Interface Control Document PLASMA FACING COMPONENTS : IN-VESSEL

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PREPARED BY:	**Kathleen Lukazik**	10/11/2019 12:52:21 PM
	Kathleen Lukazik,	
REVIEWED BY:	**Robert A. Ellis**	10/11/2019 2:07:27 PM
	Robert A. Ellis,	
REVIEWED BY:	**George D. Loesser**	10/11/2019 2:50:52 PM
	George D. Loesser,	
REVIEWED BY:	**Peter Dugan**	10/17/2019 11:07:00 AM
	Peter Dugan,	
REVIEWED BY:	**Jonathan Klabacha**	10/30/2019 2:30:47 PM
	Jonathan Klabacha,	
APPROVED BY:	**Yuhu Zhai**	10/31/2019 1:36:55 PM
	Yuhu Zhai,	

PRINCETON PLASMA PHYSICS LABORATORY
P.O. BOX 451
PRINCETON, N.J. 08543

National Spherical Torus eXperiment Upgrade

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Interface Control Document

PLASMA FACING COMPONENTS: IN-VESSEL STRUCTURES

NSTX-U-ICD-001-PFC-IVS-00

Revision 0
May 9, 2019

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Prepared By: P. Dugan, Systems Engineering

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Reviewed By: J. Klabacha, Plasma Facing Component COG

____
Reviewed: D. Loesser, Vacuum Vessel and Internal Hardware RE

____
Reviewed: R. Ellis, Diagnostics RE

____
Reviewed By: Y. Zhai, NSTX-U Project Engineer

Change Record

Revision	Date	Description of Change
0	May 9, 2019	Initial Release

References

[1] SYSTEM REQUIREMENTS DOCUMENT, Plasma Facing Components, NSTX-U-RQMT-SRD-003-00.

[2] SYSTEM REQUIREMENTS DOCUMENT, VACUUM VESSEL AND INTERNAL HARDWARE, NSTX-U-RQMT-SRD-004-01.

[3] GENERAL REQUIREMENTS DOCUMENT, NSTX-U-RQMT-GRD-001-01.

[4] Plasma Facing Components Final Design Review Outboard Divertor (OBD) Rows 3-5 Tiles, September 28, 2018.

[5] Plasma Facing Components Final Design Review Outboard Divertor Rows 1-2, 28 September 2018.

[6] Thermal Analysis of Neutral Beam Armor Array, NSTXU-CALC-11-05-00, September 22, 2011.

7] Analysis of Secondary Passive Plate with Diagnostic Cutouts,NSTX-CALC-12-11-00, May 07, 2013.

[8] Disruption Analysis of Passive Plates, Vacuum Vessel and Components, NSTXU-CALC-12-01-01, February, 2012.

[9] Armor Plate Backing Plate NSTXU-CALC-24-02-00 February 17, 2011.

10] Thermal Analysis Requirements, NSTX-U-RQMT-RD-013-00-00.

[11] Fields and Bdts for Further Analysis of PFC's NSTXU-CALC-11-08-00.

12] NSTXU Recovery Global Heat Balance Calculations, NSTXU-CALC-10-06-00.

[13] NSTX-U Disruption Analysis Requirements, NSTX-U-RQMT-RD-003-01.

[14] OBD12 Halo restraints, NSTXU-CALC-11-23-00.

[15] Eddy current calculation (conservative), NSTXU-CALC-11-24-00.

[16] EM Loads on PCHERS variant, NSTXU-CALC-11-12-00.

[17] Thermal and structural on OBD12 tile and variants, NSTXU-CALC-11-27-00.

[18] Thermal and structural on Row 3 Tiles and Variants Styles 1 and 2, NSTXU-CALC-11-14-00.

[19] Thermal and structural on Row 4 Tiles and Variants Styles 1 and 2, NSTXU-CALC-11-15-00.

[20] Thermal and structural on Row 5 Tiles and Variants Styles 1 and 2, NSTXU-CALC-11-16-00.

1. Purpose

This document describes the various interfaces between the Plasma Facing Components and the In-Vessel Structures. The interface locations and boundaries that connect the Plasma Facing Components to the In-Vessel Structures are identified based on different interface types.

2. Scope

The PFCs consist of Center Stack First Wall, Center Stack Angle Section, Vertical and Horizontal Targets, Outboard Divertor, Passive Plates, Neutral Beam Armor, and Thermocouples. The In-Vessel Structure Components address Passive Plates, Outboard Divertors, and Neutral Beam Armor. The scope of this document addresses any defined interfaces between these identified system elements.

3. Responsibilities

The interfaces are managed between the following project OBS elements:

- Plasma Facing Component (PFC)
- Vacuum Vessel and Internal Hardware (VVIH)
- Systems Engineering and Integration

4. Interfaces

Interface requirements in the following sections are identified with the requirement prefix ICD followed by a number [ICD-PFC-IVS-X]. "X" is a sequential count beginning with 1, "PFC" represents plasma facing components, and "IVS" represents In-Vessel Structures. There is also a unique identifier for all interfaces in the format [#####-#####-X]. The identifier is a concatenation of two level 5 SBS values and the interface type.

4.1. Interfaces

The top-level interface types are defined in Table 1. Within each heading, there are sub-headings to address any special sub-elements that need consideration. For example, the Mechanical interface has four sub-elements that need to be addressed: Structural, Spatial, Location, and Wall/Floor Penetration. There are corresponding sub-sections for those interface types with sub-interfaces.

Table 1. Interface Types.

Heading	Abbreviation	Name
4.2	Me	Mechanical
4.3	Ep	Electrical Power
4.4	Si	Signal
4.5	Di	Diagnostics
4.6	Gf	Gas/Fluid
4.7	Va	Vacuum
4.8	Sw	Software
4.9	Th	Thermal
4.10	Pe	Plasma/Eddy/Halo Current

Table 2 provides the N2 Diagram identifying all the interfaces for NSTX-U, while Table 3 provides the specific details of the interface.

Table 2. N2 Diagram Interface types.

Plasma Facing Components	Me,Th, Pe		Me,Th, Va,Pe						Me	Me	Me, Pe		Me			
	In-Vessel Structure	Me,Di, Pe			Th			Me,Th, Pe	Me		Me, Di, Pe			Di		
		Vacuum Vessel Structure			Me,Va	Me, Va	Me	Me, Th, Pe	Me	Me,Va	Me,Di, Va		Si	Di,Si		
		Va	Centerstack Structure			Va, Th	Me, Gf	Me	Me	Me				Di		
		Me	Me, Th, Ep	Magnets				Me			Di		SI	Di		
Si		Me, Va			Heating Systems		Gf	Th		Me		Gf, Si	Si	Si	Si	
					Si, Va, Me, Sw, Gf	Vacuum Pumping System		Si	Si	Gf, Si	Si		Si,Va	Si	Si	
				Gf,Si			Coolant System	Gf				Gf,Sw	Si, Sw	Si		
	Th, Gf	Ep,Di, Th, Va	Ep, Gf, Th, Pe		Si		Si	Bakeout System						Me	Si, Me	
			Gf,Va	Gf,Va	Ep	Gf,Si			Gas Delivery System	Me	Va		Si,Sw	Si	Si	
		Gf	Si			Si,Gf,Va			Gf	Wall Conditioning System			Si,Sw	Si	Si	
		Me,Va	Me,Va	Me	Me	Gf,Si	Gf			Va, Ep	Diagnostics		Si,Sw	Si	Si	Si
				Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Power Systems	Si	Ep, Si	Ep, Si, Di, Gf	Ep
					Si					Me, Si	Si		Centralized Instrumentation and Control	Si, Me		
										Sw		Si	Si,Sw	Integrated Machine Operations		
								Ep							Operations & Safety Systems	
Me		Me	Me	Me	Me	Me		Me	Me	Me	Me	Me	Me	Me	Me, Ep	D-Site Locations (Test Cell

Table 3. Callout.

PFCs	Me,Th, Pe
	In-Vessel Structures

The following sections address each of the interfaces. Section 5 addresses off-project interfaces. Off-project in this case represents an external interface.

4.2. Mechanical Interfaces

This paragraph addresses any type of mechanical interfaces to include structural, spatial, and location dependent interfaces or areas where penetrations into a wall or floor are required. These are identified independently as the interface parameters will likely be different.

4.2.1. Structural Interfaces

This identifies any interfaces between the system elements that require a structural interface. This could be based on various forces placed on the system and by the system.

Identifier	Interface	References
1.1.1.1.7-1.1.1.2.3-S	The **Neutral Beam Armor PFC** are mounted to the **Neutral Beam Armor** surface where they react to loads.	See 4.2.1.1 Drawings DB1166, DB1150, DB1162, BD1155, DB1409.
1.1.1.1.6-1.1.1.2.1-S	**Passive Plate PFC** tiles react to disruptions loads to the **Passive Plates**. Flexing of the plate transfers the load to the tiles at plasma facing copper surface of the passive plate.	See 4.2.1.2 Drawings NSTX042, NSTX062 NSTX070,NSTX189, NSTX045, DB1325, DB1321, DB1048,
1.1.1.1.5-1.1.1.2.2-S	**Outboard Divertor PFC** tiles react to disruptions loads to the divertor structures at surface of the **Outboard Divertor** structures.	See 4.2.1.3 Ref 17, Ref 18, Ref 19, Ref 20 Drawings ED1408, 1407, 1406 ED1403, ED1402, ED1401, ED1384

4.2.1.1. Neutral Beam Armor

Interface Notes:

- The Neutral Beam Armor is not being updated as part of recovery scope. Existing Assembly drawings are used.
- The assembly provides a single 3/8-16 x ¾ LG FH screw that holds the tile in place on the T-Bar as defined in DB1162.

ICD-PFC-IVS-001: Drawings DB1166, DB1150, BD1162 provide the Armor plate assembly. Figure 1 is an extract from Drawing DB1150 Sheet 6 and shows the Nuts that are connected to the studs in the T-Bars through the backing plate.

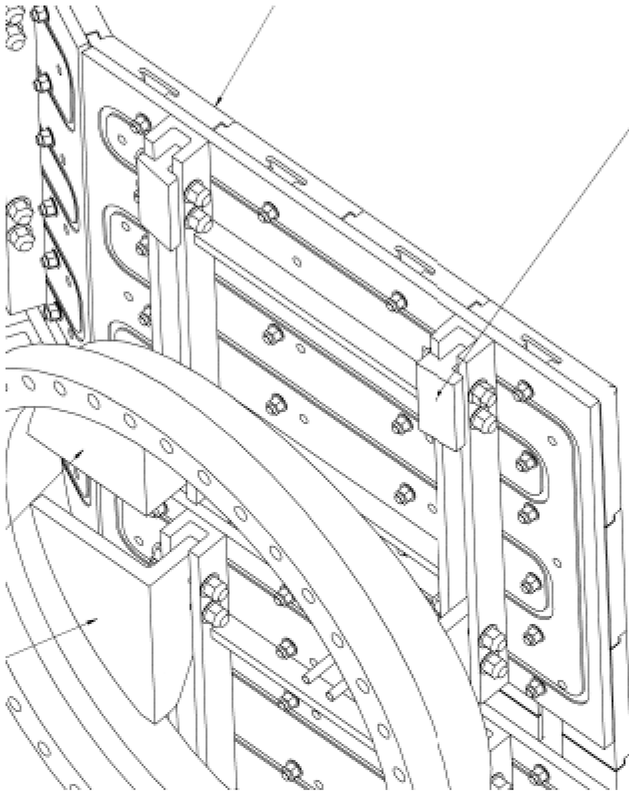


Figure 1. Armor plate ISO View

ICD-PFC-IVS-002: Drawings DB1155 and DB1409 identifies the STUD ⅜-16 UNC x1.63 LG welded in the T-Bar.

4.2.1.2. Passive Plates

Interface Notes:

- Interface between Passive plates and tile uses the existing design and are not included in recovery scope.
- A Screw FL HD DOG PT screw is used to connect the passive plate tiles to the T-Bar(Drawings NSTX045, DB1325).
- Drawing 9D1471 provides the location of the Passive plate thermocouples.

ICD-PFC-IVS-003: The secondary passive plate connects to the T-bar using a Screw, Hex SCK Button according to Section A-A of drawing NSTX070. The T-Bar is mounted to the passive plate assembly (Drawing NSTX062).

ICD-PFC-IVS-004: The primary passive plate connects to the T-bar using a Screw, Hex, SCK Button according to Detail B of drawing NSTX189 and is mounted to the passive plate Drawing (NSTX042).

4.2.1.3. Outboard Divertor

Interface notes:

- Rows 1 and 2 of the Outboard Divertor are a high heat flux region.
- Fish-scaling used.
- Rows 1 and 2 of the outboard divertor contain three types of diagnostics: Langmuir probes (2 styles), Thermocouple sensors, and Mirnov sensors on specific sheets in Drawing ED-1408
- Rows 3-5 of the Outboard Divertor contains 6 different types of sensors: Mirnov, Thermocouple, Langmuir, and Shunt.
- Rows 3-5 provide a Shear pin on each tile to enable tile alignment.
- Rows 3-5 shims provided to assure alignment during installation
- The OBD tile assembly is contained in Drawing ED1384.

ICD-PFC-IVS-005: 5/32"Hex modified shoulder screws for OBD Rows 1-2 attach the 316SS transition plate to the OBD structure as shown in Figure 1, Belleville washer is tack welded to screw. OBD Rows 1&2 screws and assembly are identified in ED1408. Row 3 Tiles are identified in Drawing 1403, Row 4 Tiles are identified in ED1404. Row 5 Tiles are identified in ED1406 and 1407. The screw for the T-Bar Connection to the divertor is SCREW, HEX, SCK BUTTON HD.

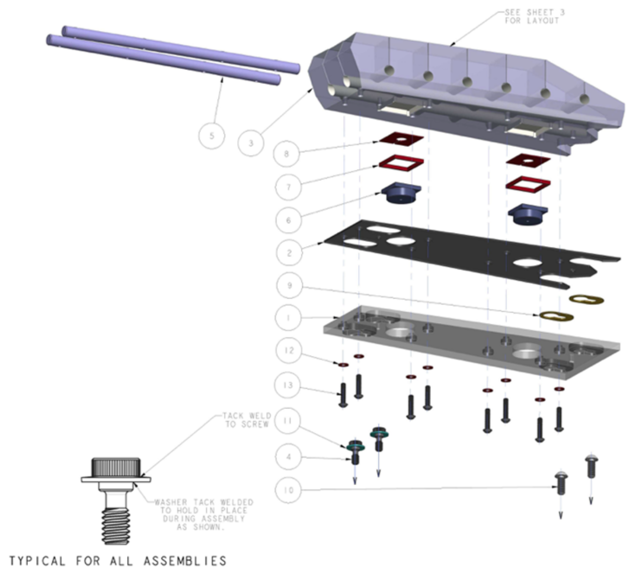


Figure 1. OBD Row 1-2 Transition Plate to Structure Interface.

ICD-PFC-IVS-006: The preload on the OBD1,2 interface is between 100 and 300 lbf each. The preload on the OBD 3,4,5 of the Bolt, T-bar for Rows 3-5 is 500 lbf.

ICD-PFC-IVS-007: The OBD Rows 3-5 connect to the copper plate with Hex, SCK, Button, HD A28 Steel screws that are integrated in the tiles through the T-bar as shown protruding from the bottom of Figure 2**.** Known misalignment of Cu baseplate slats may require shimming to achieve max tile-tile offset.

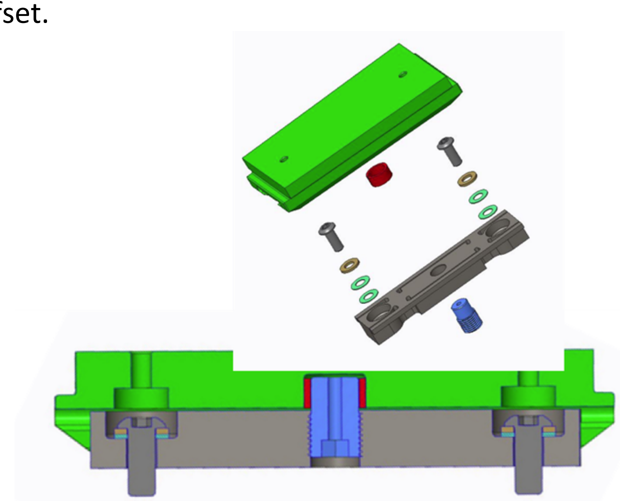


Figure 2. T-Bar to Copper Plate.

ICD-PFC-IVS-008: A layer of Grafoil exists between the T-Bar and copper plate is not shown.

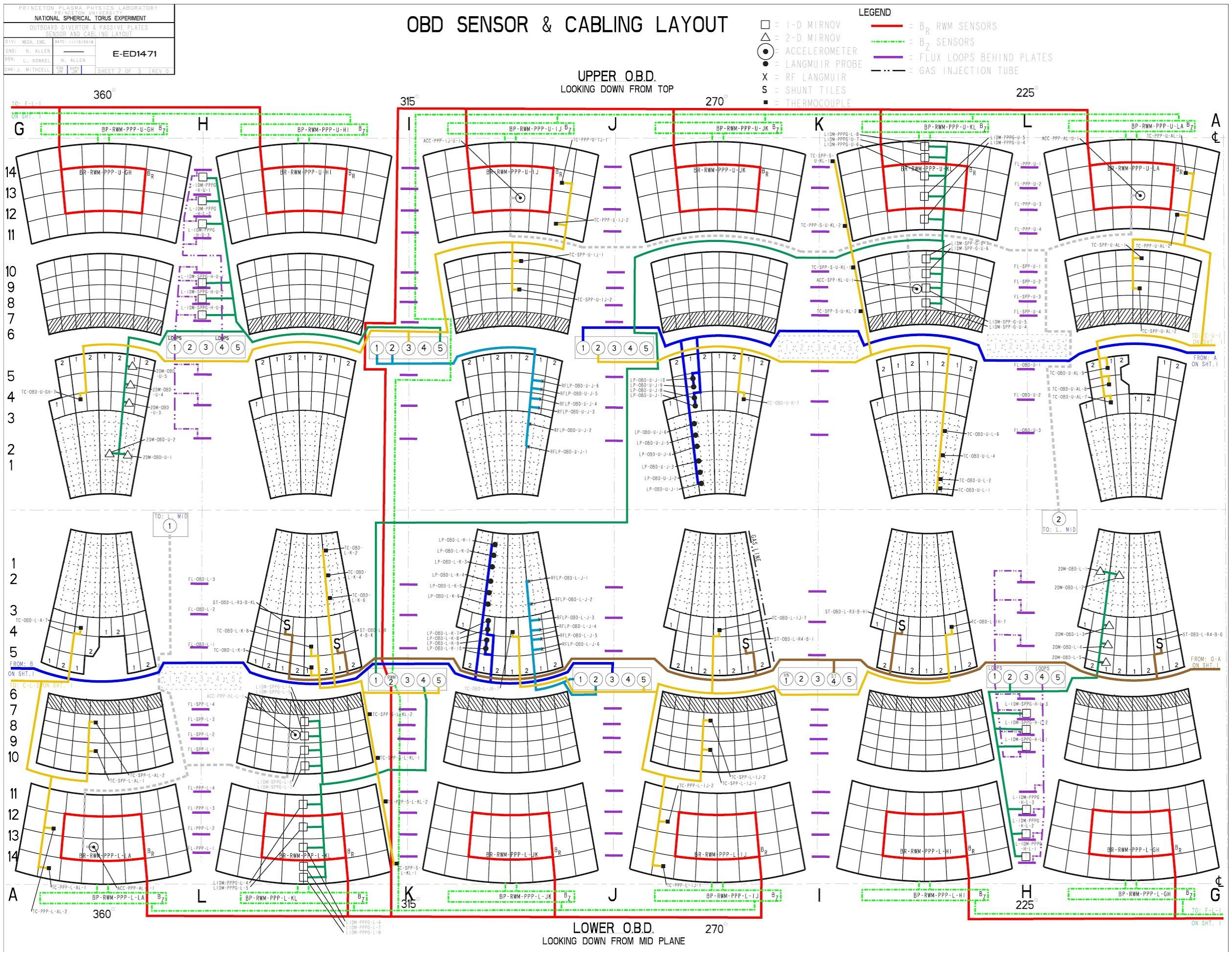
4.2.2. Spatial Interface

This identifies any interfaces between the system elements pertaining to spatial restrictions for constraints.

Identifier	Interface	References
N/A		

Interface notes:

- There is no interface identified. However, the cable runs for thermocouples the outboard divertors and passive plates to their associated ports are identified in Figure 3 Drawing ED-1471 .


OBD SENSOR & CABLING LAYOUT
PRINCETON PLASMA PHYSICS LABORATORY
NATIONAL SPHERICAL TORUS EXPERIMENT
E-ED1471
LEGEND
1-D MIRNOV
2-D MIRNOV
ACCELEROMETER
LANGMUIR PROBE
RF LANGMUIR
SHUNT TILES
THERMOCOUPLE
B_R RWM SENSORS
B_Z SENSORS
FLUX LOOPS BEHIND PLATES
GAS INJECTION TUBE
UPPER O.B.D.
LOOKING DOWN FROM TOP
LOWER O.B.D.
LOOKING DOWN FROM MID PLANE
360
315
270
225

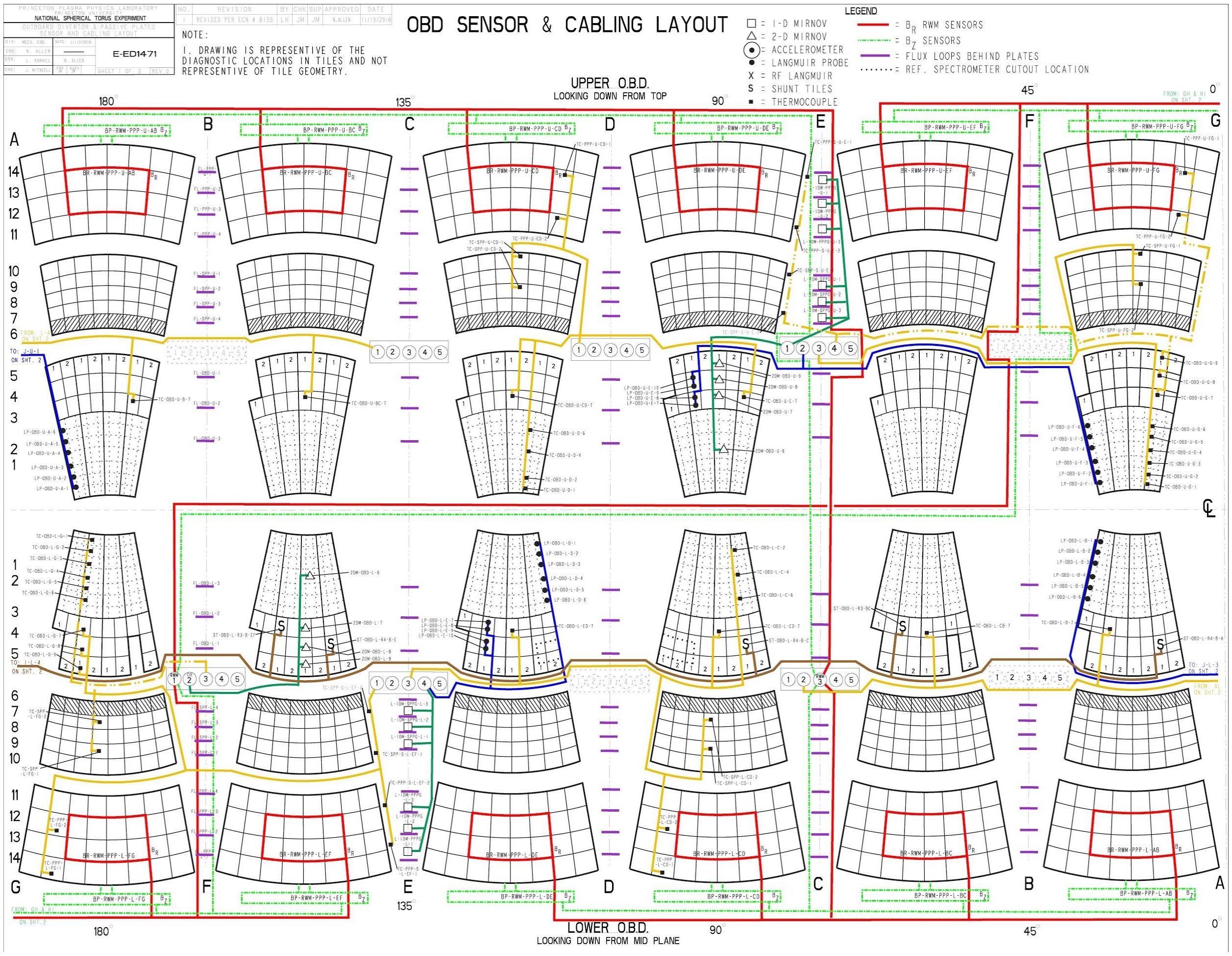


Figure 3. Sensor cabling runs

4.2.3. Location Interfaces

This identifies any interfaces between the system elements that have any particular dependencies on element location or location constraints.

Identifier	Interface	References
N/A		

4.2.4. Wall/Floor Penetration Interfaces

This identifies any interfaces between the system elements and any penetrations or modifications to the wall or floor of the D-Site building.

Identifier	Interface	References
N/A		

4.3. Electrical Power Interfaces

This identifies any interfaces between the system elements requiring AC, DC, rectification or power conditioning.

Identifier	Interface	References
N/A		

4.4. Signal Interfaces

This identifies any interfaces between the system elements and signals that are used to either send or receive control information or data. It explicitly includes the type of physical interface such as Ethernet, Fiber Optic, or any specific protocols.

Identifier	Interface	References
N/A		

4.5. Diagnostic Interfaces

This identifies any interfaces between the system elements with any instrumentation or diagnostic equipment to collect performance data.

Identifier	Interface	References
N/A		

4.6. Gas/Fluid Interfaces

This paragraph has two different types of interfaces: Gas and Fluid.

4.6.1. Gas Interfaces

This identifies any interfaces between system elements that use any type of gas (e.g., He).

Identifier	Interface	References
N/A		

4.6.2. Fluid Interfaces

This identifies any interfaces between system elements that use any type of gas (e.g., ionized water).

Identifier	Interface	References
N/A		

4.7. Vacuum Interfaces

This identifies any interfaces between the system elements that pertain to the Vacuum.

Identifier	Interface	References
1.1.1.1.8-1.1.3.3.6.V	PFC Thermocouples sensors leads leave vacuum at flange on the Vacuum Vessel flanges.	See Paragraph 4.7.1 Drawing 9D1095.

ICD-PFC-IVS-010: The feedthrough ports and sensors are documented and identified in drawing 9D1095. Each feedthrough is assigned a separate sheet and labeled per the Center Stack Designation by toroidal angle or OBD designation by Bay Each pair of wires maps to sensors is called out in the drawing.

4.8. Software Interfaces

This identifies any interfaces between system elements that use software that may exchange interfaces with other software components. This includes application programming interfaces (APIs) or any other exchange of information between different software applications.

Identifier	Interface	References
N/A		

4.9. Thermal Interfaces

This identifies any interfaces between the system elements that pertain to Thermal characteristics.

Identifier	Interface	Artifacts
1.1.1.1.6-1.1.1.2.1.T	**Passive Plate PFC** tiles transfer heat during bakeout and operations at plasma facing copper surface of the **Passive Plate.**	See Paragraph 4.9.1 Ref 12
1.1.1.1.5-1.1.1.2.2.T	**Outboard Divertor PFC** tiles transfer heat during bakeout and operations at surface of the **Outboard Divertor** structures.	See Paragraph 4.9.2 Ref 12, Ref 17
1.1.1.1.7-1.1.1.2.3.T	The **Neutral Beam Armor PFCs** are mounted to the **Neutral Beam Armor surface**, where they pass heat during bakeout and operations including the off-normal full-power beam shot.	See Paragraph 4.9.3 Ref 6, Ref 12

Interface Notes:

- The five Thermal scenarios are identified in Ref 10.
- Thermal Scenarios based on End of pulse and end of day scenarios considering thermal ratcheting throughout the day focusing on interfaces between PFCs and the support structures.
- Scenarios interfaces are identified in ranges. Using the calculation extrapolate maximum ranges based on peak scenarios at interface and peak temperature of tiles.

4.9.1. Passive Plate Thermal

ICD-PFC-IVS-012: The end of day temperature ranges peaks at 177 °C.

ICD-PFC-IVS-013: The end of pulse thermal calculation interface ranges peaks at 187°C in Scenario 4. The tile reaches a peak temperature of 217°C.

ICD-PFC-IVS-014: The bakeout temperature reaches up to 282°C on the tile.

4.9.2. Outboard Divertor

ICD-PFC-IVS-014: The temperature range at the end of the day at the for rows 1-2 peaks at 207°C in scenario 3.

ICD-PFC-IVS-015: The temperature range at the end of the day at the interface between Rows 3-5 tile and the mount peaks at 193°C in scenario 3.

ICD-PFC-IVS-014: The temperature range at the for rows 1-2 interface at the end of a pulse peaks at 216° C in scenario 3. The peak temperature at the tile peaks at 1479° C during scenario 3.

ICD-PFC-IVS-015: The temperature range at the interface at the end of a pulse between Rows 3-5 tile peaks at 195° C in scenario 3 at the structure under the tile. The peak temperature of the tile is 210° C.

ICD-PFC-IVS-016: The bakeout temperatures for Rows 1/2 is 280° C and Row 3/4/5 is 273° C.

ICD-PFC-IVS-017: Thermal growth during bakeout is ~.120" of the vessel relative to the outer vessel.

4.9.3. Neutral Beam

ICD-PFC-IVS-018: The end of day temperature peaks at 174 °C in Scenario 4 at the direct interface between the tile and the mount.

ICD-PFC-IVS-019: The end of pulse thermal calculation interface peaks at 183°C in Scenario 4. The tile reaches a peak temperature of 198°C.

ICD-PFC-IVS-020: The bakeout temperature reaches 289° C.

ICD-PFC-IVS-021: Thermal growth of the stainless-steel backing plate will be 0.18 inches during bakeout.

4.10. Plasma Interfaces

This paragraph has two different types of interfaces: Plasma and Eddie/Halo Current.

4.10.1. Plasma Interfaces

This identifies any interfaces between the system elements with the Plasma.

Identifier	Interface	References
	Defined in off-project interfaces.	

4.10.2. Eddy/Halo Current Interfaces

This identifies any interfaces between the system elements with the Eddy/Halo Currents.

Identifier	Interface	References
1.1.1.1.5-1.1.1.2.2.E	Halo currents and potentially eddy currents transferred from the **Outboard Divertor PFC** tiles and their mounting structures to the **Outboard Divertor.**	See 4.10.2.1 Ref 11, Ref 13, Ref 14, Ref 15, Ref 16
1.1.1.1.6-1.1.1.2.1.E	**Passive Plate PFC** tiles react to disruptions loads to the P**assive Plates**. Flexing of the plate transfers load to the tiles.	See 4.10.2.2 Ref 11, Ref 13.

4.10.2.1. Outboard Divertor

ICD-PFC-IVS-022: There is a HALO current that will cross the interface identified in Table 4.1 of Ref 13. Of particular interest is Case 2 Poloidal Structure Current Pushing Toward Vessel. In this case halo current fraction (F_h)= 0.35 and toroidal peaking factor (TPF) = 2.

ICD-PFC- IVS -023: There is an eddy current EM load based on B's and B dot as identified in Ref. 11 that are used in individual calculations. This calculation is design dependent and is used with the thermal, EM, and HALO calculation in the structural interfaces.

4.10.2.2. Passive Plates

ICD-PFC- IVS -024: There is a HALO current that will cross the interface is identified in Table 3.3 of Ref 13. Of particular interest is Case 1 SPP Tile Normal Current in this case halo current fraction (F_h)= 0.35 and toroidal peaking factor (TPF) = 2.

ICD-PFC- IVS -025: There is an eddy current EM load based on B's and B dot as identified in Ref. 11 that are used in individual calculations. This calculation is design dependent and is used with the thermal , EM, and HALO calculation in the structural interfaces.

5. Off-Project Interfaces

The off-project interfaces are components that are not specifically part of the NSTX-U system. They may include external systems and interfaces where the program has little control on part of the interface. They are provided for completeness.

ICD-PFC- IVS -026: The Plasma interacts with Passive Plate tile and imposes thermal and electromagnetic loads.

ICD-PFC- IVS -027: The Plasma interacts with Passive Plate tile and causes sputtering and tile erosion.

ICD-PFC- IVS -028: The Plasma interacts with Outboard Divertor tile and imposes thermal and mechanical loads. Ref 17 for rows 1&2, Ref 18 for Row 3, Ref 19 for Row 4, and Ref 20 for Row 5.

ICD-PFC- IVS -029: The Plasma interacts with Outboard Divertor tile and causes sputtering and tile erosion.

ICD-PFC- IVS -030: The Plasma interacts with Neutral Beam Armor tile and imposes thermal and mechanical loads.

ICD-PFC- IVS -031: The Plasma interacts with Neutral Beam Armor and causes sputtering and tile erosion.