



U.S. DEPARTMENT OF
ENERGY

Office of
Science

LTX

 NSTX-U

“In Vacuo” Analysis of LTX Wall Samples Exposed to Lithium & Implications for High-Z Plasma-Facing Components in NSTX-U*

R. Kaita,¹ M. Lucia,¹ R. Bell,¹ D. Boyle,¹ A. Capece,¹ M. Jaworski,¹ R. Majeski,¹ J. Schmitt,¹ and C. H. Skinner,¹ J. P. Allain,² F. Bedoya,² B. E. Koel,³ J. Roszell,³ F. Scotti,⁴ and V. Soukhanovskii⁴

¹Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ USA

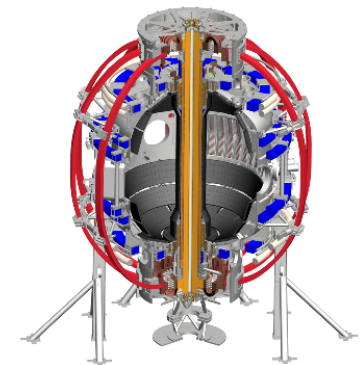
²University of Illinois at Urbana-Champaign (UIUC), Urbana, IL USA

³Department of Chemical and Biological Engineering, Princeton University, Princeton, NJ USA

⁴Lawrence Livermore National Laboratory (LLNL), Livermore, CA USA

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Outline

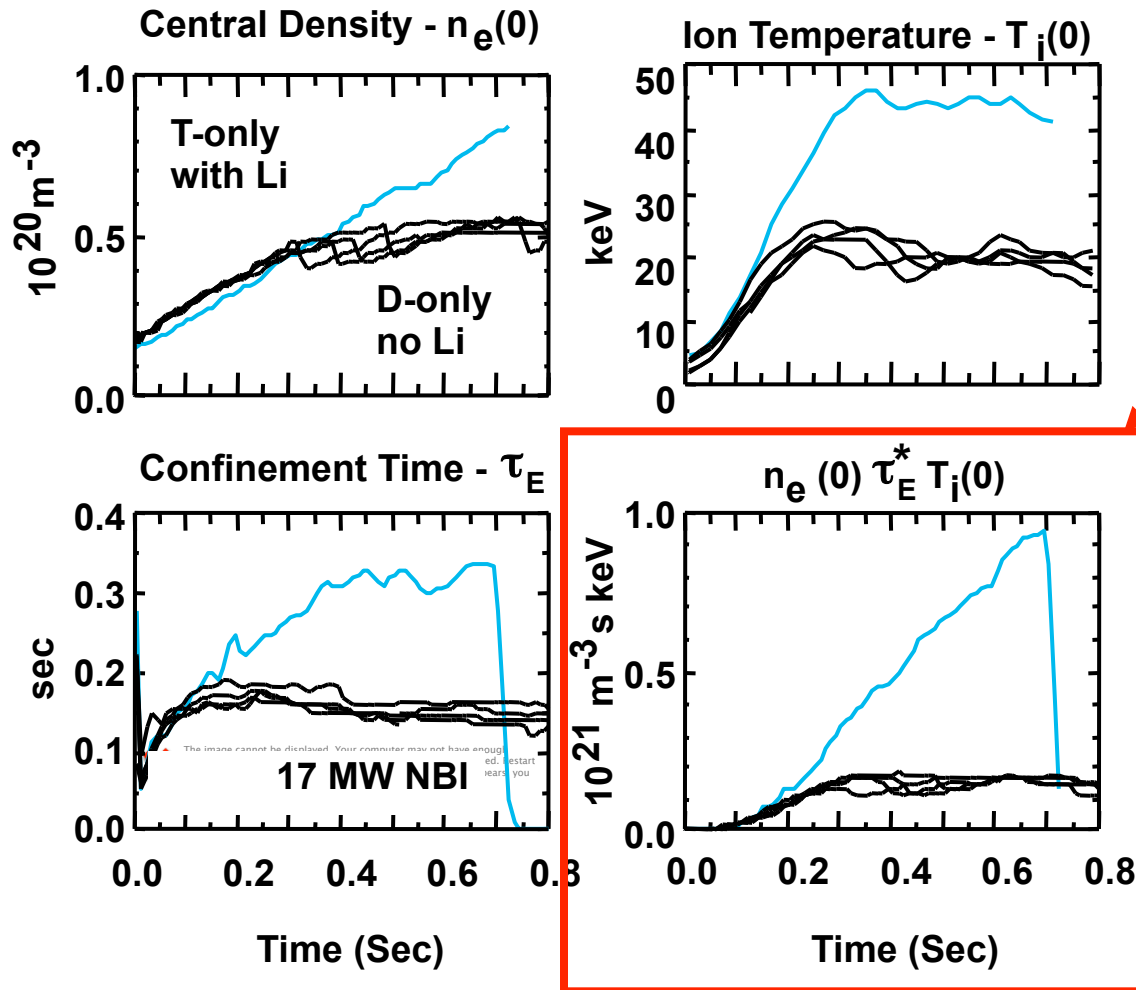
- **Initial motivation and results from application of lithium to plasma-facing surfaces**
- **Benefits *in vacuo* analysis of plasma facing components and measurements on LTX**
- **Hydrogen retention by lithium on high-Z PFCs and implications for future applications**

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Application of lithium to PFCs long used to improve plasma performance

Tritium-only Supershot in TFTR - 4 Pellets + "Painting" - with progressively larger plasmas



◆ Highest fusion "triple product" achieved with lithium wall coatings

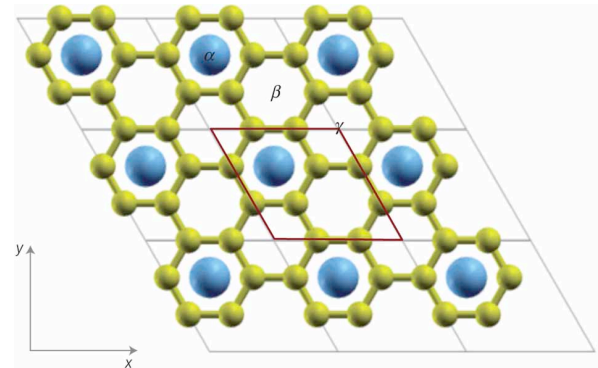
*D. Mansfield et al. –
Phys. Plasmas 3, 1893 (1996)*

Use of lithium as PFC motivated by reasonable but simple assumptions

- **Lower transport and improve confinement by reducing recycling**
 - Control electron temperature gradient instability
- **Achieve lower recycling with lithium PFCs**
 - Lithium is alkali metal with lowest Z
 - High chemical reactivity binds hydrogenic species by formation of hydride

Simple assumptions could also lead to avoiding application of lithium to graphite PFCs

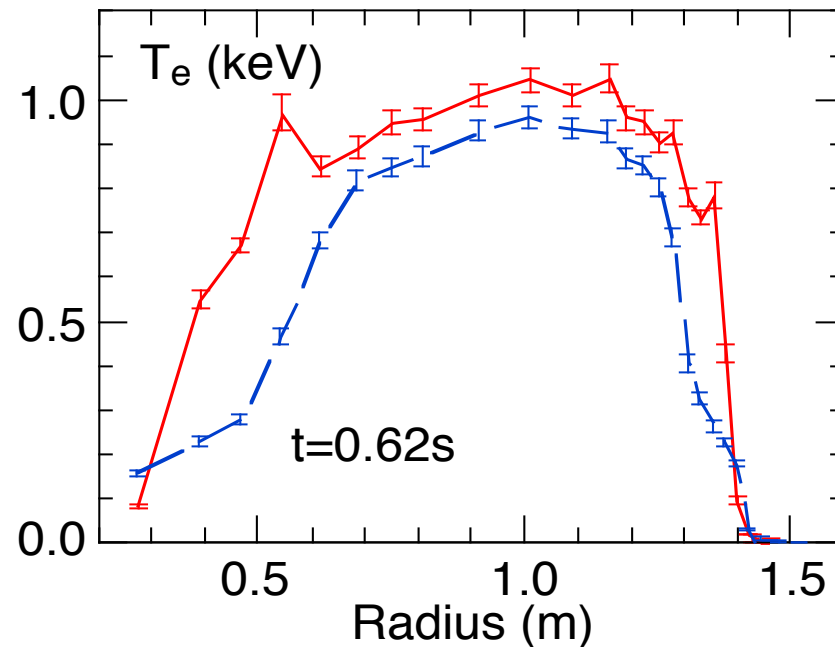
- Graphite attractive as low Z material for most high performance tokamaks to date
 - Used as PFC in TFTR, DIII-D, and NSTX/NSTX-U
- Basic chemistry means lithium should *not* be applied to graphite PFCs
 - Lithium intercalates into graphite to form several possible compounds, e. g., LiC_6



- Such intercalation compounds *not* expected to be effective in binding hydrogenic species by lithium hydride formation

“Unreasonable” effectiveness of lithium on graphite in binding hydrogen still needed explanation

- **Electron temperature profile broader after lithium PFC coating (red curve) than before lithium applied (blue curve) on NSTX**



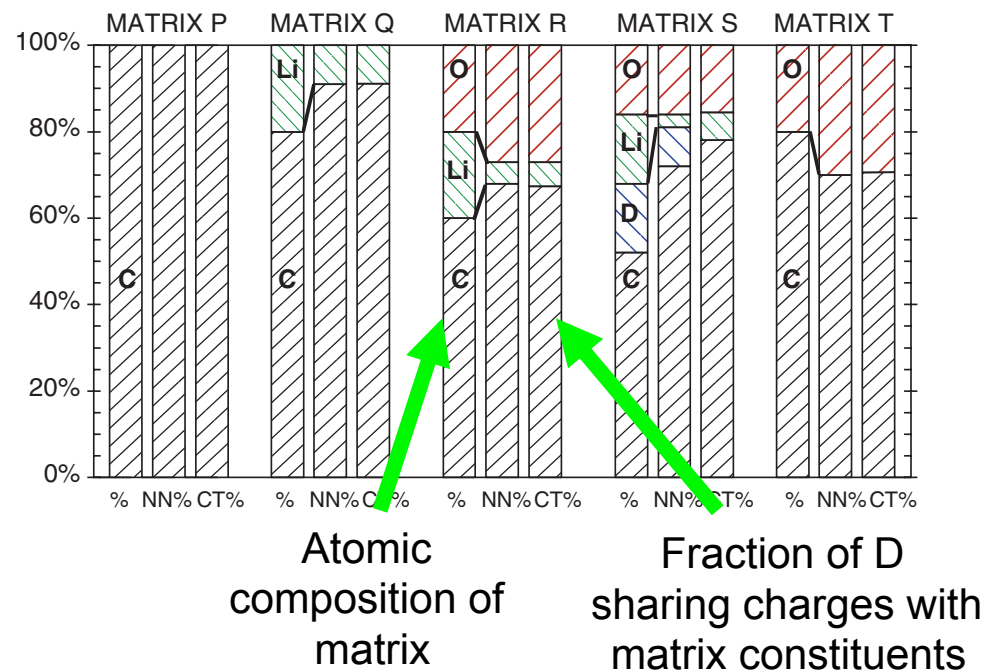
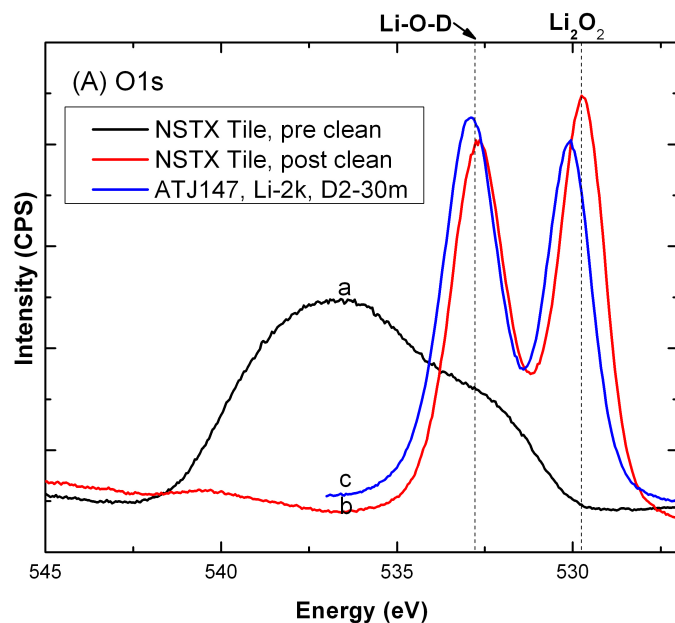
- ***Underlying mechanism remained basically unknown for almost two decades after TFTR results***

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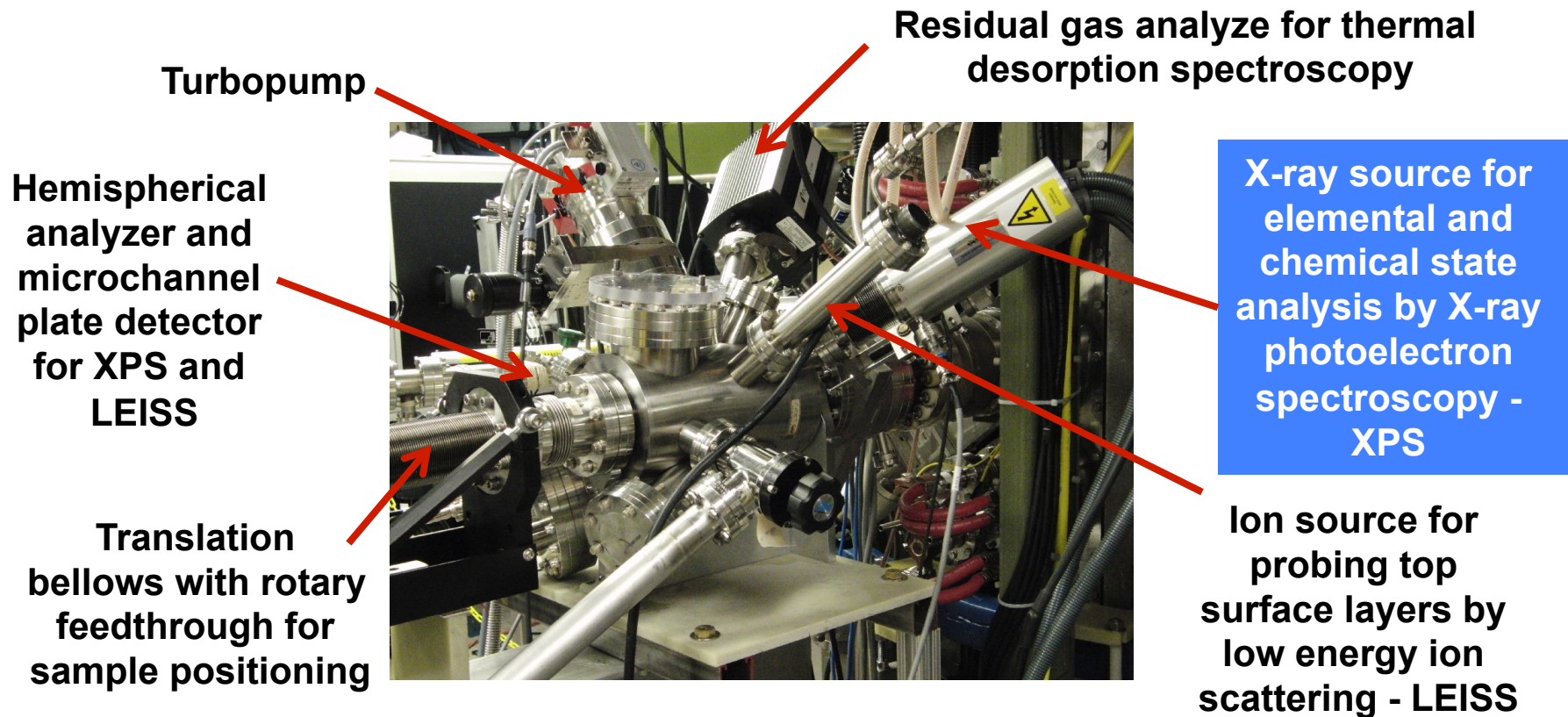
Details literally “uncovered” only after extensive post-run PFC analysis and QCMD modeling

- Examination of “cleaned” NSTX tiles revealed complexes involving lithium, oxygen, and deuterium
- Quantum-classical molecular dynamics modeling indicates that oxygen dominates bonding of incident deuterium



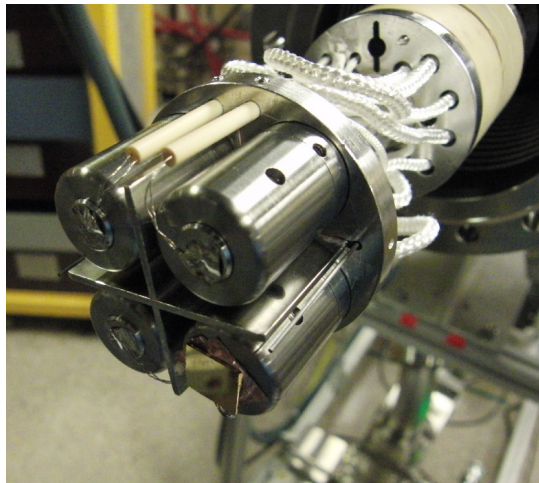
***In vacuo* analysis can make interpretation of PFC surface characteristics less complex**

Materials Analysis and Particle Probe – MAPP – allows PFC samples to be exposed to plasmas and analyzed in vacuum



MAPP used on Lithium Tokamak Experiment – LTX – for study of lithium PFCs surrounding plasma

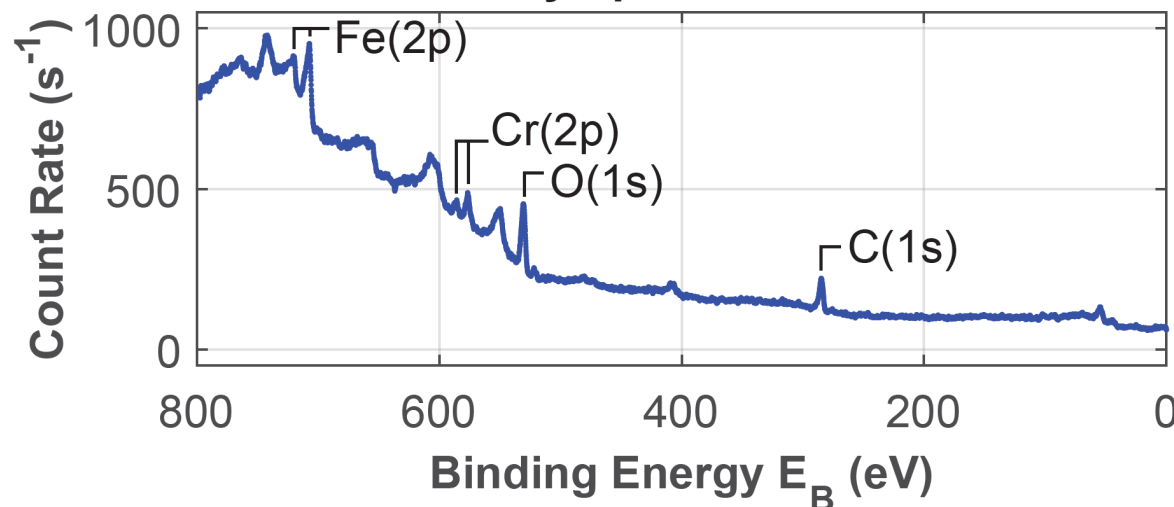
- Probe end with samples in holder –
- Stainless steel to match LTX PFC
 - TZM molybdenum to match future NSTX-U PFC
 - Gold for calibration



Probe end inserted into LTX vacuum chamber

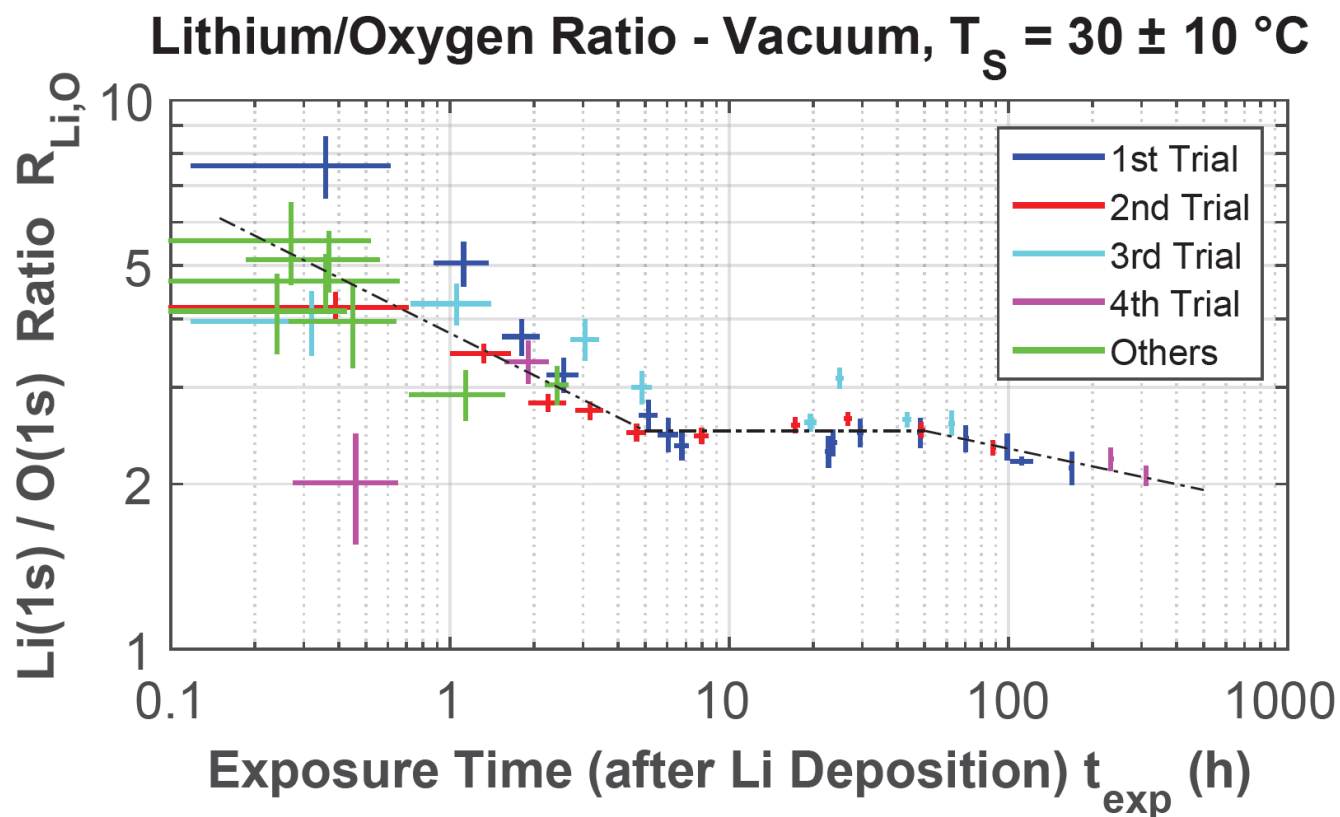
High Z PFC formed by stainless steel liner bonded to copper shell

XPS Survey Spectrum from MAPP



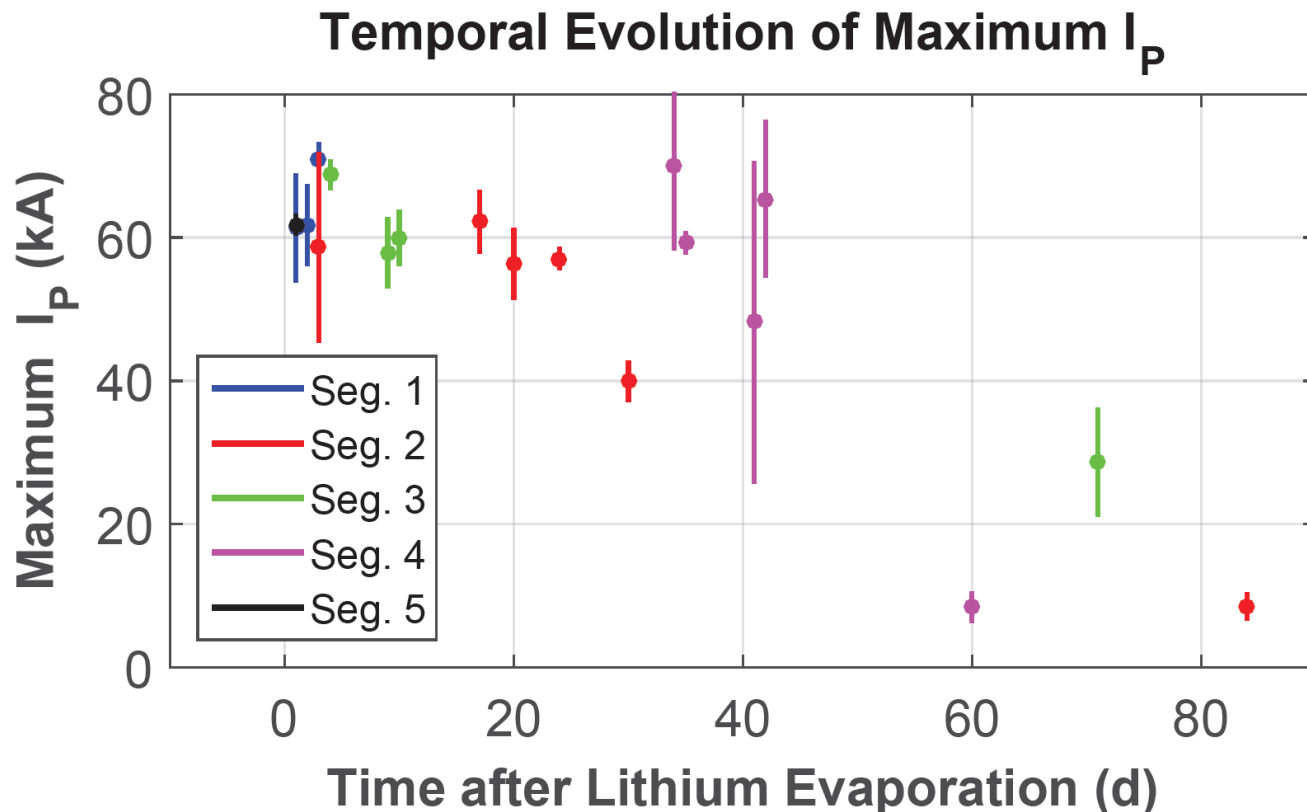
- Elemental identification – measured photoelectron energy

Measurements of surface composition after lithium application indicate formation of stable oxide layer



- Results shown from several lithium evaporation experiments
- Larger uncertainties for $R_{\text{Li,O}}$ soon after lithium deposition because of less time and lower statistics for XPS “scans”

High achievable plasma currents persisted long after evaporation in spite of lithium oxide on PFC surface



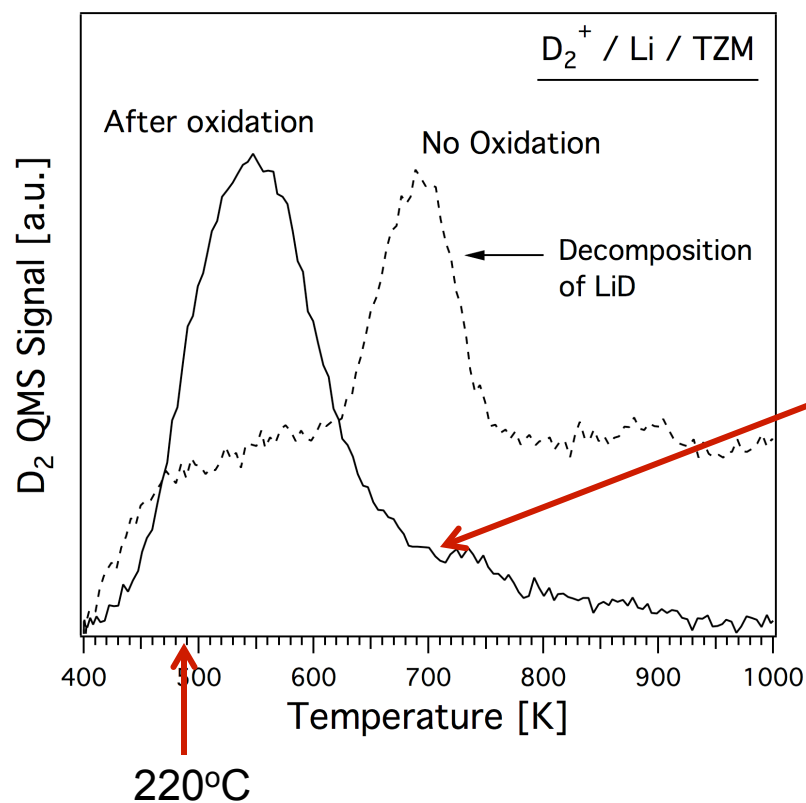
- Segments refer to different times between lithium evaporations
- Performance “decays” on time scale exceeding 1000 hours

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Evidence for binding of hydrogenic species by lithium compounds seen in laboratory experiments

Thermal desorption spectroscopy performed by heating samples and observing residual gas analyzer spectra

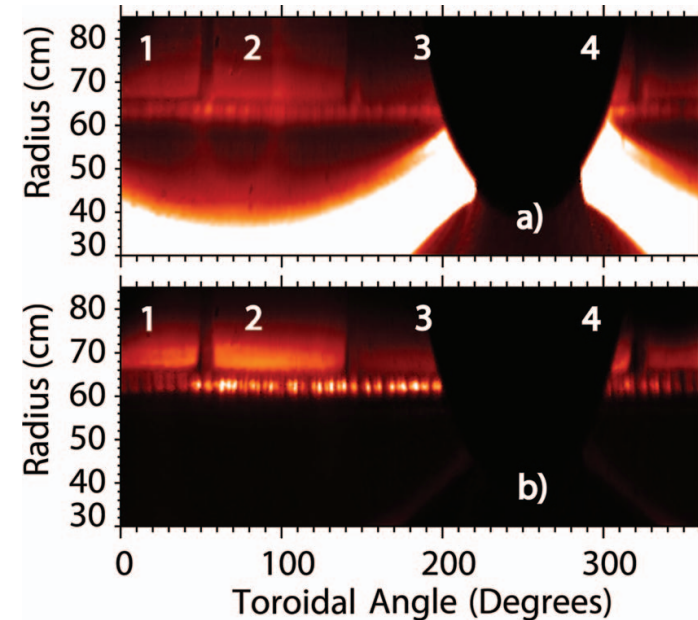


Absence of peak after oxidation consistent with inhibition of LiD formation

- Thin lithium film deposited on high-Z molybdenum - TZM - substrate
 - Exposed to D₂⁺ ions at room temperature
- Higher deuterium peak observed *after* oxidation at same temperature
 - Suggests presence of oxygen *increases* surface retention of deuterium

Temperature dependence of deuterium retention also observed with NSTX liquid lithium divertor

- 250 μ stainless steel liner brazed to 2.2 cm copper substrate
- High-Z PFC formed by $\sim 150\mu\text{m}$ plasma-sprayed porous molybdenum



Liquid lithium divertor – LLD – in NSTX

Fast camera images of four LLD segments

- LLD segments – labeled 1, 2, and 4 in figure at right – heated to 220°C
 - a) Higher D_α emission: higher recycling compared to cold segment
 - b) Higher Li I emission: more sputtering compared to cold segment

Results from lithium on high-Z PFCs suggest need for broader view of hydrogen retention

- **Experiments on LTX and NSTX with LLD and laboratory measurements show ability of surfaces containing lithium and oxygen to bind hydrogenic species**
 - Differs from lithium-carbon-oxygen complex formation with graphite PFCs
 - Similar in *not* retaining hydrogen by forming lithium hydride on “clean” lithium surface
 - Implies lithium evaporation may still be adequate for investigating physics of low recycling as NSTX-U transitions to high-Z PFCs
 - Potential for oxidation to inhibit lithium tritide formation may help address concerns over tritium inventory in PFCs
- **Challenge remains control of lithium surface temperature**
 - Weakly-bound hydrogenic species released from surface at relatively low temperatures
 - Mitigation mechanisms like “vapor shielding” may be possible