He Bubble Formation in Liquid Metals: Status of SNL/CA Experiments

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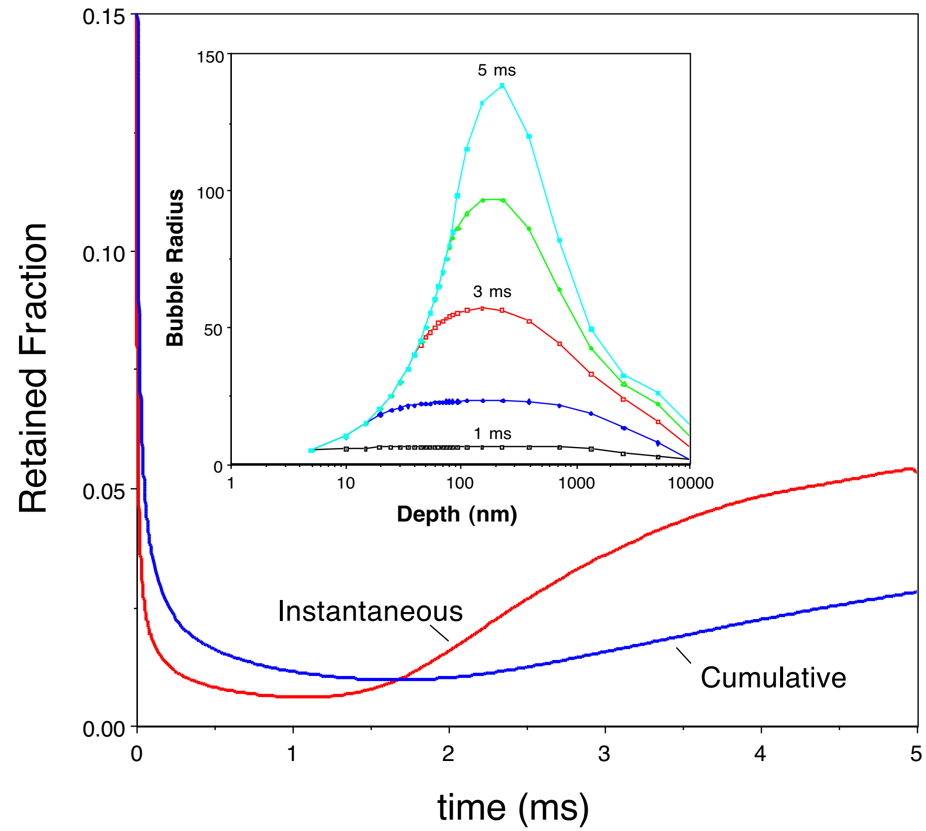
Experimental Goal: Test our model of He bubble evolution
Benchmark the code at low flux

Status of two Penning Trap Experiments:
- Depth profiling trap -- apparatus nearly completed
- Re-emission mini-trap -- report on preliminary results

The experiments are quantifying the helium dynamically retained within the liquid metal.

- Sandia's modified Nano-Bubble Evolution code (BubbE) predicts:
  Liquid Ga or Sn at 600 K, exposed to a He flux of 10 mA/cm^2, will retain 10^{14}-10^{15} He/cm^2 in bubbles within 1-2 μm deep.
- This concentration should be present in steady-state.
- Liquid metal is exposed to He$^+$ fluxes in Penning traps.
- Dynamic retention is being measured
  - by ^{3}He(d,p)^{4}He NRA
  - by He Re-emission.



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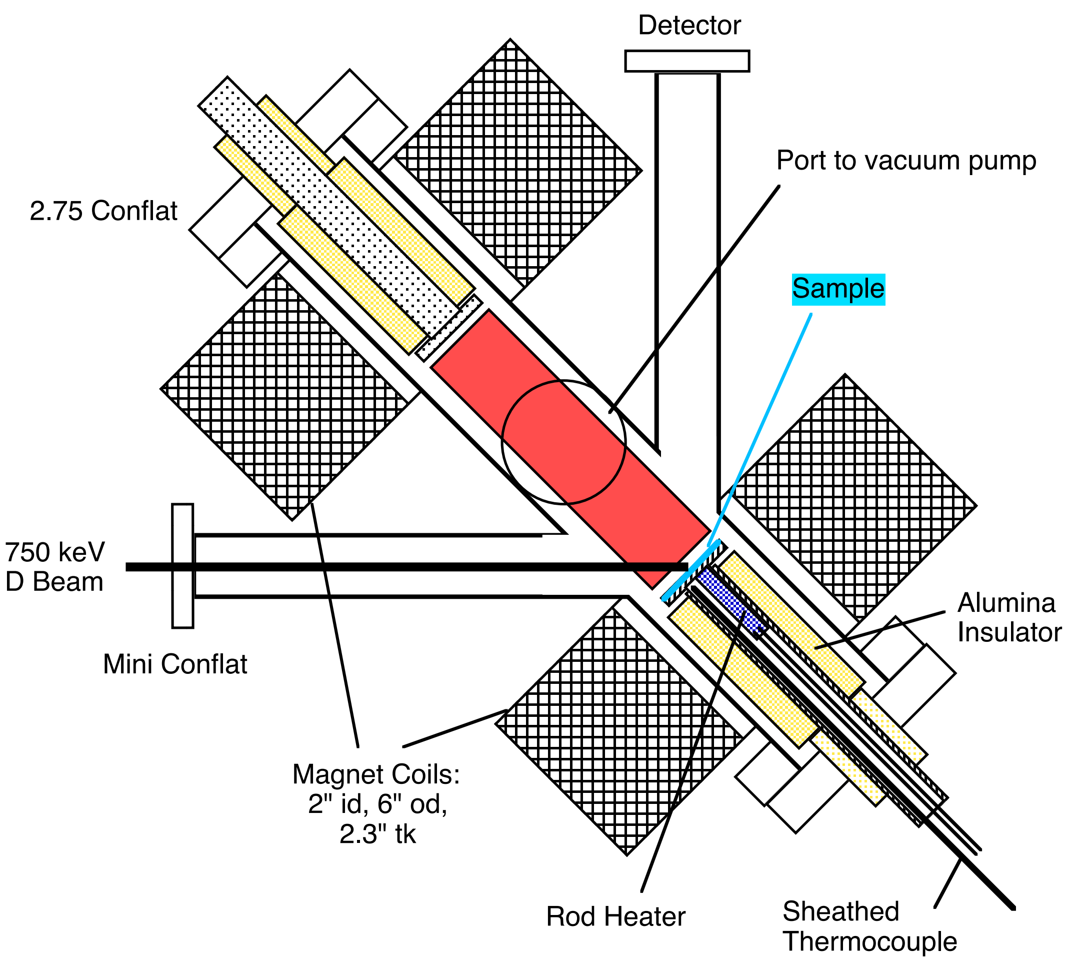
He Depth Profiling Experiments are using SNL-CA's shielded deuteron accelerator facility.



- Penning trap produces flux of 10^{21} He/m^2-s at 1 keV.
- Liquid metal (1 cm^2) covers one trap (cathode) plate.
- ^{3}He added to plasma is profiled in LiqM by d^+ beam.
- High steady-state retention will signify bubble formation.
  - Temperature dependence will be compared with code.
- Trap assembly and vacuum hardware nearing completion.

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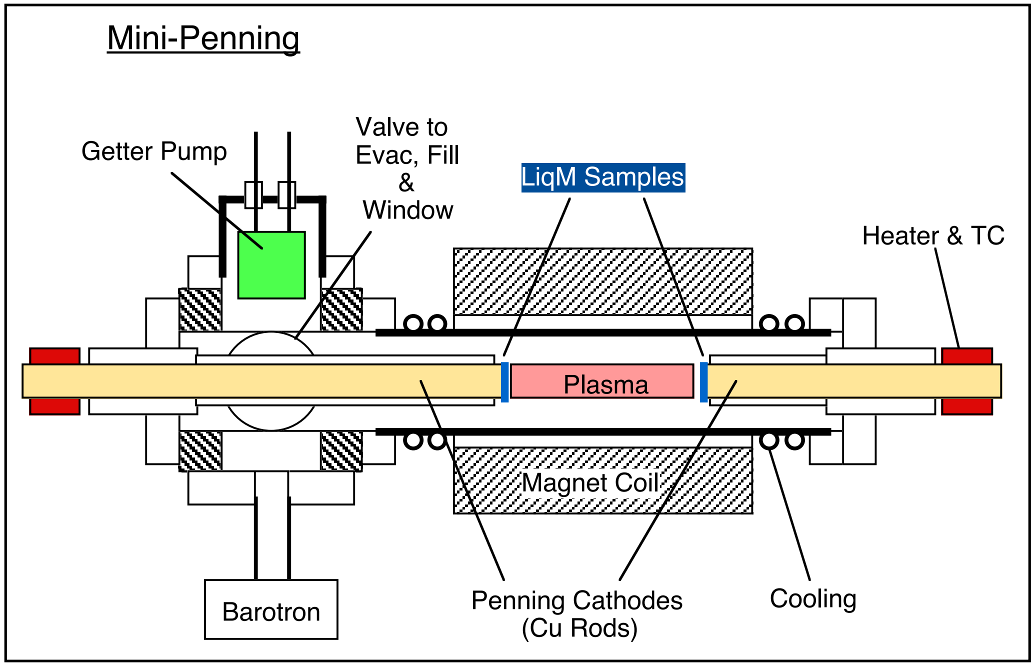
He Re-emission Experiments are examining the He in nano-bubbles by desorption.

- It uses a small volume (40 cc), getter-pumped He Penning discharge with Liquid Metal cathodes.
- The quantity of He in the LiqM is determined from He pressure changes.
  - For solids, He disappears
  - For liq Ga, He re-appears
- Sagging of liq Ga required a vertical trap orientation to minimize variation film thickness.



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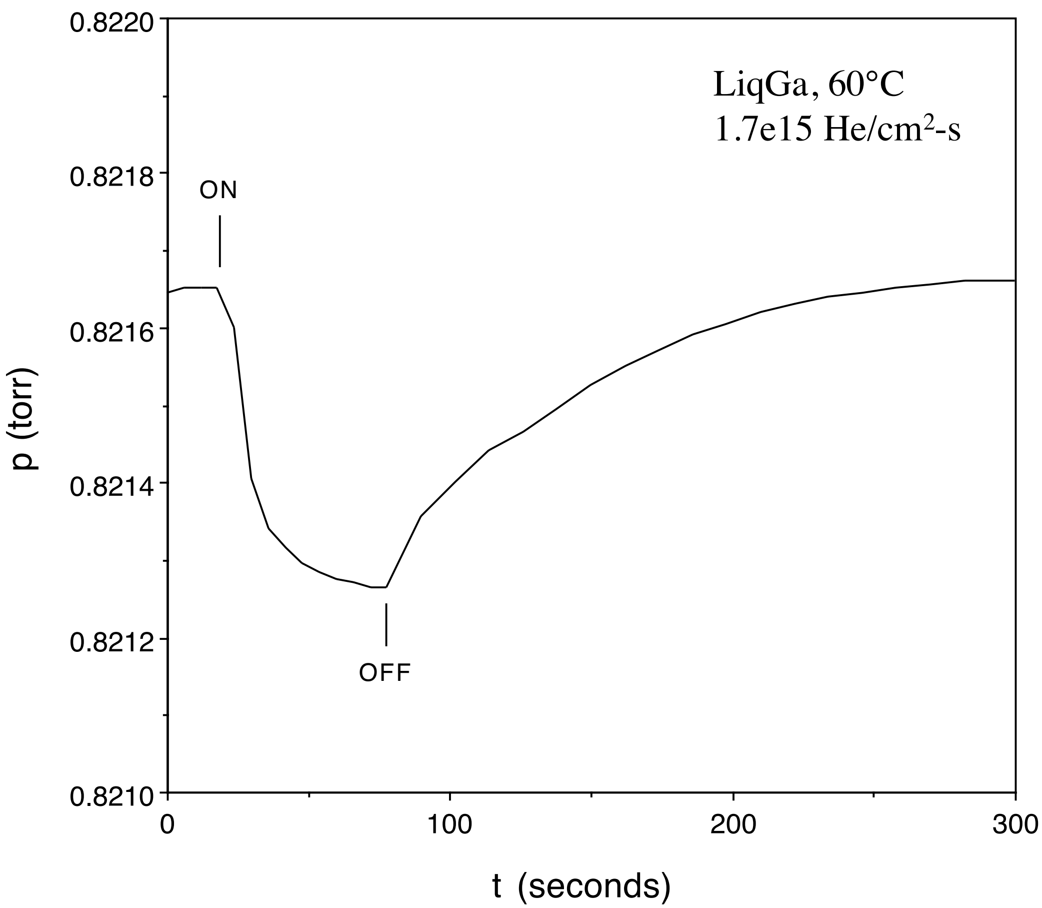
Re-emission experiment shows good sensitivity to He pumping behavior.



- Experiments to date:
  Liquid Ga
  60-125°C
  1-5 $\times 10^{15}$ He/cm^2-s

- Early ON, OFF transients were quite reproducible.

- Behavior became solid-like with continued operation, probably due to contamination.

Magnitude and temperature dependence of pumping behavior indicates bubble formation.

- Observed magnitude is more than calculated in diffusion profile but less than with BubbE code.
  (BubbE code has not been run long enough to reach equilibrium.)

- Observed magnitude increases with T
  - in agreement with enlarging bubbles.
  - opposite to normal diffusion behavior.

	Temp(°C)	He quantity
Observed (from Δp)	60	6e14 He
	90	1e15
	125	3e15
Calculated in diff profile	125	1.5e12
	325	5.4e11
Code prediction with bubbles	60	2e16 at 0.1s
	225	(1e13 at 7ms)
	325	(2e13 at 7ms)

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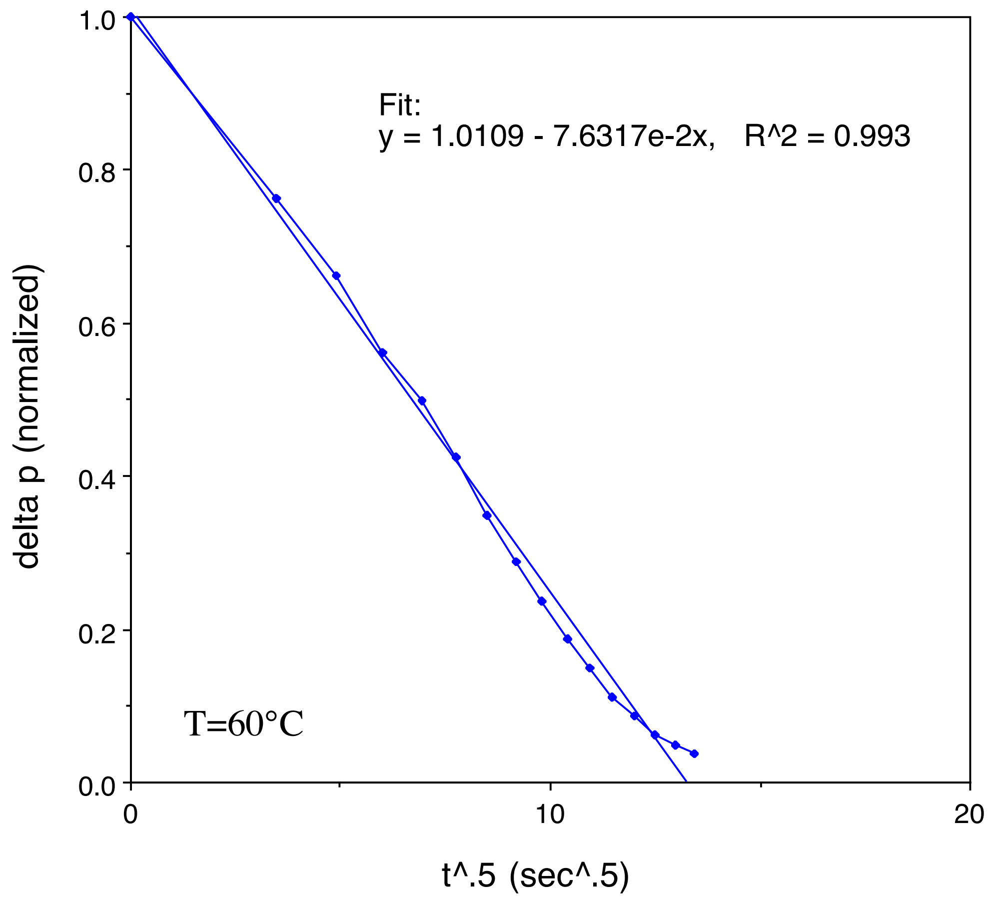
The re-emission time constant is consistent with bubble formation.



- Approximate $t^{1/2}$ time dependence for draining of slab:
  $M(t)/M(0) \approx (4Dt/\pi a^2)^{1/2}$

  - With estimated Ga film thickness ≈ .25 mm, fit gives $D \approx 3\times10^{-6}$ cm^2/s

- Liq Ga self-diffusion:
  $D(55°C) = 2.6\times10^{-5}$ cm^2/s

- 10x lower diffusivity requires
  $Dia_{bubble} = 10Dia_{Ga} \approx 2.7$ nm or about 4000 He/bubble.

Summary of preliminary conclusions:

• Experiments with mini-Penning trap support He bubble formation under even modest plasma fluxes.

Magnitude of pumping effect is
- too large for diffusion profile.

Pumping increases with temperature:
- opposite to diffusive retention
- consistent with growing bubbles.

Long time constant for re-emission
- indicates 10x slower diffusive release
- is consistent with 4000 atom (3nm) bubbles.

• BubbE code predicts He bubble formation under test conditions.
- Several days of run time were required for bubble growth to become apparent.
- Previous calculations were too short to see effect.

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