Progress in the Flowing Liquid-surface Retention Experiment

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ALPS Meeting
November 17-20, 2003 Oak Brook, IL

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Talk Roadmap

- Brief description of FLIRE
- He retention measurements on FLIRE
- He diffusion measurements on FLIRE
- Concluding remarks

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DESCRIPTION OF THE FLIRE FACILITY

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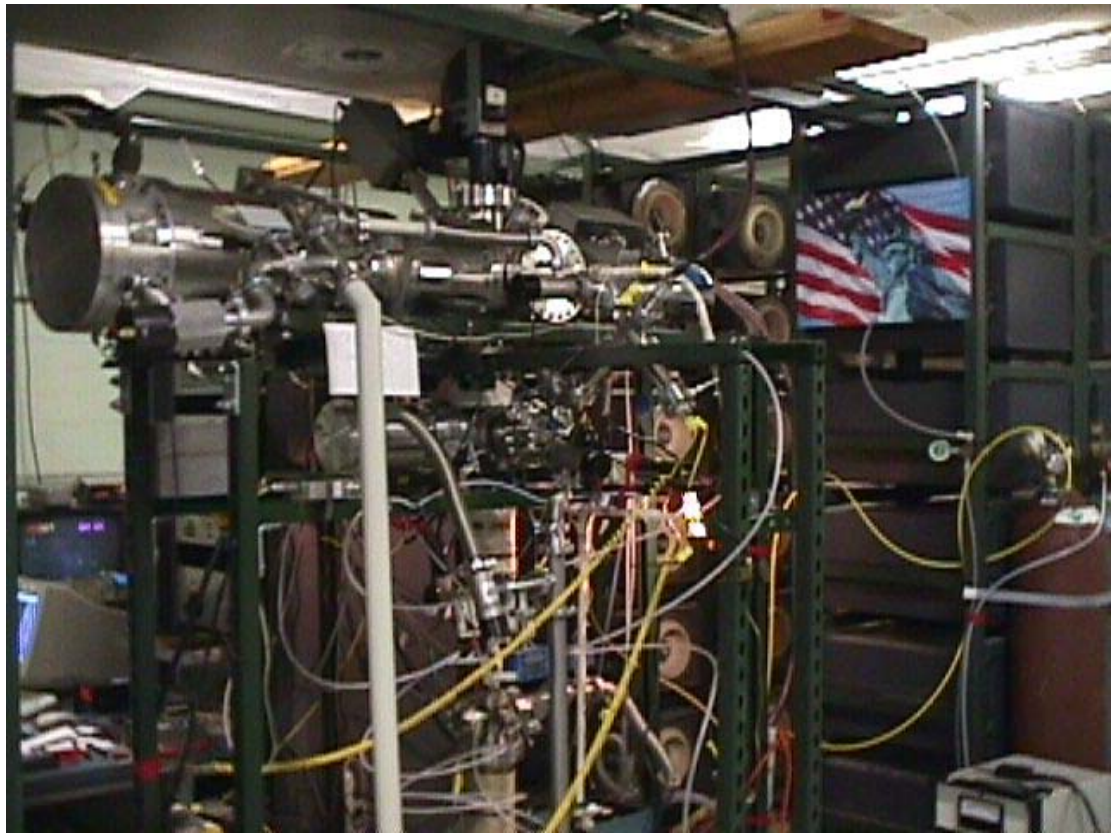
The FLIRE facility at UIUC

- FLIRE was built to study the interaction between flowing metal and an ion beam
- Construction started May 2001
- At this stage, low-current ion beam (2 – 3 μA)
- Metal flow velocities between 0.5 – 1.5 m/s



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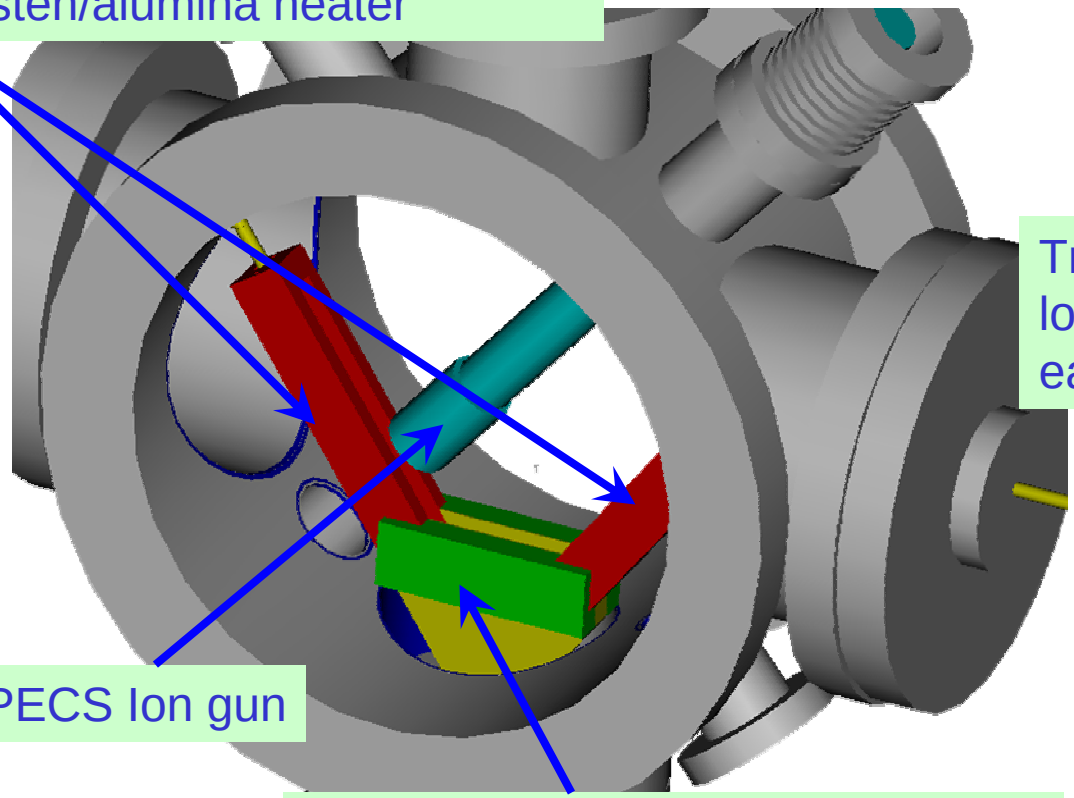
FLIRE Internal components

SS ramp slides into stainless steel bracket. Each ramp is heated by a tungsten/alumina heater



Transfer line tube from lower reservoir (one on each side)

SPECS Ion gun

SS bracket is welded to a 6” flange attached to the upper chamber

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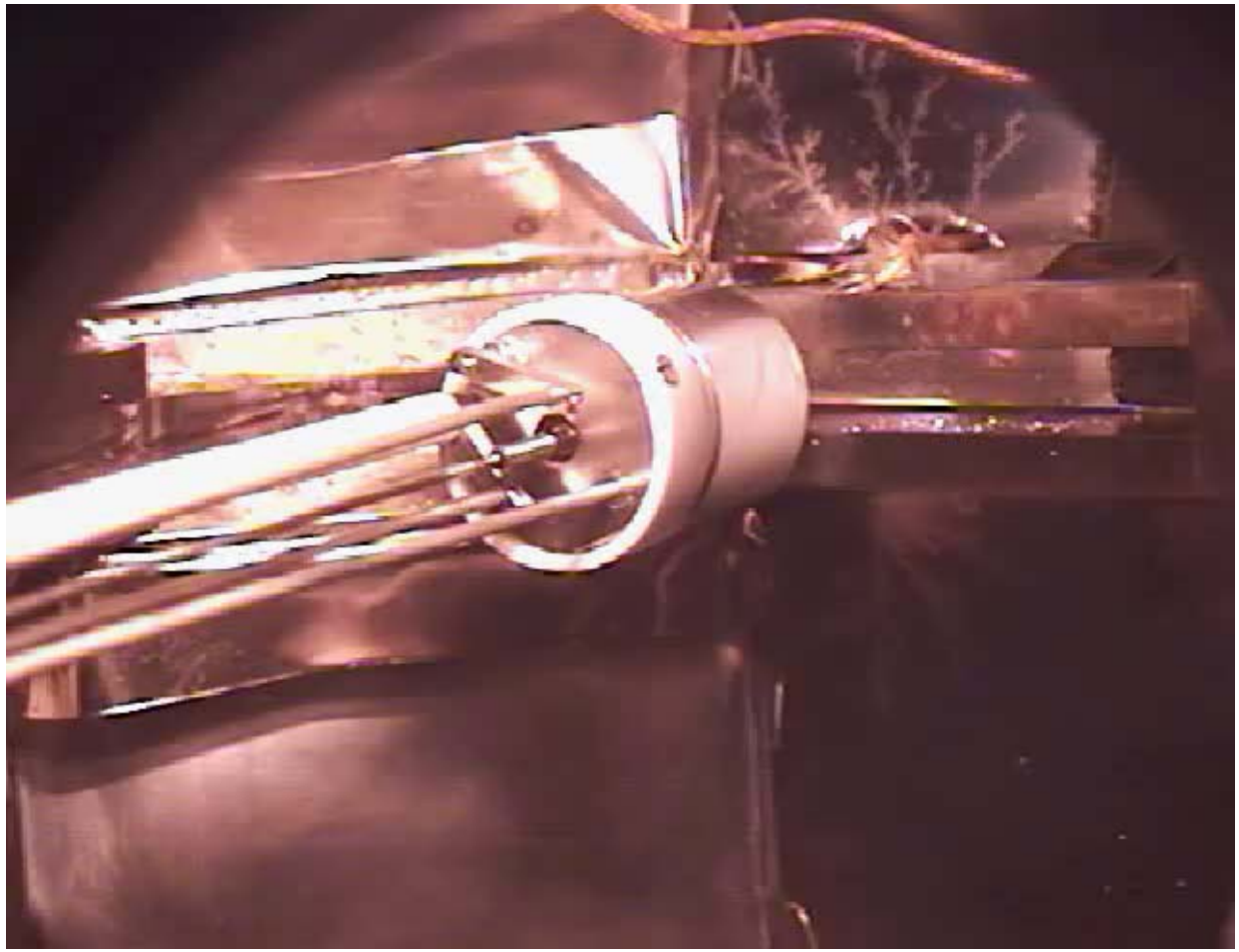
Lithium Flow with Ion Gun



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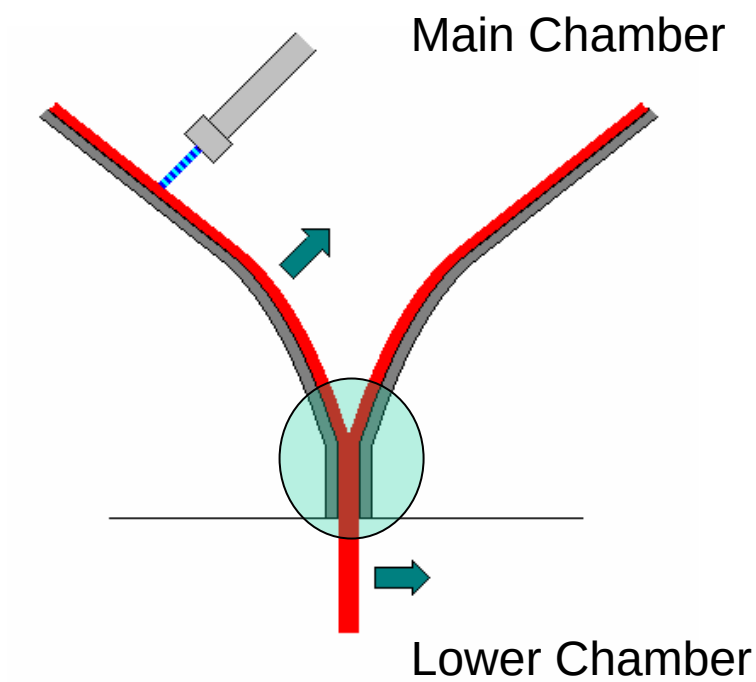
How FLIRE works

- Two SS ramps inside the main chamber, held by a bracket piece
- Small aperture connecting the two chambers plugged by molten Li from last run
- Li flows down the two ramps while bombarded with ion gun
- The metal seal between the two chambers is preserved
- Some implanted particles escape on the main chamber…
- … and some in the lower chamber
- Release in the bottom is measured with an RGA



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HELIUM RETENTION MEASUREMENTS

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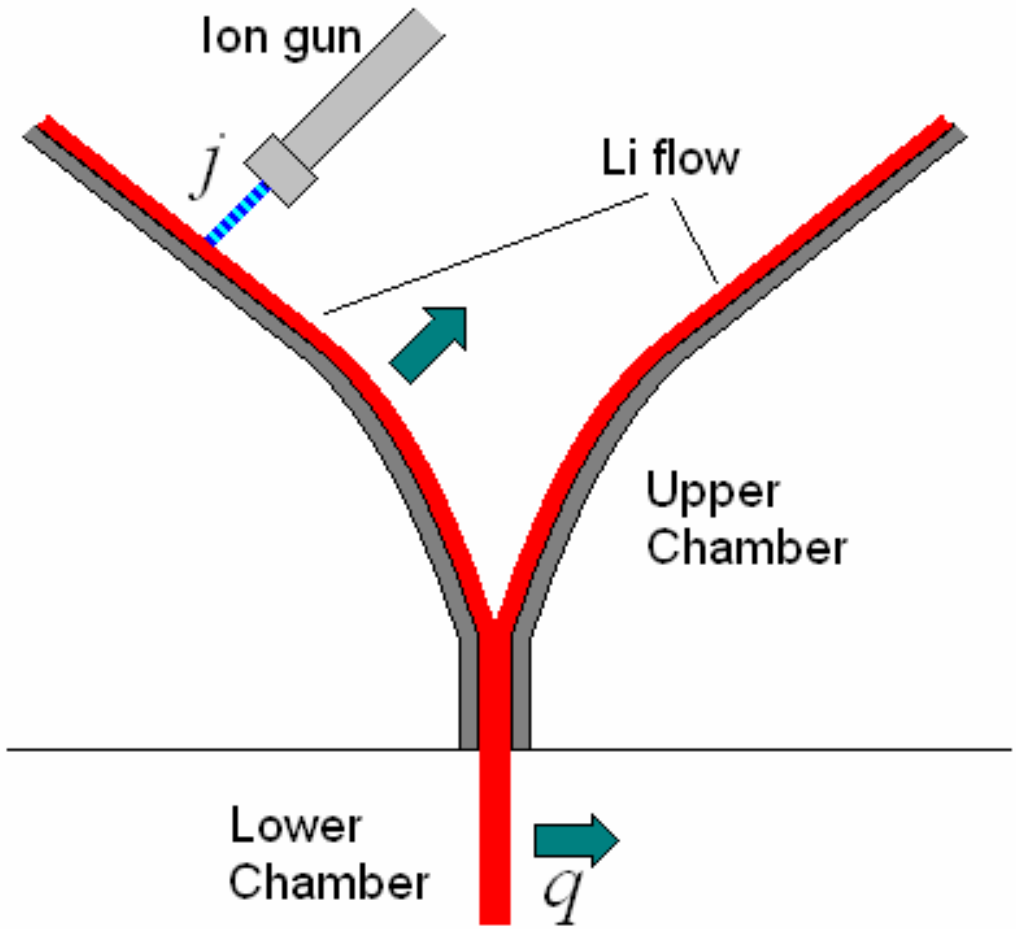
How retention is measured

- The retention coefficient is defined as:

$$R = \frac{q}{j}$$

q: release rate in the lower chamber

j: injection rate in the upper chamber



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Release rate in lower chamber

- The equation for the rate of change of He particles in the second chamber is

$$V\frac{dn}{dt} = q - \frac{P}{kT}S$$

At steady state, the time derivative is zero, so:

$$q = \frac{P}{kT}S$$

P: steady state pressure

T: He gas temperature

S: Pumping speed

k: Boltzman constant

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Assumptions for the calculation of retention

- Very small reflection (< 1% for all energies, calculated with VFTRIM)
- Constant pumping speed in the lower chamber
- Constant volume in the lower chamber
- No long-term trapping of He in Li (all He transported comes out immediately)

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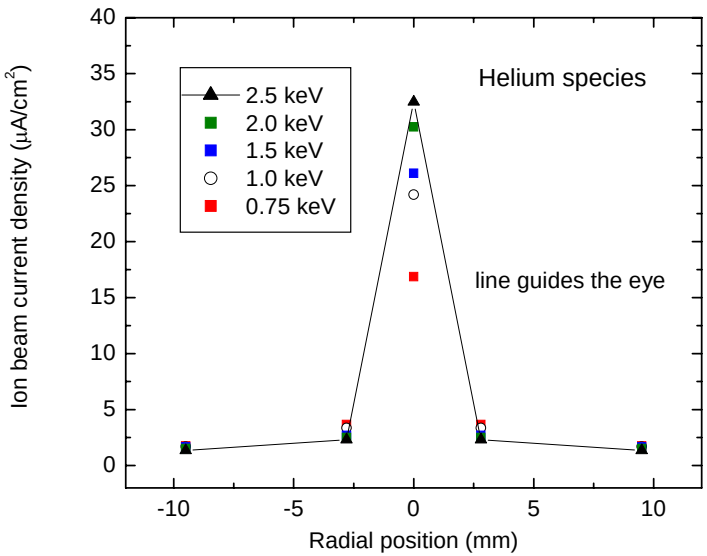
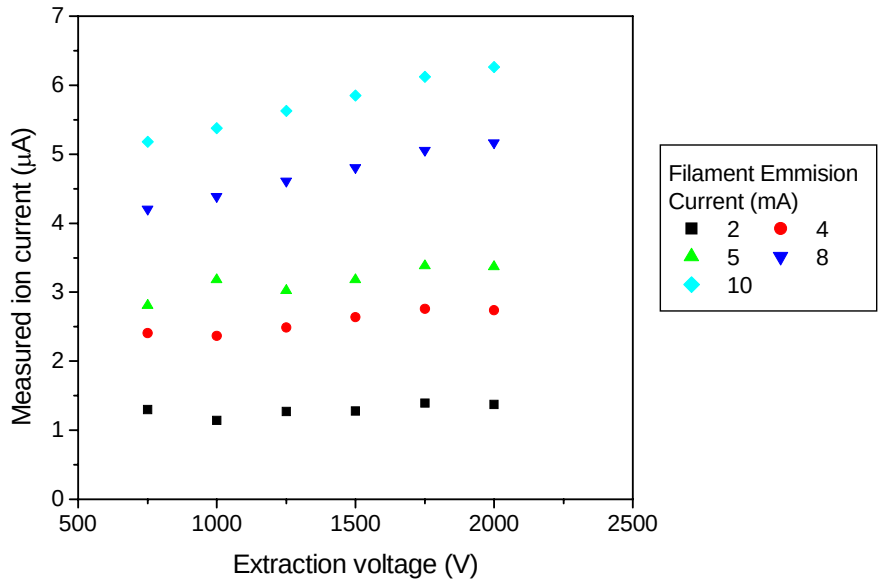
Ion beam data





- Hot filament source
- Beam radius under 5 mm
- Total current on the order of 3 μA @ 5mA filament emission setting (used in most measurements)

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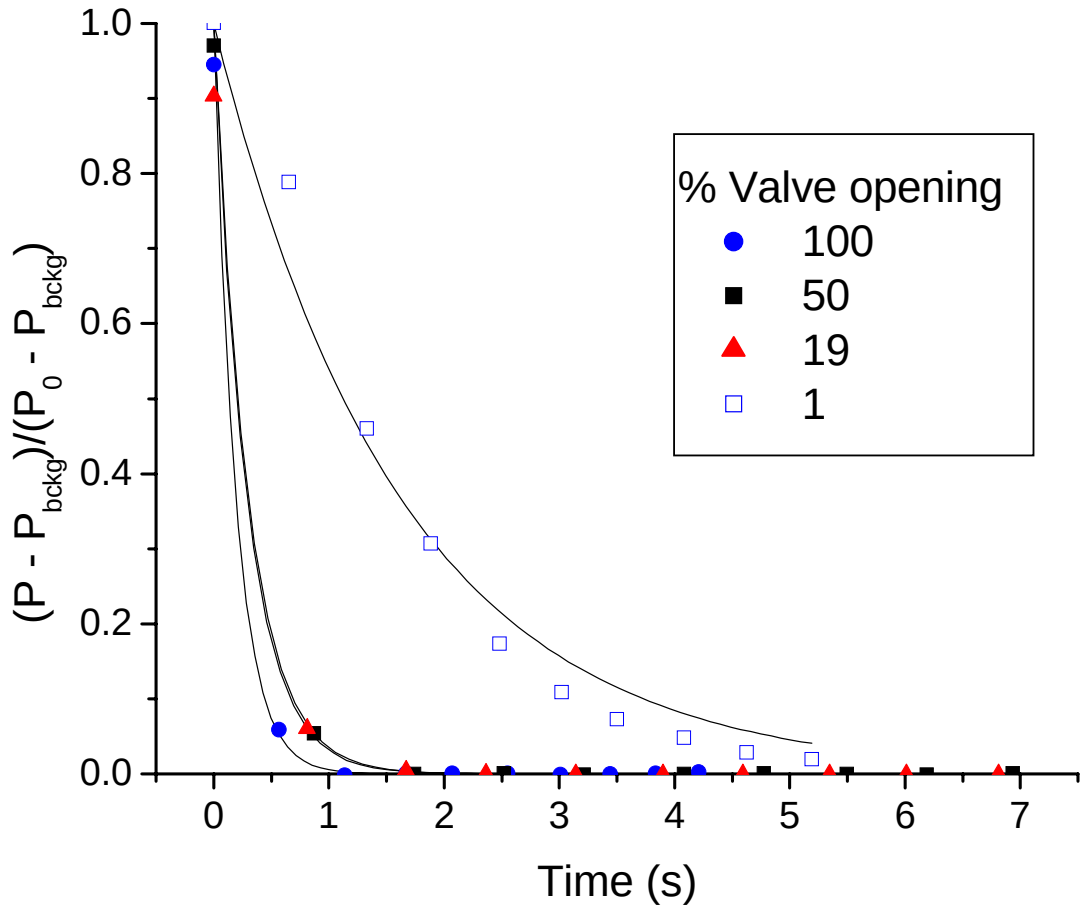
Pumping speed calculations

- Pumping speed is a critical parameter for retention calculations
- Originally, cryogenic pump was used to evacuate the lower chamber
- However, non-constant pumping speed represents a problem
- Turbomolecular pump w/ variable opening valve will be used now

TMP pumping speed



Smallest pumping speed is 4600 ± 300 cm^3/s

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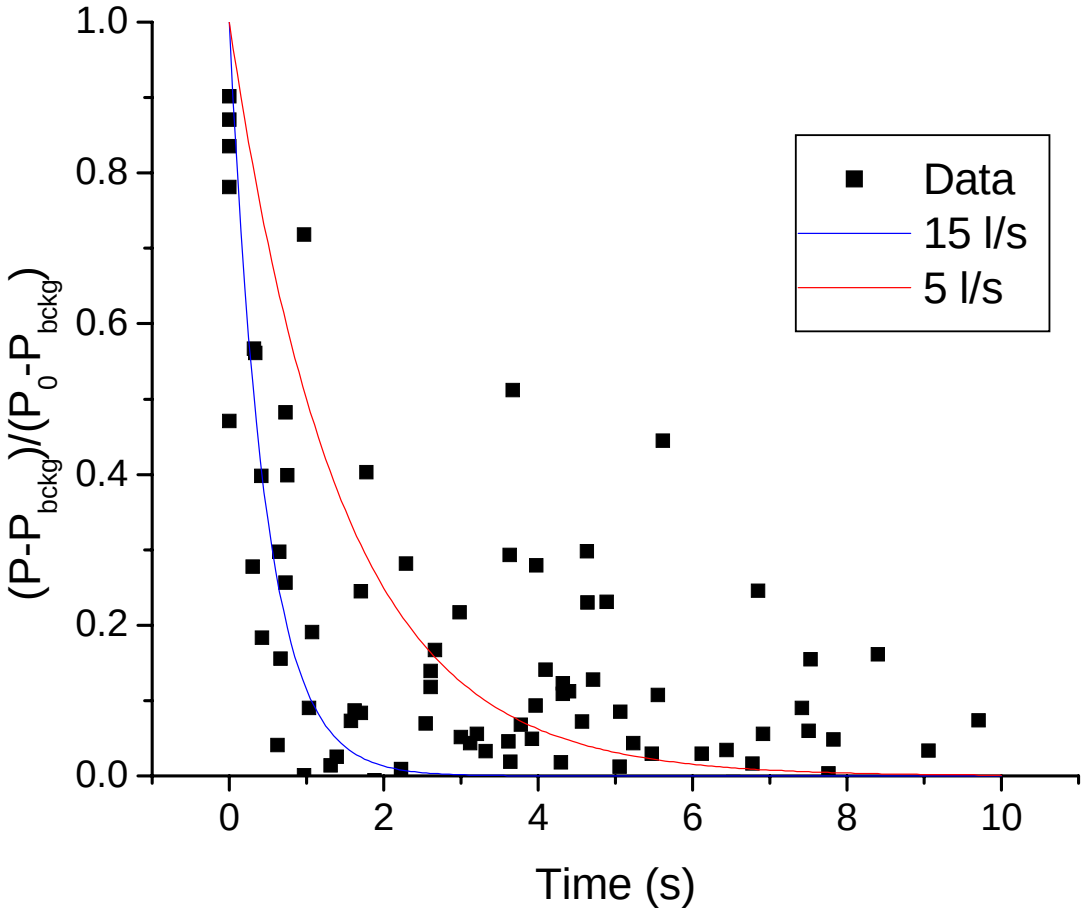
Cryo pumping speed



- Curve obtained from ends of multiple runs
- Pumping speed of 15 liters/sec! (too high?)

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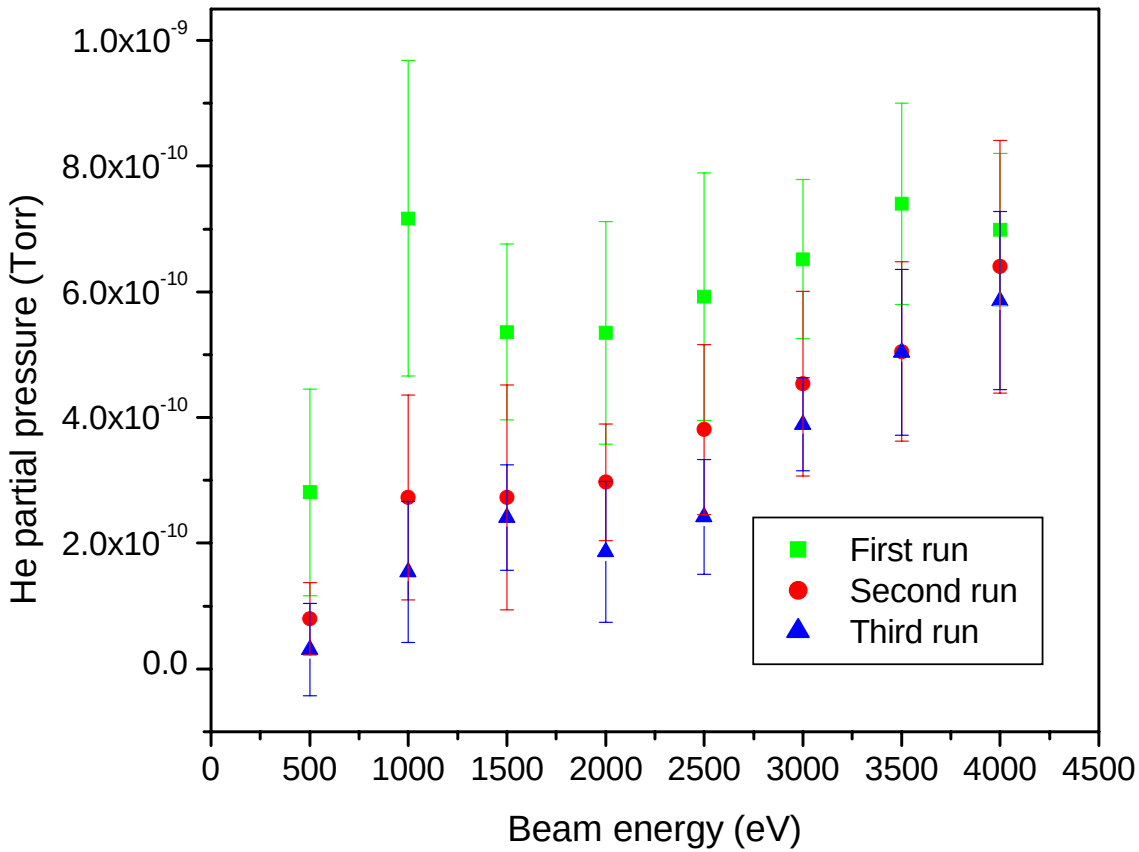
Effect of flow rate on retention

- Three runs per lithium charge
- Tank discharge conditions change between these three runs
- Second and third runs are similar, depending on conditions



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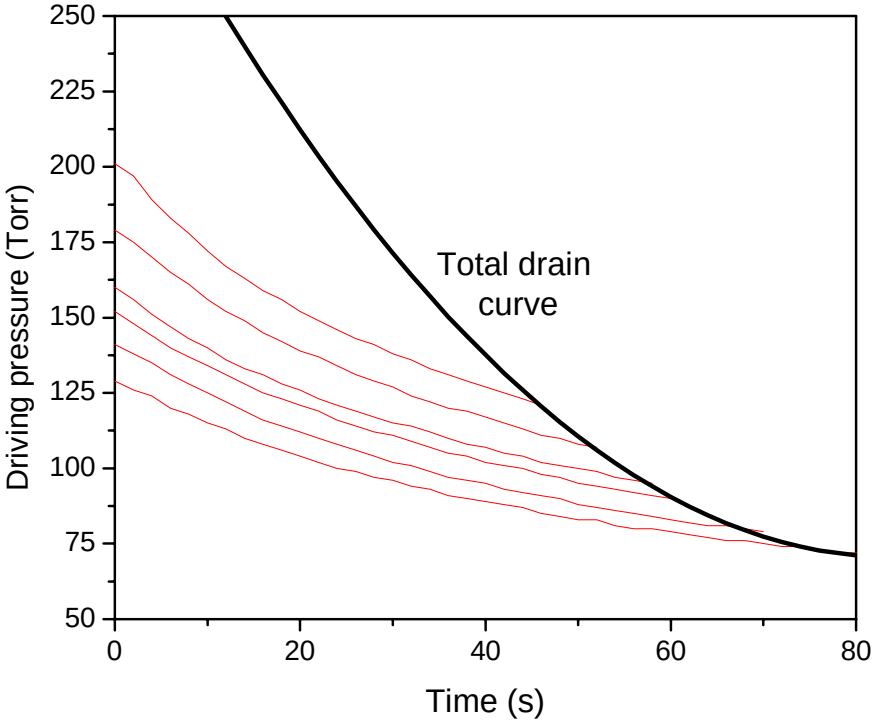
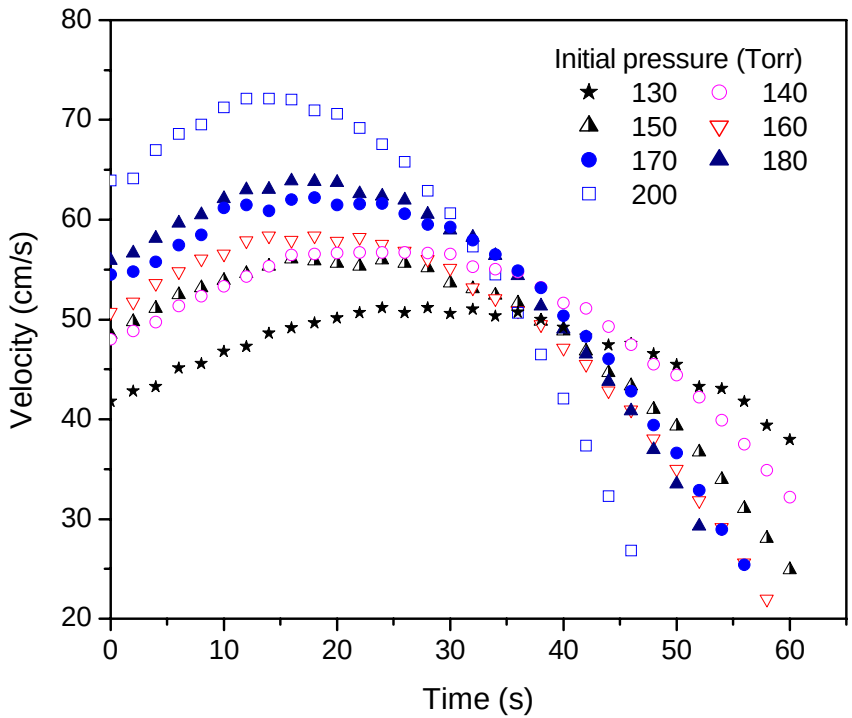
Driving pressure and flow rate evolution during tank drain





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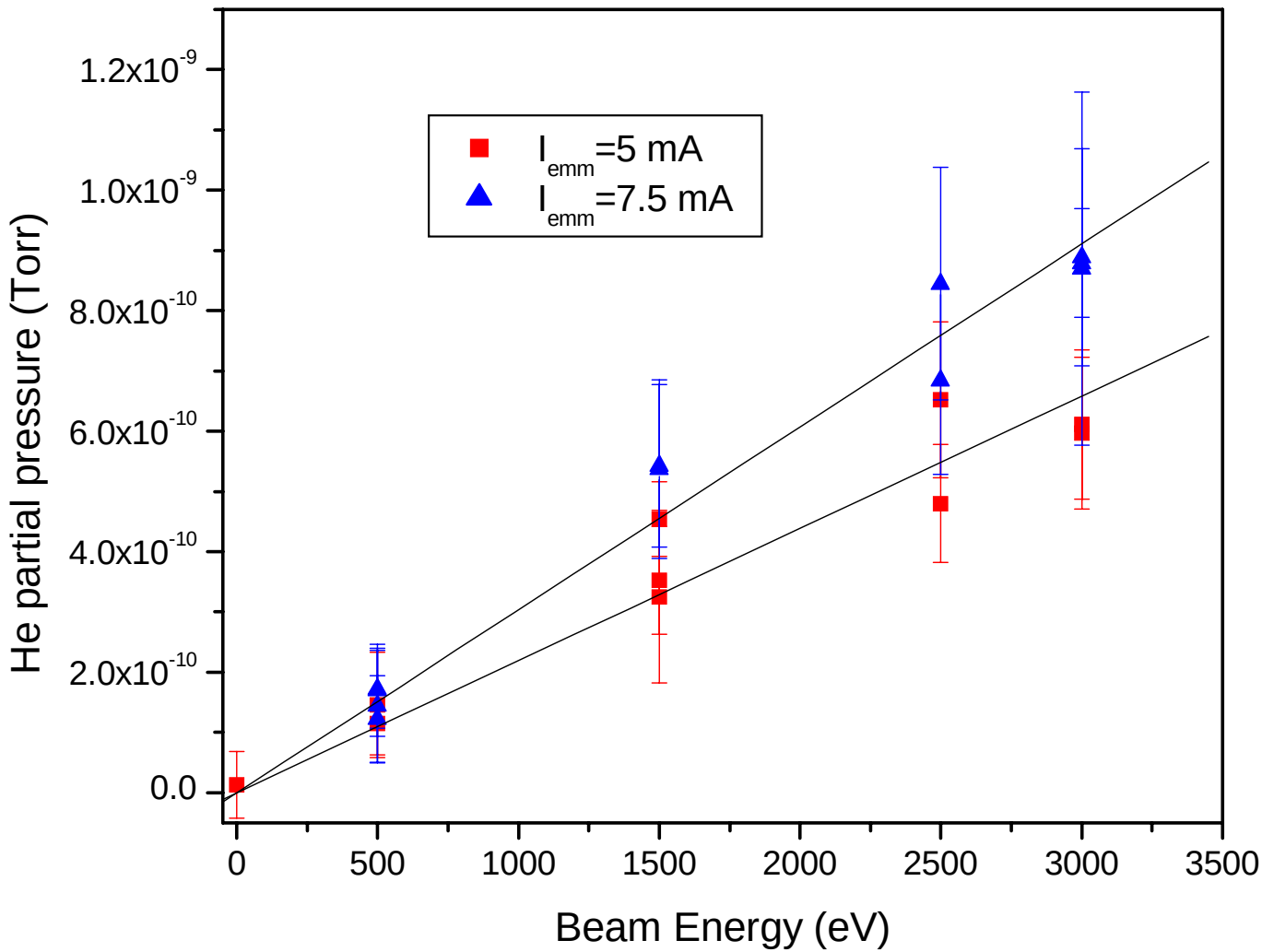
Retention for two ion currents



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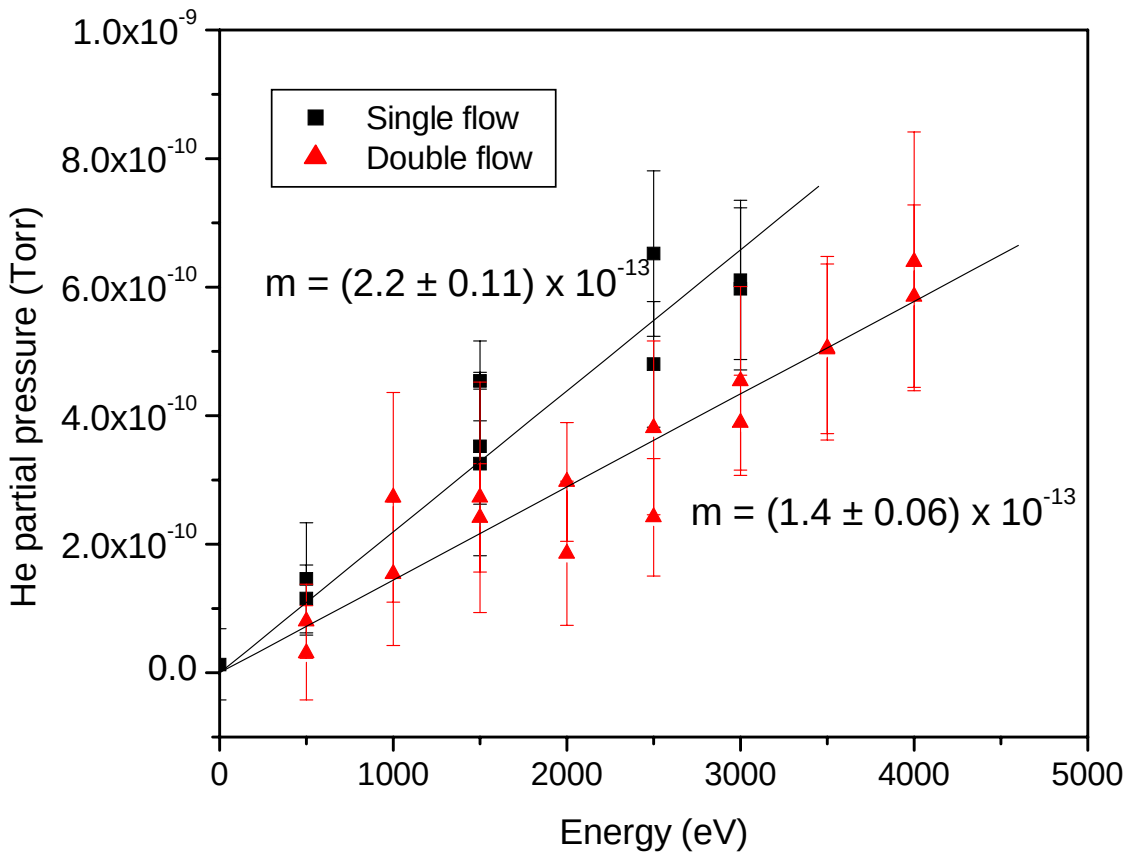
Retention is independent of irradiating flux

- Two data sets were taken for two different ion gun emission currents
- All other parameters are constant
- Ratio of emission currents is 2/3
- Ratio of slopes for the two sets is 0.72 ± 0.04
- Agrees with ratio from independent ion current measurements (also 2/3)
- Indicates independence with implanted current

Single vs double flow



- Single flow shows more retention
- May be related to the increase in velocity
- Ratio of slopes is close to $\sqrt{2}$ (twice the velocity for single flow)

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HELIUM DIFFUSION ESTIMATES

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Model for diffusion estimation

- Both diffusive and convective transport

$$v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial x^2} + G(x,y)$$

C: Concentration of implanted particles

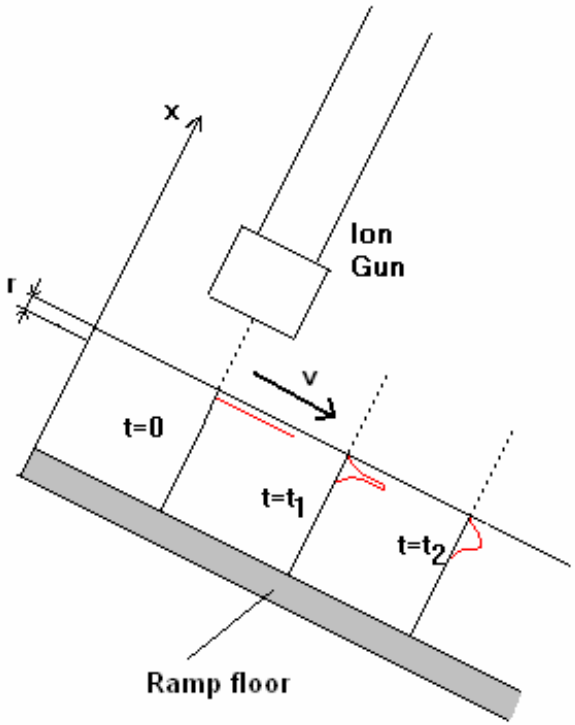
y: Distance parallel to the flow

x: Distance perpendicular to the flow

v: Flow velocity

D: diffusion coefficient

G: Particle source term



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Assumptions and boundary conditions

- Metal surface at x=0
- Semi-infinite domain
- Instantaneous release (valid only for monoatomic, inert gases, like He)
- Implantation occurs at y=0 and all particles are implanted at a distance r
- No significant amount of the relevant gas before implantation (y<0)
- Implantation volume is $W\,dx\,dy$

$$C(x=0,y)=0$$

$$C(x=\infty,y)=0$$

$$C(y=0,x)=0$$

$$G(x,y)=\frac{\phi}{W}\delta(x-r)\delta(y)$$

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Concentration profile and transport to lower chamber

- The general solution of the PDE describing the concentration is:

$$C = \int_0^\infty \partial\xi \int_0^y \frac{G(\xi,\eta)}{\sqrt{4\pi D(y-\eta)/v}} \left[\exp\left(-\frac{(x-\xi)^2}{4D(y-\eta)/v} \right) - \exp\left(-\frac{(x+\xi)^2}{4D(y-\eta)/v} \right) \partial\eta \right]$$

- Knowing the concentration profile C, the injection rate into the lower chamber q is evaluated as:

$$q = \int_0^\infty vC(x, y = y_0)dA = vW \int_0^\infty C(x, y = y_0)dx$$

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Expression for retention

- From the model the following expression for retention is obtained:

$$R = erf\left(\frac{1}{2}\sqrt{\frac{vr^2}{DL}}\right) \approx \frac{r}{2}\sqrt{\frac{v}{DL}}$$

$$D = \frac{vr^2}{4LR^2}$$

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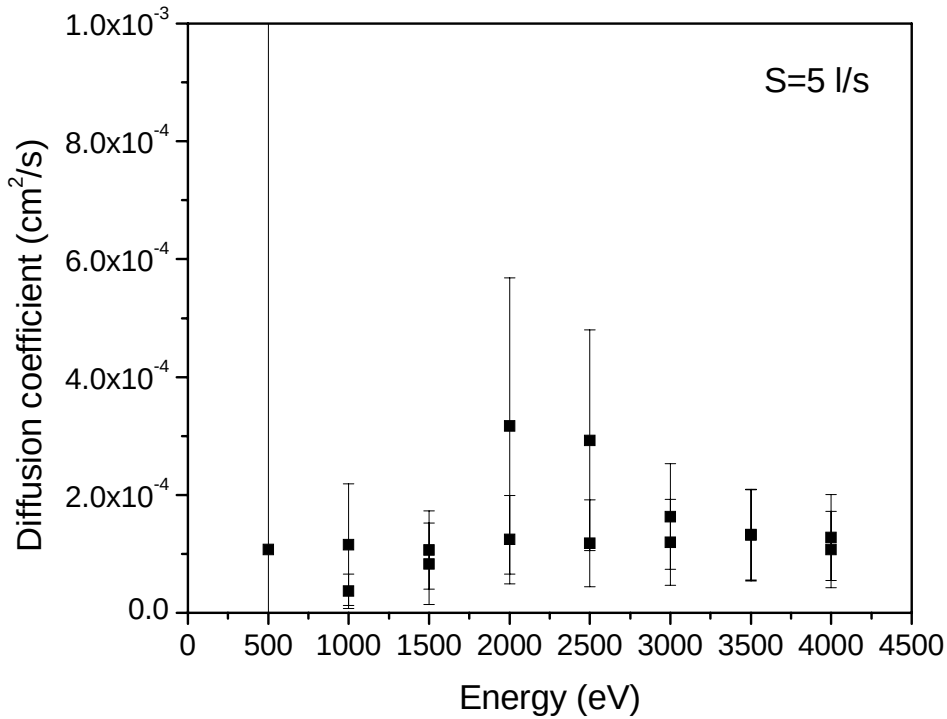
Diffusion coefficient values

- Numbers are low due to very high pumping speed
- Qualitatively, D does not depend on E (as it should be)
- Accurate measurement of pumping speed is needed
- Switch to turbopump will improve the accuracy



- v = 60 ± 15 cm/s (140 Torr driving pressure)
- L = 10 cm ± 10%
- Double flow

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CONCLUDING REMARKS

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Unresolved issues

- Model for retention assumes all the He comes out
- This fact is not confirmed yet
- 1D Simulations appear to show that only a fraction of He comes out promptly
- TDS experiments for He will be performed soon to look for subsequent release of He

Concluding remarks

- Qualitative behavior of retention and diffusion coefficients match the one expected from model
- More accurate pumping speed values are required to verify the magnitude of measured coefficients
- Issue of long-term He release needs further study
- Model can be modified to account for He not released promtply

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Concluding remarks (cont'd)

- Hydrogen retention experiments on FLIRE have commenced (see W. Olczak's talk)
- TDS system has been tested
- Will be used to show if He is trapped long-term inside the material

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