Mass Production of Targets for Inertial Fusion Energy

D.T. Goodin,[1] **R.C. Cook**,[2] N.B. Alexander,[1] K.J. Boehm,[3] L.C. Carlson,[3]
D.G. Czechowicz,[1] G.W. Flint,[1] D.A. Geller,[4] J.K. Hoffer,[4] J.F. Hund,[1]
A. Nikroo,[1] R.R. Paguio,[1] R.W. Petzoldt,[1] D.G. Schroen,[1]
J.D. Sheliak,[1] M.S. Tillack[3]

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA
[2]Lawrence Livermore National Laboratory Livermore, California, USA
[3]University of California San Diego, La Jolla, California, USA
[4]Los Alamos National Laboratory, Los Alamos, New Mexico, USA

Third Moscow Workshop on Targets and Applications
Moscow, Russia
October 15-19, 2007

GENERAL ATOMICS

Acknowledgements

Funding via Naval Research Laboratory (NRL) - *High Average Power Laser (HAPL) program*

NRL - *John Sethian, Bertie Robson, Steve Obenschain, Andy Schmidt, Denis Columbant*

Schafer - *Don Bittner, John Kames, Nicole Petta, Jon Streit*

UCSD - *Kurt Boehm, Landon Carlson, Lane Carlson, Tom Lawrence, Jon Spalding, Jeremy Stromsoe, Mark Tillack, Rene Raffray*

University of Rochester - *David Harding, Tom Jones*

Los Alamos - *Jim Hoffer, Drew Geller, John Sheliak*

UCLA - *Robin Garrell*

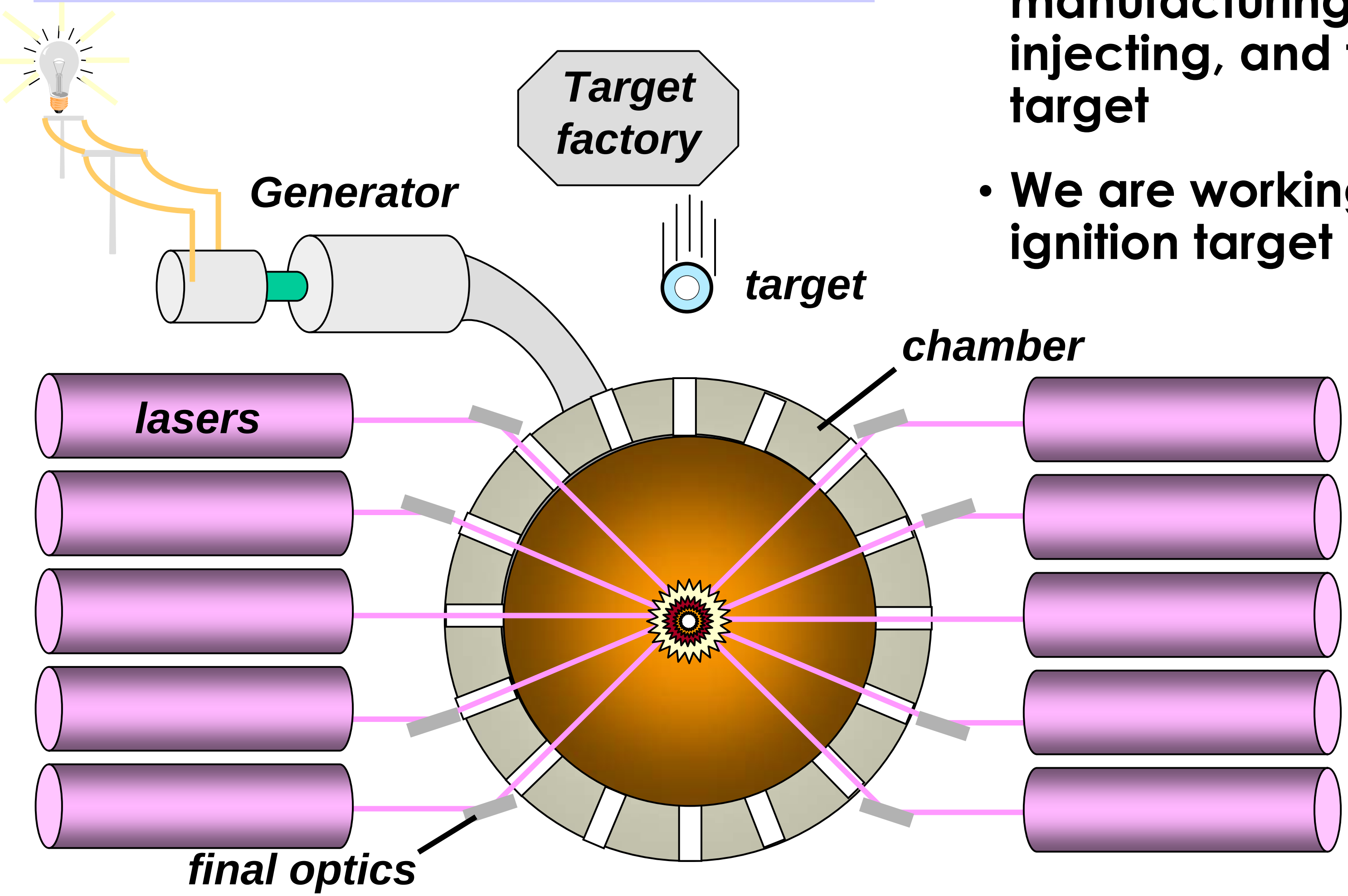
Lawrence Livermore - *John Perkins*

General Atomics - *Dan Goodin, Neil Alexander, Amy Bozek, Graham Flint, Dan Frey, Remy Gallix, Jared Hund, Abbas Nikroo, Reny Paguio, Ron Petzoldt, Diana Schroen, Sheida Saeidi, Emanuil Valmianski*

Top-level objective = show feasibility of economical target fabrication for commercial fusion

Our objective is to develop the "target factory" for HAPL

Dry wall, direct-drive, laser fusion



- "Target factory" involves manufacturing, filling, injecting, and tracking the target
- We are working towards an ignition target

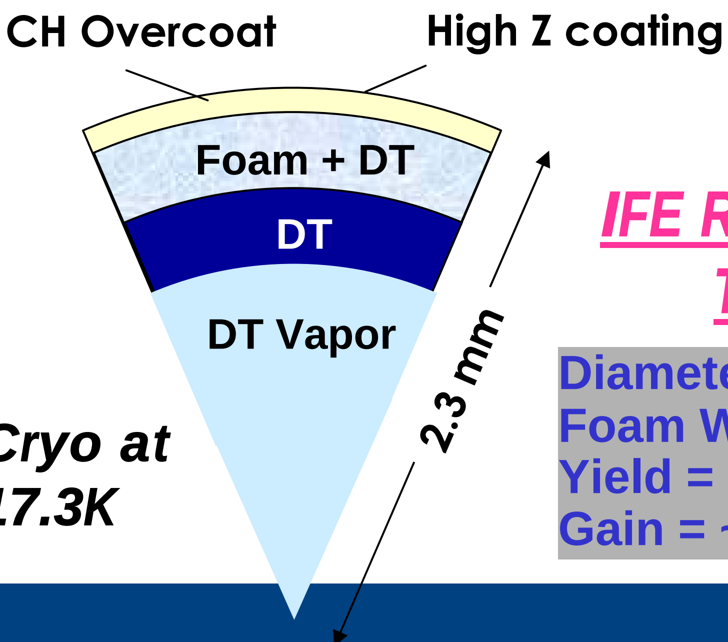
~500,000 targets/day for 1000 MW(e) power plant

IFE ignition targets have been defined

- ***Potential manufacturing processes that are adaptable to mass-production identified***
- ***An experimental demonstration program for each process step laid out and initiated***
- ***A "baseline" target design identified and good progress made on its fabrication ....***

Basic process steps

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

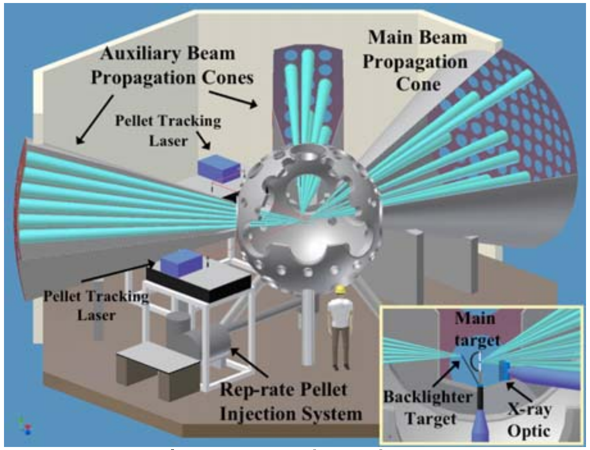


Cryo at 17.3K

IFE Reference Target

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

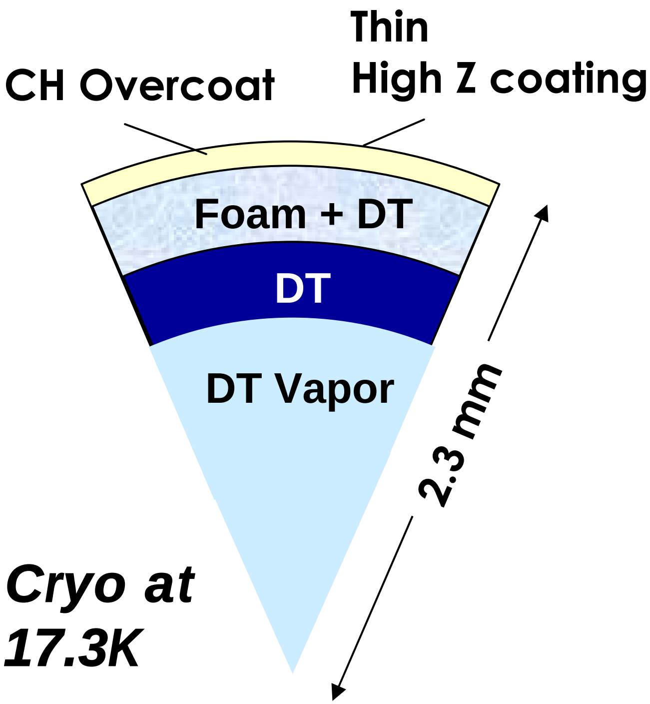
Fusion Test Facility (FTF) proposed next step



Naval Research Laboratory

Foam target progress assisted by ICF-IFE synergism

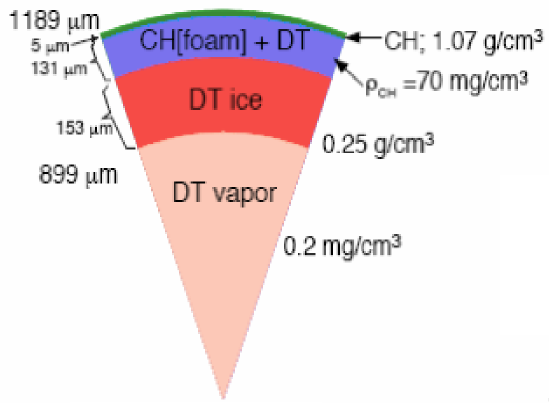
IFE reference target

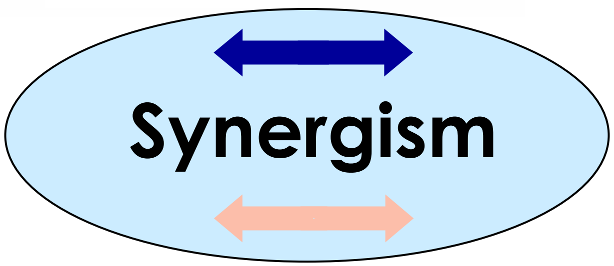


Cryo at 17.3K

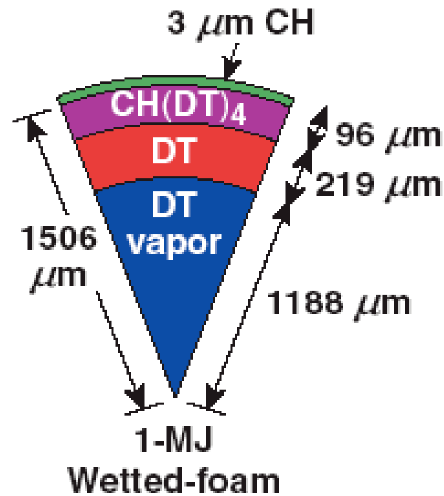
FTF target

Diameter = ~2.4 mm





Alternate direct drive NIF ignition target



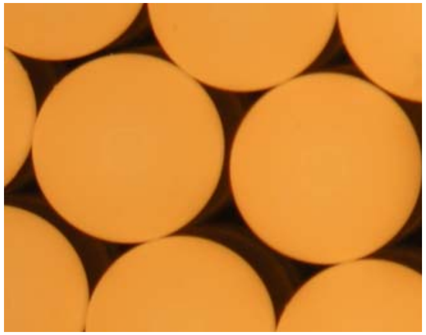
Diameter = ~3 mm (~ 1 mm on Omega)

Baseline foam material chosen for HAPL = divinylbenzene (DVB)

Resorcinol formaldehyde foam (RF)

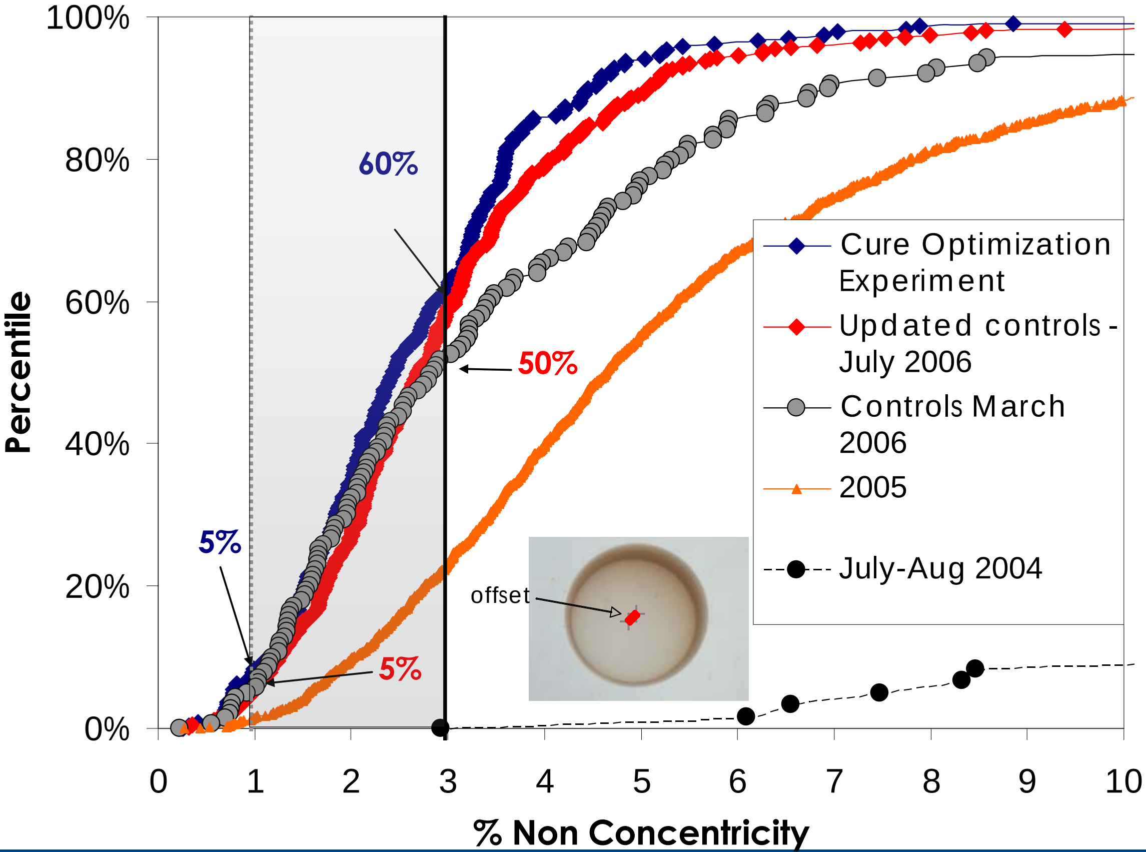
"Beyond the basics" on foam capsules

IFE-sized (~4 mm OD) divinybenzene (DVB) foam capsules



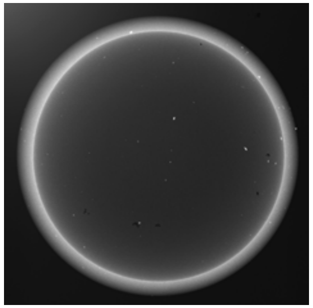
FTF-sized (~2.4 mm OD) DVB foam capsules

- ***Optimization of rotobeaker "curing" to improve Non-Concentricity (NC)***
- ***Yields of DVB foam capsules at 1 to 3% NC improved dramatically***

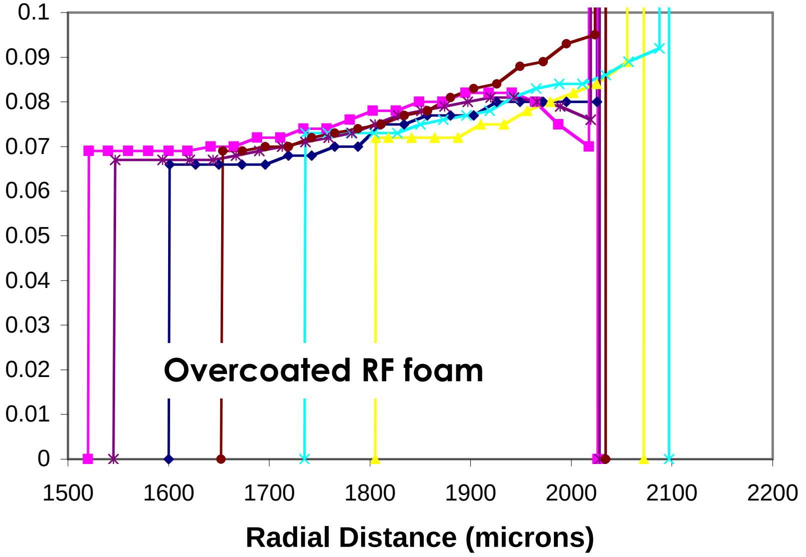


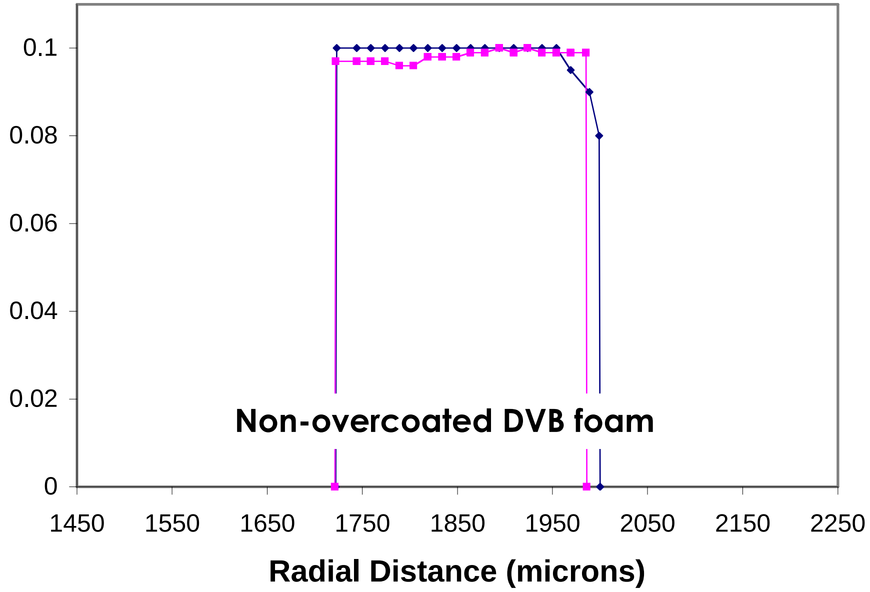
Foam capsules - characterization in detail

- ***Contact radiography for detailed foam shell characterization***

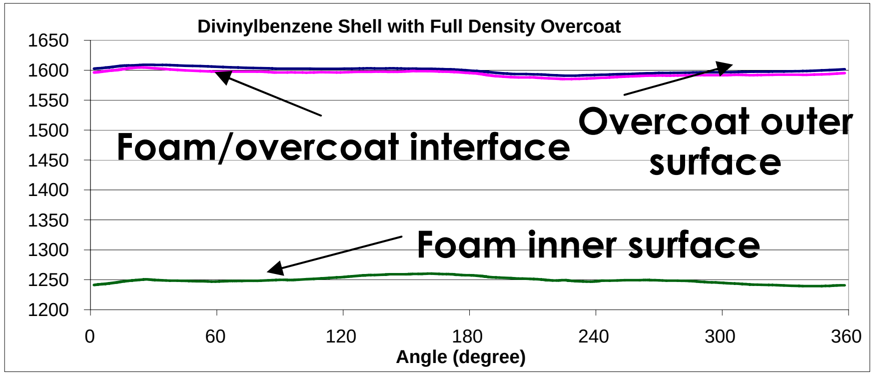


Density profile of the foam as function of radius





A view inside the foam shell - next step interface roughness power spectrum



Checklist of foam capsule progress

Attribute	Value	Tolerance	Meet?	Comments
Composition	DVB	(Low O/N)	Yes	DVB is original baseline foam
Diameter	4.6 mm	±0.2	Yes	Controlled by process flows Characterization: optical
Wall thickness	176 µm	±20	Yes	Controlled by process flows
Density	≤100 mg/cc	[25%]	Yes	Calculated, measured optically
Pore size	~1 µm	<3 µm	Yes	Qualitative by SEM - 1 to 3 µm
Out of round	<1 % of radius	--	Yes	Limited data, but never an issue
Non-concentricity	< 1-3% wall th.	--	Yes	Basic feasibility demo'd, yields 5 to 60%

So does this mean we're finished? (no…)

Overcoats for the foam capsules are a current focus!

Status - for polyvinyl phenol on DVB foam (original baseline, made by interfacial polycondensation)

Attribute	Value	Tolerance	Meet?	Comments
Composition	CH +	O/N OK	Yes	Polyvinyl phenol was "baseline", others possible
Thickness	1 µm	±1	No	Originally 1 µm, ~10 microns may be acceptable
Surface finish	<50 nm	--	No	
Permeability	Holds DT at cryo	--	No	Low yield of overcoats,shrinkage, implosion, "microcracks" common
Strength	For filling	--	Not yet shown	

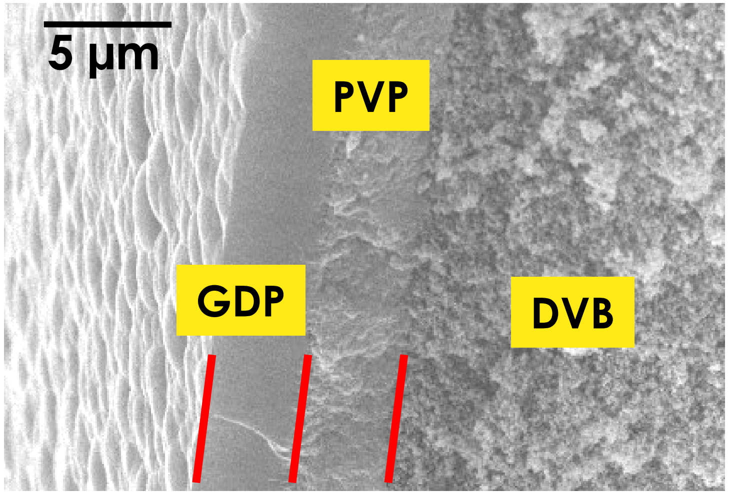
A major difficulty is overcoating (sealing) hi-aspect ratio shell at wet stage

Alternate approaches to the original, baseline method for overcoats have been evaluated

Evaluated two major approaches..

1. *Two-step process - fill DVB pores with PVP then GDP coat*
2. *Switch to smaller-pore foam like resorcinol formaldehyde (RF)*

PVP overcoated with GDP

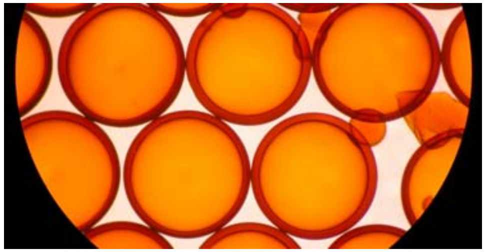


Cross section of coated DVB shell

Oxygen content of RF OK'd by designers

Successful at Omega size (~1 mm OD)

RF foam, with <0.1 µm pore size, directly overcoated with GDP

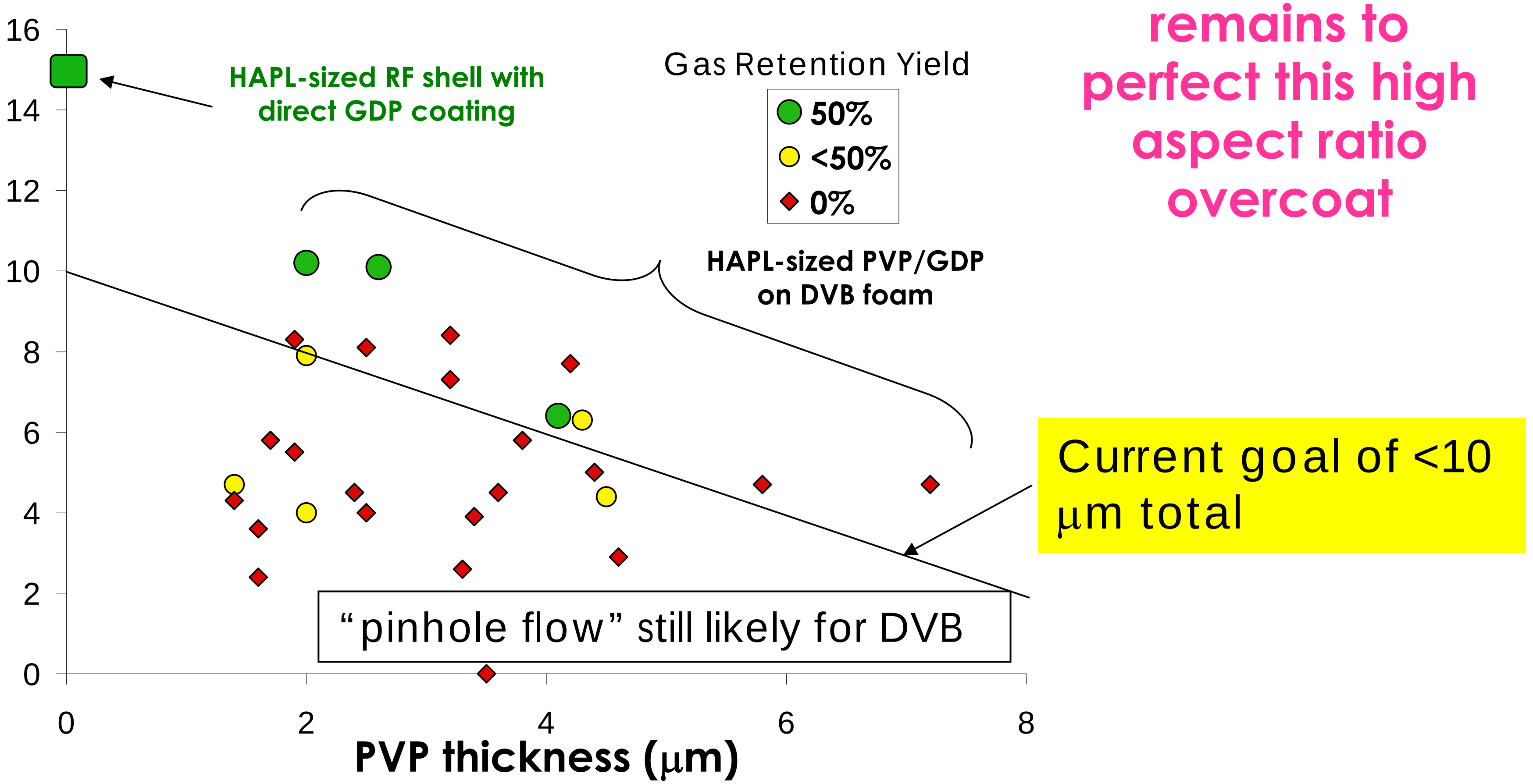


…the simpler approach turns out to be best

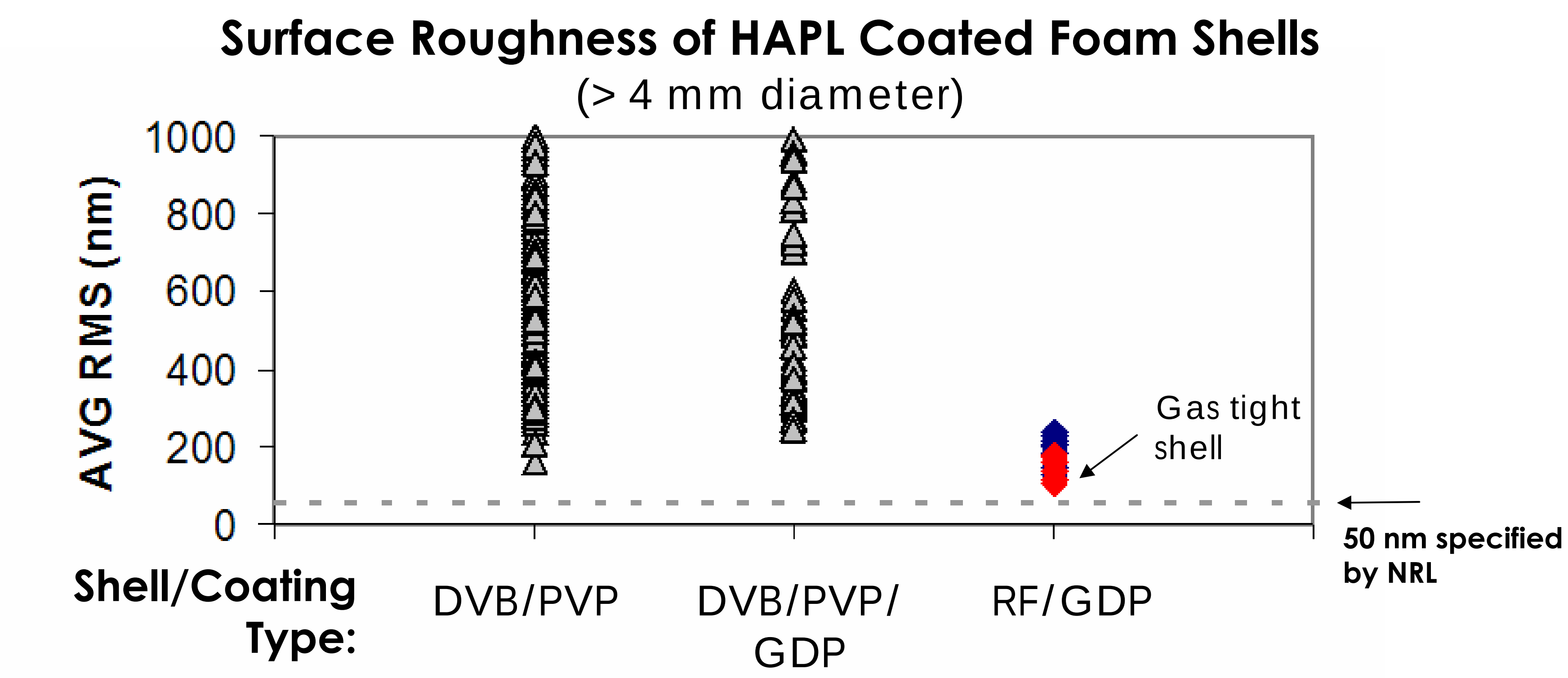
The first gastight HAPL-sized foam capsule - GDP on RF

- ***Half-life with deuterium testing confirms permeation flow - not "pinholes"***

Significant work remains to perfect this high aspect ratio overcoat



Coated RF foam shells are smoother than over-coated DVB shells



The recent gas tight RF/GDP shell is one of the smoothest so far

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

A cryogenic fluidized bed has been constructed to demo mass-production layering

- ***Static controlled***
- ***Scoping tests show good randomization***
- ***Initial cryostat cooldowns to ~ 11K with 0.5 atm He as fluidizer***
- ***Method to "grab" one shell for characterization has been done at cryogenic conditions (movie?)***

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Shells (empty) at 11 Kelvin

UCSD

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Target injection now has several acceleration options …

Previously demonstrated:

-Velocity ≥400 m/s, time jitter 0.5 ms, 2-piece sabot separation in vacuum
-Target placement accuracy of 10 mm at 17 meters standoff (1σ)

Gas-gun with 2-piece sabot to protect target

Magnetic diversion reduces gas in chamber, reduces heating, and allows slower injection

Range of options, including:

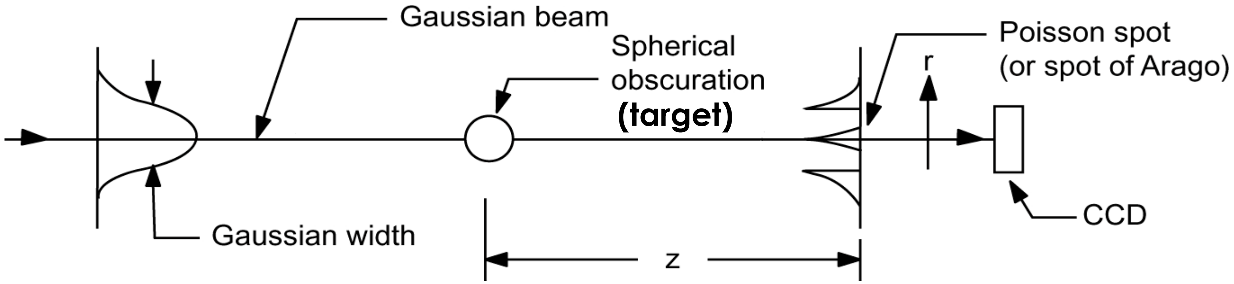
1. Gas-gun for >400 m/s
2. "EM Slingshot" concept for 50-100 m/s

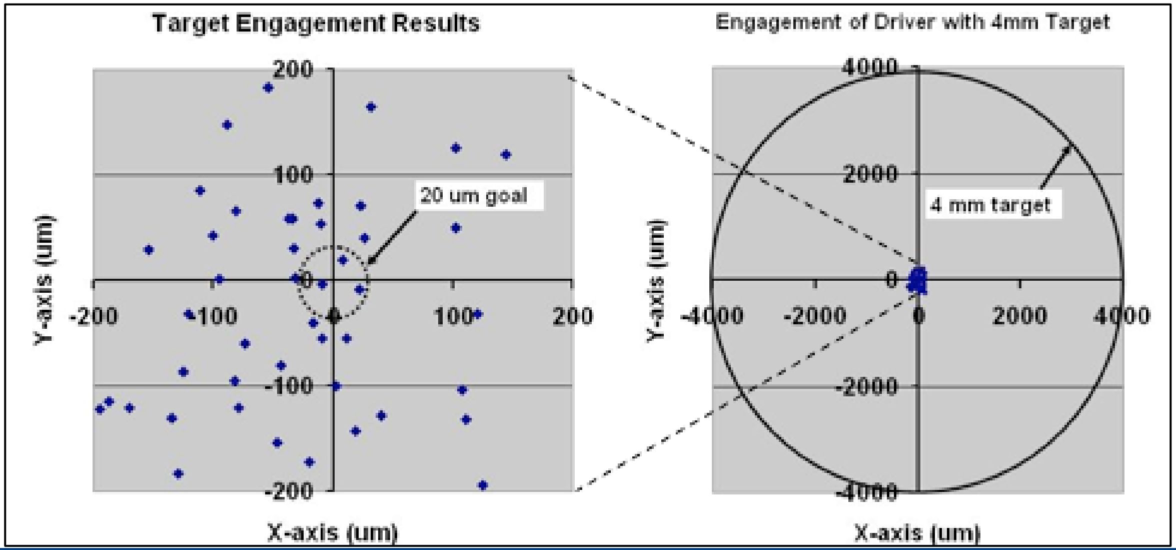
Improved accuracy demo'd at 50 m/s (without 2-piece sabot)
→4 mm at 17 m (1σ), **and done with ~1 mg (PαMS shells) projectiles**

Tracking - optical table demo of "hit-on-fly" engagement

- IFE requirement is alignment of lasers and target to 20 μm
- System using lasers, optics and fast steering mirror
- Also - "glint" from target ~1 ms before the shot aligns optical train (target itself is the reference point)

Fast steering mirror for demo (commercial)





- Scaled experiment, velocity ~ 5 m/s
- Accuracy of hitting "on-the-fly" is ~125 microns now (1σ)
- Working toward 20 micron goal for demo

UCSD

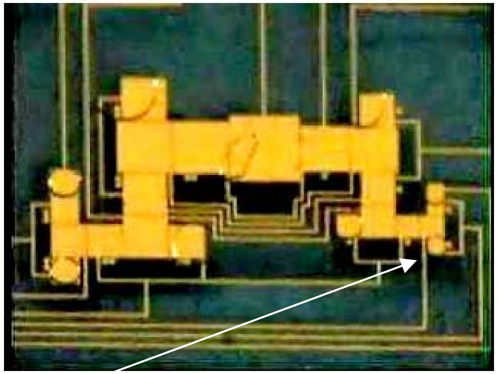
Also evaluating "advanced" techniques for capsule fabrication

Collaboration with UR and UCLA to evaluate new "microfluidic" methods of manipulating capsules

- "Micro-fluidics" can manipulate small quantities -> e.g., "lab on a chip" chemical reactors….
- Dielectrophoresis (DEP) - difference in electrical properties of inner/outer droplet to control capsule geometry with DEP

QuickTime™ and a
Video decompressor
are needed to see this picture.

Micro-siphon, 100 micron passages, Tom Jones, UR



750 pl droplet formation device, Robin Garrell, UCLA

- A collaboration has been formed between UCLA, Univ. of Rochester, and GA (UC Discovery Grant)
  - → Implement E field manipulation in existing GA droplet generation process for higher yield concentricity

Summary/Conclusions

1. Moving "beyond the basics" in demonstrating laser fusion target supply
    - Mass-production identified for each step
    - Demo programs underway with good progress
    - Advanced methods being evaluated

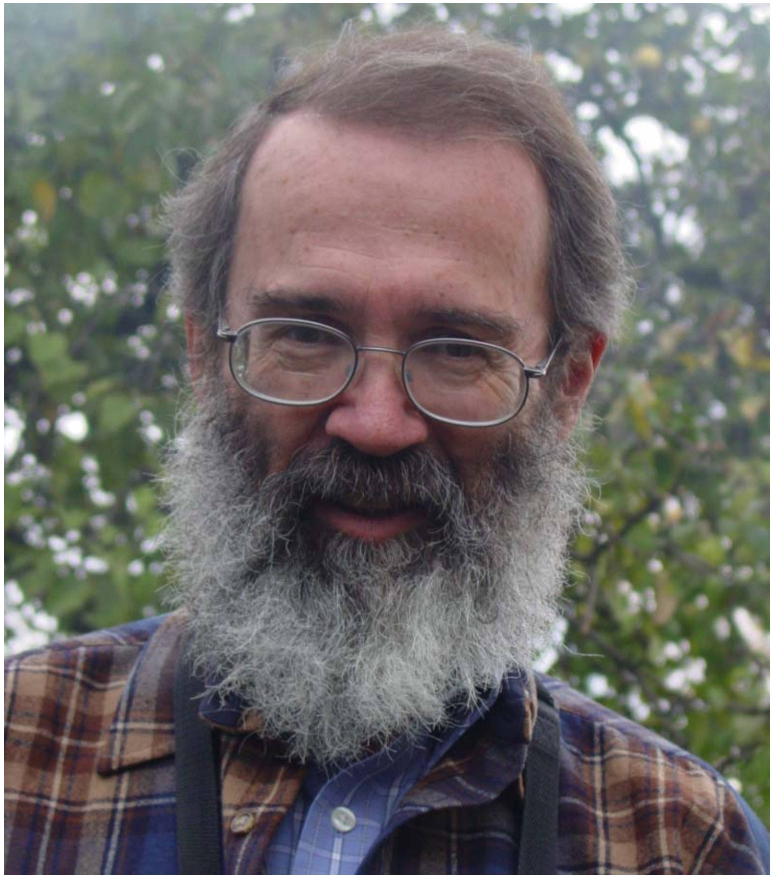
2. Basic foam capsules can be made
    - Focus now on yield curves and detailed specifications

3. Working to get gastight, smooth overcoats - first one made

4. Mass production demo for layering now undergoing cold checkouts

5. A range of target injection methodologies available

6. Tracking and engagement table-top demo is closing in on our goal of 20 micron alignment in a scaled experiment



R.C. Cook