NSTX-U is sponsored by the
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Fusion Energy Sciences

Update on JRT 2017 and R(17-2) Milestone

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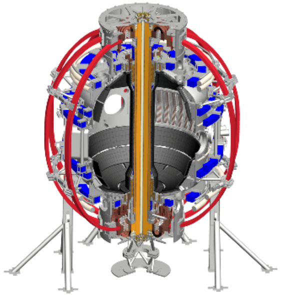
FY2017 Research Milestone status meeting
PPPL
31 March 2017

Lawrence Livermore National Laboratory

PPPL



JRT-2017: FES Multi-Facility Joint Research Target / Milestone (Led by DIII-D)

- Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices, including ITER. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.

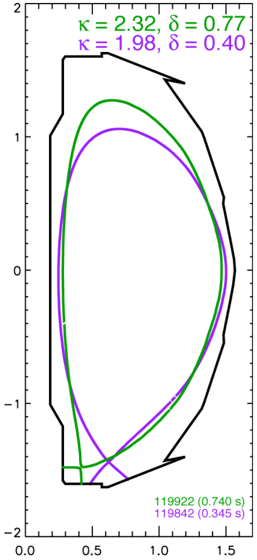
Scope of JRT-2017 contribution from NSTX-U

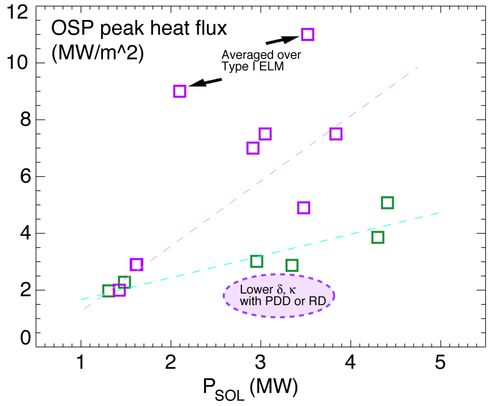
- No divertor experimental data from NSTX-U
- Proposed additional analysis of NSTX divertor experiments to
  - Summarize operating space and characteristics of a partially detached divertor in NSTX
  - Analyze how detachment in NSTX depends on the divertor flux expansion
  - Analyze how the radial extent of the partially detached region depends on divertor scrape-off layer width and gas seeding
  - Compare to multi-fluid transport model predictions
- Large experimental NSTX database, however, few divertor diagnostic measurements
  - XP605, XP708, XP814, XP816, XP826, XP1045, XP1050

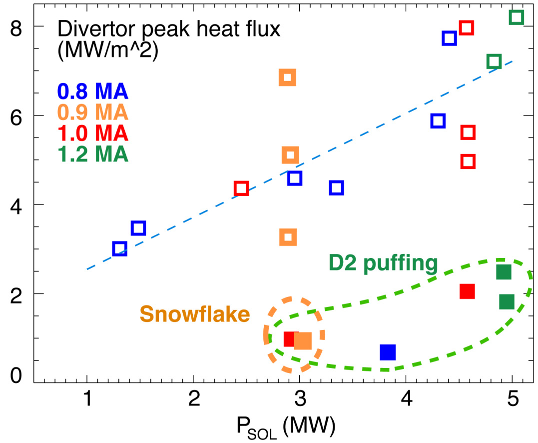
Partial detachment operating space in NSTX

- Only no lithium data (2004-2008)
- Standard divertor configuration
  - Compact (small geometric area - ST)
  - High divertor power and peak heat flux
  - Never reaches detachment naturally at high n_e~0.9 n_G
  - Detachment onset strongly depend on
    - Magnetic flux expansion
    - Gas puffing location
    - Plasma current (B_p, λ_q ?)

	NSTX high κ,δ	Tokamak
Aspect ratio	1.3	2.7
In-out SOL area ratio	1:3	~ 2:3
Parallel connection length $L_{\|\|}$, midplane to target (m)	8-12	30-80
$L_{\|\|}$, X-point to target (m)	5-8	10-20
Angle at target (deg)	5-15	1-2

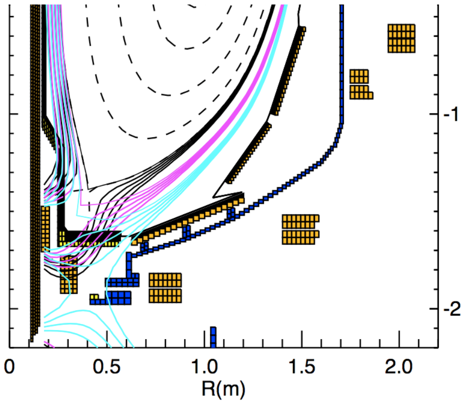


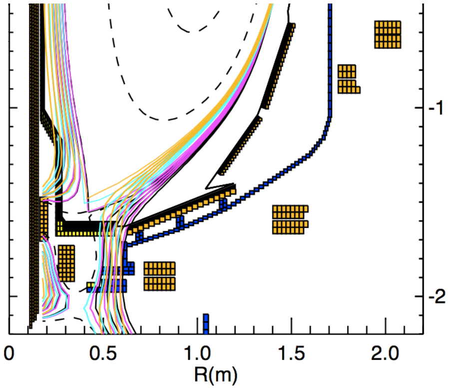


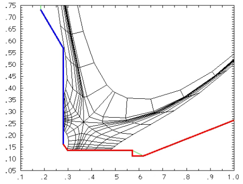


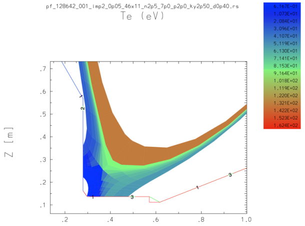
Detachment onset dependence on flux expansion investigated

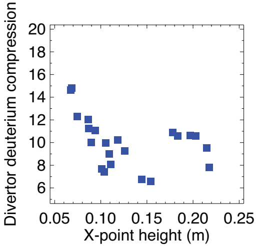
- Only transient detachment with divertor gas puffing at low δ (low f_{exp})
  - High $q_{||}$ concentrated in small physical volume
- At high-δ, dedicated XP to study transition to detachment as function of f_{exp} and R_{OSP} (area expansion)
  - Approached detachment at lower X-point height
  - High flux expansion provides higher “plasma plugging” efficiency and higher volumetric losses
    - Higher neutral compression
    - Higher impurity radiation
  - UEDGE modeling (O. Izacard)







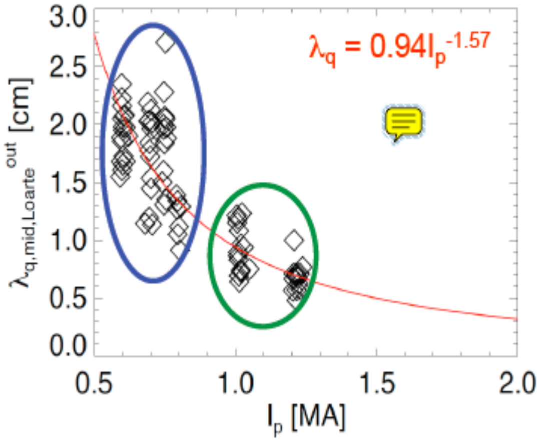


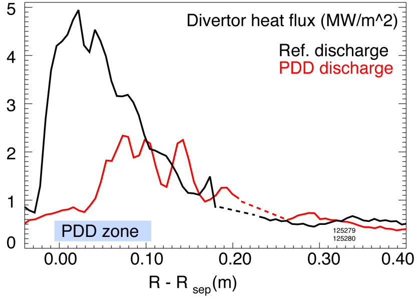


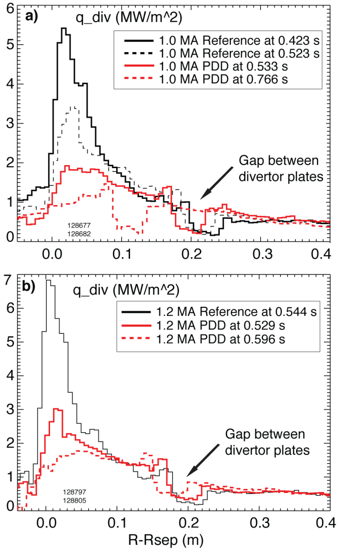
Experiment	Coils	X-pt height	OSP major radius	Flux expansion
# 1	PF1AL	6-23 cm	0.30-0.39 m	6-26
# 2	PF1AL & PF1B	4-11 cm	0.42-0.45 m	14-35

Connection between partial detachment extent and SOL power width λ_q investigated

- SOL power width is a function of $1/I_p$ (B_p)
  - Balance between parallel and cross-field transport
- Can extent of detachment be linked to radial transport via λ_q
- NSTX data at $\delta\sim 0.5$ and $\delta\sim 0.7$ in a range of I_p and P_{NBI}
  - SOL width contracts with I_p
  - Divertor peak heat flux varies directly with I_p and P_{NBI} and inversely with flux expansion
- Interpretive UEDGE modeling expected







R(17-2): Advanced divertor operating scenario modeling for NSTX-U

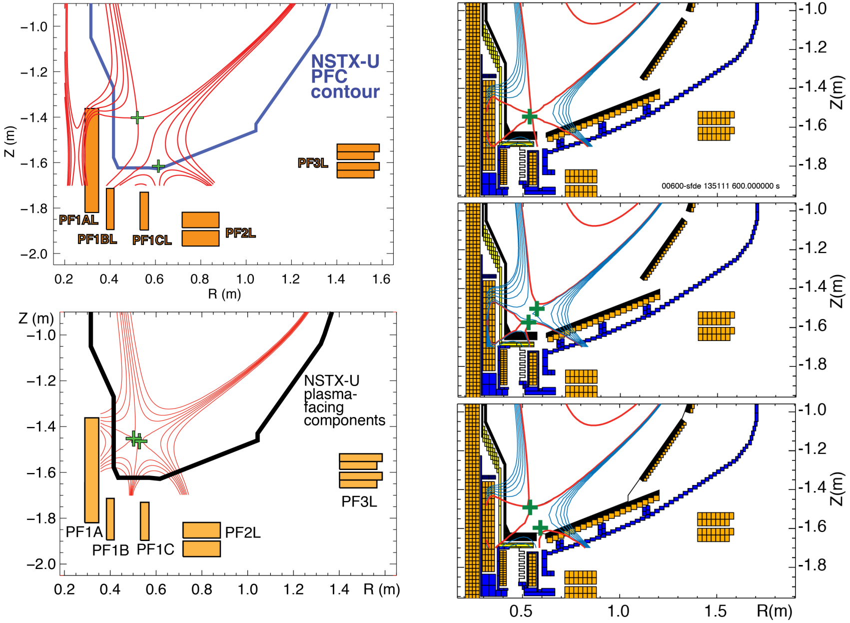
Divertor power exhaust is a critical issue for ITER and next-step tokamaks, and advanced magnetic divertor configurations are being developed and tested to provide candidate solutions for high heat flux and excessive material erosion expected in future facilities. NSTX-U will enable access to a number of advanced divertor configurations including snowflake and X-divertors thanks to a flexible set of divertor poloidal field coils. A range of scrape-off-layer (SOL) widths and high parallel heat fluxes expected in NSTX-U with I_P = 1-2 MA, P_{NBI} = 6-12 MW will enable critical tests of the underlying physics of advanced divertor configurations. To guide the experiments, modeling of advanced divertor scenarios and transport will be performed. Divertor radiation and heat fluxes as functions of current, input power, density, and seeded impurities will be studied. Predictive free-boundary codes including ISOLVER and CORSICA will be used to study the operational space of advanced divertor configurations under various solenoid and poloidal field coil current states. The recently developed GINGRED code will be utilized for numerical grid generation for divertor configurations with multiple X-points. Transport and radiation in these advanced divertor configurations will be modeled using SOLPS and UEDGE multi-fluid two-dimensional transport codes and will include studies of the effects of poloidal variation of transport coefficients. The impact of 3D fields on advanced divertor configurations will also be studied using M3D-C1 and EMC3-ERENE codes to understand how small non-axisymmetric perturbation fields may change plasma parameters inside the separatrix and in the divertor. This research will provide a significant step in advanced divertor concept development for NSTX-U and future conventional and spherical tokamaks.

Summary of planned R(17-2) tasks

- Operational space of advanced divertor configurations under various solenoid and poloidal field coil current states.
- Transport and radiation in advanced divertor configurations will be modeled
- Impact of 3D fields on advanced divertor configurations

Advanced magnetic divertor configuration equilibria modeling

- Impact of partial divertor coil set, ohmic flux swing, cryo-pump geometry
  - Snowflake divertor configurations with ISOLVER (PPPL, LLNL)
  - X-divertor configurations with CORSICA (UT)
- Waiting for finalized (or near-final) divertor poloidal field coil layout

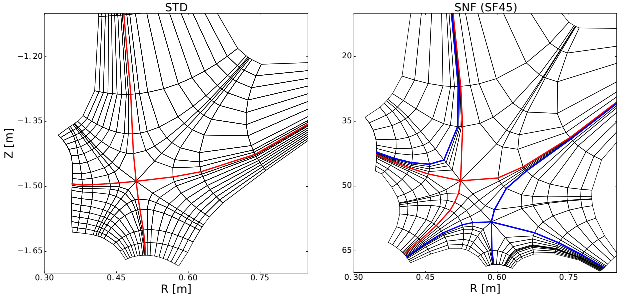


Snowflake divertor configurations for NSTX-U

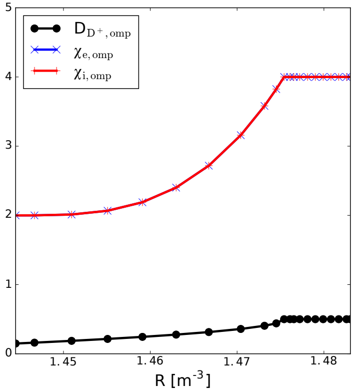
With PF1B		Without PF1B

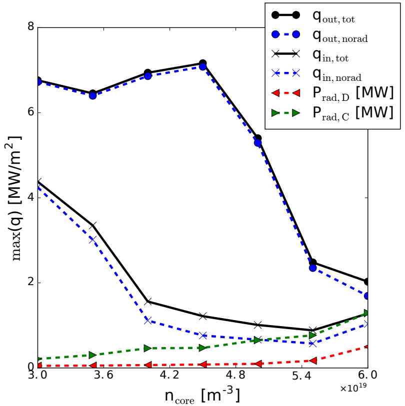
Modeling of transport and radiation in advanced divertor configurations with 2D multi-fluid codes

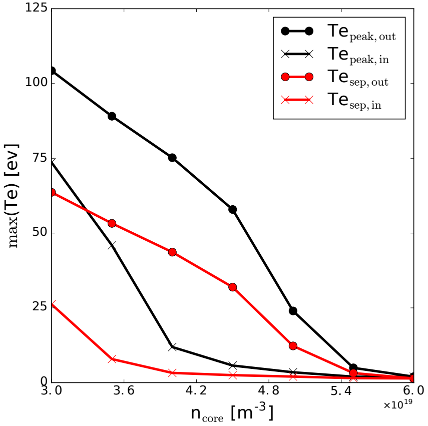
- X-divertor with SOLPS (UT)
  - Preliminary results shown in NSTX-U Monday Meeting 01/23/2017
- Standard and snowflake divertor with UEDGE (LLNL, O. Izacard)
  - 2 MA, 1 T, P_{SOL}=10 MW
  - NSTX-like transport (D, χ), electron/ion - 50/50
  - Charge-state resolved carbon, constant D for all ions
  - R=0.99

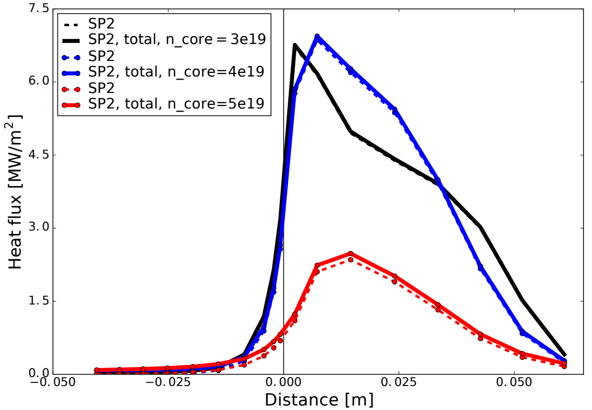


Standard divertor









Impact of 3D fields on advanced divertors

- Modeling of advanced divertor configurations with 3D fields
  - Plasma response and RMP strength using M3D-C1 (General Atomics, PPPL)
    - G. Canal et.al., M3D-C1 simulations of the plasma response to non-axisymmetric magnetic perturbations in the NSTX-U snowflake divertor, Submitted to NUCLEAR FUSION (2016)
  - Field line tracing, 3D multi-fluid and neutral transport using FLARE, EMC3-EIRENE (U. Wisconsin)
    - H. Frerichs et.al., Exploration of magnetic perturbation effects on advanced divertor configurations in NSTX-U, PHYS. PLASMAS (2016)
    - I. Waters, on-going PhD thesis work, APS 2016

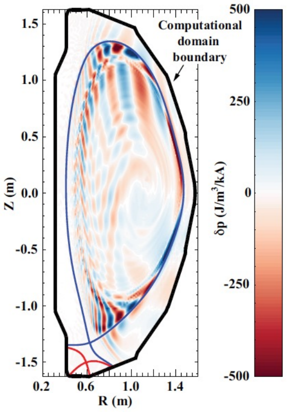


Figure 5. Perturbation of the total plasma pressure from the two-fluid plasma response to an externally applied $n = 3$ magnetic perturbation.

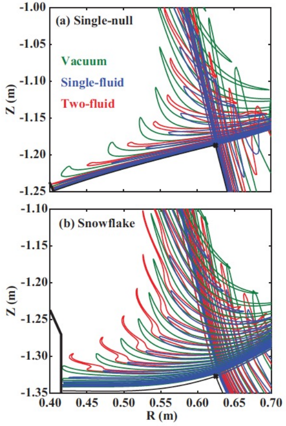


Figure 10. Manifolds of (a) SN and (b) SF configurations calculated using the vacuum approach (no plasma response) and with the single- and two-fluid plasma responses.

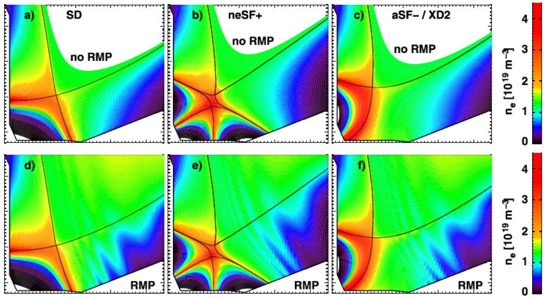


FIG. 8. Comparison of the edge plasma density with and without magnetic perturbations: (a) and (d) standard divertor configuration, (b) and (e) near exact snowflake configuration, and (c) and (f) asymmetric snowflake minus/X-divertor configuration. The position of the unperturbed separatrix is marked in black for reference.