NSTX

National Spherical Torus Experiment

NSTX

GENERAL REQUIREMENTS DOCUMENT

NSTX-RQMTS-GRD-018

Revision 2

December 8, 1998

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NSTX GENERAL REQUIREMENTS DOCUMENT

RECORD OF CHANGES

Revision	Date	CR	Description of Change
First Issue	12/10/96		
1	~~3/3/97~~ 3/3/98	003	1.1.2.b, added Day 0 and Day 1 categories; 1.1.2 c clarified diagnostics upgrades, added automatic GDC upgrade, added antenna upgrades; Table 1.1.2-1 clarified for up to 2 beamlines, clarified PFC/VV req'ts for NBI upgrade; revised fig 1.1.3.1; added 1.1.3 c and Table 1.1.3-2; added 1.1.4 c & d; 1.2.1 g & h revised wording; 1.2.2 a deleted reference to S-1 domes, f added isolation & grounding req'ts for CHI; 1.2.3.1 c deleted req't for galvanically separate PF circuits; 1.3.1 a deleted req't for shared RF usage w/PBX-M, b changed nomenclature to refer to 12 strap antenna, cdeleted requirement for subsets of sources at different frequencies; Table 1.5-1 complete revision; added 1.4.5 GDC, noted Day 1 Req't; 1.5 b changed AC rms to DC; 1.6.3 b added PF3 bipolarity requirement; 1.7.Noted Data Acquisition System Day 1 Req't, d Noted Day 1 Req't; 2.1.2.3 c added 25 year life req't for infrastructure changes; adde 2.1.2.3 e & f; 2.1.3.1 added "Upgrade"; 2.1.3.2 a deleted 15MW; 2.1.3.3 a added upgrade possibility of 2nd NB line; 2.1.3.5 added Automatic GDC Upgrade; 2.2.2 b revised CHI parameters; added 2.2.2 c; 2.2.4 a added possiblity of 2nd NB line; 2.3.3 Noted Day 1 Req't, revised 2.3.3 a; added 2.3.4; added 2.5; deleted 2.6.1 a,b,c,d; revised Table 2.6-1; 2.7.1 a specified field null target location; 2.7.4 a revised wording; added 2.7.5; 2.8 a changed disruption probability from 10 to 50%, changed rate from 0.5 to 1MA/ms;

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2	12/8/98	009 017 026 037	Revision 2 issued to correct typographic errors in Revision 1 date and footer date included in Revision 1. Revision 1 was issued as an attachment to CR-003. Revision 1 had incorrect date (3/3/97 should have been 3/3/98) and footer had incorrect date (October 20, 1997 should have been March 3, 1998). Incorporated the following approved CR's. CR-009-VV Upgrade (1.2.2 a deleted) CR-017 added PF-5 1.2.3a added PF5 & deleted 4a, Table 1.2.3.1-1 added PF5a&b and deleted PF4a, Table 1.2.3.1-2 added PF circuit 10, added 1.2.3.1g (designated existing 1.2.3.1g to h) CR-026 CHI power feed changes (1.6.4a and 2.2.2a) CR-037 Biasing outer VV for CHI (1.1.5b, 1.2.2d and 1.3.2a)

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Preface

The mission of the National Spherical Torus Experiment (NSTX) is to assess the physics performance of the Spherical Torus (ST) concept, in which the aspect ratio (ratio of major radius (R_0) to minor radius (a), R_0/a) is much lower than most machines built to date. Supporting objectives are to:

- Exploit techniques for non-inductive current drive and profile control that are consistent with efficient continuous operation of a fusion reactor without a central solenoid.
- Maximize the use of existing facilities and components so as to minimize the cost of the project.

Top-level performance requirements for NSTX, along with cost and schedule objectives, are included in the Project Definition Statement (PDS).

Operational requirements and physics performance objectives are given in the Project Requirements Document (PRD).

The General Requirements Document (GRD) defines the overall engineering requirements.

System Requirements Documents (SRD) and System Design Descriptions (SDD) shall be written for each major element of the Work Breakdown Structure (WBS) and shall provide the detailed basis for the engineering design of the machine.

The order of precedence for these requirements is the PDS, PRD, GRD, SRD, SDD.

1 Functions, Configuration & Essential Features

The functions, configuration and essential features of the NSTX machine and the various hardware elements of the WBS are outlined in the following.

1.1 General

1.1.1 Location

a. The NSTX machine shall be installed in the PPPL D-site Hot Cell, henceforth referred to as the NSTX Test Cell.

1.1.2 Design Basis and Upgrades

a. This GRD provides, in subsequent sections, the baseline requirements for NSTX and provides additional information concerning upgrades.

b. The baseline work scope is subdivided into two parts, namely that which shall be in place at the time of first plasma and funded within the Total Project Cost (TPC), henceforth referred to as Day 0 scope, and that which will follow as the operational research program progresses, henceforth referred to as Day 1 scope[1]. Unless otherwise specified herein, all requirements specified herein are applicable to the Day 0 scope. Day 1 items include the following:

- Glow Discharge Cleaning (GDC)
- Data Acquisition System
- Advanced Plasma diagnostics
    - IR Camera
    - Slow Diamagnetic Loop
    - Multichannel Bolometer
    - Survey Spectrometer (SPRED)
    - Soft X-Ray Imaging System
    - H_α detectors
    - CHERS
    - High-throughput CHERS background array
    - X-ray pulse height analysis
    - Neutral particle analyzer

[1]"Memorandum of Understanding Between PPPL and OFES on the NSTX Project Scope & Schedule", 3/1/98

- Visible spectrometer

Note: Vacuum Vessel interface (port covers with diagnostic attachment features) for the advanced plasma diagnostics listed above shall be included as part of the Day 0 workscope.

c. Upgrades consist of scope which is contemplated at present but may or may not be undertaken, depending on the evolution of the experimental program and the budgetary constraints. In order to minimize the life cycle cost of the NSTX program and make optimum use of the facility, the baseline design of NSTX shall not preclude the possibility of the upgrades, and shall facilitate the upgrades whenever possible and cost effective. Upgrades presently contemplated include the following:

- EC start-up upgrade
- Coaxial Helicity Injection (CHI) current sustainment
- Addition of Neutral Beam injection (NBI)
- Long pulse operation (with center stack replacement)
- Addition of pellet injector
- Plasma diagnostics upgrades
    - electron temperature profile measurement
    - plasma current profile measurement
- Automatic control for Glow Discharge Cleaning (GDC) between pulses
- Antenna tilting to align with the field lines
- Antenna bipolar drive

d. No design features related to the EC upgrade are required in the baseline NSTX facility.

e. Any design features related to the CHI current sustainment mode which are required on the torus and which cannot be readily added at a later date shall be included in the baseline. Design features on ancillary systems are not required for the baseline.

f. Design features related to the NBI upgrade and the plan for their implementation shall be as indicated in Table 1.1.2-1.

Table 1.1.2-1: Plan for NBI Upgrade Features

Design Feature	Schedule
Plasma Facing Components (PFC) additional power dissipation*	U
PFC protective armor for NB shine-through and inadvertent loading	U
PFC beam dumps	U
Vacuum Vessel (VV) additional power dissipation**	U
VV port compatibility and availability (up to two beamlines)	B
Vacuum Pumping System (VPS) exhaust capability	B
Cooling Water System (CWS) NB source cooling capacity	U
Power Systems (PS) AC power (up to two beamlines)	B
Central I&C additional control, data acquisition, and data network capacity	U
Facility space and provision for installation of NBI and related services	B

B = To be included in baseline
U = to be deferred until upgrade, unless convenient to include in baseline at minimal cost

* = During combined NBI + RF operations if the heating power exceeds the baseline then the pulse duration and repetition period shall be limited in accordance with the capability of the baseline PFCs, unless a PFC upgrade is undertaken.
** = During combined NBI + RF operations if the heating power exceeds the baseline then the pulse duration and/or repetition period shall be limited such that the average heat load is within the cooling capability of the baseline VV design, unless a VV cooling upgrade is undertaken.
g. Design features related to the long pulse upgrade and the plan for their implementation shall be as indicated in Table 1.1.2-2.

Table 1.1.2-2: Plan for Long Pulse Upgrade Features

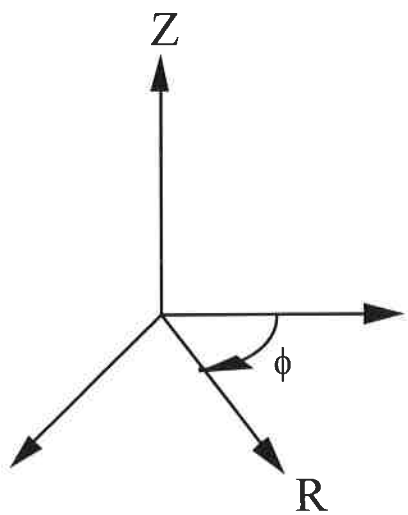
Design Feature	Schedule
PFC active cooling	U
Toroidal Field (TF) magnet inner legs	U
Toroidal Field (TF) magnet outer legs	B
Ohmic Heating (OH) magnet	not req'd
Poloidal Field (PF) magnets	B
Plasma Heating & Current Drive long pulse capability	U
Cooling Water System (CWS) additional cooling capacity	U
Gas Delivery System (GDS) long pulse capacity	U
Plasma Diagnostics long pulse capability	U
Power Systems (PS) AC and DC long pulse power supply	U
Central I&C long pulse control and data acquisition capability	U

B = To be included in baseline
U = to be deferred until upgrade, unless convenient to include in baseline at minimal cost

h. Baseline design features related to the pellet injector upgrade and the diagnostics upgrades require only the provision for space and access to a suitable Vacuum Vessel port, and are inherent in the baseline; no special provisions are therefore required in the baseline.

1.1.3 Directions of Fields & Currents

a. Figure 1.1.3-1 defines the positive sense of the right-handed coordinate system which shall be used on NSTX.



NSTX Coordinate System
Figure 1.1.3-1

Referring to Figure 1.1.3-1 the definition of positive sense of currents and fields on NSTX shall be as indicated in Table 1.1.3-1.

Table 1.1.3-1: NSTX Current/Field (+) Directions

Current/Field	Nominal Direction
Plasma Current	(+) ϕ
Poloidal Coil Currents	(+) ϕ
Toroidal Field	(+) ϕ
Radial Field	(+) R
Vertical Field	(+) Z

b. Except for the RF launchers and the PFCs, all components of NSTX shall be designed to permit operation with plasma current in either ϕ direction and toroidal field in either direction. The RF launchers and PFCs shall be designed to permit operation with plasma current in either ϕ direction, but with toroidal field always in opposite ϕ direction.

c. Toroidal angle $\phi = 0$ degrees shall correspond to the "north" direction, where the north-south axis in this context is defined as a line parallel with the walls of the NSTX Test Cell which run approximately in the magnetic (compass) north-south direction. Furthermore, given this 0 degree reference, proceeding clockwise viewed from above, the centerlines of the ports on the midplane occur at angles as given in Table 1.1.3-2.

Table 1.1.3-2: NSTX Port Centerline Angles

Port	Angle
A	15
B	45
C	75
D	105
E	135
F	165
G	195
H	225
I	255
J	285
K	315
L	345

1.1.4 Material Selection

a. All materials to be used in the torus and peripheral equipment (R 3.0 m, |Z| 3.0m) must have a relative magnetic permeability 1.02 unless otherwise authorized by the Project.

b. Because of its deleterious effect on the High Harmonic Fast Wave heating, the presence of ordinary hydrogen is to be avoided in the vacuum chamber. Therefore its use is not planned as a fuel for NSTX, and no NSTX components should introduce it.

c. All materials utilized within the primary vacuum boundary shall be on the PPPL Vacuum Committee approved list, or shall be approved by the committee.

d. All materials utilized within the primary vacuum boundary shall be designed to withstand the anticipated temperatures during operation and bakeout (section 2.3.2).

1.1.5 General Electrical Isolation Requirements

a. All instrumentation shall be isolated via optical and/or magnetic (isolation transformer) means prior to exiting the test cell boundary. The isolation shall be rated to withstand a one minute DC hipot test at 5kV.

b. All ancillary components which are in mechanical contact with the vacuum vessel shall be electrically isolated from the vacuum vessel. The isolation shall be rated to withstand a one minute AC hipot test at 2 kV AC rms.

c. Conducting loops formed by metallic structures within a radius of 3 meters from the centerline of the torus shall be broken by insulating breaks. The insulation shall be rated to withstand a one minute AC hipot test at 2 kV AC rms.

1.2 WBS 1 Torus Systems

1.2.1 Plasma Facing Components

a. All surfaces which face the plasma (Plasma Facing Components (PFCs)) shall consist of carbon based materials designed to absorb the heat and radiation flux from the plasma and heating systems, to minimize the influx of impurities to the plasma, and to withstand the electromagnetic forces associated with plasma disruption.

b. The PFCs shall include inboard and outboard divertor plates for absorption of the high heat flux due to plasma operation with Double Null (DN) and Single Null (SN) separatrices (X-points), as well as limiter (Natural Divertor) configurations.

c. The PFCs shall include passive stabilizers consisting of upper and lower plates connected in a saddle configuration, with toroidal electrical breaks to avoid closed conducting toroidal loops. The precise passive stabilizer geometry requirements and electrical characteristics shall be established as part of the design evolution based on inputs provided by the NSTX Project Physics Group.

d. The PFCs shall include poloidal limiters to constrain the boundary of cross sectional space occupied by the plasma. The passive stabilizers and inner wall act as toroidal limiters.

e. All PFCs shall be designed to accommodate a high temperature bakeout mode to liberate trapped impurities.

f. All PFCs shall be designed to accommodate a helium glow discharge cleaning mode.

g. Passive stabilizers shall be electrically connected to the Vacuum Vessel via their mounting structures.

h. Passive stabilizers shall be designed to be removable after the machine has been assembled.

1.2.2 Vacuum Vessel & Support Structure

a. The center stack casing shall be mechanically connected to, but electrically isolated from, the upper and lower domes via a ceramic insulator, so as to complete the vacuum boundary but allow for a potential difference between the center stack casing and the remainder of the vacuum vessel for CHI.

b. Sufficient ports shall be provided with dimensions compatible with the requirements of all types of Heating & Current drive systems (refer to section 1.3) as well as diagnostic systems. Additional openings shall be provided for personnel access.

c. Vacuum Vessel ports for High Harmonic Fast Wave (HHFW, refer to section 1.3.1) heating and current drive antennas shall accomodate the RF feedthroughs associated with the antenna mounting, and shall be located in accordance with the phasing requirements of the HHFW system.

d. The lower dome of the outer section of the Vacuum Vessel shall be connected electrically via eight toroidally symmetric connections to a single point connection, which is designed to permit biasing (≤2kVDC) of the outer Vacuum Vessel during CHI operations, and grounding of the outer Vacuum Vessel at other times. Isolation shall be rated to withstand a one minute DC hipot test at 2kV. Connections shall be sized to carry the current during CHI operations as well as the return of the current during bakeout heating of the center stack casing.

e. Four toroidally symmetric connection points shall be provided at the top and bottom of the center stack casing. Connections shall be sized to carry the current during CHI operations as well as the return of the current during bakeout heating of the center stack casing.

1.2.3 Magnets

1.2.3.1 Poloidal Field (PF) Magnets

a. The PF magnets shall consist of an Ohmic Heating (OH) central solenoid magnet, shaping field magnets (PF1a, PF1b), and outer PF magnets (PF2a, 2b, 3a,3b,4b,4c, and PF5) as listed in Table 1.2.3.1-1.

Table 1.2.3.1-1: PF Magnets

Designation	Source
OH	New
PF1a	New
PF1b	New
PF2a	S-1, EF-1a
PF2b	S-1, EF-1b
PF3a	S-1, EF-2a
PF3b	S-1, EF-2b
PF4b	S-1, EF-3b
PF4c	S-1, EF-3c
PF5a	New
PF5b	New

b. The PF coil system shall be symmetric about the mid plane, defined as the horizontal plane which passes through the elevation of maximum plasma radial extent, except for PF1b which shall consist of a lower coil only.

c. The PF coils listed in Table 1.2.3.1-1 shall be connected in series groups with independent current control as indicated in Table 1.2.3.1-2.

Table 1.2.3.1-2: Independent PF Circuits

PF Circuit	Coil Grouping
1	OH
2	PF1a, upper
3	PF1a, lower
4	PF1b, lower
5	PF2a, PF2b, upper
6	PF2a, PF2b, lower
7	PF3a, PF3b, upper
8	PF3a, PF3b, lower
9	PF4b,PF4c, upper & lower
10	PF5a, PF5b, upper & lower

d. All series coil connections indicted in Table 1.2.3.1-2 shall result in current flow which is equal in magnitude, and in the same ϕ direction, in the series connected coils.

e. All aspects of the PF coil design shall be compatible with NSTX operation with plasma current and toroidal field in either ϕ direction.

f. OH coil current and PF1b coil current shall always be in the same ϕ direction.

g. Operation of the PF4 and PF5 circuits shall be mutually exclusive.

h. PF coil geometries and current scenarios shall be established as part of the design evolution based on inputs provided by the NSTX Project Physics Group, consistent with the requirements for start up field null quality and loop voltage generation, as well as plasma equilibrium control.

1.2.3.2 Toroidal Field (TF) Magnets

a. The TF magnets shall consist of separate inner leg and outer leg components, all connected in series. The utilization of cross sectional area in the center stack of the machine shall be optimized to maximize the conductor cross sectional area.

b. All aspects of the TF coil design shall be compatible with NSTX operation with plasma current and toroidal field in either ϕ direction.

1.3 WBS 2 Plasma Heating & Current Drive Systems

1.3.1 High Harmonic Fast Wave (HHFW)

a. The HHFW system shall utilize RF power produced by the six existing Tokamak Fusion Test Reactor (TFTR) Ion Cyclotron Range of Frequencies (ICRF) sources.
b. The HHFW system shall utilize a twelve strap antenna mounted on the vacuum vessel wall in the gap between the upper and lower passive stabilizing plates. The antenna shall be arranged toroidally between the NSTX vacuum vessel mid plane ports. Each current strap shall include a back plane, a Faraday shield, and a local (bumper) limiter structure. The antenna shall be compatible with bakeout and glow discharge modes of operation.

c. The twelve antennas shall be capable of operating at frequencies in the range of 30MHz to 40MHz. All RF generators operating at any single frequency shall be phase locked to provide control over the wave number spectrum excited in the plasma at that frequency.

d. Switches shall be provided to isolate HHFW power from the NSTX test cell. These switches shall be interlocked with the test cell access control system.

1.3.2 Coaxial Helicity Injection (CHI)

a. The center stack casing and inner wall of the bore of the machine, including the inboard divertor plates, shall be electrically isolated from the remainder of the Vacuum Vessel to permit the biasing of this structure with respect to the Vacuum Vessel, to drive a poloidal component of plasma current. Both the center stack casing and the oyer Vacuum Vessel shall be isolated from ground such that either one can be grounded during CHI operations, with the other biased at the CHI potential.

b. The PFCs which form the electrodes from which the CHI current flows shall be designed to dissipate the local power generation due to the CHI current, during normal and fault conditions, and shall be designed to withstand the electromagnetic forces due the fault current deliverable by the CHI power supply system.

1.3.3 Electron Cyclotron (EC) Preionization

a. The EC system shall provide microwave RF power in the electron cyclotron range of frequencies for preionization.

b. One EC launcher shall be installed at an outboard location in the Vacuum Vessel to direct the microwave radiation toward the desired absorption location. The launcher must be compatible with bakeout and glow discharge modes. The launcher shall have a vacuum window connecting it to the external transmission system. This window must have low electrical loss at microwave frequencies and satisfy the thermal and mechanical requirements for vacuum interfaces.

c. Switches shall be provided to isolate EC power from the NSTX test cell. These switches shall be interlocked with the test cell access control system.

1.4 WBS 3 Auxiliary Systems

1.4.1 Vacuum Pumping System (VPS)

a. The VPS shall provide the required high vacuum environment for plasma operations. It shall exhaust the spent plasma constituents after each pulse, and shall exhaust the impurities associated with the bakeout and glow discharge cleaning of the PFCs.

b. The VPS shall be equipped with redundant Residual Gas Analyzers (RGA).

1.4.2 Cooling Water Systems (CWS)

a. The CWS shall provide the required cooling water of the required quality, temperature, pressure and flow for all NSTX systems.
b. Instrumentation shall be provided to monitor the flow rate in all individual magnet coil and bus bar cooling paths.

c. Instrumentation shall be provided to monitor the inlet and outlet water temperature of a subset of the magnet coil cooling paths, with provision for alarming both high and low temperature conditions.

d. The CWS and NSTX facility Heating, Ventilation, and Air Conditioning (HVAC) system shall include dew point controls to prevent condensation on water cooled components in the NSTX test cell.

1.4.3 Gas Delivery System (GDS)

a. The GDS shall provide the required gas injection for NSTX for deuterium and helium as required for conditioning and plasma operations.

b. Three piezoelectric valves shall be provided to control gas injection to the Vacuum Vessel. The valves shall be supplied by manifolds which connect to four source tanks in such a way that any valve can be supplied from any source tank.

1.4.4 Bakeout System

a. The bakeout system shall include means for heating the surfaces of the PFCs to the required temperatures for an indefinite period while maintaining the Vacuum Vessel and components connected thereto to temperatures within their temperature ratings.

1.4.5 Glow Discharge Cleaning (GDC) System (Day 1 Requirement)

a. NSTX shall be equipped with a GDC system for cleaning, under zero field conditions, the internal Vacuum Vessel surfaces via the bombardment of ions formed during the glow process.

1.5 WBS 4 Plasma Diagnostics

a. The baseline plasma diagnostics set shall consist of the elements listed in Table 1.5-1.

Table 1.5-1: Baseline NSTX Diagnostics Set

Availability	Diagnostic	Function
Day 0	Plasma current Rogowski coils	Total plasma current
	Eddy current Rogowski coils	Halo current monitoring
	Flux loops	Poloidal flux for plasma control
	B_θ, B_ρ coils	Plasma control/magnetic fluctuations
	Mirnov coils	Magnetic fluctuations
	Visible TV camera	External shape for plasma control
	1 mm microwave interferometer	Line-integrated plasma density
	Langmuir probes/thermocouples[2]	Divertor parameters
Day 1	IR camera	Heat loads
	"Slow" diamagnetic loop (using toroidal field coil)	Stored energy
	Multichannel bolometer	Radiated power profile
	Survey spectrometer (SPRED)	Plasma impurities
	Soft X-ray imaging system	Plasma instabilities and fluctuations
	H_α detectors	Edge recycling
	CHERS[1]	Ion temperature & toroidal rotation
	High-throughput CHERS background array	Background subtraction for CHERS and $Z_{eff}(r)$ from visible continuum
	X-ray pulse height analysis	Core electron temperature
	Neutral particle analyzer	Core ion temperature and fast ions
	Visible spectrometer	Edge/divertor spectroscopy

[1]CHERS: Charge-Exchange Recombination Spectroscopy
[2]Diagnostics incorporated into plasma facing components

b. Diagnostic elements which must be located in the center stack between the OH coil ground plane and the center stack casing (e.g. Rogowski coils, Flux loops) shall be referenced to ground and shall be insulated to withstand the full CHI voltage. The insulation shall be rated for a one minute DC hipot test at 5kV.

1.6 WBS 5 Power Systems

1.6.1 AC Power Systems

a. The AC Power Systems shall provide all electrical power required for the NSTX facility.

1.6.2 TF Power Conversion System

a. The TF Power Conversion System shall be designed to provide a constant current in the TF magnets during an NSTX discharge based on a reference current input signal provided in real time.

b. Bus links or other means shall be provided in order that the current in the TF magnets can be driven in either direction. The polarity reversal procedure shall require 4 hours or less.

c. No-load disconnect switches shall be provided to isolate the TF Power System from the connections to the TF magnets. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the TF magnets. These switches shall be interlocked with test cell access control.

d. Redundant measurements of TF current shall be provided.

e. The TF Power Conversion System shall include protection to avoid the delivery of current which would overheat the TF magnets, assuming that their coolant conditions are nominal.

1.6.3 PF Power Conversion System

a. PF Power System shall be designed to provide a variable current in the PF magnet circuits (listed in Table 1.2.3.1-2) during an NSTX discharge based on a reference current input signal provided in real time.

b. All PF circuits except for OH and PF3 shall be unipolar during a pulse. OH bipolarity is required to maximize the flux swing provided by the OH coil. PF3 bipolarity is required to provide cancellation of the stray field from the OH coil during plasma initiation, after which time a current of the opposite polarity is required for plasma equilibrium and shaping.

c. Bus links or other means shall be provided in order that the current in the PF magnets can be driven in either direction. The polarity reversal procedure shall require 4 hours or less.

d. No-load disconnect switches shall be provided to isolate the PF Power System from the connections to the PF magnets. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the PF magnets. These switches shall be interlocked with test cell access control.

e. Redundant measurements of each PF current shall be provided.

f. The PF Power Conversion System shall include protection to avoid the delivery of current which would overheat the PF magnets, assuming that their coolant conditions are nominal.

1.6.4 CHI Power Conversion System

a. The baseline CHI Power System shall be designed to deliver a controlled current into the CHI electrodes with one electrode connected to the center stack, and the other electrode connected to the outer vacuum vessel.

b. Protective features shall be included to prevent the application of excess voltage to the electrode associated with the center stack.

c. Bus links or other means shall be provided in order that the current in the CHI circuit can be driven in either direction. The polarity reversal procedure shall require 4 hours or less.

c. No-load disconnect switches shall be provided to isolate the CHI Power System from the connections to the CHI load circuit. In addition, no-load grounding switches shall be provided to ground the terminals of the connections to the CHI load circuit. These switched shall be interlocked with test cell access control.

1.7 WBS 6 Central Instrumentation & Control (I&C) System

a. The Central I&C system shall provide all supervisory control and monitoring of the NSTX facility, including:

- Plant Control and Monitoring (asynchronous routine control and monitoring)
- Synchronization (synchronization of triggered actions from master clock events)
- Plasma Control Processor and Input/Output Interface (digital processor and I/O hardware fo for interface with plasma control measurements and actuators)
- Safety Interlocks (master supervisory control of experiment)
- Access Control (control and monitoring of access to the NSTX Test Cell)

• Data Acquisition (Day 1 Requirement) (periodic sampling, acquisition and display of regularly sampled data, and acquisition and display of data sampled and stored by remote devices)

b. The Central I&C system shall provide reference signals to local I&C systems (provided by responsible WBS elements) for local feedback control, but is not required to close the loop for feedback control of plant processes.

c. The NSTX Control Room shall be installed in the location previously occupied by the TFTR Control Room.

d. The design of the Central I&C system shall facilitate access to archived NSTX data, as well as the control of diagnostic data acquisition systems, by parties outside of the NSTX control room (e.g. remote collaborators, physicists inside and outside of PPPL) (Day 1 Requirement).

e. The Central I&C system shall provide sixteen (16) electrically isolated, general purpose signal channels between the test cell and the control room. These signals shall be displayed in the control room in real-time.

1.8 WBS 72 Project Physics

a. NSTX Project Physics shall be responsible for the specification of all Plasma Control hardware and software.

b. NSTX Project Physics shall provide the requirements to the other WBS elements as listed in this document which are directly related to plasma behavior including the following.

• PF coil current centers required to achieve NSTX mission

• PF coil current scenarios and equilibria which are required to achieve NSTX mission including:

- establishment of required field null quality for plasma initiation
- establishment of required loop voltage for plasma initiation
- reference plasma scenarios
- plasma shape and profile flexibility equilibria
- feed back control of radial and vertical position, as well as divertor strike point position

• PF coil voltage requirements due to:

- basic scenarios
- feedback control of radial and vertical position, as well as divertor strike point position

• Geometric and electrical characteristics of passive plates

• Description of cross sectional boundary of space occupied by plasma for all modes of operation

• Maximum heat loads on PFCs, including divertor plates and limiters, due to plasma operation and CHI

• Currents and voltages in passive structures and PF coils due to plasma disruption.

• Effective impedance presented to CHI power supply circuit

2 Performance & Operational Requirements

2.1 General

2.1.1 Definitions

a. The events listed in Table 2.1.1-1 (in their nominal sequence of occurrence) are defined for the purposes of requirements definition.

Table 2.1.1-1: Definition of Events

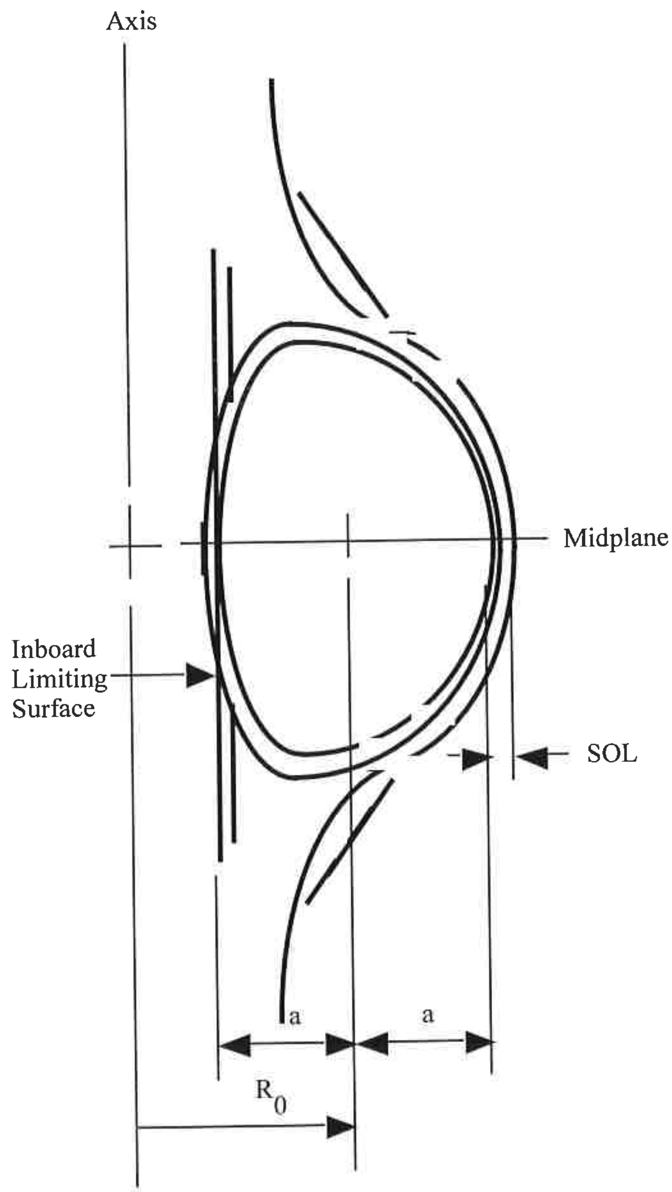
Name	Definition
SOP	Start of Pulse (start of power supply energization)
SOPTF	Start of Pulse TF (start of TF current)
SOPPF	Start of Pulse PF (start of PF current)
SOFTF	Start of Flat Top TF
SOI	Start of Initiation
EOI	End of Initiation
SOD	Start of Plasma Discharge
SOF	Start of Plasma Flat Top
SOX	Start of X-point
EOX	End of X-point
EOF	End of Plasma Flat Top
EOD	End of Plasma Discharge
EOFTF	End of Flat Top TF
EOPPF	End of Pulse PF (end of PF current)
EOPTF	End of Pulse TF (end of TF current)
EOP	End of Pulse (end of power supply energization)

b. The plasma major radius (R_0) is defined as the radius from the major axis of the torus to the center of the plasma on the mid plane. The plasma minor radius (a) is defined as the half width of the plasma on the mid plane. The nominal major radius of NSTX shall be 0.854 meters.

c. All required flux swings (volt-seconds) are measured at R_0, on the mid plane.

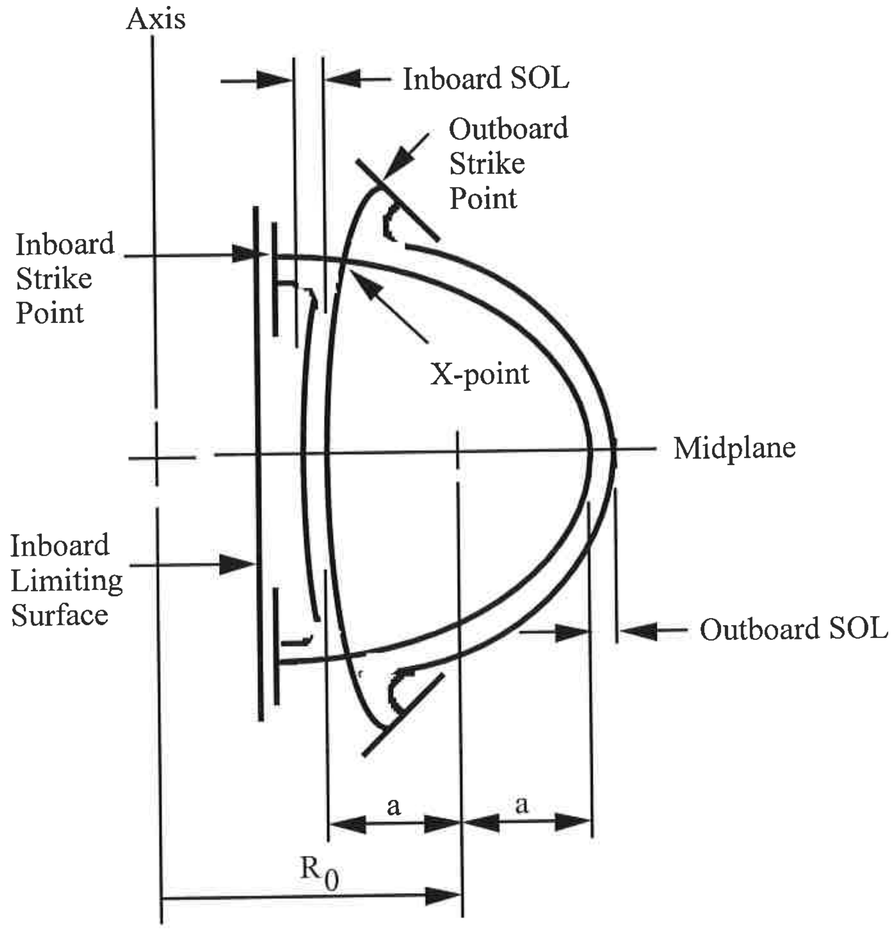
d. All required loop voltages are measured at R_0, on the mid plane at the EOI event time.

e. For limiter (Natural Divertor, ND) plasmas, the plasma edge is defined herein as the flux surface which is tangent with the inboard limiting surface at the mid plane. The Scrape Off Layer (SOL) is defined herein as the region between the plasma edge and the flux surface which contains approximately $1- \varepsilon^{-3}$ 95% of the particle power loss from the plasma. A fraction of the SOL impinges on the inboard limiting surface; the remainder impinges on other PFCs. Refer to Figure 1.1.2-1.



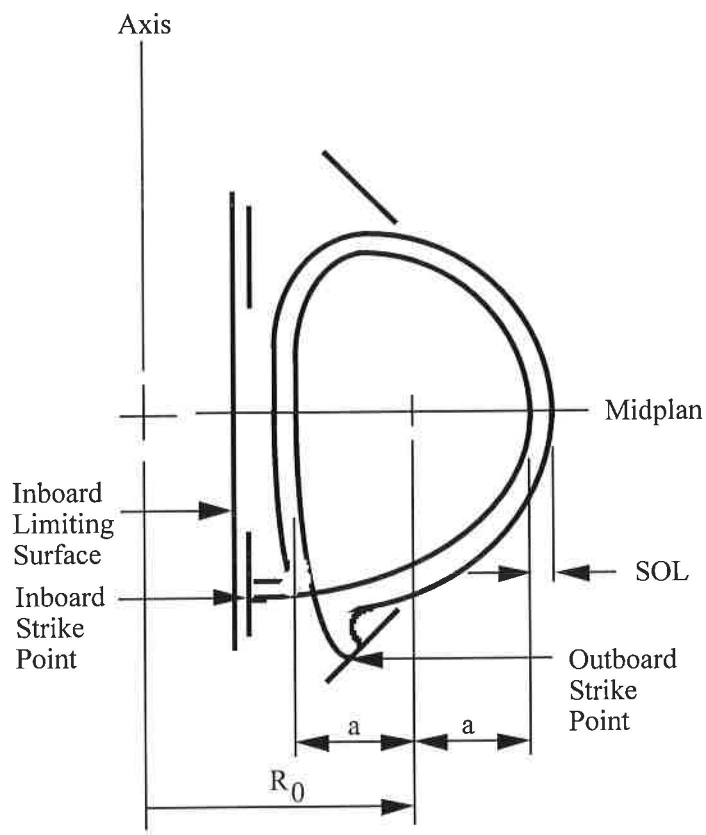
Limiter (Natural Divertor) Plasma
Figure 2.1.1-1

f. For Double Null (DN) X-point divertor plasmas, the inboard and outboard plasma edges are defined as the flux surfaces which pass through the X-points and which intersect the mid plane at R_0+/- a. These flux surfaces extend beyond the X-point and impinge on the inboard and outboard divertors at the inboard and outboard strike points, respectively. Refer to Figure 2.1.1-2.



Double Null Plasma
Figure 2.1.1-2

g. For Single Null (SN) X-point divertor plasmas, the plasma edge is defined as the flux surface which passes through the active X-point and which intersect the mid plane at R_0+/- a. This flux surface extends beyond the X-point and impinges on the inboard and outboard divertors at the inboard and outboard strike points, respectively. Refer to Figure 2.1.1-3.



Single Null Plasma
Figure 2.1.1-2

2.1.2 Baseline Requirements

2.1.2.1 Plasma Scenarios

a. The baseline NSTX facility shall be designed to provide the plasma scenarios given in Table 2.1.2.1-1.

Table 2.1.2.1-1: NSTX Plasma Scenarios

SCENARIO	**START-UP[1]**	**CURRENT SUSTAINMENT[2]**	**CONFIGURATION[3]**
I	Inductive	Inductive	ND, DN
II	CHI	 Inductive, HHFWCD	SN ND, DN, (SN)
III	Inductive (Half-Swing)	HHFWCD	ND, DN
IV	Inductive (Half-Swing)	 CHI[4], HHFWCD	ND, DN, (SN) SN[5]
V	CHI	CHI[4], HHFWCD	SN[5]

[1] EC Pre-ionization shall be utilized in all start-up scenarios
[2] Contributions from the bootstrap current are expected during the sustainment phase
[3] ND - Natural Divertor; DN - Double Null X-Point; SN - Single Null X-Point
[4] CHI during sustainment phase shall be an upgrade
[5] SN during sustainment phase if CHI used then; DN or ND otherwise

a. In order to promote reliable plasma initiation and operational flexibility, EC is applied in all scenarios to provide initial plasma breakdown and (in case of the ECH upgrade) to facilitate sufficient current ramp-up rate. For Scenarios I, II, and IV, which utilize OH during the start-up, the OH loop voltage (in absence of a plasma) shall be at least 3.0 V. For the scenarios that utilize coaxial helicity injection (CHI) during start-up or sustainment, a SN configuration will be used during the portion of the discharge in which CHI is applied. In all the scenarios, a portion of the full 1 MA plasma current is expected to be driven non-inductively by varying amounts of bootstrap current.

2.1.2.1.1 Scenario I (OH/OH)

Scenario I is characterized by inductively ramping the initial EC pre ionized plasma current to a full current of 1 MA in 0.2 to 0.4 sec, holding the current flat for approximately 0.5 sec, and then ramping the plasma current down in approximately 0.2 sec. Auxiliary heating will be applied during the ramp-up phase and current flattop phase to increase the plasma stored energy and temperature, and to attain high-β_t and maintain this state during the current flattop. β_t will be ramped down with the plasma current. Approximately 1.0 volt-seconds are supplied between the start and end of the plasma pulse (0.6 volt-seconds from the OH). The high harmonic heating technique will be developed in this scenario. Plasmas will be in either the Natural Divertor or Double Null configuration.

2.1.2.1.2 Scenario II (CHI/OH/HHFW)

Scenario II is characterized by establishing a 0.5 MA target plasma using Coaxial Helicity Injection and EC preionization, ramping the current to 1 MA and holding it constant for up to 0.5 sec using a one-half OH swing and/or High Harmonic Fast Wave current drive, and then ramping the plasma current down. Auxiliary heating will be applied during the 0.5 to 1.0 MA ramp-up phase and during the current flattop phase to increase the plasma temperature, stored energy, and to maximize β_t, maintaining high-β_t during the current flattop period. Up to 0.5 volt-seconds are supplied during the sustainment phase (I_p 0.5 MA). The plasma will be in a Single Null Divertor Configuration during the time the CHI is applied, and in either a Natural Divertor, Double Null (or Single Null) Divertor configuration thereafter. Other startup scenarios, such as utilizing EC and HHFW heating, may be attempted.

2.1.2.1.3 Scenario III (OH, HHFW)

Scenario III is characterized by inductively ramping the initial EC preionized plasma current to a full current of 1 MA in 0.2 to 0.4 sec, holding the current flat for up to 4.5 sec using High Harmonic Fast Wave current drive, and then ramping the plasma current down. Auxiliary heating will be applied during the ramp-up phase and current flattop phase to increase the plasma stored energy and temperature, and to attain high-β_t and maintain this state during the current flattop. β_t will be ramped down with the plasma current. Approximately 0.65 volt-seconds are supplied between the start and end of the plasma pulse. The high harmonic current drive technique will be developed in this scenario. Plasmas will be in either the Natural Divertor or Double Null Divertor configuration.

2.1.2.1.4 Scenario IV (OH/HHFW, CHI)

Scenario IV is characterized by inductively ramping the initial EC preionized plasma current to at least 0.5 MA in 0.2 to 0.4 sec, ramping the current up to 1 MA and holding it constant for up to 4.5 sec using Fast Wave Current Drive and/or Coaxial Helicity Injection (upgrade), and then ramping the plasma current down. Auxiliary heating will be applied during the ramp-up phase and during the current flattop phase to increase the plasma temperature, stored energy, and to maximize β_t (maximizing bootstrap current), and maintaining high-β_t during the current flattop phase. Up to 0.65 volt-seconds are supplied between the start and end of the plasma pulse. The plasma will be in a Natural Divertor, or Double or Single Null Divertor configuration during the start-up phase (before the CHI is on), and a Single Null Divertor configuration during the time the CHI is applied.

2.1.2.1.5 Scenario V (CHI/HHFW, CHI)

Scenario V is characterized by fully non-inductive operation. A target plasma of 0.5 MA will be created using CHI and EC preionization, and then the plasma current will be ramped up and maintained at the 1.0 MA level using a combination of HHFW, CHI (upgrade), and bootstrap currents. Auxiliary heating will be applied during the ramp-up phase and during the current flattop phase to increase the plasma temperature, stored energy, and to maximize β_t (maximizing bootstrap current), and maintaining high-β_t during the current flattop phase. The plasma will be in a Single Null Divertor configuration during the time the CHI is applied. If the 1 MA plasma current can be maintained solely by HHFW current drive and bootstrap current, the configuration will be relaxed into one of Natural Divertor or Double Null Divertor.

2.1.2.2 Scenario Requirements

a. For all reference scenarios described herein the TF flat top shall extend for the full duration of plasma current, i.e. SOFTF SOI, and EOD EOFTF.

b. For all reference scenarios described herein the nominal toroidal field shall be 3.0 kG at R_0. However, it shall be possible to operate with a toroidal field at 6.0kG with a TF flat top (SOFTF to EOFTF) duration of 0.6 seconds.

c. The peak-to-average toroidal field ripple shall be 0.5% over the entire plasma cross section.

d. For all reference scenarios described herein the PF current distributions at SOI, EOI, SOD, SOF, SOX, EOX, EOF, and EOD shall be specified by the NSTX Project Physics group.

e. For all reference scenarios described herein the gap between the outboard plasma edge at the mid plane and the surface of the HHFW antennas shall be 2.0 cm.

f. For all reference scenarios described herein the heating/current drive power shall be applied to the plasma for the full duration SOD to EOD, except for the EC which shall be applied only during the interval SOI to EOI, with a maximum duration of 5 mS in the baseline, 100mS in case of the EC upgrade.

g. Operation of the CHI is limited to Single Null plasma configurations.

2.1.2.2 Flexibility

a. In addition to the basic scenarios described in section 2.1.2.1 the design of the NSTX machine shall provide flexibility in terms of variation of plasma shape during the interval between SOF and EOF, which require PF current distributions different from those associated with the basic scenarios. Plasma edge, SOL, and PFC heat load requirements described for the basic scenarios will still apply, however.

b. For all flexibility points the PF current distributions shall be specified by the NSTX Project Physics group.

2.1.2.3 Pulse Repetition Period & Operating Life

a. For the Inductive Scenario (Scenario I) the baseline NSTX machine shall be designed for a pulse repetition period of 600 seconds and a maximum of 48 pulses per 24 hour period.

b. For the Non-Inductive Scenarios (Scenario II, III, and IV) the baseline NSTX machine shall be designed for a pulse repetition period of 300 seconds and a maximum of 96 pulses per 24 hour period.

c. The NSTX machine shall be designed to operate for a period of 10 years. However, new equipment related to the D-site infrastructure (building and utilities) shall be designed for a 25 year operating life.

d. NSTX operation shall be assumed to consist of 96 pulses per day, 5 days per week, 3 weeks per month, 9 months per year, for 10 years (total of 130,000 pulses). Non-operating times are available for maintenance.

e. For design purposes the distribution of pulses shall be assumed as follows:

- 1/3 of the pulses will be double-swung OH covering inductive only, short pulse operation
- 2/3 of the pulses will be single-swung OH covering non-inductive current drive studies

f. Approximately 25% of of all the shots shall be at high toroidal field (6 kG). This proportion will be split into double-swung and single-swung OH in the same proportion as 3 kG operation.

2.1.3 Upgrades

a. The upgrades described herein are envisioned as possibilities which may or may not be undertaken, depending on experience gained with NSTX operation, and other factors. The baseline design of NSTX should facilitate the upgrades when possible without significant cost impact. As a minimum, the baseline design shall permit eventual upgrade and the upgrade path shall be identified as part of the baseline design process.

2.1.3.1 Electron Cyclotron Upgrade (EC)

a. To begin the physics investigation of the EC torus formation start-up, an existing Oak Ridge National Laboratory (ORNL) system, 200 kW power for 100 msec, shall be used.

2.1.3.2 CHI Current Sustainment Power Supply Upgrade

a. The CHI current sustainment power supply would be required to provide a current of 20.0 kA for the full duration SOD to EOD.

2.1.3.3 Neutral Beam Injection (NBI) Upgrade

a. The NSTX design shall consider an upgrade which would, initially, place one TFTR Neutral Beam Injector on NSTX, operating in the range of 80 to 110kV with corresponding power to the plasma of 5.33 to 7.33MW, for 5 seconds once every 300 seconds. Provision shall also be included for the possible implementation of a second TFTR Neutral Beam Injector at a later date.

b. The baseline design for all NSTX components shall identify an upgrade path for the neutral beam upgrade.

2.1.3.4 Long Pulse Upgrade

a. The NSTX design shall consider an upgrade which would remove the baseline TF and OH magnets, and place a new TF magnet in the center stack. The NSTX plasma pulse length shall be assumed to be 60 seconds for this upgrade. The long pulse repetition period shall be 3600 seconds.

b. The baseline design for all NSTX components shall identify an upgrade path for the long pulse operation.

2.1.3.5 Other Upgrades

a. GDC and related systems shall be designed for an upgrade to automatic GDC operation between NSTX discharges; however the baseline NSTX device is not required to provide automatic shutters, e.g. which may be required of some components.

. b. No quantitative performance or operational requirements are given at this time for the Pellet Injection upgrade.

2.2 Plasma Heating and Current Drive

2.2.1 High Harmonic Fast Wave (HHFW) Heating & Current Drive

a. The HHFW system shall be designed to deliver 6 MW of power to the plasma for 5 seconds, once every 300 seconds.

2.2.2 Coaxial Helicity Injection (CHI)

a. The CHI powers system shall be designed to provide a controlled current waveform with a peak current of 50.0 kA, and rise time ≤ 5mS.

b. For purposes of sizing the CHI power system components, the plasma (viewed from the external circuit terminals) may be modeled by an inductance of 80.0 μH, and aresistance of 7.0m .

c. Based on the nominal discharge current and equivalent circuit parameters above, the nominal voltage across the CHI electrodes is approximately 1kV. However, to provide flexibility, the design voltage level shall be 2kV. All related electrical insulation shall withstand a one minute, 5kV DC hipot test.

2.2.3 Electron Cyclotron (EC) Preionization

a. The EC system shall be designed to deliver 20kW of power for 5 msec to the plasma.

2.2.4 NBI Upgrade

a. The NBI system (if the initial one beam line upgrade is undertaken) shall be assumed to deliver 5 MW to the plasma at 80kV for 5 seconds once every 300 seconds. The total power to be accomodated in the case of a two beam line upgrade is TBD.

2.2.5 Total Upgrade Auxiliary Heating Power

a. PFCs and Vacuum Vessel cooling systems shall be designed to dissipate 6MW for 5 seconds once every 300 seconds.

2.3 Vacuum and Wall Conditioning

2.3.1 Base Pressure

a. The NSTX shall operate in high vacuum conditions with a base partial pressure of 1×10^{-8} torr for fuel gases (Z 2) and a base partial pressure of 1×10^{-9} torr for impurity gases ($Z > 2$) at 65°C.

b. The impurity gas load during pump down to base pressure shall not exceed 1×10^{-5} torr-l/s.

c. The vacuum pumping system shall be capable of evacuating the Vacuum Vessel from atmospheric pressure to 10^{-3} torr in less than 3 hours.

d. The vacuum pumping system shall be capable of evacuating the Vacuum Vessel from 2×10^{-3} Torr to 1×10^{-7} Torr during the interval between each NSTX pulse with a fuel gas load of TBD liters.

e. The vacuum pumping system shall maintain a vacuum of 10^{-2} Torr during Glow Discharge Cleaning (GDC).

2.3.2 Bakeout

a. The surfaces of the PFCs shall be heated during bakeout to 350°C.

b. The temperature of the inner Vacuum Vessel surfaces shall be heated to at least 150°C.

c. Bakeout heaters shall be designed to heat the Vacuum Vessel and PFCs to the required temperature in 48 hours. After completion of bakeout, the machine shall be cooled down to an operation temperature (nominally room temperature) in less than 24 hours.

2.3.3 Glow Discharge Cleaning (Day 1 Requirement)

a. The NSTX shall be equipped to provide glow discharge cleaning (GDC) mode with DC glow in the range of 5 ~ 30 mtorr of D or He at voltages up to ~450 V and currents up to ~20 A for indefinitely long periods .

2.3.4 Pre-shot Temperature

a. In-vessel components shall be maintained at temperatures not less than 50°C between discharges.

2.4 Fueling

2.4.1 Gas Injection

a. The NSTX shall be provided with a programmable gas injection system capable of supplying deuterium, and helium gases to the outboard mid plane with a maximum throughput of 50 Torr-l/s.

2.5 Limiter Requirements

a. The inner wall shall act as the inboard limiter.

b. Passive plates and HHFW antenna shielding shall act as the outboard limiter.

2.6 Plasma Facing Components

a. PFCs shall withstand the heat loads given in Table 2.6-1[2] for the rated (SOD to EOD) pulse duration at the rated NSTX duty cycle, without (as a design goal) divertor strike point sweeping. However, if technology limits dictate the need for sweeping in some cases then sweeping or other means for heat flux amelioration shall be considered.

Table 2.6-1: PFC Heat Loads

Scenario	Parameter	Inner Div		Outer Div		Inner Wall	Total	
		Upper	Lower	Upper	Lower			
Natural Divertor	Total Power						6.0	MW
	Radiated Power						1.8	MW
	Non-Radiated Power	0.0	0.0	1.1	1.1	2.1	4.2	MW
	Power Flux Width	0.000	0.000	0.094	0.094	2.000		m
	Peak Flux	0.0	0.0	4.3	4.3	1.9		MW/m^2
Double Null	Total Power						6.0	MW
	Radiated Power						1.8	MW
	Non-Radiated Power	0.4	0.4	1.7	1.7	0.0	4.2	MW
	Power Flux Width	0.038	0.038	0.038	0.038	2.000		m
	Peak Flux	5.1	5.1	17.1	17.1	0.0		MW/m^2
Single Null	Total Power						6.0	MW
	Radiated Power						1.8	MW
	Non-Radiated Power	0.0	1.4	0.0	2.8	0.0	4.2	MW
	Power Flux Width	0.000	0.092	0.000	0.100	2.000		m
	Peak Flux	0.0	7.0	0.0	10.8	0.0		MW/m^2

b. Heat flux on the divertors shall be assumed to impinge over a region beginning at the strike point and ending at a distance of equal to the power flux width ( ) given in Table 2.6-1. The peak heat flux given in Table 2.6-1 occurs at the strike point. The heat flux (q) along the power flux width shall be assumed equal to $q(x) = q_{peak} * \varepsilon^{-x/}$ where x = 0 occurs at the strike point.

[2] "NSTX Divertor Heat Flux Estimates", S. Kaye, 10/24/96

c. Heat flux on the inner wall shall be assumed to impinge symmetrically about the midplane with a profile as given in Table 2.6-2 and Figure 2.6-1. The profile shown yields a total power deposition of 1 watt over a cylinder with radius of 0.175 m and height of 2.0 m. For a particular scenario therefore the profile shall be scaled by total power on the inner wall given in Table 2.6-1.

Table 2.6-2: Normalized Inner Wall Heat Flux Profile

Z(m)	q(W/m^2)
0	0.70
0.2	0.41
0.4	0.90
0.6	0.35
0.7	0.41
1.0	0.00

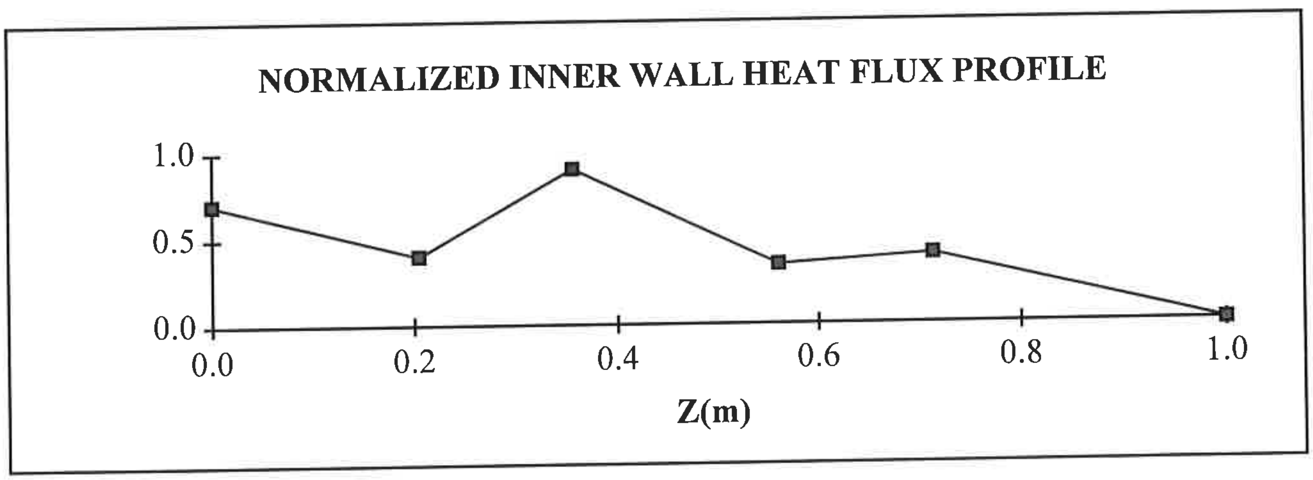


Figure 2.6-1: Normalized Inner Wall Heat Flux Profile

2.7 Plasma Initiation and Equilibrium Control

2 7.1 Plasma Initiation

a. The NSTX PF/OH magnets and power systems shall be designed to produce a loop voltage 3.0V and a field null (2 Gauss) region 40 cm diameter for 2 mS at a target located at r=0.8 m on the midplane.

2.7.2 Radial Plasma Position Control

a. The NSTX machine shall include a feedback equilibrium control capability which will provide radial plasma position control such that:

• the radial location of the last closed flux surface on the outboard mid plane can be maintained within ±1.0 cm of nominal.

• the radial location of the last closed flux surface on the outboard mid plane can be moved by ±2 cm from nominal in approximately 10 msec, in response to needs for RF coupling

Coil current and voltage requirements (in addition to those required to accomplish the basic scenario) shall be specified by NSTX Project Physics.

2.7.3 Vertical Plasma Position Control

a. Conducting structure (passive plates) shall be provided which decrease the growth rate of the vertical instability. Precise geometry and required electrical characteristics of passive plates shall be provided by NSTX Project Physics.

b. The NSTX machine shall include a feedback equilibrium control capability which will provide vertical position control such that the location of the centroid of the plasma can be maintained within ±–1.0 cm of nominal.. Coil current and voltage requirements (in addition to those required to accomplish the basic scenario) shall be specified by NSTX Project Physics.

2.7.4 Divertor X-Point Position Control

a. The NSTX machine shall include a feedback equilibrium control system which will provide X-point position control such

• that the location of the outboard X-point can be maintained within ±1.0 cm of nominal. Coil current and voltage requirements (in addition to those required to accomplish the basic scenario) shall be specified by NSTX Project Physics

• the location of the outboard X-point can be moved ±12 cm along the divertor surface with a response time of 2.0 seconds. Coil current and voltage requirements (in addition to those required to accomplish the basic scenario) shall be specified by NSTX Project Physics

2.7.5 Field Errors

a. To avoid locked modes from non-axisymmetric fields (including those from coil misalignment, bus work, coil feeds, coil cross-overs, and magnetic materials), the m=2 n=1 component of the vacuum error field (at the q=2 surface) shall be limited to 5 gauss[3]. If necessary, compensation coils must be installed.

2.8 Plasma Disruptions

a. The device shall be designed to accommodate major disruptions characterized by:

- vertical or radial displacement
- a thermal quench occurring in 0.1-1 ms
- a current decay with a time-varying decay rate, such that the peak rate is 0. 1 MA/ms
- a peak poloidal halo current up to 10% of the maximum plasma current prior to the disruption, with a toroidal peaking factor of 2:1; that is, the toroidal dependence of the halo current is $[1 + \cos(\phi - \phi_0)]$, for all toroidal phase angles ϕ_0 from 0 to 2* . Halo current entry/exit locations shall assume a separation of 1.0m with vertical displacement + or - 0.25m about the midplane.
- a frequency of occurrence of 50 % in any phase or mode of operation.

3 Design Criteria

3.1 General Design Guidelines

a. General design guidelines[4] for various operating conditions, based on probability of occurrence, are provided in Table 4.1-1.

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[3] "NSTX Non-Axisymmetric Field Error Tolerances", S. Kaye, 12/18/96

[4] The definition of operating conditions and general design guidelines are consistent with BNL 51444 Rev. 1

Table 3.1-1: General Design Guidelines

Operating Condition	Description	P, Probability Of Occurrence In A Year	General Design Guidelines
Normal Events	Events that are planned to occur regularly in the course of facility operation	P=1	Provide safe and reliable operation
Anticipated Events	Events of moderate frequency which may occur once or more in the lifetime of a facility	1>P 10^{-2}	The facility should be capable of returning to operation without extensive corrective action or repair
Unlikely Events	Events which are not anticipated but which may occur during the lifetime of a facility	10^{-2}>P 10^{-4}	The facility should be capable of returning to operation following potentially extensive corrective actions or repairs, as necessary
Extremely Unlikely Events	Events which are limiting faults and are not expected to occur during the lifetime of a facility but are postulated because of their safety consequences	10^{-4}>P 10^{-6}	Facility damage may preclude returning to operation
Incredible Events	Events of extremely low probability of occurrence or of non-mechanistic origin	P<10^{-6}	Not considered in the design

3.2 Facilities Design Criteria

b. The NSTX torus structure shall be designed to satisfy the Department of Energy (DOE) standard for natural phenomena hazard (NPH) events[5]. Only the effects of earthquake shall be considered for the NSTX torus structure. DOE requires the use of Performance Categories (PC) to specify the relative risk, environmental impact, importance, and cost of each facility. The assessment for seismic loading and evaluation for seismic response shall be followed to determine that the design of the structure is acceptable with respect to the performance goals[6]. There are no safety class items associated with the NSTX machine since its failure would not result in the release of significant quantities of hazardous materials. On this basis the seismic performance goal for NSTX torus structure is to maintain worker safety and it shall be placed in NPH Performance Category 1 (PC-1).

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[5]U.S. Department of Energy, "Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems, and Components', DOE-STD-1021-93, July. 1993

[6]U.S. Department of Energy, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities", DOE-STD-1020-934 April. 1994

Those SSCs whose failure would adversely effect the performance of the NSTX torus structure or create a threat to worker safety shall also be placed in PC-1. All other systems shall be placed in PC-0 and will thus have no seismic design requirements.

The DOE design criteria[5] allow the PC-1 structures, systems, and components (SSC) to be designed using the simplified approaches specified in building code, such as Uniform Building Code (UBC)[7]. The NSTX torus structure shall be installed in the D-site Hot Cell. The seismic design shall consider the response to the motion of the machine floor rather than the ground motion. According to UBC code, static analysis approach may be used for determining the seismic effects. For PC-1 SSCs the design forces may be based on the total lateral seismic forces F_p given by UBC provisions:

$$F_p = Z\, I\, C_p\, W_P = 0.135\, W_p$$

Where:

Z	= a seismic zone factor. For PPPL , Z=0.09g[8]
I	= an importance factor. For PC-1, I = 1.00
C_p	= a horizontal force factor. C_p = 1.5 for non-rigid elements.
W_p	= the weight of element or component

The lateral force shall be distributed in proportion to the mass distribution of the machine. Forces shall be applied in the horizontal directions that result in the most critical loadings for design.

b. NSTX conventional facilities shall be designed in accordance with DOE 6430.1A General Design Criteria and applicable national codes referenced therein.

4 Environmental, Safety, and Health (ES&H) Requirements

4.1 Policy Statement

a. The design, manufacture, fabrication, construction, installation, test, operation, maintenance, modification, and eventual decontamination and decommissioning of the NSTX shall be

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[7]'Uniform Building Code', 1991 Edition, International Conference of Building Officials, Whittier, CA 1991

[8]U.S. Department of Energy, "Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites", DOE-STD-1024-92 December, 1992

accomplished in a manner that will protect personnel, visitors, the public, property and the environment from injury. Pursuant to this policy, the NSTX project shall:

- Comply with all applicable Federal, State, Local, and PPPL ES&H regulations;
- Assess and minimize the risks inherent in the NSTX program;
- Actively encourage ES&H awareness on the part of NSTX personnel and visitors.

In particular, NSTX shall be designed and operated in accordance with DOE Orders and PPPL Environment, Safety and Health Directives. In the event of conflicts between DOE Orders and PPPL Environment, Safety and Health Directives, DOE Orders shall take precedence.

4.2 Radiological Design Objectives

a. All operations must be planned to incorporate the radiation safety guidelines, practices, and procedures included in PPPL ES&HD 5008, Section 10.

b. Radiological design objectives and regulatory limits to be observed in the design and operation of the NSTX facility[9] are defined in Table 4.2-1.

[9] All operations must be planned to incorporate the radiation safety guidelines, practices, and procedures included in PPPL EHSD 5008, Section 10.

Table 4.2-1: Radiological Design Objectives

Condition		P, Probability Of Occurrence In A Year	Public Exposure[10]		Occupational Exposure	
			Regulatory Limit (rem per yr)	Design Objective (rem per yr)	Regulatory Limit (rem per yr)	Design Objective (rem per yr)
Routine Operation[11]	Normal Operations	P 1	0.1 total 0.01 airborne[12] 0.004 drinking water	0.01 total	5	1
	Anticipated Events	1>P 10^{-2}	0.5 total (including normal operation)	0.05 per event		
Accidents[13]	Unlikely Events	10^{-2}>P 10^{-4}	2.5	0.5	ref[14]	ref[13]
	Extremely Unlikely Events	10^{-4}>P 10^{-6}	25	5[15]	ref[16]	ref[15]
	Incredible Events	$P<10^{-6}$	NA	NA	NA	NA

5 Decontamination and Decommissioning Requirements

a. A plan for the decontamination and decommissioning (D&D) of NSTX shall be developed in accordance with DOE Directives.

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10 Evaluated at the PPPL site boundary.

11 Dose equivalent to an individual from routine operations (rem per year unless otherwise indicated)

12 Compliance with this limit is to be determined by calculating the highest effective dose equivalent to any member of the public at any off site point where there is a residence, school, business, or office.

13 Dose equivalent to an individual from an accidental release (rem per event)

14 Refer to PPPL EHSD Section 10, Chapter 12 for emergency personnel exposure limits.

15 For design basis accidents (DBAs), i.e., postulated accidents or natural forces and resulting conditions for which the confinement structure, systems, components, and equipment must meet their functional goals, the design objective is 0.5 rem.

16 Refer to PPPL EHSD Section 10, Chapter 12 for emergency personnel exposure limits.

b. None of the waste packages projected in the D&D plan to be generated during the end of life disposal of NSTX (including a small amount of mixed waste) shall exceed Class A low level waste limits as defined in existing 10CFR61 regulations.