



GENERAL ATOMICS
AND AFFILIATED COMPANIES



DEVELOPMENT OF A PROTOTYPE IFE FOAM CAPSULE TARGET

Second US/Japan Workshop on Target Fabrication,
Injection and Tracking

General Atomics
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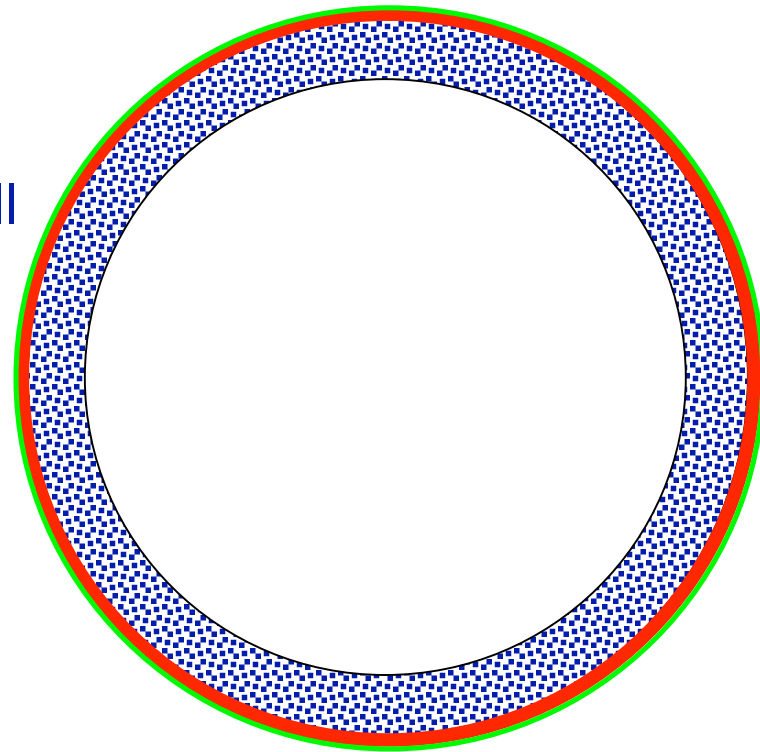


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We Were Asked To Produce A Hollow Plastic Foam Shell With An Overcoat.

- Design is specified by NRL.
- 4 mm diameter shell
- 300 micron polymer foam wall
 - CH polymer
 - ~ 1 micron cell size
 - 10 - 100 mg/cm³
- 1 micron polymer overcoat
- 0.03 micron metallic coating





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Similar Overcoated Foam Targets Had Been Made.

- ILE produced 0.8 mm diameter, 30 micron wall shells from an acrylate foam system. (Takagi, et al)
- LLNL/Schafer produced 2 mm, 100 micron wall shells from both the acrylate and resorcinol-formaldehyde foam systems.
- There are two very significant differences in the NRL IFE design.
 - The foam polymer can contain only carbon and hydrogen, no oxygen.
 - The diameter of the shell is doubled.

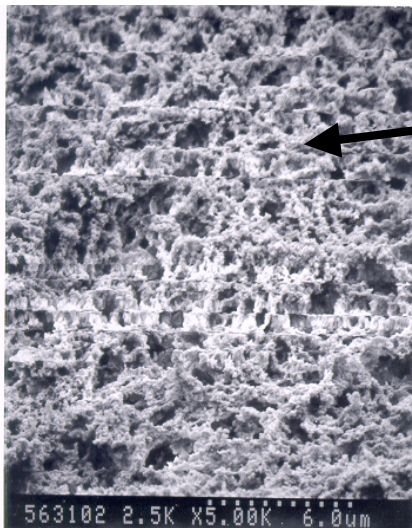


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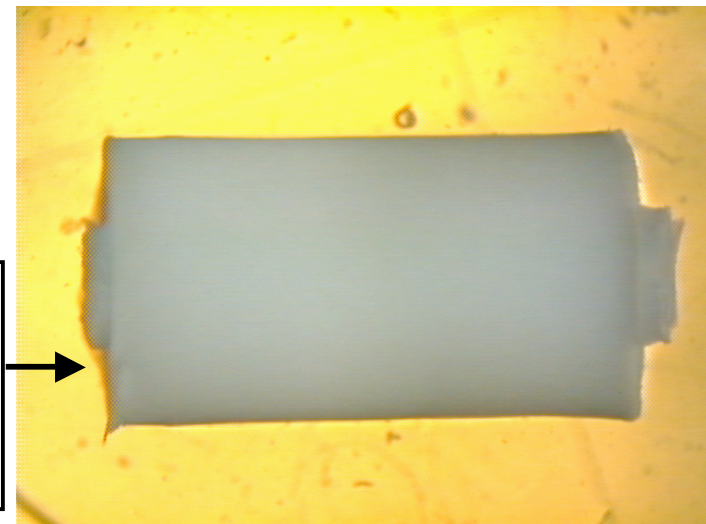
First We Created A Suitable CH Foam.

- Divinyl benzene ($C_{10}H_{10}$) can be used to make foams within a density range of 10 - 250 mg/cm³.
- The process is analogous to the acrylate foams.
- At 10 mg/cm³ the average cell size appears to be about 1.6 microns.
- The foam is cast to near net shape, shrinkage is very minimal.



This SEM shows the cell size and morphology of a 10 mg/cm³ foam.

This photograph shows a 14 mg/cm³ foam in isopropanol. It was cast with tabs at each end.

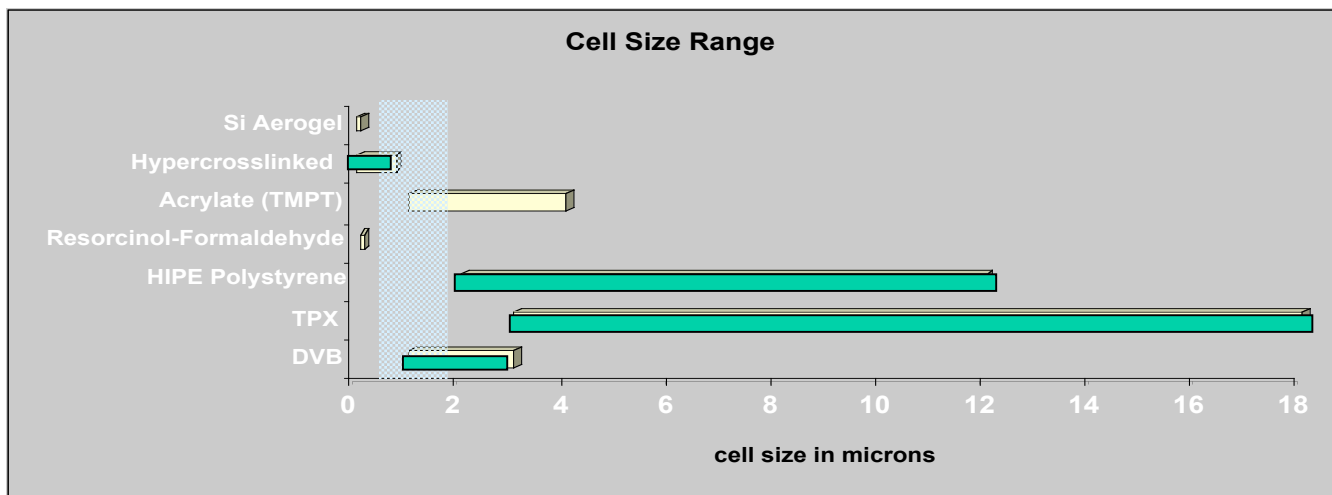
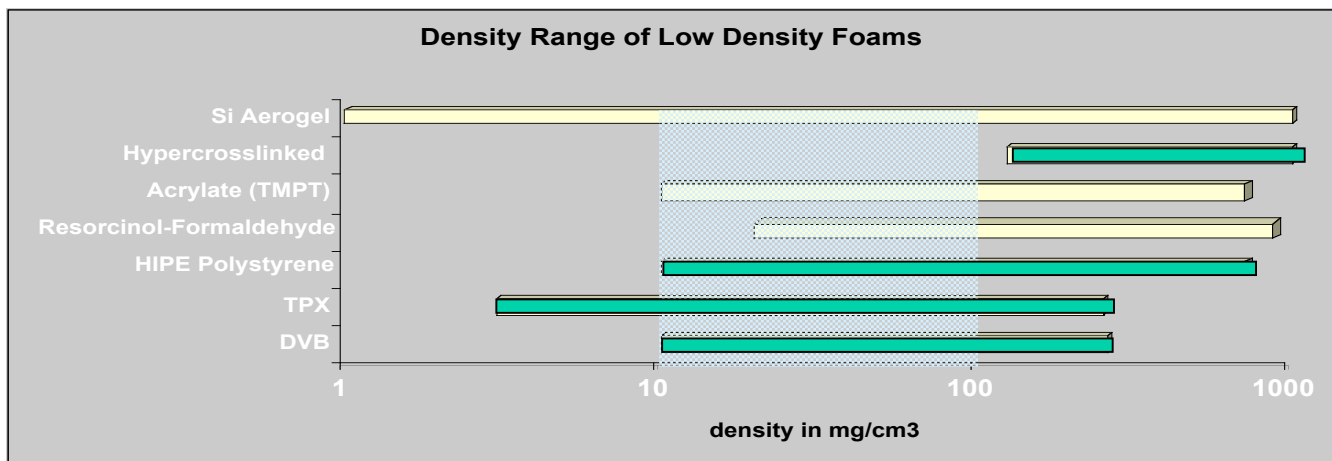




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The DVB Foam Has A Unique Set Of Properties.



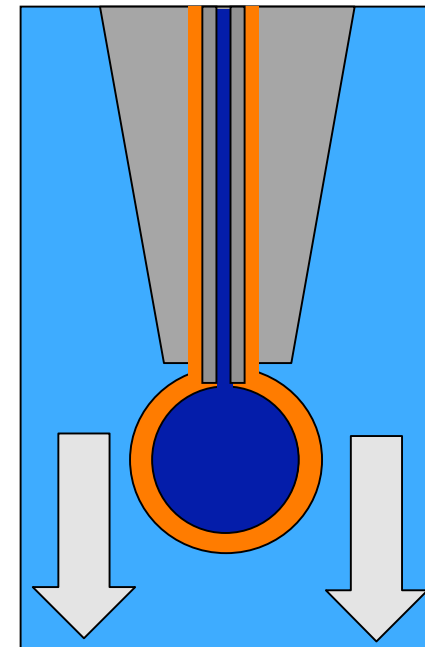


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To Make Shells, We Microencapsulate Using A Droplet Generator.

- **Inner Water Phase:**
 - D_2O / H_2O Blend
 - flows through innermost needle.
- **Organic Phase:**
 - dibutyl phthalate, DVB, radical initiator
 - flows through second needle.
- **Stripping Phase:**
 - 5 % PVA in H_2O
 - strips off organic/water drop.



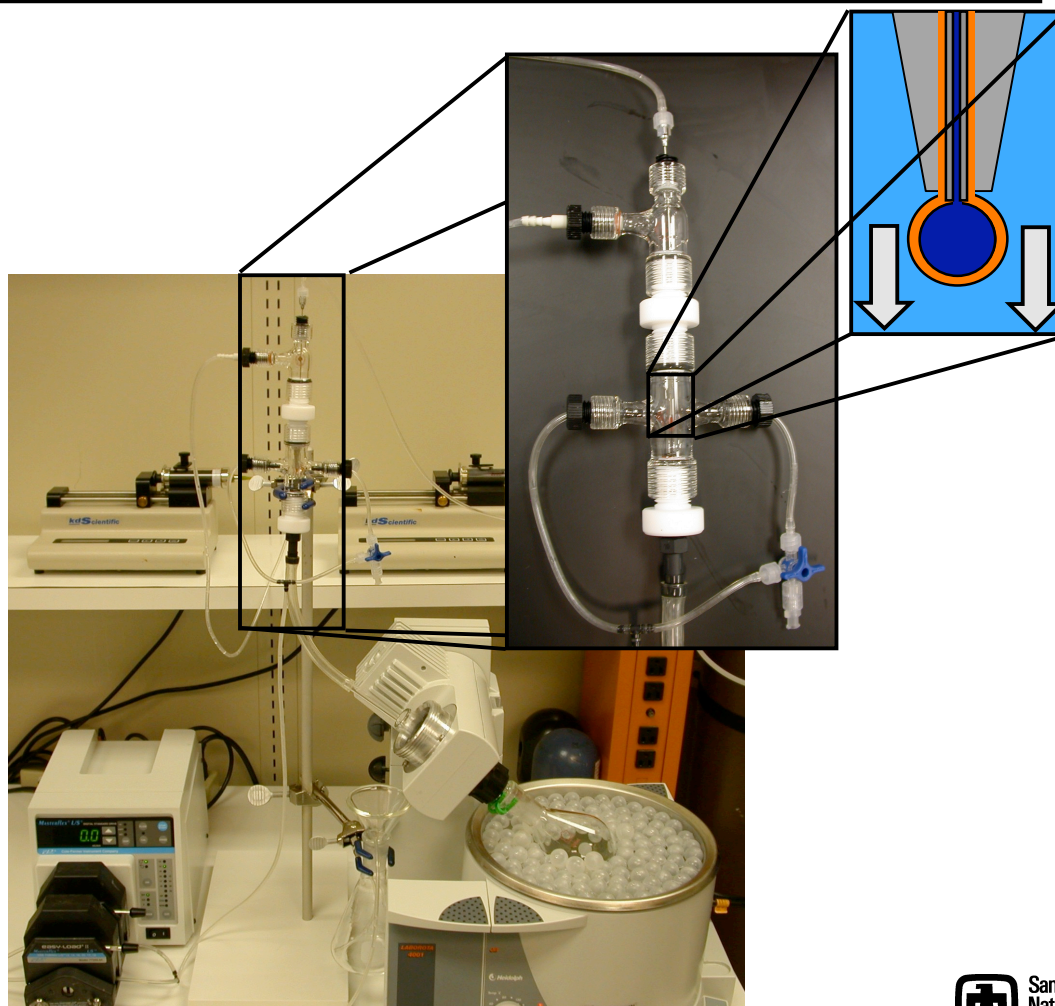


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Our Droplet Generator Is Made From “Off the Shelf” Parts.

- System consists of two syringe pumps, stripping fluid pump, triple orifice, and rotary evaporator.
- System is readily adaptable to making shells with different diameter and wall thickness by changing flow rate and needles.



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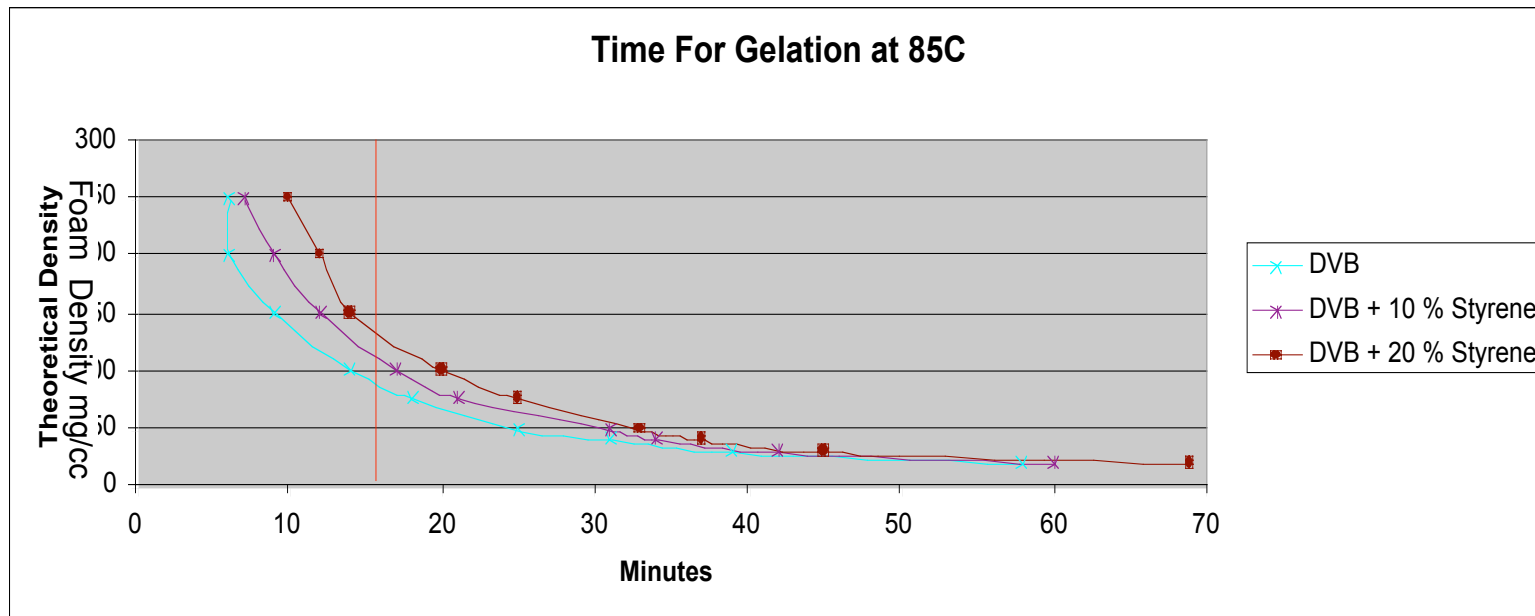


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The DVB Must Polymerize Quickly Or The Complex Drop Will Be Destroyed By Rotation.

- **Drop must gel 15 minutes after formation to avoid breakage.**
- **Temperature, initiators, and addition of other CH monomers were investigated to hopefully hasten gelation.**
- **Monomer concentration is most importantly factor.**
- **To compensate for the slow gelation, we must start the polymerization before microencapsulation.**





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The Keys to Making a Spherical Uniform Shells Are Density, Interfacial Tension, and Agitation

- **Much Work has focused on density matching.**
 - **Density matching helps center the inner and outer drop, but density is a function of temperature..**
- **Influences of interfacial tension and agitation need to be studied further as will be seen.**
 - **M. Takagi, R. Cook, R. Stephens, J. Gibson, S. Paguio, "Decreasing Out-Of-Round in Poly(_-Methyl Styrene) Mandrels by Increasing Interfacial Tension," Fusion Technology, Vol. 38, p. 46 July 2000.**
 - **T. Norimatsu, Y. Izawa, K. Mima, P. M. Gresho, "Modeling of the Centering Force in a Compound Emulsion to Make Uniform Plastic Shells for Laser Fusion Targets," Fusion Technology, Vol. 35, p. 146, March 1999.**

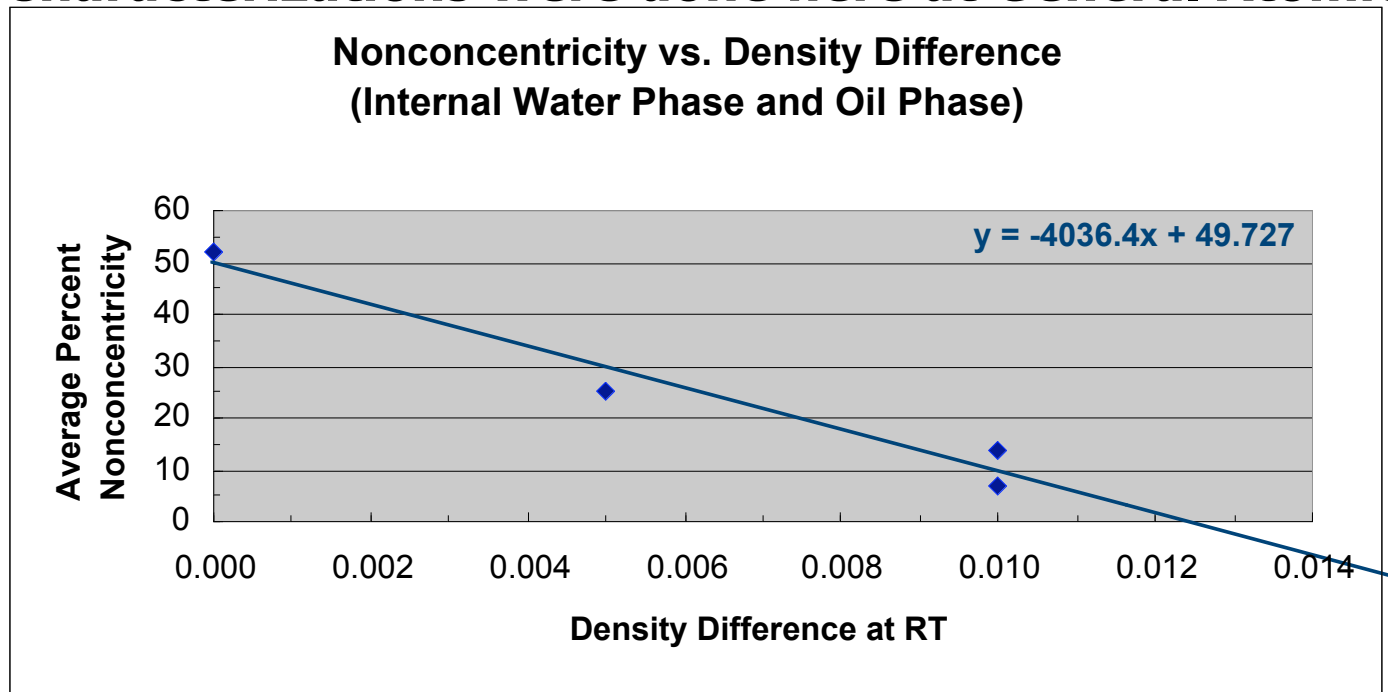


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Initial Density Matching Results Were Very Promising.

- **We measure the densities of the oil phase and internal water phase at ambient temperature.**
- **The polymerization occurs at 85° C, the density of the organic phase will be reduced more than the density of the water phase.**
- **Characterizations were done here at General Atomics.**



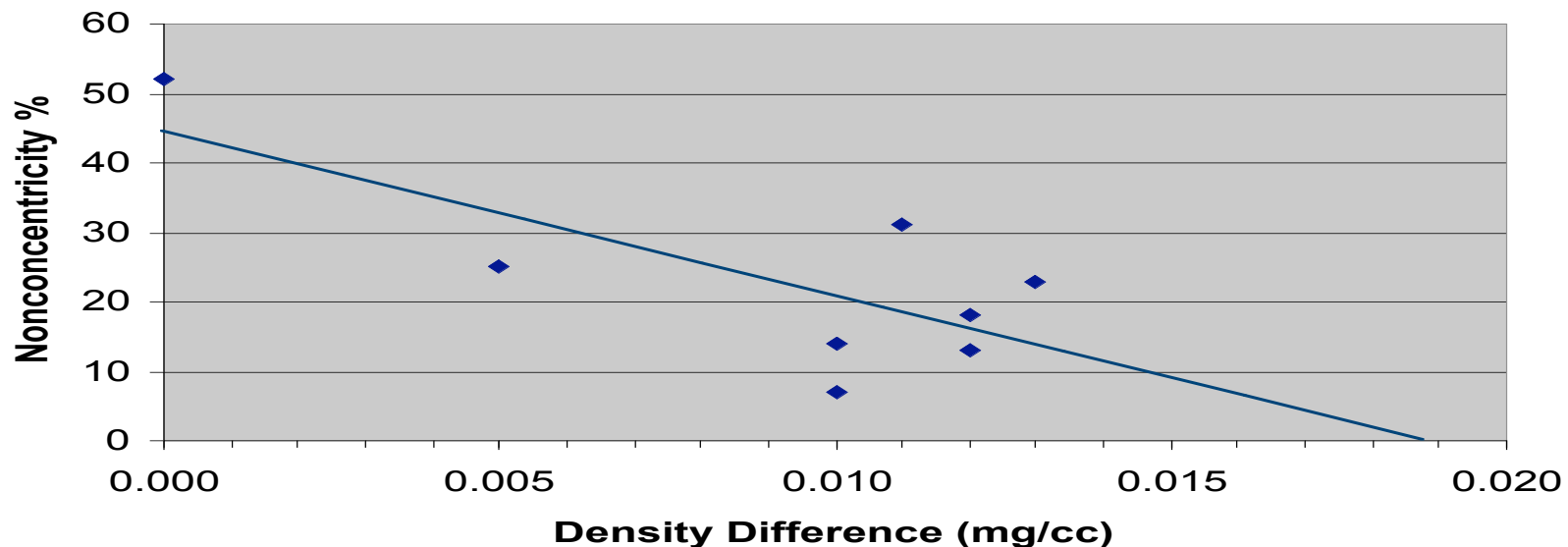


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Additional Density Matching Results Reminded Us How Difficult This May Be.

- After more data was collected in the 0.010 to 0.012 g/cc range, the trend appeared to be less clear. Optimum now appears to be about 0.019 g/cc.
- If the optimum was exceeded a "V" shape would be expected when the data is plotted in this manner.

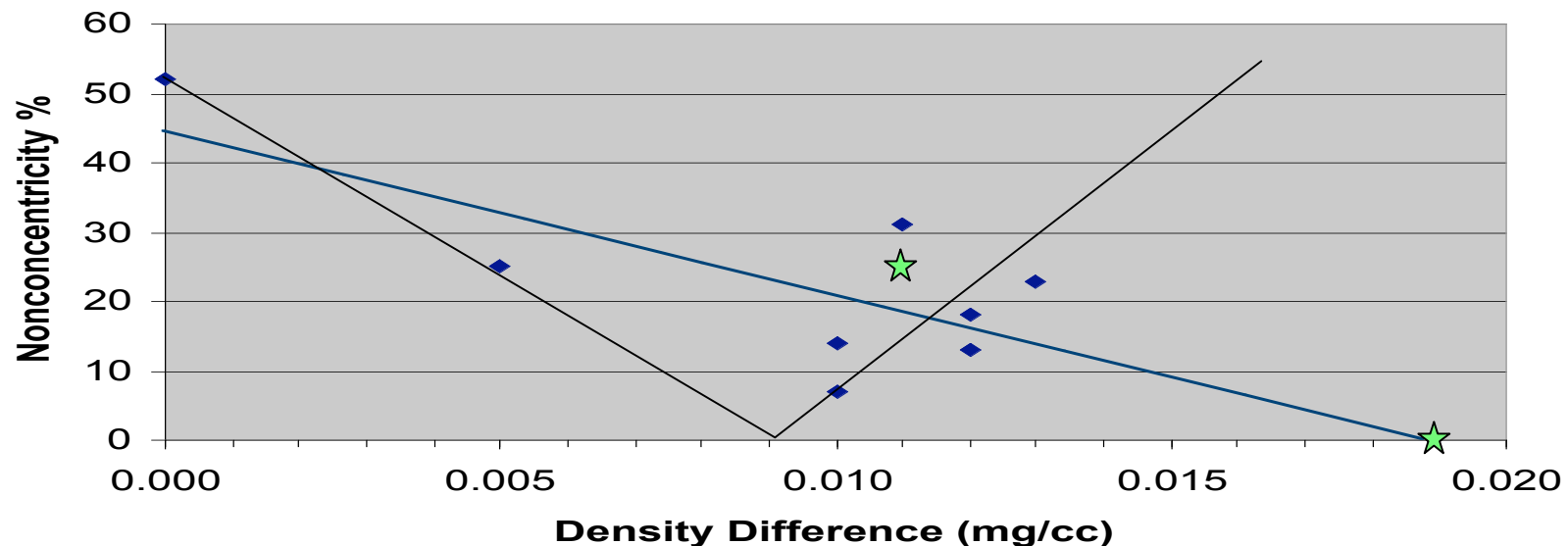




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Reinterpreted Density Matching Data Gives Two Possible Answers.



- We need to examine the results for a greater than .015 density difference to clarify the situation.
- Other factors may have dominated the results - temperature, interfacial tension, agitation.

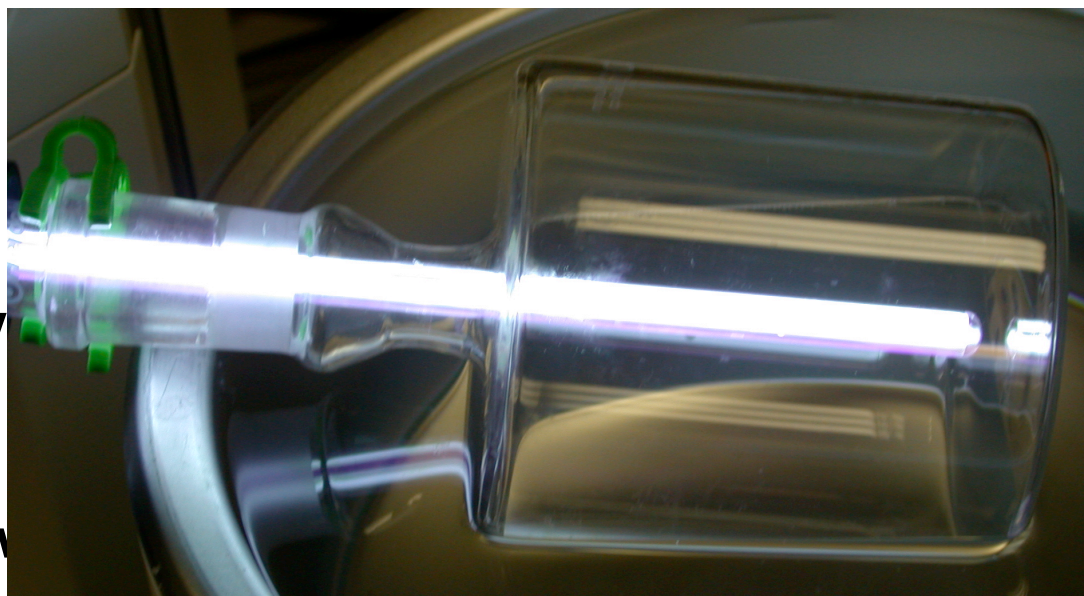
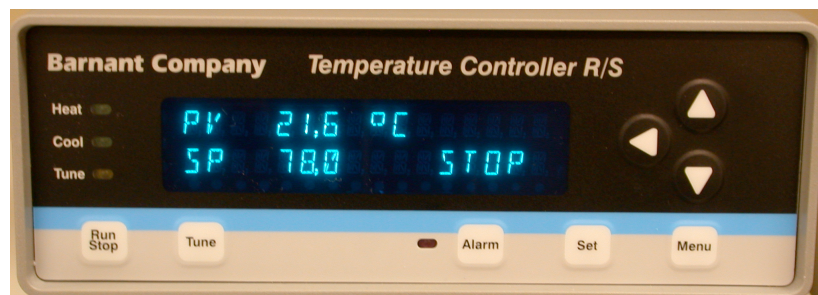


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Temperature Control Is Being Improved.

- Temperature in gelation flask was found to vary from 65-73 °C.
- A temperature controller was obtained to minimize temperature fluctuations.
- DVB polymerization experiments using UV initiation performed.
- Polymerization achieved, but too slow to be useful.



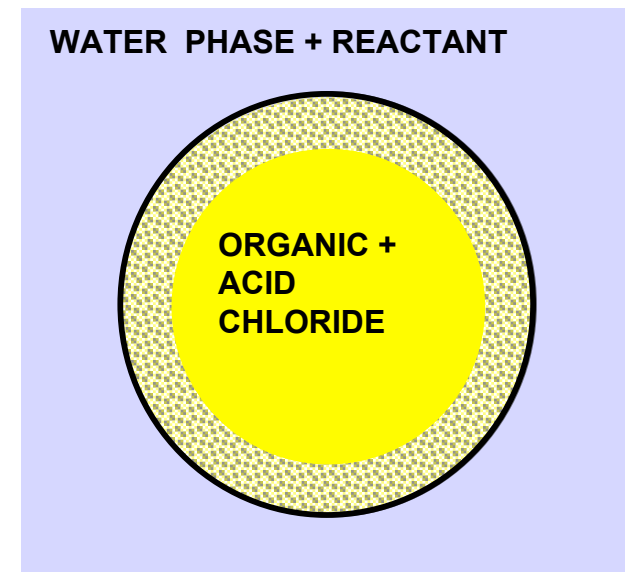


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To Overcoat The Polymer Shells, We Are Using A Technique Developed At ILE.

- **ILE overcoated acrylate shells, we previously overcoated RF shells using an interfacial polymerization.**
- **The reaction occurs at the interface between the water and organic phases.**
- **It is a multi-step process that requires time and labor.**
- **There are a variety of reactants that can be used to optimize the resultant wall.**



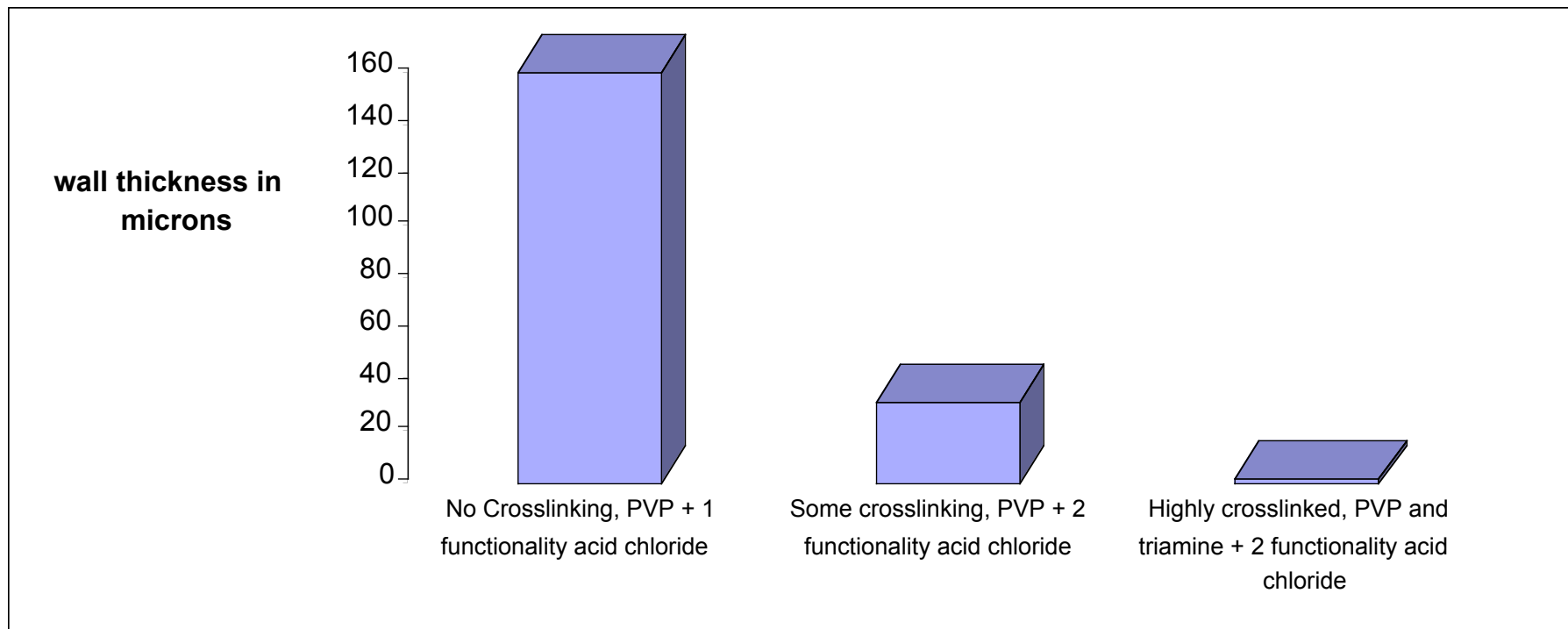


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For Example, The Wall Thickness Is A Function Of The Polymer Crosslinking.

- Typical reactants are polyvinyl phenol (PVP) and acid chlorides.



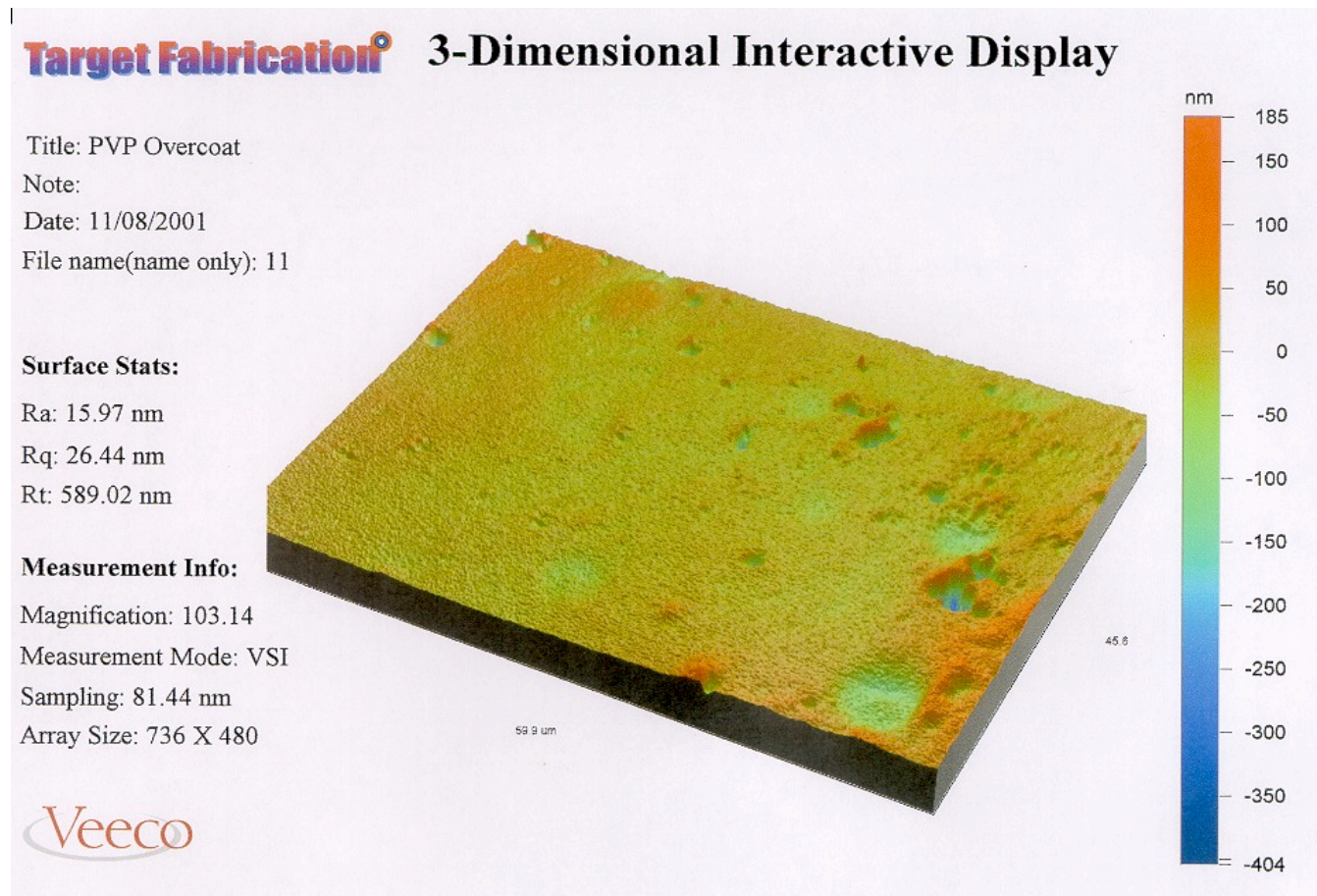


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The Surface Finish Of The Overcoat Is Critical.

- The intrinsic surface finish produced by the PVP and triamine with isophthalyol dichloride looks very good.



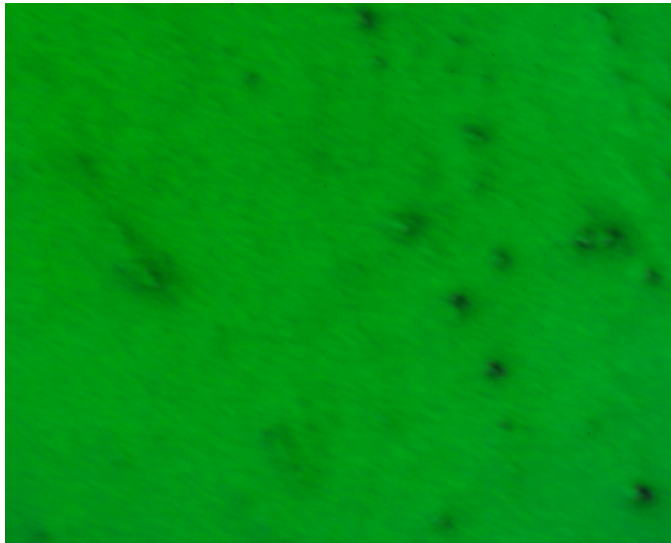
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We Can Confirm Overcoating on “Wet Capsules” Using Confocal Microscopy.



Uncoated Shell



Coated Shell

- **Confocal image of shell**
- **900X magnification**
- **Image is 100 microns across**
- **All of these features are submicron in depth.**

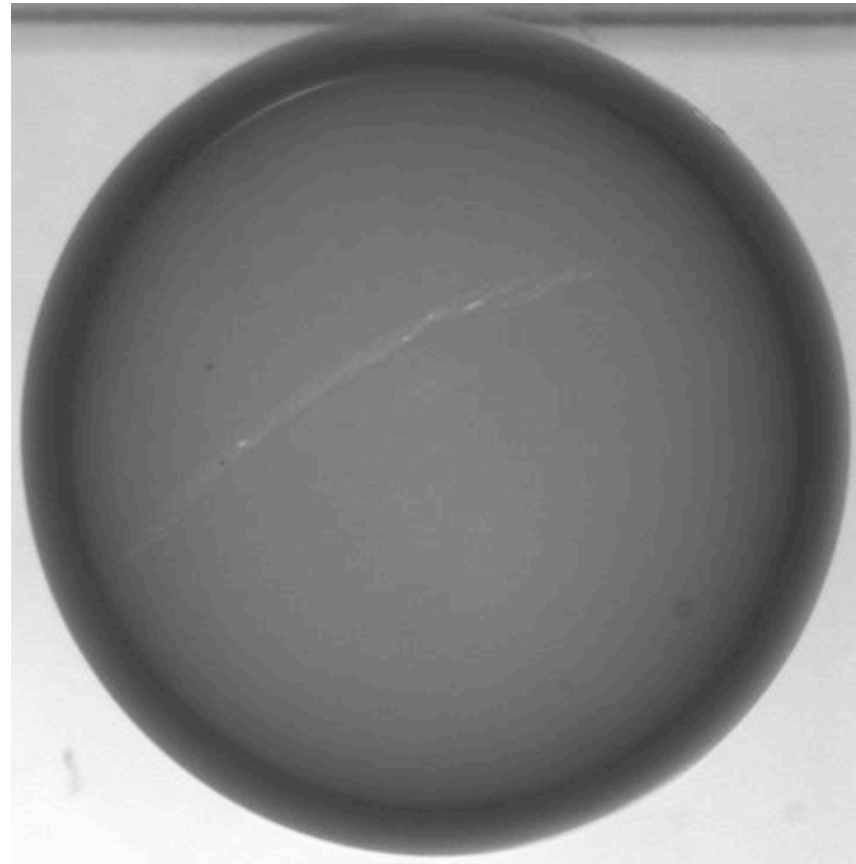


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We Need To Overcome Shell Characterization Issues.

- **Shells do not ship well - ~25% broken or cracked after shipment.**
- **~95% Broken or cracked after exchanging to DBP for characterization (estimates and image from GA). Handling needs to be minimized.**
- **To overcome these two problems we will begin characterizing the capsules at Sandia.**

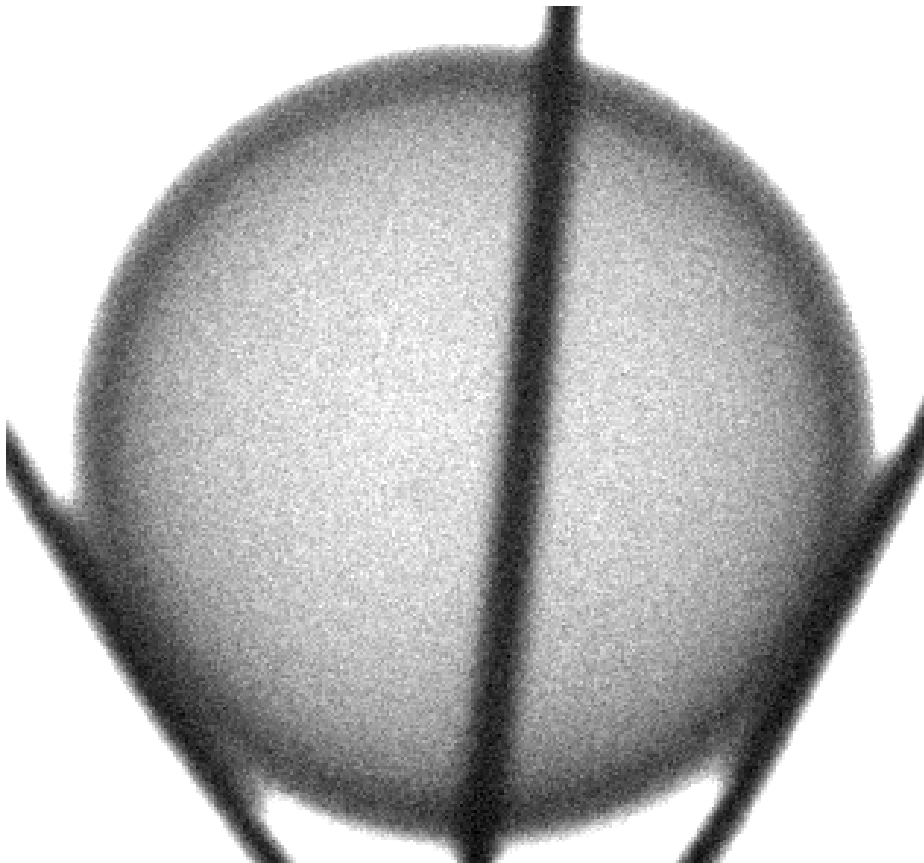




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We Will Combine Optical Characterization With Radiographic Characterization.



- **This is a radiograph of a DVB foam shell.**
- **System is being modified for foam needs: optimizing energy and adding rotation.**
- **System currently has ~28 micron resolution .**
- **Also designing system with ~10 micron resolution – Planned for FY04.**



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There Is Much Work That Needs To Be Done.

- **Determine optimal density matching and its significance.**
- **Determine advantage of using PVA or PAA system.**
- **Determine methods to reduce shell cracking.**
- **Develop x-ray radiography characterization system.**
- **Develop wet characterization system at Sandia.**





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Nevertheless, We Have A Prototype IFE Capsule.

- **DVB is an appropriate polymer for the foam (density, cell size, elemental composition).**
- **It has been microencapsulated to produce 4 mm diameter capsules with densities between 50-100 mg/cm³.**
- **It is chemically compatible with a polymer overcoating process that can produce walls of the appropriate thickness and surface finish.**

