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Recycling and pumping characterization of the LLD-1 module

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and NSTX Research Team

Lithium Research Thrust Session
NSTX Research Forum
Princeton, NJ
2 December 2009

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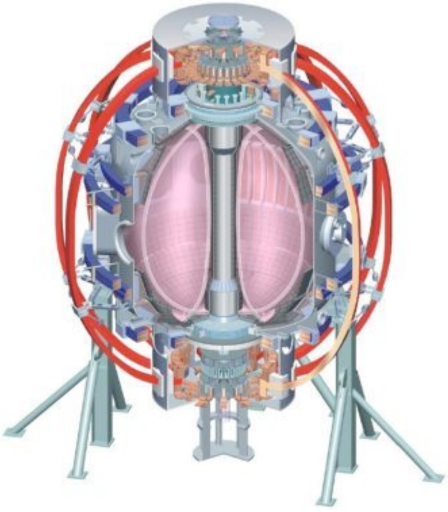


Goals and motivation for this XP

- Focus on SOL / divertor transport and plasma-material interaction
  - LLD pumping capability
    - Compare to LITER results from FY2008-2009
    - How does pumping and recycling depend on
      - Divertor ion flux (core ion density)
      - LLD temperature (cold, warm, warmer)
  - SOL heat and particle transport regimes
    - Document SOL collisionality change
    - Parallel and radial electron and ion transport
    - Impurity sources and transport
  - Divertor heat flux handling

This XP would extend the LLD commissioning XP results to a wider operating / physics space

- Extend the LLD commissioning XP results as follows:
  - Use SGI and LFS gas if necessary to obtain a range of core ion densities
    - As a result, obtain a proportional range of ion fluxes to divertor plate
    - Can probably support $n_d \sim 1\text{-}6 \times 10^{19}$ m^{-3} in steady-state
  - Use a range of LLD temperatures between 150 and 300 C
    - LLD commiss. XP should provide understanding on LLD higher temp. limitation
    - Lithium erosion changes by factor of ~3 between 215 and 300 C
    - Lithium evaporation changes between 215 and 300 C
    - Deuterium diffusion, solubility and LiD decomposition rate change
  - Use high to medium triangularity shapes ($R_{OSP} \sim 0.4 – 0.65$ m)

Aim at accurate measurements of particle balance, ion and impurity sources, pumping

- LLD pumping capability
  - Use particle balance models for “wall” inventory and τ_p^* essentially characterizing pumping
    - From simple 0D models to sophisticated 0D models (e.g., A. Pigarov’s particle balance model)
  - Measure SOL density response to singular flat-top SGI pulses (“pumpout”)
    - Use FireTip channel 7 if operational
    - Use divertor probes and D emission spectroscopy
  - Use D emission spectroscopy and probes to measure local recycling coefficients
    - Characterise ionization source and recycling coefficients across lower divertor, in upper divertor, on center stack

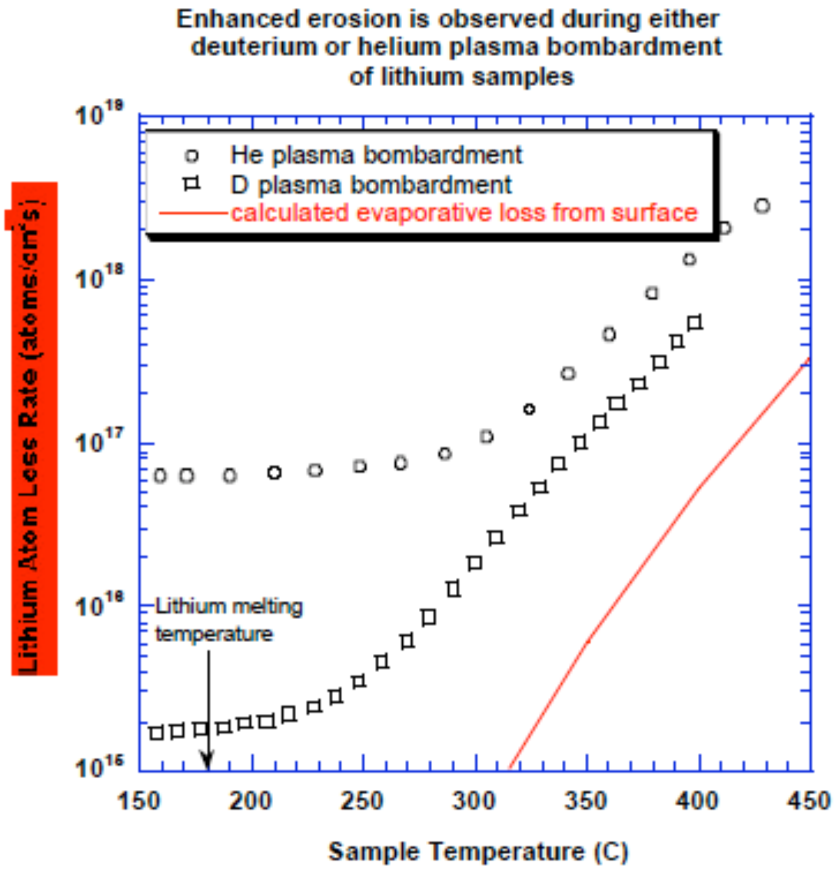
Study SOL parallel and radial transport regimes

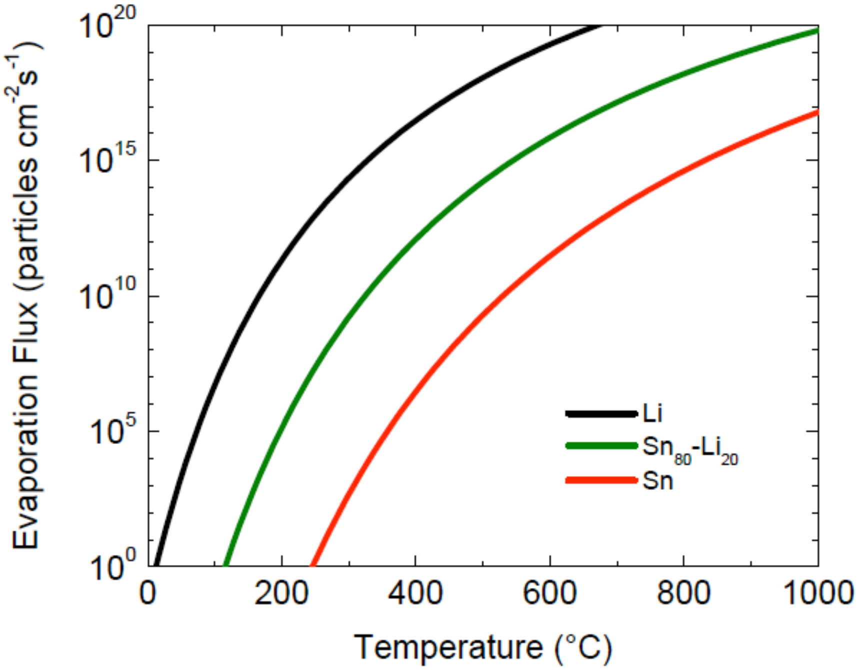
- Effect on SOL / divertor transport
  - Measure impurity source profiles
    - Use divertor cameras for Li I, Li II, C II profiles, S/XB factors from ADAS for impurity flux measurements
    - Multi-channel spectroscopy for molecular emission in lower divertor - e.g., Fulcher bands for D_2 fluxes, other bands for lithium and carbon radicals and dimers (e.g., McLean's proposal)

  - What can we say about parallel heat transport?
    - T_e gradients, T_i gradients
    - Conductive vs convective
  - What can we say about radial ion and impurity transport?
    - Use GPI to characterize blob velocity and size
    - Use UEDGE for impurity transport modeling

Backup

Erosion and evaporation rate of liquid lithium (courtesy of R. Doerner, A. Hassanein)





Summary of my APS poster “Modifications in SOL and divertor conditions with lithium coatings…”

- Evaporative lithium coatings on carbon PFCs modify divertor and SOL sources
  - Lower divertor, upper divertor and inner wall recycling was reduced by up to 50 %
  - Local recycling coefficients reduced on inner wall and far SOL, remained similar in the outer strike point region
  - Lower divertor carbon source from physical sputtering also reduced
  - Divertor lithium influx increased, however, lithium was retained in divertor

- SOL transport regime changes from high-recycling to sheath-limited
  - Apparently small parallel T_e gradient
  - Detached inner divertor re-attaches, X-point MARFEs disappear

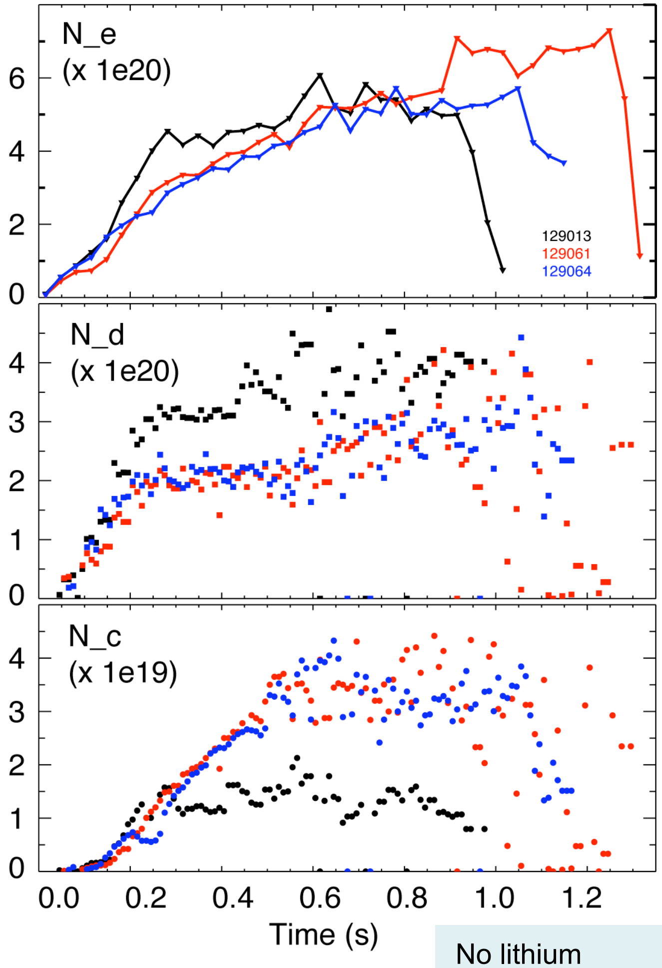
- Pedestal and core confinement improvement leads to
  - Reduction of ion inventory (density) by up to 50 % due to surface pumping
  - Effective screening of lithium from core plasma
  - Carbon and high-Z impurity accumulation
  - P_{rad} increases in the core, P_{SOL} significantly reduces

Comparison with cryo-pumps

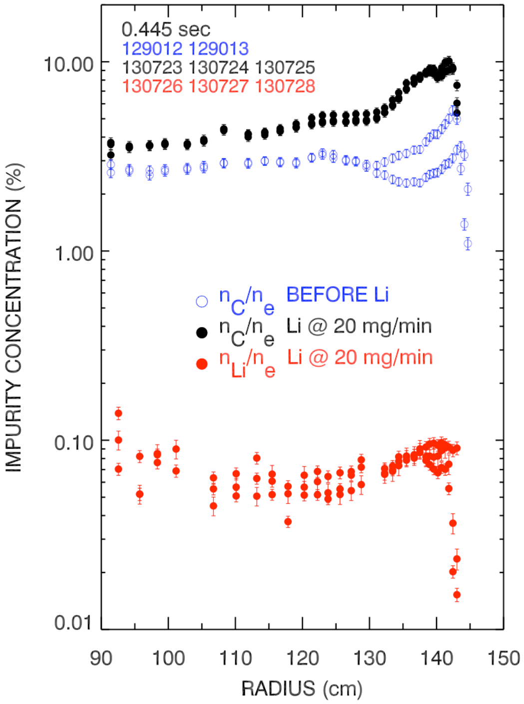
- Cryo-pumping (e.g., DIII-D experience)
  - Significant in-vessel hardware modifications
  - Inflexibility in plasma shaping due to the need of proximity to strike point
  - Calibrated pumping rate
  - Demonstrated density control
  - Compatibility with radiative divertor

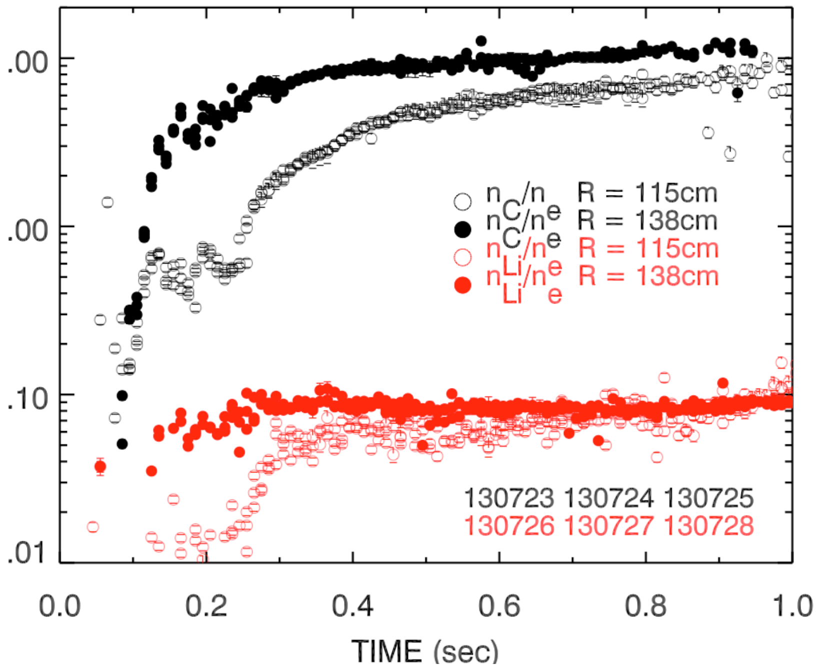
- Lithium coatings on graphite PFCs (NSTX LITER experience)
  - Flexibility in plasma shaping
  - Need for operational scenario development for each pumping and fueling rate
  - Multiple side effects (good and bad) on plasma core and edge

Ion inventory is well controlled in discharges with lithium, core carbon accumulates, lithium is screened out



No lithium (129013)
190 mg Lithium (129061)
600 mg lithium (129064)





- Impurity density profiles from CHERS
  - C VI, n = 8-7 transition, 529.1 nm
  - Li III, n = 7-5 transition, 516.7 nm
- Lithium concentration much lower than carbon concentration
  - $n_C/n_{Li} \sim 100$
- Carbon increases with Li evaporation

Dynamic particle balance model indicates strong pumping by lithium

$$\frac{dN_p}{dt} = \Gamma_{gas} + \Gamma_{NBI} + \Gamma_{NBI\_cold} + \Gamma_{NBI\_cryo} + \Gamma_{wall} + \Gamma_{pump} + \frac{dN_n}{dt}$$

Change of particle inventory

Gas feed rate

NBI fueling rate

NBI cryopump rate

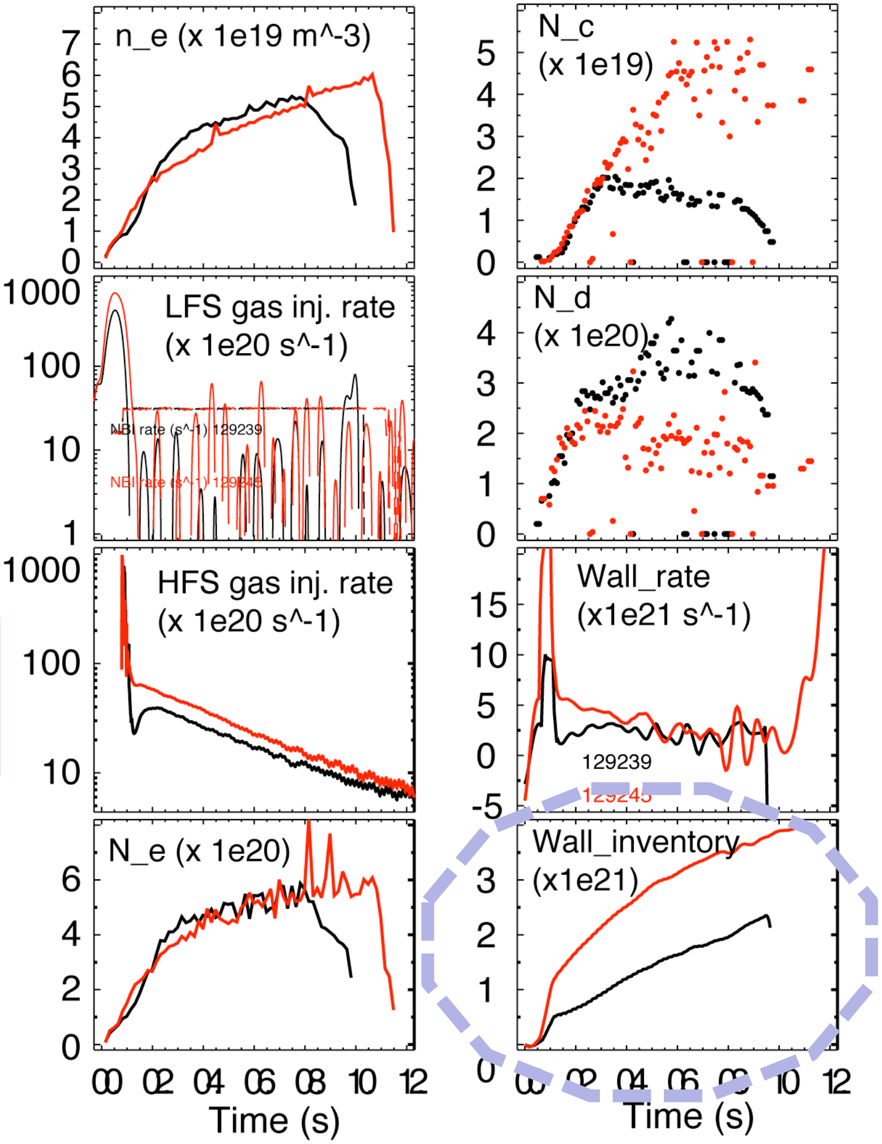
Ion density $n_i = n_e \frac{Z - Z_{eff}}{Z - 1}$

Fueling efficiency $\eta = \frac{N_p(t)}{N_{src}(t)}$

Rewrite global particle balance equation as:

$$\frac{dN_p}{dt} = \eta_{gas} S_{gas} + \eta_{NBI} S_{NBI} + S_{recy} - \frac{N_p}{\tau_p}$$

No lithium
(129013)
190 mg Lithium
(129061)



A long pulse H-mode discharge scenario with SGI fueling and controlled N_i was developed

- Used SGI-only fueling
- LITER rate 6-9 mg/min
- Ion density control
- N_i constant, while N_e is rising due to carbon