National Spherical Torus eXperiment Upgrade

National Spherical Torus Experiment-Upgrade

NSTX-U

SYSTEM REQUIREMENTS DOCUMENT

Plasma Facing Components

NSTX-U-RQMT-SRD-003-00

Revision 0

December 15, 2017

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Change Record

Revision	Date	Description of Change
0	12/15/17	Initial Release

Table of Contents

References

[1] NSTX-SRD-11-031, *System Requirements Document, Plasma Facing Components*
[2] NSTX-U-SRD-111-013, *System Requirements Document, Plasma Facing Components*
[3] NSTX-U-RQMT-GRD-001, *NSTX-U General Requirements Document*
[4] PFCR-MEMO-010-00, *Heat Fluxes on the IBDH and Near OBD Regions*
[5] PFCR-MEMO-009-00, *Heat Fluxes on the Vertical Target*
[6] PFCR-MEMO-008-00, *Heat Fluxes on the CSAS and Far OBD Region*
[7] NSTX-CRIT-0001-02, *NSTX Structural Design Criteria*
[8] NSTX-U-RQMT-RD-003, *NSTX-U Disruption Requirements*
[9] NSTX-U-RQMT-RD-014, *Thermal Analysis Requirements*
[10] PFCR-MEMO-003-00, *Carbon Blooms and CFCs*
[11] NSTX-U-RQMT-RD-004, *PFC Diagnostics and Gas Delivery*
[12] NSTXU-CALC-11-05-00, *Thermal Analysis of Neutral Beam Armor Array*
[13] NSTXU-CALC-24-02-00, *Armor Plate Backing Plate (Neutral Beam Armor E/M)*

0.0 Scope

a. This document provides requirements for plasma facing components on NSTX-U. All statements in this document supersede the requirements in [1] and [2] in the event of conflict.

b. The format of this document, including interfaces specifications, is provided in the General Requirements Document [3].

c. Tile regions are named in this document as described in Table 0-1. :

Table 0-1: Full name and acronyms used to describe plasma facing component regions.

Name	**Acronym**
Center Stack First Wall	CSFW
Center Stack Angled Section	CSAS
Inboard Divertor Vertical	IBDV
Inboard Divertor Horizontal	IBDH
Outboard Divertor	OBD
Secondary Passive Plates	SPP
Primary Passive Plates	PPP

1.0 Functions

The plasma facing components are designed with two complementary goals:

a. They must protect the metallic structures of the vessel (the vessel wall, passive plates, etc.) from damaging heat fluxes from the plasma.

b. They must protect the plasma from contaminating influx of medium- and high-Z impurities.

Specific tile areas have specific functions such as :

IBDH Tiles

c. The IBDH tiles protect the horizontal casing flange and any cooling features mounted to that flange, while protecting the plasma from impurities generated from those objects. They also protect the PF-1c coil reentrant flanges, in concert with the outboard divertor PFCs.

d. The IBDH tiles are a primary heat flux handling surface for the outer magnetic strikepoint for high performance (H-mode) plasmas.

e. Additional information on the research program uses of these tiles can be found in Ref. [4]

IBDV Tiles

f. The IBDV tiles protect the centerstack casing, while protecting the plasma from impurities generated by that surface.

g. The IBDV tiles are a primary heat flux handling surface for the inner magnetic strikepoint for high performance (H-mode) plasmas.

h. Additional information on the research program uses of these tiles can be found in Ref. [5]

CSFW Tiles

i. The CSFW tiles are used to protect the centerstack casing, while protecting the plasma from impurities generated by that surface.

j. The CSFW tiles are the primary heat flux handling surface during discharge initiation and rampdown, and may serve as a heat flux handling surface for inner wall limited plasmas.

CSAS Tiles

k. The CSAS tiles are used to protect the angled part of the center stack casing, while protecting the plasma from impurities generated by that surface.

l. The CSAS tiles are a primary heat flux handling surface for the inner magnetic strikepoint for lower elongation plasmas.

m. Additional information on the research program uses of these tiles can be found in Ref. [6].

OBD Tiles

n. The OBD tiles are used to protect the outboard divertors, while protecting the plasma from impurities generated by that surface. They also protect the PF-1c coil reentrant flanges, in concert with the inboard horizontal target PFCs.

o. The OBD tiles are a primary heat flux handling surface for the outer magnetic strikepoint for L-mode plasmas, and as well as some H-mode plasmas.

p. Additional information on the research program uses of these tiles can be found in Refs. [4, 6].

Passive Plate Tiles

q. The passive plate tiles are used to protect the surface of the copper primary and secondary passive plates, while protecting the plasma from impurities generated by that surface.

2.0 Materials and Design Requirements

2.1: Materials Requirements

a: All PFCs in NSTX-Upgrade shall be made from either fine grain isotropic graphite, or from other carbon based materials, for instance carbon-carbon composites, here referred to as CFCs.

b. The exception to this is the RF antenna guard which can be made from boron nitride. The RF antenna guard shall not be regarded as a surface on which it is acceptable to intentionally limit the plasma.

c: For isotropic graphite and carbon-carbon composites, the brittle materials qualification shall be used, as per the structural design criterion [7], where PFCs are defined as critical components.

d: The PFCs themselves and any related materials should be compatible with an ultra-high vacuum environment, as approved by the PPPL Vacuum Materials Committee.

e: PFCs should be compatible over their lifetime with the following:

- Application of boron thin films as deposited by the dTMB system.
- Application of lithium thin films as deposited, for instance, by the LITER probes, including the ability to remove lithium deposited on front surfaces and in tile gaps; a scheme should be developed for this cleaning as a product of the design. Lithium coatings of up to 0.02" should be anticipated for regions immediately under the LITER probes.[1]
- Glow discharge cleaning with hydrogen, deuterium, helium, neon, and argon.

e: Non-ferritic materials should be used for all fasteners. SS316, A286, or Inconel are preferred. Magnetic permeability requirements shall be adhered to as per reference [3].

[1] Email from Mike Jaworski to Stefan Gerhardt, 9/11/2017

Table 2.1-1: Temperature and durations for tile bakeout following machining (note: only required as per 2.1.f)

Temp (degC)	Time at Temperature (hours)
1300	5
1200	7
1100	9
1000	11
900	13
800	16
750	18
650	22
550	27

f: Following manufacture and before diagnostic installation or final installation on NSTX-U, the PFCs should be compatible with, and subject to, a high temperature bake following one of the the protocols in Table 2.1-1[2]. 1000 degC for 11 hours is the recommended case.

2.2: Mechanical Design Requirements

a: Disruption mechanical and thermal loads shall be computed as per the NSTX-U Disruption Specification [8].

b: Tile designs should have a well defined current path for halo currents entering the tile front surface to flow to backing structures.

c: The design of the IBDH and OBD tiles (top and bottom) should accommodate halo currents bridging that gap during disruptions, with currents levels as per Ref. [8].

2.3 Field Helicity Requirements

a. The field directions are indicated in Figures 2.3.1 and 2.3.2, along with exaggerated ramped tiles. Field lines approach the surfaces at very shallow angles, and those given in tables of Section 4 are referenced such that 90^o would make the field line normal to the PFC surface.

b. In two cases, the sign of the field line helicity may vary:

[2] The values from NSTX-SPEC-11-047 and W7X-SPEC-TDUS-014

- The horizontal target (IBDH) may have heat from either the inner or outer strikepoint deposited on it; these two cases have opposite field helicity at the strikepoint. For the purpose of this document, “standard target helicity” refers to the field line direction when the Outer Strike Point (OSP) is located on the IBDH tiles, for clockwise toroidal field and counter-clockwise plasma current (when viewing the tokamak from above). “Reversed target helicity” refers to cases where this direction is reversed.
- The vertical target (IBDV) typically receives heat from the inner strikepoint, called “standard target helicity” in this document. In rare cases, the IBDV may have heat from the outer strikepoint fall on the portion nearest the horizontal target, or have intermediate legs of advanced divertors. These rares cases will have “reversed target helicity”.

c. For the IBDH and OBD, “standard” helicity is illustrated as per Fig. 2.3-1.

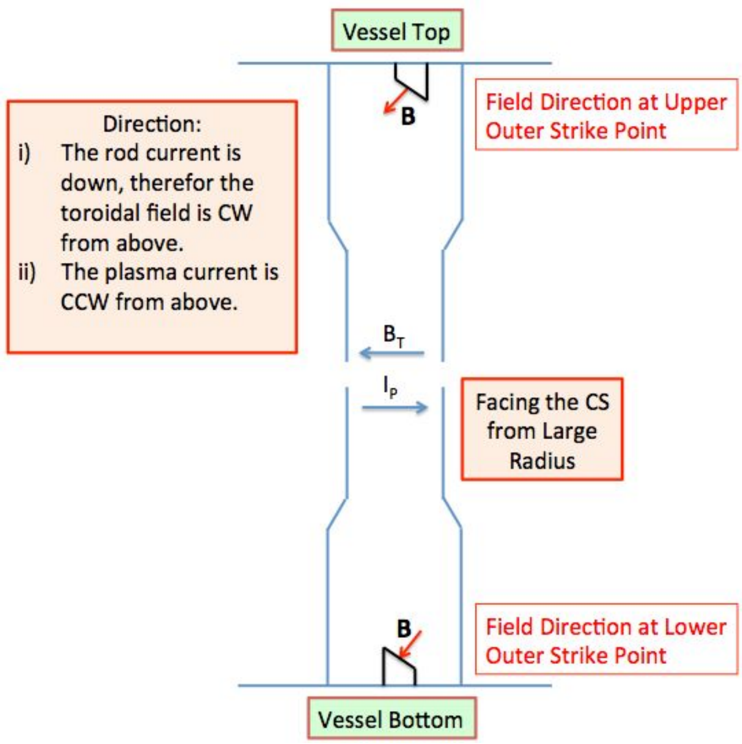

Fig: 2.3-1: *Field line direction on the horizontal target for “Standard Helicity”*

d. For the IBDV, “standard” helicity is illustrated as per Fig. 2.3-2.

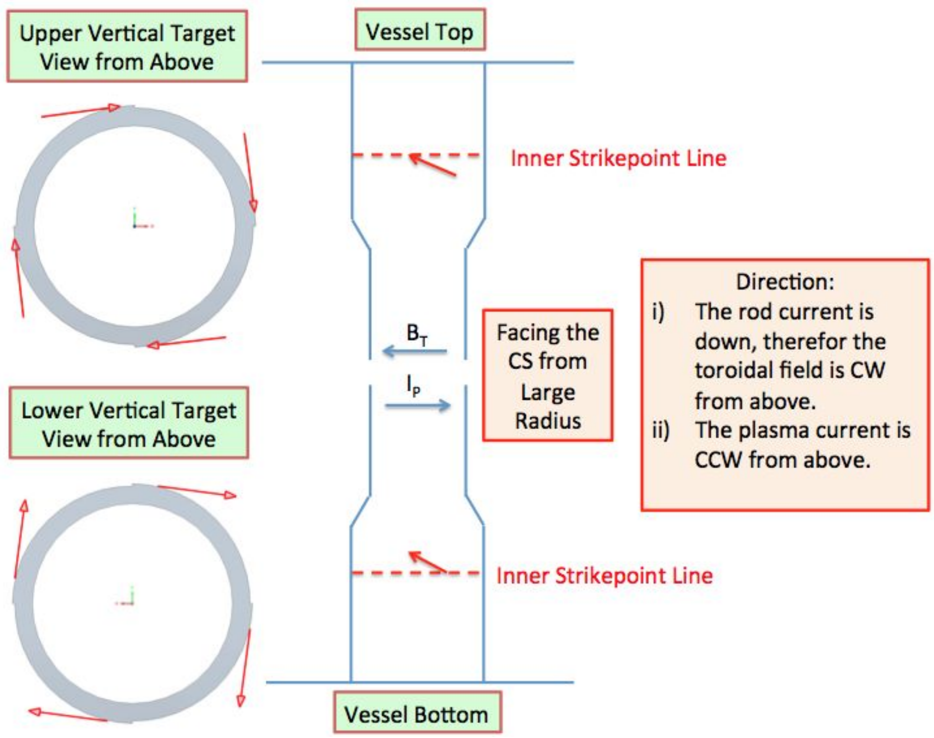

Fig: 2.3-2*: Field line direction on the vertical target for “Standard Helicity”*

It is assumed that heat flux is due to parallel conduction in the plasma, such that heat flows along the magnetic field line from the midplane towards the PFC surface in both cases, regardless of field line direction.

3: Configuration Requirements and Essential Features

3.1: Thermal Requirements:

a: The design scenarios described in sections below shall be qualified for repetition rate of ≤ 2400 second repetition rate with the base cooling. Baseline cooling is defined in Reference [9]. . [

b: A 1200 second repetition rate shall be possible with application of additional cooling, but no modifications to the tokamak core. [9]

c: Tiles shall be designed so that the peak surface temperature of the wetted top face, away from local peaks at the edges (as defined in 3.1-d), at the end of the pulse shall not exceed 1600 ^{o}C [10]; disruption heating need not be included in this consideration.

d: Tiles shall be designed so that the edge temperatures of local surface features (e.g. access holes) or edge features of non-shaped tiles shall not exceed 2000 ^{o}C and meet 3.1-c at distance of 2 mm from the edge/feature ; disruption heating need not be included in this consideration.

e: Unless otherwise stated, the duration of heat flux is to be taken as 5 seconds.

f: PFC surface/edge temperatures may exceed those listed in 3.1-c and 3.1-d following disruption loads given in Ref [8] , but bulk tile stress limits must not be exceeded.

g: The tiles and fasteners should be qualified for the full lifetime of NSTX-U as per the GRD shot spectrum [3]. In particular, the mechanical performance noted here shall be qualified for 20,000 cycles.[3]

h: Tile designs with surfaces shaped to favor one target helicity (referred colloquially as 'ramping' or 'fishscaling') may be used if necessary. Specifics of the helicity direction are identified generally in Section 2.3, and in Section 4.1-4.9 per each individual PFC region.

i: When tile surface shaping (see 3.1-h) is utilized, edges must meet the same surface temperature limit as the wetted area (3.1-c). Reversed helicity cases shall be held to the same temperature limit as edges (see 3.1-d).

j: Vertical gaps, front-surface holes, etc. are allowed provided that designs can meet stress and temperature requirements.

K: Emissivity of 0.7 shall be used for calculations.

3.2: Bakeout Considerations

a: All in-vessel graphite, including that used for PFCs, shall be capable of being baked to at least 300 C, with the note that the higher He inlet temperatures may result in some tiles exceeding this temperature by some 10s of degrees.

b: The gap between the upper IBDH and OBD tiles should be designed to satisfy a 1000 Voltage differential without arcing as per a Paschen's curve. The following pressure levels and gas species should be evaluated: atmospheric pressure of air, NSTX-U operational vacuum with D_2 ($1x10^{-8}$ Torr), and NSTX-U bake out with water vapor ($5x10^{-4}$ Torr - $5x10^{-6}$ Torr).

3.3: PFC Locations and Spatial Configuration

a: PFCs should conform to the envelope stated in Figure 3.3.1 and Table 3.3.1. The table indicates the nominal PFC boundary, as well as allowed radial or vertical size increases of the PFCs in order to meet requirements.

[3] erosion of the tile surface from disruptions or normal operations may impact the tile surface rampings. The impact of this erosion is not considered in this lifetime assessment.

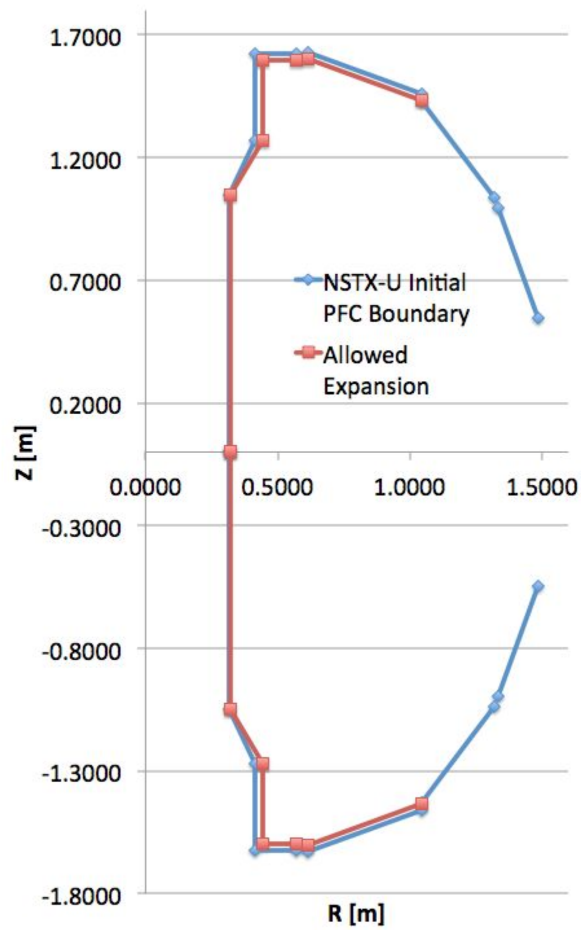

Figure 3.3.1*: NSTX-U PFC boundary and allowed expansion of PFCs to accommodate new requirements*

b: The center radius of the IBDH/OBDR1 interface shall be at R=59.5 +/- 0.5 cm.

c: PFCs design should ensure that there is no large line-of sight from the plasma to the centerstack casing, centerstack bellows, or outer vacuum vessel in the “polar regions” or PF-1c reentrant housing; included in this is the requirement that graphite armor be present in continuous form from the outboard divertor to the secondary passive plates as per Fig. 3.3.1. Here, “large gaps” do not preclude nominally small tile-to-tile gaps.

d: Regions on the casing and divertors not protected from direct lines of sight shall be minimized. Any gap wider than 1 mm must be evaluated and approved during the design review process.

Table 3.3.1*: Baseline PFC boundary and allowed expansion of PFCs to accommodate requirements*

	R	Z	Allowed ΔR	Allowed ΔZ
	m	m	m	m
Upper CS	0.3148	0.0000	0.0050	0.0000
	0.3148	1.0500	0.0050	0.0000
	0.4150	1.2700	0.0300	0.0000
	0.4150	1.6234	0.0300	-0.0254
	0.5715	1.6234	0.0000	-0.0254
Upper OBD	0.6171	1.6280	0.0000	-0.0254
	1.0433	1.4603	0.0000	-0.0254
Upper SPP	1.0433	1.4300		
	1.3192	1.0397		
Upper PPP	1.3358	0.9976		
	1.4851	0.5450		
Lower PPP	1.4851	-0.5450		
	1.3358	-0.9976		
Lower SPP	1.3192	-1.0397		
	1.0433	-1.4300		
Lower OBD	1.0433	-1.4603	0.0000	0.0254
	0.6171	-1.6280	0.0000	0.0254
Lower CS	0.5715	-1.6234	0.0000	0.0254
	0.4150	-1.6234	0.0300	0.0254
	0.4150	-1.2700	0.0300	0.0000
	0.3148	-1.0500	0.0050	0.0000
	0.3148	0.0000	0.0050	0.0000

3.4: Diagnostic Requirements

a. PFCs shall accommodate the following types of sensors :

- Langmuir probes
- Mirnov coils
- Rogowski coils
- Shunt tiles
- Thermocouples

b. Detailed requirements for PFC diagnostics for specific locations are provided in Ref. [11]

3.5: Installation and Maintenance Requirements

a: No module or single component installed by a single person shall weigh more than 50 lbs, per OSHA recommendation, unless lifting and handling equipment and procedures are specially developed.

b: Any module and component must fit through the Bay A duct without the use of an overhead crane.

c: Tiles of the base design should be able to bear the weight and typical movement of technicians working in vessel. For design purposes, this can be assumed to be 300 lbf distributed over an area of 4 in^2. Langmuir probe tips or other specific fine features are an exception to this rule, and may require protection.

d: The design shall be such that removal replacement of any tile shall not mandate the removal of the center-stack or outboard divertor copper/stainless structure.

e: An assembly sequence shall be provided with the design that takes account of machine assembly (including CS insertion to the machine), wire management, and any industrial hygiene and health physics concerns.

f: No permanently installed component on the outboard divertor shall extend inside the radius of the main vessel flanges (R_{vessel_flange}=23.625"), and no permanently installed component on the CS shall extend more than ¼" beyond the radius of the CS horizontal flanges (R_{flange}=21.875", for $R_{max}=R_{flange}+1/4$ = 22.125").

3.6: In-Vessel Requirements for Gas Delivery:

Specific detailed requirements for gas fueling interfaces are provided in Ref. [11]

a. Two gas fuelling outlets shall be provided near the CS midplane for core fuelling.

b. One gas fuelling outlet shall be provided near the CSAS tiles on the upper portion of the CS for core fuelling.

c. Two gas fuelling outlets shall be provided near the corner of the row 1 tiles in the outboard divertor for divertor fuelling.

d. Two gas fueling lines, with outlets near the upper and lower IBDH/IBDV interfaces, shall be provided for private flux region divertor fuelling.

4.0 Baseline Performance and Operational Requirements

This section defines the heat load requirements by location. The mechanical pre-loads and thermal loads so-derived should be added to those from halo currents and eddy currents.

The heat fluxes in the tables below are based on the Ref [4-6]. All justification for these requirements can be found in those memos.

a. For some cases an extent is given. This extent should be used to define a triangular heat flux profile, as shown in Figure 4.0.1, that should be able to be located anywhere over the Range of Application.

b. if there is no 'Extent' given, or is stated as "full", then the heat flux should be applied uniformly over the Range of Application.

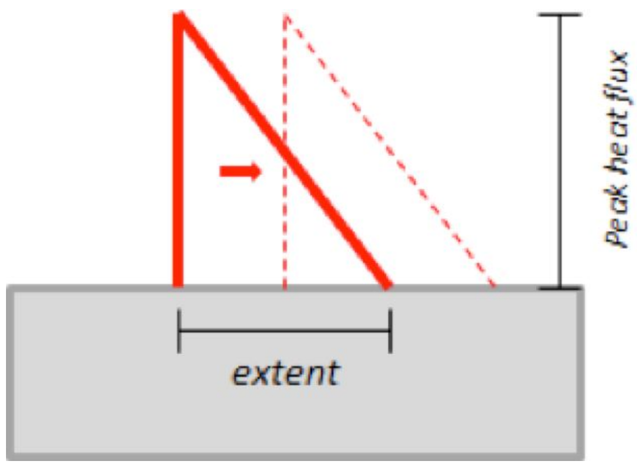

Figure 4.0.1: Example of heat flux profile that should be used for stationary cases in the region-specific requirements tables in Section 4.1-4.5.

To judge if PFCs satisfy requirements, heat fluxes should be applied as described over the PFC surface, at the given angles of incidence for the listed duration. If PFC designs are shown to not meet these requirements, relaxation may be granted:

- more accurate profiles of field directions and heat flux magnitudes along the divertor surface can be made available, by contacting the Head of the PFC Requirements Working Group and/or the Head of NSTX-U Research Operations.
- reduction of the ultimate parameters may be feasible, but the impact on NSTX-U operational space must be taken into consideration, and modifications to these requirements be done in coordination with the Head of NSTX-U Research Operations and the NSTX-U Research Director.

4.1: CS First Wall (CSFW)

a: The nominal alignment target of .030" between adjacent tiles shall be used. There is not an expectation that eccentricities in the casing itself will be compensated out by this tile installation.

b: A uniform normal heat flux of 1 MW/m^2 for 5 seconds should be used. This is consistent with the 100% radiation scenario defined in Section 4.1.5 of the GRD [1], but computed for the CSFW geometry.

4.2 Inner Horizontal Target

a: Heat flux requirements on this surface are given in Table 4.2-1.

Note that there is a region for R<0.47 where reduced thermal performance is allowed.

IBDH	**Case # ->**	**1**	**2**	**3**	**4**	**5**
Range of Application	m	0.47 < R < 0.6			R < 0.6	R < 0.47
Extent	cm	15	full	7.0	full	full
Max Angle	degrees	1.0	5.0	3.6	-1	4.0
Min Angle	degrees	1.0	1.5	3.6	-5	1.0
Heat Flux	MW/m^2	7.0	5.5	14	1	3.5
Duration	sec	5	5	1	1	5
Reference Scenario	---	Stationary High Ip/Bt w/ large poloidal flux expansion	High Ip/Bt Long Pulse Swept Case	Stationary High Power Short Pulse	Reversed Helicity Requirement	Spill Over From HHF Regions

***Table 4.2-1**: Required heat flux parameters for the IBDH. Cases 1 through 3 have the "normal" helicity.*

4.3: Vertical Target

a: Heat flux requirements on the vertical target are as per Table 4.3-1. [R23]

IBDV	Case# ->	1	2	3	4
Range of Application	m	1.27< |Z| < 1.5	1.27< |Z| < 1.5	|Z|>1.5	|Z| > 1.27
Extent	cm	11	13	10	full
Max Angle	degrees	5.5	6.0	4.0	-1
Min Angle	degrees	2.0	2.0	1.0	-5
Heat Flux	MW/m^2	5.0	10	3.5	1
Duration	s	5	1	5	1
Reference		High I_p and B_T DN w/ Sweeping	LSN Sweeping	Spill Over from Scans in HHF region	Reversed Helicity Requirement

Table 4.3-1*: Heat flux requirements on the vertical target*

4.4: Outboard Divertor

a. The outboard divertor should be designed to handle heat flux from an outer strike point. Unlike the IBDH and IBDV, no reversed target helicity heat flux handling is required. The helicity is as indicated in Fig. 3.2.1

b: The requirements so derived are shown in Tables 4.4-1 through 4.4-3 [4,6]

c. Field line impingement on metal components at diagnostic cut-outs shall be prevented by custom protective tile features.

<u>Near OBD</u> (aka R1,R2)	**Case # ->**	**1**	**2**	**3**	**4**
Range of Application	m	R < 0.7	R < 0.7	0.70 < R < 0.81	0.6 < R < 0.85
Extent	cm	13	10	full	10
Max Angle	degrees	1.0	5.0	4.4	6.0
Min Angle	degrees	1.0	1.5	2.6	6.0
Heat Flux	MW/m^2	6.0	5.5	3.0	11
Duration	sec	5	5	5	1
Reference Scenario	---	'Spillover' for stationary large poloidal flux expansion	'Spillover' for High Ip/Bt Long Pulse Swept Case	Swept Case on OBD	High Power Short Pulse

***Table 4.4-1**: Heat fluxes on the OBD Row 1 & 2 tiles*

<u>OBD-R3</u>	**Case # ->**	**1**	**2**
Max Angle	degrees	7.9	10
Min Angle	degrees	2.2	8.5
Heat Flux	MW/m^2	10.5	3.0
Duration	sec	1.0	5.0
Reference Scenario		short duration high power	MPFC Far-OBD MAPP Scan

***Table 4.4-2**: Heat fluxes on the OBD Row 3 tiles*

OBD-R4/5	Case # ->	1	2	3	4
Max Angle	degrees	14	8.2	16.5	10
Min Angle	degrees	9.2	4.8	13.5	8.5
Heat Flux	MW/m^2	4.3	1.8	3.0	3.0
Duration	sec	2.0	2.0	2.0	5.0
Reference Scenario		High I_P/B_T LSN Swept L-Mode	Low I_P/B_T LSN Swept L-Mode	High I_P/B_T LSN Swept L-Mode	MPFC Far-OBD MAPP Scan

***Table 4.4-3**: Heat fluxes on the OBD Row 4 & 5 tiles*

4.5: CSAS

a: Heat fluxes for the CSAS are as per Ref. [6], and provided in Table 4.5-1. Total energy input is also provided.

b: The poloidal extent of the heating can be taken as that which provides the correct energy for the given heat flux. See Ref. [9].

CSAS	Case # ->	1	2	3
Max Angle	degrees	9.2	4.0	12
Min Angle	degrees	7.3	2.5	9.5
Heat Flux	MW/m^2	5.2	1.0	3.6
Duration	sec	2.0	2.0	2.0
Energy	MJ	1.26	0.63	0.84
Reference Scenario		High I_P/B_T LSN L-Mode, 3 MW	Low I_P/B_T LSN L-Mode, 1.5 MW	High I_P/B_T LSN L-Mode, 2 MW

***Table 4.5-1**: Heat flux requirement for the CSAS.*

4.6: Passive Plates

a: The passive plate PFCs shall be qualified to a normal heat flux implied by the 100% radiated power scenario from the GRD.

b: This statement applied to both the primary and secondary passive plates.

4.7: Outboard Limiter

NSTX-U does not possess a true outboard limiter. BN antenna guards protect the antenna, but are not designed for direct plasma contact.

This section will be updated in a future revision to this document if such a limiter is deemed necessary.

4.8 Neutral Beam Armor

a: The neutral beam armor shall tolerate radiative normal heat fluxes implied by the 100% radiated power scenario from the GRD.

b: The armor must also tolerate neutral beam fluxes, as described in Ref. [12] & [13]. These need not be applied simultaneously with the radiative heat flux from the plasma.

4.9 Regions not otherwise specified

This section will be updated in a future revision to this document to specify requirements for other regions, e.g., minimum heat fluxes for components not protected by PFCs including expected fluxes during disruptions.

5.0 Interfaces

The baseline interfaces for PFCs are described in Table 5-1 - 5-6.

Table 5-1: Interfaces for the passive plate PFCs (WBS 1.1.1.1.4)

Interfacing System	Interfacing WBS	Type of Interface	Interface Boundary	Interface Description	Required Interface Documentation
Passive Plates	1.1.1.2.1	Structural, Thermal	At plasma facing copper surface of the passive plate	Tiles react disruptions loads to the passive plates, as well as transfer heat during bakeout and operations. Flexing of the plate transfers load to the tiles	Mechanical Drawings, Calculations for i) forces ii) heat balance
Diagnostics	1.1.1.1.6, 1.4.1.2.3	Spatial	Graphite boundary of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic	i: Thermocouples mounted in tiles. ii: RWM B_p sensors on primary passive plate front surface	Mechanical Drawings, CWDs
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance

Table 5-2: Interfaces for the outboard divertor[4] PFCs (WBS 1.1.1.1.3)

Interfacing System	Interfacing WBS	Type of Interface	Interface Boundary	Interface Description	Required Interface Documentation
Outboard Divertor Structures	1.1.1.2.2	Structural, Thermal	At surface of the outboard divertor structures	Tiles react disruptions loads to the divertor structures, as well as transfer heat during bakeout and operations.	Mechanical Drawings, Calculations for i) forces ii) heat balance
PFC Diagnostics	1.4.1.2, 1.4.1.17, 1.1.1.1.6	Spatial	Graphite boundary of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic	Mirnov coils, thermocouples, shunt tiles, and langmuir probes are installed in or between the tiles.	Mechanical Drawings, Calculations for stresses at tile features, CWDs
Viewing Diagnostics	1.4.1.13, 1.4.1.14	Spatial	At edge of tiles in the gaps of OBD rows 4 & 5	Many plasma diagnostics view through gaps in the OBD in rows 4 & 5, having their field of view set by the edges of tiles.	---
Horizontal Target PFCs	1.1.1.1.2	Spatial	At tile surfaces or edges in the region of the previous CHI gap	i) Minimal radial gap between tiles consistent with installation requirements electrical requirements, and mechanical displacements. These include thermal growth of the casing during operations and bakeout, static EM loads, and lateral halo current loads. ii) At room temperature, there should be no difference in vertical position (Z) between the outermost point on the IBDH and innermost point on the OBD-R1	Mechanical Drawings
Gas Delivery Tubes for Plasma Fuelling	1.3.4.7	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
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads. ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance

[4] The HHF OBD-R2 and LHF OBD-R3 tiles should be designed with a step such that |Z| increases when moving radially outward across the interface.

Table 5-3: Interfaces for the inner horizontal target (IBDH) PFCs (WBS 1.1.1.1.2)

Interfacing System	**Interfacing WBS**	**Type of Interface**	**Interface Boundary**	**Interface Description**	**Required Interface Documentation**
Casing	1.1.3.3.4	Structural, Thermal	At the surface of the casing flange or cooling plate.	Tiles and their backing structures react disruptions loads to the casing, as well as transfer heat during bakeout and operations.	Mechanical Drawings, Calculations for i) forces ii) heat balance
Diagnostics	1.4.1.2, 1.4.1.17, 1.1.1.1.6	Spatial	Graphite surface of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic	i) Mirnov coils, thermocouples,, and langmuir probes are installed in or between the tiles. ii) Holes in low heat flux region for access from organ pipes	Mechanical Drawings, Calculations for stresses at tile features
Outboard Divertor Row 1 Tiles	1.1.1.1.3	Spatial	At tile surfaces or edges in the region of the previous CHI gap	i) Minimal radial gap between tiles consistent with installation requirements electrical requirements, and mechanical displacements. These include thermal growth of the casing during operations and bakeout, static EM loads, and lateral halo current loads ii) At room temperature, there should be no difference in vertical position (Z) between the outermost point on the IBDH and innermost point on the OBD-R1	Mechanical Drawings, Calculations for expected displacements
Vertical Target Tiles	1.1.1.1.2	Spatial	At surface or edges of tiles.	Wireways and tubing routes bridging the IBDV and IBDH must be aligned	Mechanical Drawing
Gas Delivery Tubes for Plasma Fuelling	1.3.4.7	Spatial	Surface of gas delivery tube	i) Provision in tiles or backing structures to run tubes for shoulder, midplane, and divertor gas injection lines. ii) Potential orifice for divertor injection	Mechanical Drawing
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads. ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance

Table 5-4: Interfaces for the inner vertical target[5] (IBDV) PFCs (WBS 1.1.1.1.2)

Interfacing System	Interfacing WBS	Type of Interface	Interface Boundary	Interface Description	Required Interface Documentation
Casing	1.1.3.3.4	Structural, Thermal	At the surface of the casing.	Vertical target tiles, or structures designed to hold these tiles, are mounted to the casing, reacting loads on the PFCs and transferring heat to PFCs during bakeout and from PFCs during operations.	Mechanical Drawings, Calculations for i) forces ii) heat balance
Diagnostics	1.4.1.2, 1.4.1.17, 1.1.1.1.6	Spatial	Graphite surface of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic.	i) Thermocouples, Langmuir probes, Mirnov coils, and Rogowski coils mounted wit in or between the tiles ii) Wireways allowing wires from CSFW diagnostics	Mechanical Drawing, Calculations for stresses at tile features
Horizontal target tiles	1.1.1.1.2	Spatial	At surface or edges of tiles.	Wireways and tubing routes bridging the IBDV and IBDH must be aligned	Mechanical Drawing
CSAS Tiles	1.1.1.1.2	Spatial	At surface or edges of tiles	i) CSAS tiles shall shadow IBDV tiles when viewed from the midplane. ii) Wireways and tubing routes on CSAS and IBDV must be aligned	Mechanical Drawing
Gas Delivery Tubes for Plasma Fuelling	1.3.4.7	Spatial	Surface of gas delivery tube	i) Provision in tiles or backing structures to run tubes for shoulder, midplane, and divertor gas injection lines. ii) Potential orifice for divertor injection	Mechanical Drawings
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads. ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance

[5] The HHF IBDV and LHF IBDV interface shall be designed with a step such that R decreases when increasing |Z|.

Table 5-5: Interfaces for the Center Stack Angled Section (CSAS) PFCs (WBS 1.1.1.1.2)

Interfacing System	Interfacing WBS	Type of Interface	Interface Boundary	Interface Description	Required Interface Documentation
Casing	1.1.3.3.4	Structural, Thermal	At surface of casing.	CSAS tiles are mounted to the casing, reacting loads on the PFCs and transferring heat to PFCs during bakeout and from PFCs during operations.	Mechanical Drawings, Calculations for i) forces ii) heat balance
Diagnostics	1.1.1.1.6	Spatial	Graphite surface of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic	i) Thermocouples in the tiles ii) Wireways allowing wires from CSFW diagnostics	Mechanical Drawings, Calculations for stresses at tile features
Gas Delivery Tubes for Plasma Fuelling	1.3.4.7	Spatial	Surface of gas delivery tube	Provision for i) shoulder injector gas lines and outlets ii) midplane injector gas lines	Mechanical Drawing
Vertical Target Tiles	1.1.1.1.2	Spatial	The surfaces/edges of the tiles	i) CSAS tiles shall shadow IBDV tiles when viewed from the midplane. ii) Wireways and tubing routes on CSAS and IBDV must be aligned	Mechanical Drawing
CSFW Tiles	1.1.1.1.1	Spatial	The surfaces/edges of the tiles	Wireways and tubing routes on CSAS and CSFW must be aligned	Mechanical Drawing
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads. ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance

Table 5-6: Interfaces for the Center Stack First Wall (CSFW) PFCs (WBS 1.1.1.1.1)

Interfacing System	Interfacing WBS	Type of Interface	Interface Boundary	Interface Description	Required Interface Documentation
Casing	1.1.3.3.4	Structural, Thermal	At surface of casing.	CSFW tiles are mounted to the casing, reacting loads on the PFCs and transferring heat to PFCs during bakeout and from PFCs during operations.	Mechanical Drawings, Calculations for i) forces ii) heat balance
Diagnostics	1.4.1.2, 1.4.1.17, 1.1.1.1.6	Spatial	Graphite surface of the tile, in some cases machined by PFC engineering to provide a space or volume for the diagnostic	i) Thermocouples, Mirnov coils, shunt tiles, and Langmuir probes in the tiles ii) Wireways allowing wires from CSFW diagnostics	Mechanical Drawing, Calculations for stresses at tile features
CSAS Tiles	1.1.1.1.2	Spatial	At tile surfaces/edges	Wireways and tubing routes on CSAS and CSFW must be aligned	Mechanical Drawing
Gas Delivery Tubes for Plasma Fuelling	1.3.4.7	Spatial	Surface of gas delivery tube	Tiles shall have provision for tube routing and gas deliver orifices	Mechanical Drawings
Plasma	---	Plasma	Front surface of tiles	Plasma interacting with tile: i) imposes thermal and mechanical loads. ii) Causes sputtering and tile erosion.	Calculation for forces and heat balance