Engineering Assessment of a National High-Power Advanced Torus Experiment (NHTX)

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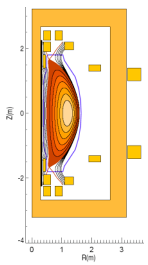
Abstract

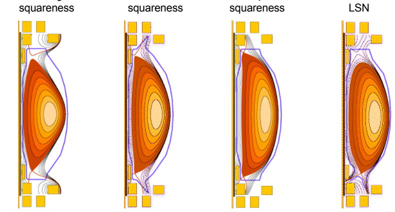
- High heat flux power handling of plasma exhaust is not adequately addressed in the currently planned world program
- P/R, the ratio of exhaust power P to the radius R at which the divertor is located, is the crictical parameter
- Fusion power plant designs typically require P/R in the range of 100 MW/m
- New long pulse machines (KSTAR, EAST, JT60SA will operate at P/R ~ 15 MW/m, while ITER will operate at P/R ~ 24 MW/m
- A compact device can be constructed at PPPL using existing infrastructure which could operate at P/R ~ 50
- The device could be designed with high heat flux testing as a primary objective and facilitate experiments on multiple advanced divertor concepts in a preparatory D-D environment, along with a limited DT phase at the end of the mission
- *The mission for the **N**ational **H**igh-power advanced **T**orus E**x**periment (NHTX) is to study the integration of a high-power-flux plasma-boundary interface with high-confinement, high-beta, non-inductive plasma operation*
- Parametric studies identified minimum R0 design point (R0=1m, A=1.8, Bt=2T, Ip=3.5MA) which can handle up to 50MW (P/R=50)
- This assessment study has identified conceptual solutions to the various issues and provides a point of departure for continued development of the NHTX concept

Design Point & Cross Section

	DD	DT
R0[m]	1.0	1.0
A	1.8	1.8
κ,δ	2.7,0.6	2.7,0.7
Ip[MA]	3.5	3.5
Bt [T]	2.0	2.0
β_N	5.0%	5.0%
β_T	16.3%	16.3%
fGW	56.1%	36.0%
fBS	77.0%	67.3%
Tavg[keV]	3.7	5.1
HH98	1.30	1.30
Q	0.0	0.7
P_fusion [MW]	0.0	30.6
P_aux[MW]	50.0	44.6



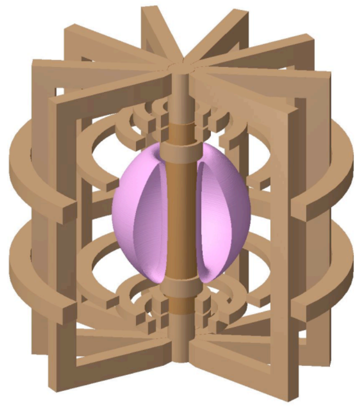
Flexibility in Shape & Divertor Geometry

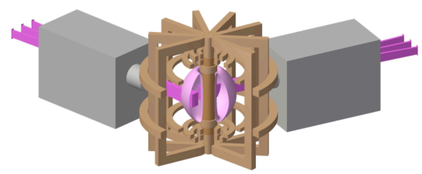


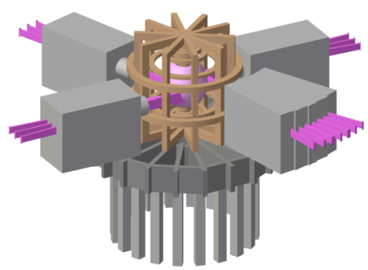
- Wide range of divertor X-point shapes obtainable
- Flux expansion from 3 ~ 30

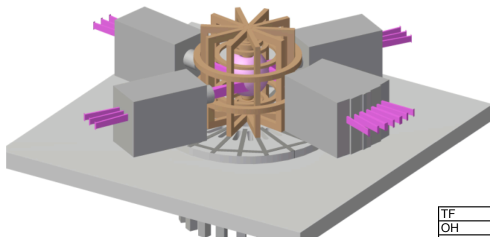
Mission Elements & Design Features

Mission Element	Relevent Design Features
High P/R	Low A, pulsed solenoid for initiation/ramp only, minimum R0
Non-inductive Ip sustainment	NBI on & off axis current drive with aiming at R0=1.0m +/- 20cm
Long (1000s) DD pulse capability, once per hour	Water-cooled Cu magnets, NBI modifications for 1000s, 300MW power from grid, 400kgal water tank
Flexible x-point divertor configurations	Multiple inner PF coils
Provision for multiple divertor & first wall test articles	Demountable TF, cylindrical outer VV with removable lid
Provision for hot (400 ~ 600C) reactor-relevant first wall	Removable inner VV heated/cooled by helium, water-cooled cylindrical outer VV, separated by vacuum gap and thermally isolated mounts
DT capability (e.g. 1000 shots @ 2s, 100 shots at 20s)	Contamination region limited to removable inner VV, shielding afforded by water jacket around outer VV plus TFTR Test Cell
Low cost	Design simplicity, use of existing PPPL infrastructure: buildings, electric power, AC/DC converters, NBI

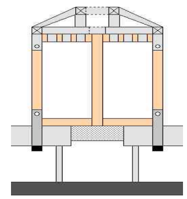








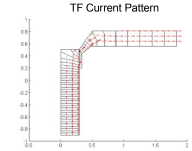
TF Structural Support



- TF outer legs transfer vertical load between umbrella and floor beams
- Floor plug for TF leads, water lines, and gravity support of center stack
- X-braces handle out-of-plane loads on TF outer legs
- Entire top structure removable via crane
- Center stack handling via crane within Test Cell height constraint

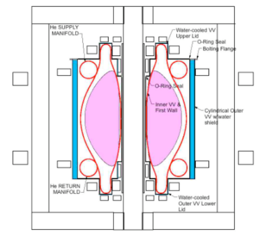
TF Joint

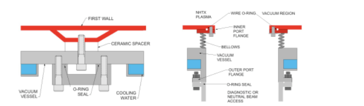
TF Current Pattern



- Vertical lap joint provides large area and optimized current density
- In-plane magnetic forces close the joint
- Out-of-plane forces minimized by alignment of J_tf with Br_oh

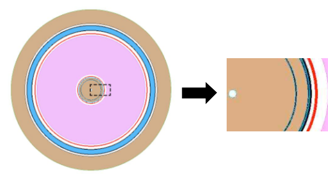
Double Vacuum Vessel





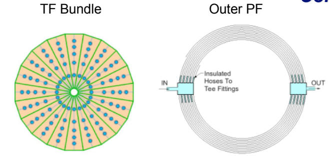
- Cylindrical outer VV water-cooled w/water jacket for shielding
- Hot (400~600C) helium heated/cooled inner VV
- Upper TF & top lid of outer VV removable by crane
- Inner VV and divertor test modules removable by crane access
- Inner VV attachment features based on access from outside

Radial Build



Seq. No.	System	Details	Radial Thickness (millimeters)	Radial Range (millimeters)_
1	none	hole	18.2	0<R<18.2
2	Inner TF	Conductors & Insulation	272.6	18.2<R<290.8
3	none	TF/OH assembly gap	3.2	290.8<R<294
4	OH solenoid	OH tension tube	3.6	294<R<297.6
5	OH solenoid	OH Insulation	3.8	297.6<R<301.4
6	OH solenoid	OH conductor	43	301.4<R<344.4
7	OH solenoid	OH Insulation	3.8	344.4<R<348.2
8	none	OH/VV assembly gap	3.8	348.2<R<352
9	Outer Vacuum Vessel	Water Jacket Wall	3	352<R<355
10	Outer Vacuum Vesse	Cooling Water	3	355<R<358
11	Outer Vacuum Vesse	Structural Wall	10	358<R<368
12	Gap	Vacuum Space ForThermal Insulation	14	368<R<382
13	Hot First Wall	Helium Carrying Pipes	6	382<R<388
14	Hot First Wall	First Wall Structure	6	388<R<394
15	Gap	Plasma/wall clearance	50	394<R<444
16	PLASMA	Last Closed Flux Surface	1111	444<R<1555
17	Gap	Plasma/wall clearance	50	1555<R<1605
18	Hot First Wall	First Wall Structure	6	1605>R>1611
19	Hot First Wall	Helium Carrying Pipes	6	1611<R<1617
20	Gap	Vacuum Space ForThermal Insulation	83	1617<R<1700
21	Outer Vacuum Vessel	Structural Wall	10	1700<R<1710
22	Outer Vacuum Vessel	Cooling &Shielding Water	120	1710<R<1840
23	Outer Vacuum Vessel	Water Jacket Wall	10	1840<R<1850
24	none	Airspace Gap	50	1850<R<1900
25	(*) PF Coils	(*) PF5U2 & PF5L2 Coil Shadows	(*)400	(*) 1900<R<2300

Coil Cooling



- Aggressive cooling of TF turns ~ 25% water fraction
- Strip wound outer PF coils with half-turn edge cooling
- Conventional inner PF coils with extruded cooling hole
- Edge cooling of TF outer legs

Power Supply

	Ramp				Flat Top		
	P[MW]	Q[MVAR]	S[MVA]	W[MJ]	P[MW]	Q[MVAR]	S[MVA]
TF	96	72	120		88	83	120
OH	308	71	316	59	0	0	0
PF	100	0	100	50	37	93	100
NBI/RF	0	0	0		166	96	191
BOP	10	7.5	12		10	7.5	12
				Tot-->	300		

- New TF power supply, 240V/500kA
- OH & PF use existing power supplies
- TF & aux heating systems via grid
- OH & PF systems via existing MG set
- 300MW from grid, approved by local utility
- Reactive compensation to ~ unity p.f.