

Job 55, System Design and Integration, entails WBS 1.5 system integration and the integration with other, external WBS elements by the Job Manager and other key individuals in Power Systems. It also includes costs for the Job Manager's time to manage the WBS 1.5 jobs, conduct or attend, design and status reviews. Lastly the Job provides time and costs associated with power system testing and commissioning.

1.2 Are Estimated Cost And Schedule Credible And Realistic To Support A Baseline?

1.2.1 Yes, the Reviewer believes the estimated costs for all WBS 1.5 Jobs are credible and realistic. Below are the cost estimates, which do not include contingency, and which might differ somewhat from the official project numbers.

Job 51, AC Power, $62k. This is a small, but important, job. The cost estimate and schedule for implementation are reasonable.

Job 52, Reactivate Power Converters, $48k. This is a small, but important, job. The cost estimate and schedule are reasonable.

Job 53, TF DC Systems, $1,650k. This is a very large job. Although the tasks in the Job are not technically complex, they are difficult from the standpoints of planning and installation. The Reviewer considers the cost estimate reasonable. Even considering the installation difficulties, the allotted time of 28 months (plus 8 months contingency) for installation is generous, but probably constrained by machine installation.

Job 54, Control and Protection Systems, $1,878k. This very large, expensive Job requires significant design, documentation, fabrication, and assembly. However, based on the discussion and the Reviewer's understanding of the tasks, the estimated cost is reasonable and the allotted time of 24 months (from now through April 2012) for design and purchase, is credible.

Job 5008, Digital Coil Protection System, $1,500k. This Job requires considerable design development. PPPL will mitigate the cost by building on their knowledge of similar, albeit less sophisticated systems. Furthermore, the assigned personnel are experts. This will facilitate the development. The cost estimate and schedule are reasonable.

Job 55 System Design and Integration, $670k. The Reviewer considers the cost estimate reasonable, and the eight months allotted time for component, subsystem, and integrated system testing generous

1.3 Is The Basis Of Contingency Reasonable?

1.3.1 Based on the magnitude and costs of the Jobs, and the furnished risk analysis (with good logic) the Reviewer's opinion is that the contingency is adequate for all Jobs, but they require tight management. The Reviewer considers the contingency for each job is appropriate based on the magnitude and difficulty associated with each job. Below are the contingencies, which might differ somewhat from the approved project values.

Job 51, AC Power, $62k, 10% contingency

Job 52, Reactivate Power Converters, $48k, 10% contingency

Job 53, TF DC Systems, $1,650k, 15% to 30% contingencies

Job 54, Control and Protection Systems, $1,878k, 20% contingencies

Job 5008, Digital Coil Protection Systems, $1,500k, 20% contingency

Job 55, System Design and Integration, $670k, 10% contingency

1.4 Have the appropriate technical, cost and schedule risks been identified?

1.4.1 The opinion of the Reviewer is yes, the Job Manager identified technical, cost, and schedule risks. The risk mitigations of cost and schedule contingency are adequate.

Job 51, AC Power, reactivate some experimental AC circuits and them bring up to Code is essentially a refurbishment task with very little technical, cost or schedule risk.

Job 52, Reactivate Power Converters, is essentially a refurbishment task with very little technical, cost or schedule risk.

Job 53, TF DC Systems. The risks here are the 1000kcmil cable copper cost, which is volatile and subject to market forces. This same concern applies to the new reactors, whether their windings are aluminum or copper. The Job Manager is aware of the installation difficulties associated with the tasks in this Job and applied adequate cost contingency. The schedule risk is minimal given the 28-month installation period, which is generous when the considering the WBS 1.5 scope in isolation.

Job 54, Control and Protection Systems, represents significant design efforts, but the identified personnel are experienced and the technology is new, but not first-of-a –kind. The major challenge here is to keep people on the task and not have them distracted. The Job manager is aware of this.

Job 5008, Digital Coil Protection Systems, require significant design effort, but identified personnel are experienced and experts. Although this task will employ new technology (hardware), the logic and algorithms represent advancements from similar, but less sophisticated systems already in place. Furthermore, there is a good development/implementation plan in place. This plan has the consensus of the design Team and management. Design and other work have already begun.

Job 55, System Design and Integration. A good portion of this task is level-of-effort project management. The risks associated with this effort are minimal. Even though problems are always uncovered during integrated system testing (that is the purpose of doing the testing in the first place), the system testing costs, and schedule appear adequate.

1.5 PPPL Contacts and Acknowledgements

1.5.1 PPPL's Mr. Raki Ramakrishnan (the Job Manager) prepared the bulk of the WBS 1.5 review material. The Job Manager presented strong and well-developed plans. The Reviewer felt the overall presentation was well prepared. PPPL's Messrs Charlie Neumeyer and Bob Woolley provided supplemental descriptions and technical data about the Digital Coil Protection System (DCPS). All of them did a commendable job. They made the Reviewer's task easy.

2. FINDINGS

2.1 The WBS 1.5 Team

2.1.1 Power Systems and associated control systems personnel are experienced. The Team is adequate and consists of six engineers, six technicians, and two designers. The Reviewer considers this quantity of engineer and technician personnel adequate. The Reviewer thinks the designer quantity is light, but also feels PPPL can augment the designer quantity rather quickly by subcontractors, if needed. The Reviewer bases the staff adequacy finding on management assurances that the NSTX project is, and will be, top priority, regardless of any present or future PPPL projects. This is acutely true for the engineers that will be designing the coil protection systems. A disruption of their efforts can play havoc with the schedule.

2.2 Tasks

2.2.1 Several control and instrumentation replacement tasks require replacing twenty-year-old equipment. This requires significant design effort. However, although the technology (hardware primarily) will be new, the control methods and algorithms will be based on existing concepts. This mitigates the difficulty.

2.3 Installation

2.3.1 The Power Systems installation effort is dependent upon the complex installation of the machine effort. There undoubtedly will be interferences that will require negotiation among parties and technical solutions. The installation effort will require a strong central manger and the installation sequence carefully planned.

3. COMMENTS

3.1 Grounding

3.1.1 The present NSTX facility earth mesh (grounding) adequacy is questionable. The Reviewer observed two or more separate (facility and diagnostic) grounding systems under the vessel. There was a verbal report from a PPPL employee and physical evidence of EMI noise affecting diagnostics and instrumentation. There appears to be a conscious attempt to employ a single-point ground approach (isolated tray sections, no bonding, etc). Under the facility earth mesh (FEM) concept (see the Recommendations later in this Closeout Report) the cable trays would be bonded and form an essential part of a fine mesh.

3.2 Contingency Parts

3.2.1 The review revealed no budget or effort evident to mitigate the effect of losses, misplacements, or failures of critical components or equipment on the "first plasma" milestone.

3.3 Arc Flash Analysis

3.3.1 Not enough emphasis is evident regarding arc flash analysis and labeling.

Post-review note: *In an October 12, 2010 email, the WBS 1.5 Job manager sent the Reviewer a list of the AC premises equipment analyzed and labeled for the arc flash hazard. This alleviates Reviewer's concern, but since the power conversion equipment itself is presumably unanalyzed and unlabeled, maintenance, or other personnel, must adopt the higher category PPE associated with the upstream AC feeders when servicing power conversion equipment.*

3.4 NRTL Certification

3.4.1 Not enough emphasis was evident regarding the requirement for Nationally Recognized Testing Laboratory (NRTL) or PPPL certified purchased and re-purposed equipment. NFPA 70E-2009, Article 350-6 specifically requires listing of all electrical, electronic, and electromechanical equipment by a Nationally Recognized Testing Laboratory or certified safe for use by the local Authority Having Jurisdiction (AHJ), which is PPPL, prior to use.

4. REVIEWER RECOMMENDATIONS

4.1 Adopt Facility Earth Mesh (FEM) Grounding

4.1.1 Reviewer feels strongly the separate, single-point grounding systems currently in evidence and described by NSTX personnel might prove unsafe[1] and will be noisy. It will be difficult, expensive, and frustrating to correct an improperly designed and installed grounding system after machine commissioning. Reviewer recommends PPPL combine all the Safety, Power, Control, RF and Diagnostic system grounds into one, common, properly designed, quiet grounding system. Reviewers urge PPPL adoption of a single Facility Earth Mesh concept. A properly designed system consists of a mesh fine enough to present a low-impedance to the highest expected operating and noise frequencies.

4.1.2 Other facilities have attempted separate ground systems without success. Separate ground systems are difficult to achieve and are confusing. Furthermore, separate ground systems pose personnel safety hazards. Reviewer strongly urges a change in concept. There should be one common FEM system. The Reviewer lists some design criteria here.

- The ground system should be capable of limiting step and touch potentials to < 50V (generally accepted international threshold for safe/hazardous voltage) for personnel safety.
- The ground mesh should be fine enough to accommodate the highest RF frequencies.
- In general, ground loops are undesirable and are unavoidable. However, you can make loop areas small so as not to pose problems.
- The Job manager is requiring the use of differential and common mode noise filters in the input and output filter lines of new power supplies. This is a positive step. Any retrofitted or re-purposed power supplies should include these filters.
- The Reviewer endorses the use of covered cable trays as a means of attenuating generated EMI. Of course, cable sizes will have to increase to accommodate the higher conductor temperatures resulting from reduced cable tray ventilation.

4.1.3 The upgrade of the NSTX represents an opportunity to incorporate a grounding system (Facility Earth Mesh) that will provide both personnel safety and immunity to electromagnetic interference (EMI). The Reviewer noted the NSTX upgrade would increase power converter operating currents and magnetic fields. This is another motivation to improve upon and correct any deficiencies in the present system. Adoption of an appropriate FEM is not expensive (the cost would roughly add approximately $200k to the upgrade cost) if correctly implemented as part of the design and installation efforts. Corrections after the machine assembly would be much more expensive (> $200k), so it is important to get it right now. PPPL needs to decide soon.

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[1] *The Reviewer did NOT observe any imminent hazard during the tour of the NSTX. Furthermore, the Reviewer believes the PPPL safety groups have inspected and certified the system as safe; the machine is de-energized prior to personnel access to equipment or components containing exposed electrical conductors, and it has been operating for several years without incident. Another safety "enhancement" is the fact that, in practice, it is almost impossible to construct grounding systems that are truly isolated. Distinctions between the separate systems become blurred. Compromises most always occur.*

4.1.4 Prior to any PPPL decision regarding the grounding, the Reviewer suggests the Job Manager contact Mr. Keith Armstrong in the UK. Mr. Armstrong is absolutely the authority in this field and his email address is cherryclough@aol.com. His website is at www.cherryclough.com. Mr. Armstrong could come to PPPL to look the situation, confirm, or dismiss this recommendation, and if necessary provide his own recommendations for implementation.

Post-review note: *The ITER project recently engaged Mr. Armstrong as the FEM (grounding) consultant. The project invited Mr. Armstrong to speak at a conference in France from November 30 – December 1, 2010. This is an opportunity for the PPPL ITER representative(s) to listen and speak to Mr. Armstrong.*

Post-review note: *The Reviewer sent by email to the Job Manager, a presentation given at a June 2010 CERN Power Conversion conference and a report of recommendations to solve problems on the Australian Synchrotron Light Source. These documents (appended to this Closeout Report) provide information and justifications relative to FEM systems.*

Post-review note: *The Reviewer received and has read the following papers provide by the Job Manager:*

- *AC Power and Grounding for TFTR Diagnostic Systems, circa 1986*
- *TFTR Grounding System, paper for unknown conference, date unknown*
- *Electrical Grounding System TFTR Neutral Beam Power Supply*
- *TPX Grounding for Equipment and Personnel Safety*

After reading the above documents, the Reviewer concedes the NSTX Upgrade will present unique magnetic fields, conditions, and challenges relative to the particle accelerators for which the Reviewer has experience. Furthermore, the Reviewer recognizes, and is aware of, the unique and special experience, talents, and knowledge of the NSTX personnel. On the other hand, the Reviewer also strongly feels the philosophy and physics of an integrated, low-impedance FEM for personnel safety and low EMI remained unchanged, regardless of machine type or configuration. The recommendations in this Closeout Report remain unchanged.

4.1.5 The Power Systems Job Manager is an appropriate and logical person to lead the FEM effort, since the power converters that generate the coil magnetic fields and generate significant EMI as part of normal thyristor on/off switching. However, there will be noisy equipment in the systems of other disciplines and their leaders must contribute to the effort.

4.2 Certify All Electrical Equipment Prior To Use

NFPA 70E-2009, Article 350-6 specifically requires listing of all electrical, electronic, and electromechanical equipment by a Nationally Recognized Testing Laboratory or certified safe for use by the local Authority Having Jurisdiction (AHJ), which is PPPL, prior to use. In the 2009 edition, the NFPA makes clear that the requirement is applicable to laboratories and R&D facilities. It requires listing of all electrical equipment by a Nationally Recognized Testing laboratory (NRTL) prior to use. If not listed, then PPPL, as the Authority Having Jurisdiction must certify it as safe (even if this means making corrections to the equipment) The Reviewer recommends PPPL compliance with this requirement. The SLAC National Accelerator Laboratory (and other National Laboratories) has some experience in this area and can provide guidance upon request.

4.3 Develop Detailed, Comprehensive and Integrated Installation Plans

4.3.1 Because the installation is complex, prior to shutdown, the Job Manager must prepare detailed demolition, installation, and commissioning plans and schedules. The Job manager must integrate all subsystem plans and schedules and link them all together, as integration is a key ingredient for success.

4.3.2 The Job Manager must hold regularly scheduled meetings with the Power Systems Team to communicate progress, and resolve conflicts or other problems.

4.3.3 Prior to (say one month before) the planned shutdown, as part of the readiness review, the Job Manager must declare all materials and components needed for installation are on hand, and account for them.

4.3.4 System integration requires a lot of communication between technical groups. The Reviewer suggests the Job Manager have as many systems built and bench tested as soon as possible to minimize the time and maximize the success of the integration of magnets, power supplies, controls, utilities, etc.

4.3.5 Consider the use of 3-D CAD tools, like Solid Edge to design and integrate the layout of NSTX cell mechanical and electrical cable and raceway systems prior to installation to reduce the number of physical interferences during installation.

4.4 Include Purchase of Contingency Components and Equipment

4.4.1 Include contingency quantities for components or equipment that are long lead, critical for the first plasma milestone, critical for subsequent operation on, and/or are one-of-a kind. Regardless of whether the cost contingency accommodates inclusion of these items, or they require additional budget, they must be included in the initial equipment purchases.

4.5 Purchase NBPS HV Cable Soon

4.5.1 Although not a part of WBS 1.5, Neutral Beam PS high voltage triaxial accel cable is special, long lead and has only one supplier. Suggest adding this to list of components for priority purchase.

4.6 Early As Possible Power System Installation

4.6.1 Permit Power System installation as soon as possible to minimize interferences, escalation of cost of materials, escalation of cost of labor.

4.7 Safety

4.7.1 Although not a safety review, nevertheless, for a project of the scale of the NSTX upgrade to succeed without injury, a comprehensive and detailed safety plan is essential. The plan should address work planning and control, and the safety hazards and their mitigations. Some mitigation steps include lock and tag procedures, the use of personal protective equipment (PPE), and removal of hazardous energy from all equipment before demolition. This energy includes the energy stored in capacitors, inductors, springs, compressed gases and liquids, hot and cold temperatures, etc. Adopt a comprehensive Control of Hazardous Energy (CoHE) Program as soon as possible. An excellent guide for electrical work safety and PPE requirements is the American National Fire Protection Association (NFPA) Standard NFPA 70E, “Standard for Electrical safety in the Workplace”.

5. TOURS

5.1 NSTX Cell and FCPC Buildings

5.1.1 The Reviewer toured the NSTX Cell and the Field Coil Power Conversion Buildings to obtain a sense of the magnitude of the NSTX Upgrade and the associated difficulties. Several members of NSTX management and the WBS 1.5 Job Manager hosted the tours. The tours were extremely valuable and essential, considering the brief time allotted for the review.

6. CONCLUDING REMARKS

6.1 Conclusions

6.1.1 The Reviewer was impressed with NSTX upgrade progress and presentation personnel. The Reviewer feels that PPPL is currently on track to realize a successful design and installation, if detailed planning is as good as the conceptual plans. Because of the rather large and complex NSTX upgrade work scope, limited review time, and lack of familiarity with the NSTX, the Reviewer cannot say with complete certainty that PPPL has covered all contingencies. However, the overall impression at this time is the WBS 1.5 technical scope, estimated cost, schedule, and contingencies are adequate and are on target.

6.1.2 The Reviewer strongly believes the WBS 1.5 Team is experienced knowledgeable, energetic, and technically strong. The Team possesses the ability to plan and potentially carry out such an ambitious undertaking.

6.1.3 The Reviewer wishes PPPL good luck and hope to have contributed, even if in a small way, to the eventual NSTX Upgrade success.