

## Work Authorization Document

### NSTX Upgrade Project

<b>Control Account #:</b>	2300	<b>Title:</b>	ECH Analysis
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<b>WBS</b>	1.2.3	<b>Title:</b>	Electron Cyclotron Heating
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**Period of Performance:** 01 April 2010 through 06 June 2011

<b>Authorized Budget:</b>	\$84	<b>Control Account Manager:</b>	Titus
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<b>Revision #:</b>	0	<b>Revision Date:</b>	July-11
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**Authorized Work Description:**

The Electron Cyclotron Heating System provides breakdown and startup assist through an electron cyclotron heating system. The system will be composed of an AC/DC power conversion system, gyrotron source, transmission system, vacuum window and launcher. Any ECH specific diagnostics will be included and interfaced to Central I&C.

This scope of the WBS element for the NSTX Upgrade covers the ECH and other antenna systems, and miscellaneous diagnostics and components attached to the vessel which will be affected by the increases in EM and thermal loading. Disruption loads on the ECH waveguide will be evaluated for the Center Stack Upgrade Fields and field transients. Discussions with heating system experts regarding the performance of the ECH system for the higher Center Stack Upgrade fields indicate that no modification to the resonant frequency or other operational characteristic for the system will require upgrade. Only disruption qualification is planned. No previous qualification has been identified, so the resources include creation of a new calculation – not a review of an existing calculation as is the case for ICRH.

**Attachments:**

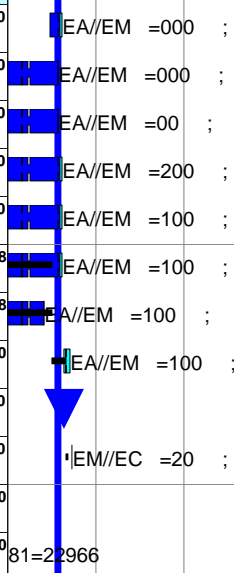
- 1- A detailed Control Account schedule showing all work packages and planning packages.
- 2- Budgeted Cost by month.
- 3- Original Work Authorization Form (WAF)
- 4- WBS Dictionary sheet that defines the scope of work for this WBS element.

#### Control Account History

ECP#	Implement Date	Prior Budget	New Budget	Signature

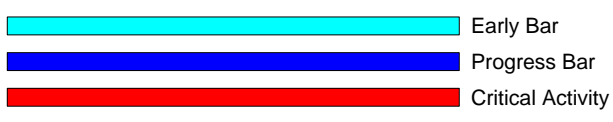
Approvals	Name	Signature	Date
NSTX-U Project Manager	R. Strykowski		
Control Account Manager	Titus		
Functional Manager	P. Heitzenroeder		

Activity ID	Activity Description	Work Days	BASELINE START	Forecast Start	BASELINE FINISH	Forecast Finish	Schedule Slip (Days)	Total Float	Budgeted Cost	PPCT	Earned value cost (BCWP)	Planned value cost (BCWS)	FY11	FY12	FY13	FY14	FY15	FY16					
<b>NSTX Upgrade Project</b>																							
Subtotal		310	01APR10A	01APR10A	06JUN11	24JUN11	-14	121	84,191.50		58,233.11	70,710.96											
<b>Job: 2300 - Other Analysis-TITUS</b>																							
Subtotal		310	01APR10A	01APR10A	06JUN11	24JUN11	-14	121	84,191.50		58,233.11	70,710.96											
2300-0010A	Analyses of RF MHD Shield Disruptive Loads	37*		25MAR11A		16MAY11	0	125	0.00	85	0.00	0.00											
2300-0011	Run Other GRD disruptions for the HHFW antenna	228*	01JUN10A	01JUN10A	31AUG10A	28APR11A	-163		0.00	100	0.00	0.00											
2300-0012	Updat HHFW Antenna	228*	01JUN10A	01JUN10A	31AUG10A	28APR11A	-163		0.00	100	0.00	0.00											
2300-0013	Maintain/Update Diagnostic Database	240*	01JUN10A	01JUN10A	31AUG10A	16MAY11	-175	125	0.00	99.	0.00	0.00											
2300-0014	File Preliminary Database/Study	240*	01JUN10A	01JUN10A	31AUG10A	16MAY11	-175	146	0.00	99.	0.00	0.00											
2300-0015	Check/Complete Disruption and Thermal Analyses	175*	01SEP10A	01SEP10A	01APR11	16MAY11	-31	125	19,013.72	85	16,115.13	18,958.98											
2300-0016	Present/track recommendations	154*	01SEP10A	01SEP10A	01APR11	28FEB11A	24		18,897.18	100	18,958.98	18,958.98											
2300-0018	FDR Prep	21*	04APR11	19MAY11	27MAY11	17JUN11	-14	123	19,268.00		0.00	9,634.00											
2300-0018A	Other Analysis - Peer review	0				18MAY11*	0	123	0.00		0.00	0.00											
2300-0019	CONDUCT FDR	3	31MAY11	22JUN11*	06JUN11	24JUN11	-14	121	3,853.60		0.00	0.00											
FY102300	FY10 Actual Cost	22	01APR10A	01APR10A	30APR10A	30APR10A	0		3,904.00	100	3,904.00	3,904.00											
FY102300A	FY10 Actual Cost	110	03MAY10A	03MAY10A	30SEP10A	30SEP10A	0		19,255.00	100	19,255.00	19,255.00											



Data Date 30APR11 1105  
 Run Date 20MAY11 10:52  
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**NSTX UPGRADES  
 RESOURCE LOADED SCHEDULE  
 CD-2 Schedule  
 April 2011**









## Annex I – WBS Dictionary

This Work Breakdown Structure (WBS) organizes and defines the scope of the NSTX Upgrade using the WBS as established by the original NSTX project and modified to accommodate the NSTX Upgrade.

<u>WBS</u>			
<u>L1</u>	<u>L2</u>	<u>L3</u>	<u>Description</u>
1			<b>NSTX UPGRADE PROJECT</b>
	<b>1.1</b>		<b>Torus Systems</b>
		1.1.0	Project Integrated Model
		1.1.1	Plasma Facing Components
		1.1.2	Vacuum Vessel and Support Structure
		1.1.3	Magnet Systems
	<b>1.2</b>		<b>Plasma Heating and Current Drive Systems</b>
		1.2.1	High Harmonic Fast Wave (HHFW)
		1.2.2	Coaxial Helicity Injection (CHI) Current Drive
		1.2.3	Electron Cyclotron Heating (ECH)
		1.2.4	Neutral Beam Injection (NBI)
	<b>1.3</b>		<b>Auxiliary Systems</b>
		1.3.1	Vacuum Pumping System
		1.3.2	Coolant Systems
		1.3.3	Bakeout Heating System
		1.3.4	Gas Delivery System
		1.3.5	Glow Discharge Cleaning System
	<b>1.4</b>		<b>Plasma Diagnostics</b>
		1.4.1	Plasma Diagnostics
	<b>1.5</b>		<b>Power Systems</b>
		1.5.1	AC Power Systems
		1.5.2	AC/DC Converters
		1.5.3	DC Systems
		1.5.4	Control and Protection System
		1.5.5	General Power Systems and Integration
	<b>1.6</b>		<b>Central Instrumentation and Controls (I&amp;C)</b>
		1.6.1	Control System
		1.6.2	Data Acquisition System
	<b>1.7</b>		<b>Project Support &amp; Integration</b>
		1.7.1	Project Management and Integration
		1.7.2	Project Physics
		1.7.3	Integrated Systems Tests
	<b>1.8</b>		<b>Site Preparation and Assembly</b>
		1.8.1	Site Preparation
		1.8.2	Torus Assembly and Construction

## Annex I – WBS Dictionary

**WBS Element: 1.2** **WBS Level: 2**

**WBS Title: Plasma Heating and Current Drive Systems**

**Definition:** The heating and current drive systems include all the auxiliary plasma heating and current drive systems. This WBS element includes the High Harmonic Fast Wave (HHFW) Current Drive System, the Coaxial Helicity Injection (CHI) Current Drive System, the Electron Cyclotron Heating (ECH) System, and the Neutral Beam Injection (NBI) System. Only ECH (WBS 1.2.3) and Neutral Beam Injection (WBS 1.2.4) are impacted by the NSTX Upgrade Project. The scope of the work contains engineering design, R&D, mockups, procurement activities, component fabrication, installation, and System Testing. Installation of the WBS 2 systems is included in the individual WBS 2, level 3 elements.

**WBS Element: 1.2.1** **WBS Level: 3**

**WBS Title: High Harmonic Fast Wave (HHFW)**

**Definition:** The High Harmonic Fast Wave System provides radio frequency (rf) energy to the plasma for the purpose of plasma heating and current drive. The components of such a system include generators, transmission lines, tuning systems, antennas and their associated diagnostic and control systems. The system includes components inside the vacuum vessel (antennas and feed-throughs) in the test cell (transmission and tuning components) and in the RF power rooms (AC/DC power conversion system, RF generators, switches and loads). There are no changes to the HHFW System as part of the NSTX Upgrade Project.

**WBS Element: 1.2.2** **WBS Level: 3**

**WBS Title: Coaxial Helicity Injection (CHI) Current Drive**

**Definition:** The Coaxial Helicity Injection System is to provide helicity injection to aid startup and provide edge current profile control. The main hardware elements required fall under other WBS's. These include a ceramic break in the vacuum vessel (WBS 1.1.3) the poloidal coil system (WBS 1.1.3) and a power supply (WBS 1.5). In this WBS element the task is to assure that the various components of the system are compatible with helicity injection and that the Central I&C required is provided. There are no changes to the CHI System as part of the NSTX Upgrade Project.

**WBS Element: 1.2.3** **WBS Level: 3**

**WBS Title: Electron Cyclotron Heating (ECH)**

**Definition:** The Electron Cyclotron Heating System provides breakdown and startup assist through an electron cyclotron heating system. The system will be composed of an AC/DC power conversion system, gyrotron source, transmission system, vacuum window and launcher. Any ECH specific diagnostics will be included and interfaced to Central I&C.

This scope of the WBS element for the NSTX Upgrade covers the ECH and other antenna systems, and miscellaneous diagnostics and components attached to the vessel which will be affected by the increases in EM and

## Annex I – WBS Dictionary

thermal loading. Disruption loads on the ECH waveguide will be evaluated for the Center Stack Upgrade Fields and field transients. Discussions with heating system experts regarding the performance of the ECH system for the higher Center Stack Upgrade fields indicate that no modification to the resonant frequency or other operational characteristic for the system will require upgrade. Only disruption qualification is planned. No previous qualification has been identified, so the resources include creation of a new calculation – not a review of an existing calculation as is the case for ICRH.

**{Electron Cyclotron Heating (Job 2300)}**

**WBS Element: 1.2.4**

**WBS Level: 3**

**WBS Title: Neutral Beam Injection (NBI)**

**Definition:** The Neutral Beam Injection System Upgrade provides a second Neutral Beam as part of the NSTX Upgrade Project. The second NBI is identical to the one already installed on NSTX. An existing TFTR beam will be decontaminated, refurbished, and installed on NSTX. This WBS element includes the NBI source refurbishment; the TFTR beamline decontamination, refurbishment and relocation to the NSTX Test Cell; the 2<sup>nd</sup> NBI Services; the NBI armor modifications; the 2<sup>nd</sup> NBI Power, Controls and Instrumentation; the 2<sup>nd</sup> NBI Duct and vacuum vessel modifications; and the NSTX Test Cell equipment removals and relocations necessary to accommodate the 2<sup>nd</sup> NBI. Vacuum Pumping System Modifications necessary to accommodate the 2<sup>nd</sup> NBI are included in WBS element 1.3. NBI Management and Health Physics support are included in element WBS 1.7.

**WBS Element: 1.2.4.2**

**WBS Level: 4**

**WBS Title: NBI Source Refurbishment**

**Definition:** This WBS element includes the activities to refurbish three neutral beam ion sources for the 2<sup>nd</sup> Neutral beamline, as currently being performed for the installed Neutral beamline 1.

**{Source Refurbishment (Job 2420)}**

**WBS Element: 1.2.4.3**

**WBS Level: 4**

**WBS Title: NSTX Beamline 2 Decontamination**

**Definition:** This WBS element includes the disassembly and decontamination activities of a TFTR Neutral Beam beamline in preparation for beamline refurbishment and reuse as an NSTX upgrade.

**{NSTX Beamline 2 Decontamination (Job 2430)}**

**WBS Element: 1.2.4.4**

**WBS Level: 4**

**WBS Title: NBI Beamline Refurbishment and Relocation**

**Definition:** This WBS element includes refurbishment of a TFTR NBI and its relocation to the NSTX test cell.

Included in this WBS element are the activities necessary to refurbish a TFTR Neutral Beam beamline for use on NSTX. This scope includes



## Work Approval Form (WAF)

**Cost Center:** 9417  
**Job Number:** 2300  
**Job Title:** Miscellaneous Diagnostic and Antenna Qualification  
**Job Manager:** P. Titus

**Description:**


At the beginning of the CDR, this task covered the ECH and other antenna systems, and was expanded to include miscellaneous diagnostics and components attached to the vessel which will be effected by the increases in EM , thermal, nuclear, dynamic loading and space allocation. A data base of antennas and diagnostics was created and elements sensitive to CSU changes were investigated. This included thin sheet metal shutters that may have thermal issues with higher power and eddy current loading.

**Schedule:**

See Tab B or attached

**Approvals:**

  
Job Manager July 21 2010

  
Project Manager 8/3/10

  
Engineering Department Head 8/3/10







Design Maturity		Design Complexity			Design Maturity Definition		
		Low	Medium	High			
Low	-15%	+25%	-20%	+40%	-30%	+60%	Final design available. All design features/requirements well known. No further design development or evolution expected that will impact estimate.
Medium	-10%	+15%	-15%	+25%	-20%	+40%	
High	-5%	+10%	-10%	+15%	-15%	+25%	
					No better than conceptual design basis currently available. Design details, procedures, etc. still need much development and evolution of requirements beyond estimate basis is likely and expected.		
Design Complexity		Design Maturity			Design Complexity Definition		
		Low	Medium	High			
Low					Work is fairly well understood -- either standard construction or repetition of activities performed in past. Little likelihood of estimate not being well understood and requirements not being well defined.		
Medium					More complex work requirements that have potential to impact cost and schedule estimates. Limited experience performing similar tasks, so ability to estimate accurately is somewhat suspect		
High					Extremely challenging tasks and/or requirements. Unique or first-of-a-kind assembly or work tasks. No good basis for estimating work exists so there is a high degree of estimate uncertainty. Based on standard industry and DOE estimate classifications (Per AACEI Recommended		

**Cost Center:**  
**Job Number:**  
**Job Title:**  
**Job Manager:**

9417  
 2300  
 Miscellaneous Diagnostic and Antenna Qualification  
 P. Titus

**Materials and Subcontracts (M&S)**

**Basis of Estimate**

Description:

CATEGORIZATION CODES:	
1 - National Standards	
2 - Engineering Judgement/Experience	
3 - Estimates/Data from External Sources (e.g., W7X, ATF, etc.)	
4 - Previous PP/LORNL Experience (e.g., FTFR, NSTX, PLT, etc.)	
5 - Prototype Data/Test Results	
6 - Catalogue Price/Vendor Quote	
7 - Placed Contracts	
8 - Actual experience for NCSX Work	
9 - Other	

1	\$	-	#DIV/0!
2	\$	-	#DIV/0!
3	\$	-	#DIV/0!
4	\$	-	#DIV/0!
5	\$	-	#DIV/0!
6	\$	-	#DIV/0!
7	\$	-	#DIV/0!
8	\$	-	#DIV/0!
9	\$	-	#DIV/0!
TOTALS			\$ - #DIV/0!

**NSTX UPGRADE WAF STATUS**

9/1/2009

Cost Center	Work Package	Job #	WBS	Responsible Job Manager	WAF Forecast Completion	WAF Received	WAF Input to P3	Prelim. Estimate (\$K)	WAF Reviewed	Analysis Tasks	Engr	Prelim Design Hrs	Final Design Hrs	
<b>1.2 Plasma Heating and Current Drive Systems</b>														
1180	2***	2310	1.2.1 High Harmonic Fast Wave	P. Titus										
1180	2***	2310	1.2.2 Coaxial Helicity Injection	P. Titus										
1180	2***	2310	1.2.3 Electron Cyclotron Heating	P. Titus										
												Disruption : Ellis/Zhang	300	300
												Document Simmons	40	40
<b>1.2.4 Neutral Beam Injection</b>														
				T.Stevens										
<b>1.2.4.1 NBI Project Support</b>														
1180	2***	2410	1.2.4.1 NBI Project Support	T. Stevens		14-Aug-09	14-Aug-09							
<b>1.2.4.2 NBI - Sources</b>														
1180	2***	2420	1.2.4.2 NBI - Sources	M. Cropper		14-Aug-09	14-Aug-09							
<b>1.2.4.3 NBI - Decontamination</b>														
1180	2***	2430	1.2.4.3 NBI - Decontamination	T. Stevens		14-Aug-09	14-Aug-09							
<b>1.2.4.4 NBI - Beamline Reloc.</b>														
1180	2***	2440	1.2.4.4 NBI - Beamline Reloc.	M. Denault		14-Aug-09	14-Aug-09							
<b>1.2.4.5 NBI - Services</b>														
1180	2***	2450	1.2.4.5 NBI - Services	M. Denault		14-Aug-09	14-Aug-09							
<b>1.2.4.6 NBI - Armor/Protective</b>														
1180	2***	2460	1.2.4.6 NBI - Armor/Protective	C. Prinskis										
<b>1.2.4.7 NBI - Power &amp; Control</b>														
1180	2***	2470	1.2.4.7.1 NBI - Power	R. Raki		14-Aug-09	14-Aug-09							
<b>1.2.4.7.2 NBI - Control</b>														
1180	2***	2475	1.2.4.7.2 NBI - Control	M. Cropper		14-Aug-09	14-Aug-09							
<b>1.2.4.8 NBI - Nozzle/Duct</b>														
1180	2***	2480	1.2.4.8 NBI - Nozzle/Duct	C. Prinskis		14-Aug-09	14-Aug-09							
<b>1.2.4.9 NBI - Equipment Removal</b>														
1180	2***	2490	1.2.4.9 NBI - Equipment Removal	E. Perry		6-Aug-09	6-Aug-09	#####						
<b>1.3 Auxiliary Systems</b>														
				W. Blanchard										
<b>1.3.1 Vacuum Pumping Systems</b>														
1170	3***	?	1.3.1 Vacuum Pumping Systems	L. Dudek										
<b>1.3.2 Coolant Systems</b>														
				M. Denault										
				Water Cooling System Mods for CSU - Includes design, analysis, fabrication and installation of a new pump, and hardware upgrade on the cooling water system to permit the OH coil to operate at 600 psig	M. Denault		11-Sep-09							
1170	3***	3200	1.3.2 Coolant Systems	M. Denault										
<b>1.3.3 Bakeout System</b>														
				W. Blanchard										
				Bakeout System mods for CSU - Includes upgrade to the power supply system to permit ohmic heating of the center stack casing for 350 C bakeout of the CS Tiles	L. Dudek		11-Sep-09							
1170	3***	3300	1.3.3 Bakeout System	W. Blanchard										
<b>1.3.4 Gas Delivery Systems</b>														
				W. Blanchard										
				Gas Delivery System Mods for CSU - Includes the design, fabrication and installation of the Gas Delivery System on the new Centerstack.	W. Blanchard		11-Sep-09							
1170	3***	3400	1.3.4 Gas Delivery Systems	W. Blanchard										
<b>1.3.5 Glow Discharge Cleaning System</b>														
				L. Dudek										
n/a			1.3.5 Glow Discharge Cleaning System	L. Dudek										
<b>1.4 Plasma Diagnostics</b>														
				R. Kiata										

		<b>1.4.1 Plasma Diagnostics</b>	<b>R. Kaita</b>	
1170	4***	4100	Center Stack Diagnostics for CSU - Includes design and fabrications of CS magnetics diagnostics to replace units removed with old center stack	11-Sep-09

Disruption I Zhang 40 80

		<b>1.5 Power Systems</b>	<b>Raki</b>	
1170	5***	5100	1.5.1 AC Power Systems	Raki 11-Sep-09
1170	5***	5200	1.5.2 TF Power Conversion Systems	Raki 11-Sep-09
1170	5***	5300	1.5.3 PF/OH Power Conversion System	Raki 11-Sep-09
1170	5***	5400	1.5.4 CHI Power Conversion System	Raki 11-Sep-09
1170	5***	5500	1.5.5 General Power Systems and Inter	Raki 11-Sep-09

			<b>COIL BUS RUNS -</b>	<b>J. Chrzanowski</b>	<b>11-Sep-09</b>
1170	5***	5501	Includes design and fabrication of bus runs/supports for the OH/TF/Inner PF and CHI Includes bus from coils to air-cooled bus in test cell west side		

Bus Loren Bryant 60

1170	6***	6100	<b>1.6 Central Instrumentation &amp; Control</b>	<b>P. Sichta</b>	<b>?</b>
			1.6.1 Control System	P. Sichta	
			1.6.2 Data Acquisition System	P. Sichta	

			<b>1.7 Project Support &amp; Integration</b>	<b>E.Perry</b>	
1170	7***	7100	1.7.1 Project Management & Integration	L. Dudek	?
1170	7***	7200	1.7.2 Project Physics	J. Menard	?
1170	7***	7300	1.7.3 Integrated Systems Test	C. Gentile	?

			<b>1.8 Site Preparation and Torus Assembly</b>	<b>E.Perry</b>	
1170	8***	8100	1.8.1 Site Preparation	E.Perry	?

			<b>1.8.2 Torus Assembly</b>	<b>E.Perry</b>	
1170	8***	8200	Centerstack and Coil structure Installation - Covers the materials and labor to install the centerstack and related hardware and the upgraded coil support structures		?

Analysis of Willard 100

380 580 Hrs  
3.166667 4.833333 Man-Months

Prelim Des #####  
Preliminary 2/15/2010 4 Months  
Final Desig 2/15/2010  
Final Desig ##### 10 Months