Approval of CD-2 for the
National Spherical Torus Experiment (NSTX) Upgrade Project
Princeton Plasma Physics Laboratory
DOE Princeton Site Office (SSO)

Office of Science
Office of Fusion Energy Sciences

A. Purpose

The purpose of this paper is to document the review by the Office of Science Energy System Acquisition Advisory Board-Equivalent for the critical decision "Approve Performance Baseline (CD-2)" for the NSTX (National Spherical Torus Experiment) Upgrade Project.

The CD-0 Mission Need for the NSTX Upgrade Project was approved by the Deputy Director of Science Program of the Office of Science, Dr. Patricia Dehmer on February 23, 2009. The proposed NSTX Upgrade Project has been selected to meet that mission need and the project will thus be referred to as the NSTX Upgrade Project. The CD-1 Alternative Selection and Cost Range for the NSTX Upgrade Project was approved by the Associate Director for Fusion Energy Sciences (FES), Dr. Edmund Synakowski on April 15, 2010. The NSTX Upgrade Project will include an upgrade of the NSTX central magnets ("center-stack") and the installation of a second Neutral Beam Injection (NBI) plasma heating and current drive system which will significantly expand the NSTX device and plasma parameters closer to next-step Spherical Torus (ST) conditions and provide a broader physics basis for the successful operation of ITER.

B. Mission Need

The mission of the 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 in ITER. The plasma confinement capability, and achievable plasma temperature, scale strongly with plasma current in the tokamak and ST. Plasma current in the range of 1 million amperes (1 mega-ampere) is required to access plasma temperatures needed to understand ST physics under fusion-relevant conditions. The only existing DOE facility capable of producing mega-ampere-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 would double the NSTX toroidal magnetic field to

1 Tesla and enable a doubling of the maximum plasma current to 2 MA (million amperes) for the first time in STs. The center-stack upgrade 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 ST operation and 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 operation 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 in DOE-FES reviews conducted on July 28–31, 2008. The review panel specifically endorsed NSTX upgrade plans which form the central elements of the NSTX Five Year Program Plan.

Advantages of upgrading NSTX include cost and schedule savings from utilization of the existing NSTX facility and related available infrastructure while minimizing the disruption to ongoing ST research. NSTX was originally designed for upgradable center-stack and the second NBI capability. Most existing diagnostic systems are compatible with these upgraded capabilities. Construction of a new ST facility with similar capability could offer increased flexibility and/or design improvements, however it would require significantly higher cost and time as the NSTX site credit is significant ~ $200 M, and the disruption to ongoing ST research if existing ST facilities were not operated during the design and construction phase of a new ST facility. Based on the above considerations, upgrading the existing NSTX facility is the most promising and practical path to close ST capability gaps in a timely and cost-effective manner.

C. Project Scope Baseline

The NSTX center-stack upgrade entails the replacement of the slender central column, which holds a subset of the NSTX magnets, with a wider column (by ~ 13 cm in radius), capable of ~ 2x higher confining magnetic fields to bring NSTX to within approximately a factor of two of next-step STs and longer pulses to validate physics at current relaxed conditions ("physics" steady-state). The NSTX center-stack is replaceable as an integrated assembly such that the work to remove the existing center-stack and install the new one can be carried out in a few months. The original NSTX General Requirements Document anticipated a new center-stack with longer pulse and higher field, and the design of NSTX includes suitable provision in related components (toroidal field (TF) outer legs, poloidal field (PF) coils, power supplies, etc.) The key technical approach for the NSTX center-stack upgrade project is the fabrication and assembly of a new center-stack assembly, consisting of the inner legs of the toroidal field (TF) coil, the ohmic heating (OH) solenoid, the center-stack casing, the center-stack plasma facing components, the inboard plasma facing components, and the inboard PF-1 coils. The project scope also includes associated sensors (TF joint sensors, magnetic sensors and thermocouples), reconfiguration of the TF power supplies for higher current operations, and enhancements of support structures for higher field and higher current operation.

The NSTX second NBI entails moving a TFTR Neutral Beam heating and current drive system to NSTX, thereby doubling the NSTX neutral beam power and injecting more tangentially, similar to the injection geometry proposed for next-step STs. The NSTX second NBI project task is similar to the first NBI system installed in FY2000. The project will largely utilize one of the existing four TFTR NBI systems. The second NBI will be installed at Bay K where the vacuum vessel Bay K port area will be modified. The new duct will require a new circular and rectangular bellows and an appropriate set of protective shields. The new duct will also incorporate a vacuum pump duct. Prior to the second NBI installation, the NSTX Test Cell Bay K area must be cleared which includes the Bay L pump duct, Bay K diagnostics, existing platforms, diagnostic and vacuum system racks, and gas injection system racks. Following the second neutral beam installation, the vacuum pumping and gas injection control racks will be relocated and brought back to an operational state. For this second NBI upgrade, decontamination of the TFTR beam line (a large high vacuum stainless steel box enclosure containing various NBI components including cryogenic-panels, beam dump, bending magnets, calorimeter, etc.) will take place prior to refurbishment. Replacement components will be fabricated for items which cannot be satisfactorily decontaminated.

D. Project Cost and Schedule Baseline

The preliminary cost range at CD-0 for the NSTX Upgrade Project is $71 – 95M. The cost range as updated for CD-1 is $74.7-$92.9M. The currently CD-2 planned cost and associated funding profile is given in Table 1 below. The NSTX Upgrade Project will have a total project cost (TPC) of $94.3M and a CD-4 completion date of September 2015 with $17M (or 27%) cost contingency and 12 months of schedule contingency. The CD-2 baseline has incorporated the results of several cost reduction and value engineering studies and validation reviews.

	CD-2 TOTAL	FY 2009 Actual Cost	FY 2010 Actual Cost	FY 2011	FY 2012 (OUTAGE)	FY 2013 (OUTAGE)	FY 2014 (OUTAGE)	FY 2015
NSTX UPGRADE BASELINE COST ESTIMATE ($K)								
Base Estimate =	**$77,283**	**$5,146**	**$8,323**	**$8,666**	**$11,961**	**$20,737**	**$22,452**	**$0**
Contingency % =	**27%**			*11%*	*22%*	*22%*	*23%*	
Contingency	**$16,992**			$912	$2,669	$4,543	$5,089	$3,779
Baseline Plan =	**$94,276**	**$5,146**	**$ 8,323**	**$ 9,578**	**$14,630**	**$25,280**	**$27,540**	**$ 3,779**
Available Funding =				**$9,578**	**$14,630**	**$25,280**	**$27,540**	**$28,000 ***

Table 1. NSTX Upgrade Project Funding Profile and Cost/Schedule

The following list is the critical decision milestones for the NSTX Upgrade Project:

Receive CD-0 approval..Feb-2009 (A)

Receive CD-1 approval... Apr-2010 (A)

Receive CD-2 approval.. Jan-2011

Receive CD-3 approval.. Jan-2012

CD-4 Project Complete..Sep-2015

E. Acquisition Strategy

An Acquisition Strategy (AS) has been approved by the Director, Office of Science, and reviewed by the DOE Science Office of Project Assessment (OPA) as a prerequisite for CD-1.

F. Environmental Strategy

The NSTX Upgrade Project has undergone review under the National Environmental Policy Act (NEPA) and the DOE has determined that this project meets the requirements for a Categorical Exclusion (CX) under Appendix B to Subpart D of the DOE NEPA Implementing Procedure Rule (10CFR1021). Activities involving potential radiological exposures will be conducted in accordance with existing radiological safety requirements, which are in compliance with relevant DOE rules including 10 CFR 835.

The NSTX Upgrade Project will incorporate the institutional Integrated Safety Management (ISM) Plan that has been approved by DOE.

G. Risk Management

The NSTX Upgrade Project Environmental Safety & Health (ES&H) risks have been identified on the NSTX Upgrade Project preliminary hazard assessment document. These are addressed via institutional line management ES&H program, such as PPPL's Integrated Safety Management program.

The NSTX Upgrade Project's Acquisition Strategy also examines project risk at a corporate level across a broad array of functional areas (e.g., functionality, workforce issues, regulatory issues, stakeholder involvement, etc.). The risks are categorized as either high, moderate or low (unlikely), and provide mitigation plans for risks greater than the designation of 'low'.

The NSTX Upgrade Project has also developed a Risk Management Plan as part of the Project Execution Plan. The NTSX Upgrade Project's Integrated Project Team (IPT) expects the project to manage risk as a line responsibility. Risks are identified by WBS Level 2 managers based on probability of occurrence and impact/consequence. The NSTX Upgrade Project management reviews the results and classifies the risks as high, medium, or low based on a "Risk Classification Matrix." Risk Mitigation Plans are developed for all risks rated as either high or moderate and successful implementation will be tracked by the project management team on a Risk Registry.

Technology and engineering risks for this project are low. STs have been constructed before and no foreseeable technical risks outside of those technical risks associated with construction and operation of STs are expected from this project. The project has been designed to minimize technical and engineering risks by exploiting previous experience and proven technology to the greatest extent possible. Items with higher technical risk have an R&D phase and carry higher contingency.

The NSTX Upgrade Project Manager and project team will manage the cost and schedule risk. Contingencies have been built into the estimates for each part of the project, and schedule float is incorporated in the project plan.

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Submitted by:

12/13/2010

Jeffrey Makiel
Federal Project Director
National Spherical Torus Experiment (NSTX) Upgrade Project
DOE Princeton Site Office

Date

12/14/2010

Barry Sullivan
Program Manager
Office of Fusion Energy Sciences
Office of Science

Date

14 Dec 2010

Mark Koepke
Acting Director
Research Division
Office of Fusion Energy Sciences
Office of Science

Date

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Recommendations

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-2 for the NSTX Upgrade Project- as noted below.

________________________________ 12/16/10 Yes ✓ No____
ESAAB Secretariat, Office of Project Assessment Date

________________________________ Yes____ No____
Representative, Non-Proponent SC Program Office Date

________________________________ Yes____ No____
Representative, Office of Budget Date

________________________________ 12/16/10 Yes ✓ No____
Representative, Environmental, Safety and Health Division Date

________________________________ Yes____ No____
Representative, Safeguards and Security Division Date

________________________________ 12/16/10 Yes ✓ No____
Representative, Facilities and Infrastructure Division Date

________________________________ Yes____ No____
Representative, Grants and Contracts Division Date

Approval

Based on the information presented above and at this review Critical Decision-2 (CD-2): Approve Performance Baseline, for the NSTX Upgrade Project is approved.

________________________________ 12/20/10
Edmund Synakowski Date
Director, Office of Fusion Energy Sciences
Office of Science