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.

WBS L1	L2	L3	Description
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	1.7		**Project Support & Integration**
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	1.8		**Site Preparation and Assembly**
		1.8.1	Site Preparation
		1.8.2	Torus Assembly and Construction

WBS Element: 1 **WBS Level: 1**
WBS Title: NSTX Upgrade Project
Definition: The replacement of the entire Center Stack Assembly (CSA) and installation of a second Neutral Beam Injection (NBI) system on NSTX is planned to allow an improved understanding of the Spherical Torus (ST) magnetic confinement configuration which is needed to establish the physics basis for next-step ST facilities, broaden the scientific understanding of plasma confinement for ITER, and maintain U.S. world leadership in ST research capabilities. In particular, operation at higher magnetic field with reduced plasma collisionality is needed to extend the plasma physics understanding of the ST toward next-step ST facilities and ITER. Controllable fully-non-inductive current-drive will also contribute to assessing the ST as a potentially cost-effective path to fusion energy.

WBS Element: 1.1 **WBS Level: 2**
WBS Title: Torus Systems
Definition: The torus systems include all the systems and related elements within the boundary of the NSTX support structure. This WBS element includes the Plasma Facing Components (WBS 1.1), Vacuum Vessel & Support Structure (WBS 1.2), and Magnet Systems (WBS 1.3). The scope of the work contains engineering design, R&D, mockups, procurement activities, and component fabrication. Assembly of the Torus System is included in WBS 1.8.

WBS Element: 1.1.0 **WBS Level: 3**
WBS Title: Project Integrated Model
Definition: This WBS element includes development of a project integrated model and the associated analysis support of the overall NSTX Upgrade Project.

As a result of the NSTX Upgrade Project, the NSTX global models and analyses will need to be updated. This WBS element includes analytical support for global models and analysis not presently identified. The global model will provide the basis for updating the analysis to qualify components and identify areas of the tokamak requiring further analysis. Identified plasma scenarios and power supply current limit analyses will be run in the global model and current sets that require further analysis will be identified. These analyses also serve to check the results of more detailed analyses.
{Center Stack Upgrade (CSU) analytical Support (Job 1000)}

WBS Element: 1.1.1 **WBS Level: 3**
WBS Title: Plasma Facing Components
Definition: The plasma facing components (PFCs) include all the systems and related elements that serve to protect the vacuum vessel from the charged particles and radiation flux from the plasma. These include the plasma facing tiles and mounting components, passive stabilizers, inner wall

protection, divertor area strike plates, and local I&C. This element consists of the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project will require new PFCs on the new Center Stack Casing (CSC) and the new Inboard divertor (IBD). This WBS element includes the design and analysis for both the CS and IBD PFCs, design modifications to the PFC tiles to accommodate surface diagnostics, including design of the tile mounting schemes and routing plans for diagnostic wires, generation of required documentation such as checked calculations, specifications and procedures, the procurement and installation of all PFC tiles and hardware on the CSC and IBD.
{Center Stack Upgrade (CSU) PFCs (Job 1001)}

In addition the NSTX Upgrade will require analysis of the passive plates for disruption and thermal loads. CDR level calculations were performed that addressed one of five disruptions. The remaining identified disruptions are to be completed during Preliminary Design. During Final design, analysis updates are expected as a result of preliminary design evolution. Modest hardware upgrades are anticipated are anticipated as part of this task. Additions of accelerometers or other diagnostics to benchmark calculations with actual performance in NSTX are also anticipated. This analysis effort is included in this WBS element.
{Passive Plate Analysis and Upgrade Activity (Job 1002)}

With the exception of the modifications identified above, no additional modifications to the PFCs are anticipated.

WBS Element: 1.1.2 **WBS Level: 3**
WBS Title: Vacuum Vessel and Support Structure

Definition: The vacuum vessel & support structure (VVSS) consists of the vacuum chamber, not including the PFCs, all ports and vacuum boundary closures and the torus support structure which provides the overall supporting mechanism for the torus components to the test cell floor. This WBS element includes the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project will require that the existing VVSS be modified to accommodate the new center stack structure, including the umbrella structure and the new center stack support structure. This WBS element includes the analytical and CAD design of the support structures associated with the Magnet upgrade activities. The scope includes; the Vacuum Vessel & Structural Support, the Outer TF Structures, the Outer PF Coil Structures, the Umbrella Structural Reinforcement, the CS Support Pedestal and miscellaneous Vacuum Vessel Structural Supports. It also includes the procurement and fabrication of these structures, but

does not include installation costs. Installations costs are included in WBS 1.8. {Vacuum Vessel & Support Structure (Job 1200)}

WBS Element: 1.1.3 **WBS Level: 3**
WBS Title: Magnet Systems

Definition: The magnet system consists of the outer Poloidal Field (PF) coils (PF#2-5), the outer Toroidal Field (TF) coil legs, and the Center Stack Assembly (CSA). The CSA contains the inner TF coil legs, the TF coil joint (flex bus assembly), the OH solenoid, the shaping coils, and the center stack casing. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication of the magnet systems up to and including the magnet system coil buswork, but does not include installation costs. Installations costs are included in WBS 1.8

The NSTX Upgrade Project will require engineering, analysis, design procurement and fabrication of a new CSA, replacement of two outer TF coil legs, and a fabrication of a new TF coil joint

This WBS element provides CAD design support for the overall assembly drawings associated with the CSA upgrade. It also includes some time for space allocation studies associated with the magnet upgrades. CAD design support for individual components is included in the specific component jobs.
{Center Stack Upgrade Project Design Support (Job 1300)}

WBS Element: 1.1.3.1 **WBS Level: 4**
WBS Title: Outer Poloidal Field Coils (PF #3-5)

Definition: The outer Poloidal Field coils (PF 3-5) consist of 5 poloidal field coils PF 3 upper and lower, PF 4 upper and lower and PF 5. There are no changes to the outer PF coils as part of the NSTX Upgrade Project scope.

WBS Element: 1.1.3.2 **WBS Level: 4**
WBS Title: Outer Toroidal Field Coils

Definition: The outer Toroidal Field coils subsystem consists of the coil sections that make up the 12 TF outer legs. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication. For the NSTX Upgrade Project two (2) new Outer TF coils will be fabricated to replace existing ones. This WBS element includes the fabrication of (2) new Outer TF coils to replace the existing leaking OTF#7 and OTF#11 in NSTX. The scope includes the procurement of conductor, insulation material, aluminum castings and supports necessary to fabricate a new OTF coils. Coil fabrication will be performed in-house. This scope does not include costs associated with installation. Installations costs are included in WBS 1.8
{Outer Toroidal Field Coil Repairs (Job 1301)}

WBS Element: 1.1.3.3 **WBS Level: 4**
WBS Title: Center Stack Assembly (CSA)

Definition: The CSA consists of the inner TF coil legs, the OH solenoid, the shaping coils, and the center stack casing. Also included in this WBS element are the TF coil joint (flex bus assembly) and the ceramic break assembly. The scope of this WBS element includes the design, analysis, prototypes (as required), procurement activities, fabrication and assembly of the Center Stack.

WBS Element: 1.1.3.3.1 **WBS Level: 5**
WBS Title: Center Stack - TF Inner Legs/Bundle

Definition: The TF inner leg subsystem consists of the new coil sections that will make up the TF inner bore and bundle. Also included in the scope of this WBS element is the TF coil joint (flex bus assembly) and testing of the new TF coil joint design.

For the NSTX Upgrade Project a new TF Inner Leg will be fabricated. This WBS element includes the design of the TF Bundle, the TF flex bus and flex bus supports and includes all analytical and CAD design efforts for these components. It also includes the early procurement of the TF conductor [80 lengths] and procurement of the TF flex bus and supports. It does not include the procurement/fabrication of the Inner TF bundle, which is included as part of the OH procurement in WBS 1.1.3.3.2.
{Inner Toroidal Field Bundle (Job 1304)}

. For the NSTX Upgrade Project a test stand to measure the required performance parameters on the new NSTX TF joint design will be designed and fabricated. Test parameter measurements and cyclic lifetime tests of the new TF joint will be performed and testing data will be compiled. The test stand will be modified for revised design configurations as needed and tests repeated with a final comprehensive test report generated that includes all test data.
{TF Joint Stand & Performance Test (Job 1303)}

WBS Element: 1.1.3.3.2 **WBS Level: 5**
WBS Title: Ohmic Heating Solenoid

Definition: The ohmic heating solenoid subsystem consists of the new coils that will make up the center solenoid. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication.

For the NSTX Upgrade a new OH Solenoid will be fabricated. This WBS element includes the design & fabrication of a new OH solenoid and associated components including a belleville washer spring assembly and support structures for the NSTX upgrades. It also includes all analytical & CAD design efforts. Includes advance procurement of the copper conductor and co-wound [glass/Kapton] insulation. Also includes the procurement of the Micro-therm insulation, conductive paint.
Includes the procurement and engineering oversight for the combined OH

and TF bundle assembly. A single vendor will fabricate both components. {Ohmic Heating Solenoid (Job 1305)}

WBS Element: 1.1.3.3.3 **WBS Level: 5**
WBS Title: Inner Poloidal Field Coils
Definition: The inner poloidal/shaping coils subsystem consists of the new coils that will make up the poloidal field coils 1A, 1B and 1C. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication.

For the NSTX Upgrade three new sets of inner poloidal field coils will be installed. This WBS element include the design and procurement of the Inner poloidal field coils and supports which includes all analytical and CAD design efforts for these components. It includes the early procurement of the PF conductor and co-wound [Glass/Kapton] insulation. {Inner Poloidal Field Coils (Job 1306)}

WBS Element: 1.1.3.3.4 **WBS Level: 5**
WBS Title: Center Stack Casing and Assembly
Definition: This WBS element includes the design and fabrication of the Center Stack casing and ceramic break assembly for the upgraded Center Stack as well as the assembly of the new Center Stack.

The Center Stack Casing effort includes analysis and CAD design for the casing components; the procurement of the Inconel tubing, forgings, bellows and organ pipes; the fabrication of Center Stack support legs; the procurement/fabrication of a new ceramic break assembly; the in-house assembly of the casing components; and mounting of the PF1A and PF1B structure/coils to the casing.
{CS Casing (Job 1307)}

The Center Stack Assembly effort involves all activities associated with the assembly of the Center Stack and includes design modifications and upgrade of the coil assembly stand; procedures for assembling the Center Stack and for installation; assembly of the Center Stack components including the OH/TF coil supports, mounting of the surface diagnostics and thermal blanket, inconel casing and inner PF coils and setup and tear down of the Center Stack assembly area.
{Center Stack Assembly (Job 1302)}

WBS Element: 1.1.3.4 **WBS Level: 4**
WBS Title: Coil Bus Runs
Definition: This WBS element includes the design and fabrication of the coil bus runs/supports between the NSTX coils and the FCPC cable terminations located in the NSTX test cell.
{Coil Bus Runs (Job 5501)}

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

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 2nd NBI Services; the NBI armor modifications; the 2nd NBI Power, Controls and Instrumentation; the 2nd NBI Duct and vacuum vessel modifications; and the NSTX Test Cell equipment removals and relocations necessary to accommodate the 2nd NBI. Vacuum Pumping System Modifications necessary to accommodate the 2nd 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 2nd 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

replacing copper impinged parts as required and refurbishment of the seals, thermocouple wiring, and bellows (cal and spool) as needed.
{NSTX Beamline 2 Refurbishment (Job 2440)}

Also included in this WBS element are the efforts necessary to relocate a TFTR neutral beam line and ancillary equipment into the NSTX test cell. This includes High Voltage Enclosures (HVEs) and the complete beam box.
{NSTX Beamline 2 Relocation (Job 2425)}

WBS Element: 1.2.4.5 **WBS Level: 4**
WBS Title: NSTX Beamline 2 Services
Definition: This WBS element includes the efforts to provide services to the new neutral beam beamline and ancillary equipment in NSTX test cell. These services include water, cryogenic systems, gas supplies, and vacuum lines.
{NSTX Beamline 2 Services (Job 2450)}

WBS Element: 1.2.4.6 **WBS Level: 4**
WBS Title: NBI Armor
Definition: This WBS element includes the design, fabrication, and installation of upgraded and relocated neutral beam armor including cooling and instrumentation work.
{NBI Armor (Job 2460)}

WBS Element: 1.2.4.7 **WBS Level: 4**
WBS Title: NBI Beamline 2 Power and Controls
Definition: This WBS element includes providing power, controls and instrumentation for the 2nd Neutral beamline.

Included in this WBS element is providing power for the NBI beamline 2. NB2 is planned to be powered from the TFTR NB4 A, B, & C line ups. The electrical equipment in these line ups will be reactivated. The TFTR NB4 HVEs will be relocated to the NSTX Test Cell as part of WBS element 1.2.4.4. New triax cables will be installed with terminations from the Modregs to the HVEs. New Decel coaxial cables will be installed from the Decel supplies to the Sources. The Arc, Filament, Magnet, and the 208 feeds, to HVEs cables, will be spliced in the TFTR Test Cell basement to new cabling designed and installed from the TFTR Basement to the NSTX Test Cell. The fiber cables also will be spliced with additional lengths recovered from other TFTR line ups. The AC auxiliaries and Grounding for the NB2 will be designed and installed.
{NBI Power System (Job 2470)}

Also included in this WBS element are the controls and instrumentation for the NB2. The work covers PLC, programming, control racks, new thermocouples, TC scanner, miscellaneous controls, and control cabling. The work also includes the gradient grid upgrade. System integration and testing will also be performed as part of this effort.

{NBI Controls & Instrumentation (Job 2475)}

WBS Element: 1.2.4.8 **WBS Level: 4**
WBS Title: NSTX Beamline 2 Duct & vacuum Vessel Modifications
Definition: This WBS element includes the design, and fabrication of all components connecting the Neutral Beam Box to NSTX, and the connecting ductwork and modifications to NSTX Vacuum Vessel to accommodate the second beamline.
{NSTX NB2 Duct & VV Mods (Job 2480)}

WBS Element: 1.2.4.9 **WBS Level: 4**
WBS Title: NSTX Test Cell Equipment Removals/Relocations
Definition: This WBS element covers moving of racks and diagnostics to clear space in the NSTX Test Cell (NTC) for the second Neutral Beamline. Racks to be removed and re-installed in a new location are #419, 431-435, 440-445, 447-449, 488. Racks 456 and 489 will be removed and excess. This scope also includes the fabrication and installation of five sections of platform at elevation 118' on the west side of the NTC to accommodate the racks being re-installed in the NTC. Racks #441-445 will be relocated to the Gallery east of the NTC. Diagnostics to be removed are those from the midplanes of Bay J and Bay K as well as those on the present pump duct. The diagnostics from Bay J will be re-installed ~5" outboard of their present position. IR windows and the Transmission Grating Spectrometer will be relocated to the new NB duct. Ion gages, filaments and the RGA will be relocated to the new pump duct under the NB2 duct. SPRED and LOWEUS will be relocated to Bay L. The Thomson Scattering Beam Dump Window will be relocated to between Bays K and L.
{NTC Equipment Removals/Relocations (Job 2490)}

WBS Element: 1.3 **WBS Level: 2**
WBS Title: Auxiliary Systems
Definition: The auxiliary systems include all the mechanical non-torus support systems for NSTX. This WBS element includes the Vacuum Pumping System, the Coolant Systems, the Bakeout Heating System, Gas Delivery System and the Glow Discharge Cleaning System. The scope of the work contains engineering design, R&D, mockups, procurement activities, component fabrication, and System Testing. Installation of the WBS 3 systems is included in the individual WBS 3, level 3 elements.

WBS Element: 1.3.1 **WBS Level: 3**
WBS Title: Vacuum Pumping System
Definition: The Vacuum Pumping System provides the source and distribution of all vacuum pumping to NSTX. This includes the roughing pumps as well as the turbo pumps and any backing pumps to:

- Provide the initial high vacuum environment with minimum impurities for plasma formation;

- Evacuate the spent plasma constituents at the end of each pulse prior to the next plasma pulse;
- Remove impurities liberated during bakeout and/or discharge cleaning of the vacuum vessel interior; and
- Provide instrumentation and a Residual Gas Analyzer.

This WBS element also includes the controllers for all pumps and any baffles for backstreaming.

In order to accommodate the installation of the 2nd NBI on NSTX the existing Vacuum Pumping System will be modified. This WBS element includes the design, fabrication, and installation of a new vessel pumping system and includes new pump ducts off of the Neutral Beamline 2 duct, mechanical and electrical isolation of the system, vacuum diagnostic relocation, magnetic shielding and support of TVPS TMPs, and TMP service connections.
{NSTX NB2 TVPS (Job 2485)}

WBS Element: 1.3.2 **WBS Level: 3**
WBS Title: Coolant Systems
Definition: The Coolant System provides cooling water to remove heat generated from NSTX systems during experimental operations. The systems include the:

- TF/PF bus and coil cooling water system;
- Center stack cooling water system;
- Component cooling water system; and the
- Ohmic heating cooling water system.

These systems will provide cooling water for normal operations and discharge cleaning of the vacuum vessel. This WBS includes engineering design, analysis, procurement activities, component fabrication and installation to the coil, bus and component cooling manifolds at the torus.

The new Center Stack on NSTX will require modifications to the existing coolant system. This WBS element will provide water cooling services to the new Center Stack and ancillary equipment in the NSTX test cell.
{Water System Coolant Modifications for CSU (Job 3200)}

WBS Element: 1.3.3 **WBS Level: 3**
WBS Title: Bakeout Heating System
Definition: The Bakeout Heating System provides a heating system to bake out the vacuum vessel. It includes a heating blanket system for the vacuum vessel and the insulation for that system. It includes a supplementary heating system for the center stack coil subsystems. The controls and interlocks for safe operation of this system is included. This WBS element includes the engineering design, analysis, procurement activities and component fabrication.

This WBS element includes the purchase of a new more powerful power supply, to replace the existing one, to be used for electrical heating of the vessel. It is proposed to buy a 0-8V, 8000 amps for the application. Suitable cable leads will be fabricated and necessary interlocks will be incorporated.
{NSTX CSU Bakeout System Mods (Job 3300)}

WBS Element: 1.3.4 **WBS Level: 3**
WBS Title: Gas Delivery Systems
Definition: The Gas Delivery Systems provides storage and delivery of gases to and from NSTX systems during experimental operations. These systems provide:

- Storage of on-site inventories of gases for use in NSTX plasma physics and future neutral beam experiments;
- Delivery of prescribed quantities of gases at prescribed purity levels and flow rates;
- Delivery of gases continuously or in pulses of prescribed shape and duration; and
- Evacuation of delivery lines and components required for delivery.

This WBS includes engineering design, analysis, procurement activities, component fabrication and installation to the coil, bus and component cooling manifolds at the torus.

This WBS element includes the design, fabrication and installation, and test of two center stack fueling lines and modifications of the gas delivery assemblies.
{Gas delivery system modifications (Job 3400)}

WBS Element: 1.3.5 **WBS Level: 3**
WBS Title: Glow Discharge Cleaning System
Definition: The Glow Discharge Cleaning (GDC) System establishes and controls the GDC process in NSTX. GDC is a mode of vacuum conditioning in which the vacuum vessel internal surfaces are cleaned by the bombardment of ions formed during the glow process. This WBS includes engineering design, analysis, procurement activities, component fabrication and installation of the GDC system. There are no changes to the Glow Discharge Cleaning system as part of the NSTX Upgrade Project.

WBS Element: 1.4 **WBS Level: 2**
WBS Title: Plasma Diagnostics
Definition: The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The near term emphasis will be on detailed measurements of plasma profiles, using equipment presently available at PPPL. The long term objective will be to provide input for advanced plasma control systems, using new concepts and systems developed by the national NSTX team.

WBS Element: 1.4.1 **WBS Level: 3**
WBS Title: Plasma Diagnostics
Definition: The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The diagnostic subsystems included in this WBS are:

- Magnetic measurement diagnostics;
- Current density profile diagnostics;
- Laser and microwave diagnostics;
- Visible and total radiation diagnostics;
- Ultra violet and x-ray diagnostics;
- Particle measurement diagnostics;
- Divertor diagnostics; and
- Plasma Edge and vacuum diagnostics.

The NSTX Center Stack Upgrade will require new magnetics diagnostics to be installed This WBS element includes the design and fabrications of Center Stack magnetics diagnostics to replace units removed with the old Center Stack. Installation of these diagnostics is included in WBS element 1.1.3.3.4.
{Center Stack Upgrade Diagnostics (Job 4100)}

WBS Element: 1.5 **WBS Level: 2**
WBS Title: Power Systems
Definition: The Power Systems WBS element includes the engineering, design, prototyping, procurement and installation of all the systems and related elements that provide conditioned electrical power and energy to the NSTX systems. It includes the AC Power Systems, the AC/DC Convertors, the DC Systems, the Control and Protection System, and System Design and Integration.

WBS Element: 1.5.1 **WBS Level: 3**
WBS Title: AC Power Systems
Definition: The scope of the AC Power Systems WBS element is to provide the supply and distribution of all AC power to NSTX. This includes all the experimental and auxiliary loads.

WBS Element: 1.5.2 **WBS Level: 3**
WBS Title: AC/DC Converters
Definition: The scope of the AC/DC Converters WBS element is to reactivate existing AC/DC Converters that have not been used since the shutdown of TFTR for use by NSTX.

WBS Element: 1.5.3 **WBS Level: 3**
WBS Title: DC Systems
Definition: The scope of the DC Systems WBS element is to receive AC input power and deliver controlled DC output power to the NSTX coil systems. This

includes power cabling changes, DC Reactor changes, associated raceway changes, and changes required in the Power Cable Termination Structure (PCTS) inside the NSTX Test Cell.

WBS Element: 1.5.4 **WBS Level: 3**
WBS Title: Control and Protection System
Definition: The scope of the Control and Protection System WBS element is to control and protect the power loop components for all magnet circuits. This includes the design of hardwired interlock system, kirk-keys, real time controls, the PC Link, Firing Generator, and Fault Detector changes, measurement of signals, changes to existing coil protection devices and design of a new digital coil protection system.

WBS Element: 1.5.5 **WBS Level: 3**
WBS Title: General Power Systems and Integration
Definition: This WBS element covers general power systems activities including interaction with the designers of other WBS elements, design review support and procedure preparations as well as the administrative and supervisory efforts for the NSTX Power Systems.

The Center stack upgrade entails the TF feed to be 1kV, 129.8kA for 7.45 seconds every 2400 seconds. Design shall be such that the pulse period can be reduced to 1200 seconds. This requires complete redesign of the TF power system. Replacement of the fault detector (FD) and the Firing generator (FG) is required for fast and reliable response to fault conditions. The HCS will be upgraded with a PLC. The OH power supply will be also redesigned to have the capability of 8kV, +/-24kA; the FD and FG of the OH system will also be changed. OH CLRs will be replaced with calculated optimum requirements. A Digital Coil Protection (DCP) System will be designed and implemented.
{NSTX Center Stack Upgrade Power Systems (Job 5000)}

WBS Element: 1.6 **WBS Level: 2**
WBS Title: Central Instrumentation and Controls (I&C)
Definition: The scope of this WBS element is to develop a Central Instrumentation and Control (I&C) System that will provide remote control, monitoring, data acquisition and data management for the NSTX subsystems during machine operation. The Central I&C System will be developed, to varying degrees, in conjunction with all other WBS elements and will consist of two major elements: the Control System and the Data Acquisition System. Local I&C system controllers, field instrumentation and wiring are included in the individual subsystems.

The NSTX Upgrade will be capable of producing plasmas on the order of 10 seconds; to-date they are less than two seconds. This WBS element includes the modifications to the Central I&C System to support the NSTX Upgrade. For dozens of CAMAC and PC-based data acquisition systems this will require an upgrade, and in some cases replacement. The

real-time plasma control system may require an upgrade to accommodate additional input/output signals, control loops, and a longer control period. The networks, back-end compute servers, and data storage systems will need to be upgraded to achieve reasonable performance for time-sensitive functions. Some test cell racks will be relocated; there will be a modest effort required to route the control, timing, and communication cabling and qualify the systems.
{Central I&C and Data Acquisition (Job 6100)}

WBS Element: 1.7 **WBS Level: 2**
WBS Title: Project Support & Integration
Definition: Project support and integration includes the non-hardware related subsystems such as overall Project Management and Administration, Project Physics as well as Integrated Systems Testing support.

WBS Element: 1.7.1 **WBS Level: 3**
WBS Title: Project Management and Integration
Definition: The project management and integration WBS element consists of all the activities necessary to plan, monitor, integrate and control, and report on the progress of the NSTX Upgrade Project which includes technical, business, and administrative planning and support; organizing, directing, coordinating, controlling, reviewing and approving project actions.

WBS Element: 1.7.1.1 **WBS Level: 4**
WBS Title: Project Management & Integration
This WBS element includes overall management; a Project Manager, Deputy Project Manager, and Project Controls support to manage, monitor, integrate, control, and report on the progress on the NSTX Upgrade. Also included in this WBS element is System Engineering support and support for updating of the General Arrangement Drawings for the NSTX Test Cell as well as funds for independent reviewers as necessary.
{Project Management and Integration (Job 7100)}

WBS Element: 1.7.1.2 **WBS Level: 4**
WBS Title: Center Stack Upgrade Management
Definition: Level of Effort job to cover the oversight of Center Stack Upgrade work which includes a Manager, Project Engineering support and support and to cover Center Stack engineer's time to prepare for and participate in project cost and schedule reviews.
{NSTX CSU Project Management (Job 7200)}

WBS Element: 1.7.1.3 **WBS Level: 4**
WBS Title: Neutral Beam Upgrade Management
Definition: Level of Effort job to cover the oversight of the 2nd Neutral Beam Upgrade work which includes a Manager, Engineering support and support and to

cover Neutral Beam engineer's time to prepare for and participate in project cost and schedule reviews.
{NBI Project Support & Integration (Job 7300)}

WBS Element: 1.7.1.4 **WBS Level: 4**
WBS Title: Health Physics Support
Definition: This WBS element includes the effort necessary for continuous health physics (HP) support for the Neutral beamline decontamination, refurbishment, and relocation to the NTC as well as the HP support for equipment removal and relocations being accomplished under WBS 1.2.4.
{Health Physics Technical Support (Job 7400)}

Also included in this WBS element are the home office Health Physics efforts necessary to support the collection of radiological analyses of various environmental samples and bioassay samples, and the collection of analyses of data on the gamma radiation spectra of radioactive material at PPPL that are allocated to all Laboratory projects based on their usage of Health Physics staff.
{NSTX Upgrade Health Physics Allocations (Job 7700)}

WBS Element: 1.7.1.5 **WBS Level: 4**
WBS Title: Direct Allocations (Job 7710)
Definition: This WBS element includes the costs to cover Laboratory Engineering and Scientific Computing and Environmental Services that are allocated to all Laboratory projects based on their funding levels.
{NSTX Upgrade Direct Allocations (Job 7710)}

WBS Element: 1.7.2 **WBS Level: 3**
WBS Title: Project Physics
Definition: Project Physics includes the definition of requirements necessary to meet the overall NSTX mission and supporting objectives, physics analysis supporting the project's design and construction activities, and definition of R&D needs. In addition it includes the provision of hardware and software required for plasma control.
Project Physics is not included in the scope of the Upgrade Project.

WBS Element: 1.7.3 **WBS Level: 3**
WBS Title: Integrated Systems Tests
Definition: This element includes all of the activities associated with the support of development of all necessary procedures and documents to support the integrated tests, and to support performance of the pre-operational integrated system tests culminating in first plasma.

The WBS element includes Convening the NSTX Activity Certification Committee (ACC) for comprehensive review the upgrades. Prepare and make presentation to the PPPL ES&H Executive Safety Board for

issuance of appropriate Safety Certificate parameters for operation of NSTX with new enhanced operating capabilities; preparation of documentation (procedures) for safely integrating the upgrades for operations within NSTX safe operating parameters; working with NSTX Operations Group for the successful integration of the upgrades.
{Integrated Systems Test (Job 7900)}

WBS Element: 1.8 **WBS Level: 2**
WBS Title: Site Preparation and Assembly
Definition: Site preparation and torus assembly includes modifications to the existing NSTX Test Cell components and subsystems and the assembly and installation of all Torus Systems (WBS 1.1). Modifications to other PPPL facilities, components, and subsystems outside the NSTX Test Cell and the assembly and installation of non-torus components and subsystems are included in the individual components and subsystems.

WBS Element: 1.8.1 **WBS Level: 3**
WBS Title: Site Preparation
Definition: This WBS element includes construction of the NSTX machine platform and the modifications to the NSTX Test Cell. There are no activities in this WBS element as part of the NSTX Upgrade Project. NTC equipment removals, relocations and platform modifications necessary to support installation of the 2nd NBI are included in WBS element 1.2.4.2.

WBS Element: 1.8.2 **WBS Level: 3**
WBS Title: Torus Assembly and Construction
Definition: Torus Assembly and construction includes the assembly and installation of the NSTX torus, coils systems and all associated supports including construction management. This WBS element includes removal of equipment for clearance and accessibility, moving existing coils, cutting off existing supports mounted on the vacuum vessel and installing a new external cage support structure and reinstalling, testing and commissioning the equipment removed.
{Installation of the Coil Support System (Job 8200)}

Also included in this WBS element is the removal of the existing Center Stack and installation of the NSTX Upgraded Center Stack, followed by closing up the vacuum vessel, pumping down, leak checking, bakeout and machine area scrubs to be ready for Integrated System Testing.
{CS Removal & Re-Installation/Pumpdown/Bakeout (Job 8250)}