Particle retention of flowing liquid lithium in FLIRE

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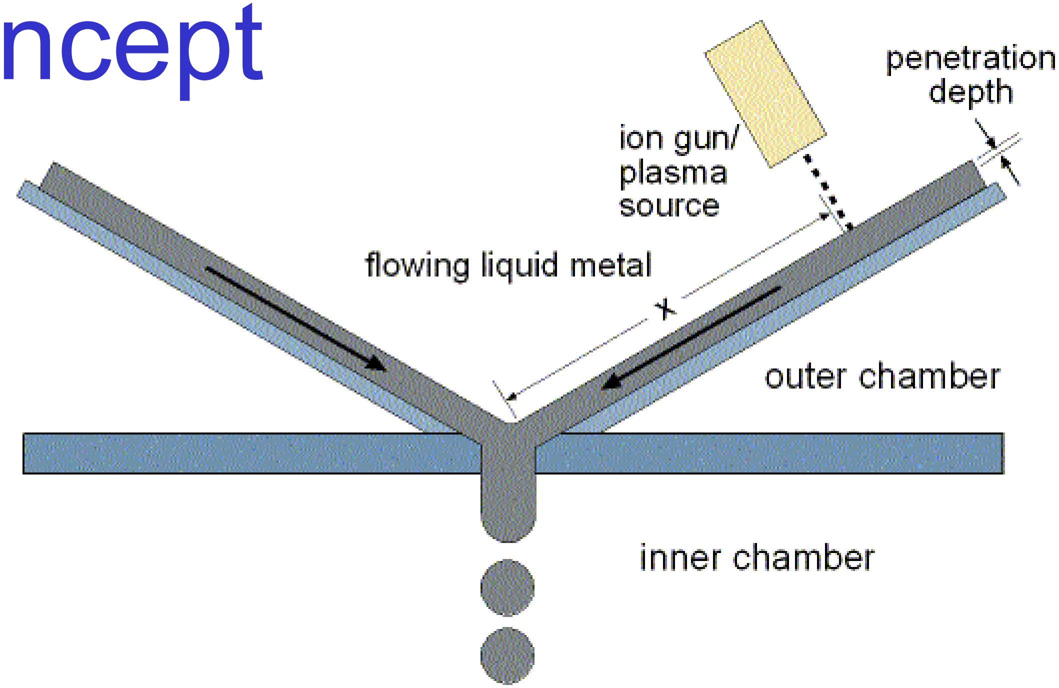
Outline

- Goals and Objectives of the FLIRE facility
- FLIRE Experiment Set-up and Data Analysis
- He retention in flowing liquid lithium
- H retention in flowing liquid lithium
- TDS/Purification system design
- Plasma-liquid interactions: current progress
- Future plans and upgrades
- Phase I FY 2003 proposals related to FLIRE facility
- PMI-UIUC FY 2002 Milestones
- PMI-UIUC Budget

FLIRE (Flowing LIquid Retention Experiment) Goals

- FLIRE is providing fundamental data on the retention of He, H, and other gases injected by an ion beam into flowing liquid surfaces such as lithium (ALPS funding and Phase I STTR grant).
- FLIRE will has been upgraded to use a plasma source to generate the incident particles and associated effects (Phase II STTR grant just begun).
- Further upgrades will modify the experiment to:
  - Study high-flux phenomena such as ELMs and disruptions
  - Implement new diagnostics to measure: LM film thickness, erosion, surface temperature gradients among others.
  - Study the ability to flow liquid metals through magnetic field gradients in addition to studying effects of eddy-currents

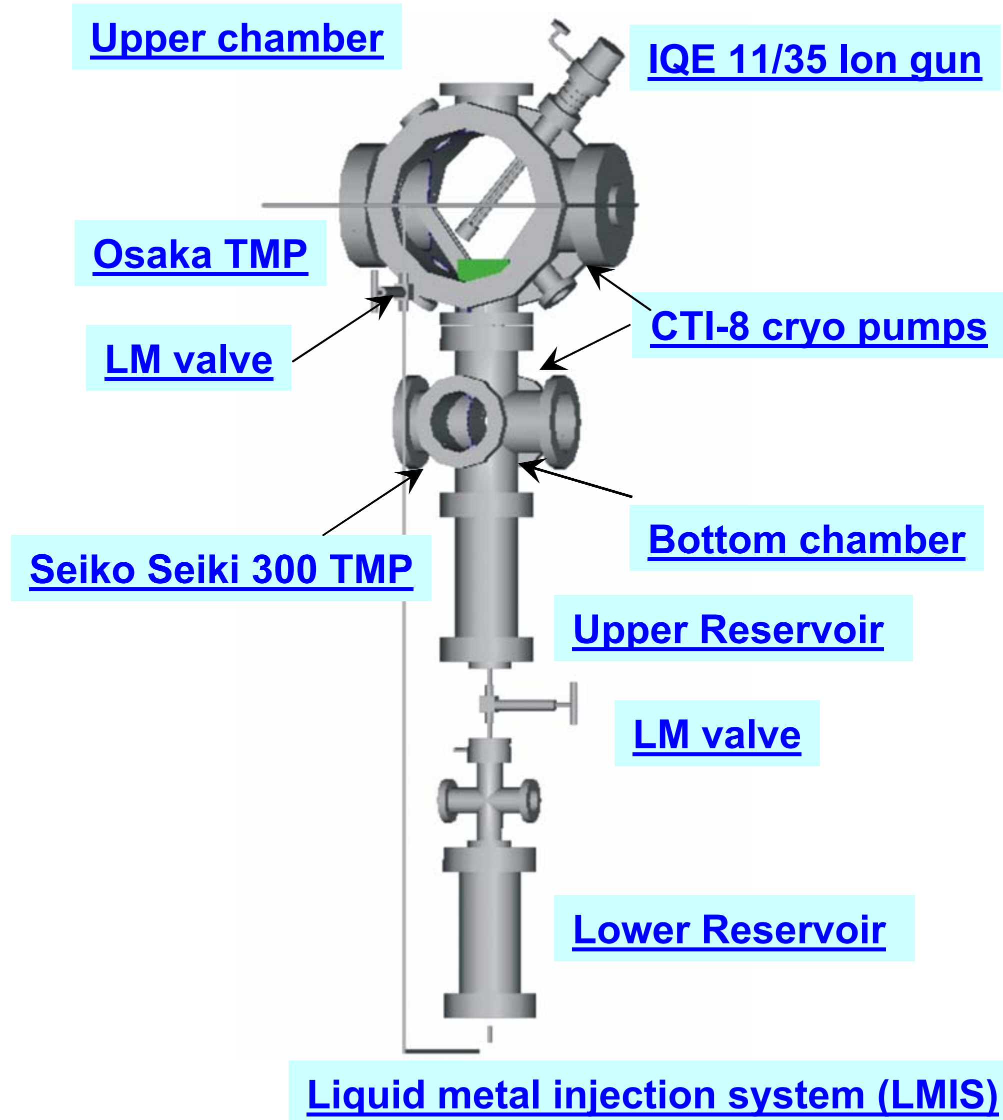
FLIRE concept



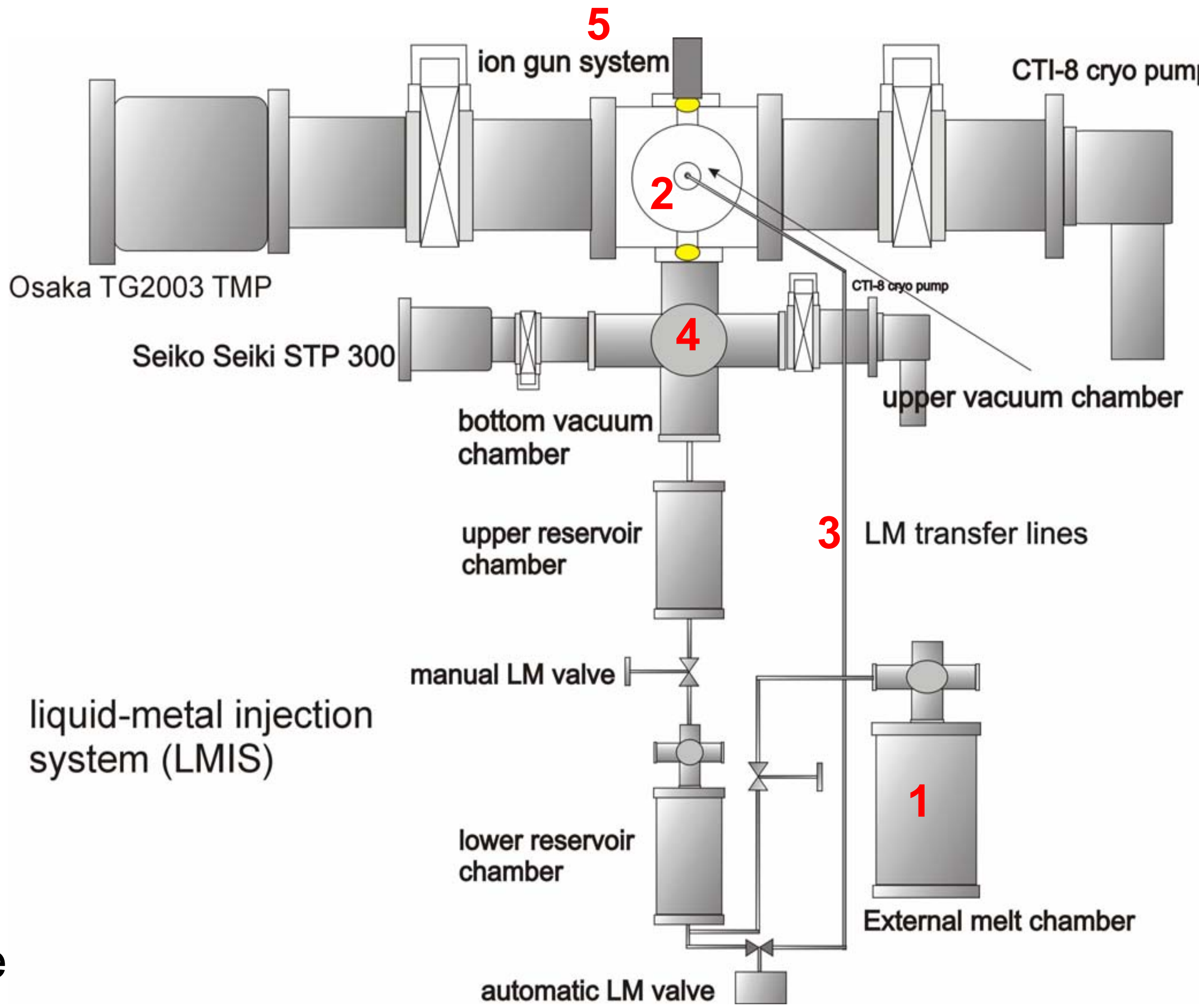
- The flowing liquid metal creates a vacuum seal between the upper and bottom chambers.
- Two ramps are provided to ensure the surface layer in which H/He particles are trapped, folds into the middle of the flow and travels to the bottom chamber.
- Flow can last between 20-60 seconds, then is recharged.

General FLIRE Experimental Design

- The vacuum system is composed of 2 TMPs and 2 cryo pumps.
- SPECS IQE 11/35 Ion gun source provides 10^{14} ions/cm^2/sec.
- Upper and lower chamber are connected by 0.3 cm^2 orifice.
- Upper and lower reservoirs hold and transport liquid Li
- RGA-QMS system for both chambers
- LM compatible valves



- Lithium loading procedure designed with use of external melt chamber and argon flow in a glove box
- Melting procedure melts lithium under argon atmosphere
- Once melting is in place,the liquid is transferred to the lower reservoir
- Then liquid Li is injected from the lower reservoir to the main chamber



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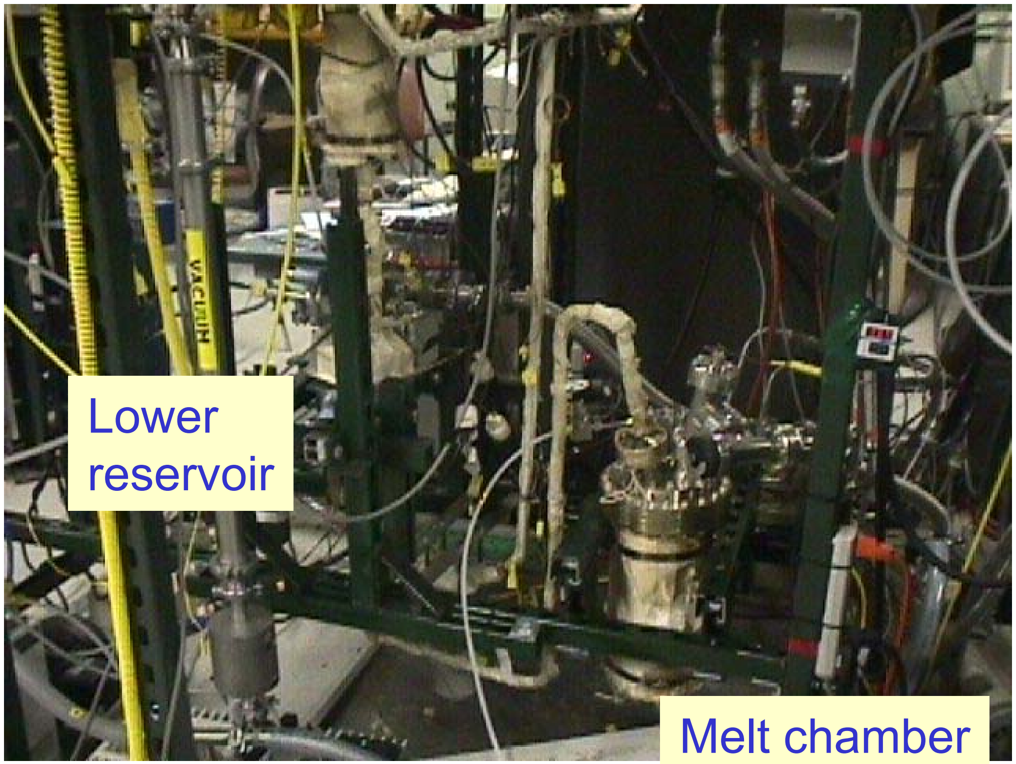
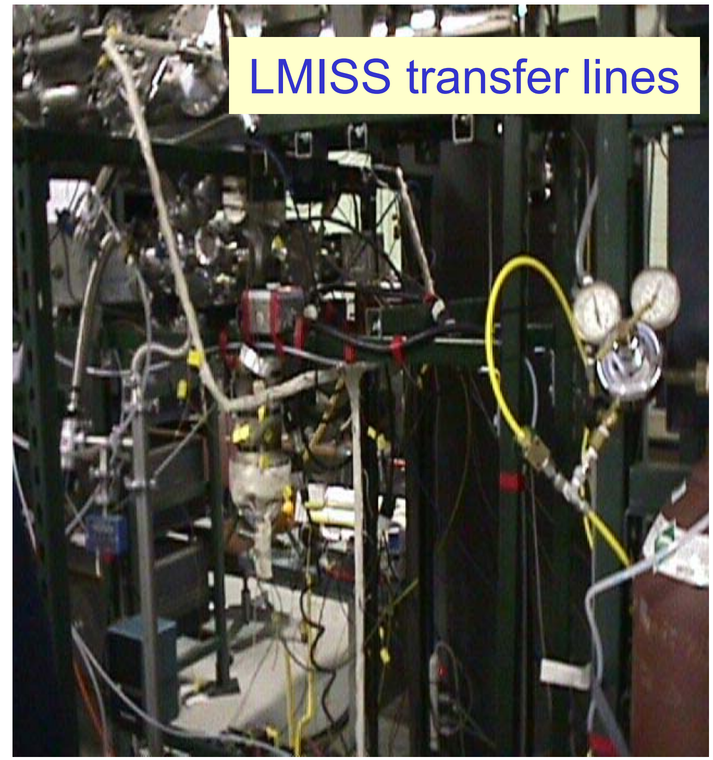
Liquid Metal Injection/Storage System





- LMISS consists of an external melt chamber with transfer lines heated to ~ 300 °C connected to lower reservoir shown on left.

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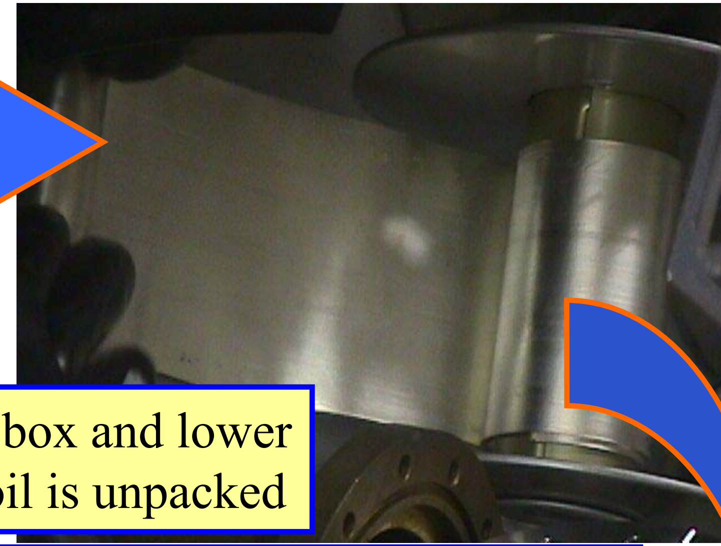
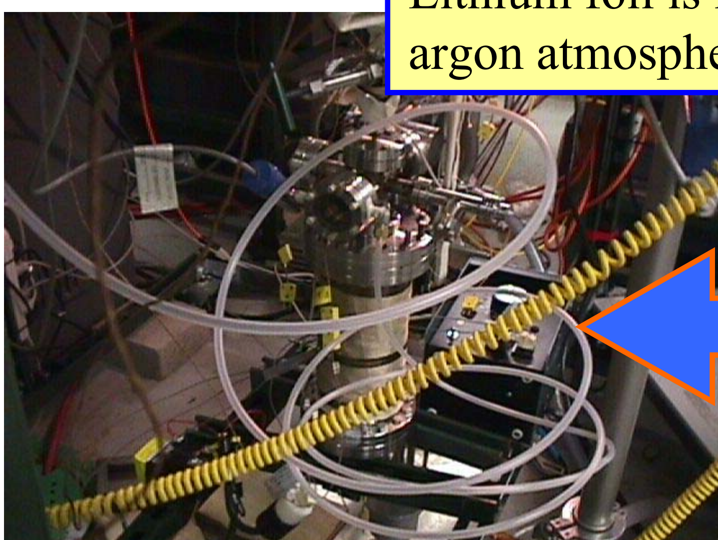
Lithium loading procedure in FLIRE



Argon flows in glove box and lower reservoir as lithium foil is unpacked

Lithium foil is inserted into the lower reservoir under argon atmosphere and then is installed on FLIRE



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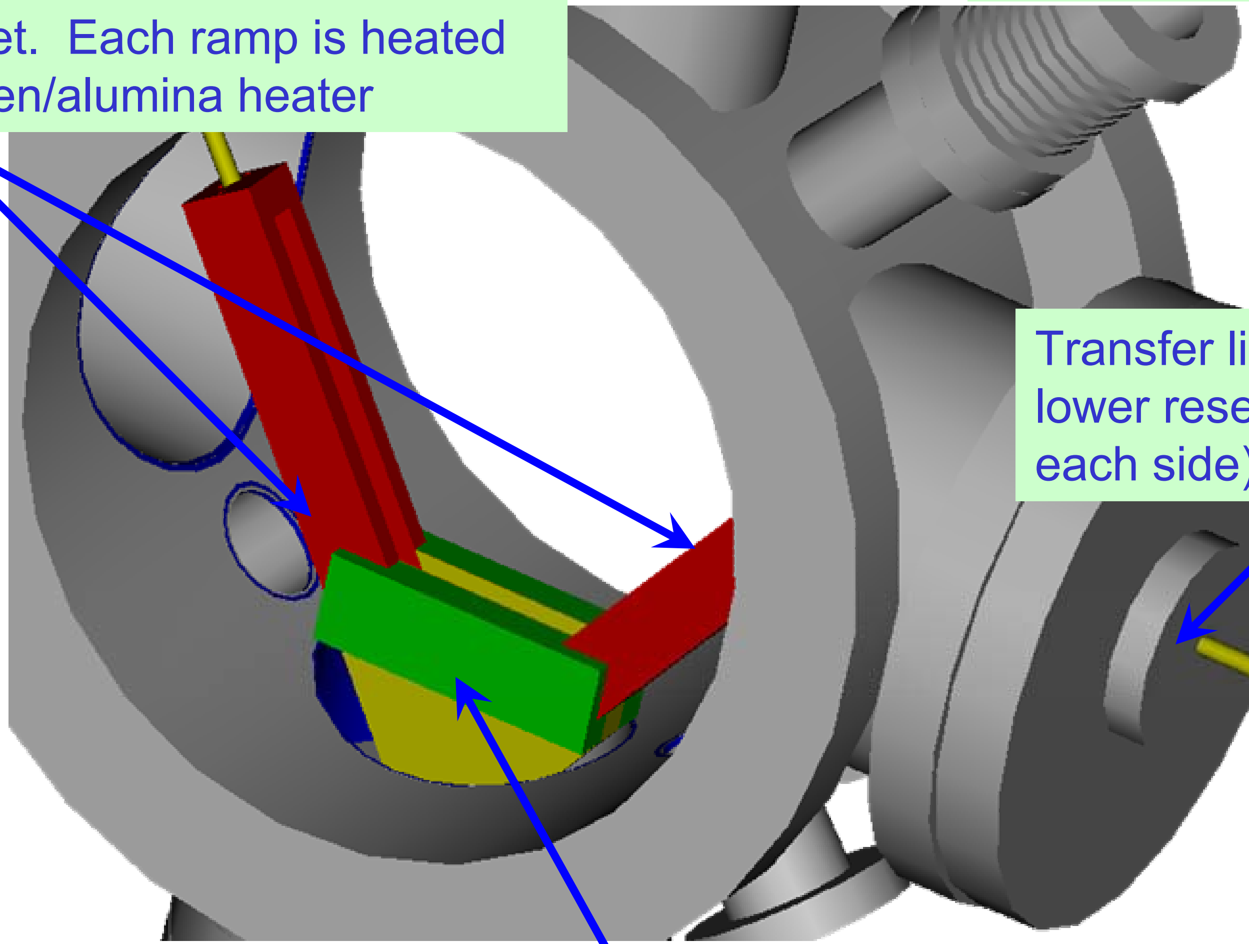
Liquid metal injection system ramps and bracket



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Lithium flowing down the ramps (see nogun.mpg)

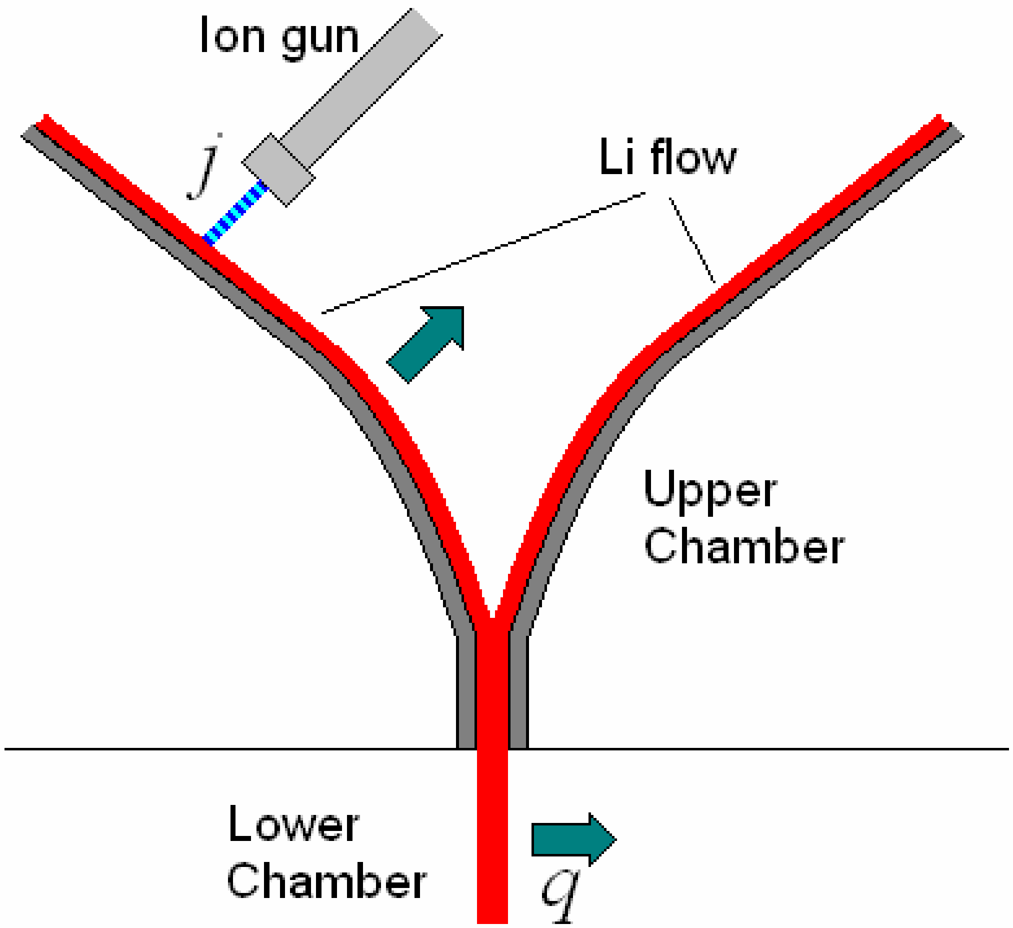
Definition of retention coefficient

- The retention coefficient is given by:

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

q: release rate in the lower chamber

j: injection rate in the upper chamber



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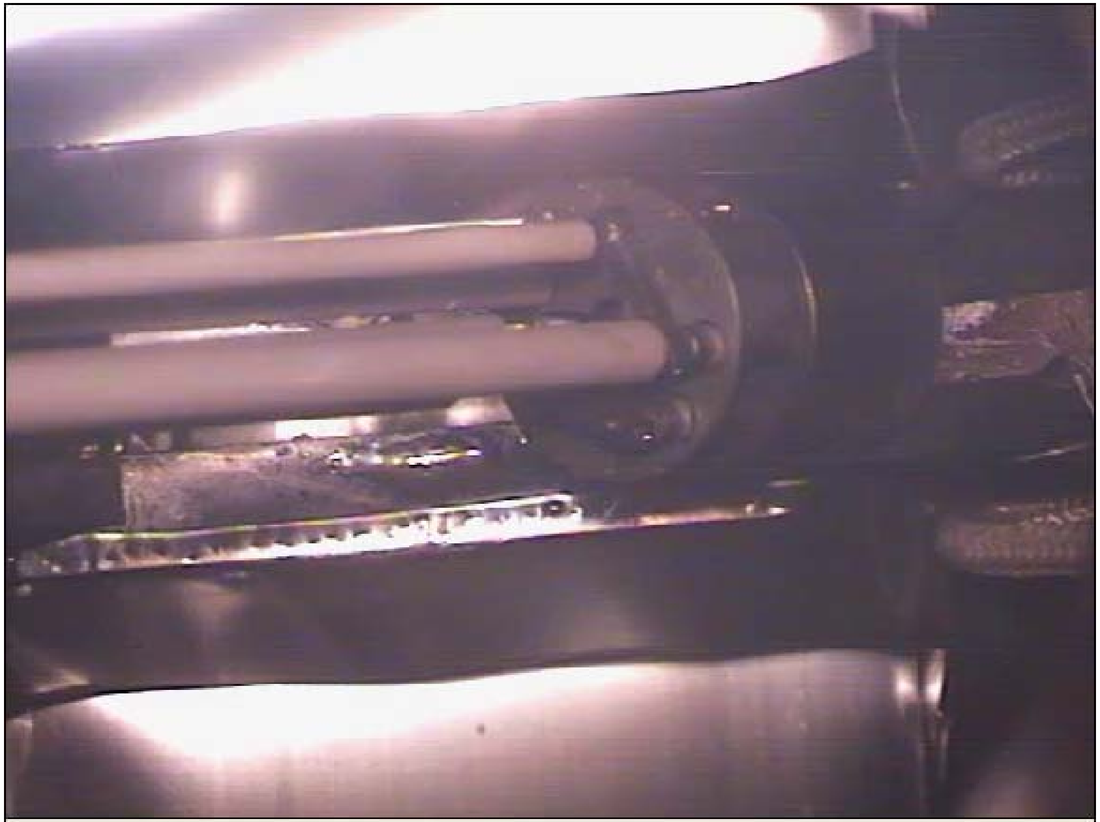
Li flow during ion gun operation
(see gun.mpg)



flow with ion gun.avi

Calculation of D from He retention data

- From analytical model[1], the retention coefficient is given by:

$$R = erf\left(\frac{1}{2\sqrt{\theta}}\right) \qquad \theta = \frac{DL}{vr^2}$$

$$D = \frac{vr^2}{4L\left[erf^{-1}(R)\right]^2}$$

v: flow velocity

r: mean implantation range

L: path length from striking point to exit

[1] Allain et al. *Fus Eng. Des.* **61-62C**, p. 245 (2002)

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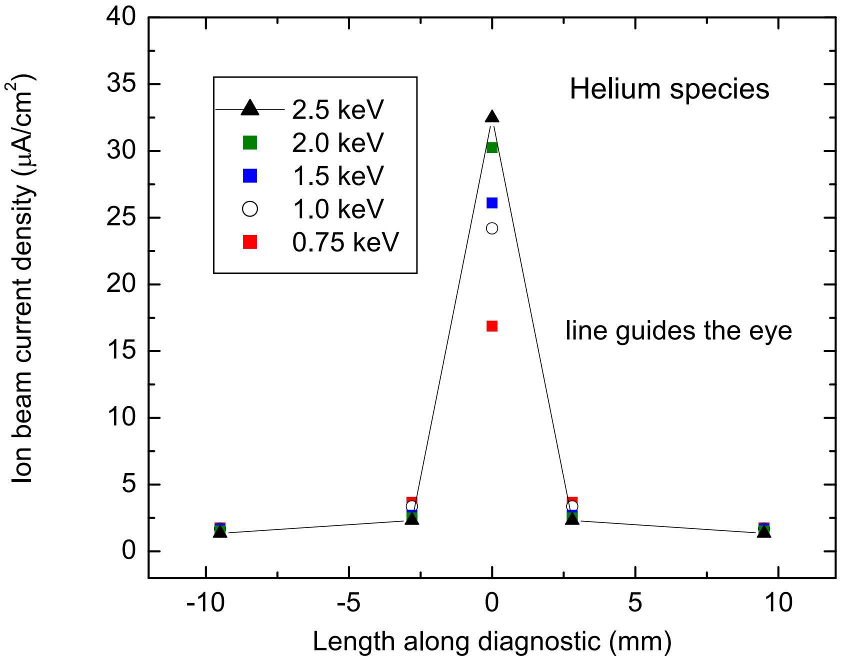
Injection rate calculation

- Obtained from the ion gun current
- Gun initial calibration assumed to hold, since no in-situ current diagnostic is available
- Uncertainty of ion current: 0.1 μA



$$j = \frac{I}{q_e}$$

q_e: electronic charge in C

I: current in A

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

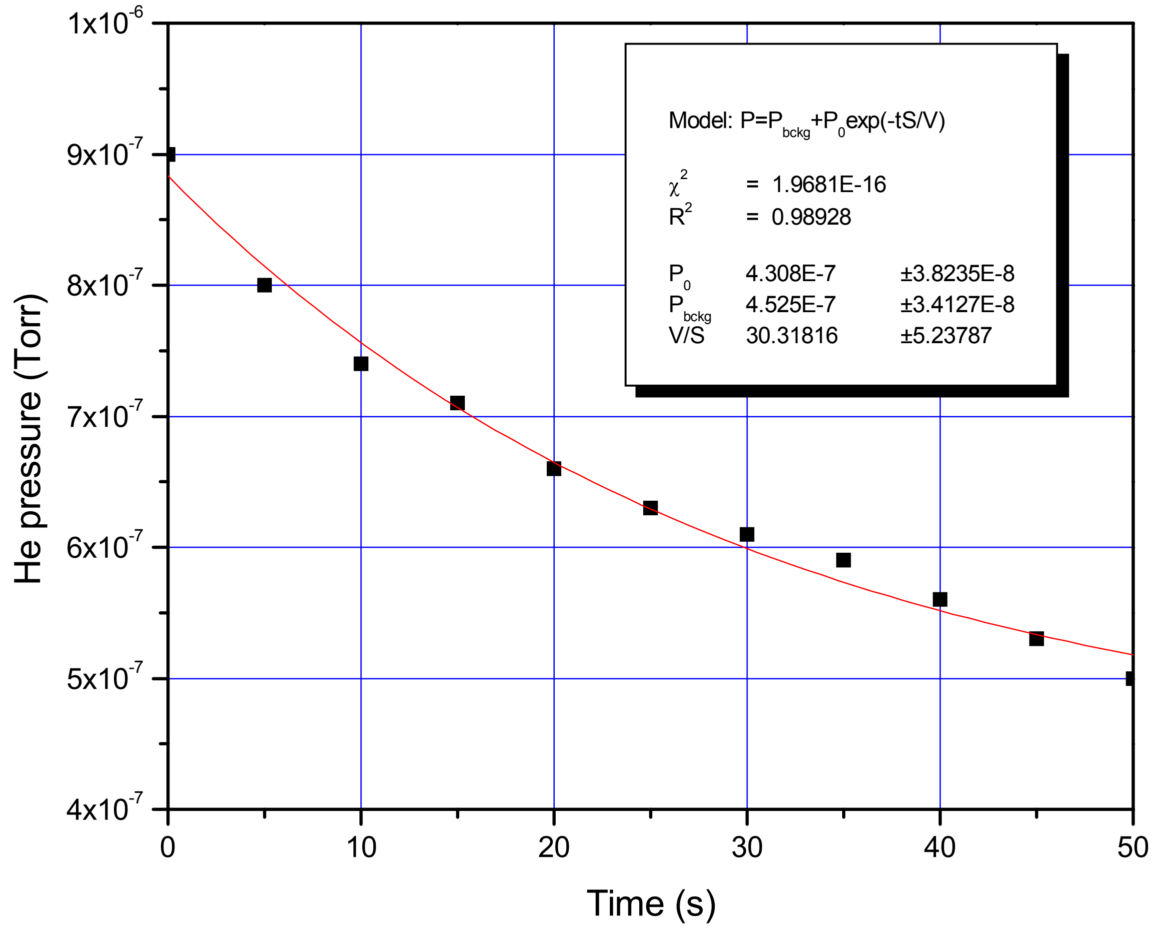
S: Pumping speed

Pumping speed

- Pumping speed is kept low to increase the signal-to-noise ratio in the pressure measurements
- Volume of the chamber is 7360 cm^3
- Pump out data fitted to a model of the form:

$$P(t) = P_{bckg} + P_0 e^{-tS/V}$$

Pumping speed (cont'd)



$S = 242.74 \pm 50\ \text{cm}^3/\text{s}$

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Retention coefficient

Hence, the retention coefficient is given by:

$$R = \frac{q}{j} \qquad j = \frac{I}{q_e} \qquad q = \frac{P}{kT} S$$

$$R = 1.55x10^6 \frac{PS}{IT}$$

P [=] Torr

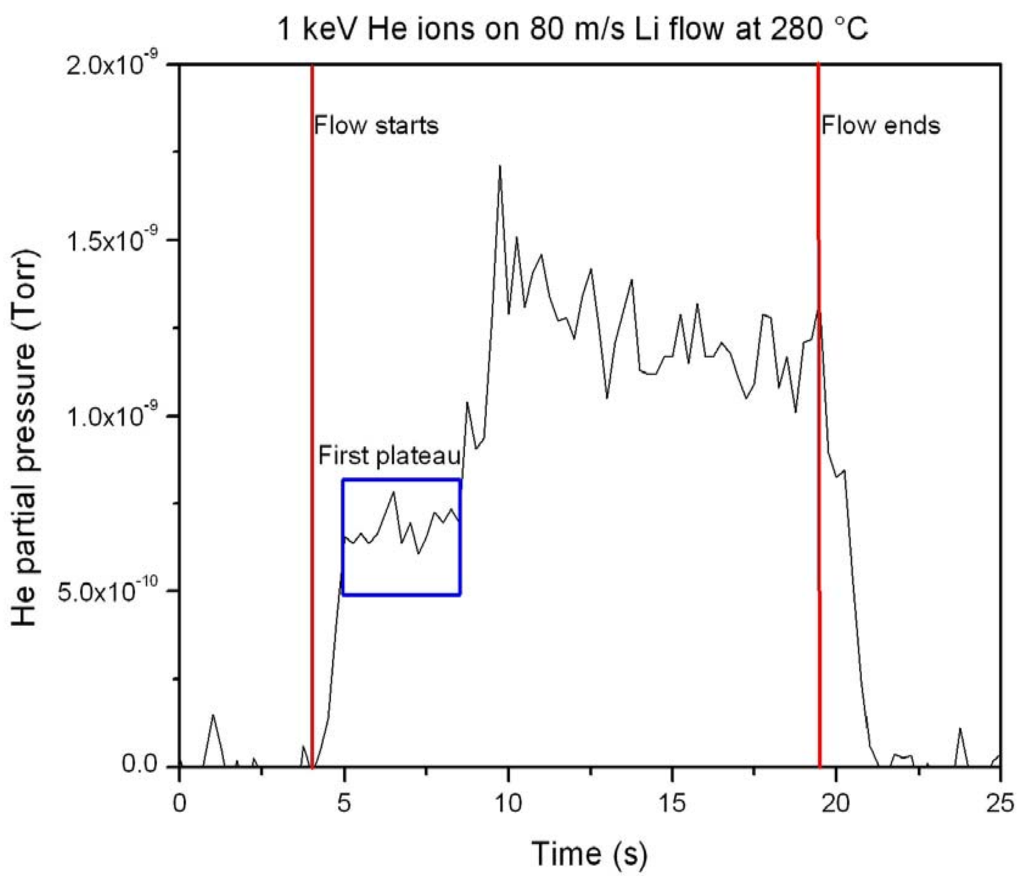
I [=] A

S [=] cm^3/s

T[=]K

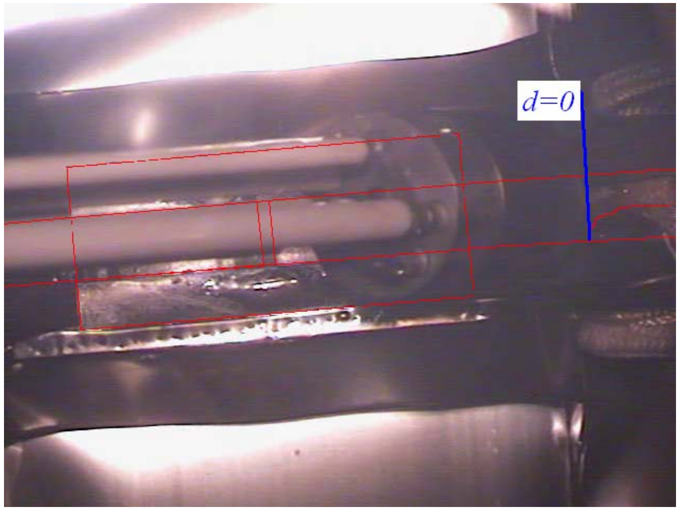
Steady state He pressure

- Only the first pressure plateau is used, since only the initial velocity is known accurately
- Uncertainty is equal to the standard deviation in the first plateau
- Peak is caused by fluctuations in the flow regime and/or pooling on the bracket

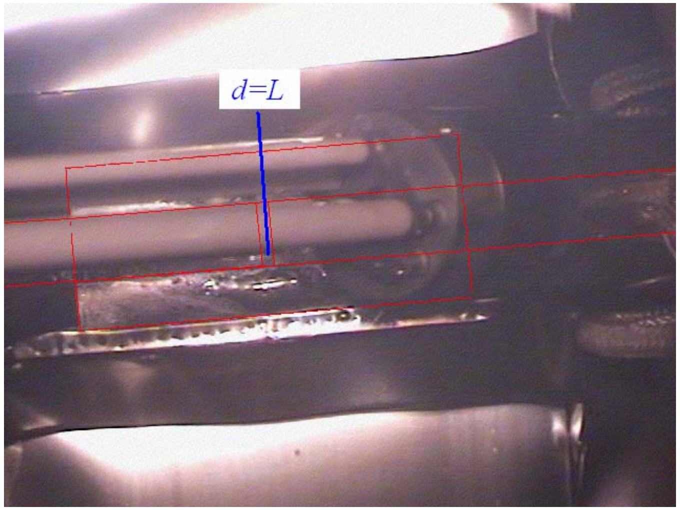


Flow velocity calculations

- Lithium flow velocity is estimated from video capture at 30 frames per second. Time uncertainty is 1/30 sec, distance uncertainty is 1 cm
- Final flow velocity is the average of all the video captures



t = 0 s



t = 4/30 s

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Retention coefficient results

		Beam energy (keV)		
		1.0	**1.5**	**2.0**
flow velocity (cm/s)	**59.6**	$1.57 \pm 0.49 \times 10^{-4}$	$3.16 \pm 0.72 \times 10^{-4}$	$3.49 \pm 0.88 \times 10^{-4}$
	61.2	$3.41 \pm 0.90 \times 10^{-4}$	$3.03 \pm 0.67 \times 10^{-4}$	$4.10 \pm 0.94 \times 10^{-4}$
	79.5	$3.73 \pm 0.90 \times 10^{-4}$	$3.24 \pm 0.83 \times 10^{-4}$	$3.79 \pm 0.90 \times 10^{-4}$
	119.3	$3.31 \pm 0.78 \times 10^{-4}$	$4.74 \pm 1.11 \times 10^{-4}$	$4.33 \pm 1.20 \times 10^{-4}$

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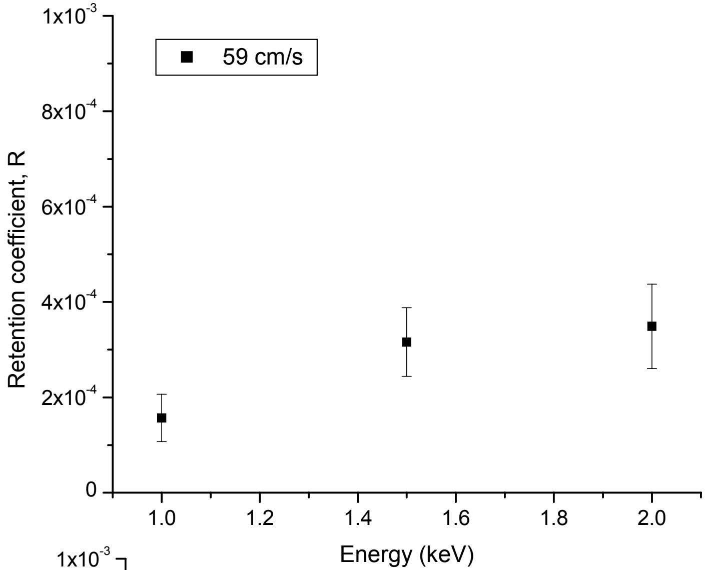
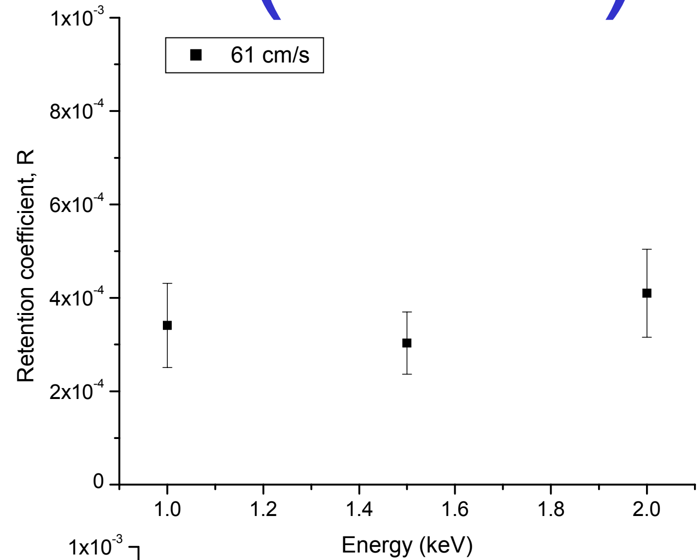
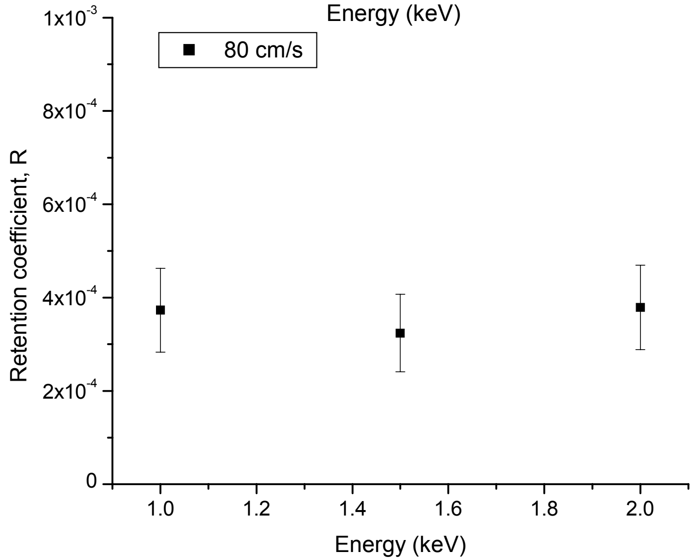
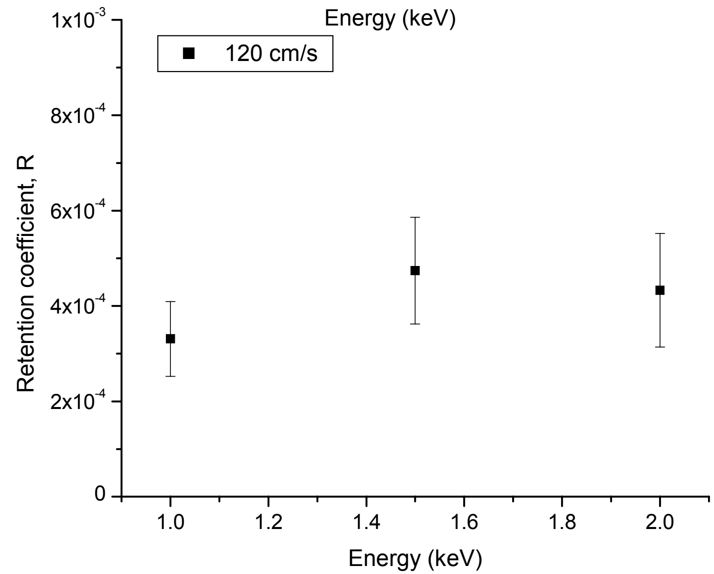
Retention results (cont'd)









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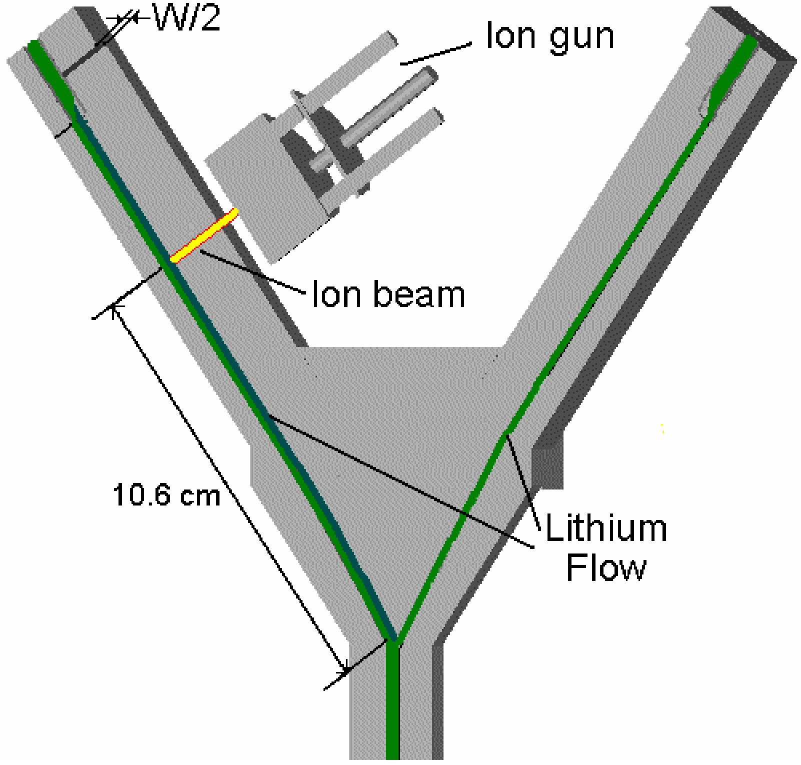
Range calculations

- Range of He is obtained by using SRIM
- Uncertainty was set to 10 Å
- Model assumes all deposition occurs at the mean range

Energy (keV)	Range (10^{-8} cm)
1	485
1.5	765
2	1030

Path length estimation

- Path length is obtained from the chamber CAD drawings
- Uncertainty of 1 cm, since the gun is not perfectly straight



Inverse error function

- To obtain D as a function of R, the inverse error function needs to be evaluated
- The following series expansion was used for the calculation
- The series was cut at the fourth term

$$\operatorname{erf}^{-1}(z) == \sum_{k=0}^{\infty} \frac{c_k}{2k+1} \left(\frac{\sqrt{\pi}}{2} z \right)^{2k+1} /; c_0 == 1 \wedge c_k == \sum_{m=0}^{n-1} \frac{c_m c_{k-1-m}}{(m+1)(2m-1)}$$

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Diffusion of implanted He in flowing liquid lithium

- Once all the parameters are known, D is calculated with this expression:

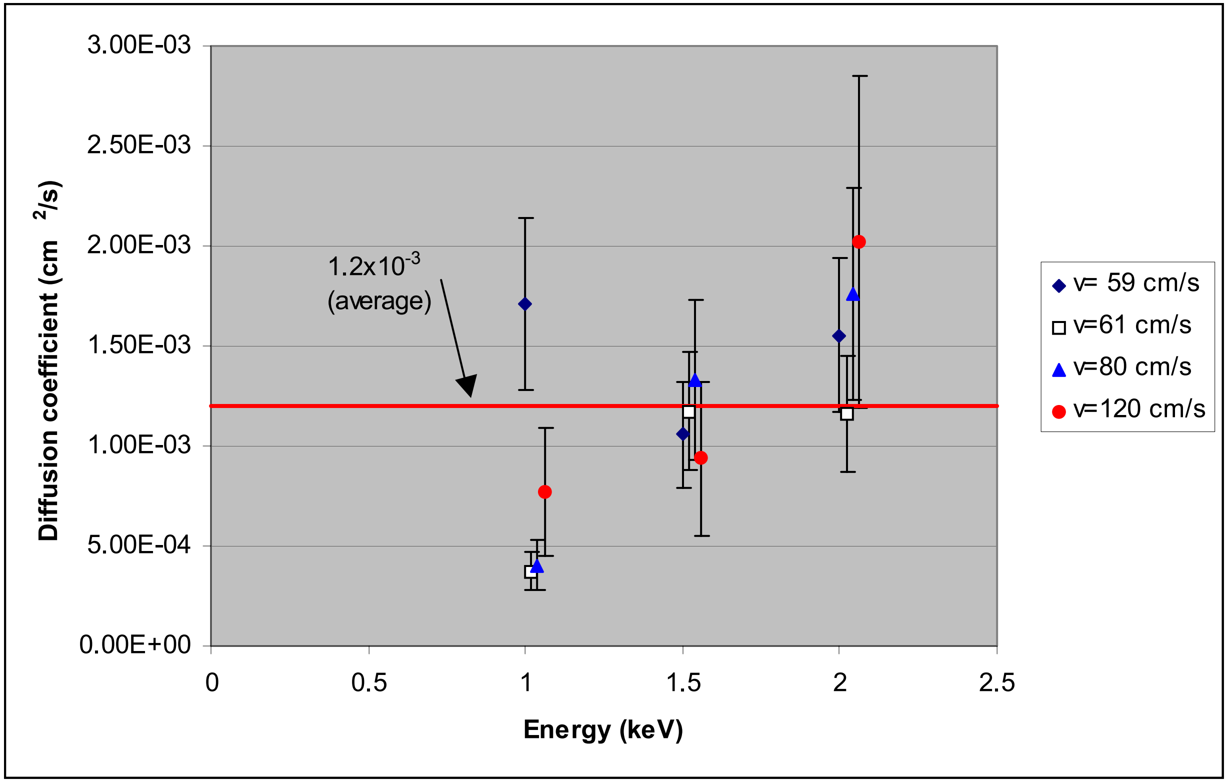
$$D = \frac{vr^2}{4L\left[erf^{-1}(R)\right]^2}$$

- Temperature was set at 280 ± 10 °C

Diffusion coefficient results for He in flowing liquid lithium

		Beam energy (keV)		
		1.0	**1.5**	**2.0**
flow velocity (cm/s)	**59.6**	$1.71 \pm 0.43 \times 10^{-3}$	$1.06 \pm 0.26 \times 10^{-3}$	$1.55 \pm 0.39 \times 10^{-3}$
	61.2	$3.71 \pm 0.95 \times 10^{-4}$	$1.17 \pm 0.30 \times 10^{-3}$	$1.16 \pm 0.30 \times 10^{-3}$
	79.5	$4.04 \pm 0.12 \times 10^{-4}$	$1.34 \pm 0.40 \times 10^{-3}$	$1.80 \pm 0.53 \times 10^{-3}$
	119.3	$7.70 \pm 3.20 \times 10^{-4}$	$9.40 \pm 3.84 \times 10^{-4}$	$2.02 \pm 0.83 \times 10^{-3}$

Diffusion coefficient values



- Velocity variation appears to be random
- Energy variation suggests mean range approximation may not be valid
  - will use distributed profile
  - surface not flat
  - mixing may occur

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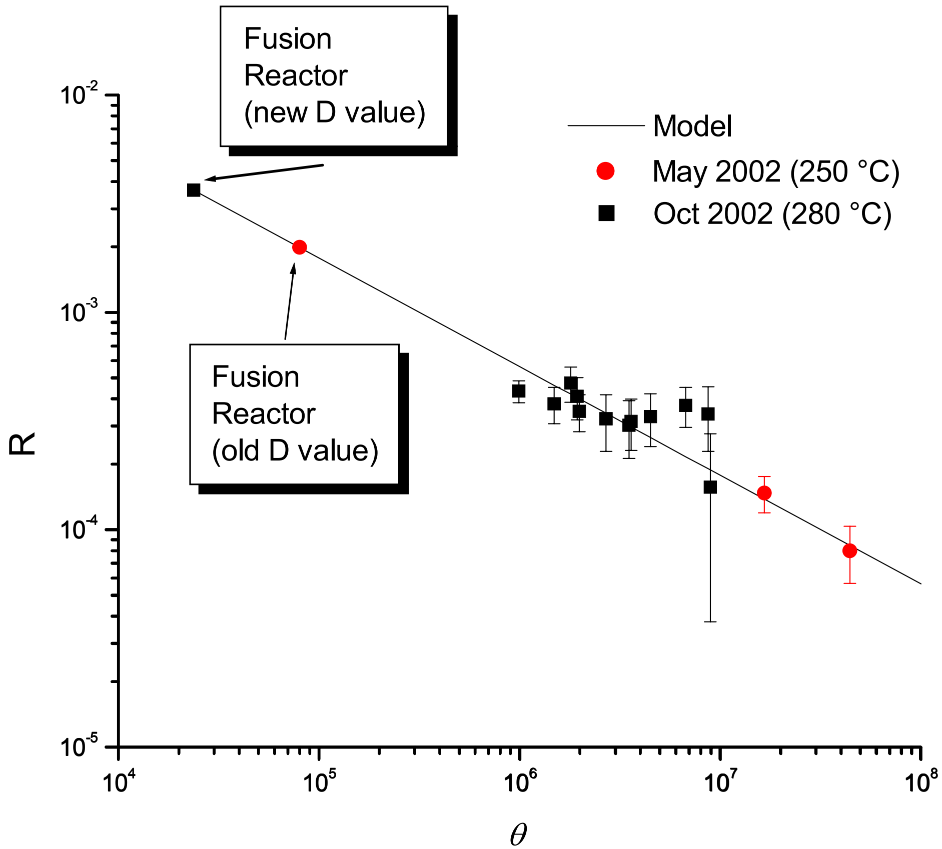
Implications for fusion

- May 2002 data, $D = (4.5 \pm 2.5)\times10^{-3}$ cm^2/s
- October 2002 data, $D = (1.2 \pm 0.12)\times10^{-3}$ cm^2/s



Deuterium retention in flowing liquid lithium

- Unlike He, D is very soluble in Li
- Chemical bonding with Li can occur, leading to long-term D trapping
- Release is recombination-limited
  - Evidence of this is found in recent static liquid Li experiments in PISCES-B[1]
  - Our experiments confirm the release mechanism

[1]M.J. Baldwin, et al. Nucl. Fusion, 42 (2002) 1318

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Diffusion of implanted deuterium in flowing liquid lithium

- For the recombination-limited case[1], the retention coefficient has the same functional form:

$$R = erf\left(\frac{1}{2\sqrt{\theta}}\right)$$

- However, the dimensionless parameter definition changes, and now is given by:

$$\theta = \frac{K_{rec} \cdot j \cdot y_0}{vD}$$

[1]M.S. Kazimi, et al., Fusion Technology, 23 (1993) 208.

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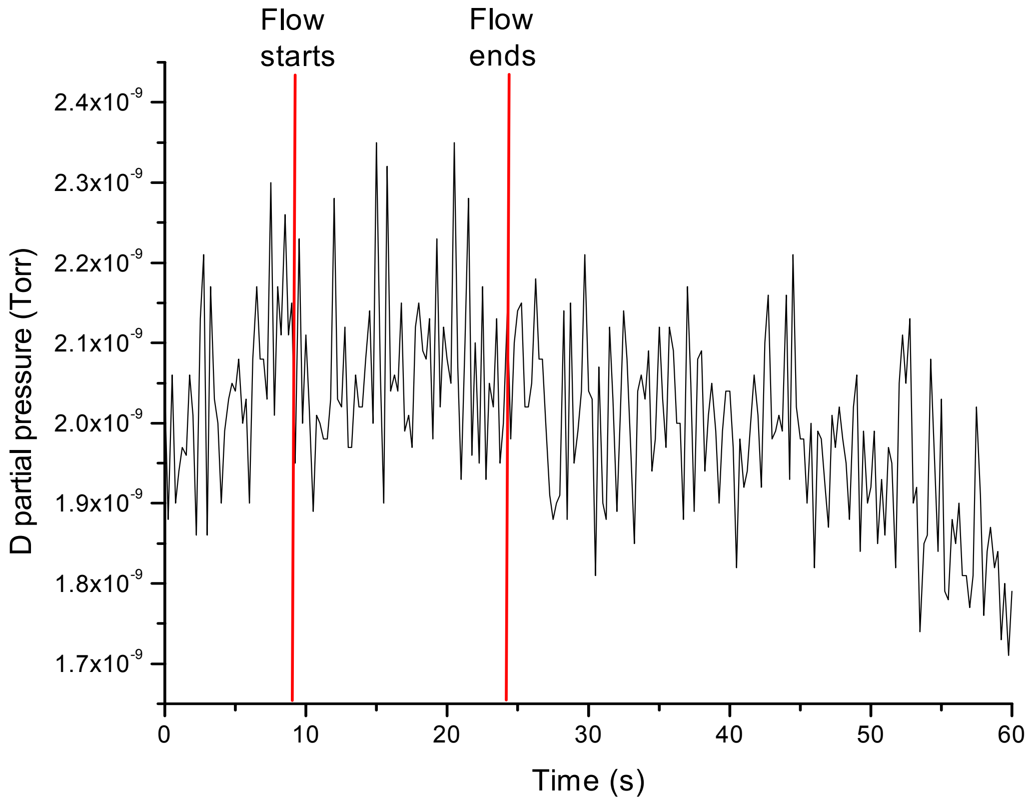
Li under D irradiation

- 2.5 μA, 1 keV Deuterium beam
- 80 cm/s Li flow velocity
- Pumping speed of 250 cm^3/s
- No noticeable increase for these conditions



Exposure of static Li to D_2 gas

- The residual amount of Li that stays trapped in the orifice was exposed to 2.5×10^{-7} Torr of D_2 gas
- 5 min and 10 min exposure was done
- After time is elapsed, it is dropped into the lower chamber by flowing a small amount of Li
- The equation for the rate of change of D particles in the lower chamber is:

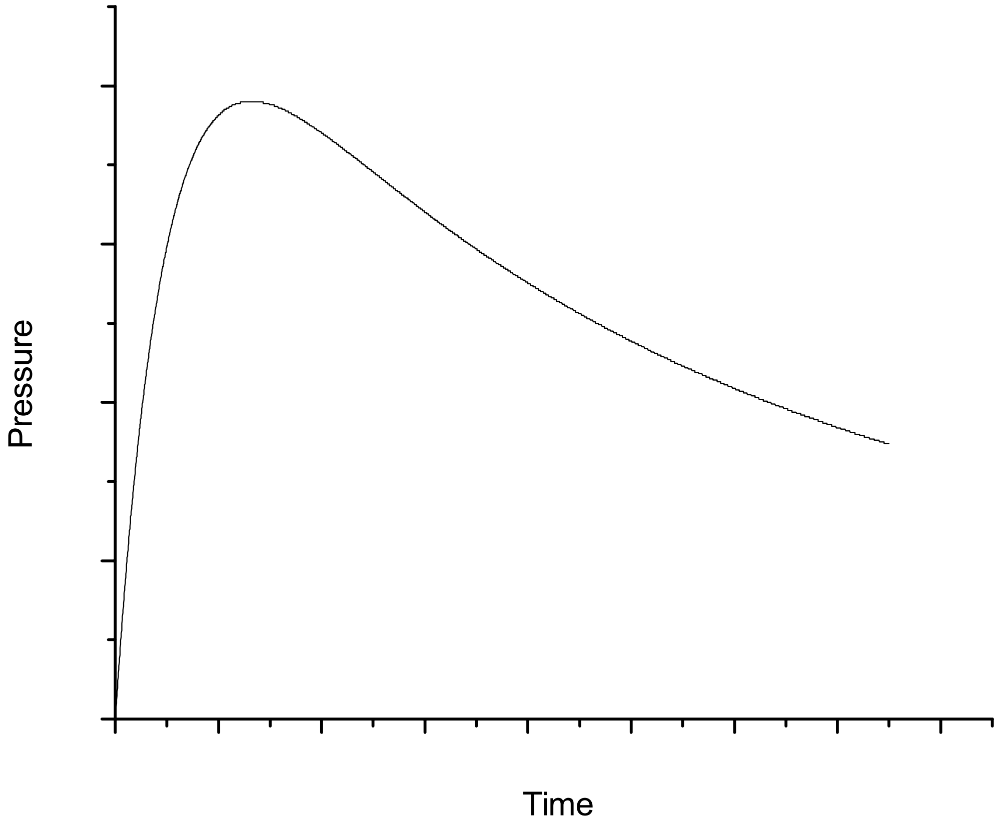
$$\frac{dP}{dt} = K_1 C_s^2 - PS$$

Balance between pumpout and desorption from the wall

$$\frac{dC_s}{dt} = -K_2 C_s^2$$

Desorption from the surface of the metal

Analytic model



- The pressure evolution expected from the desorption model is shown
- Free parameters can be fitted to match experimental data
- Data on surface concentration and recombination rates can be estimated
- Results could be compared to recombination measurements in PISCES-B

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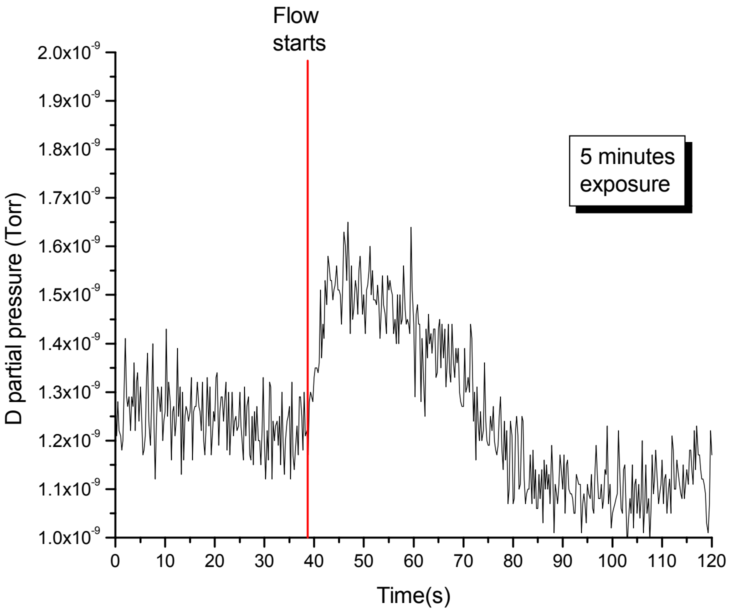
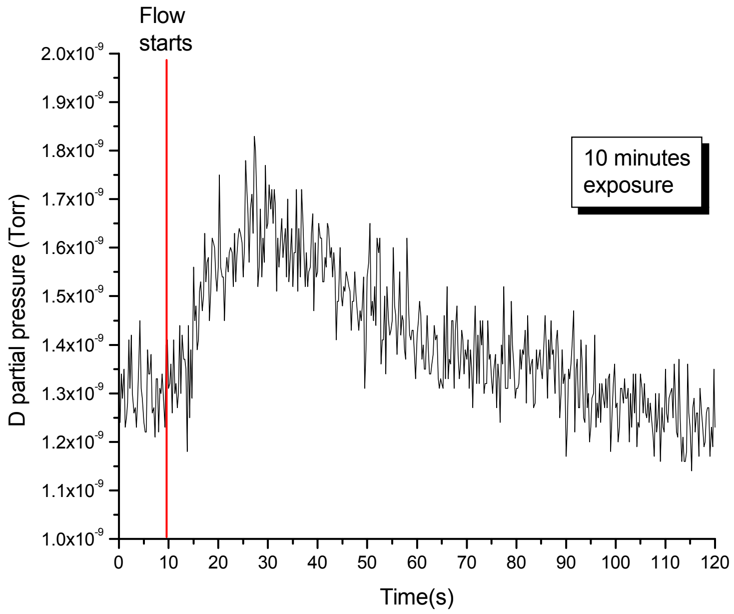
Results for Li exposure to D_2 gas

- It takes twice the time for the sample exposed for 10 minutes to get back to background level compared to the sample exposed for 5 minutes
- Sample that was exposed longer absorbed more and therefore desorbs more





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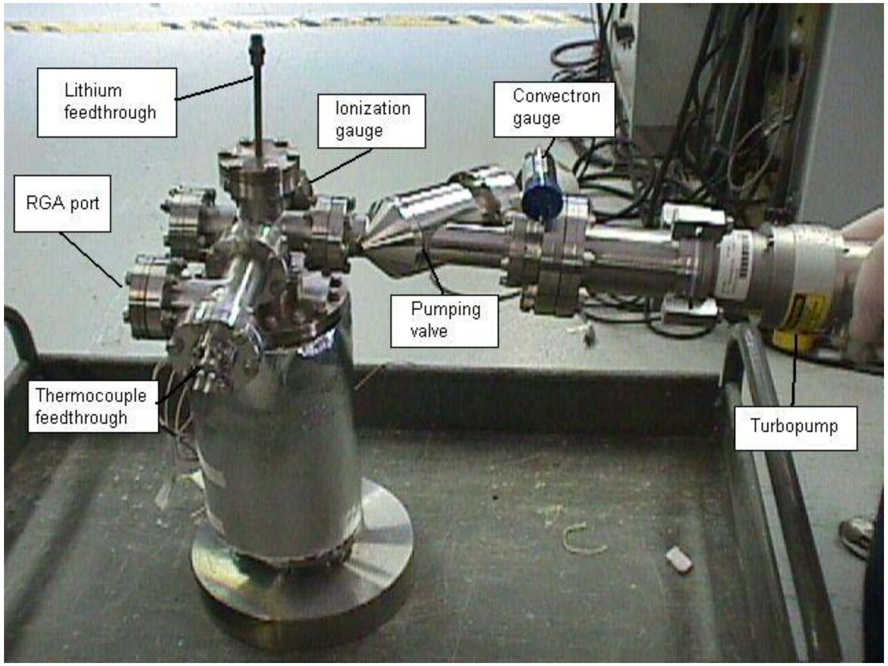
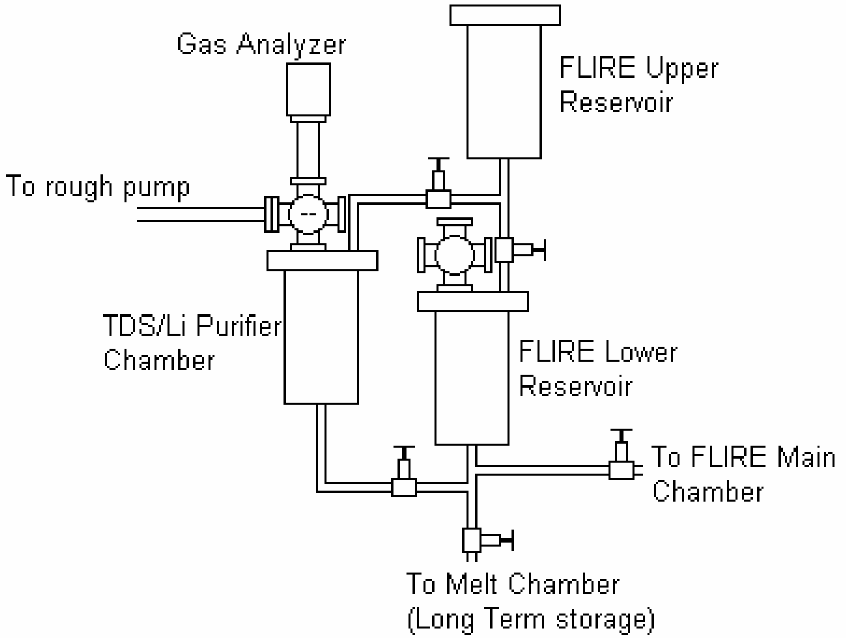
New TDS/Purification System will be installed in FLIRE during the next few weeks





- A new TDS (thermal desorption spectroscopy)/ Purification chamber is being installed in FLIRE to measure hydrogen retention/recombination properties of chemically bound species in the flowing liquid lithium

Comparison of diffusivity of D in liquid lithium measured in FLIRE to existing literature

- C. Guminski in Liquid Metal Systems, H.U. Borgstedt ed. Plenum Press 1995
  - Diffusion coefficient of H in static liquid lithium at 523 K is about 4.7 x 10^{-5} cm^2/sec
- R. Causey, J. Nucl. Mater. 300 (2002) 91.
  - Diffusion coefficient of hydrogen in liquid Li over literature quoted averages 10^{-4} cm^2/sec
- FLIRE Results in flowing liquid lithium
  - Diffusion coefficient of H in flowing liquid lithium at about 553 K averages

Plasma-liquid interactions in FLIRE

- Ex-situ tests conducted on hollow cathode plasma source with mock-up ramp geometry
- The source can deliver an average 10^{15} ions/cm^2/sec flux
- Source has been installed in FLIRE and initial measurements with a helium plasma conducted at temperatures near 250 $\pm$ 10 °C

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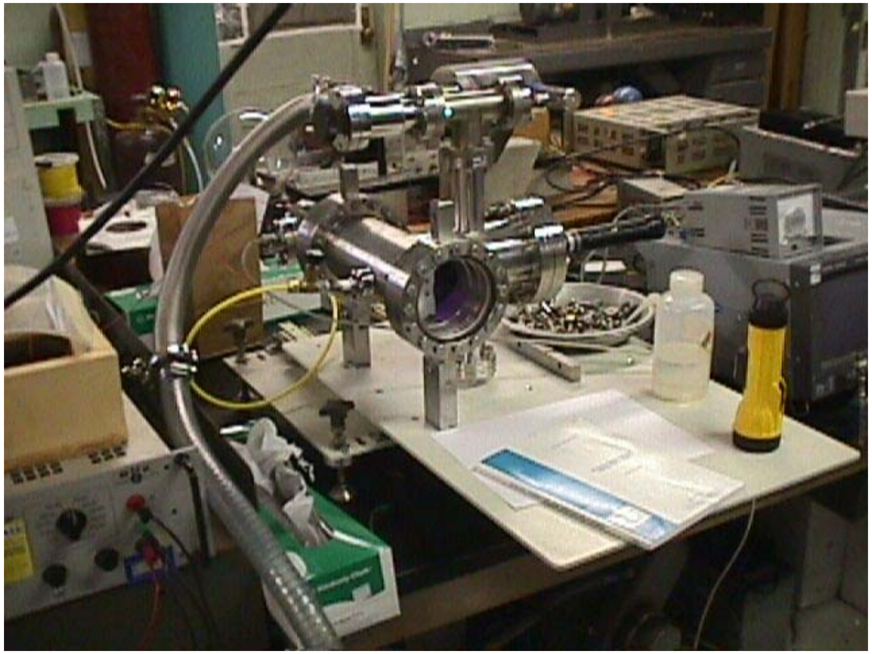
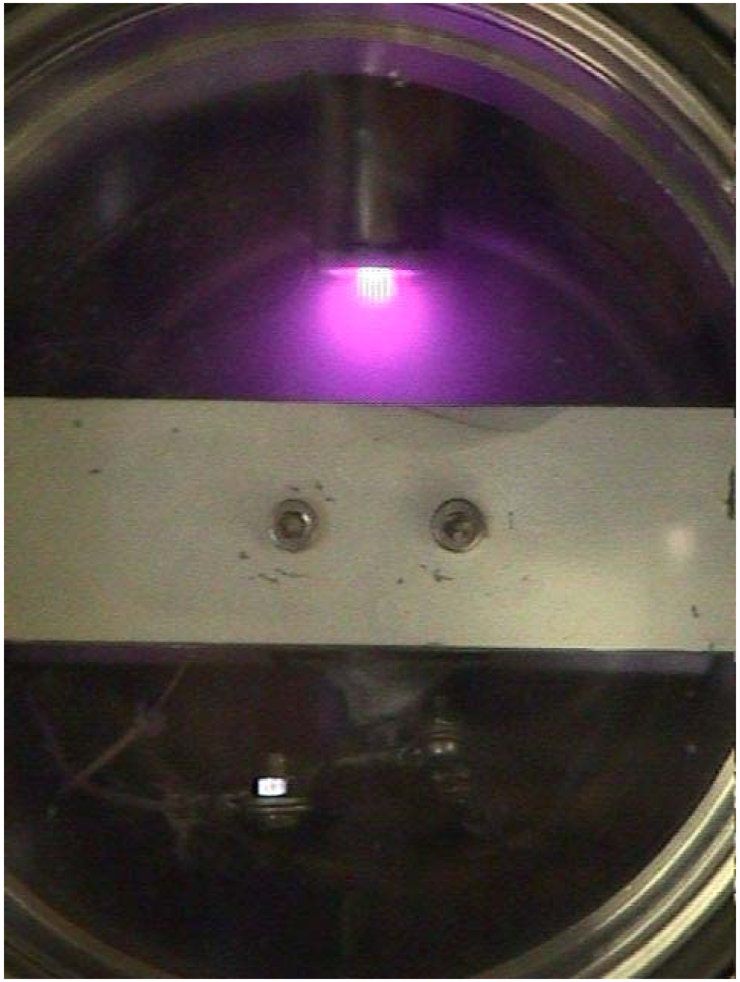
Hollow cathode plasma source tests





- Hollow cathode source can provide fluxes of the order of 10^{15} ions/cm^2/sec.
- Plasma-liquid experiments have begun with He plasmas and will continue with hydrogen plasmas in the near future.

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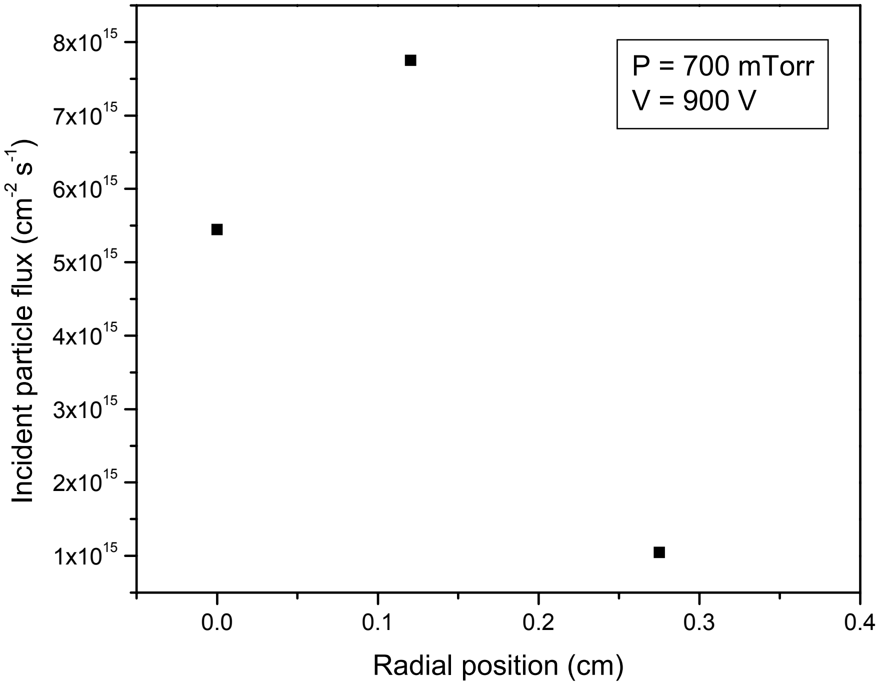
Plasma source characterization



- The set of concentric rings shown on the right was used to obtain the current density profile shown on the left

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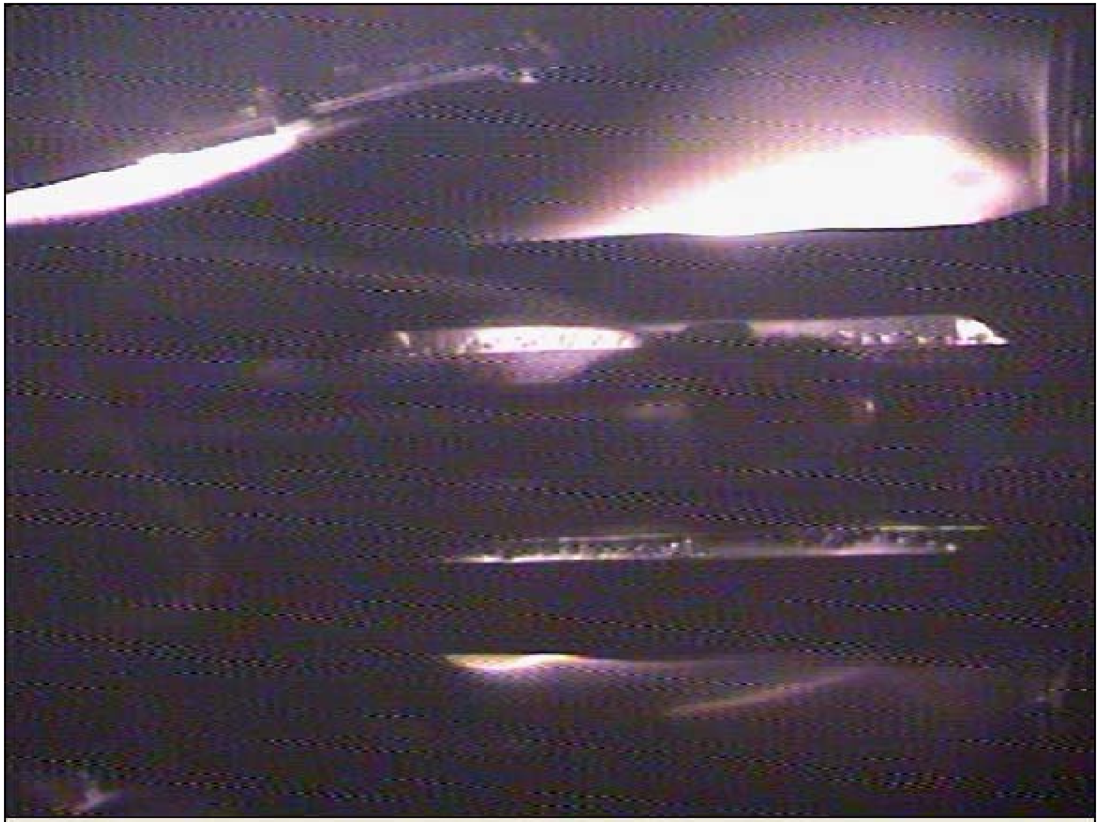
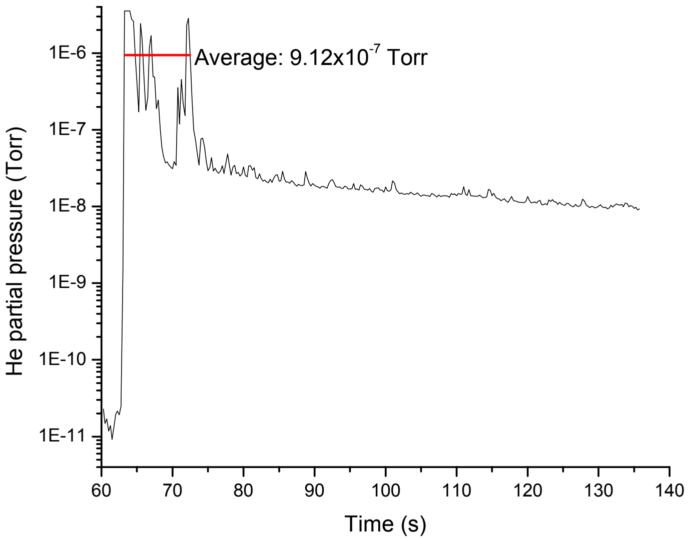
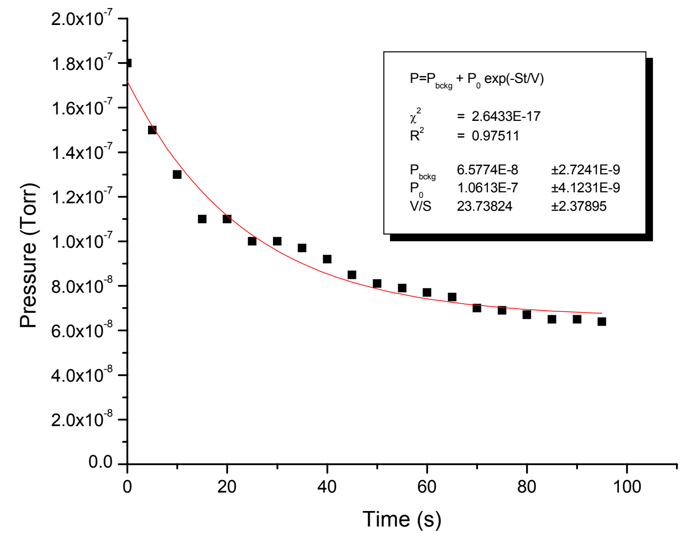
Plasma source in operation on FLIRE (see plasma.mpg)



flow with plasma.avi

He plasma source results





- By using the same analysis as for the beam case, with I = 760 μA, P = 9x10^{-7} Torr, T = 473 K and S = 310 cm^3/s, the calculated retention coefficient is retention coefficient of 1200!
- Possible reason: Bombardment-induced adsorption of the neutral helium background gas? Capture of bubbles?
- More experiments underway

FY 2002 Accomplishments

- Design and construction of FLIRE facility, FLIRE component tests, liquid lithium loading and melting.
- Measurements of He and D retention/diffusion in flowing liquid lithium under a variety of experimental conditions with ion source.
- Measurement of He retention/diffusion in flowing liquid lithium under a moderate plasma flux.
- Measurement of liquid lithium sputtering dependence with target temperature for H, D, He and Li bombardment at oblique incidence.
- Measurement of solid and liquid tin sputtering dependence with incident particle energy and target temperature at oblique incidence for both H, D and He bombardment.
- Modeling of lithium sputtering in liquid state and tin sputtering in both solid and liquid states.

FY 2002 Accomplishments (cont.)

- Measurement of liquid lithium and liquid tin-lithium secondary ion sputtered fraction dependence with target temperature for H, D, He and Li bombardment at oblique incidence.
- Measurement of deuterium treatment effect on liquid lithium sputtering and its dependence on liquid lithium temperature.
- Modeling of hydrocarbon reflection under various surface conditions at thermal and epithermal energies with molecular dynamics.
- Modeling of low energy reflection of lithium atoms from liquid lithium surface under various surface conditions.
- Semi-analytical modeling of backscattered ion probability from lithium surfaces.
- Monte Carlo modeling of NSO/FIRE first wall – divertor physics using WBC+, VFTRIM, DEGAS 2 and UEDGE.

Publications during FY 2002

1. J.P. Allain and D.N. Ruzic, “Measurements and modelling of solid phase lithium sputtering” 42 (2002) 202.
2. J.P. Allain and D.N. Ruzic, in *NATO Science Series: Hydrogen and Helium Recycling at Plasma Facing Materials*, edited by A. Hassanein (Kluwer Academic Publishers, Dordrecht, 2002), Vol. 54, pp. 73.
3. M.D. Coventry, J.P. Allain, D.N. Ruzic, “D^+, He^+ and H^+ sputtering of solid and liquid phase tin”, Journal of Nuclear Materials, accepted August 2002.
4. J.P. Allain, M.D. Coventry, D.N. Ruzic, “Temperature dependence of liquid lithium sputtering from oblique 700 eV ions”, Journal of Nuclear Materials, accepted August 2002.
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IIAX FY 2003 Milestones

1. Temperature dependence investigation of H^+,D^+, D_2^+ and D_3^+ bombardment at oblique incidence of liquid lithium**. (level of effort: 10% of total, priority: HIGH; ALPS, ALIST related addressing: enhanced sputtering, evaporation issues, erosion limits in NSTX Li module)**
2. Molecular dynamics studies of liquid lithium and its temperature-dependent sputtering and reflection characteristics at epithermal and hyperthermal energies. **(level of effort: 10%, priority: HIGH; ALPS, ALIST related addressing: sputtering, reflection issues, PMI concerns in NSTX Li module)**
3. Temperature dependence of the secondary sputtered ion emission from solid and liquid tin under various bombardment conditions. **(level of effort: 10%, priority: HIGH; ALPS related addressing: surface effects)**
4. Continue temperature dependence investigation (experiments and modeling) of H^+, D^+, He^+ and Li^+ bombardment at oblique incidence from tin surfaces. This will include study of Gibbsian segregation effects with temperature for Li^+ bombardment of tin.**(level of effort: 10%, priority: HIGH; ALPS, ALIST, APEX related addressing: sputtering, erosion issues for divertor/first wall candidate liquid metals)**
5. Study of the ion-induced electron emission yield from various solid and liquid metals including: Li, Sn, Ta (for comparison) and SnLi. **(level of effort: 10%, priority: HIGH; ALPS related addressing: erosion mechanisms of liquid metals)**
6. Surface analysis and study of tin-lithium surface composition effects on lithium sputtering. **(level of effort: 2% of total, priority: LOW; ALPS related addressing: segregation rate mechanisms)**

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PMI Modeling FY 2003 Milestones

Molecular Dynamics Studies FY 2003 Tasks

1. Reflection of carbon dimers and trimers on hydrogenated carbon surfaces. **(priority: HIGH; PFC related work)**
2. Development of carbon "soft" layers and calculation of reflection coefficient of carbon atoms, dimers, trimers, and the whole spectrum of hydrocarbon molecules from these layers. Comparison to experimental measurements of carbon/hydrocarbon reflection or sticking coefficients. Comparison to original hydrogenated carbon surfaces and development of a physical understanding of their differences. **(priority: HIGH; PFC related work)**
3. Extend the Brenner hydrocarbon potential to be applicable at higher energies, by combining with a high-energy potential at the small interaction distance end. **(priority: HIGH; PFC related work)**
4. Improve the modeling capability, e.g. speed, to be able to investigate temperature effects on the H:C surfaces. Attempt to see thermal desorption of hydrogen from higher temperature surfaces. Compare these results to the experimentally known saturation levels of hydrogen in carbon at different temperatures. **(priority: HIGH; PFC related work)**
5. Develop a physical model of the how reflection is effected by using the "soft" redeposited carbon layer versus a carbon hydrogenated surface ("original surface"). Determine whether the probability of reflection depends on differences in the surface, e.g. hybridization. How incident energy and angle, or surface temperature affect the reflection coefficient. **(priority: HIGH; PFC related work)**
6. Molecular dynamics studies of liquid lithium and its temperature-dependent sputtering and reflection characteristics at epithermal and hyperthermal energies. In addition, first principle calculations of backscattered and sputtered ionization probabilities. **(priority: HIGH; ALPS, ALIST related addressing: sputtering, reflection issues)**

PMI Modeling FY 2003 Milestones (cont.)

Monte Carlo simulations Studies FY 2003 Tasks

1. NSO/FIRE modeling (priority: HIGH; PFC issues related addressing: tokamak transport) including: refinement of SOL models used in FIRE Be/W mixed material analysis to see how the amount of beryllium sputtered from the first wall is effected. Continue to use the modeling tools to investigate other regimes or scenarios in cooperation with Argonne National Laboratory. **(priority: HIGH; NSO/FIRE related work)**

2. Modifications are being implemented for the current VFTRIM code. The new code, called DYNFTRIM, will be a hybrid between the VFTRIM and TRIDYN codes. From VFTRIM, the treatment of the surface as a fractal will be preserved. From TRIDYN, the capability of modeling dynamic composition changes on the target sample and local saturation effects will be added. **(priority: HIGH; ALPS, ALIST, APEX related addressing: sputtering, erosion issues for divertor/first wall candidate liquid metals)**

3. Continue pertinent VFTRIM-3D modeling addressing PMI tasks. **(HIGH; ALPS, ALIST, APEX related addressing: sputtering, erosion issues for divertor/first wall candidate materials)**

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FLIRE FY 2003 Milestones

1. Continue diffusion measurements as a function of flow velocity, liquid metal temperature, and incident particle energy. **(priority: HIGH; ALPS, APEX, ALIST related)**

2 Continue He+ and H+ particle retention measurements and modeling in flowing liquid lithium under ion and moderate plasma bombardment. **(level of effort: 10% of total, priority: HIGH; ALPS, APEX, ALIST related addressing: particle retention issue on flowing liquids)**

3 Design and implementation of new TDS/Purification system for hydrogen release studies from liquid lithium. **(level of effort: 7%, priority: HIGH; ALPS, APEX, ALIST related addressing: particle retention issue on flowing liquids)**

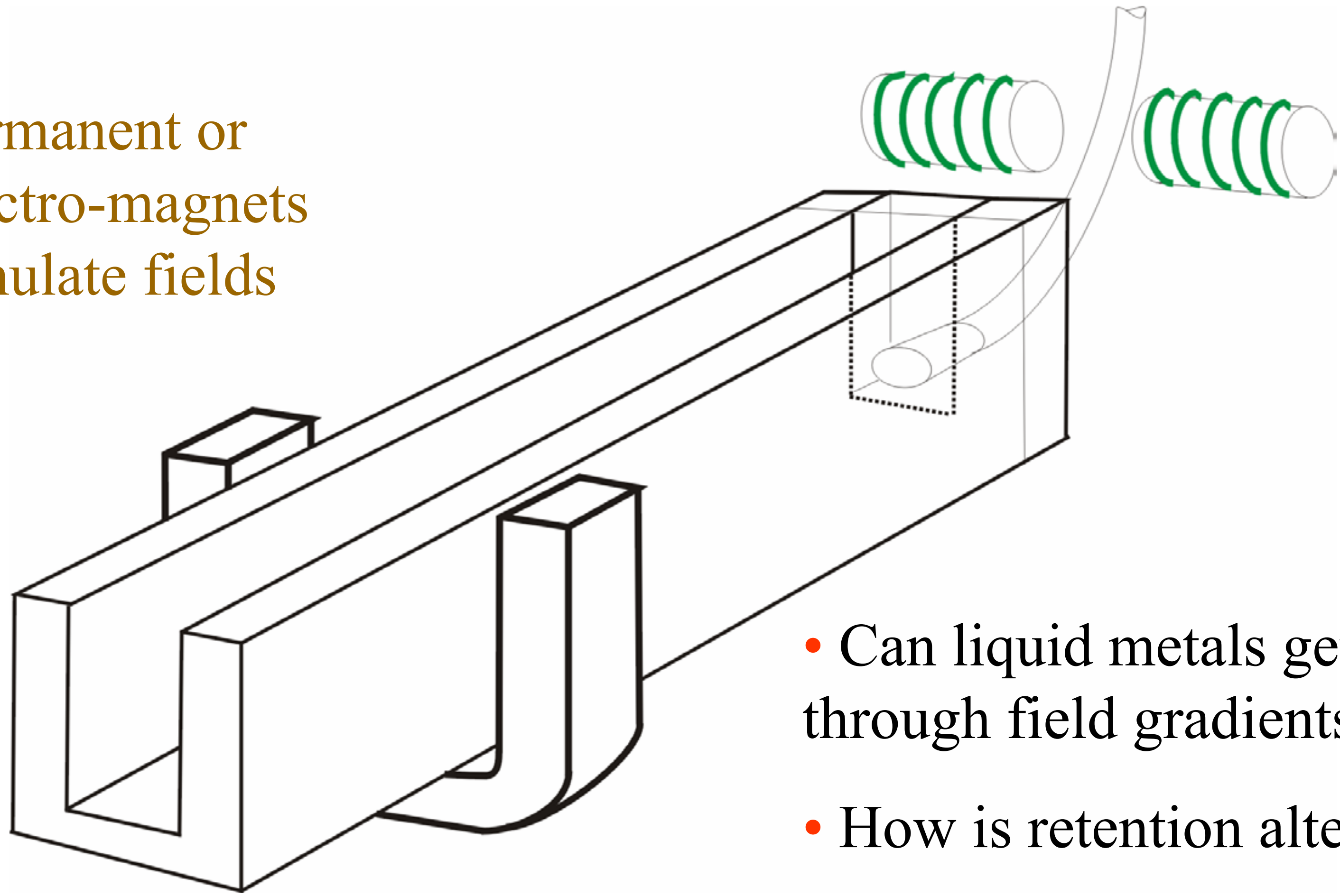
4 Design of plasma gun for plasma-material interaction studies under high-flux (10^{15} to 10^{17} particles/cm^2/sec) conditions. These studies will simulate off-normal events such as disruptions or ELM's in current tokamaks. Installation will begin in FY 2004. **(level of effort: 10%, priority: HIGH; ALPS, APEX, ALIST related addressing: particle retention under high heat flux bombardment of flowing liquids)**

5 With more funding implementation of other candidate liquid metals (e.g. Ga, Sn, SnLi) could be studied. **(level of effort: 7% of total, priority: HIGH; ALPS, APEX, ALIST related addressing: measurements of retention properties of flowing liquids)**

6 Upgrade of FLIRE system with mockup MHD experiments including permanent magnets or electromagnets simulating fusion device-like field configurations. In addition localized electrodes will be installed to study effects of induced eddy currents on particle retention of free-surface flowing liquids. This will include pertinent modeling work of these effects. **(level of effort: 4% of total, priority: MEDIUM; ALPS, APEX, ALIST related addressing: measurements of MHD-related effect on retention properties of flowing liquids)**

FLIRE MHD capabilities

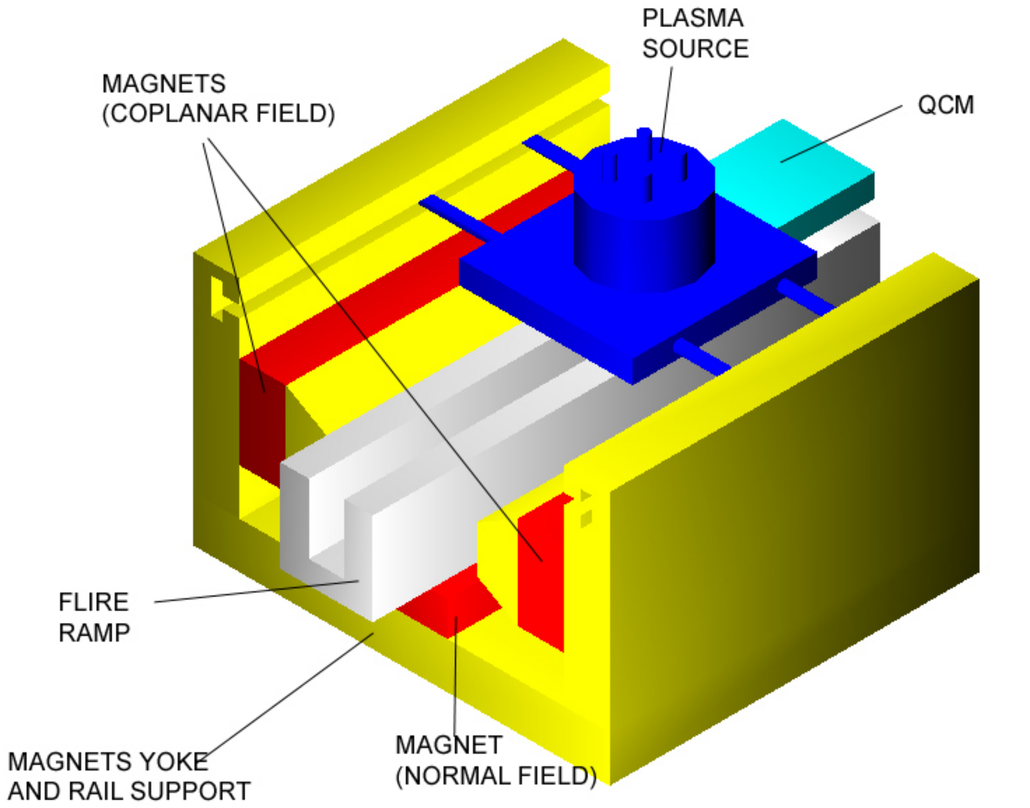
Permanent or electro-magnets simulate fields



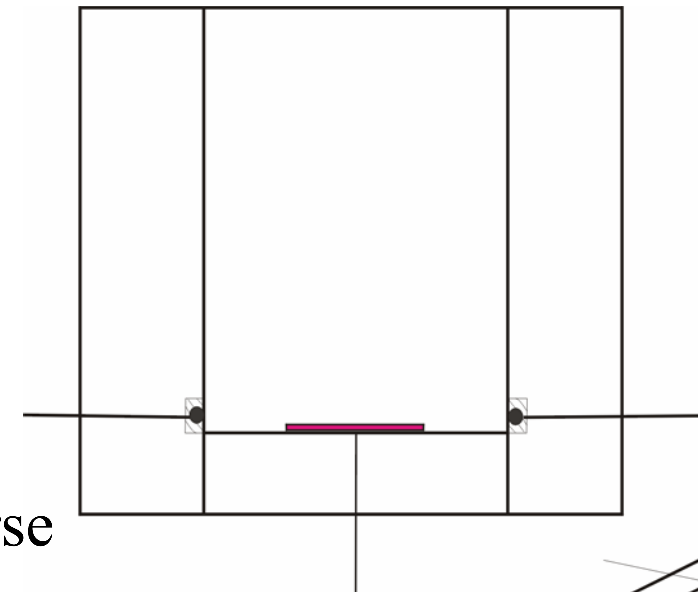
- Can liquid metals get through field gradients?
- How is retention altered?

Rail system will include magnets to study MHD effects on flowing liquids

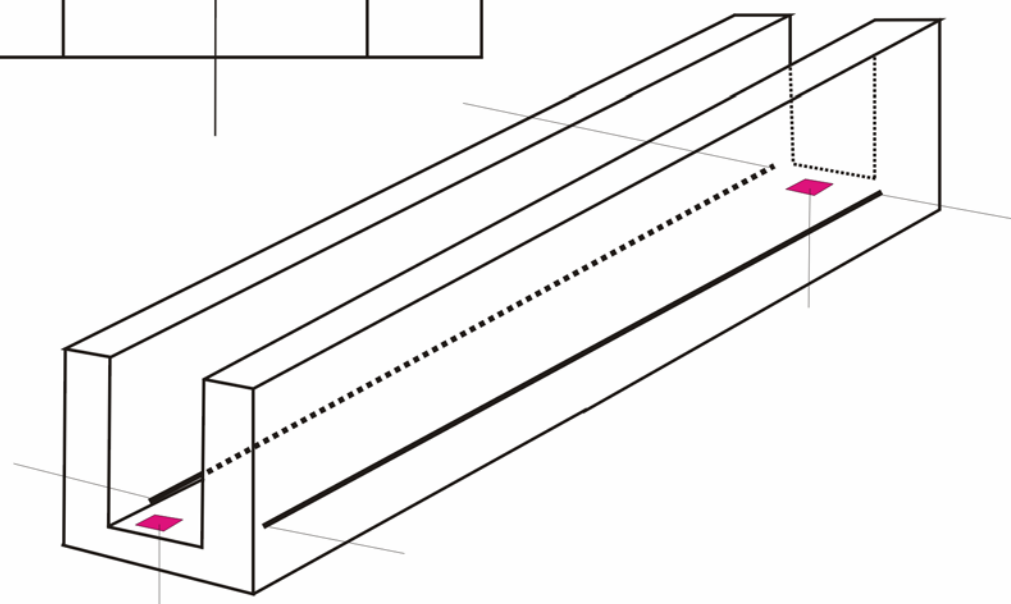
- New rail system will allow for variation of plasma source strike point along lithium flow.
- Phase II work will add the capability for external magnetic field generation on flowing liquid lithium.
- In addition to MHD effects on the flow, any effects on retention/diffusivity will assessed.
- In-situ diagnostics including QCM technology for erosion and ultrasound techniques to measure flowing liquid lithium film thickness will be implemented.



FLIRE MHD capabilities (cont.)



Embedded electrodes in ramps allow the simulation of eddy or intentional currents transverse or parallel to flow



- Will transverse or parallel currents disrupt flow?
- How is retention altered?

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FY 2003 Budget Request

UIUC FY 2002 Budget	($ K)	UIUC FY 2003 Request	($K)
ALPS	172	**ALPS**	185
APEX	10	**APEX**	10
ANL subcontract	51	**ANL subcontract**	81
Totals	**233**	**Totals**	**276**
<u>Budget Detail</u>			
PMI Experiments			
IIAX (Ion-surface Interaction Experiment)	92		95
FLIRE (Flowing Liquid Surface Retention Experiment)	90		100
PMI Modeling		Additional student to overlap with D.A. Alman for 9 months	30
PMI (e.g. molecular dynamics, VFTRIM, etc…)	24		24
NSO/FIRE	27		27

Proposed Ga experiment in FLIRE

- Measurements of D retention/diffusivity in flowing liquid Ga using an ion beam
- Measurements of D retention/diffusivity in flowing liquid Ga using a moderate flux plasma
- Measurements of chemically bound D in Ga using Thermal Desorption Spectroscopy
- Experiments will look at dependence with temperature, incident particle energy, and flowing liquid Ga velocity
- Measurements of He retention/diffusivity in flowing liquid Ga (lower priority)

Gallium - Lithium

- Could introduce measured quantities to Li and observe changes in particle retention
- Can be done as a function of temperature and energy for both ion beams and plasma implantation

Items needed to carry out Ga experiments in FLIRE

- New parts for liquid metal injection/storage system (including melt chamber, heater lines, reservoir tanks, ramps, TDS chamber, liquid metal valves)
- 3 liters of Ga (18 kg)
- Some additional personnel

estimated additional cost -- $30,000

Ga experiments in IIAX

- Measure sputtering yield as a function of energy for D, He, Ne, others?
- Measure temperature variation of sputtering yield
- Measure secondary ion fraction of sputtered Ga – probably near zero

priorities and costs need assessment

Phase I Proposal Plans for FY 2003

- High heat flux source to be installed in FLIRE by mid fiscal year 2004 to study free surface flowing liquid interactions under conditions relevant to off-normal fusion events.
- Extends funding to FLIRE facility while providing more time for thorough investigation of liquid/plasma interactions in current Phase II grant.
- Extension of funding could also enable FLIRE to incorporate other liquids of interest namely: liquid Ga or Sn.
- More funding will also provide needed human resources to continue meeting important milestones, address key ALIST issues and identify commercialization opportunities from research development in FLIRE.

High flux plasma source considerations

- This plasma source will operate in a pulsed manner with power flux levels of 100 kW/cm^2 (1 GW/m^2) for 100 μs to 1.0 ms at a repetition of ~ 10 Hz. The energy distribution of the incident particles would ideally be similar to those expected in the divertor region during off-normal events.
- Principal components to develop for new design
  - Discharge region geometry to achieve desired plasma
  - Pulse triggering in parallel with pulsed gas puffing
  - Pulse-forming network (PFN) and matching network
- Plasma source options in addition to new design
  - Deflagration gun delivers both a high density and high energy plasma
  - Present devices considered: PLADIS (UNM) & VIKE (Russia)

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