



Supported by



Modeling core impurity reduction via divertor gas injection in NSTX

Coll of Wm & Marv Columbia U CompX **General Atomics** FIU INL Johns Hopkins U LANL LLNL Lodestar MIT Lehiah U **Nova Photonics** ORNL PPPL **Princeton U** Purdue U SNL Think Tank. Inc. **UC Davis UC Irvine** UCLA UCSD **U** Colorado **U Illinois U** Maryland **U** Rochester **U** Tennessee U Tulsa **U** Washington **U Wisconsin** X Science LLC

Eric T. Meier¹

V. A. Soukhanovskii¹, R. E. Bell², S. Gerhardt², R. Kaita², H. W. Kugel², B. P. LeBlanc², S. F. Paul², T. D. Rognlien¹, F. Scotti², M. V. Umansky¹ and the NSTX Research Team ¹Lawrence Livermore National Laboratory ²Princeton Plasma Physics Laboratory

Plasma Facing Components PPPL, Princeton, NJ June 18-22, 2012





Culham Sci Ctr York U Chubu U Fukui U Hiroshima U Hyogo U Kyoto U Kyushu U Kyushu Tokai U NIFS Niigata U **U** Tokvo JAEA Inst for Nucl Res. Kiev loffe Inst TRINITI Chonbuk Natl U NFRI KAIST POSTECH Seoul Natl U ASIPP CIEMAT FOM Inst DIFFER ENEA, Frascati CEA. Cadarache **IPP, Jülich IPP, Garching** ASCR, Czech Rep

Office of

ENERGY Science

In NSTX, lithium conditioning led to impurity accumulation

- Lithium conditioning → impurity accumulation
 - Lithium-induced edge stabilization suppresses ELMs, allowing accumulation
- High impurity concentration can be problematic
 - P_{rad} up to 2 MW (largely due to high-Z impurities)
 - Lack of density control
 - Z_{eff} increase \rightarrow resistivity increase
- Impurity control techniques on NSTX
 - ELM triggering with resonant magnetic perturbations (RMPs) [Canik PRL 2010]
 - Control plasma-wall interaction during startup phase
 - Partially detached divertor scenarios (gas puff, impurity seeding, snowflake)
 - Deuterium gas puffing [Scotti APS 2010]



Divertor deuterium puffing on NSTX reduced impurity concentration by up to 30%

- ~20 torr-l injected in 0.1 sec
 - Core plasma retains desirable properties
 - Outer divertor remains attached
 - Carbon concentration reduced 30%
- Deuterium puffing might...
 - Reduce sputtered influx
 - Modify parallel impurity transport
 - Divertor impurity retention
 - Other?





The UEDGE 2D fluid transport code is used to study effects of gas puffing on carbon transport



- Multi-species carbon model ($C^{1+} C^{6+}$)
- 0.96 < psi < 1.028 → ~6 mm SOL
- $D_{perp} = 0.5 \text{ m}^2/\text{s}, \chi_{i,e} = 1.5 \text{ m}^2/\text{s}$
- Target recycling is 90% [Canik PoP 2011]; Wall recycling is 100%
- Zero flux BC for neutral D and C at core
- Fixed core flux of D⁺
- No drift effects
- Inward carbon pinch, v_{pinch} =-25 m/s
- Scan from 0 to 1200 atom-amps continuous D injection
 - Experimental rate is 2000 A for 0.1 s

UEDGE includes physical and chemical carbon sputtering

- UEDGE includes physical and chemical sputtering of carbon
 - Physical and chemical sputtering models are from DIVIMP (U. Toronto)
 - Actual NSTX vessel wall is far from outer UEDGE boundary
 - Sputter yield reduced 10x at outer UEDGE boundary
 - T_{target} =500 K and T_{wall} =300 K assumed for all gas puff rates
 - Experimental T_{target} drops from ~600 K to ~400 K
- Lithium coating effects are not modeled
 - Complicated Li-C-D-O interaction still under investigation [e.g., Scotti PSI 2012]
- C-C and Li-C sputtering not included

Reducing energy from 100 to 20 eV, chemical sputtering goes up and physical sputtering goes down.





Midplane T_e matches well; T_i, n_e, n_i, not well-matched



🔘 NSTX-U

Outer divertor D_{α} profiles show good agreement; UEDGE CII profiles with large injection are too high



Outer divertor sees large temperature and heat flux reduction with 1000 A injection

OUTBOARD DIVERTOR PLATE (probname = 13) OUTBOARD DIVERTOR PLATE (probname = 138767 ION DENSITY ION & ELEC TEMPERATURES ION DENSITY ION & ELEC TEMPERATURES 6×10²⁰ 60 10×10¹⁹ 5×10²⁰ 50 8 8×10¹⁹ (0N DENSITY (/m*#3) (Exx4/) 4×10²⁰ 40 TEMPERATURE (aV) (VB) 6 6×10¹⁹ 30 3×10²⁰ TEMPERATURE DENSITY 4 4×1019 2×10²⁰ 20 2×10¹⁹ 2 1020 10 NOI 0 0 0 0 0 8 0 8 0 20.00.00.00.00.00 0 2 2 8 6 5 5 5 8 8 ION PARTICLE FLUX TOTAL HEAT FLUX TOTAL HEAT FLUX ION PARTICLE FLUX 7×10⁶ 50000 6×10⁶ 25000 20×10⁵ 40000 5×10⁶ 20000 ION FLUX (A/max2) HEAT FLUX (V/m##2) (N/ntd2) (A/hax2) 15×10⁵ 30000 4×10⁶ 15000 3×106 10×10⁵ 20000 HEAT FLUX FLUX . . 10000 2×10⁶ 5×10⁵ S 10000 5000 106 0 0 0 0 2 2 8 6 5 5 5 22886555 0 8 0 2 2 3 8 5 5 4 8 8 0 8 0 22886555 DISTANCE (n) DISTANCE (m) DISTANCE (m) DISTANCE (m)

No injection

1000 A injection



Carbon concentration is reduced with increasing deuterium gas injection



- Carbon point conc. @ mp sep. vs. Igas
- Carbon concentration at the • midplane separatrix is reduced by over 50% with 1200 A puff

- Max divertor temperatures 60 ••••Te max,in. ----Ti max,in. •••• Te max, out. 30 🛨 Ti max, out. 20 10 0 600 800 1000 1200 0 200 400 Igas, A
- Divertor temperatures are ulletreduced dramatically



Total sputtered flux remains nearly constant



 Sputtered flux is dominated by inner and outer divertor sources

- Physical sputtered flux drops, but chemical sputtered flux rises



D gas injection causes D and C flow away from outer divertor





Total impurity density near the X-point is reduced with deuterium gas injection

Data is plotted along a field line on the 2 mm flux surface.



- n_{imp} rises at outer target, but falls (slightly) at outer midplane
- n_{imp} at X-point height is reduced
- n_{imp}/n_{imp,max} shows large relative reduction
 - Divertor retention?



Deuterium gas injection prevents carbon flow stagnation near outer midplane

Data is plotted along a field line on the 2 mm flux surface.



Conclusions

- UEDGE gas puff study shows carbon impurity reduction with divertor deuterium gas injection
 - Observed reduction trend is consistent with experiment
 - Reduction seems related to "flow-through" of C past outer midplane
 - Carbon buildup at outer midplane is prevented
 - Reduction of carbon source is not seen
- Simulations could be improved in future work
 - Double null grid would give larger SOL and include upper divertor physics
 - More closely matching midplane profiles and divertor spectroscopy would increase confidence



Backup slides



D and C profiles...

(Abscissa is the distance from the outer midplane along a field line on the 2 mm flux surface.)



NSTX-U

Plasma Facing Components – Modeling Core Impurity Reduction, E. T. Meier (July 2-6, 2012)

Divertor diagnostics include IR and visible cameras, divertor spectrometry, and tile Langmuir probes

- IR camera used to determine heat flux
- Visible cameras can be filtered to provide D_{α} data
- Langmuir probes provide sparse data
 - Other comments???





With deuterium injection, recycling increases dramatically, but changes to C transport are more subtle



🔘 NSTX-U

With 1000 A injection, inner divertor temperature and heat flux fall dramatically

0 A injection

1000 A injection





Heat flux comparison...





1000 A puff

TOTAL HEAT FLUX

DISTANCE (m)

0

20.00.00.00.00.00

lgas (A)	P_SOL (MW)	Pdiv_in (MW)	Pdiv_out (MW)	Pwall (MW)	Prad
0	3	0.44	0.95	1.51	0.22
1000	3	0.27	0.37	1.92	0.50



Assessment of radial impurity current



- 1. (Black) Poloidal impurity current (into a cell) / total current (into a cell)
- 2. (Red) Impurity ion density
- 3. (Blue) Deuterium ion density

Abscissa is poloidal distance from outer midplane. Data is plotted for the 2 mm flux surface (iysptrx+6) are plotted.

```
1: plot ipc(1:nx)/itc(1:nx) ltmp(1:nx,iy)-ltmp0
2: plot nimp(1:nx)/max(nimp(1:nx)) ltmp(1:nx,iy)-ltmp0 color=red
3: plot ni(1:nx,iy,1)/max(ni(1:nx,iy,1)) ltmp(1:nx,iy)-ltmp0 color=blue
```

Radial deuterium fluxes, 0 A









1. plot fn1y(1xpt1+1.1xpt2,1ysptrx,1) lpol(1xpt1+1.1xpt2,1ysptrx)-lpol0 color-blue 2. plot fngy(1xpt1+1.1xpt2,1ysptrx,1) lpol(1xpt1+1.1xpt2,1ysptrx)-lpol0 color-red



Radial deuterium fluxes, 1000 A



1: plot fniy(ixpt1+1:ixpt2.0.1) lpol(ixpt1+1:ixpt2.0)-lpol0 color-blue 2: plot fngy(ixpt1+1:ixpt2.0.1) lpol(ixpt1+1:ixpt2.0)-lpol0 color-red





0

N

Neutral gas density ...



