National Spherical Torus eXperiment Upgrade

National Spherical Torus Experiment-Upgrade

NSTX-U

SYSTEM REQUIREMENTS DOCUMENT

VACUUM VESSEL AND INTERNAL HARDWARE

NSTX-U-RQMT-SRD-004-03

February 5, 2019

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Change Record

Revision	**Date**	**Description of Change**
0	1/1/2018	Initial Release
1	3/14/2018	Modified signature block as per new QAPD and ENG-050
		Replaced all interface tables from Rev. 0 with new tables, based on the interface spreadsheet
		Added Reference 14
		Added 10.3.7h, regarding requirement for monitoring preload
		Added 3.1f and 3.1g, regarding the functions of the ports on the vacuum vessel.
		Changed 10.3.1b from Engineering Director to Project Engineer
		Added 10.3.5b and 3.3h regarding need for bakeout connections to handle disruption loads under some circumstances.
		Added 7.4c regarding leak-tight requirement in in-vessel tubing.
2	7/23/18	Added 4.3g-j, requiring robust electrical connections between the plates and their brackets (see VVIH-180605-SPG-01); “renumbered” the following requirements
		Clarified 10.3.7e, that only some inner-PF coils may require mechanical preload
		Adjust 10.3.7a & b to have tables, and to clarify the means of providing alignment
		Adjusted various signatures (changed mechanical TA, CE, PE)
3	2/5/19	Modest wording change on 10.3.7a
		Clarifies 10.3.6.a that the 300-350 C temperature requirement is for the tiles, and the casing must accommodate any temperature that facilitates the tile temperature
		Added “Inner-PF Coil Supports” to the title of Section 10
		Added 10.3.4c with the requirement to evacuate the double O-ring interspaces
		Small modification to 10.3.2b
		Rewrite 10.4.3 to improve specification of coil ground insulation temperature limits
		Updated Mechanical TA and Project Engineer names
		Updated 10.3.5a regarding the current split on the bakeout bus

References

[1] NSTX-U-RQMT-GRD-001, *NSTX-U General Requirements Document*
[2] NSTX-U-RQMT-RD-010-00, *NSTX-U Magnetic Permeability Requirements*
[3] NSTX-CRIT-0001-02, *NSTX Structural Design Criteria*
[4] NSTX-U Design Point Spreadsheet,
https://sites.google.com/pppl.gov/systemengineering/home
[5] NSTXU-CALC-10-03-00, *Design Point Calculations for NSTX Center Stack Upgrade*
[6] NSTX-U-RQMT-RD-003, *NSTX-U Disruption Requirements*
[7] ES-MECH-15, *Pressure Systems Program*
[8] NSTX-U-RQMT-RD-013-00, *Thermal Analysis Requirements*
[9] NSTX-U-RQMT-SRD-005-00, *NSTX-U SRD - Auxiliary Systems*
[10] NSTX-U-RQMT-SRD-003, *NSTX-U SRD - Plasma Facing Components*
[11] NSTX-U-RQMT-SRD-011, *NSTX-U SRD - Diagnostics*
[12] DIS-170511-SPG-02, *Design Guidance for halo currents in NSTX-Upgrade*
[13] NSTX-U-RQMT-RD-005, *CS Air Side Diagnostics*
[14] MAG-190205-SPG-01, *Limit on the Ground Wall Temperature for NSTX-U Coils Manufactured from CTD-425*
[15] NSTX-U-RQMT-RD-011, *NSTX-U Dimensional Control*

1. Scope and Format

a. The format of this document, including interfaces specifications, is provided in the General Requirements Document [1]. This includes a list of common acronyms.

2. Common Requirements

a. All materials exposed to the high vacuum within the plasma chamber must be approved by the PPPL Vacuum Materials Committee for high vacuum compatibility.

b. Permeability requirements are as per the *NSTX-U Magnetic Permeability Requirements* [2], while mechanical design shall be governed by the *NSTX-U Structural Design Criteria* [3].

c. Static EM loads are defined in the Design Point Spreadsheet [4,5], while disruption loads are derived from the NSTX-U Disruption Analysis Requirements [6].

d. Up-down symmetry of the vessel shall be maintained to the greatest extent possible.

e. Toroidally continuous passive structures shall be minimized to the extent that other design constraints permit, and shall be made of high resistivity materials where possible.

f. All viton O-rings shall be maintained under 180 degC under all thermal scenarios (bakeout, plasma operations,...)

g. All materials utilized within the primary vacuum boundary shall be designed to withstand the anticipated temperatures during plasma and bakeout operation.

h. All materials at risk of exposure to lithium films shall be approved for use under that condition.

i. As noted in the GRD [1], all components shall be designed for PF & TF coil currents up to 100% of their ampere-turns, with either polarity of OH current at 100% of its ampere-turns and with Ip=0 or $\neq$ 0. If this is not possible, exception may be taken as per the GRD [1].

j. All pressure systems shall conform to PPPL standard ES-MECH-015. [7]

k. Thermal scenarios for the casing are described in the document *Thermal Analysis Requirements* [8].

l. Systems that are thermally cycled during bakeout shall be designed consistent with the guidance in Ref. [9]

3. Vacuum Vessel, Ports, and Vessel Legs (SBS 1.1.2.1)

3.1: Functions

The functions of the vacuum vessel are to:

a. Provide a vacuum boundary around the plasma suitable for high vacuum conditions.

b. Provide structural support for the outboard divertor structure, neutral beam armor, passive plates, and other miscellaneous in-vessel components.

c. Provide access and structural support for gas injection systems, plasma heating and current drive systems (NB drift ducts & the HHFW antenna), passive plates and the neutral beam armor, in-vessel heating and cooling systems, and specific diagnostics supported by the vessel.

d. Provide structural support for the coils systems including the poloidal field coils number PF #2 a & b, PF# 3a &b, PF#4 b & c, and PF#5 a & b, as well as the outer TF coil legs and the RWM coils.

The function of the Vessel Legs are to:

e. Provide the overall support mechanism for the vacuum vessel and all torus components which are attached to it.

The function of the vacuum vessel ports are to:

f. Provide means for customized port covers to attach to the vessel. The port covers may be customized for various diagnostic and auxiliary system functions.

g. Provide means for heating systems to interface to the plasma (attachment points for neutral beam drift ducts, HHFW antenna feedthroughs).

3.2: Materials and Design Requirements

a. See Section 1.

b. The VV & support structures shall be designed to withstand all loads during normal operation as described in Ref [3].

c. The VV & support structures shall be designed to withstand all loads during bakeout as described in Ref. [3].

3.3: Configuration Requirements & Essential Features

a. The vacuum vessel shall be oriented so that the TF inner legs have a vertical orientation.

b. The vacuum vessel is a single walled enclosure consisting of an upper and lower domes and a straight cylindrical center section.

c. The vessel proper (cylinder and domes) shall be constructed of 304 stainless steel and have a nominal wall thickness of 5/8 inch. Additional ports and features associated with the vessel shall by default be fabricated from 316 SS or materials of similar magnetic permeability [2], unless specific dispensation is given.

d. The upper and lower domes each have 11 primary ports as well as a number of smaller auxiliary ports. The cylindrical section of the vessel shall have a sufficient number of large ports and smaller ports to accommodate plasma heating, diagnostic and pumping configuration requirements.

e. The cylindrical section shall include ports to accommodate the use of two TFTR Neutral Beam Injectors injecting at the device midplane. The first injector shall have tangency radii of R_{tan}=[50,60,70] cm, while the second injector shall have tangency radii of R_{tan}=[110,120,130] cm.

f. The lower dome of the outer section of the Vacuum Vessel shall be electrically grounded via three approximately toroidally symmetric connections to a single point connection to the facility ground, which is designed to permit opening for the purpose of testing of the integrity of electrical isolation between the Vacuum Vessel and other components and structures. Isolation shall be rated to withstand a one minute AC hipot test at 2kV rms. Grounding connections shall have provision for monitoring for ground faults.

g. All vacuum vessel flanges shall provide a vacuum seal compatible with high vacuum (pressure $< 2\times10^{-8}$ torr following bakeout) and bakeout conditions [9].

h. The vacuum vessel support legs shall support the vacuum vessel and all components attached to the vessel including in-vessel structures, plasma facing components, TF outer legs, outer PF coils, and other components mounted to the vessel.

i. All support legs will be attached directly to the NSTX-U test cell floor.

j. Three approximately toroidally symmetric connection points shall be provided at the top and bottom of the vacuum vessel. Connections shall be sized to carry the current for arbitrary duration during bakeout heating of the center stack casing. A total casing current of 8 kA shall be assumed for the purposes of design.

h. If these electrical connections remain in place during operations, then their design shall accommodate loads during operations, including disruption loads

3.4: Baseline Performance & Operational Requirements

a. The vacuum vessel and torus support structure shall be capable of operation in high vacuum conditions with a base partial pressure of $\leq 2x10^{-8}$ torr following bakeout.

3.5: Upgrade Performance & Operational Requirements

a. The vacuum vessel may in the future be actively cooled by the tubes applied to the vessel skin. [9]

3.6: Interfaces

***Table 3.6-1**: Interfaces for the vacuum vessel (SBS 1.1.2.1.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.3.2.1	Bakeout Bus Work	Electrical Power	At vessel surface	The three bakeout electrical connections are mounted to the vessel surface	Mechanical Drawing
1.2.4.3	Beamline Ducts	Vacuum	Front face of flanges at Bays A and K	Drift ducts are mounted to the flanges at Bays A and K w/ single O-ring vacuum seals.	Mechanical Drawings
1.2.4.3	Beamline Ducts	Structural	Front face of flanges at Bays A and K	Vacuum side-load applied to vessel when NB TIVs are open.	Mechanical Drawings
1.2.1.10	HHFW Antennae	Structural	At vessel inner surface	The antenna is mounted to the vessel inner wall	Mechanical Drawings
1.2.1.10	HHFW Antennae	Vacuum	At vessel port flanges	The antenna uses vessel ports for the RF feedthroughs, which therefore provide part of the vacuum boundary	Mechanical Drawings
1.1.1.2.3	Neutral Bean Armor Mechanical	Structural	At vessel wall surface, where bracketry is welded to vessel.	The neutral beam shine through armor is mounted to the vessel wall at Bay G, with the vessel reacting all loads on the armor.	Mechanical Drawings, Calculation
1.3.4.2.1	Main Chamber Fueling	Spatial	At the vessel flange to which the injector is mounted.	The injectors for the gas injection systems are typically mounted on flange welded directly to the vessel.	Mechanical Drawing(s)
1.1.1.2.2	Outboard Divertors	Spatial, Structural	At the vessel inner skin	The outboard divertor structures are mounted via clevesis to the vessel.	Mechanical Drawings, Calculations
1.4.1.2.6	High Frequency MHD Sensors	Structural	At the vessel surface	Magnetic diagnostics are mounted to the vessel wall	Mechanical Schematic/Layout
1.3.5.3	Li Evaporator	Vacuum,	The flange on the	LITER probes have port covers on the	Mechanical

	(LITER)	Structural	vessel ports.	vessel, provide both vacuum boundaries and some structural interface	Drawing
1.3.5.1.2	In-Vessel GDC Probes + Filaments	Spatial, Structural, Electrical Power	At the vessel inner skin	GDC electrodes and filaments are mounted to the vessel inner wall, which supports them. The vessel is also the cathode of the system.	Mechanical Schematic/Layout, Electrical Schematic
1.1.2.1.3	Vessel Legs	Structural	At sliding joints on vessel	Vessel legs support the vessel against all relevant load cases.	Mechanical Drawing, Calculation
1.4.1.2.7	TAE Antennas	Structural	At the vessel inner skin	TAE Antennas are mounted to the vessel wall, which supports them.	Mechanical Schematic, Calculation
1.4.1.7	BES	Spatial, Structural	At the weld of the custom penetration on the vessel.	Special vessel penetrations designed to provide appropriate views for the BES diagnostic.	Mechanical Drawings
1.4.1.6	FIDA	Spatial, Structural	At the weld of the custom penetration on the vessel.	Special vessel penetrations designed to provide appropriate views for the T-FIDA diagnostic.	Mechanical Drawings
1.4.1	Diagnostics	Structural	At the vessel inner skin	Some diagnostics such as sample coupons and Faraday cups are mounted to inner vessel wall. Viewing dumps are also mounted to the wall. Accelerometers are mounted to the vessel inner wall.	Mechanical Drawings or Schematics
1.4.1.22	Diagnostic Port Covers	Vacuum	At vacuum flanges on the vessel	Numerous diagnostic port covers are mounted to vacuum flanges on the vessel. These port covers often support multiple diagnostics, and so cannot be attributed to any single diagnostic system.	Mechanical Drawings of Diagnostic Port Covers
1.7.3.4.4	Vessel Voltage Monitors	Electrical Signal	At connection point of lead on the vessel	Vessel voltage monitors measure high-frequency transients on the vacuum vessel during operations	Electrical Schematic
1.1.2.1.2	Umbrella structure & Spoked Lids	Structural	At sliding joints on the vessel	Umbrella structure is interfaces to the vessel with sliding joints to accommodate thermal variations, vertical forces, torques from the TF	Mechanical Drawing, Calculation
1.3.3.2.1	Bakeout Bus Work	Thermal	At vessel surface	The joint must tolerate a range of thermal scenarios, from room temperature to the full outer vessel bakeout temperature	Calculation
1.3.3.2.1	Bakeout Bus Work	Structural	At vessel surface	disruption JxB forces reacted at joint	Calculation, Mechanical Drawing
1.3.3.2.1	Bakeout Bus Work	Eddy/Halo Current	At vessel surface	Halo current will flow through connections bridging inner and outer vessel, applying load to the bus work.	Calculation
1.1.1.2.1	Passive plates	Structural	Welds of the fixed brackets to vessel wall	Brackets welded to vessel wall are used to support plates	Mechanical Drawing, Calculation
1.3.3.1.3	In-Vessel Helium Lines	Structural	At vessel skin	In-vessel tubing/manifolds are supported from the vessel wall.	N/A
1.1.2.2	Vacuum Vessel Thermocouples	Diagnostic	At surface of vessel skin	Thermocouples used to measure vessel temperature during bakeout and	Mechanical Drawing

				operations	
1.1.2.3.1	Outer TF Truss System	Structural	At surface of vessel skin	The vessel supports are used to transfer load from the outer TF legs to the vessel	Mechanical Drawings, Calculation
1.1.2.3.2	Outer PF Supports	Structural	At surface of vessel skin	The vessel supports are used to transfer load from the outer-PF coils to the vessel	Mechanical Drawings, Calculation
1.1.3.5	Resistive Wall Mode Coils	Structural	At the vessel outer radius	The RWM coils are mounted directly to the vessel	Mechanical Drawings, Calculation
1.3.3.1.4	He Feedthroughs	Structural	The weld connecting the feedthrough to the vessel port extension	The He feedthrough is welded to a tube which is oriented horizontally and welded to the vessel at the end opposite the feedthrough.	Mechanical Drawing, Calculation
1.3.5.2	Trimethylboron (TMB) System	Gas	Ports on the outer vacuum vessel wall	provides ports for injection of gas for GDC and dTMB	P&ID
1.2.3	Electron Cyclotron Pre-Ionization (ECH)	Structural	At vessel flanges	RF launchers mount to vessel flanges	Mechanical Drawing
1.2.3	Electron Cyclotron Pre-Ionization (ECH)	Vacuum	At vessel flanges	Window as part of laucher forms vacuum boundary	Mechanical Drawing
1.4.1.2.1	Plasma Current Rogowski System	Structural	Vacuum vessel outer surface	Rogowski Coils mounted on outer surface of vacuum vessel via insulated supports	Mechanical Drawing
1.4.1.2.2	Mirnov and Flux Loop System	Diagnostic	Vacuum vessel inner and outer surfaces	Poloidal Flux Loops mounted on inner and outer surfaces of vacuum vessel; leads mounted to vessel surface.	Mechanical Drawing
1.4.1.3	Multi-pulse Thompson Scattering (MPTS)	Vacuum	Ports on vacuum vessel	Laser beam entrance and exit flight tubes (with windows) on vacuum vessel ports; blackening of inner vessel wall required within field of view of the collection optics, in order to reduce stray light	Mechanical drawing
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Structural	at surface of main vessel flange	Interface must carry vertical and side loads	Mechanical Drawing, Calculation
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	vacuum	at surface of main vessel flange	Interface has double O-ring seal w/ pumped interspace where break assembly meets the main vessel	Mechanical Drawing
1.1.1.2.2	Outboard Divertors	Eddy/Halo Current	At points where outboard divertors attach to the vessel	Halo currents that flow into or out of the outboard divertor	N/A
1.3.3.2.1	Bakeout Bus Work	Other	At flange on casing	The vacuum vessel is grounded via the bakeout bus work	Electrical Schematic
1.4.1.5.1	Toroidal CHERS	Other	Vessel inner surface	View dumps or blackening required where optics views intersect the vessel	N/A
1.4.1.9.1	SSNPAs	Vacuum	At flange on vessel	SSNPAs bolt to vessel, making vacuum seal	Mechanical Drawing
1.4.1.9.1	SSNPAs	Structural	At flange on vessel	SSNPAs bolt to vessel, supporting the diagnostic	Mechanical Drawing
1.4.1.9.2	iFLIP	Structural	Inner surface of	iFLIP is mounted to the inside vessel wall	Mechanical

			vessel		Drawing
1.4.1.9.3	sFLIP	Structural	At inner surface of vessel	sFLIP mounted to the vessel wall	Mechanical Drawing
1.4.1.9.3	sFLIP	Vacuum	At flange on vessel	sFLIP vacuum boundary is a window mounted on a vessel flange	N/A
1.4.1.9.4	Fusion Products Detector Probe	Vacuum	At flange on vessel (future)	fusion products detector interfaces to the vessel via a TIV (future)	Mechanical Drawing (future)
1.4.1.5.1	Toroidal CHERS	Vacuum	At flange on vessel	CHERS background view is via window mounted directly to vessel	N/A
1.3.3.3.2	MTWS Manifolds and Vessel-Mounted Piping	Thermal	At vessel surface	MTWS tubing is attached to the vessel surface	Schematic
1.3.3.3.2	MTWS Manifolds and Vessel-Mounted Piping	Structural	At vessel surface	MTWS tubing has transfer heat to, or removes heat from, the vacuum vessel, during bakeout and potentially during operations	Calculation
1.3.3.1.4	He Feedthroughs	Vacuum	The weld connecting the feedthrough to the vessel port extension	The He feedthrough is welded to a tube which is oriented horizontally and welded to the vessel at the end opposite the feedthrough. This weld is a primary vacuum seal.	Mechanical Drawing, Calculation

Table 3.6-2*: Interfaces for the umbrella structures and spoked lids (SBS 1.1.2.1.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.5.3	Li Evaporator (LITER)	Structural	At the flange of the port cover that is dedicated to LITER.	LITER probes are mounted on umbrella structures	Mechanical Drawing
1.1.3.2	TF outer legs	Structural	At surface of blocks that are glued to the TF outer legs	TF torques are reacted through the umbrella structure	Mechanical Drawing, Calculation
1.3.1.7	Interspace Vacuum Pumping System	Structural	At surface of umbrella	IVPS manifolds mounted to the surface of the umbrella structure	Mechanical Drawing
1.1.3.3.1	TF Inner Legs	Structural	At the interface between the torque plate and the spoked lid.	Torque is transferred to the upper umbrella structure through the spoked lid	Calculations, Mechanical Design Drawings
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Surface of spoked lid	Sensors measure strain in the spoked lides	Mechanical Drawing
1.1.3.3.7	Pedestal	Structural	At the underside of the upper plate on the pedestal	The lower spoked lid segments are bolted to the pedestal	Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Structural	At sliding joints on the vessel	Umbrella structure is interfaces to the vessel with sliding joints to accommodate thermal variations, vertical forces, torques from the TF	Mechanical Drawing, Calculation
1.1.3.4	Bus Bar Systems and Bus Tower	structural	Where supports are welded/bolted to umbrella	Supports for the -1a, -1b, & -1c leads are supported from the umbrella structure.	Mechanical Drawing, Calculation
1.3.4.3.2	Massive gas	Structural	At surface of umbrella	lower MGI valve is supported by	Mechanical

	injectors			the lower umbrella	Drawing
1.4.1.5.2	Poloidal CHERS	Spatial	N/A	Poloidal CHERS optics assemblies reside within the arches of the umbrella structure, largely blocking from any additional	Mechanical Drawing
1.1.3.4	Bus Bar Systems and Bus Tower	Spatial	N/A	Bus bars for the PF-1a, -1b, -1c, and -2 coils enter/leave the umbrella structure through the arches	Mechanical Drawing
1.1.3.4	Bus Bar Systems and Bus Tower	Spatial	N/A	Bus bars for the TF and OH coils enter the umbrella through the opening in the spoked lid.	Mechanical Drawing
1.3.4.3.1	High field side injectors	Spatial	N/A	Gas lines for high-field side injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.3.2	Massive gas injectors	Spatial	N/A	Gas lines and electrical signals for massive gas injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.3.2	Massive gas injectors	Spatial	N/A	Vacuum piping for the lower massive gas injector enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.2.5	Private Flux Region Fueling	Spatial	N/A	Gas lines for the private flux region injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.1.3.3.9	Horizontal Target Cooling System	Spatial	N/A	Helium lines for the horizontal target cooling system enter/leave through the arches in the umbrella structure	Mechanical Drawing
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Spatial	N/A	Water lines for the horizontal target cooling system enter/leave through the arches in the umbrella structure	Mechanical Drawing
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Spatial	N/A	Water lines for the PF-1a, -1b, -1c, and -2 coils enter/leave through the arches in the umbrella structure	Mechanical Drawing
1.3.2.1.3	OH Water Pre-Heater System	Spatial	N/A	Water lines to and from the OH coil pass through the umbrella arches	Mechanical Drawing

***Table 3.6-3**: Interfaces for the vessel legs (SBS 1.1.2.1.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.1	Vacuum vessel	Structural	At sliding joints on vessel	Vessel legs support the vessel against all relevant load cases.	Mechanical Drawing, Calculation
1.8.1.1.8	NTC Floor	Structural	At NTC floor surface	Gravity, seismic loads, and	Calculation,

				global torquest are transferred to the NTC floor	Mechanical Drawings

4. Passive Plates (SBS 1.1.1.2.1)

4.1: Functions

The function of the passive plates are to:

a. Provide MHD stabilization via induced currents for the high performance plasmas.

4.2: Materials and Design Requirements

a. The passive plates shall be made of high strength copper material, i.e. CuCrZr.

4.3: Configuration Requirements & Essential Features

a. The passive plates shall consist of primary (closest to midplane) and secondary (furthest from midplane) groupings, one set above the midplane and one set below the midplane of the NSTX-U device.

b. There shall be 12 passive plates per each of the four rows, for a total of 48 plates.

c. Each row shall be made up of a series of ½" thick conically shaped copper plates.

d. The passive plates shall be mounted to brackets extending from the outer vacuum vessel cylinder, and will be located from machined surfaces on these brackets.

e. The passive plates and their mounting structures shall be designed to withstand all loads during operation and bakeout as per Reference [3].

f. The passive plates shall be electrically connected to the vessel via their mounting structures. The connections shall contain provisions to facilitate removal of individual plates for modification to accommodate access for future diagnostic upgrades.

g. The plates shall have a well defined and reliable route for currents to pass through the plates to their mounting structures, on both toroidal ends of the plate.

h. At least one electrical connection mechanism shall exist between the plate/bracket combination and the weld ears at each end of the plate to facilitate the requirement in g).

i. If possible, the jumper noted in h) should be augmented by a second parallel path to enhance the current sharing and ensure redundancy.

j. The jumpers noted in h) should preserve as much of the resistance of the mounting structures as possible, i.e. provide a solid electrical path from the plate to the mounting structure while not shorting out a large section of the mounting structure.

k. The overall size of the individual plates making up the stabilizers must be such that they can be passed through the large horizontal vacuum vessel ports and easily manipulated by no more than two persons.

l. The plate support features shall be traced with SS tubing to facilitate bakeout of the PFCs on the passive plate surface.

m. The nominal locations of the plate front surface shall be as in Table 4.3-1 and Figure 4.3-1. Deviations of up to 1 cm in the average radius are acceptable, with deviations of +/-0.5 cm from that average allowed.

	R	Z
	m	m
Upper SPP	1.175	1.351
	1.113	1.375
	1.340	1.054
Upper PPP	1.360	1.006
	1.509	0.553

Table 4.3-1: *Spatial locations of the front surface of the passive plates. The lower plates are reflection symmetric about the midplane, i.e. Z -> -Z.*

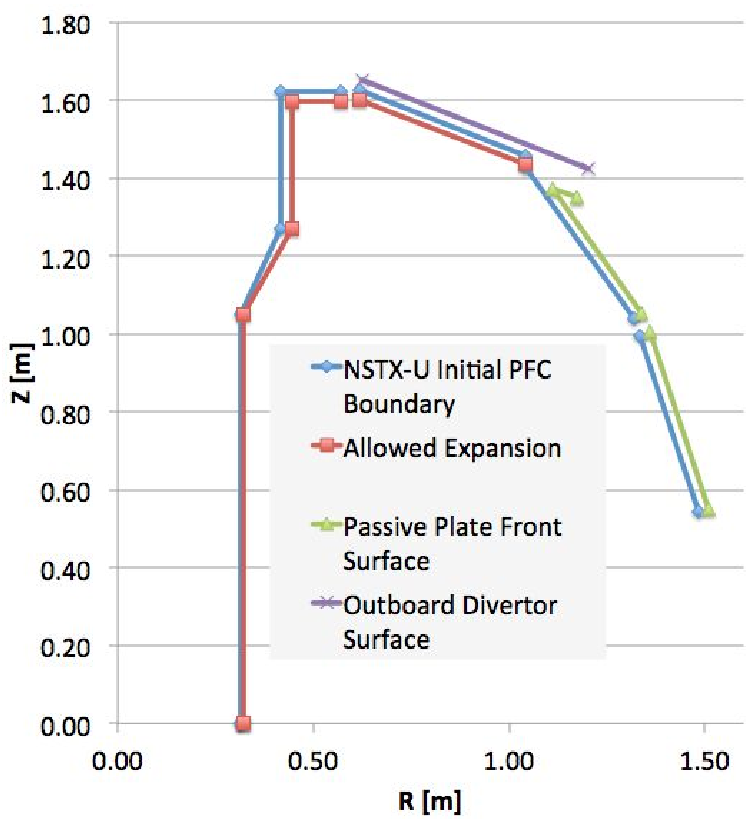

Figure 4.3-1*: Spatial locations of the front surface of the passive plates and outboard divertors*

4.4: Baseline Performance & Operational Requirements

a. The trace tubing shall be rated for the temperature (450 C) and pressure (300 PSIG) of the bakeout helium system.

4.5: Upgrade Performance & Operational Requirements

a. Active cooling of the passive plates via their bracket trace tubing may be applied in the future.

4.6: Interfaces

Table 4.6-1*: Interfaces for the passive plates (SBS 1.1.1.2.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.1	Vacuum vessel	Structural	Welds of the fixed brackets to vessel wall	Brackets welded to vessel wall are used to support plates	Mechanical Drawing, Calculation
1.3.3.1.3	In-Vessel Helium Lines	Eddy/Halo Current	At surface of tubes	During disruptions and other transients, current can transfer	Mechanical Drawing,

				between the tubes and the plate brackets	Calculation
1.4.1.2.3	RWM Sensors	Structural	At the tabs that hold the sensor boxes	The RWM poloidal field sensors (BP) sensors are supported from the primary passive plates	Calculation
1.7.3.4.3	Passive Plate and Vessel Accelerometers	Diagnostic	At surface of plate	Accelerometers measure motion of passive plates during disruptions	CWD
0.1.1.2	Plasma	Structural	---	plates provide a stabilizing force on the plasma via induced currents.	---
1.1.1.1.6	Passive Plate PFCs	Structural	At plasma facing copper surface of the passive plate	Tiles react disruptions loads to the passive plates. Flexing of the plate transfers load to the tiles	Mechanical Drawings, Calculations
1.1.1.1.6	Passive Plate PFCs	Thermal	At plasma facing copper surface of the passive plate	Tiles transfer heat during bakeout and operations	Mechanical Drawings, Calculations
1.3.3.1.3	In-Vessel Helium Lines	Thermal	At surface of tubes	Heating tubes used to transfer heat to the plates during bakeout	Mechanical Drawing, Calculation
1.3.3.1.3	In-Vessel Helium Lines	Structural	At surface of tubes	Plate brackets provide structural support of the tubes, and motion of plates can transfer load to the tubes.	Mechanical Drawing, Calculation
1.1.2.2	Vacuum Vessel Thermocouples	Diagnostic	At surface of plate.	Thermocouples measure temperature of plates	CWD
1.4.1.2.2	Mirnov and Flux Loop System	Diagnostic	Passive Plates	Poloidal Flux Loops mounted in grooves behind the primary and secondary passive plates, used to estimate current flowing in plates	Mechanical Drawing
1.4.1.2.2	Mirnov and Flux Loop System	Structural	Passive Plates	Mirnov Sensors mounted behind and between the passive plates	Mechanical Drawing
1.1.1.1.6	Passive Plate PFCs	Eddy/Halo Current	At plasma facing copper surface of the passive plate	Tiles react disruptions loads to the passive plates. Flexing of the plate transfers load to the tiles	Calculations

5. Outboard Divertor Structures (SBS 1.1.1.2.2)

5.1: Functions

The function of the outboard divertor structures are to

a. support the tiles that provide a heat flux handling surface for plasma scenarios with the outer strike-point at radii greater than ~0.65 m.

This power handling surface shall be graphite tiles, described in SBS 1.1.1.1.5. [10]

5.2: Materials & Design Requirements

a. See Section 1.

5.3: Configuration Requirements & Essential Features

a. The outboard divertor area strike plates shall consist of segmented upper and lower toroidal ring assemblies, bridged by copper plates which are then covered by protective tiles.

b. These ring assemblies shall be mounted, on the vacuum side, to the two vacuum vessel domes, concentric to the center stack.

c. The outboard divertor plates shall be traced with stainless steel tubing for active temperature control during bakeout and, as a potential future upgrade, during operation.

d. There shall be standard cutouts in the ring and copper plate assemblies at each vertical dome port to allow for diagnostic views. Some diagnostics may need larger or customized cutouts.

e. The dimension of the divertor top surface shall designed as in Table 5.3-1

	R	Z
	m	m
OBD	0.62636	1.65164
	1.20378	1.4242

Table 5.3-1: Spatial locations of the front surface of the upper outboard divertors. The lower outboard divertor surface is reflection-symmetric about the midplane, i.e. Z -> -Z.

f. The outboard divertors and trace tubing shall be designed to withstand all loads during operation as elaborated in Ref. [3].

g. No permanently installed component on the outboard divertor shall extend inside the radius of the main vessel flanges (R_{vessel_flange}=23.625”),

5.4: Baseline Performance & Operational Requirements

a. The trace tubing shall be rated for the maximum temperature (450 C) and pressure (300 PSIG) of the hot helium system.

5.5: Upgrade Performance & Operational Requirements

There are no upgrade requirements.

5.6: Interfaces

***Table 5.6-1**: Interfaces for the outboard divertor (SBS 1.1.1.2.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.3.1.3	In-Vessel Helium	Thermal	At surface of	Lines are used to bring heat into	Mechanical

	Lines		heating/cooling line	the divertor plates during bakeout, and may in the future be used to extract heat between discharges	Drawing
1.3.4.2.3	Outboard Divertor Injection Systems	Spatial	surface of gas tubing	Outboard divertor structures may be slightly modified to accommodate gas delivery lines.	Mechanical Drawing
1.3.5.3	Li Evaporator (LITER)	Spatial	cut-outs in outboard divertor aligned with dome ports	LITER probe is driven to a position in the gaps of the outboard divertor when it is evaporating.	N/A
1.4.1.19	MAPP	Spatial	In diagnostic gap at large radius in the outboard divertor	Gap into which the MAPP probe is inserted for surface science measurements	N/A
1.4.1.2.8	Tile and Rogowski Halo Current Measurements	Eddy/Halo Current	At surface of divertor	Shunt tiles measure current flowing through tiles to the divertor slats	Mechanical Drawing
1.4.1.5.2	Poloidal CHERS	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma for the PCHERS system	N/A
1.4.1.6	FIDA	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma	N/A
1.4.1.13	Visible Spectroscopy	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma	N/A
1.4.1.13.1	Filterscopes	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma	N/A
1.4.1.19	MAPP	Spatial	At cut-out in outboard divertor structures	Cut-out allows probe insertion	N/A
1.4.1.20	Bolometers & Vacuum Radiation Sensors	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma	N/A
1.4.1.21	IR Cameras for Thermography	Spatial	At cut-out in outboard divertor structures	Cut-out allows diagnostic views of the plasma	N/A
1.1.2.1.1	Vacuum vessel	Eddy/Halo Current	At points where outboard divertors attach to the vessel	Halo currents that flow into or out of the outboard divertor	N/A
1.1.1.1.5	Outboard Divertor PFCs	Structural	At surface of the outboard divertor structures	Tiles react disruptions loads to the divertor structures	Mechanical Drawings, Calculations for i) forces, ii) heat balance
1.1.1.1.5	Outboard Divertor PFCs	Thermal	At surface of the outboard divertor structures	Tiles transfer heat during bakeout and operations.	Mechanical Drawings, Calculations for i) forces, ii) heat balance
1.1.2.1.1	Vacuum vessel	Spatial, Structural	At the vessel inner skin	The outboard divertor structures are mounted via clevesis to the vessel.	Mechanical Drawings, Calculations
1.3.3.1.3	In-Vessel Helium Lines	Structural	At surface of heating/cooling line	Divertors provide structural support for the lines.	Mechanical Drawing

1.1.2.2	Vacuum Vessel Thermocouples	Diagnostic	At surface of plate.	Thermocouples measure temperature of outboard divertor mechanical structures	CWD
1.3.3.1.3	In-Vessel Helium Lines	Eddy/Halo Current	At surface of heating/cooling line	Currents during disruptions can transfer to/from the plates and heating/cooling lines	Mechanical Drawing
1.1.1.1.5	Outboard Divertor PFCs	Eddy/Halo Current	At surface of outboard divertor copper structures	Halo currents and potentially eddy currents transferred from the tiles and their mounting structures to the outboard divertor	N/A

6. Neutral Beam Armor Mechanical Structures (SBS 1.1.1.2.3)

6.1: Functions

The function of the neutral beam armor is to

a. Protect the vessel wall from neutral beam power from

- conditioning and neutral beam armor shots, or
- power that is not intercepted by the plasma.

This power handling surface shall be graphite tiles, described in SBS 1.1.1.1.5. [10]

The function of the mechanical structures of the neutral beam armor are to:

b. Provide mechanical structures to support the tiles, as well as transfer heat to the tiles (bakeout), or remove the heat (neutral beam operations).

6.2: Materials Requirements

a. See Section 1.

6.3: Configuration Requirements & Essential Features

a. The armor mechanical structures shall be supported from the vessel wall.

b. The armor mechanical structures shall use the midplane port at Bay H for electrical and fluid or gas feedthroughs for the armor.

c. The armor mechanical structures shall have provision for mounting graphite tiles facing the plasma and neutral beam.

d. The armor mechanical structures shall have provision to allow the MSE-LIF diagnostic neutral beam to pass through into the plasma.

e. The armor shall be traced with stainless steel tubing for active temperature control during bakeout and operation.

f. The armor shall be designed to withstand all loads during operation as described in Ref [3].

6.4: Baseline Performance & Operational Requirements

a. Armor shall be designed to absorb a full duration and full energy or full power pulse from all ion sources simultaneously, without damage to the vessel or underlying metallic structures. The beam energy vs. voltage is described in the GRD [1].

b. Trace tubing shall facilitate bakeout of the PFC tiles on the armor to > 300 C.

c. Trace tubing used in the neutral beam armor heating/cooling loops shall be rated for the maximum temperature and pressure of the hot helium system (450 C & 300 PSI).

6.5: Upgrade Performance & Operational Requirements

a. An upgrade to active cooling of the armor with He may be required for particular operations scenarios.

6.6: Interfaces

Table 6.6-1: *Interfaces for the neutral beam armor mechanical structures (SBS 1.1.1.2.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.2.4.9	Generated Neutral Beam	Thermal	At the surface of the PFC Tiles	Power from the neutral beam impinges on the armor PFC tiles, a fraction of which is ultimately transferred to the armor mechanical structures	Mechanical Calculation
1.3.3.1.2	Ex-Vessel Helium Manifolds	Gas	At He feedthrough	The hot helium distribution system feeds helium to the armor during bakeout.	Mechanical Drawing
1.1.1.1.7	Neutral Bean Armor PFCs	Structural	At surface of armor	The PFC are mounted to the armor surface, where they react loads	Mechanical Drawing, Calculation
1.1.1.1.7	Neutral Bean Armor PFCs	Thermal	At surface of armor	The PFC are mounted to the armor surface, where they pass heat during bakeout and operations including the off-normal full-power beam shot.	Mechanical Drawing, Calculation
1.4.1.8	MSE	Spatial	---	line-of-sight access is provided to enable the MSE-LIF neutral beam to enter the plasma	Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Structural	At vessel wall surface, where bracketry is welded to vessel.	The neutral beam shine through armor is mounted to the vessel wall at Bay G, with the vessel reacting all loads on the armor.	Mechanical Drawings, Calculation

7. In-Vessel Heating/Cooling Tubing (SBS 1.3.3.1.3)

7.1: Functions

The function of the in-vessel heating/cooling tubing is to:

a: Distribute hot helium to the in-vessel structures, in order to heat graphite components to >300 C.

b. In an upgrade scenario, distribute helium to in-vessel components in order to cool them between discharges

7.2: Materials Requirements

a. See Section 1

7.3: Configuration Requirements & Essential Features

a. The in-vessel heating/cooling tubes shall interface to the hot helium vessel feedthroughs [9].

b. Trace tubing shall convey hot helium to the following structures, for purposes of elevating their temperature to bake out PFC tiles[1]:

- Primary passive plate brackets
- Secondary passive plate brackets
- Outboard divertor structures

7.4: Baseline Performance & Operational Requirements

a. Tubing shall be rated for the maximum temperature and pressure of the hot helium system (450 C and 300 PSI).

b. Tubing shall accommodate all load cases during operations and bakeout as described in Ref. [3].

c. Tubes shall be leak-tight as per GRD.

7.5: Upgrade Performance & Operational Requirements

a. There tubes may be used in a cooling function with He gas in the future.

[1] The neutral beam armor has its own trace tubing system, as described in Section 6.

7.6: Interfaces

Table 7.6-1*: Interfaces for the in-vessel heating/cooling distribution system (SBS 1.3.3.1.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.1.2.2	Outboard Divertors	Structural	At surface of heating/cooling line	Divertors provide structural support for the lines.	Mechanical Drawing
1.1.1.2.1	Passive plates	Thermal	At surface of tubes	Heating tubes used to transfer heat to the plates during bakeout	Mechanical Drawing, Calculation
1.1.1.2.1	Passive plates	Structural	At surface of tubes	Plate brackets provide structural support of the tubes, and motion of plates can transfer load to the tubes.	Mechanical Drawing, Calculation
1.3.3.1.4	He Feedthroughs	Gas	Immediately after the feedthrough or any compliant component associated with the feedthrough	The vessel feedthroughs are connected to the in-vessel He piping via a compliant section.	Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Structural	At vessel skin	In-vessel tubing/manifolds are supported from the vessel wall.	N/A
1.1.2.2	Vacuum Vessel Thermocouples	Diagnostic	At surface of tube	Thermocouples measure temperature of select tubing components.	Mechanical Drawing
1.1.1.2.2	Outboard Divertors	Eddy/Halo Current	At surface of heating/cooling line	Currents during disruptions can transfer to/from the plates and heating/cooling lines	Mechanical Drawing
1.1.1.2.1	Passive plates	Eddy/Halo Current	At surface of tubes	During disruptions and other transients, current can transfer between the tubes and the plate brackets	Mechanical Drawing, Calculation
1.1.1.2.2	Outboard Divertors	Thermal	At surface of heating/cooling line	Lines are used to bring heat into the divertor plates during bakeout, and may in the future be used to extract heat between discharges	Mechanical Drawing

8. Vessel, Passive Plate, Outboard Divertor and In-Vessel Tubing Thermocouples (SBS 1.1.2.2)

8.1: Functions

The function of these thermocouples (TCs) are:

a. Measure the temperature of the vacuum vessel, passive plates, in-vessel tubing and outboard divertor during operations and bakeout.

These complement the thermocouples mounted within the PFCs [11].

8.2: Materials and Design Requirements

a. See Section 1.

b. Thermocouples should be electrically isolated from the metallic structures to which they are attached.

8.3: Configuration Requirements & Essential Features

a. The vessel thermocouples shall be electrically isolated from the vessel.

b. Within the constraints provided by the physical features and geometry of the vessel, the vessel thermocouples shall be uniformly distributed on the vessel surface.

c. The passive plate thermocouples shall be located on the back sides of selected plates (facing away from the plasma)

d. Outboard divertor thermocouples shall be installed on selected Cu components of the divertor in a way that does not interfere with the PFC tiles.

8.4: Baseline Performance & Operational Requirements

a. The vessel thermocouples should be capable of measuring from at least 10 degC to 250 degC, with an accuracy of 5 degC or less.

b. The passive plate, tubing, and outboard divertor thermocouples should be capable of measuring from at least 10 degC to 500 degC, with an accuracy of 5 degC or less.

8.5: Upgrade Performance & Operational Requirements

8.6: Interfaces

***Table 8.6-1**: Interfaces for the Vessel TCs (SBS 1.1.2.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.1.2.2	Outboard Divertors	Diagnostic	At surface of plate.	Thermocouples measure temperature of outboard divertor mechanical structures	CWD
1.1.2.1.1	Vacuum vessel	Diagnostic	At surface of vessel skin	Thermocouples used to measure vessel temperature during bakeout and operations	Mechanical Drawing
1.1.1.2.1	Passive plates	Diagnostic	At surface of plate.	Thermocouples measure temperature of plates	CWD
1.6.1.1	Control I/O systems	Electrical Signal	At the electronics input	Voltages from the TCs are digitized and calibrated to provide temperature data, archived.	CWD
1.3.3.1.3	In-Vessel Helium Lines	Diagnostic	At surface of tube	Thermocouples measure temperature of select tubing components.	Mechanical Drawing
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support cables for thermocouples	N/A

9. Coil Support Structures (SBS 1.1.2.3)

9.1: Functions

The function of the coil support structures shall be to support the coils off of the vacuum vessel. In particular, they shall:

a. provide support for the outer legs of the TF coils against all loads (electromagnetic, seismic, other)

b. provide support for the outer PF coils (PF-5, PF-4, PF-3, and PF-2) against all loads (electromagnetic, seismic, other)

9.2: Materials and Design Requirements

a. See Section 1.

9.3: Configuration Requirements & Essential Features

<u>9.3.1 TF Outer Legs</u>

a. The TF outer legs shall be supported by i) systems of trusses and tie-bars, located above and below the midplane and connected to the vacuum vessel, and ii) the umbrella structures.

b. The supports for the TF outer legs shall accommodate thermal scenarios during bakeout with < 1 day used to field modify the supports both before and after the bake.

c. The supports for the TF outer legs shall accommodate thermal scenarios and EM loads during operations, as described in Ref. [3].

d. All aspects of the TF coil support shall be compatible with NSTX-U operation with plasma current and toroidal field in either ϕ direction.

<u>9.3.2 Outer PF Coils</u>

a. Structural support of the PF coils shall restrain against vertical motion when subject to electromagnetic loads, while also providing required radial restraints. Structural support of the PF coils shall restrain free body motion of the coil due to all EM loads. Coil elastic deformation, within design allowables, due to the combined effects of the EM loads and the coil supports is allowed[2].

[2] Selected coil deformations will be measured with the instrumentation described in NSTX-U-RQMT-SRD-011.

b. The outer PF mounting structures shall designed with allowance for the range of coil and vessel thermal scenarios, including bakeout and plasma operations, ensuring that the coils remain centered.

c. The PF-4 and PF-5 coils shall be restrained from radial thermal growth at two opposing locations, allowing an n=2 deformation under thermal growth. The toroidal angle of one restraint shall coincide with the lead block of the coil to inhibit coil motion near the leads.

d. All aspects of the PF coil support shall be compatible with NSTX-U operation with plasma current and toroidal field in either ϕ direction.

9.4: Baseline Performance & Operational Requirements

a. Vertical loads on the coils, and combinations of coils, may be found in the design point spreadsheet.

9.5: Upgrade Performance & Operational Requirements

a. There are no upgrade requirements on the coil support structures.

9.6: Interfaces

Table 9.6-1*: Interfaces for the outer TF truss system (SBS 1.1.2.3.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.2	TF outer legs	Structural	The outside of the coil ground insulation and/or ground plane.	Mechanical support interface with allowance for thermal and EM distortions	Calculations, Mechanical Design Drawings
1.1.2.1.1	Vacuum vessel	Structural	At surface of vessel skin	The vessel supports are used to transfer load from the outer TF legs to the vessel	Mechanical Drawings, Calculation
1.3.3.1.2	Ex-Vessel Helium Manifolds	Structural	Where supports attach to the TF Truss system	Helium manifolds for the neutral beam armor are supported from the outer TF support system	Mechanical Drawing
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Surface of truss	Sensors measure strain in the TF trusses	Mechanical Drawing

Table 9.6-2*: Interfaces for the outer PF support structures (SBS 1.1.2.3.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.1	Vacuum vessel	Structural	At surface of vessel skin	The vessel supports are used to transfer load from the outer-PF coils to the vessel	Mechanical Drawings, Calculation
1.1.3.4	Bus Bar Systems	Structural	At surface of support	Some inner-PF and PF-2 lead	Mechanical

	and Bus Tower		structure	supports are mounted to the PF-3 coil support	Drawing, Calculation
1.3.5.2	Trimethylboron (TMB) System	Structural	Where clamps attach to PF support	Gas delivery line for the dTMB system supported by the outer PF supports	Mechanical Drawing
1.3.4.2.1	Main Chamber Fueling	---	At surface of PF support	Some main chamber fueling systems are supported from the outer PF supports	N/A
1.3.3.3.2	MTWS Manifolds and Vessel-Mounted Piping	Structural	Where support attaches to outer-PF support	Manifolds supported by the Outer PF supports, which are in turn attached to the vessel	Mechanical Drawing
1.3.3.1.2	Ex-Vessel Helium Manifolds	Structural	Where support attaches to outer-PF support	Helium manifolds are supported from the outer-PF support weldments on the vacuum vessel.	Mechanical Drawing
1.1.3.1	Outer PF coils	Structural	The outside of the coil ground insulation and/or ground plane.	Mechanical support interface with allowance for thermal and EM distortions	Calculations, Mechanical Design Drawings
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Surface of slide mechanism	Sensors measure displacements of the radial slides.	Mechanical Drawing

10. CS Casing Assembly, Inner-PF Coil Supports, Pedestal, and Ceramic Breaks (SBS 1.1.3.3.4)

10.1: Functions

The functions of the CS Casing and Inner-PF coil supports are:

a. Form the inner vacuum boundary

b. Support, and in some cases provide preload to, the PF-1aU, PF-1aL, PF-1bU, and PF-1bL coils.

c. Provide the resistive element to heat the tiles which are mounted to the casing.

d. Provide cooling function to remove heat from plasma heating and current drive systems, and a heating function to heat tiles in the divertor region for bakeout.

e. Provide a mounting structure for graphite tiles.

The function of the CS Pedestal is:

f. To support the CS against gravity, while assisting in the distribution of other loads such a launching loads on the center magnet assembly or the transferring of torque from the inner magnet assembly.

The function of the Ceramic Break is:

g. To break the electrical continuity of the vessel so that DC current injected across the break must flow through the CS casing, providing a heating function.

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10.2: Materials and Design Requirements

a. See Section 1.

b. Lateral displacements at the top of the CS due to toroidally asymmetric halo currents shall be restrained, either in the base thermal case or the fully ratcheted case, via transfer to the outer vessel. Provisions shall be made to restrain CS lateral motion due to EM loads. Restraints must accommodate CS thermal growth and vertical displacements due to EM loads.

c. Any part which will achieve the full bakeout temperature while exposed to atmosphere shall be made from a material which can tolerate this combination of temperature and environment.

10.3: Configuration Requirements & Essential Features

10.3.1 Assembly

a: All parts that must be crane lifted into place shall have an engineered lifting fixture or provision for connection to the crane.

b: No permanently installed component on the CS shall extend more than ¼" beyond the radius of the CS horizontal flanges (R_{flange}=21.875", for R_{max}=R_{flange}+1/4 = 22.125"). Any exceptions to these rules must be granted by the NSTX-U Project Engineer or Construction Manager.

c. The PF1c/insulating ring assemblies, both upper and lower, shall be removable without removing the centerstack.

d. The pedestal design shall allow it to be removed with the centerstack temporarily supported from above.

e. The mating of the OH/TF magnet assembly to the casing shall include provision to adjust the position and tilt of the magnet assembly within the casing within the travel allowed by existing geometry.

10.3.2 Coil Thermal Isolation

a. The center stack casing shall include an air gap and/or insulating material in the annular region surrounding the OH and inner-PF coils for the purpose of thermal and electrical isolation between the coil and the casing.

b. Thermal isolation shall be designed to protect the OH coil, PF-1a coils, PF-1b coils, PF-1c coils, and surrounding magnetics diagnostics from excess temperatures due to heat influx from bakeout and from normal operations, including fault scenarios such as loss-of cooling scenarios.

10.3.3 Ceramic Insulator Assembly

a: The NSTX-U device shall have only a single ceramic insulator between the outer vacuum vessel and the centerstack casing. The design shall locate this insulator at the top of the machine.

b: Insulator materials other than alumina may be considered.

c: The ceramic insulator should be suspended between double O-rings. This suspension should be designed such that no deflection, thermal, EM, or otherwise, can result in unacceptable loading of the insulator as per the structural design criterion. Mechanical clamping of the ceramic insulator shall not "bottom out" the metal flange to ceramic gap under any conditions.

d. Provision should be made on any bolt insulating sleeves or features to prevent water contaminating the isolation provided by the break.

10.3.4 Vacuum Seals

a. No single elastomer seals shall be used on the primary seals between the CS assembly and the outer vacuum vessel. Acceptable vacuum seal technologies include:

- Double viton O-rings with pumped interspaces
- Metal seals with a secondary seal (viton or metal) and pumped interspace
- Welded lip seals

b. Provision shall be made to leak-check all primary vacuum seals that interface the centerstack casing to the outer vessel before full machine pump-down.

c. If double O-rings are selected for the seals, then provision shall be made to evacuate the interspace between the O-rings.

10.3.5 Electrical Considerations

a. The center stack casing shall have three electrical connections top and bottom sized for passing of the bakeout current (8 kA total for design purposes, 5.3 kA per leg[3]). They should be toroidally aligned to the connections on the outer vessel.

b. If these electrical connections remain in place during operations, then their design shall accommodate loads during operations, including disruption loads.

10.3.6 Heating and Cooling

a. The center stack casing shall tolerate the full range of CSFW, IBDV, and IBDH tile required bakeout temperatures (300 C minimum to 350 C maximum average tile temperature over the full casing surface).

Note: the casing temperature that supports the tile bakeout temperature shall be determined by calculation or experiment.

b. Provision shall be made via heating/cooling features to heat or cool the horizontal and vertical inner divertor targets, at both the CS top and bottom. Water may be used for cooling if outside the primary vacuum boundary; gas cooling must be used used if the features are on the vacuum side and do not have other secondary containment.

[3] 5.3 kA is derived from a ⅓ split of the 8000 kA, with a factor of 2 safety factor.

c. The center stack casing shall accommodate the passage of a current in the Z direction for the purpose of resistive heating as a source of heat during the bakeout mode.

d. The center stack casing shall have compliant features (bellows) to accommodate the differential thermal expansion between the vacuum vessel and the casing for the full range of potential thermal differentials, including bakeout and operations scenarios.

e. These bellows shall be electrically protected from ohmic heating and electromagnetic loads during bakeout and operations, including disruption loads. [12]

f. Insulation may be used to mitigate thermal stresses in bellows or other components.

10.3.7 Coil Supports

a. The PF-1a and -1b coils shall be constrained by support structures that facilitate the mandrel-less approach to coil manufacture. These structures shall have the features in Table 10.3.7-1:

Table 10.3.7-1: Requirements on the PF-1a and PF-1b support structures

1	Minimal toroidal conductivity of metallic components
2	Thermal isolation from hot surface during operations and bakeout scenarios.
3	Support which maintains the coil centered position against radial, sideways, and vertical loads from all static and dynamic load cases.
4	Ability to align coil centers to external structures by either i) radial adjustment features (within the available clearance), or ii) accurate machining of components.

b. PF1c shall be in a reentrant flange that forms the vacuum boundary, accommodating the mandrel-less approach to coil manufacture. The assembly shall have the features in Table 10.3.7-2.

Table 10.3.7-2: Requirements on the PF-1c support structures

1	have provision for maintaining the centered position of the coils while providing adequate stiffness to overcome any non-axisymmetric radial load
2	Ability to align coil centers to external structures by either i) radial adjustment features (within the available clearance), or ii) accurate machining of components.

c. Structural support of the OH coil shall allow for axial thermal expansion while ensuring that the coil motion is constrained to allowable levels when subject to electromagnetic loads.

d: Designs should minimize to the largest extent possible any welding in close proximity to coil insulation, and steps to protect ground insulation should be defined and taken during assembly to minimize risk of insulation compromise.

e: Designs for inner-PF coil supports shall apply the required coil preloads as determined by magnet designs.

f: The casing coil support structures should provide access routes for the three plasma current rogowski sensors to leave the CS assembly

g: The casing coil support structures should provide access routes for thermocouple and flux loop wires on the inner-PF and OH coil to leave the CS assembly. [8]

h: For coils where pre-load is required, sensors shall be installed to monitor that preload.

10.3.8 Diagnostics

a. Diagnostics on the casing, inner-PF coils, and OH coil are described in Ref. [13].

10.3.9 Lateral Load Bearing Structures

a. These lateral load bearing structures shall have designs that do not risk the seating of O-rings or place load on the ceramic insulators.

b. Provision should be made in the design of these restraints for the installation of strain, pressure, or other sensor that can be used to diagnose lateral loading on the casing.

10.3.10 Pedestal

a. The pedestal shall be designed to handle all loads associated with the support of the center column, including but not limited to dead weight, EM vertical loads, and global torques.

b. The pedestal shall be designed to accommodate the access of auxiliary components (cooling hose, instrumentation cabling as appropriate, etc.) to the CS assembly.

c. Pedestal design shall have features which provide adjustment of the TFOH bundle and the CS Assembly.

10.4: Baseline Performance & Operational Requirements

10.4.1 Electrical

a. The casing electrical insulation with respect to ground shall be designed for a 2 kV rms high-pot test voltage of duration 1 minute.

b. The ceramic insulator design should be capable of at least 1000 V DC standoff (2E+1, where E is the negligible bakeout power supply voltage), and have an equivalent in-vessel creep distance larger than 3 times the maximum IBDH/OBD tile gap.

10.4.2 Heating and Cooling

a. All cooling loops that are additionally intended to supply hot He shall be qualified at the rated temperature (450 C) and pressure (300 PSIG) of the bakeout system.

b. Explicit thermal scenarios that the heating and cooling systems shall accommodate are provided in Ref. [9].

10.4.3 Coil Thermal Isolation

a: Structures should be designed so that i) coil ground insulation does not exceed 140 °C [14] and ii) any glass reinforced plastic/laminate material does not exceed its rated service or operation temperature. These criteria shall apply under any possible thermal scenario (operations, bakeout, etc.).

b. The insulation or design features protecting the OH and PF-1a/b/c coils from the any elevated temperature metallic structures (casing, coil housings, etc) should provide at least 1 hour response time against the temperature limits noted in 10.4.3a following a coil loss of cooling condition during bakeout or operations.

c. Any deviations from 10.4.3a) and b) shall be limited to the surface of the ground insulation, and shall be demonstrated to be acceptable by analysis and/or test for all relevant structural and electrical considerations.

10.4.4 Alignment

a. Alignment requirements will be given in a separate reference [15].

10.5: Upgrade Performance & Operational Requirements

a. An increase in the design pressure for the heating/cooling loops, compared to that used in bakeout, may be required to accommodate the full cooling function.

10.6: Interfaces

***Table 10.6-1**: Interfaces for the CS casing (SBS 1.1.3.3.6)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.9	Horizontal Target Cooling System	thermal	At grafoil between the cooling plate and the casing flange	The horizontal target cooling system will transfer heat the casing flange through the grafoil	Mechanical Drawing, Calculation
1.1.3.3.9	Horizontal Target Cooling System	structural	At grafoil between the cooling plate and the casing flange	Loads on the horizontal target cooling system/plate will be transferred to the casing.	Mechanical Drawing, Calculation
1.1.3.3.10	Vertical Target Cooling System	thermal	At air-side surface of the casing	The vertical target cooling system removes heat from the CS transition sleeve	Mechanical Drawing, Calculation
1.1.3.3.10	Vertical Target Cooling System	structural	At air-side surface of the casing	The vertical target cooling system is mechanically connected to the air-side of the transition sleeve, supported against gravity, eddy current, and other loads. Attachments need to support multiple thermal scenarios.	Mechanical Drawing, Calculation
1.1.1.1.3	Vertical Target PFCs	Eddy/Halo Current	At casing surface	Halo currents and potentially eddy currents transferred from the tiles and their mounting structures to the casing.	N/A
1.1.1.1.2	CSAS PFCs	Eddy/Halo Current	At casing surface	Halo currents and potentially eddy currents transferred from the tiles and their mounting structures to the casing.	N/A
1.1.1.1.1	Center Stack First Wall PFCs	Eddy/Halo Current	At casing surface	Halo currents and potentially eddy currents transferred from the tiles and their mounting structures to the casing.	Calculation
1.1.3.3.9	Horizontal Target Cooling System	Eddy/Halo Current	at grafoil between the cooling plate and the casing flange	Halo current will pass through the plates into the casing	Calculation
1.1.3.3.9	Horizontal Target Cooling System	Spatial	at grafoil between the cooling plate and the casing flange	The target plate needs to provide access to all organ pipes on the casing flanges, without reduction in access.	Mechanical Drawing
1.1.3.3.11	PF-1a Support Structure	structural	via the casing support weldment	The PF-1a support structures are interfaced to the casing via the PF-1b structures and the casing support weldment	Mechanical Drawing, Calculation
1.1.3.3.12	PF-1b Support Structure	structural	via the casing support weldment	The PF-1b support structures are interfaced to the casing via the casing support weldment	Mechanical Drawing, Calculation
1.1.1.1.3	Vertical Target PFCs	Structural	At the surface of the casing.	Vertical target tiles, or structures designed to hold these tiles, are mounted to the casing, reacting loads on the PFCs	Mechanical Drawings, Calculations for forces
1.1.1.1.3	Vertical Target PFCs	Thermal	At the surface of the casing.	Vertical target tiles, or structures designed to hold these tiles, are mounted to the casing, transferring heat to PFCs during	Mechanical Drawings, Calculations for heat balance

				bakeout and from PFCs during operations.	
1.1.1.1.2	CSAS PFCs	Structural	At surface of casing.	CSAS tiles are mounted to the casing, reacting loads PFCs during operations.	Mechanical Drawings, Calculations for forces
1.1.1.1.2	CSAS PFCs	Thermal	At surface of casing.	CSAS tiles are mounted to the casing, transferring heat to PFCs during bakeout and from PFCs during operations.	Mechanical Drawings, Calculations for heat balance
1.1.1.1.1	Center Stack First Wall PFCs	Structural	At surface of casing.	CSFW tiles are mounted to the casing, reacting loads on the PFCs	Mechanical Drawings, Calculations for forces
1.1.1.1.1	Center Stack First Wall PFCs	Thermal	At surface of casing.	CSFW tiles are mounted to the casing, transferring heat to PFCs during bakeout and from PFCs during operations.	Mechanical Drawings, Calculations for heat balance
1.1.3.3.2	Ohmic Heating Solenoid	Thermal	immediately outside of coil ground wall	Microtherm to provide thermal isolation	Calculation, Mechanical Design Drawings
1.3.3.2.1	Bakeout Bus Work	Electrical Power	At horizontal flange surface	The three bakeout connections are mounted to the flange surface on the air side.	Mechanical Drawing
1.3.4.3.1	High field side injectors	Gas	At organ pipe flange	high field side injector gas enters the in-vessel tubing at the end of the organ pipe	Mechanical Drawing
1.3.4.3.1	High field side injectors	Vacuum	At organ pipe flange	high field side injector gas has a vacuum interface to the casing at the end of the organ pipe	Mechanical Drawing
1.3.4.3.2	Massive gas injectors	Vacuum	At organ pipe flange	Massive gas injector has a vacuum interface at the flange on the end of the organ pipe	Mechanical Drawing
1.3.4.3.2	Massive gas injectors	Gas	At organ pipe flange	Massive gas injector gas enters at the end of the organ pipe	Mechanical Drawing
1.3.4.2.5	Private Flux Region Fueling	Vacuum	At organ pipe flange	Private flux region fueling system has vacuum interface at the organ pipe	Mechanical Drawing
1.3.4.2.5	Private Flux Region Fueling	Gas	At organ pipe flange	Private flux region fueling gas enters at the end of the organ pipe	Mechanical Drawing
1.1.3.3.3	PF-1a Coils	thermal	At surface of coil	microtherm blanket provides thermal isolation between coils and casing	Mechanical drawing, Calculation
1.1.3.3.4	PF-1b Coils	thermal	At surface of coil	microtherm blanket provides thermal isolation between coils and casing	Mechanical drawing, Calculation
1.1.3.3.2	Ohmic Heating Solenoid	Other	At the connection to the casing	OH ground plane is references to the inner vessel ground.	Electrical Schematic
1.1.3.3.11	PF-1a Support Structure	Structural	At casing support weldment surface	React vertical and side loads to the casing	Mechanical Drawing
1.1.3.3.12	PF-1b Support Structure	Structural	At casing support weldment surface	React vertical and side loads to the casing	Mechanical Drawing
1.1.3.3.1	TF Inner Legs	Structural	At surface of G10 plate bonded to the lower inner legs.	The casing is supported by the inner-TF legs, via a series of components including the OH skirt and casing support weldment	Mechanical Drawing
1.1.1.1.8	PFC	Vacuum	At flange on end of	Sensors leads leave vacuum via	Wiring Diagram

	Thermocouples		organ pipe	the organ pipes on the casing flanges	
1.4.1.2.2	Mirnov and Flux Loop System	Vacuum	At flange on end of organ pipe	Sensors leads leave vacuum via the organ pipes on the casing flanges	Wiring Diagram
1.4.1.17	Langmuir Probes	Vacuum	At flange on end of organ pipe	Sensors leads leave vacuum via the organ pipes on the casing flanges	Wiring Diagram
1.4.1.2.8	Tile and Rogowski Halo Current Measurements	Vacuum	At flange on end of organ pipe	Sensors leads leave vacuum via the organ pipes on the casing flanges	Wiring Diagram
1.1.1.1.3	Vertical Target PFCs	Spatial	At casing surface	Allowance for wire bundles from CSFW, CSAS, and IBDV diagnostic wires to run to the organ pipes on the casing flange; allowance for gas delivery tubing	Wiring Schematic, Mechanical Drawing
1.1.1.1.2	CSAS PFCs	Spatial	At surface of casing	Allowance for wire bundles from the CSFW and CSAS diagnostics; allowance for gas delivery tubing	Mechanical Drawing
1.1.1.1.1	Center Stack First Wall PFCs	Spatial	At surface of casing	Allowance for wire bundles from the CSFW diagnostics; allowance for gas delivery tubing	Mechanical Drawing
1.3.3.2.1	Bakeout Bus Work	Eddy/Halo Current	At surface of air-side casing flange	Halo current will flow through connections bridging inner and outer vessel, applying load to the bus work.	Calculation
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Vacuum	at the flange where the flange on the casing bellows meets up with -1c case	Double O-ring seal w/ pumped interspace at the interface.	Mechanical Drawing
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Structural	at the flange where the flange on the casing bellows meets up with -1c case	Structural loading at minimum to pull the bellows tight.	Mechanical Drawing
1.3.3.2.1	Bakeout Bus Work	Structural	At surface of casing	disruption JxB forces reacted at joint	Calculation, Mechanical Drawing
1.3.3.2.1	Bakeout Bus Work	Thermal	At surface of casing	water-cooled bus work components connected to casing that will range in temperature from room temperature to bakeout temperature	Calculation
1.3.3.2.1	Bakeout Bus Work	Other	At vessel surface	The casing is grounded via the bakeout bus work	Electrical Schematic
1.4.1.2.8	Tile and Rogowski Halo Current Measurements	Structural	At surface of casing	Halo current rogowski coils are wrapped around the casing, under the tiles	Mechanical Drawing

Table 10.6-2*: Interfaces for the CS pedestal (SBS 1.1.3.3.7)*

Interfacing	Interfacing	Nature of	Interface	Interface Description	Required Interface

SBS	System	Interface	Boundary		Documentation
1.8.1.1.8	NTC Floor	Structural	At NTC floor surface	The pedestal sits on the test cell floor	Mechanical Drawing
1.1.2.1.2	Umbrella structure & Spoked Lids	Structural	At the underside of the upper plate on the pedestal	The lower spoked lid segments are bolted to the pedestal	Mechanical Drawing
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Spatial	on the ID of the pedestal	The pedestal has provision for hoses for the TF inner legs to pass through	Mechanical Drawing
1.1.3.3.1	TF Inner Legs	Structural	At the interface between the lower torque plate and the upper surface of the pedestal.	The CS pedestal supports the Inner TF legs, as well as the rest of the CS assembly, against gravity, as well as supporting the TF out-of-plane loads.	Calculations, Mechanical Design Drawings
1.8.1.1.8	NTC Floor	Structural	At NTC floor surface	Gravity, seismic loads, and global torquest are transferred to the NTC floor	Calculation, Mechanical Drawings

***Table 10.6-3**: Interfaces for the Ceramic Break Assembly and PF-1c Support (SBS 1.1.3.3.8)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.5	PF-1c Coils	Structural	Surface of ground wall insulation	Inner-PF coils are supported against all loads by the CS assembly	Calculation, Mechanical Design Drawing
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At fittings	Hose connections to cooling loops on ceramic break assemblies and CS Casing	P&ID
1.7.3.4.4	Vessel Voltage Monitors	Diagnostic	At the location of the connection of the high voltage lead	Voltage monitors measure the time evolving (and transient) voltage on the ceramic break assembly, on the inner-vessel side.	Electrical Schematic
1.1.3.3.6	Center Stack Casing	Vacuum	at the flange where the flange on the casing bellows meets up with -1c case	Double O-ring seal w/ pumped interspace at the interface.	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	Structural	at the flange where the flange on the casing bellows meets up with -1c case	Structural loading at minimum to pull the bellows tight.	Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Structural	at surface of main vessel flange	Interface must carry vertical and side loads	Mechanical Drawing, Calculation
1.1.2.1.1	Vacuum vessel	vacuum	at surface of main vessel flange	Interface has double O-ring seal w/ pumped interspace where break assembly meets the main vessel	Mechanical Drawing
1.1.3.3.13	Lateral Support Structures	Structural	at the location where the lateral supports attach to the -1c support or ceramic break	lateral supports transmit side loads from the CS assembly, to the outer vessel; the lateral supports interface to the CS assembly at the -1c assembly	Calculation, Mechanical Drawing
1.3.1.7	Interspace Vacuum	Vacuum	At ports on the ceramic break	IVPS pumps out O-rings on the ceramic break assembly	Mechanical Drawing, P&ID

	Pumping System		assembly		
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At water fittings on the end of each cooling loop	Provides cooling water to the air-side cooling loop on the casing and the ceramic break	P&ID
1.1.3.3.5	PF-1c Coils	Structural	At surface of coil support structures	Coil leads are supported as they extend from the winding pack	Mechanical drawing, Calculation

Table 10.6-4*: Interfaces for the Horizontal Target Cooling System (SBS 1.1.3.3.9)*

Interfacing SBS	**Interfacing System**	**Nature of Interface**	**Interface Boundary**	**Interface Description**	**Required Interface Documentation**
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Helium lines for the horizontal target cooling system enter/leave through the arches in the umbrella structure	Mechanical Drawing
1.1.1.1.4	Horizontal Target PFCs	Structural	At the surface of the casing flange or cooling plate.	Tiles and their backing structures react disruptions loads to the casing	Mechanical Drawings, Calculations for forces
1.1.1.1.4	Horizontal Target PFCs	Thermal	At the surface of the casing flange or cooling plate.	Tiles and their backing structures transfer heat during bakeout and operations.	Mechanical Drawings, Calculations for heat balance
1.3.3.1.2	Ex-Vessel Helium Manifolds	Gas	At flow control valve on the He distribution system	He is fed to the in-vessel heating/cooling features	P&ID
1.1.3.3.6	Center Stack Casing	thermal	At grafoil between the cooling plate and the casing flange	The horizontal target cooling system will transfer heat the casing flange through the grafoil	Mechanical Drawing, Calculation
1.1.3.3.6	Center Stack Casing	structural	At grafoil between the cooling plate and the casing flange	Loads on the horizontal target cooling system/plate will be transferred to the casing.	Mechanical Drawing, Calculation
1.1.1.1.4	Horizontal Target PFCs	Eddy/Halo Current	At surface of the target cooling system	Halo currents and potentially eddy currents transferred from the tiles and their mounting structures to the horizontal target cooling system'	N/A
1.1.3.3.6	Center Stack Casing	Eddy/Halo Current	at grafoil between the cooling plate and the casing flange	Halo current will pass through the plates into the casing	Calculation
1.1.3.3.6	Center Stack Casing	Spatial	at grafoil between the cooling plate and the casing flange	The target plate needs to provide access to all organ pipes on the casing flanges, without reduction in access.	Mechanical Drawing
1.1.1.1.4	Horizontal Target PFCs	Spatial	At surface of cooling plate	Allowance for wire bundles from CSFW, CSAS, and IBDV diagnostic wires to run to the organ pipes on the casing flange; allowance for gas	Mechanical Drawing

				delivery tubing	

Table 10.6-5: *Interfaces for the Vertical Target Cooling System (SBS 1.1.3.3.10)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At fitting on the cooling system, where elastomer hose connects	Cooling water is provided to cooling features on the vertical target	P&ID
1.1.3.3.3	PF-1a Coils	spatial	at the surface of the heat transfer tubes	heat transfer tubes need to allow the PF-1a coil to fit through with sufficient clearance for alignment.	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	thermal	At air-side surface of the casing	The vertical target cooling system removes heat from the CS transition sleeve	Mechanical Drawing, Calculation
1.1.3.3.6	Center Stack Casing	structural	At air-side surface of the casing	The vertical target cooling system is mechanically connected to the air-side of the transition sleeve, supported against gravity, eddy current, and other loads. Attachments need to support multiple thermal scenarios.	Mechanical Drawing, Calculation

Table 10.6-6: *Interfaces for the PF-1a Support Structures (SBS 1.1.3.3.11)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.3	PF-1a Coils	Structural	Surface of ground wall insulation	Inner-PF coils are supported against all loads by the CS assembly. Pre-load is applied to the coils by the coil supports.	Calculation, Mechanical Design Drawing
1.1.3.3.6	Center Stack Casing	Structural	At casing support weldment surface	React vertical and side loads to the casing	Mechanical Drawing
1.1.3.3.13	Lateral Support Structures	Structural	at the location where the lateral supports attach to the -1a coil support	lateral supports transmit side loads from the CS assembly, to the outer vessel; the lateral supports interface to the CS assembly at the -1a structure	Calculation, Mechanical Drawing
1.7.3.4	Machine Instrumentation	Diagnostic	At whatever surface supports the sensor	Measure the pre-load on the -1a coil	Mechanical Drawing
1.3.4.3.2	Massive gas injectors	Structural	At base of MGI valve supports	The MGI valve sits on the PF-1a support or equivalent, providing mechanical support where it is connected to an organ pipe	Mechanical Drawing
1.4.1.2.1	Plasma Current Rogowski System	Spatial	At surface of rogowski	Rogowski coils must pass through holes in the PF-1a support structure to exit the CS assembly	Mechanical Drawing
1.1.3.3.3	PF-1a Coils	Structural	At surface of coil support structures	Coil leads are supported as they extend from the winding pack	Mechanical drawing, Calculation

1.1.3.3.6	Center Stack Casing	structural	via the casing support weldment	The PF-1a support structures are interfaced to the casing via the PF-1b structures and the casing support weldment	Mechanical Drawing, Calculation
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Where sensor mounts to assembly	Sensor(s) used to detect pre-load on the PF-1a coils.	Mechanical Drawing

***Table 10.6-7**: Interfaces for the PF-1b Support Structures (SBS 1.1.3.3.12)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.4	PF-1b Coils	Structural	Surface of ground wall insulation	Inner-PF coils are supported against all loads by the CS assembly. Pre-load is applied to the coils by the coil supports.	Calculation, Mechanical Design Drawing
1.1.3.3.6	Center Stack Casing	Structural	At casing support weldment surface	React vertical and side loads to the casing	Mechanical Drawing
1.7.3.4	Machine Instrumentation	Diagnostic	At whatever surface supports the sensor	Measure the pre-load on the -1b coil	Mechanical Drawing
1.1.3.3.4	PF-1b Coils	Structural	At surface of coil support structures	Coil leads are supported as they extend from the winding pack	Mechanical drawing, Calculation
1.1.3.3.6	Center Stack Casing	structural	via the casing support weldment	The PF-1b support structures are interfaced to the casing via the casing support weldment	Mechanical Drawing, Calculation
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Where sensor mounts to assembly	Sensors used to detect pre-load on the PF-1b coils.	Mechanical Drawing

***Table 10.6-8**: Interfaces for the Casing Lateral Support Structures (SBS 1.1.3.3.13)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.4	Machine Instrumentation	Diagnostic	At the sensor surface	Lateral forces/displacements of the CS measured across the upper bellows gap.	CWD
1.7.3.4.1	Fiber Optic Strain, Temp., Disp. Meas.	Diagnostic	Surface of support member	Sensors measure strain or pressure in the load bearing members of the CS lateral supports	Mechanical Drawing
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Structural	at the location where the lateral supports attach to the -1c support or ceramic break	lateral supports transmit side loads from the CS assembly, to the outer vessel; the lateral supports interface to the CS assembly at the -1c assembly	Calculation, Mechanical Drawing
1.1.3.3.11	PF-1a Support Structure	Structural	at the location where the lateral supports attach to the -1a coil support	lateral supports transmit side loads from the CS assembly, to the outer vessel; the lateral supports interface to the CS assembly at the -1a structure	Calculation, Mechanical Drawing