NCSX Research Preparation Costs

Charge #5. Although not part of a Major Item of Equipment project such as NCSX, and therefore not addressed in the CDR, the preparations made during the fabrication phase for the subsequent operations phase are important. Therefore, please comment separately on the plans and estimates to be presented by the project for such preparations including (a) diagnostic capability during operations, and (b) planning and analysis for the NCSX research program.

Introduction

During the period (FY2003-07) that the NCSX fabrication project is producing the equipment required at the start of operations (plus 3 MW of neutral beam heating power), a parallel research preparation activity will be carried out so that the program will be able to proceed as effectively as possible after First Plasma (March, 2007). This is very similar to the approach followed on NSTX. The goal of NCSX research preparations is to prepare analytical and hardware tools that will be needed beyond the first plasma and flux-surface mapping phases of the research program. As part of this effort, the NCSX experimental program plan will be developed in more detail. An additional goal is to maintain an active physics component of the NCSX program, with connections to other confinement research programs, while the NCSX machine is being fabricated. Research activities such as these are not within the scope of the NCSX Major Item of Equipment fabrication project but are necessary for the program to make the best use of the facility once it becomes available. The experimental plans, equipment needs and preparation requirements are described in detail in the document, "Mission, Experimental Plan, and Preparations." This document summarizes the costs of research preparation.

Scope and Cost Estimate

The NCSX research preparation effort will focus on four areas: plasma control, boundary control, diagnostics, and radiofrequency heating. In FY2003-2005, while operation is still a few years away, the emphasis will be on preparation of physics analysis tools and applying them in the physics design of hardware upgrades. Starting in FY-2006, the effort will expand to begin the engineering and fabrication of long-lead hardware upgrades. These include diagnostics needed for the Ohmic phase (Phase III), which will begin 6-8 months after First Plasma, and additional diagnostics, plasma-facing components, and trim coils needed for the initial auxiliary heating phase (Phase IV), which will begin 14-16 months after First Plasma.

In estimating the cost of research preparation, physicists and design engineers involved in these activities are budgeted through FY-2006. Starting in FY-2007, these staff would be covered by the NCSX research operations budget. Hardware upgrade cost estimates are based on pre-

conceptual designs. Included are those upgrade projects that must begin in FY-2006 and continue in order to be ready by FY-2007 or FY-2008; hardware costs through FY-2008 are shown for completeness.

A. Plasma Control

The NCSX discharge simulations developed during conceptual design have provided an initial scoping of plasma control issues. During the plasma evolution from vacuum to a high-beta state the coil currents must be controlled, based on the state of the plasma, to ensure that the system follows a stable trajectory. Helical field trim coils are likely to be needed to control magnetic islands. Plasma control strategies for a range of operating scenarios will be developed as part of research preparations. The NCSX team will adapt tools that are available (e.g., the VMEC and PIES equilibrium codes) or being developed (e.g., the 3D equilibrium reconstruction code being developed by the Theory program) to define control system requirements, including algorithms, input to the fabrication project on the magnetic diagnostic configuration, and design of trim coils. The initial testing of plasma control strategies will occur during the Ohmic phase (Phase III). The trim coils are expected to become important starting with the initial auxiliary heating phase (Phase IV). The engineering and fabrication effort for trim coils will start in FY-2006 so they can be ready for installation in FY-2008 for the start of Phase IV.

Table A.1 Plasma Control Preparation Costs ($M)

	2003	2004	2005	2006	2007	2008
Research & Design	0.4	0.5	0.5	0.6	*	*
Trim Coils				0.4	1.5	0.4

* Operating budgets start in FY-2007.

B. Boundary Control

The NCSX plasma-facing components (PFC) will be implemented in a phased manner, leading to an envisioned pumped divertor. Determining the optimum strategy requires application of analytical tools and incorporation of experimental results from foreign stellarator divertor experiments. The edge plasma and neutrals modeling effort for NCSX, started as part of conceptual design, will continue under research preparations to set requirements on the placement of components and to estimate applicable heat and particle loads. It will also produce analytical tools needed to interpret data from boundary diagnostics. The NCSX team will apply tools such as the MFBE field-line following code (from Germany), the PIES equilibrium code, the Degas neutrals transport code, and the Boris 3D edge simulation code being developed by Germany with U.S. collaboration. The engineering and fabrication effort for plasma-facing

components needed for high-power heating experiments will start in FY-2006 so they can be ready for installation in FY-2008 for the start of Phase IV. An upgrade to the bakeout system will be necessary at that time to support 350 C in situ bakeout of the carbon PFCs.

Table B.1 Boundary Control Preparation Costs ($M)

	2003	2004	2005	2006	2007	2008
Research & Design	0.4	0.5	0.5	0.6	*	*
PFCs				1.0	2.7	3.7
350 C Bakeout					0.1	0.7

* Operating budgets start in FY-2007.

C. Diagnostics

The fabrication project will only provide the diagnostics needed for First Plasma and magnetic flux surface mapping. However, the NCSX facility is designed to accommodate the extensive set of diagnostics that will be needed for the planned physics program. Diagnostics for the Ohmic phase (Phase III) and beyond will be added as they become needed by the program, as is typical in fusion confinement experiments. The engineering and fabrication effort for Phase III diagnostics will start in FY-2006 so they can be ready for installation in FY-2007 and 2008, as needed for Phase III. The effort on Phase IV diagnostics will begin in FY-2007. The Phase III and IV diagnostics consist of a large number of individual projects costing less than $2M each; most are less than $1M.The diagnostics needed for each phase of the research program are tabulated and discussed in the Engineering Design Document, WBS 3.

Table C.1 Diagnostic Preparation Costs ($M)

	2003	2004	2005	2006	2007	2008
Research & Design	0.1	0.1	0.4	0.7	*	*
Phase III diagnostics				1.2	1.6	1.3
Phase IV diagnostics					0.8	1.3

* Operating budgets start in FY-2007.

D. Radiofrequency Heating

The NCSX facility is designed to accommodate up to 6 MW of radiofrequency heating power as a future upgrade. Provision has been made in the vacuum vessel design for the installation of launchers on the high-field side for a heating scenario based on mode conversion of fast waves to ion Bernstein waves. Existing 20-30 MHz sources would be used. Implementation of high-power radiofrequency heating would most likely occur in FY-2009 or later, after gaining initial experience with neutral beam injection, the primary heating system. However, it may be

advantageous to begin radiofrequency heating experiments with a low-power prototype launcher as early as possible. The research preparation activity will analyze options for launchers and circuit configurations for range of prototype and upgrade scenarios. Engineering and fabrication efforts would not start until sometime after First Plasma, and would be proposed as part of the research program.

Table D.1 Radiofrequency Heating Preparation Costs ($M)

	2003	2004	2005	2006	2007	2008
Research & Design	0.1	0.1	0.2	0.2	*	*

* Operating budgets start in FY-2007.

Summary

The NCSX research preparation efforts will in FY-2003, effectively a continuation of selected activities from the conceptual design phase. Engineering and fabrication of hardware upgrades needed beyond the flux-surface mapping phase will begin in FY-2006, the year preceding First Plasma, similar to the plan followed by NSTX, so that they will be ready for installation when needed. The estimated NCSX research preparation costs are summarized in the following table.

Summary of NCSX Research Preparation Costs ($M)

	2003	2004	2005	2006	2007	2008
Research & Design	1.0	1.2	1.6	2.1	*	*
Trim Coils				0.4	1.5	0.4
PFCs				1.0	2.7	3.7
350 C Bakeout					0.1	0.7
Phase III diagnostics				1.2	1.6	1.3
Phase IV diagnostics					0.8	1.3
Total	1.0	1.2	1.6	4.7	*	*

* Operating budgets start in FY-2007.