Progress in Cradle-to-grave Direct Drive Target Supply Scenarios

C. Adams, N. Alexander, W. Baugh, G. Besenbruch, L. Brown, T. Drake, D. Goodin, A. Greenwood, M. Hollins, B. McQuillan, E. Merriweather, A. Nikroo, A. Nobile, C. Shearer, R. Stemke

Presented by Dan Goodin

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Naval Research Laboratory
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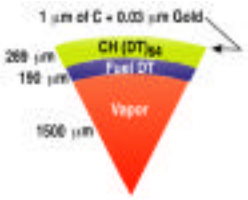
GENERAL ATOMICS

Overview of potential cradle-to-grave scenarios being investigated or considered

Target Design



Rad. Preheat (I)

Empty Outer Foam (II)

Thick Capsule (III)

Target Fabrication → **Filling** → **Layering** → **Injection**

Foam shell by microencapsulation
Seal coat by interfacial polycondensation
Gold coat by sputter-coating
Characterization (Elsner)

Foam shells by microencapsulation; seal coat by interfacial polycondensation (Schafer); High-Z by sputter-coating; Characterization (Elsner)

Foam shells by microencapsulation; seal coat by interfacial polycondensation?

Foam shell by microencapsulation
Seal coat by interfacial polycondensation
Or
Injection molding around GDP mandrel

Or

Injection molding around mandrel?

Foam shell by microencapsulation
Or
Coatings by GDP or spray-dry in a fluidized bed

Or

Coatings by GDP or spray-dry in a fluidized bed

Permeation

Permeation (liquid injection?)

Permeation or liquid injection

Cryogenic fluidized bed
Or
In-Sabot

Cryogenic fluidized bed or in-sabot

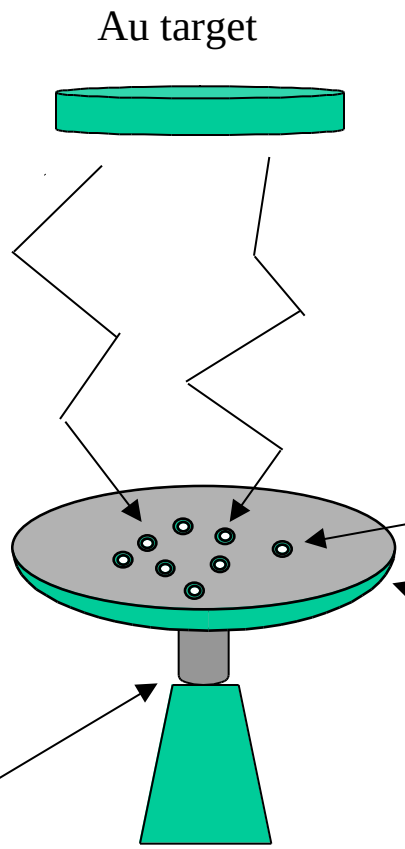
Gas-gun
Or
Electromagnetic (Petzoldt)

Gas gun or electromagnetic (Petzoldt)

GENERAL ATOMICS

PAMS shells have been gold coated in a sputter-coater for permeation measurements

- Issues involved:
  - Au deposition on shells
  - Thickness measurements
  - Permeability measurements

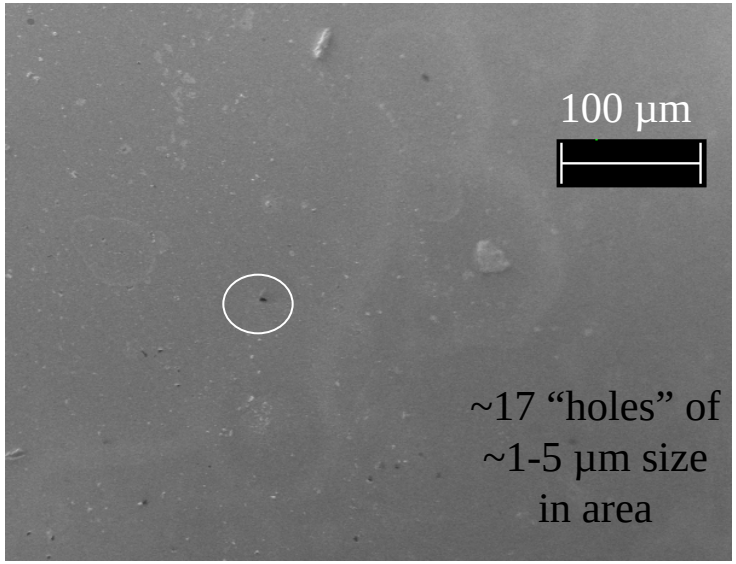


- Knobs:
  - Pressure
  - Power
  - Source-to-substrate distance
  - Bouncing

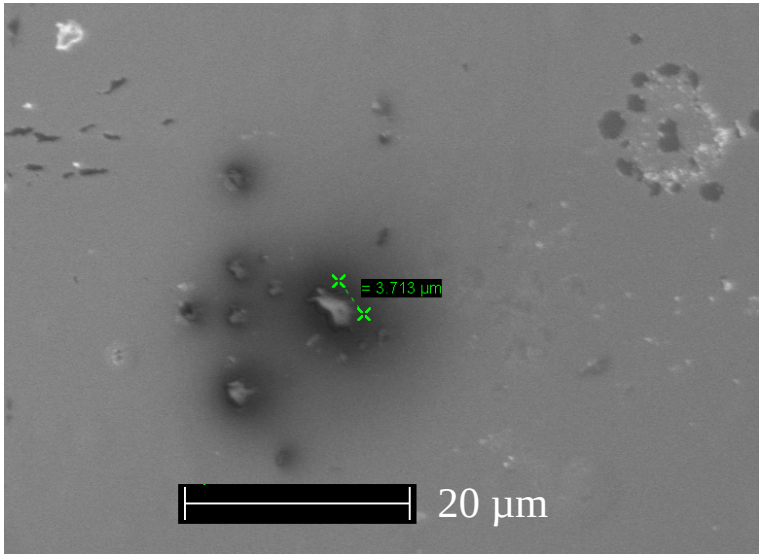
.... Success so far is being able to coat spherical shells and to permeate gasses through them

GENERAL ATOMICS

Varying degree of defects are observed in first coatings - probably from shell to shell collisions

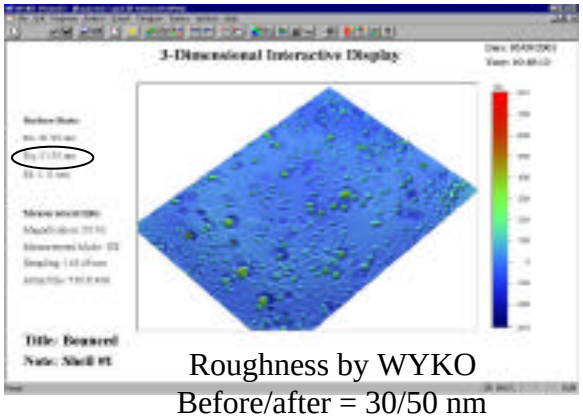


SEM image of Au coated polymer shell Debris a problem at this point?

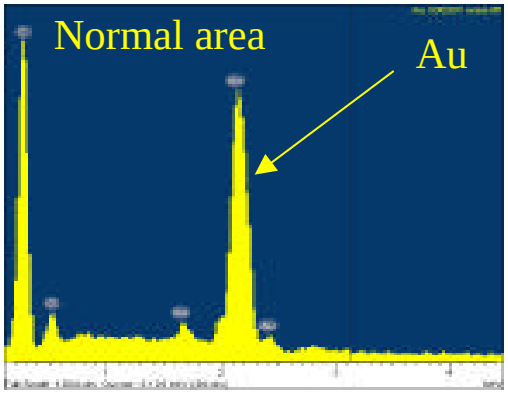


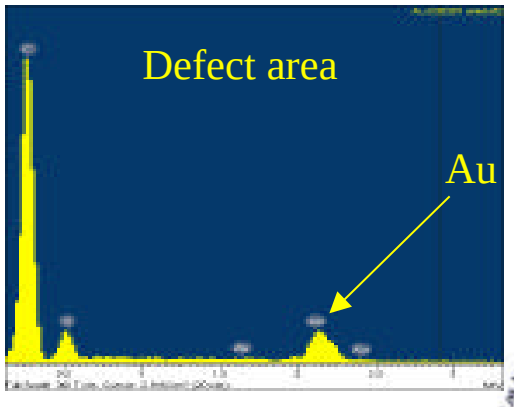
250Å, Permeability ~0.1x that of mandrel

200Å, Permeability ~0.2x that of mandrel



Roughness by WYKO
Before/after = 30/50 nm

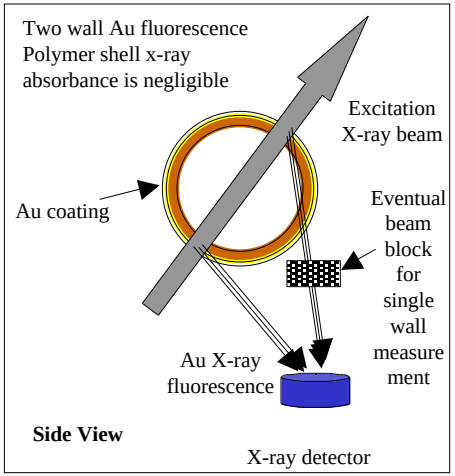


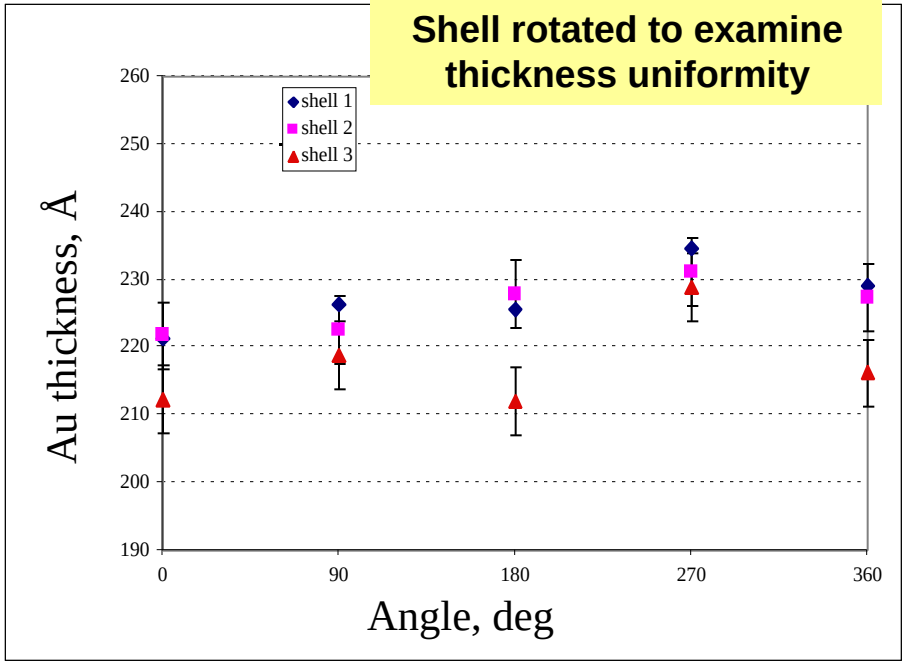


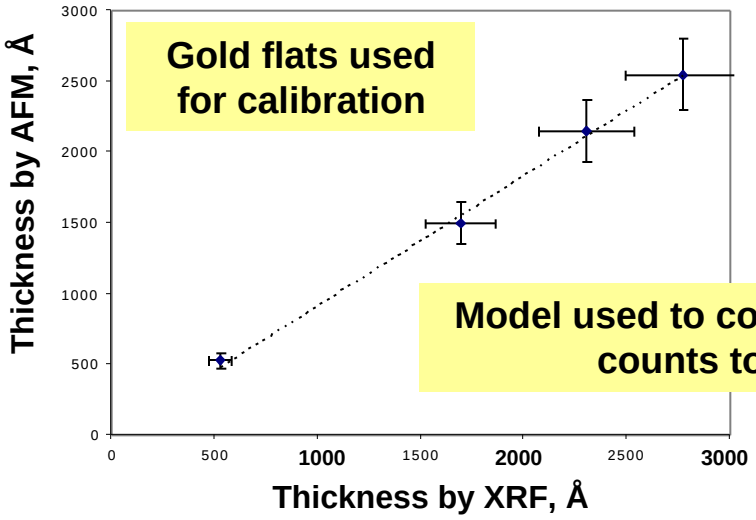
GENERAL ATOMICS

.... EDX shows reduced gold within the defects

X-ray fluorescence was used to determine gold coating thickness







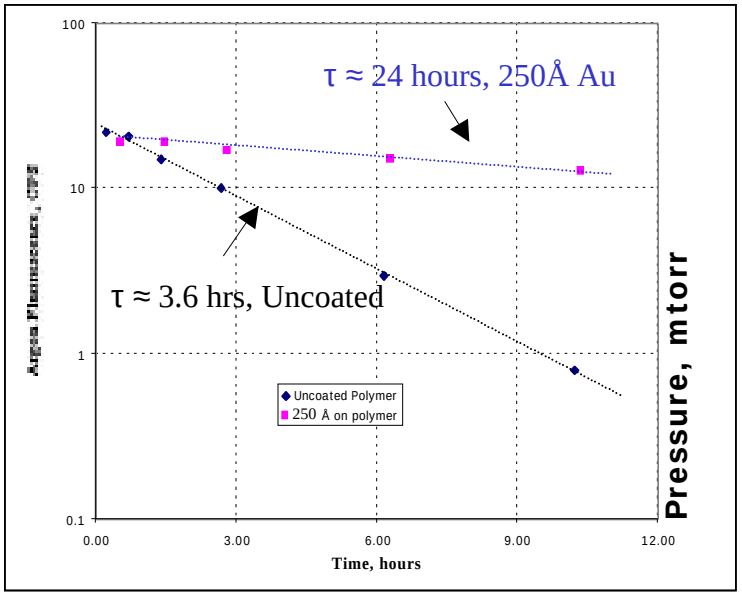
…. Initial thickness uniformity was 4-7%

Model used to convert fluorescence counts to thickness

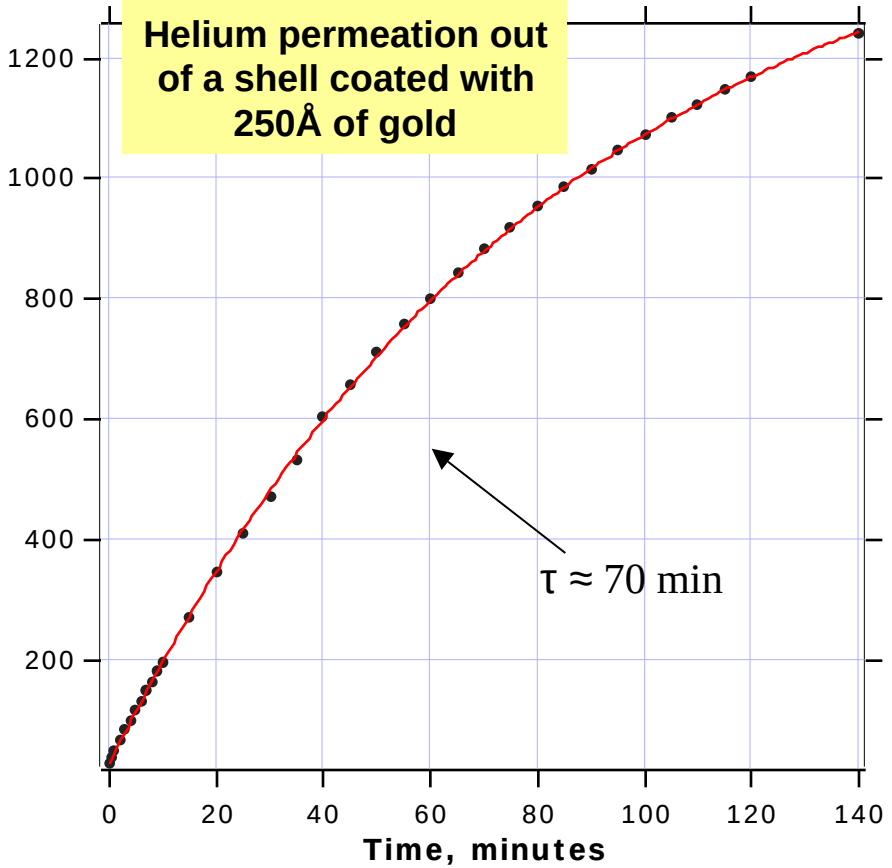
…. XRF gave accurate measure of thickness on flats

GENERAL ATOMICS

Initial samples show about 10x longer to fill with gold coating applied



Argon could be permeated through the gold-coated shell at room temperature



For the uncoated shell measured τ ≈ 8 min

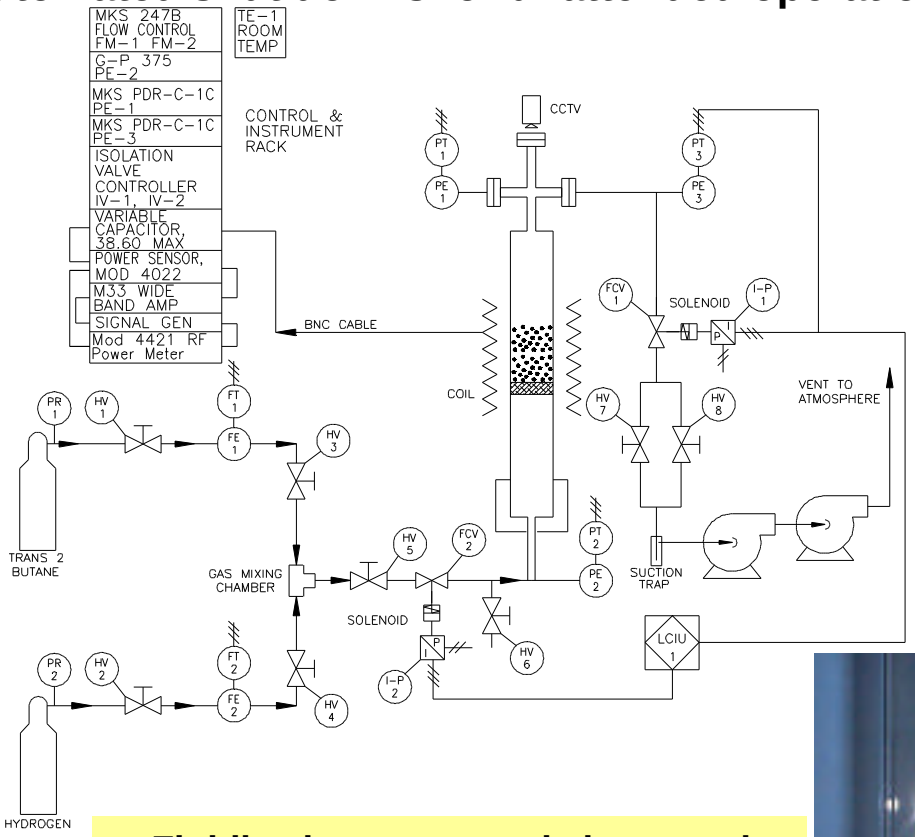
Large area defects are likely not responsible for all of permeation as their estimated area < 300th of shell area.

GENERAL ATOMICS

.... Next: measure HD, vary conditions

Fluidized bed is ready for GDP parametric studies

- **Dedicated setup now in place for mass-production parametric studies**
- **Automated shut downs for unattended operation**



Test rig for studies

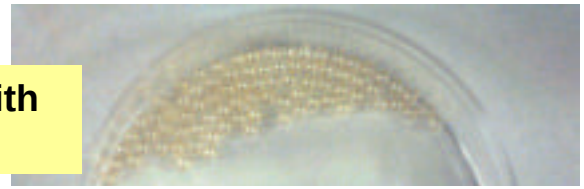
Fluidization was greatly improved with frit instead of cone

Reproducibility runs good so far...

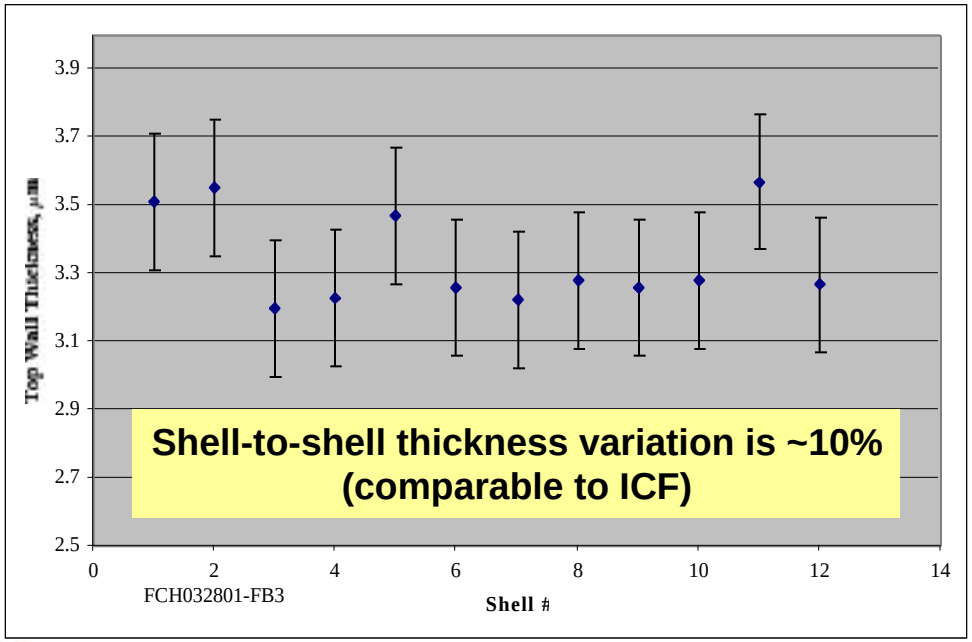
GENERAL ATOMICS

Multiple GDP coating runs have shown reproducible thickness and coating rates

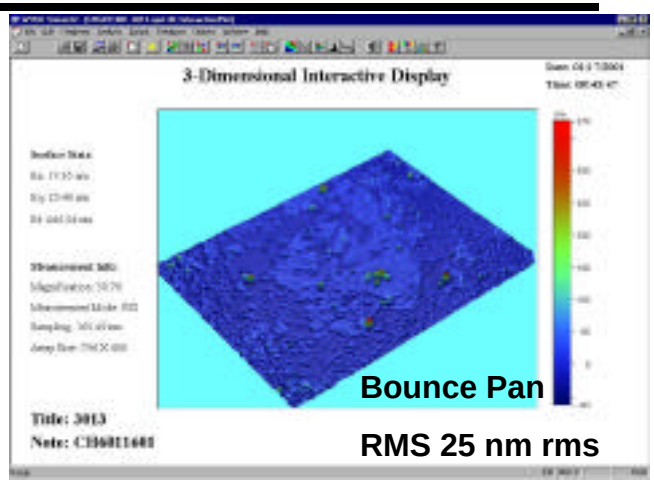
- 5 runs at nominal conditions gave consistent results
- Further runs will investigate effect of gas flow and RF power

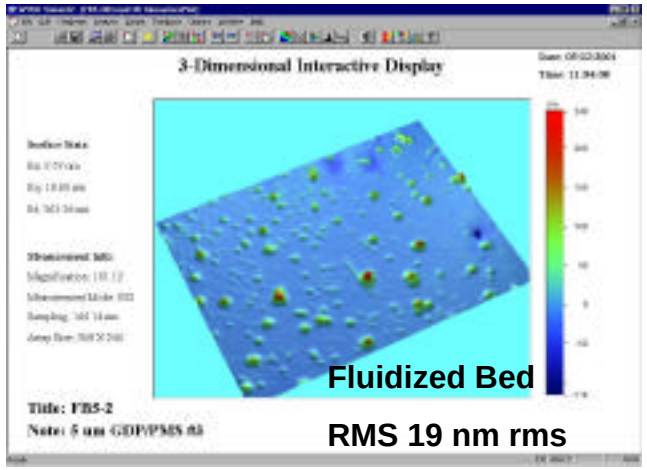


Shells coated with ~3 μm of GDP



Shell-to-shell thickness variation is ~10% (comparable to ICF)



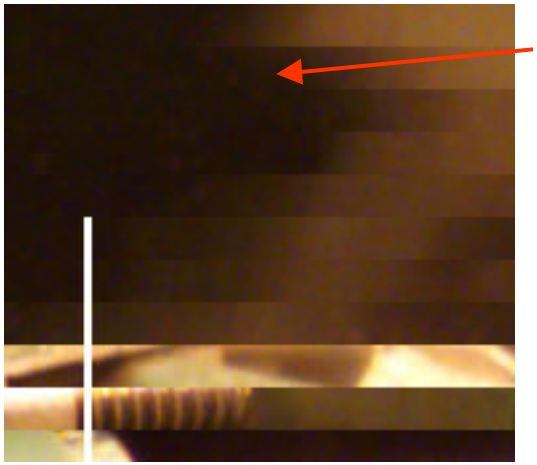


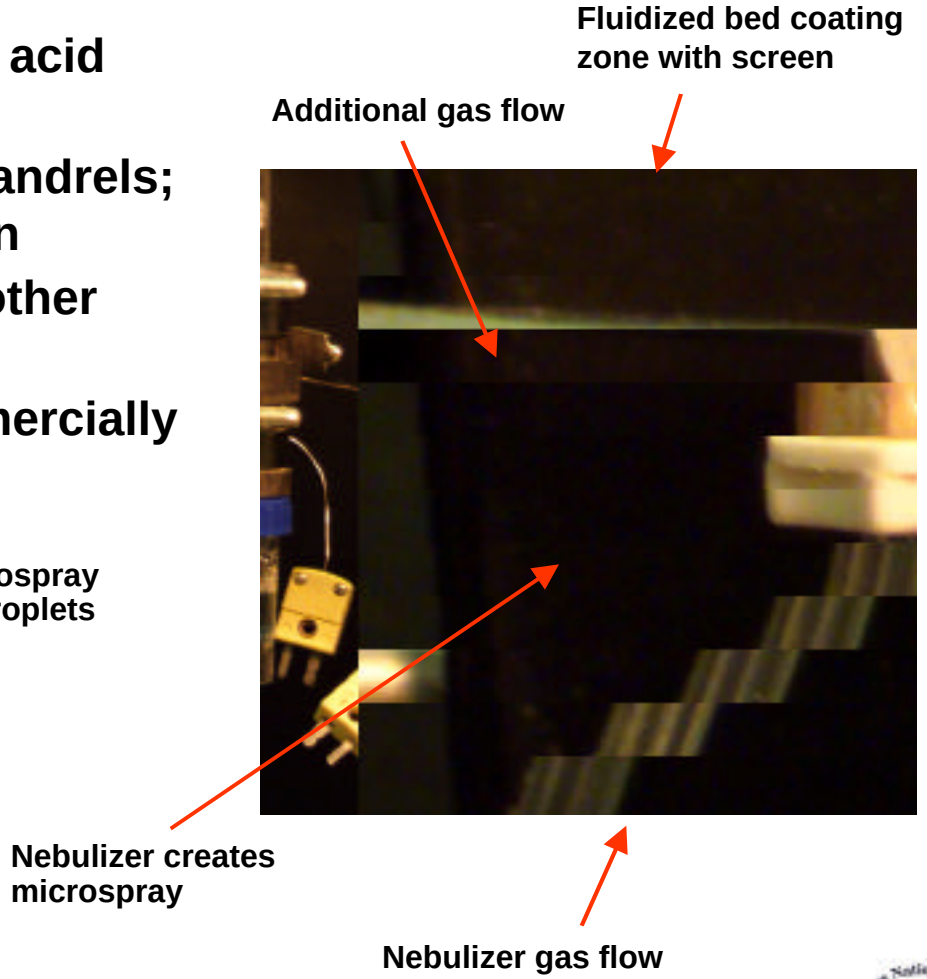
.... On comparable mandrels, the coating roughness is comparable

GENERAL ATOMICS

An alternative mass-production coating method is solution spray-drying in a fluidized bed

- Initial coatings with 7% polyamic acid (polyimide precursor) in DMSO
- Approx. 2 mm diameter PAMS mandrels; 100 capsules coated in 8 hour run
- Other solutions possible - PVA, other polyimide precursors, etc.
- Process uses inexpensive, commercially available components

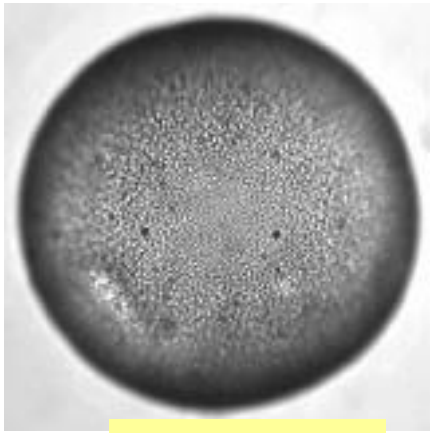




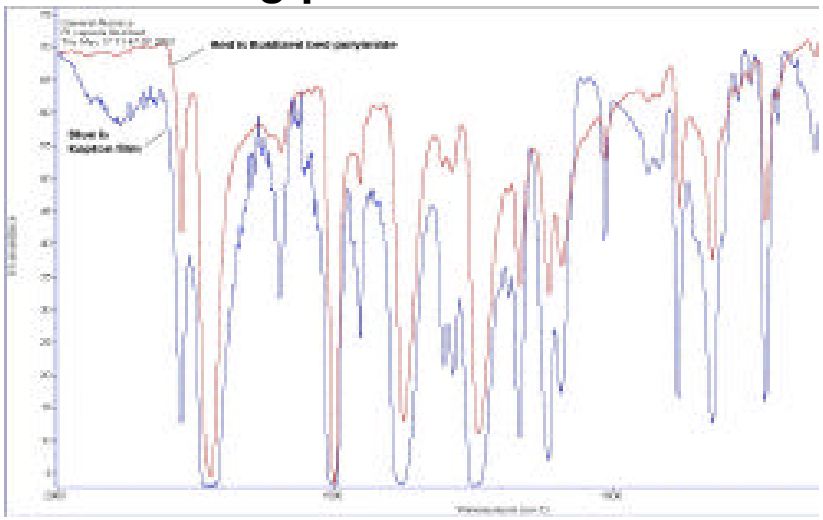
GENERAL ATOMICS

Solution spray-drying results are encouraging

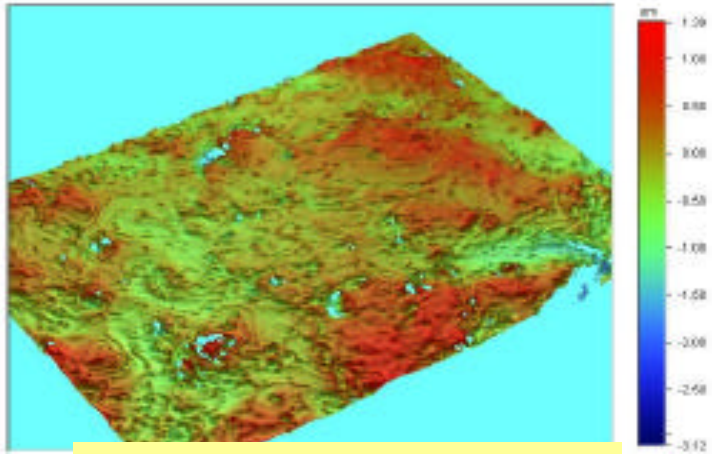
- Were able to demonstrate polyamic acid coatings in a fluidized bed in just a few weeks of effort
- Imidized at 300°C with std. process; removed PAMS
- Wall thickness ~1.5 microns; fully imidized by FTIR
- Surface finish is rough; working on vapor smoothing process in the bed



2 mm PI capsule



FTIR spectra of PI capsule (red) matches Kapton HN film spectra (blue)



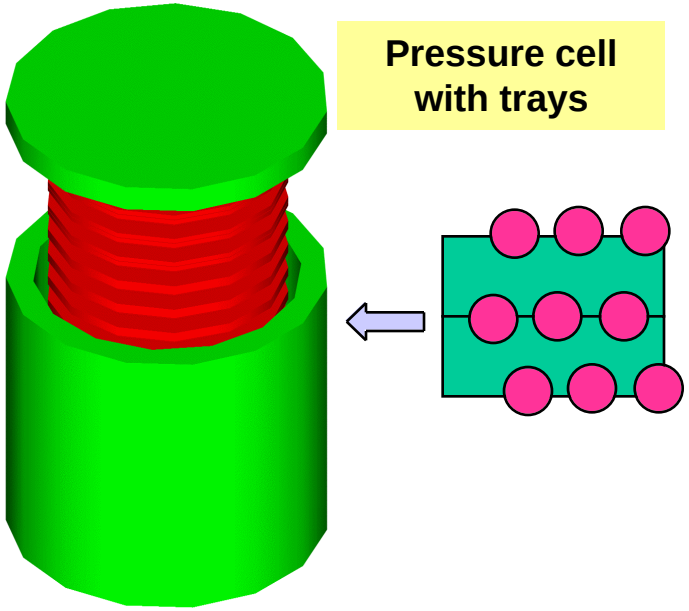
WYCO image of PI capsule surface

GENERAL ATOMICS

.... If successful, other potential applications possible

Permeation filling - evaluation of equipment sizing

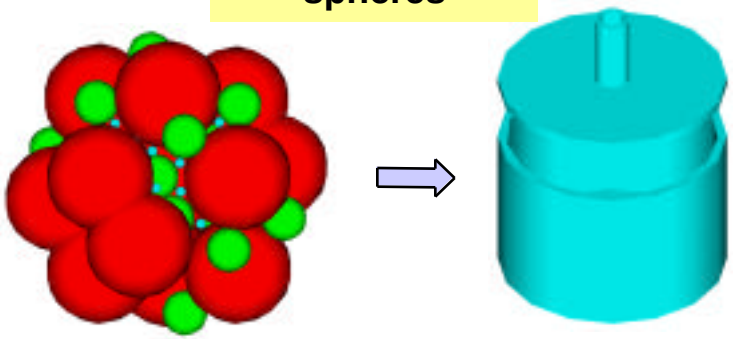
- Cells sized for 288,000 targets per cell (for 8 hours of operation at 10 Hz)
  - Sizes are quite reasonable; number required depends on fill time
- Void reduction to reduce tritium inventory
- Trays can be unloaded by pouring into funnel to layering bed
- Microspheres must be sieved out before proceeding to layering bed



Pressure cell with trays

36” I.D. X 40” Tall, 8 trays

Pressure cell with 3 sizes of spheres



11.81” I.D. x 7.87” Tall

GENERAL ATOMICS

…. Microspheres result in much smaller cell sizes, but sieving may be an issue

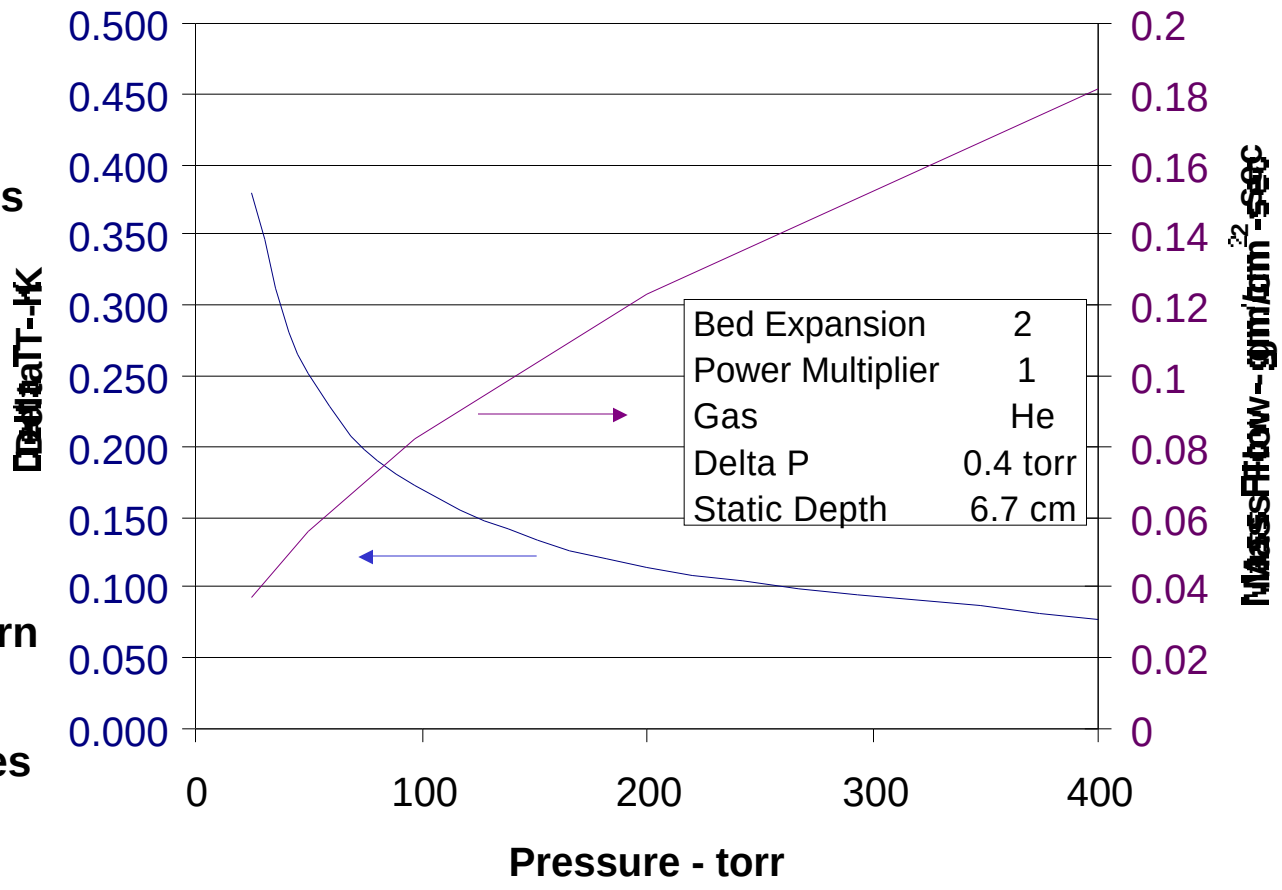
Evaluation of cryogenic fluidized bed layering is ongoing with Schafer/GA/LANL personnel

- Coordination meeting at Schafer April 6, 2001
  - GA, LANL, Schafer - preliminary process selections
  - Agreed to avoid precise temperature ramping (as for NIF) for batches
  - Goal for layering time of 15 minutes with 10-30X energy input
  - Basic fluidized bed requirements outlined, including:
    - Temperature uniformity around shell: ± 25μK
    - Temperature control on incoming gas: ± 10mK
    - Bed gradient control: To be evaluated
    - Maximum hold time after layering: 24 hours
    - Maximum time after filling before shot: 5 days
- Agreed to evaluate options such as HD or DD as fluidizing medium
- Potential issue of helium diffusion through shells identified (excess He affecting gain)

GENERAL ATOMICS

It is extremely difficult to remove the heat from the targets in a “simple” fluidized bed concept

- Light targets require little fluidizing gas
- Pressure limited to avoid crushing thin-walled shells
- Much higher pressures possible for thick-walled shells
- Higher gas flows cool better but expand the bed and make it violent
- Cracking/erosion a concern at high expansion factors
- Augmented layering makes it much worse
- Creative solutions will be needed

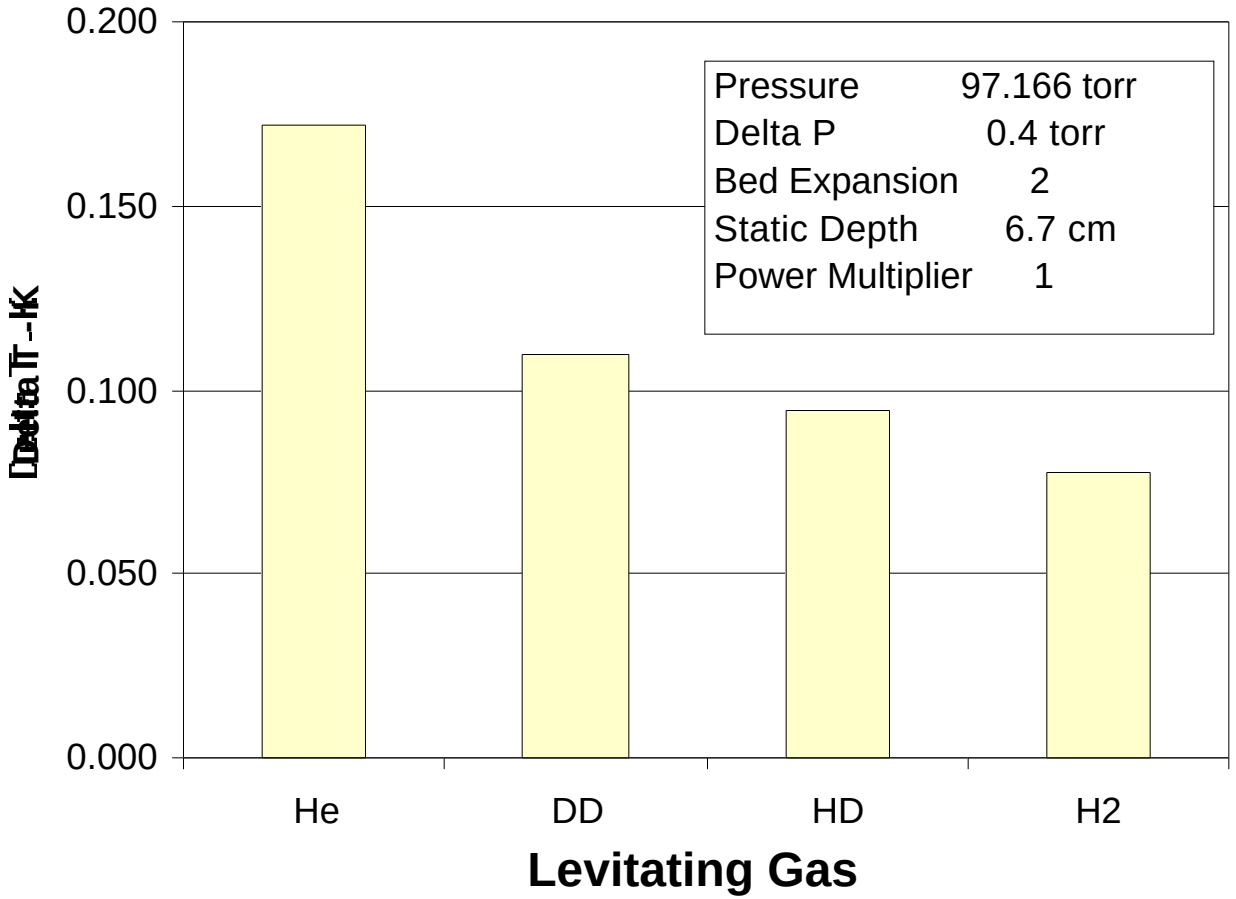


.... A number of options are being evaluated

GENERAL ATOMICS

Use of hydrogen isotopes reduces the bed ΔT somewhat - but doesn't solve the issue

Pressure for hydrogens are limited to their vapor pressure at the coldest point in the system



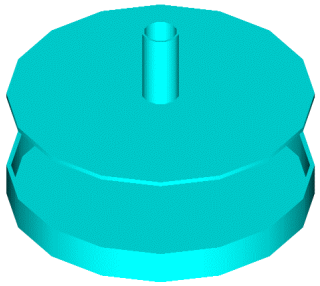
.... More creative options are needed!

GENERAL ATOMICS

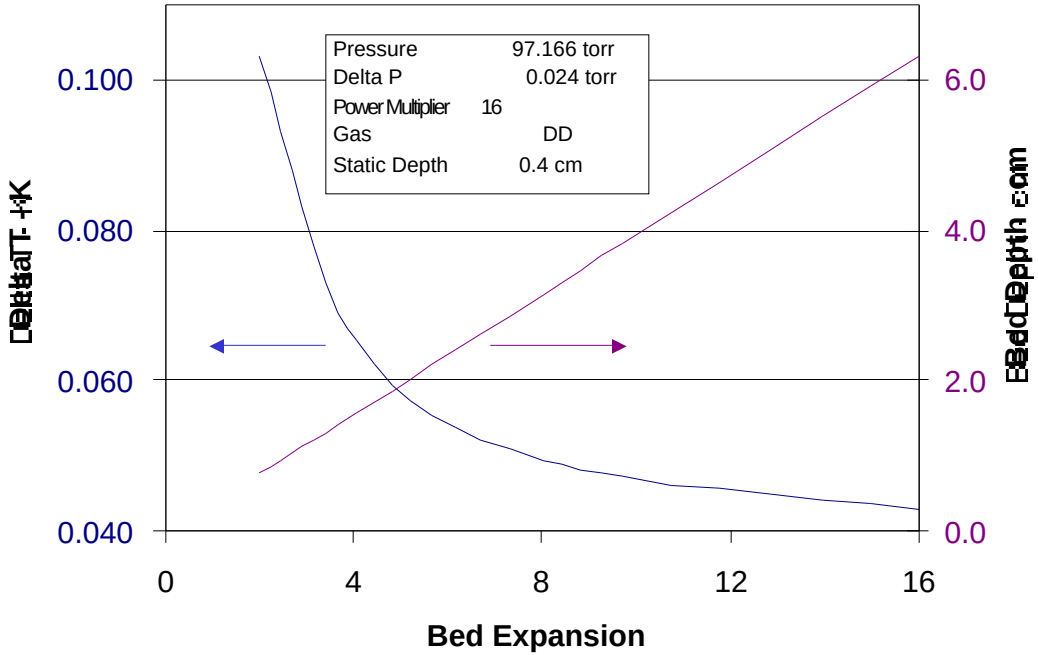
There are a number of potential solutions

- **Live with "large" ΔT – it may even be good**
  - **Rapid temperature cycling produces a constant average wall temperature**
  - **Temperature cycling tends to dissolve smaller crystallites and may lead to single crystal growth**
- **Shallow beds aren't really that large (~40 cm) if the layering time is short**

SHALLOW WIDE BED

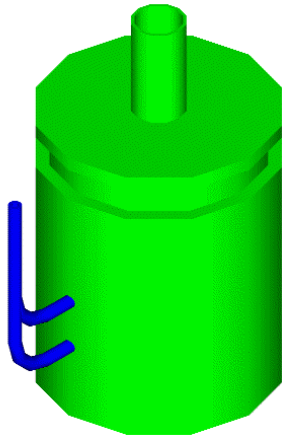


15.75" I.D. for a 15 minute target supply

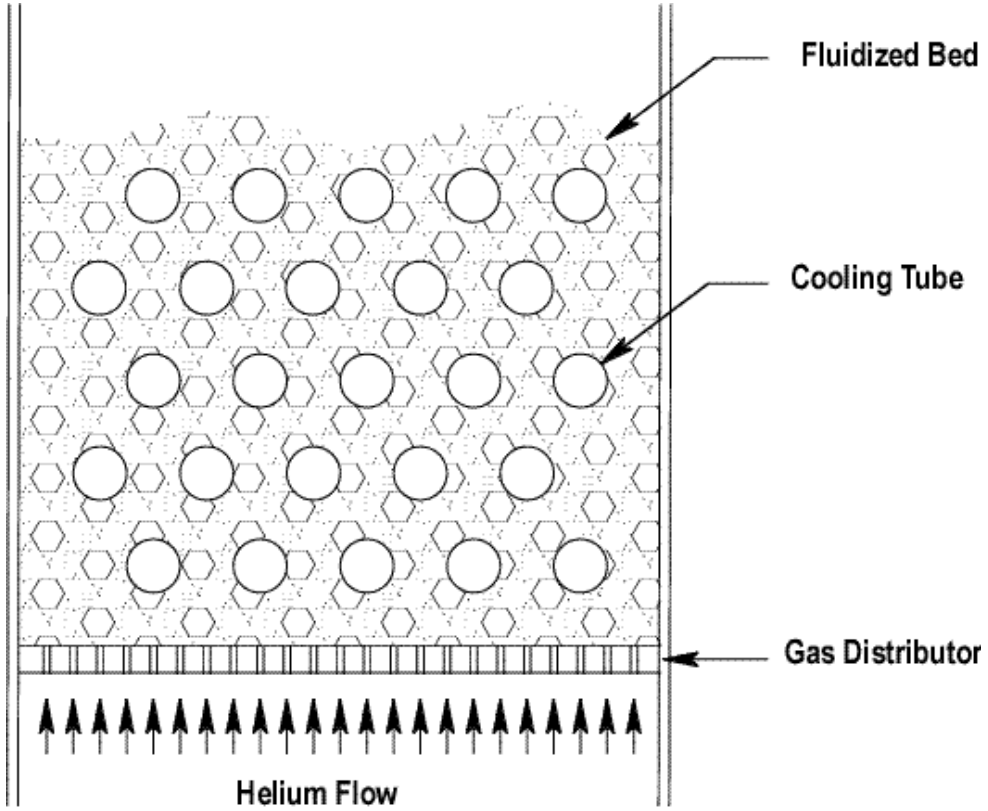


.... May be to be too violent for outer foam targets or thin walls (?)

Introduce cooling tubes into a deep bed - effectively make a stack of monolayers



7.87” I.D. x 8.66” tall for a 15 minute target supply



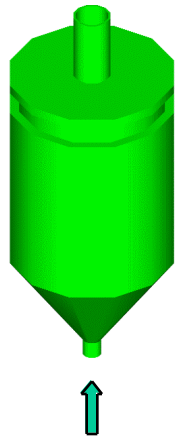
Concern over collisions with stationary tubes making cracking worse

.... Backup to monolayer

GENERAL ATOMICS

Other “advanced” solutions to be considered

- Add HD or H_2 mist to the fluidizing gas
- Add D_2 snowballs to bed
  - Sublimating solid D_2 in bed will maintain constant, thermodynamically defined temperature (18.2K at 97.166 torr)
- Use “rotary kiln” geometry to give continuous delivery of layered targets
  - Add D_2 snow with targets at entrance to “kiln” such that it is all gone at the exit



INJECT HYDROGEN MIST INTO FLUIDZING GAS

.... Evaluations are continuing, meanwhile a demonstration of fluidized bed layering with room temperature surrogates is being pursued

GENERAL ATOMICS

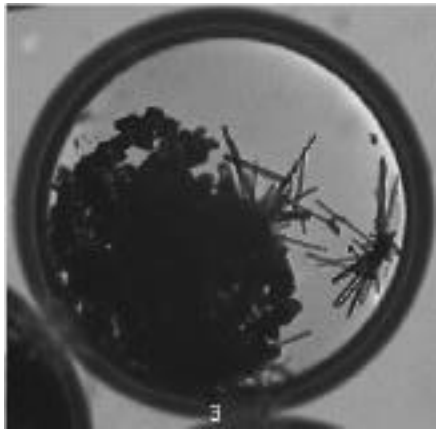
Demonstrate mass layering with a room temperature surrogate - instead of hydrogen

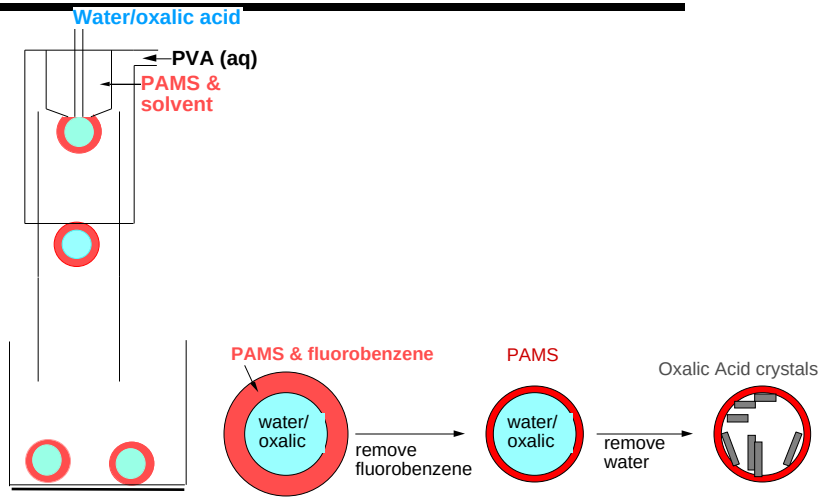
- Basic concept = use a more convenient surrogate to demonstrate fluidized bed layering and evaluate operating parameters
- Allows use of room temperature characterization equipment
- Two methods to introduce material into shells
  - Micro-encapsulate with surrogate dissolved in solution as shells are formed
    - quick
    - amount of surrogate limited by solubility
    - limited chemical compatibility with process
  - Diffusion fill pre-made capsules
    - better surrogate choices
- Oxalic acid used for micro-encapsulation
- Neopentyl alcohol chosen for diffusion (2,2 Dimethyl 1, propanol)

.... Goal is to determine if methods are promising enough to commit to a cryogenic system using hydrogen isotopes

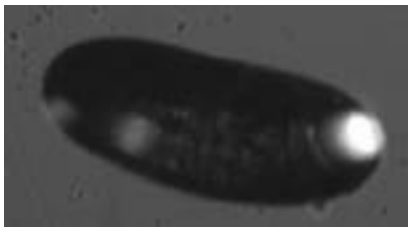
GENERAL ATOMICS

Initial surrogates produced via microencapsulation

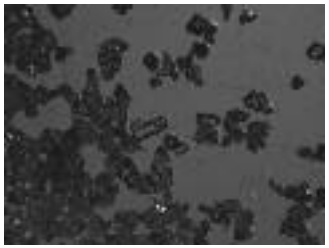




- **PAMS shells containing oxalic acid**
- **Oxalic acid dissolved into inner water droplet stream for capsule production**
- **Capsules have OD of 1030μm and wall of 19μm, oxalic acid in shell equivalent of 13μm layer**
- **Diffusion of Neopentyl alcohol into larger GDP shells next**



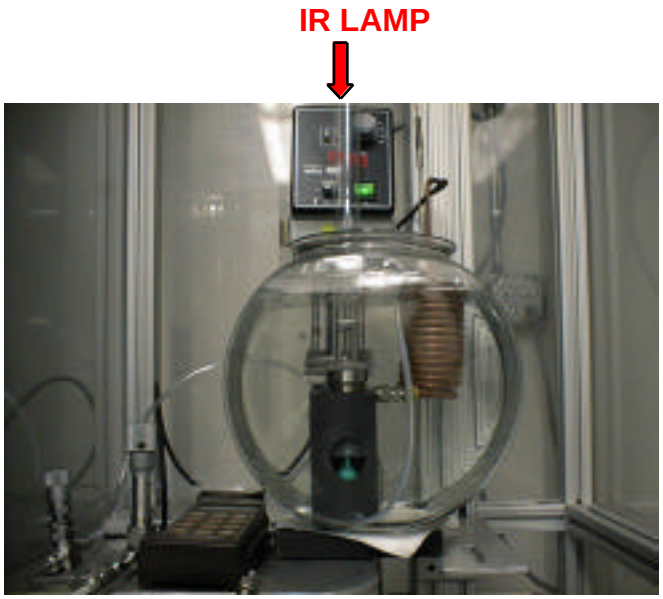
Neopentyl Alcohol

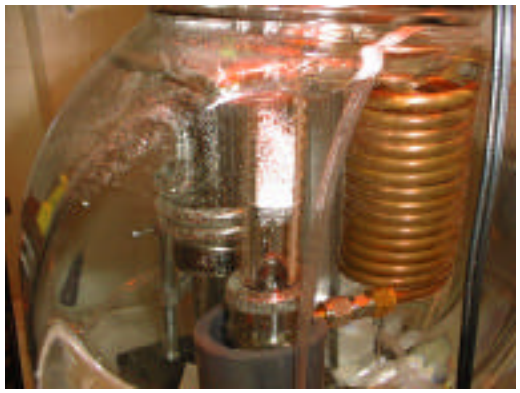


Oxalic Acid

GENERAL ATOMICS

Fluidized bed capsules want to clump together from electrostatic attraction



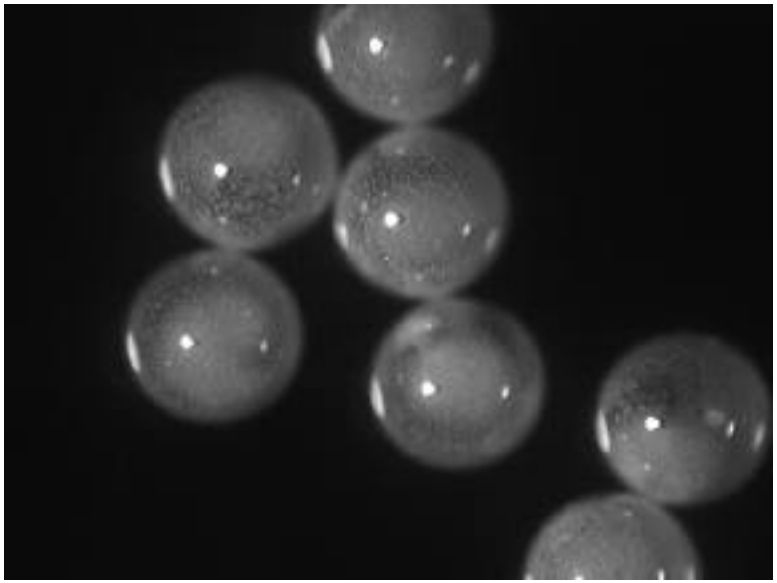


- Clumping solved with nebulizer introducing DMSO mist into the fluidizing flow stream
  - -Not cryo-compatible
  - -Bigger, fuller, heavier capsules may clump less
- Fluidization of capsule bed achieved
- Layering experiments just started

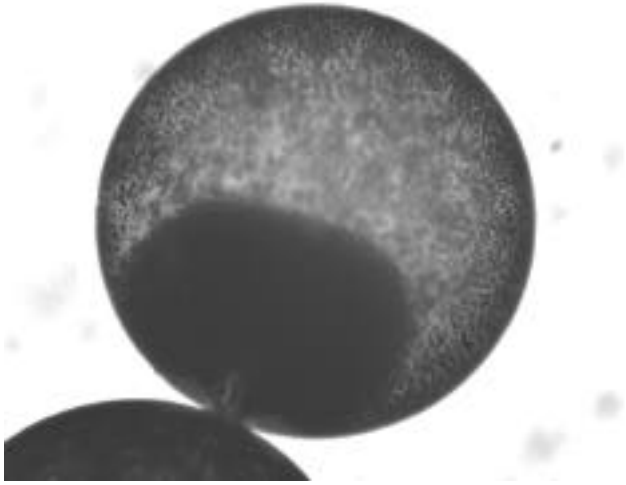
GENERAL ATOMICS

Fluidized bed mass layering is starting to show hints of success

- 2.5 hrs, 45°C, Low IR
- More than 50% had acid coverage over entire inner surface
- ~100% showed some acid movement
- Bed held ~2000 capsules, 3 broke in ~6 hrs in 3 retrievals from bed



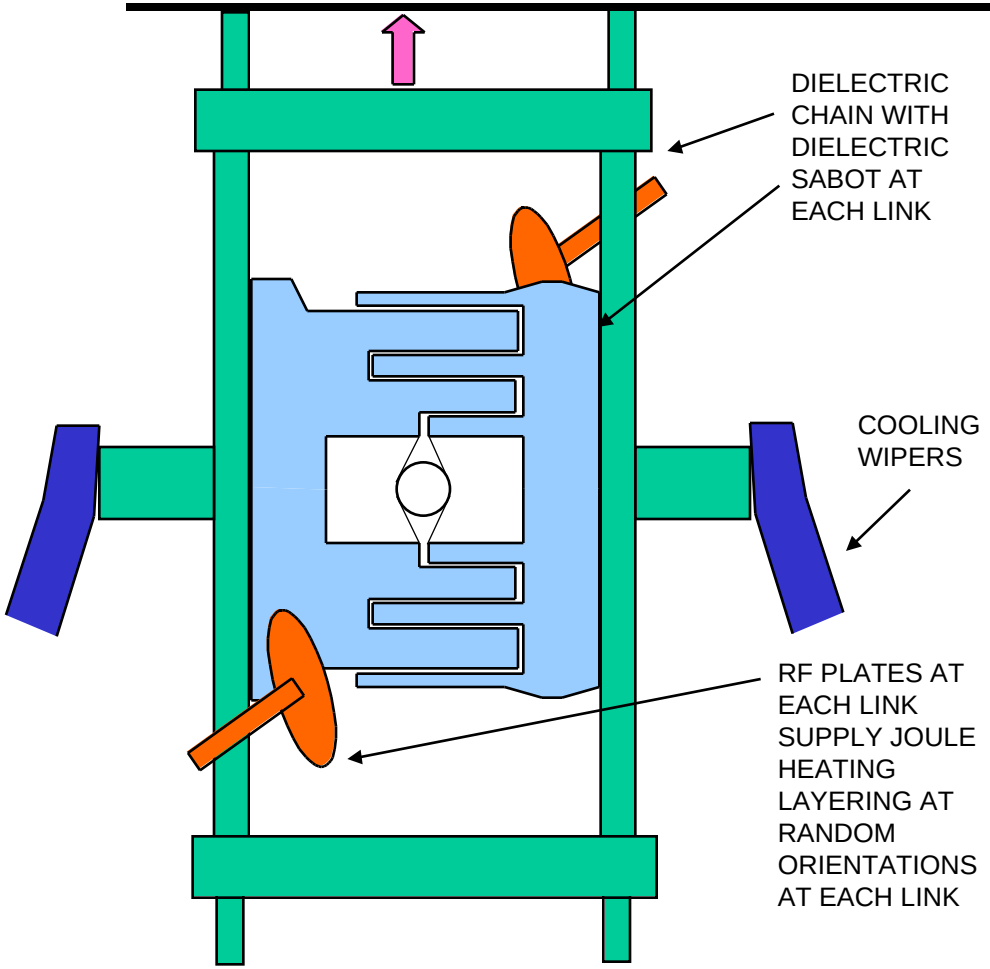
Top-lit view

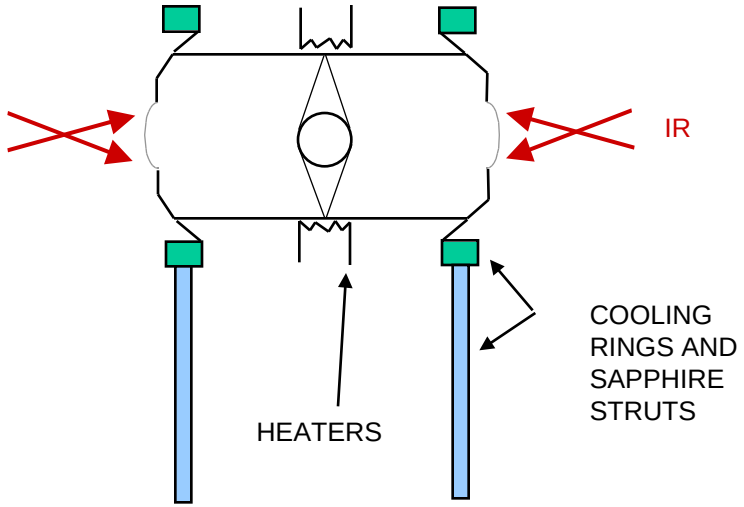


Back-lit view

GENERAL ATOMICS

Layering a capsule in a sabot is akin to layering a capsule in a hohlraum

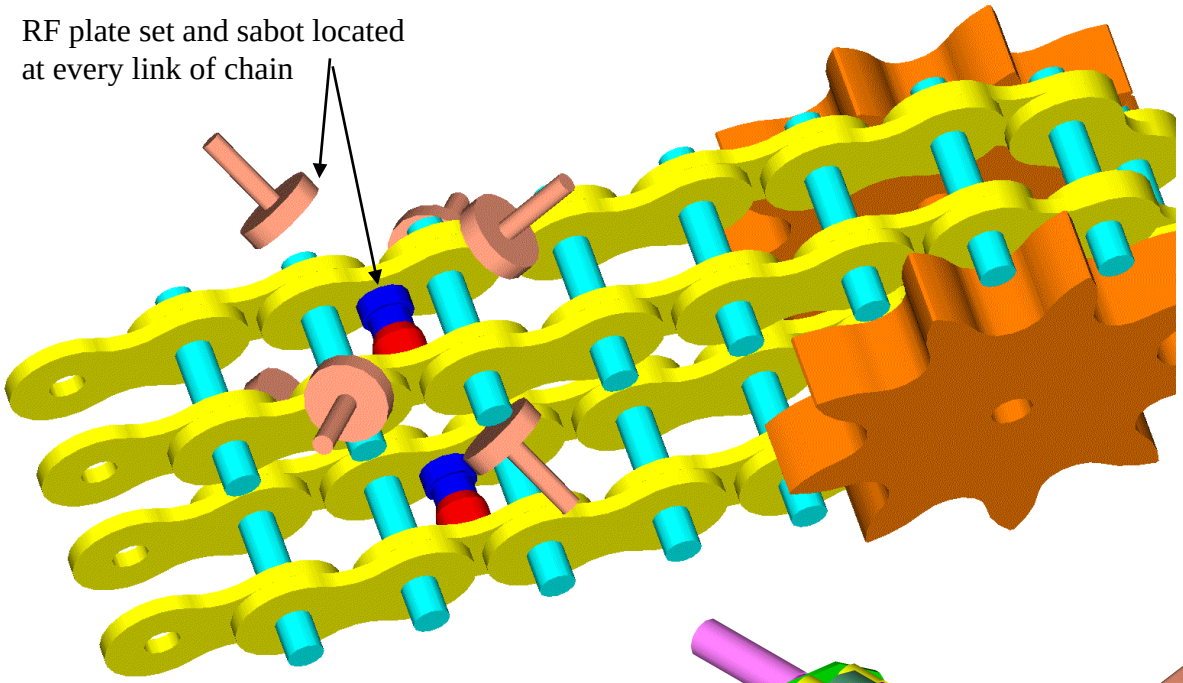




- **For hohlraum, ends cooled and constant thickness walls heated at waist by IR or heaters**
- **For sabot, chain cools ends and waist made hotter by tailored thermal conductance (thinner at waist)**
- **For 5 cm links, 5 Hz shot rate and 15 min layering time need 225 m of chain**
- **Chain may be serpentined into smaller volume (10 m x4.5m x 1m)**

GENERAL ATOMICS

Layering "Ammo-Belt" makes layering a continuous, determined process, however has many parts



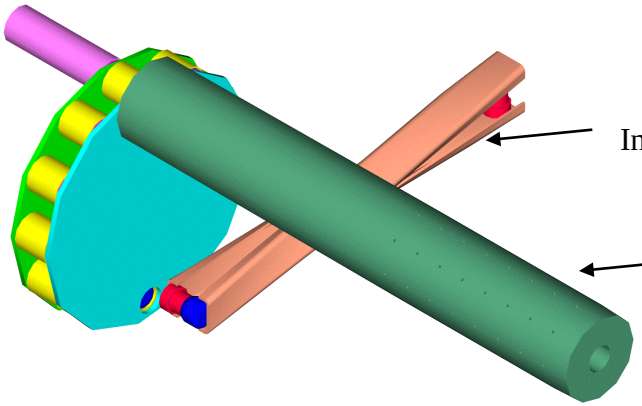
1.Target filled and cooled in permeation cell

2.Targets loaded into sabots

3. Sabot slipped into links of chain

4. target layered in chain stations

5. sabot pushed out of chain into injector loader



- Dielectric chain and sabot used
- RF E-field direction cycled around at each station to maintain layer uniformity
- As links approach injector, RF power reduced and temperature adjusted to 18.2K

GENERAL ATOMICS

Summary and conclusions

High-Z Coatings

- Gold coatings placed onto shells
- Thickness and uniformity measured and in range of interest
- Permeation through coating is possible
- Optimization and parametric studies needed

Target Coatings

- GDP fluidized bed coater setup
- Showing reproducible results and good coatings
- Ready for parametric studies
- Solution spray-drying methods showing promise

Layering

- Fluidized beds being evaluated, not so simple but many options
- Layering of surrogate being used to demonstrate potential for methods
- In-sabot method being evaluated as alternate

.... Cradle-to-grave scenarios for target fabrication, filling, layering, and injection are well underway

GENERAL ATOMICS