# Initial results for reactivity of lithium films on a molybdenum substrate

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Acknowledgments:

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# Need for benchmark data on fundamental surface physics of Li

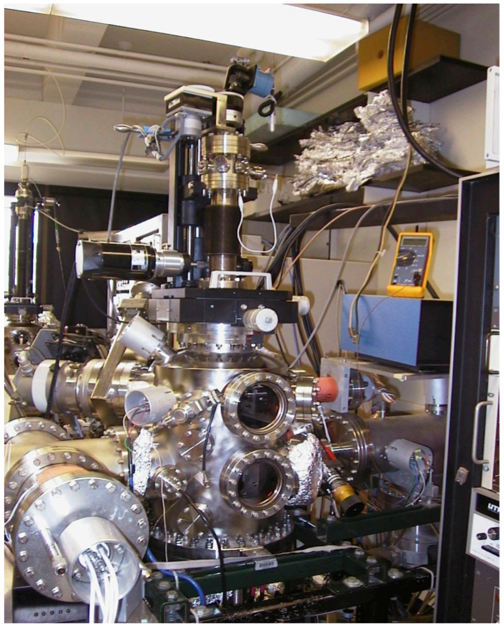
- Density control will be important for optimizing and controlling high non-inductive current-drive fraction scenarios in NSTX-U.
- Lithium conditioning of PFCs has been shown to pump hydrogenic species however contamination by residual gases is believed to limit its performance.
- A quantitative understanding of the influence of residual gases on lithium adsorption of deuterium by lithium will facilitate predictions of particle control in NSTX-U.

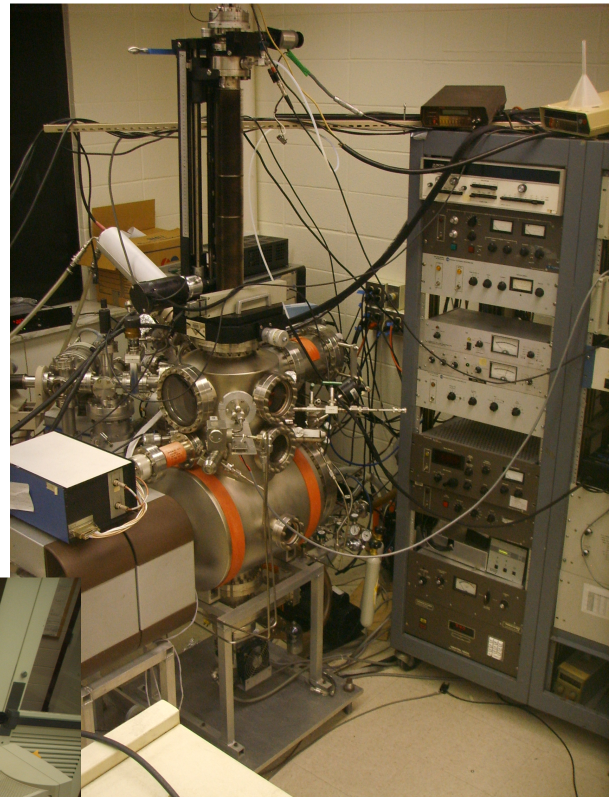
## Opportunity:

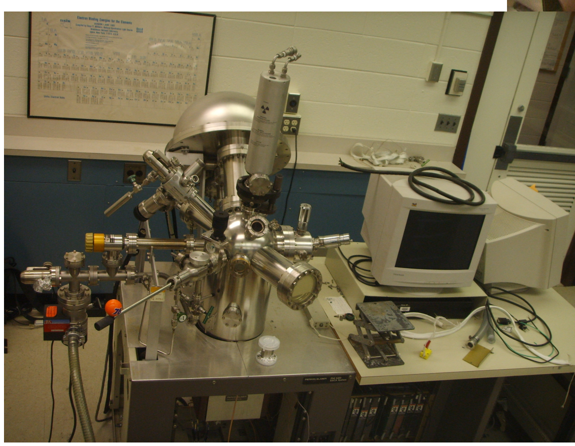
Fundamental data on plasma- Li-PFC interactions will lay the groundwork, and reduce the risk for innovative PFCs in NSTX-U.

Minimizing advanced Li-PFC risk is also critical for NSTX-U's missions in other ST areas.
(C. Skinner)

# New materials characterization labs at PPPL

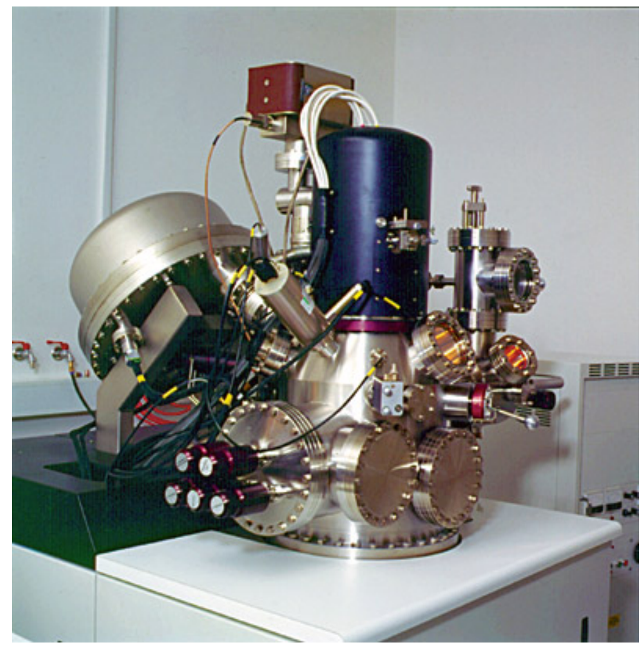






**T260**

**C123**



# Initial studies to assist with quantitative projections for pumping and D recycling by Li coatings

- X-ray Photoelectron Spectroscopy (XPS) of gas reactions with solid Li
  - Uptake kinetics and reaction rates
  - Surface reaction products and compound formation
- Temperature Programmed Desorption (TPD) studies of Li films on Mo
  - Thermal stability and wetting
  - Metal-metal and metal-oxide bonding energies
- Auger Electron Spectroscopy (AES) and TPD studies of gas reactions with Li films on Mo
  - Thermal stability and wetting
  - Reaction pathways and decomposition products


"Plasma Facing Surface Composition During NSTX Li Experiments", **C.H. Skinner**, R. Sullenberger, B.E. Koel, M. Jaworski, H.W. Kugel, *20th International Conference on Plasma Surface Interactions in Controlled Fusion Devices*, Aachen, Germany, May 2012

"Plasma facing surface composition during Li evaporation on NSTX and LTX", **C.H. Skinner**, R. Majeski and B.E. Koel, *2nd International Symposium on Lithium Applications for Fusion Devices*, Princeton, NJ, April 2011

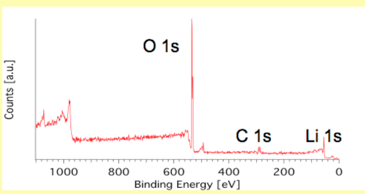
"Plasma facing surface composition during Li evaporation on NSTX and LTX", **C. H. Skinner**, H.W. Kugel, R. Majeski, R. Kaita, R. Sullenberger, V. Surla and B.E. Koel, *53rd Annual Meeting of the APS Division of Plasma Physics,* Salt Lake City, Utah, November 2011

# XPS studies of gas reactions with solid Li

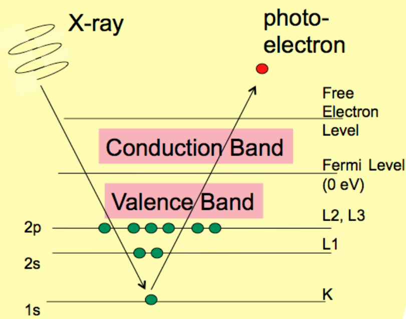
## Li surface oxidation tracked by X-ray photoelectron spectroscopy

Monochromatic Al Kα x-rays (1486.6 eV) photoionize atoms. Emitted photo-electron energies are measured with high resolution 300 mm radius hemispherical electrostatic analyzer. Photo-electron energy reveals chemical state of top ~ 20 monolayers

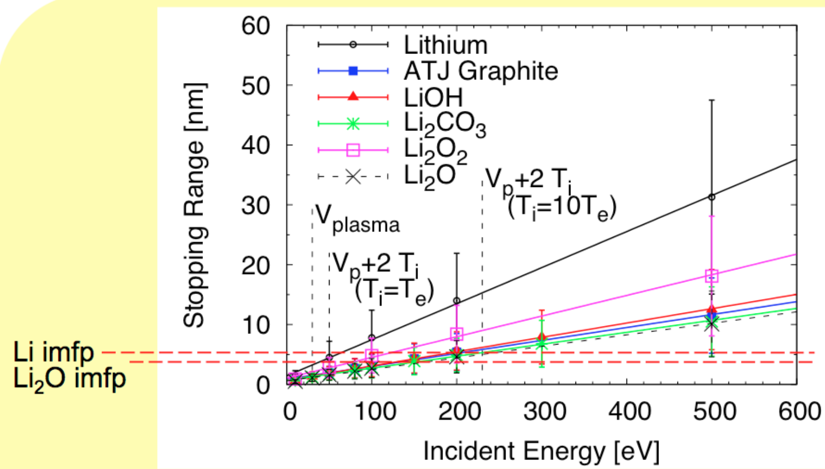
Electron Binding Energy = X-ray energy hν − Electron Kinetic Energy




Broad scan XPS spectrum before gas exposure.



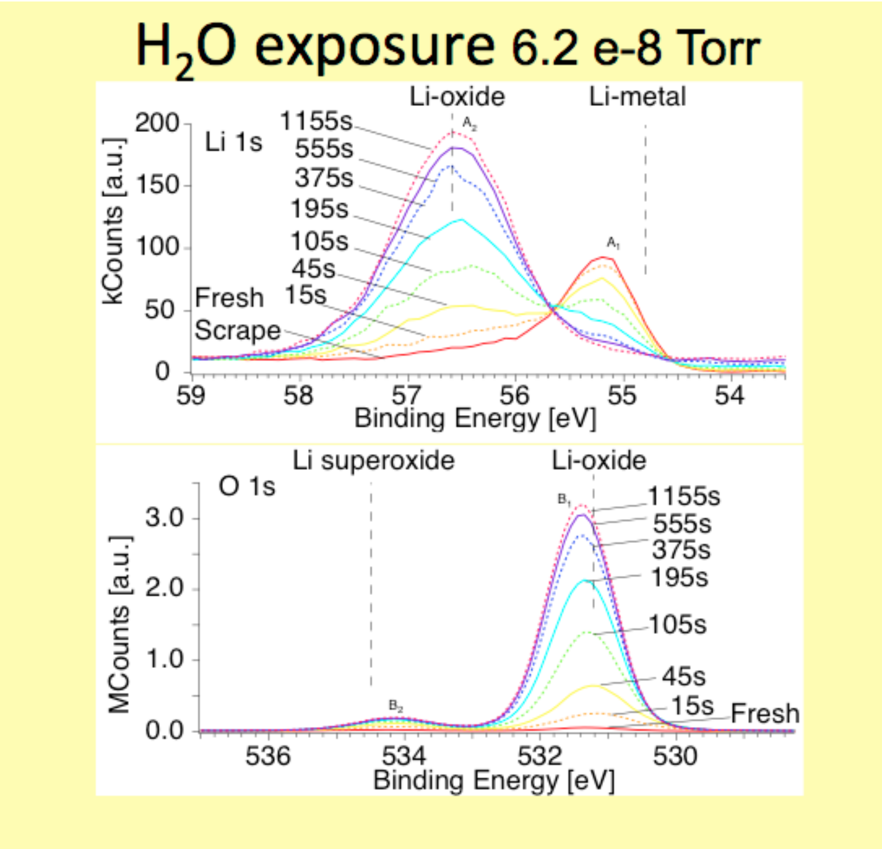

## XPS photoelectron range similar to D stopping range

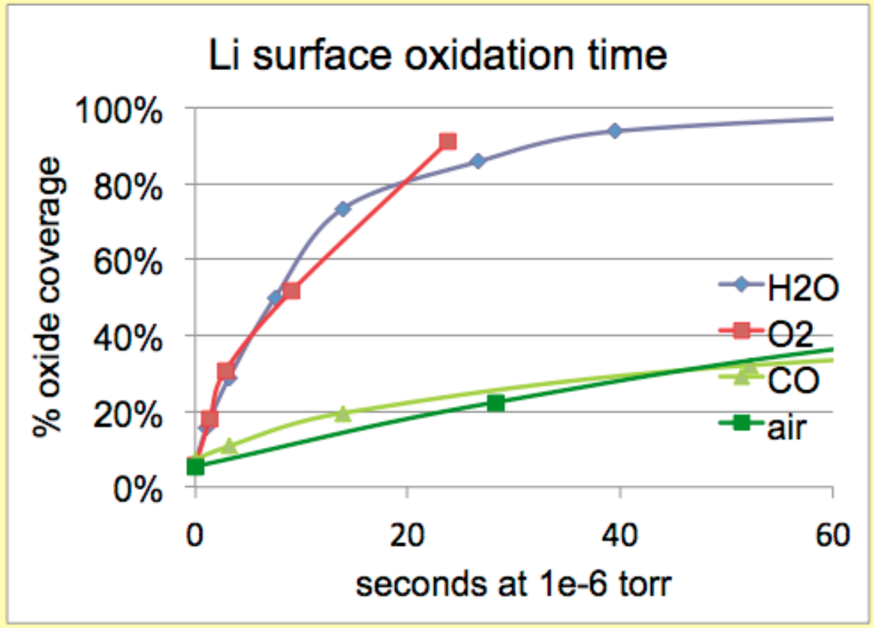



TRIM calculations M. Jaworski

Inelastic mean free path of XPS photoelectron in Li = 5.36 nm, in $Li_2O$ = 3.47 nm

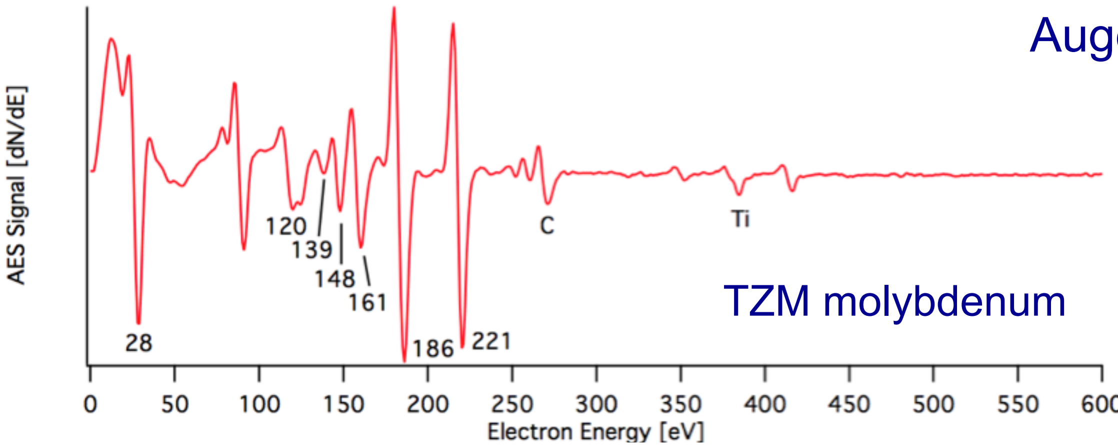
# Lithium oxide signal increases with $H_2O$ exposure time

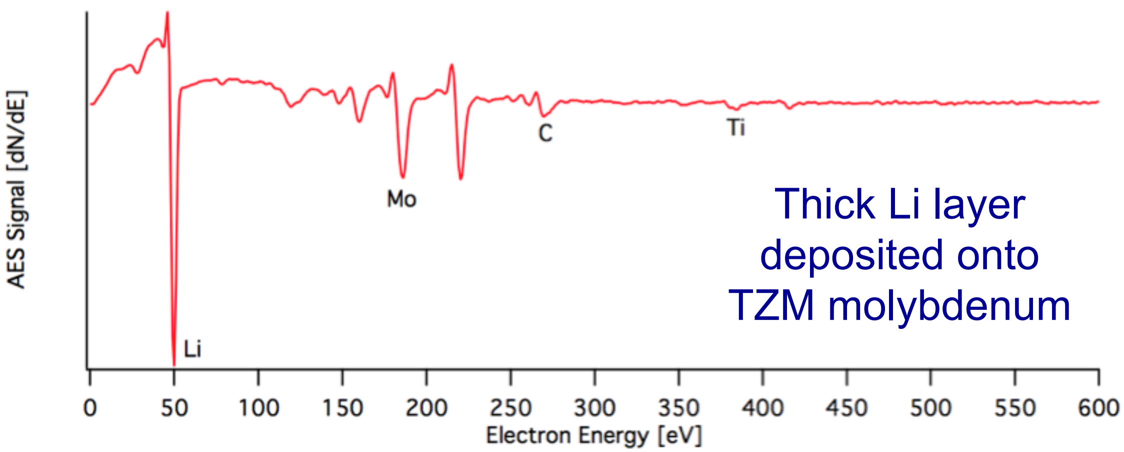


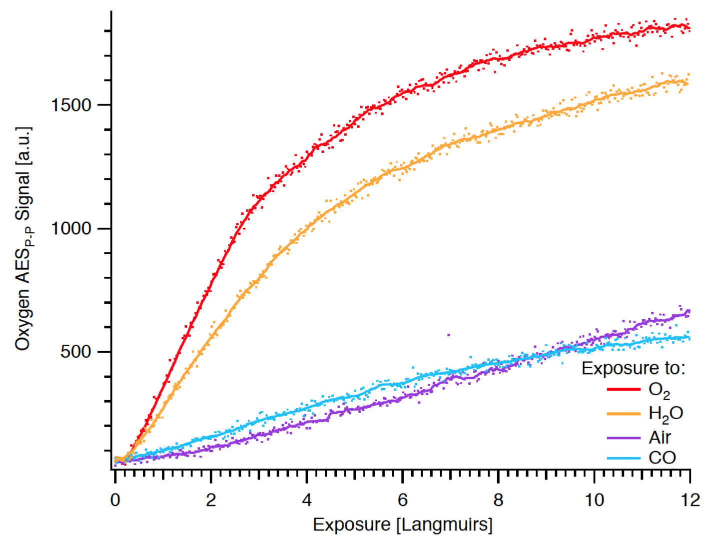
# AES studies of Li films on Mo

## Auger electron spectroscopy (AES)



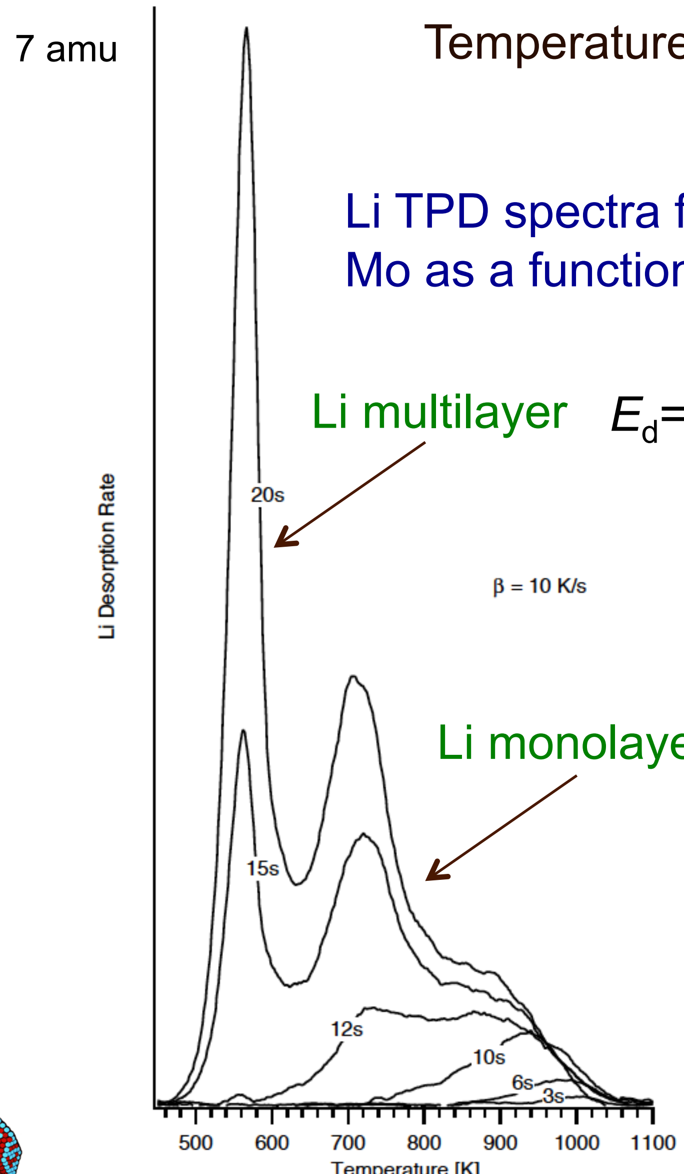




Oxidation of Li films on TZM molybdenum



# TPD studies of Li films on Mo

Temperature programmed desorption (TPD) mass spectroscopy




Li TPD spectra from Li on TZM Mo as a function of Li deposition

Li multilayer $E_d$=137 kJ/mol

Li monolayer $E_d$=179- 259 kJ/mol

# Summary and Future Plans

- A clean Li surface is oxidized to > 5 nm depth in 20 s by $10^{-6}$ torr of $O_2$ or $H_2O$. Oxidation from CO is much slower.
- After a typical NSTX shot the $H_2O$ partial pressure decreases from $3x10^{-6}$ torr – $3x10^{-8}$ torr with a corresponding oxidation time of 6 – 600 s.
- PFC surface after Li evaporation is a mixed material rather than a pure 'lithium coating'.
- Surface composition in flowing Li-PFC  system will depend on base vacuum pressure and Li flow rate.

## Future Plans:

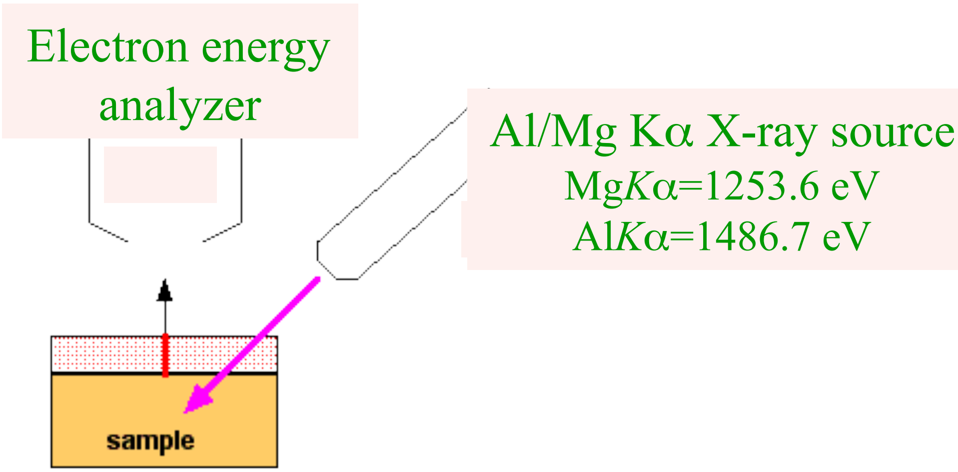
- Gas uptake kinetics and reaction rates on Li films, including effects of temperature, film thickness, and substrate type and preparation.
- Study effect of gas exposures on Li film thermal stability and wetting.
- Evaluate the thermal stability and decomposition mechanism of surface compounds formed from gas exposures
- Identify surface reaction products and compounds formed from gas exposures
- D atom, D ion, and D plasma sources to make D pumping measurements of clean and contaminated Li films on Mo

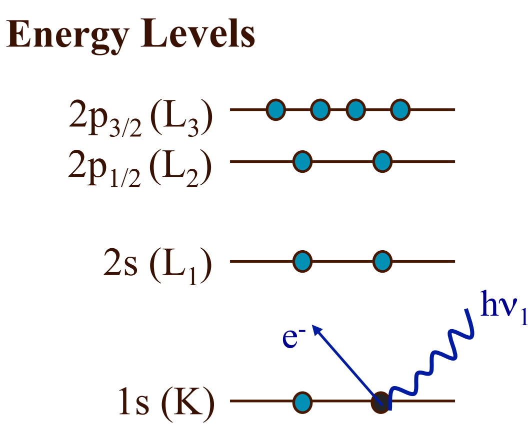
Goal: *D retention in Li  vs. residual gas exposure, substrate temperature and fluence for incorporation in SOLPS model (Canik)*

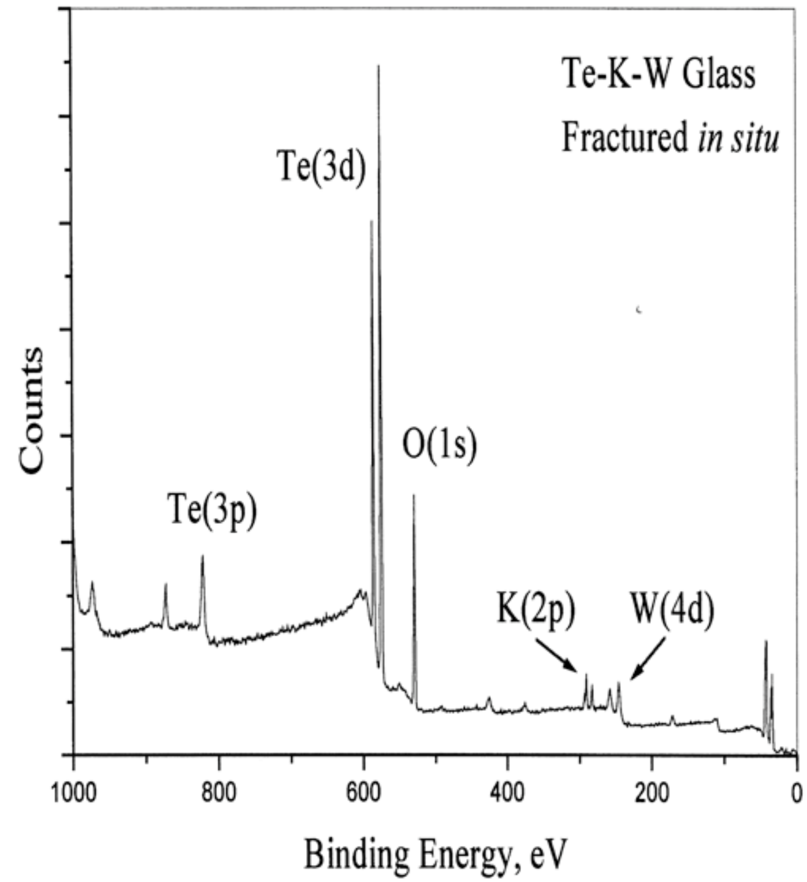
PPPL

# XPS studies of gas reactions with solid Li

X-ray Photoelectron Spectroscopy (XPS)*



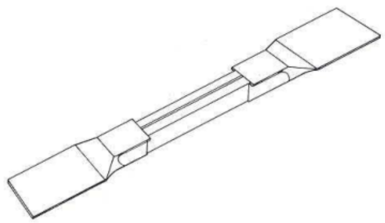



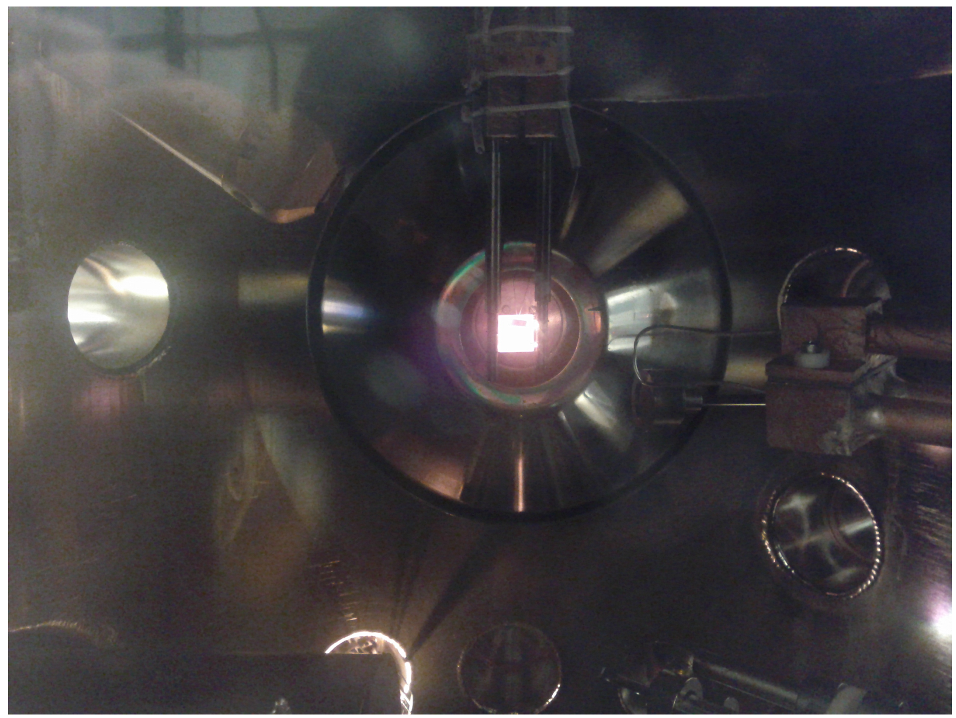

*Electron Spectroscopy for Chemical Analysis (ESCA)

# AES and TPD studies of Li films on Mo

SAES Li getter source

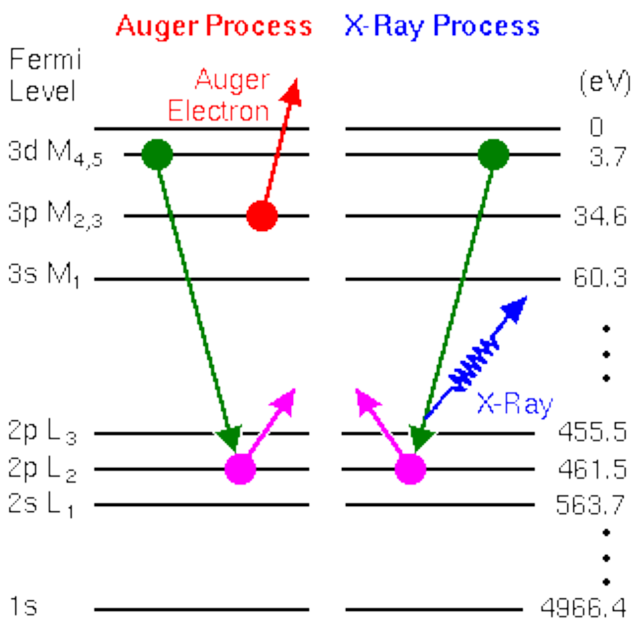



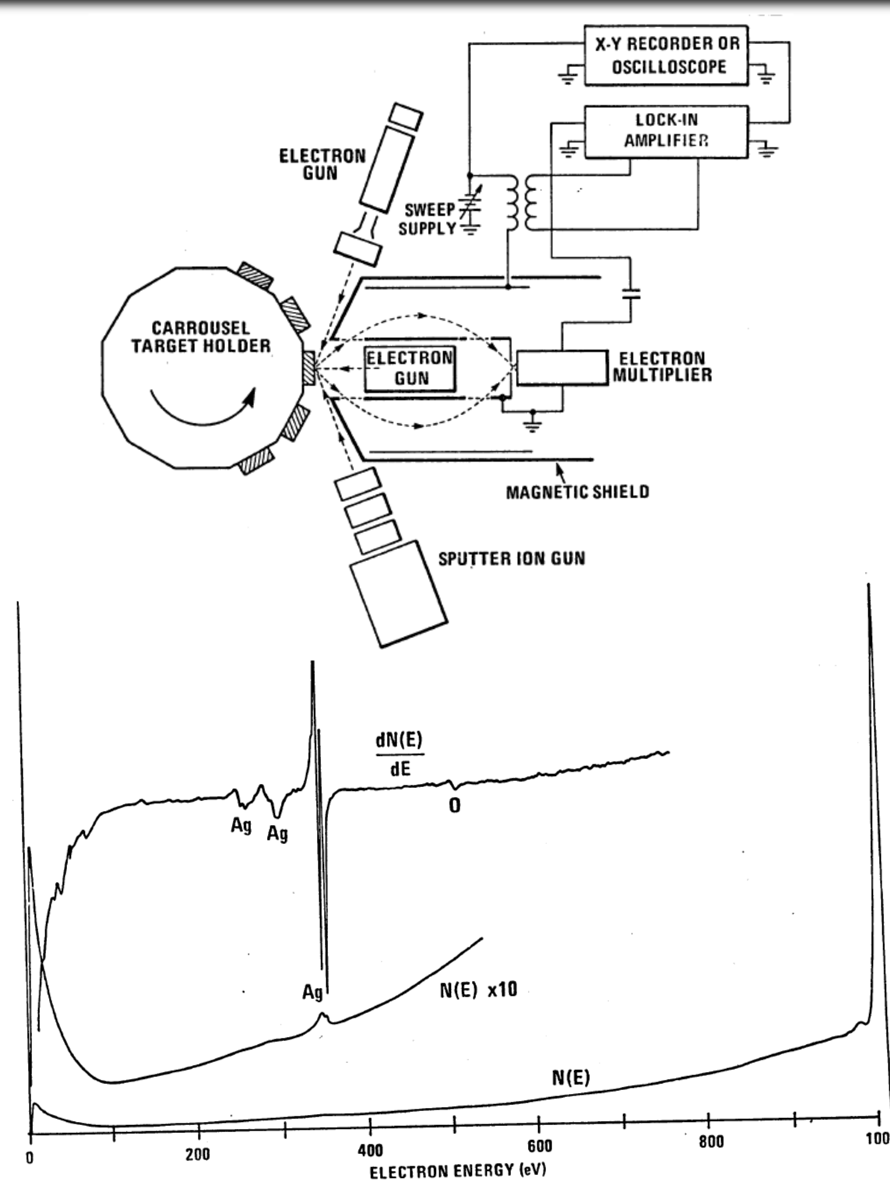
TZM Molybdenum sample



# AES and TPD studies of gas reactions with Li films on Mo

Auger electron spectroscopy (AES)



# Temperature Programmed Desorption (TPD)

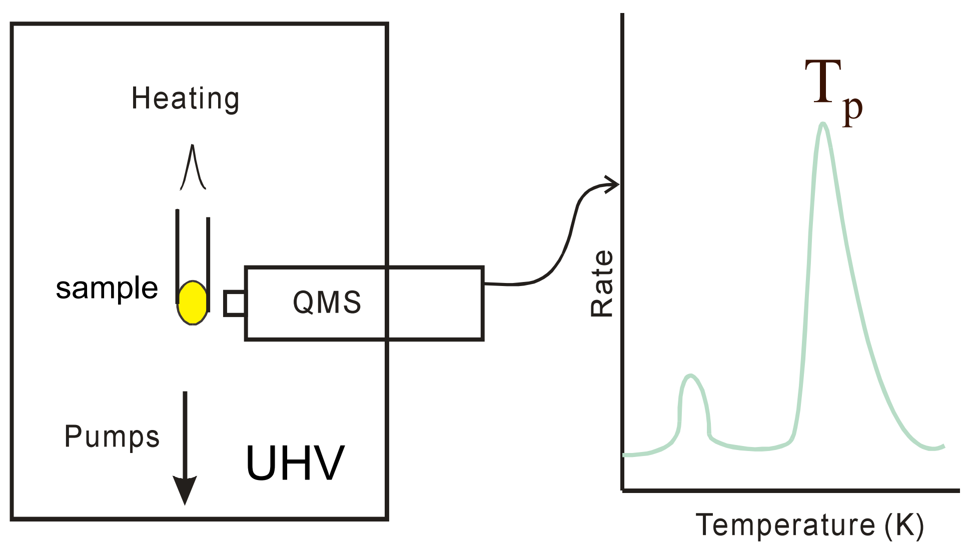
Desorption rate, $r_d = d\theta/dt = k_d\, \theta^n = \nu_n \exp -E_d/RT\, \theta^n$

$E_d$ = desorption activation energy

Heating rate, $\beta = dT/dt$

A surface is heated and a mass spectrometer is used to measure the products desorbing from the surface.

In a dynamically pumped system, the pressure is proportional to the desorption rate.




$$\frac{E_d}{RT_p^2} = \frac{\nu}{\beta}\exp\left(\frac{E_d}{RT_p}\right)$$

Information from TPD:

- reaction products & coverages
- reaction pathways
- desorption activation energies
- distribution of binding sites