Impact of potential polar region modifications on research and scenarios for ASC TSG

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On behalf of the NSTX-U ASC TSG

Impact of the proposed changes to the polar region
May 24, 2017

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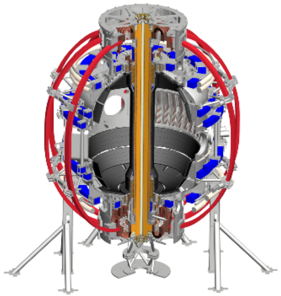


Response organized by research thrusts identified in 5 year plan

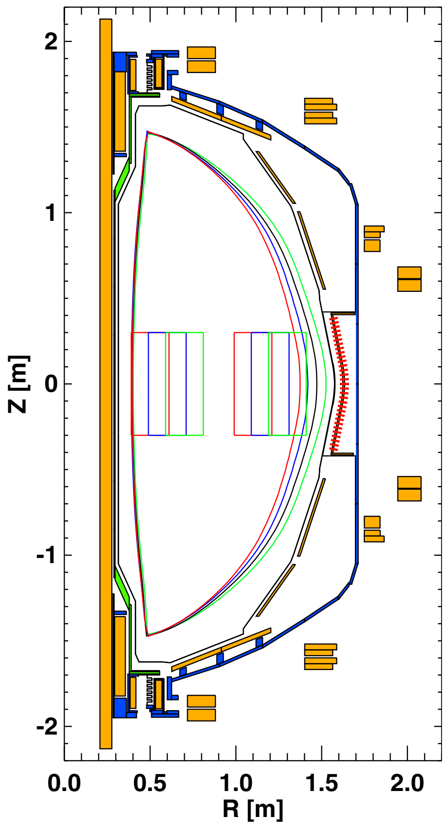
- Scenario development

Type	B_T (T)	I_p (MA)	P_{inj} (MW)	T_{pulse} (s)
Full performance	1	2	10	5
High power	1	2	**> 10**	< 5
Non-inductive	1	**< 2**	≥ 10	≤ 5
Long pulse	< 1	< 2	< 10	**> 5**

- Axisymmetric Control
  - Snowflake and X-divertor control
  - Integration of tile protection into active control
- Disruption avoidance via controlled shutdown
- Scenario optimization for next step devices

Scenario targets guided by TRANSP modeling of NSTX-U scenarios

- Most comprehensive study of scenarios completed by S. Gerhardt
  - Nuclear Fusion 52 (2012) 083020
- All calculations use high-κ, high-δ shape with matched inner boundary
  - Attractive for increased stability, non-inductive current drive
  - Outer gap is scanned to alter NBI deposition and κ
- Two shapes of n,T profiles: flat and peaked
  - Scale n for target f_{GW}
  - Flat Z_{eff} profile
  - T_e scaled for confinement assumption
  - T_i neoclassical



Modifications to the polar region aim to enable full performance scenario

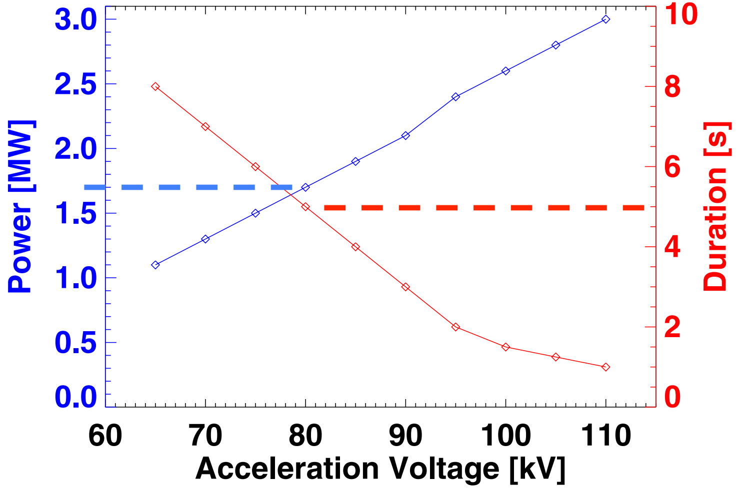
- Achieve I_p = 2MA at t_{pulse} = 5s with q_{min} > 1
  - Max I_p increases with confinement and broad profiles
  - Optimizes to high f_{GW}

- ASC TSG should address these questions to inform on-going calculations of the heat flux (next slides):
  - Is 10 MW of NBI heating achievable and sufficient for this scenario?
  - What is the minimum elongation that is feasible for these scenarios?

Voltage (kV)	Profiles	Scaling	B_T (T)	I_p (kA)	P_{inj} (MW)	f_{GW}	f_{BS}	q_{95}	$\nu^*_{e,\rho=0.5}$	τ_{CR} (s)	β_N	W_{tot} (kJ)	W_{fast}/W_{tot}
80	Broad	$H_{98y,2}=1$	1	1850	10.2	1.05	0.41	7.3	0.16	0.46	4.5	1079	0.03
80	Broad	$H_{ST}=1$	1	2000	10.2	1.03	0.49	7.1	0.12	0.61	5.4	1417	0.03
80	Narrow	$H_{98y,2}=1$	1	1450	10.2	1.03	0.42	7.6	0.10	0.39	4.2	757	0.07
80	Narrow	$H_{ST}=1$	1	1850	10.2	1.04	0.50	6.9	0.06	0.63	5.5	1307	0.04

Is 10 MW NBI heating achievable and sufficient for the full performance scenario?

- How much power is needed for this scenario?
  - Can we achieve this goal at lower NBI power?
  - How much NBI power needs to be reserved for ramp-up and ramp-down?



- Can we develop a scenario with beam modulations in order to get CHERs data?

However, we know that 10MW for 5s is a reasonable limiting case

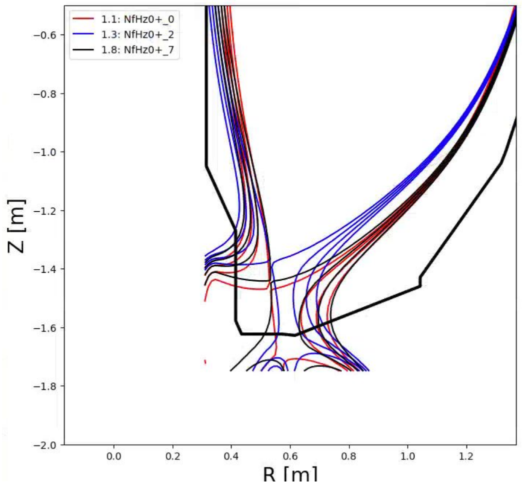
What is the minimum feasible elongation for full performance scenario?

- As the X-points move closer to midplane, κ is reduced for fixed inner and outer gaps
  - This motion of the X-points makes the field lines steeper at the divertor surfaces, can result in higher heat fluxes

- What I_p is achievable in these lower κ scenarios?

Table 3.2.1: Heat flux characteristics for stationary cases on the inner horizontal divertor.

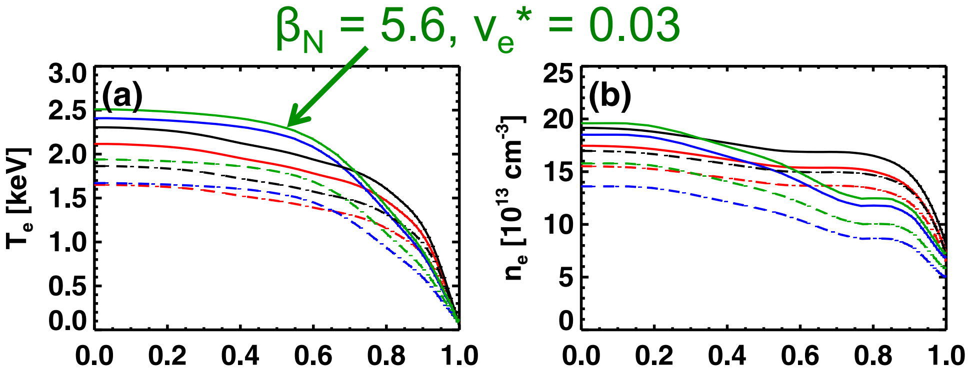
Case Name	Geqdsk file	Peak Heat Flux	E-folding width	q_{peak} Radius	Strike Point Radius	|Inclination Angle at Strike Point|	Priority
	---	MW/m^2	cm	m	m	degrees	---
1.1	NfHz0+_0	6.41	14.5	0.566	0.549	0.90	1
1.3	NfHz0+_2	10.6	4.38	0.568	0.559	1.6	2
1.8	NfHz0+_7	8.51	5.70	0.526	0.514	1.2	1



High power scenarios aim to expand the accessible regimes in shorter pulses

- Lower n_e ($f_{GW} < 1$) will probably require higher P_{inj} to keep $q_{min} > 1$
  - Increase off-axis current drive, increase τ_{cur}
- Examine confinement, stability, etc. at larger β_N and lower ν_e^*

NBI (kV)	P_{inj} (MW)	Max flattop (s)	f_{GW}	Ip (MA)
80	10.2	5	0.74	1.25 – 1.8
90	12.6	3	0.74	1.35 – 1.9
100	15.6	1.5	0.74	1.45 – 1.98
80	10.2	5	1.04	1.45 – 2.0



All: B_T=1.0 T, Six NB sources, f_{GW}=0.72
80 kV, Broad Profiles, I_P=1600 kA for H_{98}=1, I_P=1800 kA for H_{ST}=1
80 kV, Narrow Profiles, I_P=1250 kA for H_{98}=1, I_P=1700 kA for H_{ST}=1
100 kV, Broad Profiles, I_P=1750 kA for H_{98}=1, I_P=1975 kA for H_{ST}=1
100 kV, Narrow Profiles, I_P=1450 kA for H_{98}=1, I_P=1800 kA for H_{ST}=1

100% non-inductive current discharges will probably run at I_p < 2 MA

- Target shapes comparable to high-current scenarios
  - Lower I_p should result in larger λ_q

B_T [T]	P_{inj} [MW]	Heating Pulse Duration [s]	I_P Range [kA]	τ_{CR} [s]
0.75	6.8	5.0	$600<I_P<800$	$0.3< \tau_{CR} <0.4$
0.75	8.4	3.0	$675<I_P<850$	$0.3< \tau_{CR} <0.45$
1.0	10.2	5.0	$750<I_P<1200$	$0.35< \tau_{CR} <0.75$
1.0	12.6	3.0	$875<I_P<1300$	$0.4< \tau_{CR} <0.8$
1.0	15.6	1.5	$1000<I_P<1450$	$0.4< \tau_{CR} <0.85$

Table 9.1: Selected parameters for 100% non-inductive scenarios at f_{GW}=0.7 in NSTX-U. See Table 2 and Appendix 1 of Ref. [19] for additional information.

- We see no reason that 100% non-inductive scenarios will be incompatible with flux expansion, strike-point sweeps and/or snowflake divertor configurations

Long-pulse discharges run at lower fields

- Long pulse (t_{pulse} > 5s) discharges would either:
  - Run with lower voltage beams (< 80 keV)
  - Or modulate the beams
- I_p limited by I^2t heating of OH coil
- Examples of 10s discharges at B_T = 0.75 T:
  - 6 x 65 keV beams for 8 seconds
  - 6 x 80 keV beams modulated 50/50 for 10 seconds

NBI (kV)	P_{inj} (MW)	Max flattop (s)	f_{GW}	Ip (MA)
65	6.6	8	0.73	1.0 – 1.25
80	5.1	10	0.73	0.85 – 1.1

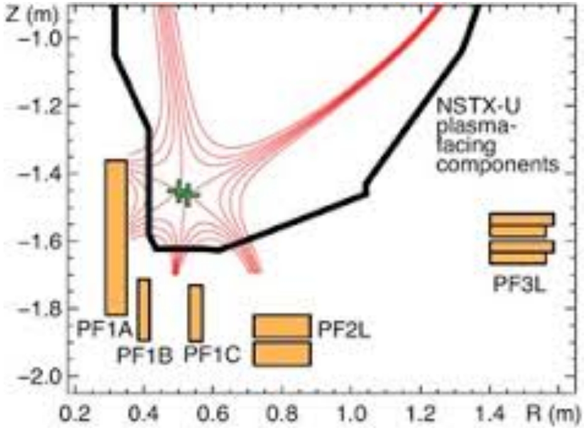
Experiments within Control Thrust may require proper staging of tile modification/ protection

- Experiments do not place strict requirements on the heating or pulse length
  - Most control work is performed in fiducial-like discharges
  - Exception may be current profile control development, which favors low density, low temperature conditions

- Divertor control and protection development requires some margin for error while commissioning
  - Snowflake, X-divertor, flux-expansion, sweeps…
  - Either perform commissioning with tiles that can tolerate control errors or have adequate protection

Commissioning of the snowflake controller will be challenging if reverse helicity is not allowed

- ASC focuses on experiments that commission the control algorithms
- Number / location of magnetic sensors in polar regions should be maintained (or increased!)
- Experiments would benefit from trying full range of snowflake shapes
  - Improves confidence in control and the optimization of algorithm
- Reverse helicity may occur while testing
  - Either calculate that this is not an issue, perform experiments without fish-scaled tiles or implement active heat-flux protection
- Similar arguments can be made for X-divertor & flux expansion control



Other considerations raised in the ASC memo

- Development of control aimed at active avoidance of heat flux limits must be considered
  - These algorithms would attempt to mitigate heat flux to avoid reaching a threshold that ends the discharge

- Soft-shutdown development should consider where the power is going to land (research thrust 3)
  - Fast loss of stored energy, particularly after an H-L transition
  - Elongation reduction will put strike points on new locations
  - Timing of transition to inboard limiter

- Research thrust 4 encompasses experiments that aim to optimize high-performance scenarios for next step devices
  - Tile heating limits will constrain the experiments rather than the other way around