National Spherical Torus Experiment

NSTX UPGRADE PROJECT

HAZARD ANALYSIS REPORT

November 9, 2011

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NSTX Upgrade Project Hazard Analysis Report

1. INTRODUCTION

This document comprises the Hazard Analysis Report for the National Spherical Torus Experiment (NSTX) Upgrade Project required by DOE O 413.3B, "Program and Project Management for the Acquisition of Capital Assets". This Hazard Analysis Report will support the revision to the existing NSTX Safety Assessment Document (SAD) that will be done prior to Project Completion (CD-4).

2. PROJECT DESCRIPTION

The NSTX device has been in operation at the Princeton Plasma Physics Laboratory (PPPL) since 1999. The NSTX Upgrade Project will replace the current NSTX center stack (CS) assembly with a new larger radius CS assembly, and will add a second neutral beamline (NBL) formerly used for the Tokamak Fusion Test Reactor (TFTR) Project onto the NSTX experiment. These upgrades will contribute to understanding Spherical Torus (ST) configuration physics by allowing: (1) study of high beta (ratio of plasma pressure to magnetic field pressure) plasmas at reduced particle collisionality; (2) assessment of full non-inductive current drive operation; and (3) prototyping of heat and particle exhaust solutions for next-step facilities. Descriptions of the existing NSTX experiment and facility can be found in the NSTX Safety Assessment Document (SAD). Details on the specific construction/installation work tasks that will be undertaken for the NSTX Upgrade Project can be found in the Scope of Work section of the "Health and Safety Plan for NSTX Upgrade Project Tasks in the NSTX Test Cell".

2.1 Center Stack (CS) Assembly

The new CS Assembly will provide higher toroidal magnetic fields (1 Tesla) and plasma currents (2 MegaAmperes) than presently attainable, and would allow these parameters to be maintained for longer time periods (5 seconds) than currently possible on NSTX. This would allow production of higher temperature plasmas to reduce collisionality of plasma particles (thereby providing hoped for enhanced confinement), as well as more efficient non-inductive current drive sources and better plasma performance.

Work activities include installations of:

- New Toroidal Field (TF) Hub Assembly
- New TF Flag Assemblies
- New Ceramic Break
- New Inner TF Bundle

- New Ohmic Heating (OH) Coil
- New Inconel Casing and Insulation
- New Plasma Facing Component (PFC) Tiles
- New Poloidal Field (PF) 1a, b & c Coils

In addition, the following will be accomplished:

- Install reinforcements to existing coil structures (umbrella structure, outer TF coil legs, and possibly the vacuum vessel) to handle the increased magnetic loads
- Install new PF/TF/OH bus connections
- Repair leaks and improve the existing cooling water system to cool the outer TF coil legs separately from the inner legs
- Replace the Center Stack Diagnostics
- Upgrade the TF Coil power supply to support full field capability of 1 Tesla

2.2 Second Neutral Beamline

The second neutral beamline (NBL), which was formerly used in the Tokamak Fusion Test Reactor (TFTR) experiments, will provide up to two times higher plasma current drive efficiency and current profile control than currently available with only the existing one NSTX NBL. This will enhance heating and current drive for plasma start-up, sustainment, heat flux. and transport studies.

Many of the necessary activities involve duplicating the services and equipment already provided for the existing NSTX NBL to facilitate operation of the second NBL.

Work activities include:

- Evaluation and refurbishment of internal NBL components, as needed (e.g., cryo-pumping panels, bending magnets, etc.)
- Relocation of one NBL from the former TFTR Test Cell to the NSTX Test Cell
- Provision of a second set of NBL services, i.e., power, water, vacuum and cryogenics, for operation
- Modification of the NSTX Bay K port and fabrication and installation of a duct assembly to connect the second NBL to the NSTX torus
- Refurbishment and installation of existing neutral beam ion sources onto the second NBL

- Installation of tiled water-cooled armor plating inside the NSTX torus to protect in-vessel impinged surfaces
- Routing high voltage power supplies and neutral beam controls to the NSTX Test Cell, and installing/re-commissioning existing High Voltage Enclosures and transmission lines
- Relocating the present NSTX torus vacuum pumping duct, vacuum control systems, gas injection systems, and diagnostic systems displaced by the addition of the second NBL
- Reworking of NSTX platforms and modification of the fire detection and suppression systems under the platforms

2.3 Nuclear Facility Analysis

The NSTX Upgrade Project was assessed by PPPL in 2009 with regard to the status of NSTX as a Below Hazard Category 3 Facility (Ref: Letter, A. Cohen to J. Makiel, 7/8/09). It was determined that based on the classification criteria of DOE-STD-1027-92, NSTX would continue to be designated a Below Hazard Category 3 Facility after implementation of the Upgrades, and the requirements of 10CFR830 Subpart B would not be applicable.

3. OPERATIONAL READINESS PROCESS

PPPL uses ESHD 5008 (PPPL Environment, Safety & Health Manual) Section 11 ("Operations Hazard Criteria and Safety Certification") as part of its implementation of the Integrated Safety Management (ISM) Guiding Principle for Operations Authorization of experimental projects. The approval process to commence NSTX operations after the Upgrades are in place will follow the applicable provisions of PPPL ESHD 5008 Section 11, which include:

- Preparation and review of the revised NSTX SAD and its approval by the PPPL Safety Review Committee.
- NSTX Activity Certification Committee (ACC) safety review of planned NSTX operations with the Upgrades. The members of the NSTX ACC include both PPPL and DOE Princeton Site Office (PSO) personnel that have been appointed by the PPPL ES&H Executive Board (ES&H/EB), which consists of senior Laboratory managers and is chaired by the Deputy Director for Operations. The NSTX ACC will review the revised NSTX SAD, preoperational test plans, and operating procedures relevant to the safe conduct of NSTX Upgrade operations. It will also include one or more safety walkthroughs to review the physical aspects of the Upgrades.
- A report by the ACC to the PPPL ES&H Executive Board (ES&H/EB) on the findings of its safety review, which will include a recommendation on a revision to the existing

NSTX Safety Certificate that would authorize NSTX operations with the Upgrades, and any relevant conditions or limitations on those operations.

- If approved by the ES&H/EB, issuance of the revised NSTX Safety Certificate authorizing operations with the Upgrades. This step would also be dependent on the outcome of a planned DOE Operational Readiness Assessment (ORA), as indicated in the June 30, 2010 letter from J. Faul to S. Prager (Subject: "NSTX Upgrade Project – Operational Readiness Assessment"). In accordance with this letter, the ORA will occur prior to CD-4.

4. HAZARD ANALYSIS

Hazards associated with the construction/installation, operation and decommissioning of the NSTX Upgrade Project have been evaluated and potential impacts and their mitigation assessed. In addition, the risks posed by each hazard, both pre- and post- mitigation, have been determined based on the risk approach documented in Attachment 1 of PPPL Procedure ENG-032, "Work Planning Procedure", which is reproduced below. Risks are characterized as Standard, Serious or Major.

Risk Type	Level 1. Major	Level 2. Serious	Level 3. Standard
Mission / Program Impact	Potential for failure to cause (1) Significant adverse impact (≥6 months) to completion of a PPPL Project or/collaboration, or to achieving key performance goals/milestones, or (2) Halt of operations for greater than six months (3) Failure to meet DOE or Presidential milestones.	Potential for failure to cause (1) Moderately adverse impact (3-6 months) to a PPPL Project/collaboration (2) Halting, delaying or significantly limiting operations for 1-6 months, or (3) Failure to meet FWP or PEP approved performance goals.	Potential for Minimal impact to a PPPL task, system, component or operations due to a failure.
Environment, Safety, Health and Security	Potential for failure to cause (1) Death, total disability or other severe adverse impact on the health or safety of a worker or the public, (2) Exposure/release to/of radiation or radioactive or hazardous material ≥ 50% of PPPL or regulatory limits, or (3) Environmental damage beyond site boundary or requiring cleanup costs greater than $250k.	Potential for failure to cause (1) Lost time injury or illness, (2) Exposure/release to/of radiation or radioactive or hazardous material <50% of PPPL or regulatory limits but ≥10% of those limits, or (3) On-site environmental damage requiring cleanup costs less than $250k but ≥$25k. (4) Threat to nuclear material (tritium); threat to sensitive equipment, parts and technology	Potential for failure to cause (1) Injury or illness not resulting in lost time, (2) Exposure/release to/of radiation or radioactive or hazardous material <10% of PPPL or regulatory limits, or (3) Negligible impact on the environment that can be mitigated completely at costs <$25k.
Cost (includes all costs – design, mfr, etc.)	Potential for failure to cause financial loss or damage to a facility or equipment of $1,000,000 or more.	Potential for failure to cause financial loss or damage to a facility or equipment of $250,000 -$1,000,000.	Potential for failure to cause financial loss or damage less than $250,000.
Compliance	Potential for inadvertent noncompliance with local, state or federal laws, regulations, contract requirements, or DOE requirements that result in fines or disciplinary actions or require emergency notification of a regulatory agency.	Potential for inadvertent noncompliance with regulations or administrative orders resulting in notification of regulatory agency (e.g., Notices of Violation/Deficiency) or requiring non-routine reporting to an agency.	Potential for minor noncompliance with established management practices, policies or procedures.

Hazard	Identification, Mitigation and Risk Analysis
Ionizing Radiation	_ Operation of NSTX with the Upgrades is expected to increase ionizing radiation via enhanced neutron generation by up to a factor of 40 on an annual basis, compared with pre-Upgrade operations. This will result in the generation of up to 4.0E18 DD neutrons/yr and an estimated maximum of 0.1938 Ci/yr of tritium from the D-D reactions. If this tritium produced were released to the environment via the D-Site stack, the dose at the nearest business would be ~5E-4 mrem/yr. Note that the 40CFR61 Subpart H limit is 10 mrem/yr, and EPA approval to construct is required at 0.1 mrem/yr. The maximum offsite dose from Upgrade operations will be (scaled based on NSTX SAD Table 3) 6E-3 mrem/yr (limit is 10 mrem/yr). Upgrade Project operations will also result in some increased gamma radiation generation from plasma operations, increased activation of NSTX components and some tritium contamination of internal NSTX components, particularly the torus vacuum vessel interior. This increase in activation radionuclides and tritium generated by Upgrade Project operations will not change the current NSTX designation as a Below Category 3 Facility (see Section 2.3 above). _ Pre-mitigation risks to workers and public/environment are: Standard for construction/installation, Major for workers and Standard for public/environment for operations, and Standard for decommissioning. _ Mitigation will include the following: the NSTX Test Cell (NTC) walls, floor and roof are constructed of reinforced concrete with thicknesses ranging from 2 ft (floor) to 5.5 ft (roof high point), which provides shielding (whose effectiveness will be evaluated against the relevant design objectives in 10CFR835.1002); personnel occupancy of the NTC will be excluded and other areas deemed necessary by the PPPL Health Physics Division will be controlled by engineered and/or administrative means (based on evaluation of exposure levels in areas external to the NTC) during plasma operation and neutral beam conditioning; the Health Physics Division will regularly monitor and survey NSTX radiation and contamination levels and needed radiological controls will be imposed on potentially exposed workers in accordance with PPPL policies and procedures (including the DOE approved PPPL Radiation Protection Program and ESHD 5008 Section 10) during all phases; radiation monitoring of potentially exposed NSTX workers will continue; and monitoring of tritium releases to the

Hazard	Identification, Mitigation and Risk Analysis
	environment (air and water) will continue to ensure low impacts and compliance with 5008 Section 10 requirements. _ Post-mitigation risks to workers and public/environment are Standard for all phases of the Upgrade Project.
Electrical	_ High voltage electrical equipment is present in the NSTX Test Cell (NTC) and other areas associated with NSTX (e.g., Field Coil Power Conversion Building, Neutral Beam Power Conversion Building, Motor Generator Building). Most of this equipment, particularly external to the NTC, is in enclosed cabinets, but shock, burn and/or arc flash hazards are present particularly under faulted conditions. Hazards are enhanced when work is being done on or near electrical equipment. _ Pre-mitigation risks to workers are Major for construction/installation, operations and decommissioning. _ Mitigation for construction/installation and decommissioning will include use of Job Hazard Analyses (JHAs) to assess specific hazards and control measures, following of lockout/tagout procedures per ESH-016, adherence to electrical safety provisions of ESHD 5008 Section 2 and installation procedures (which apply requirements of NFPA 70 and 70E), use of GFCI extension cords for all 100V power tool connections, and electrical safety training of workers per ESHD 5008 Section 2 Chapter 3. _ Mitigation for operations will include selection of electrical equipment and the design and construction of electrical distribution systems in compliance with national codes and standards wherever possible, controlling access to hazardous areas via the NSTX Safety System (Hardwired Interlock System and Safety Lockout Device) as described in the NSTX SAD, and isolating all instrumentation via optical and/or magnetic (magnetic transformer) means prior to exiting the NTC boundary to prevent electrical hazards from being transmitted outside the NSTX Test Cell (NTC) boundary. _ Post-mitigation risks to workers are Standard for all phases of the Upgrade Project.
Fire	_ Fire hazards during all phases include hot work activities that involve welding, plasma torch cutting, grinding and brazing. There will be more of these activities during the construction/installation and decommissioning phases than during operations (including maintenance periods and outages between runs). During the operation phase, fire risk also includes electrical faults, use of solvents for cleaning, use of pyrophoric Trimethylboron (TMB) for boronization, and use of

Hazard	Identification, Mitigation and Risk Analysis
	lithium which can react with moisture when unpassivated. _ Pre-mitigation risks to the facility and workers are Major for construction/installation, operations and decommissioning. _ Mitigation includes the NTC fire detection system, which consists of ionization smoke detectors and rate of rise heat detectors located at the ceiling and aspirated smoke detection (VESDA) under the platforms. NTC fire suppression is a pre-action type automatic water sprinkler system similarly located. In addition, fire dampers (with heat sensitive links) are included in HVAC ductwork where it penetrates the NTC wall. Mitigation for hot work will include use of JHAs, issuance of hot work permits, use of fire retardant clothing, and following provisions of ESHD 5008 Section 9 Chapter 15 on Welding, Cutting and Other Hot Work. Mitigation for TMB use includes use of procedures, low inventory of TMB, and use of leak detectors. Mitigation for lithium includes transport in sealed containers under argon atmosphere, venting (for lithium passivation) and cleaning of the vacuum vessel interior prior to worker entry, and presence of Class D (Lith-X) fire extinguishers during lithium handling activities. _ Post-mitigation risks to workers are Standard for all phases of the Upgrade Project.
Earthquake	_ PPPL is not located in a seismically active area. In the unlikely event of a serious earthquake, principle hazards include damage to buildings and/or structures, and harm to workers from falling objects. _ Pre-mitigation risks to the facility and workers are Major for all phases. _ Mitigation includes the following: the NTC, along with the rest of the D-Site experimental complex structures, has been determined to have adequate capacity to remain functional under the overall loads due to an earthquake with a horizontal ground acceleration of 0.13g. The NSTX platforms are designed for 0.09g, the seismic requirements of the NSTX torus structure. Equipment associated with the NSTX Upgrades are designed and built consistent with these requirements. Additional details can be found in the NSTX SAD. _ Post-mitigation risks to the facility and workers are Standard for all phases.
Vacuum Windows	_ Vacuum windows in the torus vacuum vessel are a potential hazard to personnel as well as to equipment. If a window fails there may be flying debris. If the opening is large enough, an individual may be drawn to, or into, the opening, potentially

Hazard	Identification, Mitigation and Risk Analysis
	causing injury. _ Pre-mitigation risk to workers during operations from uncovered windows is Major. There are no risks to workers for construction/installation and decommissioning (torus should be at atmospheric pressure during these phases). _ Mitigation is provided by protective covers on windows per ESHD 5008 Section 9 Chapter 14 (Vacuum Windows). _ Post-mitigation risks to the facility and workers are Standard.
Magnetic Fields	_ During NSTX operations, magnetic field hazards may exist from the mechanical forces (or interference) exerted by the magnetic field upon ferromagnetic tools and medical implants (e.g., cardiac pacemakers). Adverse effects may also be produced from forces upon implanted devices such as suture staples, aneurysm clips, and prostheses. In addition, touching ungrounded objects that have acquired an induced electrical charge in a strong sub-radiofrequency (≤30 kHz) magnetic field can result in electrical shocks. _ Pre-mitigation risk to workers for operations is Serious. There are no risks to workers for construction/installation and decommissioning (no magnetic fields). _ Mitigation is provided by preventing personnel from entering the NTC during plasma operations via the NSTX Safety System (Hardwired Interlock System and Safety Lockout Device) as described in the NSTX SAD. During a hot access (access while coils are energized but plasma formation is prevented), the magnetic field strength that personnel are exposed to will be controlled so as not to exceed the ACGIH threshold limit value for routine occupational exposure. See ESHD 5008, Section 4. _ Post-mitigation risks to workers are Standard.
Radiofrequency (RF) Fields	_ At sufficiently high intensities, exposure to RF fields can produce a variety of adverse health effects. Such effects include cataracts of the eye, overloading of the thermoregulatory response, thermal injury, altered behavioral patterns, convulsions, and decreased endurance. _ Pre-mitigation risk to workers for operations is Major. There are no risks to workers for construction/installation and decommissioning (no RF fields). _ Mitigation includes designs of RF systems with leakage levels that comply with IEEE Standard C95.1-1991 (outside the test cell), and these systems are routinely checked for leakage (see ESHD 5008, Section 4). In addition, RF transmission into the NTC is prevented by the Hardwired Interlock System whenever personnel have access to the NTC (see NSTX SAD).

Hazard	Identification, Mitigation and Risk Analysis
	_ Post-mitigation risks to workers are Standard.
Mechanical	_ Hazards include magnetically propelled projectiles, arc splatter due to magnet or electrical bus failures, and gas cylinder projectiles caused by sudden cylinder valve failure (e.g., due to falling of the cylinder and breakage of the valve). _ Pre-mitigation risks to workers are Major for all phases (note that magnets will not be energized for construction/installation and decommissioning phases, so the risk from this source will not be present at those times). _ Mitigation during operations is provided by preventing personnel from entering the NTC during plasma operations via the NSTX Safety System (Hardwired Interlock System and Safety Lockout Device) as described in the NSTX SAD. During a hot access into the NTC, personnel are required to stay in a protective enclosure to protect against magnetically propelled projectiles or possible arc splatter that may attend an electrical bus failure. During all phases, gas cylinders are stored/installed in accordance with PPPL safety procedures (ESHD 5008 Section 9 Chapter 2) to prevent breaking the cylinder valves, which could propel the cylinders due to a rapid release of gas. _ Post-mitigation risks to workers are Standard for all phases.
Hot Fluids	_ The NSTX Upgrade Project (as has the NSTX Project) will use a Low Temperature Bakeout Heating/Cooling System, which is run with water at temperatures up to 150°C, and a High Temperature Bakeout Heating/Cooling System, which uses pressurized helium at temperatures up to 420°C, to bakeout gases from the torus and plasma facing components. Hazards during the operations phase include burns due to contact with high temperature fluids or system components, and potential for injuries from contact with released pressurized helium (due to system leakage). _ Pre-mitigation risks to workers are Major for operations. There are no risks to workers for construction/installation and decommissioning (no use of bakeout systems). – Mitigation for operations includes the following: the Low Temperature Bakeout Heating/Cooling System was hydrostatically tested to at least 1.5 times its operating pressure prior to operations. The High Temperature Bakeout Heating/Cooling System was pneumatically tested to 1.3 times its operating pressure prior to operations. Procedures for operating these systems requires precautions to be taken to prevent personnel contact with hot surfaces, including restricting access to areas where hot pipe or components are present,

Hazard	Identification, Mitigation and Risk Analysis
	posting of warning signs, and personnel training. _ Post-mitigation risks to workers are Standard.
Gases/Cryogenics /Lithium	_ Gases used during NSTX operations include standard gases such as nitrogen, argon and helium, and specialized gases such as deuterium, sulfur hexafluoride (SF6) and Trimethylboron (TMB). Cryogens used for cooling of neutral beam cryopanels include liquid nitrogen and liquid helium. Lithium is applied to the interior of the torus and to plasma facing components to enhance plasma confinement. All of these have been used for years during NSTX operations and will continue to be used after the Upgrades have been installed. Hazards include asphyxiation (due to gas and cryogen releases), worker health effects from exposure to TMB, and "burn-type" injuries from contact with cold cryogenic liquids. Lithium hazards include fire or explosion hazards due to the high reactivity of lithium, and health hazards due to the corrosive and toxic nature of some stable end products of lithium reactions. Lithium will be passivated (reacted in a controlled fashion with moist air), cryogens will be warmed up and pumped out, SF6 will be removed back to gas cylinders outside the NTC, and TMB bottles will be stored outside the NTC for phases other than operations. _ Pre-mitigation risk to workers for operations is Major. There are no risks to workers for construction/installation and decommissioning. Systems and components handling SF6 (which is used as an electrical insulator in high voltage systems such as the neutral beam injectors) have been carefully examined for leakage potential and fittings tightened to reduce leakage of this greenhouse gas to the environment to the extent possible. _ Mitigation during operations is as follows: • The content of the largest gas cylinder (311 cubic ft.) constitutes less than 0.1% of the volume of the NTC (approximately 354,000 cubic ft.). Thus, oxygen concentrations in the NTC would remain at safe levels for personnel even if a gas cylinder's entire contents were released to the room. • Since SF_6 is heavier than air and can displace oxygen, leakage of the gas could be hazardous to personnel occupying an enclosed area below the leak point. Personnel protection is provided by strategic location of SF_6 detection in the NTC to provide local evacuation alarms.

Hazard	Identification, Mitigation and Risk Analysis
Gases/Cryogenics /Lithium	• Trimethylboron (TMB) used in the boronization process is toxic (7ppm TLV, based upon the TLV of the reaction product B_2O_3) and pyrophoric in air. Protective measures include low TMB inventory (≤50 g), prior leak checking of components that will be TMB pressurized above 1 atm, use of portable leak detectors, limiting NTC access during boronization to only TMB trained personnel, interlocks that halt TMB injection on loss of plasma discharge or glow discharge current, and nitrogen purging of the stack vent line during TMB injection. • Cryogenic system subsections which may be isolated by valves or other means are provided with pressure relief devices. Appropriate personal protective equipment (PPE) is used by personnel engaged in handling cryogenic fluids. Pressure relief devices have been installed to preclude rupture of sections of the system by excessive internal pressure. All piping has been designed for maximum operating pressure and tested in accordance with applicable ANSI codes. Only materials suitable for cryogenic service are used if in contact with cryogenic fluids or subject to cryogenic temperatures. Consequently, severe rupture of cryogenic system lines are highly unlikely. Assuming a catastrophic failure of a neutral beamline (NBL) released the entire contents of its liquid helium dewar (700 liters), liquid helium panels and piping (50 liters), and liquid nitrogen panels and piping (147 liters), a total of 22,040 cubic ft of gas would be released to the NTC. Assuming no active ventilation (and no other means of exhausting the evolved gas), and that only oxygen is displaced in the 354,000 cubic ft NTC, the concentration of oxygen in the NTC would drop from 20.9% to 19.6%, which is not considered oxygen deficient (per ESHD 5008 Section 8 Chapter 5). However, the operation of cryogenic system pressure detection, closure of system valving to isolate affected areas, presence of burst discs to relieve pressure, and the operation of NBL vacuum pumping systems to exhaust gas leaking into the beam box to the stack would be expected to prevent large scale releases to the NTC.

Hazard	Identification, Mitigation and Risk Analysis
Gases/Cryogenics /Lithium	• Lithium safety precautions include avoiding contact with sources of moisture, conducting fabrication and transport of pellet material under an argon atmosphere, receipt and disposal of lithium material in sealed containers, presence of special (LITH-X) fire extinguishers during lithium loading activities and transport to the NTC, venting & cleaning of the vacuum vessel prior to allowing worker entry after lithium experiments, and performing work activities according to approved procedures and using proper PPE. _ Post-mitigation risk to workers for operations is Standard.
Lasers	_ Several NSTX diagnostics use high energy Class IV and Class IIIb lasers, and will continue to do so during NSTX Upgrade operations. Lasers emit intense, coherent, electromagnetic radiation that is potentially dangerous to the eye and skin. Other hazards associated with lasers include electrical, fire, and chemical hazards. _ Pre-mitigation risk to workers for operations is Serious. There are no risks to workers for construction/installation and decommissioning (lasers will be non-operational). _ All lasers are operated and controlled under the Laboratory's Laser Safety Program, which is documented in ESHD 5008 Section 3 and is based on ANSI Z136.1. High energy laser diagnostics systems are operated by trained personnel under Laser Safe Operating Procedures (LSOPs) approved by the PPPL Laser Safety Officer. LSOPs specify protective measures to prevent laser exposures to personnel, and to isolate hazards during operation, maintenance and testing. Entry to the NTC during Multi Pulsed Thomson Scattering (MPTS) diagnostic laser operations (which includes a Class IV YAG laser system) are performed only under carefully controlled hot access conditions. _ Post-mitigation risk to workers for operations is Standard.

Hazard	Identification, Mitigation and Risk Analysis
Confined Spaces	– Entry to the torus vacuum vessel and neutral beam enclosures, which are confined spaces, will be required for construction/installation, operations and decommissioning. Hazards of entry to confined spaces include but are not limited to exposure to hazardous atmospheres, difficulty leaving the space (particularly in an emergency), and exposure to high voltage. _ Pre-mitigation risks to workers are Major. _ Mitigation is achieved through adherence to the PPPL confined space entry requirements outlined in ESHD 5008 Section 8 Chapter 5. These include mandatory confined space entry training for entrants, obtaining a confined space entry permit and following its steps prior to and during entry to a confined space, and designation of a safety watch outside the space. _ Post-mitigation risks to workers are Standard.
Material Handling (crane & rigging operations)	– Significant material handling via cranes and rigging equipment will occur during construction/installation and decommissioning, and some handling will also occur during operations (i.e., maintenance periods and outages between runs). Hazards during these activities range from minor injuries and/or minor property damage, to fatalities and/or major property losses. _ Pre-mitigation risks to workers and the facility are Major. _ Mitigation is achieved through application of the PPPL Hoisting and Rigging Program documented in PPPL procedure ENG-021, and the PPPL Hoisting and Rigging Standard (ES-MECH-007). ENG-021 describes the responsibilities and authorities for mechanical hoisting operation where rigging is required on the PPPL site. The Standard describes the requirements for mechanical hoisting operation, lift equipment inspection testing and maintenance, training and qualification for operating/using any lift equipment and procurement of rigging equipment or services. Only qualified crane operators may operate cranes at PPPL and only qualified riggers may perform rigging. _ Post-mitigation risks to workers and the facility are Standard.

Hazard	Identification, Mitigation and Risk Analysis
Waste Handling	_ Hazardous and low-level radioactive waste may be generated during all phases of the NSTX Upgrade Project. Hazards during these activities include potential exposures of workers to radiation, radioactive or hazardous chemical substances during handling activities; loss of control of material; and inadvertent transfer of waste to inappropriate locations or disposal facilities. _ Pre-mitigation risks due to the potential for regulatory non-compliances are Major; risks to workers, the public and environment are standard. _ Mitigation is achieved through implementation of the PPPL hazardous and radioactive waste procedures documented in Laboratory procedure EWM-001 (Hazardous Waste Management), policies and procedures for control of radioactive material documented in ESHD 5008 Section 10 and PPPL Health Physics Division procedures, and waste management and handling procedures of the PPPL Environmental Services Division. _ Post-mitigation risks are Standard.
Environmental	_ Environmental hazards for the NSTX Upgrade Project are discussed under Ionizing Radiation and Waste Handling above. A categorical exclusion under the DOE NEPA rule (10CFR1021) was determined and documented on 3/31/09. _ Environmental risks for all phases of the Project are Standard.
Chemicals	_ In addition to chemicals already mentioned previously, NSTX Upgrade activities will involve use of cleaning solvents (e.g., alcohol), hydrogen peroxide (3%), ozone, cutting fluids, cable pulling lubricants, Windex, Citro-clean, vinegar and distilled water. Hazards of chemical use are indicated on the Material Safety Data Sheets (MSDSs) for each chemical, which are required to be obtained by and available for each user per ESHD 5008 Section 8 Chapter 13 (ES&H Review of Procurements). _ Pre-mitigation risks vary from Standard to Major depending on the specific chemical. _ Mitigation includes the following: the safe handling and storage of chemicals must follow the safety requirements in ESHD 5008 Section 8 Chapters 1 (Chemicals) and 12 (Hazard Communication), and all chemical users must be trained per the requirements of Chapter 12. In addition, all chemicals purchased for use on the Upgrade Project (and at PPPL) must have a safety review by an Industrial Hygienist per ESHD 5008 Section 8 Chapter 13 (ES&H Review of Procurements). Specific control measures for chemical use for NSTX Upgrade

Hazard	**Identification, Mitigation and Risk Analysis**
	tasks are indicated on the Job Hazard Analysis (JHA) for each task, and are reviewed by workers during the pre-job briefings. _ Post-mitigation risks for all phases are Standard.
Elevated Work (Fall Hazards)	_ Fall hazards due to elevated work (including work from ladders, aerial lifts and scaffolds) will be present for much of the construction/installation and decommissioning activities, and to a lesser extent during operations (i.e., maintenance periods and outages between runs). Potential consequences range up to serious injuries and fatalities. _ Pre-mitigation risks are Major. _ Mitigation includes using personal fall arrest systems when working on equipment (e.g., top of the torus vacuum vessel) and on aerial boom lifts, installation of guardrail systems whenever possible, and using workers trained on ladder, scaffold, and aerial lift safety requirements of ESHD 5008 Section 9 Chapters 5 and 8. All personnel who will be performing elevated work requiring the use of personal fall arrest systems will also receive fall protection training per ESHD 5008 Section 9 Chapter 16. _ Post-mitigation risks for all phases are Standard.
Uneven Work Surfaces	_ Uneven work surfaces, which may be encountered by workers in the torus vacuum vessel, on or in a neutral beamline, or elsewhere in the NTC, can cause slips, trips and falls whose consequences range from minor injuries to fatalities. _ Pre-mitigation risks during all phases are Major. _ Mitigation will include installation of platforms to provide an even surface for workers whenever possible (e.g., inside the torus vacuum vessel), and marking of uneven surfaces to increase visibility. _ Post-mitigation risks for all phases are Standard.
Noise	_ Noise at high levels can cause hearing loss, interference with communication, and annoyance. During the NSTX Upgrade Project, noise hazards may be present from use of loud tools during any phase. _ Pre-mitigation risks for all phases are Serious. _ Mitigation for any potential exposures to high noise levels will include measurements and evaluations of noise levels by PPPL Industrial Hygiene; coordination among Industrial Hygiene, Occupational Medicine, workers and their supervisors to determine and implement the best approaches to mitigate exposures; and use of personal protective equipment (e.g., ear plugs) when necessary. The requirements of ESHD 5008 Section 8 Chapter 8 (Noise Control and Hearing Conservation)

Hazard	**Identification, Mitigation and Risk Analysis**
	will be followed. _ Post-mitigation risks for all phases are Standard.
Ergonomics	_ NSTX Upgrade Project tasks requiring repetitive motions, lifting and awkward positions can cause musculoskeletal injuries that can result in lost time from work. _ Pre-mitigation risks during all phases are Serious. _ Mitigation includes work breaks, lifting aids, and redesign of tasks (where possible) to minimize ergonomic hazards. Guidance for safe manual lifting is included in ESHD 5008 Section 9 Chapter 4. The Job Hazard Analysis form calls out ergonomics as a potential hazard to be considered in job planning, and contacting PPPL Industrial Hygiene for consultation is a control measure to be considered when this hazard applies. _ Post-mitigation risks for all phases are Standard.

5. SUMMARY

Proper system design, construction and the presence of features and processes that mitigate the effect of failures will ensure the safety of personnel during the NSTX Upgrade Project. During operations, personnel will generally be excluded from areas such as the NSTX Test Cell (NTC), the NSTX bus tunnel in the Test Cell Basement and other relevant areas when hazards exist, by the use of hardwired interlocks, procedures, signage, indicator lights and training. Entry to hazardous areas during all phases will be controlled and limited to trained personnel using carefully prescribed procedures and protective measures.

During the construction/installation and decommissioning phases, PPPL Safety Division representatives will periodically inspect the work site to determine that sufficient safety practices and equipment are in use. PPPL Health Physics Division representatives will provide support as needed for any radiological activities. Toolbox safety meetings will be held each week to discuss general safety issues. When a new task is begun and prior to each lift, a short pre-job briefing will be held to discuss procedures and the associated Job Hazard Analysis.

Occupational injuries and illnesses will be reported to the Laboratory Occupational Medicine Office, and will be subsequently investigated by the PPPL Safety Division and other relevant personnel for lessons learned (see ESHD 5008 Section 9 Chapter 10, "Accident Investigation", and PPPL procedure GEN-029, "Investigation and Follow-up of Adverse Events and Conditions"). NSTX Upgrade Project areas will also be periodically reviewed during Management Safety Walkthroughs per PPPL Policy P-084 ("Management Safety Walkthroughs") and line management reviews per PPPL Organization Document O-027 ("Line Management Safety Organization").

Implementation of the hazard mitigations described in this Hazard Analysis Report will maintain risks associated with the NSTX Upgrade Project at the Standard level.