# Advanced Cryogenic Wetted-Foam Technologies at the Z Facility

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A.J. Lopez[1], D.L. Hanson[1], K.P. Shelton[1], J.M. Villalva[1], M.E. Cuneo[1], S. Slutz[1], R.A. Vesey[1], D.G. Schroen[2], K. Tomlinson[2], B. Blue[2]

[1] Sandia National Laboratories, Albuquerque, New Mexico 87185, USA

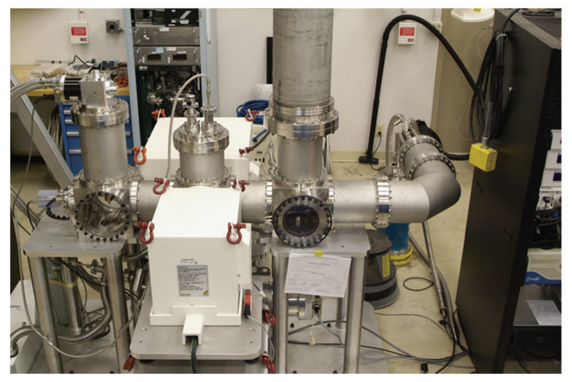
[2] General Atomics, San Diego, California, 92121, USA

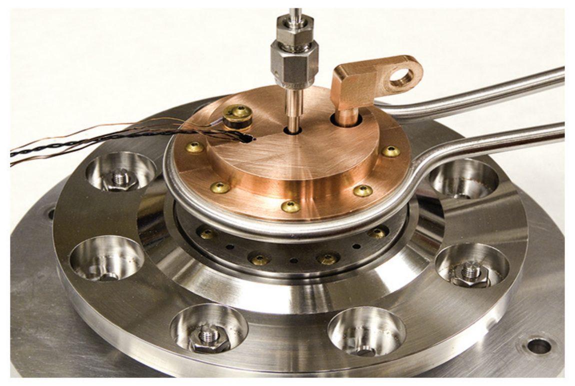
A wide variety of techniques have been developed for fielding cryogenic High Energy Density Physics (HEDP) experiments on Sandia's Z Facility. As part of this effort, we have developed a cryogenic wetted-foam and target fabrication; high precision cryogenic cooling and liquid level adjustment; and x-ray computed (CT) characterizaion. This presentation will describe these procedures in detail and will provide examples of the fabrication, cryogenic, and characterization techniques and data.

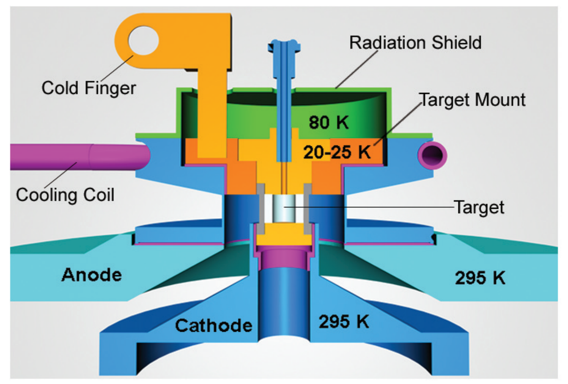
## Cryogenic Test Hardware

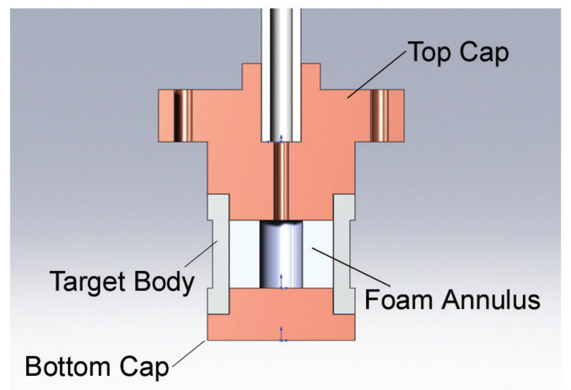
The cryogenic test system utilizes conduction heat transfer to cool a target filled with deuterium gas. When cooled below the boiling point, the gas condenses into a liquid state, filling the cylindrical target with LD2. Test hardware utilized includes, but is not limited to the following:

- Modular MDC Vacuum Chamber
- Custom Xradia x-ray imaging system
- Lakeshore 340 Temperature Controllers
- Gas Handling System
- Cryostat (LHe, LN2 reservoirs)
- Anode and Cathode (Mock-Up)
- Current Return Can (Mock-Up)
- Target Mount Hardware
- Radiation Shield
- Target Assembly







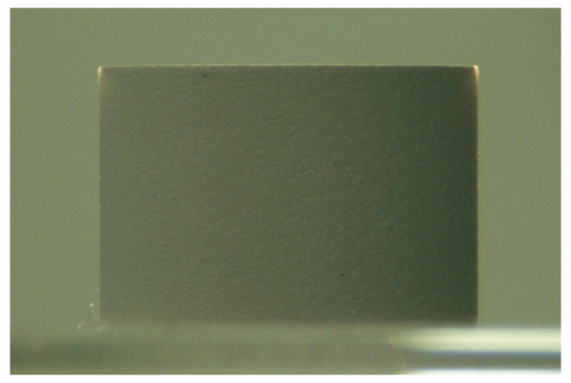



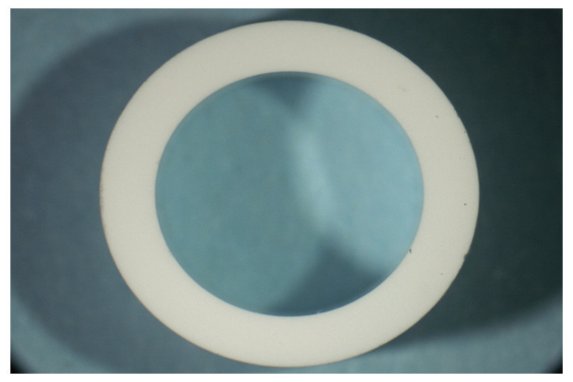

## Foam Development

- Foam: HIPE Polystyrene
- Density Range: 15-700 mg/cc
- Pore Size: 1-10 microns
- Dopants: Halogens, Physical dispersions, Embedded objects
- Chemical Composition: CH
- Production Issues: Molded or machined to shape, vacuum dried

All of the foams are produced from a solution. It is the capillary forces placed on the foam during the removal of the solvent that determines the lowest possible density. To minimize the capillary forces, the foams are dried by heat and vacuum, freeze drying, or supercritical CO2 drying.

The foams are machined to shape using a Precitech Freeform700 5-axis milling machine.





## Target Characterization Techniques

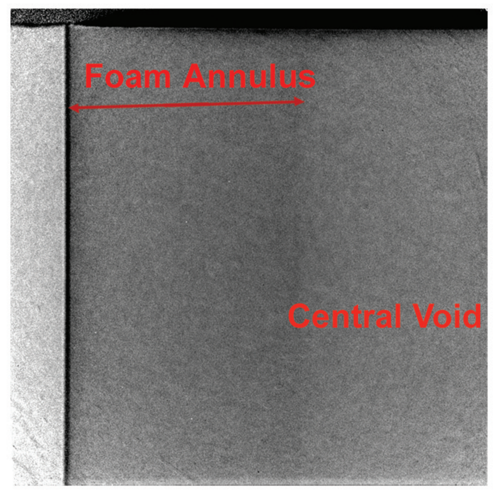
**Targets are characterized utilizing the following:**

- Xradia MicroXCT-200 X-ray imaging system used to confirm wall thickness uniformity and proper form
- Interferometry of surface finish of machined components
- Density characterization and dopant concentration of foam
- Photograph to document final assembly state

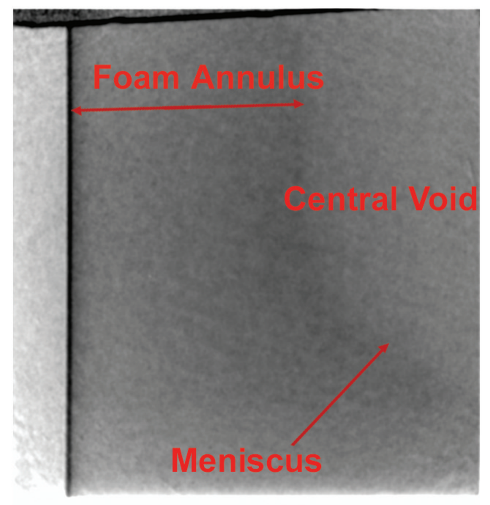

## Xradia Images of a Wetted-Foam Annulus

The x-ray images below clearly show the outline of the foam annulus when filled with LD2. In initial background images taken (not shown) prior to liquid state, the foam annuius was not visible. Once wetted, the foam is clearly visible, with the desired meniscus fill level visible at the target bottom.

**Target Top Left**

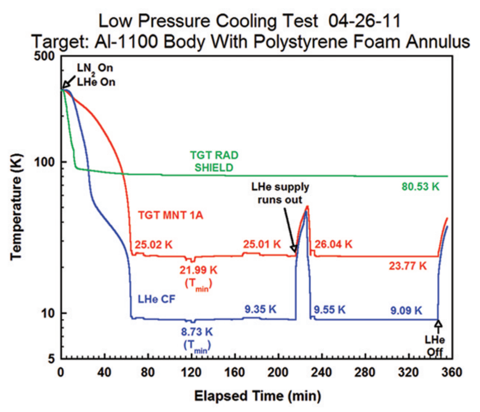



**Target Bottom Left**

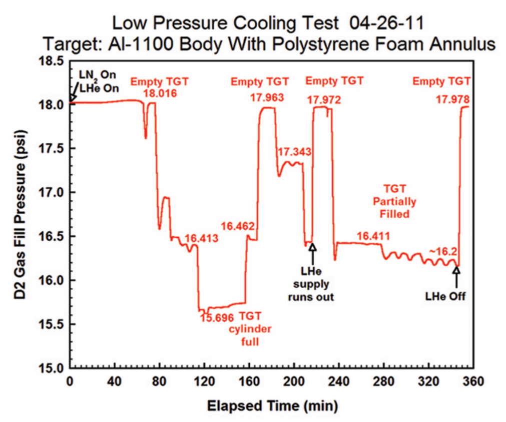



## Cryogenic Cooling Test to Study Wetted-Foam Partial Fills

On April 26th, we performed a cooling test on a target with a foam annulus, filled with deuterium gas, to study partial fill issues. The test target, made of an Al-1100 cylindrical body and copper end caps, contained a polystyrene foam annulus for wicking/wetting LD2. Determining the fractional pressure change between empty and full states provides a measure of the LD2 fill level of the target cylinder. We performed temperature and presure measurements to determine the total pressure change required to completely fill the target cylinder. Starting from an empty target, the foam was partially and then completely filled to observe differences in LD2 distribution. It was desired to have a small amount of liquid in the bottom of the target, providing an indicator of a fully filled foam target.

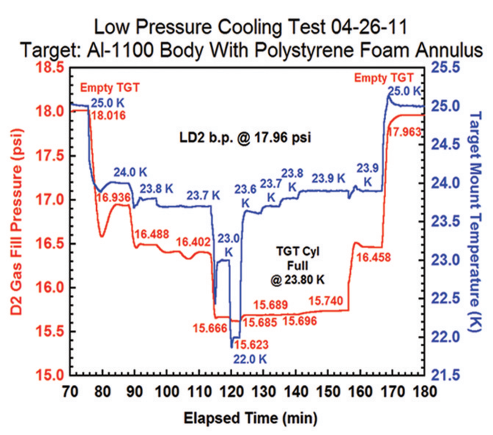



The target was cooled to 25 K in about 60 min, then followed by partial fill tests.

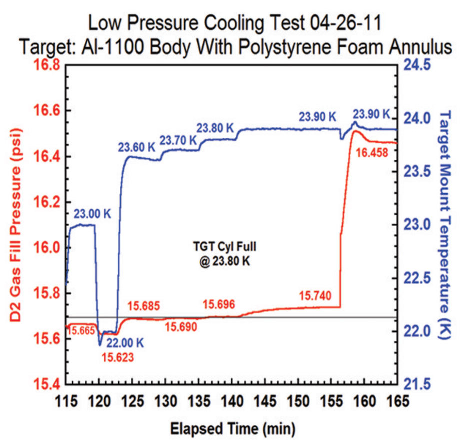



The D2 pressure is measured in a closed system having a large volume compared to the target.

Condensation of D2 gas into liquid results in a volume reduction by a factor ~800, producing an easily measurable change in pressure.




The foam introduces a thermal disconnect between target ends, thus the target had to be filled and then emptied slowly to determine $\Delta$ Ptot

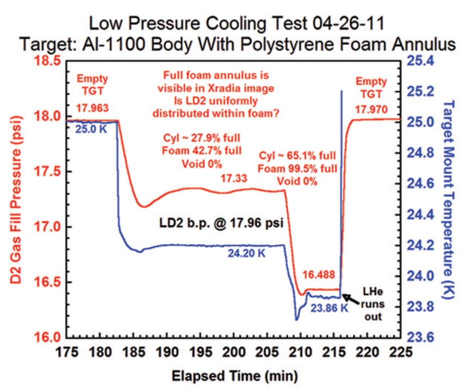



The target is completely full at temperatures below 23.8 K.

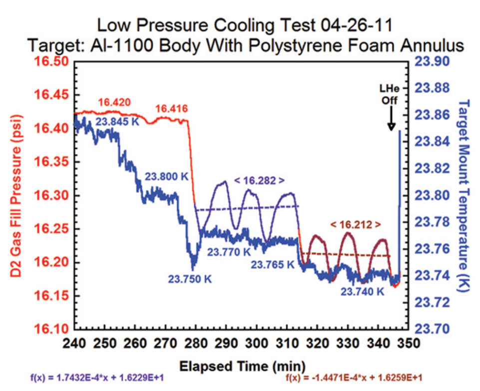
$\Delta$ Ptot = 17.963 psi - 15.696 psi = 2.267 psi

Fractional Pressure Change (FPC): FPC = [17.963-P(T)]/2.267

Foam completely filled for FPC ~0.654



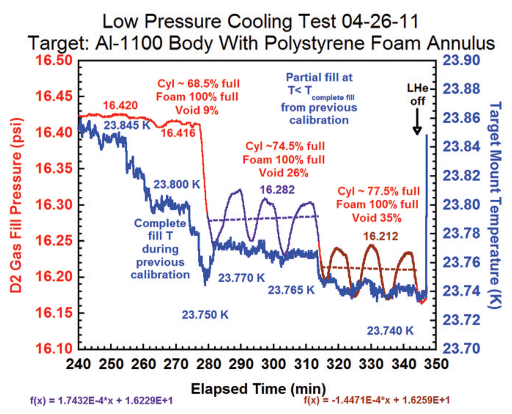

The full outline of the foam annulus is visible in an Xradia image when foam is 43% full, suggesting the wicked LD2 is distributed throughout the foam volume.



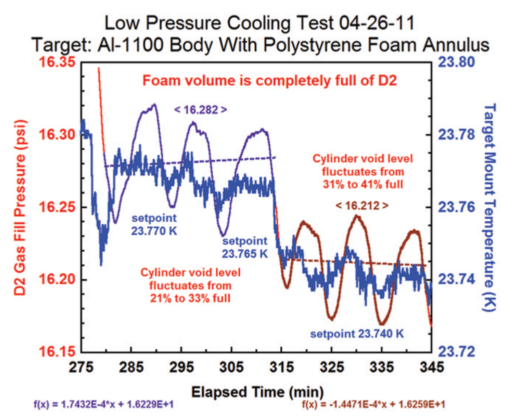

The temperature change between an empty and full cylinder is less than 600 mK.

$\Delta$ T for a 10% change in fill level is only about 100 mK.

The thermal disconnect and stability of the target fill process is very different with the foam annulus in place than for an empty cylinder.




The total pressure change, $\Delta$ Ptot from empty to full and the fractional pressure change $\Delta$ P/ $\Delta$ Ptot required to achieve a given fill level in the foam and void are the important parameters.




Cyclical T fluctuations at partial fill levels of interest are now on the order of 5 mK and lead to P fluctuations of ~ 0.04 psi.

In spite of these fluctuations, the foam annulus should remain completely full; T oscillations translate into few percent fluctuations in the fill level of the central void.

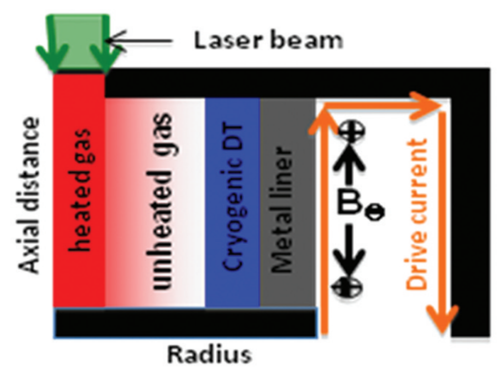
T and P fluctations for a target with no foam were much more stable, with fluctuations on the order of 1 mK and 0.001 psi. The foam apparently delays heat exchange radially and axially, setting up cyclical processes preventing true stability.

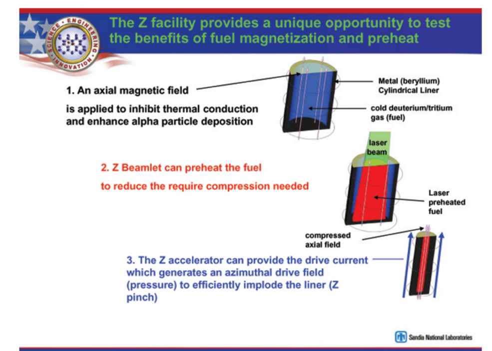
## Application to MagLIF Concept

Numerical solutions indicate high-gain magnetized inertial fusion (MIF) is possible in cylindrical liner implosions based on the MagLIF (Magnetized Liner Inertial Fusion) concept with a dense layer of cryogenically cooled deuterium-tritium (DT) fuel surrounding the magnetized preheated gas.

Relative to the standard MagLIF configuration, the high-gain MagLIF configuration incorporates a dense cryogenic layer of DT inside surface of the metal liner, motivating the wetted-foam development.

Cryogenic development testing, using LD2, achieved the MagLIF requirement of a wetted-foam annulus layer. Continued development of wetted-foam techniques would require reconfiguration of the gas fill tube to accomodate the laser beam.



S.A. Slutz et al., "Pulsed-power-driven cylindrical liner implosions of laser preheated fuel magnetized with an axial field", Phys. Plasmas 17, 056303 (2010)

S.A. Slutz and R.A. Vesey, "High-Gain Magnetized Inertial Fusion", Submitted for Phys. Rev. Lett publication (2011)

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