LANL Cryogenic Pressure Loader (CPL): Inertial Fusion Target Layering Research Tool

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ABSTRACT: Many designs of targets for inertial fusion research and ignition in OMEGA, NIF, LMJ, and future facilities rely upon beta-radiation driven layering or symmetrizing of spherical cryogenic deuterium-tritium (DT) ice layers contained within plastic or metal shells. In most concepts symmetry considerations prohibit the use of gas filling tubes for admitting DT into the target shells. For plastic shells this requirement necessitates permeation filling at room temperature followed by cooling to cryogenic temperatures (~30 K) before removal of the gas overpressure. At Los Alamos National Laboratory (LANL) we have developed the Cryogenic Pressure Loader (CPL) as a testbed for studying the filling and layering of plastic inertial fusion targets with DT. The CPL consists of a cryostat, which contains a high-pressure cell for permeation and has optical access for investigating the dynamics of beta-layering. The cryostat is housed within a tritium glovebox that contains support manifolds necessary for supplying high pressure DT. The CPL shares some design elements with the Cryogenic Target Handling System at the University of Rochester's OMEGA facility to allow some testing of tritium handling issues related to that system. The CPL has the capability to permeation fill plastic targets to pressures up to 1000 atmospheres and to cool them to 15 K. The CPL's permeation cell size can accommodate a wide range of targets and target mount structures – making it an ideal tool for testing a range of current and future target concepts. Future modifications could add diagnostic or layering tools such as infra-red light or resonant ultra-sound spectroscopy to supplement optical data acquisition.

The CPL is located in a LANL tritium facility and has been thoroughly acceptance tested using deuterium. DT operations on the CPL are approved and will begin during summer 2002. This poster presents results from two successful deuterium target fills.

Cryogenic ICF Target Criteria and Production Technique

ICF target designs call for:

- 1-2 mm diameter Plastic or Be shells with ~100 μm thick solid DT layers on the inner surface
- The inner DT surface must be uniform to ~1 μm rms
- The outer ablator surface must be uniform to ~30 nm rms--thus fill tubes are prohibited

Procedure to fill and layer targets:

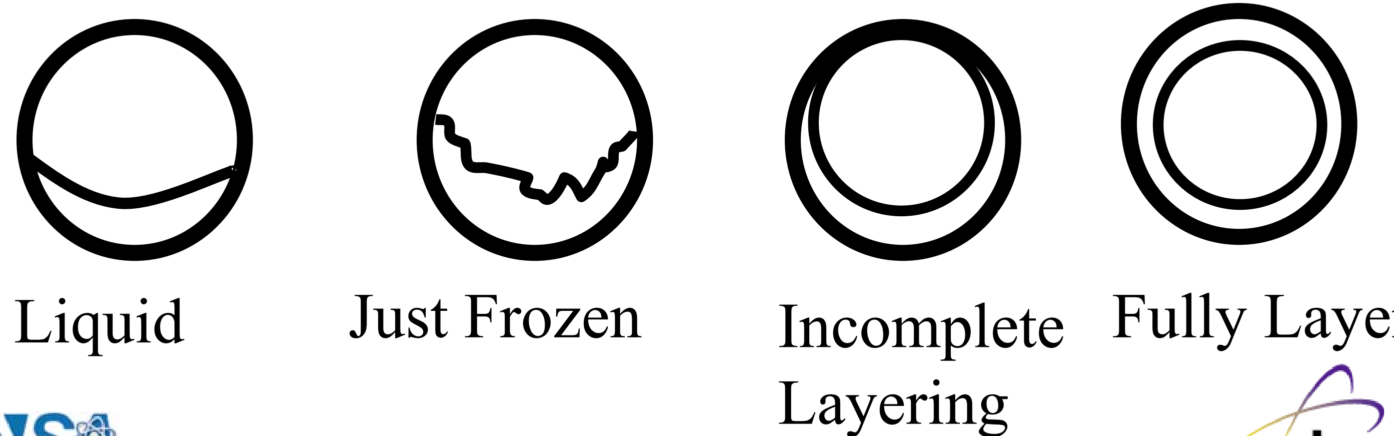
- Target shells are permeation filled with DT at high pressure and room temperature
- The targets are cooled to condense the DT so that the excess DT may be removed
- Targets are further cooled to freeze DT and Beta-Layering occurs forming uniform, smooth layers

The Beta-Layering Process

• Beta decay heating drives mass transfer to achieve temperature equilibrium at DT solid-vapor interfaces

• Interface temperature depends on wall temperature and solid DT layer thickness

• For isothermal spherical walls, the equilibrium condition is isothermal solid-vapor interface *and uniform DT shell thickness*



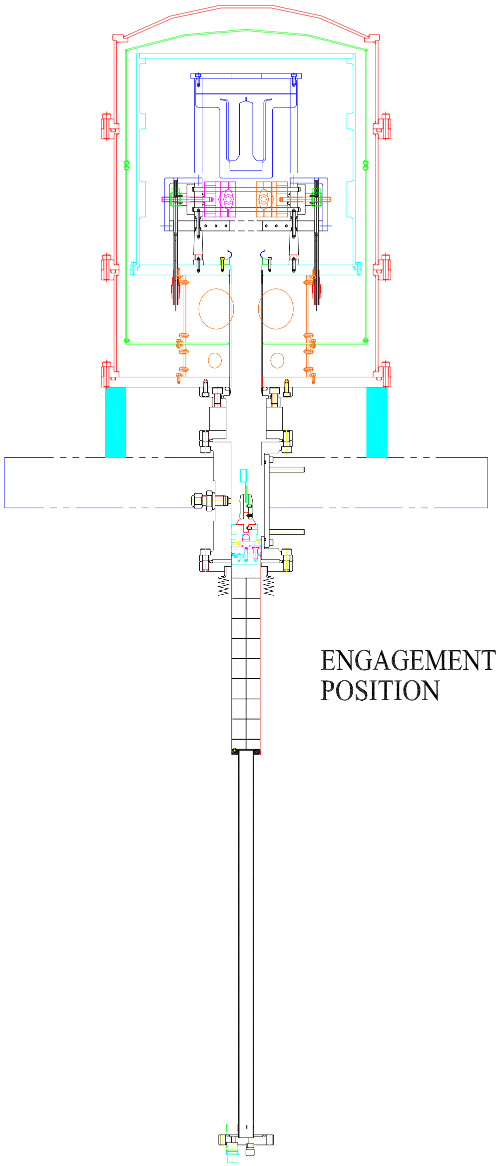
Cryogenic Pressure Loader (CPL)

- CPL will test elements of the Omega Cryogenic Target Handling System (CTHS) to provide advanced DT data
  - Permeation cell and some target shells are exact copies of the CTHS allowing advance evaluation of permeation filling
  - Tritium migration within the cryostat will be measured
  - Beta layering studies will evaluate the layering environment and target mount structure
- CPL will be a Versatile Research Tool
  - Can accommodate Omega, NIF, or future IFE targets
  - Can pressurize to 1000 atm
  - Ability to rotate layered sample to obtain multiple views
  - Can be cooled to 15 K by a single cryocooler in ~25 hours
  - Extra space and feedthroughs allow for future experiments: enhanced layering, resonant ultrasound, hohlraum prototyping...

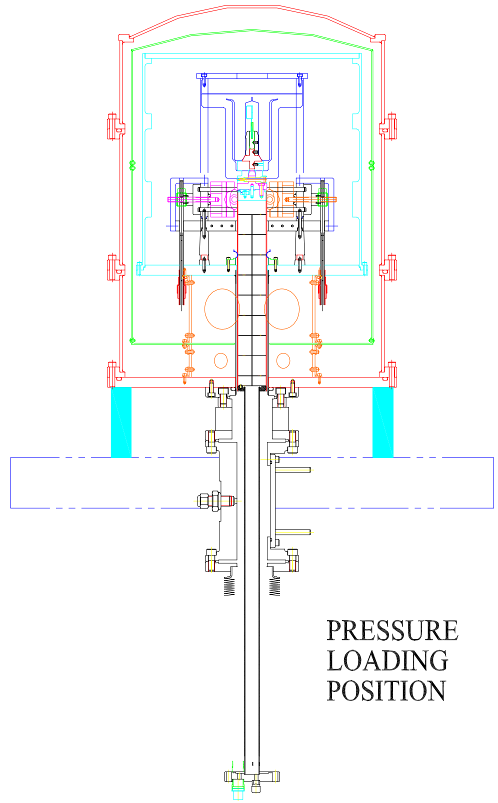
Simplified Diagram of the Cryogenic Pressure Loader

Showing connections to facility systems

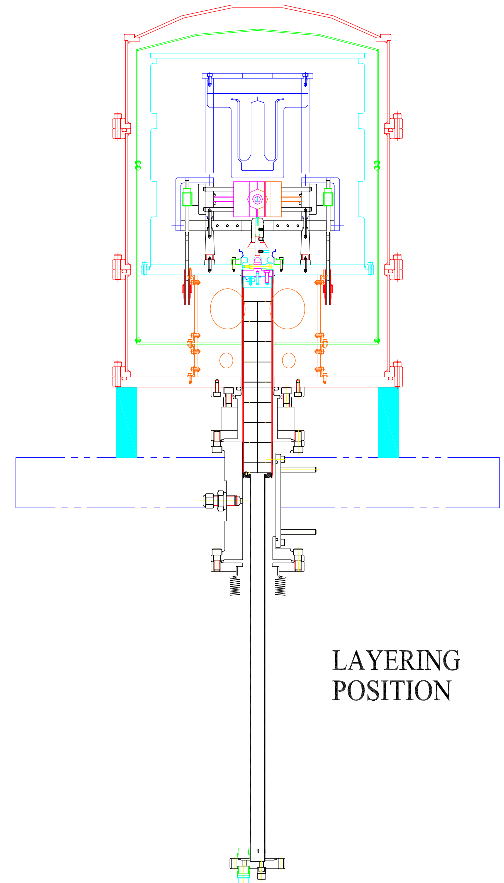
Major steps in CPL operation



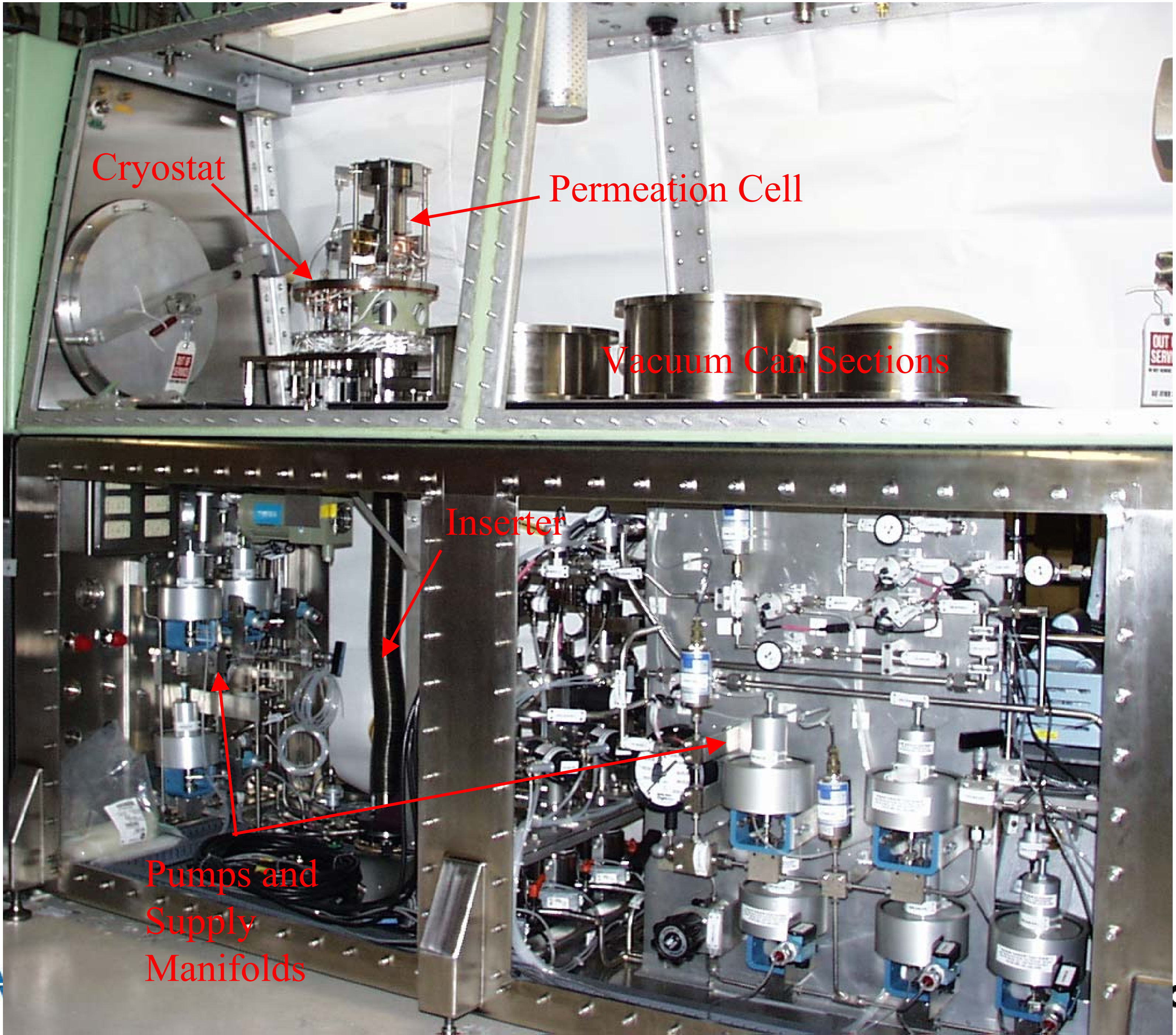
1. Mount target on inserter
2. Raise inserter



3. Engage breechlock
4. Pressurize diaphragm
5. Pressurize DT space
6. Permeation fill target
7. Cool cryostat to 20 K
8. Pump away excess DT
9. Release diaphragm pressure
10. Disengage breechlock



11. Lower inserter
12 Bring layering hemispheres together to form sphere
13. Observe beta layering


Cryostat
Permeation Cell
Vacuum Can Sections
Inserter
Pumps and
Supply
Manifolds

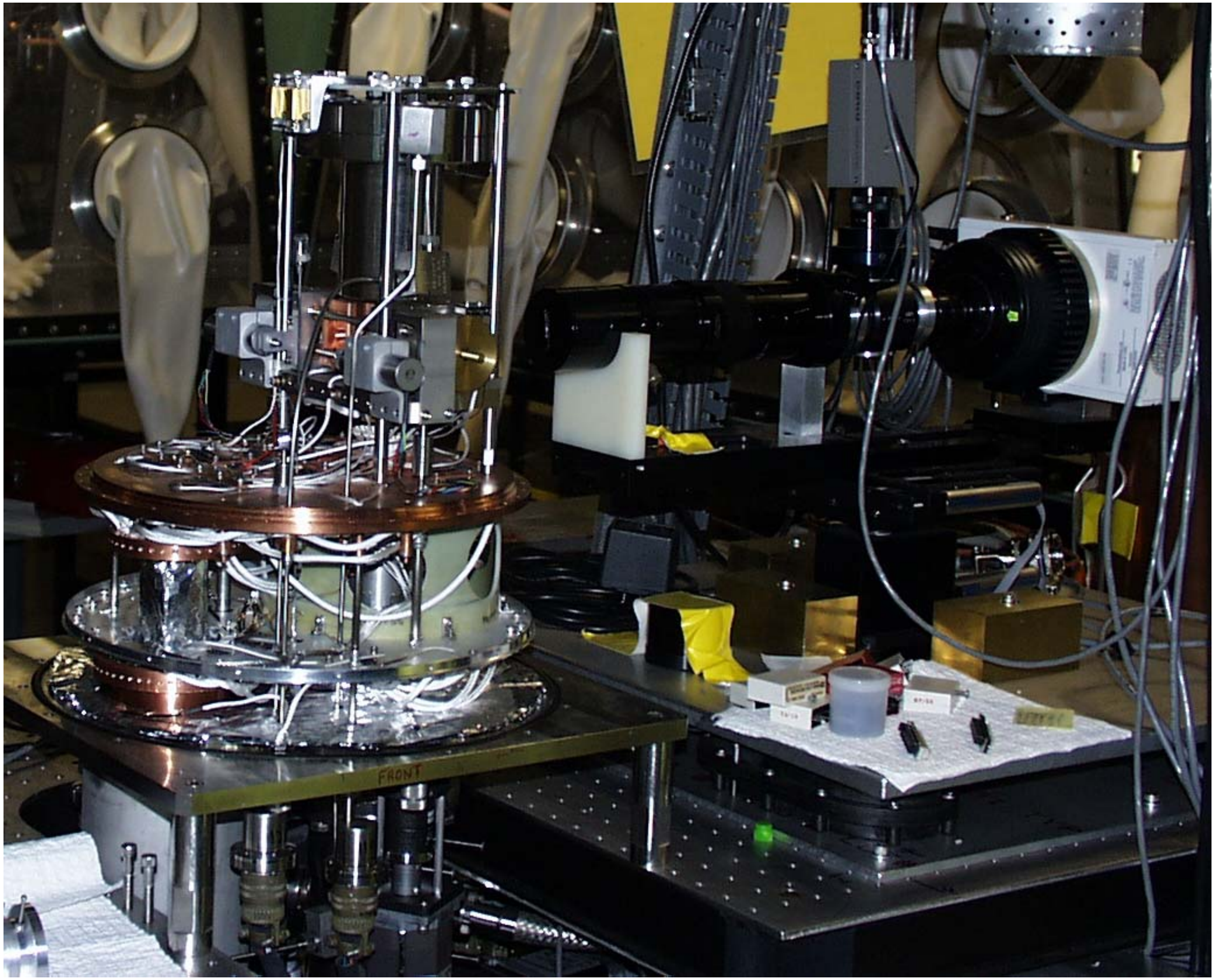
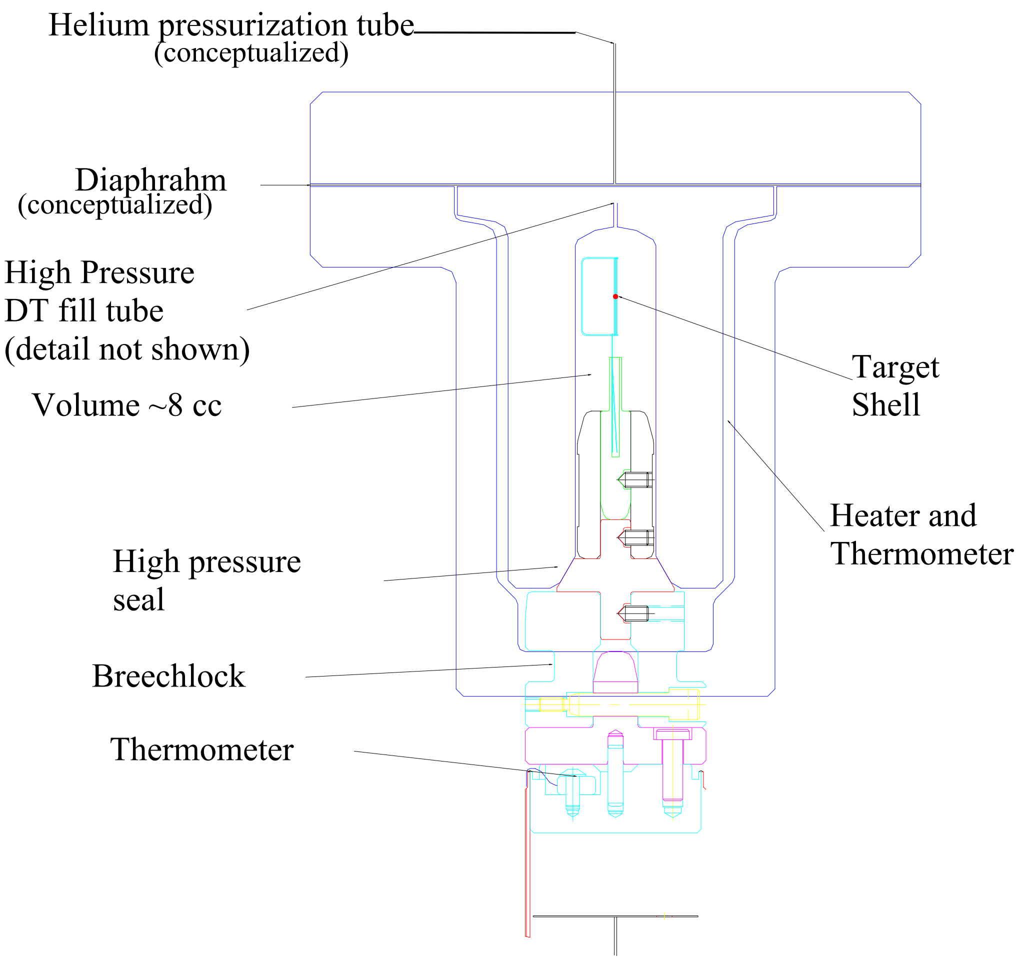


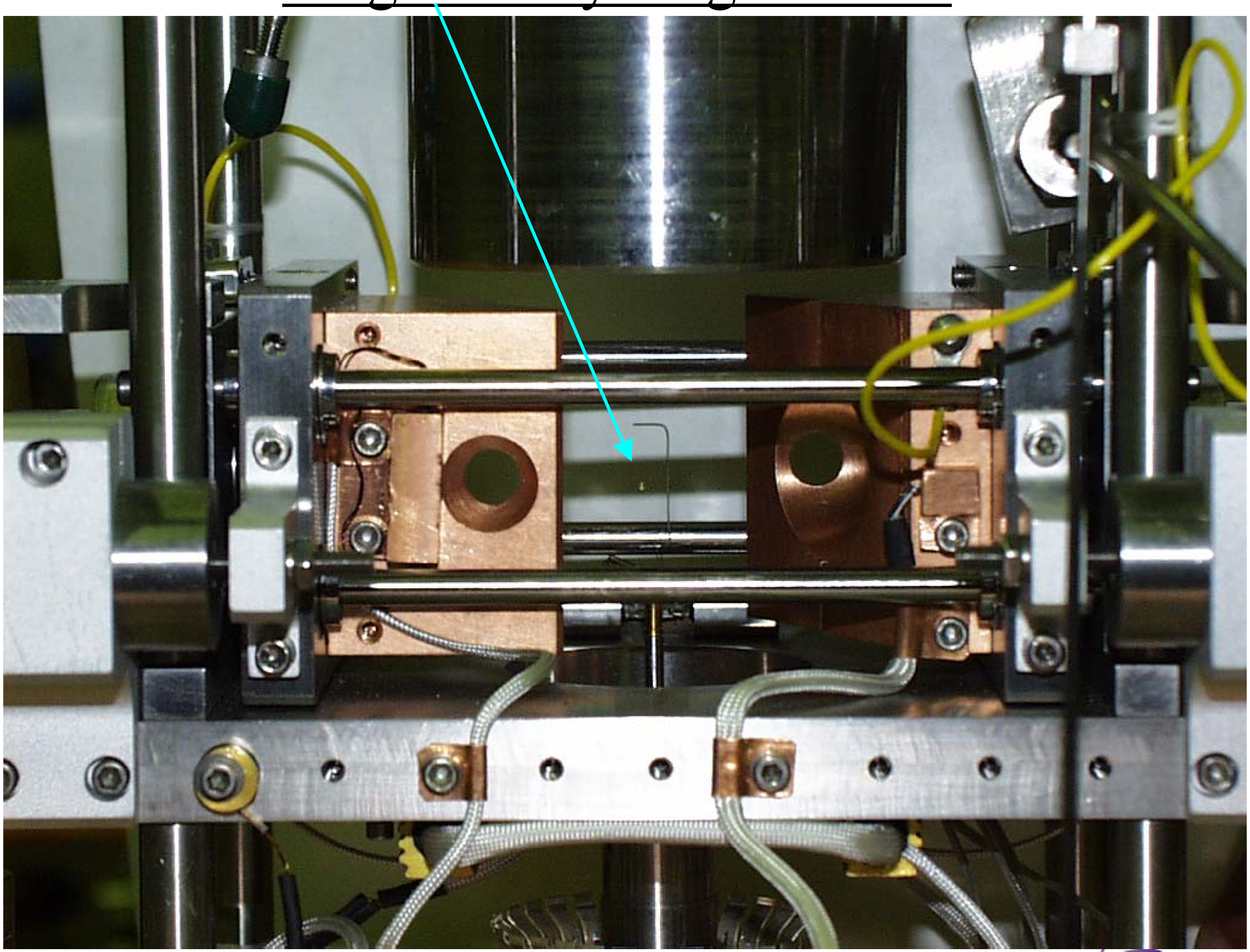
Photo showing the CPL cryostat with cans removed and the optical system. One camera provides real-time video, the other has mega-pixel resolution.

Permeation Cell* Details



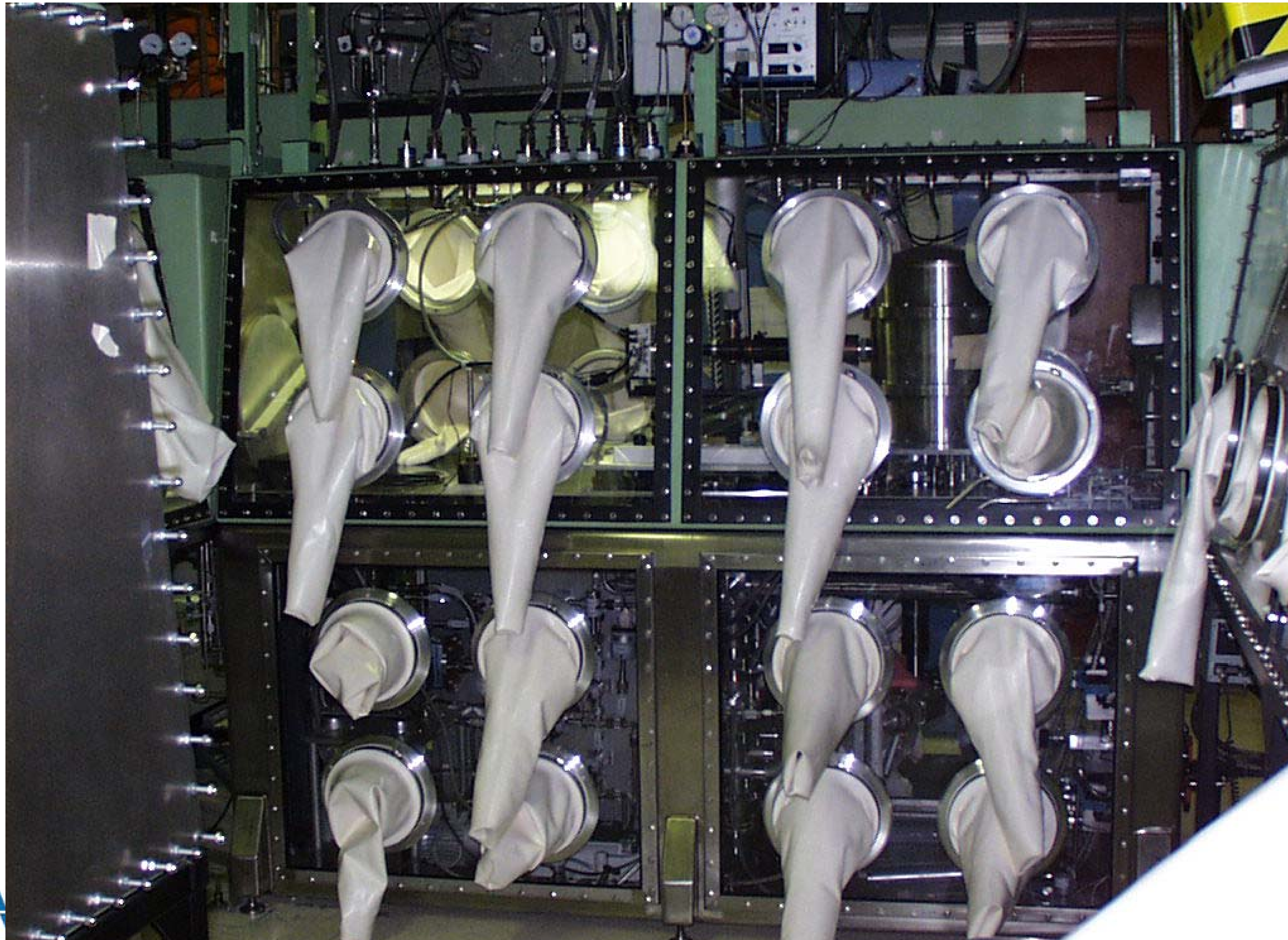
*Designed and fabricated by General Atomics

Layering Sphere Assembly with Target at Layering Position



In March 2001 the CPL Glovebox was brought "on line"

- Glovebox closed up and helium leak tested
- Glovebox exhausts connected to tritium waste treatment system



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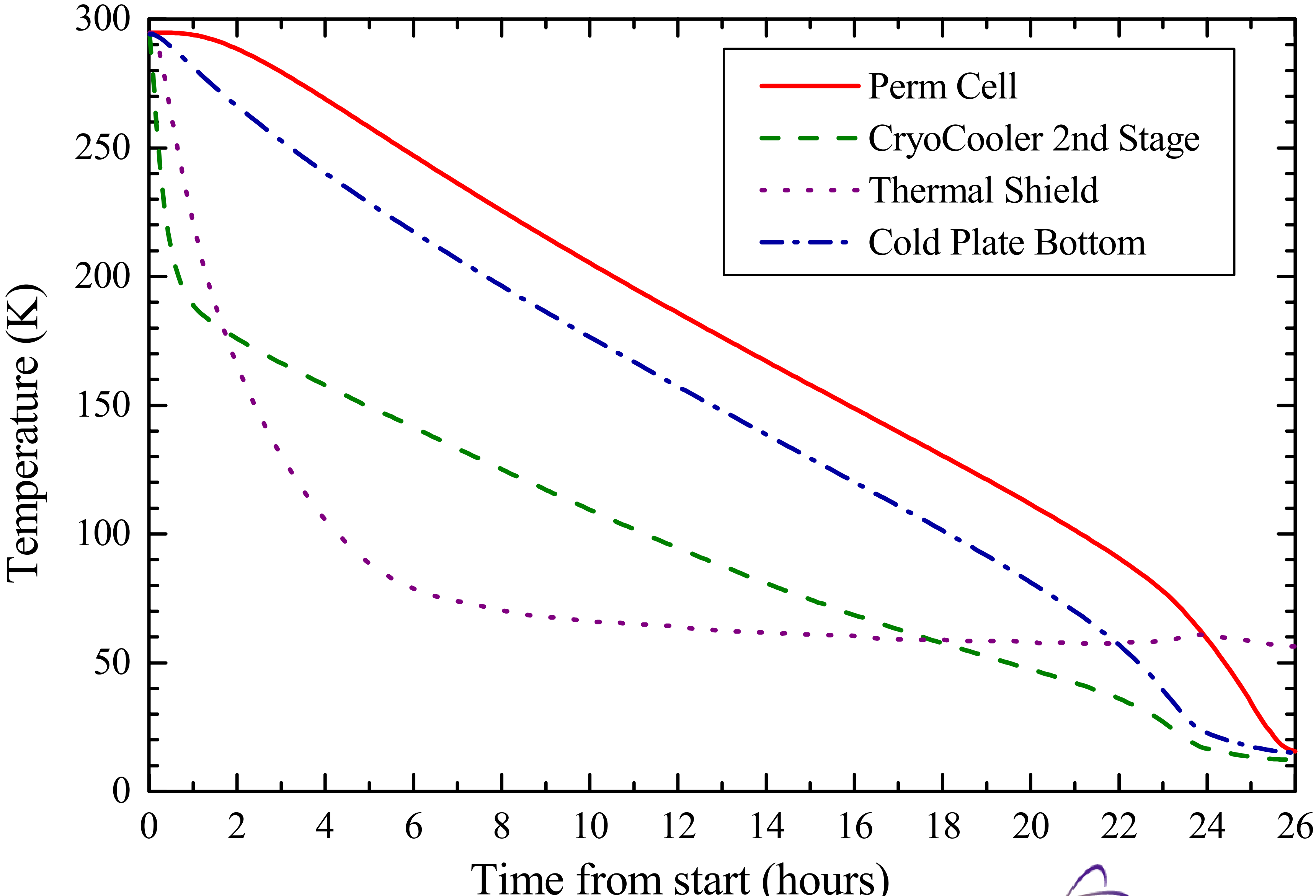
Acceptance Testing Results

- The system has been thermally cycled >10 times
- High pressure plumbing has been leak tested with high pressure deuterium
- Characterization of metering valve completed
- Hardware and management reviews completed successfully
- Two target fills performed with D_2
- Approval granted to begin testing with tritium
  - initial testing is progressing with 0.1% T_2 in D_2
  - subsequent tests with increasing amounts of T_2 up to 50% T_2 in D_2

Thermal Performance of a CPL cooldown



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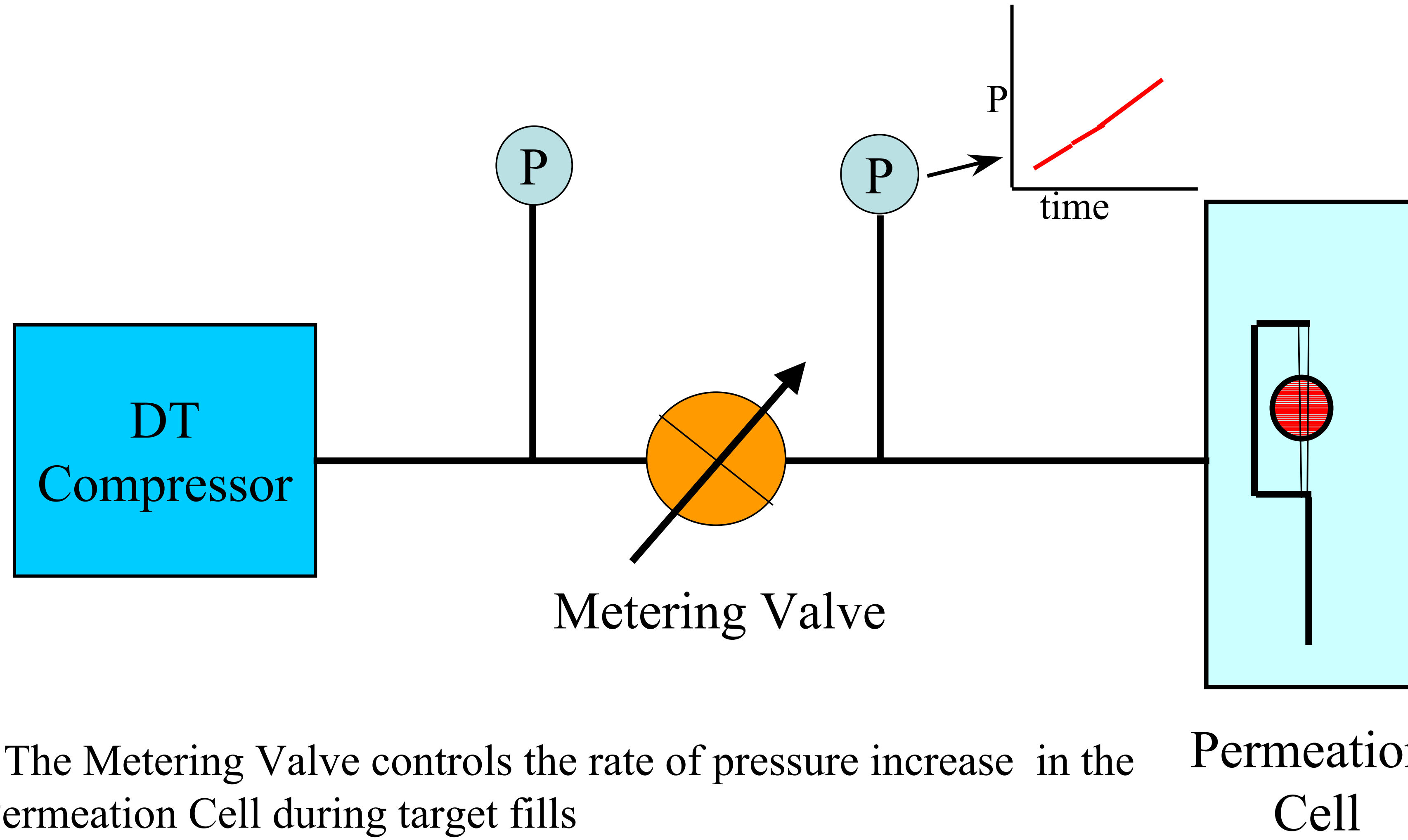
Metering Valve Characterization



- The Metering Valve controls the rate of pressure increase in the Permeation Cell during target fills
- Desired Rate < $P_b/2t_c$ (~0.25 psi/sec for 1900μX13μ GDP spheres)
- Computerized tracking of Perm Cell pressure and pressurization rate

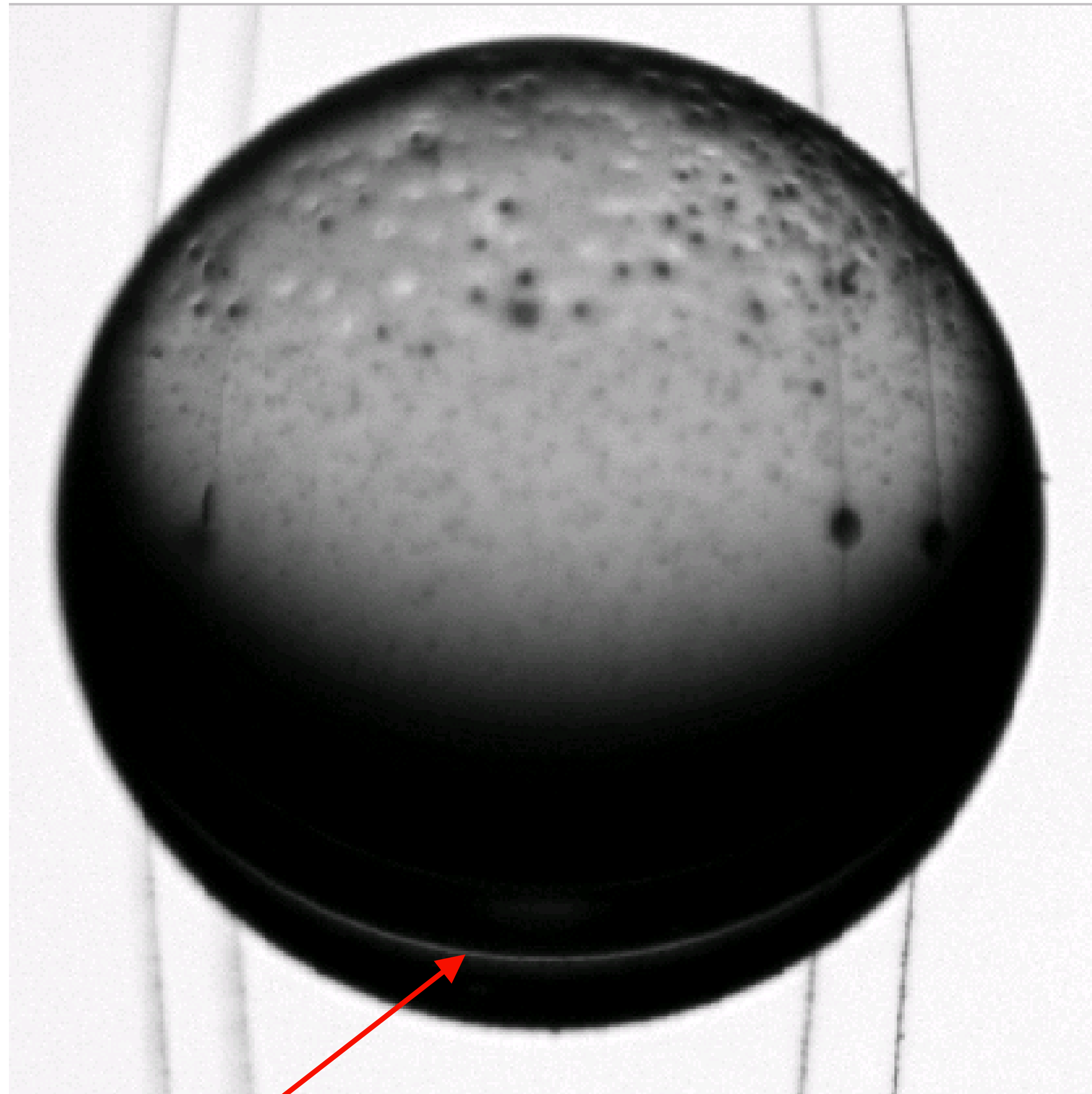
Possible Future IFE Experiments for the CPL

- Test exposure to infrared heating to simulate thermal conditions of target injection
- Test novel freezing techniques for unmounted targets
- The CPL can perform any plastic target layering experiment that requires:
  - DT at pressures of ≤ 1000 atm
  - Cryogenics to 15 K
  - Dimensions ≤ 16 mm dia. X 65 mm length

Deuterium Fills of Polymer Targets

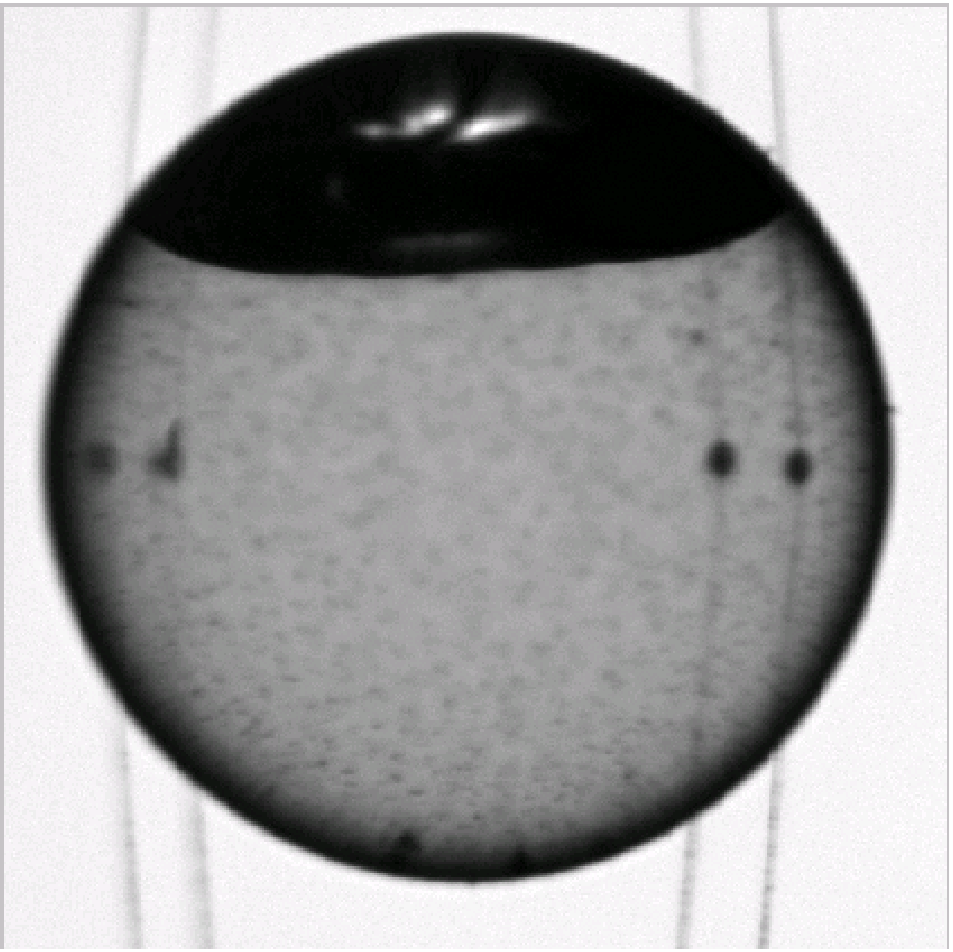
Spider Web Mounted Spheres

2mm (l) and 1mm (r) (Mounting by University of Rochester)

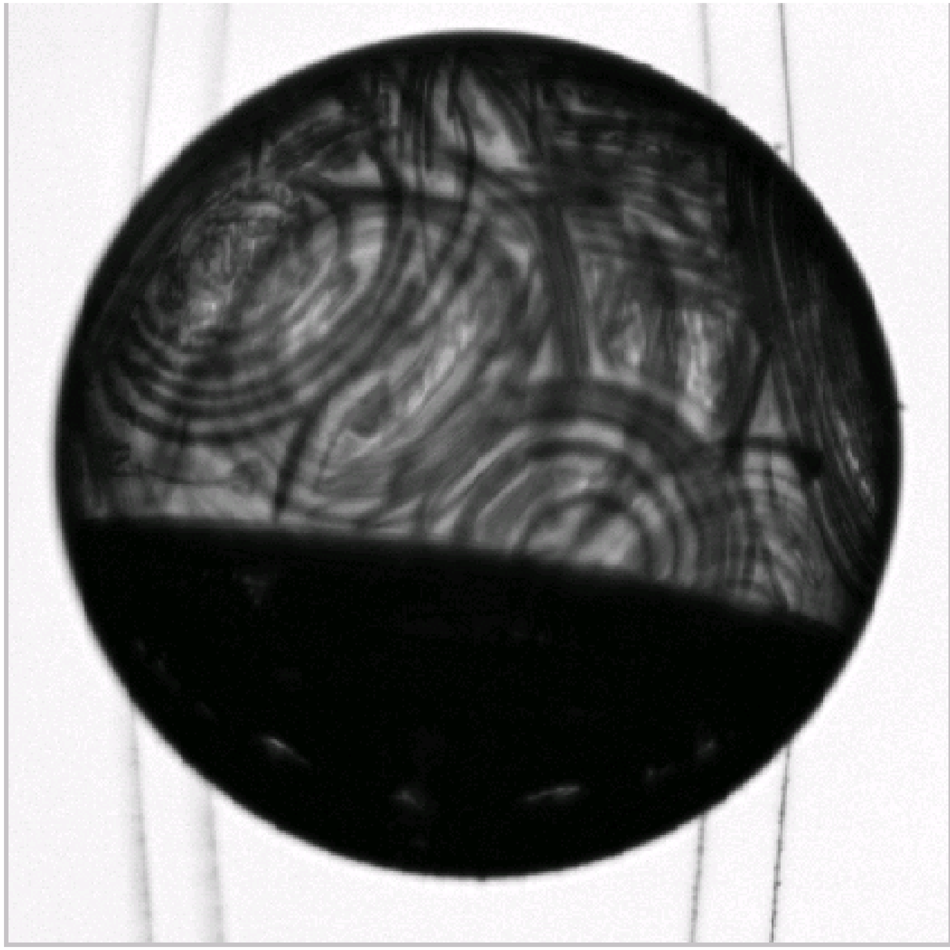


D_2 liquid in 2mm sphere; note spots of air

Solid D_2 in 2mm Shell



Solid D_2 after overnight freeze with layering sphere open



Solid D_2 after 5 minute freeze with beautiful pattern that was never reproduced

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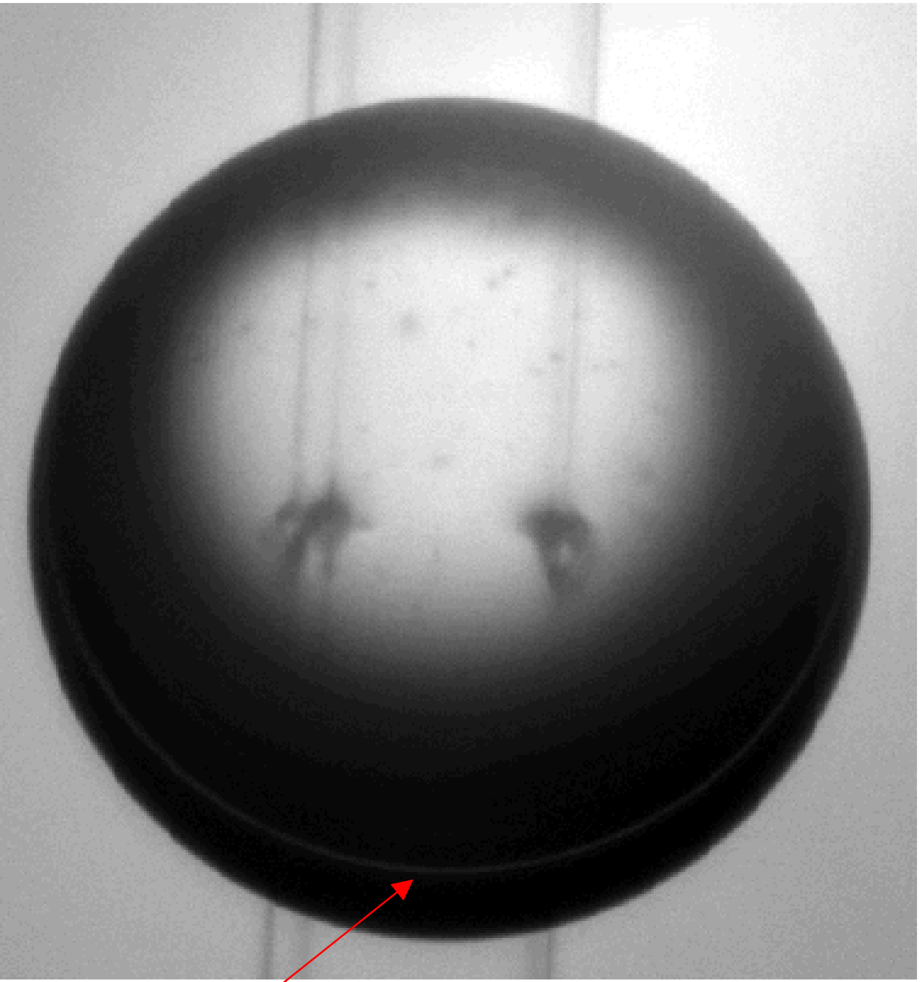
Second Successful CPL D_2 Target Fill

During November 2002 the Los Alamos Cryogenic Pressure Loader (CPL) team (in ESA-TSE) performed the second deuterium permeation fill on the CPL of a fill tubeless plastic ICF target sphere. The filling took place between November 4 and November 21, 2002 to a pressure of approximately 4500 psia. After filling the capsule sat at room temperature in the sealed permeation cell until December 2, when the cryostat cooldown was commenced. On December 4 the permeation cell was opened and the target sphere was intact and contained D_2 liquid. The one month exposure to high pressure D_2 does not appear to have adversely affected the shell material.

The target sphere was 920 um diameter with 20 um wall thickness.

During this cooldown the "dots" seen in two previous cooldowns (surmised to be frozen air) were not seen.

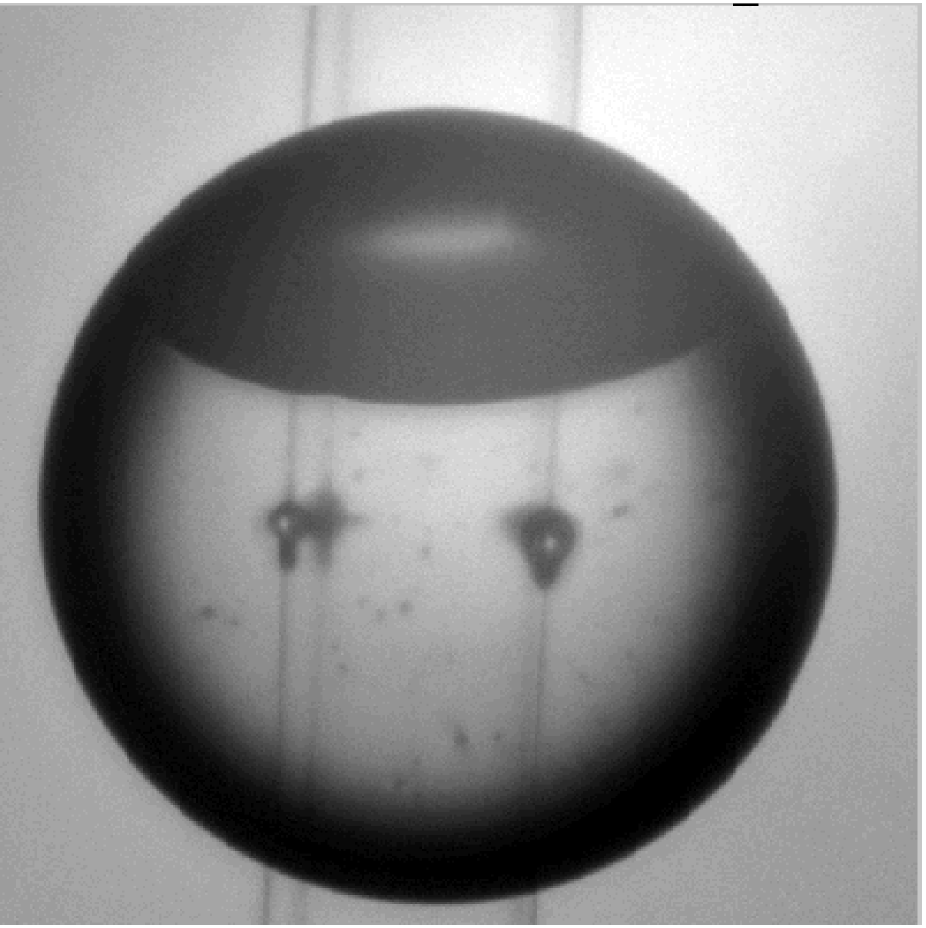
D_2 Fill of 1mm Sphere



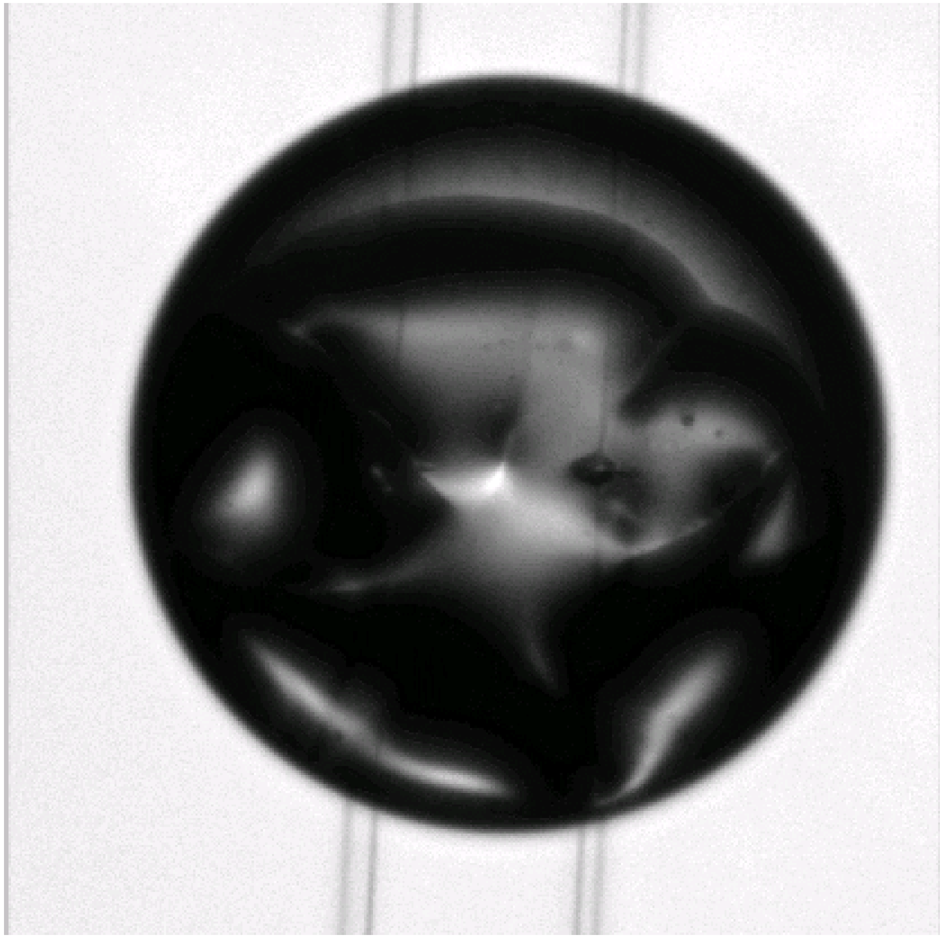
Liquid level shown by faint bright band, Meniscus shown by dark shadow

Solid after a relatively quick freeze

D_2 Fill of 1mm Sphere



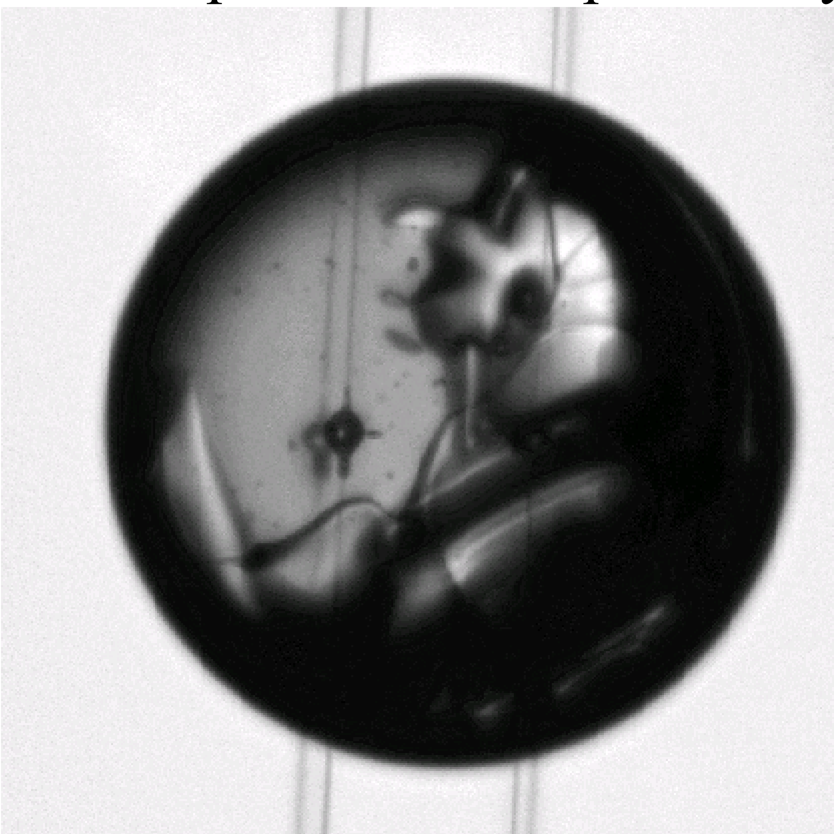
Solid D_2 after overnight freeze, the solid is all at the top due to a thermal gradient (layering sphere was fully opened)

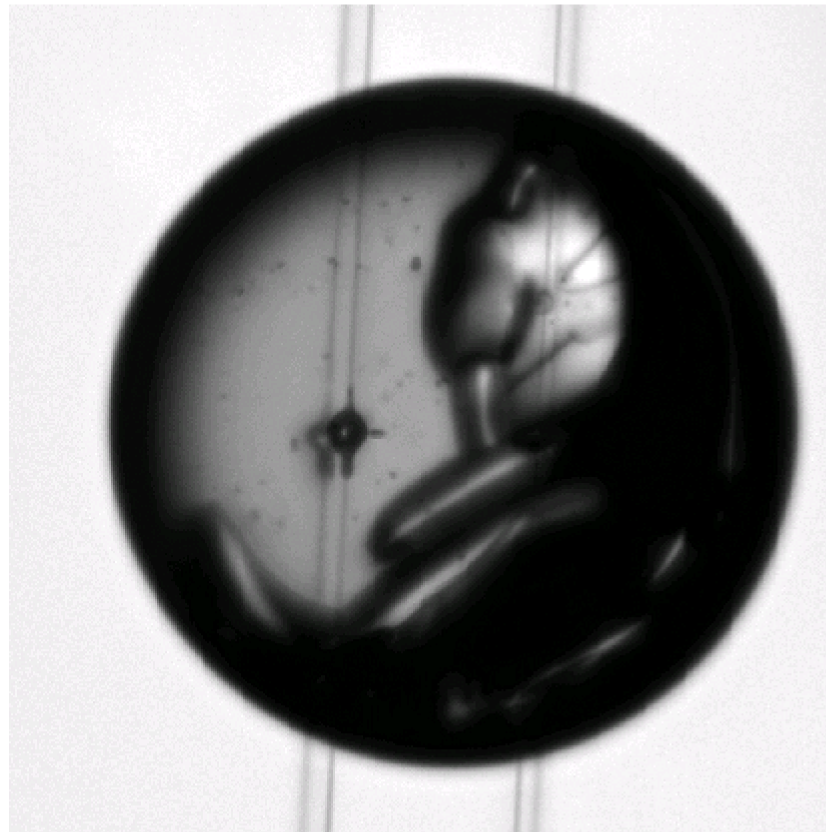


Solid D_2 after overnight freeze with the layering sphere closed

D_2 Fill of 1mm Sphere

Two pictures taken after freezing with the left CPL layering hemisphere at ~18.7 K and right hemisphere at ~18.4 K. Left picture taken about 45 minutes after freeze started, right picture taken about 75 minutes after freeze started. Note that the layering hemispheres were separated by about 2 mm for this freeze.





Summary

• The CPL was designed and built with the ability to study DT fuel layering in a variety of inertial fusion capsules

• All pre-operational evaluations have been successfully completed

• High Pressure testing has been performed on the CPL

• Two full D_2 target filling operations have been performed

• Tritium operations have begun with ~0.1% T_2 in D_2