Office of Project Assessment
CD-4 Review Report on the

National Spherical Torus Experiment (NSTX) Upgrade Project

at Princeton Plasma Physics Laboratory

September 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the National Spherical Tokomak Experiment Upgrade (NSTX-U) project was conducted on September 2, 2015 at the Princeton Plasma Physics Laboratory (PPPL). The review was conducted by the Office of Project Assessment (OPA), and chaired by Kin Chao. The purpose of this review was to determine whether the NSTX-U project has fulfilled the requirements for Critical Decision 4 (CD-4), Project Completion, and is ready for CD-4 approval by the Project Management Executive (PME). Overall, the Committee supported NSTX-U proceeding to CD-4 after the Committee's recommendations that are required to be addressed prior to CD-4 are completed.

Technical

All elements of the technical scope have been accomplished. This includes the verification that all Key Performance Parameters were met, including the following: plasma current operation above 50 kA (140 kA achieved) and Neutral Beam operation at 40 kV for 50 msec (45 kV, 100 msec achieved). The project experienced two major technical upsets (Aquapour and Ohmic Heating arc event), which resulted in reviews by both a PPPL panel and an external panels. All recommendations made by those panels have been implemented by the project team. Regarding the remaining Aquapour in the Centerstack assembly, an analysis of the Operational Plan was conducted that indicates there will not be a significant impact to machine performance. Key elements of transition planning appear to be well developed, although they have not been integrated into a single, formal document.

Cost and Schedule

The project team is forecasting an estimate-at-complete (EAC) of $93.6 million; this includes a $100K estimate for August and September. All costs directly related to the project appear to have been captured, including the repair costs associated with the Ohmic Heating (OH) arc event. Of the $17 million in contingency approved at CD-2, $17.1 million was needed for cost overruns, $0.5 million for the mitigation of the OH arc event, $3.5 million was returned to contingency as a result of over estimates, and $2.3 million was used for scope enhancements. This has resulted in $0.6 million in contingency available for use by the Fusion Energy Sciences (FES) program.

Regarding schedule contingency, nearly all of the 12 months was required to successfully complete the project. In addition, the project was also dependent on the 6 months gained in the beginning of the project, but not included in the baseline, because of a NSTX machine failure.

Additional information should be included into the Lessons Learned document. For example, the large use of contingency on the Center Stack assembly and fabrication, which doubled from $13.5 million to $26.7 million.

Management

Throughout the upgrade the project team was very professional and did an excellent job of

addressing the full range of technical challenges. Safety performance throughout the project was very good given scope and nature of work, duration, and work environment.

The draft project closeout report is adequate, but should be improved by adding a comprehensive, yet succinct project narrative as the executive summary. Furthermore, a strong technical edit of the entire report should be conducted after all improvements have been incorporated. Lessons learned should be revisited to incorporate all key lessons and to make them more reader-friendly. The project team needs to translate existing transition to operations planning into a formal Project Transition to Operations Plan.

Key Recommendations

Prior to CD-4 ESAAB

- Prepare a formal Transition to Operations Plan.
- Ensure all CD-4 prerequisite documents are appropriately integrated and updated.
- Request approval of CD-4 when Committee recommendations are complete.

Post CD-4 ESSAB

- Address deuterium explosion hazard in vessel in the Safety Analysis Document. Evaluate whether it needs to be added to the Safety Envelope and the Summary on Maximum Credible Incidents.
- Implement Item #6 in Aquapour Operational Impact Review—modify PLC to handle failure of Toroidal Field Coil cooling.
- Continue to make the project's lessons learned documentation more complete and reader-friendly (Final Project Closeout Report).

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1. INTRODUCTION

The mission of the National Spherical Torus Experiment (NSTX) program is to explore the properties of compact and high normalized pressure spherical torus (ST) magnetic fusion plasmas. The compact and accessible ST configuration is potentially advantageous for the development of fusion energy and also broadens and improves the scientific understanding of plasma confinement at the ITER project. The plasma confinement capability, and the achievable plasma temperature, scale strongly with plasma current in the tokamak and the ST. Plasma current in the range of 1 MA (million amperes) is required to access plasma temperatures needed to understand ST physics under fusion-relevant conditions. The only existing Department of Energy (DOE) facility capable of producing MA-class ST plasmas is the NSTX facility.

The ST shares many features in common with the conventional tokamak, but several important differences have also been identified—for example the scaling of turbulent energy transport with the frequency of inter-particle collisions. Understanding the causes of these differences is important not only to ST research, but also for developing a predictive capability for magnetic confinement generally. The new Center Stack (CS) would double the NSTX toroidal magnetic field (TF) to 1 Tesla and enable a doubling of the maximum plasma current to 2 MA for the first time in STs. The Center Stack Upgrade (CSU) combined with the installation of a second Neutral Beam Injection (NBI) will enable operation at higher magnetic field, current, and plasma temperature, thereby reducing the plasma collisionality to values substantially closer to those projected for next-step ST facilities and for ITER. Access to reduced collisionality will extend the plasma physics understanding of the ST and aid in the development of predictive capability for plasma confinement. Further, controllable fully-non-inductive-current-sustainment is predicted to be provided by the second NBI, and would enable tests of the potential for steady-state.

The ST operation will contribute to assessing the ST as a cost-effective path to fusion energy. The ST is particularly well suited to provide a cost effective test-bed to bridge several gaps from successful ITER operations to a demonstration fusion power plant (demo) as identified in the Fusion Energy Sciences Advisory Committee (FESAC) report issued October 2007 and entitled, "Priorities, Gaps and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy". More recently, in November 2008, the "Report of the FESAC Toroidal Alternates Panel" also found that the ST offers the potential for an attractive test facility for developing fusion components. Upgrading the NSTX facility could significantly narrow or close capability gaps identified above. In support of these upgrades, the NSTX collaborative research team developed its Five Year Program Plan for 2009-2013, which was favorably peer reviewed and strongly endorsed during the DOE/Office of Science (SC) review conducted July 28-31, 2008. The Review Committee specifically endorsed the NSTX Upgrade plans, which form the central elements of the NSTX Five-Year Program Plan.

2. TECHNICAL

2.1 Findings

All elements of the technical scope as defined in the Project Execution Plan and the Key Performance Parameters required for satisfaction of CD-4 have been accomplished, including plasma current operation above 50 kA (140 kA achieved) and NB operation at 40 kV for 50 msec (45 kV, 100 msec achieved).

CAMs have signed off the completion of all technical WBS elements. With one exception, all action items from all reviews have been completed. Both major technical upsets (Aquapour and OH arc) were reviewed by both internal and external panels and recommendations followed.

2.2 Comments

The project has done an excellent job of addressing the full range of technical challenges and has addressed problems in a professional manner.

Key elements of transition planning appear to be well developed, although they have not been integrated into a single, formal document.

Analysis of the Operational plan to mitigate the remaining Aquapour indicates there will not be a significant impact on machine performance.

There is an on-going effort to commission key sensors and validate key engineering analysis as NSTX-U moves towards full parameters. This effort should continue and be managed with higher visibility and reviewed periodically to maintain focus.

Firm up development of inspection and maintenance plan (e.g. critical welds, bolt torques, joint resistance, etc.) with defined intervals and integrate into rollover schedule.

Additional discussion should be included in Lessons Learned concerning the large use of contingency on the Center Stack assembly and fabrication.

The process of Operations group review of XP's should be formalized.

2.3 Recommendation s

1. Address D_2 explosion hazard in vessel in the Safety Assessment Document (SAD). Evaluate whether it needs to be added to the Safety Envelope and the Summary on Maximum Credible Incidents (after CD-4).

2. Implement Item #6 in Aquapour Operational Impact Review—Modify PLC to handle failure of TF cooling (after CD-4).

3. COST and SCHEDULE

3.1 Findings

PROJECT STATUS: CD-4		
Project Type	MIE	
CD-1	Planned: Dec 09	Actual: Apr 10
CD-2	Planned: Jan 11	Actual: Dec 10
CD-3	Planned: Jan 12	Actual: Dec 11
CD-4	Planned: Sep 15	Actual: Sep 15 (F)
TPC Percent Complete	Planned: 100%	Actual: 99.9%
TPC Cost to Date	$93.6M	
TPC Committed to Date	$93.6M	
TPC	$94.3M	
TEC	$80.2M	
Contingency Cost (w/Mgmt Reserve)	$ 600K	600% to go
Contingency Schedule on CD-4	0.5 months	100%
CPI Cumulative	0.95	
SPI Cumulative	1.00	

The NSTX Upgrade project EAC is $93.6 million and includes a cost estimate of $100K per month for August and September activities.

The NSTX Upgrade TPC is $94.3 million.

At CD-2, the cost contingency of $17.0 million was comprised of three elements:

- Task-by-task activity assessment for unknowns and uncertainties,
- Weighted assessment of tabulated risk events, and
- Standing army costs related to project schedule contingency.

Of the $17 million cost contingency at CD-2, $0.6 million is remaining based on the EAC and the table below is a summary of the calls for (and returns to) contingency.

Table 3-1. Summary of Contingency Calls/Returns

Contingency ($M)		Reason
At CD-2	17.0	
	-17.1	Cost overruns
	-0.5	Post OH arc event mitigation
	+3.5	Over estimates
	-2.3	Scope enhancement
At CD-4	0.6	Remaining for use by FES program

The center stack fabrication cost twice the original estimate.

Approximately 80 percent of the project scope was accomplished using “in-house” resources.

The project classified the majority of the cost and schedule overruns related to activities as unknowns. Approximately $10 million of the $17 million cost contingency was used for work classified as unknowns.

The CD-4 early finish date was September 2014 and the CD-4 baseline project completion date is September 2015.

Nearly all the 12 months of schedule contingency between the early finish date and the baseline completion date was used, in addition to using the 11.6 months of schedule contingency created by the earlier than planned approval of the “begin upgrade outage” milestone for hardware removal.

The project has processed 136 Engineering Change Proposals.

3.2 Comments

The NSTX machine failure near the beginning of the NSTX Upgrade project proved to be beneficial for project success. It created a schedule opportunity for an earlier than planned start of hardware removal and thus led to additional schedule contingency.

Significant under estimating of cost and schedule led to the use of nearly all the contingency.

It was stated that the August costs were less than $100K and the September costs were estimated to be about $20K that total to less than the $200K included in the EAC for these two months.

There are no concerns for future vendor claims, in part because most of the scope was conducted in-house; therefore, the remaining $0.6 million should be available to the FES program.

Although the lessons learned matrix does identify the under estimating of cost and schedule for the overall project, the project has not identified this as one of the major or key lessons learned in the draft closeout report. In particular, the center stack fabrication cost twice as much as the original estimate.
Consider adding or enhancing a lesson learned regarding vendor management of Everson Tesla.

The CAM oversight of procurement of hardware components was less than adequate.

While EVMS performance reporting was good, it did not necessarily accurately convey the project status at the summary level. In particular, the early start of the upgrade outage gave the project additional schedule that was not reflected in the performance reporting.

All costs associated with the project appear to have been captured, including the costs associated with the OH arc event, and a justification document was developed and signed by PPPL and review by BHSO.

3.3 Recommendations

3. Update the Lessons Learned after CD-4.

4. The project is ready to proceed to CD-4 approval.

4. PROJECT MANAGEMENT

4.1 Findings and Comments

The Committee recognized the very high quality of work performed on all aspects of new and upgraded components. While building on past experience, many aspects of the project incorporated new and challenging activities in design, fabrication, and installation. Despite several setbacks during the project, the project team is recognized and commended for their resilience in overcoming expected and unexpected obstacles. The safety record of the project was very good.

The Committee reviewed the documentation submitted by the Princeton Plasma Physics Laboratory (PPPL) purporting all pre-requisite requirements have been satisfactorily completed in support of achieving CD-4, Project Completion. Most critically, achievement of KPPs were appropriately measured, documented, and independently verified by a qualified, independent expert. Additionally, each Cost Account Manager prepared and submitted formal declarations that their assigned scope as described in the project's WBS is complete.

A draft Project Completion Report was provided to the Committee addressing all required topics. While the draft report is adequate for this stage of the project and to support requesting CD-4 approval, the project is encouraged to continue its work to improve the overall quality of the report over the next few months as it prepares for final submission. Specifically, the executive summary should provide a brief narrative that describes key events that influenced the project from start-up to completion. Additional attention should be focused on improving lessons learned following comments by the Committee to include lessons not captured; to expand on key lessons learned; and to do a strong technical edit to make the lessons more reader friendly (e.g., define or use less acronyms).

While it is clear from presentations to the Committee that the project is well prepared for initial operations and research activities, their extensive planning is not defined in a formal transition to operations plan.

4.2 Recommendations

5. Prepare a formal Transition to Operations Plan (prior to CD-4 ESAAB).

6. Ensure all CD-4 prerequisite documents are appropriately integrated and updated (prior to CD-4 ESAAB).

7. Continue to make the project's lessons learned documentation more complete and reader-friendly (Final Project Closeout Report).

8. Request approval of CD-4 when the Committee recommendations are complete.

Appendix A Charge Memo

Department of Energy
Washington, DC 20585

July 22, 2015

MEMORANDUM FOR STEPHEN W. MEADOR
DIRECTOR
OFFICE OF PROJECT ASSESSMENT
OFFICE OF SCIENCE

FROM: EDMUND J. SYNAKOWSKI
ASSOCIATE DIRECTOR OF THE OFFICE OF SCIENCE
FOR FUSION ENERGY SCIENCES

SUBJECT: Department of Energy (DOE) Review of the National Spherical Torus Experiment – Upgrade (NSTX-U) Major Item of Equipment (MIE) Project

I request that your office organize and lead an Office of Science Independent Project Review of the NSTX-U MIE project at the Princeton Plasma Physics Laboratory on September 2, 2015. The purpose of this review is to determine whether the NSTX-U project has fulfilled the requirements for Critical Decision 4 (CD-4), "Project Completion" and is ready to request CD-4 approval by the Acquisition Executive (AE).

The objective of the NSTX-U project has been to design, build, install and test the in-scope equipment to allow the NSTX machine to operate at the following increased levels:

- Toroidal Field from 0.5 tesla to 1.0 tesla;
- Pulse length from ~1.0 second to 5.0 seconds;
- Plasma current from 1MA to 2MA;
- Neutral beam heating from 5-7MW to 10-14MW

The scope consists of two major elements: fabrication and installation of a Center Stack upgrade and installation of a 2nd Neutral Beamline.

In carrying out its charge, the Committee should include responses to the following questions:

1. Has the NSTX-U project met all CD-4 requirements, which includes: completing the technical scope and achieving the Key Performance Parameters as defined in the Project Execution Plan?

2. Is the transition to operations plan adequate to transition the NSTX-U project to research operations?

3. Is the draft project closeout report adequate and have the lessons learned from the project been identified and captured in a draft document?

4. Is the NSTX-U project ready for approval of CD-4, Project Completion?

Barry Sullivan will serve as the Fusion Energy Sciences point of contact for this review. I would appreciate receiving your committee's report within 30 days of the review's conclusion.

cc:
F. Crescenzo, PSO
A. Indelicato, PSO
S. Prager, PPPL
M. Ono, PPPL
M. Williams, PPPL
R. Strykowsky, PPPL
J. May, SC-24.1
J. Van Dam, SC-24.2
M. Foster, SC-24.2
B. Sullivan, SC-24.1
C. Clark, SC-28
K. Chao, SC-28

Appendix B Review Committee

DOE/SC (CD-4) Review of the
National Spherical Torus Experiment - Upgrade (NSTX-U) Project at PPPL
September 2, 2015

REVIEW COMMITTEE PARTICIPANTS

DOE Chairperson

Kin Chao, DOE/SC

Review Committee

Subcommittee 1: Technical
*Arnie Kellman, General Atomics
Tom McManamy, retired ORNL

Subcommittee 2: Cost and Schedule
* David Arakawa, DOE/ORSO
Tim Maier, DOE/SC

Subcommittee 3: Management
*Stephen Meador, DOE/SC

*Lead

Observers

Ed Synakowski, DOE/SC
Joe May, DOE/SC
Barry Sullivan, DOE/SC
Tony Indelicato, DOE/PSO
Robert Gordon, DOE/BHSO

Appendix C Review Agenda

DOE/SC (CD-4) Review of the
National Spherical Torus Experiment - Upgrade (NSTX-U) Project at PPPL
September 2, 2015

AGENDA

Wednesday, September 2, 2015—Site-C Lyman Spitzer Building (LSB), Room B318

8:00 am	DOE Executive Session (DOE and Review Committee Only) ..... K. Chao
	• Charge to Committee ..... B. Sullivan
	• Federal Project Director's Perspective ..... A. Indelicato
8:30 am	Welcome and Introductions ..... S. Prager
8:35 am	Project Overview, Closeout Activities, Lesson Learned ..... R. Strykowsky
9:50 am	Transition to Operations ..... S. Gerhart
10:20 am	Questions and Discussion ..... R. Strykowsky
10:35 am	Break
10:45 am	Tour
11:15 am	Breakout Sessions ..... R. Strykowsky
12:15 pm	Lunch for Committee
1:00 pm	Breakout Sessions ..... R. Strykowsky
2:45 pm	DOE Executive Session ..... DOE, Committee
4:00 pm	Closeout ..... DOE, Committee, PPPL
4:30 pm	Adjourn

Appendix D Management Chart