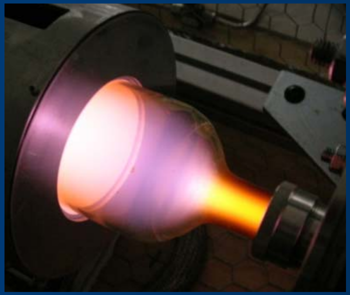
Target Activities for Inertial Fusion Energy



Target Fabrication, Layering, Injection & Tracking

Presented by Jared Hund

General Atomics

2nd European Target Fabrication Workshop

27th & 28th October 2008

Cosener's House, Abingdon, UK.

Inertial Fusion Energy funding in the USA - HAPL

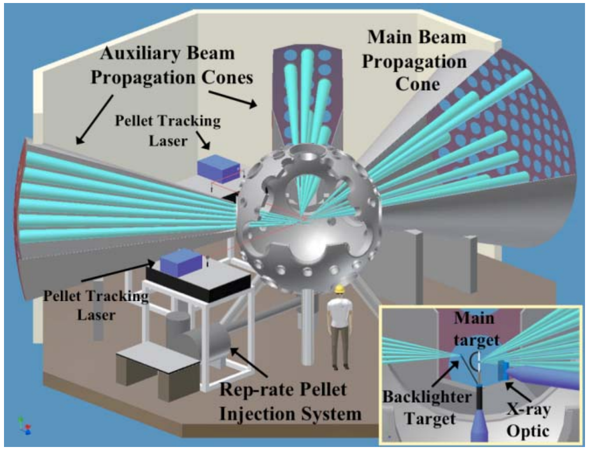
- **"Target Technology" funding via the High Average Power Laser (HAPL) program (leveraged from larger "Inertial Confinement Fusion" program)**
- **HAPL is organized by the Naval Research Laboratory (NRL), Washington DC**
- **General Atomics plays a major role in target development for IFE**
  - Others are also contributing to IFE target technology - NRL, Schafer, UCSD, University of Rochester, Lawrence Livermore, UCLA, Los Alamos

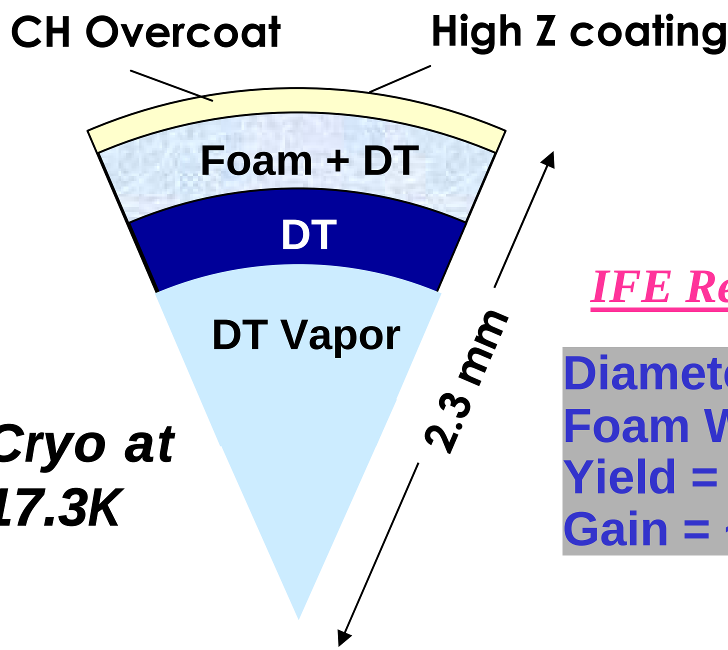
"IFE Target technology" includes manufacturing, filling, layering, injecting, tracking, and engaging the target - i.e., fueling system for power plant

HAPL has a reference, high gain, ignition target design - current work is to manufacture it to specs

- ***Ongoing iteration with target designers and fabricators is necessary***
  - *iterations have contributed to recent successes*
- ***Proposed manufacturing processes***
  - *scaleable to 500,000/day at low cost*
  - *amenable near-term demo*

Fusion Test Facility (FTF) proposed next step - smaller target





Cryo at 17.3K

IFE Reference Target

Diameter = ~4.6 mm
Foam Wall = ~176 μm
Yield = ~350 MJ
Gain = ~150

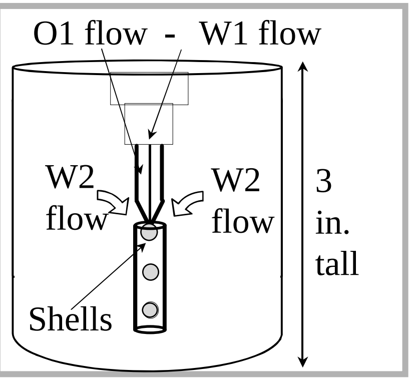
Basic process steps - lab demonstrations for each step

1. ***Fab foam capsule***
2. ***Overcoat foam***
3. ***Fill/layer fusion fuel***
4. ***Inject***
5. ***Track and engage***

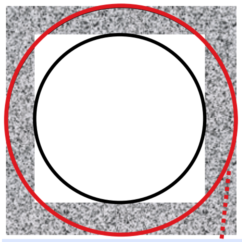
HAPL has reference process for each step of a direct-drive laser fusion target supply

1) Fabricate foam capsules

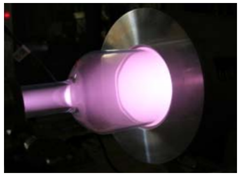
Micro-encapsulation



2) Overcoats



A) Interfacial reaction



B) GDP coating, sputter (M)

Highly isothermal environment

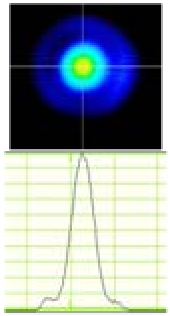
3) DT Fuel Layer

Layering cryostat

Fluidized bed

Accelerator *gas-gun, others*

4) Inject Target

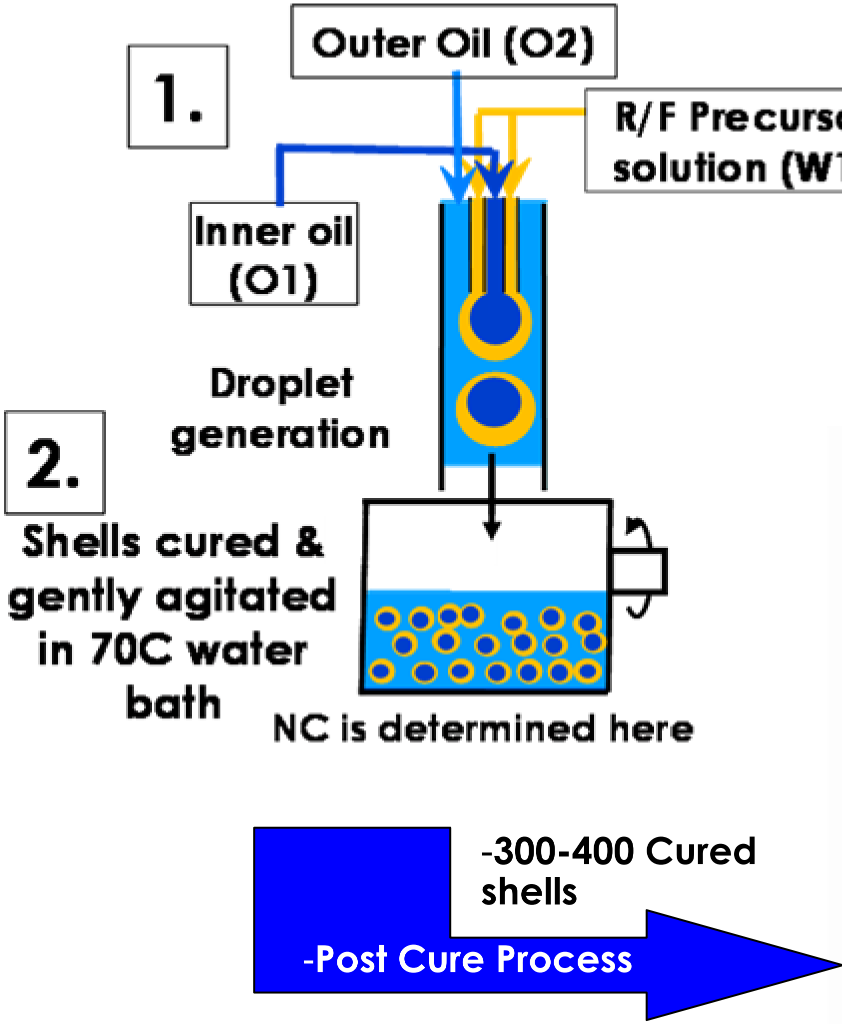


5) Track Target

Optical systems

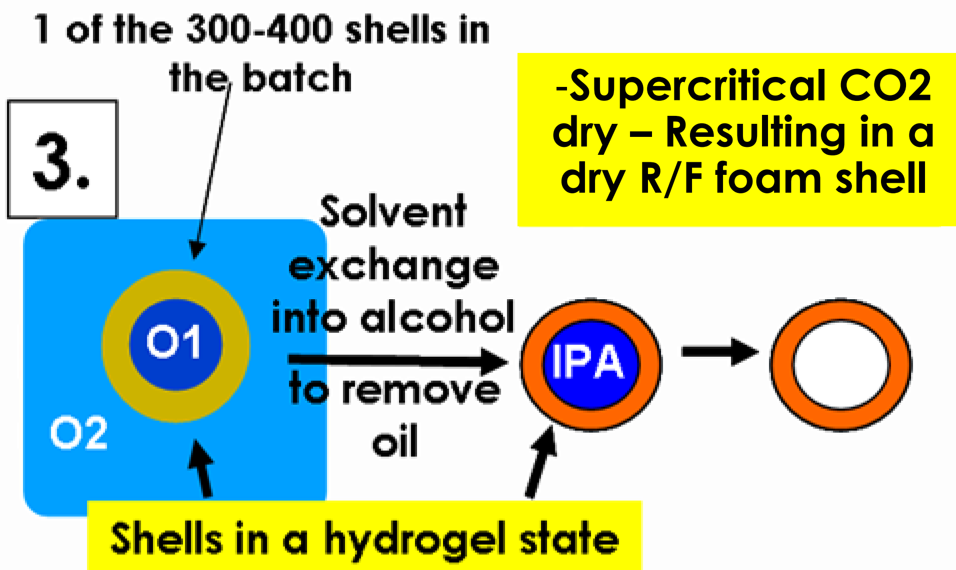
Lab demonstrations for each step...

Foam shells are fabricated using a triple orifice droplet generator



3 Steps

1. Droplet generation
2. Curing
3. Solvent exchange & drying

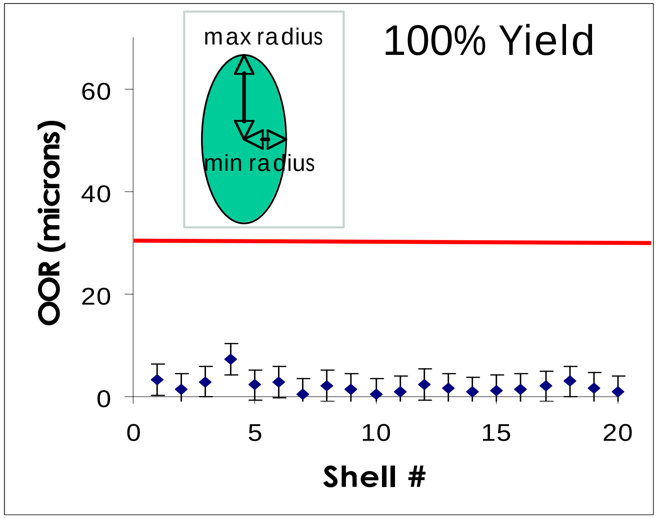


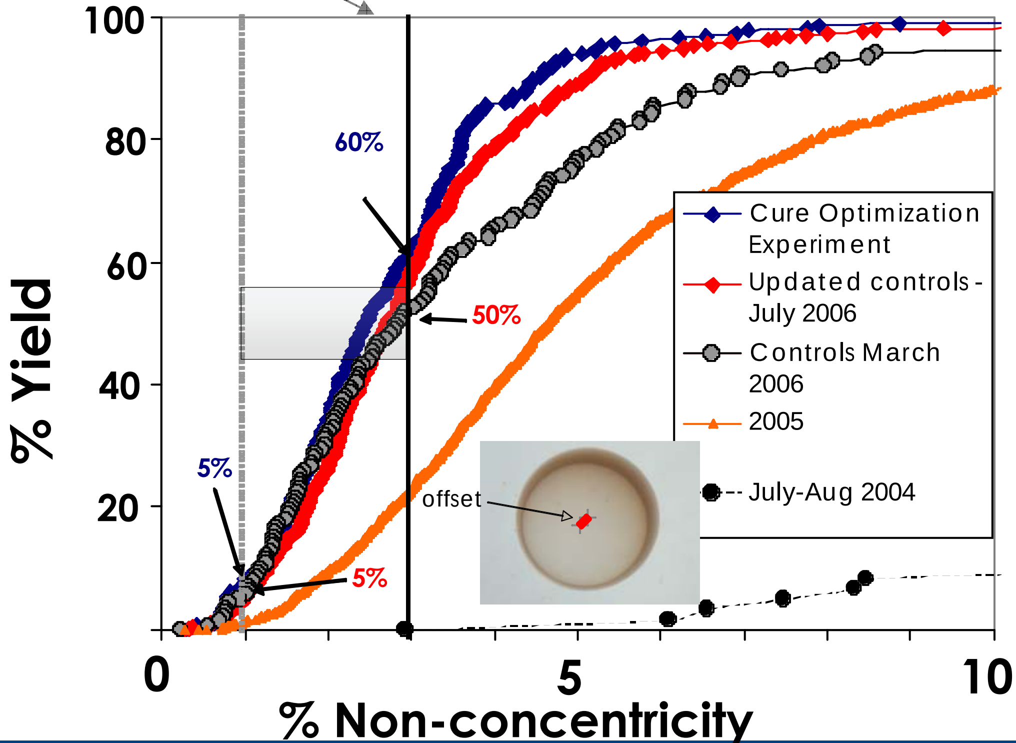
There are two candidates for foam capsules…

DVB foam capsules ~4 mm OD

- ***Started with divinyl benzene (DVB) foam***
  - *-No O,N; hi-strength at low density (20 mg/cc); evolved…*
- ***Good progress with DVB, e.g., diameter, density (-->100 mg/cc) OOR, wall uniformity***
- ***"Best" Out-Of-Round (OOR) and wall uniformity (non-concentricity)***

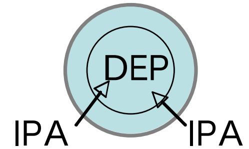
Out of Round data for DVB

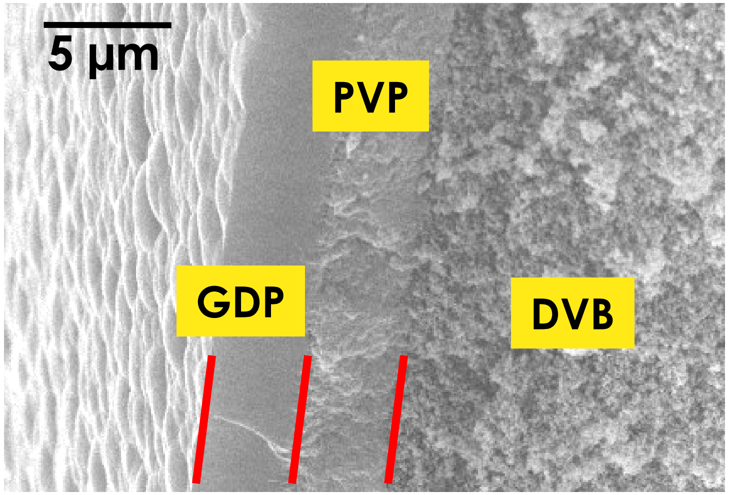




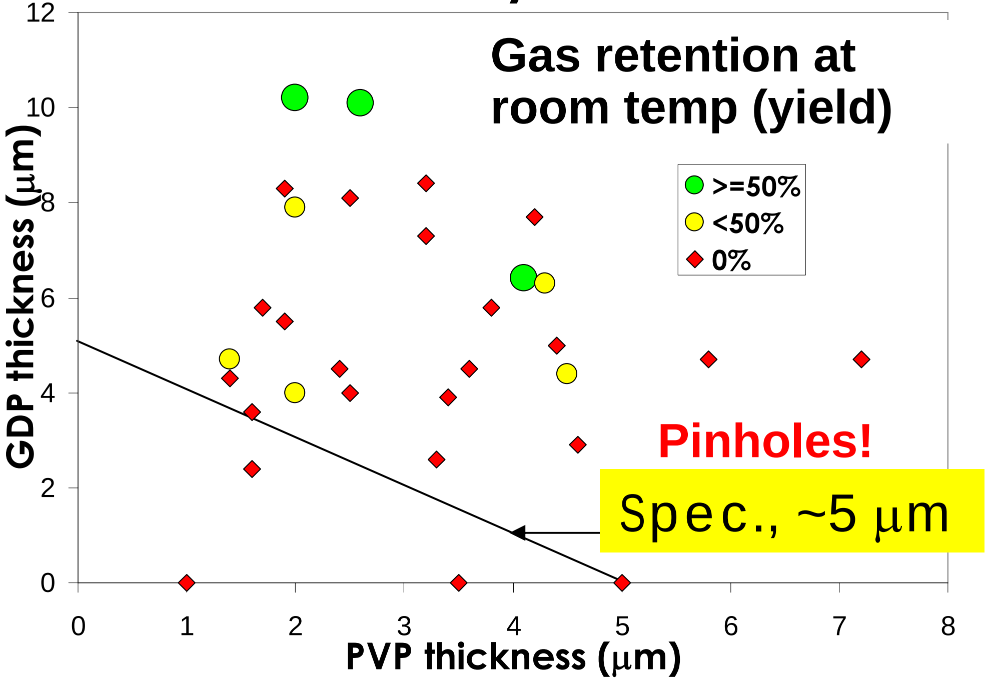
So what's the issue…the overcoat

- Large DVB pores (1-3 μm) precludes "dry" overcoating
- Tried "wet" methods - damage upon exchanges and drying
- Tried two-coating method…





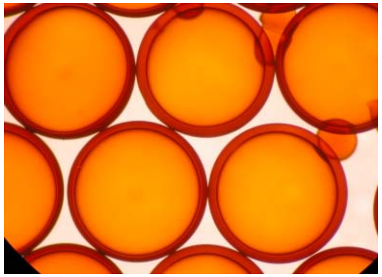
Cross section of coated DVB shell



For coated DVB, no shells held gas at cryogenic temperatures

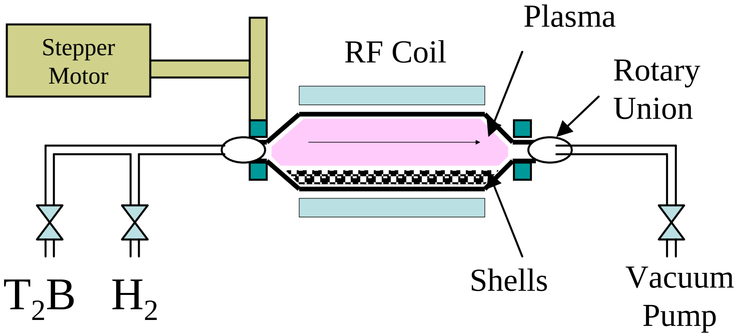
The smaller pore size of resorcinol formaldehyde (RF) foam allows direct GDP overcoating

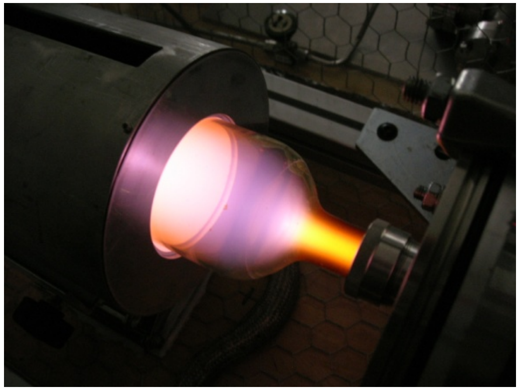
Oxygen content of RF OK'd by designers



RF foam, with <0.1 μm pore size, can be directly overcoated via Glow Discharge Polymer (GDP)

- **A horizontal rotary GDP coater ("rotocoater") has produced gastight HAPL shells**
  - geometry different than established ICF technique
  - produced the best coatings yet
  - scalable to mass production



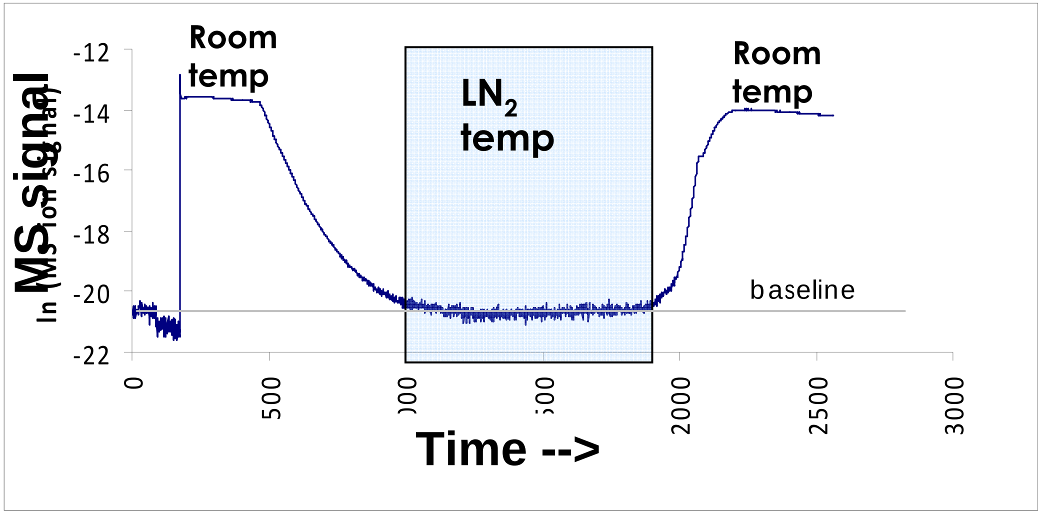


-~5 inch diameter coating tube

2) Capsule Overcoat

An essential function of the overcoat is to permeate at room temperature - then seal at cryogenic temperature

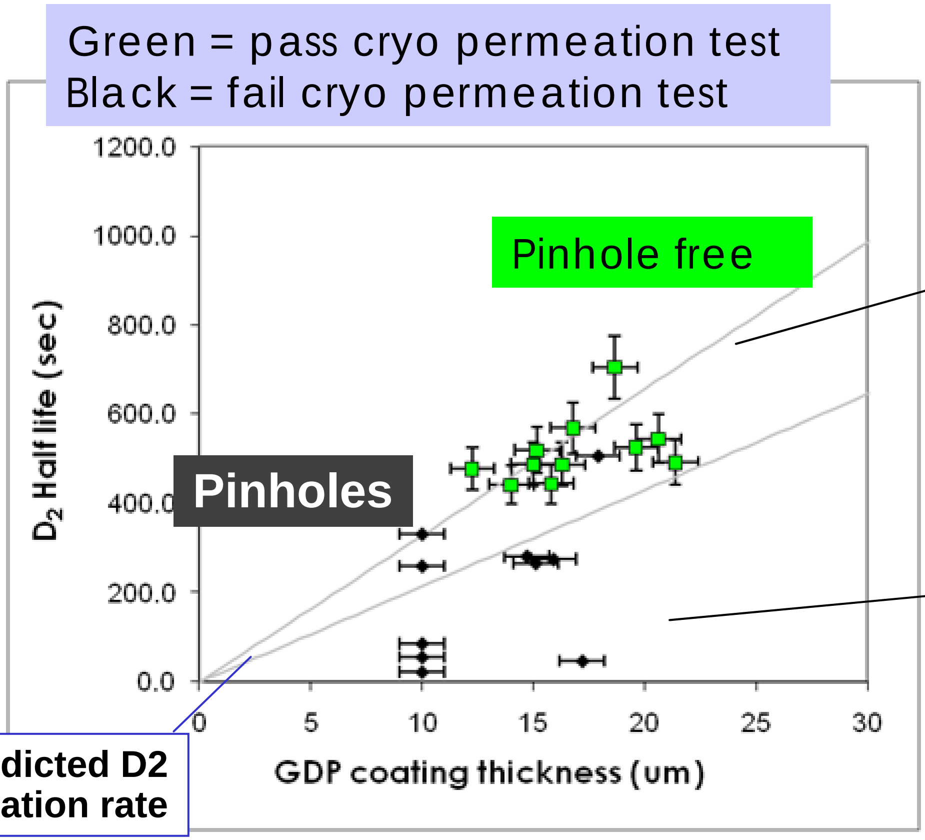
- Shells filled with D_2 - leak rate measured with mass spec
- Leak rate measured at room and liquid nitrogen temperatures
  - Distinguish between pinhole and permeation flow



Example shown: 4 mm diameter 25 um of GDP on RF

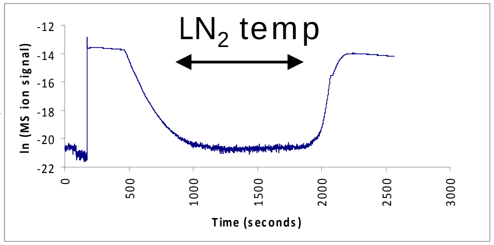
The shells are tested to be “gas tight” and can survive cryo cooling and warming cycle

Recent improvements in coatings have decreased the minimum GDP layer for gas retention

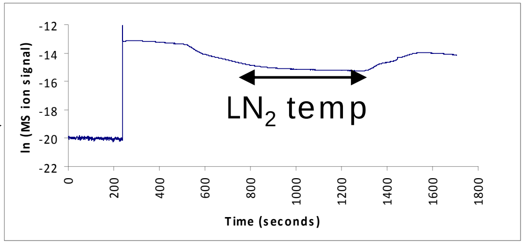


Leak Mechanisms:

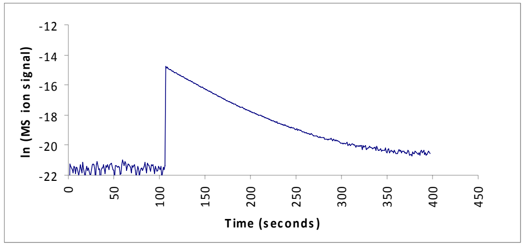
Good – permeation leak only



Bad – pinhole leak



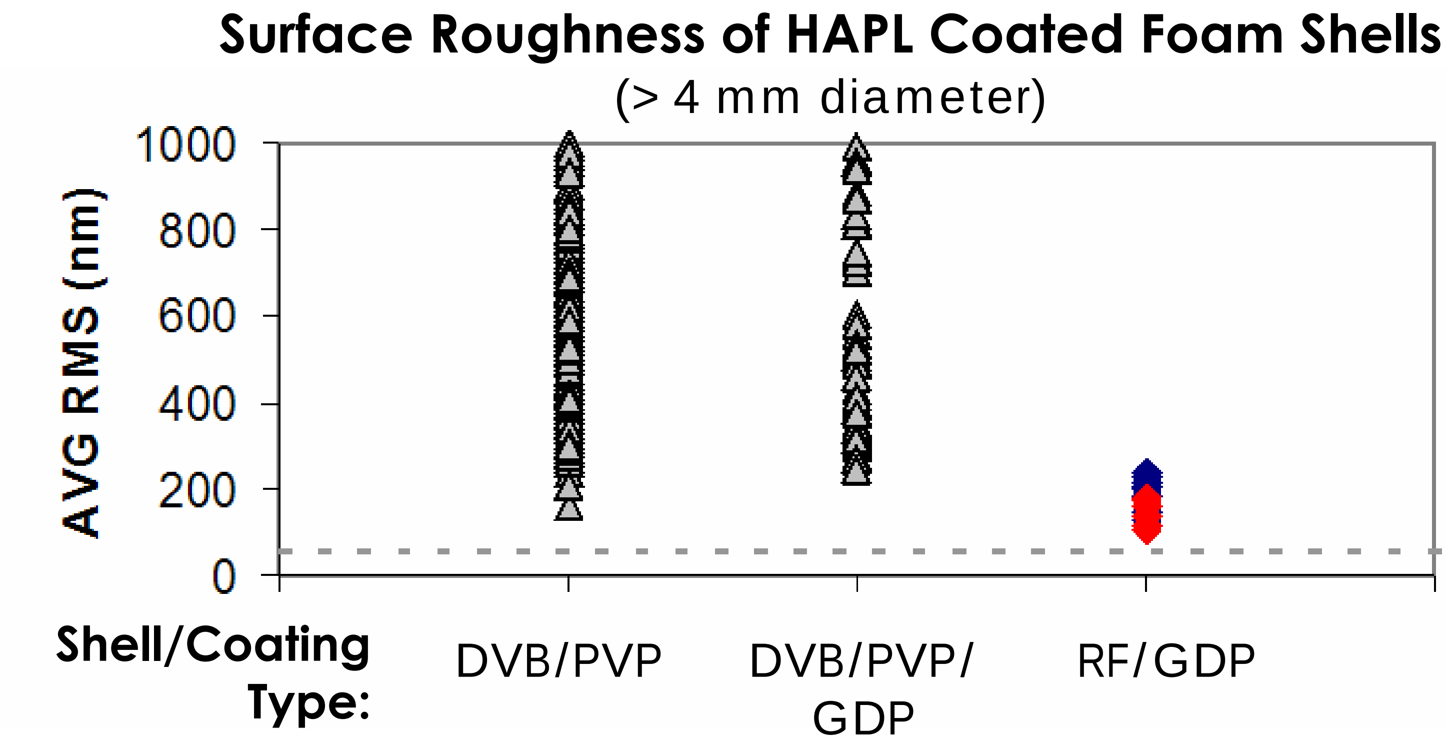
Ugly – viscous flow leak



Parameterize coating conditions
250 mtorr--> 50 mtorr coating pressure

Cryo-successful overcoat thicknesses are now approaching 10 microns

Coated R/F foam shells are also smoother than over-coated DVB shells



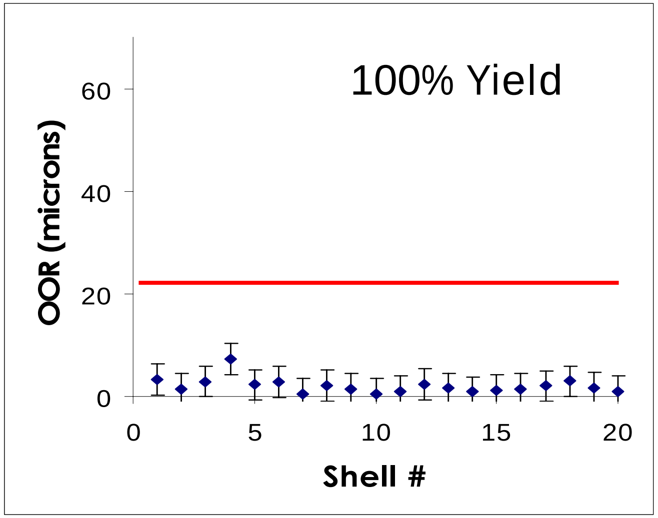
Optical Profiler (WYKO) measurements acquired at 20x, with a 300 x 200 um area

1) Foam Capsules

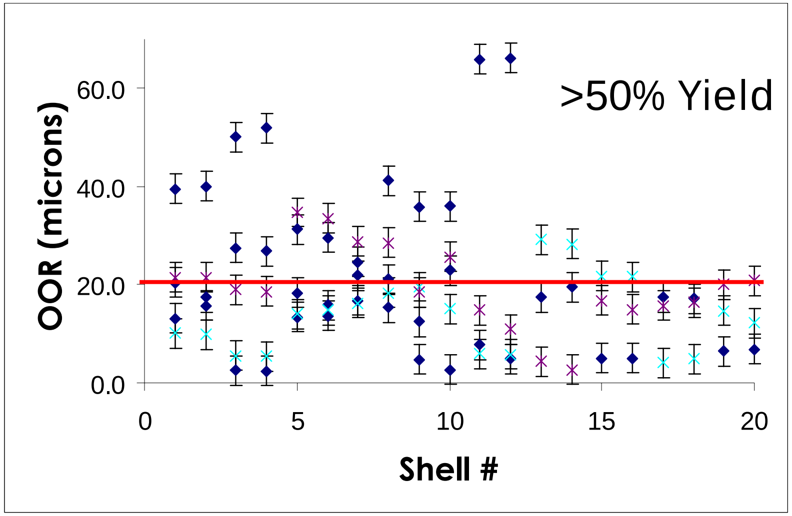
The DVB capsule meets the sphericity specification, but RF still requires work

- **The yield of RF capsules that meet the 1% of radius Out-of-Round (OOR) specification is >50%**
- **The RF wall uniformity is also a current point of work**

DVB Capsule Data



RF Capsule Data



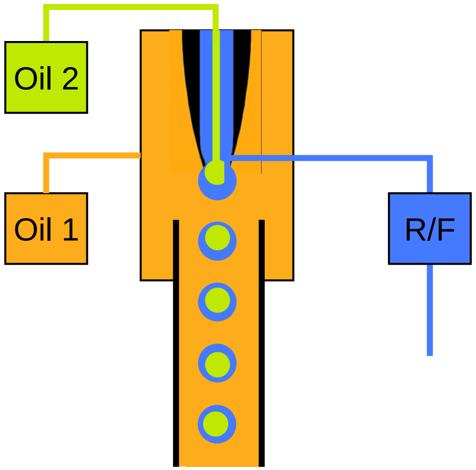
OOR = (max radius – min radius)

A potential fix for this is to increase the interfacial tension of the RF system before curing

Backup techniques for target fab are also being evaluated - UCLA/GA collaboration on microfluidics

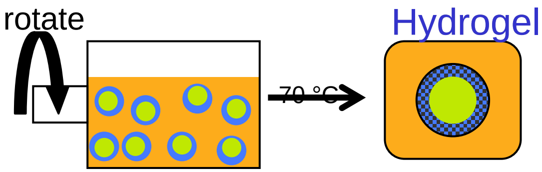
Challenge 1: controlling size and size distribution

Nozzles used to form double emulsion



***NEW:* Droplet microfluidics**
- Controlled volume dispensing
- Spontaneous double-emulsion formation
- Programmed transport

Challenge 2:
Obtaining high yield of well-centered particles



***NEW:* DEP (**Dielectrophoresis): Use external field to center inner droplet before polymerizing.

1. Microfluidics and DEP can be automated
2. Scalable (parallel processing)
3. Potentially higher yield of targets that meet spec's

Mass production layering experiment is being brought online …

- Static controlled
- Scoping tests show randomization
- Initial cryostat cooldowns to ~ 11K
- Method to "grab" one shell for characterization has been done at cryogenic conditions

Cryo-bed

Helium circulator and heat exchangers

UCSD

Target injection has several acceleration options …

Previously - demonstrated:

-Injection velocity of ≥400 m/s, time jitter of 0.5 ms

-Target placement accuracy 1 σ of 10 mm at 17 meters

2-piece sabot

- Magnetic diversion
- Reduces gas in chamber
- Reduces target heating and required injection velocity
- More options - simpler accelerator systems

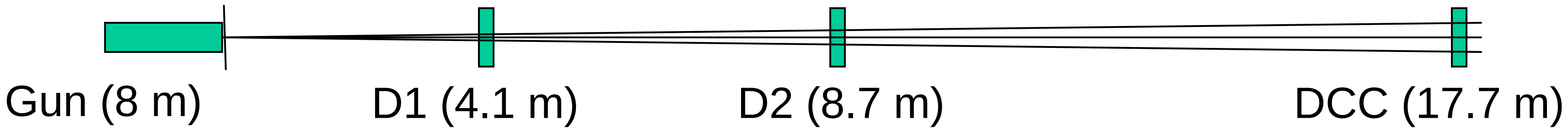
Current design: "1-sided" target seat

Accuracy 4 mm @ 17 m, 1 σ, with ~1 mg projectiles

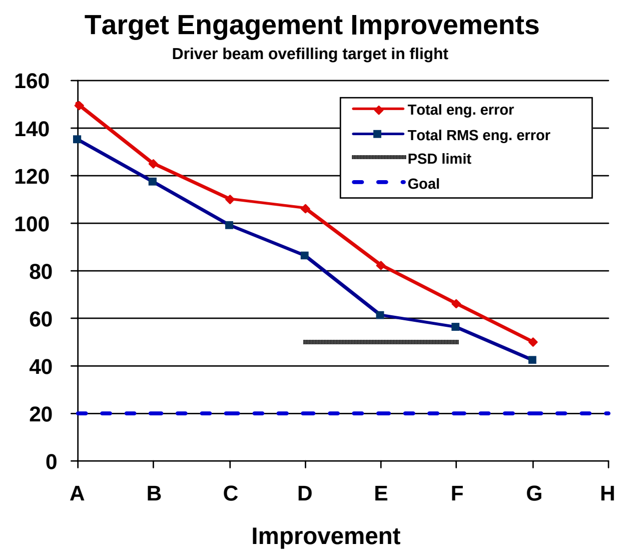
5) Tracking and engagement

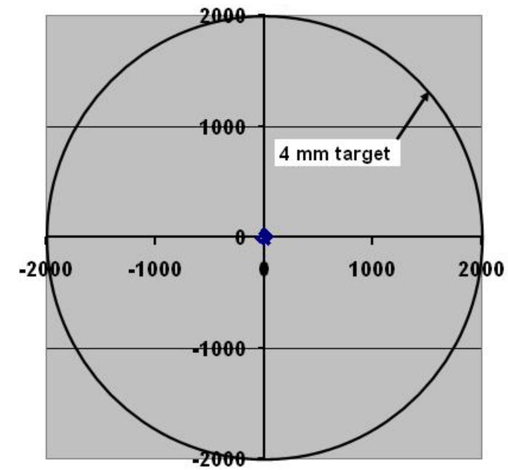
Basic direct drive requirement is alignment of the lasers and the target to within 20 microns

- **<u>Initially</u> - demo'd "ex-chamber" sensors, prediction to ~500 μm**



- **Added "in-chamber" systems (continuous tracking)**
- **"Glint" system allows target itself to be the alignment point for the driver beam ~ 1 ms before each shot**
- **Bench-top setup for scaled demonstration of engagement**

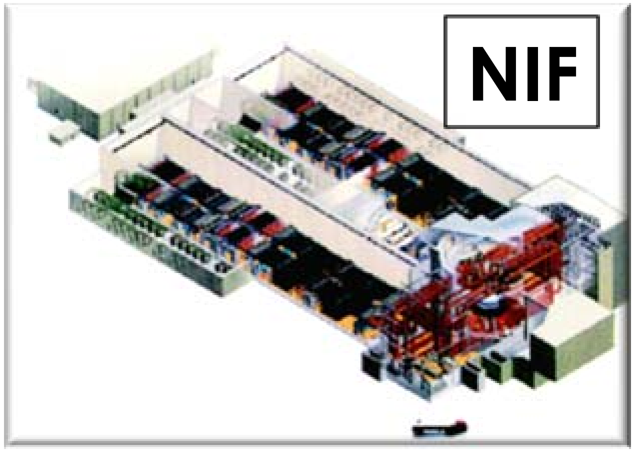




Current engagement: 40 μm RMS

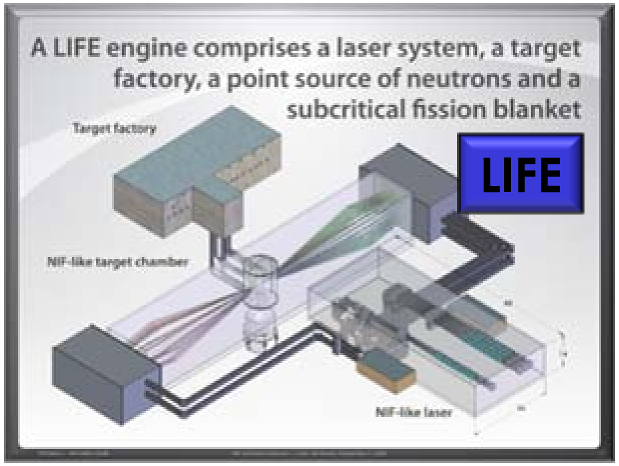
NIF ignition is expected to lead to increased effort in IFE area

Single-shot

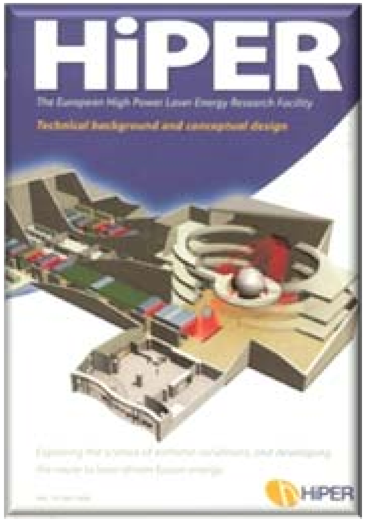


IGNITION

Rep-rated



LLNL - LIFE



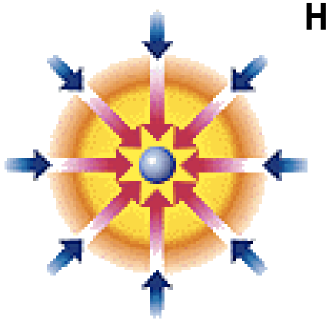
COMMERCIAL IFE

POWER PLANT

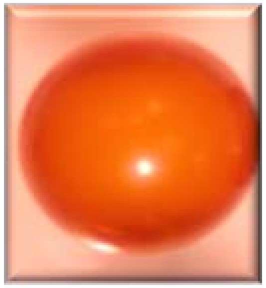
Rep-rated capability is coming online today (RAL)

Two Paths to IFE — Hot Spot ignition and Fast Ignition

- **Hot spot ignition is "traditional way"**

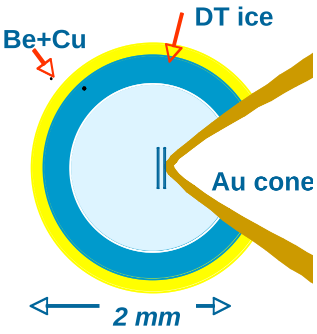


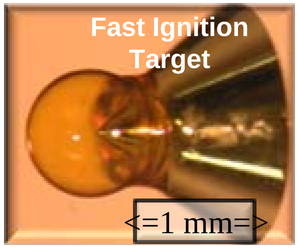
Hot spot — foam capsule with overcoats



Drive laser energy 1 MJ
Gain 10–40

- **Fast ignition emerging approach**
- **Target is the key!**





Community excited about FI-IFE

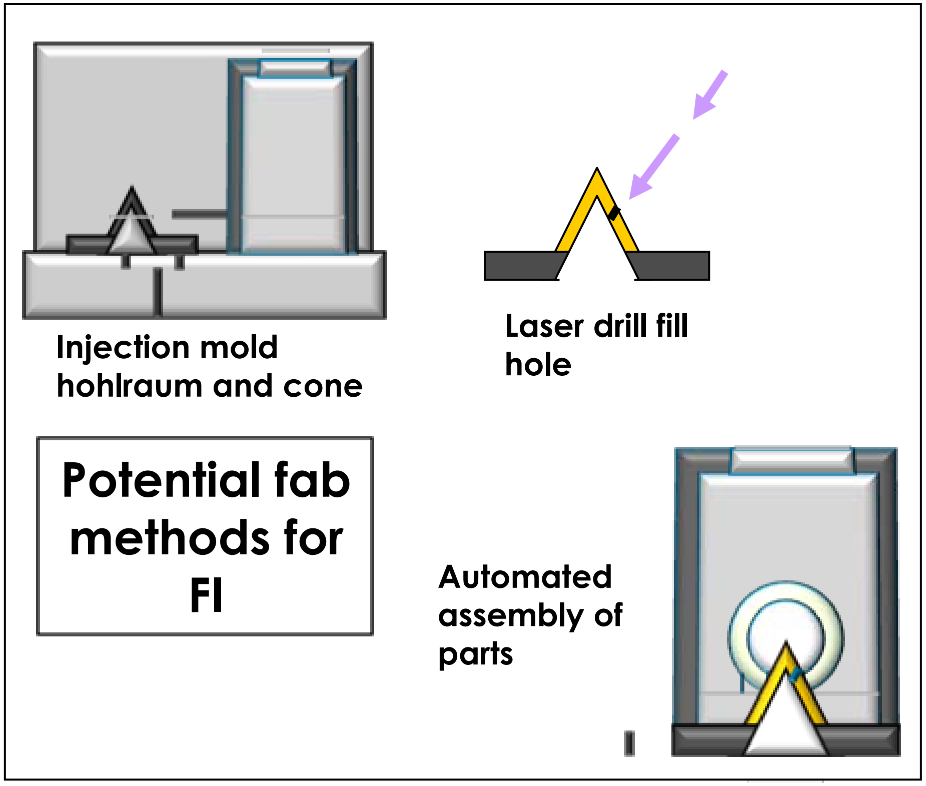
Drive laser energy 0.2 MJ
Gain 300

FI — higher gain at lower driver energy: reduces recirculating power, driver cost and COE (approach used in HiPER, Japanese, and possibly LIFE/LLNL)

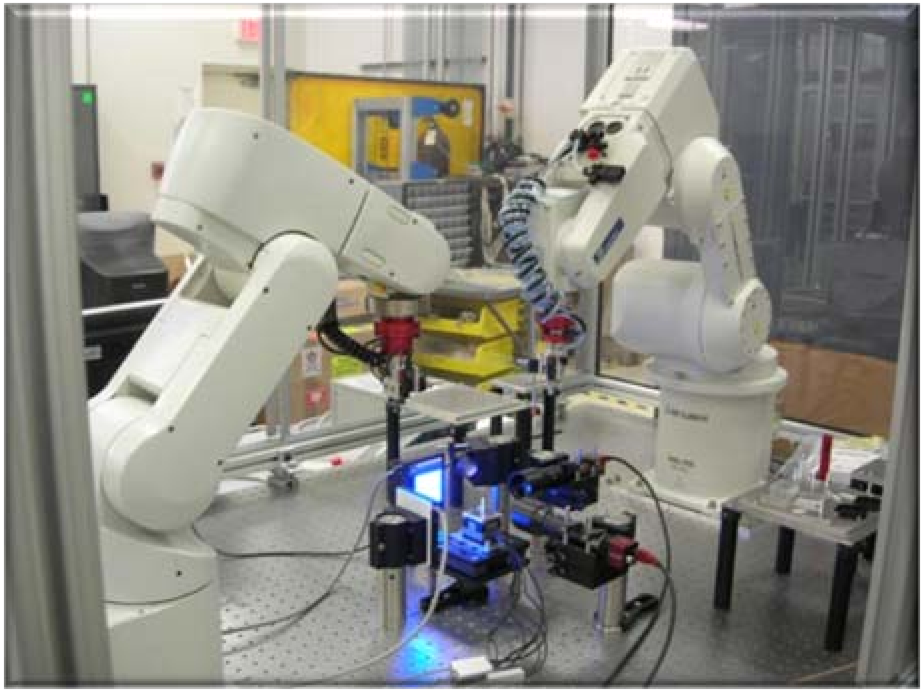
Rep-rated targets (1000's/day) are "on the path" to IFE (up to millions/day)…

Robotic assembly methods will be needed for rep-rated target implementation

- GA setup robotic assembly system in 2008
- Applicable to rep-rated targets (100's to 1000's/day)
- In 2009 we will implement robotic assembly methods for FI targets

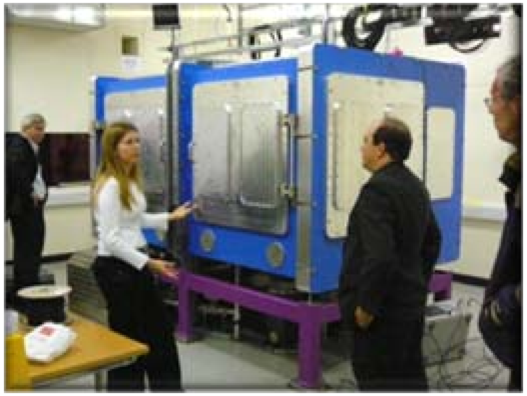


GA target assembly robots



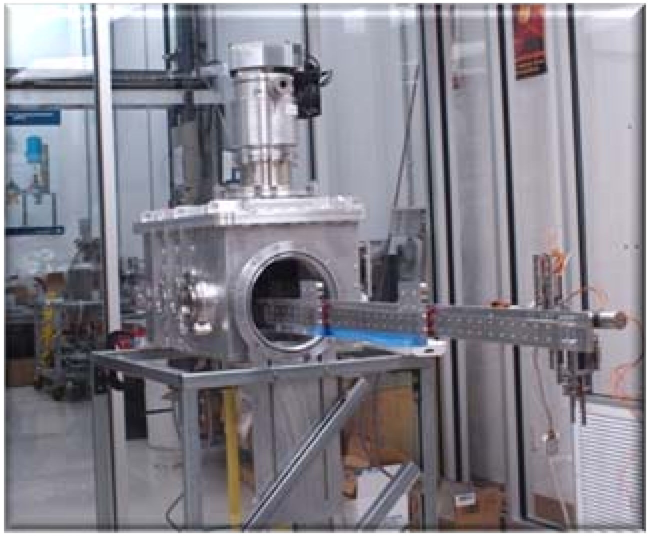
Joint IR&D task with Rutherford Appleton Laboratory to develop automated assembly and install target inserter

- Rep-rated Gemini laser at RAL will need 1000's of targets and be operated in 2009
- GA built an automated and EMI-tolerant insertion system in collaboration with RAL engineers in 2008
- In 2009 GA/RAL will operate this inserter and perfect rep-rated and EMI-tolerant operations



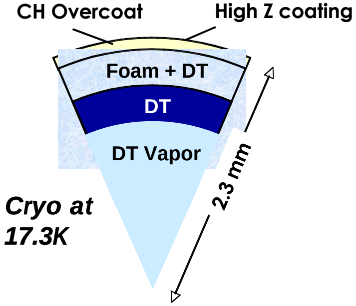
Gemini laser

EMI-tolerant positioner



EMI-tolerant target inserter

Summary/Conclusions - GA's role in IFE and rep-rated



1. GA is a major participant in target development for HAPL (direct-drive)
2. We are developing mass-production processes for a HAPL target
   - Near-term demo for each process step
   - Also evaluating "advanced" backup fab methods with UC Discovery Grant
3. We see rep-rated developments as "on the path" to IFE
4. GA/RAL collaboration for robotic assembly and for rep-rated target insertion
5. We expect to see major advances in rep-rated capability in the community in 2009