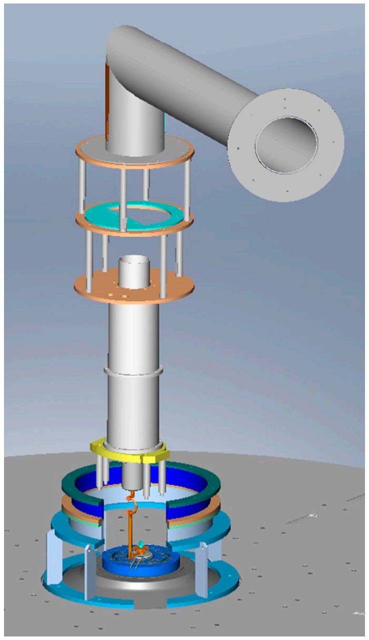
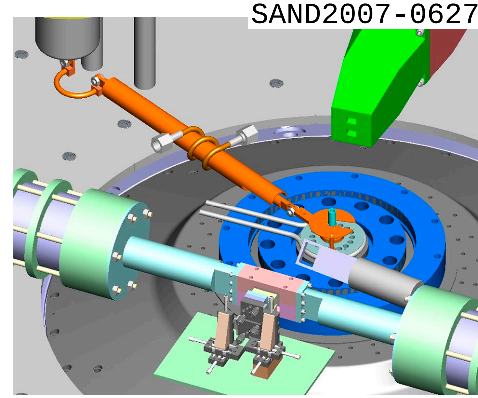
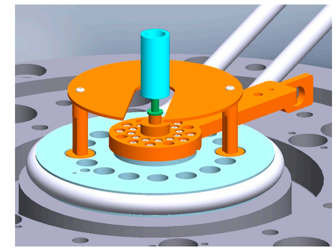
SAND2007-0627C







Grand Challenge LDRD Workshop

January 23-25, 2007

Cryogenics for Imploding Liner Experiments on ZR

D.L. Hanson, D.B. Sinars, J. L. McKenney

Sandia National Laboratories* Albuquerque, NM 87185-1193

R.R. Johnston, K. Youngman

Ktech Corporation Albuquerque, NM

H.S. McLean, W.B. Brown, R.L. Hibbard

Lawrence Livermore National Laboratory Livermore, CA

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract AC04-94AL8500.

Sandia National Laboratories

Ktech CORPORATION

Outline

- **Review of cryogenics infrastructure for Z experiments**
  - **Cryogenic thermal equivalent salad bowl target**
  - **Z center section cooling system**
  - **Cryogenics lab setup for pre-shot testing**
- **Data from preshot tests and Z experiments**
  - **Cooling histories**
  - **Radiography of salad bowl targets**
- **Cryogenics on ZR**
  - **Modifications to salad bowl target**
  - **ZR cryogenics infrastructure**
- **Building 984 remodel for cryogenics testing and parts fabrication**

In FY05-06, a cryogenic system for filling liner targets with LD_2 was developed and fielded on Z

Near-term requirements of system:

- **Completely fill salad bowl targets with LD_2 for Z "full tank" experiments**
- **Partially fill salad bowl targets with LD_2 and characterize the fill level and meniscus shape using radiographic imaging**

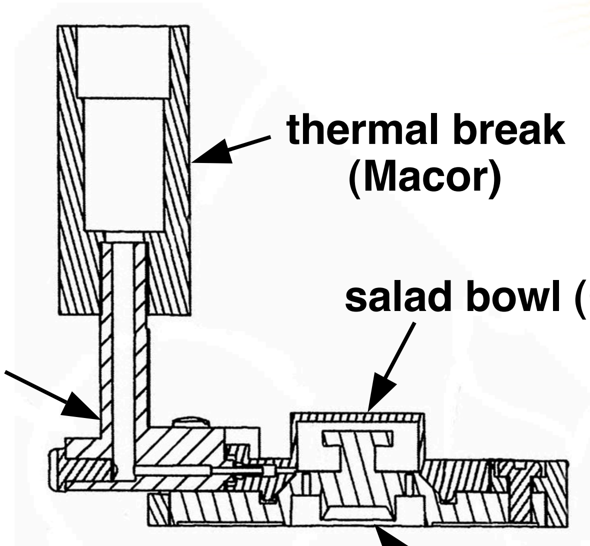
Accomplishments:

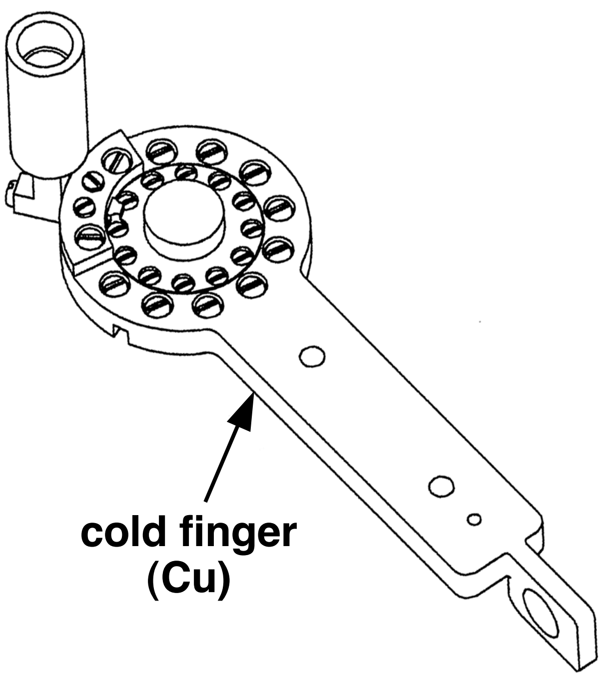
- **Developed cryogenic cooling system and cryogenic target configuration for Z**
- **Measured LD_2 fill levels and meniscus shapes at several partial fill levels for Be salad bowl shot targets using a LLNL Xradia 100 kV radiography system**
- **Fielded four full tank and three partial fill experiments on Z using this cryogenic system**

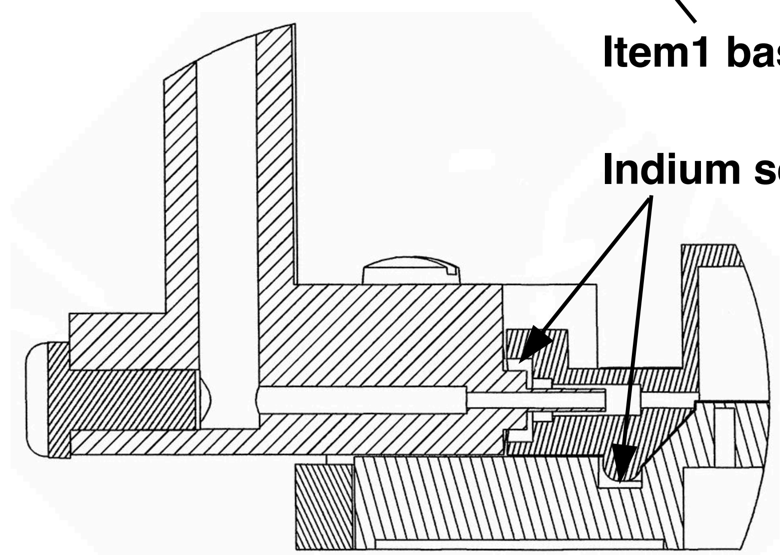
We developed a cryogenic thermal equivalent target for lab cryo testing

Generic thermal Issues:

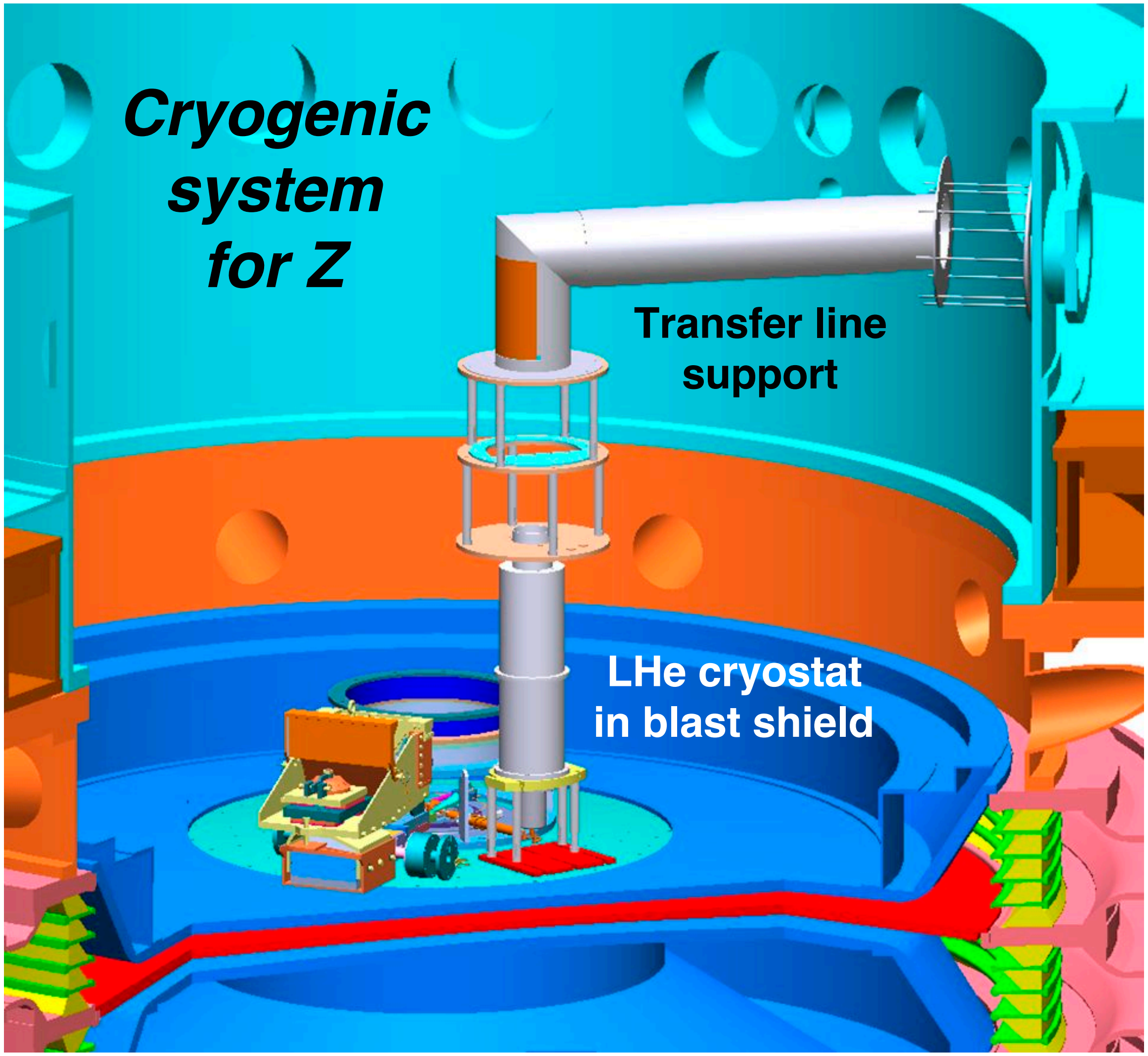
- Cryogenic vacuum seals
- Operating temperature range
- Cooling Al target base
- Partial fill control

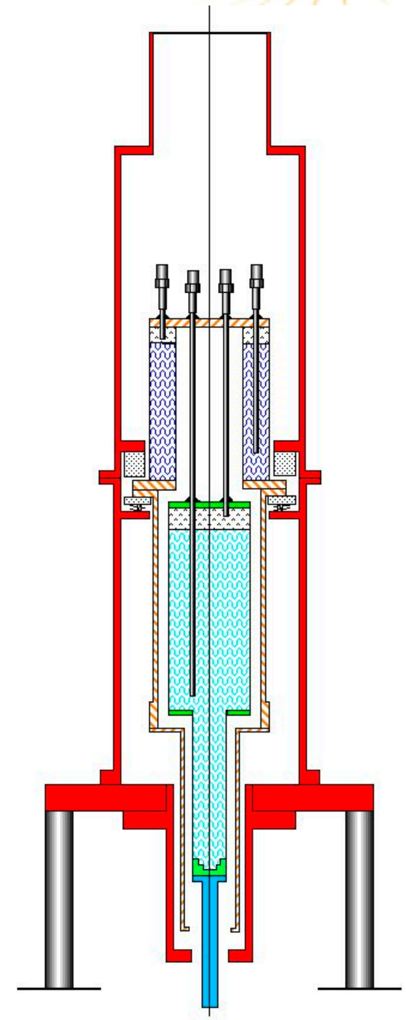






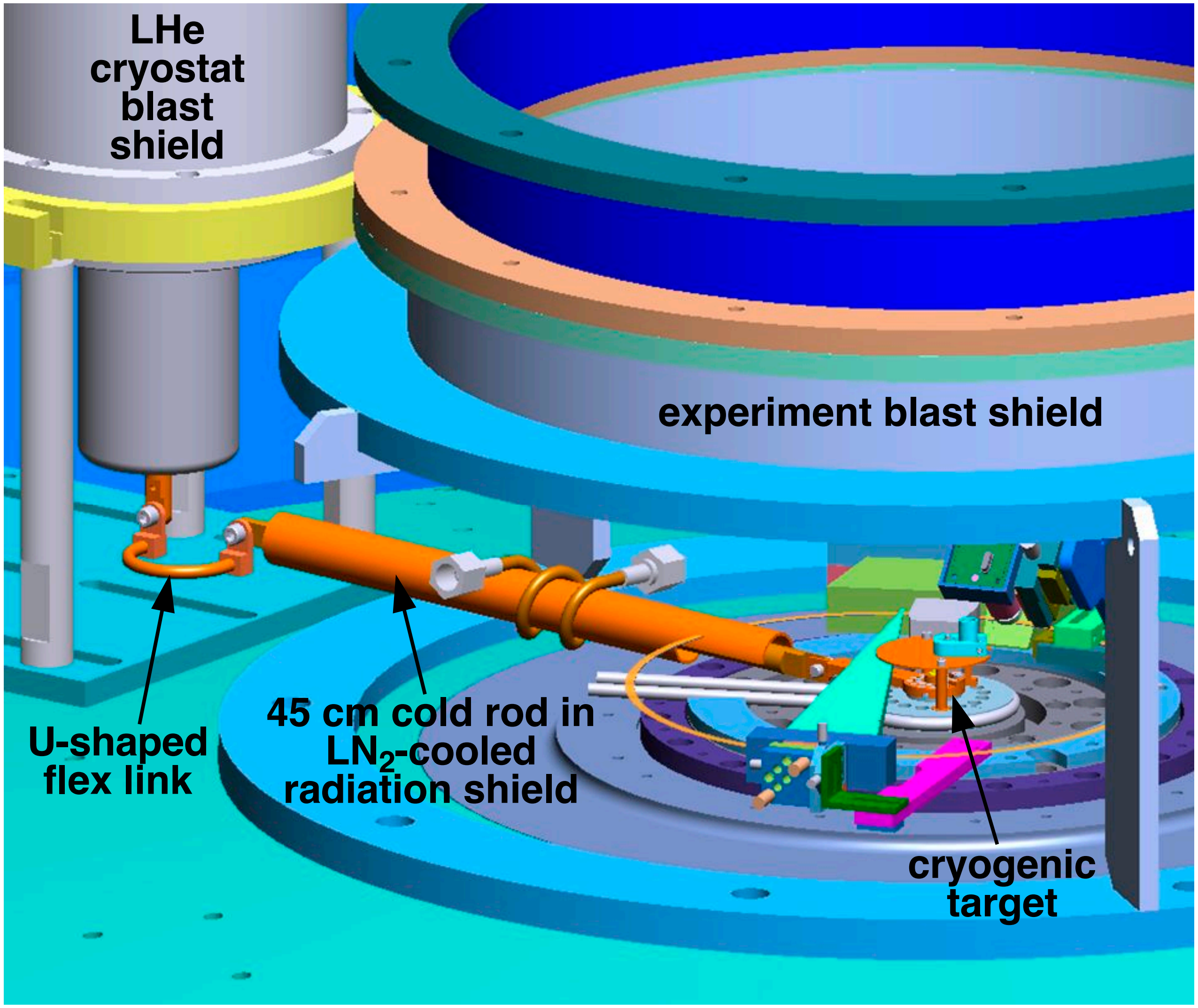
Cooling on Z was provided by a LHe cryostat shock-mounted in a blast shield for survivability





LHe cryostat in blast shield

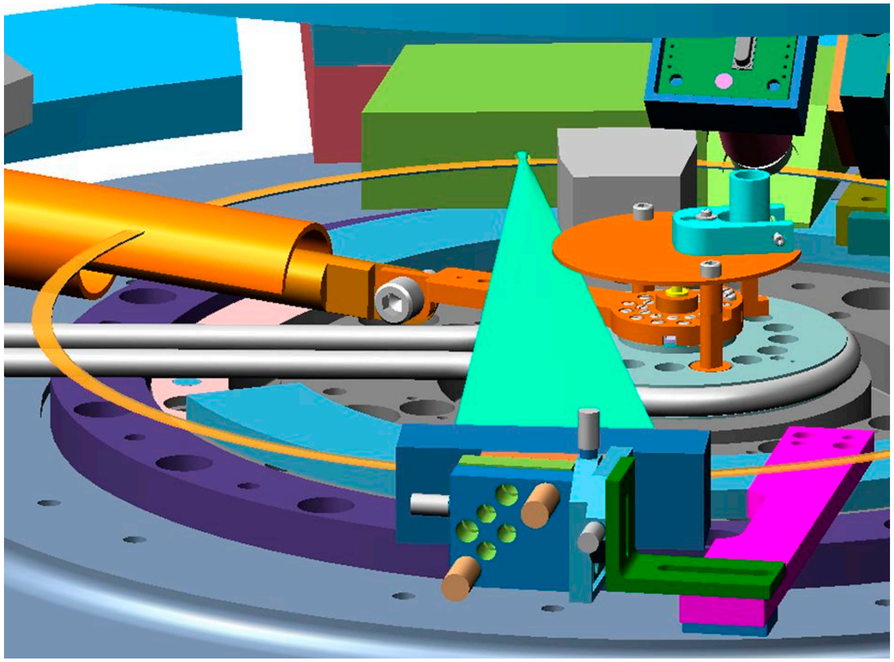
The target is cooled by heat conduction to the LHe cryostat through a long cold rod

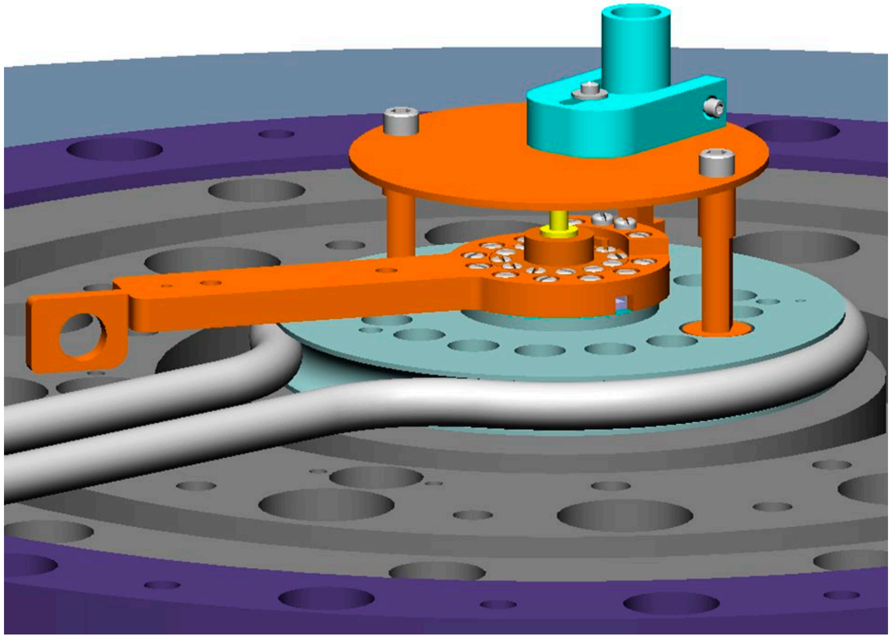


Cooling system configured around monochromatic crystal imaging diagnostic for use with ZBL backlighter

Sandia National Laboratories

The target assembly is partially surrounded by a LN_2-cooled anode radiation shield to reduce the heat load

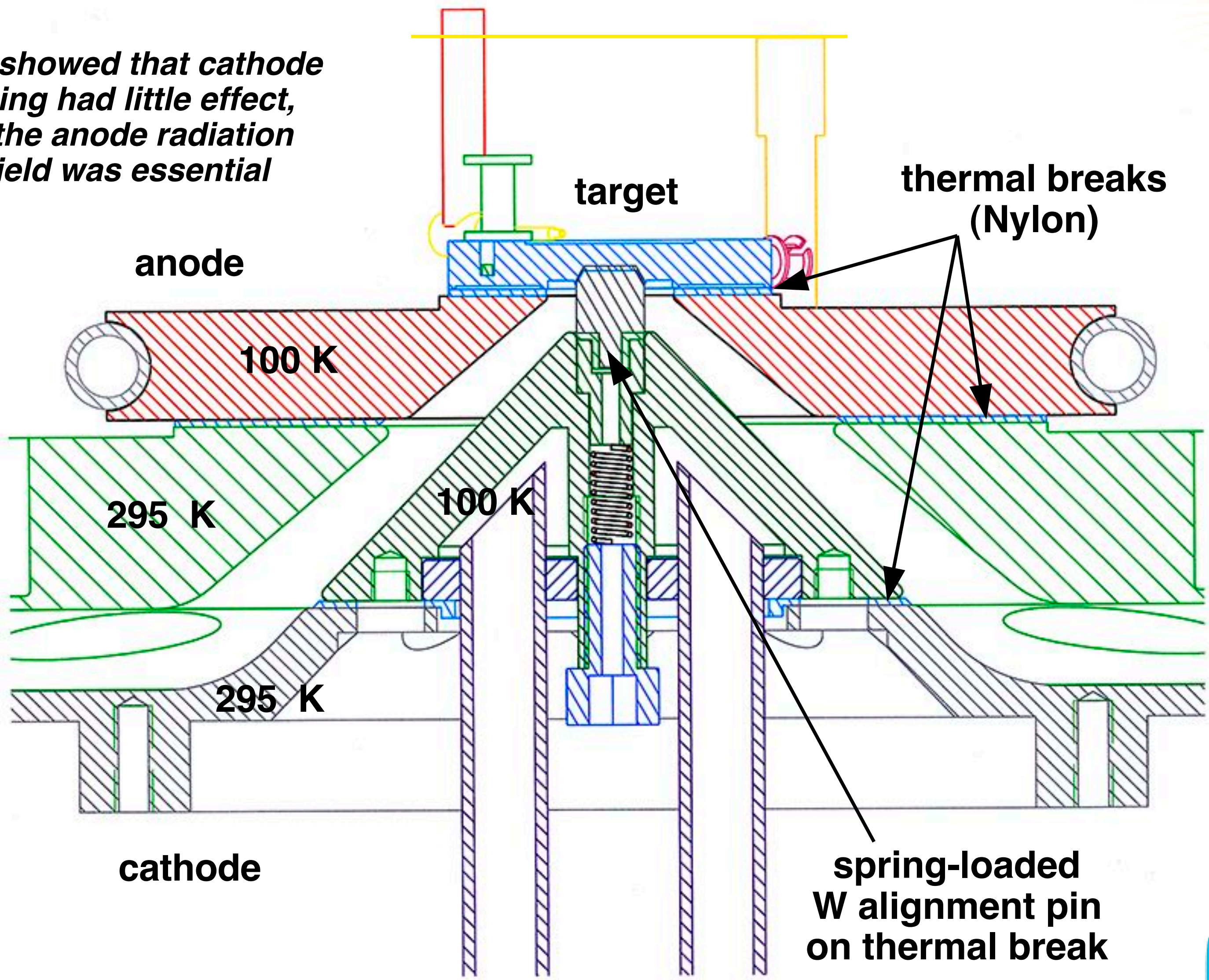




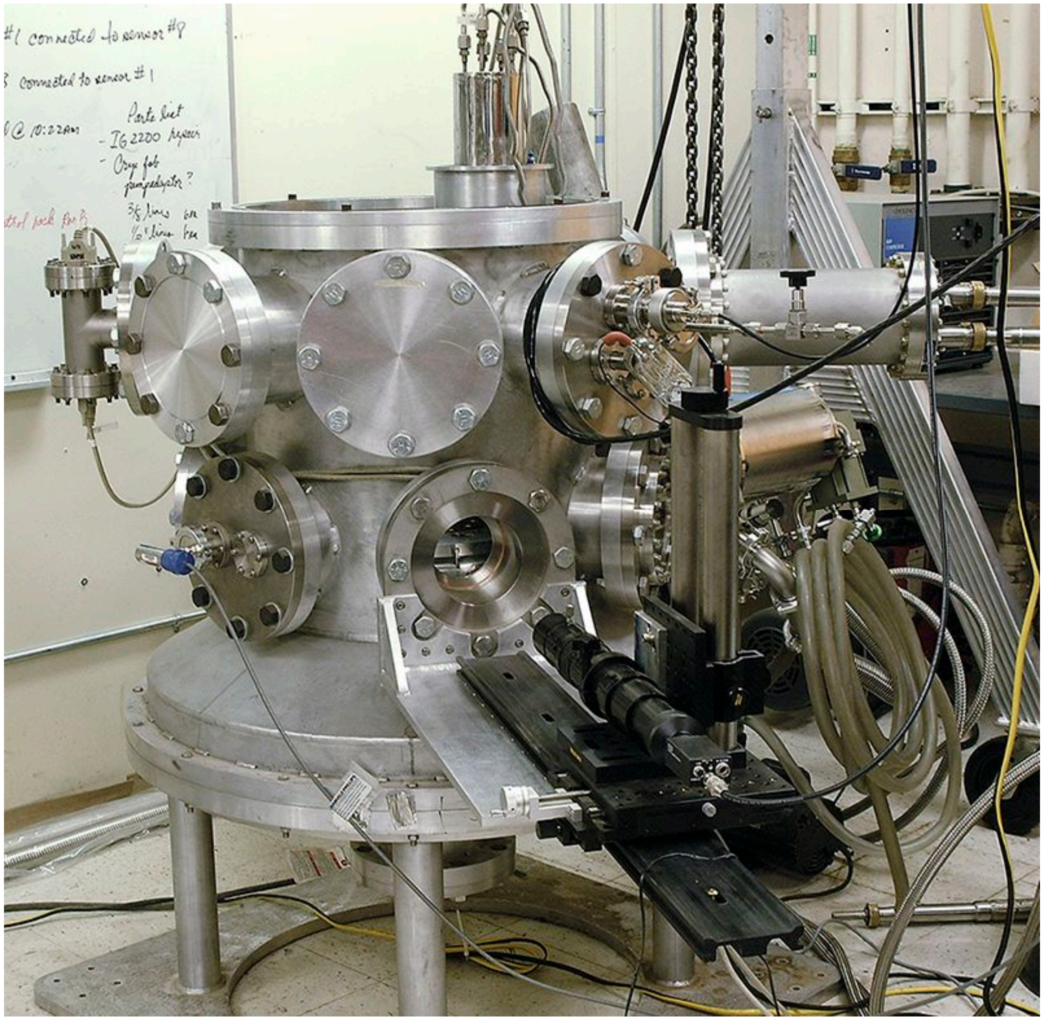
The deuterium gas reservoir (18 psi) is a closed, constant volume gas line connected to the target volume by a gas fill tube

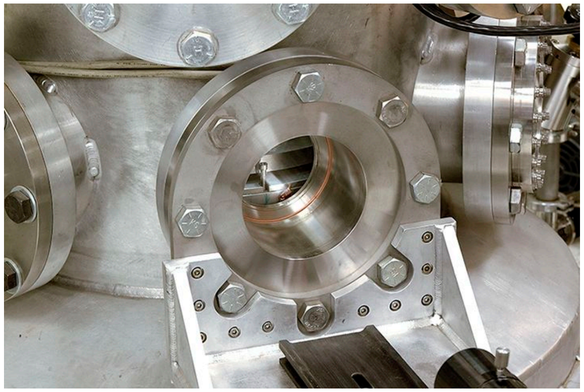
Initially, both the anode and cathode were cooled with LN_2 to serve as a radiation shield for the target

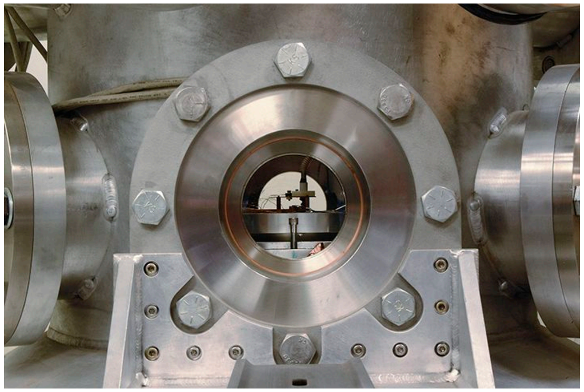
Tests showed that cathode cooling had little effect, but the anode radiation shield was essential



We have a cryogenics lab in Bldg 961 Rm 5 that is used for development of cryogenic target systems

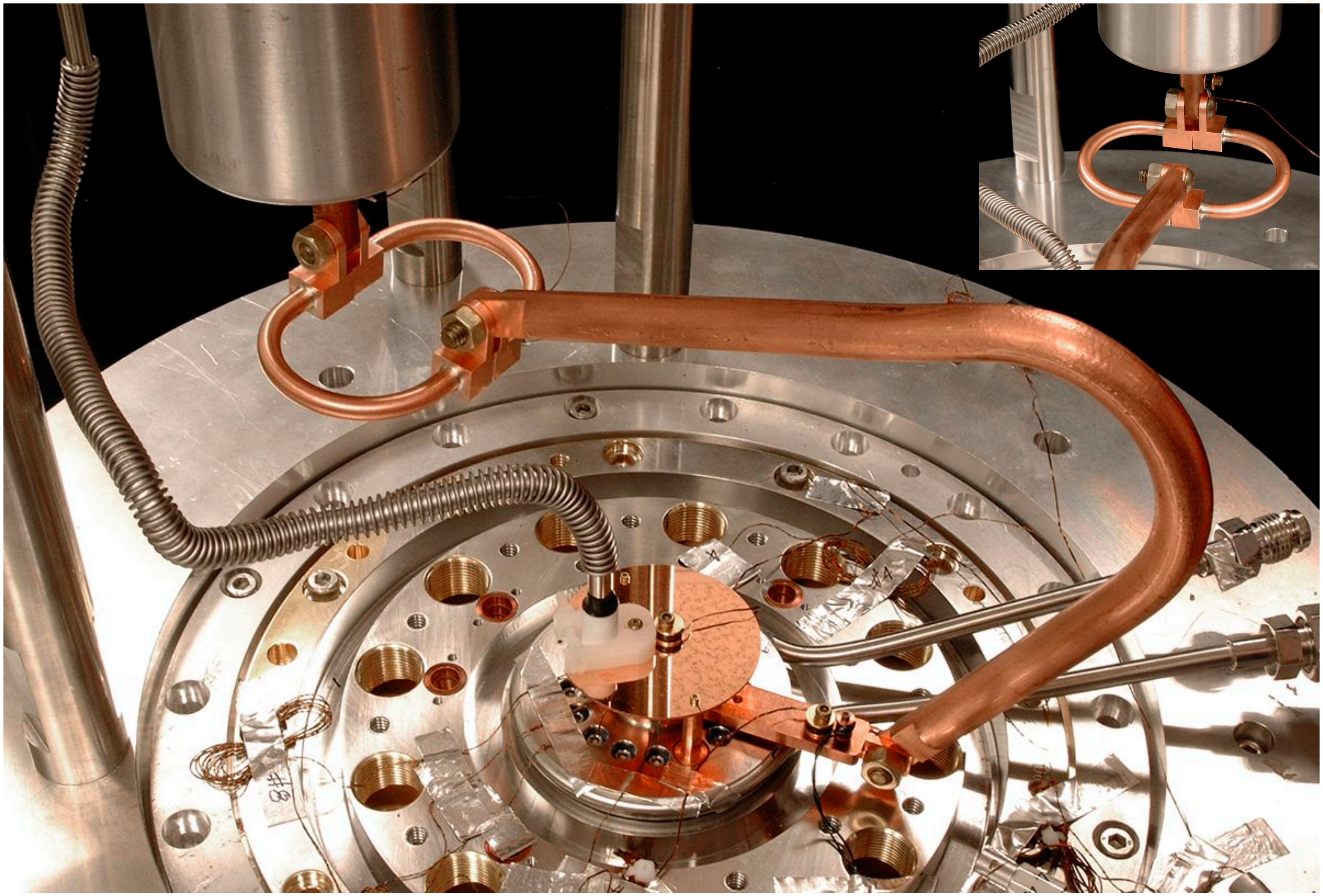






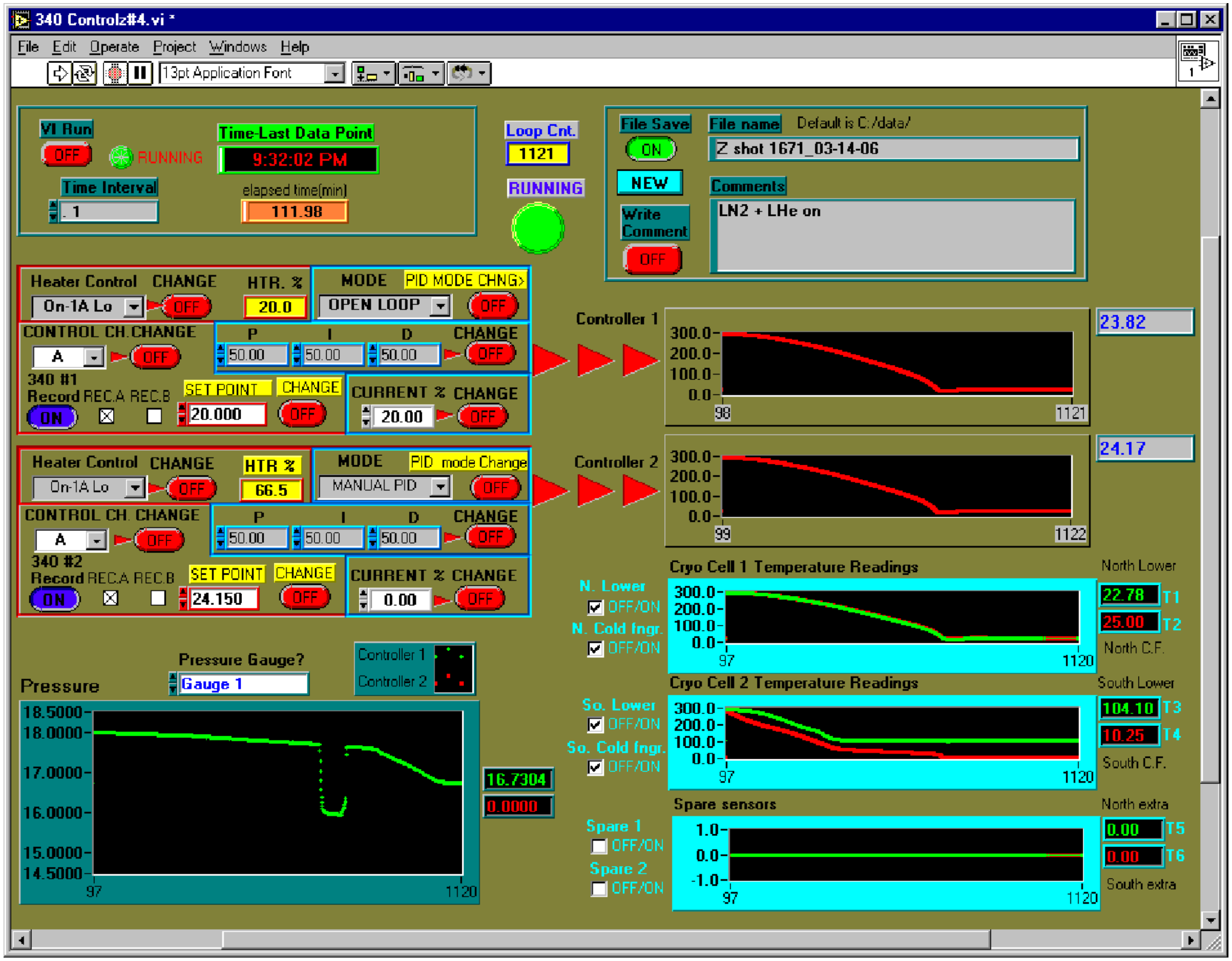
Sandia National Laboratories

The standard setup to locate the target at lab chamber center uses an unshielded cold rod and double flex link



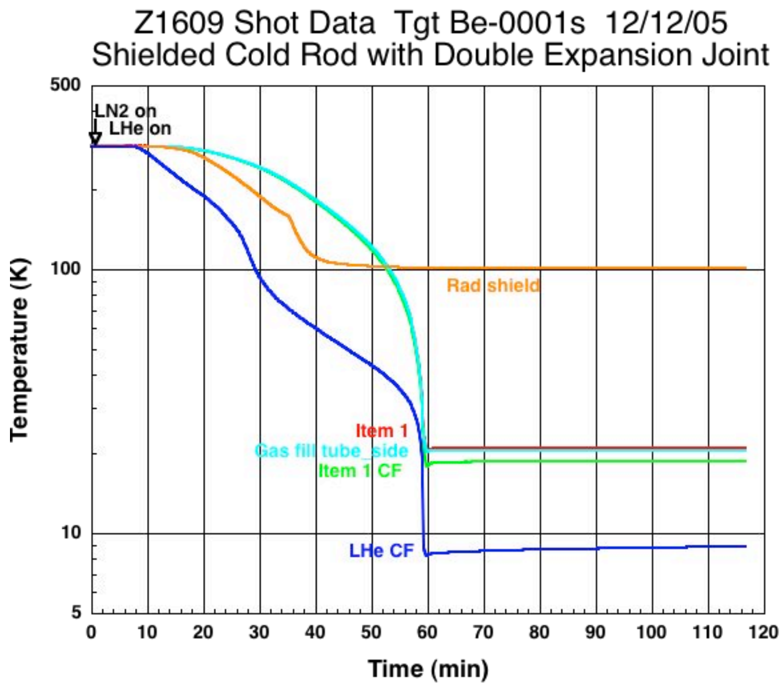
Sandia National Laboratories

A LabView vi program is used to set feedback control parameters and record P and T data during a test

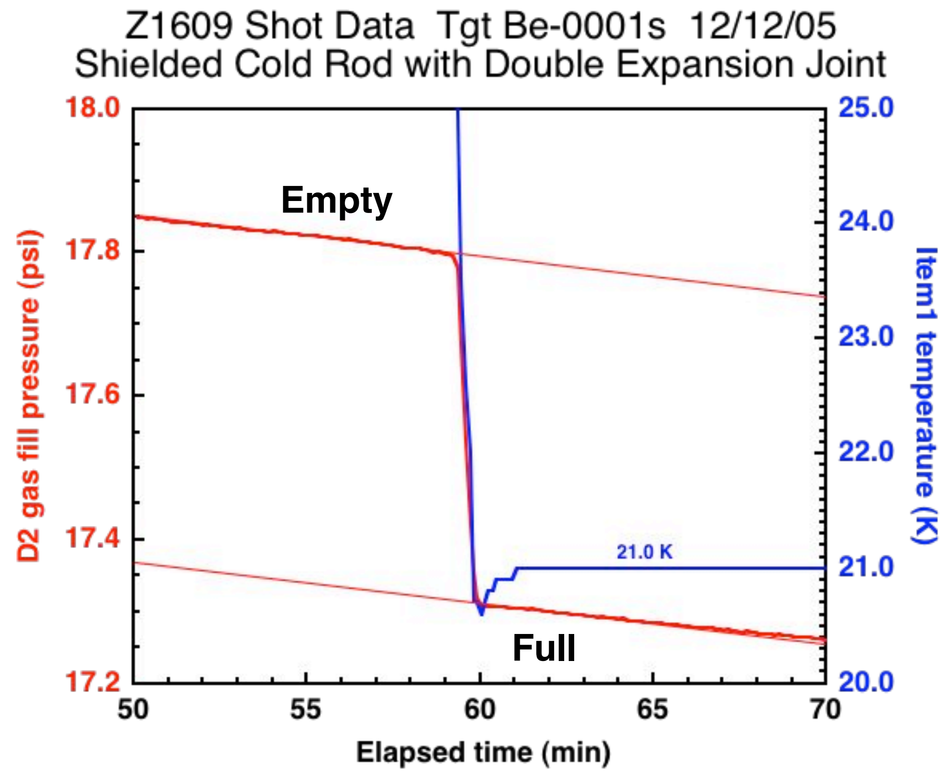


Sandia National Laboratories

The first GC LDRD cryogenic shots attempted on Z were "full tank" shots with salad bowl targets

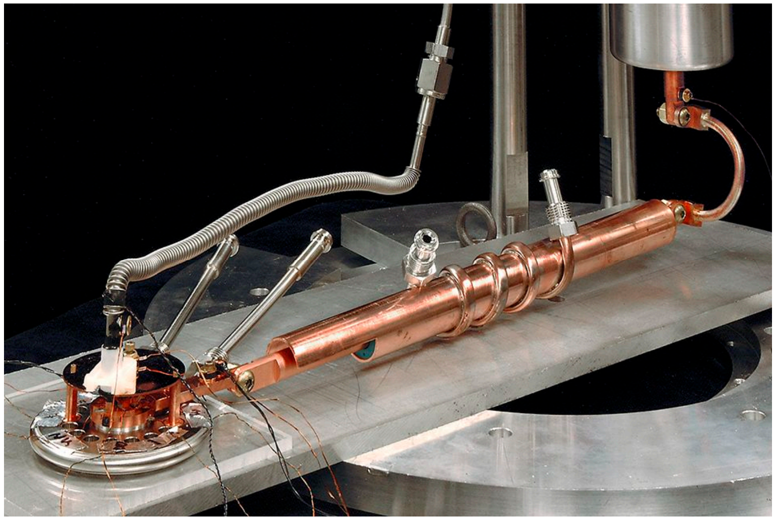


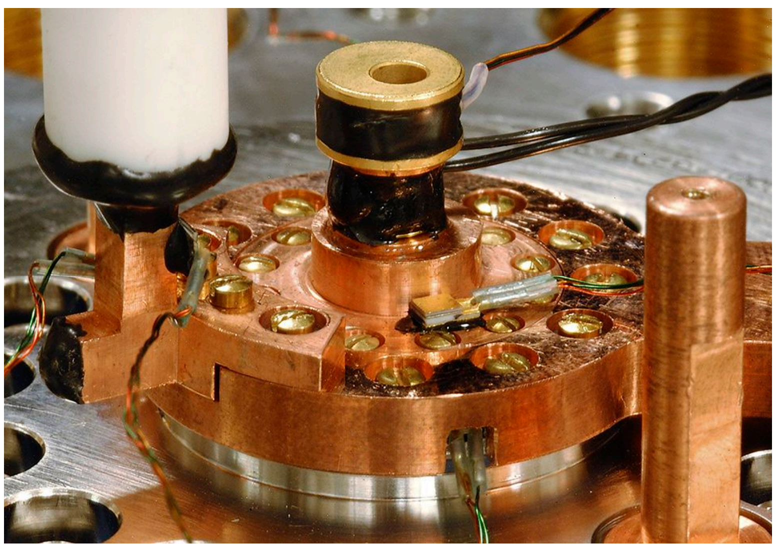
Cooldown and fill for a "full tank" shot on Z requires about 65 min
For this shot, the target fill had to be maintained for an additional 50 min to recover from a Z machine fault

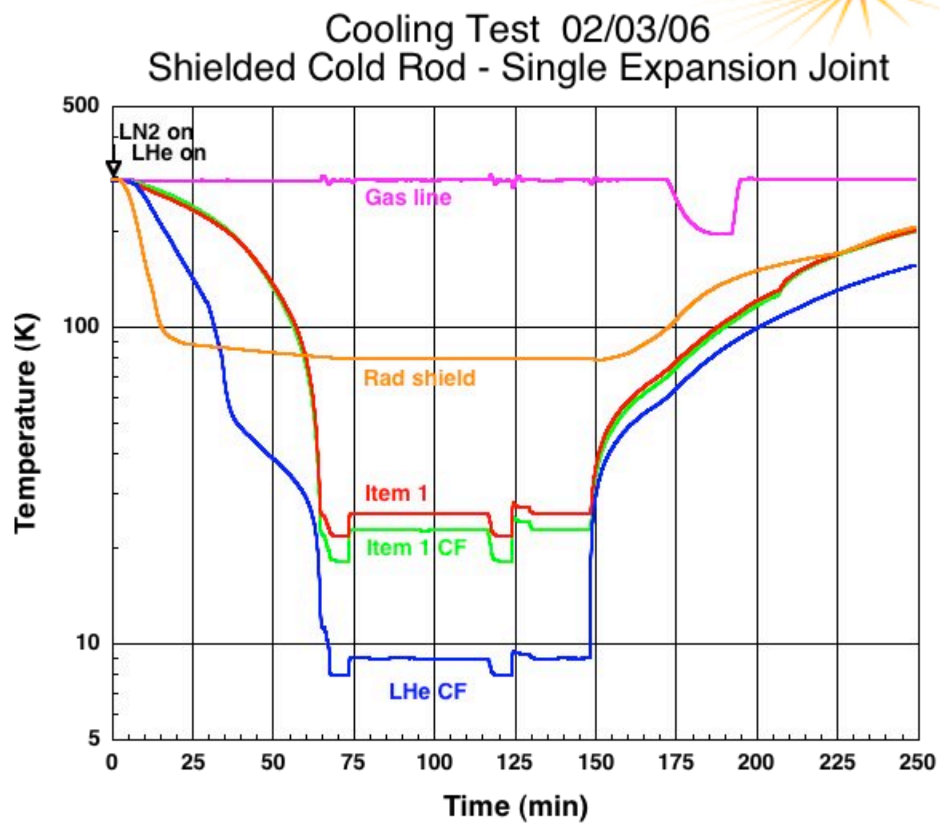


The abrupt P change from condensation of LD_2 is superimposed on a slow ambient P change from cooling of gas in the gas lines

Cooling tests were performed to duplicate the conditions required for partial fill on Z

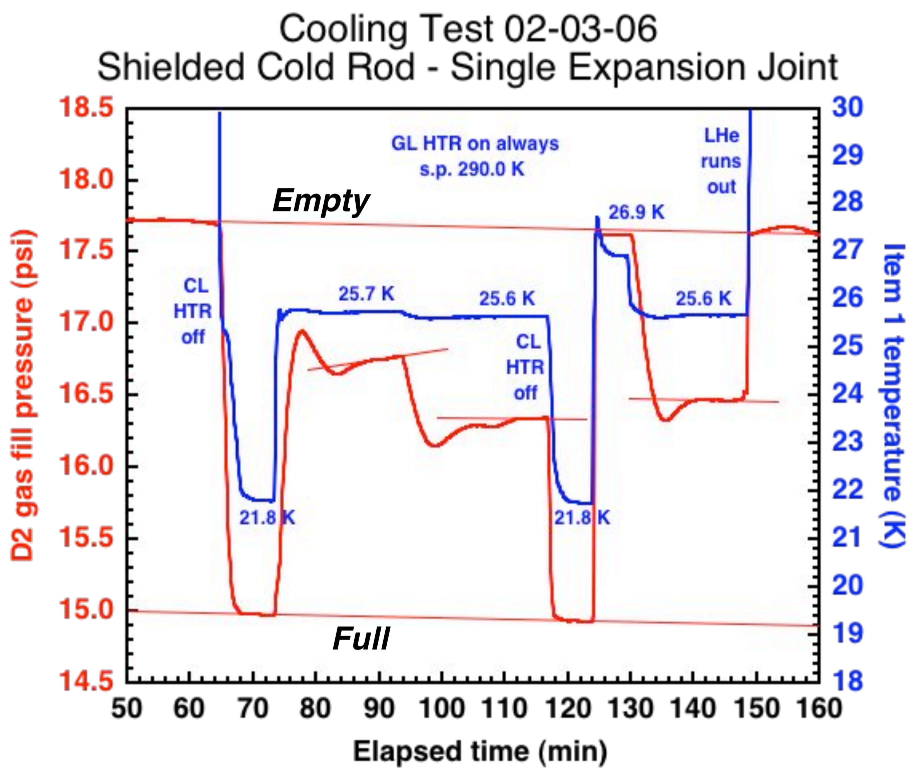


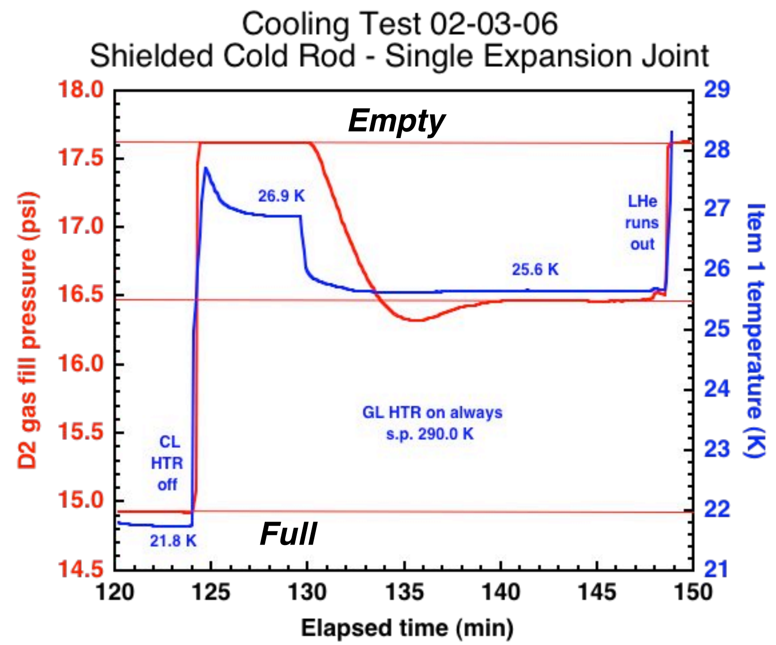




- Single flex joint with cold rod shield reduces cooling power at target to permit operation in 21-27K temperature range
- Precision T control and well-defined hot spot provided by dome heater for fill stability

Filling the target from an empty state results in rapid equilibration and constant fill level



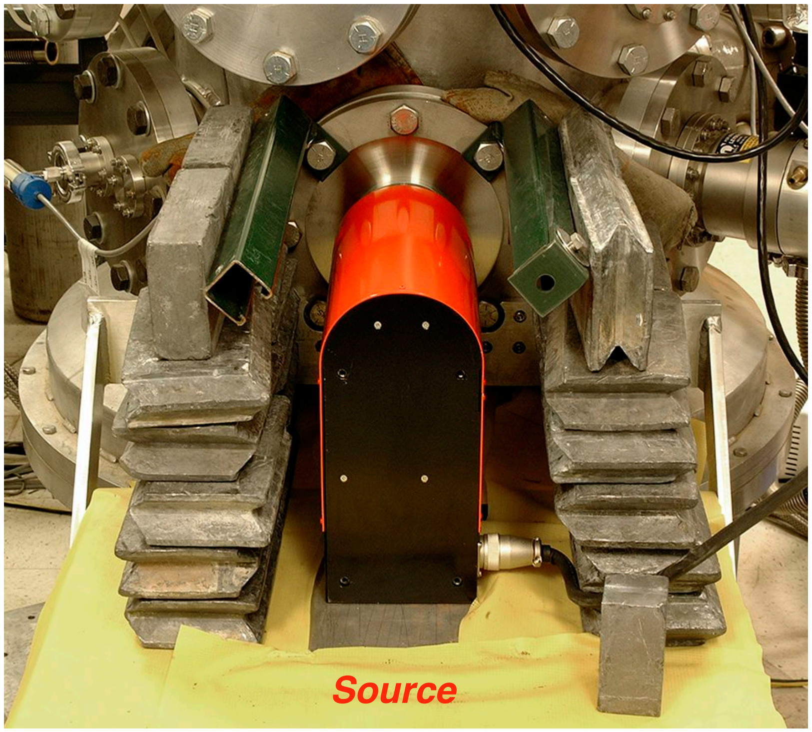


Partial fill achieved by evaporating LD_2 from a full target involves heat exchange among several coupled target components (including the entire fill tube) and the liquid during the phase transition and therefore takes longer to stabilize than condensing LD_2 in the base of an empty target

Sandia National Laboratories

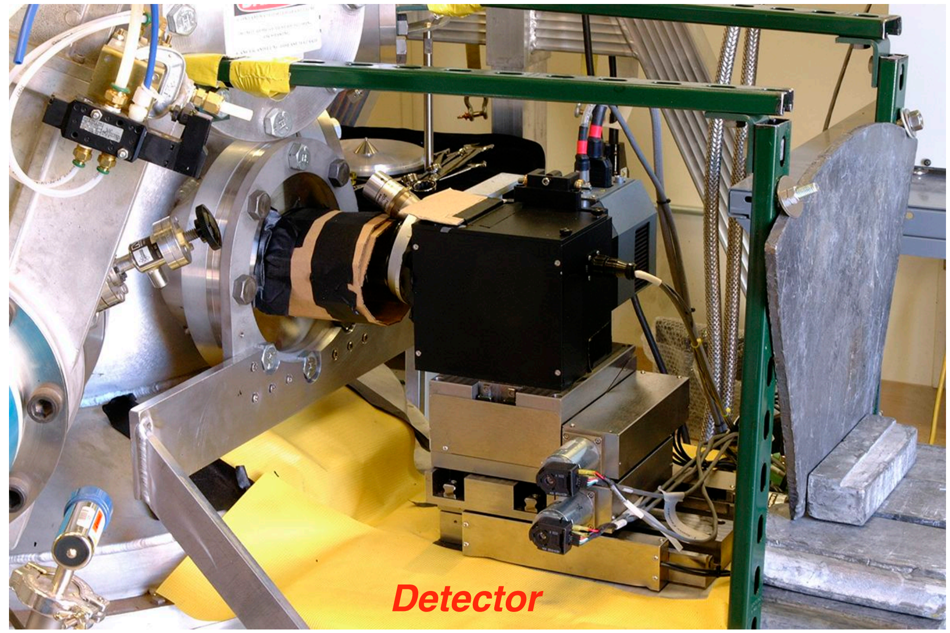
Harry McLean and Bill Brown brought an Xradia radiography system from LLNL to image the fill line in targets

Xradia Micro XCT Radiography System



Hamamatsu micro-focus x-ray source 150 kV 0.066 mA
containing 3.5 mm thick W collimator with 2 mm diam hole
Source mounted on computer-controlled x-y translation stage
Operating range 60-100 kV with tube current of 0.04 mA
Exposure times 0.5 - 8 min

Flux during warmup at 150 kV 0.066 mA
2 REM/min behind detector
2 REM/hr at source
Pb shielding and RWP required for operation in 961/5

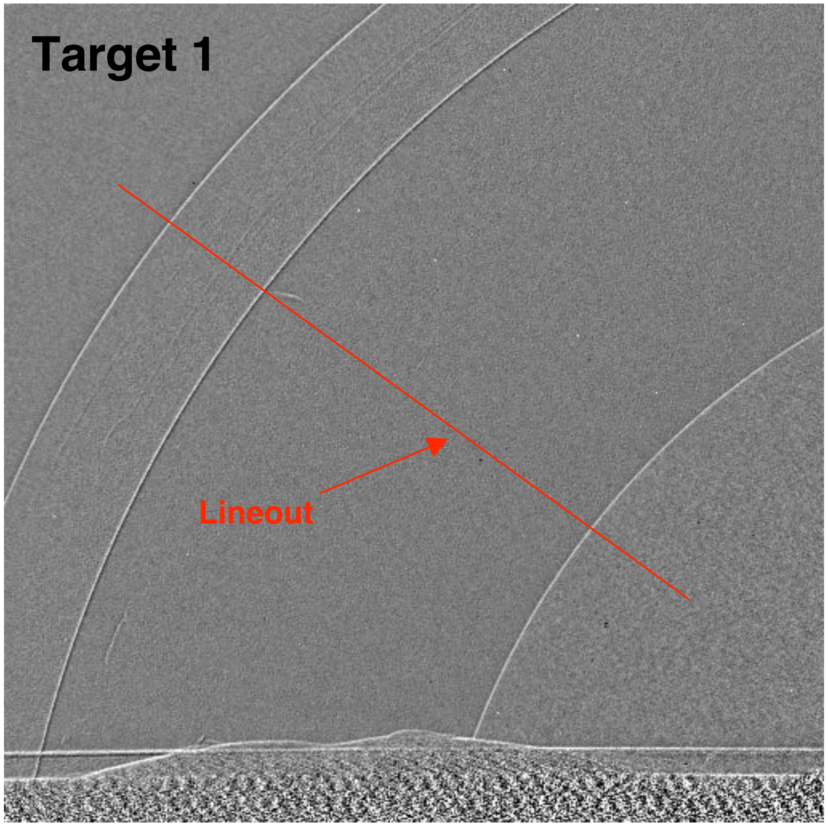


Cooled 2048 x 2048 16 bit dynamic range CCD optically coupled with a tube lens and turning mirror to a microscope objective and CsI scintillator

Detector mounted on computer-controlled x-y-z translation stage
Output is 16-bit digital radiograph

Sandia National Laboratories

Contrast between LD_2 and Be wall is low in radiography images of salad bowl target



100 kVp, 0.04 mA
120 Sec Integration
5X FOV Setting (4.4mm X 4.4mm)
4 X 4 Binning, 1 Frame Avg
762 mm SDD, 381 mm SOD
Pixel pitch 5.7μm

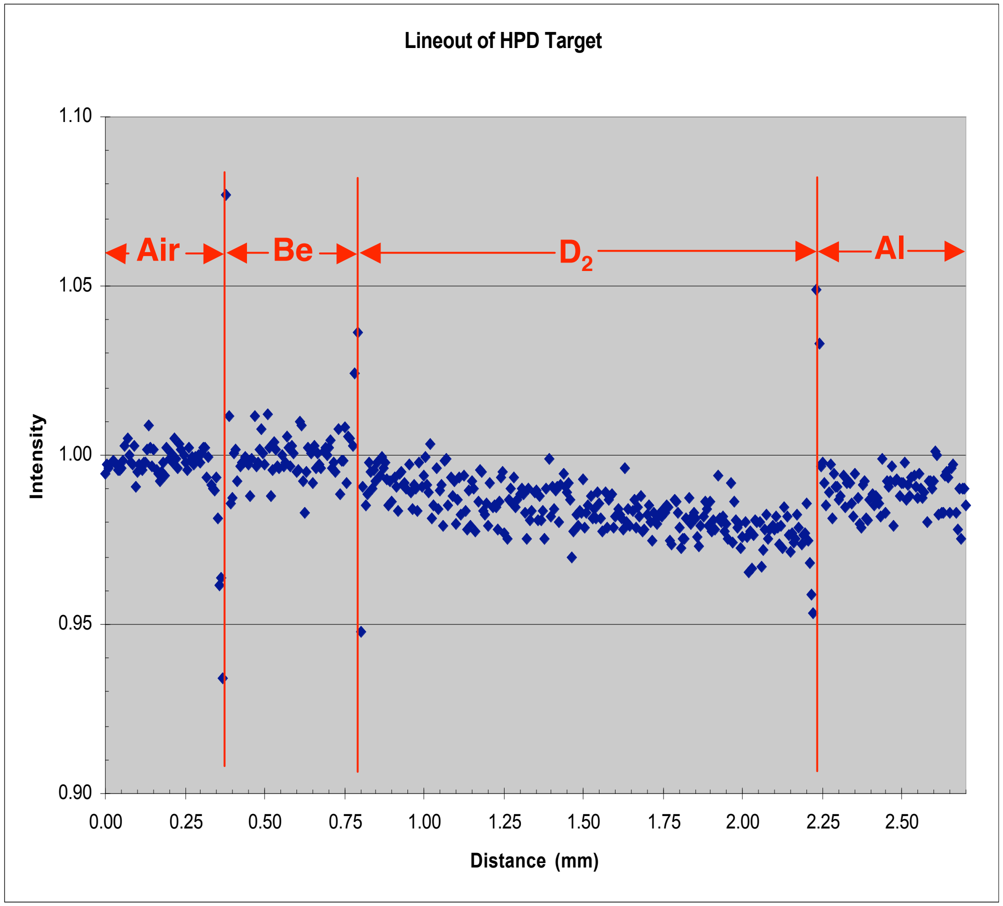
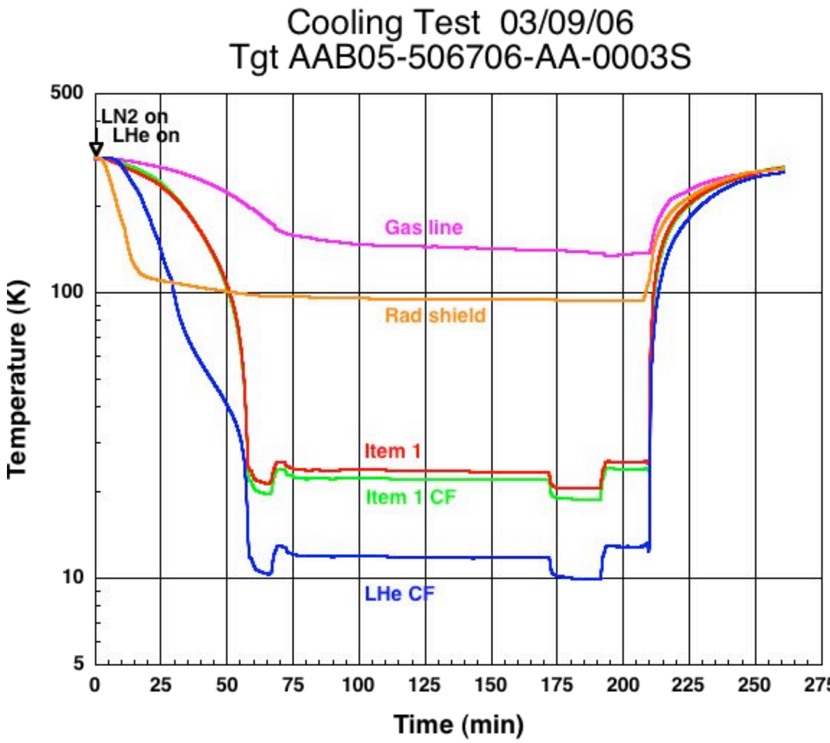
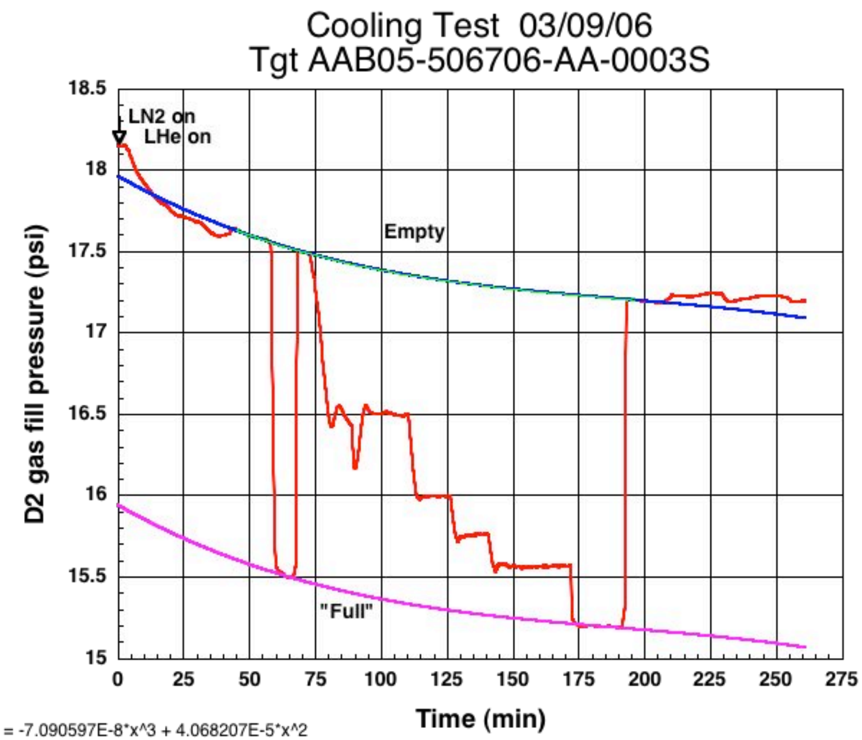


Image of deuterium filled target divided by empty target with lineout showing deuterium attenuation

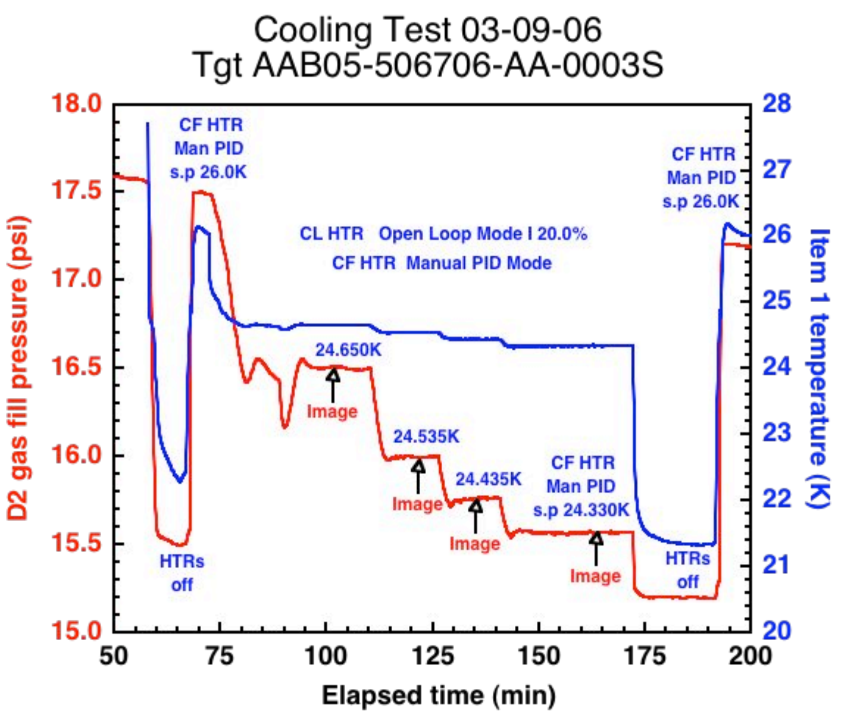
The LD_2 fill level was imaged at four values of fractional P change for Tgt -0003S (Z1671)

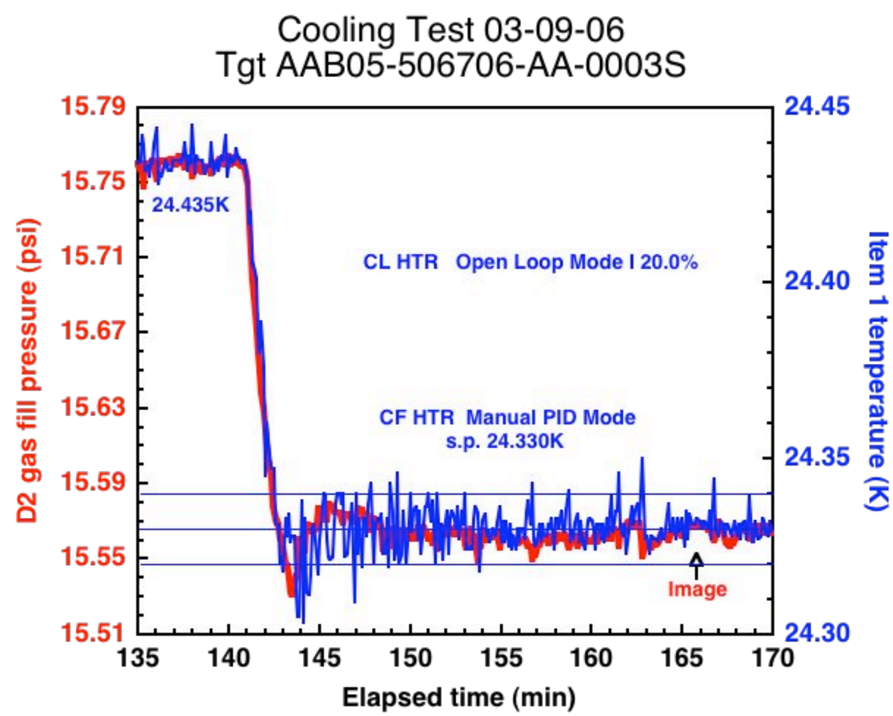




f(x) = -7.090597E-8*x^3 + 4.068207E-5*x^2
+ -9.137493E-3*x + 1.796210E+1

A constant fill level was maintained at each constant T setpoint to allow multiple 2-5 min x-ray exposures of target

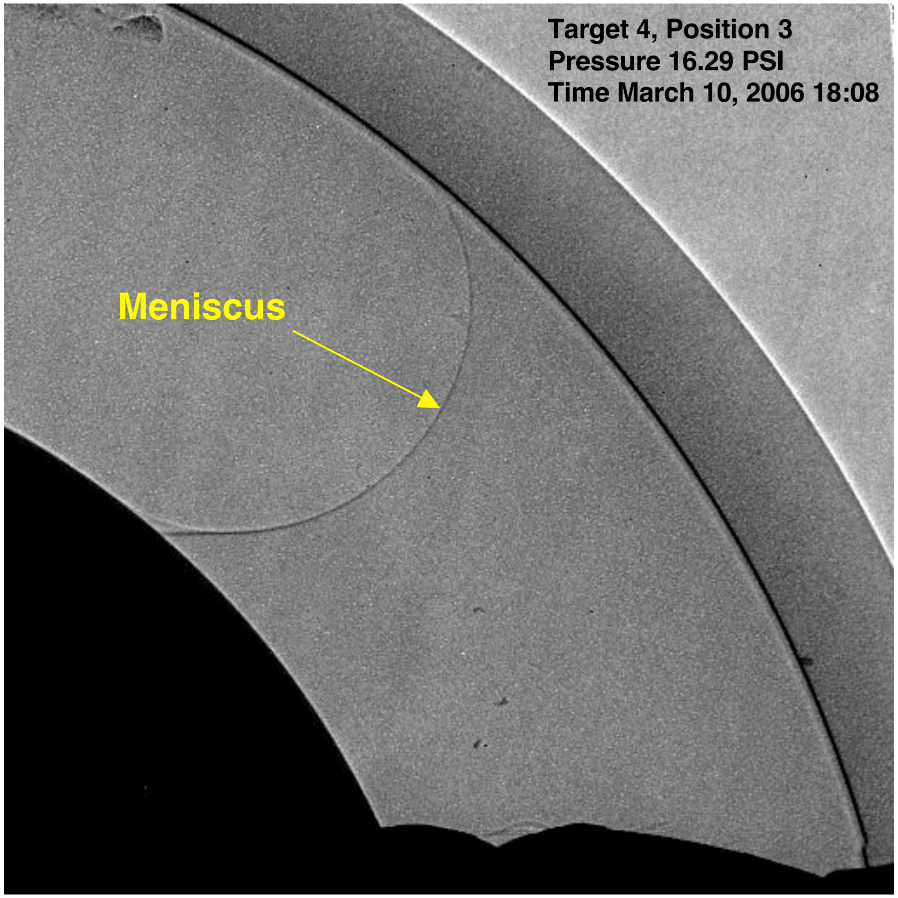




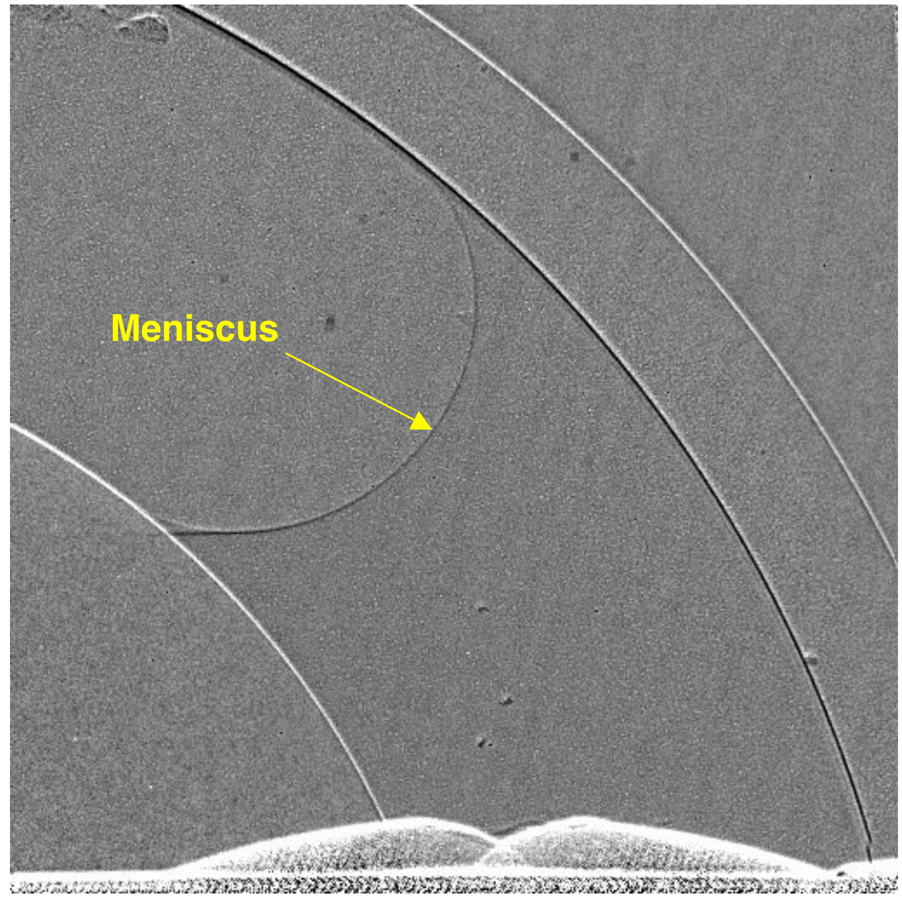
Use of Lakeshore Model 340 controller with T control of the target assembly at the mK level made possible very constant mass fill levels with fluctuations in fractional pressure change of < 0.1% over 25 min

Sandia National Laboratories

It was possible to obtain high quality x-ray images of the LD_2 meniscus with this system for correlation of fractional pressure change with fill level

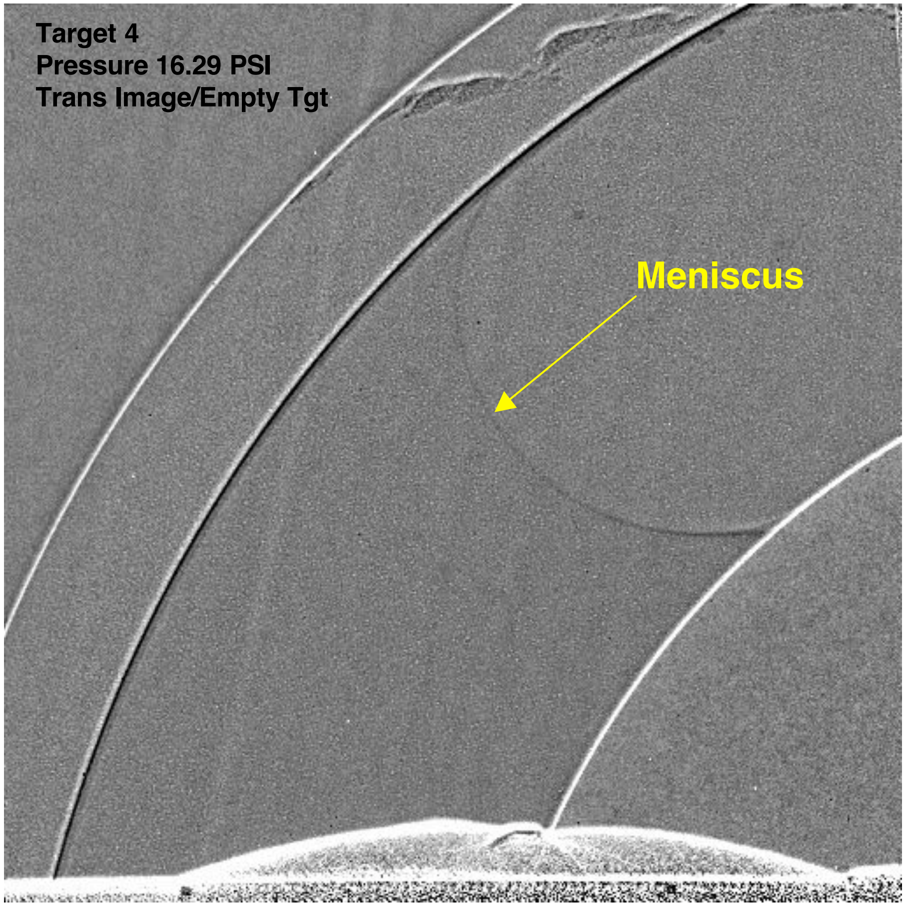


Transmission Image (I/I_0)

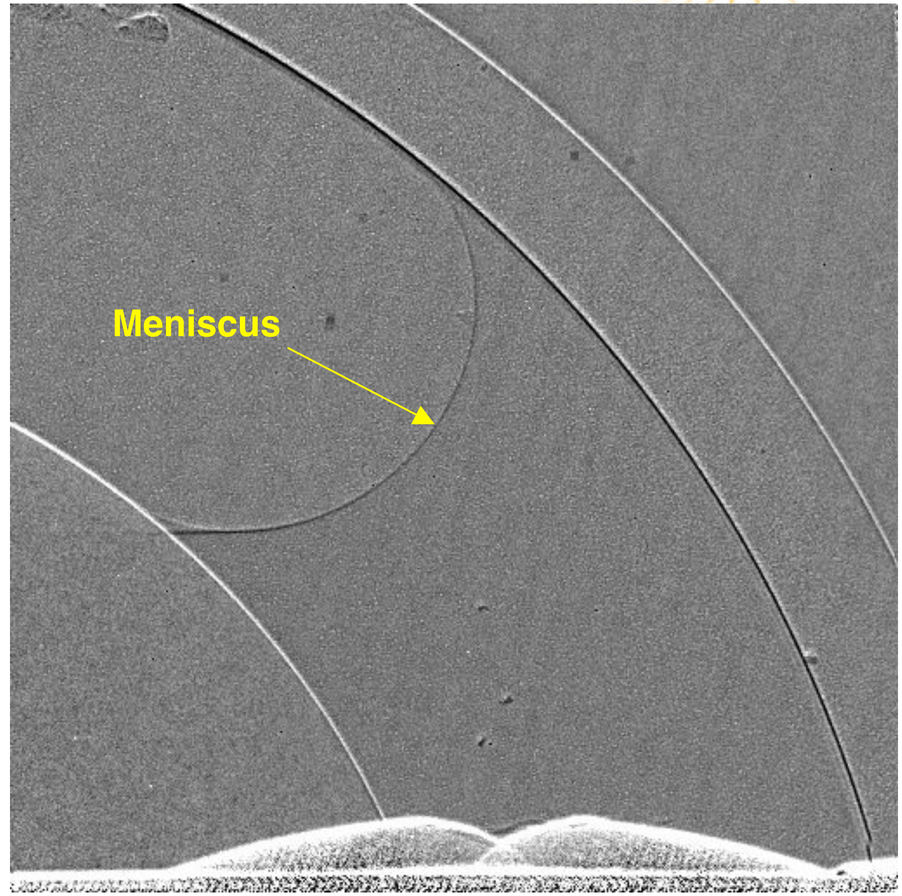


Trans Image/Empty Tgt

It was possible to obtain high quality x-ray images of the LD_2 meniscus with this system for correlation of fractional pressure change with fill level

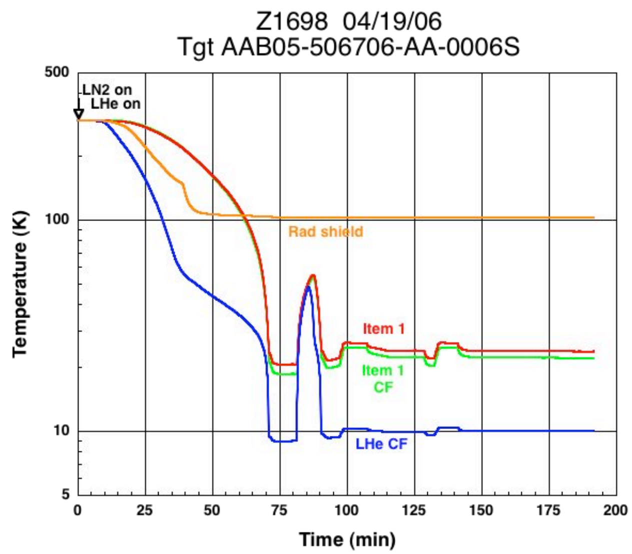


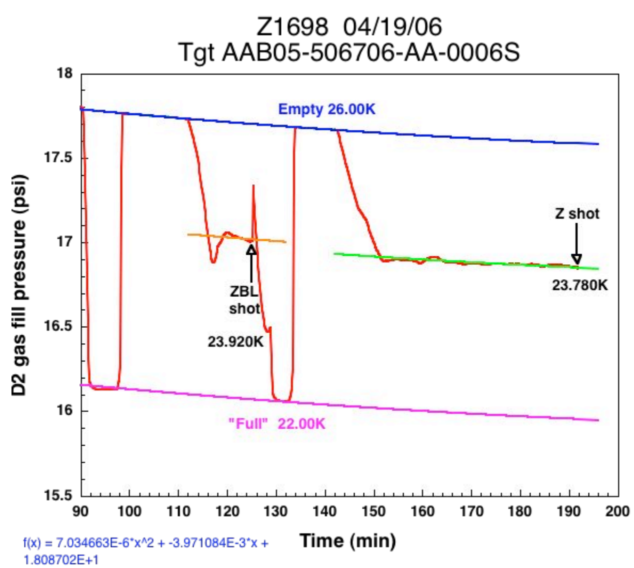
Position 1

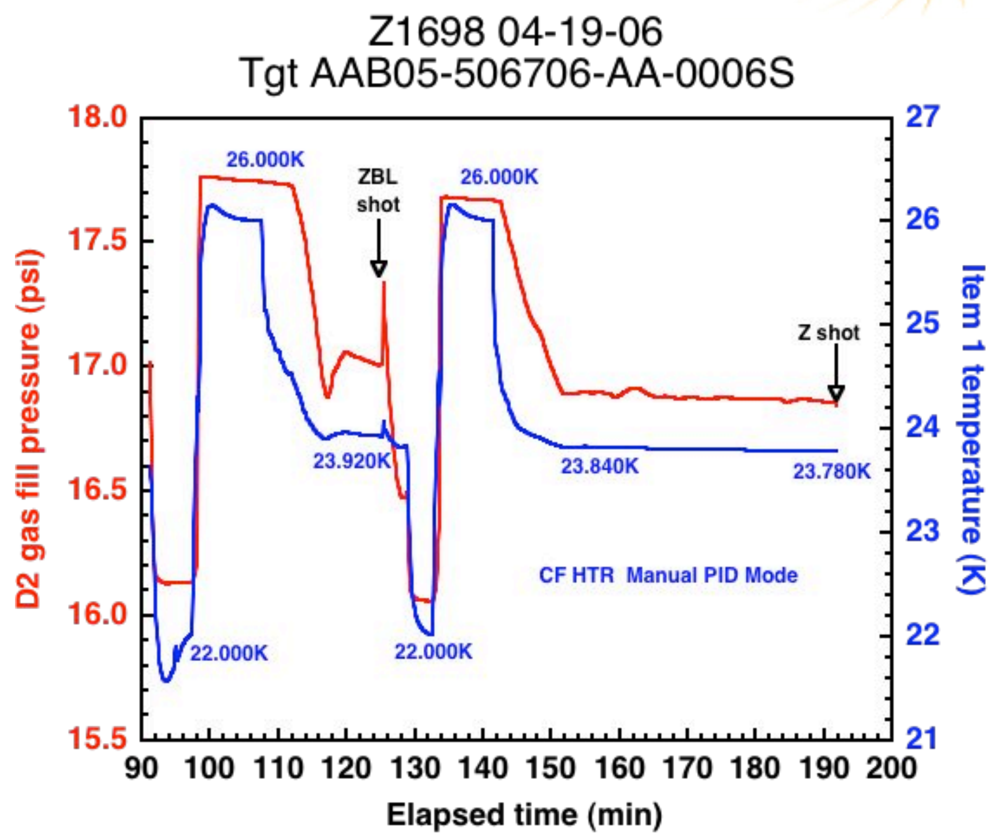


Position 3

On shot Z1698, a preshot ZBL radiograph was attempted at a fill level of approximately 40%





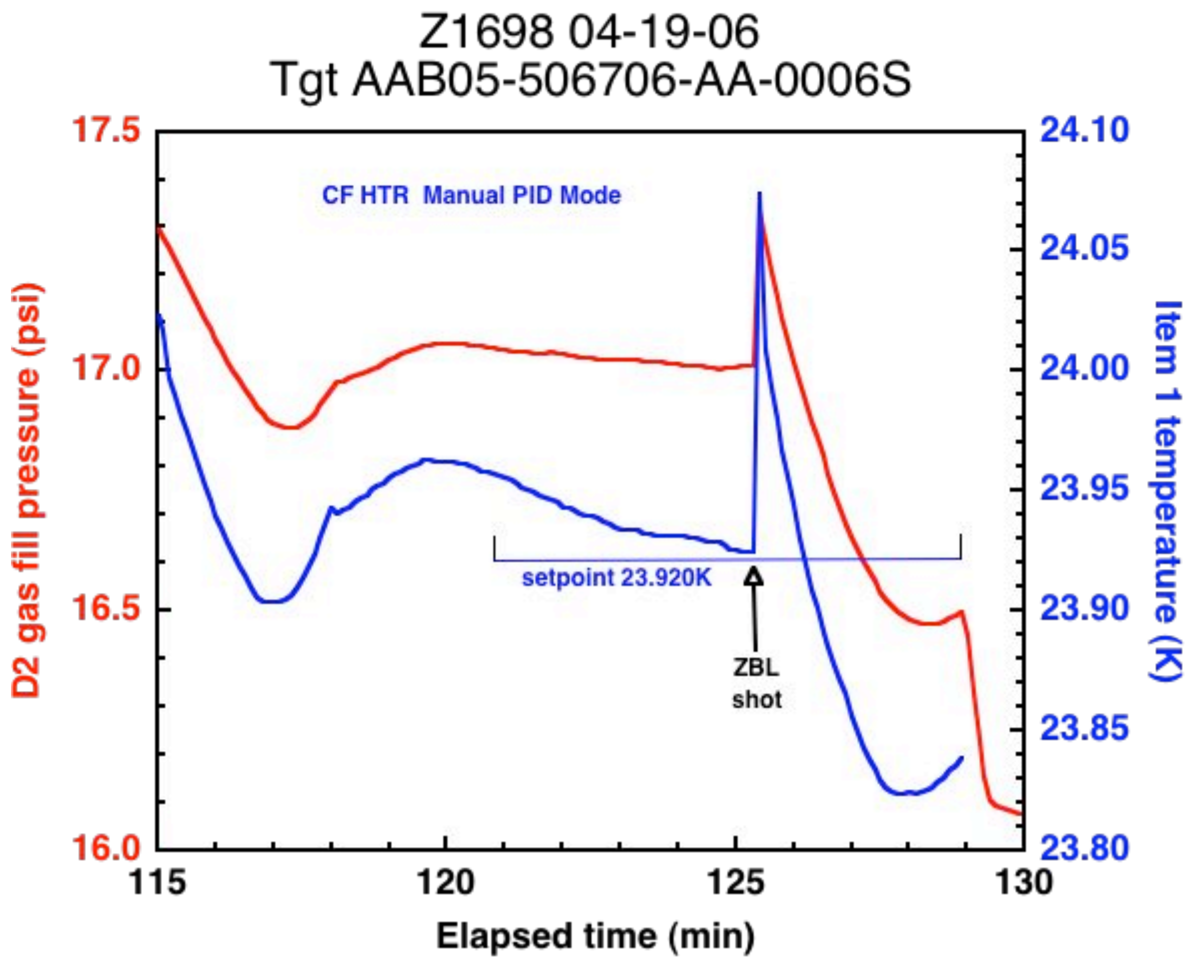


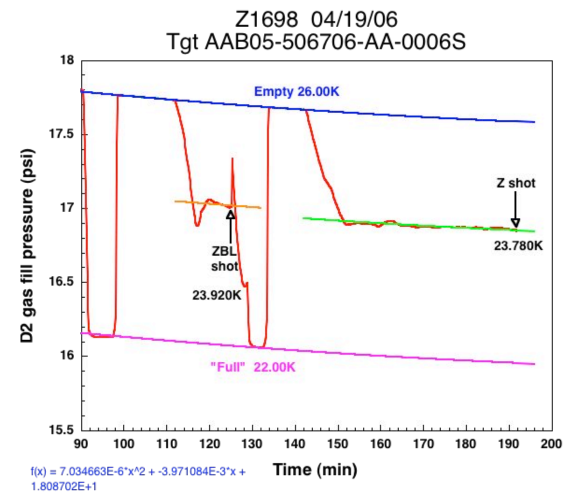
Fractional P change at time of ZBL firing = 40%

Fractional P change at time of Z firing = 45%

Sandia National Laboratories

Firing ZBL deposited sufficient energy in the target to disrupt thermal equilibrium and require reset of fill level





Absorption of x rays and scattered 2ω light caused a T jump changing the fill level and then an overshoot during recovery
- Fill level was reset and then maintained for 40 min for Z shot

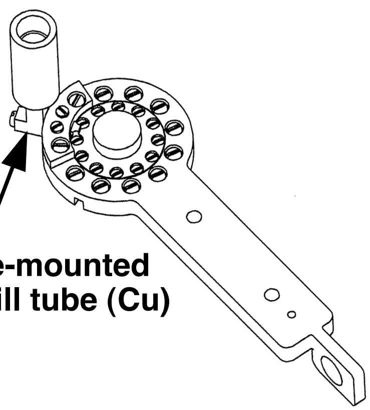
Sandia National Laboratories

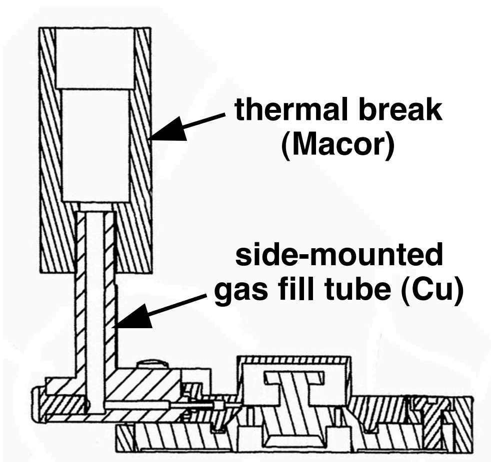
A number of cryogenic design and infrastructure enhancements are planned for ZR

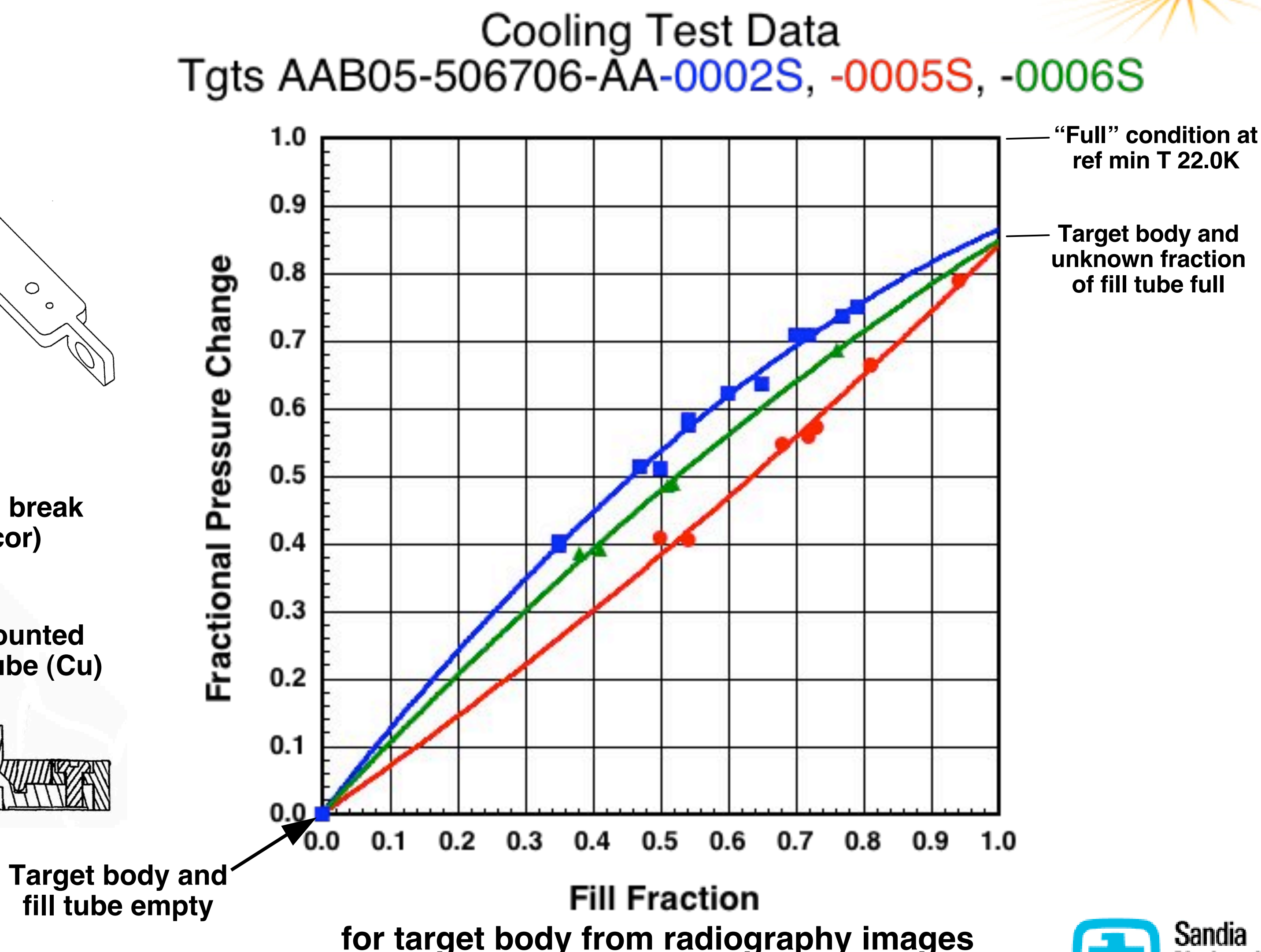
- Modifications to salad bowl target design
- ZR cooling configuration with cryostat mounted on experiment blast shield for improved LOS access and flexibility, simplified cryo assembly
- ZR center section Xradia system for *in-situ* pre-shot radiography of partial-fill cryogenic liner and other targets
- Fiber-optics-based control system for ZR
- Upgraded hardware and software for LabView data acquisition
- Use of COSMOS with SolidWorks for 3D finite element thermal modeling of our cryogenic systems
- Building 984 remodel for cryogenics testing and parts fabrication
- New test chamber for cryogenic testing in Bldg 984
- Xradia system for lab test chamber

Sandia National Laboratories

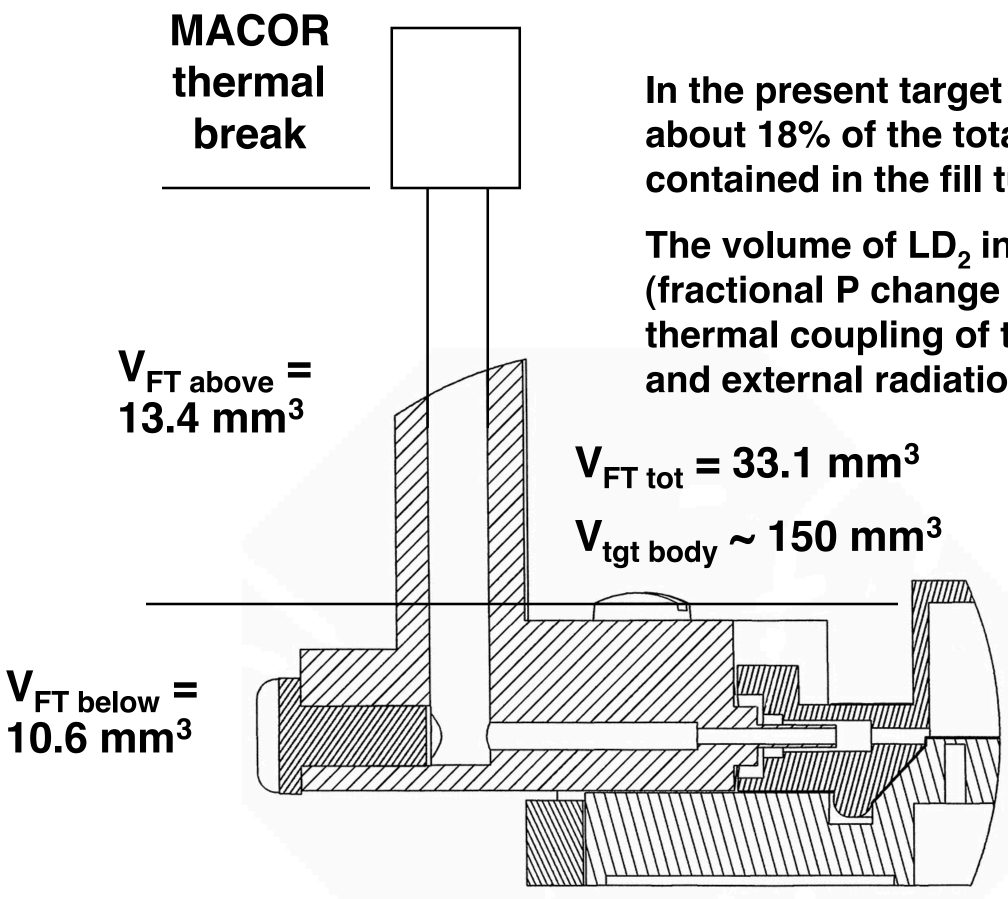
Fractional pressure change vs salad bowl fill level varies from target to target with side-mounted fill tube







One factor that contributes to uncertainty in target fill levels determined from fractional P change is the "full" liquid volume



Gas fill tube assembly on UCM target

In the present target design with a side-mounted fill tube, about 18% of the total volume of the target assembly is contained in the fill tube

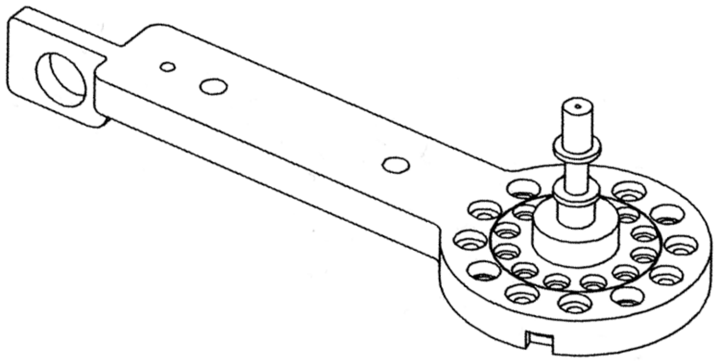
The volume of LD_2 in the fill tube at the "full" condition (fractional P change = 1.0) depends on the target T, the thermal coupling of the fill tube to the target assembly, and external radiation heat loads on the large area fill tube

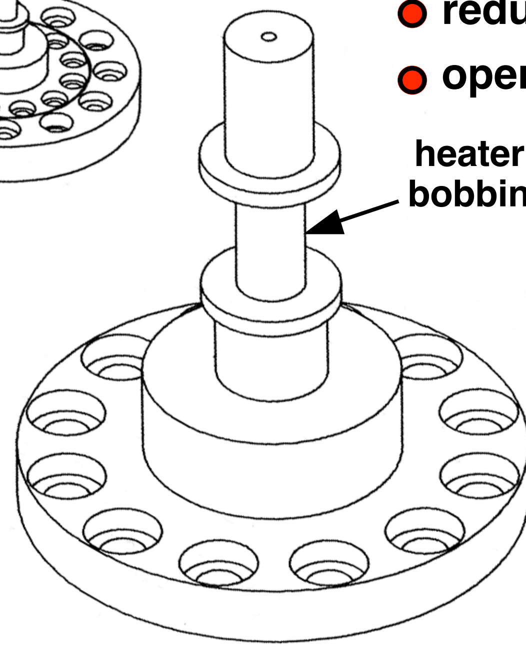
Near term solution:
Correlate fill level with P change measured in lab tests for some reference "full" condition (min T) and attempt to establish identical conditions on the Z shot

Long term solution:
Eliminate all uncertainty in "full" condition by mounting an axial fill tube with negligible V on top of salad bowl so all condensed liquid is in target

Sandia National Laboratories

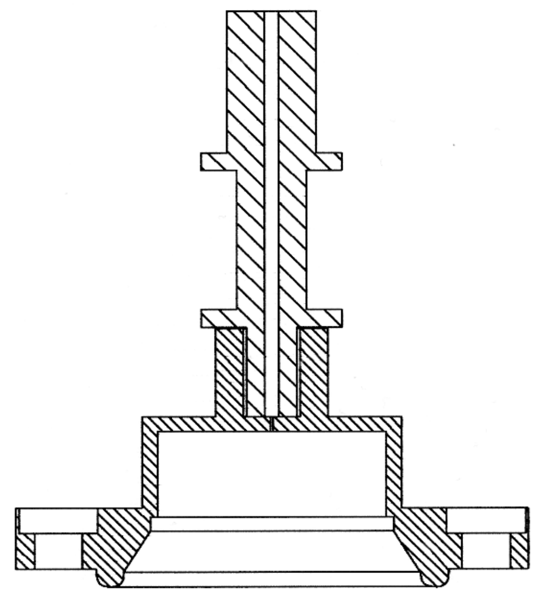
Uncertainty in the "full" liquid level can be eliminated by using a low volume on-axis fill tube

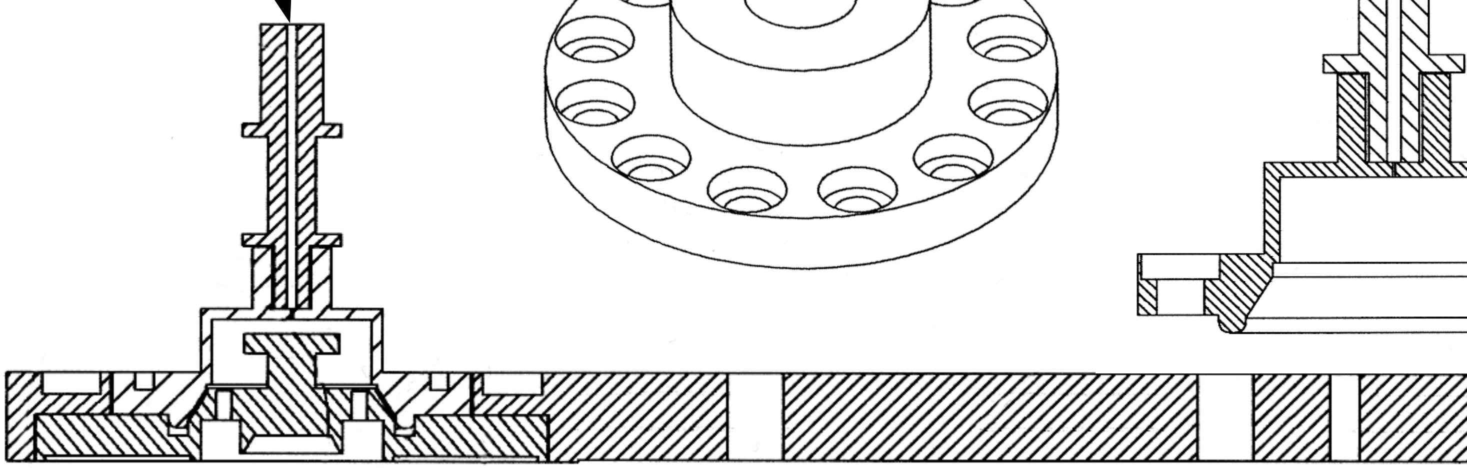




On-axis fill tube:

- simplifies fabrication and assembly
- reduces uncertainty in fill mass
- opens up additional lines of sight

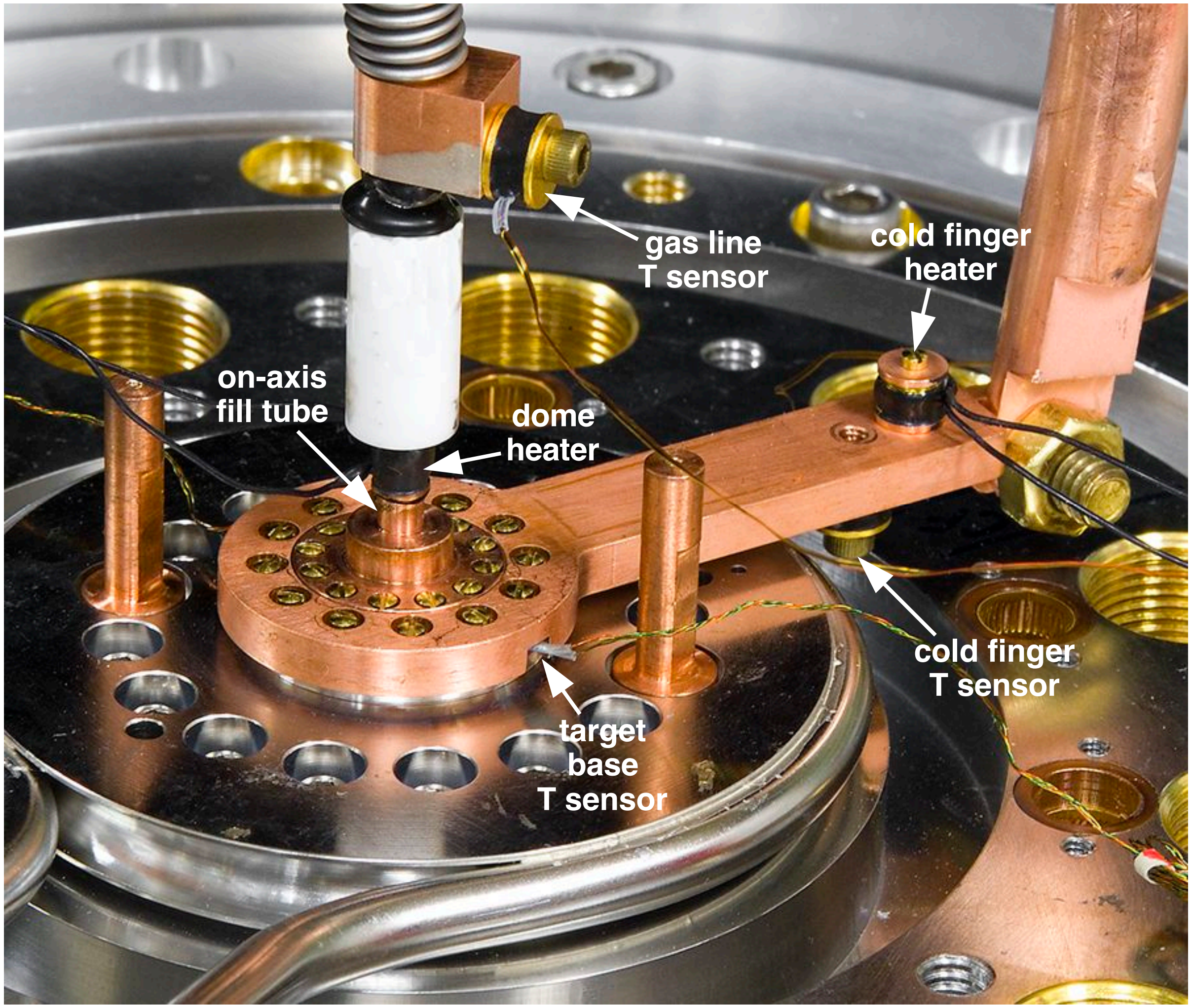




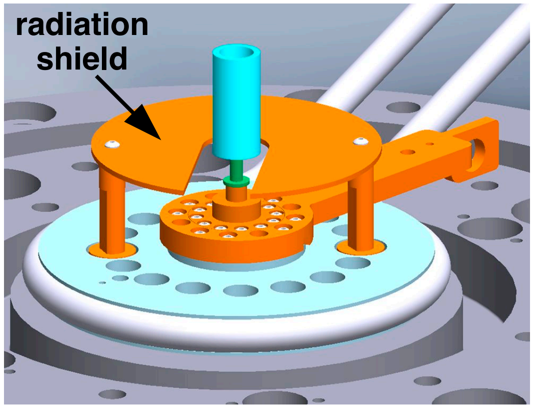
A minimum of 99% of the fractional pressure change will now result from liquid condensed in the target body

Sandia National Laboratories

Cooling tests for a thermal equivalent salad bowl target with a top-mounted fill tube are in progress

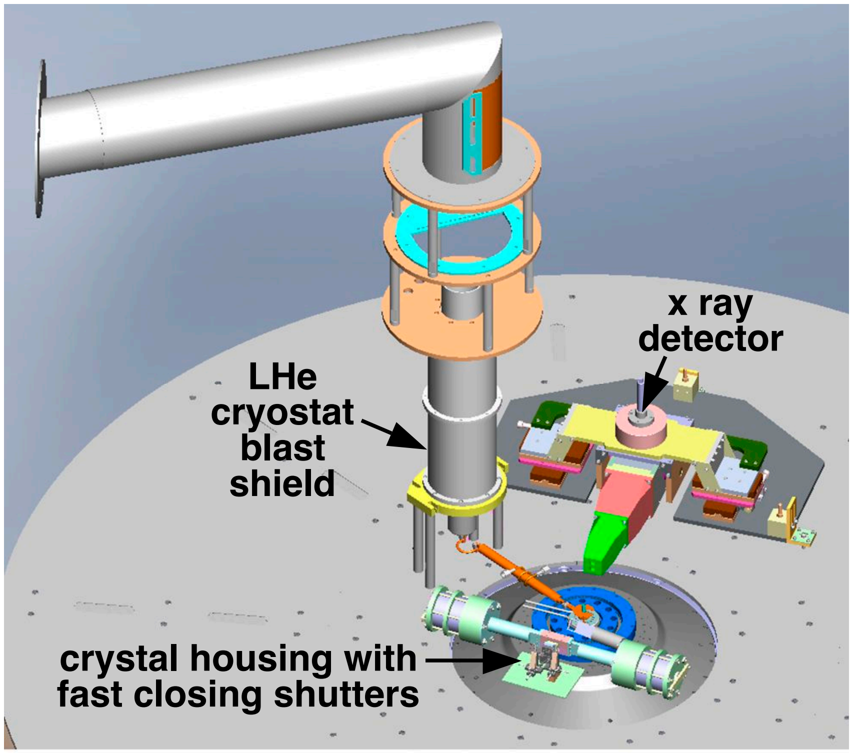


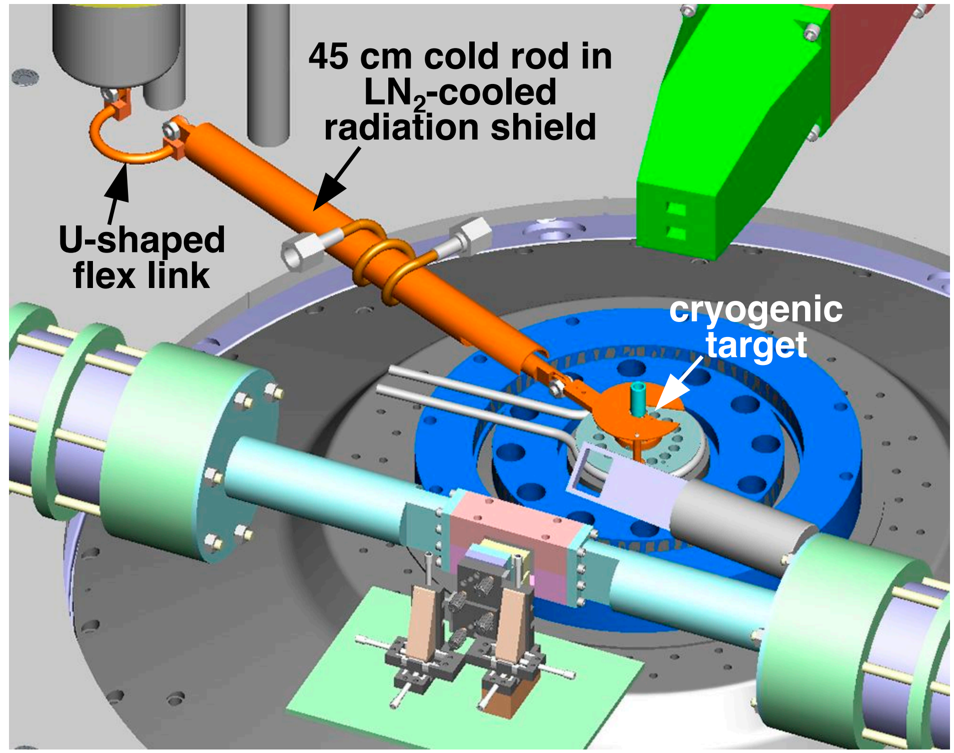
Thermal equivalent target shown with anode radiation shield removed



Sandia National Laboratories

On ZR, the cryostat would be mounted to the side when used with the ZBL backlighter imaging system

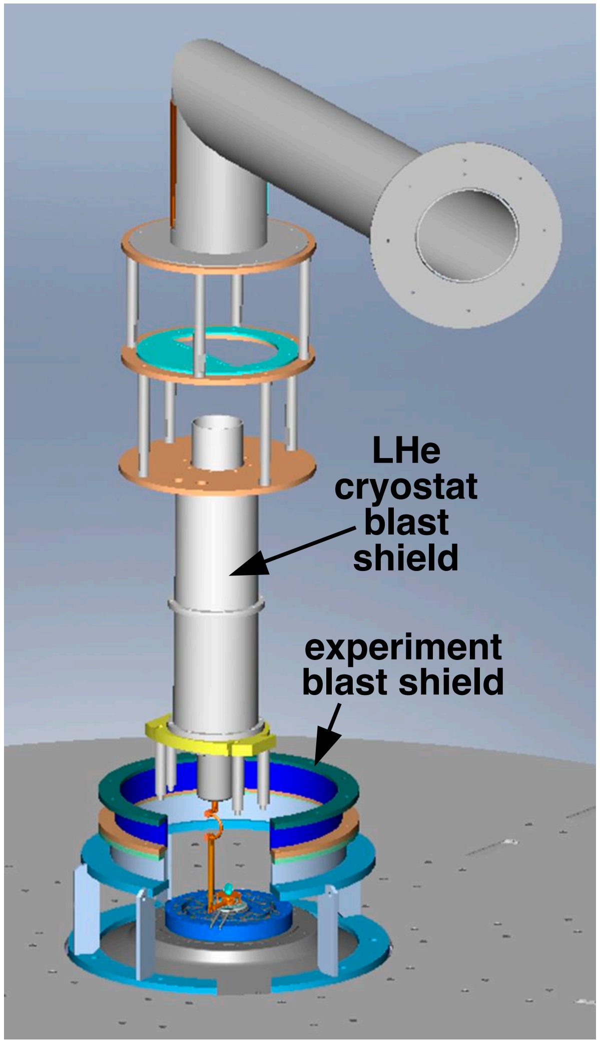


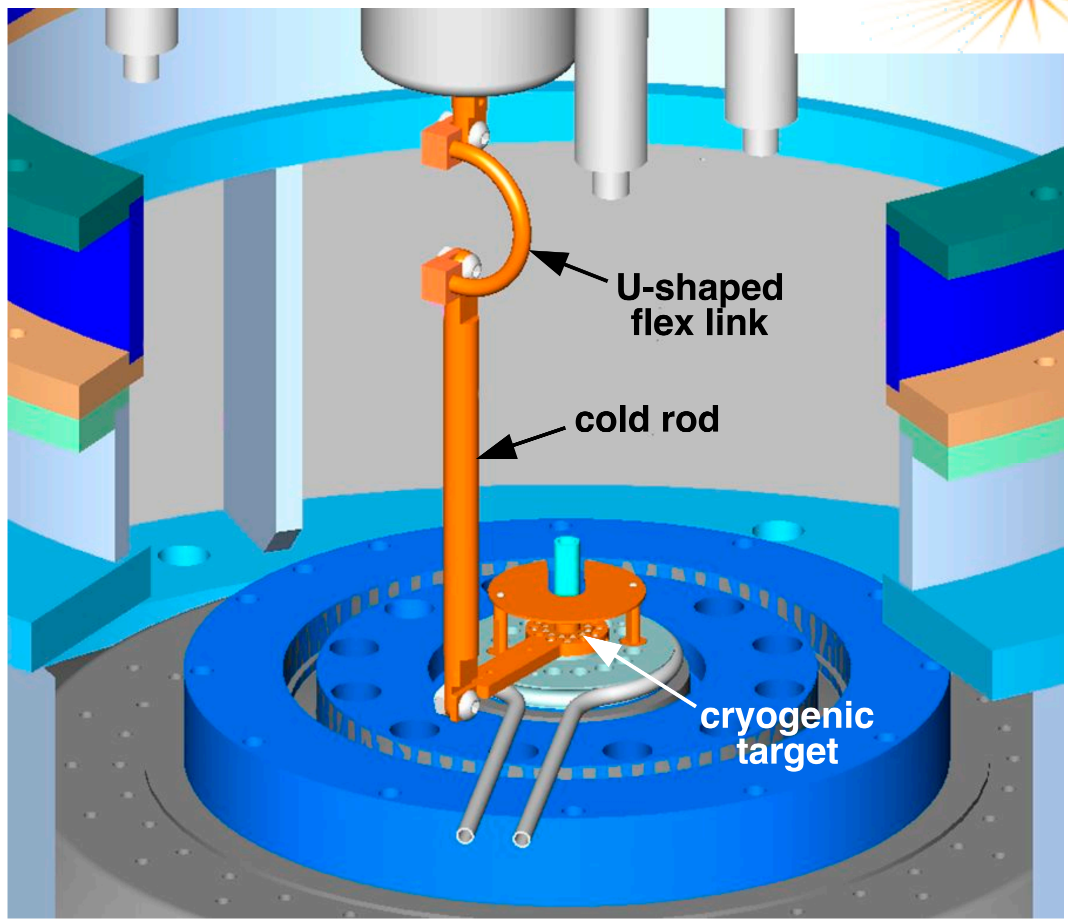


Cooling system configured around multi-frame monochromatic crystal imaging diagnostic for use with ZBL backlighter

Sandia National Laboratories

When the ZBL backlighter is not being used, the cryostat can be mounted on top of the experiment blast shield

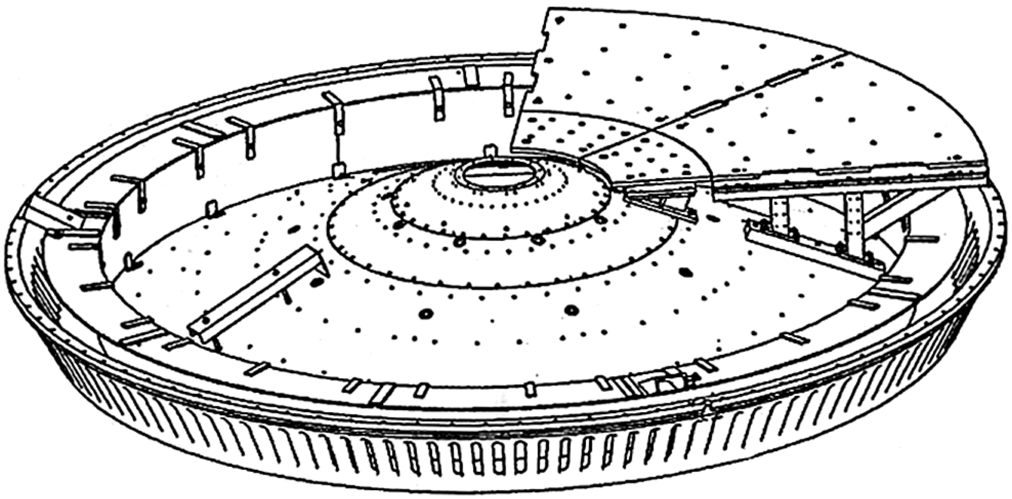




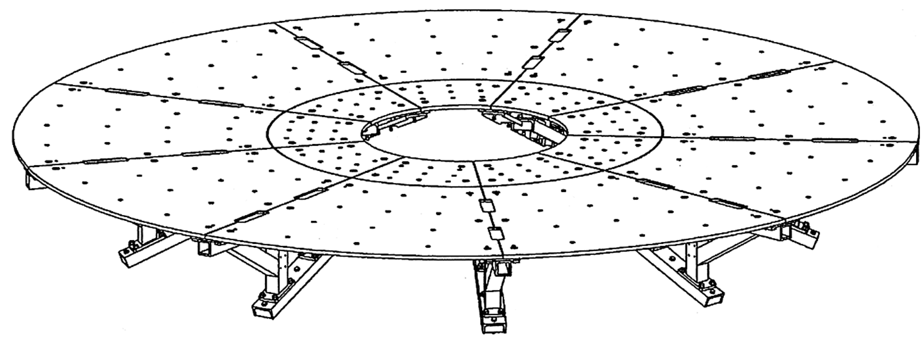
In principle, the cold rod could be positioned in the same plane as the radiation shield posts so that no diagnostic LOS is blocked

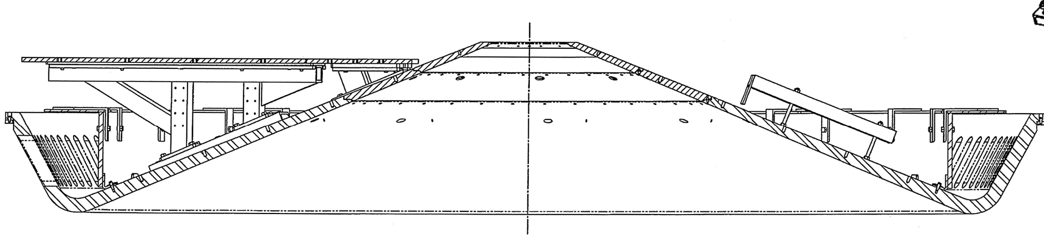
Sandia National Laboratories

The ZR target position has been raised to allow improved diagnostic access at 0 deg LOS



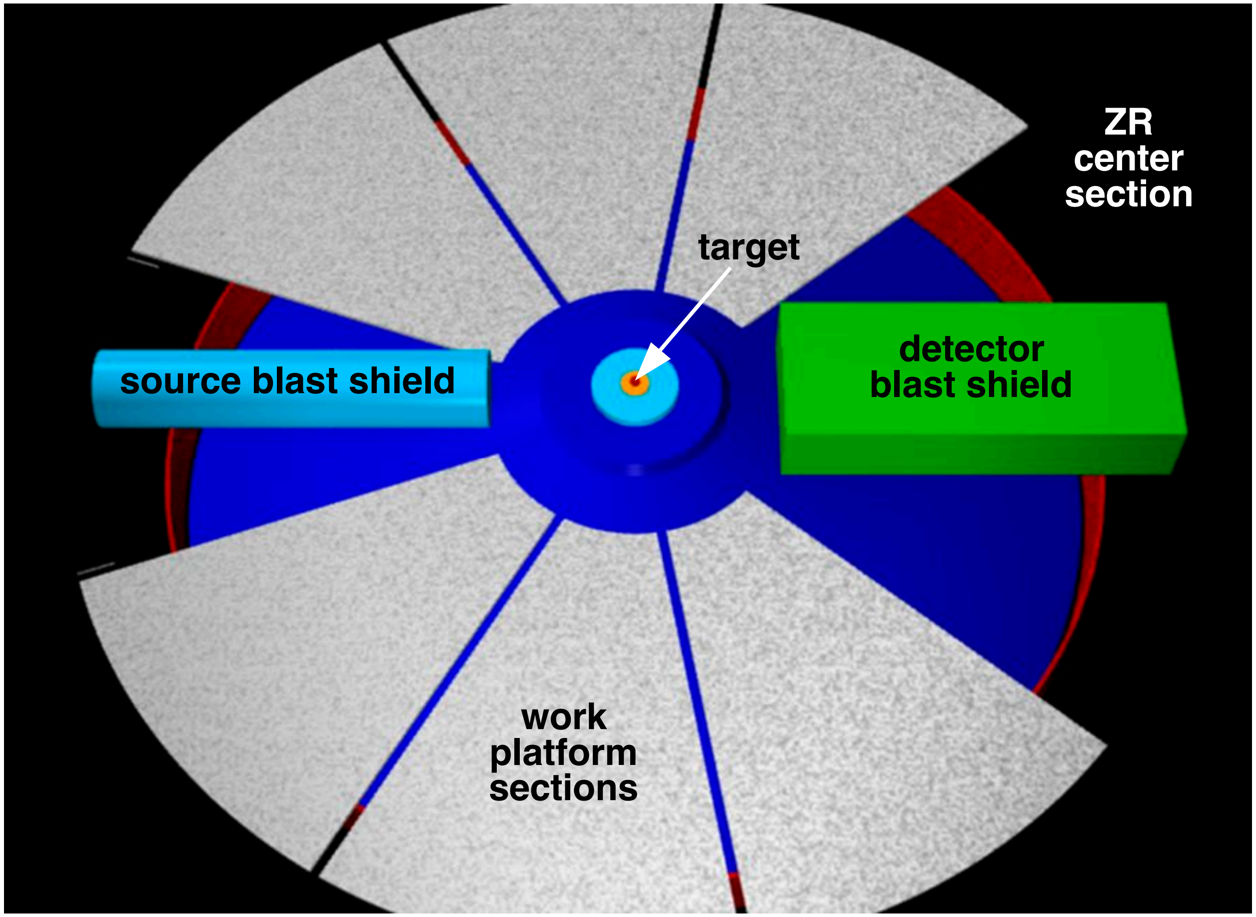
ZR center section with conical MITL and flat work platfom





Sandia National Laboratories

We want to develop a system using Xradia technology for high resolution pre-shot in-situ radiography of ZR targets



Radiography of targets in the ZR center section would require repackaging and cooling of Xradia system components for operation in shuttered blast shields mounted in a vacuum

We are planning to move the cryogenics testing lab to Building 984 in FY07

Advantages of move:

Bldg. 984 will be a permanent Limited Area for fabrication, storage, and testing of classified targets

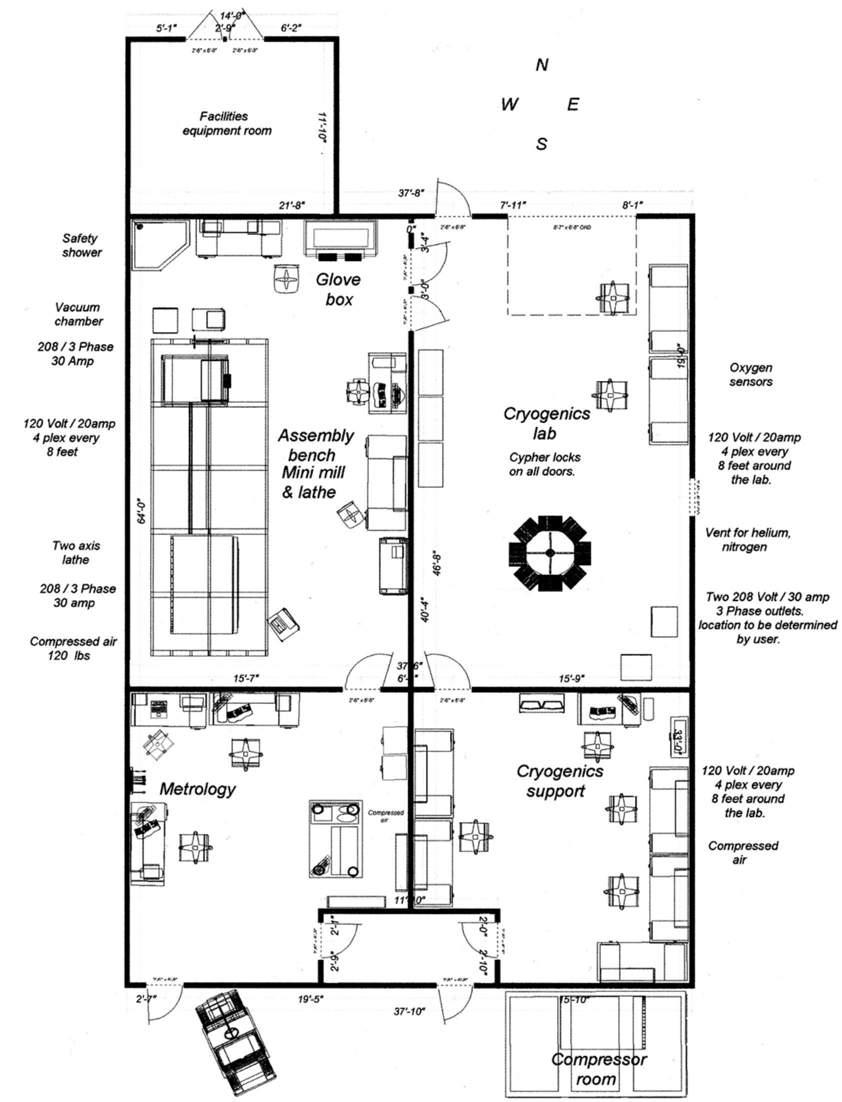
More space available for cryo test chamber, equipment and dewar storage

Dedicated data acquisition and target assembly room available in B984

Half of building can be dedicated to Be target parts fabrication

Sandia National Laboratories

The space in B984 will be equally divided between cryogenics testing activities and target machining

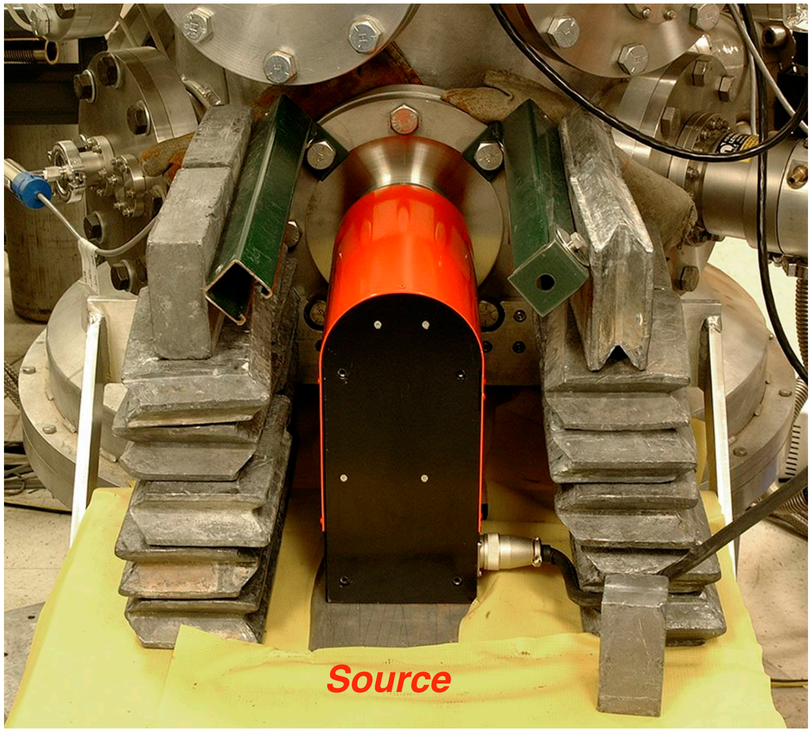


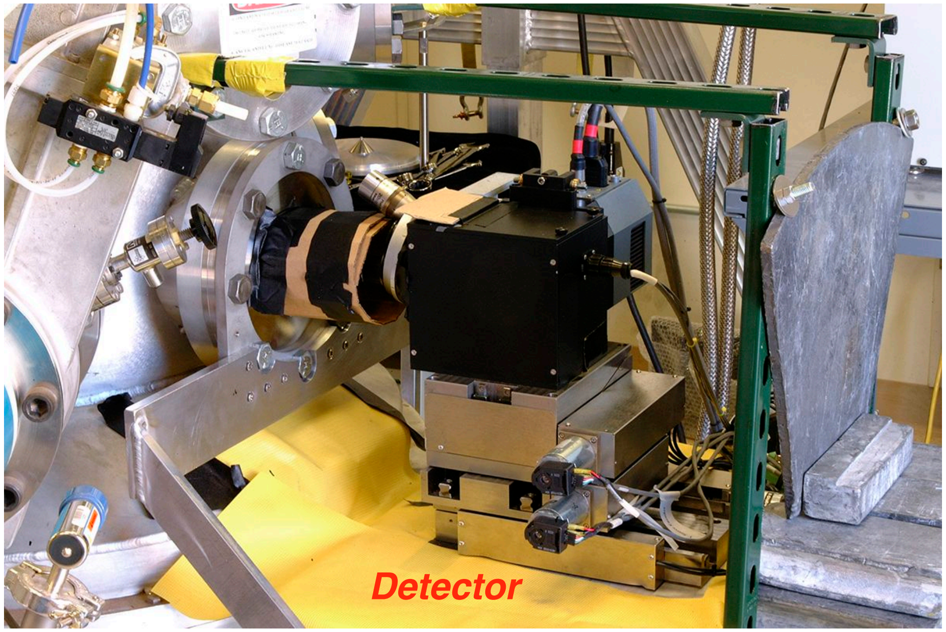
Building 984 Layout

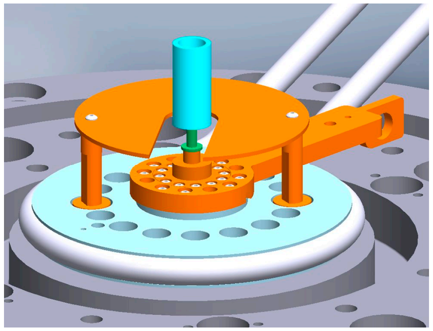
Sandia National Laboratories

We want to purchase an Xradia radiography system for target imaging in the cryo lab chamber

Xradia Micro XCT Radiography System







Summary

- A survivable cryogenic system with precision control has been developed for filling salad bowl targets with liquid deuterium on Z
- Four full tank and three partial fill experiments have been successfully fielded on Z using this cryogenic system
- LD_2 meniscus was imaged at several partial fill levels for each Be salad bowl shot target in lab tests using a LLNL Xradia 100 kV radiography system
- Building on this work, a number of cryogenic design and infrastructure enhancements are planned for ZR, including:

  Top-mounted fill tube for salad bowl target

  Alternative cryo configurations for increased LOS access

  Xradia system in ZR center section for preshot radiography

  Larger cryo lab in Limited Area building

  New test chamber with Xradia radiography system

Sandia National Laboratories

Ktech CORPORATION