NSTX

National Spherical Torus Experiment

NSTX-U

SYSTEM REQUIREMENTS DOCUMENT

PLASMA FACING COMPONENTS

NSTX-U-SRD-111-013

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NSTX SYSTEM REQUIREMENTS DOCUMENT

RECORD OF CHANGES

Revision	Date	TRB	Description of Change

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Introduction

This System Requirements Document (SRD) defines the requirements for the Plasma Facing Components (WBS 1.1.1) of the National Spherical Torus Experiment Upgrade (NSTX-U).

References to the requirements identified herein are cited in the body of the document using serial numbers preceded by an "R" and are listed in the Appendix.

Plasma Facing Components Requirements

1.0 Functions

The Plasma Facing Components (PFC) consist of plasma facing graphite and CFC tiles and mounting hardware, passive stabilizers, inner wall protection, divertor area strike plate assemblies and local Instrumentation and Control.

The functions of the Plasma Facing Components are to:

a. Provide sufficient MHD wall stabilization for the high performance plasmas.

b. Provide protection for the vacuum vessel and diagnostics from the anticipated heat loads.

2.0 Configuration Requirements & Essential Features

2.1 Overall Geometry

a. The plasma facing components include the inner wall armor, divertor area strike plates, passive stabilizers, and associated plasma facing tiles. The PFC designs (in particular the location of the front plasma facing surfaces) shall conform to the geometries defined on Figure PFC-2.1-1 and given in Table PFC-2.1-1, which describes the 3-d surfaces via 2-d line segments assumed swept through toroidal angle 0 to 360 degrees. Data given in table corresponds to PFCs above midplane; corresponding mirror image PFCs are located below midplane.

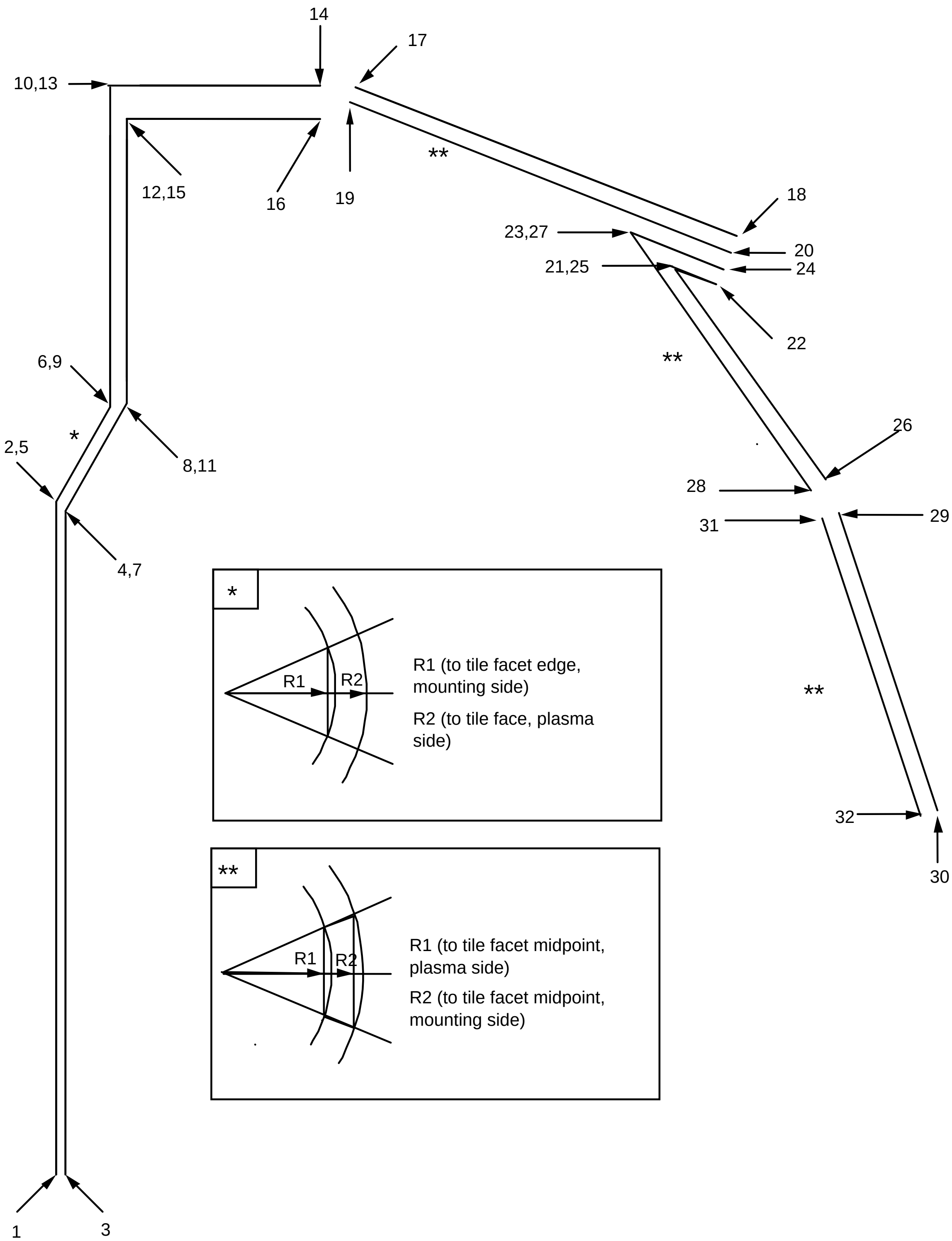

Figure PFC-2.1-1 PFC Geometry

Table PFC-2.1-1 PFC Geometry (Inches)

		#	R (in)	Z (in)	#	R (in)	Z (in)
Inner Wall	Struct	1	11.644	0.000	2	11.644	42.105
	PFC	3	12.394	0.000	4	12.394	41.339
Inner Wall/Inboard Divertor Angled Section	Struct	5	11.644	42.105	6	15.340	50.217
	PFC	7	12.394	41.339	8	16.340	50.000
Inboard Divertor Vertical Section	Struct	9	15.340	50.217	10	15.340	65.913
	PFC	11	16.340	50.000	12	16.340	63.913
Inboard Divertor Horizontal Section	Struct	13	15.340	65.913	14	22.25	65.913
	PFC	15	16.340	63.913	16	22.500	63.913
Outboard Divertor	Struct	17	24.660	65.025	18	47.393	56.071
	PFC	19	24.294	64.095	20	47.027	55.141
Slot	Struct	21	43.823	54.143	22	46.256	53.184
	PFC	23	41.074	56.300	24	46.623	54.115
Secondary Passive Plate	Struct	25	43.823	54.143	26	52.752	41.509
	PFC	27	41.074	56.300	28	51.935	40.932
Primary Passive Plate	Struct	29	53.540	39.594	30	59.416	21.775
	PFC	31	52.592	39.276	32	58.468	21.457

b. Surfaces of plasma facing tiles located on convex structures shall be machined to a convex shape to conform to the surfaces given in Table PFC-2.1-1.

c. For surfaces of plasma facing tiles located on concave structures, if discrete flat faced tiles are used to approximate the required curved surfaces, the center of the flat faces shall be tangent to the surfaces given in Table PFC-2.1-1.

Table PFC-2.1-1 PFC Geometry (Centimeters)

		#	R(cm)	Z(cm)	#	R(cm)	Z(cm)
Inner Wall	Struct	1	29.576	0.000	2	29.576	106.947
	PFC	3	31.481	0.000	4	31.481	105.001
Inner Wall/Inboard Divertor Angled Section	Struct	5	29.576	106.947	6	38.964	127.551
	PFC	7	31.481	105.001	8	41.504	127.000
Inboard Divertor Vertical Section	Struct	9	38.964	127.551	10	38.964	167.419
	PFC	11	41.504	127.000	12	41.504	162.339
Inboard Divertor Horizontal Section	Struct	13	38.964	167.419	14	56.515	167.419
	PFC	15	41.504	162.339	16	57.150	162.339
Outboard Divertor	Struct	17	62.636	165.164	18	120.378	142.420
	PFC	19	61.706	162.800	20	119.447	140.057
Slot	Struct	21	111.311	137.523	22	117.490	135.089
	PFC	23	104.327	143.003	24	118.421	137.452
Secondary Passive Plate	Struct	25	111.311	137.523	26	133.989	105.433
	PFC	27	104.327	143.003	28	131.915	103.967
Primary Passive Plate	Struct	29	135.992	100.569	30	150.917	55.309
	PFC	31	133.584	99.761	32	148.509	54.501

2.2 Passive Stabilizers

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

b. Each stabilizer shall be made up of a series of conically shaped copper plates. Each stabilizer shall have a minimum of one toroidal electrical break. [R1].

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

d. The passive stabilizers shall be electrically connected to the vessel via their mounting structures [R2]. The connections shall contain provisions to allow for alignment adjustments and facilitate removal of individual plates for modification to accommodate access for future diagnostic upgrades.

e. The overall size of the individual plates making up the stabilizers must be such that they can be passed through the large horizontal vacuum vessel ports (largest dimension not greater than 20 in.) and easily manipulated by no more than two persons ($\leq$ 125 lb.) [R3].

g. The plasma facing surfaces of the stabilizers shall be protected with graphite tiles. (Union Carbide - ATJ or equivalent)

h. The plasma facing surface of the attached tiles shall be installed such that they are aligned relative to adjacent tile surfaces within +/-0.5mm.

i. Toroidal gaps shall be provided between adjacent passive stabilizer plates at a minimum of 4 locations spaced 90 degrees apart and at a maximum of 12 locations spaced 30 degrees apart. The gaps shall provide a 2 inch clear path for diagnostic viewing of the plasma.

2.3 Centerstack Tiles

a. The Centerstack Vertical Section (CS VS) shall be composed of carbon tiles attached to the center stack casing.

b. The tiles shall be designed and fabricated such that the plasma facing surfaces of the tiles will be aligned relative to adjacent tile surfaces within +/-0.005 to +/-0.01 without individual adjustment.

c. The tiles shall be mounted in such a way that heat transfer from the tiles to the center stack casing is minimized.

d. Slots shall be provided in the backside of at least half the tiles such that diagnostic wires and magnetic diagnostics can be positioned between the center stack casing and the tiles.

2.4 Inboard Divertor Tiles

a. The In-Board Divertor (IBD) tiles shall consist of carbon tiles attached to the center stack casing.

b. The tiles shall be designed and fabricated such that the plasma facing surfaces of the tiles will be aligned relative to adjacent tile surfaces within +/-0.005 to +/-0.01.

c. The poloidal extent of the IBD tiles shall be such that it eliminates all line-of-sight between the upper and lower ceramic ring/bellows assemblies and the plasma.

d. The IBD tiles shall be in contact with the CS casing, which will be actively cooled.

2.5 Outboard Divertor Tiles

a. The Out-Board Divertor (OBD) tiles shall consist of segmented upper and lower toroidal rings composed of copper plates covered with protective tiles.

b. The OBD tiles shall be attached to the upper and lower domes of the vacuum vessel, and will be located relative to machined features on these domes to within +/- 0.2 mm

c. The tiles shall be designed and fabricated such that the plasma facing surfaces of the tiles will be aligned relative to adjacent tile surfaces within +/-0.5mm.

d. The OBD tiles shall be traced with stainless steel tubing for active temperature control during bakeout and operation.

3.0 Performance & Operational Requirements

All materials for the PFCs, their connections and mountings must :

a. Be approved for high vacuum compatibility [R4].

b. Be bakeable to 350°C [R5].

c. Have a relative magnetic permeability of ≤ 1.02 [R6]. Exceptions must have prior NSTX project approval.

d. Be compatible with Glow Discharge Cleaning [R7].

3.1 Baseline Operation

a. For baseline operation there will be no active cooling of the plasma facing components during a plasma discharge. However, the plasma facing tiles on the outer passive stabilizer and in the divertor regions will be thermally attached to actively cooled plates, such that the tiles will cool to the plate temperature between discharges. The inner wall armor will be thermally isolated from the center stack casing and must rely on radiation cooling to the other plasma facing tiles between discharges. The tiles must accommodate a heat flux for the baseline duty cycle as described in Table PFC-3.1-1 [R8].

Table PFC-3.1-1: Max PFC Heat Loads for Baseline NSTX Duty Cycle

Component	Max Value	Units	Ref
Passive Stabilizers	0.13	MW/m^2	R8

Centerstack Vertical Section	0.1	MW/m2	R8
Inboard Divertor Area Strike Plates	6.05	MW/m2	R8
Outboard Divertor Area Strike Plates	15.27	MW/m2	R8

Table 3.1-2: PFC Heat Loads for Baseline NSTX Operation Scenarios

	NSTX				NSTX_CSU		
	ND	SND	DND		SND	DND	
Major Radius [R0]	0.854	0.854	0.854	m	0.9344	0.9344	m
Aspect Ratio [A]	1.27	1.27	1.27		1.5	1.5	
Minor Radius [a]	0.6745	0.6745	0.6745	m	0.6229	0.6229	m
Total Heating power (nbi+rf+ohmic) [Pheat]	6	6	6	MW	14	14	MW
Fusion power gain [Q]	0	0	0		0	0	
Fusion power [Pfusion]	0	0	0	MW	0	0	MW
Alpha power [Palpha]	0	0	0	MW	0	0	MW
Neutron power [Pneutron]	0	0	0	MW	0	0	MW
Power fraction radiated from core [frad_core]	0.125	0.125	0.125		0.125	0.125	
Power fraction in SOL [fsol]	0.88	0.88	0.88		0.88	0.88	
Total Power in SOL [Psol]	5.25	5.25	5.25	MW	12.25	12.25	MW
Single Null (1) or Double Null (2)	2	1	2		1	2	
Center Stack...							
SOL Power fraction to Center Stack [fcs/fsol]	0.5	0	0		0	0	
Total Power to Center Stack [Pcs]	2.63	0	0	MW	0	0	MW
Power Dissipation Half Height [h]	1	1	1		1	1	
Power Dissipation Area [Acs]	2.26	2.26	2.26	m^2	3.91	3.91	m^2
Average Loss Power Flux [qcs]	1.16	0	0	MW/m^2	0	0	MW/m^2
Peaking factor	1	1	1		1	1	
Peak Power Flux	1.16	0	0	MW/m^2	0	0	MW/m^2
Tpulse	5	5	5	sec	5	5	sec
WCenter Stack	5.82	0	0	MW/m^2	0	0	MJ/m^2
Trep	300	300	300	sec	1200	1200	sec
Pavg Center Stack	19.39	0	0	W/m^2	0	0	W/m^2
Inboard Divertor....							
SOL Power fraction to divertor [fdiv/fsol]	0	0.25	0.2		0.25	0.2	
Power fraction radiated at divertor [frad,div]	0	0	0		0	0	
Up/down asymmetry [Ku/l]	1	1	1		1	1	
Power flux width at midplane [?mp]	0.01	0.01	0.01	m	0.01	0.01	m
Flux expansion factor [fflux]	30	20	20		20	20	
Private flux region additional area factor [fpfr]	0.33	0.33	0.33		0.33	0.33	
Incidence angle [alpha]	60	60	60	degrees	60	60	degrees
Radius to strike point [Rsp]	0.23	0.23	0.23	m	0.42	0.42	m

Power flux width at divertor [?div]	0.46	0.31	0.31	m	0.31	0.31	m
Divertor target area	0.66	0.44	0.44	m^2	0.8	0.8	m^2
Power to divertor [Pdiv]	0	1.31	0.53	MW	3.06	1.23	MW
Average power flux [qavg]	0	2.99	1.19	MW/m^2	3.82	1.53	MW/m^2
Peak power flux [qpeak]	0	4.73	1.89	MW/m^2	6.05	2.42	MW/m^2
Total Power in Inboard Divertors [Pibd]	0	1.31	1.05	MW	3.06	2.45	MW
Outboard Divertor....							
SOL Power fraction to divertor [fdiv/fsol]	0.5	0.75	0.8		0.75	0.8	
Power fraction radiated at divertor [frad,div]	0	0	0		0	0	
Up/down asymmetry [Ku/l]	1	1	1		1	1	
Power flux width at midplane [?mp]	0.01	0.01	0.01	m	0.01	0.01	m
Flux expansion factor [fflux]	5	20	20		20	20	
Private flux region additional area factor [fpfr]	0.33	0.33	0.33		0.33	0.33	
Incidence angle [alpha]	45	60	60	degrees	60	60	degrees
Radius to strike point [Rsp]	0.3	0.3	0.3	m	0.49	0.49	m
Power flux width at divertor [?div]	0.09	0.31	0.31	m	0.31	0.31	m
Divertor target area	0.18	0.58	0.58	m^2	0.95	0.95	m^2
Power to divertor [Pdiv]	1.31	3.94	2.1	MW	9.19	4.9	MW
Average power flux [qavg]	7.4	6.8	3.63	MW/m^2	9.65	5.15	MW/m^2
Peak power flux [qpeak]	11.71	10.76	5.74	MW/m^2	15.27	8.15	MW/m^2
Total Power in Outboard Divertors [Pobd]	2.63	3.94	4.2	MW	9.19	9.8	MW
First Wall...							
Total Power to First Wall [Pfw]	0.75	0.75	0.75	MW	1.75	1.75	MW
Area of First Wall [Afw]	24.74	24.74	24.74	m^2	27.85	27.85	m^2
Average Neutron Power Flux [qnfw]	0	0	0	MW/m^2	0	0	MW/m^2
Average Loss Power Flux [qfw]	0.03	0.03	0.03	MW/m^2	0.06	0.06	MW/m^2
Peaking factor	2	2	2		2	2	
Peak Power Flux	0.06	0.06	0.06	MW/m^2	0.13	0.13	MW/m^2
Tpulse	5	5	5	sec	5	5	sec
Wfirst wall	0.3	0.3	0.3	MJm^2	0.63	0.63	MJ/m^2
Trep	1200	1200	1200	sec	1200	1200	sec
Pavg first wall	0.25	0.25	0.25	W/m^2	0.52	0.52	W/m^2

	Paux	Tpulse	Trep	Pavg
Existing NSTX practice, typ.	4	1	300	13
NSTX CSU baseline heating, upgraded rep rate	9	5	1200	38
NSTX CSU upgraded heating, upgraded rep rate	14	5	1200	58

NSTX CSU baseline heating, upgraded rep rate	9	5	2400	19	
NSTX CSU baseline heating, baseline rep rate	14	5	2400	29	

b. The peak temperature limit for the graphite tiles shall be 1200°C.

c. The peak temperature limits for the carbon-carbon tiles shall be 1200°C.

APPENDIX

#	Description	Value	Units	Reference
1	Passive Stabilizer Requirements	n.a.	n.a.	NSTX GRD, sec. 1.2.1.c
2	Passive Stabilizer Mounting Requirements	n.a.	n.a.	NSTX GRD, sec. 1.2.1.g
3	Passive Stabilizer Removal Requirement	n.a.	n.a.	NSTX GRD, sec. 1.2.1.h
4	High Vacuum Compatibility Requirement	n.a.	n.a.	NSTX-U GRD, sec. 3.3.1, and NSTX GRD sec. 1.1.4.c
5	Bakeout Temperature	350	°C	NSTX-U GRD, sec. 2.7.c
6	Relative Magnetic Permeability	$\leq$1.02	n.a.	GRD, sec. 2.7.a
7	Glow Discharge Cleaning	n.a.	n.a.	GRD, sec. 3.1.1.h
8	Heat Loads	n.a	n.a	Design point document, Heat Loads: http://www.pppl.gov/~neumeyer/NSTX_CSU/Design_Point.html