National Spherical Torus eXperiment Upgrade

National Spherical Tokamak Experiment-Upgrade

NSTX-Upgrade

SYSTEM REQUIREMENTS DOCUMENT

AUXILIARY SYSTEMS

NSTX-U-RQMT-SRD-005-02

January 19, 2020

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Change Record

Revision	Date	Description of Change
0	12/11/17	Initial Release
1	3/20/18	Replaced interface tables with data from interface spreadsheet
		Added statement on duration and # of bakeouts
		Modified signature block as per new QAPD and ENG-050
		Added 2.1f, requiring the stand-alone cooling water system
		Added 2.2d, requiring that all vacuum systems exhaust out the D-Site stack
		Adjusted order of Argon purge system requirements in Section 6.
		Clarified the definition of a leak in Section 6.3 and 6.4.
		Modified 5.3e to note requirement for dedicated vacuum pump on the Gas Delivery System
		Added 2.1g to note requirement for a probe movement system. Added 2.3.5 to provide configuration requirements for that system.
		Adjusted the lettering and sub-sections in 3.3.
		Added 2.3.2c regarding requirement for remote control and monitoring of the IVPS
		Added section 2.3.5, describing configuration requirements for the probe drive system
		Added 4.5b, on future upgrade to archive additional bakeout information via Central I&C systems
		Added 6.3.1i, regarding archiving of GDC parameters via Central I&C systems
2	1/19/20	Changed WBS → SBS everywhere to be consistent with modern laboratory practice
		Updated signatures on first page
		Added 2.3.3d requiring TVPS to have an interface to the CCS.
		Added 3.3.1j requiring the Cooling Water System to have an interface to the CCS
		Added Section 3.3.4 on additional loss of flow scenarios, this time associated with the outer-PF coils
		Added 4.3 l requiring the bakeout system to interface to the CCS
		Updated interface tables to account for CCS interface, eliminate HIS interface

NSTX-U SYSTEM REQUIREMENTS DOCUMENT

References

[1] NSTX-U-RQMT-GRD-001, NSTX-U General Requirements Document
[2] ES-MECH-15, Pressure Systems Program
[3] NSTX-U Design Point Spreadsheet,
https://sites.google.com/pppl.gov/systemengineering/home
[4] NSTX-U-RQMT-RD-010, NSTX-U Magnetic Permeability Requirements
[5] NSTX-CRIT-0001-02, NSTX Structural Design Criteria
[6] NSTX-U-RQMT-SRD-004, NSTX-U SRD - Vacuum Vessel and Internal Hardware
[7] NSTX-U-RQMT-SRD-012, NSTX-U SRD - Operations and Safety Systems
[8] NSTX-U-RQMT-RD-027, NSTX-U Configured Controlled Safeguards
[9] NSTX-U-RQMT-RD-004, PFC Diagnostics and Fuelling
[10] NSTX-U-RQMT-RD-012, NSTX-U Gas Delivery and Injection System Parameters

1: Scope and Format

a. The auxiliary systems consist of the vacuum pumping system (WBS 1.3.1), the water cooling system (SBS 1.3.2), the bakeout heating system (WBS 1.3.3), the gas delivery system (SBS 1.3.4), and the wall conditioning systems (WBS 1.3.5).

b. The requirements for each of the five WBS elements are given in the following sections.

c. The format of this document, including interfaces specifications, is provided in the General Requirements Document [1].

2. Vacuum Pumping System (SBS 1.3.1)

2.1: Functions

a. The NSTX-U vacuum system establishes and maintains the vacuum environment within the NSTX-U vacuum vessel. It consists of pumping systems, associated piping and valves capable of achieving high vacuum, various pressure sensing elements and transducers, and an analytical system capable of discriminating gas species. It also includes a dedicated control system for interlocking and remote operation.

b. The NSTX-U torus vacuum pumping system (TVPS) shall perform the following functions:

- Roughdown of the NSTX-U device from atmosphere to base pressure.
- Provide a high vacuum environment compatible with the NSTX-U experimental program.
- Remove plasma exhaust and fuelling/GDC gas between discharges.
- Minimize and maintain impurity levels as required.
- Provide analytical capability for monitoring and control of machine vacuum condition.
- Provide pumping and control of pressure for Glow Discharge Cleaning (GDC) and boronization modes.
- Be compatible with, and provide pumping for vacuum vessel bakeout.
- Provide appropriate safety interlocks for personnel and equipment safety.

c. A separate vacuum system shall be used to provide intermediate vacuum for sealing locations utilizing double O-ring seals with pumped interspace; this system will be called the Interspace Vacuum Pumping System within this document (IVPS).

d. The system shall provide for remote actuation of torus interface valves (TIVs) and shutters.

e. The dedicated vacuum control PLC shall provide centralized control over the TVPS, IVPS, shutter and TIV control system, and wall conditioning systems, and provide HMI capability.

f. A dedicated cooling water system shall provide cooling water to those vacuum pumps that require continuous cooling water.

g. A system shall be provided to control the position of movable diagnostic probes, including position and TIV interlocking.

2.2. Material and Design Requirements

a. Magnetic and vacuum materials shall be as described in the NSTX-U GRD [1].

b. The design of the vacuum system shall be compatible with PPPL standard ES-MECH-15 [2].

c. The system shall be designed to facilitate a 1200 s repetition rate.

d. All vacuum pumping systems with exposure to NSTX-U machine vacuum shall exhaust through the D-Site vent stack via the NSTX-U vacuum exhaust line.

2.3: Configuration Requirements & Essential Features

3.2.1: TVPS

a. The TVPS shall consist of a pair of water-cooled turbo molecular (momentum transfer) pumps and at least one positive displacement mechanical pump.

b. Turbomolecular pumps, as well as the RGA and vacuum vessel pressure gauges shall be located on, or close to the vacuum vessel to maximize conductance. Here, “close” is defined by meeting the performance requirements in the following section. All components shall be capable of operation in the stray magnetic field close to the NSTX-U device.

c. Service ports, strategically located on the vacuum system shall be provided to facilitate maintenance and leak checking.

d. Pressure gauges capable of monitoring pressure from atmosphere to high vacuum shall be located on the vacuum vessel or appropriate appendages.

e. Redundant Residual Gas Analyzers (RGA) capable of discriminating gas species shall be employed.

f. The RGA shall function in both high vacuum configuration, and higher pressure situations such as GDC and bakeout.

g. Capability for monitoring and remote control of machine vacuum system components from the control room shall be provided.

h. Provisions shall be made to bring the vacuum system up to atmospheric pressure using dry gaseous nitrogen or argon.

i. All exhaust gases from TVPS shall be directed to the facility elevated exhaust stack.

j. Pumping systems, pressure gauges, and RGAs shall be electrically isolated from the vessel as per GRD.

2.3.2: IVPS

a. The IVPS shall consist of a dry vacuum pump, with manifolding to provide adequate conductance connections between the pumps and the double O-ring locations on the machine.

b. All exhaust gases from IVPS shall be directed to the facility elevated exhaust stack.

c. Capability for monitoring and remote control of the iVPS from the control room shall be provided.

2.3.3: Vacuum PLC

a. The Vacuum PLC shall be designed to control all vacuum pumps, pneumatic TIVs & shutters, all pneumatic and solenoid valves in the gas delivery and injection system (SBS 1.3.4), and the functions of the GDC and dTMB systems (SBS 1.3.5).

b. The design should have an HMI with control from remote locations including the control room and bottle rack.

c. The design of the Vacuum PLC I/O capability shall be designed with expansion as a critical consideration.

d. The Vacuum PLC shall be capable of receiving permissive information from the Centralized Control System (CCS), enabling operations which it controls (GDC, etc) to be terminated upon revocation of the permissive.

2.3.4: Shutter and TIV Control System

a. The shutter and TIV control system shall provide remote control and status information for all pneumatic shutters and TIVs on NSTX-U.

b. The system shall be synchronized to the NSTX-U central clock and provide preset configurations for all shutters and TIVs, i.e. plasma operations, GDC, etc.

2.3.5: Probe Drive Control System

a. The probe drive control system shall provide the capability to remotely monitor and control the positions of movable probes on NSTX-U (LITER, MAPP, etc.).

b. The system shall have capabilities to prevent the closure of torus isolation valves on an inserted probe, and to prevent the insertion of the probe into a closed TIV..

2.4 Baseline Performance & Operational Requirements

2.4.1 TVPS

a. The roughing pump(s) shall be capable of evacuating the vacuum vessel from atmosphere to $1x10^{-3}$ Torr in less than 4 hours.

b. The TVPS shall be capable of achieving a base pressure of $2x10^{-8}$ Torr, excluding fuelling gas, after the vacuum vessel has been baked out.

c. The system shall be capable of evacuating plasma gas loads and establishing -an adequate pressure between machine pulses on a 1200 s cycle, including the impact of inter-shot GDC periods.

d. The high vacuum pressure sensing elements shall provide one or more signals to the real-time control system. The latency between a change in the vessel pressure and the change voltage output should be less than 100ms.

e. The RGA system shall be able to scan and provide resolution of $1x10^{-11}$ Torr partial pressure for masses 1 to 60.

f. The vacuum system shall be capable of supporting GDC mode of operation as described in Section 5 of this SRD.

g. The mechanical pump backing system shall be capable of maintaining less than 2 Torr at the exhaust of the TMPs under all conditions such as GDC and TMB operations.

h. The mechanical pumps shall be capable of evacuating the NSTX-U vacuum vessel from atmosphere to 5×10^{-2} Torr, and shall be capable of backing the turbomolecular pumps during operation and GDC..

2.4.2 IVPS

a. The IVPS shall be designed to provide vacuum pressures of $5x10^{-2}$ Torr at the inlet ports to the interspaces in a dead-ended configuration.

2.5. Upgrade Performance & Operational Requirements

a. The IVPS shall be designed such that expansion to additional interspaces can be accommodated. These may include, but not be limited to, diagnostic seals or seals on the neutral beam ducts.

b. Continual expansion of the number of TIVs and vessel shutters should be anticipated, and such expandability designed into the system.

c. An expansion of RGA archiving capability for continuous and shot-based archiving may be taken.

d. The vacuum controls shall provide an interface with Plant I&C to allow remote monitoring and control requests, data trending, and distributed display of system information.

2.6. Interfaces

Table 2.6-1*: Interfaces for the Vacuum and Roughing Pumps (SBS 1.3.1.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.2.4.3	Beamline Ducts	Vacuum	Flanges on the bottom of the drift duct	TVPS turbo pumps pump NSTX-U through, ducts mounted to the flanges at the bottom of the drift duct.	Mechanical Drawing
0.1.1.8	D-Site Vent Stack	Gas	Vacuum exhaust line	TVPS exhausts through the D-Site Stack	P&ID
0.1.1.9	D-Site Instrument Air	Gas	Where air line connects to valves	Control of vacuum system valves	P&ID
1.3.1.4	Vacuum System PLC	Electrical Signal	At PLC output block	Vacuum system PLC controls and monitors valve position and provides commands & interlocks to pumps.	CWD
1.2.4.2	Beamlines	Structural	At location where clamps and supports touch beamline	Piping for the system is attached to the side of the beamline	Mechanical Drawing
1.8.1.1.8	NTC Floor	Structural	At NTC floor surface	Various pumps are supported on the test cell floor	General Arrangement Drawing
1.3.5.2	Trimethylbor on (TMB) System	Vacuum	6” TVPS foreline	Vacuum System PLC and the TMB at the 6" TVPS Foreline	Mechanical drawing, P&ID
1.3.1.6	Vacuum Pump Cooling Water System	Fluid	Vacuum pump	The water cooling system supplies cooling water to TVPS pumps, TP01, TP02 and MP02	P&ID
1.8.1.1.1	NTC Platforms	Structural	At platform support surface	Vacuum lines supported by the platforms	Mechanical Drawing
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Cables associated with pumps reside in trays	N/A
1.8.1.1.2	NTC Cable Trays	Structural	At tray surface	Tubing supported from trays, cables in trays	N/A

***Table 2.6-2**: Interfaces for the Vacuum Gauges and Residual Gas Analyzers (SBS 1.3.1.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.6.1.1	Control I/O systems	Electrical Signal	Front panel of digitizer	Vacuum pressure measurements provided to the Data Acquisition systems	CWD
1.7.3.6.1	FPDP Data Stream	Electrical Signal	Breakout panel of SAD	Vacuum pressure measurements provided to the real-time data stream	CWD
1.3.1.1	Valves, Vacuum Pumps and Roughing Pumps	Vacuum	At flanges on the TVPS risers	RGA and vacuum gauges mounted to the risers on TVPS	CWD
1.3.1.4	Vacuum System PLC	Electrical Signal	At connector block on PLC	Various pressure gauge signals are brought into the PLC; valve positions and pump status are controlled	CWD
0.1.1.8	D-Site Vent Stack	Gas	Vacuum exhaust line	RGA vacuum system exhausts through the D-Site Stack	P&ID
0.1.1.9	Instrument Air	Gas	Where air line connects to valve	Control of vacuum system valves	P&ID
1.2.4.7	Neutral Beam Control Systems	Software	PLC Permissive	Vacuum pressure interlock provided through the vacuum PLC.	CWD
1.8.1.3	North and East Galleries	Location	N/A	Electronics for gauges reside in cages in the gallery	General Arrangement
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Signals from gauges use cable trays	N/A
1.8.1.1.5	NTC Penetrations	Spatial	At the penetration	Signals from gauges use NTC penetrations	N/A
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support cables for the vacuum gauges and RGA	N/A

***Table 2.6-3**: Interfaces for the TIV and Shutter Actuation System (SBS 1.3.1.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.9	Instrument Air	Gas	Where instrument air connects to manifolds in the system	Compressed air provided for the TIV and shutter actuation system	P&ID
1.4.1.19	MAPP	Electrical Signal	Limit switches box on the probe.	Prevent Shutter/TIV movement when probe inserted	CWD
1.3.5.4	Granule Injector	Electrical Signal	Limit switches box on the probe.	Prevent Shutter/TIV movement when shroud is inserted	CWD
1.3.4.2.2	Supersonic Gas Injector	Electrical Signal	Limit switches box on the probe.	Prevent Shutter/TIV movement when probe inserted	CWD
1.3.5.3	Li Evaporator (LITER)	Electrical Signal	Limit switches box on the probe.	Prevent Shutter/TIV movement when probe inserted	CWD
1.3.5.3	Li Evaporator (LITER)	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the LITER assembly	P&ID
1.4.1.3	Multi-pulse Thompson Scattering (MPTS)	Electrical Signal	Shutters on port	Shutter control and status signals	CWD
1.4.1.3	Multi-pulse Thompson Scattering (MPTS)	Gas	Where air line connects to valve or shutter mechanism	Control of shutters and TIVs for MPTS	P&ID
1.4.1.4	Plasma TV	Gas	Where air line connects to valve or shutter mechanism	Control of shutters for the plasma TV	P&ID
1.4.1.5.1	Toroidal CHERS	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on Toroidal CHERS diagnostics	P&ID
1.4.1.5.2	Poloidal CHERS	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on Poloidal CHERS diagnostics	P&ID
1.4.1.6	FIDA	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on FIDA diagnostics	P&ID
1.4.1.7	BES	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on BES diagnostic	P&ID
1.4.1.8	MSE	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on MSE diagnostics	P&ID
1.4.1.12	Microwave Diagnostics	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on various microwave diagnostics	P&ID
1.4.1.13	Visible Spectroscopy	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on various visible spectroscopy diagnostics	P&ID
1.4.1.13.1	Filterscopes	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on various filterscope diagnostics	P&ID
1.4.1.14	Physics Imaging Systems	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on various physics imaging systems	P&ID

1.4.1.15	Vacuum Spectroscopy	Gas	Where air line connects to valve or shutter mechanism	Control of TIVs on vacuum spectrometer diagnostics	P&ID
1.4.1.19	MAPP	Gas	Where air line connects to valve or shutter mechanism	Control of TIV on MAPP	P&ID
1.4.1.21	IR Cameras for Thermography	Gas	Where air line connects to valve or shutter mechanism	Control of shutters on IR cameras used for thermography	P&ID
1.3.5.4	Granule Injector	Gas	Where air line connects to valve or shutter mechanism	actuation of the shutter on the LGI	P&ID
1.3.4.2.1	Main Chamber Fueling	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID
1.3.4.2.2	Supersonic Gas Injector	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID
1.3.4.2.3	Outboard Divertor Injection Systems	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID
1.3.4.2.4	GPI and Impurity Injectors	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID
1.3.4.2.5	Private Flux Region Fueling	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID
1.3.4.3.2	Massive gas injectors	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the valve assembly	P&ID

Table 2.6-4*: Interfaces for the Vacuum System PLC (SBS 1.3.1.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.6.1.2	Plant Control and Monitoring	Electrical Signal	PLC ethernet port, CAMAC Crate	i) Information on vacuum pressures and system status are provided to the Plant Control and Monitoring (EPICS) system for control and HMI. ii) Shot cycle synchronization information is provided to the shutter and TIV control system	CWD
1.2.4.7	Neutral Beam Control Systems	Electrical Signal	At connector on vacuum PLC.	Control/interlock signals	CWD
1.7.3.2	Vessel and Diagnostic Grounds	Electrical Signal	At connector on the Vacuum PLC	Control/status signals at connector on the Vacuum PLC	CWD
1.3.4.1	Gas Storage and Delivery Systems	Electrical Signal	At PLC output block	Vacuum PLC controls various valves on the gas delivery systems	CWD
1.3.1.7	Interspace Vacuum Pumping System	Electrical Signal	At output block of PLC	Control and HMI of the IVPS provided by the vacuum PLC	CWD
1.3.3.4	Bakeout PLC and Controls	Electrical Signal	At PLC Data Highway Connector	Vacuum System PLC provides interlock signals to the Bakeout PLC during bakeout operations at PLC Data Highway Connector	CWD
1.7.3.8	Central Control System (CCS)	Electrical Signal	At I/O block of PLC	CCS provides equivalent to previously existing "No-Facility ESTOP" and "LOOP SET" equivalent signals to the vacuum system PLC	CWD
1.3.4.2.2	Supersonic Gas Injector	Electrical Signal	At connector block of PLC	Used to monitor limit switches on probe drive	CWD
1.3.5.2	Trimethylboron (TMB) System	Electrical Signal	TVPS main PLC	TVPS main PLC provides control and interlock of TMB system	CWD
1.3.5.3	Li Evaporator (LITER)	Electrical Signal	Ethernet Network	Data written to epics using Channel Access	CWD
1.3.5.1.1	GDC + Filament Power Supplies	Electrical Signal	At output of PLC	Control of various parameters of the GDC system from the HMI of the vacuum PLC at output of PLC	CWD
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At PLC I/O connectors	Vacuum PLC provides permissives, can control valves	CWD
1.3.1.6	Vacuum Pump Cooling Water System	Fluid	TVPS main PLC	Provides control and interlock of cooling system	CWD
1.3.1.5	Probe drive controls	Electrical Signal	Probe limit switch box	Prevent Shutter/TIV movement when probes are inserted	CWD
1.3.1.2	Vacuum Gauges and Residual Gas Analyzers	Electrical Signal	At connector block on PLC	Various pressure gauge signals are brought into the PLC; valve positions and pump status are controlled	CWD
1.3.4.4	Argon purge system	Electrical Signal	At connector on PLC	Argon purge system controlled by the vacuum PLC	CWD
1.8.1.3	North and East Galleries	Location	N/A	Vacuum system PLC components reside in the gallery	N/A
1.3.1.1	Valves, Vacuum Pumps and Roughing Pumps	Electrical Signal	At PLC output block	Vacuum system PLC controls and monitors valve position and provides commands & interlocks to pumps.	CWD
1.7.3.2.2	Ground Fault Monitor PLC & Electronics	Fiber Optic	Serial link	Information is passed between the Ground Fault Monitor and Vacuum System PLCs	CWD

***Table 2.6-5**: Interfaces for the Probe drive controls (SBS 1.3.1.5)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.4.2.2	Supersonic Gas Injector	Electrical Signal	At electrical connectors on probe drive	Control of the supersonic gas injector position	CWD
1.3.5.3	Li Evaporator (LITER)	Electrical Signal	At electrical connectors on probe drive	Control of the LITER position	CWD
1.4.1.9.4	Fusion Products Detector Probe	Electrical Signal	At electrical connectors on probe drive (future)	Control of the Fusion Product Probe position (future)	CWD (future)
1.4.1.19	MAPP	Electrical Signal	At electrical connectors on probe drive	Control of the MAPP position	CWD
1.6.1.2	Plant Control and Monitoring	Electrical Signal	At RS232 connector	Plant Control and Monitoring (EPICS) system provides commands to the probe drive controller.	CWD
1.3.1.4	Vacuum System PLC	Electrical Signal	Probe limit switch box	Prevent Shutter/TIV movement when probes are inserted	CWD
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support cables for probe drive controls	N/A

***Table 2.6-6**: Interfaces for the Vacuum Pump Cooling Water System (SBS 1.3.1.6)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.5.2	Trimethylboron (TMB) System	Fluid	Vacuum pump	The water cooling system supplies cooling water to TMB pump, MP08	P&ID
1.3.1.1	Valves, Vacuum Pumps and Roughing Pumps	Fluid	Vacuum pump	The water cooling system supplies cooling water to TVPS pumps, TP01, TP02 and MP02	P&ID
0.1.1.5	D-Site Potable Water	Fluid	Potable water connection	The potable water system in NTC will be used to fill the cooling system and as backup cooling water to cool vacuum pumps in case of chiller failure	P&ID
1.3.1.4	Vacuum System PLC	Fluid	TVPS main PLC	Provides control and interlock of cooling system	CWD
1.2.4.7	Neutral Beam Control Systems	Electrical Signal	NB PLC	provides cooling water interlock	CWD
1.2.4.4	Neutral Beam Services	Fluid	At port on turbo	Cooling water for NB pump provided by TVPS cooling system.	P&ID

***Table 2.6-7**: Interfaces for the Interspace Vacuum Pumping System (SBS 1.3.1.7)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.8	D-Site Vent Stack	Gas	Vacuum exhaust line	IVPS exhausts through the D-Site Stack	P&ID
0.1.1.9	Instrument Air	Gas	Where instrument air connects to manifolds in the system	Compressed air provided for the TIV and shutter actuation system	P&ID
1.1.3.3	Center Stack Assembly	Vacuum	At vacuum ports on flanges.	Provision for IVPS access to interspace via access holes and fittings.	Mechanical Design Drawing, P&ID
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Vacuum	At ports on the ceramic break assembly	IVPS pumps out O-rings on the ceramic break assembly	Mechanical Drawing, P&ID
1.1.2.1.2	Umbrella structure & Spoked Lids	Structural	At surface of umbrella	IVPS manifolds mounted to the surface of the umbrella structure	Mechanical Drawing
1.8.1.1.8	NTC Floor	Structural	At NTC floor surface	IVPS pumps reside on the floor of the test cell	General Arrangement
1.3.1.4	Vacuum System PLC	Electrical Signal	At output block of PLC	Control and HMI of the IVPS provided by the vacuum PLC	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the interspace pumping system	Electrical Schematic for Directly Wired Components
1.8.1.1.2	NTC Cable Trays	Structural	At tray surface	Tubing supported from trays, cables in trays	N/A

3. Cooling Water System (CWS) (SBS 1.3.2)

3.1: Functions

a. The cooling water system shall provide continuous cooling for the coil systems, the power supply systems, the component cooling system, and the heating systems that support NSTX-U.

b. The cooling water system shall provide flow and temperature interlocks for specific circuits.

c. Specific functions include:

- Provide chilled, deionized water for heat removal from the TF, OH and PF coils.
- Provide chilled, deionized water for in-vessel components, CSC DC power injection power supplies, bus bar systems, and various diagnostics.
- Provide flow monitoring and interlock functions in particular circuit to prevent damage due to loss of flow.
- Provide outlet water temperature monitoring and interlock functions to prevent operation of coils and other components before cooldown has completed.
- Provide makeup water to Neutral Beam Systems
- Provide deionized water to FCPC

The D-site MG and NBI system incorporates its own cooling water system, and therefore does not require a water supply from SBS 1.3.2. Similarly, the vacuum pumping system has a stand-alone cooling water system (see SBS 1.3.1 requirements).

3.2: Material and Design Requirements

a. The design of the cooling water system shall be compatible with PPPL standard ES-MECH-15 [2].

3.3: Configuration Requirements & Essential Features

3.3.1: General

a. The cooling water system shall utilize existing equipment located in the D-site Pump Room. The primary cooling water pump, heat exchanger and tank shall not infringe on the space in the NSTX-U test cell.

b. The conductivity of the deionized water shall be monitored to verify it is within acceptable limits.

c. All materials in the cooling water system shall be selected for operation in deionized water.

d. A low flow signal shall be available for each flow path; this sensor shall be on the outlet side of the coil or component in each path.

e. An outlet water temperature measurement shall be available for each flow path.

f. A dedicated processor or PLC shall receive flow and temperature inputs and provide data to the central I&C system, indicating the status of each individual flow path (outlet water temperature, flow status). Magnet energization shall be disallowed if corresponding flows or temperatures are not in the allowed ranges.

g. Valves and pumps shall be controlled locally and from the D site pump room.

h. Activation of the NTC Emergency Stop buttons shall signal the water systems PLC to shut down any operating pumps delivering fluid flow to or within the NTC. This interlock shall serve as an equipment protection measure in the event of a fluid leak and is not intended to provide life-safety protection.

i. To improve operations efficiency, authorized remote control from the Plant Control and Monitoring system for specific pumps, valves, or settings shall be provided.

j. The cooling water system controls shall have the ability to receive permissive information from the Centralized Control System (CCS).

3.3.2: OH and Inner-PF Coil Cooling

a. Two high pressure booster pumps shall be configured as a primary unit and an emergency backup (redundant system) and supply boosted pressure to the OH and inner-PF cooling water supply circuit.

b. Provision shall be made in the OH cooling circuit to adjust the flow such that all of the 8 parallel paths have a similar temporal evolution of the water outlet temperature following a pulse.[1]

c. Provision shall be made in the OH cooling circuit to provide a variable inlet water temperature over the range 12-100 C, in order to reduce the cooling wave thermal stresses. The system shall be externally controllable, and have a mechanism to match the coil inlet water temperature at the end of the pulse to the temperature of the coil.

d. Loss of flow in any one OH circuit shall result in flow being terminated in all OH circuits.

e. Loss of flow in any one (or more) TF water circuit shall result in flow being terminated in all OH circuits.[2]

[1] This reduces layer-to-layer temperature gradients and associated thermal stresses.
[2] This requirement due to aquapour material located between the OH and TF coils.

f. Provision shall be made to connect potable water to the OH and inner-PF coils within 45 minutes of NTC access if a power loss event occurs during bakeout operations and backup power does not function properly.

3.3.3: TF Coil

a. The TF inner legs shall be fed with water that has previously been passed through the TF outer legs, functioning as a pre-heater.

b. Loss of flow in any one TF circuit (inner or outer leg) shall result in flow being terminated in all TF circuits and OH circuits.

3.3.4: PF Coil

a. Loss of flow in any circuit of the PF-5 coil shall result in flow being terminated in all circuits of the PF-5.

b. Loss of flow in any circuit of the PF-4 coil shall result in flow being terminated in all circuits of the PF-4.

c. Loss of flow in any pancake of the PF-2U, PF-2L, PF-3U or PF-3L coil shall result in flow being terminated in the other pancake of that coil.

3.4. Baseline Performance & Operational Requirements

a. For coils where the exit cooling water temperature may exceed 100°C the water pressure shall be maintained at the pressure required to prevent boiling.

b. The deionized water conductivity shall be less than or equal to 0.2 μmho/cm

c. The cooling water system shall provide chilled deionized cooling water to the following components in Tables 3.4-1 through 3.4-3.

d. Flow rates, temperature ranges, and similar information for coil circuits shall be found in the design point spreadsheet [3].

e. The coil cooling water inlet temperature shall be at least 2°C above the NTC dew point.

f. The cooling water system shall also provide deionized water to the Field Coil Power Conversion water distribution system.

g. The cooling water system flow switches shall be augmented by the installation of parallel flow measurement instrumentation as indicated in Table 3.4-1 through 3.4-3

***Table 3.4-1**: Coils cooled by the NSTX-U Deionized Cooling Water System*

	# of Independent Flow Paths	Flow Switch Permissive	Outlet Temperature Permissive	Flow Rate Measurement	Supply Pressure PSIG
OH Coil	8	Y	Y	Y	420
PF-1aU Coil	1	Y	Y	Y	420
PF-1aL CoiL	1	Y	Y	Y	420
PF-1bU Coil	1	Y	Y	Y	420
PF-1bL CoiL	1	Y	Y	Y	420
PF-1cU Coil	1	Y	Y	Y	420
PF-1cL CoiL	1	Y	Y	Y	420
TF Coil	36[3]	Y	Y	Y	120
PF2AU Coil	1	Y	Y	Y	120
PF2AL Coil	1	Y	Y	Y	120
PF2BU Coil	1	Y	Y	Y	120
PF2BL Coil	1	Y	Y	Y	120
PF3AU Coil	1	Y	Y	Y	120
PF3AL Coil	1	Y	Y	Y	120
PF3BU Coil	1	Y	Y	Y	120
PF3BL Coil	1	Y	Y	Y	120
PF4AU Coil	1	Y	Y	Y	120
PF4AL Coil	1	Y	Y	Y	120
PF4BU Coil	1	Y	Y	Y	120
PF4BL Coil	1	Y	Y	Y	120
PF5AU Coil	Dual Feed & Single Return	Y	Y	Y	120
PF5AL Coil	Dual Feed & Single Return	Y	Y	Y	120
PF5BU Coil	Dual Feed & Single Return	Y	Y	Y	120
PF5BL Coil	Dual Feed & Single Return	Y	Y	Y	120

***Table 3.4-2**: Bus work cooled by the NSTX-U Deionized Cooling Water System*

	# of Independent Component Flow Paths	Flow Switch Permissive	Outlet Temperature Permissive	Flow Rate Measurement	Supply Pressure PSIG
CSC Upper Vertical Target Loop	1	Y	Y	Y	120
CSC Lower Vertical Target Loop	1	Y	Y	Y	120
CHI/Bakeout Flags Upper (Bay B, J, E)	1	Y	Y	Y	120
CHI/Bakeout Flags Lower (Bay B, J, E)	1	Y	Y	Y	120
CHI/Bakeout Ring Bus & Bakeout Bus (Bus B1)	1	Y	Y	Y	120
Buswork for PF1AU, PF1CU, PF1CL (Bus B2)	1	Y	Y	Y	120

[3] Each of these 36 flow paths has a TF inner and Outer leg connected in series with the inlet on the outer leg

Buswork for PF2U, PF2L, PF4, PF1AL (Bus B3)	1	Y	Y	Y	120
Buswork for PF3U, PF3L, PF5 (Bus B4)	1	Y	Y	Y	120
Buswork for Inner TF Connector (Bus B5)	1	Y	Y	Y	120
Buswork for OH Bus (Bus B6)	1	Y	Y	Y	120

***Table 3.4-3**: Additional components cooled by the NSTX-U deionized cooling water system*

	# of Independent Component Flow Paths	Flow Switch Permissive	Outlet Temperature Permissive	Flow Rate Measurement	Supply Pressure PSIG
Upper Ceramic Break	1	Y	Y	Y	120
Neutral Beam Ducts	1 (NB1 ONLY)	N	N	Y	120
Neutral Beam Armor	1	Y	Y	Y	120
Bakeout Power Supplies	1	N	N	Y	120

3.5. Upgrade Performance & Operational Requirements

a. Additional components may be added to the cooling water system as the capabilities of the design evolve.

3.6. Interfaces

***Table 3.6-1**: Interfaces for the Low-Pressure NTC Cooling Water Distribution (SBS 1.3.2.1.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.1	TF Inner Legs	Fluid	At water fittings on both sides of the inner legs.	Provides cooling water for inner legs, after water has passed through outer legs	P&ID
1.1.3.2	TF outer legs	Fluid	At water fittings on both sides of the outer legs.	Provides cooling water for outer legs, before water is passed to inner legs	P&ID
1.1.3.1	Outer PF coils	Fluid	At water fittings on the end of each coil loop	Provides cooling water to the outer-PF	P&ID
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	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
1.1.3.4	Bus Bar Systems	Fluid	At water fittings on the end	Provides cooling water to	P&ID

	and Bus Tower		of each cooling loop	various bus bars	
1.2.4.3	Beamline Ducts	Fluid	At water fittings on the end of each cooling loop	Provides cooling water to neutral beam #1 duct	P&ID
1.3.3.2.1	Bakeout Bus Work	Fluid	At the hose fittings on the bus work	NTC low-pressure water distribution system provides cooling for the bakeout bus work.	P&ID
1.3.2.1.4	CWS Flow and Temperature Instrumentation	Fluid	At the return manifolds on the south wall	Instrumentation measures flow and temperature of the outlet water, after some length of hose	P&ID
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Water lines for the horizontal target cooling system enter/leave through the arches in the umbrella structure	Mechanical Drawing
1.3.2.3	Deionized Make-Up System	Fluid	At the feed valve for the low-pressure system	The deionized make-up system provides make-up water to the lower-pressure system.	P&ID
1.3.2.2	FCPC Cooling Water System	Thermal	At the heat exchanger	Heat exchange	P&ID
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Fluid	At the inlet to the high pressure pump	The low-pressure system provides the inlet water to the high pressure system	P&ID
1.1.3.3.8	Ceramic Break Assembly & PF-1c Support	Fluid	At fittings	Hose connections to cooling loops on ceramic break assemblies and CS Casing	P&ID
1.1.3.3.10	Vertical Target Cooling System	Fluid	At fitting on the cooling system, where elastomer hose connects	Cooling water is provided to cooling features on the vertical target	P&ID
1.3.3.2.2	Bakeout DC Power Supplies	Fluid	Location where hoses connect to the cooling water system	Provision of water cooling to the DC power supplies	P&ID
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cooling water enters through NTC penetrations.	N/A
1.2.3	Electron Cyclotron Pre-Ionization (ECH)	Fluid	At hose connection on source	Deionized cooling water provided to ECH source	P&ID
1.1.3.3.7	Pedestal	Spatial	on the ID of the pedestal	The pedestal has provision for hoses for the TF inner legs to pass through	Mechanical Drawing
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for low-pressure cooling water distribution	Electrical Schematic for Directly Wired Components
1.4.1.8	MSE	Fluid	At fittings of final hose connections	DI water used for cooling on high voltage components of the MSE-LIF system	P&ID
1.3.2.4	Water System PLC	Electrical Signal	At output block of PLC	Water system PLC controls pumps and valves on the low-pressure distribution system	CWD

***Table 3.6-2**: Interfaces for the High-Pressure NTC Cooling Water Distribution (SBS 1.3.2.1.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.5	D-Site Potable Water	fluid	At valves on the high-pressure manifolds	provides emergency potable water in case other cooling is lost during bakeout	CWD
1.3.2.1.3	OH Water Pre-Heater System	Fluid	At input to water heater	The high-pressure manifold feeds cold water to the OH water pre-heater	P&ID
1.3.2.1.4	CWS Flow and Temperature Instrumentation	Fluid	At the return manifolds on the south wall	Instrumentation measures flow and temperature of the outlet water, after some length of hose	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power provided for the high-pressure pumps in the NSTX-U test cell	Electrical Schematic for Directly Wired Components
1.1.2.1.2	Umbrella structure & Spoked Lids	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
1.1.3.3.3	PF-1a Coils	Fluid	connection between i) hose w/ fitting and ii) and fitting on the coil	Hose connections at coil leads; cold water cools outer layers first	P&ID, Mechanical Design Drawing
1.1.3.3.4	PF-1b Coils	Fluid	connection between i) hose w/ fitting and ii) and fitting on the coil	Hose connections at coil leads; cold water cools outer layers first	P&ID, Mechanical Design Drawing
1.1.3.3.5	PF-1c Coils	Fluid	connection between i) hose w/ fitting and ii) and fitting on the coil	Hose connections at coil leads; cold water cools outer layers first	P&ID, Mechanical Design Drawing
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the high-pressure cooling water distribution	CWD
1.3.2.4	Water System PLC	Electrical Signal	At output block of PLC	Water system PLC controls pumps and valves on the high-pressure distribution system	CWD
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At the inlet to the high pressure pump	The low-pressure system provides the inlet water to the high pressure system	P&ID

***Table 3.6-3**: Interfaces for the OH Water Pre-Heater System (SBS 1.3.2.1.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.2.4	Water System PLC	Electrical Signal	At output block of PLC	Provides control information to the water heater	CWD
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Water lines to and from the OH coil pass through the umbrella arches	Mechanical Drawing
1.1.3.3.2	Ohmic Heating Solenoid	Fluid	connection between i) hose w/ fitting and ii) and fitting on the coil	Hose connections at coil leads; flows controlled so that the cooling wave on the coil propagates up all layers at the same rate	P&ID, Mechanical Design Drawing
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Fluid	At input to water heater	The high-pressure manifold feeds cold water to the OH water pre-heater	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the OH water pre-heater	Electrical Schematic for Directly Wired Components

***Table 3.6-4**: Interfaces for the Flow and Temperature Instrumentation (SBS 1.3.2.1.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.2.4	Water System PLC	Electrical Signal	At connector block on PLC	The water system PLC reads various data from the flow and temperature instrumentation on the NTC south wall	CWD
1.8.1.1.4	NTC Walls	Structural	At NTC wall	Cooling water manifolds supported from south wall.	Mechanical Schematic or General Arrangement
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At the return manifolds on the south wall	Instrumentation measures flow and temperature of the outlet water, after some length of hose	P&ID
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Fluid	At the return manifolds on the south wall	Instrumentation measures flow and temperature of the outlet water, after some length of hose	P&ID

***Table 3.6-5**: Interfaces for the FCPC Cooling Water System (SBS 1.3.2.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.4	D-Site Tower Water	Thermal	Valves on Tower Water Manifolds	Heat exchange for FCPC pump (350 HP pump)	P&ID
1.5.2.1	TF Power Systems Converters	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.2.2	OH Power Systems Converters	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.2.3	PF Power Systems Converters	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to FCPC	P&ID
1.5.2.4.2	SPAs Invertors	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to the SPAs	P&ID
1.5.2.4.1	SPA DC Link	Fluid	At the supply and return pipe fittings in the D-Site Pump Room	Provides cooling water to the SPA DC-link power supply	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical Power for the FCPC cooling water system	Electrical Schematic for Directly Wired Components
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Thermal	At the heat exchanger	Heat exchange	P&ID
1.3.2.3	Deionized Make-Up System	Fluid	At the feed valve for the FCPC cooling water system	Provides make-up water to the FCPC loop	P&ID

***Table 3.6-6**: Interfaces for the Deionized Water Make-Up System (SBS 1.3.2.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.2.2	FCPC Cooling Water System	Fluid	At the feed valve for the FCPC cooling water system	Provides make-up water to the FCPC loop	P&ID
1.2.4.4	Neutral Beam Services	Fluid	Valves on expansion tanks in the D-site pump room	Provide make-up DI water to neutral beam systems	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for components of the deionized water make-up system	Electrical Schematic for Directly Wired Components
1.3.2.1.1	Low-Pressure NTC Cooling	Fluid	At the feed valve for the low-pressure system	The deionized make-up system provides make-up water to the	P&ID

	Water Distribution			lower-pressure system.	

***Table 3.6-7**: Interfaces for the Water System PLC (SBS 1.3.2.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.6.1.2	Plant Control and Monitoring	Software	Network Connection	Digital communications between dedicated water systems PLC and Plant Control and Monitoring (EPICS)	CWD
1.5.4.1	Hardwired Control System & PLC	Software	Network Connection	Digital communications between dedicated water systems PLC and FCPC PLC, PAUX Relay	CWD
1.7.3.6.5	DCPS Hardware Interface, Expansion Chassis & WDTs	Electrical Signal	Digitizer (SAD) in JA	Inputs: Status of water PLC	CWD
1.6.1.1	Control I/O systems	Electrical Signal	Cooling Water System PLC.	PLC networking/communication is used to communicate with the Cooling Water System PLC.	CWD
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Electrical Signal	At output block of PLC	Water system PLC controls pumps and valves on the low-pressure distribution system	CWD
1.3.2.1.2	High-Pressure NTC Cooling Water Distribution	Electrical Signal	At output block of PLC	Water system PLC controls pumps and valves on the high-pressure distribution system	CWD
1.1.3.4	Bus Bar Systems and Bus Tower	Electrical Signal	At the PLC I/O points	Sense-switches on the coil bus run ground switches are fed to the water systems PLC, where they can be used to determine the FCPC permissive status.	CWD
1.6.1.3	Timing and Synchronization System	Electrical Signal	At connector block on PLC	The central clock provides timing and synchronization functions for the water system PLC	CWD
1.7.3.8	Central Control System (CCS)	Electrical Signal	At isolation transformers	The CCS sends a No E-Stop signal to the PLC controlling the water systems (high pressure pump, low pressure pump, and OH Water Heater)	CWD
1.3.3.4	Bakeout PLC and Controls	Electrical Signal	Water system PLC I/O rack	Transfer of information at the Water system PLC I/O rack regarding status of cooling water flow and the Bakeout PLC and Controls in coils and vessel cooling loops.	CWD
1.3.2.1.4	CWS Flow and Temperature	Electrical Signal	At connector block on PLC	The water system PLC reads various data from the flow and	CWD

	Instrumentation			temperature instrumentation on the NTC south wall	
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the water systems PLC	Electrical Schematic for Directly Wired Components
1.3.2.1.3	OH Water Pre-Heater System	Electrical Signal	At output block of PLC	Provides control information to the water heater	CWD

4: Bakeout System (SBS 1.3.3)

4.1: Functions

a. The assembled vessel shall have a heating system with in situ bakeout for the vessel and PFC tiles. During this procedure, the gases absorbed and diffused within the vessel material are released and subsequently removed from the vessel by the Torus Vacuum Pumping System.

b. A vacuum vessel heating/cooling system shall provide for heating the vessel during the bakeout mode of operation, and in an upgrade mode cooling the vessel during long pulse operation.

4.2: Material and Design 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 Ref [4], while mechanical design shall be governed by the NSTX-U Structural Design Criteria [5].

c. The design of the various bakeout systems shall be compatible with PPPL standard ES-MECH-15.

d. For purposes of design, the bakeout system shall assumed to be operated 24 hours per day, 7 days a week, in 3 week increments, once per year, for a 20 year lifecycle. It may be assumed that multiple (3) start-stop cycles occur during each annual operations period. Note that the actual duration of any individual bakeout will be determined by the evolution of the vacuum parameters during that bakeout.

4.3: Configuration Requirements & Essential Features

<u>High Temperature Helium System</u>

a. Hot He will be circulated through the following heating paths:

- upper and lower inboard horizontal divertor target (the so-called heat transfer plate, or HTP),
- upper and lower outboard divertor,
- upper and lower primary passive plates
- upper and lower secondary passive plates
- the neutral beam armor.

b. Manifolds may be installed inside the vacuum chamber behind the passive plates to facilitate flow distribution. These manifolds and in-vessel piping are described in SBS 1.3.3.1.3 of Ref. [6]

c. All piping, feedthroughs, valves, and similar for the helium system shall be qualified for the maximum helium temperature of 450°C and pressure of 300 PSIG .

d. He shall be fed into the vacuum chamber via the 8” flanges located ~53” above and below the midplane at Bays D, H, and L/A.

e. He may be fed to heat the inner divertor via the heating/cooling loops on the inner horizontal target flanges.

f. Flow throttling valves and instrumentation shall be installed at each feedthrough to assess and adjust the flow balance for the system.

Ex-Vessel Heating System

g. Heating/cooling coils shall be mounted on the vacuum vessel exterior. High temperature water will be circulated through the coils, at a pressure sufficient to prevent the water transitioning to steam.

h. Appropriate controls and interlocks shall be made to prevent and mitigate loss-of-pressure accident scenarios.

CS DC Heating System

i. Provision shall be made to pass DC current down the center-stack casing, in order to heat the casing and therefore the tiles affixed to it. This shall include electrical connections to the vessel connection points to facilitate this injection, and the installation of appropriate DC power supply(s).

Control

j. A PLC or similar control system shall be used to coordinate the operation of the various systems. The PLC shall provide for remote operation of the bakeout systems.

k. The PLC shall provide interlock capability for the safe operation of the heating system. System-level required interlocks include:
- Loss of flow in any coil or vessel cooling path.
- Loss of functionality of any of the three individual systems
- Emergency stop near NSTX-U and near any remotely located equipment.
- Excessive vacuum vessel pressure or failure of TVPS
- PLC failures

l. The PLC shall have the capability to receive permissive signals from the Centralized Control System (CCS).

Other

m. The bake out heating system and procedures shall insulate personnel from heated surfaces. See Refs [7] and [8].

4.4: Baseline Performance & Operational Requirements

a. The external vacuum vessel heating paths shall bring the vacuum vessel to >115 degC bakeout temperature within 48 hrs; this minimum limit shall apply to all measurement locations on the vessel surface.

b. The average temperature of the vessel skin shall be maintained at a value less than 160 deg C.

c. The internal vacuum vessel heating paths and DC current heating system shall bring all carbon tiles to the specified bake out temperature of >300 deg C within 48 hrs.

d. The average temperature of PFCs over a given region (CSFW, OBD, PPPs, SPPs, etc.) shall not exceed 350 degC.

c. The port covers shall not exceed 150 degrees centigrade.

4.5: Upgrade Performance & Operational Requirements

a. Long pulse operation may require additional active cooling of the vacuum vessel by the bake out systems. This may involve use of the external vacuum vessel paths to cool the vessel skin between discharges using water, or the in-vessel cooling loops for gaseous cooling of PFCs between discharges.

b. To support post-bakeout analysis an upgrade may be done to provide continuous archiving of bakeout system conditions such as voltages and currents, supply and return temperatures, flow rates, etc.

4.6. Interfaces

***Table 4.6-1**: Interfaces for the Helium Skid and Piping (SBS 1.3.3.1.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.3.4	Bakeout PLC and Controls	Electrical Signal	At connector block on PLC	Bakeout PLC provides controls and statusing for helium skid	CWD
1.3.3.1.2	Ex-Vessel Helium Manifolds	Gas	At supply/return pipes where they first split to feed the different manifolds	The helium piping meets up with the manifolds, from which it is distributed into the vessel	P&ID
0.1.1.6	Other D-Site Physical Infrastructure	N/A	N/A	The helium skid is in the pump room, with piping routing through D-site to make their way to the test cell.	
0.1.1.1	D-Site Facility Chilled Water	Thermal	At fittings on skid	Chilled water is used for the heat exchanger on the helium skid	P&ID
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At penetration surface	Helium pipes from the pump room enter the NTC floor.	N/A
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power provided for helium skid	Electrical Schematic for Directly Wired Components
0.1.1.9	Instrument Air	Gas	At fittings on valves	Air to operate valves	P&ID

***Table 4.6-2**: Interfaces for the Ex-Vessel Helium Manifolds (SBS 1.3.3.1.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.9	Horizontal Target Cooling System	Gas	At flow control valve on the He distribution system	He is fed to the in-vessel heating/cooling features	P&ID
1.3.3.1.4	He Feedthroughs	Gas	At flex connection connection to the manifold.	Hot helium is fed to the in-vessel tubing, and therefore the passive plates and outboard divertor, via the feedthroughs on the vessel. It exits in the in-vessel lines via the same feedthroughs.	Mechanical Drawing
1.1.1.2.3	Neutral Bean Armor Mechanical	Gas	At He feedthrough	The hot helium distribution system feeds helium to the armor during bakeout.	Mechanical Drawing
1.3.3.1.1	Helium Skid & Piping	Gas	At supply/return pipes where they first split to feed the different manifolds	The helium piping meets up with the manifolds, from which it is distributed into the vessel	P&ID
1.8.1.1.1	NTC Platforms	Structural	Where support attaches to platform	Manifolds are supported from the test cell platforms	Mechanical Drawing
1.1.2.3.2	Outer PF Supports	Structural	Where support attaches to outer-PF support	Helium manifolds are supported from the outer-PF support weldments on the vacuum vessel.	Mechanical Drawing
1.1.2.3.1	Outer TF Truss System	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

***Table 4.6-3**: Interfaces for the In-Vessel Helium Lines (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

***Table 4.6-4**: Interfaces for the He Feedthroughs (SBS 1.3.3.1.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.1	Vacuum vessel	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
1.1.2.1.1	Vacuum vessel	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
1.3.3.1.3	In-Vessel Helium Lines	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
1.3.3.1.2	Ex-Vessel Helium Manifolds	Gas	At flex connection connection to the manifold.	Hot helium is fed to the in-vessel tubing, and therefore the passive plates and outboard divertor, via the feedthroughs on the vessel. It exits in the in-vessel lines via the same feedthroughs.	Mechanical Drawing

Table 4.6-5*: Interfaces for the Bakeout Bus Work (SBS 1.3.3.2.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.6	Center Stack Casing	Electrical Power	At horizontal flange surface	The three bakeout connections are mounted to the flange surface on the air side.	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	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
1.3.3.2.2	Bakeout DC Power Supplies	Electrical Power	at terminals of supply	Power supply sources current to the bus work, which in turn feeds the vessel	Schematic
1.1.3.3.6	Center Stack Casing	Structural	At surface of casing	disruption JxB forces reacted at joint	Calculation, Mechanical Drawing
1.1.3.3.6	Center Stack Casing	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
1.7.3.2	NTC Ground Fault Monitor	Spatial	at bus bars	sense coils link the bus bars	Electrical Schematic
1.1.2.1.1	Vacuum vessel	Other	At flange on casing	The vacuum vessel is grounded via the bakeout bus work	Electrical Schematic
1.1.3.3.6	Center Stack Casing	Other	At vessel surface	The casing is grounded via the bakeout bus work	Electrical Schematic
1.1.2.1.1	Vacuum vessel	Electrical Power	At vessel surface	The three bakeout electrical connections are mounted to the vessel surface	Mechanical Drawing
1.3.2.1.1	Low-Pressure NTC Cooling Water Distribution	Fluid	At the hose fittings on the bus work	NTC low-pressure water distribution system provides cooling for the bakeout bus work.	P&ID
1.1.2.1.1	Vacuum vessel	Thermal	At vessel surface	The joint must tolerate a range of thermal scenarios, from room temperature to the full outer vessel bakeout temperature	Calculation
1.1.2.1.1	Vacuum vessel	Structural	At vessel surface	disruption JxB forces reacted at joint	Calculation, Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Eddy/Halo Current	At vessel surface	Halo current will flow through connections bridging inner and outer vessel, applying load to the bus work.	Calculation
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support bakeout cabling	N/A

***Table 4.6-6**: Interfaces for the Bakeout DC Power Supplies (SBS 1.3.3.2.2)*

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	Location where hoses connect to the cooling water system	Provision of water cooling to the DC power supplies	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for bakeout DC supplies	Electrical Schematic for Directly Wired Components
1.3.3.4	Bakeout PLC and Controls	Electrical Signal	At PLC output block	The bakeout PLC has controls and statusing for the DC power supply	CWD
1.8.1.1.1	NTC Platforms	Structural	At platform floor	Power supply sits on the NTC platform	General Arrangement Drawing
1.3.3.2.1	Bakeout Bus Work	Electrical Power	at terminals of supply	Power supply sources current to the bus work, which in turn feeds the vessel	Schematic

Table 4.6-7*: Interfaces for the MTWS Skid (SBS 1.3.3.3.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.8.1.1	Test Cell	Structural	NTC floors	Skid on NTC floor, piping supported by walls and platform	General Arrangement Drawing
1.3.3.3.2	MTWS Manifolds and Vessel-Mounted Piping	Fluid	Where piping connects to skid	Water from skid pumped into piping, leading to vessel.	P&ID
1.3.3.4	Bakeout PLC and Controls	Electrical Signal	At connector block on PLC	Bakeout PLC provides controls and statusing for the MTWS	CWD
0.1.1.9	Instrument Air	Gas	At fittings on skid and valves	Used for automatic blow down of the system	P&ID
0.1.1.5	D-Site Potable Water	Fluid	At fitting on the skid	Provides water to the skid	P&ID
0.1.1.1	D-Site Facility Chilled Water	Thermal	at fittings on heat exchanger entrance	Provides water for heat exchange purposes	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the medium temperature water skid	CWD

Table 4.6-8*: Interfaces for the MTWS Manifolds and Vessel-Mounted Piping (SBS 1.3.3.3.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.1	Vacuum vessel	Thermal	At vessel surface	MTWS tubing is attached to the vessel surface	Schematic
1.1.2.1.1	Vacuum vessel	Structural	At vessel surface	MTWS tubing has transfer heat to, or removes heat from, the vacuum vessel, during bakeout and potentially during operations	Calculation
1.3.3.3.1	MTWS Skid	Fluid	Where piping connects to skid	Water from skid pumped into piping, leading to vessel.	P&ID
1.8.1.1.1	NTC Platforms	Structural	Where support attaches to platform	Manifolds are supported from the test cell platforms	Mechanical Drawing
1.1.2.3.2	Outer PF Supports	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
1.1.3.4	Bus Bar Systems and Bus Tower	Structural	Where supports attach to the bus tower	Pipes for the medium temperature water system are supported from the bus tower	Mechanical Drawing

***Table 4.6-9**: Interfaces for the Bakeout System PLC (SBS 1.3.3.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.2.4	Water System PLC	Electrical Signal	Water system PLC I/O rack	Transfer of information at the Water system PLC I/O rack regarding status of cooling water flow and the Bakeout PLC and Controls in coils and vessel cooling loops.	CWD
1.2.4.7	Neutral Beam Control Systems	Electrical Signal	At data highway connector	Interlock and status signal transfer between the Bakeout and TVPS PLC's via the NB PLC	CWD
1.7.3.8	Central Control System (CCS)	Electrical Signal	interface between PLCs	The CCS provides No-ESTOP signal to the bakeout system.	CWD
1.3.3.3.1	MTWS Skid	Electrical Signal	At connector block on PLC	Bakeout PLC provides controls and statusing for the MTWS	CWD
1.3.3.1.1	Helium Skid & Piping	Electrical Signal	At connector block on PLC	Bakeout PLC provides controls and statusing for helium skid	CWD
1.3.3.2.2	Bakeout DC Power Supplies	Structural	At platform floor	Power supply sits on the NTC platform	General Arrangement Drawing
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for the bakeout PLC and related controls	Electrical Schematic for Directly Wired Components
1.3.1.4	Vacuum System PLC	Electrical Signal	At PLC Data Highway Connector	Vacuum System PLC provides interlock signals to the Bakeout PLC during bakeout operations at PLC Data Highway Connector	CWD

1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support cables for bakeout PLC and control cabling	N/A
1.7.3.10.2	Trapped Key Status Monitoring	Electrical Signal	At PLC input block	Bakeout PLC monitors the status of select TKS keys	CWD
1.7.3.10.1	Trapped Key Hardware & Sequencing	Structural		Trapped key block mounted to control cabinet	Mechanical Drawing

5. Gas Delivery and Injection System (SBS 1.3.4)

5.1: Functions

a. The Gas Delivery System (GDS) shall provide the following functions:
- Provide means of routing gas from remote gas cylinders to injectors on or near the machine.
- Provide instrumentation and control for gas delivery
- Provide remotely controlled pump/purge capabilities

b. The Gas Injection System (GIS) shall provide the following functions
- Provide gas injection control to the vacuum chamber via piezo electric valves
- Provide gas injection control to the vacuum chamber via puff valves
- Provide gas injection for GDC via the systems noted in the previous bullets if required
- Provide gas injection via various research-specific injectors (divertor gas injectors, massive gas injections, supersonic gas injection, etc.)
- As necessary, provide in-vessel lines for delivery of gas from the injector to desired location.

5.2: Material and Design Requirements

a. The design of the gas delivery and injection system shall be compatible with PPPL standard ES-MECH-15.

5.3: Configuration Requirements & Essential Features

Gas Delivery System (GDS)

a. The GDS shall have a bottle bank allowing different gasses to be routed to different injectors on the machine.

b. The GDS shall minimize or eliminate the occurance of explosive mixtures in the system piping and hardware.

c. The GDS shall have remote operation of system via the vacuum PLC and HMI.

d. The GDS system shall be grounded to building steel.

e. The GDS shall include a dedicated vacuum pump and vent all exhaust gas to the D-site stack.

f. The GDS shall provide an interface with Plant Control and Monitoring to allow gas types, pressure gauges, valve positions, and other relevant readings to be acquired, centrally-displayed, and archived.

Gas Injection System (GIS)

a. The GIS shall have three gas injection points on the outer vacuum vessel utilizing piezo-electric valves.

b. The GIS shall have three injection points on the center column, composed of one near the ends of the CS First Wall (CSFW), and two near the midplane, utilizing puff valves. This system shall include in-vessel tubing to route gas to the orifice locations. Further details are provided in Ref. [9]

c. The GIS shall have two injection points on the lower outboard divertor, in the vicinity of the Row 1 tiles. These shall use piezo valves for injection control, and have in-vessel tubes to route gas to the orifice locations. Further details are provided in Ref. [9,10]

d. The GIS shall have two injection ports, located at or near the interface of the inboard horizontal and vertical divertor targets, one each at the top and bottom of the device. These shall use piezo valves for injection control, and may utilize in-vessel tubes for gas delivery. Further details are provided in Ref. [9,10]

e. All GIS valves shall have the injection timing controlled by the plasma control system.

f. The jitter on the timing of puff valve opening shall be less than 5 ms.

g. The GIS shall have electrical isolation of all piezo or puff valves from the vacuum vessel or CSC as per the GRD.

h. Designs shall ensure the low-pressure conditions do not occur in ceramic insulators where high voltage conditions may arise during a plasma discharge.

i. The GIS shall include valve drivers and electronics to interface to the plasma control system the vacuum system PLC, and the facility clock system

5.4 Baseline Performance & Operational Requirements

a. Specific numerical values for plenum sizes and system pressures are found in Ref. [8].

b. The aggregate throughput leakage for all injectors shall be less than 1×10^{-7} sccs air equivalent.

5.5 Upgrade Performance & Operational Requirements

a. Additional gas injection systems may be called for by the evolving research program.

5.6. Interfaces

Table 5.6-1*: Interfaces for the Gas Storage and Delivery Systems (SBS 1.3.4.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.8	D-Site Vent Stack	Gas	Burst discs outlet side	Provides exhaust path for burst discs	P&ID
1.8.1.1	Test Cell	Structural	At locations of clamps	Numerous gas delivery tubes are supported from platforms and other structures	Mechanical Schematic
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Numerous gas delivery tubes come through penetrations in the NTC wall	General Arrangement Drawing
0.1.1.8	D-Site Vent Stack	gas	At pump output	Exhaust gasses sent to the D-site stack	P&ID
0.1.1.9	Instrument Air	Gas	Where instrument air connects to valves	Compressed air provided for the GIS valve actuation system	P&ID
1.8.1.1.1	NTC Platforms	Spatial	NTC Platforms	Numerous gas delivery tubes are supported from platforms and other structures	Schematic
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Numerous gas delivery tubes come through penetrations in the NTC wall	N/A
1.3.4.3.1	High field side injectors	Gas	At fill valve input	Gas provided to high field side injector assemblies	P&ID
1.3.4.2.1	Main Chamber Fueling	Gas	At fill valve input	Gas provided to main chamber injector assemblies	P&ID
1.3.4.2.2	Supersonic Gas Injector	Gas	At fill valve input	Gas provided to SGI assembly	P&ID
1.3.4.2.3	Outboard Divertor Injection Systems	Gas	At fill valve input	Gas provided to outboard divertor injector assemblies	P&ID
1.3.4.2.4	GPI and Impurity Injectors	Gas	At fill valve input	Gas provided to GPI and impurity injector assemblies	P&ID
1.3.4.2.5	Private Flux Region Fueling	Gas	At fill valve input	Gas provided to private flux region injector assemblies	P&ID
1.3.4.3.2	Massive gas injectors	Gas	At connections on the valve itself	Gas provided to massive gas injector assemblies	P&ID
1.3.1.4	Vacuum System PLC	Electrical Signal	At PLC output block	Vacuum PLC controls various valves on the gas delivery systems	CWD
1.8.1.1.2	NTC Cable Trays	Structural	Surface of trays	Gas lines are run beneath, and supported by, cable trays	N/A
1.8.1.3	North and East Galleries	Location	N/A	Gas bottles for system reside in a cage in the gallery	General Arrangement

***Table 5.6-2**: Interfaces for the Main Chamber Piezo Valves (SBS 1.3.4.2.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to main chamber injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.1.2.1.1	Vacuum vessel	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)
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The main chamber fueling injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.5.2	Trimethylboron (TMB) System	Gas	Where dTMB line mates to assembly	dTMB system shares an injector location with a main chamber valve	P&ID
1.1.2.3.2	Outer PF Supports	---	At surface of PF support	Some main chamber fueling systems are supported from the outer PF supports	N/A
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

***Table 5.6-3**: Interfaces for the Supersonic Gas Injector (SBS 1.3.4.2.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.1.4	Vacuum System PLC	Electrical Signal	At connector block of PLC	Used to monitor limit switches on probe drive	CWD
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to SGI assembly	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.4.1.22	Diagnostic Port Covers	Vacuum	At flange on port cover	SGI is interfaced to the vessel and machine via a port cover	Mechanical Drawing
1.8.1.1.1	NTC Platforms	Structural	At platform floor	SGI is on a stand that resides on the platform	General Arrangement Drawing
1.3.1.5	Probe drive controls	Electrical Signal	At electrical connectors on probe drive	Control of the supersonic gas injector position	CWD
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The SGI receives open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.1.3	TIV and Shutter Actuation System	Electrical Signal	Limit switches box on the probe.	Prevent Shutter/TIV movement when probe inserted	CWD
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

***Table 5.6-4**: Interfaces for the Outboard Divertor Injection Piezo Valves (SBS 1.3.4.2.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to outboard divertor injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.4.1.22	Diagnostic Port Covers	Vacuum	Flange on port cover	The gas feeds for the injectors enter the vessel via flanges on the diagnostic port cover.	Mechanical Drawing
1.1.1.1.5	Outboard Divertor PFCs	Spatial	Surface of gas delivery tube	Provision in tiles to run tubes for lower outboard divertor gas fueling, including provision of an orifice.	Mechanical Drawings
1.1.1.2.2	Outboard Divertors	Spatial	surface of gas tubing	Outboard divertor structures may be slightly modified to accommodate gas delivery lines.	Mechanical Drawing
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The outboard divertor injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.5.2	Trimethylboron (TMB) System	Gas	Where dTMB line mates to assembly	Lower dTMB feed is shared with a divertor gas injector	P&ID
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

Table 5.6-5*: Interfaces for the GPI and Impurity Injector Piezo Valves (SBS 1.3.4.2.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to GPI and impurity injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.4.1.22	Diagnostic Port Covers	Vacuum	Flange on port cover	The gas feeds for the injectors enter the vessel via flanges on the diagnostic port cover.	N/A
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The GPI and impurity injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

Table 5.6-6*: Interfaces for the Private Flux Region Piezo Valves (SBS 1.3.4.2.5)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.6	Center Stack Casing	Vacuum	At organ pipe flange	Private flux region fueling system has vacuum interface at the organ pipe	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	Gas	At organ pipe flange	Private flux region fueling gas enters at the end of the organ pipe	Mechanical Drawing
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to private flux region injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.1.1.1.4	Horizontal Target PFCs	Spatial	Hole in horizontal target PFC	Gas from PFR injectors passes through holes in PFCs	Mechanical Drawing
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Gas lines for the private flux region injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the PZV valve	The private flus region injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support piezo injector cables	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor	At the penetration	Cables pass through penetrations	N/A

		Penetration			

***Table 5.6-7**: Interfaces for the High Field Side Puff Valves (SBS 1.3.4.3.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.6	Center Stack Casing	Gas	At organ pipe flange	high field side injector gas enters the in-vessel tubing at the end of the organ pipe	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	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
1.3.4.1	Gas Storage and Delivery Systems	Gas	At fill valve input	Gas provided to high field side injector assemblies	P&ID
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Gas lines for high-field side injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the valve	TIV and shutter actuation system controls pneumatic valves on the valve assembly	P&ID
1.1.1.1.4	Horizontal Target PFCs	Spatial	Surface of gas delivery tube	Provision in tiles or backing structures to run tubes for shoulder and midplane gas injection lines	Mechanical Drawing
1.1.1.1.3	Vertical Target PFCs	Spatial	Surface of gas delivery tube	Provision in tiles or backing structures to run tubes for shoulder, midplane, and divertor gas injection lines	Mechanical Drawings
1.1.1.1.2	CSAS PFCs	Spatial	Surface of gas delivery tube	Provision for i) shoulder injector gas lines and outlets ii) midplane injector gas lines	Mechanical Drawing
1.1.1.1.1	Center Stack First Wall PFCs	Spatial	Surface of gas delivery tube	Tiles shall have provision for tube routing and gas deliver orifices	Mechanical Drawings
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the interface to the solenoid	The high field side injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.5.2	Trimethylboron (TMB) System	Gas	Where dTMB line mates to assembly	dTMP system shares an injector location with a high-field side injector	P&ID
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

Table 5.6-8*: Interfaces for the Massive Gas Injector Valves (SBS 1.3.4.3.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.3.3.6	Center Stack Casing	Vacuum	At organ pipe flange	Massive gas injector has a vacuum interface at the flange on the end of the organ pipe	Mechanical Drawing
1.1.3.3.6	Center Stack Casing	Gas	At organ pipe flange	Massive gas injector gas enters at the end of the organ pipe	Mechanical Drawing
1.3.4.1	Gas Storage and Delivery Systems	Gas	At connections on the valve itself	Gas provided to massive gas injector assemblies	P&ID
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV or valve	TIV and shutter actuation system controls TIV and pneumatic valves on the valve assembly	P&ID
1.1.1.1.4	Horizontal Target PFCs	Spatial	Hole in horizontal target PFC	Gas from MGI valves passes through holes in PFCs	Mechanical Drawing
1.4.1.22	Diagnostic Port Covers	Vacuum	Flange on port cover	MGI valve assembly on outboard side connected to diagnostic port cover	Mechanical Drawing
1.8.1.1.1	NTC Platforms	Structural	Platform floor	MGI valve assembly on outboard side resides on floor	Mechanical Drawing
1.7.3.1	Hardwired Interlock System	Electrical Signal	At connector on MGI chassis	MGI chassis interocked to the access control	CWD
1.1.2.1.2	Umbrella structure & Spoked Lids	Structural	At surface of umbrella	lower MGI valve is supported by the lower umbrella	Mechanical Drawing
1.6.2.2	Data Archiving Systems	Software	N/A	MGI system receives timing information from MDS+, archives data to MDS+	N/A
1.5.1.2	D-Site Auxiliary Power	Electrical Power	wall plug	Electrical power for MGI power supplies, controls	N/A
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Gas lines and electrical signals for massive gas injectors enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.1.2.1.2	Umbrella structure & Spoked Lids	Spatial	N/A	Vacuum piping for the lower massive gas injector enter the umbrella through the arches of the umbrella structure	Mechanical Drawing
1.3.4.5	Valve Driver and Interface Systems	Electrical Signal	At the front of the control chassis	The massive gas injector control chassis receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.1.3.3.11	PF-1a Support Structure	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
1.8.1.1.2	NTC Cable Trays	Structural	At tray	Trays support cabling for the MGI system	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At the penetration	Cables pass through penetrations	N/A

***Table 5.6-9**: Interfaces for the Argon purge system (SBS 1.3.4.4)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.1.4	Vacuum System PLC	Electrical Signal	At connector on PLC	Argon purge system controlled by the vacuum PLC	CWD
1.8.1.1.4	NTC Walls	Structural	At NTC wall	Argon purge system supported by the NTC walls	General Arrangement
1.8.1.1.1	NTC Platforms	Structural	At clamps	Argon purge system supported from platforms	N/A
1.4.1.22	Diagnostic Port Covers	Vacuum	At flange on port cover	Argon purge system gas enters via port cover	N/A
0.1.1.9	Instrument Air	Gas	Where instrument air connects to valves	argon purge system valves controlled by compressed air	P&ID
1.8.1.1.2	NTC Cable Trays	Structural	At tray surface	Tubing supported from trays	N/A
0.1.1.8	D-Site Vent Stack	Gas	At port on APS connecting to vent manifold	APS has an exhaust port to the vent stack	P&ID

***Table 5.6-10**: Interfaces for the Valve Driver and Interface Systems (SBS 1.3.4.5)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.7.3.6.1	FPDP Data Stream	Electrical Signal	Output cable of realtime digital output module	All gas injection system timing information is delivered by digital output modules from the realtime data stream; gas system timing is often archived by the stream	CWD
1.6.1.1	Control I/O systems	Electrical Signal	Vacuum system PLC	OPC networking is used to communicate with the	CWD
1.3.1.4	Vacuum System PLC	Electrical Signal	At PLC I/O connectors	Vacuum PLC provides permissives, can control valves	CWD
1.3.4.3.1	High field side injectors	Electrical Signal	At the interface to the solenoid	The high field side injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.4.2.1	Main Chamber Fueling	Electrical Signal	At the PZV valve	The main chamber fueling injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.4.2.2	Supersonic Gas Injector	Electrical Signal	At the PZV valve	The SGI receives open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.4.2.3	Outboard Divertor Injection Systems	Electrical Signal	At the PZV valve	The outboard divertor injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.4.2.4	GPI and Impurity Injectors	Electrical Signal	At the PZV valve	The GPI and impurity injectors receive open/close commands from the realtime data stream via the	CWD

				valve driver and interface system	
1.3.4.2.5	Private Flux Region Fueling	Electrical Signal	At the PZV valve	The private flus region injectors receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.3.4.3.2	Massive gas injectors	Electrical Signal	At the front of the control chassis	The massive gas injector control chassis receive open/close commands from the realtime data stream via the valve driver and interface system	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Power for the valve driver and interface systems	Electrical Schematic for Directly Wired Components
1.8.1.3	North and East Galleries	Location	N/A	Valve driver system resides in a cage in the gallery	General Arrangement

6: Wall Conditioning Systems (SBS 1.3.5)

6.1: Functions

Glow Discharge Systems (SBS 1.3.5.1)

a. The Glow Discharge Cleaning System (GDC) establishes and controls the GDC process in NSTX-U. GDC is a mode of vacuum conditioning in which vacuum vessel internal surfaces are "scrubbed" clean by the bombardment of ions formed during the glow process. The GDC system is highly integrated with the TVPS and the dTMB systems.

Boronization System (SBS 1.3.5.2)

b. The boronization system utilizes the Glow Discharge System to create a glow discharge with deuterated trimethylboron (dTMB). dTMB is toxic and pyrophoric, and therefore special gas handling systems are required for this mode of operations.

Lithium Evaporator (LiTER) System (SBS 1.3.5.3)

c. The LiTER system coats the plasma facing components in NSTX-U vacuum vessel with a thin layer of solid lithium. Lithium metal is reactive and caustic, therefore direct handling of lithium should be performed in an Argon environment by trained personnel with approved procedures.

Argon Purge System (SBS 1.3.4.4)

d. A system shall be provided to purge NSTX-U with inert gas (Argon) in the event of a vacuum breach during LiTER operations.

e. Other experimental systems may arise (for instance, with lithium conditioning). These will be described in an update to this document.

6.2: Material and Design Requirements

a. The design of the glow discharge system, the dTMB system, the LITER system, and the vessel purge system shall be compatible with PPPL standard ES-MECH-15.

6.3: Configuration Requirements & Essential Features

6.3.1: GDC System

The following features shall be incorporated into the GDC design:

a. 2 or more in-vessel probes on approximately opposite sides of the chamber which act as the anode. These may be mounted to the vacuum vessel wall or mounted on probe drives.

b. Power supply for the anode probes.

c. Instrumentation and control for operation.

d. The GDC shall be remotely configurable and operable.

e. The GDC shall be capable of operating with helium and other gases.

f. The GDC system shall be capable of steady state operation, as well as between-discharge operations.

g. The GDC system shall be interlocked with the Hardwired Interlock System to prevent operation with personnel in the test cell.

h: The GDC system shall provide pre-ionization filaments near each electrode, and each filament location shall have redundant filaments.

i. The GDC voltage, current, and other relevant readings shall be acquired, centrally-displayed, and archived via the Plant Monitoring and Control system

6.3.2: dTMB System

The following features shall be incorporated into the dTMB system:

a. Dedicated gas cabinet controlled under 1 ATM to prevent gas leaking outside of the cabinet. The gas cabinet shall hold a maximum of 50 grams of dTMB.

b. dTMB leakage detection in gas cabinet with normal, warning and alarm levels and annunciations.

c. A dedicated vacuum pump capable of evacuating any section of the gas delivery system, and a He backfill system.

d. Synchronization of the gas control with the operation of the GDC system.

e. Treatment of the exhaust gas with nitrogen dilution to control the toxic gas in exhaust line at a safe level .

f. A coaxial dTMB delivery line between gas cabinet and vacuum vessel TIV. Outer jacket filled with above 1 ATM helium and pressure monitored for any gas leakage.

g. Automated switch between pure helium plasma and dTMB plasma without plasma interruption.

h. Distributed dTMB injection ports on vacuum vessel for uniform boron coating.

i. Mass flow rate of dTMB and Helium should be controlled by a Mass Flow Controller(MFC).

j. A battery backup design allows controlled shut down of the dTMB gas delivery during loss of regular power.

k. Provision for GDC using either dTMB or helium.

l: The dTMB system shall be capable of initiating a boronization session with 1 hour of starting.

6.3.3 LITER System (SBS 1.3.5.3)

The following features shall be incorporated into the LiTER system:

a. Two LiTERs shall be mounted on the upper dome of the vacuum vessel at nominally opposite toroidal angles, enabling approximately uniform coverage of the lower divertor.

b. The LiTER evaporation center line shall be aimed toward the middle of the lower divertor

c. When LiTER system is isolated from vacuum vessel by TIV valve, LiTER probe shall be capable of being pumped down to 10^{-7} torr via a pump cart

d. Liquid lithium filling shall be conducted in argon environment

e. A fully automated and interlocked linear motion system shall be designed to move the lithium reservoir in and out of the NSTX-U vacuum vessel during operation

f. A shutter shall be installed in order to block lithium evaporation during plasma operation or other times when evaporation to the PFC surfaces is not desired

g. The lithium coating process through LiTER shall be fully automated via the LiTER control system, TVPS PLC system and Plant Monitoring and Control (EPICS) system

6.3.4 Argon Vessel Purge System (SBS 1.3.4.4)

a. The vessel purge system shall have sufficient capability to bring the NSTX-U vessel fully up to atmospheric pressure with argon or other inert gas, following detection of a leak during LiTER operations.

b. The control system for the vessel purge system shall have access to both LiTER status information, the vessel pressure, and TIV status.

c. The vessel purge system shall not activate until both the NB TIVs are closed.[4]

[4] The leak that triggers the vessel purge system would result in NB TIV closure.

d. The vessel purge system shall not activate unless at least one LiTER is both at temperature and has its TIV open as one of the interlock requirements.

e. The vessel purge system shall use the pressure signals from all three vessel capacitance manometers in order to guard against false positives.

f. The argon from the Vessel Purge System shall enter the machine at the bottom of the vessel.

g. A separate vessel vent at the upper portion of the vessel shall be provided, allowing excess argon to exit the top of the machine when the Vessel Purge System is triggered.

6.4 Baseline Performance & Operational Requirements

a. The GDC operating parameters are shown in Table 6.4-1

Table 6.4-1: *GDC Operating Parameters*

Parameter	Typical	Maximum	Units
Voltage	500-700	800	volts
Current	1-2	3.75	amperes
Pressure (He)	1.5-5	7	mTorr
Throughput	1.5-5	7	Torr-l/s

b. The GDC system shall be capable of regulating the vessel pressure to 3 mTorr pressure with less than 25% amplitude variation.

c. Each LiTER shall hold approximately 80 grams of lithium

d. The LiTER shall provide Li deposition rates of 5-70 mg/min while the vacuum vessel pressure is in the 10^{-8} torr range

e. The vessel purge system shall be capable of bringing the NSTX-U vessel from base vacuum to atmospheric pressure of Argon or other inert gas within 15 minutes of trigger.

f. For the purposes of triggering the vessel purge system, a leak shall be declared when the vessel pressure exceeds 8 torr.

6.5 Upgrade Performance & Operational Requirements

a. It is expected that additional systems for deploying lithium on NSTX-U will be defined in the future.

6.6. Interfaces

Table 6.6-1*: Interfaces for the GDC + Filament Power Supplies (SBS 1.3.5.1.1)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.3.1.4	Vacuum System PLC	Electrical Signal	At output of PLC	Control of various parameters of the GDC system from the HMI of the vacuum PLC	CWD
1.3.5.1.2	In-Vessel GDC Probes + Filaments	Electrical Power	At vacuum feedthrough	Filaments and anodes in-vessel get power from the power supplies	Schematic
1.8.1.1.2	NTC Cable Trays	Structural	At tray	cabling run in the trays	N/A
1.8.1.1.5	NTC Penetrations	Wall/Floor Penetration	At penetration	cabling from North gallery area passes through penetration to enter the NTC	N/A
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for glow discharge systems	Electrical Schematic for Directly Wired Components
1.8.1.3	North and East Galleries	Location	N/A	GDC and filament power supplies reside in a cage in the gallery	General Arrangement

Table 6.6-2*: Interfaces for the In-Vessel GDC Probes + Filaments (SBS 1.3.5.1.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.4.1.22	Diagnostic Port Covers	Electrical Power	At flange on port cover	Electrical feedthroughs on port covers designed to support the current needs for the anodes and filaments	Electrical Schematic
1.1.2.1.1	Vacuum vessel	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
1.3.5.1.1	GDC + Filament Power Supplies	Electrical Power	At vacuum feedthrough	Filaments and anodes in-vessel get power from the power supplies	Schematic

***Table 6.6-3**: Interfaces for the Trimethylboron (TMB) system (SBS 1.3.5.2)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
0.1.1.8	D-Site Vent Stack	Gas	Vacuum exhaust line	dTMB system exhausts through the D-Site Stack	P&ID
1.3.1.1	Valves, Vacuum Pumps and Roughing Pumps	Vacuum	6" TVPS foreline	Vacuum System PLC,	Mechanical drawing, P&ID
1.3.1.4	Vacuum System PLC	Electrical Signal	TVPS main PLC	provides control and interlock of system	CWD
1.7.3.1	Hardwired Interlock System	Electrical Signal	Test Cell North door access control panel	The GDC high voltage is disabled if the test cell is in an unsafe configuration.	CWD
0.1.1.8	D-Site Vent Stack	Gas	Vacuum exhaust line	dTMB must exhaust through the D-Site Stack	P&ID
1.1.2.1.1	Vacuum vessel	Gas	Ports on the outer vacuum vessel wall	provides ports for injection of gas for GDC and dTMB	P&ID
1.3.4.2.1	Main Chamber Fueling	Gas	Where dTMB line mates to assembly	dTMB system shares an injector location with a main chamber valve	P&ID
1.3.4.3.1	High field side injectors	Gas	Where dTMB line mates to assembly	dTMP system shares an injector location with a high-field side injector	P&ID
1.3.4.2.3	Outboard Divertor Injection Systems	Gas	Where dTMB line mates to assembly	Lower dTMB feed is shared with a divertor gas injector	P&ID
0.1.1.9	Instrument Air	Gas	Where instrument air connects to valves	boronization system valves controlled by compressed air	P&ID
1.3.1.6	Vacuum Pump Cooling Water System	Fluid	Vacuum pump	The water cooling system supplies cooling water to TMB pump, MP08	P&ID
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for dTMB system	Electrical Schematic for Directly Wired Components
1.2.4.2	Beamlines	Structural	Where clamp parts are attached to beamline	Gas delivery line for the dTMB system supported by the beamline	Mechanical Drawing
1.1.2.3.2	Outer PF Supports	Structural	Where clamps attach to PF support	Gas delivery line for the dTMB system supported by the outer PF supports	Mechanical Drawing

***Table 6.6-4**: Interfaces for the Li Evaporator (LITER) (SBS 1.3.5.3)*

Interfacing SBS	Interfacing System	Nature of Interface	Interface Boundary	Interface Description	Required Interface Documentation
1.1.2.1.2	Umbrella structure & Spoked Lids	Structural	At the flange of the port cover that is dedicated to LITER.	LITER probes are mounted on umbrella structures	Mechanical Drawing
1.1.2.1.1	Vacuum vessel	Vacuum, Structural	The flange on the vessel ports.	LITER probes have port covers on the vessel, provide both vacuum boundaries and some structural interface	Mechanical Drawing
1.3.1.4	Vacuum System PLC	Electrical Signal	Limit switch box on the probe	Prevent Shutter/TIV movement when probe inserted	CWD
1.1.1.2.2	Outboard Divertors	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
1.1.1.1.5	Outboard Divertor PFCs	Spatial	Surface of PFCs, surface of LITER	LITER probe is driven to a position in the gaps of the outboard divertor when it is evaporating.	N/A
1.6.1.2	Plant Control and Monitoring	Electrical Signal	Ethernet Network	Data written to epics using Channel Access	CWD
1.3.1.5	Probe drive controls	Electrical Signal	At electrical connectors on probe drive	Control of the LITER position	CWD
1.5.1.2	D-Site Auxiliary Power	Electrical Power	various	Electrical power for LITER system	Electrical Schematic for Directly Wired Components
1.3.1.3	TIV and Shutter Actuation System	Gas	Where air connects to the TIV	TIV and shutter actuation system controls TIV on the LITER assembly, including preventing TIV closure when LITER inserted.	P&ID