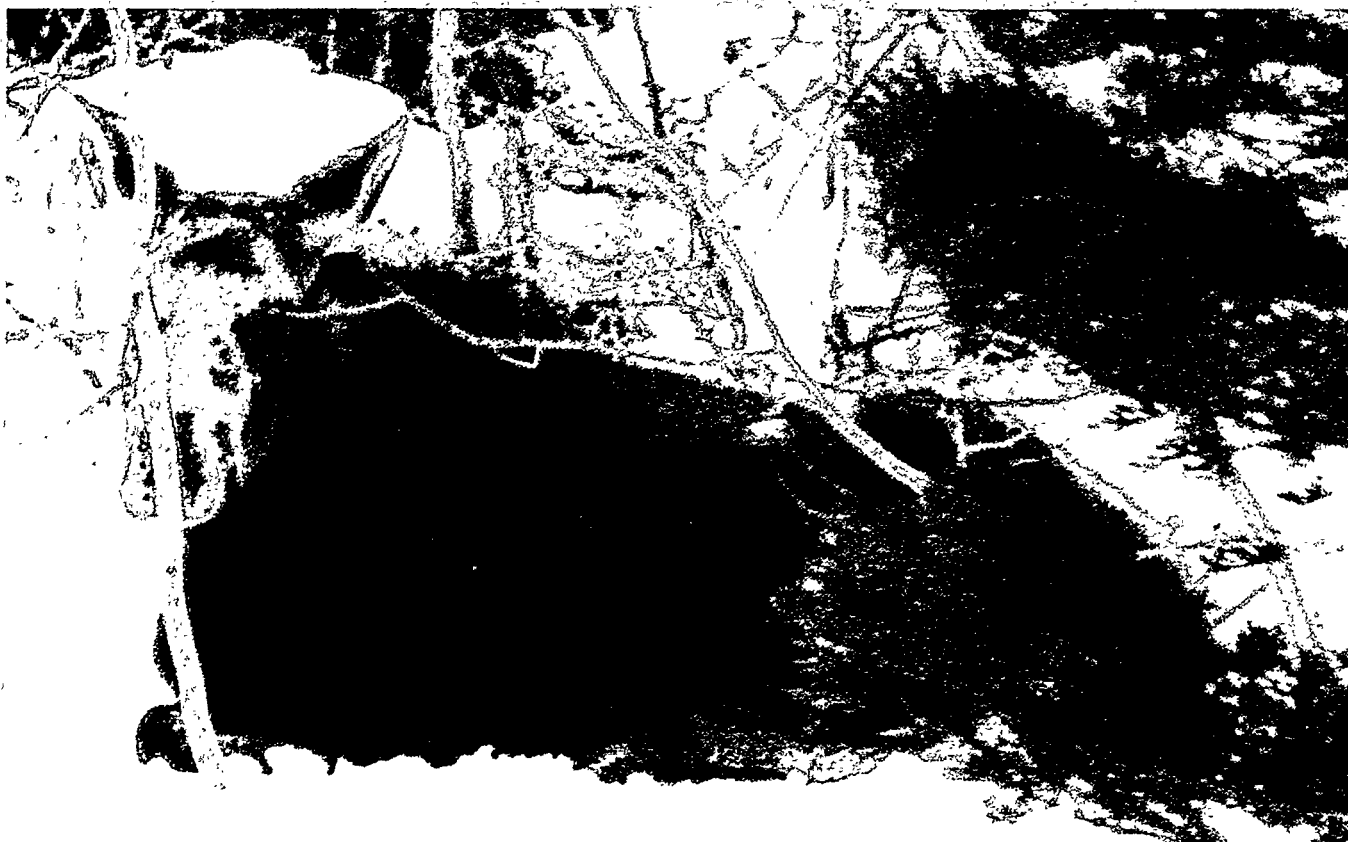


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Proceedings of the Twelfth Target Fabrication Specialists' Meeting

*Jackson Hole, Wyoming
April 19-23, 1998*



*Hosted by
Los Alamos National Laboratory
Los Alamos, New Mexico, 87545*

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*Work performed under the auspices of the U.S. Department of Energy
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From the desk of the meeting co-ordinator:

Research in fabrication for inertial confinement fusion (ICF) comprises at least three broad categories: targets for high energy density physics on existing drivers, ignition capsule fabrication, and cryogenic fuel layer formation. The latter two are being pursued primarily for the National Ignition Facility (NIF).

The Twelfth Target Fabrication Specialists' Meeting '98 was sponsored by the US DOE, hosted by Los Alamos National Laboratory, and held in Jackson Hole, Wyoming on April 19-23. Scientists from over 14 laboratories, universities, and businesses contributed over 100 papers on all aspects of ICF target fabrication. It was an exciting meeting. The NIF is well along in construction and photos of poured concrete and exposed steel added to the technical excitement. It was clear from the meeting that there has been significant progress toward the fabrication of an ignition target for NIF and that new techniques are resulting in higher quality targets for high energy density research.

TFM '98 received financial support from General Atomics, W.J. Schafer, Inc, and the Los Alamos ICF Program. I would like to acknowledge the tireless aid of Robert Cook (LLNL), for liaison with our Russian participants and the work of Jim Hoffer, Yvette Martinez, Julie Gallegos, Pam Rockage, and Ginette Andreatta in compiling these view-graph proceedings.

A handwritten signature in black ink, appearing to read 'LRF', followed by a horizontal line.

Larry R. Foreman

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Foreword from L. R. Foreman

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NIF ignition target specifications and requirements

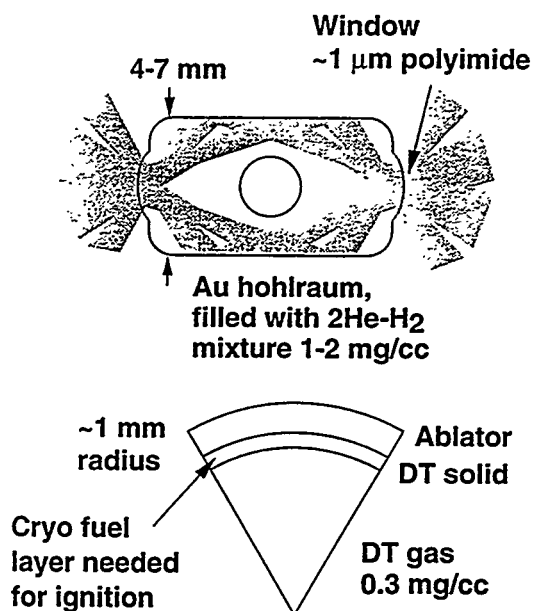
NIF ignition targets will require very tight specifications
on surface smoothness, bulk homogeneity,
laser precision, and practically every other
aspect of the experiment
"Integrated test of stockpile stewardship capability"(!)

S. W. Haan, T. R. Dittrich, M. M. Marinak
Lawrence Livermore National Laboratory
D. C. Wilson, W. S. Varnum
Los Alamos National Laboratory

Presented to
Target Fabrication Meeting 1998
April 20, 1998

SWH TFM98 Title

One of the principle goals of NIF is to get ignition
using indirect drive ICF targets like these



Spherical capsule with low-Z ablator
mounted in gas-filled gold hohlraum

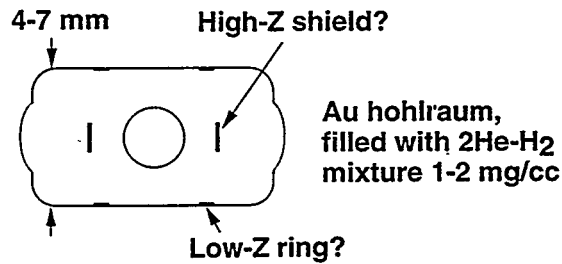
Laser heats hohlraum with carefully
tailored pulse to a carefully chosen
peak T_R , will be in range 250-350 eV

Multiple cones of laser beams to
control time-dependent asymmetry

Hohlraums gas-filled, for cryo and for
holding wall back

Ablator Be+Cu, CH+Br, CH+Ge, polyimide,...

The baseline hohlraum is simple (except cryogenics!) but there could be various options requested



Optimal hohlraum material could be gold, U, gold-gadolinium mixture, other mixtures. Could be "thin-wall", high-Z coated inside low Z. High Z $\geq 6-10\mu\text{m}$

Gas density may vary up to about 2.5 mg/cc
Optimizing inside might require bells & whistles (shields & rings)

LEH may vary from ~2mm to 100%

We don't care what's on the outside of the hohlraum (cryo tubes etc.) but:

Experiments other than optimized "pure" ignition will require windows on sides of hohlraum, shields to protect them from unconverted light, ...

Lots of other constraints: cryo design, target chamber considerations (shrapnel)

SWH TFM98 02

A laser that produces 1.8 MJ and 500 TW allows a factor of two safety margin above the ignition threshold

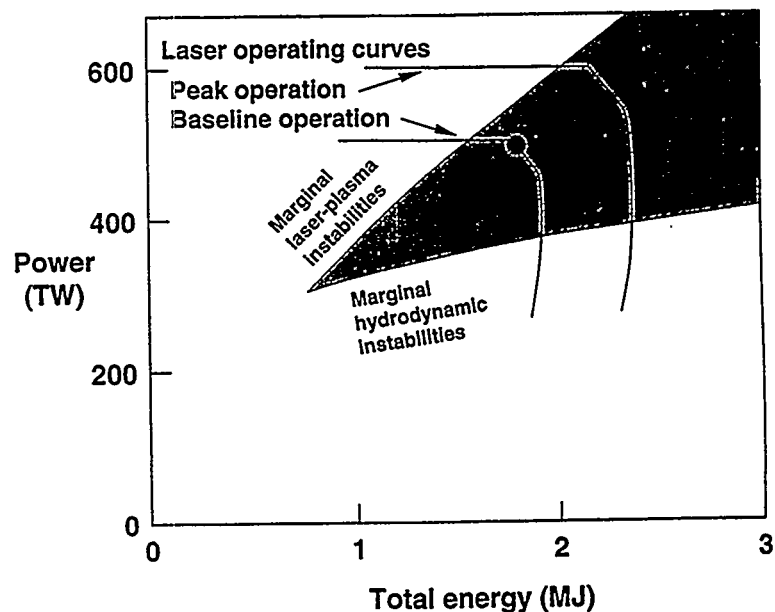


■ = Target performance region

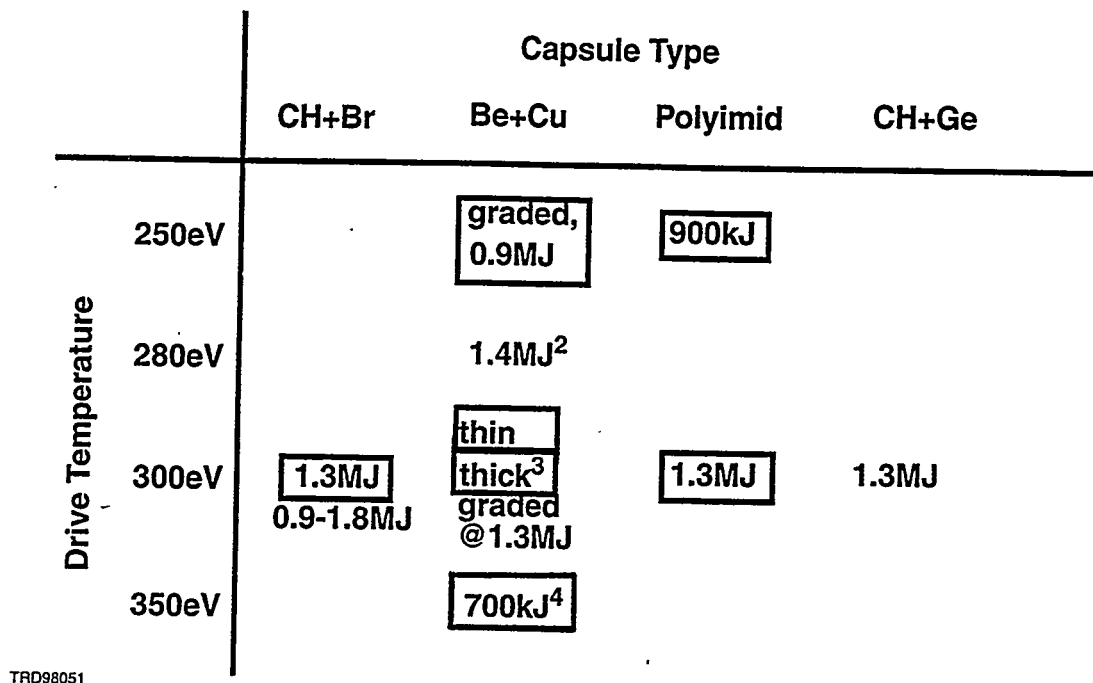
Minimum energy for ignition is 800-900 kJ according to current modeling

1.8 MJ at 500 TW provides a factor of two safety margin

This margin is enough to cover estimated uncertainties in target physics



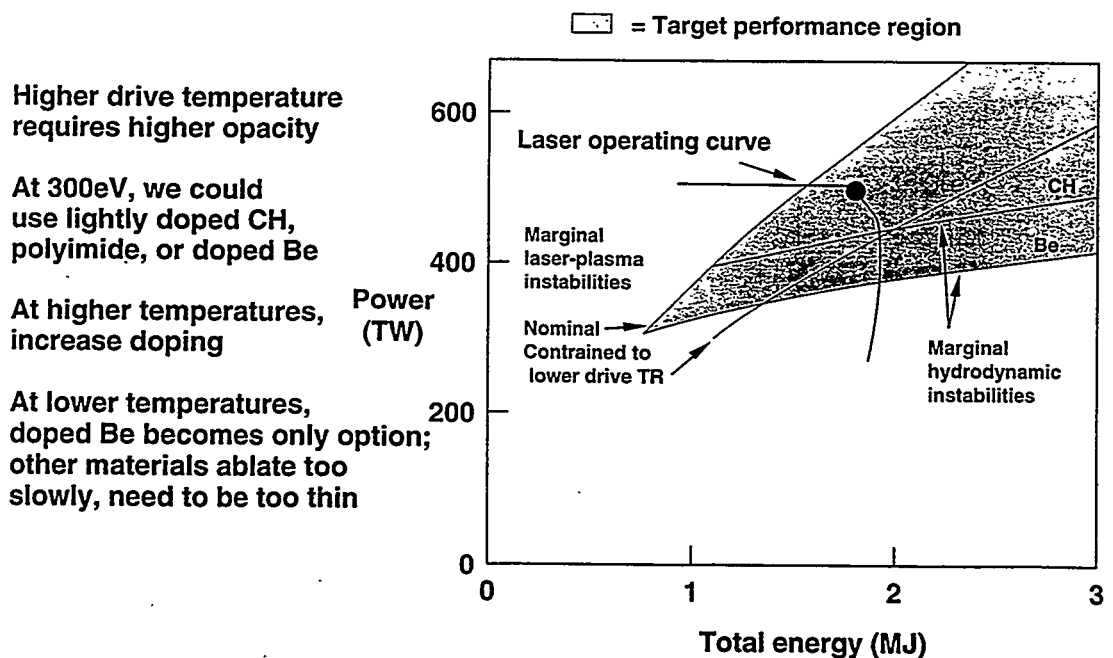
NIF capsule designs cover a range of x-ray drive temperatures, ablator materials, and total laser energies



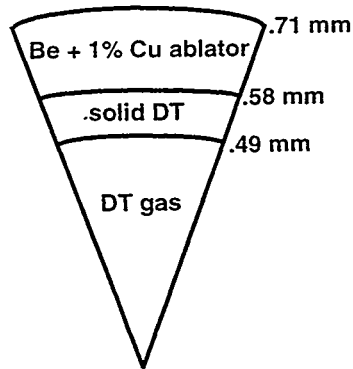
¹Haan, ²Bradley, ³Wilson, ⁴Hinkel

→ subjects of this presentation

We believe that beryllium works better than CH or polyimide at low drive temperature, and also can be made to work at higher drive temperature with doping

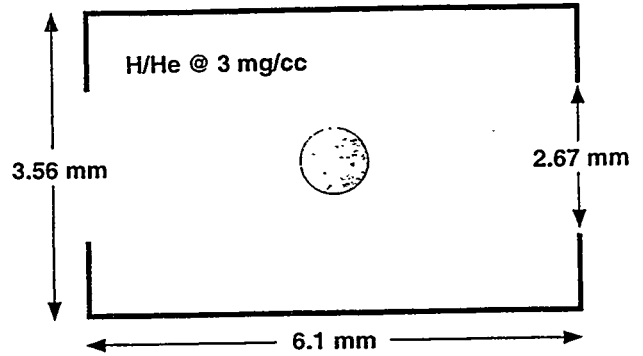


To obtain $Tr \sim 350$ eV in a NIF hohlraum, the hohlraum size (and capsule) is scaled to $\sim 64\%$ of 300 eV design



350 eV capsule radius = .71 mm

300 eV capsule radius = 1.1 mm

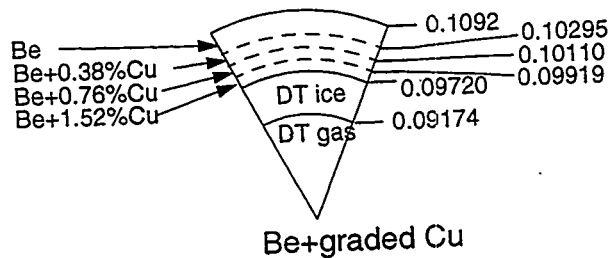


350 eV Hohlraum:
Length = 6.1 mm
Radius = 1.78 mm
LEH = 2.67 mm

300 eV Hohlraum:
Length = 9.5 mm
Radius = 2.75 mm
LEH = 2.75 mm

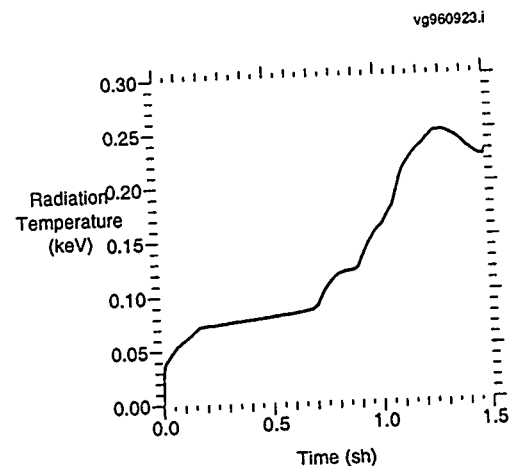
D E Hinkel 02/98

A NIF capsule with Cu graded Be, driven by a 250 eV x-ray profile from a 900 kJ, 275 TW laser, can produce 5.6 MJ fusion energy



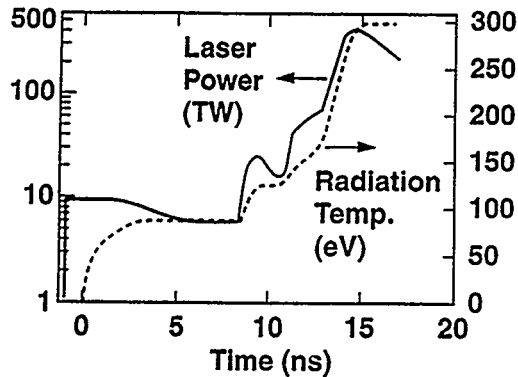
Absorbed Energy: 115 kJ
Yield: 5.6 MJ
Figure-of-Merit: 1.08

ρr_{fuel} : 1.28 g/cm²



Integrated calculations produce 3 MJ

Higher initial density of beryllium is also an advantage



Laser pulse and hohlraum temperature history carefully tailored to get implosion with minimal entropy in DT

Higher initial ablator density means shorter foot for same shock pressure in DT, less filling of hohlraum with plasma

Shorter higher foot also easier for laser

Higher initial density also reduces coupling of DT ice roughness to unstable ablation surface

Material density and composition must also be very uniform



Initial surface roughness must be 10's of nm

Perturbations can also be seeded by nonuniformities in opacity (i.e. composition) or density

Effect of density nonuniformities can be roughly estimated from equivalent column density (integral ρdr): 50nm/100 μ m corresponds to 0.05% density uniformity (maybe can be a factor of several looser...)

Opacity harder to estimate, will also be very tight

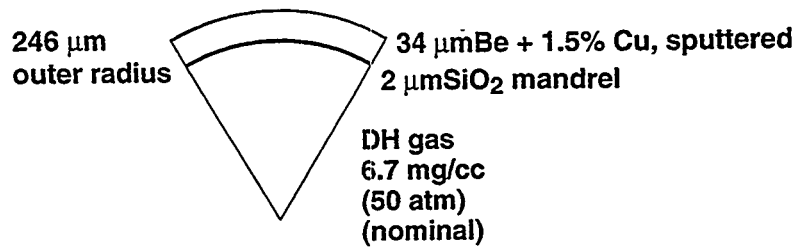
Anisotropy of shock velocity with different grain orientation could also seed perturbation growth

Evaluating the effects of these is a topic of current/future work

Recent Nova results with Be-ablator capsules were disappointing



Capsule in standard Nova hohlraum, 1ns drive



Expected good performance (close to 1D) unless beryllium was somehow bad; low growth factor for surface roughness, low convergence

Shot two on 3/25/98 (Jeff Koch et al.)

One gave very poor performance and tilted pancake image

Other gave poor yield (2e7, or about 10% of clean 1D)

X-ray images round overall but small (30 μm across, should have been 60 μm) with interesting structure

SWH TFM98 05

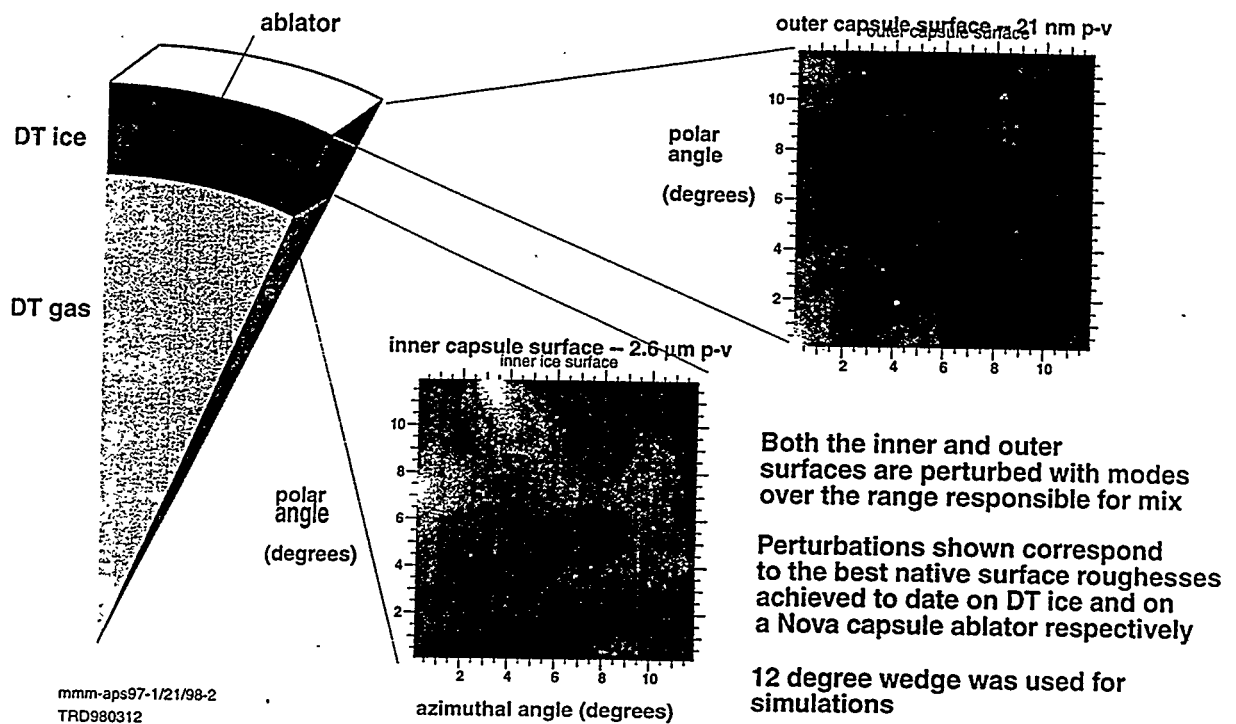
We are now doing 3D simulations of RT growth on NIF capsules



- 3D code HYDRA
- Moving mesh Eulerian hydro with interface tracker, monotonic artificial viscosity
- Includes multi-group radiation diffusion, multi-group charged particle transport, neutron energy deposition — fully detailed numerical simulation
- For 1D & 2D problems, agrees with (unclassified) LASNEX output
- First applied to Nova experiments, with excellent results (invited talk '95 APS; Marinak et al., Phys. Plasmas 3, 2070 [1996])

96X-067

Capsule only simulations examine the effects of multimode perturbations ($l=15-120$)



3-D simulations assessed the surface roughness tolerances of a set of similar NIF capsule designs¹



- Simulations of multimode hydrodynamic instability growth were performed over a portion of the capsule using the 3-D implosion code HYDRA². These were carried through ignition and burn.
- The three capsules in this study were: 1) CH+0.25%Br+5%O, i.e., the "PT", 2) thin ablator Be+0.9%Cu, 3) Polyimide ($C_{22}H_{10}N_2O_4$)
- DT ice surface multimode perturbations obtained from spanning a range of total rms values around that of the "native" surface
- Ablator surface multimode perturbations obtained from spanning a range of total rms values around that of the best Nova capsule surface

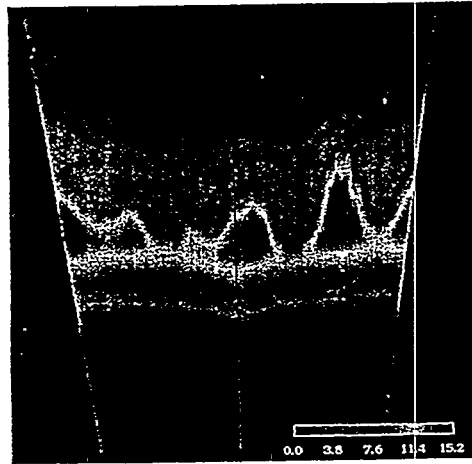
Modes with $l \sim 10-20$ assume principal importance after peak implosion velocity is reached



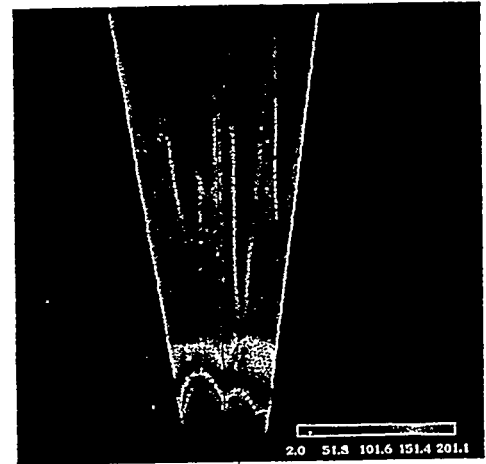
density contours on boundary planes of PT capsule

18 nm rms ablat
0.5 μm rms ice

16.5 ns



17.0 ns



Only the lower modes feed through the capsule shell and grow on the pusher-hot spot interface during deceleration

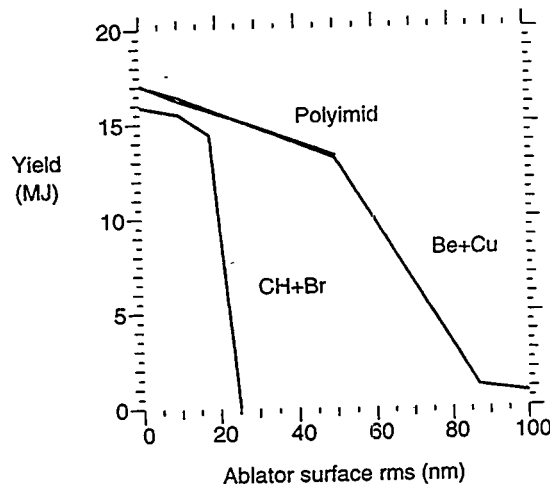
mmm-aps97-1/15/98-12
TRD980311

3-D simulations with HYDRA show the BeCu and polyimide capsules have greater tolerance to ablator surface roughness



Yield vs. ablator roughness
for best ice surfaces

vg980130.i



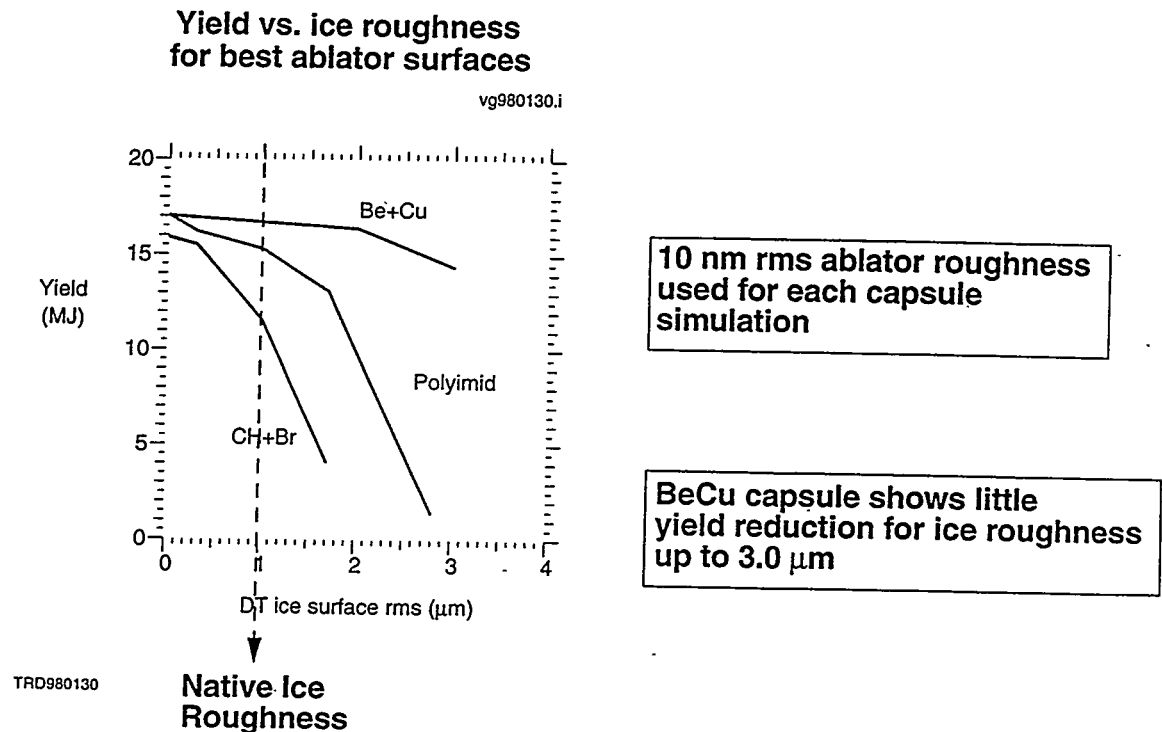
"Best ice surface" means:

1.0 μm rms for BeCu capsule
(native roughness)

0.5 μm rms for CH and polyi
(reduced from native by
RF heating)

TRD980131

3-D simulations with HYDRA show that for a given ablator roughness, the Be capsule can tolerate the roughest DT ice layers



We're still not completely sure about all the tradeoffs and optimizations related to RT growth!



Status 1-2 years ago:

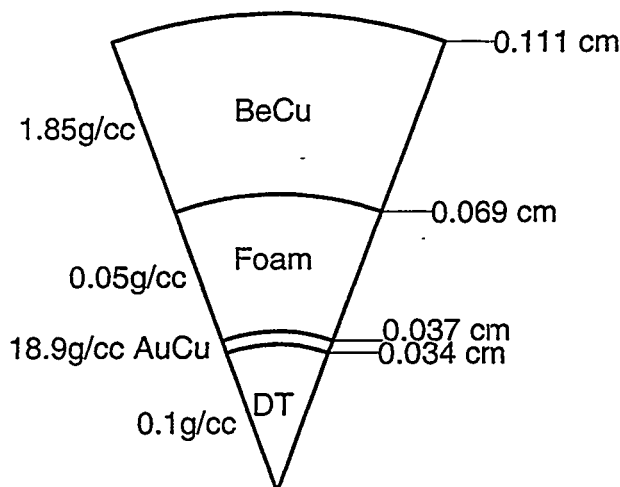
- Be better than CH at 300 eV, especially for inner surface growth
- No 3D calculations
- Short wavelengths just beginning to look like a problem for CH
- "Polyimide won't work very well at 300 eV" – Steve Haan

Status now:

- "Difference between Be and CH is mostly just ablator thickness" – Doug Wilson
- Short wavelengths bad for CH at old nominal ("PT") thickness; thicker CH may be better!
- 3D calculations showing acceptable performance for Be and polyimide at 300 eV, but with little margin
- Polyimide looks almost as good as Be at 300 eV (Tom Dittrich)
- "Oh well" – Steve Haan
- ("Polyimide won't work very well at 250eV" – Steve Haan)

There's still work to do, and experiments will be needed on Nova, Omega, and NIF

This double shell NIF capsule designed by Bill Varnum (LANL) is a possible alternate ignition design



Does not require cryogenic fuel

Does not require pulse shaped drive profile

Yield (1D)=2.5 MJ

$E_{\text{laser}}=1.8$ MJ in 6ns square pulse

$T_{\text{drive}}=320$ eV

Volume ignition rather than hotspot ignition

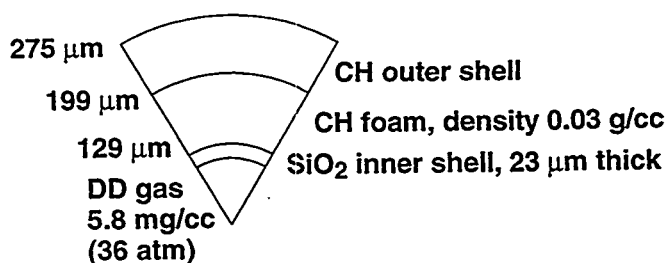
TRD980407

Recent Nova double shells gave yield at very high convergence ratio



Capsule in standard thin-wall Nova hohlraum, 1ns drive

Convergence ratio from outside 38 (same as NIF double shell)



Yield ~2% of clean 1D (very preliminary result; Bob Watt & Cris Barnes)

Yield similar to single-shell targets (HEP1) at same convergence

Plan to do shots on Omega with better symmetry

As many of you know all too well, we are putting together a detailed plan on how to get ignition

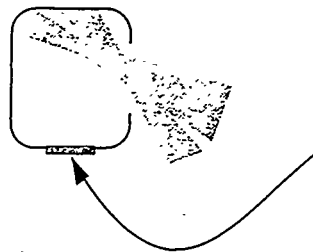


Split into wbs elements: LPI & hohlraum optimization; symmetry; ablator optimization; ignition implosions

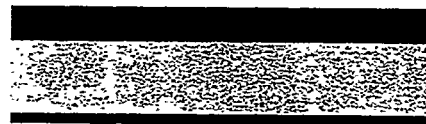
Includes experiments on Nova, Omega AND on partial NIF as more and more beams on NIF become available in 2001-2004

Partial NIF experiments will involve some peculiar fabrication issues!

NIF-scale hohlraum radius



Cryogenic package



Be
Solid Deuterium
Window?

SWH TFM98 09

Summary/Conclusion

There is a lot of work for us all to do!



We have designs that work according to our best modeling with specifications similar to current "best effort"

Actually building those targets will be a challenge!

Some possible upsides:

At this point we have a variety of options with different pros and cons

Further design optimization may increase margin (350 eV, Wilson's thicker shell idea, Be+B, polyimide)

Concerns and issues:

Beryllium material properties

(shock velocity anisotropy & grains, composition nonuniformity)

Laser-plasma instabilities may constrain us to *need* beryllium

(won't know until 2003; meanwhile need design work on polyimide at 250eV)

Target Requirements on the Path to Ignition

D. C. Wilson, P. A. Bradley, C. W. Barnes, S. E. Caldwell, R. E. Chrien, S.R. Goldman,
D. P. Smitherman, D. L. Tubbs, Los Alamos National Laboratory

The Los Alamos ICF program has made several advances in learning what is required for ignition on NIF. Our work continues to focus on beryllium – understanding why it appears less sensitive to DT ice roughness, the feed-out/feed-in phenomena, applying that understanding to new designs, performing experiments to confirm this mechanism, and studying the effects of joints in beryllium components.

I. Calculation of Capsule Stability

The copper doped beryllium ignition capsule, the Be330, (1) was design to be very similar to the point design bromine doped CH capsule (2), the PT. It had the same DT fuel mass set on the same adiabat, and achieved the same fuel pr, and had nearly the same outer radius (1105 vs 1110 μm), and was driven by the same laser energy (~1.4 MJ). But the higher density beryllium meant a more massive ablator, which compressed a mass of copper doped beryllium about equal to the DT fuel. The PT capsule was designed to allow the driving radiation field to burn completely through the CH, while the Be330 left approximately 10 μm of unablated beryllium to be imploded along with the fuel. This turned out to be the cause for the differences in sensitivity to DT ice perturbations between the Be330 and the PT, as explained in (1). The Be330 was about 4 times less sensitive than the PT to perturbations of the DT ice surface (3).

Examination of the calculations showed that when the first shock reaches the DT ice surface a rarefaction and acoustic waves carry the knowledge of the perturbed surface outward to the ablation surface, where it grows from the ablative Rayleigh-Taylor instability. This amplified perturbation then feeds through to the DT ice where, if large enough, it can disrupt ignition. The Be330 is less sensitive to DT ice roughness for two reasons. First, the perturbation carried out to the ablation front is smaller, perhaps due to the greater ablator mass. Second, the unablated mass attenuates the feed through of the ablation front perturbations to the ice by separating them from the DT fuel. Because the PT capsule was designed to burn completely through the ablator at ignition, it left no unablated plastic as a shield.

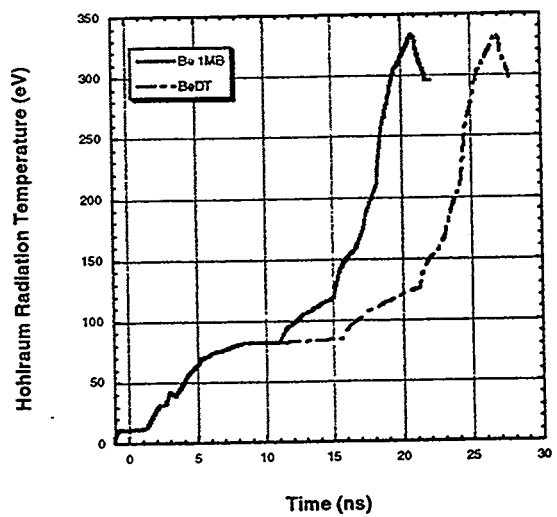
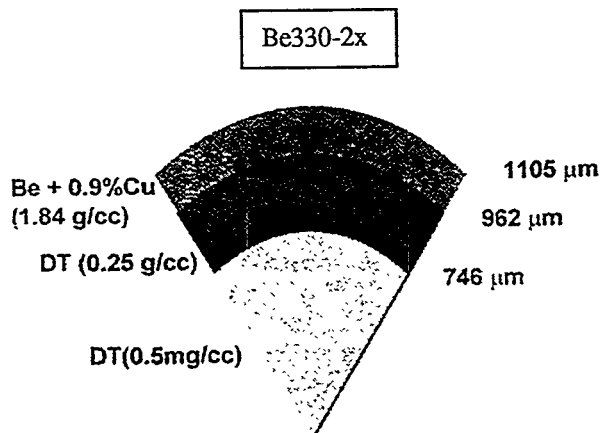
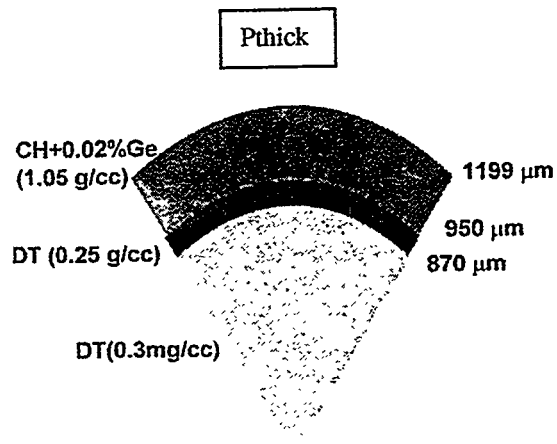
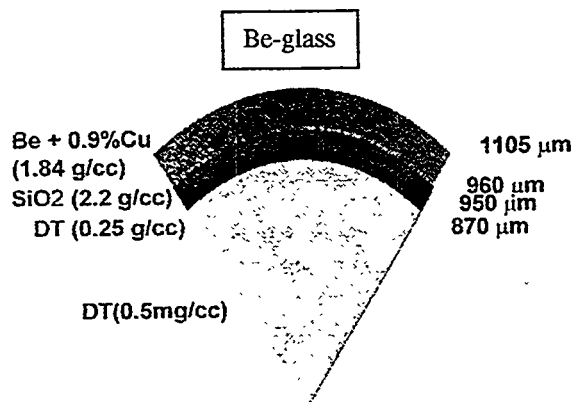
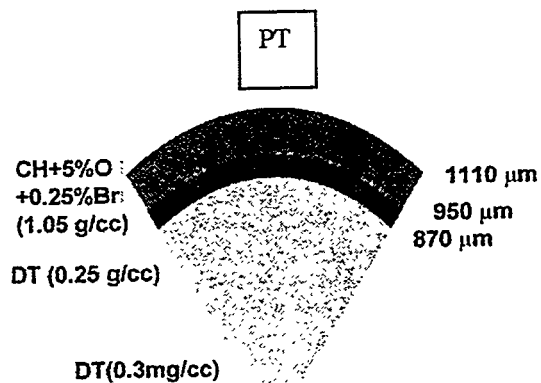
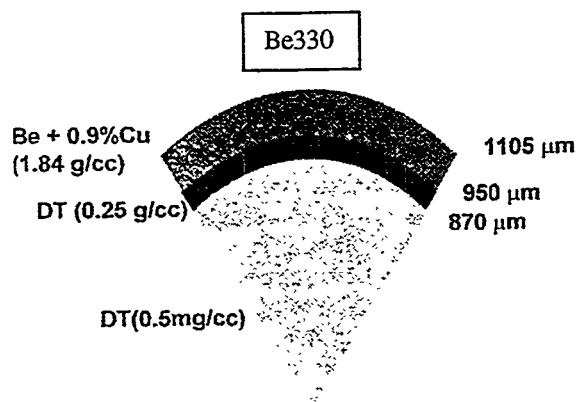
To explore computationally this feed-out/feed-in phenomenon, the addition payload, the unablated Be/Cu, can be changed or replaced in new capsule designs. Simply changing the copper dopant concentration from 0.9 atm% can change the amount of unablated Be/Cu, changing the capsule sensitivity to DT ice perturbations.

Reducing the dopant to 0.6% Cu eliminates the extra payload. Increasing the dopant to 1.2% Cu retains 50% more unablated material. By studying the perturbation amplitude at the DT ice/ Ablator interface (which initially had no perturbation), we can compare instability sensitivity of these design variations. DT ice perturbation growth is reduced by increasing the dopant concentration. The Be330 with 1.2% Cu has growth comparable to the PT, while the Be330 with 0.6% has a factor of 2 less growth. Perturbations starting on the capsules exterior show the same trend, but the PT and the Be330 with 0.9% are similar.

In addition to these dopant variations, a thick polystyrene capsule (Pthick) was designed to use the same ablator mass and carry the same mass of unablated material as the Be330. The Pthick design has 3 times less perturbation growth than the PT, and comparable to the Be330 – 1.2%.

A glass and beryllium capsule might be designed by replacing the unablated beryllium with 10 μm at density 2.2 g/cm^3 . High strength glass (~200kpsi) might be able to contain the DT gas at room temperature, and the beryllium could be coated over it, avoiding the need for a joint. The pulse shape, yield and convergence are identical to the Be330 in 1-D calculations. However 2-D calculations show it is several times more sensitive to perturbation growth at the glass/beryllium interface. It is also several times more sensitive to beryllium surface perturbations. A higher density ablator, or a lower density glass might control growth. If perturbation growth can be controlled, this might be a candidate for NIF ignition.

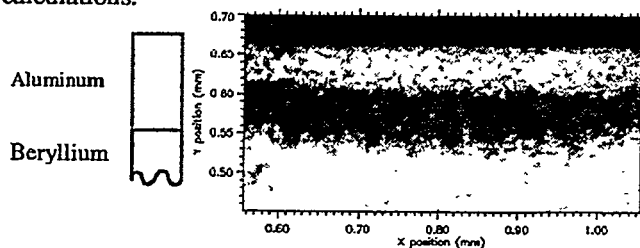
The unablated mass could be replaced by DT instead of Be/Cu. This produces the Be330-2x design, so labeled because it contains about twice as much DT. The capsule yield increases from 16 MJ to 41 MJ and its pr from 1.69 to 2.13 g/cm^2 . Because the extra payload has a lower average velocity than the DT fuel in the Be330, the average fuel velocity of the Be330-2x is lower, but the fuel velocity near the hotspot is similar. The Be330-2x has similar sensitivity to linear perturbation growth as the Be330, but requires a longer pulse to time the shocks to arrive at the ice/gas interface at about the same time, and it would require a stronger ablator shell to contain the DT at room pressure. More work needs to be done on this promising design. A scaled down version would decrease the required pulse length, and create a smaller capsule in the same hohlraum as the Be330.



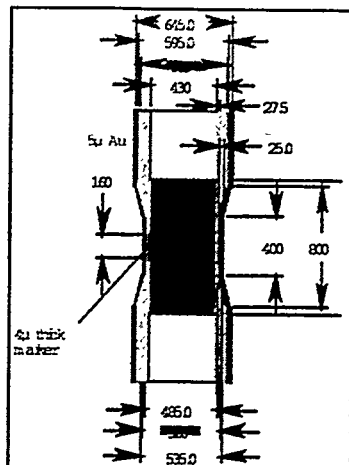
II. Instability Experiments

We need experiments as well as theory to increase our knowledge of NIF capsule behavior. Perturbation growth from surface shape asphericities and DT ice roughness can be studied. Radiation driven planar and cylindrical implosions are adding to our confidence in our calculations of growth of surface shape perturbations. Laser driven cylinders may be used to study inside surface perturbations simulating DT ice roughness. Radiation driven spherical implosions on the Omega laser can test models of instability growth from surface shape and finish, and possibly use DT ice.

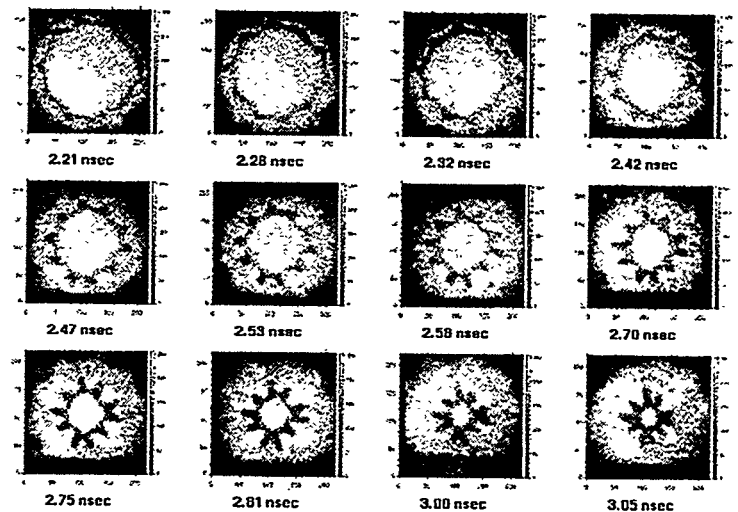
Nova experiments on aluminum/beryllium sandwiches are testing our understanding of the feed-out / feed-in process. Transmission radiography of the packages has proven quite successful in imaging the growth of perturbations placed on the surfaces away from the radiation drive. Side and backlighting measure internal perturbation growth as seen in this image. Richtmyer-Meshkov and Rayleigh-Taylor growth are visible. Preliminary results show agreement with Lasnex calculations.



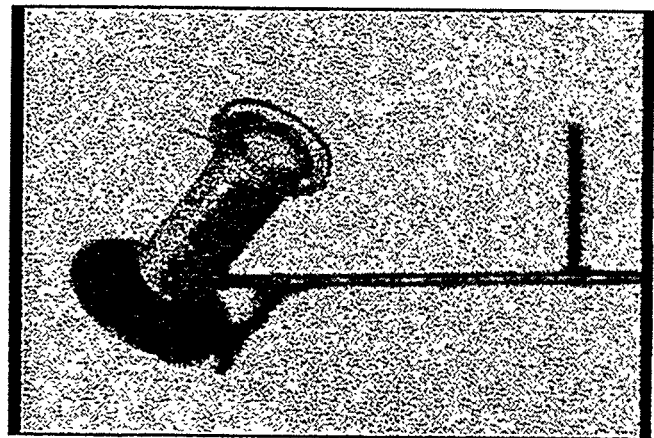
To study radiation driven instability growth in cylindrical geometry target fabricators built the complicated layered cylinders in hohlraums with sub-micron features show below using layers of brominated polystyrene on plain CH with chlorinated marker layers.



Time resolved X-ray images like those below have provided measurements of perturbation growth.



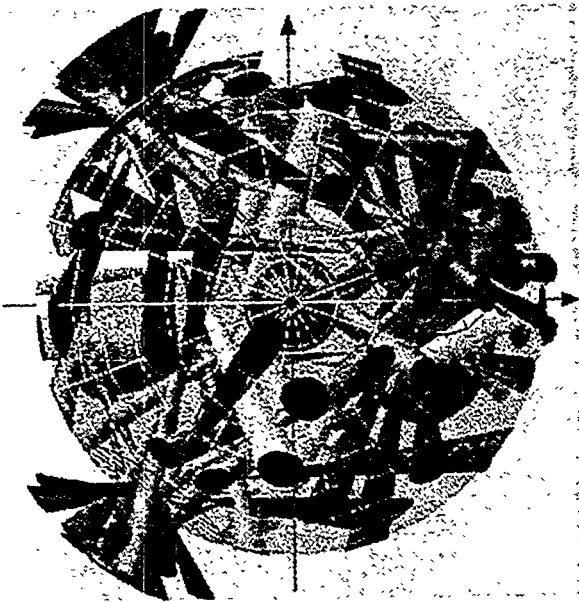
Recent (January 27-30, 1998) directly driven cylindrical implosion experiments on Omega were highly successful in creating higher convergence than those indirect drive experiments. Highly symmetric implosions were obtained using 50 drive beams and a ramped 2.5 ns pulse.



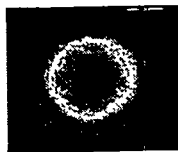
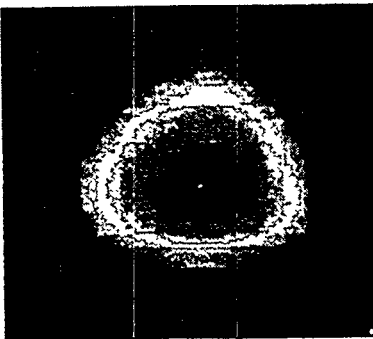
Future cylindrical targets will continue to stress fabrication capabilities. Directly driven cylinders for Omega will: 1) continue to study Rayleigh-Taylor growth from perturbations modes 10-40 with initial amplitudes of about 1 μm , 2) use perturbations on the shell inner surface, 3) study mixing of the shell interior with the foam, 4) study defects on the interior surface such as grooves and bumps, 5) use interior roughness to simulate (or actually use) DT ice, 6) and test colliding shells. New diagnostics will require new materials. Deuterated central foams will produce neutrons. Wires down the center line

will produce X-rays on shock collapse and stagnation. Very high Z (e.g Au) layers 0.5 μm thick on the inner surface as well as buried CD, Ti, and Cl doped tracer layers will help diagnose mix. Cylindrical experiments will not stop with the Omega laser, we envision indirectly driven cylinders twice as large for NIF.

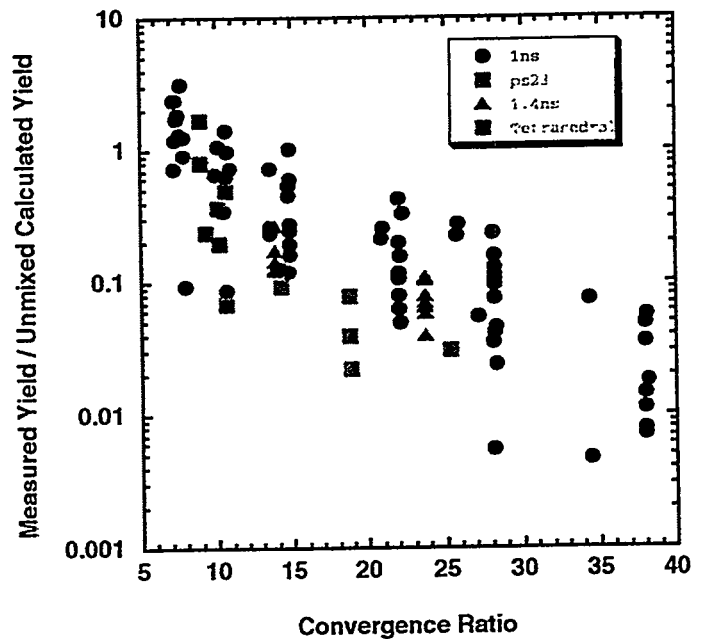
We are beginning spherical implosion experiments at Omega using a tetrahedral hohlraum and all 60 beams. The hohlraum is actually a sphere with beams entering through 4 laser entrance holes located at the corners of a tetrahedron as shown below.



The symmetry in these tetrahedral hohlraums is better than in a NIF cylindrical hohlraum, without relying on beam phasing. Calculations show this, but we have also controlled the symmetry by varying the laser entrance hole and hohlraum diameters. In one case we had the tetrahedral shaped implosion core seen below (it appears triangular in projection) and improved the symmetry to produce the smaller and more round implosion next to it.



Implosions in tetrahedral geometry have barely begun to explore one of the most important problems for ICF, the degradation of capsule neutron yield as it is converged more. This degradation is shown in the following graph which includes various data sets from the Nova laser experiments carried out by LLNL and tetrahedral implosions which to date have only tested convergences near 10. We believe this degradation is due to time dependent and 3-D asymmetries that have greater impact on target performance at high convergence, but we do not yet have experimental data to confirm this. An alternative explanation would be that high mode instability growth and mixing cause the degradation. The very symmetric tetrahedral hohlraums will allow us to test these hypotheses with very high convergence and excellent symmetry.



III. Experiments on Joints

Beryllium's high yield strength ($\sim 3.3\text{kBar}$) may allow it to contain DT at room temperature without bursting. Its high thermal conductivity simplifies cryogenic fielding. The challenge is to place DT inside with the minimal perturbation to the shell. Beryllium coating over mandrels and diffusion filling is being explored. A promising approach is brazing or autogenously bonding two machined hemispheres in DT gas. Both theory and experiments are required to determine just how thick a bond joint may be and what materials are acceptable for a NIF capsule. We have nearly completed the first set of experiments on joints in planar slabs. Cylindrical implosions will extend these to convergent geometries. Even spherical implosion experiments may be possible on the Omega laser by using $\frac{1}{2}$ scale NIF capsules in twice

normal size tetrahedral hohlraums. Simulations using the Rage computer code of a 1 μm aluminum joint in planar beryllium driven by the NIF pulse show a lag in the density and pressure front extending far from the joint. Nova experiments on 15 μm thick planar aluminum joints have begun to test our understanding. The details of aluminum joint behavior have been compared, but the images need better signal and resolution. Calculations show the shock front lags in aluminum joints and leads in CH joints out to many times the original joint thickness.

Real bonding technology is advancing faster than calculations or experiment can follow. Once actual joints in copper doped beryllium spheres are characterized, theory and experiment will have to determine whether they will be adequate. Previous experiments studied glue (simulated with CH) and aluminum braze joints. Current diffusion bonded Be/Cu joints use only 0.2 μm Cu, which diffuses into the beryllium, avoiding sharp boundaries. Cylindrical experiments can test our calculations of convergent effects using large defects. It may be possible to use $\frac{1}{2}$ NIF scale capsules directly driven by the Omega laser to test actual joints in hemispheres. Or it may be possible to test these capsules using X-ray drive in large tetrahedral hohlraums. These experiments could show defect hydrodynamics if not overwhelmed by other asymmetries.

IV. Summary

Target designers and experimentalists will be asking much from target fabrication specialists as we move along the path towards ignition on NIF. In the future we will be using increasingly complicated cylindrical targets with small amplitude sinusoidal perturbations on both surfaces, as well as bumps, grooves, and high Z layers. As Los Alamos moves its experimental program to the Omega laser, we will need: 1) improved Nova size CH and doped CH targets (with less target variability and more characterization), 2) half scale NIF beryllium targets to test joints (the burden is on theory and experiment to determine if the present joints are adequate), 3) cryogenic beryllium targets to study DT ice roughness, and 4) double shell targets to explore their failure modes. We will continue to want spherical NIF beryllium targets to be built and tested with yet more spherical surfaces (reduced asymmetries in modes 4 to 100) and greater strength (to hold more DT). The path to ignition holds many challenges for target fabrication science and technology.

References

1. D. C. Wilson et al., , Phys. Plasmas 5, 1953 (1998).
2. S. W. Haan et al., Phys Plasmas 2, 2480 (1995).
3. W. J. Krauser et al., Phys. Plasmas 3, 2084 (1996).

Production of a NIF-sized Be Alloy Capsule

R. W. Margevicius, L. Salzer, M. Salazar, D. Thoma,
C. Adams, M. Piltch, L. Jacobson, and L. Foreman

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Acknowledgments:

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contract number W7405-ENG36

General Atomics for radiography and sphere mapping

Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1998



Two Main Ignition Capsule Designs Have Fabrication Tradeoffs

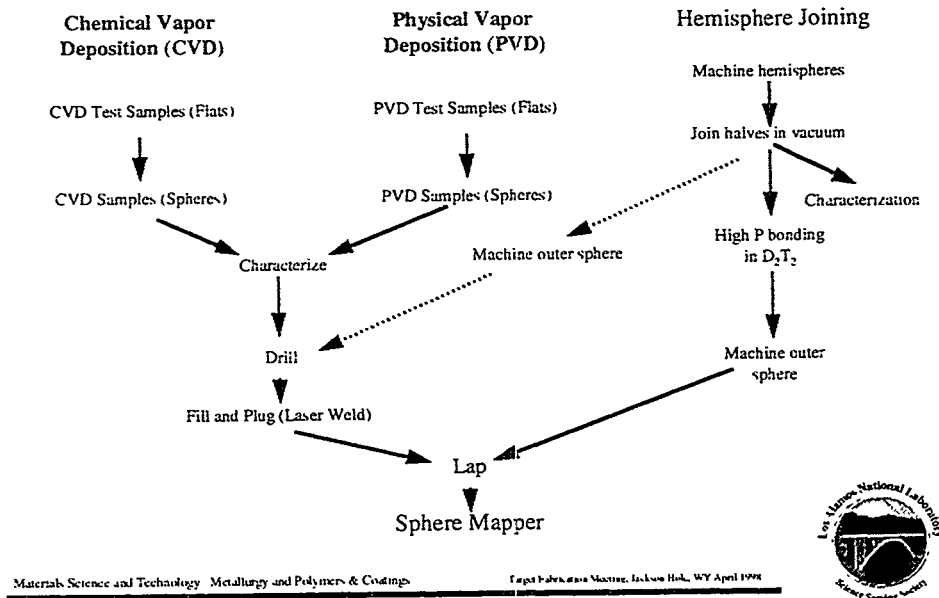
- Polymeric
 - Doped plastic ablator shell, 2 mm diam., 160 μm thick
 - Seamless permeation filling
 - Transparent
 - Thermal insulator
 - Cryogenic handling
- Beryllium
 - Be/Cu ablator shell, 2 mm diam., 155 μm thick
 - Filling by plug or joining under high pressure
 - Opaque
 - Thermal conductor
 - ✱ *Room temperature handling*

Materials Science and Technology: Metallurgy and Polymers & Coatings

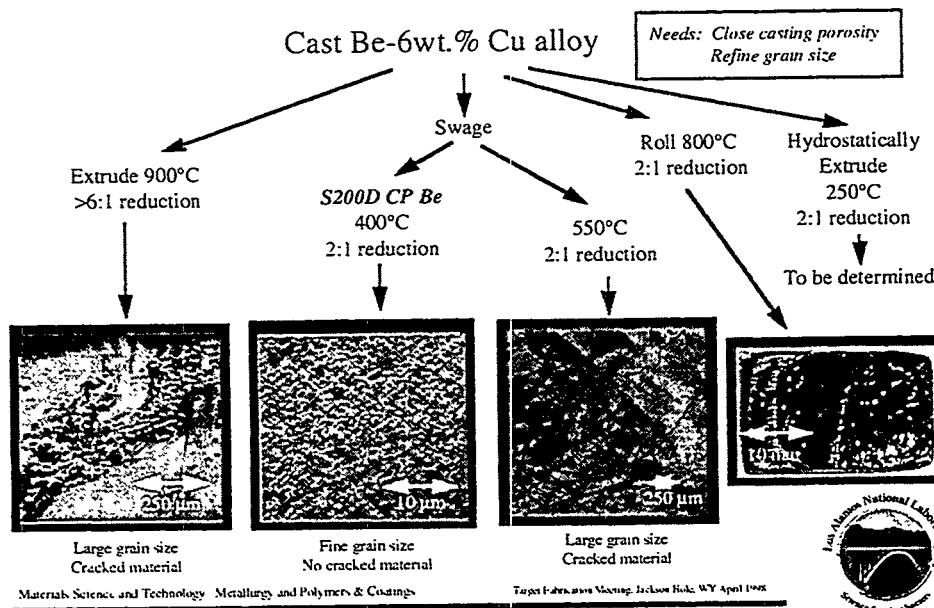
Target Fabrication Meeting, Jackson Hole, WY April 1998



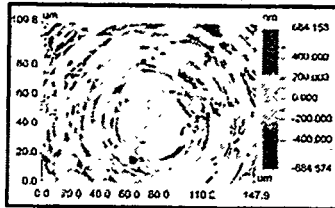
LANL Be Sphere Fabrication Paths



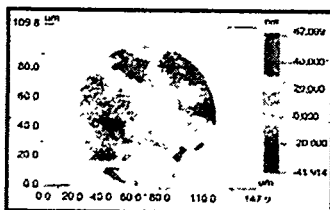
Be Thermo-mechanical Processing Routes



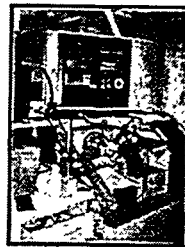
Precision Machining of Be: The Key to Target Fabrication



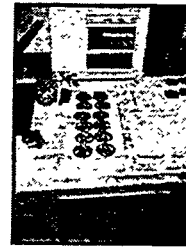
As-machined Surface
Roughness ~100 nm



As-polished Surface
Roughness ~10 nm



Air-bearing lathe
Computer control



Quick flip fixturing
Precision alignment

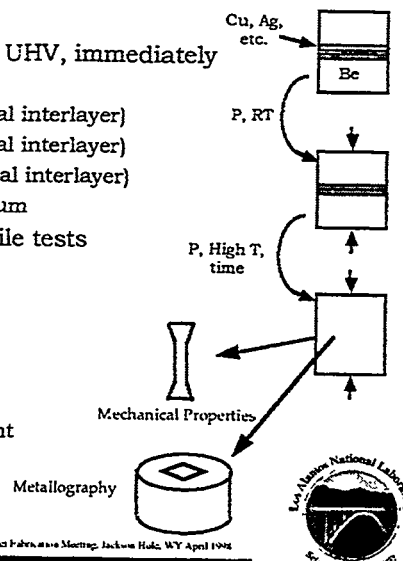
Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1998



Experimental: Bonding of Block Beryllium

- Bond large S200-D blanks
 - » Sputter-clean each faying surface in UHV, immediately deposit interlayer
 - » 0.02 μm Ag on each surface (0.04 μm total interlayer)
 - » 0.10 μm Ag on each surface (0.20 μm total interlayer)
 - » 0.10 μm Cu on each surface (0.20 μm total interlayer)
 - » 900°C for 6 hours, $\sim 10^{-6}$ - 10^{-7} torr vacuum
- Section samples for metallography, tensile tests
- Metallography
 - » Gaps
 - » Secondary phases
 - » Recrystallization
- Tensile tests
 - » Bond strength exceeds design requirement

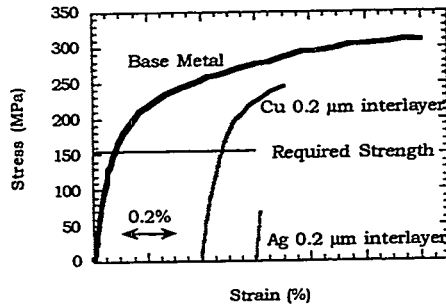


Materials Science and Technology: Metallurgy and Polymers & Coatings

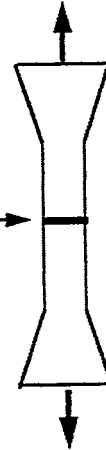
Target Fabrication Meeting, Jackson Hole, WY April 1998



Bond Strengths



Silver or
Copper
Interlayer



Sample	Prop. Limit (MPa)	0.2 % Stress (MPa)	Percent Base Metal
S200-D (base)	180	240	---
Cu interlayer	180	240	100
Ag interlayer	70	---	40

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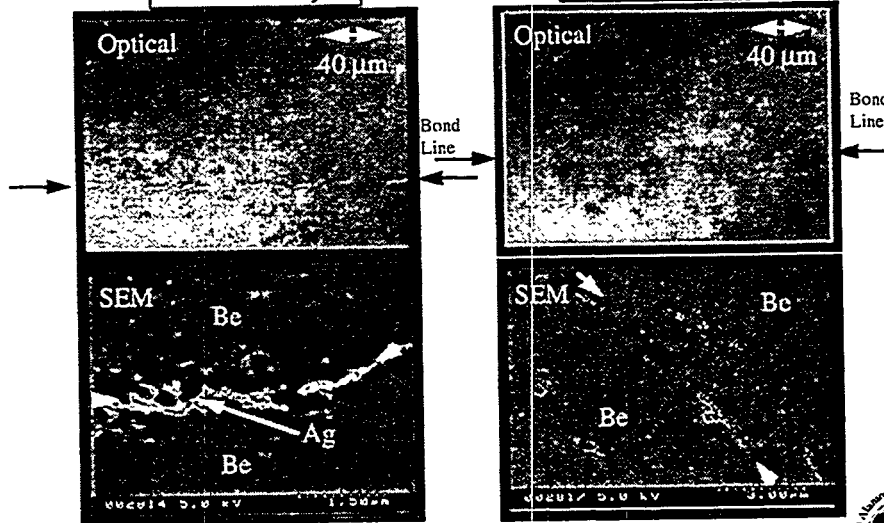
Target Fabrication Meeting, Jackson Hole, WY April 1998



Bonded Microstructures

Silver Interlayer

Copper Interlayer



Residual Ag, voids in bond line

Cu fully diffused, essentially void free

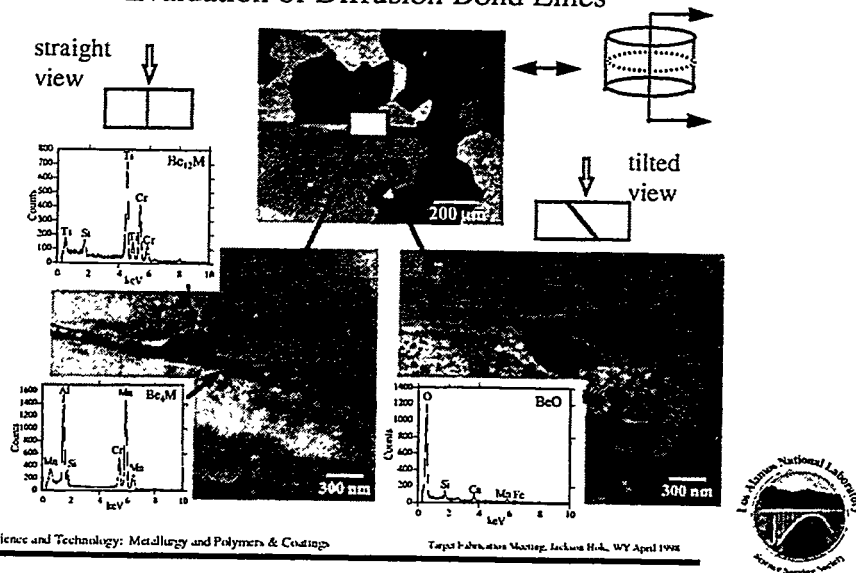
Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1998

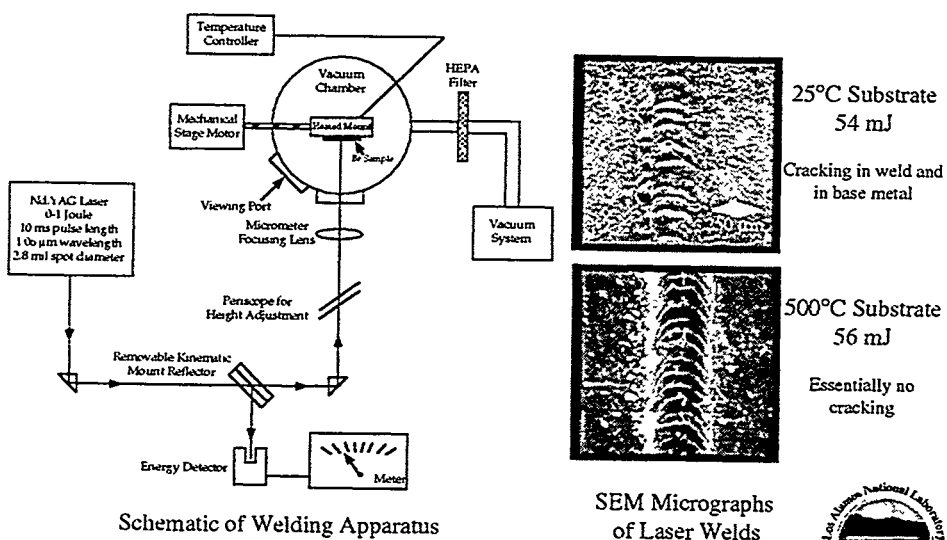


Transmission Electron Microscopy of Be Joint

Evaluation of Diffusion Bond Lines



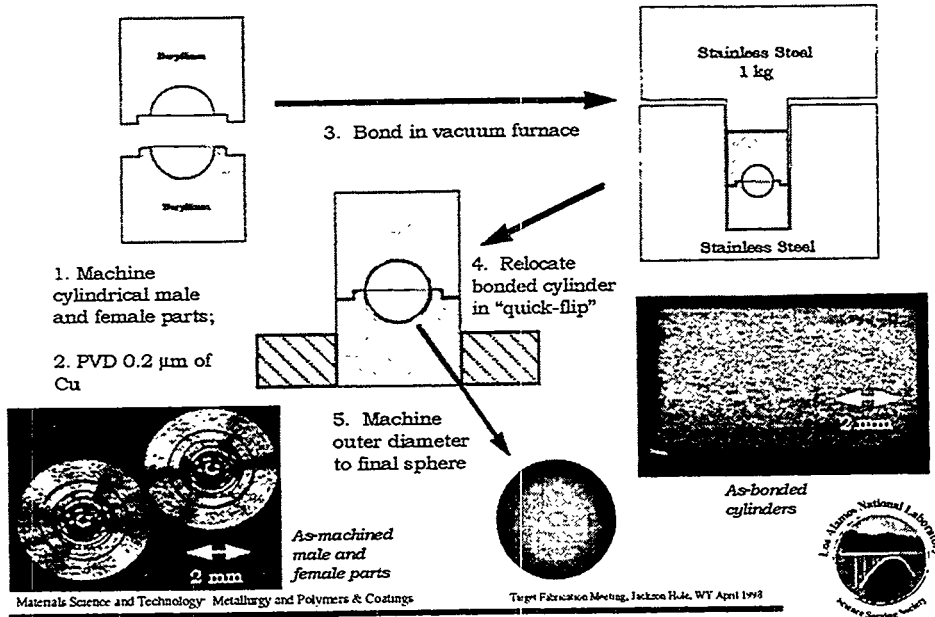
Laser Welding



Materials Science and Technology: Metallurgy and Polymers & Coatings

Tarap Fabrication Meeting, Jackson Hole, WY April 1998

Sphere Fabrication by Hemisphere Joining

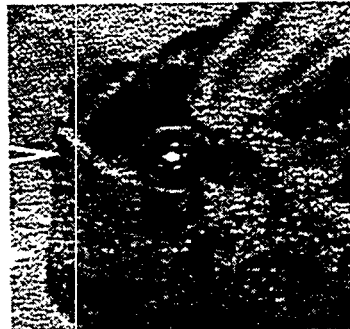


Vacuum-filled Be NIF Capsule



Overall excellent

- Wall thickness uniformity
- Joint properties
- Surface finish

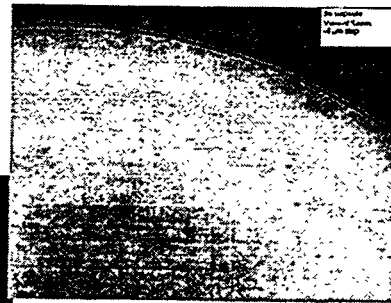


Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1998



Radiographs



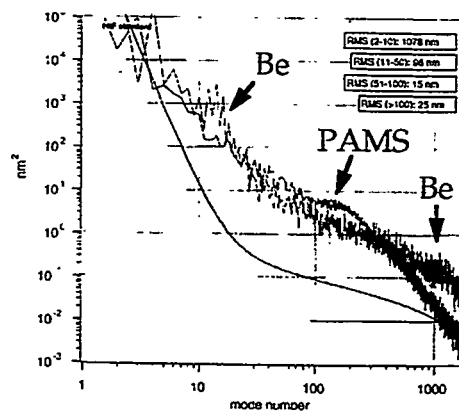
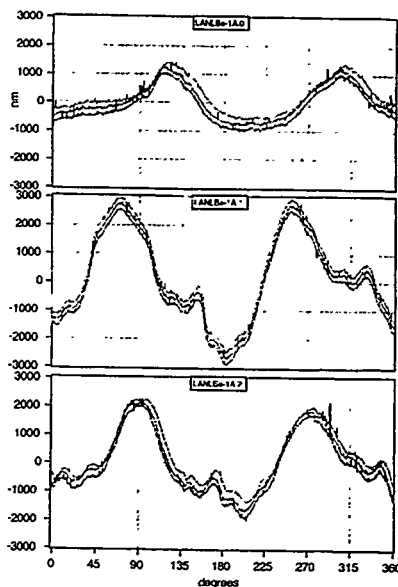
- Uniform wall thickness: excellent
 - ID machining
 - registry between halves
 - post-braze inner sphere location
- Nearly imperceptible bond joint
 - complete (?) Cu diffusion
 - no (slight?) step at joint



Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1-1993

Sphere Mapper Results



Power spectra Be v. PAMS:
slightly higher modes 1-30
slightly lower modes 30-300
slightly higher modes >300



Materials Science and Technology: Metallurgy and Polymers & Coatings

Target Fabrication Meeting, Jackson Hole, WY April 1-1993

Summary

- A vacuum-filled NIF target has been designed and fabricated.
- Surface finish on Be is between 10 and 100 nm.
- Brazing has produced joints with the right physical and mechanical properties.
- Methods for producing fine-grained, randomly oriented Be have had initial, partial successes.
- Laser welding is a viable means for the perforating and plugging of Be shells as well as possibly joining hemispheres.



Evaluation of boron-doped beryllium as an ablator for NIF target capsules



Randall McEachern
Craig Alford

University of California
 **Lawrence Livermore
National Laboratory**

Presented to:
Target Fabrication Meeting '98

Jackson Hole, WY
April 20, 1998

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Why boron?



- **Boron forms numerous intermetallic compounds with Be, making it a good candidate for creating disordered films. Fine-grained or amorphous films will generally be smoother than those with a coarser crystalline structure**
- **Smaller grains should yield a more homogeneous film—density fluctuations can seed Rayleigh-Taylor instabilities**
- **Because boron is a low-Z element, it can be added in larger quantities than heavier dopants**

Motivation2_TFSM '98.CV5

Experimental program to date



All films are deposited using three sputter guns: pure Be (DC), Be/6 at.% Cu (DC), and pure B (RF)

- **Flats: 5 μm thick films have been deposited on Si substrates with B concentrations varying from 3 at.% to ~30 at.%.**
- **Capsules: 5 to 10 μm coatings have been deposited on CH mandrels at concentrations of 10, 15, and 20 at.% B. At 15 at.%, both static and normally bouncing capsules have been used.**

Results1_TFSM '98.CV5

Outline



- 1) Motivation**
Why worry about high-frequency roughness? Why boron?
- 2) Experiments**
What we've tried so far
- 3) Results**
- 4) Conclusions (so far)**
- 5) Future directions**

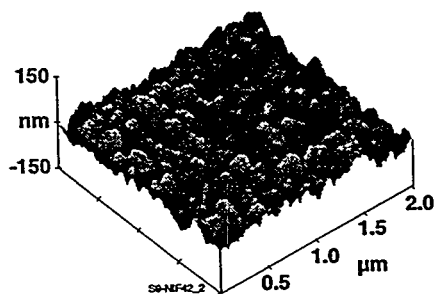
outline_TFSM '98.CV5

Why is reducing high-frequency roughness desirable?

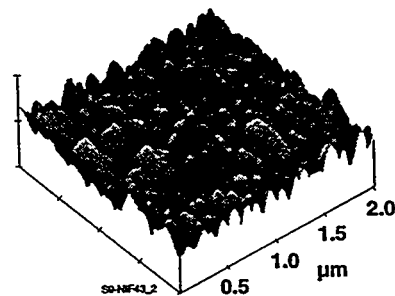


- **As deposited, Cu-doped Be typically has significant high-frequency roughness (modes > 1000)**
- **On a random surface, roughness at high modes contributes to roughness at all lower modes, so reducing high-frequency roughness also reduces the power at the intermediate modes that are probably more important for Rayleigh-Taylor stability**
- **Improving the as-deposited finish may reduce or eliminate the need for post-polishing.**

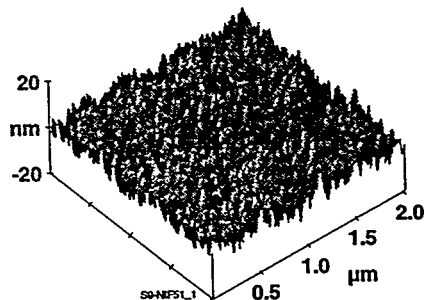
On flats, morphology changes abruptly at ~11 at.% B



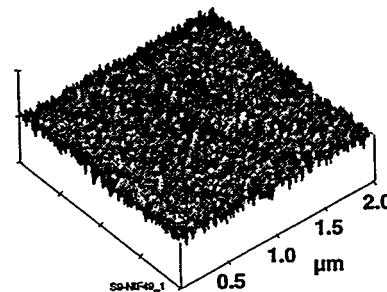
7 at.% B, $R_q=18.6$ nm



9 at.% B, $R_q=19.1$ nm



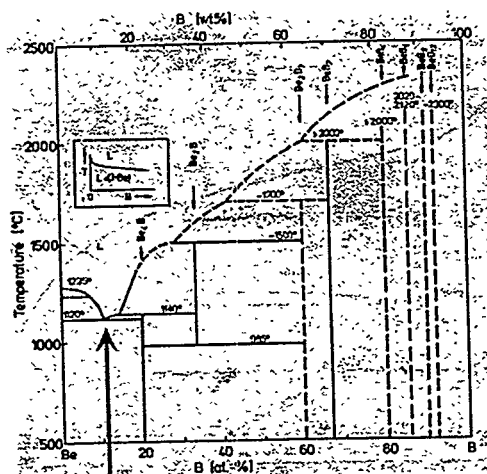
13 at.% B, $R_q=2.48$ nm



15 at.% B, $R_q=1.33$ nm

Results2_TFSM '98.CV5

Change in morphology on flats may be associated with the minimum in the Be-B liquidus curve

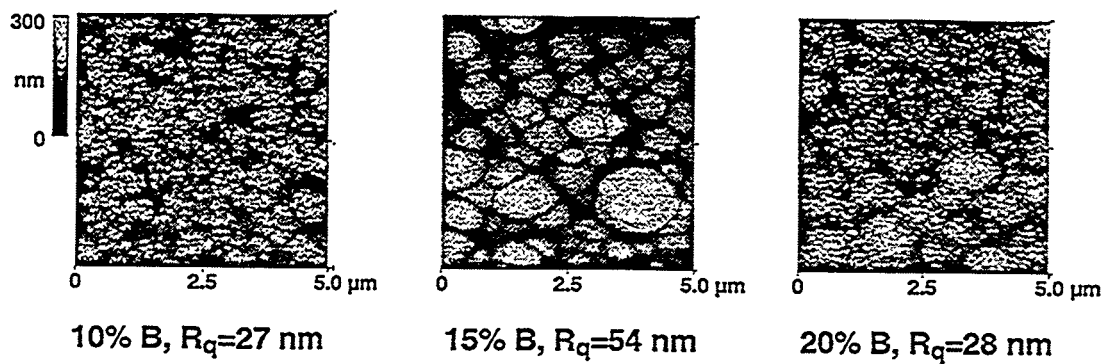


11 at.% boron

Morphology of B-doped coatings on capsules differs greatly from flats

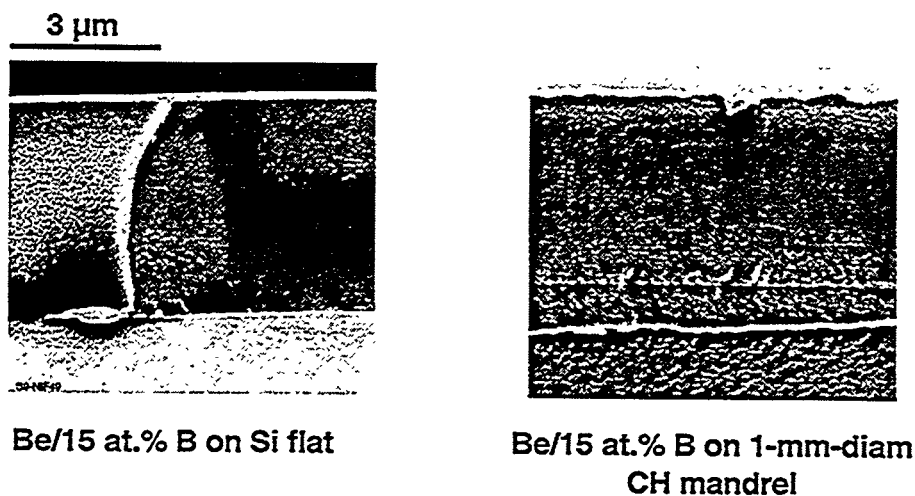


5 to 7 μm coatings on 1-mm-diam CH mandrels



Results3_TFSM '98.CV5

Cross sections are similar on flats and capsules at 15% B

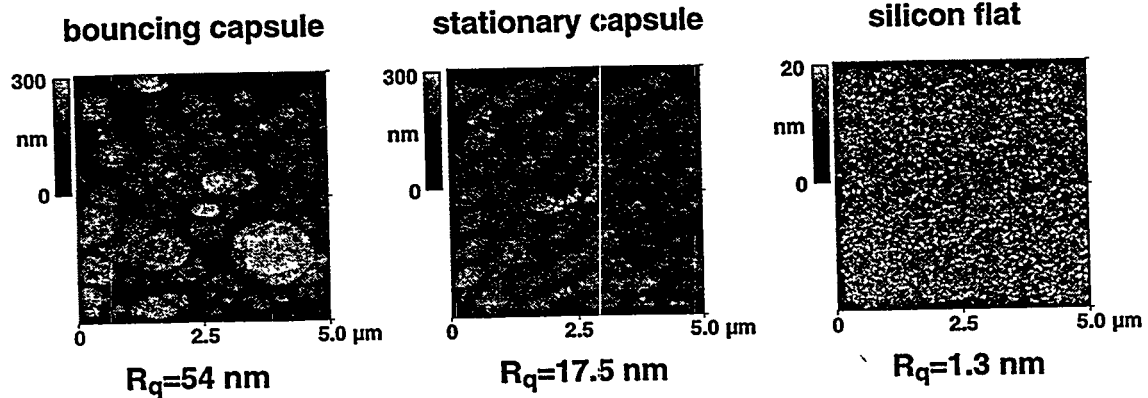


Results3a_TFSM '98.CV5

Stationary capsules are also different from flats



All films doped with 15% boron



Results4_TFSM '98.CV5

Dissimilar results on flats and capsules need to be understood



Important issues to be considered:

- **Substrate temperature**
During deposition on capsules, the substrate temperature could exceed 200°C. Silicon flats are probably at least 100° cooler.
- **Direction of deposition**
On a bouncing capsule, the flux of atoms is nearly isotropic. On flats, more atoms come in at near-normal incidence.

Other factors could also play a role:

- **Stress**
Under the coating conditions used so far, the deposited films appear to be under significant compressive stress.
- **Substrate**
Deposition on CH could be different than on oxidized silicon

Conclusions



- **Addition of boron at almost any level causes significant grain refinement**
- **Films are probably nano-crystalline, rather than amorphous, and may be highly temperature-sensitive**
- **Unusual morphology of capsule coatings remains to be explained, and may preclude use as an ablator material**

Conclusions_TFSM '98.CV5

Future directions

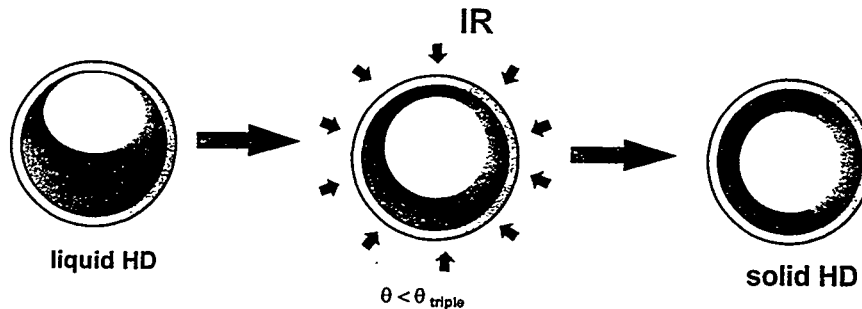


- **Deposit films at different temperatures using CH-coated planar substrates**
- **Investigate varying process conditions to reduce stress**
- **Investigate using layers of boron-doped material, rather than continuous doping**

FuturePlans_TFSM '98.CV5



Forming uniform HD layer by Infra Red heating



P.BACLET, G.MOLL, G.COLLINS, D.BITTNER, J.SANCHEZ, E.MAPOLES, S.LETTS, J.BURMANN and T.BERNAT

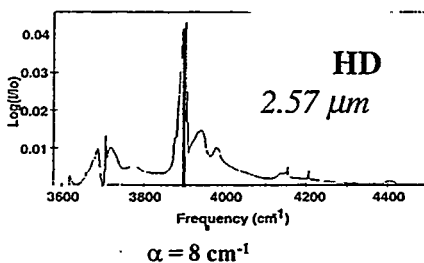
VADRAMOS
Laboratoire Micro-cibles



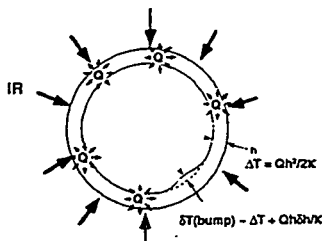
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE



Thermal gradient is generated by pumping infra-red absorption bands



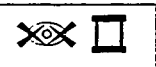
★ Absorption of IR light generates volumetric heating



★ IR heating is similar to β decay heating but $Q_{IR} \gg Q_{DT}$ and $\tau_{IR} \ll \tau_{DT}$

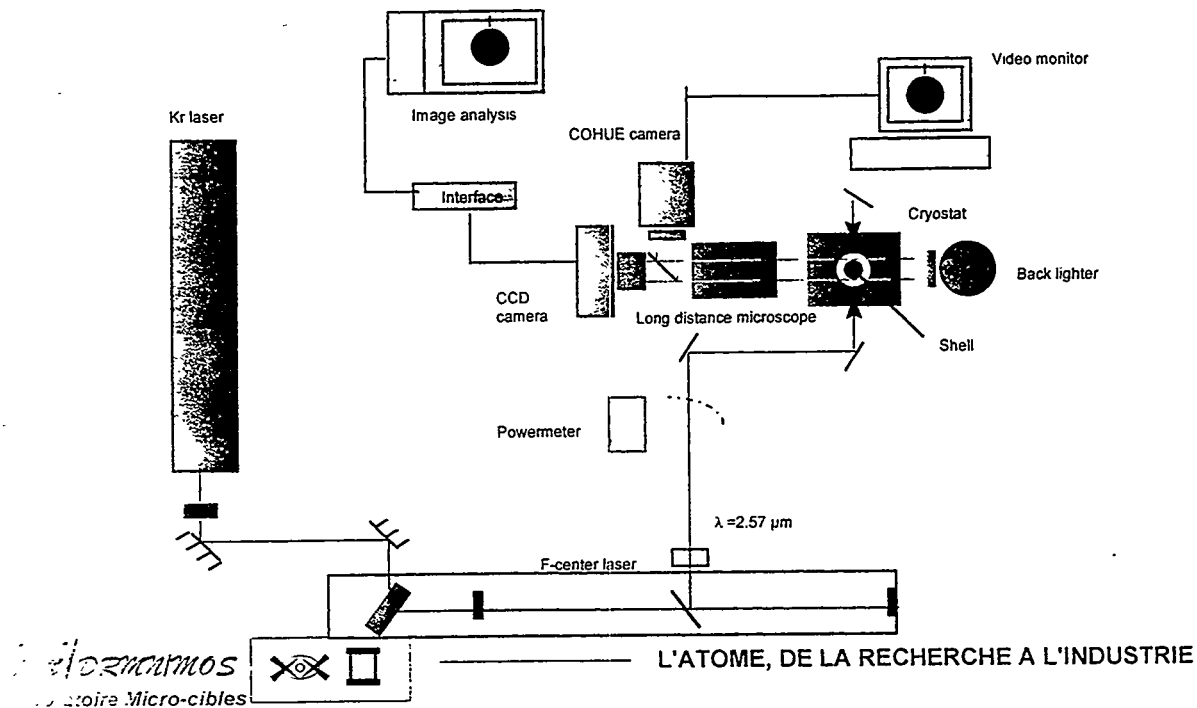
★ $[dT/dh] = Q_{IR} h/k$
thus IR can be used to reduce surface roughness

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Laboratoire Micro-cibles



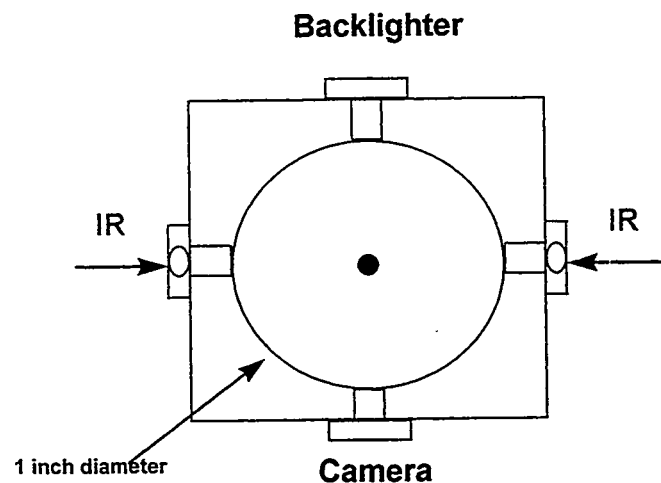
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

LLNL experimental apparatus

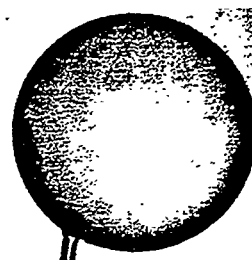


Integrating sphere designed by LLNL

★ Integrating sphere generates an uniform IR illumination



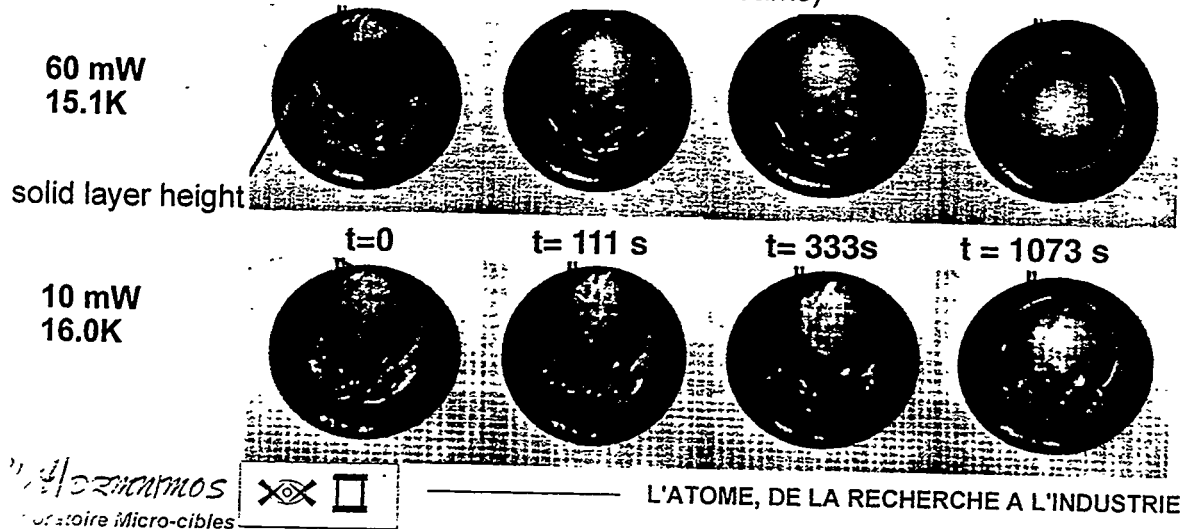
CD polymer shell is used to minimize IR absorption



1 mm OD
10μm wall
15 to 25 μm ID fill tube

Redistribution time constant measurements, τ

★ Fast freezing from liquid state and then apply IR to solid
(example with small masks on IR beams)



Time constant for several IR power

$$h = h_{inf}(1 - \exp(-t/\tau_{IR}))$$

$$\tau_{IR} = \rho \Delta H / Q_{IR}$$

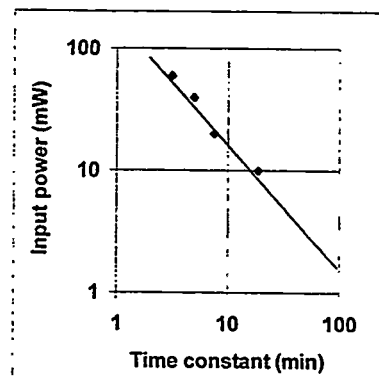
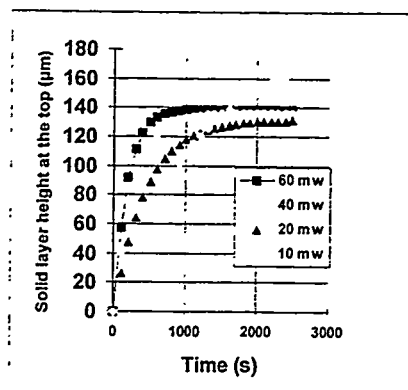
$$60 \text{ mW} \Rightarrow \tau_{IR} = 1/17 \tau_{DT}$$

$$10 \text{ mW} \Rightarrow \tau_{IR} = 1/2 \tau_{DT}$$

ρ : density
 ΔH : latent heat
 Q_{IR} : power absorbed per volume

$$\tau_{DT} = 26.1 \text{ min à } 15K$$

Time constants without masks

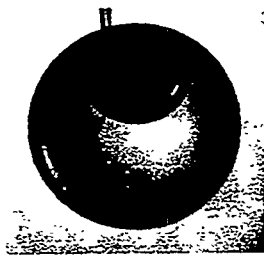




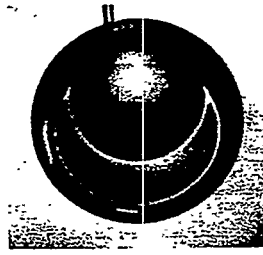
Surface roughness measurements

- ★ Apply IR to liquid and cool down to freezing onset

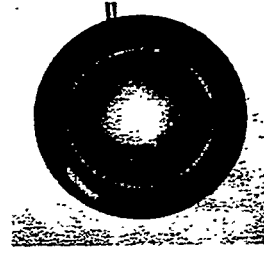
P= 18 mW



t = 0 , 16K



t=10 min, 15.9K



t = 13 min , 15.9K

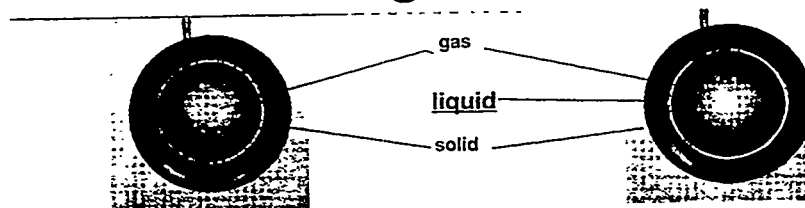
VALDORNIOS
Laboratoire Micro-cibles



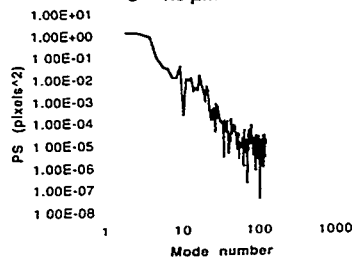
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE



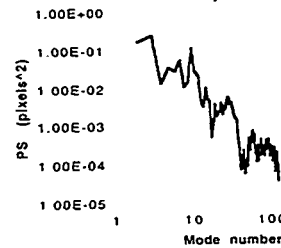
Liquid layer inside solid reduce the RMS roughness



P=47 mW
15.8 K
 $\sigma = 1.5 \mu\text{m}$



P=20 mW
15.9 K
 $\sigma = 0.9 \mu\text{m}$



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Laboratoire Micro-cibles

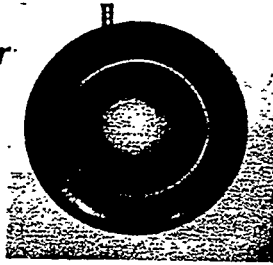


L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

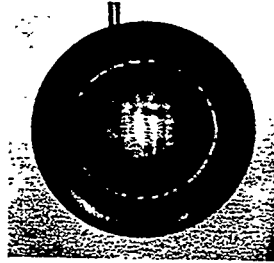


Degradation layers after turning off IR

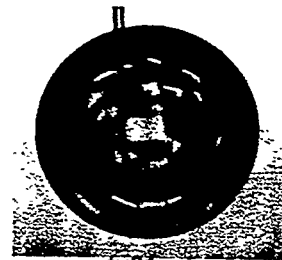
**Thick layer
and high IR power**
(50mW, 200 μ m, 15.7K)



t= 0

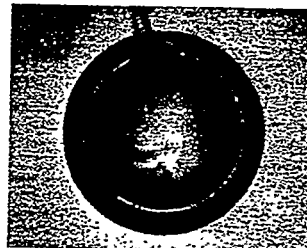
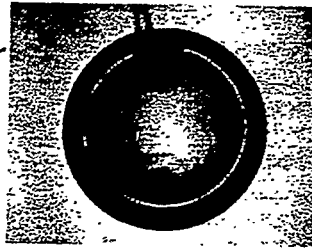


t= 12 min



t=31 min

**Thin layer
and low IR power**
(12mW, 100 μ m, 16K)



t=24 min

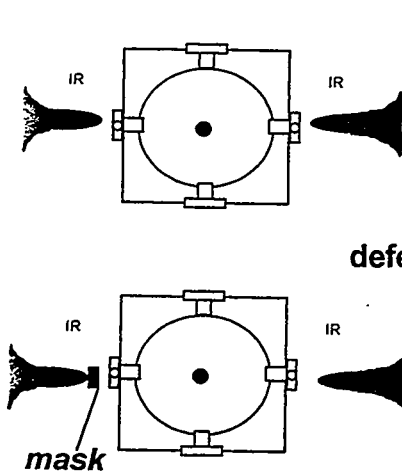
VA/DRMCMOS
Laboratoire Micro-cibles



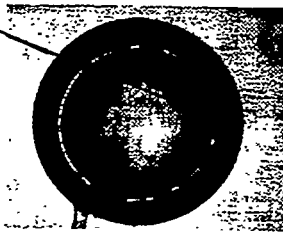
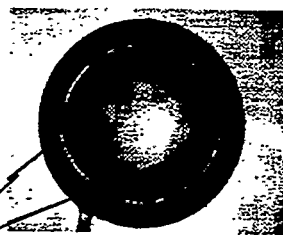
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE



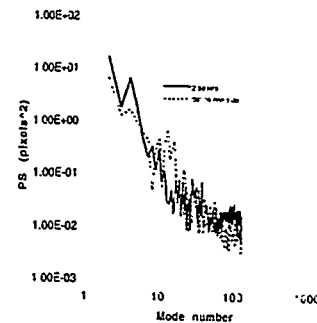
Defects due to IR injection are significantly reduced



defects



masks on one side



VA/DRMCMOS
Laboratoire Micro-cibles



L'ATOME, DE LA RECHERCHE A L'INDUSTRIE



To improve solid HD RMS inside the shell

- Temperature must be near triple point
- Put masks on the beam path and find out the right mask size to limit power loss
- Reduce asymetry from the fill tube by using a small fill tube



CONCLUSIONS

- IR heating forms and smooths HD layer in thin plastic shell
- Experiments are needed to correlate the RMS roughness to IR intensity in the shell
- More work is needed to better understand the layer degradation after turning off the IR power
- CEA planes for the next year to built an IR experimental set up for HD, D₂ and DT



Thin sputtered glass permeation barrier on plasma polymer shells

Abbas Nikroo
David Steinman
David Woodhouse

12th Target Fabrication Specialists' Meeting
April 1998
Jackson Hole, Wyoming



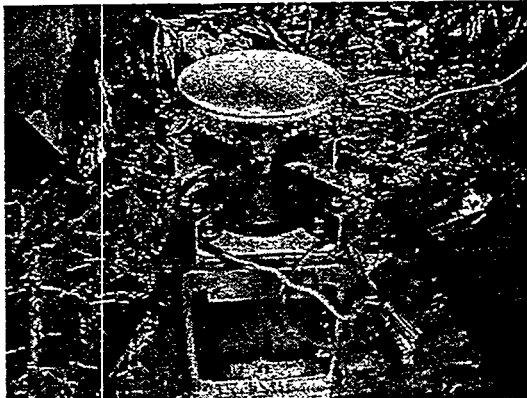
We explored the possibility of using sputtered glass as a permeation barrier

- Polyvinylalcohol (PVA) has been used as a permeation barrier for Nova targets
- Unfortunately, the PVA coating process has a very low yield (3 %).
- PVA coatings are in addition "lumpy" and result in undesired wall thickness variations.
- Glass shells are excellent containers for D_2 at room temperature .
- D_2 can be permeated through glass" quickly" at >200 C.
- Can we bounce coat shells in a glass sputtering system ?
- Will the coatings have properties similar to thermally prepared glass shells ?
- How thick a glass layer is needed ?

Coatings were carried out in a multi-user sputter coating machine



Temescal System



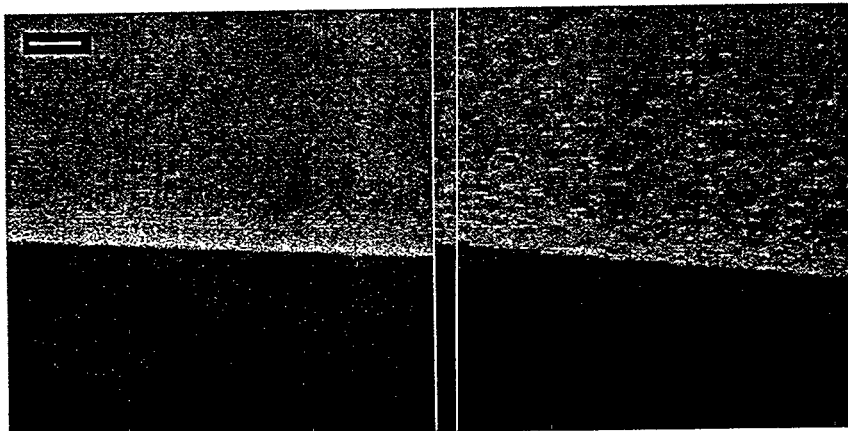
Electromagnetic Shaker

- 99.95 % pure quartz target was used.
- Sputtering was carried out using 13.6 MHz RF source
- Input power of 500 W was used for all runs.
- An electromagnetic shaker with an attached bouncer pan was used for shell agitation.
- Shaker was driven at 50-1000 Hz.
- Substrates were $\approx 900 \times 20 \mu\text{m}$ GDP shells and Si wafers.



Coatings at lower pressures yielded the densest coatings on flats

Scale
bar
= $3 \mu\text{m}$

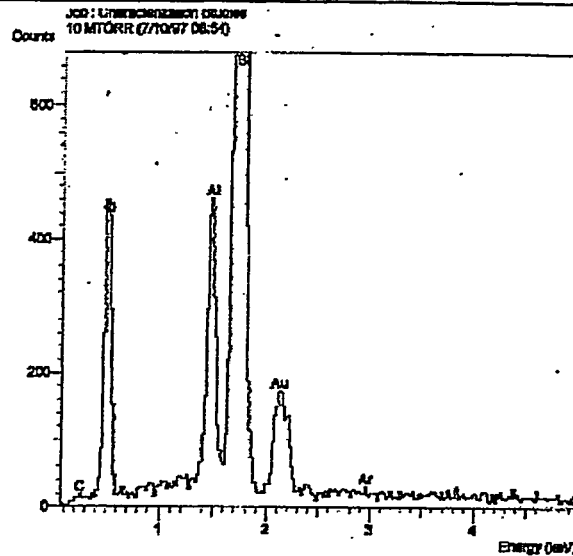


2 mtorr

10 mtorr

- In our system, the plasma could not be sustained reliably at pressure below 2 mtorr.
- Therefore, most coatings were performed at 2 mtorr

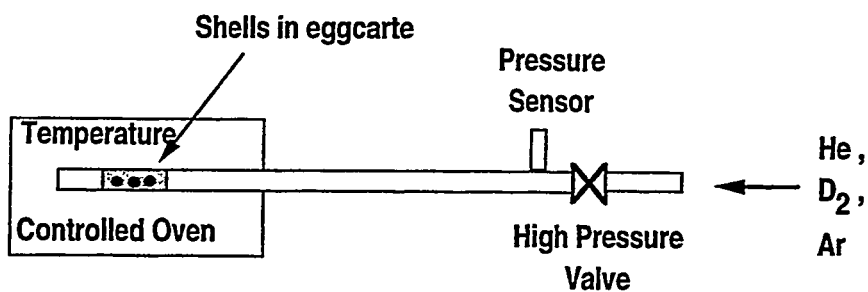
EDAX analysis of the coatings showed a small amount of aluminum in the coatings



- The aluminum target clamp was being sputtered as well as the quartz target.
- The problem appears to be particular to our coater.
- This contamination was lowest at the lowest background pressures. That corresponded to the regime we were working in (≈ 2 mtorr)



Shells were filled at elevated temperatures with the desired gases



- Shells were filled at 200 C to avoid decomposition of the inner GDP mandrel.
- Appropriate steps were taken to avoid buckling shells in the fill process.



The coating were tested by measuring the permeation half-life of shells to various gases

- The half-lives of shells were measured in several ways:

Mass Loss:

$$M_f = M_0 + \Delta M e^{-(t/\tau)}$$

Shell mass could be measured to better than 1 μg

Diameter shrinkage:

$$d_f = d_0 + \Delta d e^{-(t/\tau)}$$

Shell diameter could be measured to better than 1 μm

Direct outgassing in a sealed volume:

$$P_f = P_0 (1 - \Delta P e^{-(t/\tau)}) + ct \quad (ct) \text{ accounts for outgassing of chamber walls}$$

XRF counts (Argon Only):

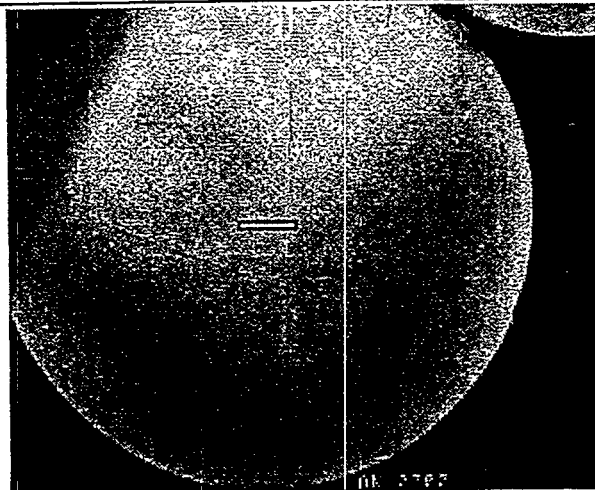
$$c_f = c_0 e^{-(t/\tau)}$$

Amount of Ar remaining in shells can be measured by XRF



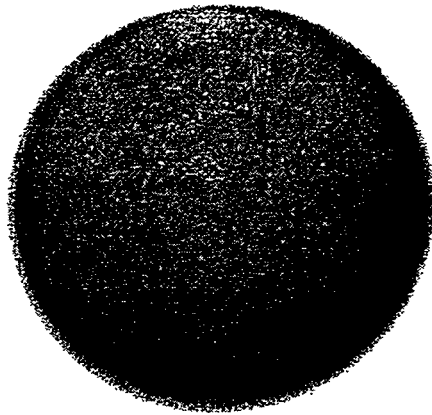
Placing GDP shells too close to the sputter gun resulted in cracking of the glass coating

scale bar = 100 μm



- $\approx 3 \mu\text{m}$ glass coating on a 1 mm shell
- The glass coating developed a long crack during deposition. The GDP mandrel was intact, but enlarged.

0.2 μm thick coatings developed tiny microcracks all around the shell

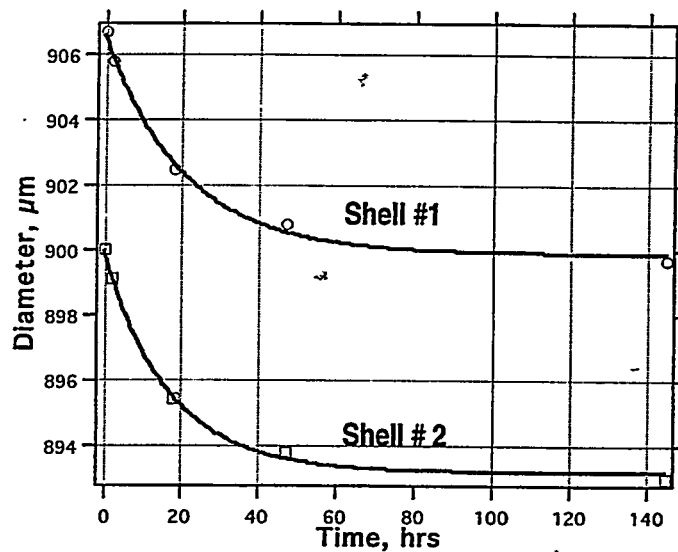


0.2 μm of sputtered glass on a 1 mm diameter GDP shell

- The cracks were easily visible optically .



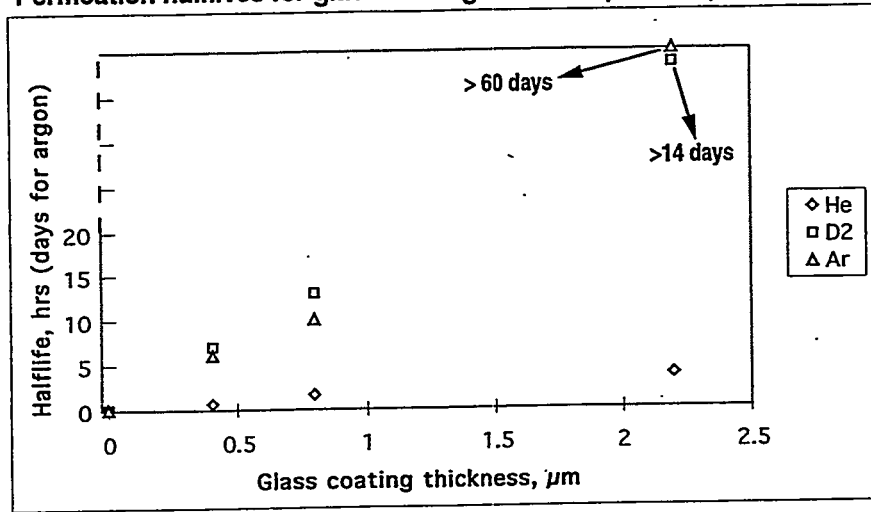
The results from the various permeation rate measurement techniques were consistent



- Sample of the diameter shrinkage of two shells initially filled with 40 atm of D_2
- Mass and direct outgassing measurements gave similar results.

Permeation rates of various gases through sputtered glass coatings were not as expected

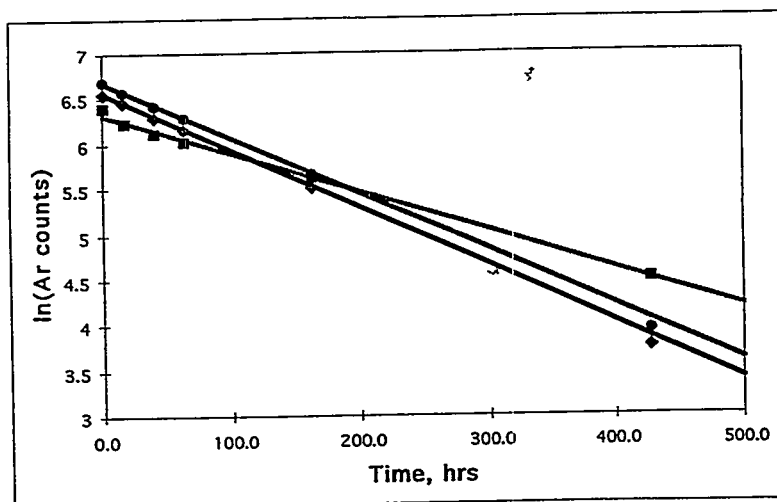
Permeation halflives for glass coatings on $\approx 900 \mu\text{m} \times 20 \mu\text{m}$ GDP shells



- Coatings thinner than $\approx 2 \mu\text{m}$ did not hold D₂ very long
- However, He permeation rates were the same as thermal glass.
- Argon could be permeated into coatings of $2 \mu\text{m}$ or less at 200 C, whereas thermal glass is virtually impermeable to argon even at much higher temperatures



Permeation rate of argon out of the glass coated shells did not change as the argon pressure decreased inside the shell

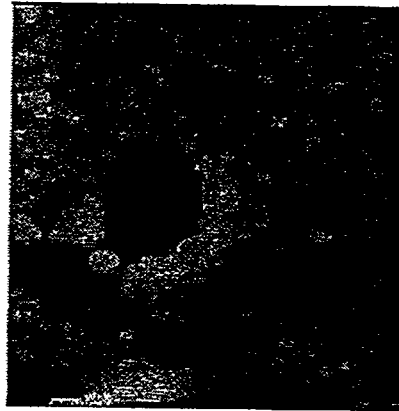


- Permeation through microcracks should decrease as the pressure inside the shell decreases.
- Argon permeation occurred with a single time constant for initial fill pressures of up to 10 atm.

Scanning AFM image of the coating revealed a dense nodular structure with apparent pinholes



SEM image; scale bar = 1 μm



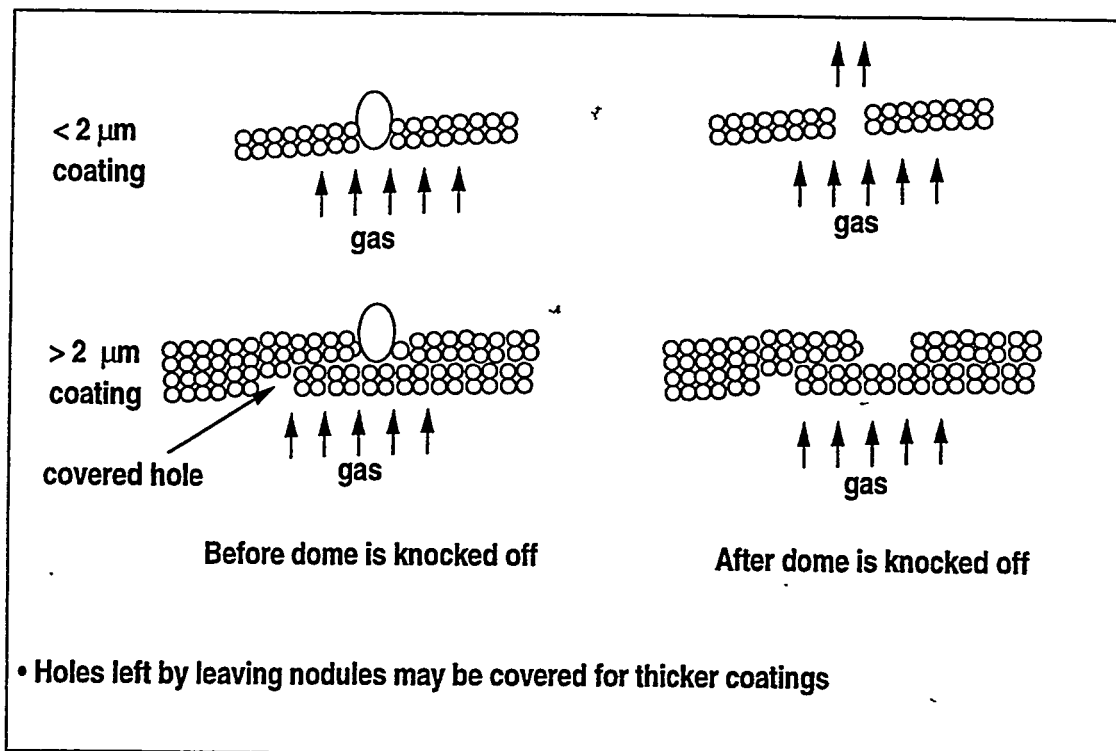
2 μm coating

5 μm x 5 μm AFM scan

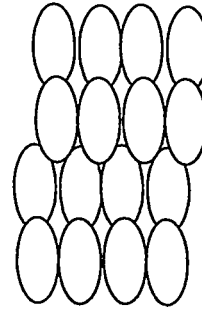
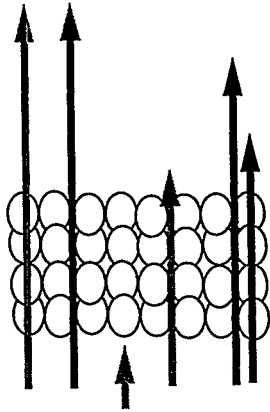
- The small pinholes could also be seen in SEM images of the coatings as well.
- Pinholes may be holes left by leaving nodules.
- For thicker coatings (>1 μm) an underlayer of glass coating could be seen in the AFM scans.



Faster gas loss through thinner coatings may be through holes left behind by larger nodules knocked off the coating



Permeation through the grain boundaries may be responsible for argon permeation through the coatings



Displaced grains in thicker coatings

Helium can permeate through the grains and grain boundaries

Deuterium can also permeate through the grains and grain boundaries, but permeation through the grain boundaries is faster.

Argon can permeate out through the numerous grain boundaries

Displaced grains in thicker coating may lead to a tortuous route out of the coating for D_2 and Ar



Sputtered glass coatings are good permeation barriers at $\geq 2 \mu\text{m}$ thickness

- In our system, coatings thinner than $2 \mu\text{m}$ appeared to be too permeable to D_2 for use for ICF targets.
- Coatings thicker than $2 \mu\text{m}$ appear to be sufficiently impermeable to D_2 to be useful for ICF targets if needed.
- The thicker ($\approx 2 \mu\text{m}$) sputtered glass coatings are permeable to argon at $\approx 200 \text{ C}$. This allows using argon as a diagnostic gas.



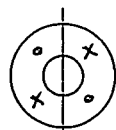
Progress in the Ultrasonic Characterization of ICF Targets

Thomas J. Asaki and Thomas C. Hale
Los Alamos National Laboratory

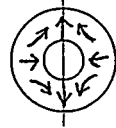
Target Fabrication Meeting '98
Jackson Hole, Wyoming

This work is supported by the U.S. Department of Energy
under contract number W7405-ENG36

Vibrational Resonant Structure of Fluid-Filled Shells



Toroidal Modes
(shear motion)
(no fluid motion)
(shape preserving)



Spheroidal Modes
(shear and compressional motion)
(solid and fluid motion)
(shape distorting)

Materials with large acoustic impedance mismatch
(e.g. DT vapor and Be/Cu)

→ Spheroidal Shell Modes
(elastic motion of free shell)

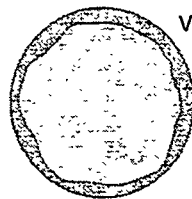
→ Acoustic Cavity Modes
(fluid motion within rigid cavity)

Progress in the Ultrasonic Characterization of ICF Targets
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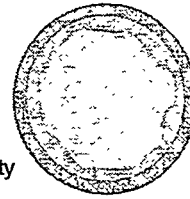
The elastic/fluid resonances of spherical shells provide information on a wide variety of target properties:

1. Elastically-driven shell modes provide shell properties
 - material homogeneity
 - joint and bonding quality
 - concentricity and symmetry
2. Acoustic cavity modes provide gas and cavity properties
 - fill density and pressure
 - low-mode cavity geometry
 - low-mode observation of beta-layering

Acoustic Resonances of an Irregular Cavity (Boundary Perturbation Theory)



Vapor-filled cavity



Beta-layered cavity

Geometric boundary: $r = a \left[1 - \sum b_{\ell m} Y_{\ell}^m \right] ; \quad b_{\ell m} \ll 1$

Acoustic resonances: f_{ns}

n is the order of the wave equation solution and
 s is the index of the zeros for a given order:

$$j_n'(2\pi f_{ns} a / c) = 0$$

Acoustic Resonances of an Irregular Cavity (cont.)
(Boundary Perturbation Theory)

$$r = a \left[1 - \sum b_{\ell m} Y_{\ell}^m \right] \quad f_{ns}$$

Radial ($n = 0$) and nonradial ($n > 0$) mode shifts $\sim b^2 \Rightarrow$ gas properties

Nonradial ($n > 0$) mode splitting $\sim b \Rightarrow$ cavity shape

Acoustic modes of order n are affected by boundary distortions of order ℓ such that $\ell \leq 2n$ and ℓ even.

Any acoustic mode $[n, s]$ is only affected by a finite number of even order boundary perturbations $[\ell, m]$

BE31-n Target Series
(1.05 mm inner radius; 3.00 mm outer radius)
(adhesively bonded hemispheres [Salazar])

$$b_{\ell 0} \quad r = a \left[1 - \sum b_{\ell 0} Y_{\ell}^0 \right]$$

ℓ	Target #1	Target #2	Target #3	Target #4	Target #5	Target #6
1					+0.002	-0.010
2		-0.011	-0.022	+0.002	-0.015	
3					+0.012	-0.022
4				+0.024	-0.012	
5						-0.004
6				+0.004		
7						-0.022
8				+0.021		
9						-0.001
10				-0.001		
11						-0.016
12				+0.014		

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Degeneracy Breaking in Nearly-Spherical Cavities

Axisymmetric Cavities

f_{ns} splits into $n+1$ modes out of a possible $2n+1$.

This is a diagnostic of axisymmetric cavities.

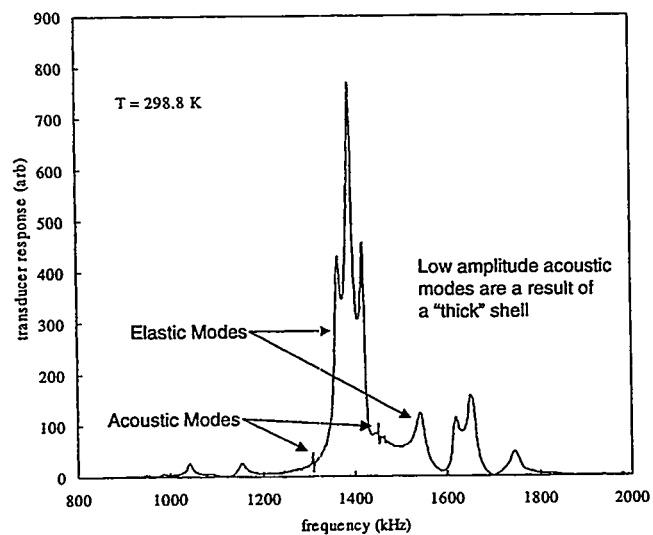
Laterally Misaligned Axisymmetric Hemishells

f_{ns} splits into $2n+1$ modes described by the single

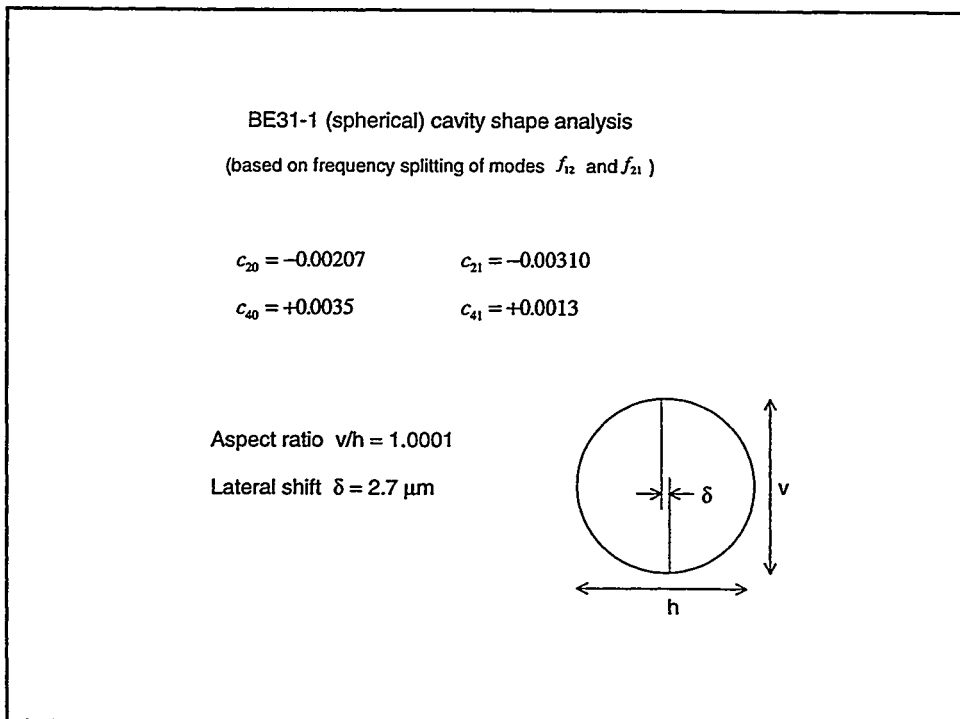
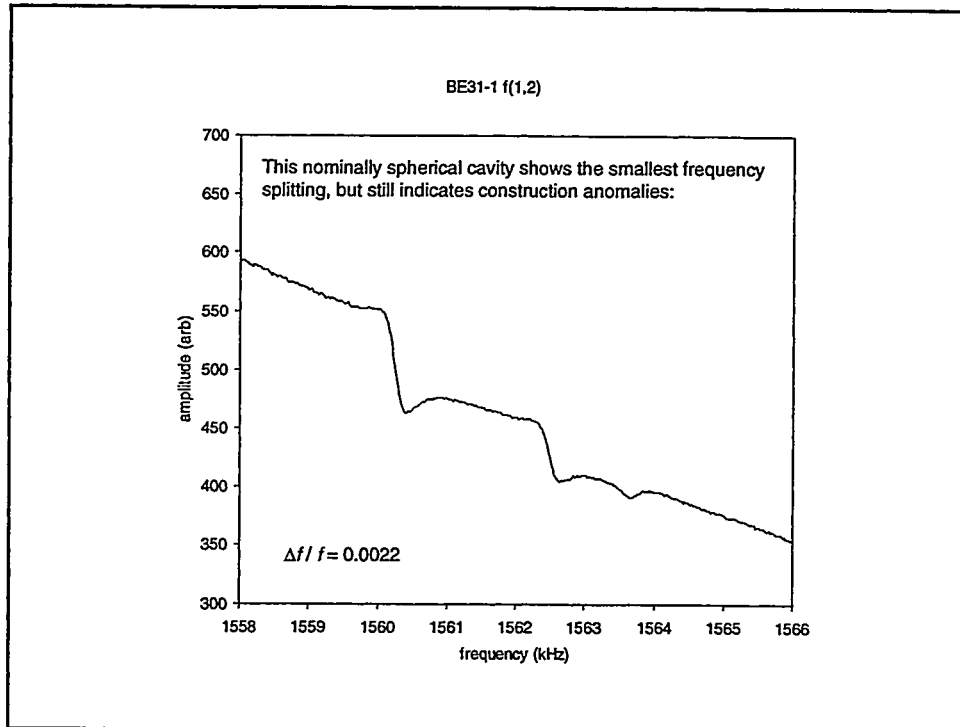
additional (non-axisymmetric) coefficient b_{21}

$$r = a \left[1 - \sum b_{\ell m} Y_{\ell}^m \right]$$

BE31-2



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Acoustically Determined Fill Pressure

	BE31-1	BE31-2	BE31-3	BE31-4	BE31-5	BE31-6
T_0 (K)	292.5	296.0	295.4	295.8	-296	296.1
P_0 (psia)	4066	4084	4031	4092	-4050	4090
P_A (psia)	4407	4569	4553	4419	1996	5225
σP_A (psia)	7	9	545	290	3	18
N	5	7	3	3	3	5

P_0 and T_0 are the reported initial fill conditions.

P_A is the acoustically measured fill pressure.

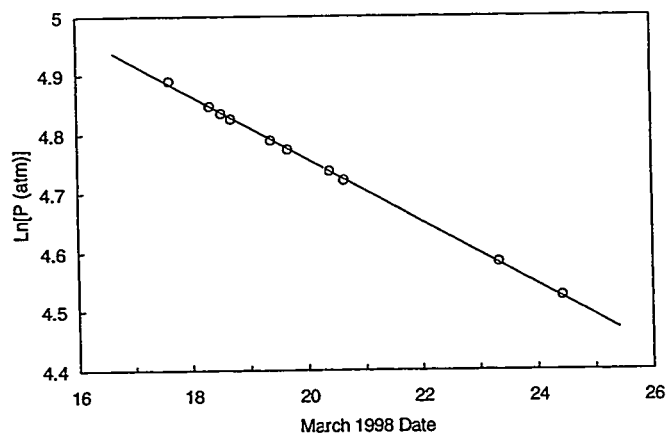
σP_A is the standard deviation for the N measurements.

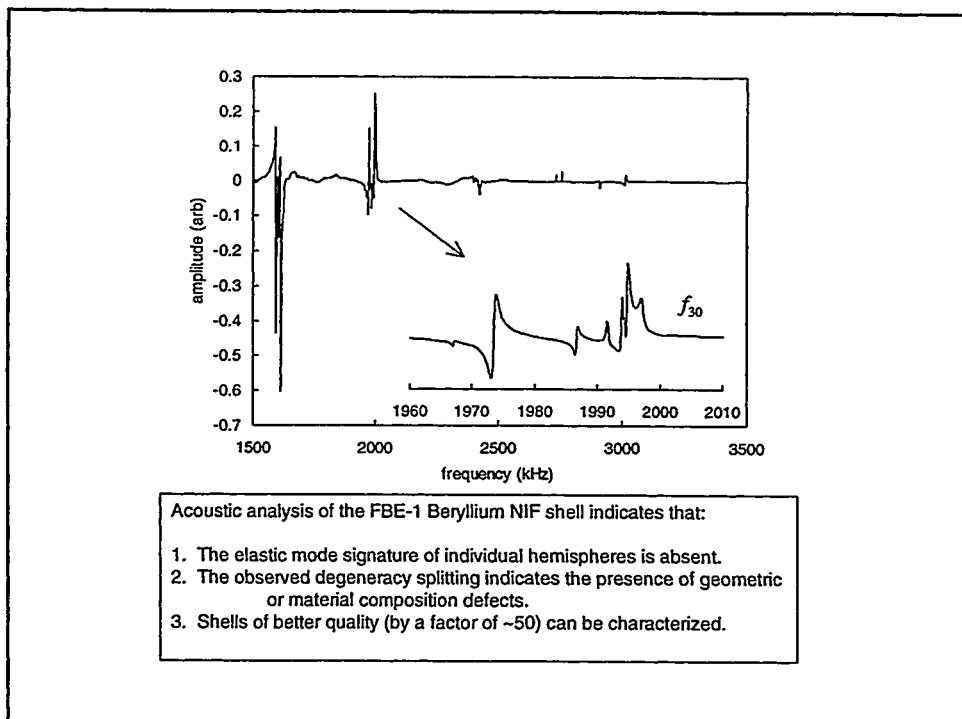
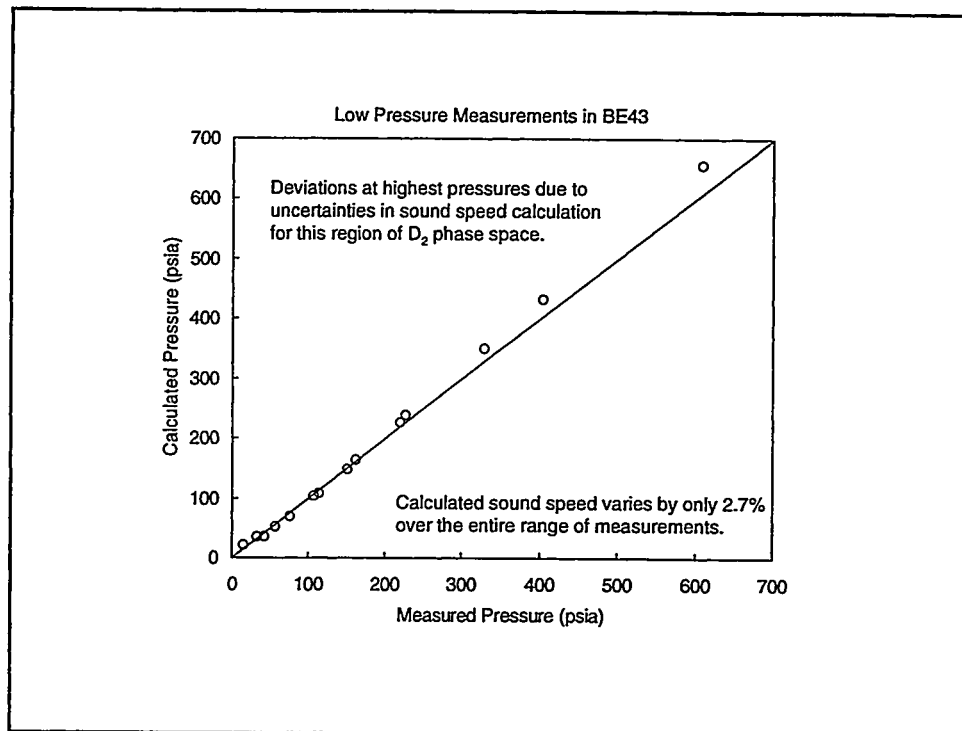
Target #5 leaks with a "half-life" of 13 days.

Targets #3 and #4 were significantly off spherical yielding unreliable P_A .

$P_A > P_0$ due to final target assembly procedure.

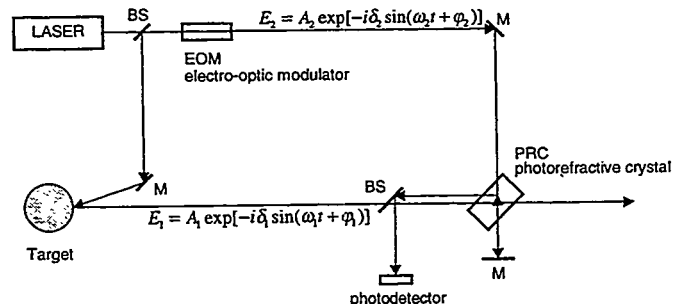
BE31-5 Leak Analysis





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Interferometrically-based non-contact vibration analysis



S/N = 100 at 1 Å displacement amplitude (specular flat surface)
non-contact excitation and detection

Summary

1. Initial fill pressure and density are calculable to within 0.5% through the frequencies of the cavity resonances.
2. Low-mode cavity shape information is obtainable through the observed resonance mode splitting. The BE31-n series appears to be highly non-axisymmetric and complete analysis is pending.
3. Initial acoustic examination of FBE-1 indicates that the bond quality is excellent, and that geometric and/or material composition defects are observable.
4. Enhanced vibrational mode detection sensitivity is being pursued through an interferometric photorefractive technique.

References

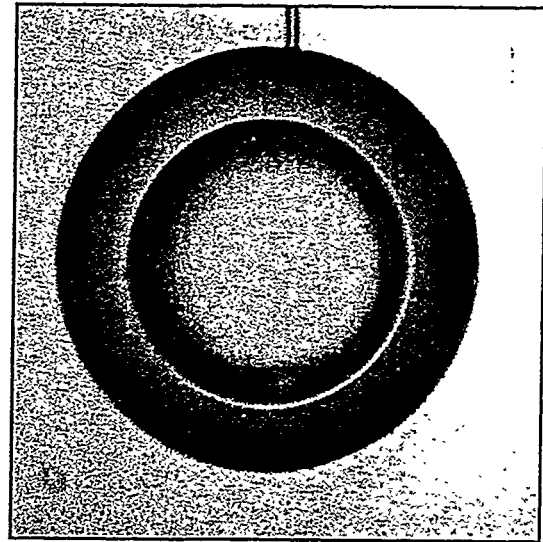
- Asaki, TJ, *et al.* "Ultrasonic characterization of inertial confinement fusion targets," *Fusion Tech.* 33, 171 (1998).
- Migliori, A and Sarrao, JL, "Resonant ultrasound spectroscopy," John Wiley & Sons, New York (1997).
- Alterman, Z, *et al.* "Oscillations of the earth," *Proc. Roy. Soc. London* 252, 80 (1959).
- Mehl, JB, "Acoustic resonance frequencies of deformed spherical resonators. II," *J. Acoust. Soc. Am.* 79, 278 (1986).
- Asaki, TJ, "Ultrasonically determined fill pressure in closed spherical shells," *Fusion Tech.*, to be submitted April 1998).

Progress in the Ultrasonic Characterization of ICF Targets
Asaki and Hale-- Los Alamos National Laboratory



J. Sater, J. Pipes, G.W. Collins,
B. Kozioziemski, D. Bittner, E.R. Mapoles

- We have consistently produced layers of $1.2 \mu\text{m}$ RMS roughness near the triple point of DT
- Freezing rate and final temperature effect the roughness of the beta layer

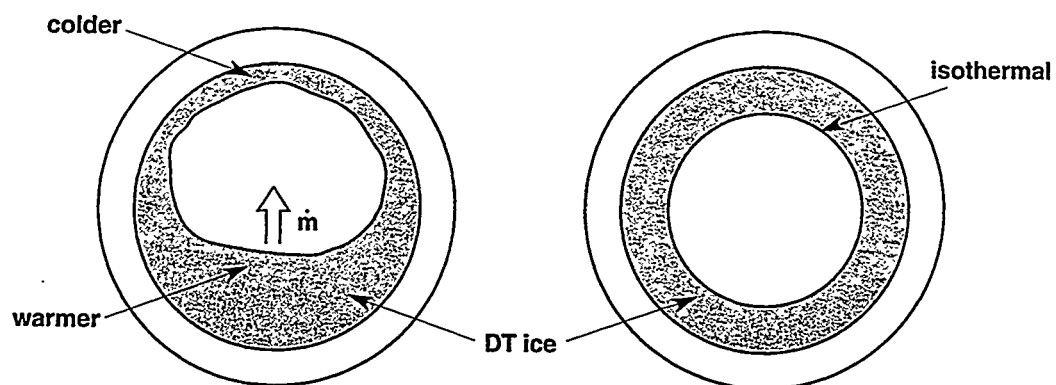


1mm diameter CD shell with
 $10 \mu\text{m}$ wall and $30 \mu\text{m}$ fill tube

Cover4_9_98

β -layering is a promising technique to provide uniform free-standing cryogenic layers for ICF targets

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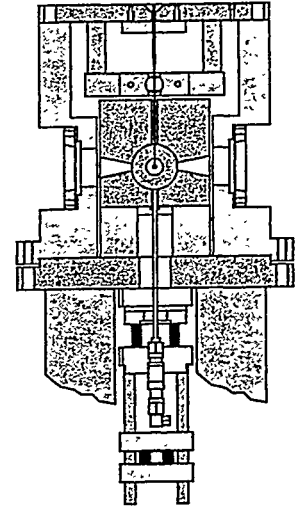
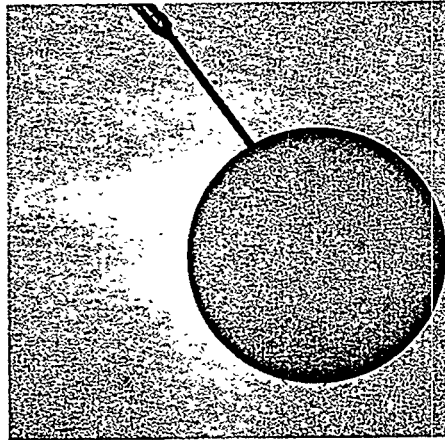
- Self-heating of DT causes thicker layers to be hotter and sublime in favor of thinner layers
- Rate: $\tau = \frac{H_s}{Q} = \frac{\text{Heat of vaporization}}{\text{Decay heat}} \sim 30 \text{ minutes}$

Layering occurs in a spherically symmetric geometry



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- Our sample cell is a 1mm plastic shell on a fill tube.
- The surrounding cavity is a 25.4 mm diameter, OFHC hollow sphere.
- Layers are made at slightly below the triple point of DT (19.7K).

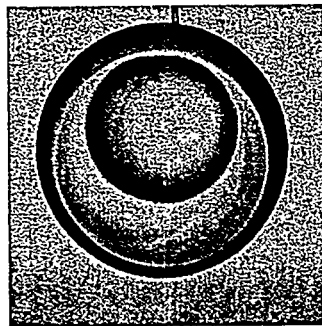


beta_onv.ai

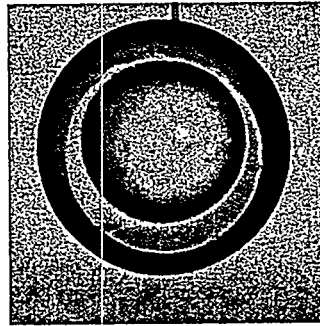
Cooling layers barely below T_{TP} and holding.



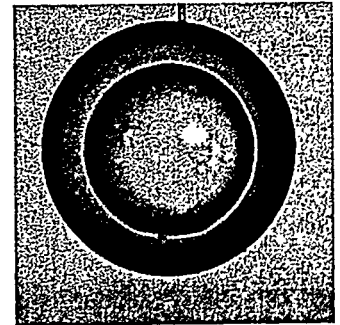
Schafer



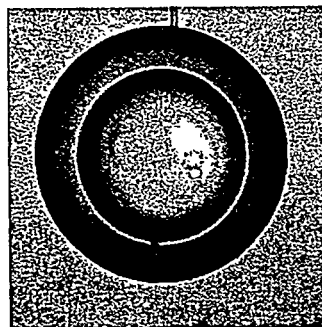
Temp. = 19.834 K



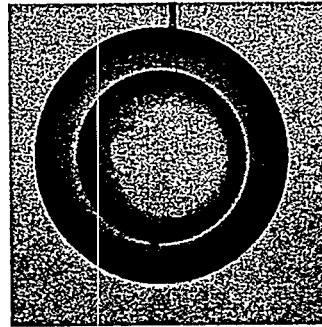
19.803K



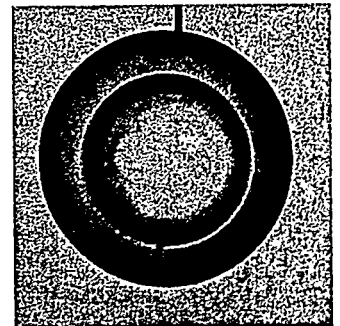
19.779K



19.779K



19.779K

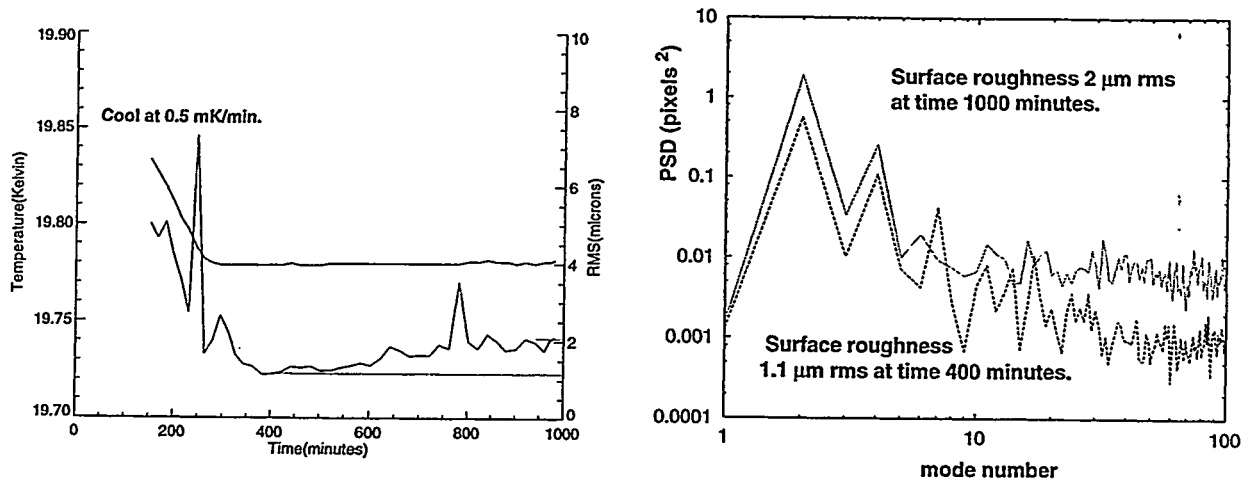


19.779K

Results from a typical experiment.



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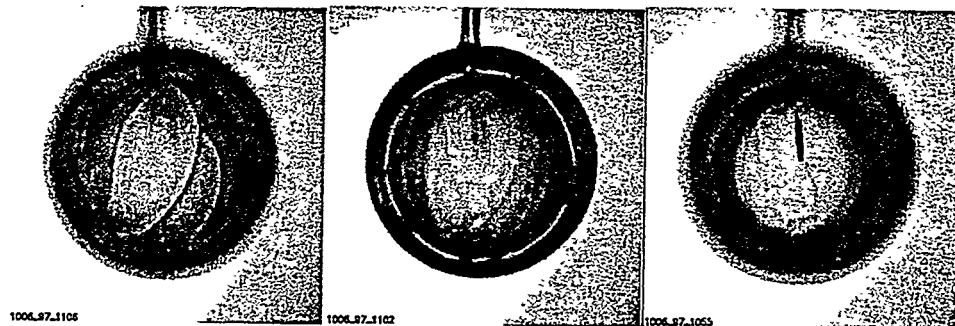
- We cool slowly through the triple point and then hold the temperature steady.
- The surface then becomes rougher over time.

standard_experiment1.ai

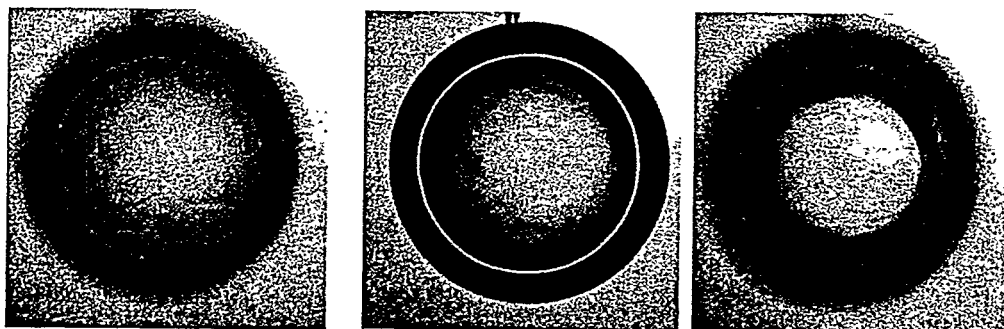
We observe large crystals when panning through the shell.



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Generic B layer after aging over a weekend.
Layer thickness is 97 microns.
Temperature is 19.62 K.

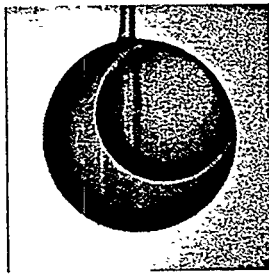


Less prominent crystal structure in smoother D2 layer.

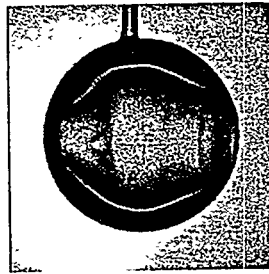
Cooling layers below $T_{TP} - 0.3K$. Layers show sign of strain on multicrystalline boundaries.



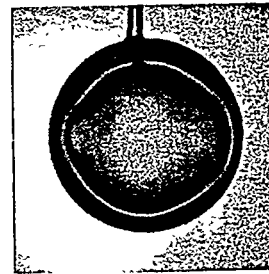
Schafer



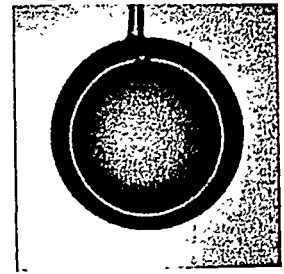
Temp. = 19.793 K



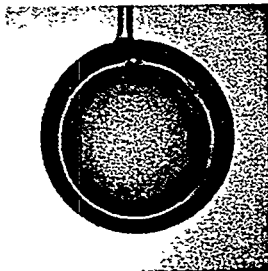
19.732 K



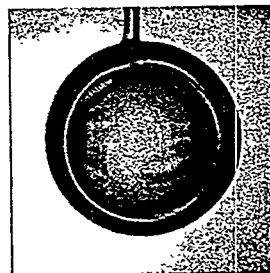
19.691 K



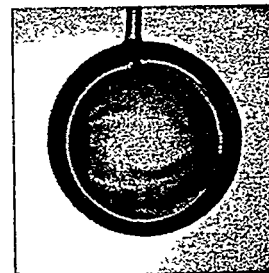
19.598 K



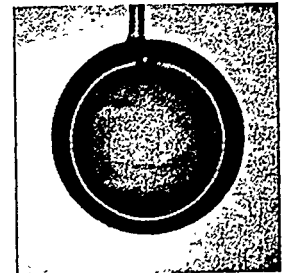
19.389 K



19.179 K



18.967 K



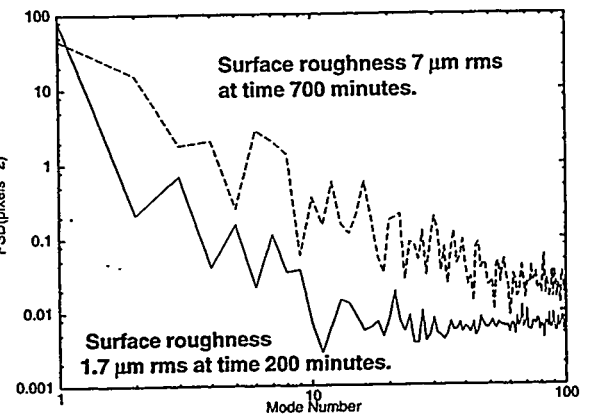
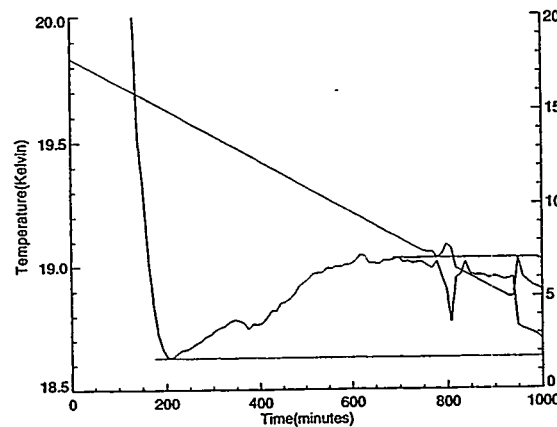
18.900 K

Slower_Cooled_BetaLayer.ai

Results from a typical experiment.



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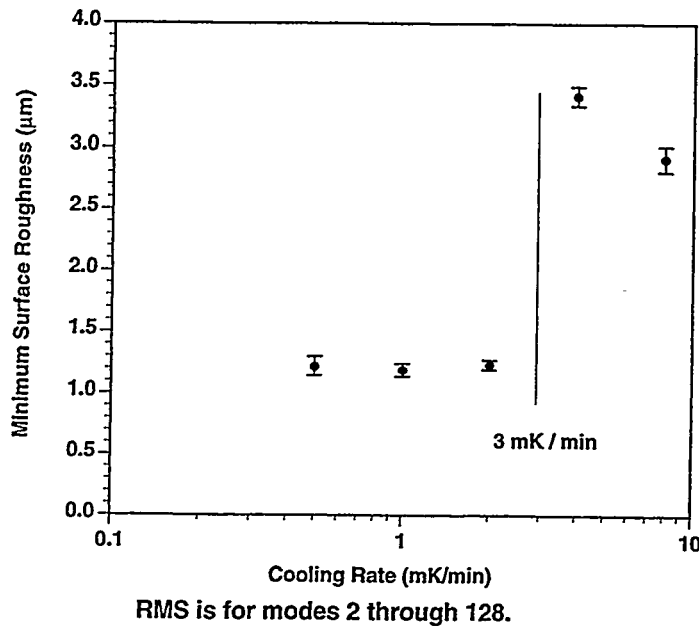


- From Souers we find that $\Delta V = 0.094$ cc/mole from 19.7 to 18.9K. Our 100 μm ice layer would shrink on the order of a few parts per thousand if layed out in an unconstrained plane.

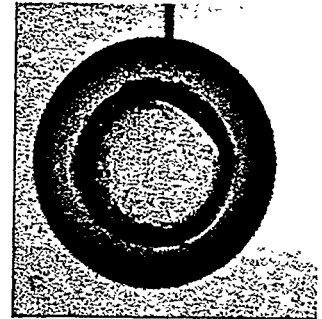
Freezing rates have a dramatic effect on layer smoothness



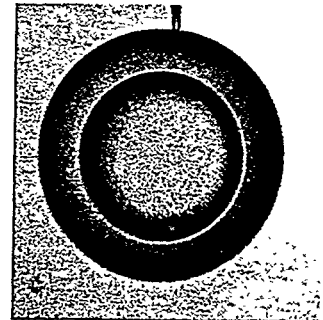
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Rapid Freeze



Slow Freeze

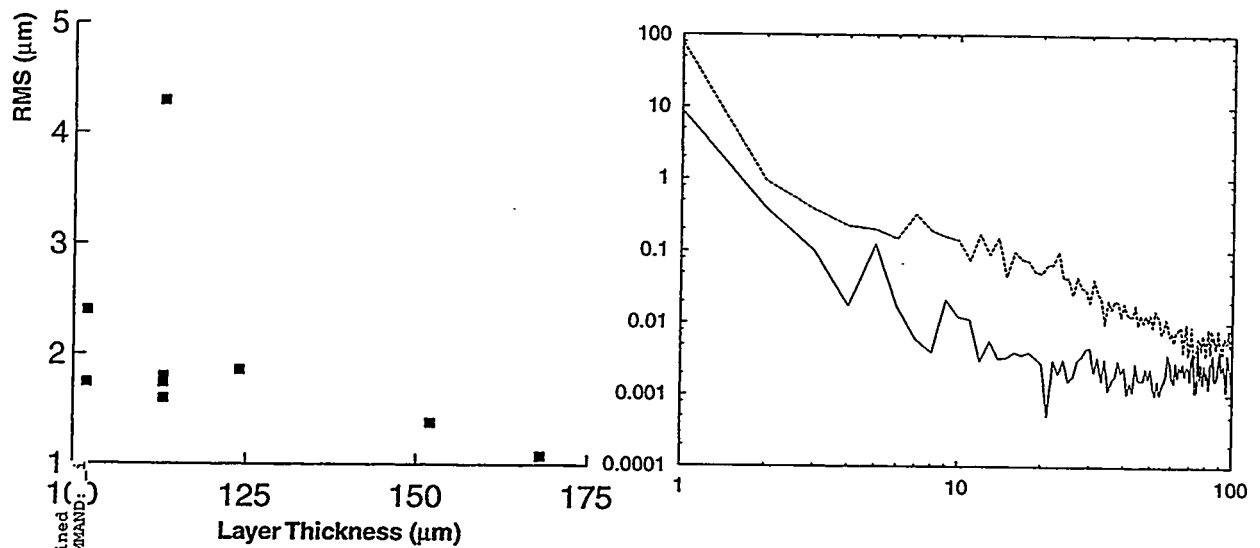


RMS_vs_Rate.ai

Surface roughness is also reduced by increasing layer thickness.



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- Cooling rates are between 1 and 2 mK/min.

123456789

CHARACTERIZATION OF THE SURFACE ROUGHNESS OF PARTS FABRICATED IN SINGLE-POINT DIAMOND TURNING MACHINES

J. L. KAAE and J. N. SMITH, Jr.

General Atomics, San Diego, California U.S.A.

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 **GENERAL ATOMICS**

- The diamond tools generally used for the micromachining of ICF components have circular-shaped tips

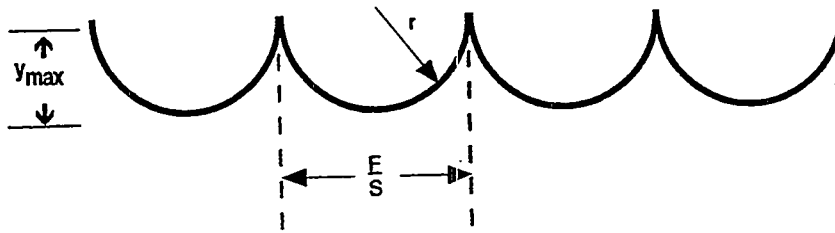


Diamond tool with a 25 μm radius tip

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 **GENERAL ATOMICS**

A SURFACE CUT WITH A ROUND TIP TOOL HAS A SCALLOPED APPEARANCE



where r = radius

F = feed rate

s = spindle speed

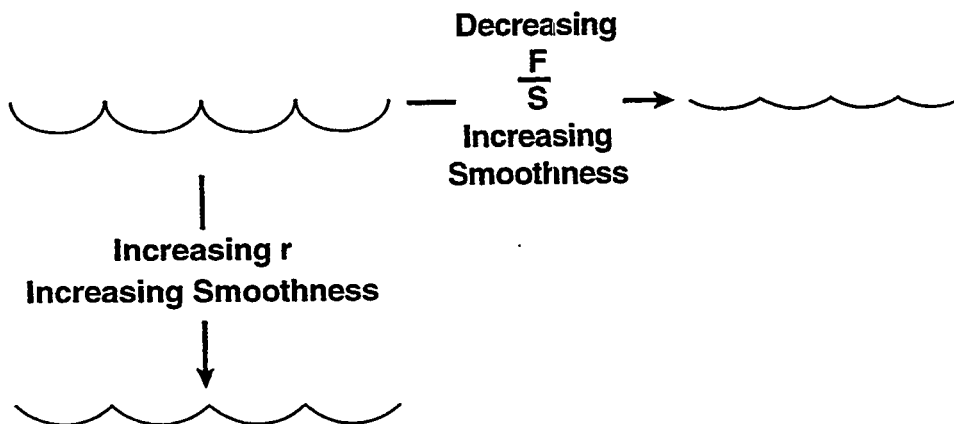
then

$$y_{\max} = r - \sqrt{r^2 - \left(\frac{F}{2S}\right)^2}$$

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GENERAL ATOMICS

QUALITATIVE EFFECTS OF $\frac{F}{S}$ AND r ON THE SURFACE SMOOTHNESS



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GENERAL ATOMICS

RMS ROUGHNESS

- Machined Surfaces are Generally Characterized by the RMS of the Roughness:

$$RMS = \sqrt{\frac{\sum_{i=0}^N (y_i - y_{avg})^2}{N}} = \sqrt{\frac{\int (y - y_{avg})^2 dx}{\int dx}}$$

- For the Scalloped Surface,

$$RMS = \sqrt{-(2y_{avg}r - y_{avg}^2) + 2y_{avg}r \left[\frac{1}{2} \sqrt{1 - \left(\frac{F}{2rS}\right)^2} + \frac{rS}{F} \sin^{-1}\left(\frac{F}{2rS}\right) \right]}$$

Where

$$y_{avg} = r \left[1 - \frac{1}{2} \sqrt{1 - \left(\frac{F}{2rS}\right)^2} - \frac{rS}{F} \sin^{-1}\left(\frac{F}{2rS}\right) \right]$$

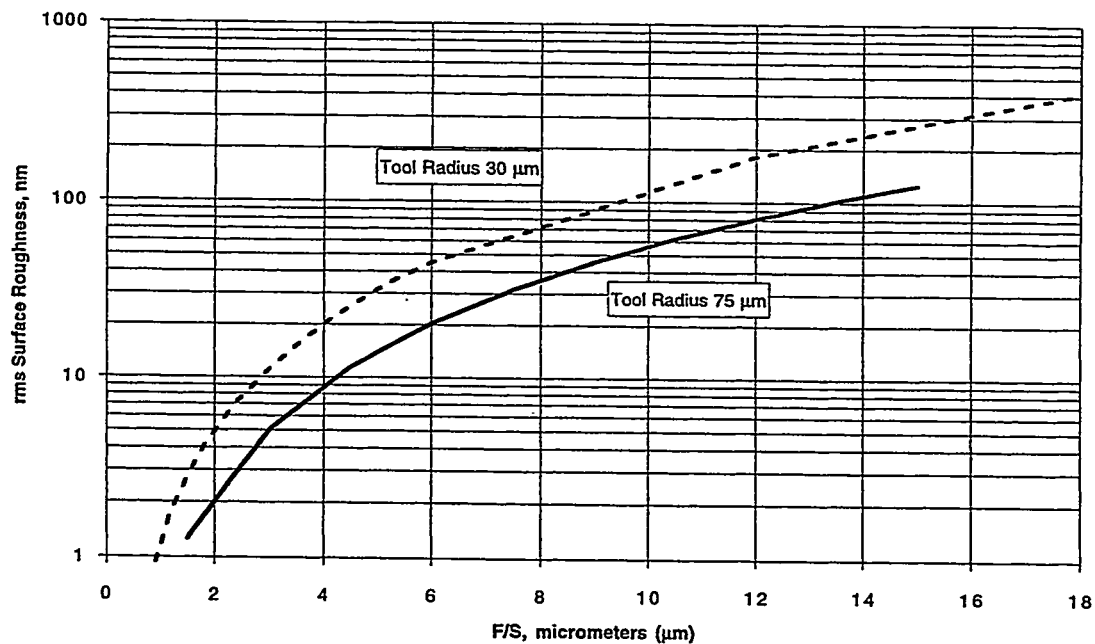
and

r = tool tip radius
F = tool feed rate
S = spindle rotational speed

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GENERAL ATOMICS

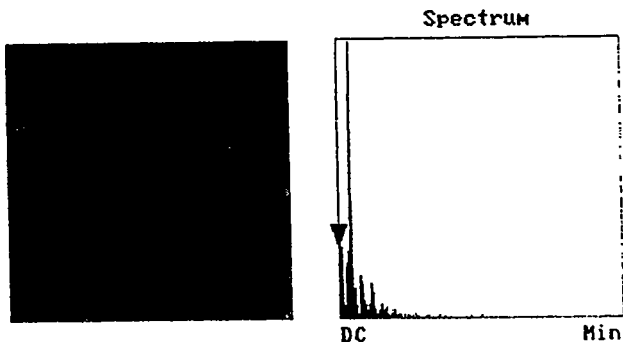
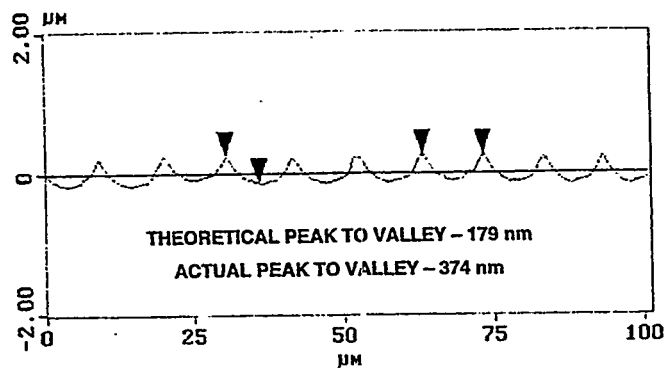
THEORETICAL RMS SURFACE ROUGHNESS



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GENERAL ATOMICS

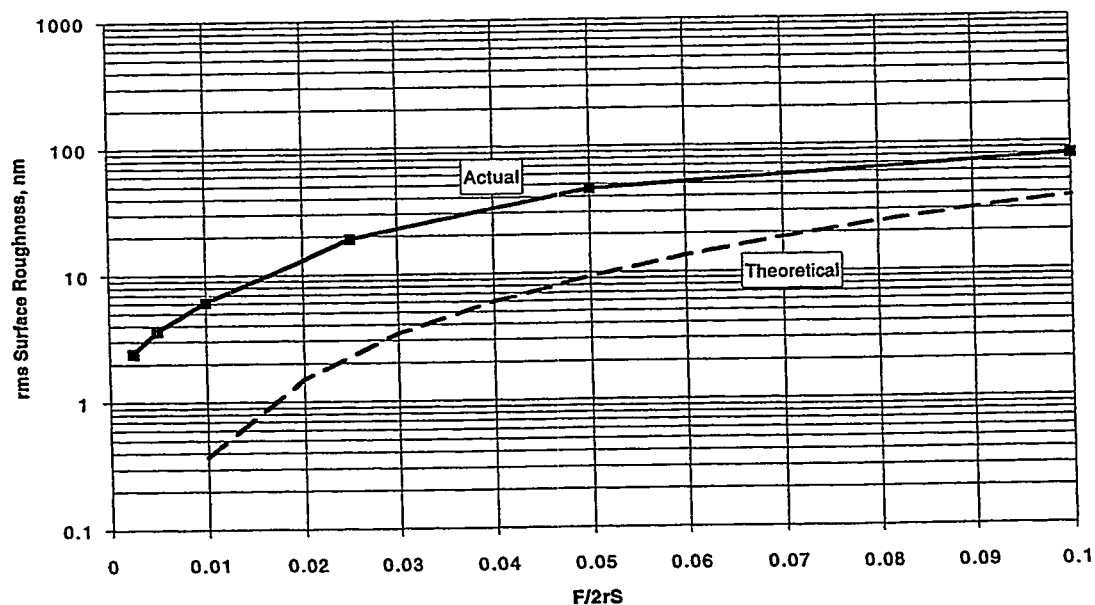
AFM TRACE OF A DIAMOND TURNED SURFACE



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GENERAL ATOMICS

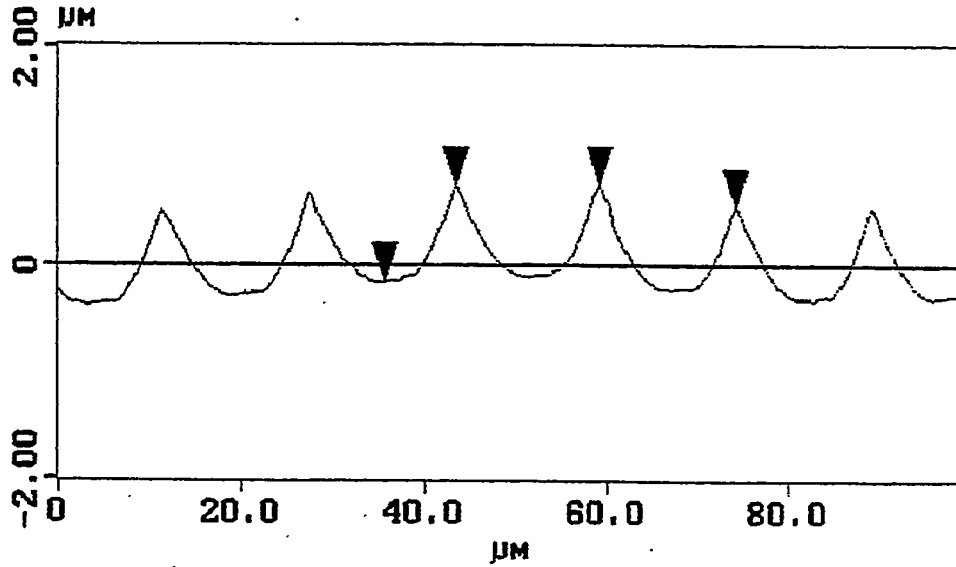
PRECITECH 2400 LATHE; TOOL WITH 25 μm RADIUS



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GENERAL ATOMICS

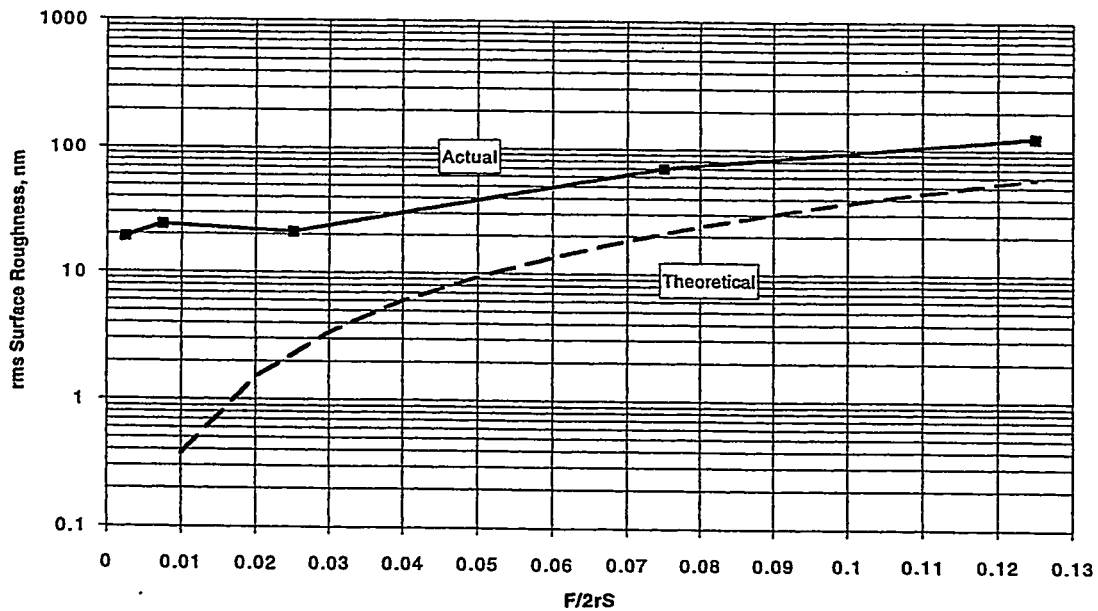
PROFILE OF SURFACE CUT WITH GRADUAL MOVEMENT OF THE TOOL POSITION



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GENERAL ATOMICS

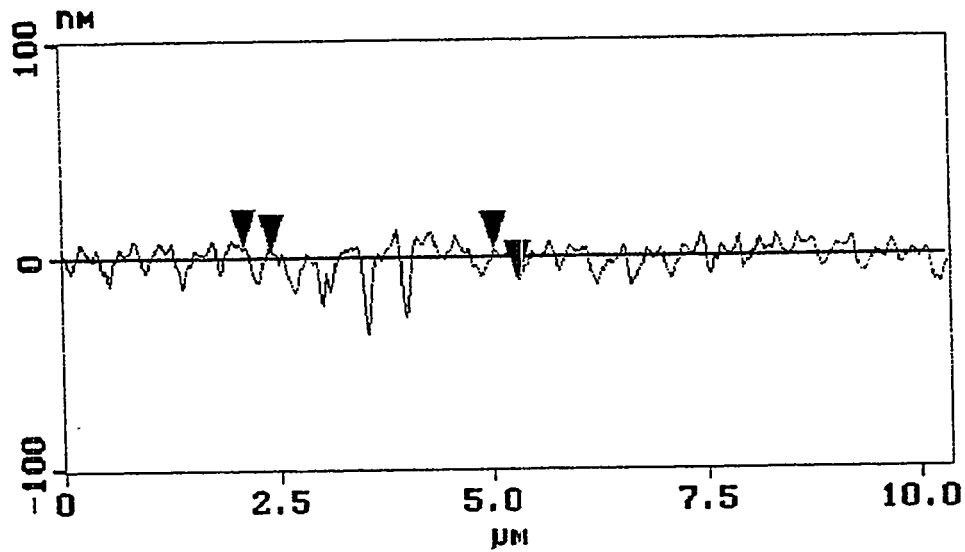
PRECITECH 2000 LATHE; TOOL WITH 25 μm RADIUS



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GENERAL ATOMICS

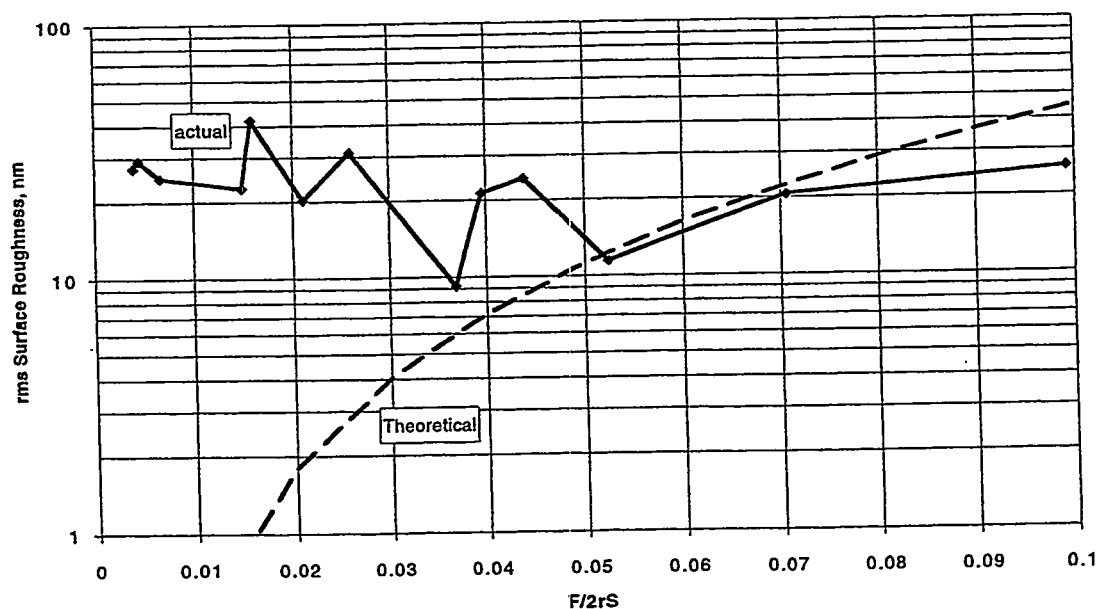
PROFILE OF SURFACE CUT WHERE SUDDEN SHIFTS IN TOOL POSITION OCCUR



Schafer

GENERAL ATOMICS

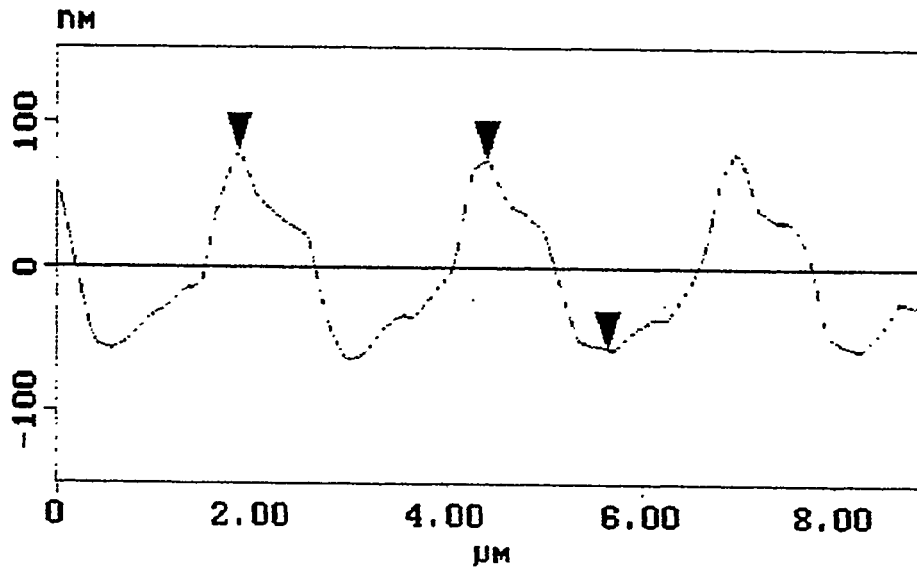
ROCKY FLATS NO. 3 LATHE; TOOL WITH 30 μm RADIUS



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GENERAL ATOMICS

PROFILE OF SURFACE CUT WITH A WORN TOOL



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GENERAL ATOMICS

FACTORS CAUSING DEVIATION OF ACTUAL SMOOTHNESS FROM THEORETICAL SMOOTHNESS

- Peak-to valley distance is larger than the theoretical distance
- Pass-to-pass variations in tool position
- Occasional large variations in tool position
- Tool tip not perfectly round

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GENERAL ATOMICS

Properties and Processing of Beryllium and Beryllium Alloys for Inertial Confinement Fusion Applications

D.J. Thoma, F. Chu, L. Dauelsberg

T. Darling, and L.A. Jacobson

Los Alamos National Laboratory

Materials Science and Technology Division

Target Fabrication Meeting

Jackson Hole, April 20, 1998

**This work is supported by the U.S. Department of Energy
under contract number W7405-ENG36**



*Alloy Design
& Development*



Outline and Goal of Study

Outline

- I. Introduction and Procedures**
- II. Properties**
- III. Implications**

Goal: Develop usable procedures and properties of Be and Be alloys that will aid in target fabrication and shock physics



*Alloy Design
& Development*



Ojectives

- **Feasibility of beryllium for NIF capsules**
 - fabrication of metal
 - performance
- **Detailed understanding of properties to optimize efforts (single Be crystals and polycrystalline alloys)**
 - elastic properties
 - plastic behavior
 - thermophysical properties



*Alloy Design
& Development*



Experimental Procedure: Arc-Melting

Cleaning is performed for beryllium used in elemental or alloy form

- Brush-Wellman vacuum cast lump (99.8%)
- Evacuated and argon purged chamber
 - Ti pieces melted to “getter” oxygen
- Impurities “slagged” out during non-consumable arc-melting
- Chemically cleaned samples
- Re-melted until slagging eliminated

BeO impurities are not desired owing to the density gradients (inclusions) in the final capsules

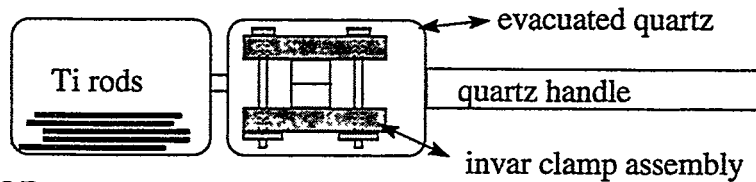


*Alloy Design
& Development*



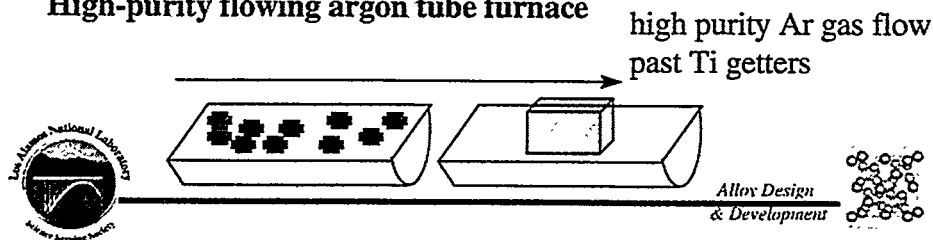
Experimental Procedure: Heat-Treatment

Double ampoule configuration



OR

High-purity flowing argon tube furnace



Experimental Procedure: Property Determination

- **Elastic Properties**
 - Resonant Ultrasound Spectroscopy (RUS)
- **Plastic Behavior**
 - Vickers Microindentation
- **Coefficient of thermal expansion**
 - RF dilatometry

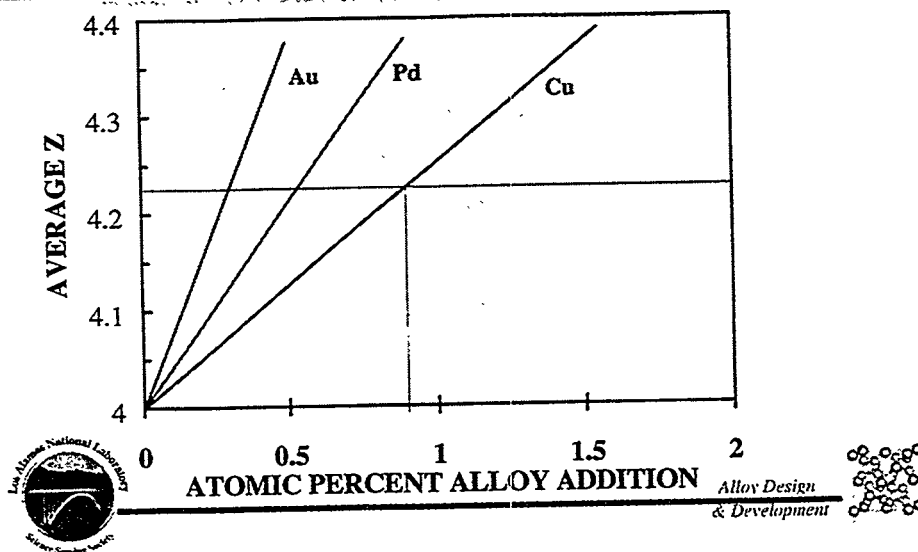
Samples: Single crystal Be (99.999%), cast Be, cast Be alloys
[alloying: Cu, Pd, Au]



Alloy Design
& Development



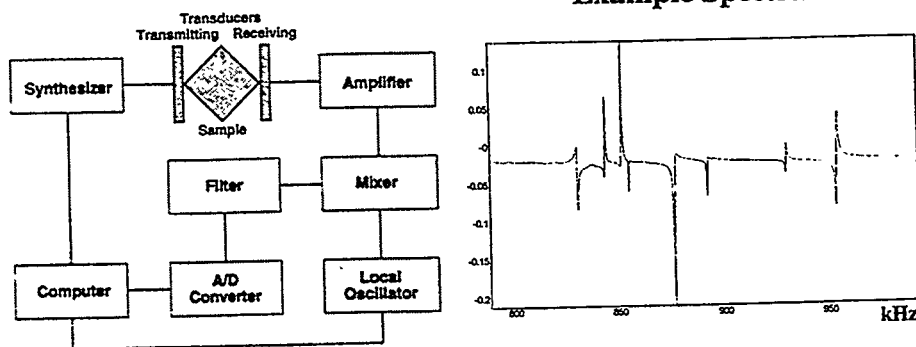
Experimental Procedure: Samples



Elastic Properties: RUS

Resonant Ultrasound Spectroscopy (RUS) Technique

Example Spectra



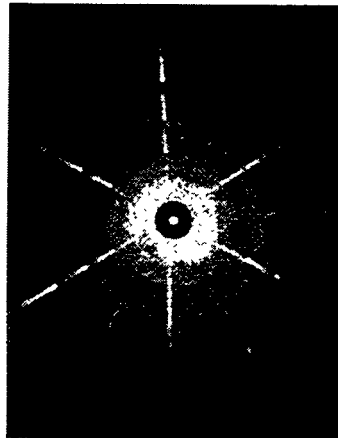
Experimental setup of RUS



Alloy Design
& Development



Single Crystal Beryllium



Laue Back Reflection

- streaking
- very short exposure times



<0001> orientation

Alloy Design
& Development



Single Crystal Properties

C_{ij}	Compliance (GPa)
C_{11}	295
C_{22}	295
C_{33}	359
C_{23}	13
C_{13}	13
C_{12}	28
C_{44}	164
C_{55}	164
C_{66}	134

Isotropic Elastic Moduli

Shear Modulus = 152 GPa
Young's Modulus = 319 GPa
Bulk Modulus = 118 GPa
Poisson's Ratio = 0.047

All values at
room temperature



Alloy Design
& Development



Other Values from RUS Data

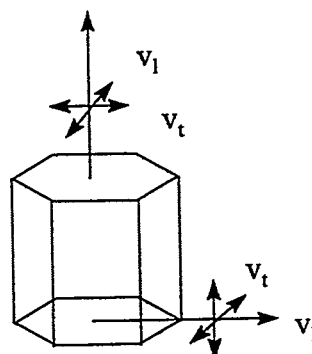
Sound Velocity

$$V_{L[0001]} = 1.40 \times 10^4 \text{ m/s}$$

$$V_{T[0001]} = 0.07 \times 10^4 \text{ m/s}$$

$$V_{L[1010]} = 1.27 \times 10^4 \text{ m/s}$$

$$V_{T[1010]} = 0.39 \times 10^4 \text{ m/s}$$



Debye Temperature

$$\Theta_D = 1496 \text{ K}$$



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& Development



Polycrystalline RUS Data

S200D values at room temperature

Isotropic Elastic Moduli (Single Crystal)

Shear Modulus = 149 GPa (152 GPa)

Young's Modulus = 313 GPa (319 GPa)

Bulk Modulus = 116 GPa (118 GPa)

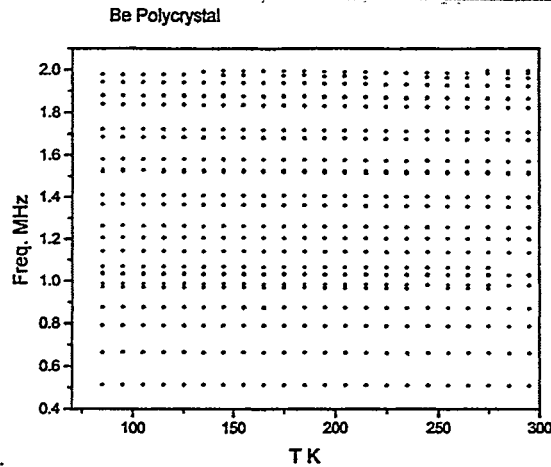
Poisson's Ratio = 0.05 (0.047)



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Polycrystalline RUS Data as a Function of Temperature



The elastic constants have virtually no temperature dependence in the regions explored



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Indentation of Pure Be



Not slagged sample

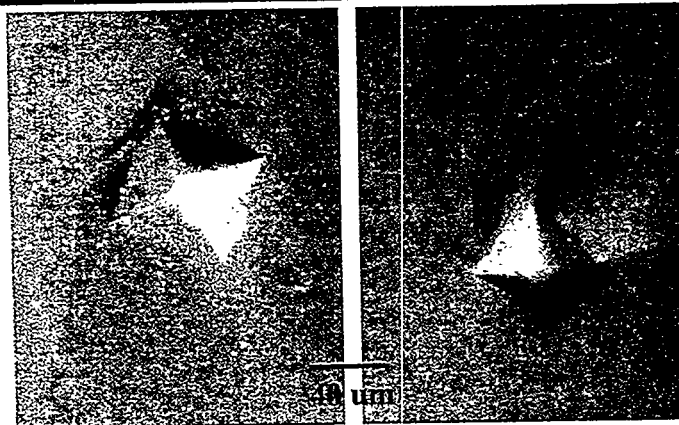
slagged sample



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& Development



Indentation of Be-0.9at.% Cu



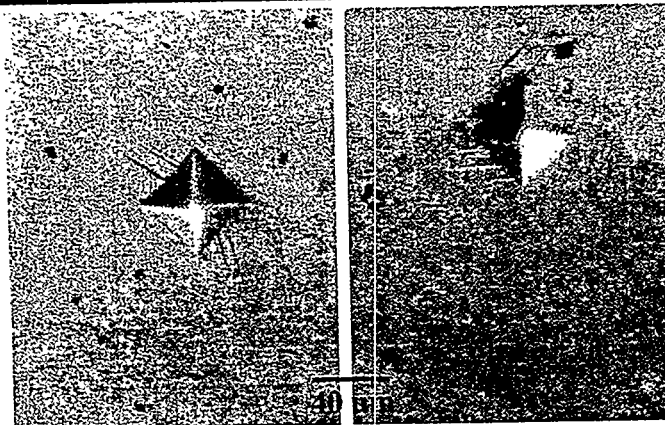
Not slagged sample

slagged sample

Alloy Design
& Development



Indentation of Au and Pd Alloys



Pd-5wt.%Au

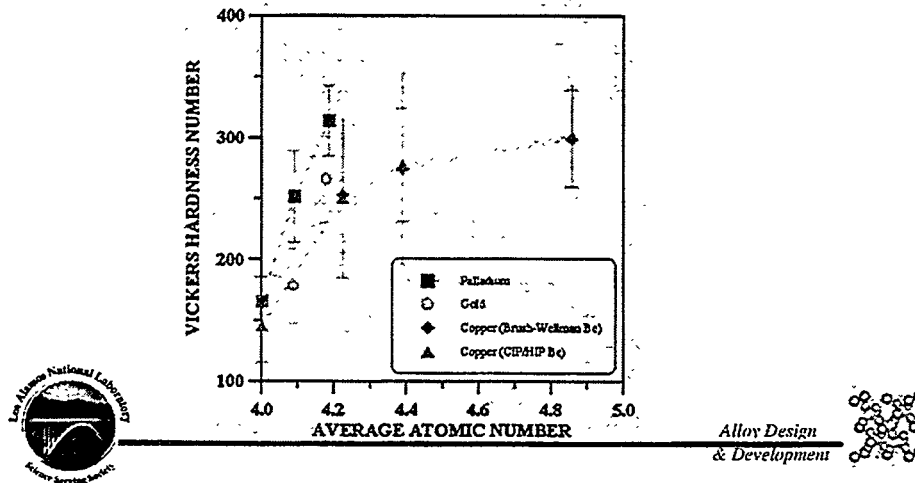
Pd-5wt.%Pd

Alloy Design
& Development



Hardness vs. Z

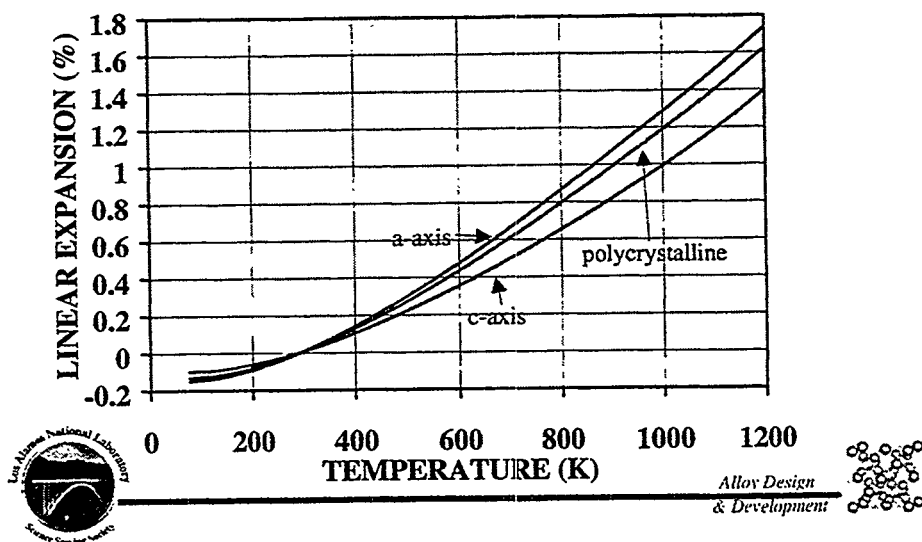
HARDNESS OF BERYLLIUM ALLOYS AS A
FUNCTION OF AVERAGE ATOMIC NUMBER



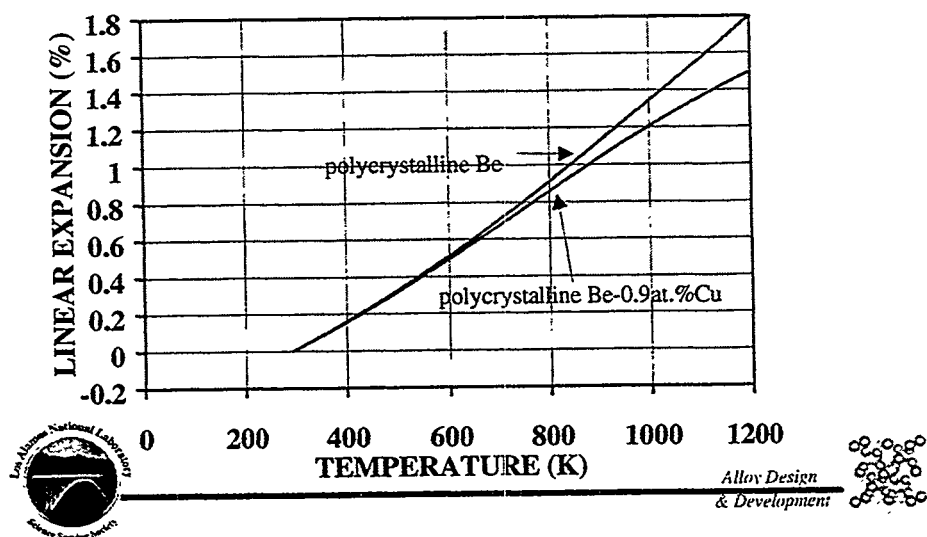
Uniqueness of Be

- x-ray back-scattering behavior - strongest
- highest Debye temperature
- Lowest Poisson's ratio
- easiest oxidation
- highest sound velocity
- highest elastic anisotropy
- highest specific Young's modulus
- $B < G$ (only graphite like this)
- largest V_l to V_t difference

Thermal Expansion of Be



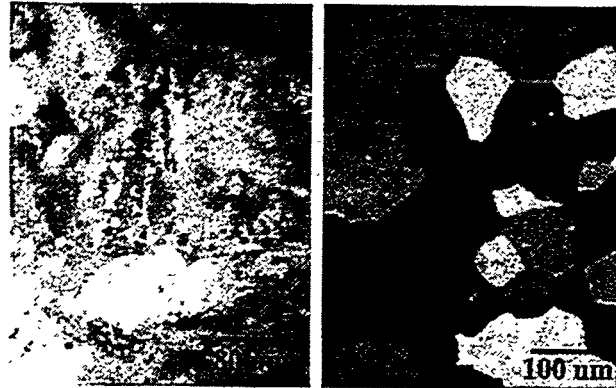
Be vs. Be-Cu CTE



Grain Growth in Be

Initial: Pure Be with an extrusion from 3/4" to 1/4" at 850°C

*transverse
sections*



Final: 2 cycles, 3 hrs./cycle, to 900°C

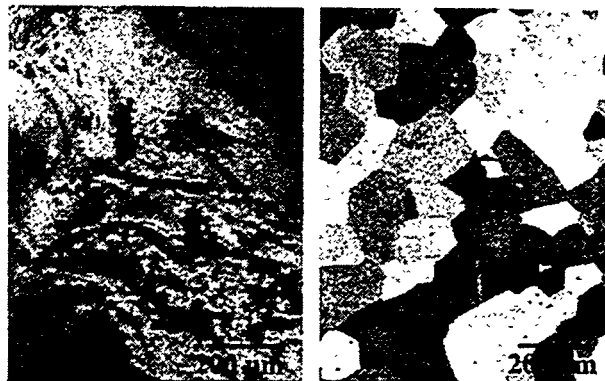
*Alloy Design
& Development*



Grain Growth in Be-0.9at.% Cu

Initial: Be-6wt% Cu with an extrusion from 3/4" to 1/4" at 850°C

*transverse
sections*



Final: 1 cycles, 1 hr./cycle, to 1000°C

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& Development*



Summary of Results

- Elastic constants have been defined to better precision and accuracy
- Sound velocity values have been determined
- The indentation of alloys show that Pd and Au strengthen greater than Cu, and increased alloy contents yield more uniform plasticity
- The a and c directions of CTE are significantly anisotropic, but polycrystalline Be-6wt% Cu has less linear expansion to 1273 K than Be



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& Development*



Implications of Results

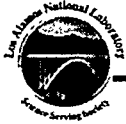
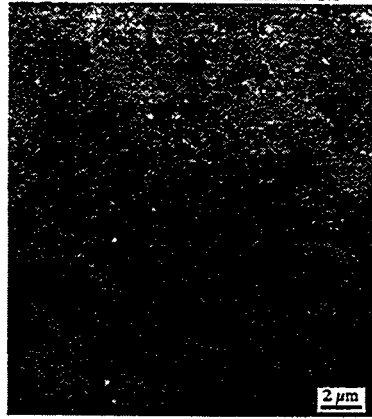
- Elastic constants and calculated values can be used for accurate performance predictions
- Coupling CTE data to elastic properties, a maximum stress of 600 MPa can be generated at a bond line when cooled from 1273 K to 17 K
- Plastic deformation is more uniform and yield strengths are higher with increased alloy content, thus producing potentially smoother machining surfaces
- Impurity control is essential for better machined surfaces
- Grain growth at 1273 K is too large for grain size control in more pure material during bonding



*Alloy Design
& Development*



Grain Refinement in Be (R.D. Field): Future Work



powder product

grain refinement

*Alloy Design
& Development*



Characterization of Be Solid State Bonds for ICF Applications

R. D. Field and D. J. Thoma (MST-6)

**Materials Science and Technology Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545**

Los Alamos
Materials Science and Technology

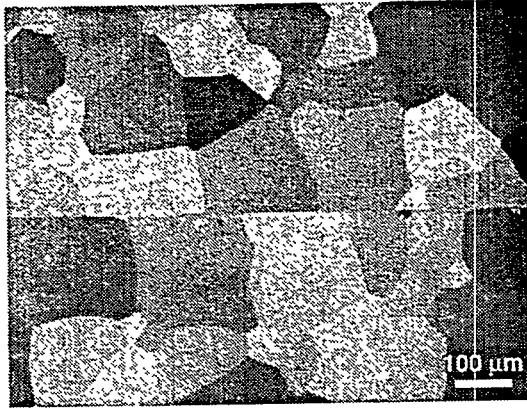
MST-6/Mar 98/RF-10

Summary of Bonds Investigated

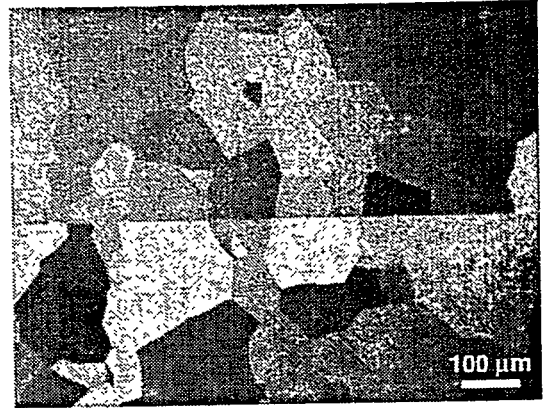
Spec.	Surface Prep.	Atmos.	Temp.	Time	Comments
I	Lathe	Vacuum	1000°C	6 h	15 nm Cu Layer on Bond Surfaces
II	3 μ m Diamond	Ar - 6% H ₂	1000°C	80 h	—
III	3 μ m Diamond	Vacuum	1000°C	63 h	Be - 0.9 at% Cu Alloy

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Optical Micrographs of Bond Joints



Bond II:
Be 0.9 at% Cu, 1000°C/63 h, vacuum



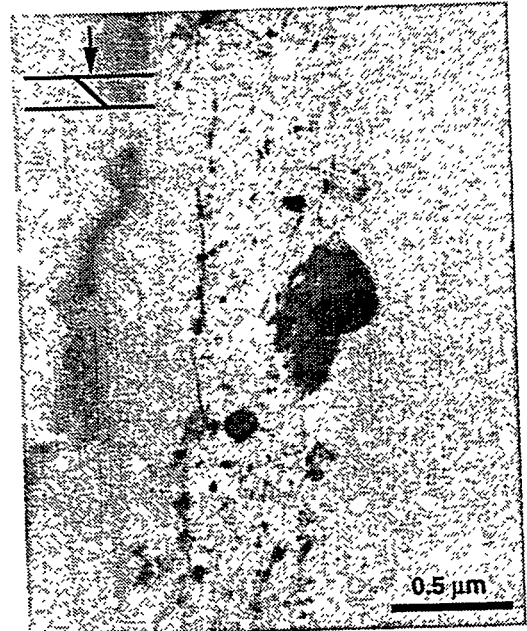
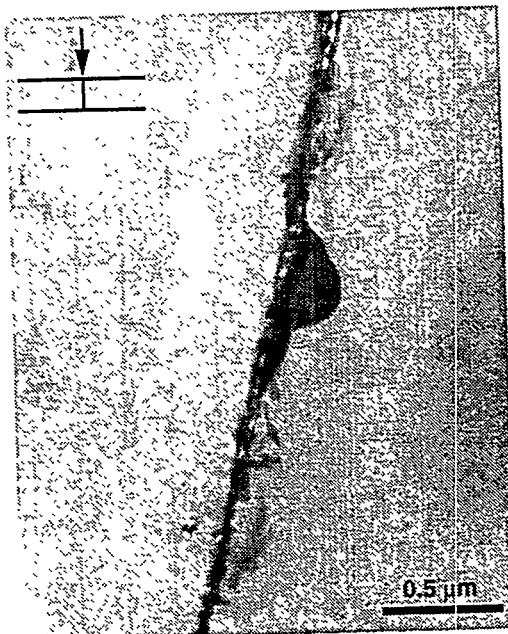
Bond III:
pure Be, 1000°C/80 h, Ar 6% H₂

- Large grain size (~200 μm)
- No cracks or large particles in interface
- No grain growth across interface

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MST-6/Mar 98/RF-2

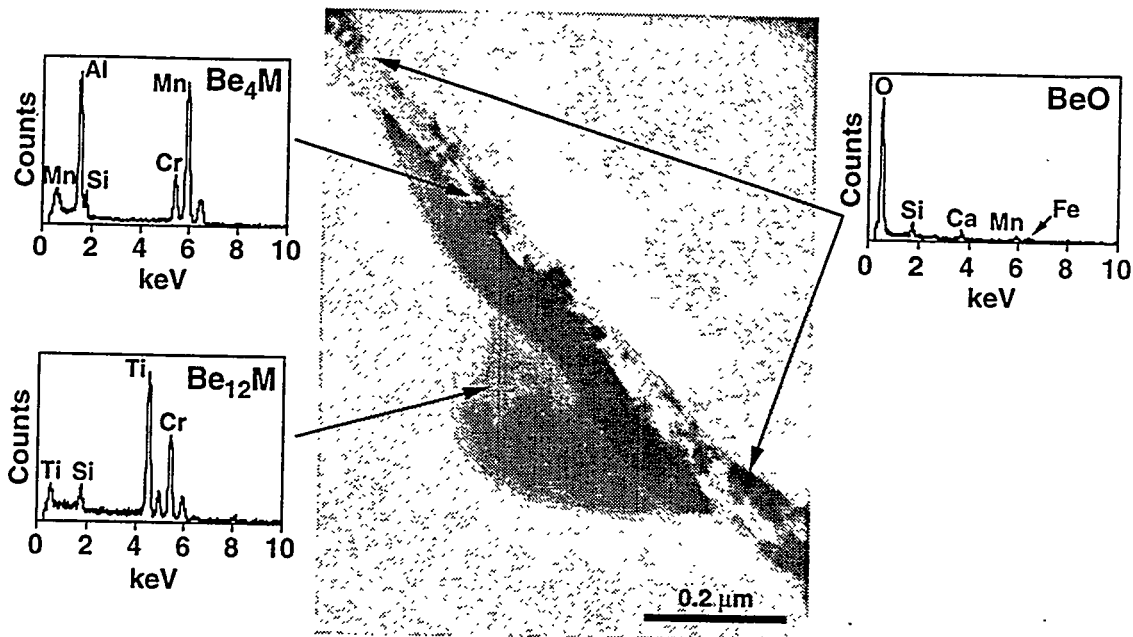
TEM of Bond I (Be + 15 nm Cu layer, 1000°C/6 h, vacuum)



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TEM of Bond I

(Be + 15 nm Cu layer, 1000°C/6 h, vacuum)

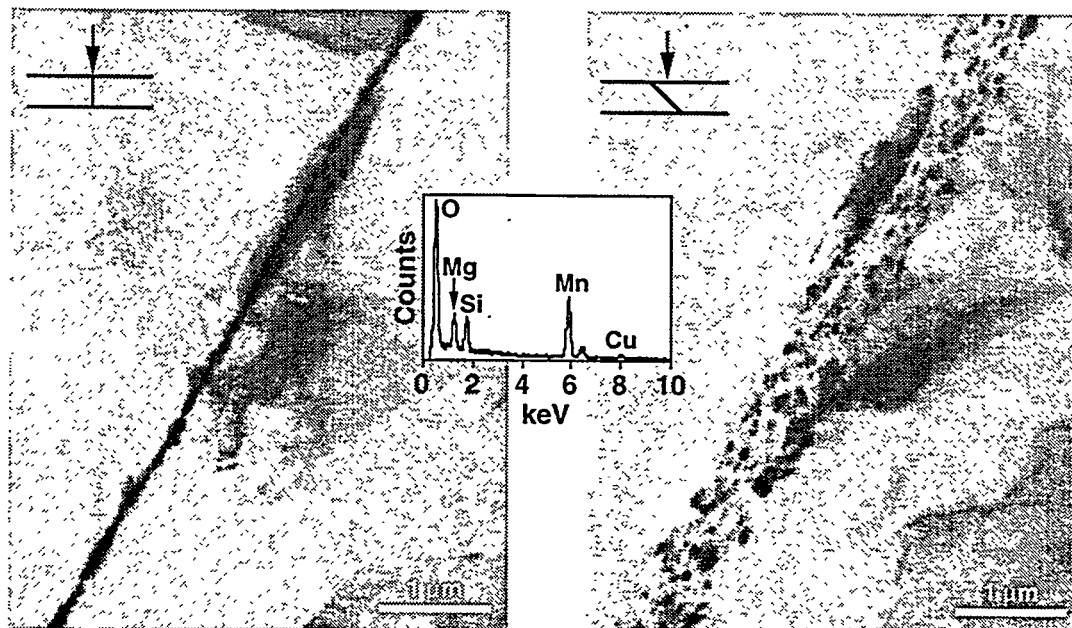


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MST-6/Mar 98/RF-4

TEM of Bond II

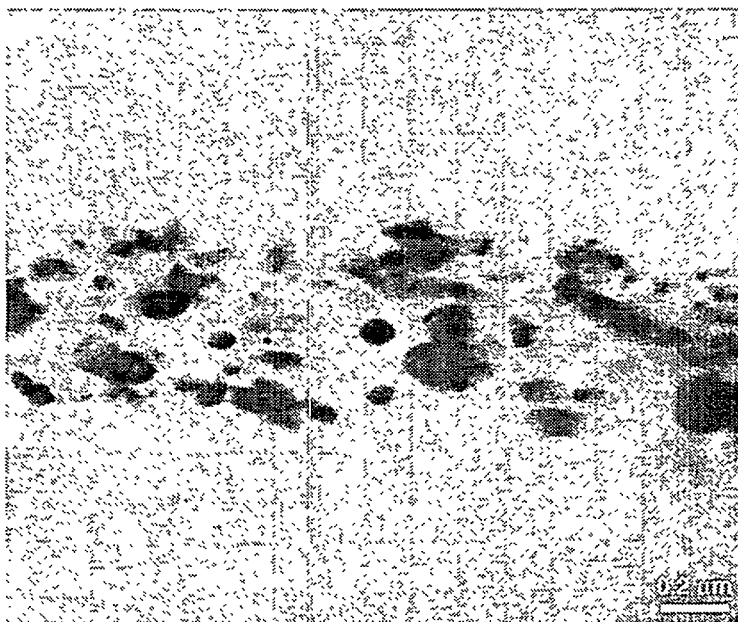
(pure Be, 1000°C/80 h, Ar 6% H₂)



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TEM of Bond II

(pure Be, 1000°C/80h, Ar 6% H₂)



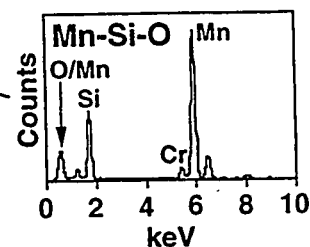
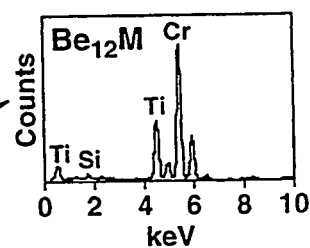
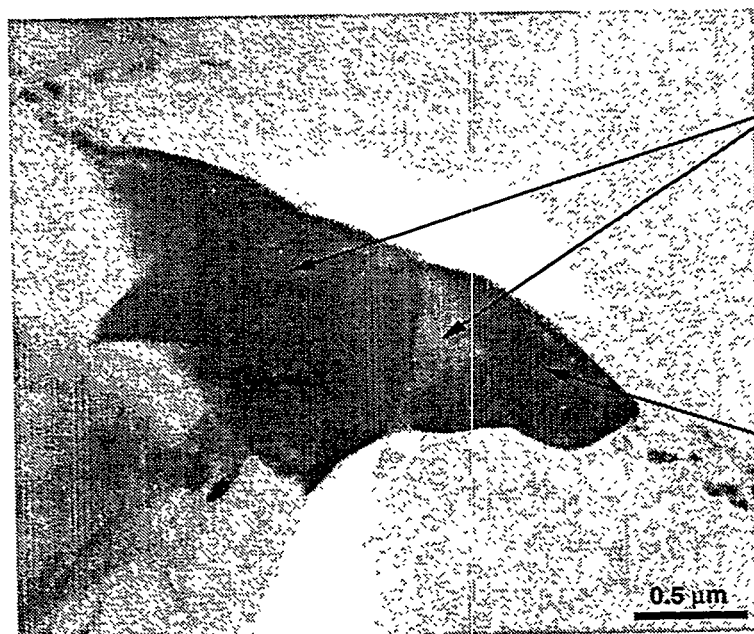
BeO along interface

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MST-6/Mar 98/RF-6

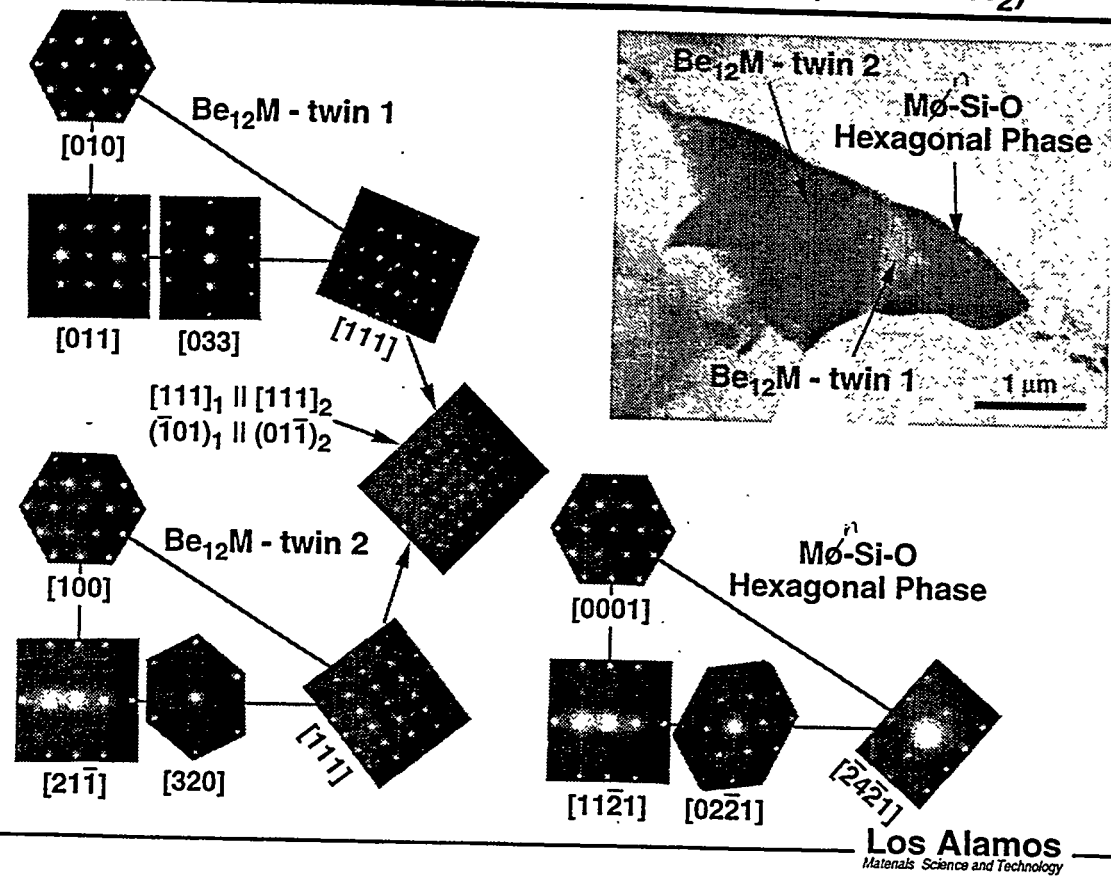
TEM of Bond II

(pure Be, 1000°C/80 h, Ar 6% H₂)



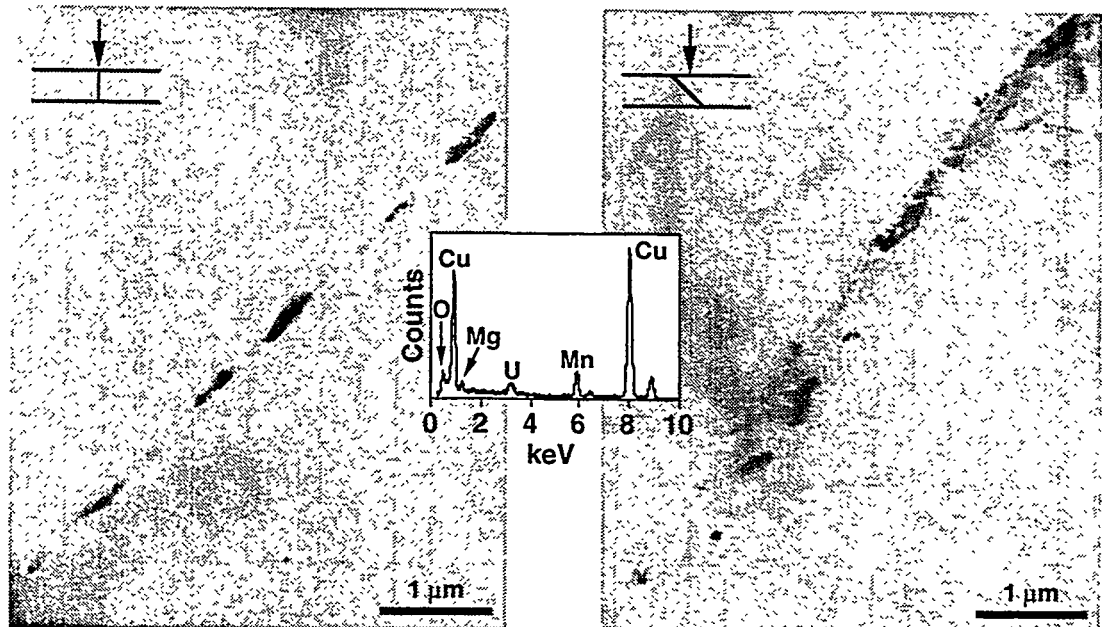
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TEM of Bond II (pure Be, 1000°C/80 h, Ar 6% H₂)



MST-6/Mar 98/RF-7

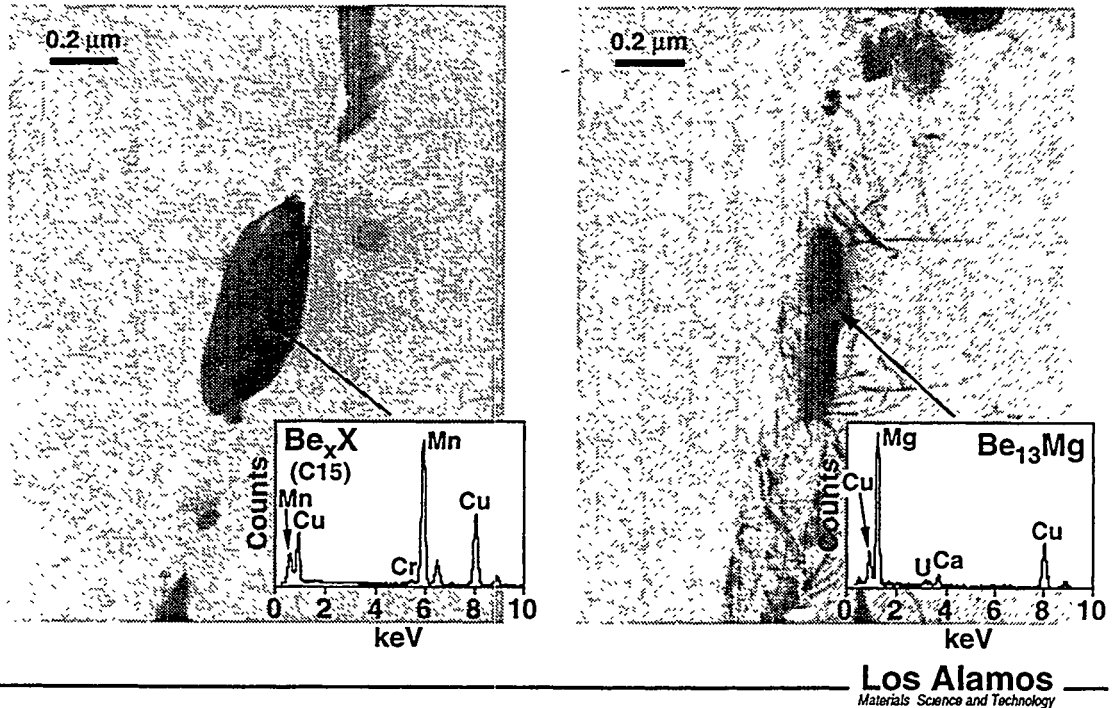
TEM of Bond III (Be 0.9 at% Cu, 1000°C/63 h, vacuum)



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TEM of Bond III

(Be 0.9 at% Cu, 1000°C/63 h, vacuum)



3

MST-6/Mar 98/RF-11

Conclusions

- Metallurgical bond is achieved - but no grain growth across the interface
- The bond line grain boundary contains numerous intermetallic and oxide precipitates
- Proper surface preparation can reduce the amount of oxide in the interface
- Careful control of the atmosphere during bonding is also required to reduce the amount of oxide in the interface

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Materials Science and Technology

Production of high strength large glass shells by sputter coating glass onto thin-walled mandrels

Abbas Nikroo

**12th Target Fabrication Specialists' Meeting
April 1998
Jackson Hole, Wyoming**



Large shells capable of holding over 100 atm of gas pressure are needed for cryogenic layering experiments

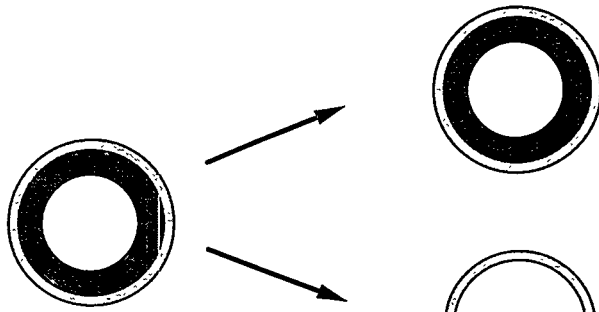
- Cryogenic layering experiments require gas pressures of >100 atm (J. Sanchez ,LLNL)
- Largest glass shells ($\approx 1500 \mu\text{m}$) that can be currently made are thin walled.
- Typical wall thickness for these shells is $\approx 3\text{-}4 \mu\text{m}$
- Therefore, these shells can only hold 20-70 atm of gas pressure depending on their quality.
- We pursued strengthening these shells by overcoating them with sputtered glass.
- Deposition process was similar to techniques used for depositing thin layers of glass for permeation barrier purposes.



Several options for making strong shells were pursued

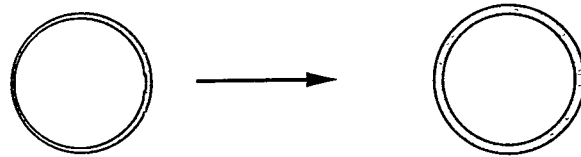
Glass coated GDP shells:

- Good starting mandrels
- Mandrel can be large ($\approx 2000 \mu\text{m}$)

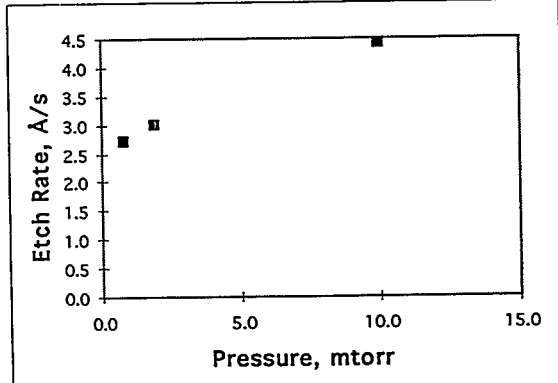
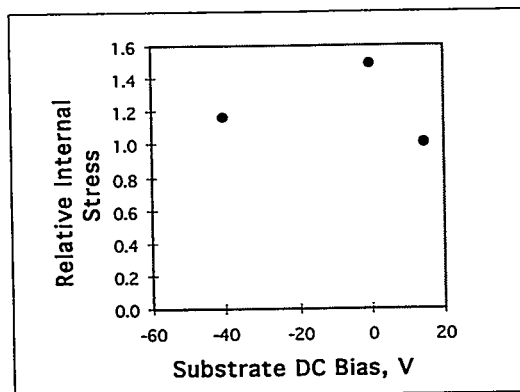


Glass coated glass shells:

- Many mandrels have wrinkles
- Mandrels limited to $<1500 \mu\text{m}$



Coating parameters were further tested by measuring film stress and etch rates on flat samples.



- Film characteristics were examined on flat Si wafers and SiO_2 slides.

- The residual stress in the glass was lowest when the substrates were floating .

- Etching coatings in Hydrofluoric Acid (HF) confirmed that the densest coatings were deposited at the lowest pressures.



The glass coated glass shells also had a rough dome-filled surface

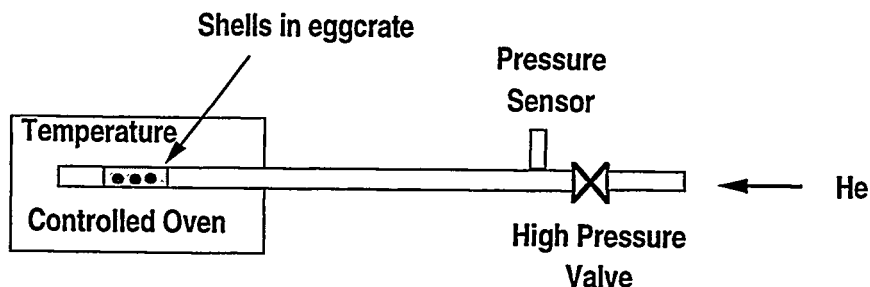


scale bar = 1 μm

- The glass coated GDP shells had a very rough surface as expected (from permeation work).
- The glass coated glass shells had a similar finish, confirming that the coating process was responsible for the rough surface.



Shells were burst tested at elevated temperatures using helium



- Glass shells were filled at 400 C to expedite the fill process.
- GDP shells had to be filled at 200 C or lower.
- Appropriate steps were taken to avoid buckling shells in the fill process.
- Helium was used for the tests because D_2 fills would have taken too long.



The survivors were tested by measuring the permeation half-life of shells to helium

- The half-lives of shells were measured in several ways:

Mass Loss:

$$M_f = M_0 + \Delta M e^{-(t/\tau)}$$

Shell mass could be measured to better than 1 μg

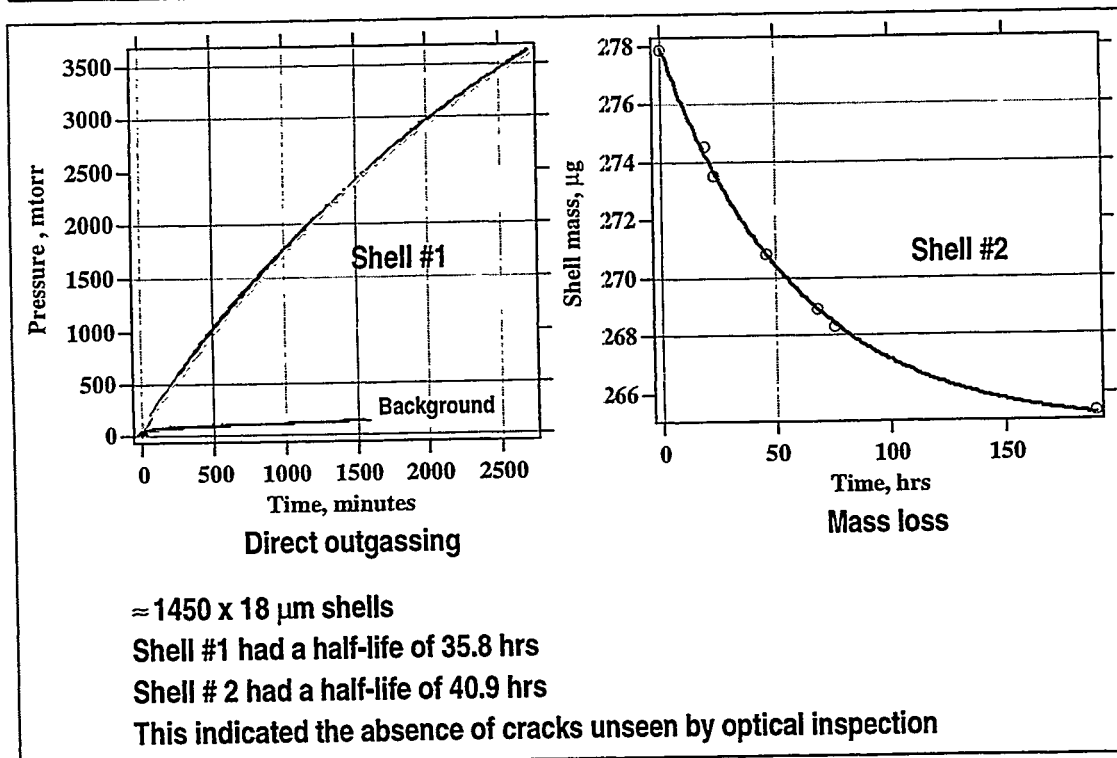
Direct outgassing in a sealed volume:

$$P_f = P_0 (1 - \Delta P e^{-(t/\tau)}) + ct$$

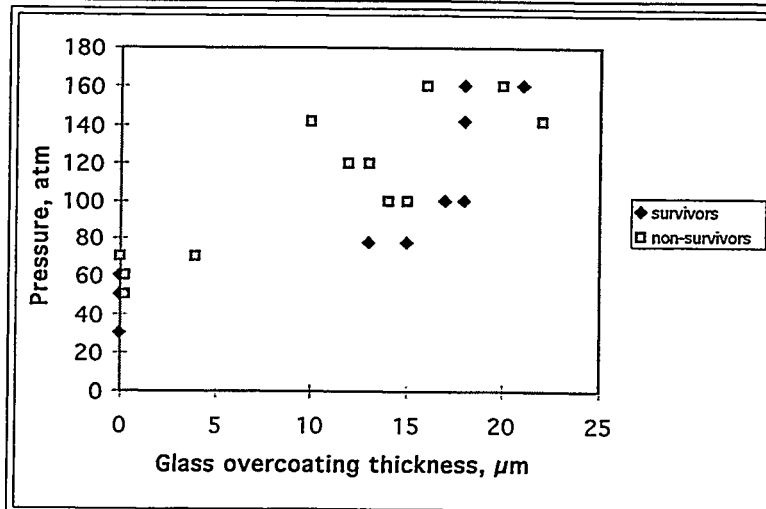
(ct) accounts for outgassing of chamber walls



Slow outgassing of helium out of shells confirmed the absence of microcracks and gas holding capability of shells



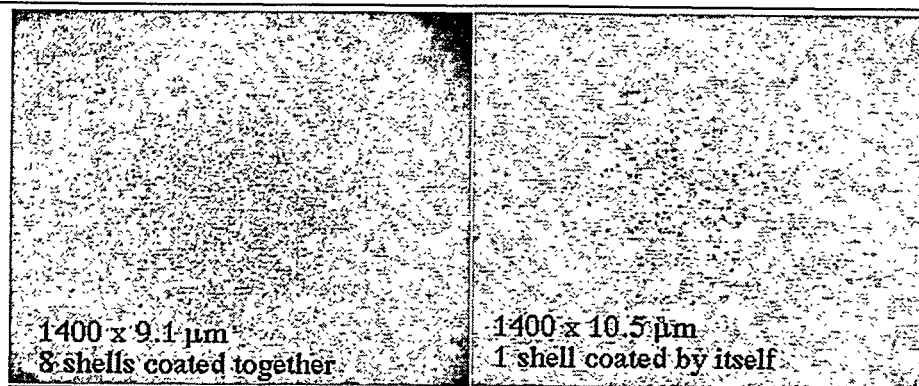
Overcoating with sputtered glass did increase the burst strength of glass shells



- Glass shells with diameters between 1200-1500 μm and thicknesses of 3-4 μm were coated and tested.
- 18-20 μm of overcoating was needed to strengthen some shells to above 100 atm burst pressure



Bounce coating one single shell by itself produced a better surface finish than coating several shells together

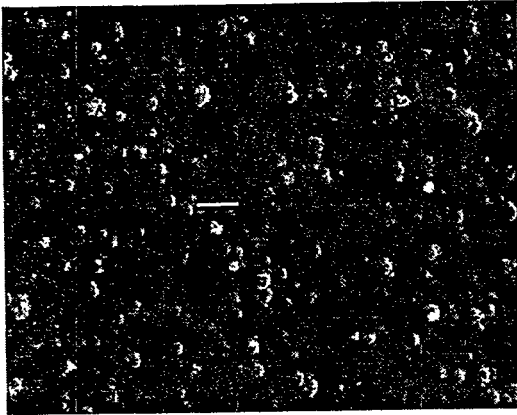


Field of view $\approx 300 \mu\text{m}$

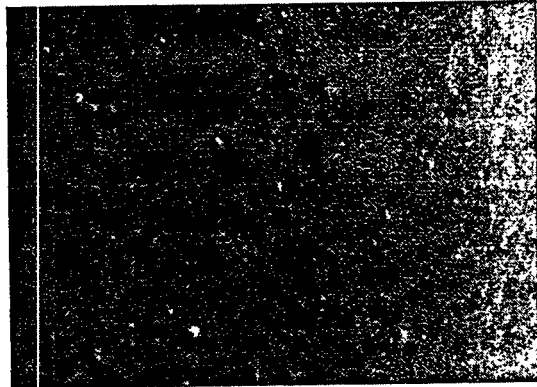
- Shells make frequent collisions with each other during deposition.
- These collisions may be responsible for producing seeds for the observed domes on the coatings.
- We await the results of LLNL optical edge detection tests on shells with these poor surfaces.



Using a spinning pan arrangement to agitate shells improved the surface finish



Bounce coated shells



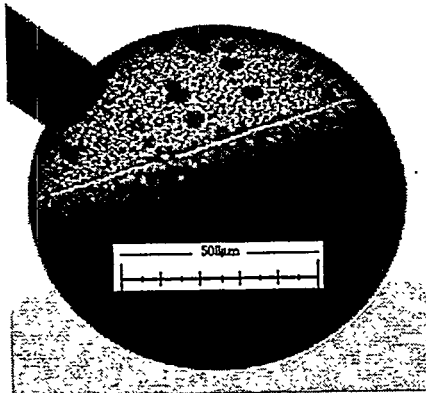
Rolled shells

scale bar = 3 μm

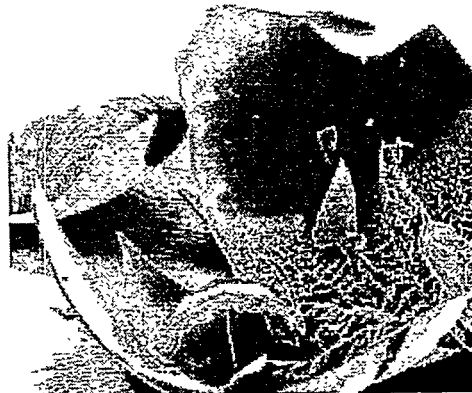
- Roll coating shells in a spinning pan reduced the density of large nodules on the surface



GDP inner mandrel melts at temperatures of $>300\text{ C}$



The GDP inner mandrel has melted to the bottom of $\approx 10\text{ }\mu\text{m}$ of glass overcoating.

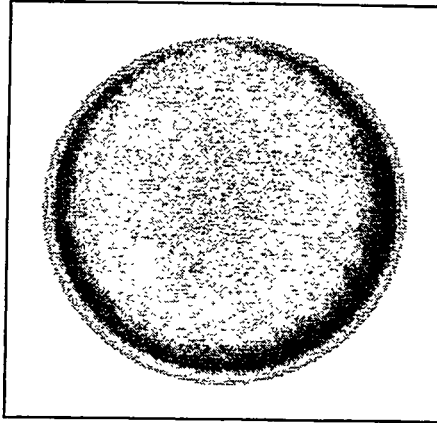


SEM image of the same shell after it was broken to examine the inside.

- GDP only "melts" in the absence of oxygen at $>\approx 300\text{ C}$.
- A GDP shell continually shrinks in presence of oxygen at $>\approx 300\text{ C}$.



GDP inner mandrel could be pyrolyzed away by heating composite shells to 360 C in air

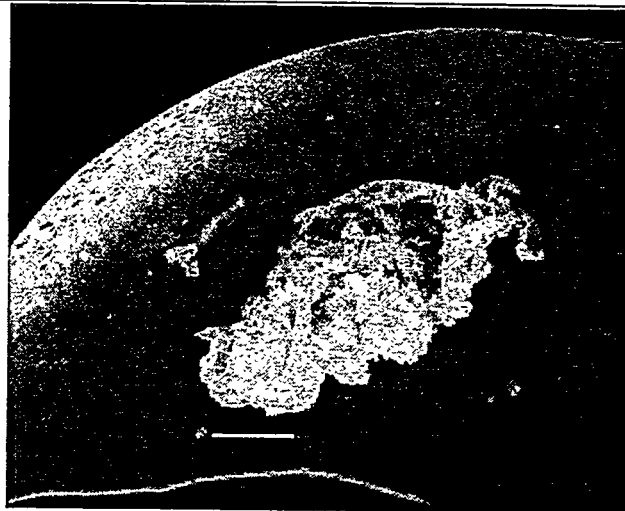


≈ 900 x 16 μm glass shell from GDP

- Glass coatings deposited at 30 mtorr background pressure were porous enough to allow extraction of the GDP inner mandrel.
- A small residue was visible inside the shell.



Pyrolysis of the inner GDP mandrel left behind a small "fluffy" residue on the inside of the shell



scale bar = 30 μm

- The residue did not disappear when the shell was heated to 1000 C !
- EDAX measurements did not reveal any carbon in the residue.
- Only elements present were Si and O.
- Residue may be parts of the inside of the coating torn away by the melting GDP.

Sputter overcoating of thin-walled glass shells increased their burst strength to over 100 atm

- Overcoating of thin-walled glass shells allows survival of shells at > 100 atm gas fills.
- The surface finish is very poor due to the large number of dome/nodules in the coating.
- Coatings without these features may provide even more strength to the starting mandrels.
- The effect of the poor surface finish on the optical layering experiments has not been determined.
- Overcoating GDP shells with glass increases the strength of GDP shells also.
- The GDP inner mandrel melts during the gas fill, if the fill is carried out at ≈ 300 C.
- Lower temperature fills take too long and are not practical.



CALIBRATION OF X-RAY FLUORESCENCE ANALYSES WITH STANDARDS AND COMPUTER MODELING

Presented by: Martin Hoppe (GA)
Richard Stephens (GA)
Annette Greenwood (GA)

Twelfth Target Fabrication Specialists'
Meeting

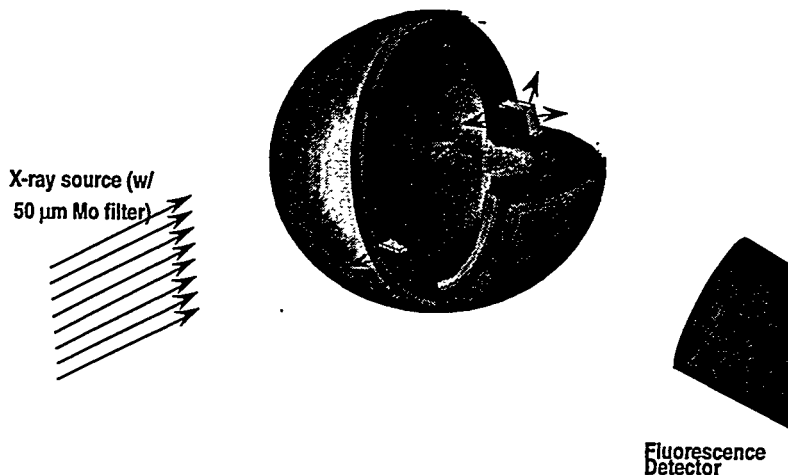
Jackson Hole, Wyoming

April 20-23, 1998



XRFeR Created to Model XRF Measurements

- Calculates fluorescence signal given dopant concentration, and structure
- Use multiple calculations to create fluorescence/signal equation
- Use equation to determine dopant concentration in deliverables



XRFeR Includes Shape and Absorption Effects

- **Spectrum**
 - Calculates emission spectrum as function of tube voltage
 - Includes filters
 - Experimental coefficient for detector response
- **Absorption**
 - Contains analytic description of absorption strength for each element
 - Each layer can be a mixture of elements - in g/cc
- **Shape**
 - Up to five layers (and an inner volume for spheres)
 - Any or all layers and volume can be doped
- **Calculations**
 - Can do batches varying any combination of parameters
 - Calculations output as tab-delimited table vs varying parameters
 - For each doped layer shell is divided into 10° segments
 - Doped inner volume can be subdivided into cubes <1% of inner diameter



XRFeR Interface is Easy to Use

Proposed shell structure

Molybdenum Tube @40.000 keV

Source filters:

th/den(Molybdenum) = 50.0 μm , 1.022e1 g/cc

Tube/Detector Angle = 120.0 degrees

Fluor(Titanium) = 4.510keV

Count multiplier = 8.860004e5

Layer divided by 5 for precise calculation

Shell: InnerRadius = 450.0 μm

Inner volume comp:

d(Argon) = 0.178e-2 g/cc

layer(1 outer) thickness = 4.0 μm

composition:

d(Carbon) = 0.930e0 g/cc

layer(2) thickness = 20.0 μm

composition:

d(Carbon) = 0.930e0 g/cc

d(Oxygen) = 0.300e-1 g/cc

layer(3) thickness = 5.0 μm

composition:

d(Carbon) = 0.850e0 g/cc

d(Titanium) = 0.320e0 g/cc

d(Oxygen) = 0.200e0 g/cc

Case ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Add Delete OK

☒ Thick doped layers

☐ Very thick doped layers

Shell Inner Rad (μm)

initial	final	step #
450.0	450.0	1

☐ Graph

outside inside

Layer ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Add Delete

Thickness (μm)

initial	final	step #
4.0		1

☐ Graph

Element # ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Add Delete

Element Carbon

Concentration (g/cc)

initial	final	step #
0.930e0		1

☐ Graph

☒ Fill Interior

Element # ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Add Delete

Element Argon

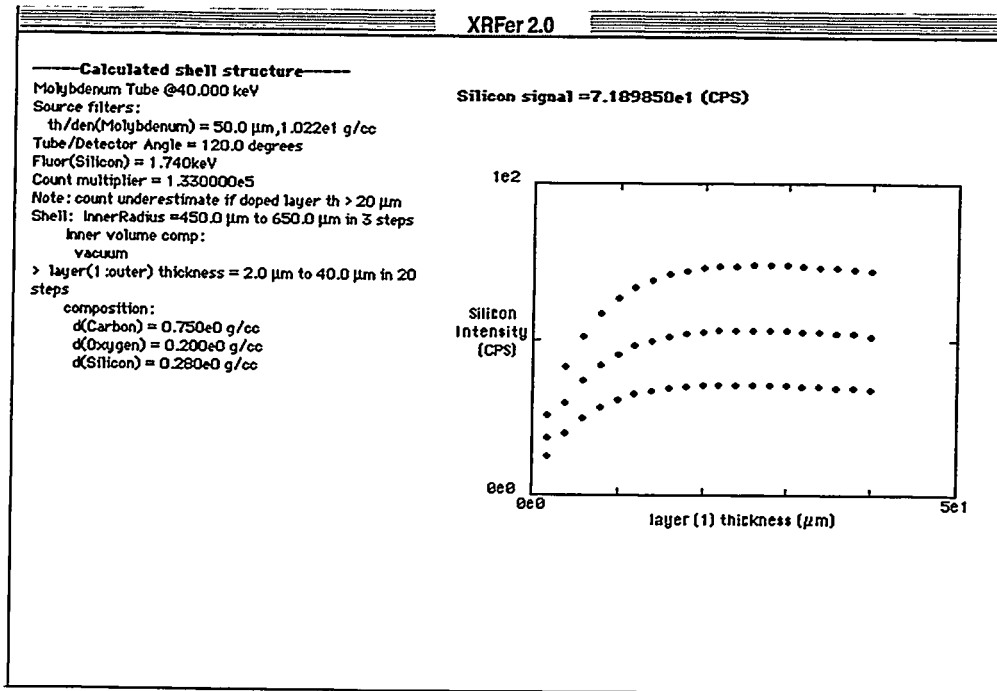
Concentration (g/cc)

initial	final	step #
0.178e-2		1

☐ Graph

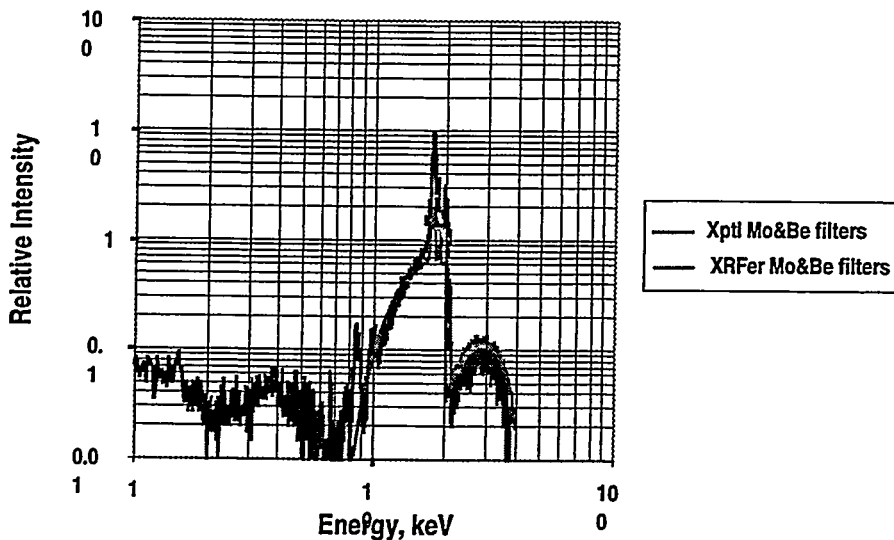


XRFe Shows and Saves Batch Results

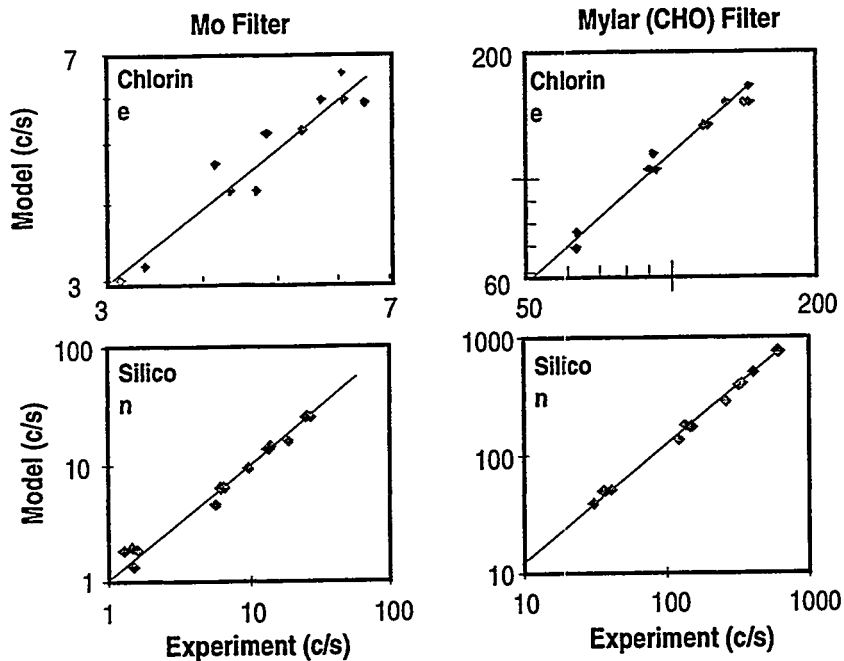


XRFe Properly Models the Excitation Spectrum

Mo x-ray tube emission – XRFe vs Experimental



XRFeR Successfully Calculates Resulting Fluorescence Changes

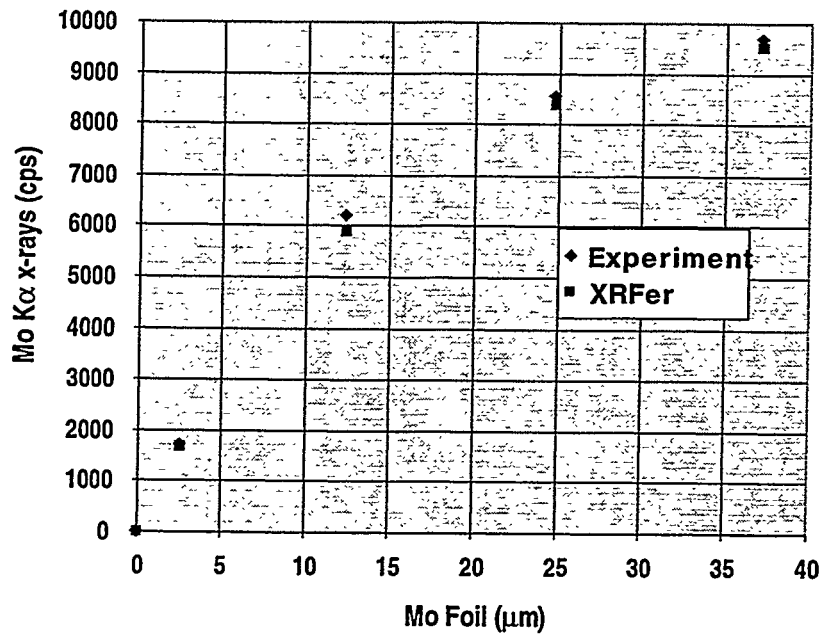


Modifications to XRFeR Program Allow for Modeling of Multi-Layered Flat Films

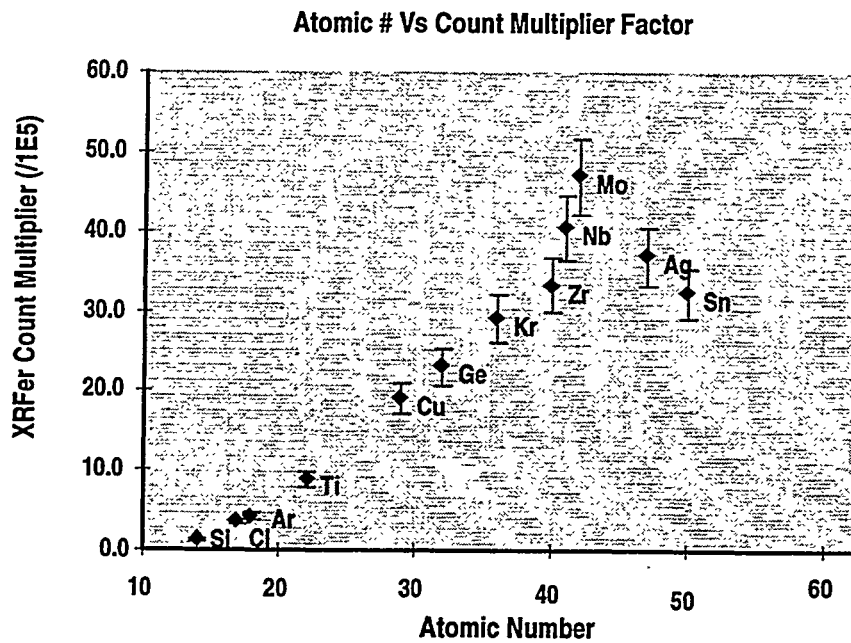
- Improves ability to measure doped, multi-layered, flat-film ICF components
- Significantly improves ease in calibration of the XRF spectrometer
 - many elements are available as pure, thin-film foils
- Resulted in the ability to determine the approximate ($\pm 10\%$) XRFeR Count Multiplier factor (CM) for all elements from Si to Sn (At # 14-50)
 - CM is a constant utilized by XRFeR to set the measured cps equal to the calculated cps - each element has a unique CM factor



XRFe Agrees with Experimental Foil Data



XRFe Count Multiplier Factor for All Elements from Silicon to Tin



XRF Generally Compares Well to Other Techniques

<u>Doped GDP Capsule</u>	<u>% Difference Relative to XRF</u>	
	<u>*RBS</u>	<u>**Combustion</u>
Si	≤10%	≤10%
Ti	≤30%	***NSM
Ge	≤20%	≤10%
Cl	~100%	≤10%

* Dr. David Harding (LLE)

** Desert Analytics (Tucson AZ)

*** Not successfully measured



XRF Calibration with Standards and XRFe

- XRFe models the tube spectrum, absorption phenomena, and geometry
 - for both multi-layered Spherical and Flat Film geometries
 - and is suited for gas filled capsules as well
- XRFe is written for Power Mac and is relatively easy to use
- Addition of Flat Film capabilities allowed calibration by interpolation for all elements from Si to Sn
- XRF results via XRFe compare favorably with other analytical techniques





Target Fabrication

A REVIEW OF CURRENT TARGET FABRICATION ACTIVITIES AT A.W.E AS RELATED TO THE CURRENT EXPERIMENTAL PROGRAMME ON THE HELEN LASER

F B Lewis

**Plasma Experimental division
Radiation Physics Department
Atomic Weapons Establishment
U K**

**Presented at the Twelfth Target fabrication Specialists meeting
Jackson Hole Wyoming April 20 - 24th 1998**

UK Attendees

Barrie Lewis	AWE
Tony Tyrrell	AWE
Colin Horsfield	AWE
Wigen Nazarov	Dundee University
Bob Keatch	Dundee University

EXPERIMENTAL PROGRAMME AREAS INVOLVING TARGET FABRICATION



EQUATION of STATE

MIX / INSTABILITY

SPALL

RADIATION FLOW

HOHLRAUM DESIGN / CHARACTERISATION

DIAGNOSTIC DEVELOPMENT

CAPSULE / CYLINDER IMPLOSION

Non LTE STUDIES

Equation Of State



Equation of State

Dimensional accuracy

Density

Range of Materials

Aluminium

Copper

Gold

Polymers

*

Alloys

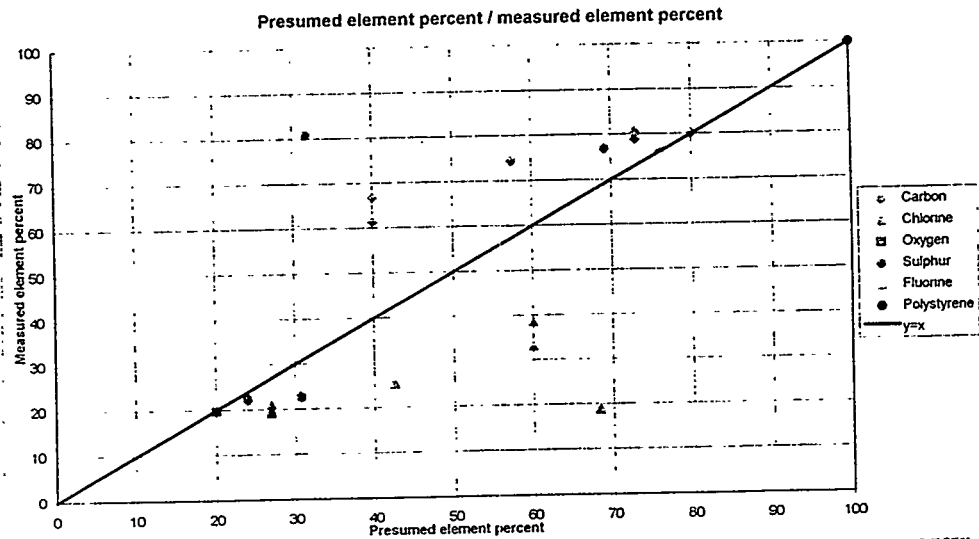
Programme specific materials and simulants

Mix / Instability

- * R M mix in low density foams
- * Ablation Front Instability
- Foam characterisation
 - Density / Uniformity - radiography
 - * Composition - EDX analysis

POLYMER EDX ANALYSIS

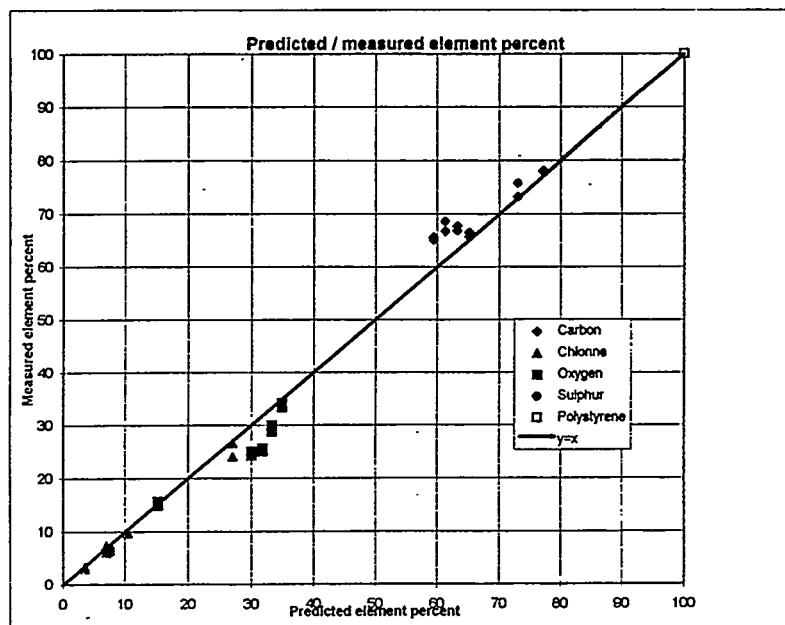
	Carbon		Chlorine		Fluorine		Oxygen		Sulphur	
	Presumed	Measured	Presumed	Measured	Presumed	Measured	Presumed	Measured	Presumed	Measured
Parylene C	73	80.72	27	19.28						
	73	80.22	27	19.78						
Parylene C dimer	73	80.15	27	19.85						
	73	78.94	27	21.06						
Parylene D	57.5	74.76	42.5	25.24						
	57.5	74.37	42.5	25.63						
Saran	31.7	81.25	68.3	18.75						
	31.7	80.89	68.3	19.11						
PVC	40	68.82	60	33.16						
	40	61.42	60	38.58						
Lexan	80	80.31					20	19.69		
	80	80.22					20	19.78		
Poly(phenylene sulphide)	69.2	77.45							30.8	22.55
	69.2	76.79							30.8	23.21
PTFE	24	22.76			76	77.04				
	24	22.12			76	77.88				



	Carbon		Chlorine		Oxygen		Sulphur	
	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
TMPTA + 3% chlorine	63.24	66.95	3.54	2.98	33.22	30.08		
	63.24	67.8	3.54	3.41	33.22	28.79		
TMPTA + 6% chlorine	61.3	66.68	7.02	6.17	31.68	25.15		
	61.3	66.88	7.02	7.46	31.68	25.66		
TMPTA + 9% chlorine	59.39	65.15	10.44	9.72	30.03	25.13		
	59.39	65.76	10.44	9.89	30.03	24.35		
Poly(4-chlorostyrene)	73	75.86	27	24.14				
	73	73.35	27	26.65				
Mylar	65.2	65.88			34.8	34.12		
	65.2	65.82			34.8	34.18		
TMPTA	65.2	66.56			34.8	33.44		
	65.2	66.64			34.8	33.36		
Polysulphone	77.14	78.19			15.24	14.99	7.62	6.81
	77.14	78.05			15.24	15.79	7.62	6.15

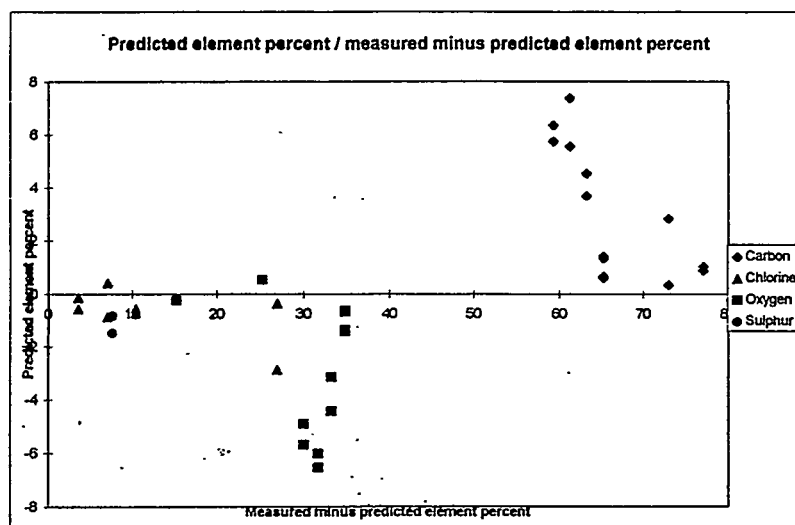
POLYMER EDX ANALYSIS

Target Fabrication



POLYMER EDX ANALYSIS

Target Fabrication



Capsule / Cylinder Implosion

Capsule Manufacture

Coatings

Hohlraum Interface

Characterisation

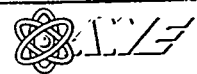
Density / Uniformity - radiography

Composition - EDX analysis

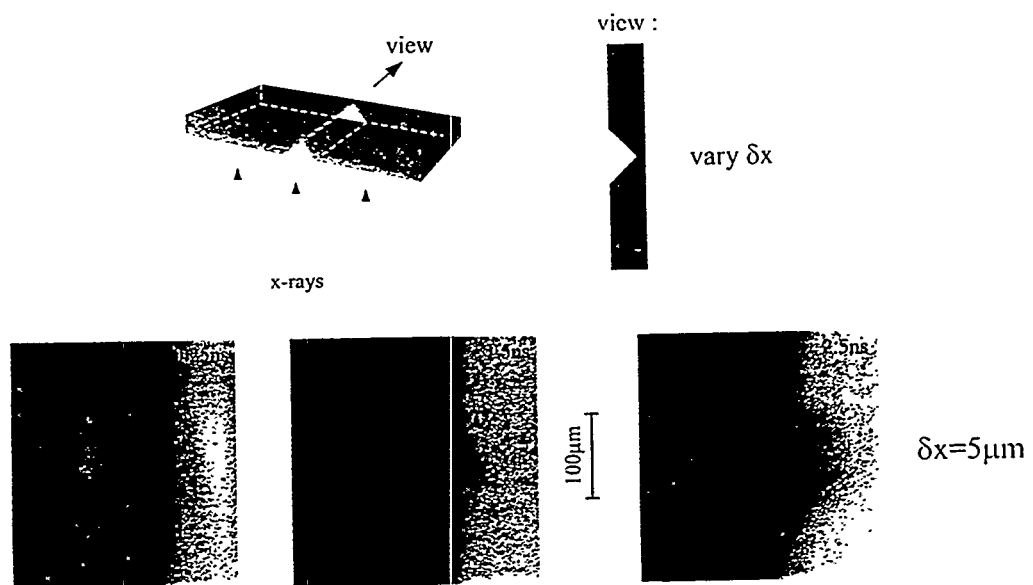
*** Joints/Defects**

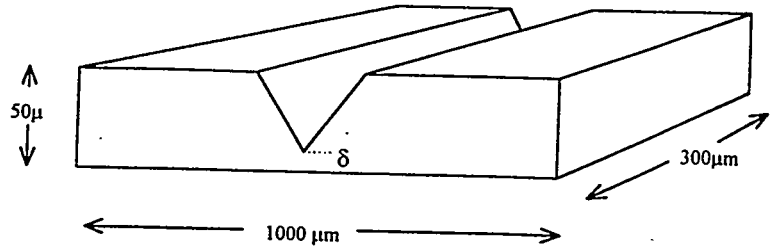
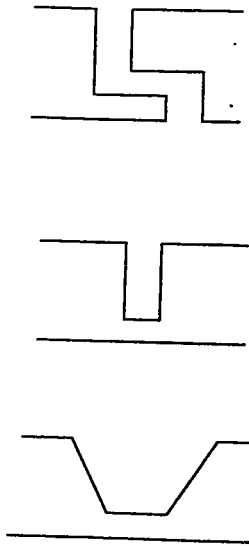
Hunting-BRAE

HELEN groove experiments



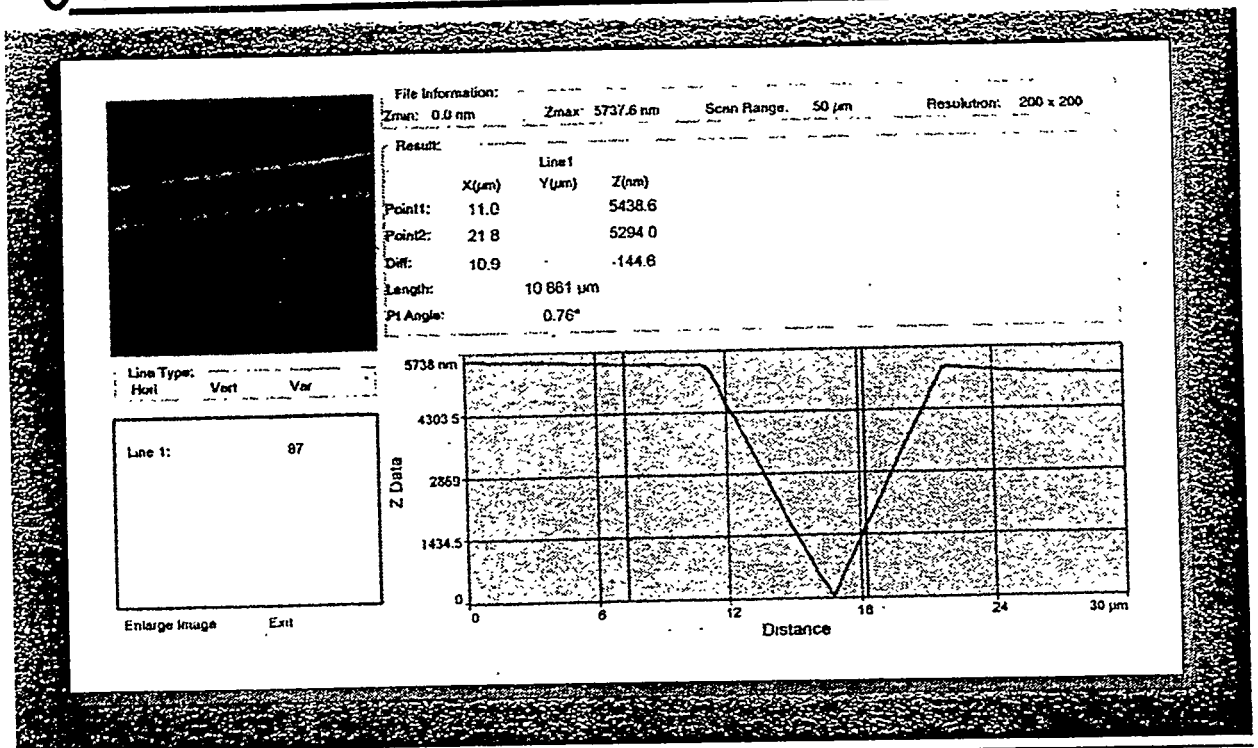
- Code predictions of perturbed radiation-hydrodynamics can vary significantly
 - fundamental tests required.
 - link to cylinder experiments.





δ ranges from 0 to 20°

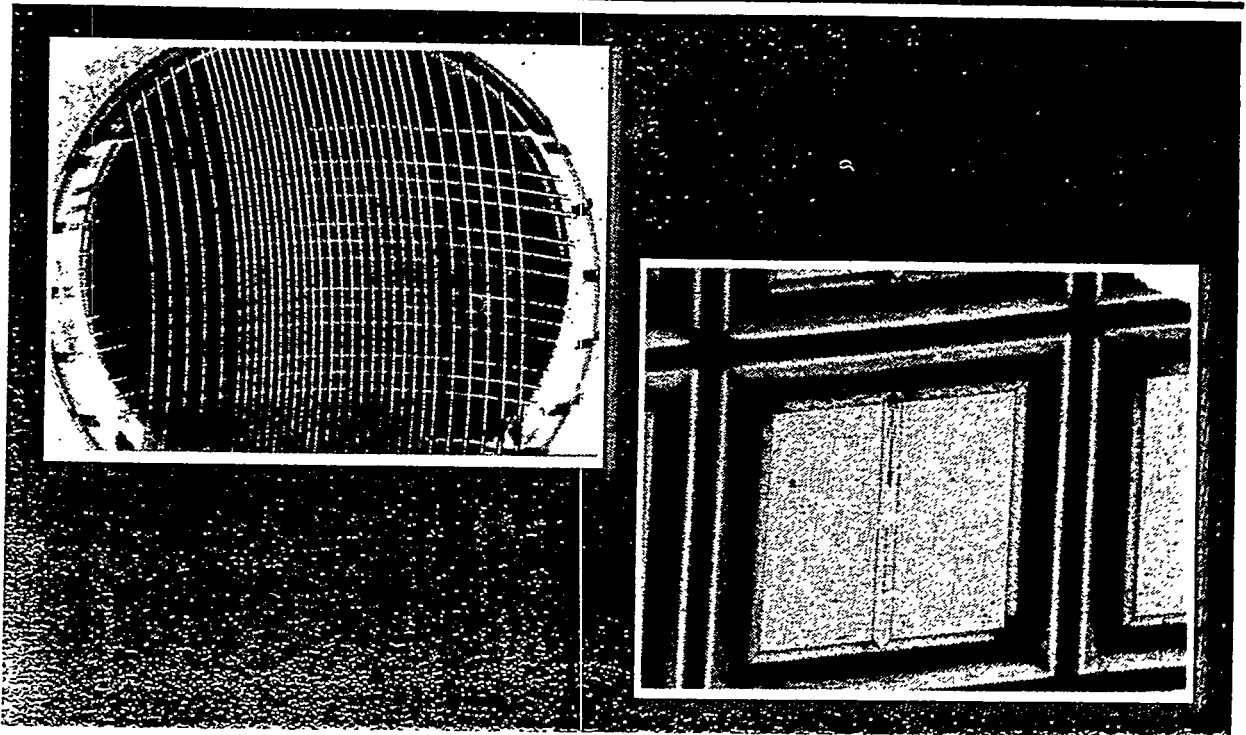
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SJM/0160/2

Groove Cutting Patterns

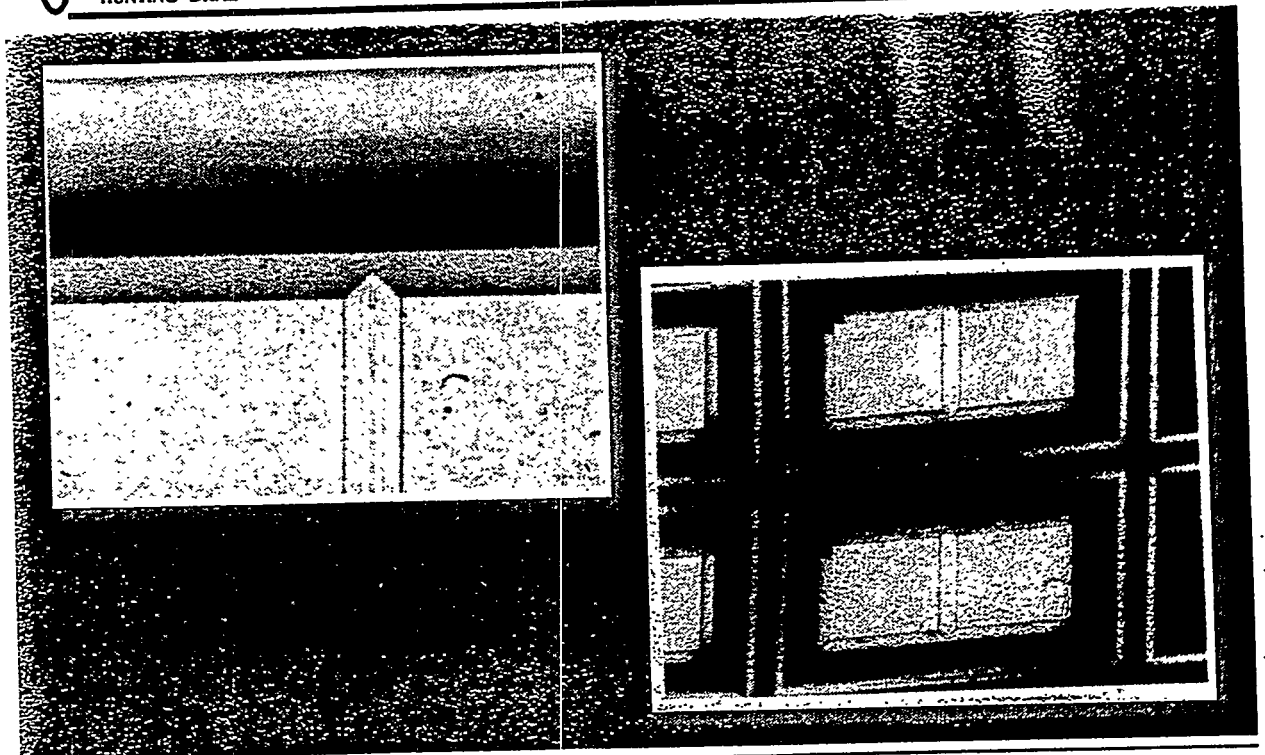


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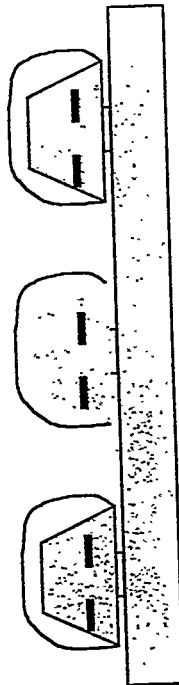
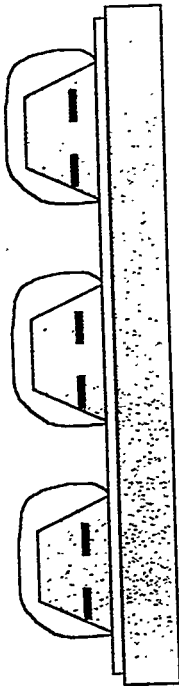
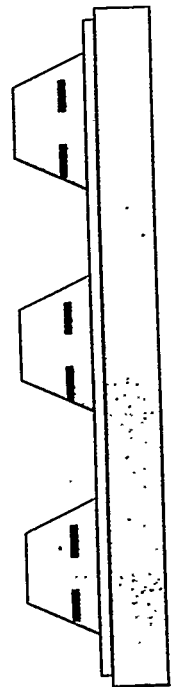


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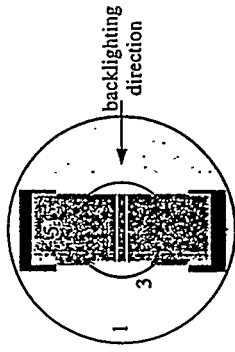
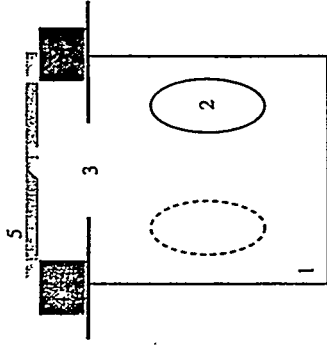
U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY



ALUMINIUM
COPPER
EPOXY RESIN

(a) side view :

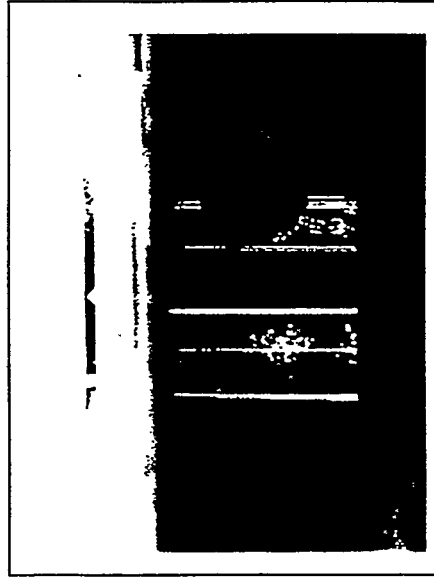
top view :



Key :

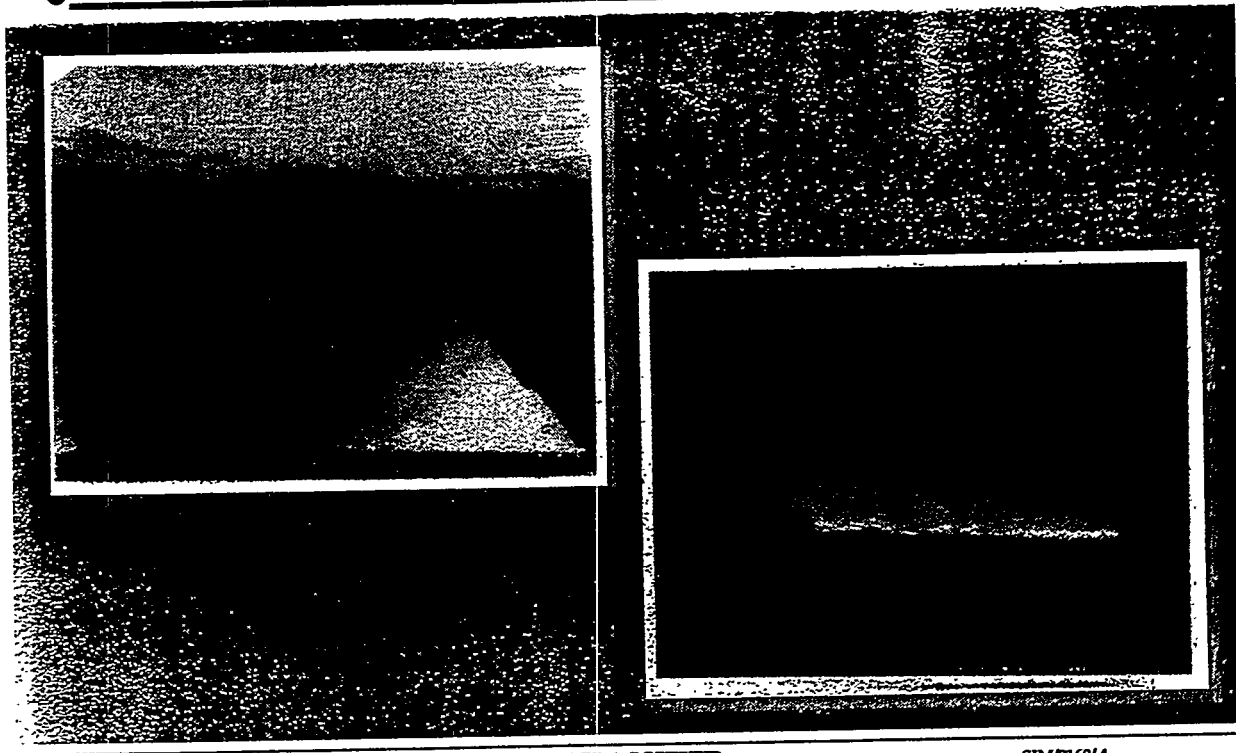
1. 1mm x 1mm standard holraum
2. 500µm diameter laser entrance holes
3. 400µm diameter drive hole
4. 200µm high spacer blocks
5. 50µm thick, 300µm wide grooved Al sample

(b)





Groove Edge Detail by SEM



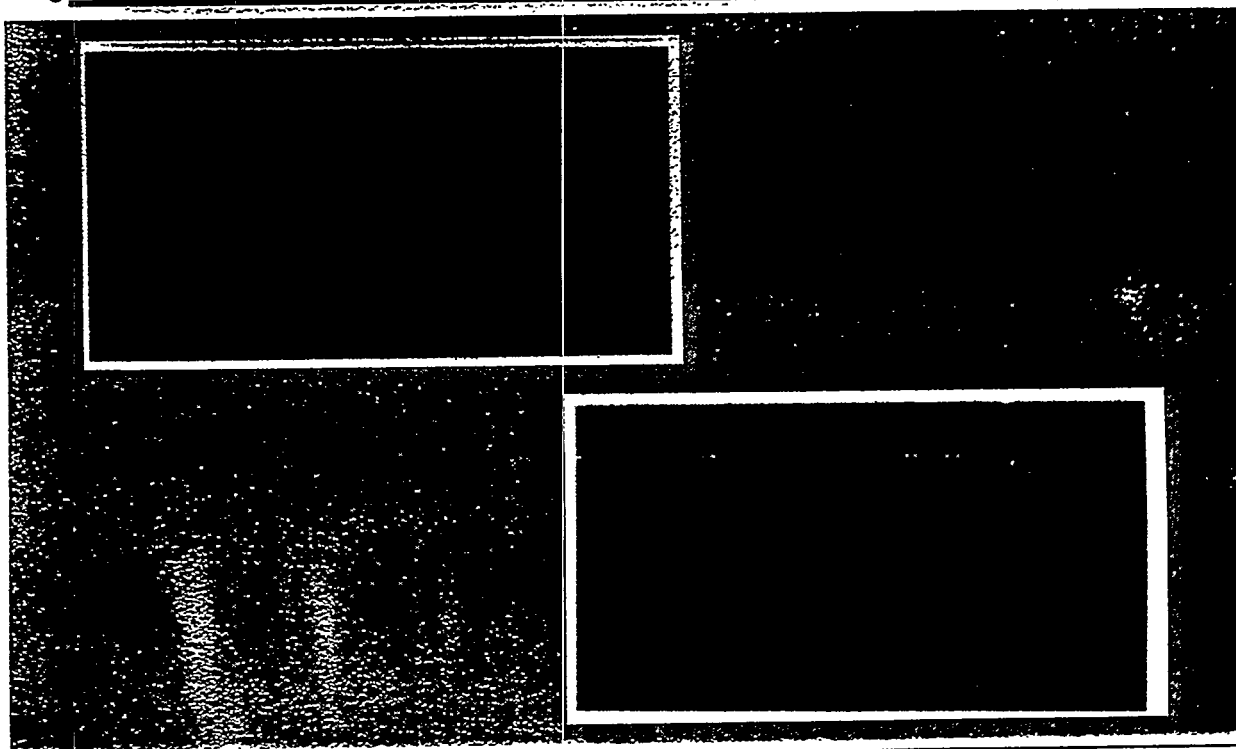
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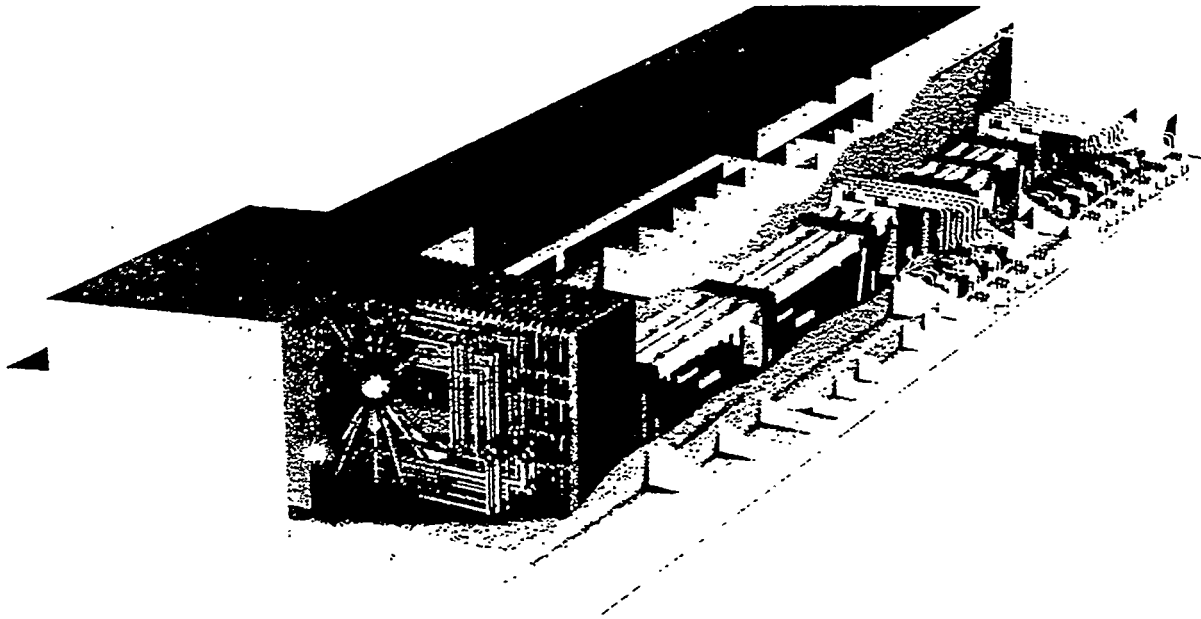
Laser Scanning Microscope Profiles



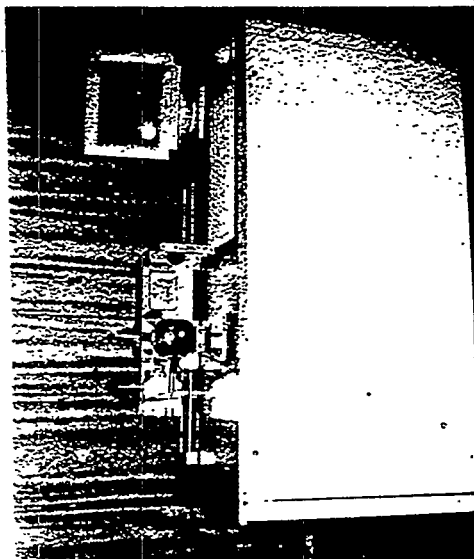
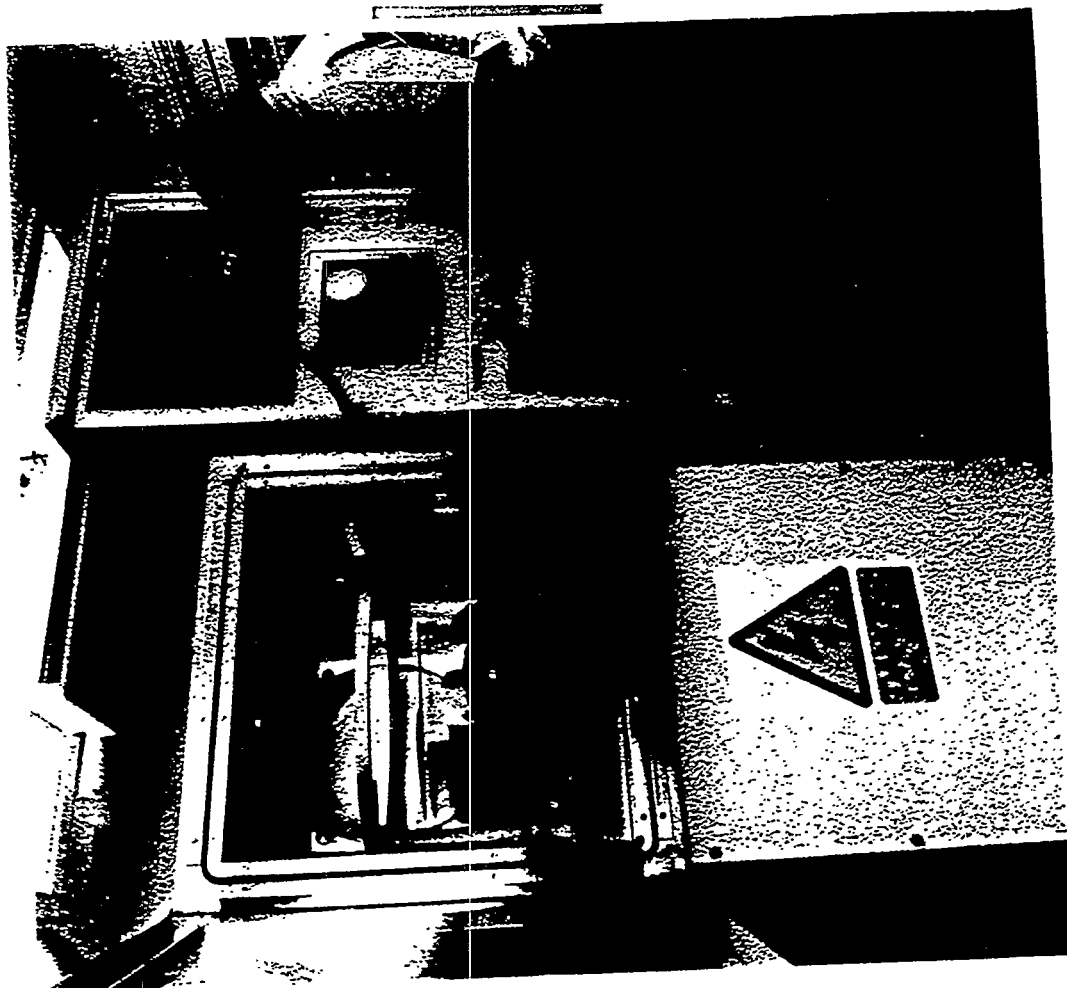
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SJM/0160/3

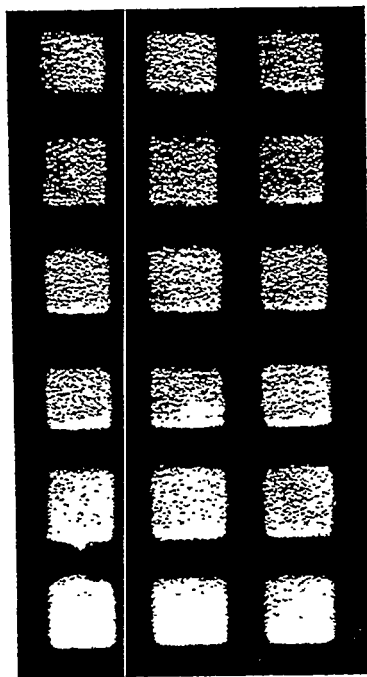
HELEN Replacement Laser



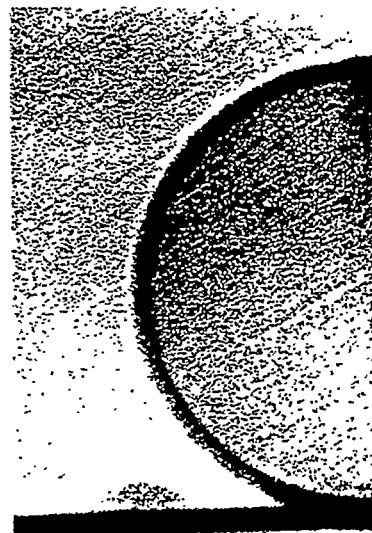
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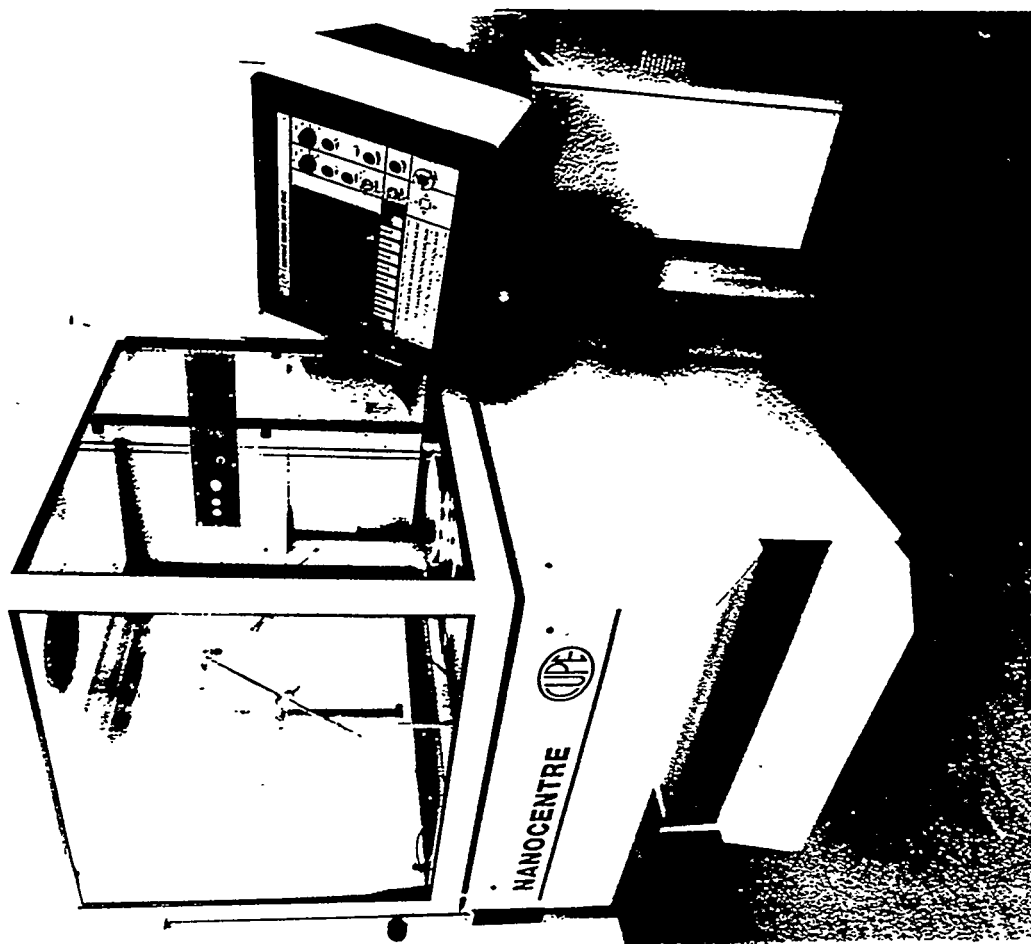
New Microfocus
X-radiography Equipment



600 cpi
Test Grid



200 μm dia.
Polymer Sphere



Techniques for Making Patterned Flat Film Targets

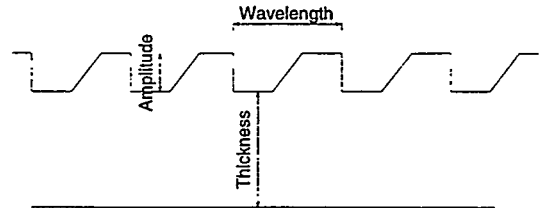
Tom Walsh, Thom Bahrs, Sue Carter,
Scott Faulk, Charles Hendricks,
Brian Motta, Katie Strube
Schafer Corporation

Specifications

- Square Wave
- Step-Ramp
- Randomly Roughened
- Sine Wave
- $\sin(x) \sin(y)$
- $A_1 \sin(k_1 x) + A_2 \sin(\phi + k_2 x)$

Specifications

- Amplitude is measured between the lowest and highest points on the pattern.
- Wavelength is the length of the repeating part of the pattern.
- Thickness is measured at the thinnest point.



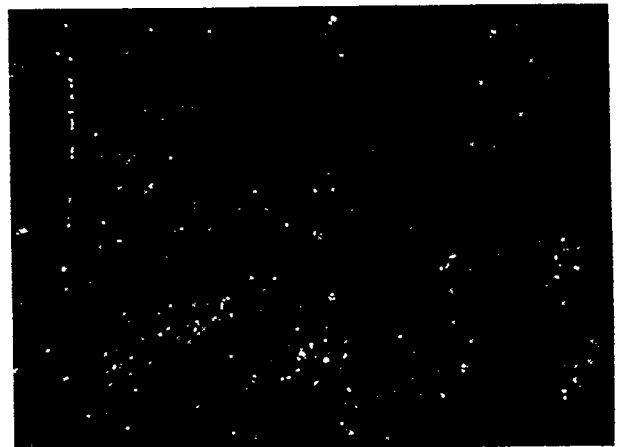
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Patterned Flat Film Targets

5

Casting Techniques

- Early patterned molds were machined in copper.
- Surface degrades with use and over time.
- Unusable after a few castings.



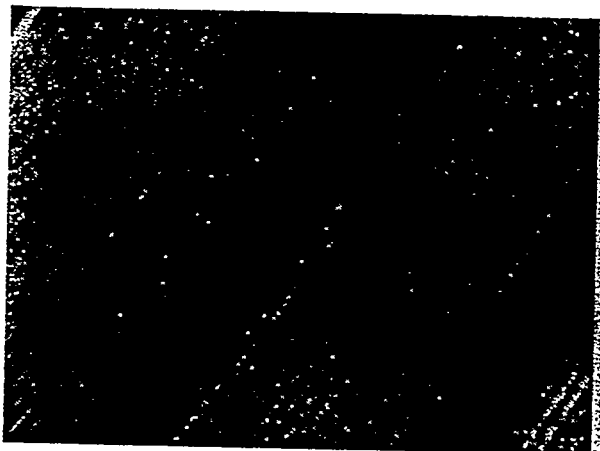
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Patterned Flat Film Targets

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Casting Techniques

- Gold coating on copper keeps surface chemically clean.
- Surface degrades physically with use.



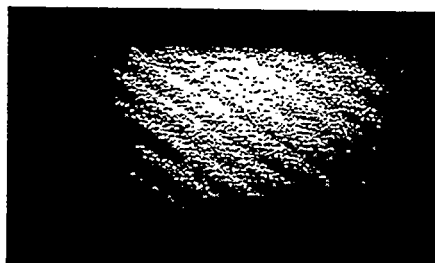
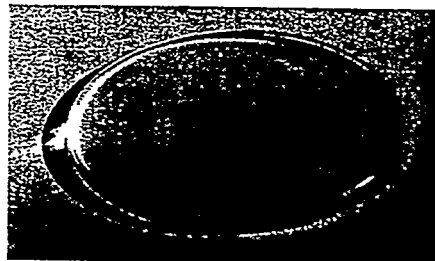
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Patterned Flat Film Targets

7

Casting Techniques

- Best results with fused silica molds.
- Surface does not degrade.
- Polystyrene lifts easily.
- Expensive (~\$4K-\$5K each)

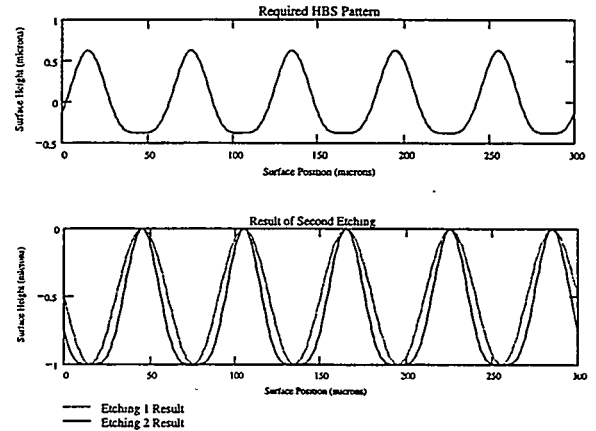


Patterned Flat Film Targets

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Specifying New Patterns

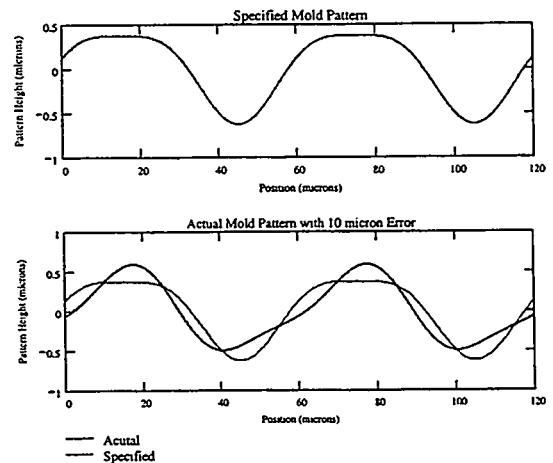
- Double Pass Etching is not straightforward.
- Cannot add material back onto substrate.
 - Usually phase shifts in etching functions can result in proper target pattern.



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Specifying New Patterns

- Two-pass etching for complex pattern presents problems:
 - Etching start point (Phase)
 - Angle between etching directions

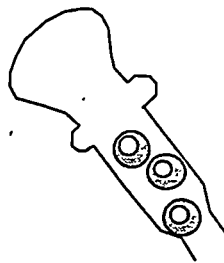


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Using Diameter to Monitor Shell Curing

R.B. Stephens, General Atomics

Information on diameters gives polymer concentration and loss rate. This data allows you to modify conditions in the stirring to accommodate changing shell properties.



- Shell preforms (compound liquid drops) can be handled!

- pipetted out of curing bath
- transferred to petri dish
- observed under microscope

(Figs 1 & 2)

- Diameter measurements characterize curing process

- diameter gives polymer concentration (beads are easier than shells)
- polymer concentration gives solvent content
- solvent content vs time gives solvent loss rate (Figs 3 & 4)

123

- Several bead and shell runs have been characterized

- Shell production parameters set product (Table 1) and curing beaker contents (Table 2)
- which determines cure rate (Table 3)

- Curing process is determined by ??

- bath temperature
- polymer concentration in solvent
- solvent layer thickness
- droplet surface/volume
- total solvent
- mixing and transport in water (stirring speed)
- water surface area

- Solvent loss rate for beads is much slower than for shells
 - thicker walls
 - less effective stirring (beads are denser - sit near bottom)
 - Cure rate determined by fractional rate of solvent loss (solvent buffers concentration until used up)
 - diffusion rates out of wall limits loss rate - scales as square of wall thickness
 - polymer concentration reduces solvent vapor pressure - solvent loss goes down with time

⇒ 1/e curing rate does not vary much with these conditions
 - Shell surface relaxation depends on polymer concentration
 - very fast at initial ~12% PAMS (never see scars)
 - very slow at ~25% PAMS (Fig. 5)
- ⇒ Use curing information to optimize stirring conditions during cure
- 1/ minimize loss while preform is very fluid
 - 2/ make walls concentric when shell shape memory is sufficiently long
 - 3/ minimize scarring when wall thickness is frozen

Table 1: Shell parameters for measured runs

run	poly conc	production w1 cc/hr	production ol cc/hr	rate l/min	initial OD μ m	initial wall μ m	final OD μ m	final wall μ m
12/16/97	.12	20	25	83	2584	306	2066	47
12/16/97	.12	20	25	83	2584	306	2066	47
1/8/98	.12	0	11	85	1603	802	791	395
3/20/98	.14	16.5	36	82	2730	437	2030	86
3/27/98	.18	0	12.5	87	1660	830	937	468
4/10/98	.14	16.5	36	95	2600	416	1999	115
4/10/98	.14	16.5	36	95	2600	416	1999	115

Table 2: Beaker contents for measured runs

run	w2 cc/min	coll. bkr initial cc	final cc	Shell No	f-b vol cc
12/16/97	97	400	1000	513	2.26
12/16/97	97	400	1000	513	2.26
1/8/98	97	400	1000	525	2.16
3/20/98	73	300	720	471	2.97
3/27/98	155	600	1050	252	0.49
4/10/98	70	450	1000	746	4.05
4/10/98	70	450	1000	746	4.05

Table 3: Cure rates for measured runs

shell run	wall μ m	total surf 10^4 mm ²	surf/ vol l/mm	bath temp C	beaker f-benzene vol cc	loss rate cc/min	l/e time min
12/16/97	306	1.08	4.76	ramp	2.26	--	--
12/16/97	306	1.08	4.76	45	2.26	--	--
1/8/98	802	0.42	1.96	ramp	2.16	--	--
3/20/98	437	1.11	3.72	45	2.97	0.015	198
3/27/98	830	0.22	4.46	45	0.49	0.0035	140
4/10/98	416	1.58	3.91	45	4.05	0.025	162
4/10/98	416	1.58	3.91	45	4.05	0.018	225

Figure 1: Beads are transferred to a Petri dish under a microscope. Supported in liquid, the distortion from density mismatch is small enough to ignore for this application. The diameter of beads decreases ~50% during curing. The index of refraction also goes up during curing, so the diameter of the bright spot in the center decreases.

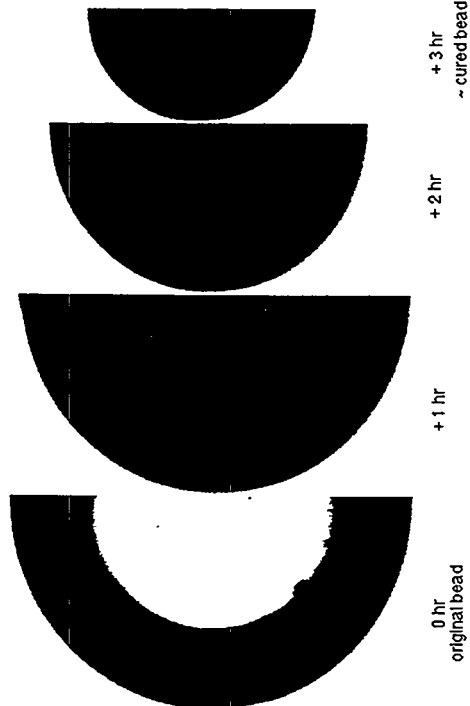


Figure 2: The diameter of shells changes ~20% during curing. The shell wall also gets thinner and increases its refractive index. The inside edge becomes better defined, and transmission through the shell goes up.

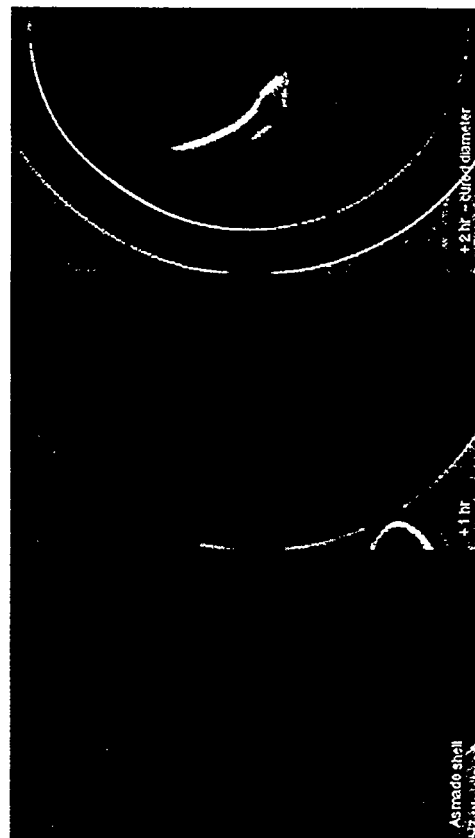


Figure 3: Measurements of diameter from images like those of beads in Fig. 1 can be used to calculate polymer concentration and solvent loss as a function of time.

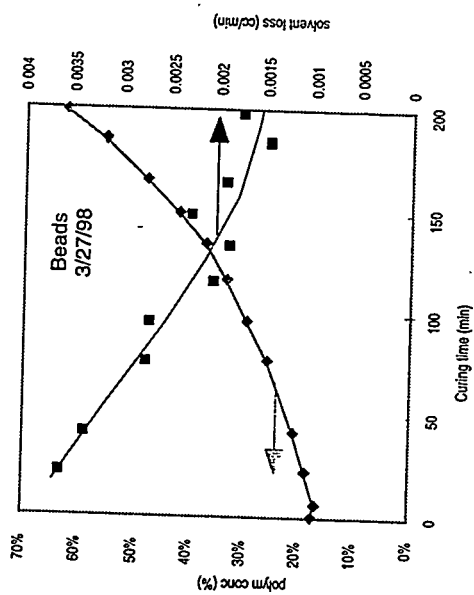


Figure 4: Measurements of diameter from images of shells like those in Fig. 2 can be used to calculate polymer concentration and solvent loss as a function of time.

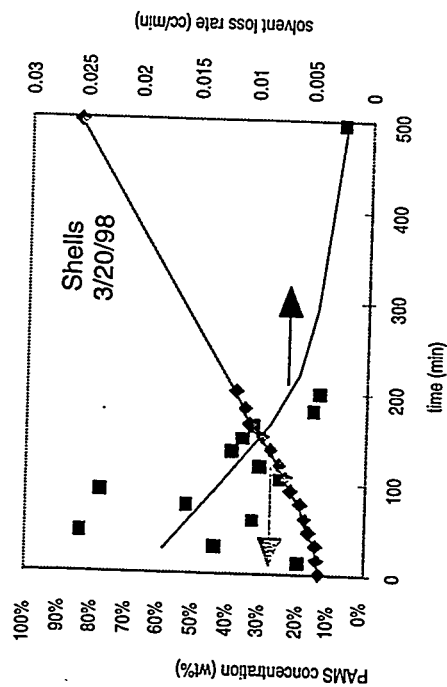
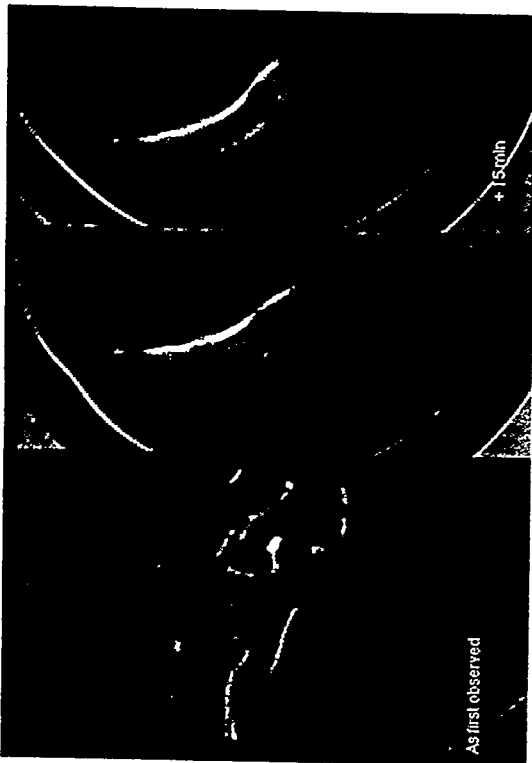


Figure 5: A surface scar on a shell healing over a period of about 15 min. The polymer concentration in this shell was ~25%.



Representative Surface Profile Power Spectra from Capsules Used in Nova and Omega Implosion Experiments

Robert Cook, Evelyn Fearon,
Randall L. McEachern, LLNL

Richard B. Stephens, General Atomics

Abstract

Typical surface profile power spectra of capsules used in Nova and Omega implosion experiments are presented. All Nova capsules are essentially identical in size and composition; their differences reflect small shell-to-shell variations. Differences among the Omega capsule power spectra can be attributed to changes in material properties with doping and (very importantly) differences in processing experience. Comparisons between Nova and Omega capsules of similar composition show the effect of the different design diameters. These capsule power spectra accurately reflect past and current production, but are only a starting point for future capabilities.

Work performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48 and by General Atomics corporation under Contract DE-AC03-95SF20732.

VG-1 4/20/98

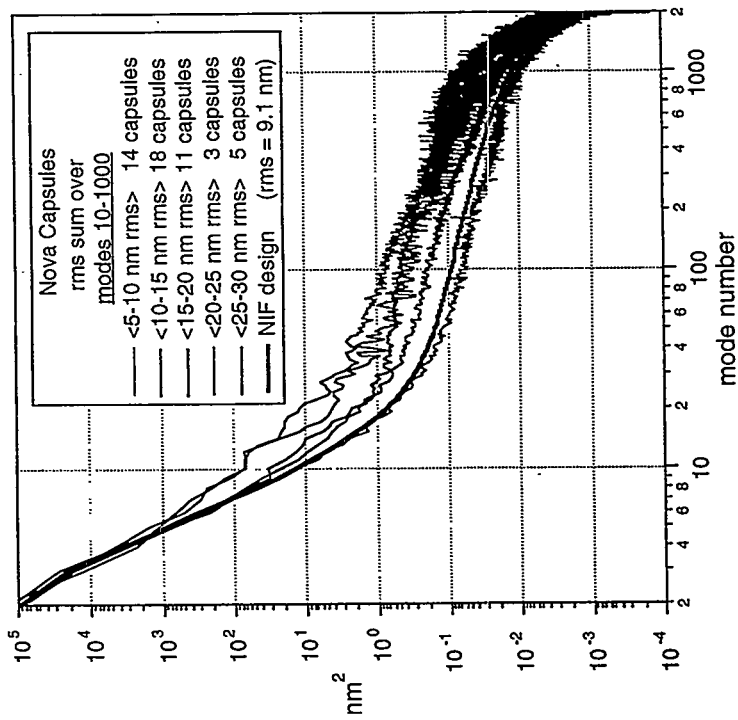
Nova Capsules

The data presented here is for ~0.5 mm diameter Nova scale capsules that were shot (or served as back-ups) on Nova since 1994. In all about 60 capsule power spectra were examined, of these 51 had rms (modes > 10) surface finishes of less than 30 nm, and the statistics for these shells are presented here. No attempt was made to examine all shells shot, but we feel that the shell data presented here is representative of "smooth capsules". 28 of the capsules date from 1994 and 1995, the remainder from 1996 and 1997.

There appears to be no significant improvement in capsule surface finish during this period although there were numerous changes in fabrication techniques. Of the 14 capsules with rms surface finishes less than 10 nm, half are from 1994-5 and half from 1996-7.

VG-2 4/20/98

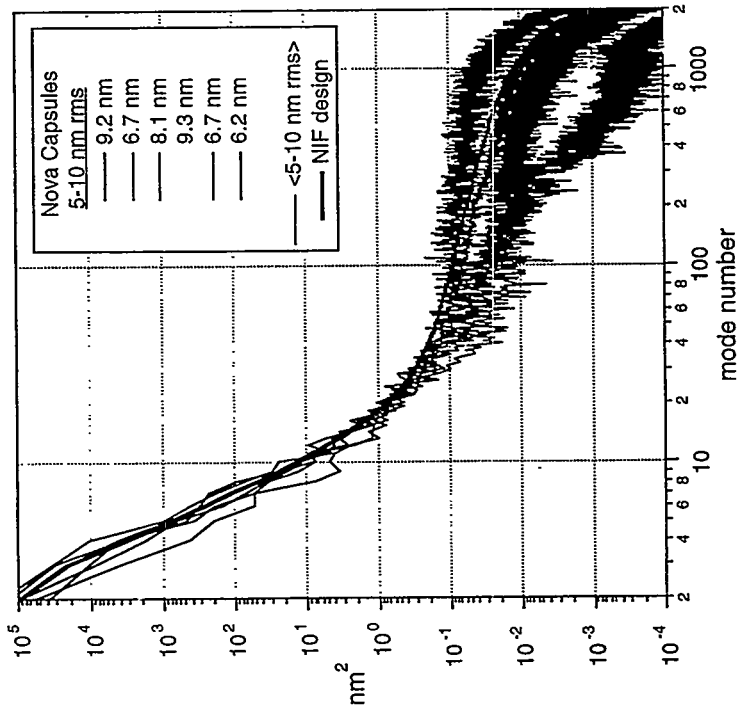
Group Averages



Shown here are the average power spectra for each grouping of capsules. For comparison the black trace is the NIF design specification. In an average sense the groups show progressively more roughness at all modes even though the groupings are dominated by the power between modes 10 and 20.

VG-3 4/20/98

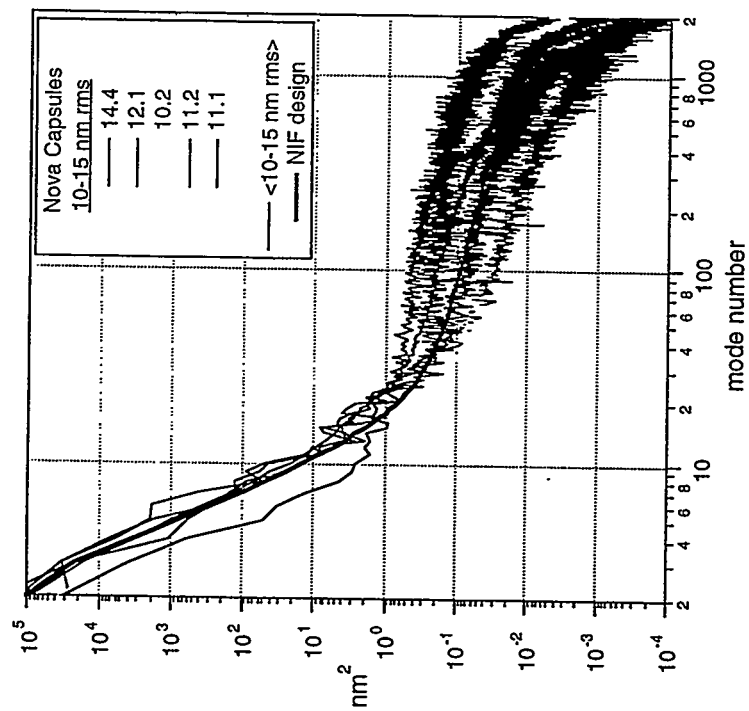
5 to 10 nm rms shells



Shown are power spectra of a selection of the 5 to 10 nm rms capsules. The differences at mode numbers greater than 30 have little effect on the total rms and are largely a result of different amounts of short length-scale surface features (debris?) encountered in the 9 AFM traces per capsule.

VG-4 4/20/98

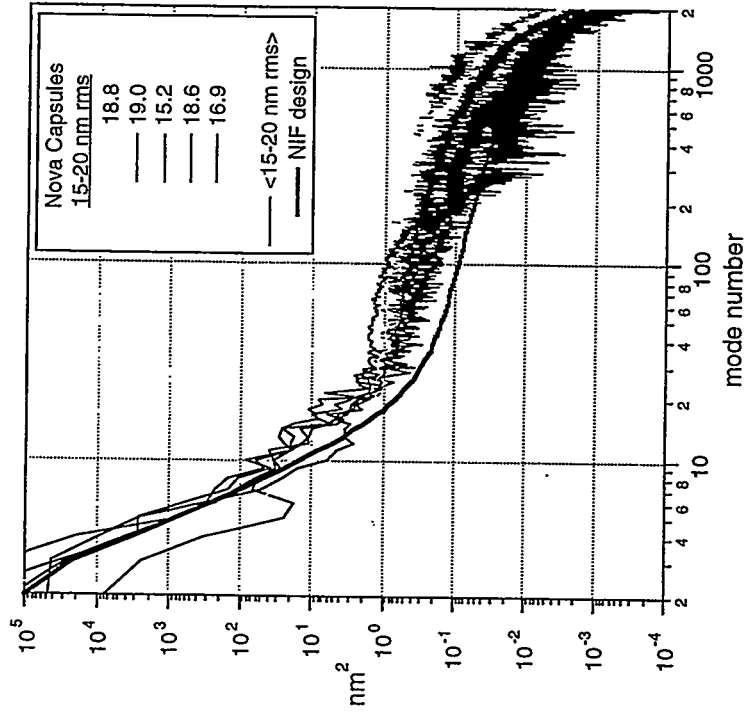
10 to 15 nm rms shells



Shown are power spectra of a selection of the 10 to 15 nm rms capsules.

VG-5 4/20/98

15 to 20 nm rms shells



Shown are power spectra of a selection of the 15 to 20 nm rms capsules.

VG-6 4/20/98

Roughness of Omega Targets

- Production is different than for Nova shells
 - use decomposable mandrel GDP/PAMS process
 - do not use a PVA gas barrier
 ⇒ The base roughness is set by the PAMS mandrel (Figs 1 & 2) w/ additional roughness from GDP thickness and doping
- Shell dimensions are larger than Nova shells
 - diameters 900-1000 μm
 - shell walls 3-50 μm
- Shell wall is variable
 - no standard 'vanilla' shell
 - plain glow discharge plasma polymer (GDP) (Fig 3)
 - GDP doped with a few percent of germanium (Fig 4)
 - 1 μm doped layers sandwiched in plain GDP (Figs 5 & 6)
- AFM traces approximately represent roughness
 - coverage depends on mode number
 - green curve represents the NIF reference curve for 2 mm shells
- Roughness depends on experience
 - delivered small numbers of each variety
 - each variety had distinct problems and required process optimization
 - domes (step falling off for mode >300 - Figs 3 & 4) caused by crowding in GDP coating pan

Power Spectra of GDP vs PAMS

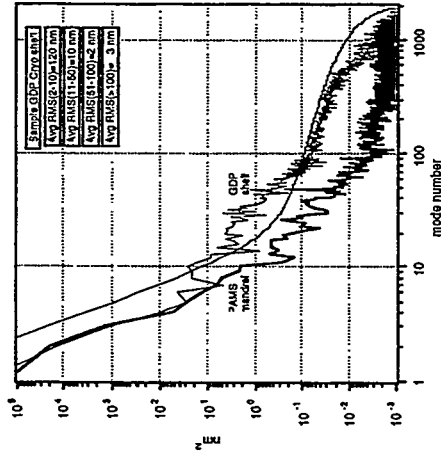


Figure 1: A plain GDP shell and a mandrel from the same PAMS batch used to make that GDP. The lowest modes are virtually identical. The deviation, from modes 10-500 are caused by a small number of localized modes, as seen in the profiles of the GDP shell below. The spike at mode ~60 in the PAMS trace is an instrumental artifact.

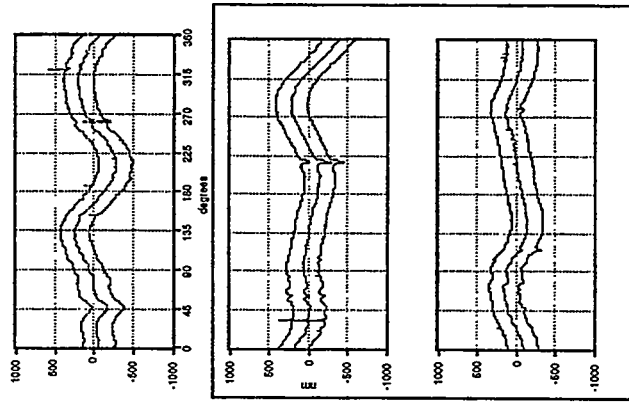


Figure 2: Profiles used to generate the GDP shell power spectrum shown above. You can see ~5 lumps which contributed to intensity in the 10-100 range. Because sets of traces are only separated by 30 μm , in each case the lump appears in all three profiles of a set. There are also higher frequency lumps (spikes whose width is not resolved on these graphs), contributing to the intensity at modes >100; these have such short wavelength that they often only appear in one trace of a set.

Power Spectra for Single layer Shell Walls

Figure 3: Plain GDP shell with 30 μm wall. Deliveries P127,128,129 made 11-12/96

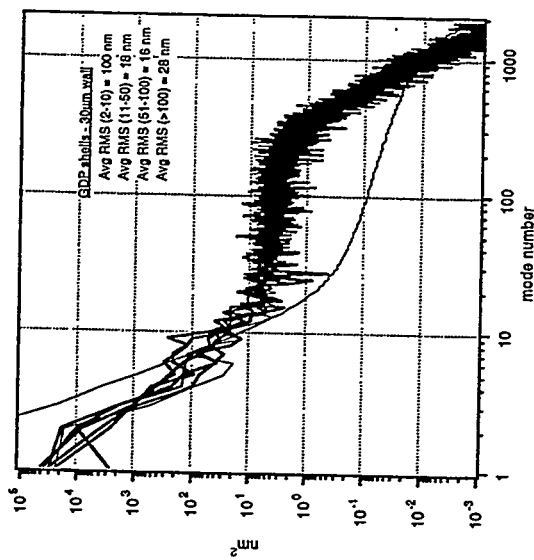
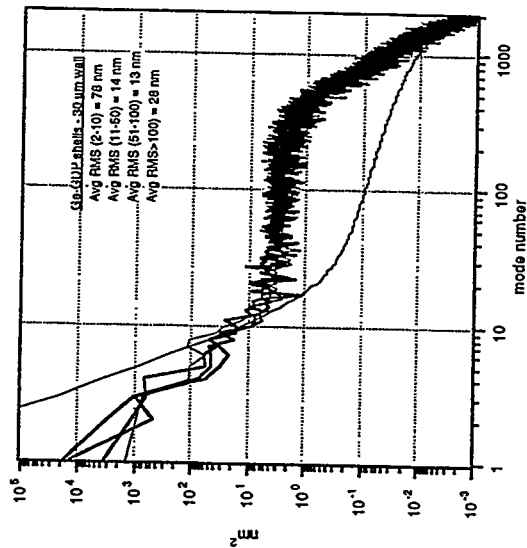


Figure 4: Germanium doped GDP shell with 30 μm wall. Deliveries P130,131 made 10-11/96



Power Spectra for Multi-layer Shell Walls

Figure 5: A 1 μm thick D-GDP layer sandwiched by plain GDP; 20 μm total wall. Deliveries P119-121, P124, P142, P153-157, P190 made between 7/96 and 7/97. The peak at mode ~8 is caused by the PAMS mandrel on which these shells were made.

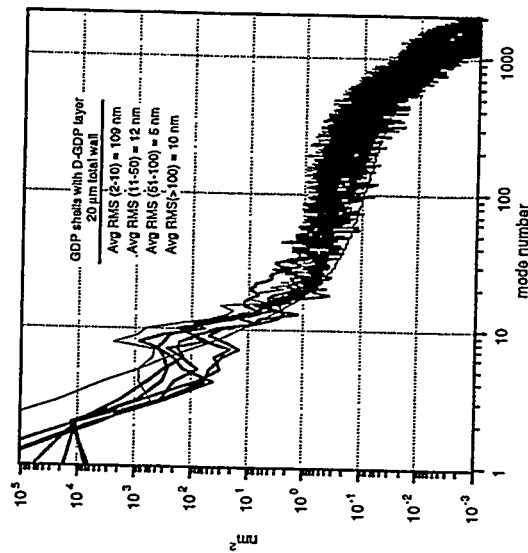
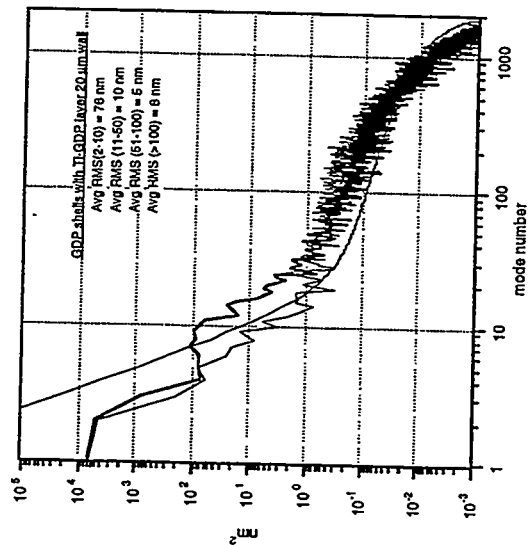


Figure 6: A 1 μm thick Ti-GDP layer sandwiched by plain or chlorine doped GDP; 20 μm total wall. Deliveries P125 and P126 made 8/96



Power Spectra of Recent PAMS

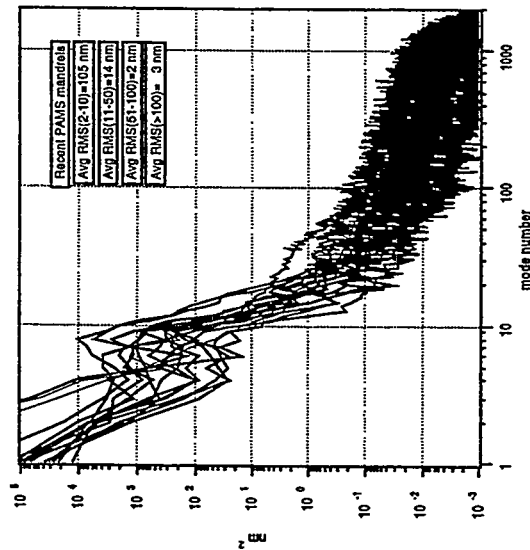


Figure 7: PAMS mandrels from all the recently made batches which have been put into inventory for future GDP shell production. Their lowest modes are virtually identical, including a peak at mode ~8. The higher modes are more variable, but the worst of them is about the same as the best delivered GDP shell.

Sphere coverage vs shell size

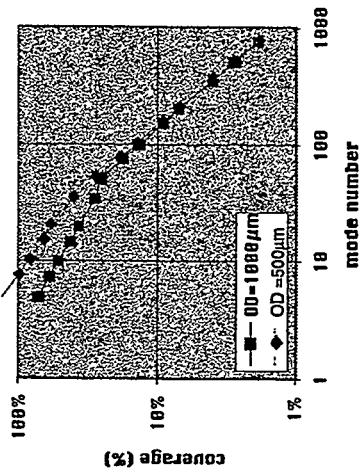
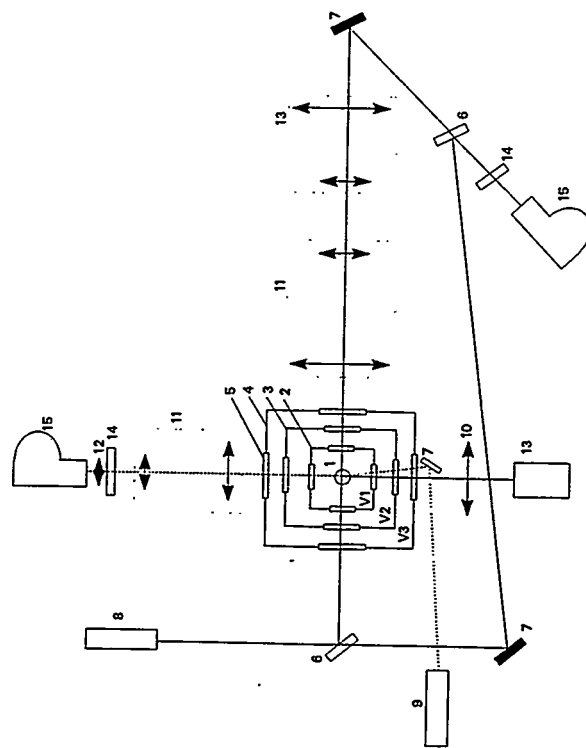


Figure 8: Probability of detecting a single Gaussian with a width corresponding to the specified shell mode number. The calculation was done for 500 and 1000 μm diameter shells and assuming 3 orthogonal sets of 3 curves each separated by 30 μm . The slope of the probability curves change at the point that the mode wavelengths are equal to the 30 μm separation between the curves. For modes less than ~50, the odds of detecting a lump are better than ~50%, so there should not be many more actual lumps with mode <50 than are detected by the current protocol.

Experimental investigation of the process of hydrogen isotopes cryogenic layer formation at spherically symmetric cooling.

V.M.Izgorodin, G.P.Nikolaev, and E.Yu.Solomatina.

Russian Federal Nuclear Center
All-Russia Research Institute of Experimental Physics
Sarov, Russia



Experimental setup.

- 1 - thermal exchange volume with a target,
- 2 - shield under the temperature of the liquid helium,
- 3 - shield under the temperature of the liquid nitrogen,
- 4 - casing, 5 - windows, 6 - glass plates, 7 - mirrors, 8 - cw laser,
- 9 - high-power cw laser, 10 - objective, 11 - telescopes,
- 12 microobjective, 13 - microscope, 14 - filters, 15 - picture cameras,

Microspheres are suspended on glass threads in the heat-exchange volume (1) which is fastened at the bottom of the cold part of the helium cryostat and is surrounded by thermal shields (2) and (3), at the temperatures of liquid helium and nitrogen, respectively. The entire cryogenic part is in vacuum insulation V_1 , V_2 , V_3 inside casing (4). Microspheres are viewed through windows (5). The heat-exchange chamber is filled with a heat-exchange gas (usually helium); its pressure is regulated by the target cooling rate.

The microinterferometer has been built on the basis of a Mach-Zehnder interferometer using mirrors (7) and glass plates (6), and in one of its paths has a cryostat, telescope (1) to relay the microsphere's image from the cryostat, microscope (1) to magnify the image and expand the beam. The second path of the interferometer contains a similar microscope for matching the wave front curvature in both arms. The microinterferometer is illuminated by cw laser radiation (8).

The scheme for obtaining the microsphere's shadowgraph consists of telescopes (11) and microobjective (12) and is backlit by radiation from a thermal light source (16). Both pictures, the shadowgraph and interferogram, are simultaneously recorded by picture cameras (15) with the frame rate up to 4000 frames/sec. Filters 14 cut off superfluous radiation.

The scheme for gas evaporation inside a microsphere consists of a high-power cw laser (9) with a shutter and a device for focusing (7) radiation onto the microsphere.

The measuring procedure is the following. The cryostat is filled with liquid helium. Then the desired pressure of the heat exchange gas is set. The pressure is measured at room temperature. The temperature of the wall of the heat exchange chamber is measured by a thermocouple. The fuel solidification inside the microsphere is determined visually. Then the shutter of the heating-laser is opened. After complete fuel evaporation the picture cameras are switched on and the heating laser is switched off. Thus was recorded the process of gaseous fuel freezing in one of the microspheres. After recording this process in all targets at various pressures the heat exchange volume was slowly heating. The time of gas melting and temperature at this moment were determined visually. Thus, the indications of thermocouples were verified according to the triple point of the gases under study. Usually, the simultaneously studied microspheres contained various hydrogen isotopes.

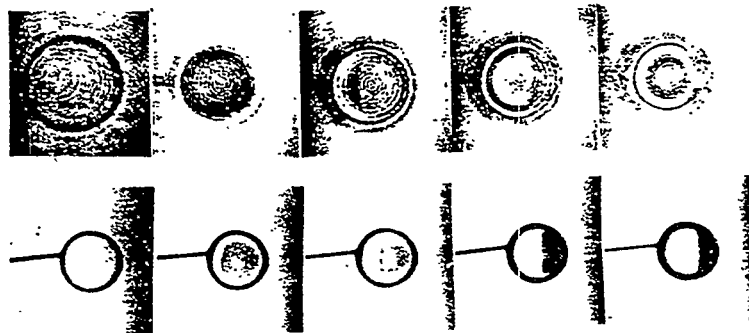
The gases under study are hydrogen, deuterium, tritium and mixtures H-D, H-T and D-T.

Formation of condensate drops.



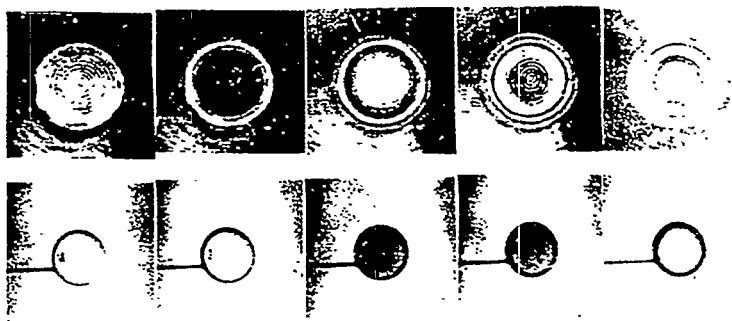
D-T mixture.

Cooling rate - 230K/s.



Deuterium.

Cooling rate - 1400K/s.



a) - target images,
b) - interferograms.

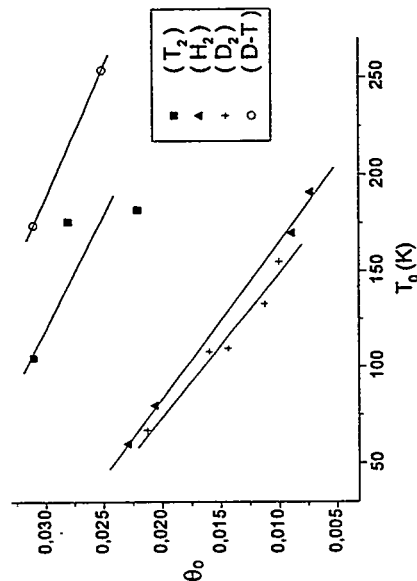
Formation of condensate drops (continuation).



In many cooling regimes we observed condensate drops in form of mist in the inner volume of a microsphere.

The drops of mist, depending on the velocity and size, either are fall to button of a microsphere (see I in figure) or scattered spherically symmetrically on to inner site of walls (see II)..

The observed nucleation and drops formation are induced by impurities in the gas. For the low temperature the impurities are frozen on the wall of microsphere. With increasing of temperature the impurity concentration increase and drops formation need a lower degree of gas overcooling.

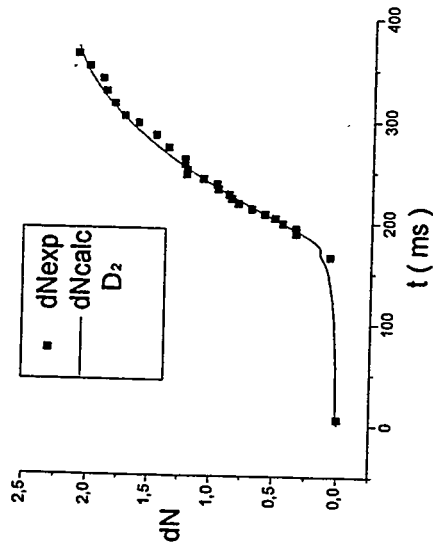


The dependence of critical overcooling on the initial temperature.

Critical overcooling is the maximum degree of gas overcooling $\theta_0 = (T_s - T) / T_s$ at which the nucleation sizes begin to grow to a supercritical size and transform to drops of mist (T is the minimal temperature of gas inside a sphere at a given moment of time, T_s is the temperature of saturated vapor corresponding to the gas pressure).

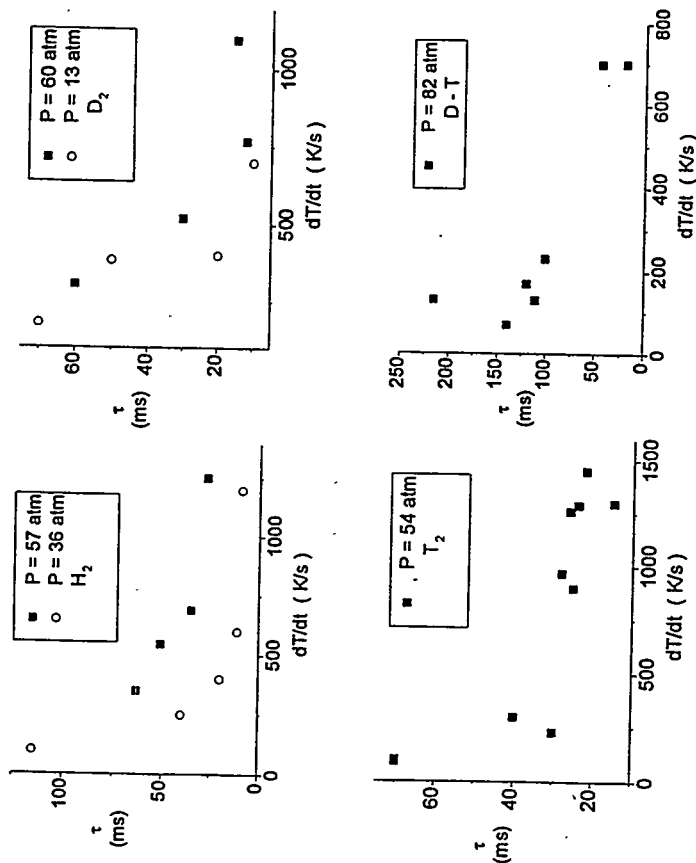
T_0 is temperature at which the cooling is begun.

The temporal and spatial distributions of temperature and density inside a microsphere, the degree of gas overcooling and the growth of condensed layer thickness are determined by calculation. Initial and boundary conditions are taken from experiment. Calculations are checked and corrected by comparing the experimental and calculated data.



Experimental and calculational temporal dependence of fringe number changing on the interferogram.

During condensation of a gas on the microsphere wall the liquid layer remains uniform in thickness for some time.



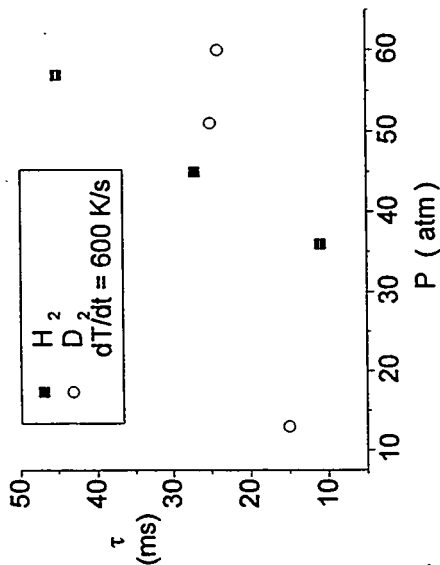
The dependence of "life-time" of uniform liquid layer on rate of the microsphere cooling.

τ is the time of conservation of thickness uniformity during condensation; in that case the layer thickness increases from 0.9 of maximum to maximum. The gas pressure is given for temperature $T = 293K$.

The "life - time" reaches 0.2 s for the D-T mixture.



Uniformity of liquid layer thickness (continuation).

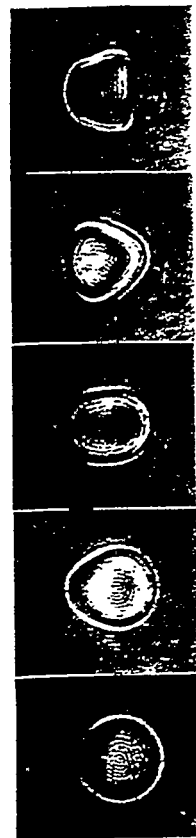


Dependence of the "life-time" of uniform liquid layer τ on the hydrogen amount inside the microsphere (P is the pressure for temperature 293K).

The maximum thickness of uniform liquid layer (d).
In case of larger thickness the liquid flows down in bottom of microsphere.

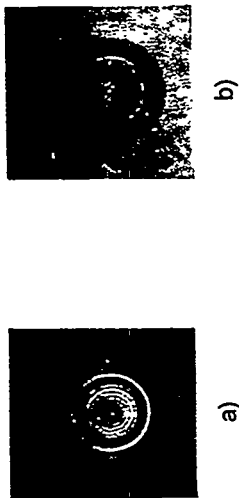
Isotope	hh	dd	tt	hd	ht	dt
d (mcm)	>3.7	>3.1	>2	>1.8	2.6	3.1

The interferograms of liquid layer of H - T mixture during condensation.



Uniformity of solid layer.

In case of the layer thickness < 3 mcm and the very large cooling rate it is possible to prepare a solid layer with the thickness nonuniformity smaller then 0.1 mcm.



Interferograms of targets with solid T_2 layer
Thickness of layer is 2 mcm..

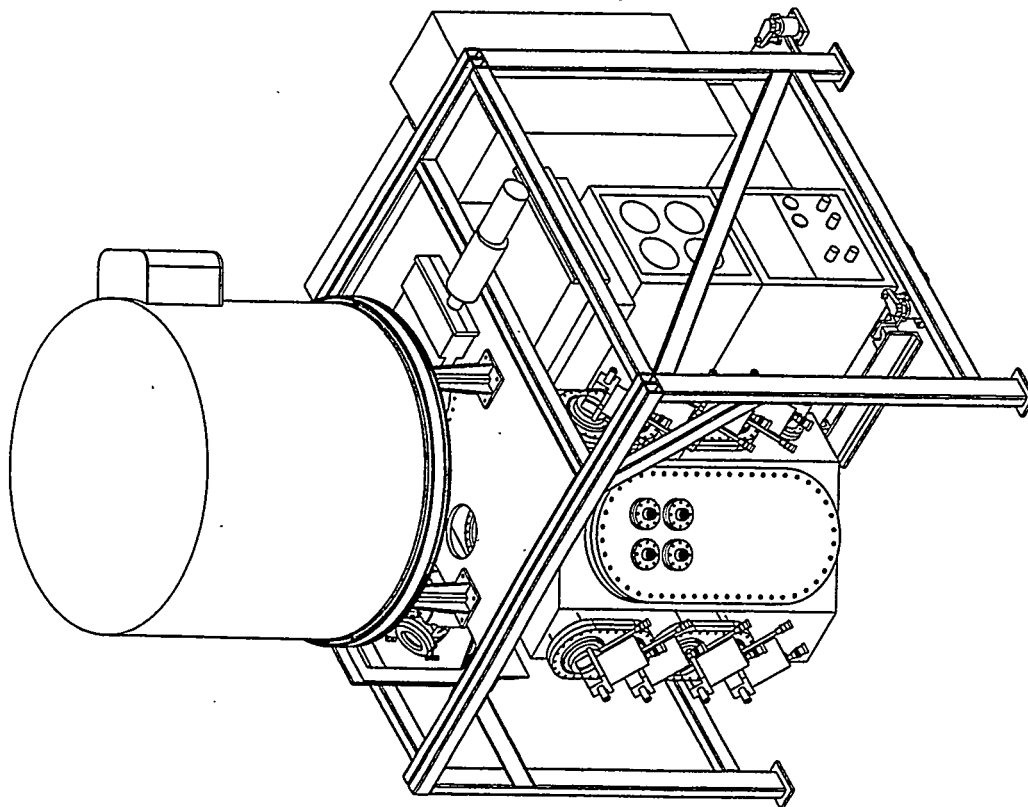
- a) Cooling rate is 1300 K/s, the time is 4 s after freezing.
- b) Cooling rate is 90 K/s, the time is 3 s after freezing.

DESIGN OF THE FILL/TRANSFER STATION FOR THE OMEGA CRYOGENIC TARGET SYSTEM

C. R. Gibson
General Atomics

General Atomics is designing, testing and fabricating a system for fielding cryogenic targets for the University of Rochester's OMEGA laser system. The equipment must be capable of routinely filling and cooling targets with a 50/50 mix of deuterium and tritium (DT) and transferring them to the Moving Cryostat which places the targets into the focus of 60 laser beams. This paper discusses the design, analysis, and fabrication of the Fill/ Transfer Station cryostat and other major components including the inserter, permeation cell, target manipulator and shroud cooler. The cryostat has two major components, a fixed base and a removable dome. The joint between the base and the dome is similar to a bayonet fitting and is sealed by a room temperature elastomeric o-ring. Since the cryostat must be housed in a glovebox, its design is driven strongly by maintenance requirements. To reach the equipment inside the cryostat, the dome is simply unbolted and lifted. The inside of the cryostat is maintained at 16 K by a closed loop helium flow system. Gaseous helium at about 200 psi flows through tubes which are brazed to the inner walls. Cooling is provided by several cryocoolers which are located external to the cryostat. Liquid nitrogen is used as a heat intercept and to precool the helium gas.

The Fill/Transfer Station is currently being assembled at General Atomics in San Diego. It will be system tested this summer and shipped to Rochester in October 1998.



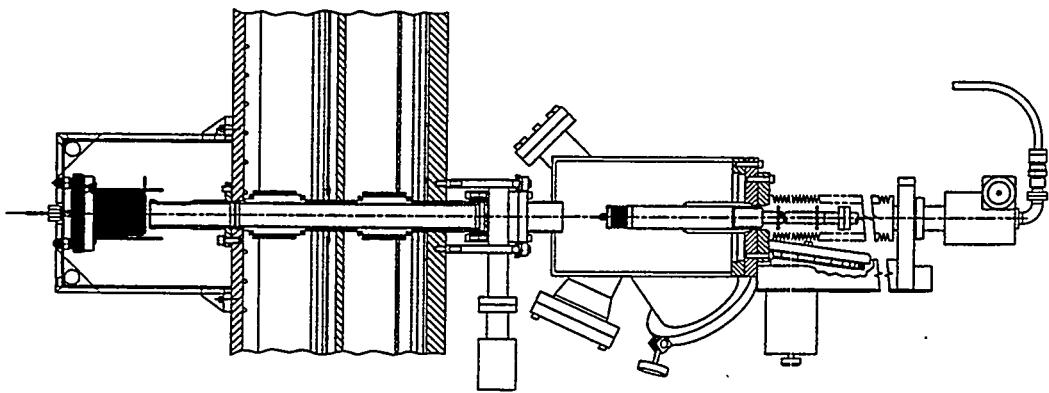
FILL / TRANSFER STATION
(SHOWN ON TEST STAND)

FILL / TRANSFER STATION OPERATIONAL STEPS

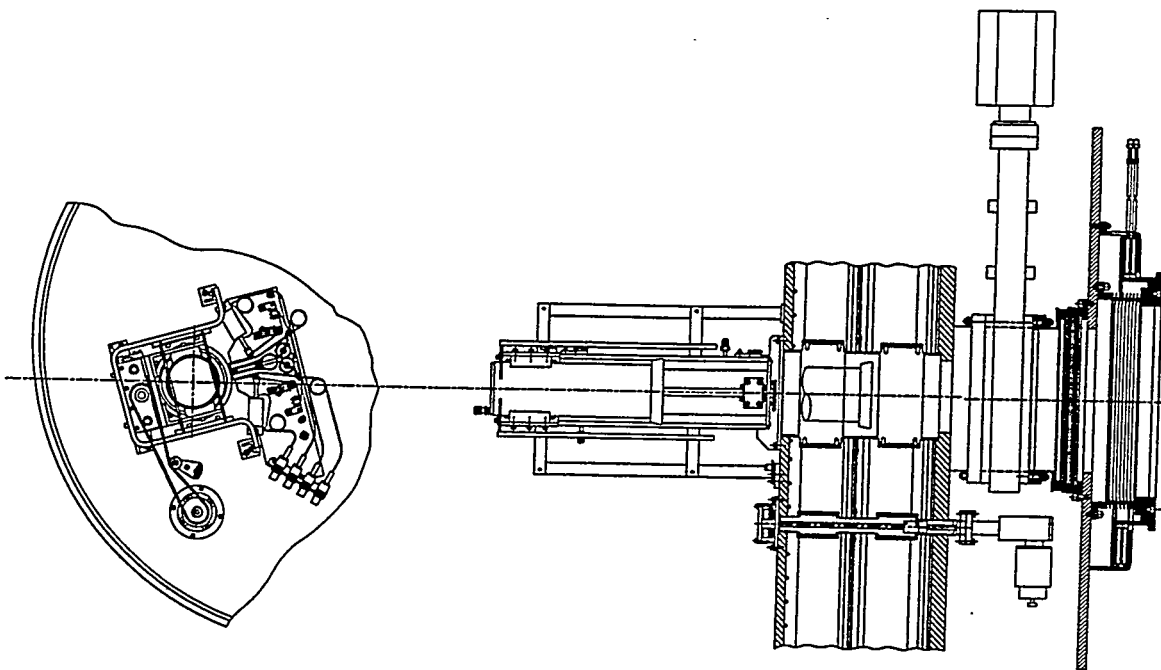
1. THE INSERTER PLACES 4 TARGETS INTO THE PERMEATION CELL.
2. THE TARGETS ARE PERMEATION FILLED TO 1500 ATM AND THEN COOLED TO >20 K.
3. THE TARGET MANIPULATOR MOVES ONE TARGET TO THE MOVING CRYOSTAT STALK.
4. THE SHROUD COOLER REMOVES THE MOVING CRYOSTAT SHROUD, COOLS IT TO >20 K, AND THEN REPLACES IT.
5. THE STALK ALIGNER LOCATES THE MOVING CRYOSTAT STALK AND BLOCKS THE CRYOSTAT PENETRATION.
6. THE COOLING MODULE COOLS THE CRYOSTAT & INTERNAL COMPONENTS.

STATUS

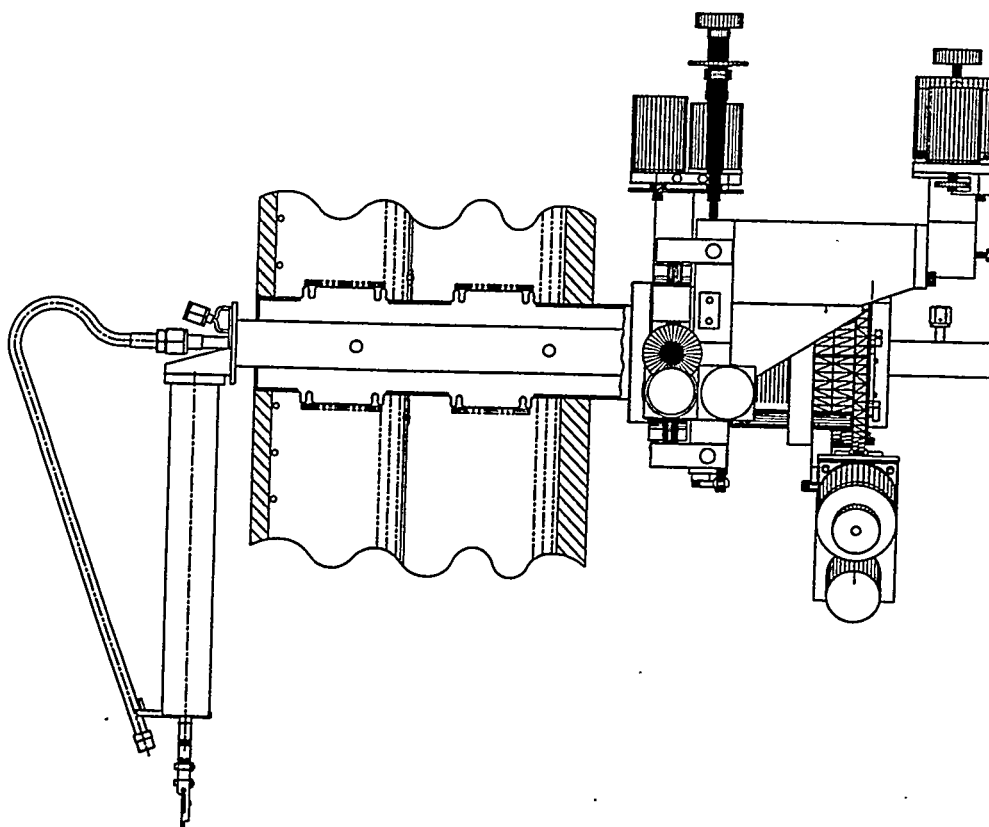
- MOST OF THE EQUIPMENT HAS ARRIVED
- CURRENTLY ASSEMBLING EQUIPMENT AND PERFORMING COMPONENT TESTS
- SYSTEM TESTS TO START SHORTLY



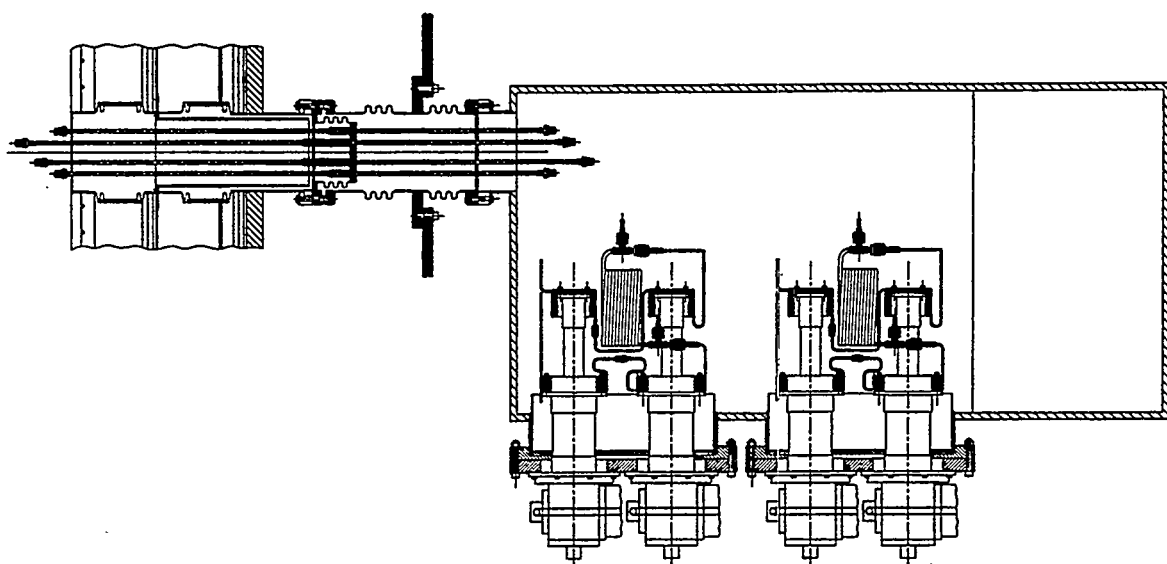
INSERTER & PERMEATION CELL



**STALK ALIGNER &
SHROUD COOLER**



TARGET MANIPULATOR



COOLING MODULE

TEST RESULTS OF EPOXY ADHESIVE ON ALUMINUM AND BERYLLIUM FOR FABRICATION OF CAPSULES AND TEST APPARATUS

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Los Alamos, New Mexico, U.S.A LA-UR-98-1325

This work is supported by the U.S. Department of Energy under contract number W7405-ENG36

ABSTRACT

Hollow spherical targets are frequently fabricated by the joining of two adhesive bonded hemispheres. Other items used in the ICF arena are also bonded using adhesives, these items are made of aluminum, stainless steel, sapphire, and various plastics.

This paper presents the physical testing results of Dexter-Hysol EA9330. The base metals were either an aluminum 6061-T6 or beryllium S200D. The uniaxial tensile (from room to liquid helium temperatures), lap shear, and creep properties of the adhesive under consideration were evaluated. We found that the highest lap shear strength was obtained when the test panel was assembled with fresh adhesive (time = 0 min.) and degraded to about 77% of that value in 120 minutes. Butt tensile strength increased from about 8 kpsi (kpsi=1000lbs/in²) at room temperature to about 19 kpsi at -269°C for both the aluminum and beryllium base metals. The lap shear strength decreased from about 5 kpsi at room temperature to about 3 kpsi at cryogenic temperatures. Creep tests in both butt tensile and lap shear configurations demonstrated a very narrow stress level for which the time to failure decreased from over 720 hours to less than 20.

Finally, the surface treatment is critical to achieving the highest strength adhesive bonds. Some inconclusive but interesting test data is presented opening the way for further investigation.

INTRODUCTION

ICF experiments require spherical targets that are frequently fabricated by the joining of two hemispheres. One method for the joining of these hemispheres is adhesive bonding. Cryogenic experimental capsules and various associated apparatus have used adhesive in their construction.

We selected several adhesives for preliminary testing and based on these results choose the epoxy adhesive Dexter-Hysol EA9330 for further testing.

The physical testing consisted of butt tensile tests, lap shear tests, creep tests, and time assembly tests on lap shear samples. The substrate materials involved in the reported tests are Aluminum 6061-T6 and Beryllium S200. Fill tubes, Be hemi-shells, Al hemi-shells, plastic hemi-shells, and other assembled parts have successfully used this adhesive at various temperatures.

A small study of degreasing solvents is also covered. The results of stress relieving Be and its effect on adhesive strength is also addressed.

MATERIALS AND METHODS

Aluminum alloy 6061 in the T-6 condition was obtained from a commercial vendor. The lap shear panels¹ were bonded in a lap shear bonding fixture. The panels are 0.62" thick 4" wide and 7" long. This fixture controls overlap to 0.5" and maintains a uniform fillet. This fixture also controls panel alignment. The applied pressure is controlled with calibrated springs. The lap shear samples were cut from single panels.

Wire electron discharge machining, was used to insure that no damage was created on the cut edges of the 1" wide samples.

Beryllium grade S200D was obtained from Brush Wellman. Butt tensile samples were made from both beryllium and aluminum having a configuration of right cylinders 2" long and a 1.128 " diameter. They were bonded in a fixture having a Teflon lined bore of 1.30" diameter and a 3" depth. This fixture minimizes the effects of a non-uniform fillet and maximizes the sample-to-bond orthogonality. A Gravitationally Controlled Pressure Application Device (GCPAD) applies pressure. Lap shear and butt tensile tests were conducted on an physical testing machine (Instron Corp. Canton Mass.) at a displacement rate of approximately 0.003 in./min.

In addition to studying the role of the substrate and testing configuration, the influence of various other parameters was also examined. Lap shear and butt tensile specimens were tested at three temperatures: room temperature (21°C), liquid nitrogen (-196°C) and liquid helium (-269°C). The effect of lag time between preparation of the adhesive and joining of the assembly was also examined. Adhesive was prepared, and 0, 15, 60, 90, or 120 minutes was allowed to lapse before the test panel was assembled. Creep tests were performed on Al 6061 in both the lap shear and the butt tensile configurations. Butt tensile samples were tested at the stress levels (as a percent of the ultimate stress attained at room temperature with no lag time) ranging from ~45% to 51.5%, while the lap shear specimens were tested at levels of 65% and below. These tests were conducted to a time at which either the sample failed or 720 hours had passed whichever came first. Finally, the effect of surface preparation for both the Al 6061 and the Be S200D was examined and is detailed below. Briefly, three degreasing solvents, Borothene (contains halogenated hydrocarbon, Chemical Design Inc. Cleveland Ohio), trichloroethylene, and methylene chloride, were tried; additionally, the Be surface was adhesively joined in either the as-machined or stress-relieved condition.

MATERIALS PREPARATION

The aluminum test samples were prepared by a chromic acid etch² as follows.

1. Vapor degrease in trichloroethylene (except as noted).
2. Immerse in Mitchel-Bradford MI-20 cleaner for 15 min. at 60 degrees Centigrade.
3. Rinse in demineralized water.
4. Dry at 60°C or less.
5. Immerse in an etchant (22-28% sulfuric acid, 2.2-2.8% sodium dichromate, balance water) for 10 to 15 minutes between 65° and 71°C.
6. Rinse in demineralized water until pH is neutral.
7. Dry no higher than 60°C.

The beryllium test samples were prepared as follows

1. Machine surface.
2. Stress relieve at 800°C/1 hours in high vacuum ($>1 \times 10^{-6}$ torr) followed by a very slow cool ($\sim 1^\circ\text{C}/\text{min.}$).
3. Vapor degrease in trichloroethylene (except as noted).
4. Immerse in Mitchel-Bradford MI-20 cleaner (detergent) for 15 min. at 60°C.
5. Rinse in demineralized water.
6. Dried in a vacuum oven at 22" Hg and 50°degrees C.

The adhesive was prepared as follows:

1. Weigh to 0.01 of a gram at a ratio of 33 parts B to 100 parts A.

2. Mix by hand vigorously for five minutes.
3. Degas in a vacuum at 22" Hg for five minutes.
4. Apply adhesive to the substrates with a metal spatula and assemble the components as quickly as possible. (The exception is the time lap study).
5. Cure the samples with a pressure of approximately 14 psi. applied by spring or weight at 23°C for 16 hours followed by 82°C for 2 hours.

RESULTS and DISCUSSION

LAP SHEAR and BUTT TENSILE

The tests reported below are the base-line samples for this evaluation. The lap shear and butt tensile samples had average fracture stresses of 4.57 ± 0.41 and 8.22 ± 0.89 kpsi, respectively.

Substrate: Al 6061-T6, Room temperature	Lap Shear	Butt Tensile
ASTM Standard	D1002	D897
No. of Samples	14	10
Average Fracture Stress (kpsi)	4.57	8.22
Standard Deviation (kpsi)	0.41	0.89

LAP SHEAR TIME STUDY

The effects of lag time between the adhesive preparation and the test panel assembly are shown in Figure 1. The fracture stress (right axis) and the normalized strength (as a percent of the strength measured at time=0 minutes, left axis) are plotted against the elapsed time. The fracture strength had a maximum of about 4.57 kpsi at 0 minutes and decreased approximately linearly with time to 3.55 kpsi at 120 minutes; this represents degradation to about 77% of the strength at 120 minutes.

BERYLLIUM BUTT TENSILE TESTS

Adhesive bonded butt tensile strength in beryllium was tested at room temperature according to ASTM D897³. Ten tests returned average fracture strength of 8.77 ± 0.50 kpsi. Some samples failed in the beryllium rather than in the adhesive. The difference between the fracture stresses for the Be failure and the adhesive failure was very small, so both values are lumped together and used as a minimum strength. The fracture in the Be can be attributed to its very brittle nature, some sharp edges acting as stress concentration points, and poor design of the holding fixture for such a brittle material.

Although tests were attempted, lap shear data is not reported, as the samples all broke prematurely because of the severe bending⁴ of the single overlap sample design and the very stiff, brittle nature of Be. A double overlap shear sample would be more appropriate for this test, but was not accomplished during these experiments.

CREEP TESTS OF ALUMINUM 6061 AT ROOM TEMPERATURE

For both the butt tensile and lap shear tests, the stress level required to cause fracture in less than 720 hours was very narrow, Figure 2. The butt tensile samples did not fail at stress levels less than 61% ultimate strength, but at 62% and above, the time for failure decreased precipitously. The same trend is

true for the lap shear specimens, but the stress levels to achieve failure times of less than 720 hours was in the range greater than 49%.

CRYOGENIC TENSILE TESTS ON BERYLLIUM AND ALUMINUM

As shown in Figure 3, butt tensile strength (left axis) increases with decreasing temperature, from about 8 kpsi at room temperature to about 19 kpsi at -269°C , for both Be S200 and Al 6061. Five beryllium samples failed at the grips and are not included in the data. Only Al 6061 was tested in lap shear (right axis, Figure 3); unlike butt tensile strength, lap shear strength decreases with decreasing temperature. A maximum lap shear strength of about 5 kpsi occurs at room temperature, and it decreases to about 3 kpsi at -269°C . The design of the lap shear sample introduces a transverse peel stress. This design flaw in the sample probably exacerbates the increased stiffness induced by cold temperature.

SURFACE PREPARATION

The goal for the adhesive is to join Be hemispheres. The components were Be S200 with an inside radius of 1 mm and an outside radius of 3 mm. It was found, however, that in the course of qualifying joint strength of actual targets with pressurized fill tubes, spheres were splitting at the joint at pressures of approximately 12% of those previously attained. In examining the process variables, it was found that the degreasing solvent was different than the one previously used. A series of Al 6061 butt tensile samples were tested to examine these variables.

The results for the surface preparation of the aluminum samples are given in Figure 4. The results of butt tensile test on Al 6061 whose surfaces were degreased using Borothene, trichloroethylene, or methylene chloride. Samples prepared with Borothene are slightly lower strength than the samples prepared with chlorinated solvents, but no statistical difference exists among the data. However, it is important to note that the samples using Borothene as a degreaser has a significant amount of adhesive failure whereas the other samples fail strictly in a cohesive manner.

Figure 5 shows tests performed with joined beryllium hemispheres. The hemispheres were joined with the adhesive, a fill tube was attached, and the center was pressurized. Notably, the combination of an as-machined surface and that using Borothene solvent yielded a very low burst strength, while the combination of stress-relief and methylene chloride give a very high adhesive strength. In fact, the capacity of the pressure generating device (25kpsi) was achieved for these samples and the spheres did not burst.

Two possible explanations exist for the dramatic increase in burst strength for the Be in Figure 5: either the methylene chloride is a much more effective degreasing agent, or the heat treatment is somehow altering the surface of the Be. Based on the tests done on Al (Figure 4), it appears that degreasing agent does not appreciably affect the burst strength. What is eminently more likely is that the heat treatment is changing the surface. Experimentally, it was observe that before the heat treatment at $800^{\circ}\text{C}/1$ hr. in high vacuum, the Be parts had a dull, silver metallic luster. After heat treatment, the parts had a slight gold tint to them, indicating the presence of beryllium oxide. Although a high vacuum was used in the heat treatment, the extremely high affinity of beryllium for oxygen causes a thin layer of adherent oxide to form. Evidently, this oxide surface is chemically much better suited for adhesive bonding than the metallic beryllium surface.

CONCLUSIONS

1. The adhesive has its highest strength when the test panel is assembled as quickly as possible.
2. The time to failure for the creep tests decreases suddenly and dramatically with stress level, the decrease happening on the order of 1% percent in the stress level for both the butt tensile and lap shear specimens.
3. Butt tensile strength increases with decreasing temperature for both the Al 6061 and Be S200D, while the lap shear decreases with decreasing temperature.

4. Surface preparation is vital to joint strength; it is very likely that an oxide layer on the surface of the beryllium after stress-relief dramatically improved the adhesion of the adhesive to the beryllium.

ACKNOWLEDGMENTS

The authors would like to thank LANL personnel for all the actual testing: Bob Aiken and Manny Pacheco for the butt tensile and lap shear testing, Harry L. Duhamel for the creep testing, and Elfino Armijo, Felix Garcia, and Lee Salzer for all the metallic test blocks, tools and hemi-shells.

LIST OF FIGURES

- Figure 1. Fracture strength vs. lag time for Al samples.
 Figure 2. Time to failure for aluminum samples.
 Figure 3. Fracture strength vs. test temperature for Al and Be samples.
 Figure 4. Burst tests on Al spheres.
 Figure 5. Burst tests on Be spheres.

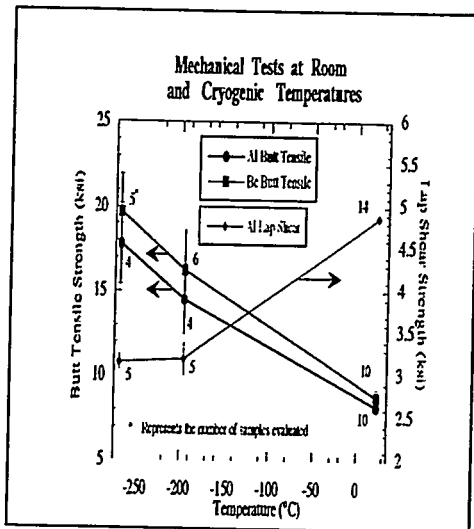


Figure 1.

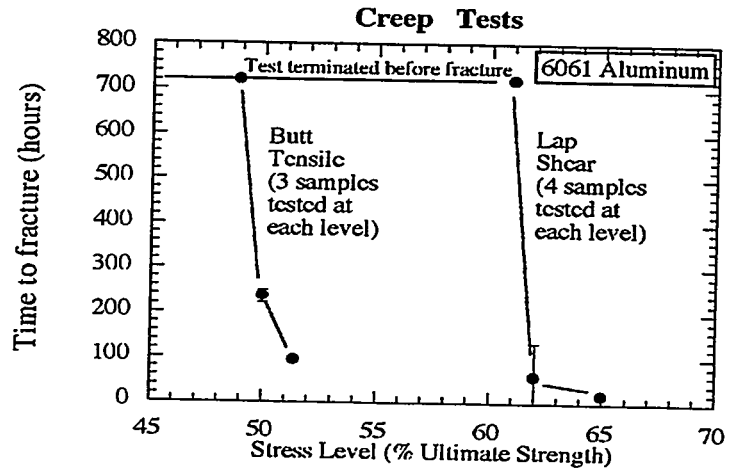


Figure 2.

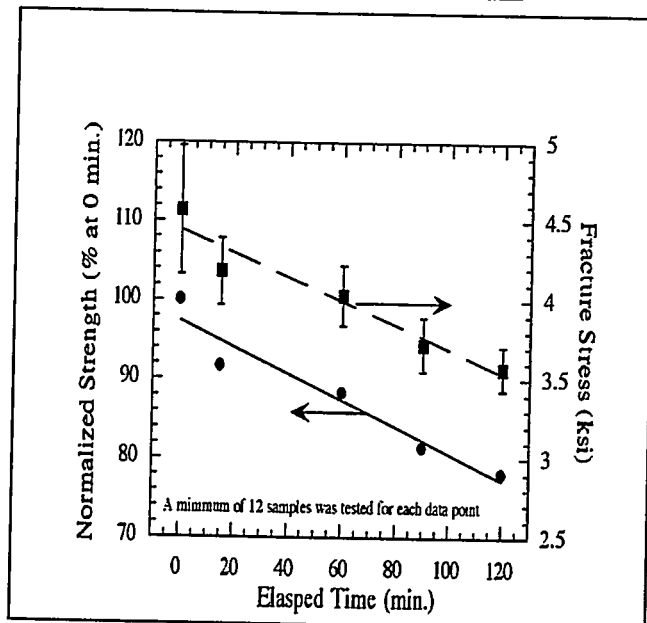


Figure 3.

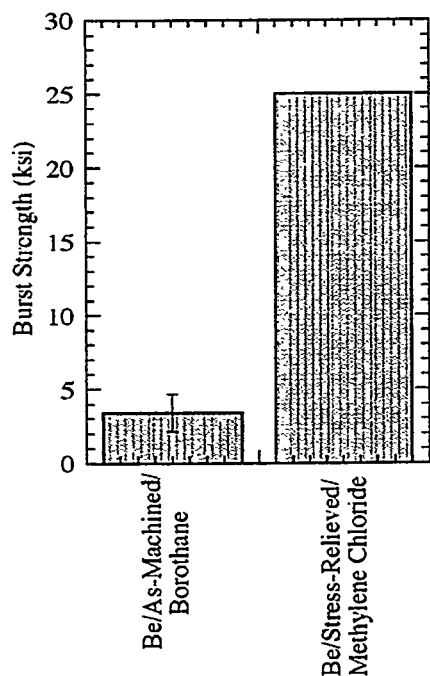


Figure 4.

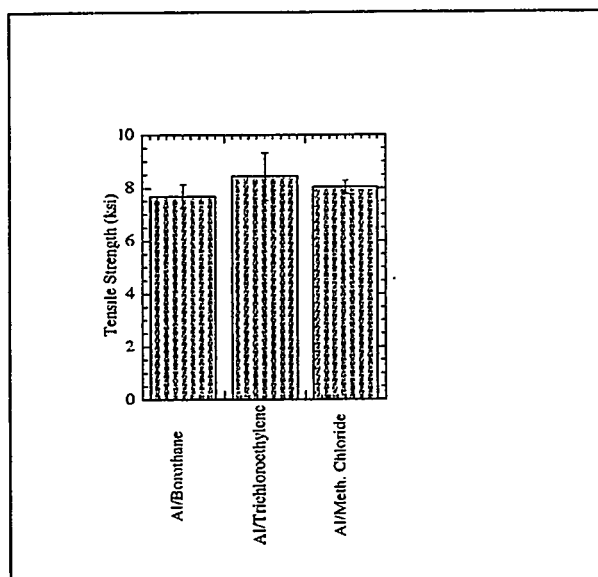


Figure 5.

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Foster Publishing Company 1964

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19428

⁴ Robert D. Adams and William C. Wake, Structural Adhesive Joints in Engineering,
Elsevier Applied Science Publishers 1984

Metal Thickness Distribution for Gold and Copper Electroplated Mandrels

F.H. Elsner and J.L. Kaae

General Atomics, San Diego, California, U.S.A.

Why is plating uniformity important?

Until recently no one had investigated the thickness uniformity of the Au and Cu electroforms produced at General Atomics for the ICF program. Upon inspection of the metal distribution it was observed that large thickness variations (as much as ~25% for copper and ~10% for gold) were observed along the length of the cylinder. These variations complicate the modeling and interpretation of the ICF experiments for which they are required, and will also have an impact on the temperature distribution and uniformity during cryogenic operations.

This presentation is directed at making experimentalists aware of the thickness variations of electroformed hohlraums and to promote discussions regarding the relative importance of metal uniformity for ICF hohlraums.

Methods for influencing uniformity.

A number of techniques are provided in the literature and from suppliers which can be used to influence the uniformity of the metal distribution. Some of the commonly suggested methods include:

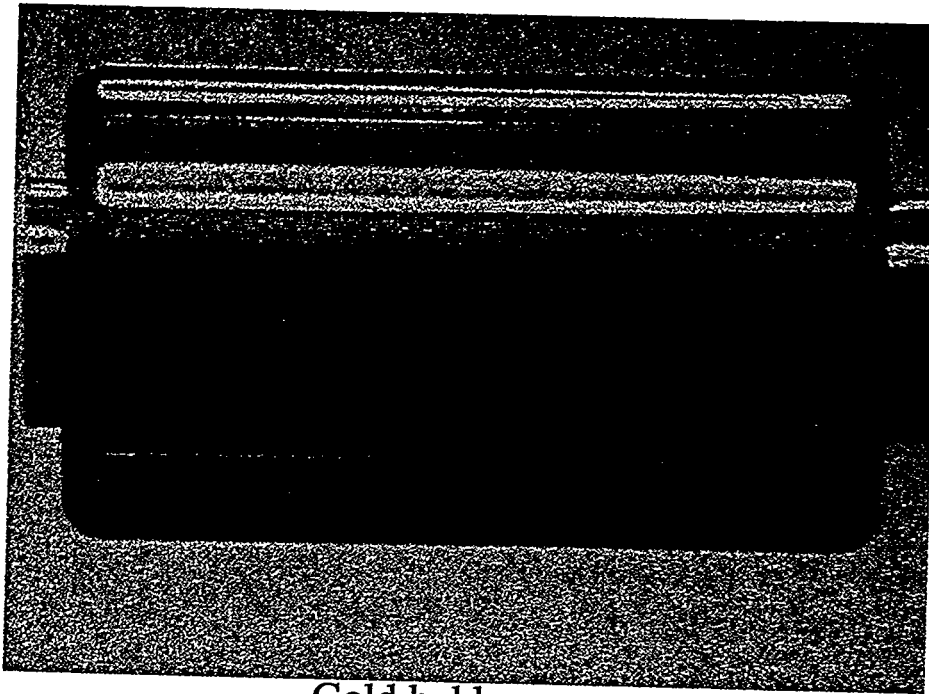
Selection and control of plating bath composition	Plating cell geometry
Modify current density	Shields
Rapid and uniform agitation	Auxiliary anodes
Careful control of anode properties	Robbers
Relative anode:cathode surface area	Periodic reverse current
Position relative to cathode	Modify mandrel geometry

Experimental observations

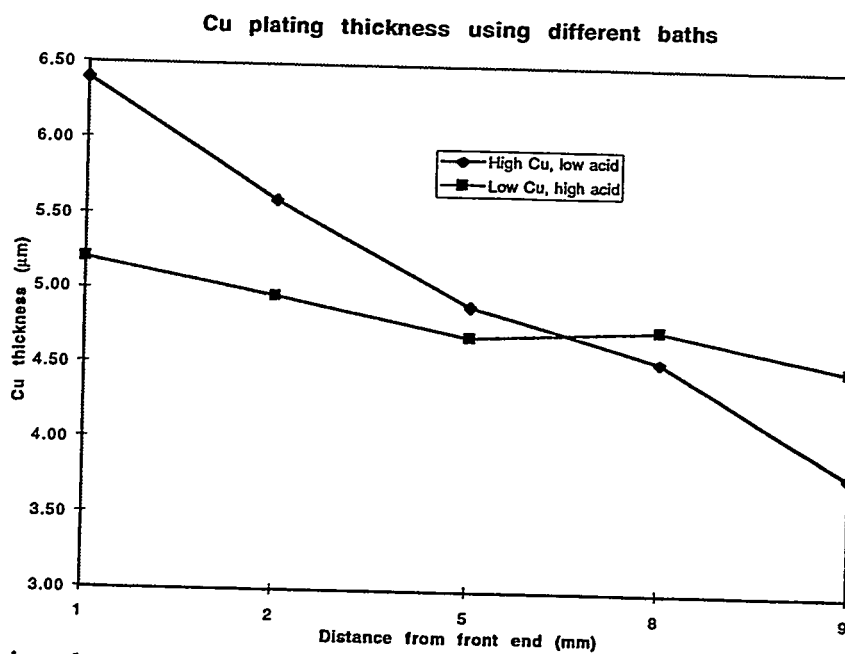
We have examined several techniques to determine their effect on uniformity.

In the case of copper electroforming, it was observed that a plating bath with a lower copper sulfate concentration and higher acid concentration greatly improved the thickness uniformity of the deposit.

In the case of gold electroforming, we attempted to influence the plating distribution by modifying the geometry of the mandrel. By extending the front LEH of the mandrel some slight improvement was obtained. We also found that increasing the radii on the edges of the mandrel caused the distribution to worsen considerably - a result which was the opposite of that predicted by conventional wisdom.

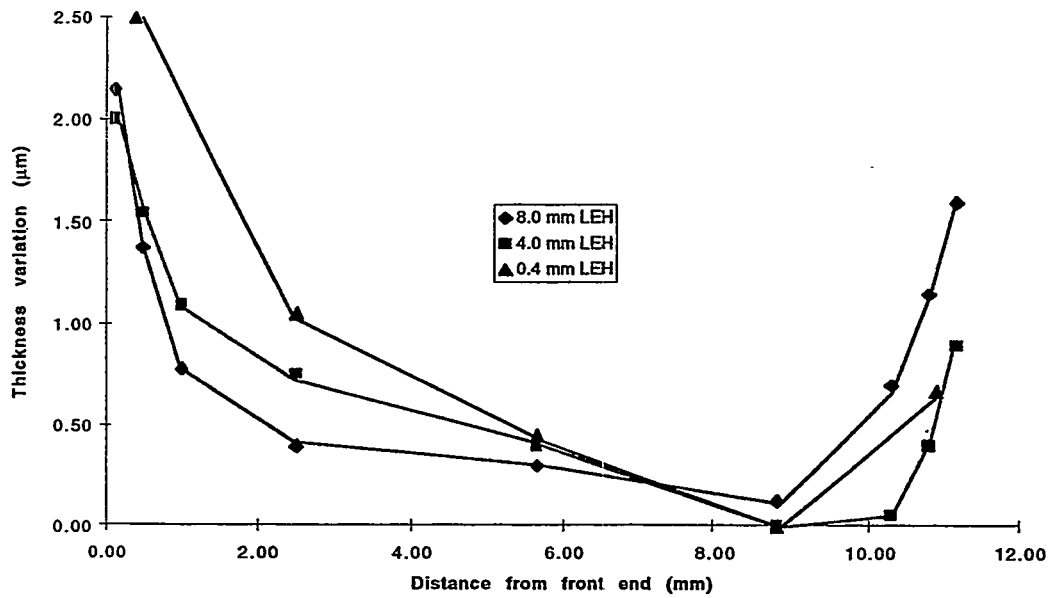


Gold hohlraum



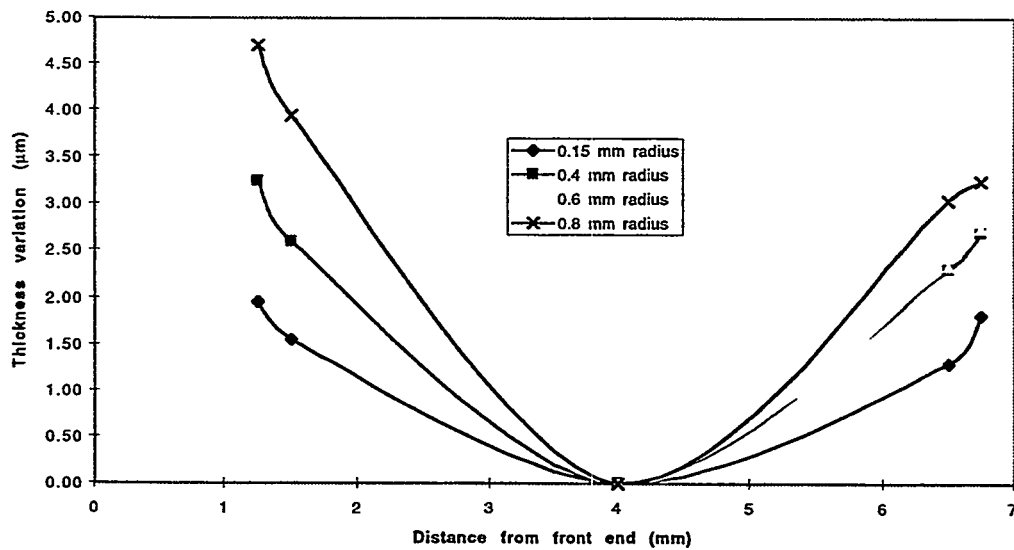
Lowering the copper concentration and increasing the acid concentration gives a plating bath with good throwing power (i.e. coats more uniformly)

Au distribution with various LEH lengths



Extending the front LEH gave a slight improvement in uniformity.

Au thickness variation vs mandrel edge radii



Conventional wisdom is that increasing the radii of sharp edges will improve the metal distribution. Our results demonstrated the opposite effect.

Conclusion

Electroformed hohlraums have a nonuniform wall thickness along the cylinder length. Experimentalists and designers should be conscious of this when planning and interpreting experiments. If more uniform distributions are required, some significant developmental efforts will be necessary to optimize the plating operation.

There are a number of various techniques for controlling metal distribution during electroplating. However, these methods are for guidance only and do not guarantee a positive result. The optimum process conditions must be verified empirically, and any changes in mandrel geometry will require reevaluation of the plating procedure.

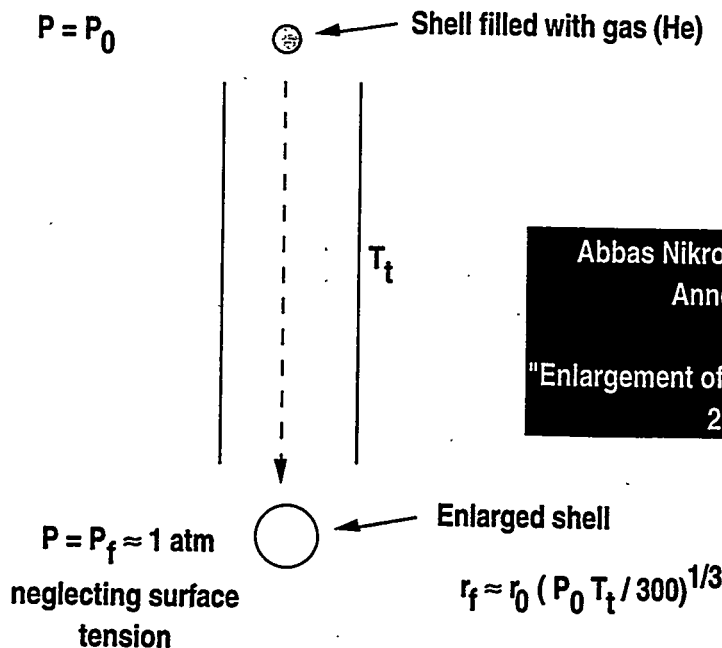
LARGE, THICK GLASS SHELLS AS PREFORMS FOR THE RE-BLOWING PROCESS

Wayne Miller
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P.O. Box 85608
San Diego CA 92186-5608

Recently, Nikroo¹ discovered that glass shells could be filled with gas and re-passed through the vertical "tower furnace" tube and blow into even larger shells. Larger and stronger shells are desirable for use in studying the layering of condensed D₂ and DT fuel and for use in experiments in SNL's Z driver. Ideal shells for the re-blowing process are about 1500 μm in diameter, have wall thicknesses greater than 6 μm , and have good concentricity. When re-blown these shells would become about 2 mm in diameter with about a 4 μm wall thickness.

Several years ago we discovered that adding helium and water vapor to the tower furnace during the gel particle to glass shell transformation would result in glass shells as large as 1600 μm diameter but with glass walls of only several micrometers thick. We have continued this study with the objective of making shells suitable for the re-blowing process. We will report on the relationships between the key processing parameters of tower furnace profile, gel particle size, tower furnace atmosphere, etc., and the resulting glass shell characteristics.

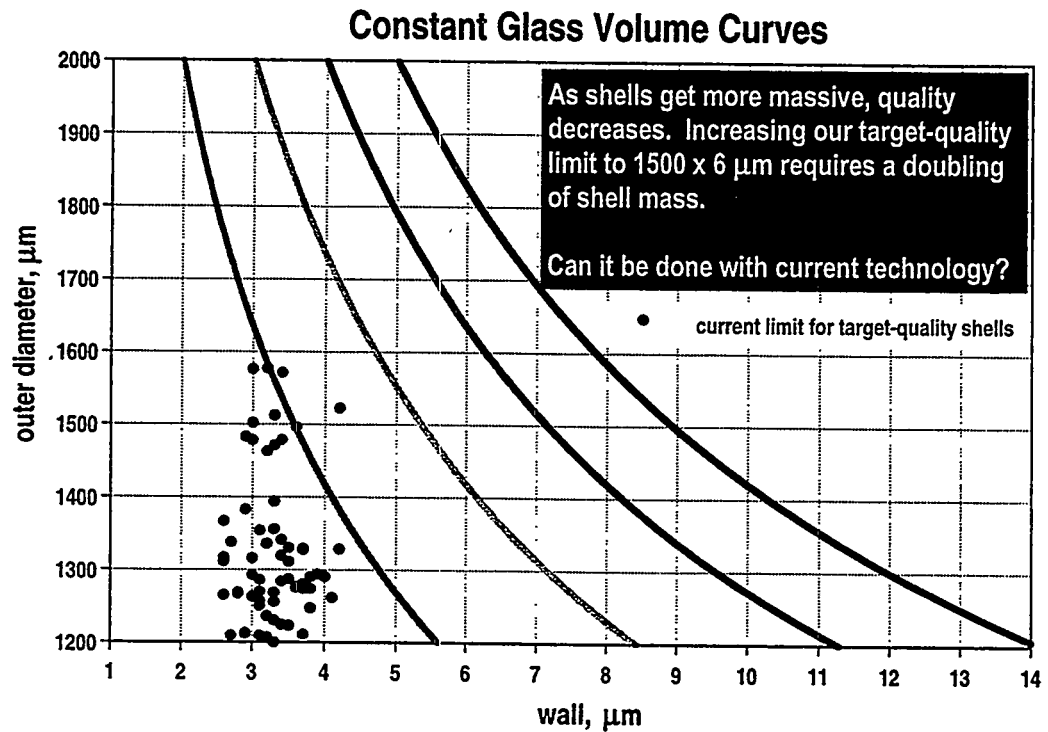
Smaller shells can be enlarged by filling them with gas and re-dropping them through a hot tower



Abbas Nikroo, David Steinman, and
Annette Greenwood

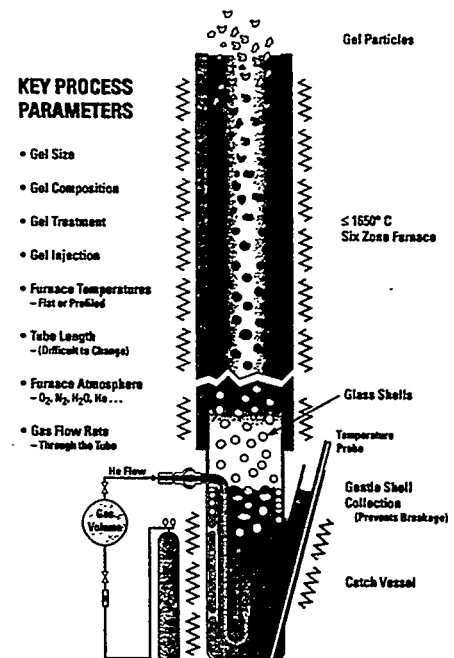
"Enlargement of Glass and Plastic Shells to
2 mm in size"

Goal: Shells for re-blowing, $\approx 1500 \times 6 \mu\text{m}$, with good concentricity



We pursued several production parameters to make the shells

- Pyrolyzing the feed gel
- The temperature of the drop tower furnace
- Water and helium partial pressures in the drop tower furnace
- Feed gels with a higher silicon concentration

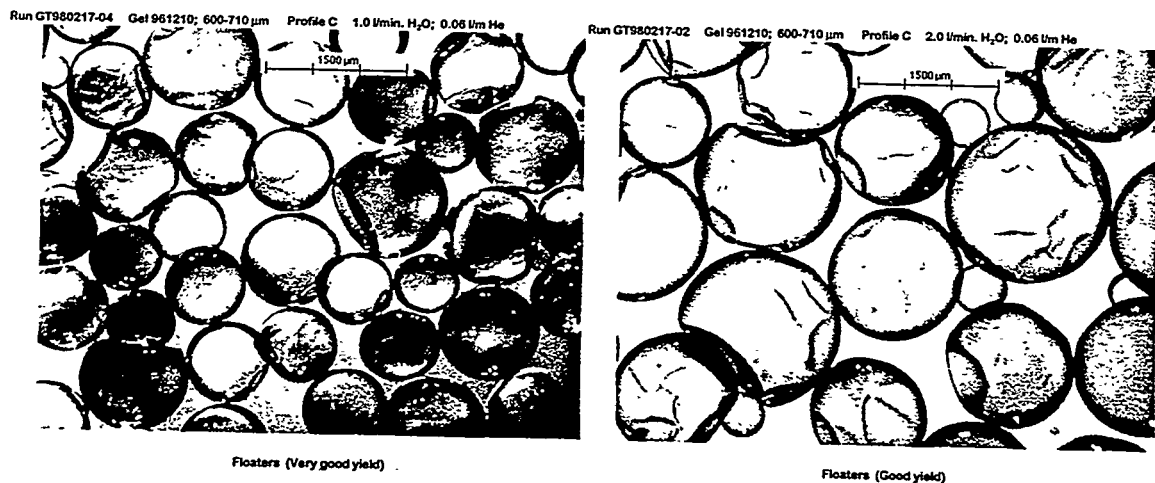


Initial conclusions: move on to other parameters

- Pyrolysis is not an effective gel treatment
- The flat tower profile at 1650°C made the largest shells
- A larger gel size was needed
 - 1100 x 5 µm shells were not massive enough to blow into 2 mm shells
- He and H₂O flow in the drop tower tube should be explored



Optimizing the parameters did not produce acceptable shells



- These shells will not re-blow into excellent shells

It's not time to punt, but new gel compositions are worth trying

- The gel used so far has the equivalent of 20% (molar) alkali oxide
 - this gel has been our best all around gel for other sizes
 - the “goopy-like” appearance of the large shells suggests that viscosity is low
 - at other sizes significant alkali is lost during passage through the drop tower, increasing the viscosity
 - the more massive amount of glass as well as a shorter drop time probably keep the alkali content high and therefore the viscosity low
- Other gels in stock have equivalent alkali oxide contents 5% and 30%
 - the gels with < 20% alkali oxide show make glass with lower viscosity



What's next?

- Complete experiments with in-stock gel
 - determine if lower alkali oxide gels will make the desired shells
 - also use duplicate gels — are gel-to-gel variations significant
- Make and test “water glass” gels
 - Ebner at KMSF used water glass shells containing Na, K, and Rb (?) making large glass shells (~1400 μm) with very good concentricity
 - if water glass gel is successful, find work-around for rapid weathering of the glass (water glass is high in alkali; glass with high alkali concentrations weather rapidly)

PROCEDURE FOR FILLING A HOHLRAUM WITH GAS

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Schafer Corporation
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Livermore CA 94550-9291

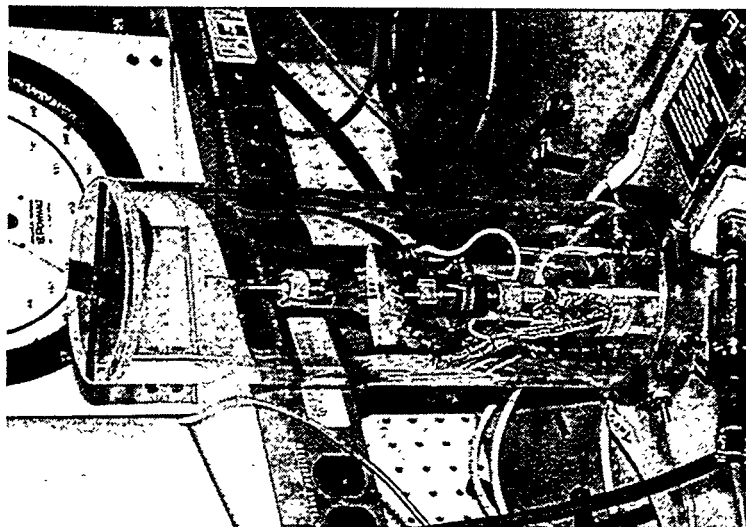
Hohlraums are filled with various gasses for Nova experiments at LLNL because the current design of NIF uses the gas filled hohlraums for two purposes:

1. Gas is used for conductive cooling of the sphere in the hohlraum.
2. To mitigate wall motion (slow the plasma blow-off).

The composition and the pressure of the gasses at the time of the shot must be known. We have developed a procedure to fill the hohlraum and ensure that the composition and pressure of the gasses are known at the time of the shot.

The hohlraum is pre-tested at vacuum to ensure a sealed environment for containing the gas fill at vacuum. The various steps used to fill a hohlraum with the requested gas will be described, from filling the gas supply bottle with pure or mixed gas to the actual fill procedure of the hohlraum.

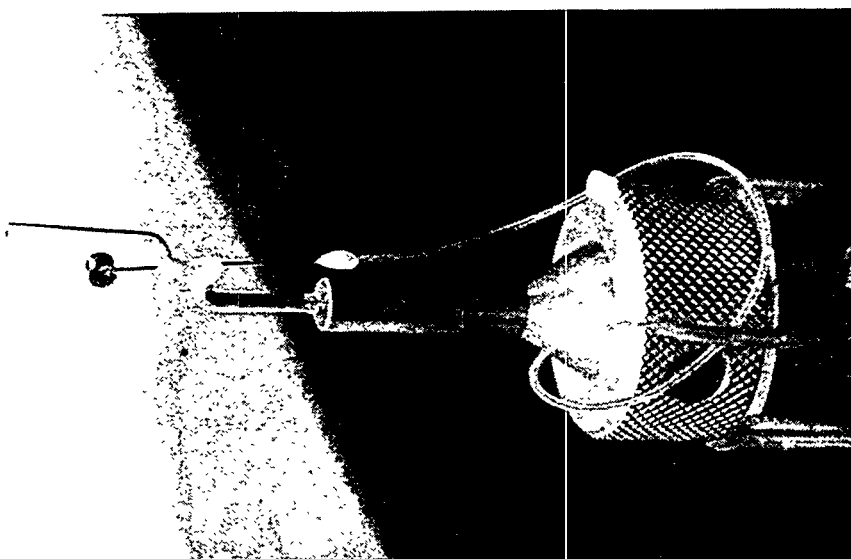
Submitted for poster format



Target in Fill Station

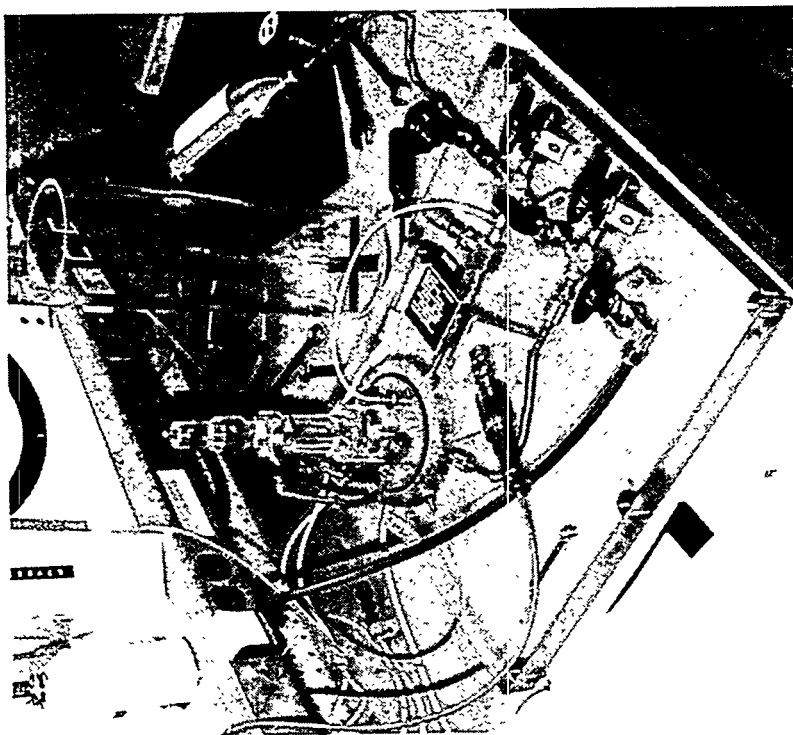


This work supported by U.S. Department of Energy under Contract No. DE-AC03-95SF20732.



LLNL Gas Target

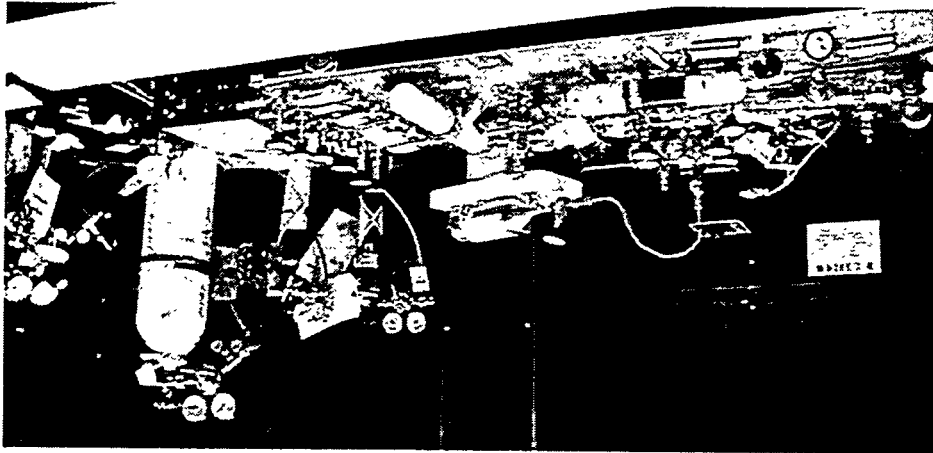
✦ **GENERAL ATOMICS**



Target Fill Station

✦ **GENERAL ATOMICS**

Gas Cylinder Mixing Station



Gas Cylinder Inventory

GAS HOHLRAUMS

Because NIF will require gas-filled hohlraums for several purposes, experiments are now being done on LLNL's Nova laser.

Gas is used for conductive cooling of sphere in the hohlraum.

Gas is used to mitigate wall motion (slow plasma blowoff).

Different gasses used in hohlraums cause a different electron density of plasma. Gas simulates different conditions inside NIF target.

Mixed gas or seeded gas is used because seed gasses produce X-rays of particular energy ratios to determine plasma temperature.

The purity of the gasses are determined with a Quadrupole Mass Spectrometer.

The procedure for ensuring the pressure of the gasses at the time of shots is accomplished with the use of the transducer/manifold assembly.

The transducer produces a voltage reading that has been calibrated to a Torr meter.

When installed in the Nova target chamber, the transducer voltage is monitored until seconds before the shot to ensure gas pressure has remained stable.



FILLING GAS CYLINDER

When a request for gas is received, if a cylinder of the requested gas is not in inventory or the pressure of the cylinder is low, the cylinder is taken to the mixing/fill station where the cylinder is connected to the gas fill manifold and filled with the requested composition of gas.

Evacuation and purging of the manifold is necessary prior to filling cylinder to ensure purity of gas composition.

The procedure for filling the cylinder with mixed gas is the same as for 100% pure gas except the manifold is purged between gasses.

When using mixed gasses, the cylinder is filled by partial pressures.

Example:

If there is a request for 80% of one type of gas, 15% of another, and 5% of a third the cylinder will be filled using the gas of the lowest percentage pressure first, then the next highest pressure, and so forth.

The simple way to calculate the percentages of gas to mix in the cylinder is to fill the cylinder to 1000 Torr. The calculation would be; 5% equals 50 Torr, 15% equals 150 Torr, and 80% equals 800 Torr for a total of 1000 Torr.

FILLING THE HOHLRAUM WITH GAS

The gas cylinder is installed on the hohlraum test/fill station.

The hohlraum has been pre-tested at vacuum to ensure a sealed environment for containment of the gas.

It is installed on a reservoir/transducer assembly and inserted into a small vacuum chamber in the fill system. The hohlraum is isolated from vacuum by an isolation valve. When the chamber is pumped down and the hohlraum has been verified to be leak-tight a final time, the isolation valve is opened slowly and the hohlraum is pumped down (equalized with vacuum chamber pressure).

When chamber and hohlraum pressures have equalized, the isolation valve is closed and gas is applied to the manifold, then the metering valve is opened slowly to pressurize the hohlraum to one atmosphere of pressure.

When target pressure is attained, all manifold valves are closed.

When it is assured the pressure is stable, the vacuum chamber, which has been isolated from the hohlraum, is brought to atmosphere.

The chamber cover is removed and the valve on the hohlraum/transducer assembly is closed.

The vacuum fill line is removed from hohlraum/manifold and the hohlraum is removed from the system.



Hohlraum Test Apparatus Modifications to Accommodate High Resolution Measurements on Thermally Shimmed Hohlraums

J. Pipes, J. J. Sanchez and W.G. Unites

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Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore
National Laboratory under Contract W-7405-Eng-48.

High Resolution Temperature Measurements require excellent Temperature Stability

Cryostat modifications to improve stability

Thermal variation isolator reduces
temperature perturbations of flow cryostat

Gas lines, thermometer and heater lead
wires and are thermally anchored to shield

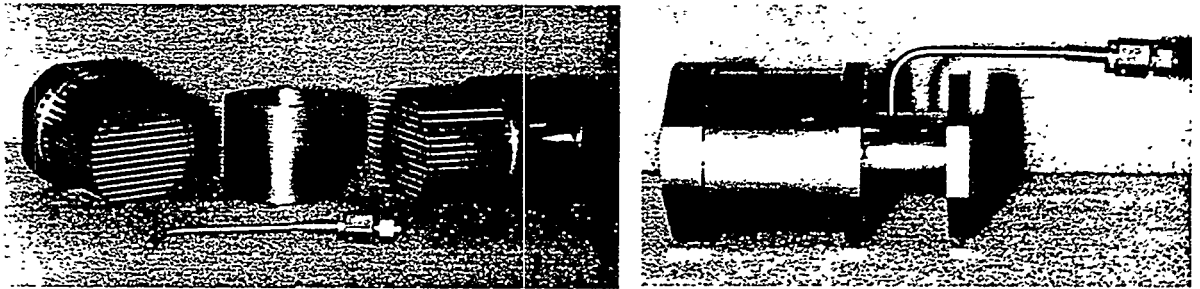
Active shield temperature control to
minimize radiation heat transfer

Liquid helium dewar pressure is controlled
to reduce flow variations

Metering of helium gas exhaust from
cryostat to improve temperature stability

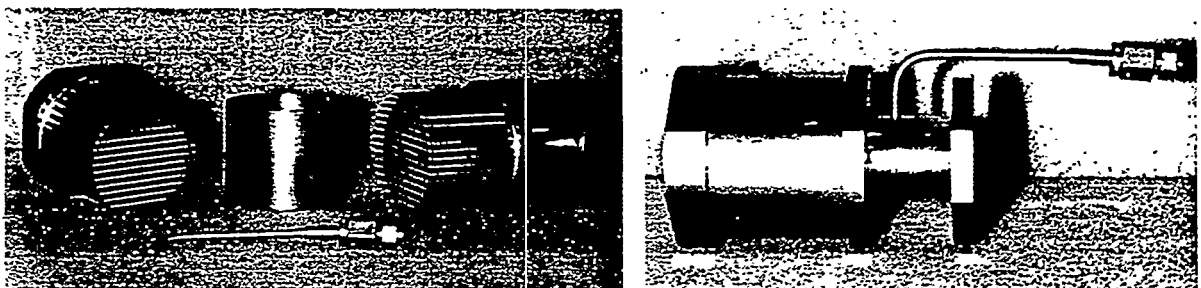
Thermal Variation Isolator

To achieve high resolution temperature measurements, temperature variations inherent to flow cryostat designs must be minimized. We have developed a thermal Isolator that will reduce the heat fluctuations to the Hohlraum. The following pictures show the design of the isolator. The isolator consists of two finned radiator flanges and a thin wall stainless tube connecting the two. The finned flanges do not touch each other. Thermal transport is achieved by filling the assembly with a partial pressure of helium. By varying the helium pressure we can control the heat conductance. The helium gas also acts as temperature damper, effectively filtering out small temperature variations from the cryostat.

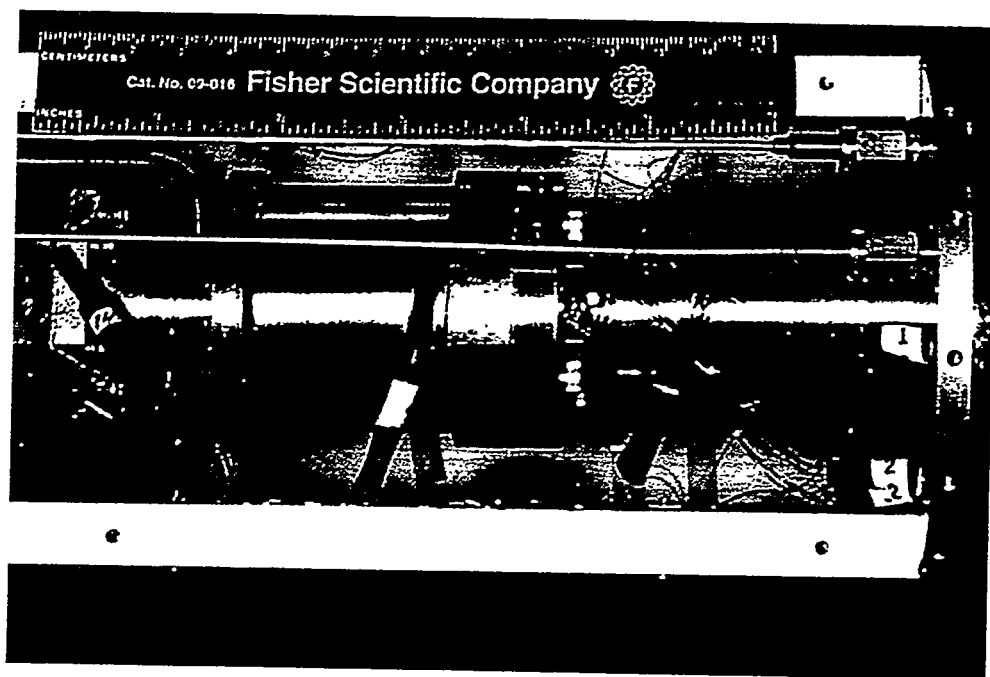


Thermal Variation Isolator

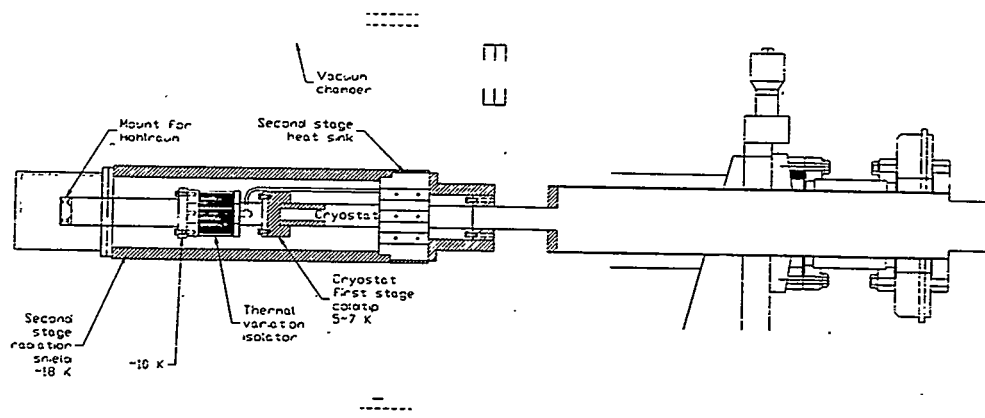
To achieve high resolution temperature measurements, temperature variations inherent to flow cryostat designs must be minimized. We have developed a thermal Isolator that will reduce the heat fluctuations to the Hohlraum. The following pictures show the design of the isolator. The isolator consists of two finned radiator flanges and a thin wall stainless tube connecting the two. The finned flanges do not touch each other. Thermal transport is achieved by filling the assembly with a partial pressure of helium. By varying the helium pressure we can control the heat conductance. The helium gas also acts as temperature damper, effectively filtering out small temperature variations from the cryostat.



Thermal variation isolator in assembly

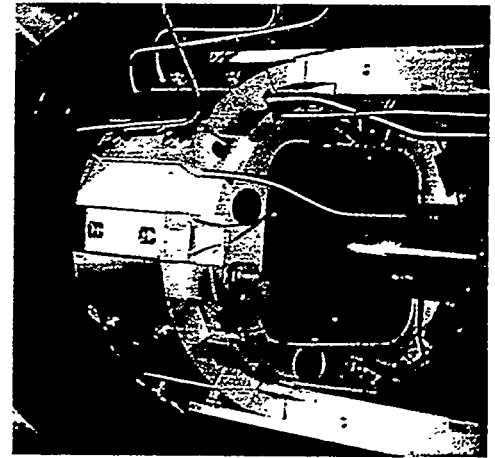
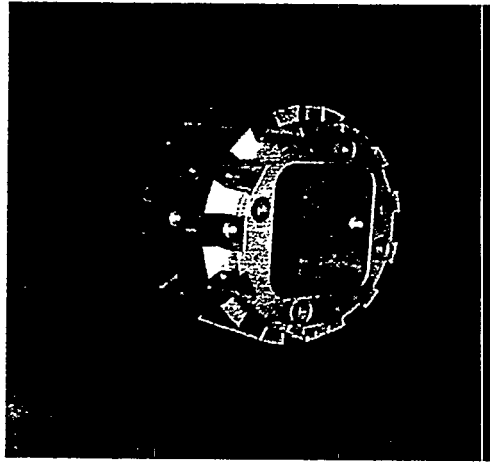


Assembly Drawing of Experiment



Heat Sinking of Thermometer and Heater Wires

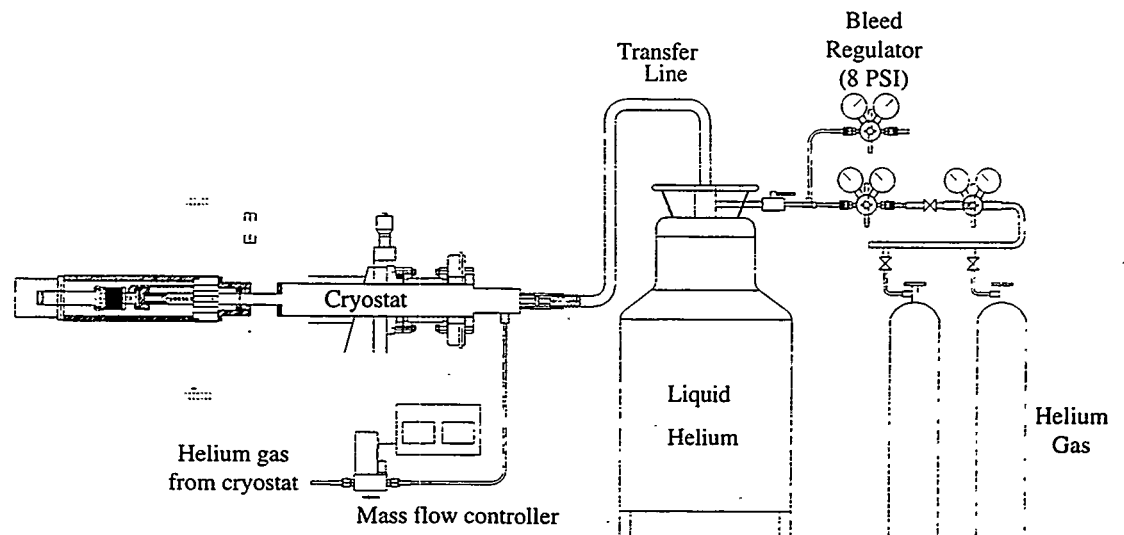
To reduce external heat loading to the Cryostat and Hohlraum assembly, we have heat sunk the thermometer and heater wires to the second stage shield which operates at nominally 20 degrees Kelvin. The wires are sandwiched between two .005 sheets of indium and clamped to the shield. A small lip on the clamp ensures that over torqueing does not occur. By securing the wires in this fashion we minimize the amount of heat that is transferred from room temperature to the cryostat first stage and Hohlraum



Controlling Liquid Helium flow

To further maximize temperature stability we have taken the following steps:

- Control of the pressure of the liquid helium dewar to $\sim 1/2$ PSI by means of high accuracy bleed regulator
- Control of the helium exsults gas from the cryostat by means of a mass flow controller



DEPOSITS IN PAMS MANDRELS

A.L. GREENWOOD, B.W. McQUILLAN, and R.B. STEPHENS

General Atomics, San Diego, California, U.S.A.

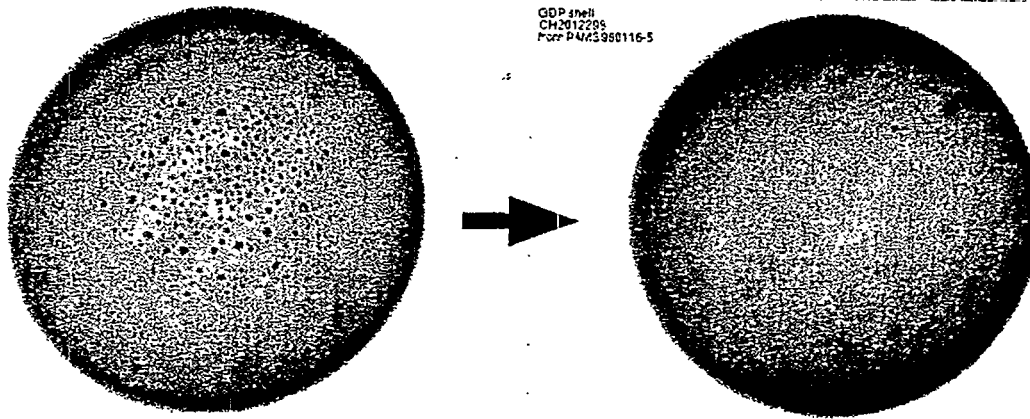
1.

Deposits in PAMS Mandrels

- The production of acceptable poly (α -methylstyrene) (PAMS) mandrels has been hindered by the appearance of deposits of an unknown material on the interior of the mandrels.
- The deposits were first discovered at the time that the number and size of vacuoles was greatly reduced in the PAMS by the addition of calcium chloride to the polyvinyl alcohol (PVA) solution.
- The amount and shape of the deposits have changed in the course of many alterations in the production method which were made to improve non-concentricity and out of round , and to eliminate the deposits.
- The presence of the deposits is important because the deposits leave a trace in the subsequent GDP shell which affects the optical clarity.
- The chemical nature of the deposits has been investigated by micro-IR. SEM analysis indicates the presence of oxygen, calcium, and chlorine.

2 a.

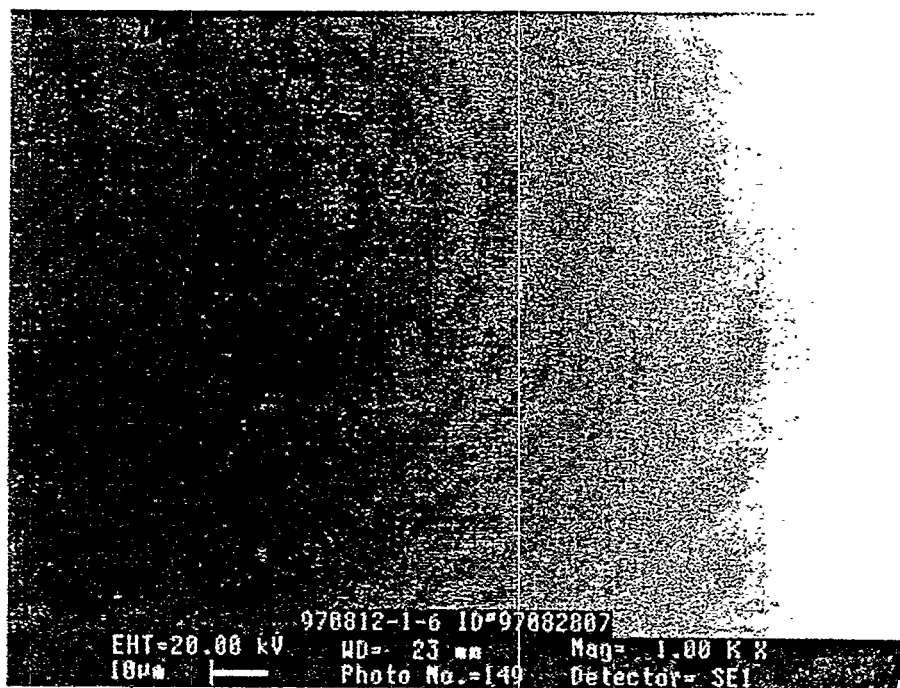
Poor PAMS = Poor GDP Shells



- Deposits are non-crystalline liquid-like forms on the interior of the shell
- Do not evaporate like water or ethanol, dissolve in water or ethanol
- EDXS analysis of PAMS shells with deposits shows Ca, Cl, O
- PAMS deposits are not substantially affected by prolonged heating at 60°C in vacuum or heating at 90°C in vacuum.
- Deposits in PAMS shells cause defects in GDP shells
 - Affects optical clarity
 - Ca and Cl have been detected in GDP shells made from PAMS with deposits

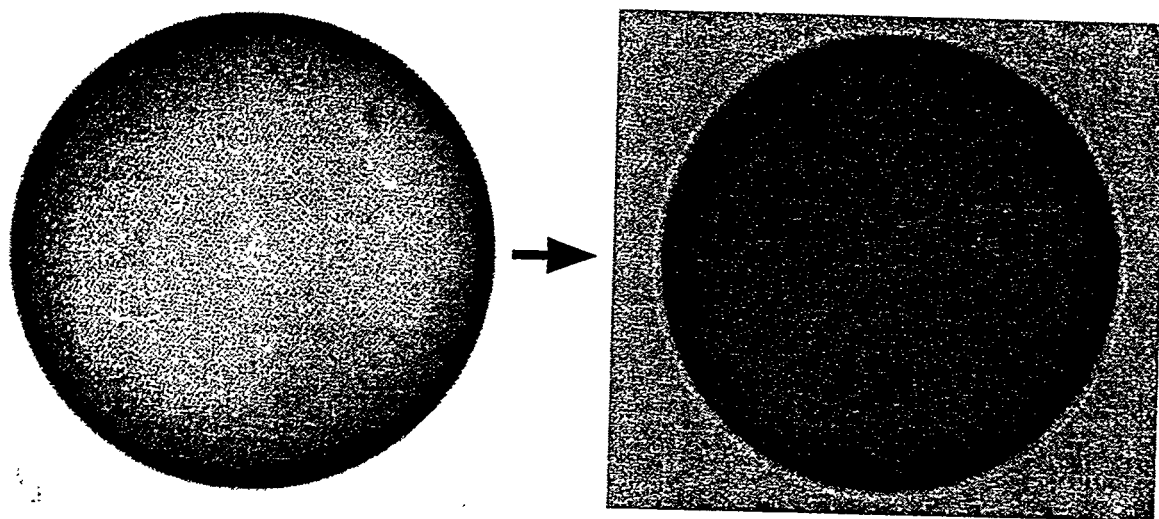
2 b.

SEM of Deposits



3 a.

Improved PAMS = Improved GDP



The improvement in the PAMS shells can be attributed to:

1. Use of PTFE filters rather than PVDF filters
2. Removal of the fluorobenzene from the O1

Future work will clarify the role each of these plays

3 b.

Other Improvements to the PAMS Mandrels

Reprecipitation of PAMS:

Removes impurities from the poly (α -methylstyrene) which may have contaminated the resulting GDP shell and decreases vacuoles

Distillation of fluorobenzene:

Removes impurities from the fluorobenzene which may affect the mandrel formation and later pyrolysis and contaminate the GDP shell

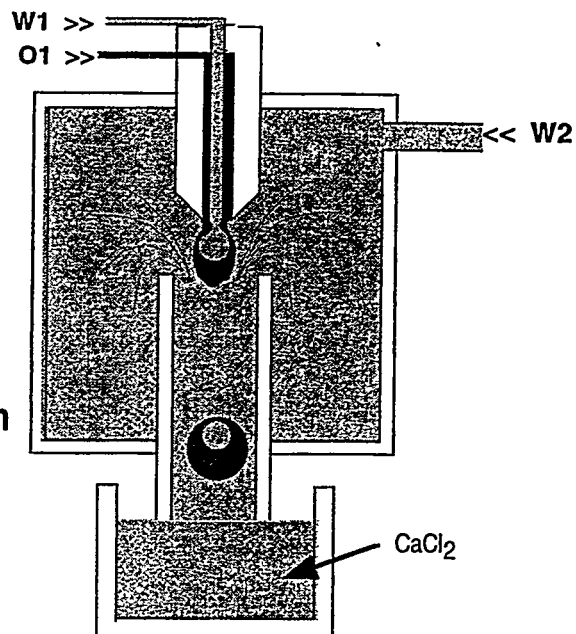
Replacement of calcium chloride with ammonium chloride:

Assures the complete removal of the salt upon pyrolysis

4.

Possible Sources of Deposits

- O1** Impurities in PAMS
Impurities in fluorobenzene
Filtration of PAMS/fluorobenzene solution
- W2** PVA or impurities in the PVA
Plasticisers from the tubing
CaCl₂ added to the curing solution
- W2** Impurities in the deionized water



W1: Deionized water

O1: 11 wt% (PAMS)
in fluorobenzene

W2: 0.2 wt% PVA in
deionized water

5.

Does Purification of PAMS Prevent Deposits?

Purification of Poly (α -Methylstyrene):

As-received PAMS is dissolved in toluene (reagent grade)
Filtered through 10 μ m filter followed by 0.8 μ m filter
Reprecipitated with ethanol (reagent grade)
Rinsed with ethanol
Vacuum dried at 40° C

This procedure should remove compounds such as lithium methoxide and lithium hydroxide associated with the original PAMS production. The presence of lithium in the final GDP shell may result in inaccurate information when the shell is used.

6. Are Impurities in the Fluorobenzene the Cause of Deposits?

Distillation of Fluorobenzene:

- Fluorobenzene as available from the manufacturer is “ 99% pure ”
- Evaporation of fluorobenzene leaves a residue, even after 300°C exposure
- EDX analysis of residue shows Ca,Cl,K
- When fluorobenzene was distilled a dark liquid remained

Use of distilled fluorobenzene did not eliminate the deposits

7. Does the Filtration of O1 Influence Deposits?

Filtration of PAMS/Fluorobenzene solution:

After dissolving the reprecipitated PAMS in the fluorobenzene the solution is filtered through a 0.2 μm filter to remove particulate matter

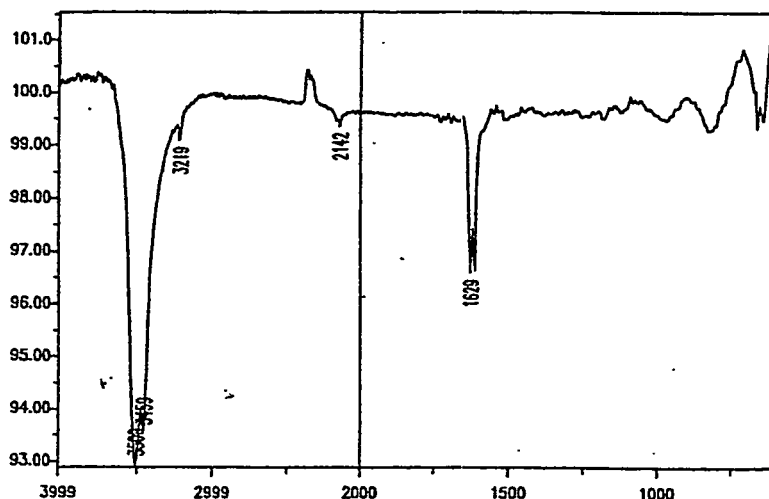
When a PVDF filter was replaced by a PTFE filter the incidence of deposits was greatly reduced !

A wetting agent in the PVDF filters may have been one of the causes of the deposits

8. Could Deposits Be PVA that Had Somehow Gotten into the Interior?

The outer water solution is typically 0.2 wt% PVA in water

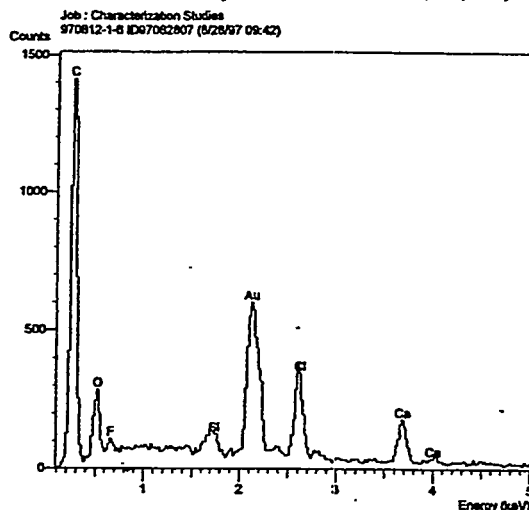
- Micro IR analysis of water extract from PAMS shell interior and GDP shell interior showed no PVA



- Variation of the PVA concentration over a range of 0.01 to 0.2 wt% had no effect on the occurrence of deposits in the PAMS shells

9. Is the Salt Addition to the Curing Solution Causing Deposits?

- Calcium chloride was added to the droplet generator collection beaker to eliminate vacuoles in the PAMS shells
- SEM analysis indicates the presence of Ca, Cl, Si, and O



- Variation of the time of addition of the salt had no effect on the deposits
- Variation of the concentration of the salt had no effect on the deposits
- Replacement of CaCl_2 with NH_4Cl had no effect on deposits

10.

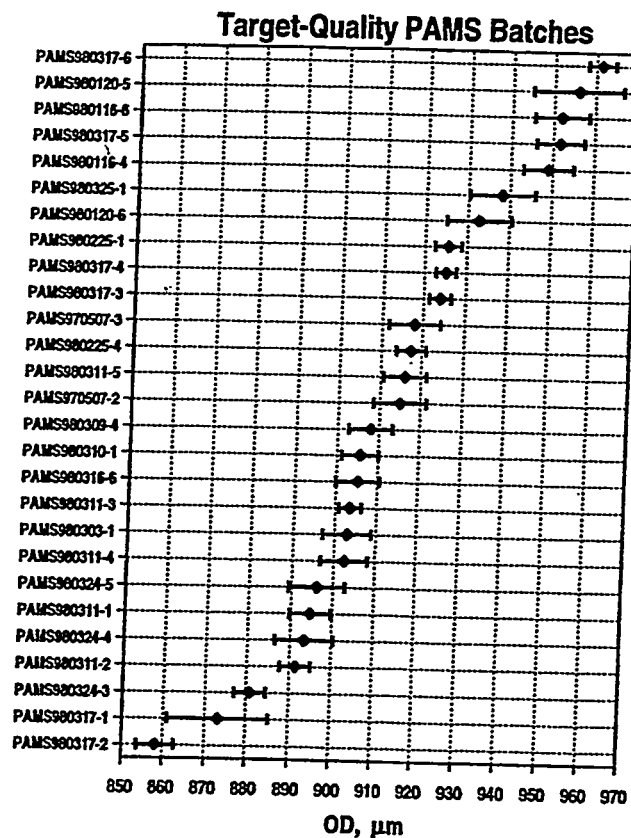
Does Fluorobenzene in W2 Cause Deposits?

Fluorobenzene:

Typically the W2 solution was saturated with fluorobenzene to affect the curing rate of the shells

The W2 is pumped into the droplet generator through tygon tubing Fluorobenzene in the W2 may extract plasticizers from the tubing

When fluorobenzene was eliminated from the W1 solution there was a decrease in the occurrence of deposits



PYROLYSIS IMPROVEMENTS TO THE GDP/PAMS PROCESS

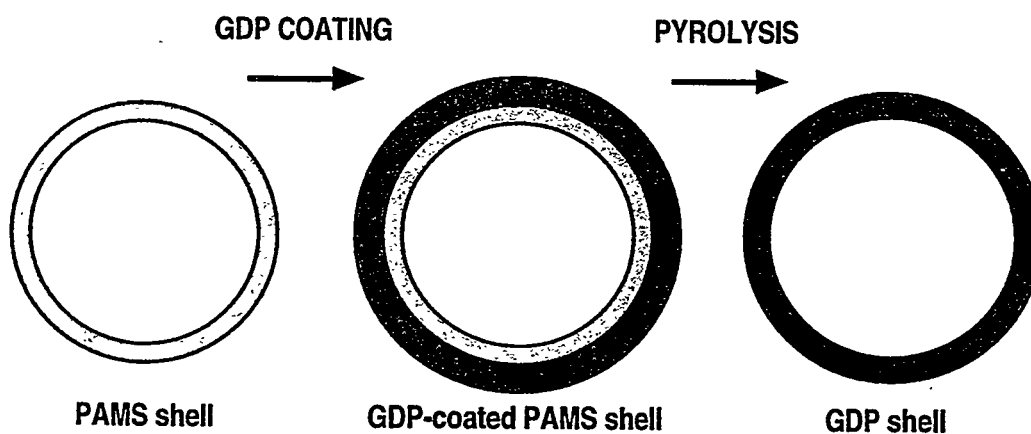
David Husband, David Steinman, Abbas Nikroo, Annette Greenwood
General Atomics, San Diego

Glow discharge polymer (GDP) coating of microencapsulated poly-alpha methyl styrene (PAMS) shells followed by pyrolysis of the PAMS leaves a uniform GDP shell with the desired wall thickness. Additives can be more easily added to the GDP layer. Improvements were made on the pyrolysis procedure.

The improvements include determination of:

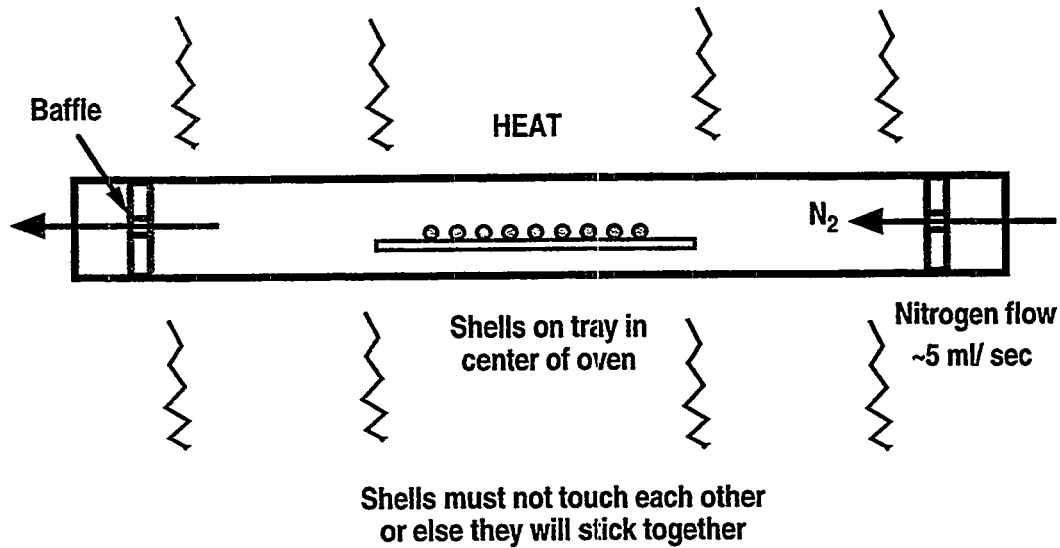
- GDP shrinkage to produce shells of required thickness and size
- 'burn time' needed for a desired target
- purge gas needed (depending on GDP thickness)
- the desired temperature within the furnace
- substrate needed to hold shells during pyrolysis

PROCESS FOR MAKING GDP SHELLS

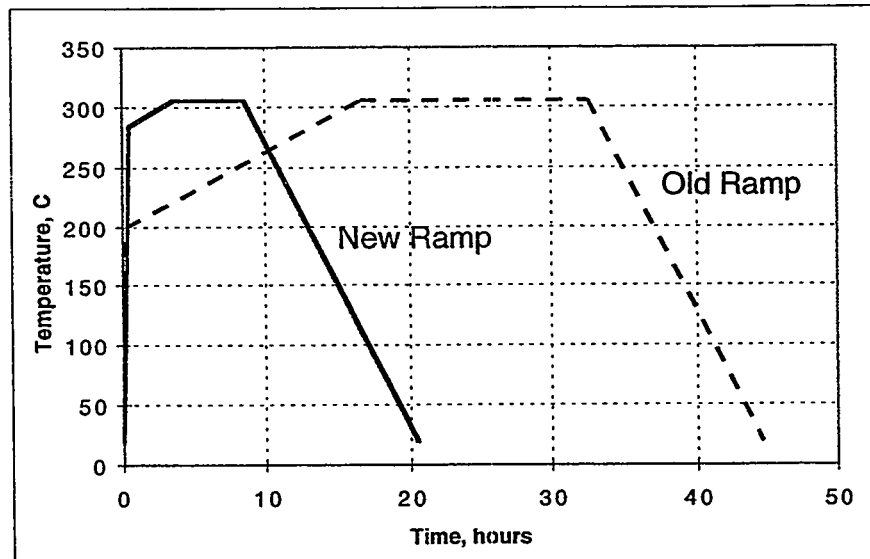


Note: shrinkage of GDP
shell walls and diameter

PYROLYSIS OVEN



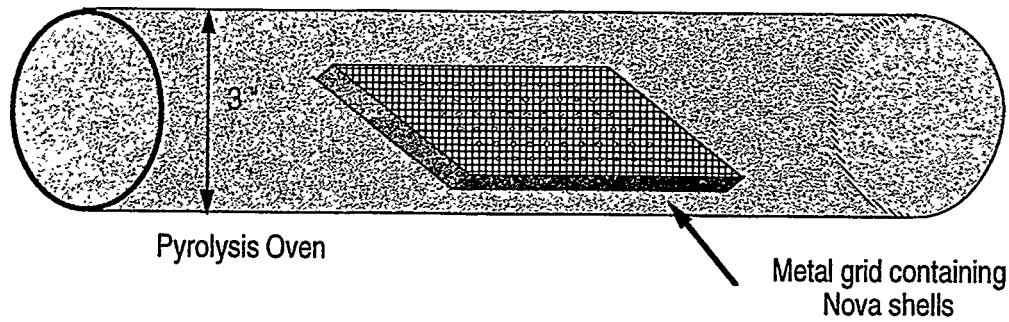
Faster ramp allows overnight pyrolysis of shells



It was found that a more aggressive temperature profile for pyrolysis did not degrade shell quality while reducing overall pyrolysis time

This increased our efficiency tremendously

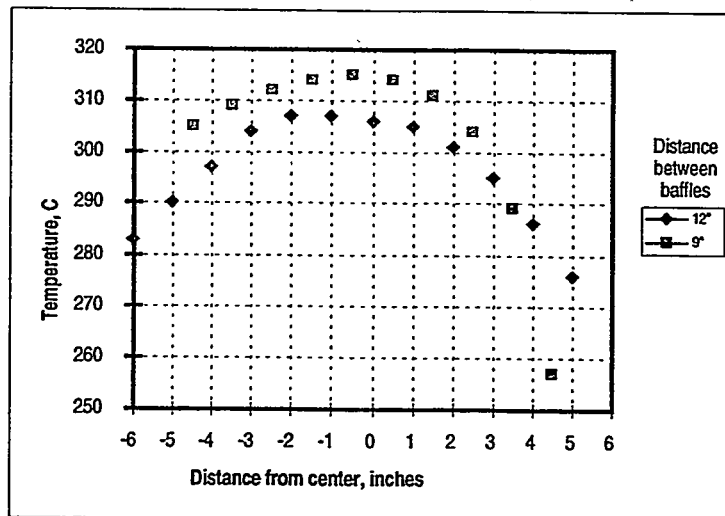
A metal grid with $\approx 600 \mu\text{m}$ holes was used to pyrolyze Nova shells



The PVA coating process for Nova shells requires thousands of GDP mandrels

The 3" diameter pyrolysis tube allows pyrolysis of over a thousand shells at a time in a metal grid

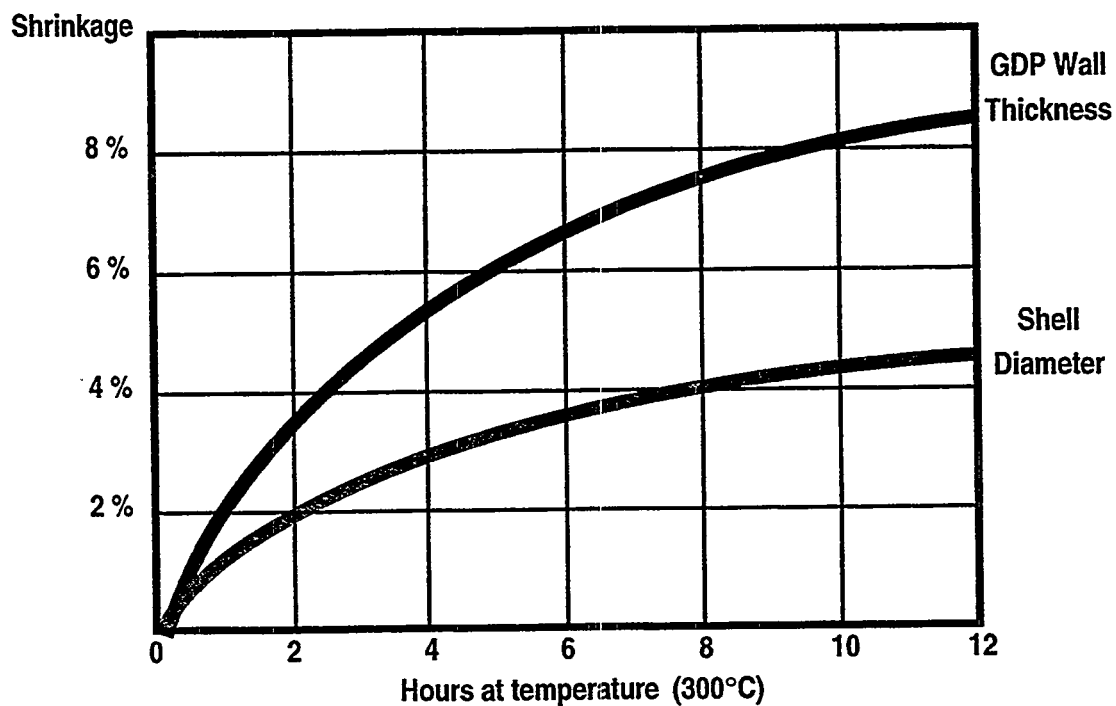
Increasing the distance between the heat baffles produces a more uniform temperature distribution in the pyrolysis tube



Tube temperature drops more sharply away from the center as the baffles are moved closer to the center.

A flatter temperature profile in the tube reduces the effects of errors in positioning of shells within the tube

SHRINKAGE IS TIME DEPENDENT

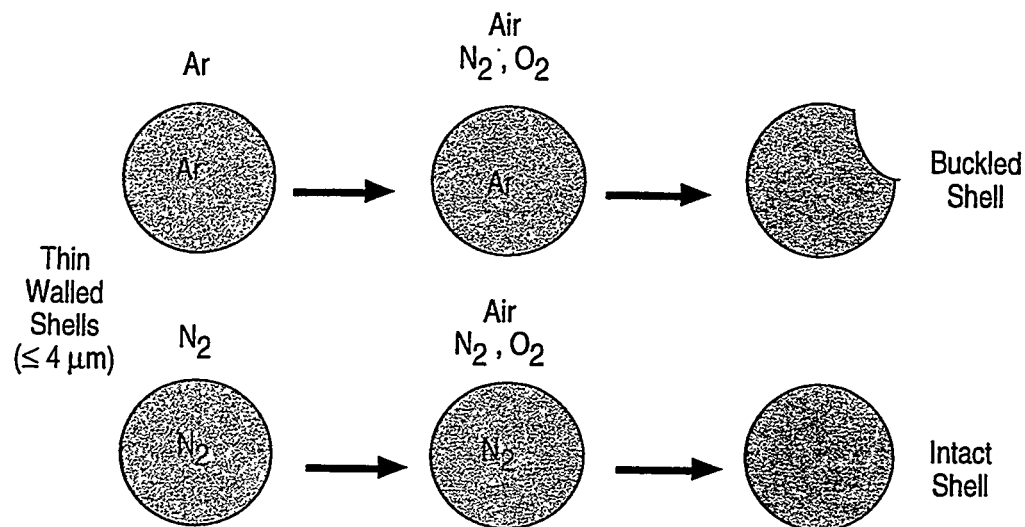


Shrinkage of GDP coated PAMS shells is dependent on the dopant in the coating

GDP type	Wall Shrinkage	Diameter Shrinkage
Undoped	10 %	6 %
Deuterated	10 %	6 %
Ge- Doped	4 %	2 %
Si-doped	0 %	0 %
Ti-Doped	20 %	4 %

Above values are for a typical 16 hour at 300 °C pyrolysis

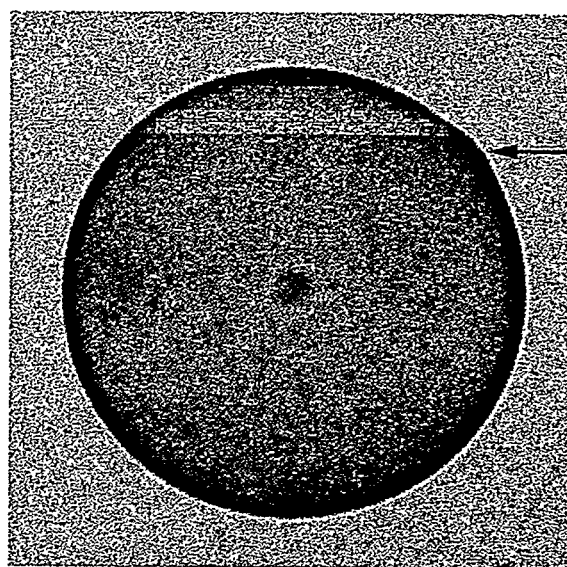
Using argon as the flow through gas in the pyrolysis process
results in buckling thin walled shells



Argon permeates out of GDP shells faster than nitrogen or oxygen

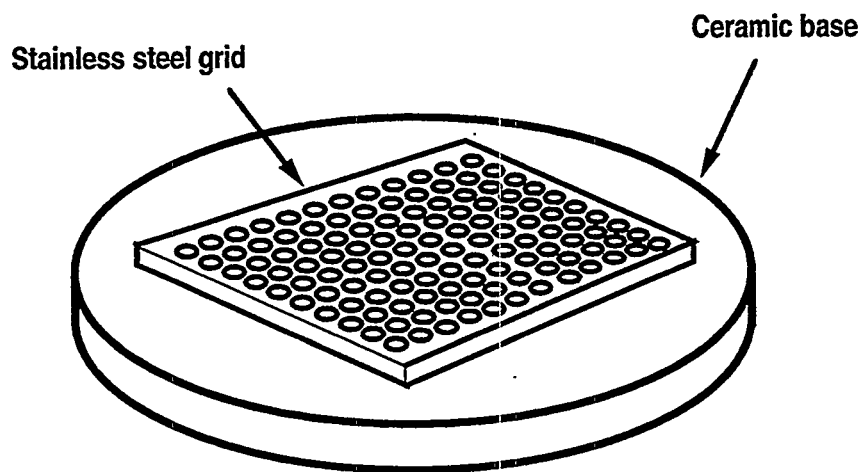
This leads to enough buckle pressure on thin walled shells to cause them to collapse

Shell pyrolyzed on a stainless steel surface

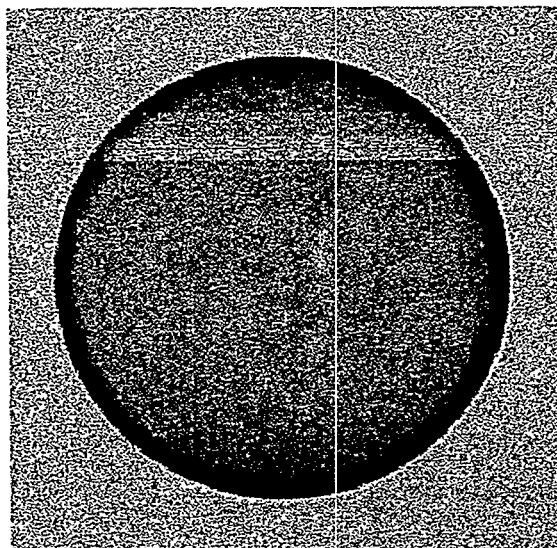


Deformation at
contact point

USING A CERAMIC BASE PREVENTS SHELL DEFORMATION



Shell pyrolyzed on a ceramic surface



No deformation

Physical Properties of Films Used in ICF Targets



Steve Letts, Mike Saculla, Chad Roberts, John Burman,
Evelyn Fearon, and Steve Buckley

Target Fabrication Meeting 1998

April 19–23, 1998

Jackson Hole, Wyoming

University of California
 Lawrence Livermore
National Laboratory

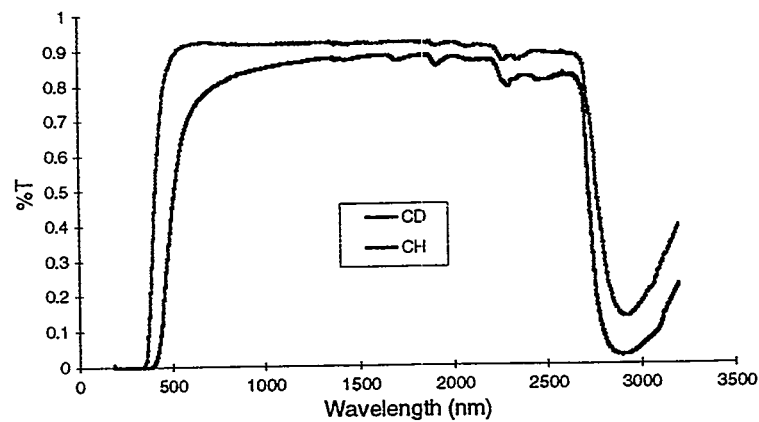
*This work was performed under the
auspices of the U.S. Department of
Energy by Lawrence Livermore
National Laboratory under contract
no. W-7405-Eng-48.

Physical properties of laser capsule polymers

- We have measured physical properties of target materials relevant to target function. Changes in transmittance affect the ability to characterize the interior of the shell and may alter radiant energy absorption of cryogenic targets. Permeation of gas through the shell determines fill and hold time of the capsule.
- Plasma polymer is one possible coating in the depolymerizing mandrel approach for shell preparation. Transmission changes were followed in plasma polymer materials as a function of time to determine the rate of free-radical oxidation. The plasma polymer is subjected to heating during the mandrel removal step. We have measured the transmission changes in the coating caused by heating at 310 C for 1000 minutes (16.7 h).
- Methods:
 - UV-Visible spectroscopy (185 to 3200 nm) to follow transmission changes caused by heating.
 - FTIR spectroscopy (7800 to 370 cm⁻¹/ 1.3 to 27 μm) to follow free-radical oxidation.
 - Microscope photometry to follow transmission changes with time
 - Helium leak detector with special temperature controlled permeation cell to measure permeation
- Helium permeation allows us to evaluate target materials for gas retention in laser targets

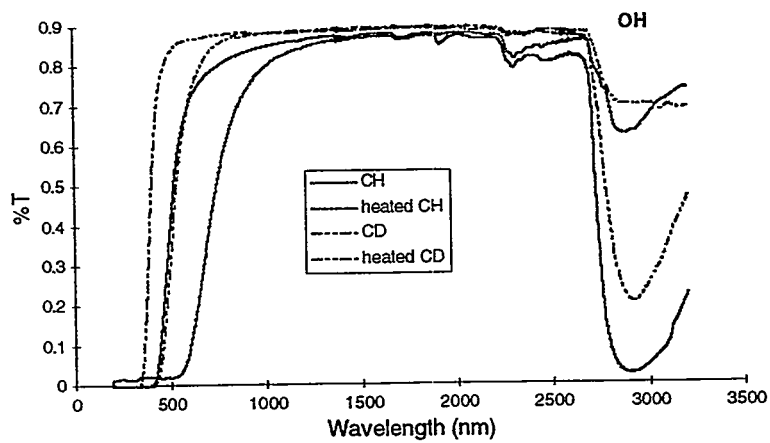
PhysPropatCFilms 041698

Deuterated plasma polymer has high visible transmission.



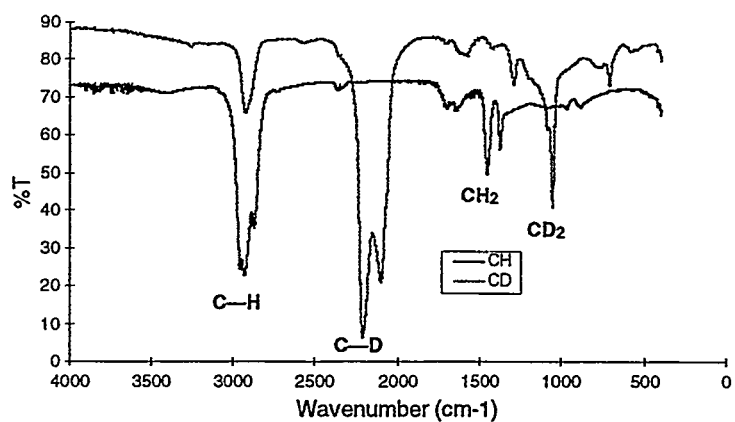
PhysPropalCFFems 041628

Heating plasma polymer reduces visible transmission and increases IR transmission.



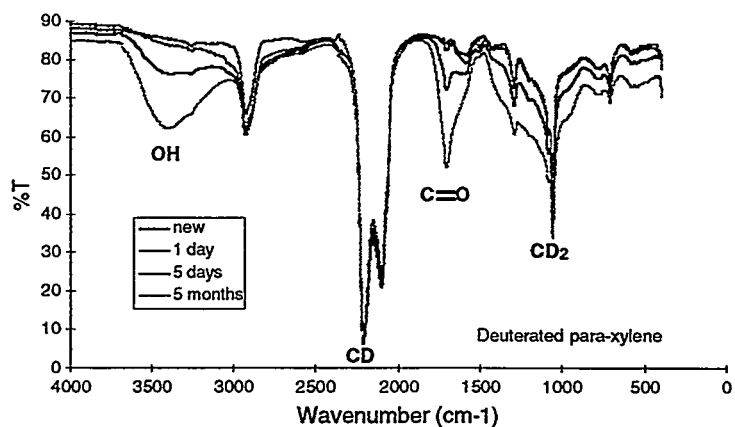
PhysPropalCFFems 041628

D₂ fuel layers can be laser heated through deuterated plasma polymer shells.



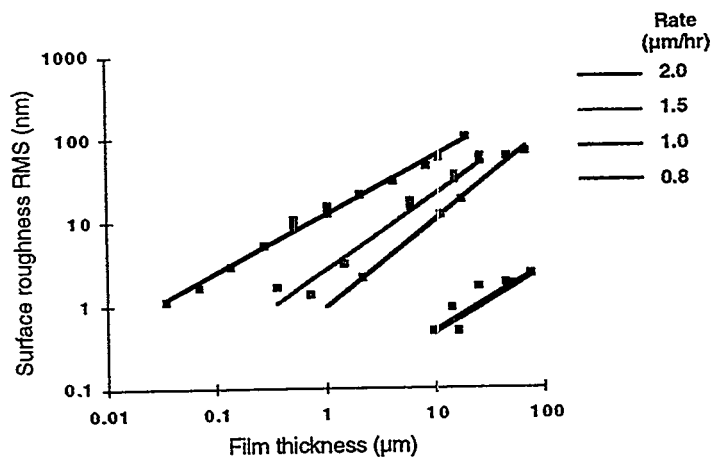
PhysPropdCFFilms 041698

Free radicals trapped in the plasma polymer coating react with oxygen over a several month period.



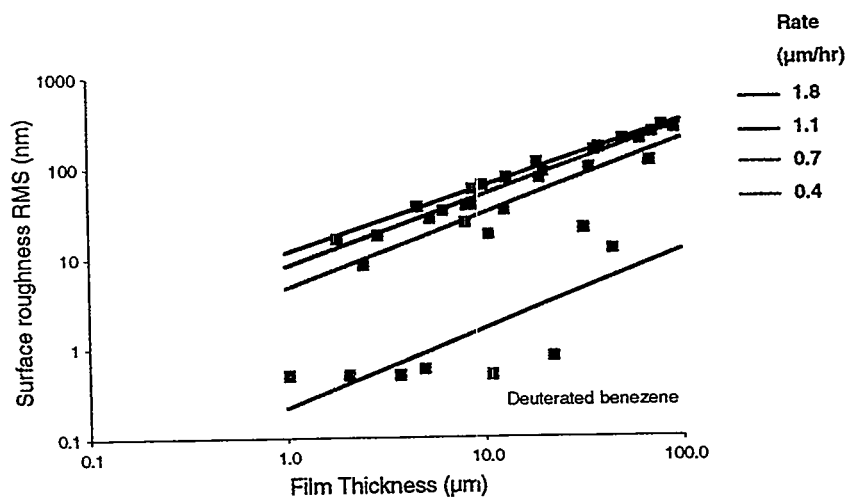
PhysPropdCFFilms 041698

The scaling of surface roughness for CH plasma polymer changes with precursor monomer flow.



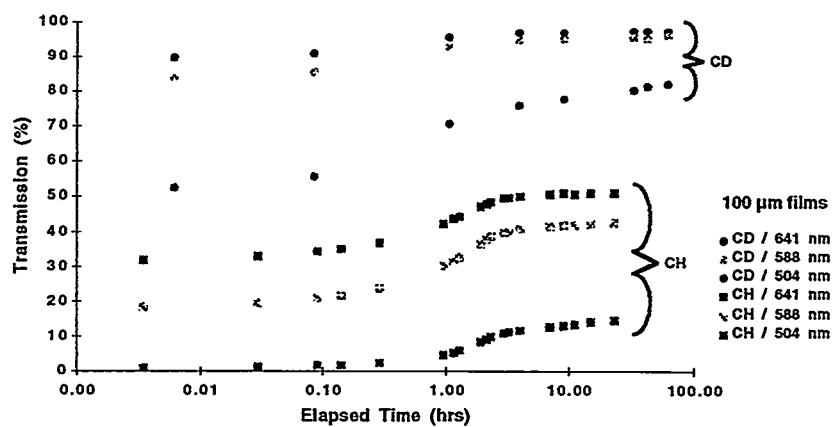
PhysPropalCFFilms 041638

The scaling of surface roughness for CD plasma polymer changes with organic flow rate.



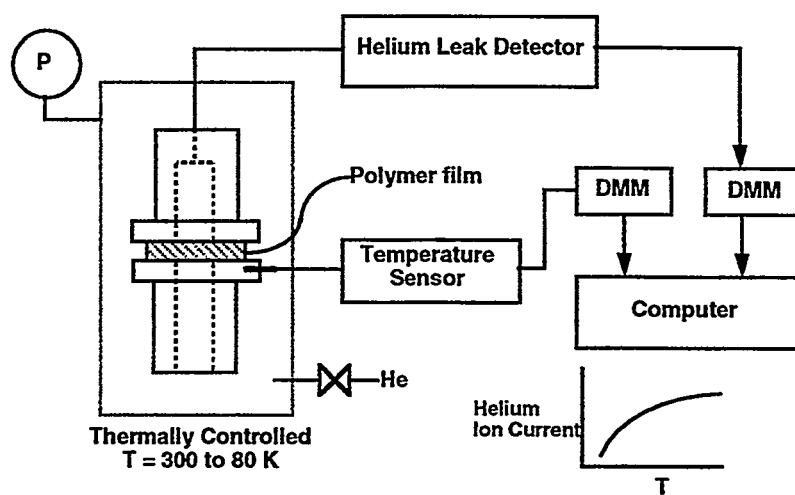
PhysPropalCFFilms 041638

Oxidation of free radicals in plasma polymer causes optical transmission to increase with time



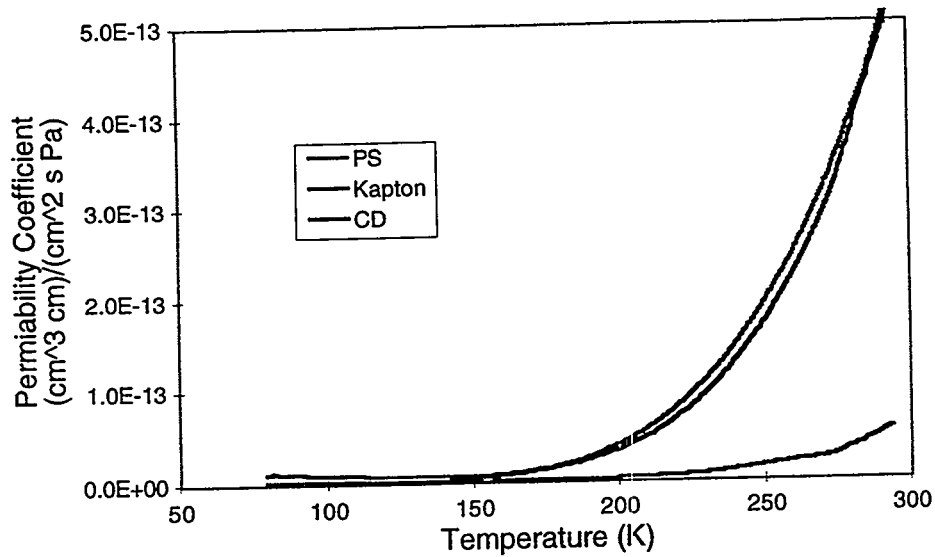
PhysPropetCFFilms 041658

A helium leak detector was used to measure gas permeability through polymer films



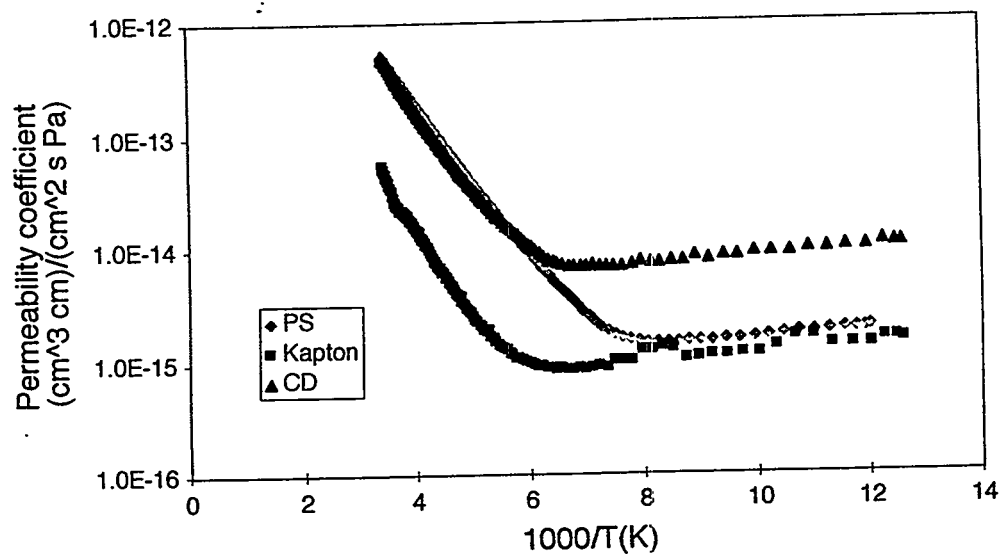
PhysPropetCFFilms 041658

Helium permeation was measured as a function of temperature for target polymer films



PhysPropstICFFilms 041698

Helium permeation is thermally activated



Conclusions



- **Visible transmission decreases for heated plasma polymer**
- **IR transmission increases with heating due to loss of OH**
- **CD plasma polymers are more transmitting than CH**
- **Visible transmission increases with time due to the oxidation of free-radicals**
- **IR absorbances (OH and C=O) increase with time due to free-radical oxidation**

PhysPropslCFFilms 041698

Polyimide Coatings from AB monomers



Target Fabrication Meeting 1998
April 19-23, 1998
Jackson Hole, Wyoming



**Chad Roberts, Mike Saculla
 and Steve Letts**

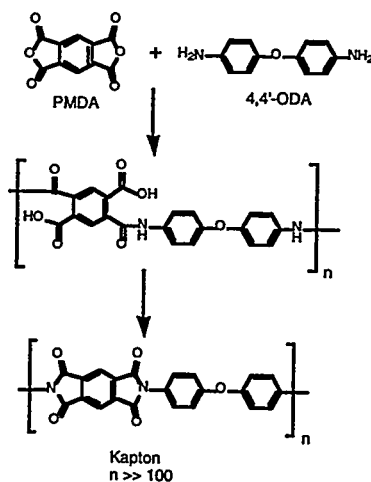
*This work was performed under the auspices of
 the U.S. Department of Energy by Lawrence
 Livermore National Laboratory under contract
 no. W-7405-Eng-48.

**Polyimides are traditionally synthesized from the
 two step, condensation reaction of two monomers.**

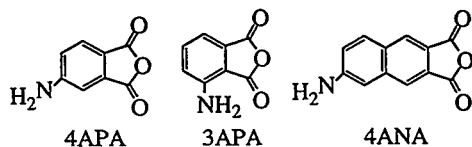
A high strength capsule is key for room temperature transport of NIF targets.

The chain length, n , controls the
tensile strength of polymer films
 and is determined by the **diamine /
 dianhydride ratio**.

Hence, the vapor pressure or
deposition rate of the two
 monomers must be perfectly
 matched to allow for the formation
 of high molecular polymer via
 vapor deposition.

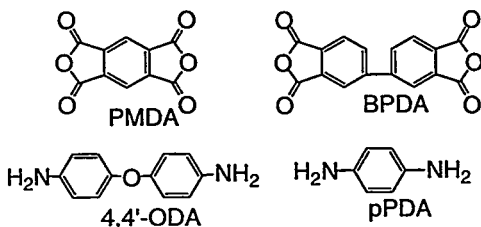


Vapor deposition of a single monomer eliminates the stoichiometry problem.



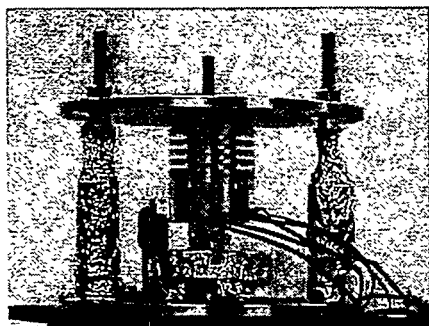
- +Inherent Stoichiometric balance
- Low Reactivity (Endothermic rxn)
- Few documented monomers and polymers and VDP

Both single monomer (A-B) and dual monomer sources (A-A/ B-B) involve the same chemistry to form polyimides.

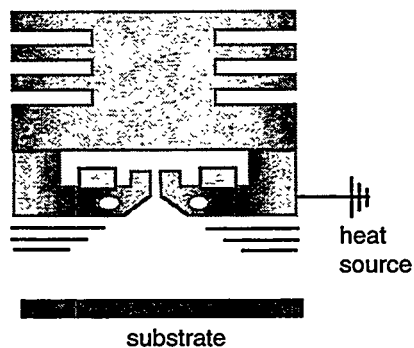


- Stoichiometric balance and mixing are critical
- +More reactive (Exothermic rxn)
- +Relatively large database

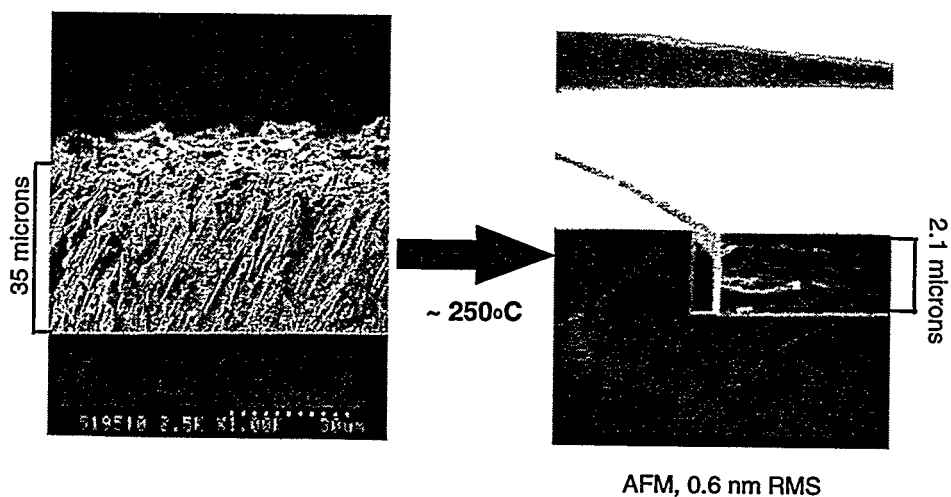
A single monomer deposition system was designed and constructed.



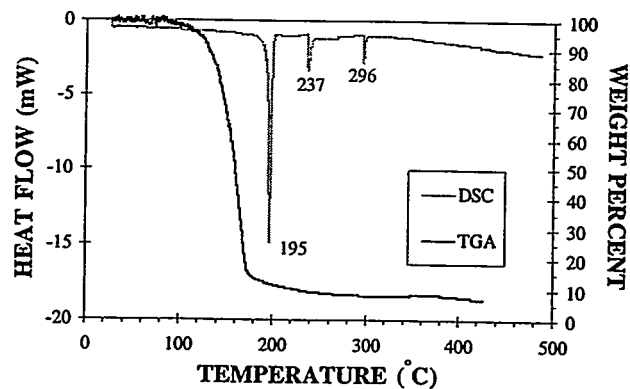
Schematic of single monomer source
(to 10^{-3} torr)



Thick 3APA coatings were formed, but sublimation is a problem during curing.

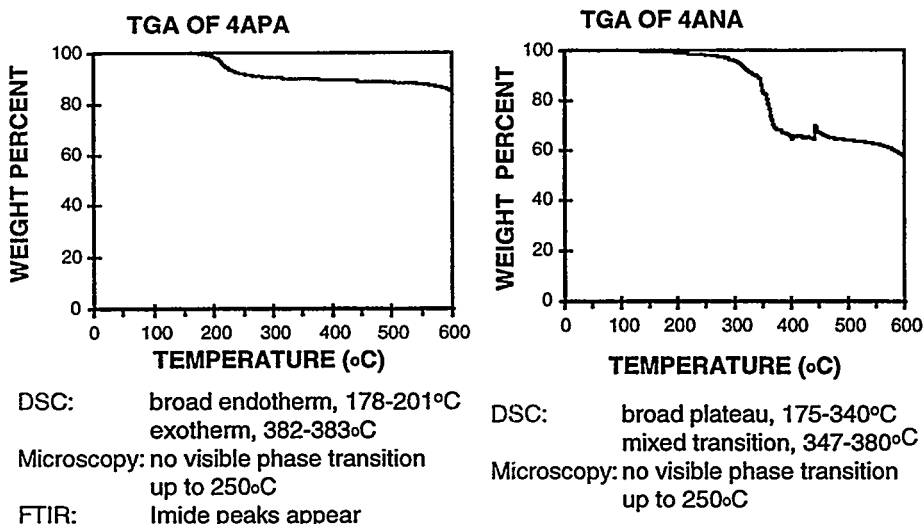


VDP results correlate with 3APA thermal analysis data.



- DSC: no reaction exotherm as expected
reaction appears to be endothermic
- TGA: 10-20 % residue after heating to 200-300°C
sublimation competes with polymerization process

VDP & processing of 4APA & 4ANA was difficult.

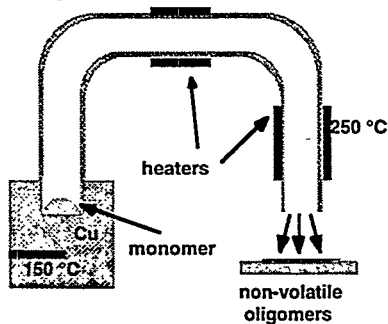


Powdery (frosty) coatings formed during deposition.

Novel processing was utilized to try to overcome the problems with 3APA.



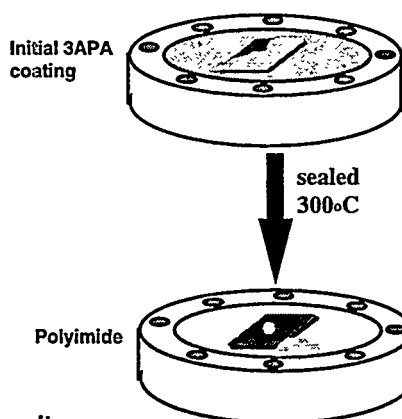
Gas phase thermal reactor was tested.



Results:

1. Polymerization and deposition in heated transfer tube.
2. No coating or coating on the substrate was unreacted 3APA.

3APA coatings were heated in confined space.



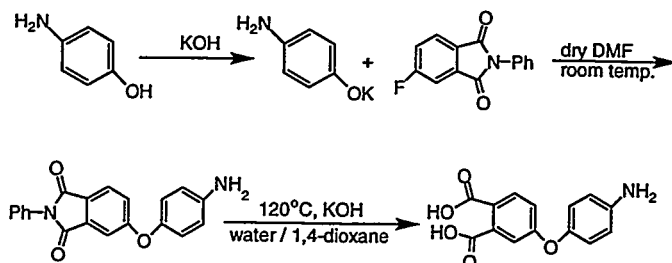
Results:

3APA coating beaded on Si substrate, flowed to form a pool of polyimide and redeposited on other surfaces.

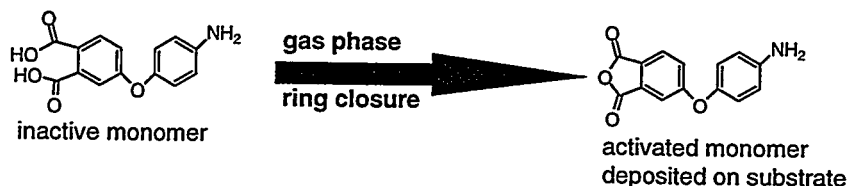
These problems may be circumvented by using a properly designed AB monomer.



New AB monomer can be synthesized.



This monomer will utilize a novel vapor deposition ring closure mechanism.



Summary and Future Work



1. A single monomer solves the problem of stoichiometry or ratio matching.
2. Mixed results were observed in examining 3APA, 4APA and 4ANA.
 - a) A smooth, 2 micron polyimide thick film was formed from a 35 micron 3APA coating.
 - b) 4APA and 4ANA were difficult to vapor deposit due to premature reaction in the source, and films could not be formed by heating deposited coatings.
5. Attempts to engineer a solution to these problems were unsuccessful or inconclusive.
6. New AB monomers are proposed which should alleviate these problems.

“Controlled Testing of Thin-Walled Capsules to Failure”

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**Target Fabrication Meeting 1998
Poster Session**

**19-23 April 1998
Jackson Hole, Wyoming**

afj TFM'98

Objective

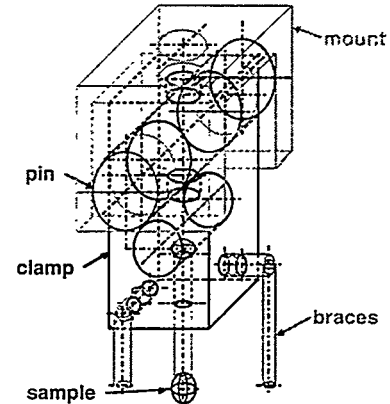


- A testing technique is developed to load thin-walled spherical capsules under uniaxial tension.
- The load is applied under constant strain which allows for determination of the elastic properties of the capsule material.
- Application of load to failure produces yielding and fracture equivalent to the loading conditions induced by internal pressurization.
- The testing of several types of capsule materials are examined including polymer and metal-composite systems.

Experimentals



- An Instron Universal tester equipped with a 5 N (1.1lb) cell applies a load **P** in tension.
- The spherical sample is bonded to pull rods that are held within pin-mounted clamps.
- The stress σ normal to the shell cross-section is **P/A** where the area **A** = $\pi(r_o^2 - r_i^2)$.
- An equivalent rupture pressure **p** = $2\sigma_f t / r_o$ can be computed at the fracture stress σ_f .

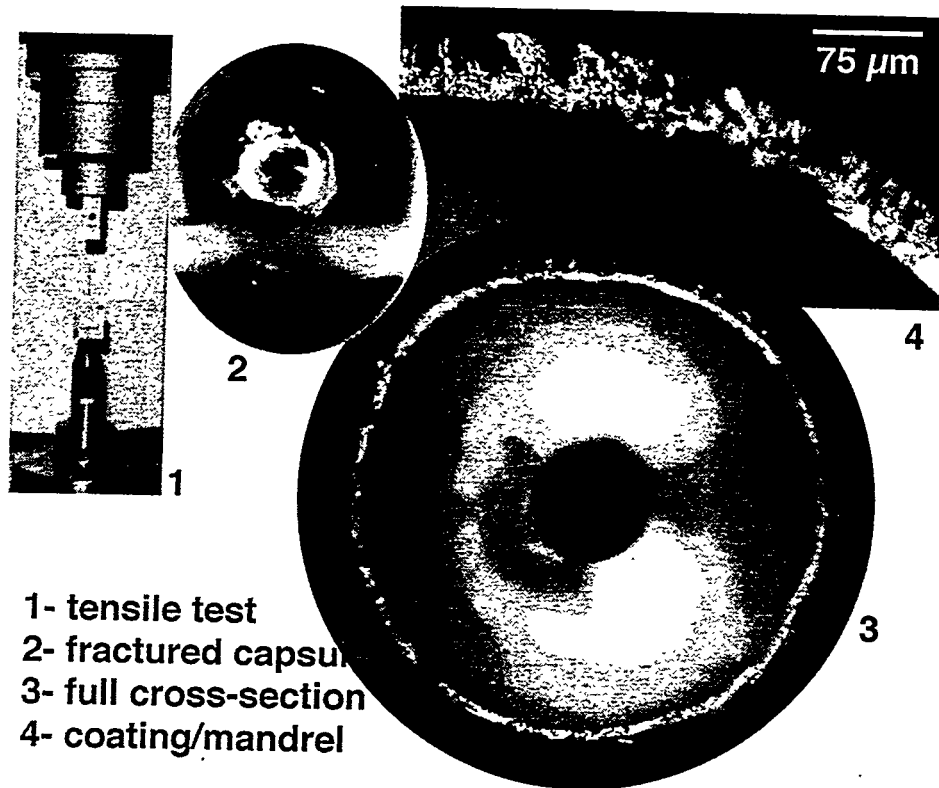


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Results



- A beryllium-coated polymer mandrel constitutes the capsule which is shown in the following image(s).
- 1- The sample is loaded in tension under constant strain to fracture in the micro-**tensile test** fixture.
 - 2- The **fractured capsule** breaks into halves.
 - 3- One of the capsule halves is imaged along its pole to reveal the **full cross-section** area in failure.
 - 4- A high magnification view of the **coating/mandrel** indicates initial fracture at the coating surface which then propagates uninterrupted through the mandrel.



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Summary



- A detailed materials property assessment is now available using this testing technique which facilitates the pressure vessel design of spherical capsules.
- The approach is novel in several ways.
 - 1- complex loading is reduced to uniaxial tension
 - 2- yield and fracture stresses are measureable
 - 3- unique contribution of substrate and coating to the capsule behavior are quantifiable
 - 4- post-fracture sample is accessible to analysis of the failure mode
 - 5- the test method is routine and inexpensive
- This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Controlling the Permeability of Shinethrough Barriers on Inertial Fusion Targets

S. Scarantino, M. D. Wittman, and D. R. Harding

University of Rochester
Laboratory for Laser Energetics



Direct-drive inertial fusion targets require a metallic shinethrough barrier to prevent the laser pulse from preheating the capsule and fuel. Typically, 1000-Å-thick Al layers used at LLE serve the additional function of retaining gas in the capsule. Cryogenic targets, however, will require highly-permeable shinethrough barriers to allow the capsule to be pressurized prior to being cooled. This study describes coating experiments designed to control the permeability of the shinethrough barrier for room-temperature and cryogenic capsules.

Aluminum layers were deposited onto polystyrene and glow-discharge polymer (GDP) capsules. (Unsupported capsules were coated using a partitioned shaker pan. Following coating, they were filled with deuterium, and the exponential time constant for gas permeating out of the capsules was measured.) The effect of different coating conditions on the measured permeation time constants was investigated: etching the capsules with an oxygen and/or argon plasma prior to deposition; biasing the shaker pan during the predeposition etch and deposition; varying the sputter-source-to-substrate distance (this has a second-order effect on the coating rate and ion-bombardment energy), using either a dc or rf (13.56-MHz) sputter discharge; adding air to the sputter gas, and varying the power delivered to the sputter source. Additionally, time constants were measured as a function of coating thickness.

The variables that had the most significant effect on time constants were the capsule (substrate) material and the coating rate. Time constants for 1000-Å-thick Al layers deposited simultaneously on polystyrene and GDP capsules differed greatly: the time constants of polystyrene capsules increased marginally above their ~3-min uncoated values, whereas GDP capsules increased to ~6h. We hypothesize that the surface energy of the substrate and the density of the aluminum film determine the grain size and intergranular porosity of the coating such that (Knudsen) diffusion through nanometer-scale interconnected pores is the dominant (fast) transport mechanism. In contrast, transport through dense, small-grained metallic films is by the classical Sievert's (slow) permeation mechanism. The morphology of the coating on each substrate was examined using scanning electron microscopy. These results are presented.

Silicon films were also evaluated since they may be a better shinethrough material for cryogenic targets. A 2000-Å-thick layer has an optical density of ~3 at 351 nm and is transparent in the near IR, which will allow IR layering and optical characterization. We have demonstrated that 2000-Å-thick silicon layers can be deposited on GDP capsules with a minimal increase 25%) of the time constant compared to that of the uncoated substrate.

Outline



- Shinethrough barriers on targets serve multiple purposes:
 - Prevent preheat of the capsule and fuel
 - Retain gas in the capsule for room-temperature experiments
 - Remain totally permeable when filling targets for cryogenic experiments
- A sputter coater has been constructed purposely for coating targets—both mounted and unsupported.
- The coater was designed to control a large number of coating parameters during the coating process.
- Experiments have been performed to determine the coating conditions that produce both long and short time constants.
- Preliminary results indicate that the surface energy of the substrate and the coating rate have a major effect on the permeation time constant.

T1282

What is the mechanism for hydrogen permeating from a coated capsule?



- If the permeability of hydrogen through bulk Al is extrapolated to thin Al films, the time constant for a 50-Å-thick coating at 25 C is $\gg 10^6$ yr.
- From Sievert's Law, permeation of H_2 through the walls of a metal capsule is

$$\frac{dP}{dt} \propto \sqrt{P}; \quad P(t) \text{ is non-exponential.}$$
- For permeation through the walls of a polymer capsule:

$$\frac{dP}{dt} \propto P; \quad P = P_0 e^{-t/\tau}$$
- The permeation through coated capsules observed to date has been exponential.

T1284

The permeation rate through the shinethrough barrier must be reproducible and controlled by way of the coating process



- OMEGA-size GDP capsules have time constants (τ) for D_2 (DT) diffusion of ~ 3 min.
- Room-temperature implosion experiments require $6 \text{ h} < \tau < 10 \text{ h}$. This is achieved by coating the capsule with 500 to 1000 Å of Al.
- For multiple-gas targets (i.e., $D_2 + \text{He, Ne, Ar, Kr, Xe, etc.}$), τ must be tailored to allow each gas to be permeated within several days.
 - This may require multiple coatings and sequential fillings.
 - Therefore, the permeability of sequential layers must also be controlled.
- Cryogenic implosion experiments require $\tau < 5$ min for the shinethrough barrier—close to that of the bare shell.

T1285

For short time constants, the gas is leaking through pinholes or large interconnected pores in the aluminum



- Assumption: The leakage rate is proportional to the exposed area:

$$\frac{\tau_{\text{bare capsule}}}{\tau_{\text{coated capsule}}} = \frac{\sum \text{Area}_{\text{pinholes}}}{\text{Area}_{\text{capsule}}}$$

- For a coated shell with

$$\tau_{\text{bare capsule}} = 3 \text{ min}, \quad \tau_{\text{coated capsule}} = 6 \text{ h}, \quad \text{diam} = 1 \text{ mm};$$

$$\sum \text{Area}_{\text{pinholes}} = 3 \times 10^4 \mu\text{m}^2$$
- Therefore, there would be 150,000 0.25- μm -sized pinholes in the capsule's coating, or one pinhole every $5 \mu\text{m}^2$.
- This is unlikely since pinholes are not evident in SEM and AFM images.

T1286

For long time constants, gas transport through the coating is dominated by Knudsen diffusion



- In the absence of discrete pinholes, gas transport through the coating is dominated by its structure (pore size, granularity), which affects the Knudsen diffusion of gas through pores and surface migration of adsorbed gases on the pores' surface.
- As the pore size becomes smaller than the mean free path of a molecule, gas/surface interactions predominate.
- The mean free path is ~5 nm for hydrogen at 10 atm.

T1206

For long time constants, gas transport through the coating is dominated by Knudsen diffusion



- The Knudsen diffusion coefficient is given by

$$D_K = 9700 r \sqrt{\frac{T}{M}} \text{ and } \frac{dn_i}{dt} = -D_K \frac{dC_i}{dx}$$

where r = pore radius, T = gas temperature,
 M = gas' molecular weight,

$\frac{dn_i}{dt}$ = rate of molecules of species i passing through surface with concentration gradient $\frac{dC_i}{dx}$

- D_K is independent of pressure.
- The morphology (how grains are connected, i.e., grain boundaries) affects the Knudsen diffusion and introduces a correction for tortuosity θ :

$$D_{\text{eff}} = \frac{D_K}{\theta}$$

T1206

A large number of coating parameters can be controlled using the new sputter coater



- Vacuum conditions: deposition pressure using real-time pressure control, gas flow rate (Ar and O₂), gas composition
- Geometry: distance between sputter head and substrate, sputter head position (particulate cleanliness), deposition rate
- Electrical conditions: rf and dc power, substrate bias, predeposition plasma exposure
- Substrate properties: substrate temperature, ion bombardment, mounted and unmounted (bounced) shells
- Coating material: conductors, dielectrics, oxides, nitrides

T1207

Method

Multiple deposition parameters are changed simultaneously



- Large excursions in variables are made to rapidly span the multivariable parameter space.

Deposition Parameter	Trial #1	Trial #2
Background pressure	10 mTorr	50 mTorr
Power	50 W	100 W
Source/pan distance	20 cm	5 cm

- Other variables are randomized, e.g., pump-down time, capsule batch, coating thickness (measured), etc.

T1206

The surface energy of the substrate determines the permeability of the coating

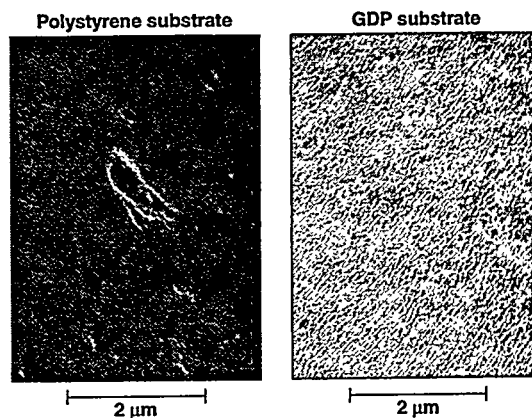


- GDP and polystyrene capsules were coated simultaneously.

Time Constant	GDP Capsule	PS Capsule
Uncoated	4.8 min	~ 3 min
Coated with 1000 Å of Al at 185 Å/min	4.75 h	3.3 min

T1400

Coatings with greatly differing permeabilities display no difference in morphology using SEM



T1401

The coating rate and number of gas-phase collisions prior to surface adsorption determine the permeability of the coating

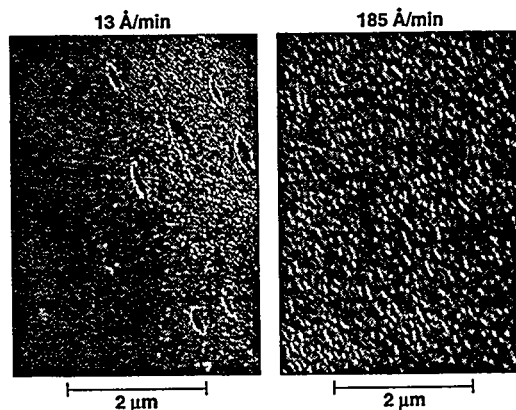


- GDP capsules were coated with Al at two different sputter-head positions at 100-W rf power.

Source/Pan Separation	Coating Rate	Time Constant
20 cm	13 Å/min	24 min
5 cm	185 Å/min	4.7 h

T1402

The more-textured film grown at a faster rate is less permeable than the smoother film



T1403

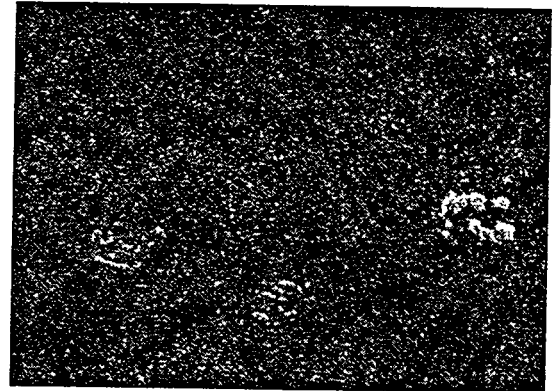
Silicon may be the shinethrough barrier of choice for cryogenic targets



- Silicon is only one atomic number higher than aluminum.
- Optical density of ~ 3 at 351 nm for a 2000-Å-thick layer.
- Transparent in the IR and near IR
 - This will allow IR heating around 4 μm .
 - Possible interferometric characterization using diode lasers (1300 or 1550 nm) with some loss in thickness resolution.
- Low electrical conductivity at low temperatures
 - This may allow joule heating.
- We have measured no reduction in permeability for GDP capsules coated with 2000-Å-thick silicon layers — $\tau \sim 3$ min.

T1406

Silicon coatings exhibit a very fine grain structure



2 μm

T1407

Conclusions



- First demonstration of unsupported aluminum coatings on GDP capsules that have long time constants for hydrogen permeation.
- First demonstration of short time constants with thick layers (1000 Å on PS) suitable for cryogenic targets.
- Permeability of the shinethrough barrier depends on the surface energy of the substrate and the coating rate (ion energy).
- Demonstration of silicon shinethrough barriers that do not impede gas flow.

T1408

Helium Bubble Dynamics in D-T Layers



Bernard Kozioziemski, Gilbert Collins, James Sater, Thomas Bernat

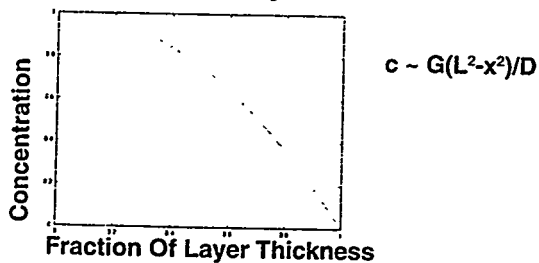
Abstract

Beta Layering experiments show the surface roughness of D-T ice decays with time to a minimum shortly after freezing as a result of bulk heating. As the ice ages the surface roughness increases, coming to a steady state value larger than the initial minimum. Helium bubbles formed within the ice from tritium decays may be responsible for the increase in surface roughness. A light scattering experiment is underway to measure the diffusion of helium bubbles through the D-T ice layer and determine their contribution to the layer roughness.

Helium Formation And Migration



- Atomic helium is produced in D-T at a rate of 0.015 mol % per (day . mol T)
- Atomic helium will diffuse through the ice layer to the ice surface and escape into the vapor region. The concentration of atomic He in the layer depends on the layer thickness and the He diffusion coefficient



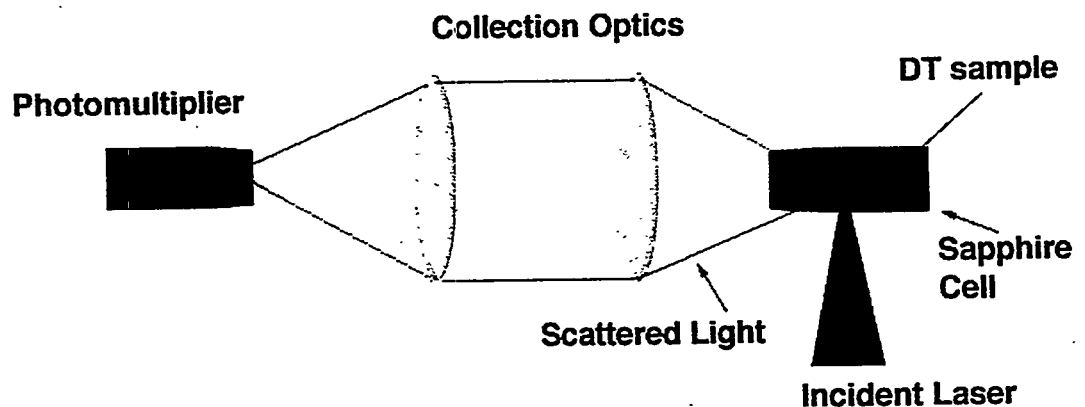
- Helium is insoluble in the D-T ice. When the concentration is high enough the helium precipitates as bubbles
- Bubbles have been observed moving through the D-T ice layer

Studying Bubble Formation



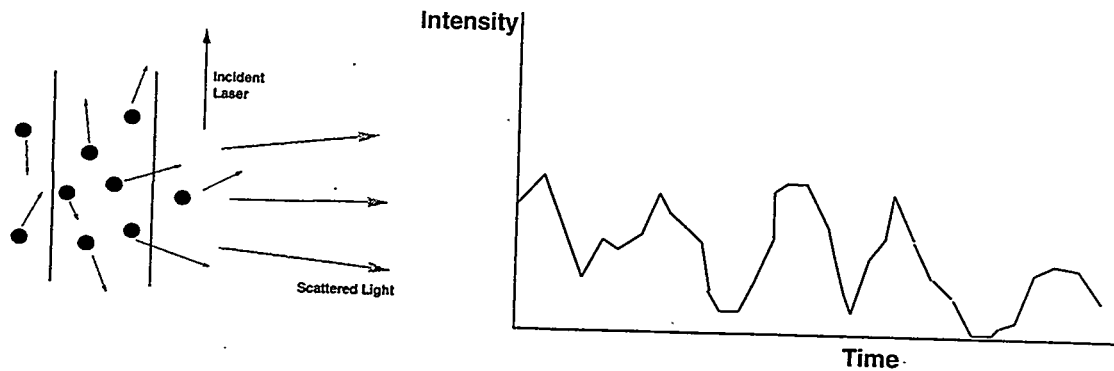
- We want to know the bubble growth rate and the speed at which they travel through the layer
- We expect the nucleation time and diffusion constant of the bubbles depend on temperature and atomic He concentration. The concentration can be varied by changing the layer thickness. The concentration at the wall in steady state is given by GL^2/D , where G is the helium generation rate, L is the ice thickness, and D is the atomic diffusion coefficient
- Past experiments have noted that bubbles move through the layer in a time on the order of hours for a thickness of order several hundreded microns. The bubble diffusion constant is then on the order of $10^{-9}\text{cm}^2/\text{s}$. The autocorrelator device can measure 10^{-7} to $10^{-13}\text{cm}^2/\text{s}$
- Measuring the bubble diffusion coefficient allows us to see if the increase in surface roughness is due to the bubbles breaking through the surface
- A model to connection the atomic diffusion coefficient with the nucleation time of the bubbles needs to be investigated
- Considerable work has been done studying helium bubble formation in metals. Nucleation models exist and serve as a starting point for application to helium in D-T

Experimental Setup



- The target cell is in a cryostat

The bubble Brownian motion results in intensity fluctuations of scattered light



- The intensity of the scattered light varies as a bubble moves through the laser beam
- The diffusion constant set the time scale for intensity fluctuations

Detection Of Bubbles



He bubbles in the size range of tens to hundreds of nanometers can be detected through light scattering as they diffuse through the layer.

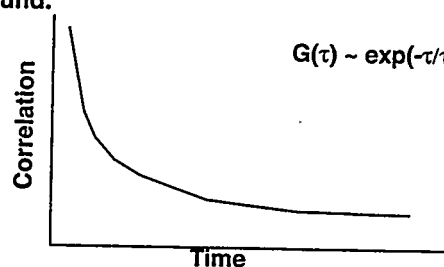
Rayleigh scattering is applicable for bubbles less than the wavelength of light, about 500 nm.

A laser is focused down to a small region, the scattering volume. As the bubbles move through this volume the intensity of the light falling on the detector fluctuates in time, due to the Brownian motion of the bubbles. The correlation time, the characteristic time it takes for the intensity to change, depends on the diffusion constant and is given by

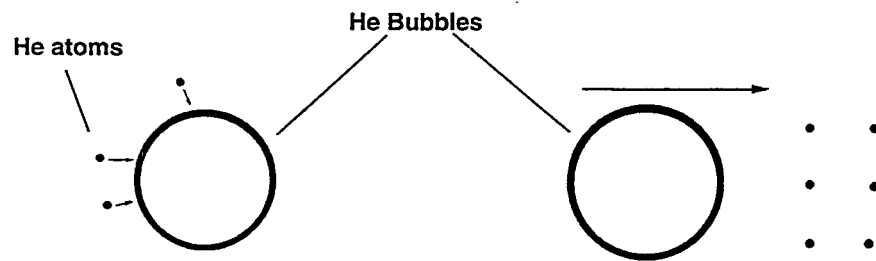
$$\tau_c = \frac{1}{q^2 D}$$

q is the scattering vector, set by the scattering geometry

A hardware correlator is able to measure the correlation time from which the diffusion constant can be found.



$G(\tau) \sim \exp(-\tau/\tau_c)$ is the intensity auto-correlation function



- Bubbles grow when He atoms diffuse into the bubble and also by sweeping out He atoms as the bubbles move through the layer
- Bubbles will coalesce when they collide

ULTRA DISPERSED (NANOSTRUCTURED) BERYLLIUM

V.V.Gorlevskiy, Yu.E.Markushkin, V.F.Petrinin

A.A. Bochvar All-Russia Science and Research Institute for Non-Organic Materials (Russian abbreviation VNIINM), State Scientific Center of Russian Federation, Moscow, Russia

Moscow State Engineering-Physical Institute (Technical University), (Russian abbreviation MIFI), Moscow, Russia

Using hydride technique we worked out a production method for ultra-dispersed beryllium powder. The product is so active that exothermic oxidation occurs even in the atmosphere of technical argon, whereas in the air the temperature of its self-heating achieves white heat.

Highly porous and non-porous beryllium were made from the powders, their properties being different from that of traditional beryllium materials [1].

The structure investigations were done by the neutron diffractometry. For subsequent structure study the unoxidized powders and highly porous beryllium were produced at once (2 - 3 g) and then sealed in the vanadium capsules designed for neutron diffraction analysis. A sample of melted beryllium having hexagonal lattice with parameters $a=2.29\text{\AA}$, $c=3.58\text{\AA}$ [2] served as a standard. The measured results for domains of coherent scattering are shown in the table 1.

It is necessary to note that the diffraction maxima are displaced to larger angles (in comparison with the standard). They are indicated on the basis of hexagonal elementary cell of less parameters $a=2.27\text{\AA}$; $c=3.56\text{\AA}$. The relative intensity of diffraction maxima changed. The coherent part (discrete maxima) of diffraction pattern dropped essentially (1.7-fold) relative to the non-coherent background of the neutron diffraction pattern. Simultaneous widening of Bregg's maxima is due to the diminished domains of coherent scattering and larger defects of the structure.

Table 1

The results of neutron diffractometry investigation of beryllium powder [3].

Annealing temperature, C	Size of coherent scattering domain, nm
unannealed sample	17
500	22
600	23
900	25

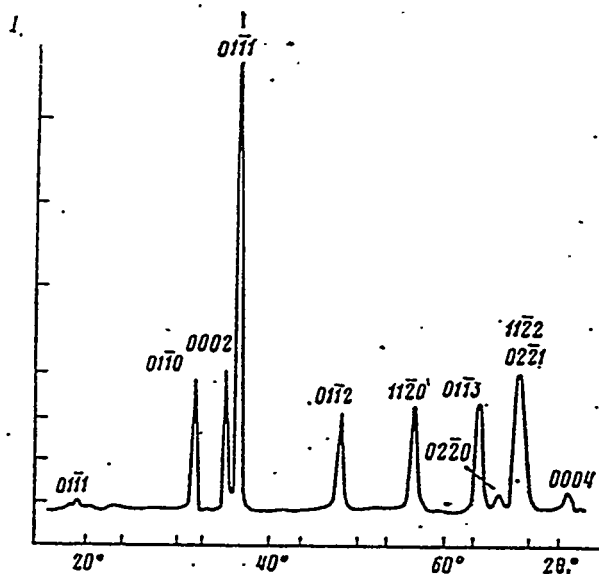


Fig. 1. Neutron diffraction pattern of the porous beryllium sample ($\rho=0.25\text{g/cm}^3$).

A comparison of experimental diffraction maxima intensity for high-porous beryllium with the one calculated for standard (table 2) gave the factor of unauthenticity $R=7.9\%$. Considering of thermal atomic oscillations allowed for an unauthenticity factor as low as 3.6%. Provided that atoms perform isotropic harmonic

oscillations in the points of crystalline lattice the parameters of these oscillations are defined. They are Debye-Waller factor $B=0.79\text{\AA}^2$ and mean-root-square displacements from the equilibrium state $\sqrt{\overline{u^2}}=0.17\text{\AA}$.

The diffraction peaks widening gave the average size of coherent scattering domains according to the known formula by Selyakov - Sherer [5]: $L=0.94\lambda/\Delta \cos \theta$ (L is the average size of coherent-scattering domains, Δ is physical widening of peaks in comparison with the standard, θ is an angle of scattering). The size of a coherent-scattering domain for highly porous beryllium was found to be $(1300\pm350)\text{\AA}$ (for powders - $170-250\text{\AA}$), which points out the similarity of the samples with the ultra-dispersed materials. After oxidation in the air of the same porous specimen until the oxide content reached $\sim 6\%$ by mass, the coherent-domain size became $550\pm95\text{\AA}$. Thus for beryllium produced of hydride the crystalline structure was shown to differ a lot from that of conventional polycrystalline beryllium produced by melting. The parameters of crystalline lattice become less, whereas the mean-root-square atom displacements grew larger. Besides, the essential amount of atoms are so far displaced from their ideal positions that they do not take part in the coherent scattering. The investigated beryllium samples consisting of particles of $1000\text{\AA}$ sizes and less do have large specific inner surface.

Table 2

Diffraction maxima intensities on the neutron diffractometry pattern for the highly porous beryllium and highly porous oxidized beryllium. Experimental I_e and calculated I_p (without thermal oscillations considered) and I_p' (with account of thermal oscillations)

hkl	I_e		I_p (standard)	I_p'	
	porous	porous oxidized		porous	porous oxidized
0110	0.0766	0.0676	0.0649	0.0762	0.0690
0002	0.0802	0.0688	0.0716	0.0822	0.0754
0111	0.3301	0.3529	0.3021	0.3438	0.3174
0112	0.0689	0.0666	0.0616	0.0638	0.0625
1120	0.0895	0.0884	0.0944	0.0944	0.0932
0113	0.1080	0.1038	0.1177	0.1045	0.1130
0220	0.0147	0.0191	0.0186	0.0161	0.0177
1122			0.1428		
	0.2157	0.2168		0.2064	0.2326
0221			0.1055		
0004	0.0162	0.0208	0.0209	0.0166	0.0193

It is known that amorphous and fine-grained metals and alloys were always of special interest to scientists and technologists. Their physical and mechanical properties may be very different from such of the metals having "ordinary" structure.

Up to now the minimum grain size for beryllium is 3-5 μm . This can be achieved in two ways. The first option is in use of traditional methods of powder metallurgy, precisely in thin grinding of beryllium in the atmosphere of argon with further hot pressing of the product [2].

The resulted metal is highly strong ($70 - 80 \text{ kg/mm}^2$) at zero specific elongation and contains essential amount of oxide inclusions along the boundary of the grains.

The second option supposes using a highly pure metal of casting origin. It should undergo a complex multi-step mechanothermal treatment, including several cycles of "extrusion-sedimentation" procedures with intermediate annealing [4]. In this case the isotropic properties are not achieved, however, metal produced by this technique is moldable due to the absence of oxide inclusions on the boundary of the grains [5].

Novel opportunities of producing porous and solid nanostructured beryllium are demonstrated by "hydride technique".

In this connection there emerged a need to study the mechanical properties of porous and non-porous beryllium as well as to compare them with the properties of hot-pressed powders of commercial beryllium.

The strength characteristics of highly porous material were investigated [6] (Table 3).

As shown on the plots of "deformation (ε) - stress (σ)" (Fig. 2) the material undergoes the fragile destruction being deformed no more than 0.9%. With regard to fragile destruction the strength characteristics

were measured in series of 3 - 8 constant-density specimens in each. Compression tests were performed on the samples of 10-mm diameter and 15-mm height. The size of the samples for bending tests were 70x15x10 mm. The deviations of samples density in a series were no more than 2%.

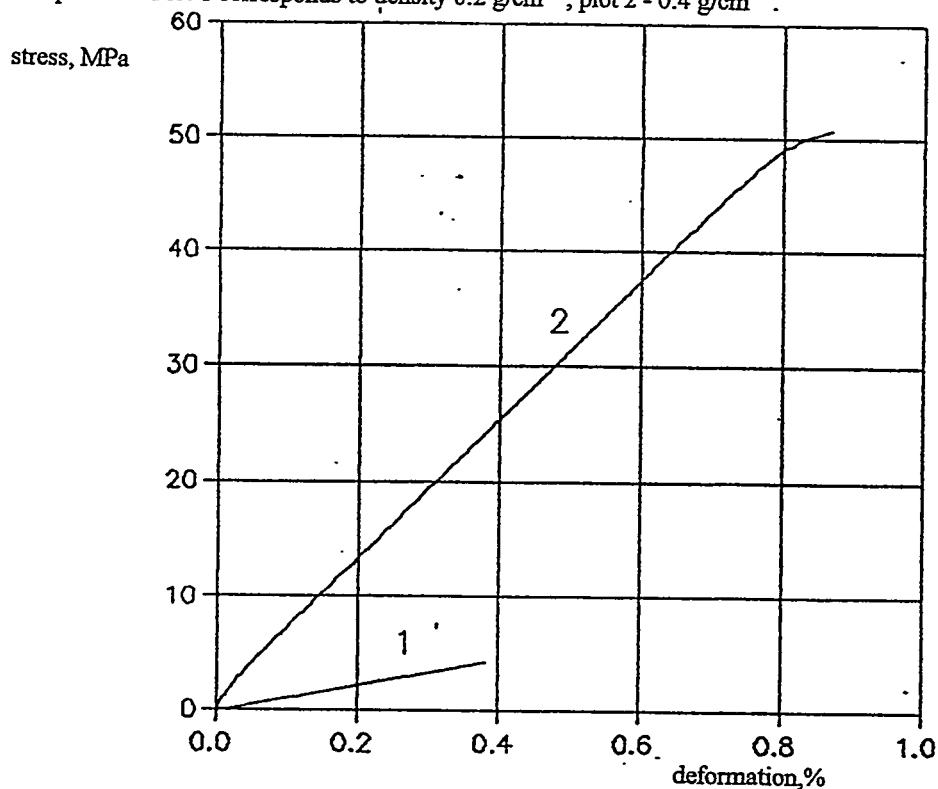
Table 3
Results of compression and bending tests for highly porous beryllium

$\rho, \text{g/cm}^3$	N	$\bar{\sigma}_c, \text{MPa}$	$\delta, \%$	N	$\bar{\sigma}_b, \text{MPa}$	$\delta, \%$
	compression			bending		
0.16	3	0.6	8.8	-	-	-
0.18	3	1.9	7.2	-	-	-
0.20	5	4.3	5.1	-	-	-
0.21	4	7.1	5.5	3	1.7	14.5
0.23	4	7.6	7.8	-	-	-
0.25	5	16.8	7.9	3	3.7	11.8
0.27	5	22.8	9.4	-	-	-
0.30	8	31.0	6.3	3	5.4	17.6
0.32	-	-	-	6	9.0	11.1
0.35	5	44.3	8.1	3	11.3	5.2
0.37	8	45.4	7.2	-	-	-
0.40	8	47.9	7.8	4	12.3	13.6
0.45	8	48.4	11.9	-	-	-
0.50	5	45.2	5.8	-	-	-
0.53	5	46.1	10.8	-	-	-

Note. N is the quantity of samples in a series, δ is the variation coefficient.

Fig. 2

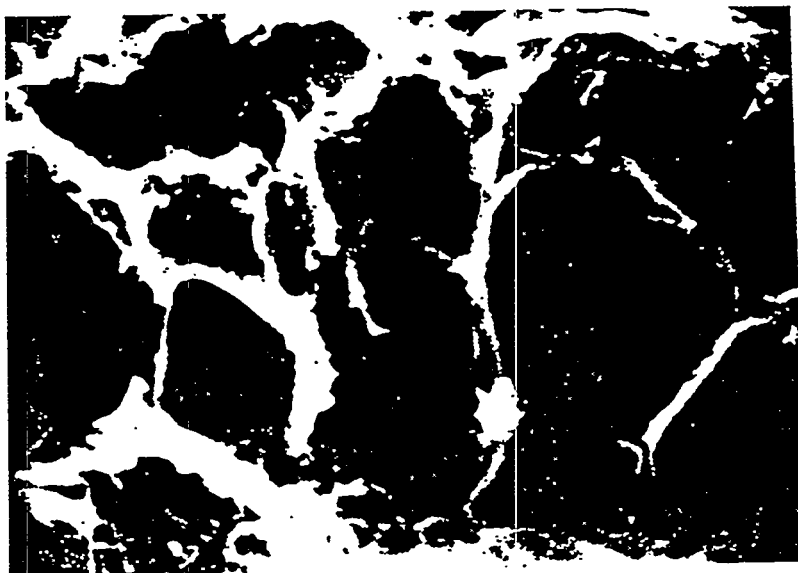
The curves "deformation - stress" for the samples of highly porous beryllium under uniaxial compression. Plot 1 corresponds to density 0.2 g/cm^3 , plot 2 - 0.4 g/cm^3 .



The results for $\sigma_{c,comp}$ are several times more than such of porous beryllium, produced by the sintering method with powders of comparable density. For example, in materials having density of 0.26 g/cm^3 the values of σ_c are 19.8 and 2.2 MPa correspondingly, which means about ten-fold relation. Besides, sintering of the ultra dispersed (UD) powder takes place at temperatures about 250 - 350 C unlike commercial powders that are sintered at temperatures 1000 - 1100 C. The cellular-structure material is then formed, the cell sizes ranging from 0.1 till 40 mcm in dependence on density. The walls between cells are no more than 1 mcm [6].

Fig. 3

Microstructure of porous beryllium ($\rho=0.26 \text{ g/cm}^3$)
x5000



The structural elements of cell walls are not seen because of nanocrystal beryllium structure, which proves the neutron diffractometry results.

We produced also the samples having porosity of 5, 10, 30%.

By means of hydrostatic weighing in decane the porosity was shown to be completely open.

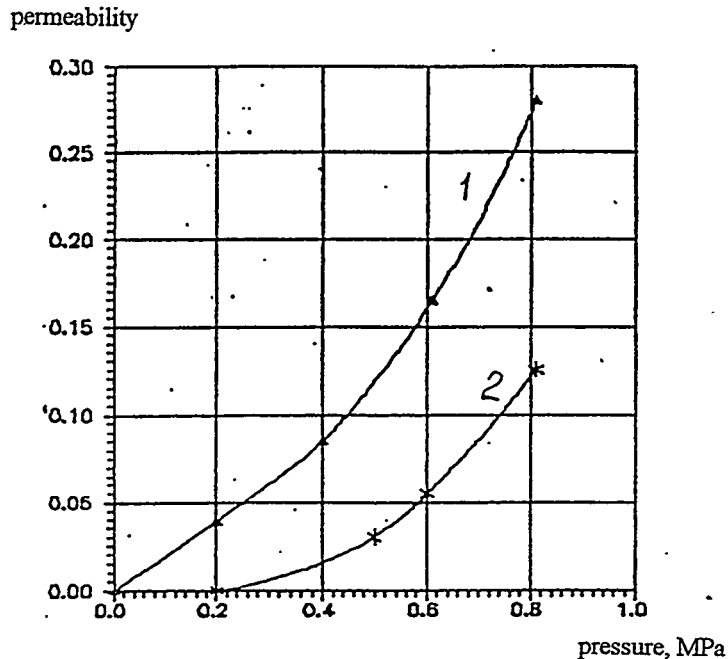
For the sample of 30% porosity the dependence of argon permeability was measured via its pressure both on the dry sample and on the sample wetted in decane (sample square being 1.71 cm^2). The results of visual observation of gas penetrating through the wetted specimen are presented in the table 4.

Table 4
Observation of argon penetration through the wetted sample

Pressure, MPa	0.21	0.23	0.25	0.40
Bubble quantity	2	5	15	Bubbles 2 mm apart
Calculated pore diameter, mcm	0.47	0.44	0.40	0.25

Fig. 4.

Argon permeability in dependence on gas pressure.



It can be seen from Fig. 4 that at 0.8 MPa pressure with corresponding pore diameter of 0.13 μm , the flow through the wetted sample is about 50% of that through the dry sample. This means that about half of the flow passes through the pores of diameters no more than 0.13 μm . Permeability of the material grows with pressure from $1.47 \cdot 10^{-16}$ at 0.2 MPa to $2.35 \cdot 10^{-16}$ at 0.8 MPa.

Through the wetted samples having porosity of 5 and 10 % at 0.8 MPa gas is not allowed. Consequently the maximum pore size can be estimated less than 0.13 μm .

The primary results on solid beryllium are measured.

The samples were done by the iso-static pressing of ultra-dispersed powder at 350-600 C.

The thermal microstresses measured by X-ray technique indicate the value of $\sim 25 \text{ kg/mm}^2$ for all the samples studied. At the same time the microhardness lies within the range 470 up to 710 kg/mm^2 depending on temperature-temporal conditions of compaction.

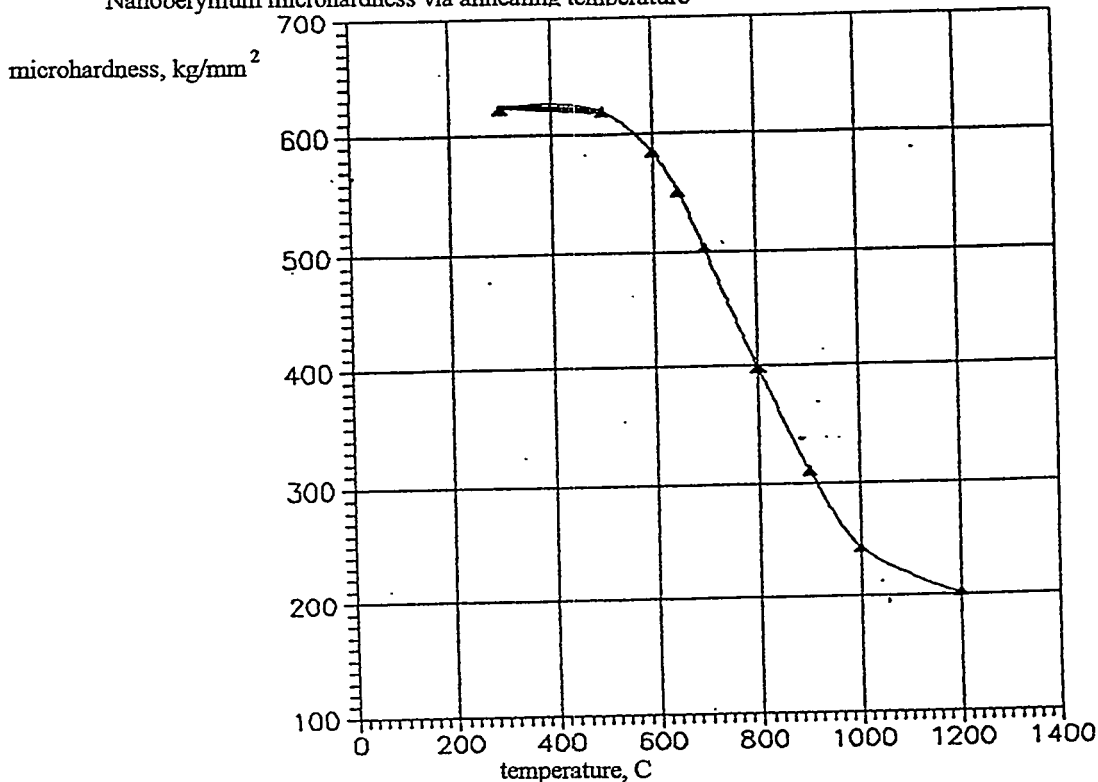
The dependence of microhardness of samples via annealing temperature is studied. Annealing was carried out during four hours. The results are shown in table 5 and Fig. 5.

Table 5
Microhardness of beryllium samples after four-hour annealing

T, C	Microhardness, kg/mm^2
300	622
500	620
600	585
650	552
700	504
800	398
900	335
1000	243
1200	198

Fig. 5

Nanoberyllium microhardness via annealing temperature



So the drop of microhardness begins at the temperatures higher than 500 °C, in the same region a slight crystal growth occurs. The samples after annealing at 1000 °C had crystal sizes less than 1 μm.

Thus the preliminary investigations of nanoberyllium properties demonstrate their difference from the properties of traditional beryllium materials. The data obtained encourage to use micro-crystalline, and especially low-porous beryllium for microcapsule fabrication.

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2. Vladimirov V.I. Physics of Metal Destruction. Moscow: Metallurgiya, 1984. (in Russian)
3. Petrunin V.F., Marchenko S.V., Kostylev F.A., Gorlevskiy V.V., Senin M.D. Neutron diffractometry of the ultra dispersed beryllium. Russian journal "Non-Organic Materials", v.20, n.1, 1984, pp. 60-62. (in Russian)
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6. Kostylev F.A., Gorlevskiy V.V., Senin M.D. Production and properties of highly porous beryllium having microcellular structure. Russian journal "Non-Organic Materials", v.31, n.4, 1995, pp.479-482. (in Russian)



Hydrogen Transport Through Be/Pd Systems*

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Materials Science and Technology contract number W7405-ENG36



Abstract

We are currently investigating novel approaches of filling Be shells for the ICF and HEDP programs. One method involves placing a small Pd plug in the shell. Pd transports hydrogen very well at elevated temperatures but does not transport it at low temperatures. Therefore, a Be shell with Pd could be filled at high temperatures and the load would not leak out once the temperature is reduced. The first step of this approach is to determine the permeation properties of Be with a Pd plug. Be discs 240 μm thick were fabricated with a 1 mm hole. These holes were then filled with Pd metal. The discs had no leaks at room temperature or at 300°C. The testing was conducted at 300°C and at a maximum pressure of 40 psig of H_2 . The disc was placed in front of a mass spectrometer to obtain a flow rate. The spectrometer response was standardized with a calibrated leak. The estimated flow rate through this Pd plug was 0.15 sccm @300°C and 40 psig. This rate should double if a Pd/Ag plug is used. It will also increase as the thickness of the plug decreases. Higher flows can also be obtained at higher temperatures and pressures. To find the rate under other pressure conditions we can use $Q = J(P_f^{0.5} - P_p^{0.5})/L$. Other transport studies were conducted on layered Pd/Be systems. These results will also be presented.

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There are at least two processes that are important in hydrogen transport.

- (1) Hydrogen adsorption and dissociation



- (2) Diffusion into and through the bulk



If (1) dominates, flow is a linear function of the pressure differential.

If (2) dominates, flow is a linear function of the differential of the square root of pressure.

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For the Pd plugs, the H_2 flow rate through the membrane is governed by Sievert's Law.

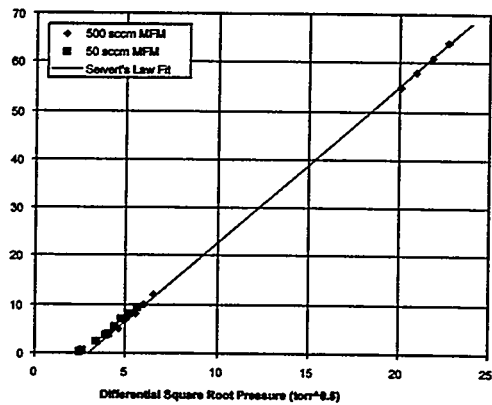
$$Q_{\text{H}_2} = \left(\frac{J}{l} \right) \cdot \left(\sqrt{P_f} - \sqrt{P_p} \right) \cdot A$$

Q_{H_2} : Flow rate	(cm ³ /min)
J: Permeability	(cm ² /(min torr ^{0.5}))
l: Membrane Thickness	(cm)
P_f : Feed Pressure	(torr)
P_p : Permeate Pressure	(torr)
A: Membrane Area	(cm ²)

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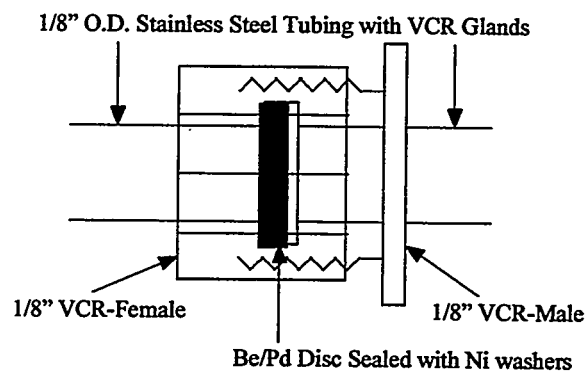
Under most pressures, H_2 transport through Pd follows Sievert's Law



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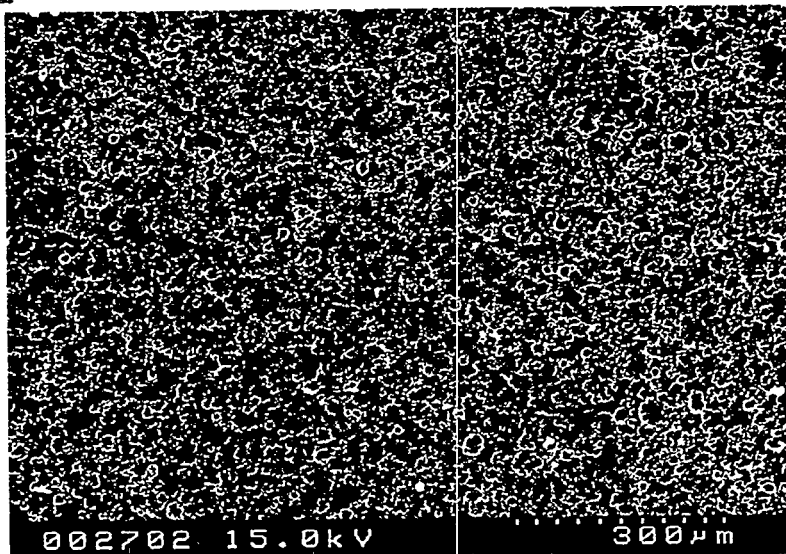
The membrane seal is made by a VCR fitting.



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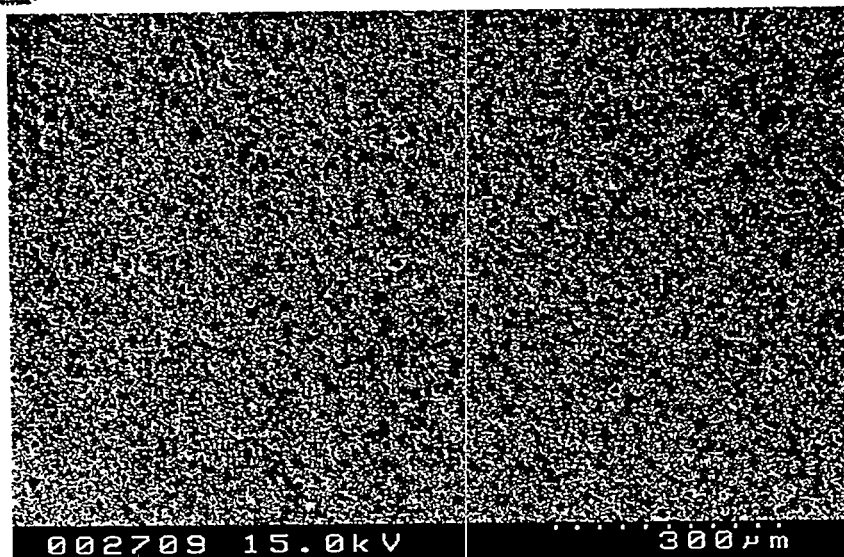
Low magnification of uncoated Be surface



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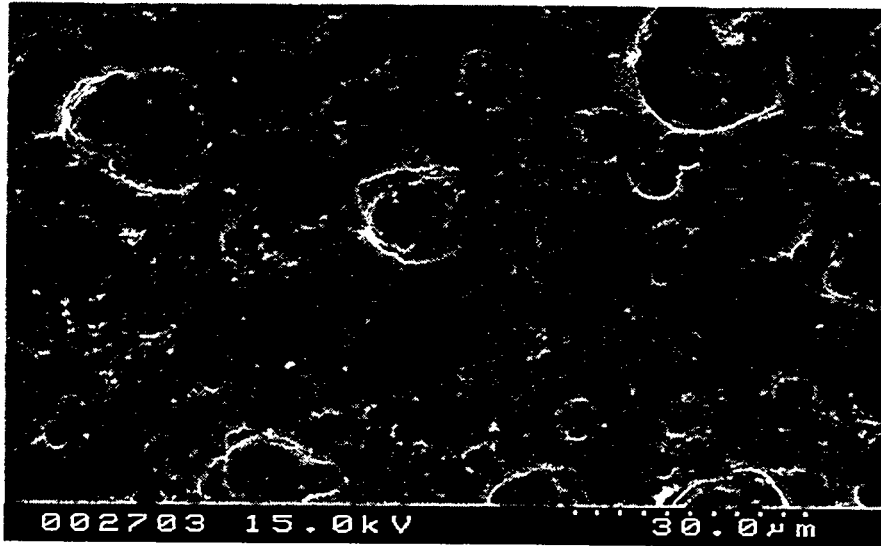
Low magnification of Pd coated Be surface



Materials Science and Technology



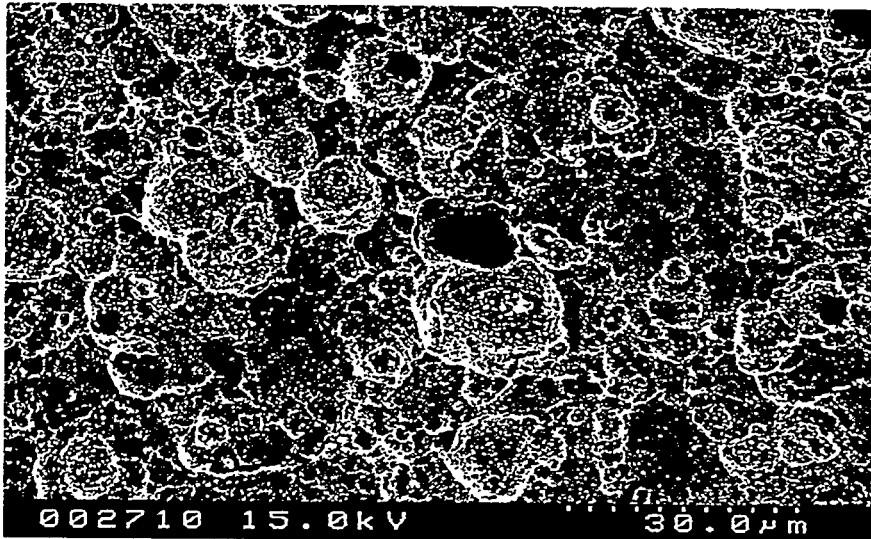
Medium magnification of uncoated Be surface



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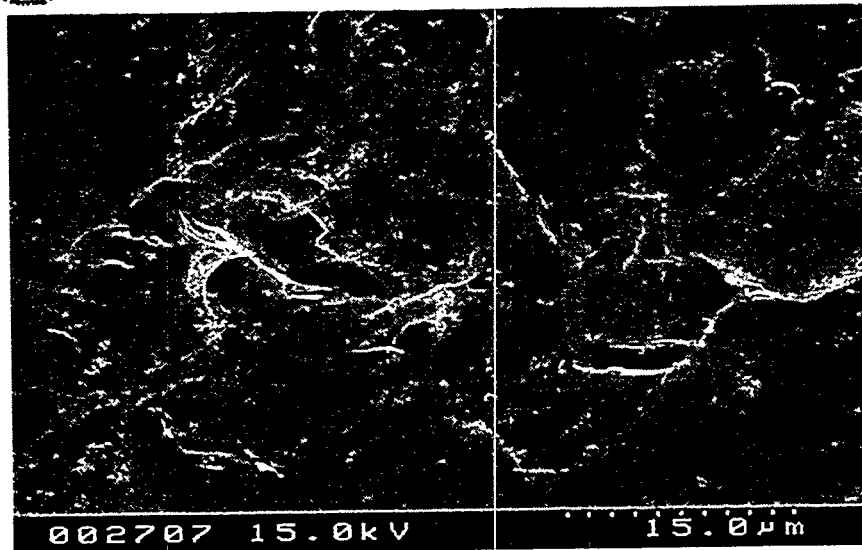
Medium magnification of Pd coated Be surface



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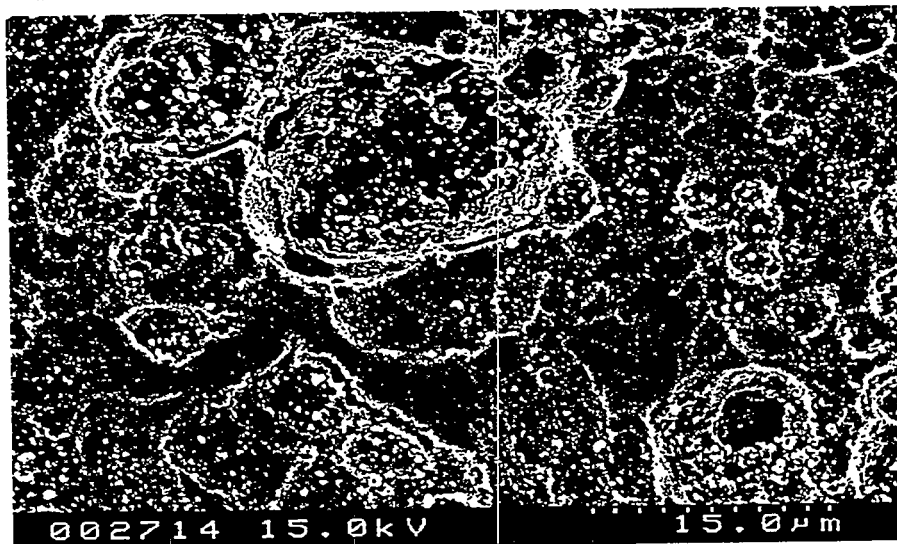
High magnification of uncoated Be surface



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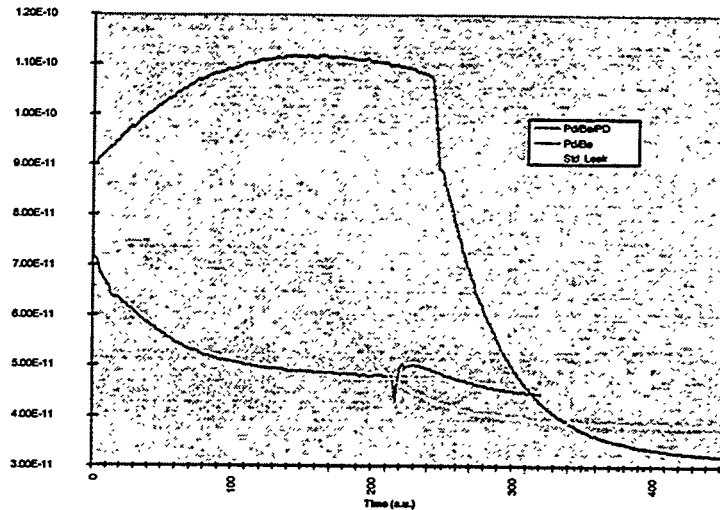
High magnification of Pd coated Be surface



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Hydrogen Flow Through Be



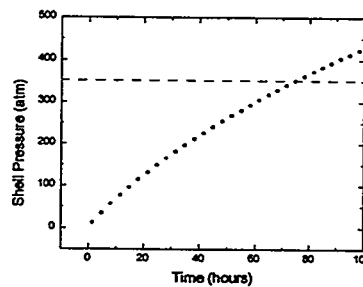
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We calculated fill times for NIF capsules based on our data

- For a Pd plug 10 μm in diameter with a 1000 atm exterior pressure of DT, the fill times are about 80 h for a NIF ignition capsule (see graph)
- For a Be shell coated with Pd inside and out, the fill times are much quicker, ~ 3 h ($T = 200$ C)

Shell Pressure versus time for a 10 μm Pd plug



Fill conditions:

$P_{\text{ext}} = 1000$ Atm; $T = 300$ C

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Conclusions

1. Be discs with Pd plugs follow Sievert's Law for flow rates.
2. Be with the top layer coated with Pd shows no measurable flows.
3. Be coated on both sides showed a flow rate of 0.069 sccm/cm^2 @ 20 psig and 200° C .
4. Further work is needed on temperature and pressure parameters.
5. Studies are needed on flow rates through polymer layers.

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FABRICATION AND TRITIUM ANALYSIS OF TRITIUM SUBSTITUTED GDP TARGETS*

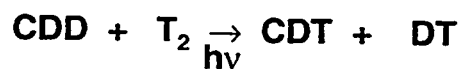
**Target Fabrication Specialists Meeting
April, 1998**

**A. Nobile and J.W. Hughes
Tritium Science and Engineering Group
Los Alamos National Laboratory, Los Alamos, N.M.**

Los Alamos

**Capability is being developed to synthesize and
analyze tritium-substituted plastic targets to serve
as surrogate cryogenic targets for OMEGA**

- **Tritium in plastic can be substituted for deuterium by UV irradiation in the presence of tritium gas:**



- **Capabilities for synthesizing tritium substituted targets has been installed, and initial testing started**
- **Goal is to produce targets with close to 50/50 DT in the polymer molecule**

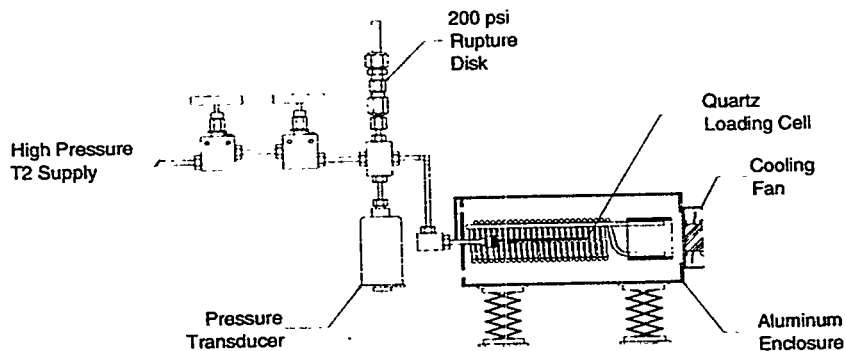
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Experimental details

- **Target tritium exposure:**
 - Targets are contained in a quartz cell capable of safely containing tritium at pressures of 200 psia or lower
 - Quartz cell is positioned within a coiled mercury vapor lamp that surrounds the quartz cell in a cylindrical manner
 - Purified high pressure tritium is supplied to and held in the quartz cell during UV irradiation of targets
- **Analysis of tritium in targets**
 - Individual targets are placed on a platinum foil and burned in flowing air
 - Air flowing over target is bubbled through ethylene glycol to dissolve water vapor from target combustion
 - Ethylene glycol is scintillation counted to determine tritium concentration
 - Tritium concentration in the glycol is used to calculate tritium content of the target

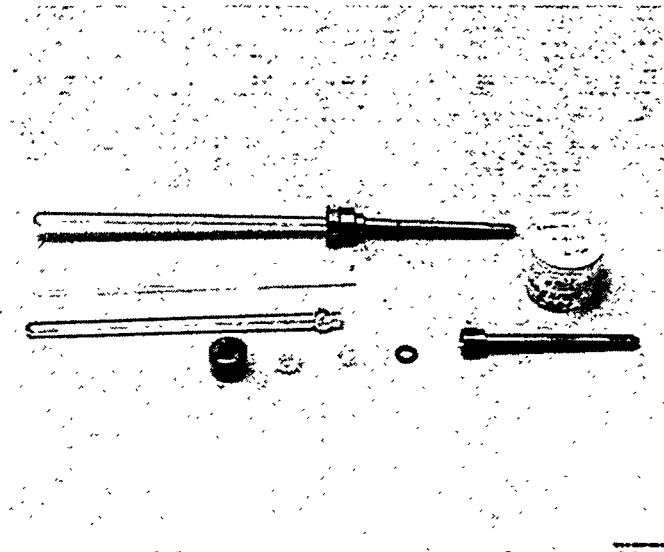
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Arrangement of the target loading apparatus



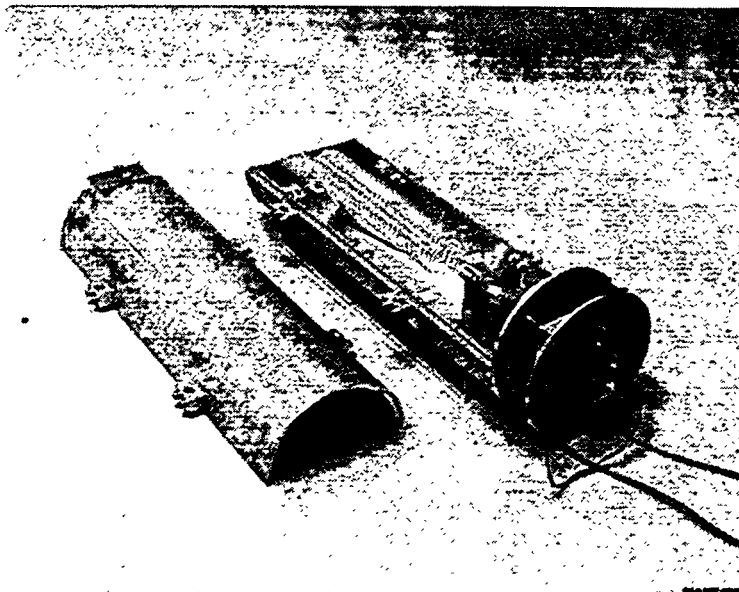
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Arrangement of quartz loading cell



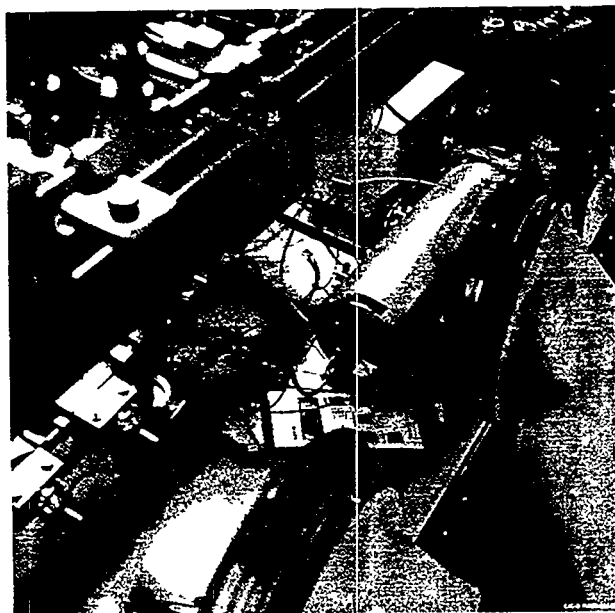
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Apparatus internal components



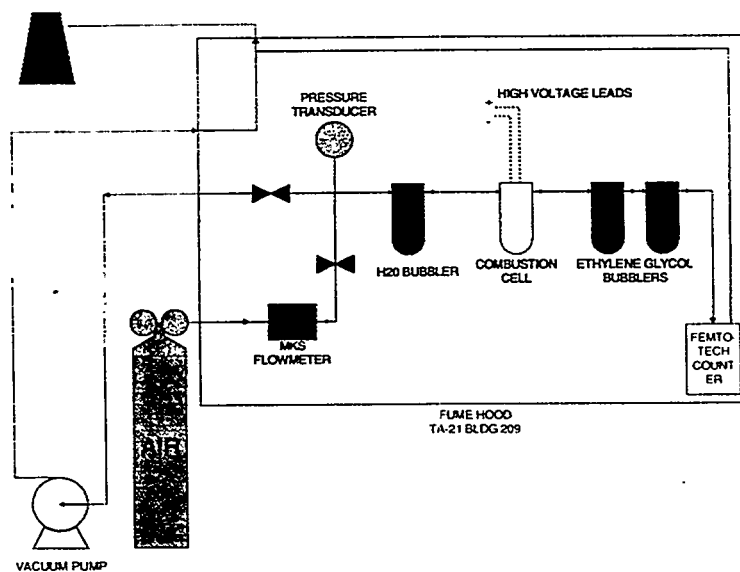
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Apparatus in the glovebox



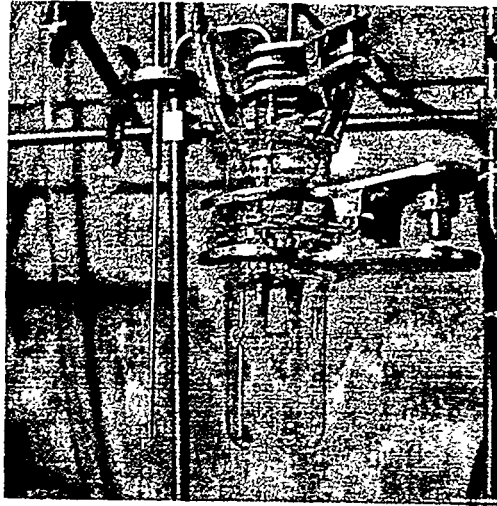
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Targets are analyzed by combustion in air followed by scintillation counting of collected water



Los Alamos

Combustion Cell



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Results from preliminary experiments

- Initial experiments were performed where targets were UV irradiated in the presence of 1% tritium in deuterium
 - Target exposure conditions:
 - 1% T_2 in D_2
 - Pressure = 40 psia
 - UV intensity = 8-10 mW/cm² at 254 nm
 - Exposure time = 48 h
 - Resulting tritium uptake in the targets only reached 0.5% of theoretical equilibrium
 - Lamp intensity was decreasing as a function of time during the run
 - Discoloration of targets was noticed after UV irradiation
-

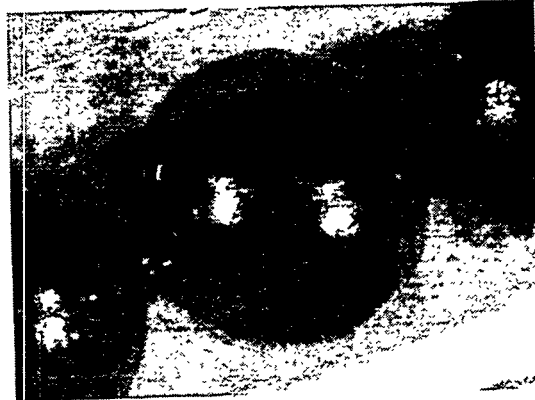
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Targets before and after UV irradiation

Before Irradiation



After Irradiation



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DIRECT DRIVE LASER FUSION: TARGET DESIGNS AND TARGET REQUIREMENTS

Presented by
J.D. Sethian
Naval Research Laboratory, Washington, DC.

People who did the work:

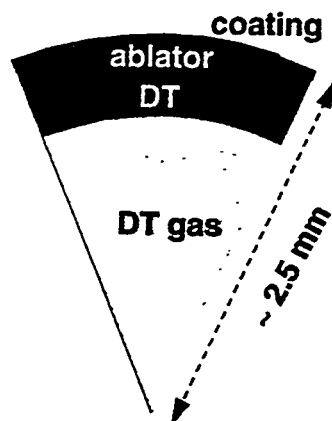
S.E. Bodner, D.G. Colombant, R.H. Lehmberg, S.P. Obenschain, and A.J. Schmitt
Plasma Physics Division, Naval Research Laboratory, Washington, DC.

J.H. Gardner and L.S. Phillips
Laboratory for Computational Physics, Naval Research Laboratory, Washington DC

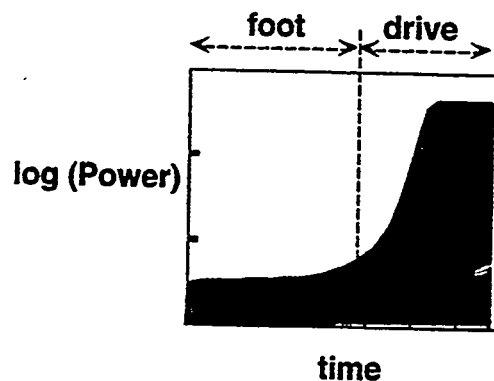
“Direct-drive” laser fusion uses a very simple geometry and laser pulse shape.

NRL

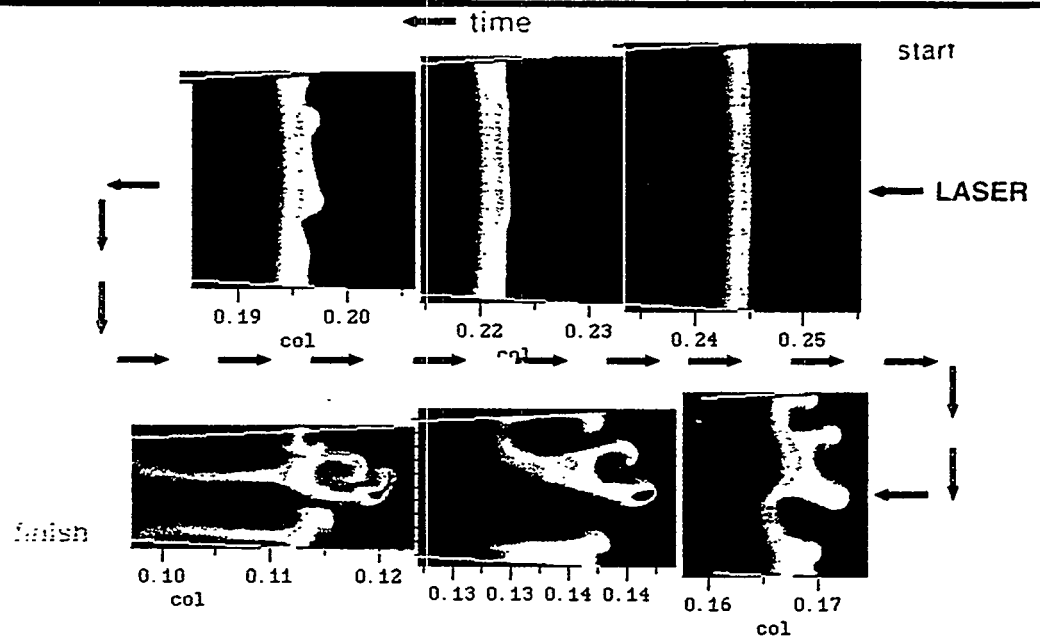
PELLET



LASER PULSE

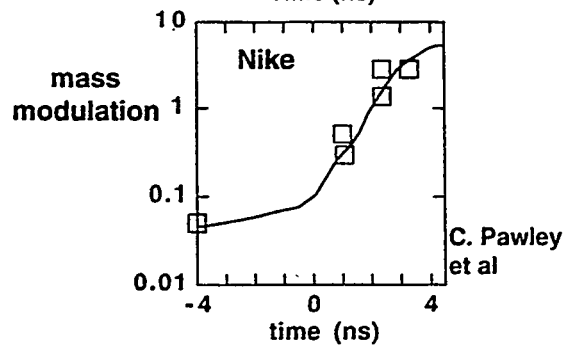
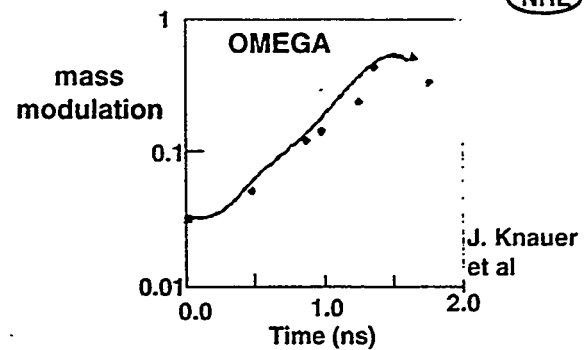
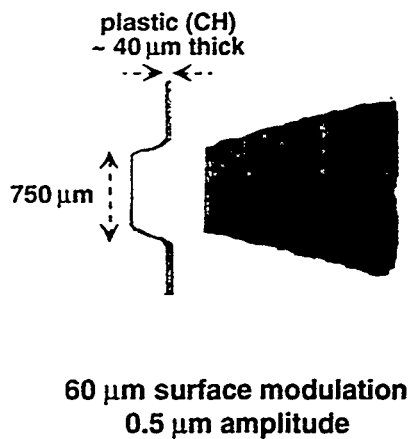


Example of a pellet design with excessive hydrodynamic instabilities.



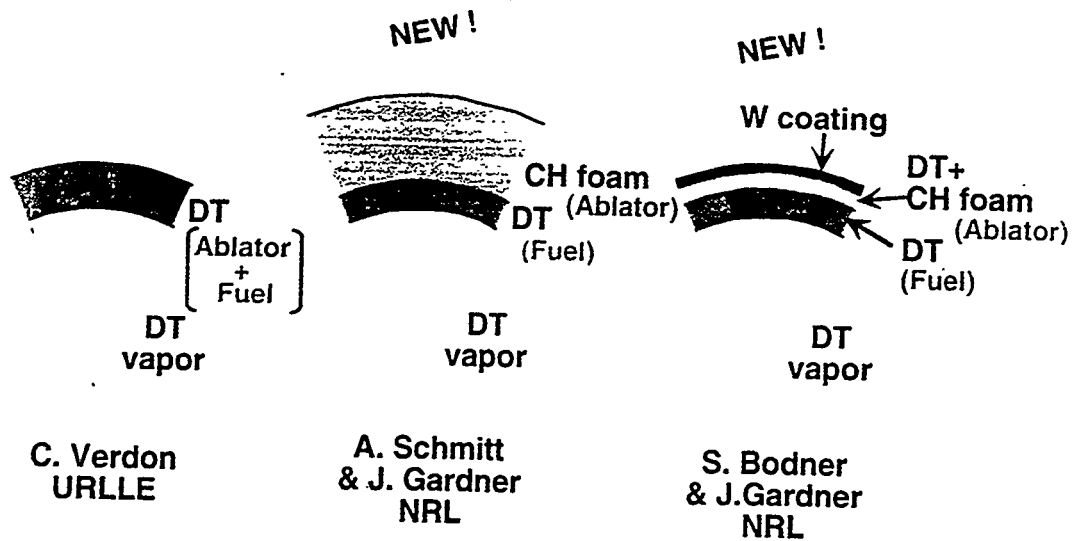
Experiments with optically-smoothed laser beams on Nike & OMEGA have evaluated RT growth.

NRL



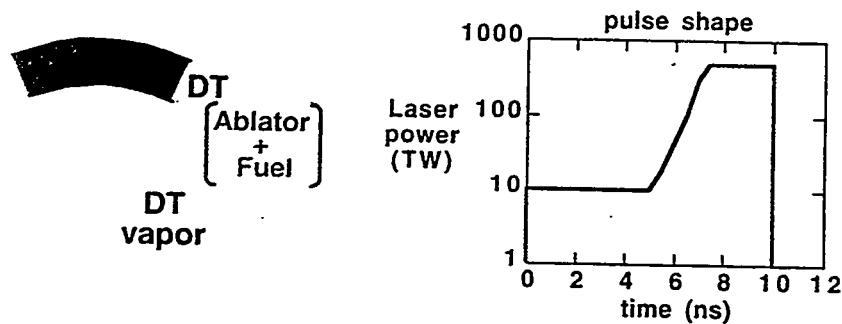
There are now three direct-drive target concepts that may produce ignition & high gain.

NRL



1. DT ablator; shock preheating (C. Verdon, URLLE, 1994)

NRL



Raising laser intensity in foot of laser pulse increases strength of first shock, raising DT isentrope.

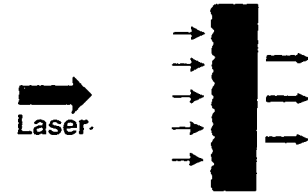
Advantages: DT ablator has highest rocket efficiency. No RT interface instability between fuel & ablator.

Disadvantage: Fuel isentrope also raised, limiting potential gain to below 100.

Higher gains may be possible if the ablator can be heated while keeping the fuel cold

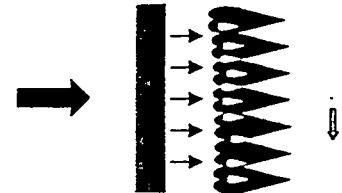
Basic ICF physics:

Preheat target (Higher Isentrope)
Less susceptible to R-T growth, but...
Lower gain due to lower density



t = 0

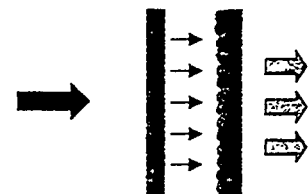
Keep Target Cold (Lower Isentrope)
In attempt to get higher gain, but target is
more susceptible to Rayleigh-Taylor Growth



t = 0

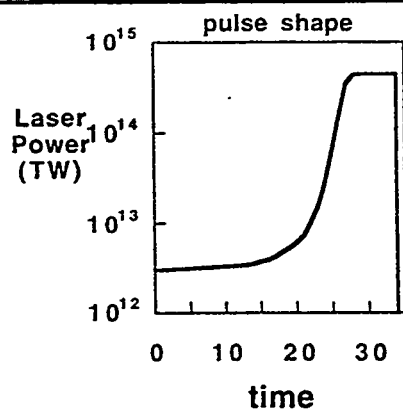
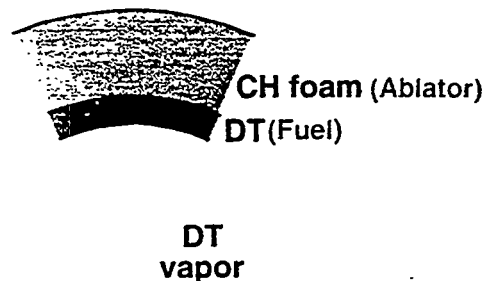
Solution:

Preheat the Ablator (stabilize R-T Growth)
Keep fuel cold (high gain)



t = 0

2. Low-density CH foam ablator; shock preheating (A. Schmitt & J. Gardner, NRL, 1997)



NRL

Low density foam has higher isentrope than DT fuel. Double shock in CH foam minimizes density jump at ablator-fuel interface.

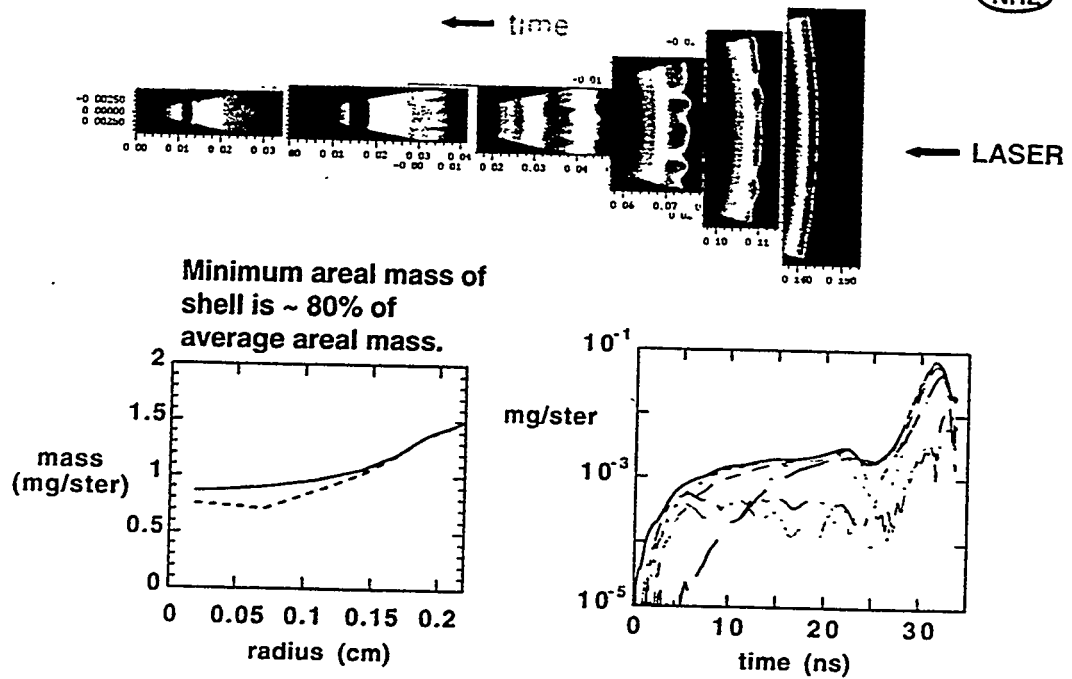
Advantages: • Higher yields may be applicable to fusion reactor.

Design now has gain ~ 80. Gains above 100 possible with optimization.

Disadvantages: Possible classical RT instability at ablator-fuel interface. Foam fabrication does not currently meet requirements.

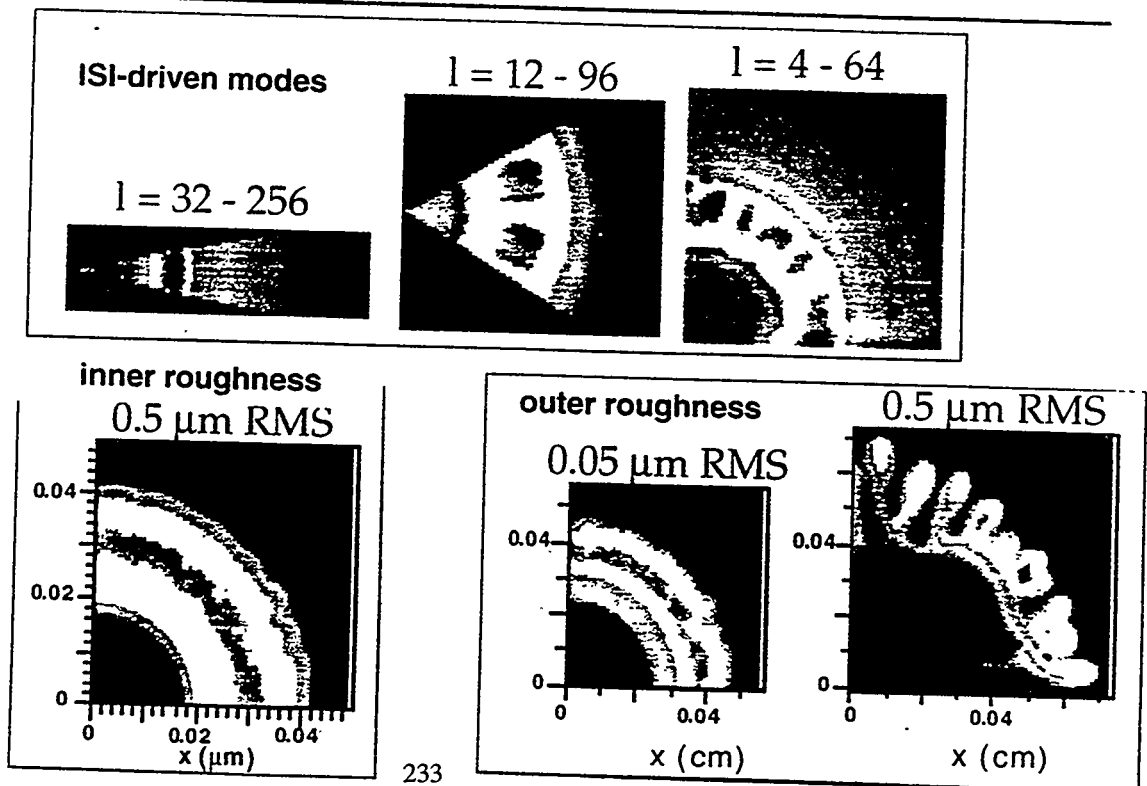
Multi-mode implosion simulations show acceptable laser imprinting & RT growth with ISI.

NRL



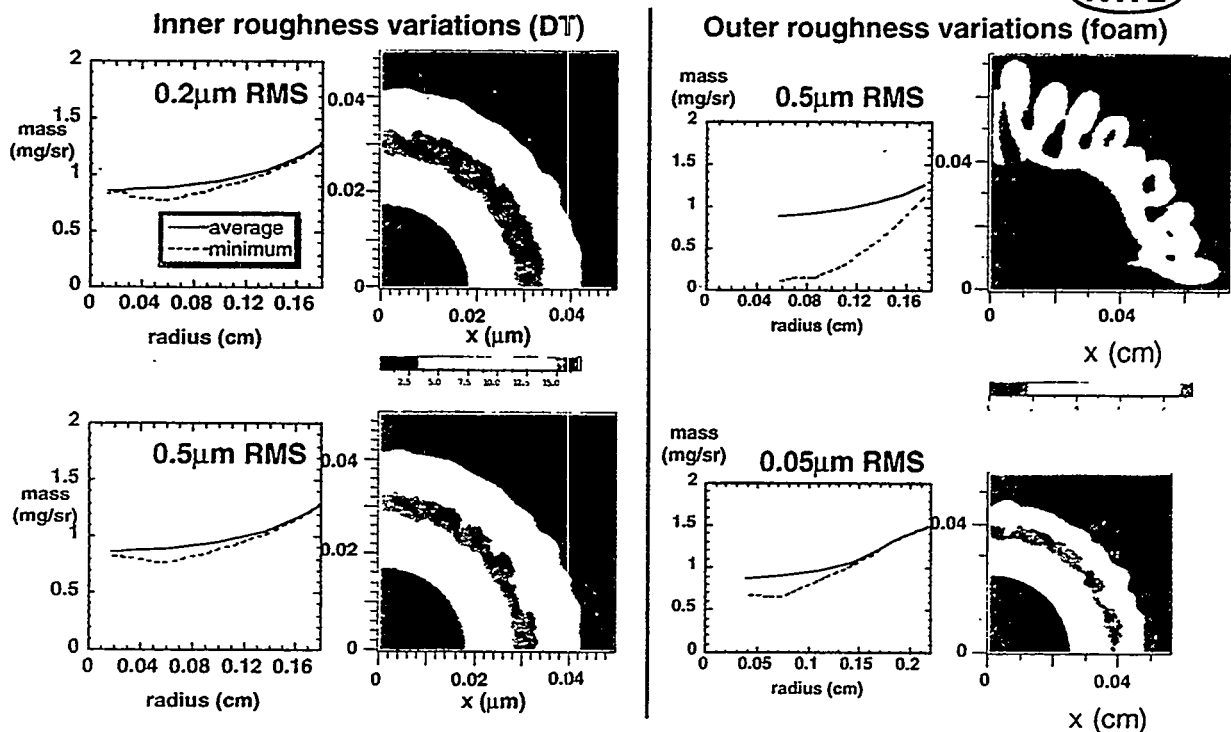
figs. from J. Gardner

Direct-drive integrated calculations indicate that empty foam ablator leads to successful implosion.



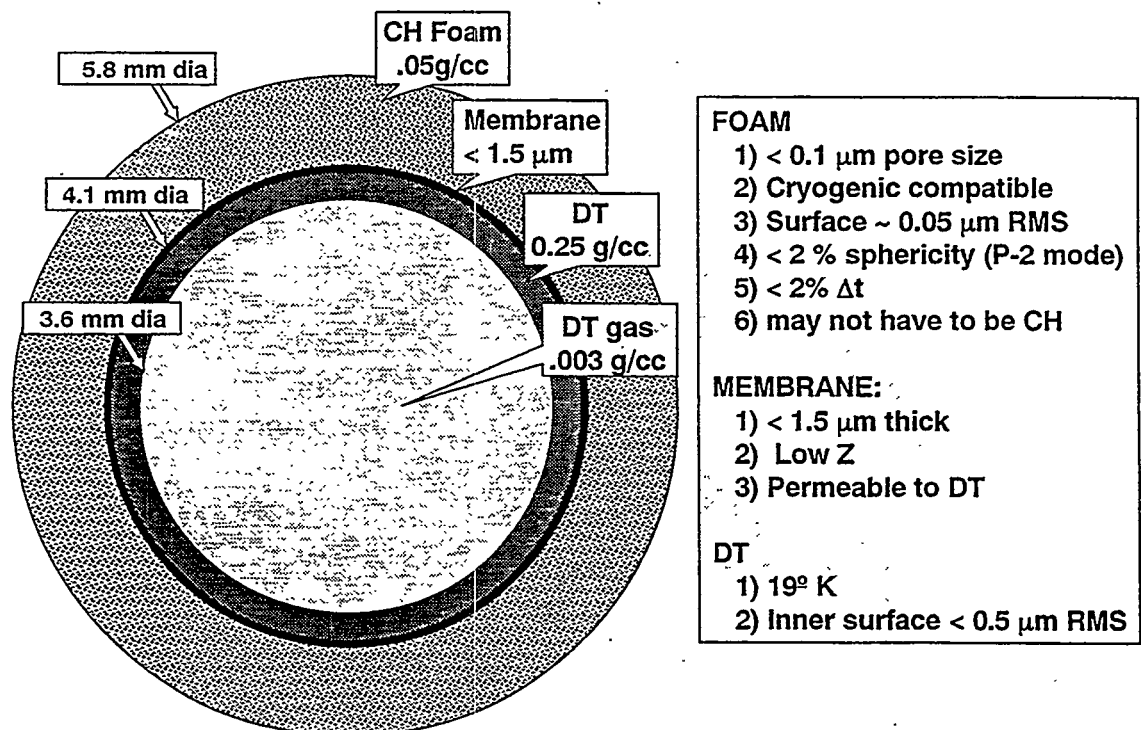
Foam ablator target requires smooth foam outer surface

NRL



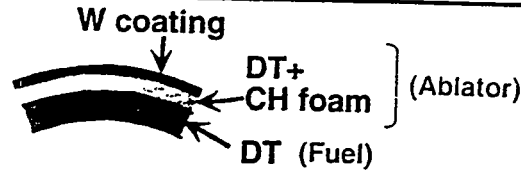
The foam target design is more sensitive to outer than inner surface perturbations

Dimensions and Requirements for Shock-heated Ablator Target



3. CH+DT ablator, W coating; radiation preheat (S. Bodner, J. Gardner, NRL, 1997)

NRL



Tungsten recommended as near-optimum
by A. Bar Shalom & M. Klapisch
(Gold specified by J. Sethian as it is much
easier to fabricate and works just as well)

CH(DT)₁₆ provides low opacity ablator for radiative preheat.

During foot of pulse, tungsten radiates below K-edge of carbon.

Tungsten ablates during foot of pulse, leaving mostly DT for efficient acceleration.

No density jump between ablator and fuel.

Very low adiabat possible for DT fuel.

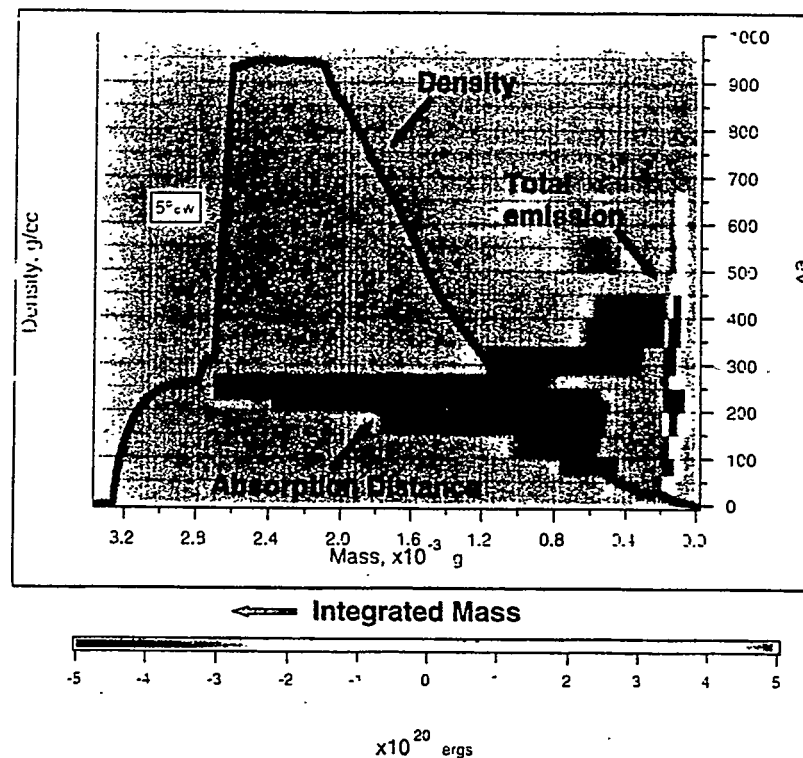
Latest designs give gain of
108 @ 2.8 MJ

Advantages: Potential of gains in excess of 100 needed for fusion reactor

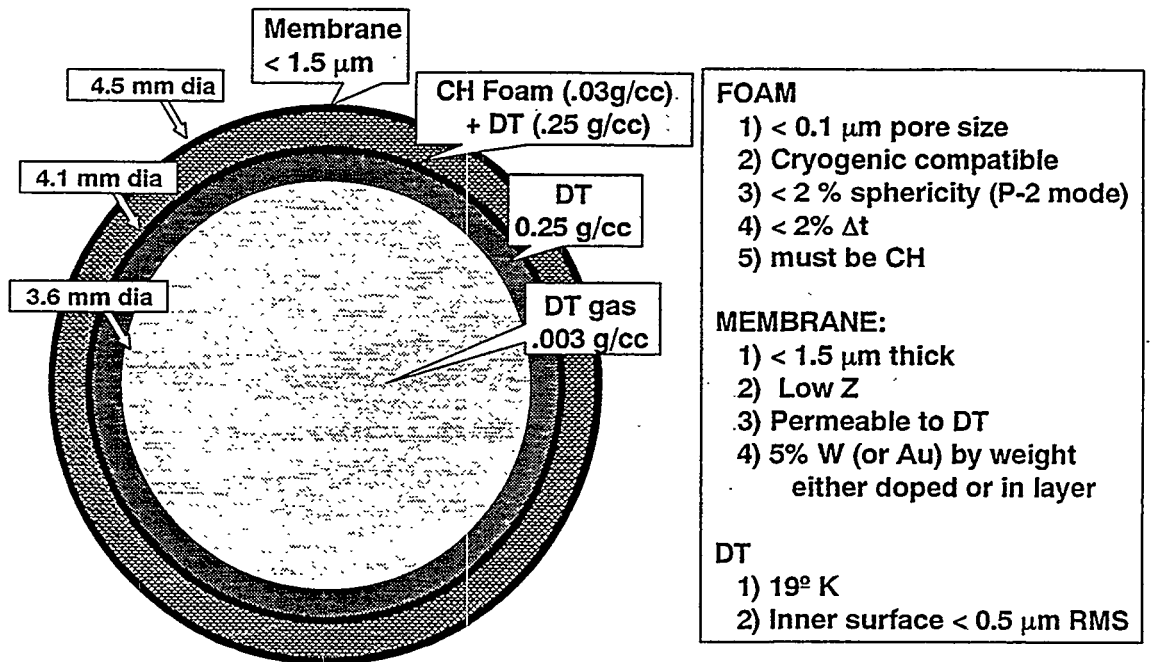
Disadvantages: ? (design still in early stage)

Calculations show Tungsten radiation penetration into CH Foam

Snapshot of target at $t = 3$ nsec



Dimensions and Requirements for Radiation-heated Ablator Target



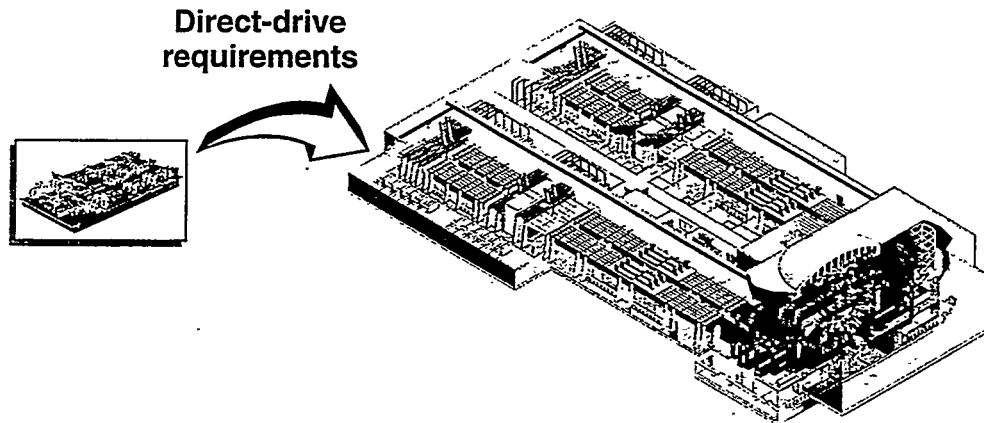
SUMMARY:

We have two promising designs to achieve high gain with direct drive

Both based on principle of heating the ablator while keeping fuel cold

- 1) Shock heated ablator: Gains up to 110,
 - a) Design looks good
 - b) Target fabrication requires smooth foam
 - c) Possibility to go to existing foams (I.e. Aerogels)
 - d) Internal membrane may be an issue
- 2) Radiation Heated Ablator: Gains over 100
 - a) Still have problems with design
 - b) Seems easier to fabricate
 - c) Need pure CH foams

Direct-Drive Capsule Requirements for the National Ignition Facility and OMEGA Laser Systems



The flexibility of solid-state glass lasers allows transfer of information from OMEGA to the NIF.

P. W. McKenty
University of Rochester
Laboratory for Laser Energetics

Target Fabrication Meeting
Jackson Hole, WY
19-23 April 1998

Direct drive is an important requirement for NIF success



Strategy

- Direct-drive cryogenic experiments on OMEGA are necessary
 - to determine the *level* of beam smoothing required on NIF for ignitions,
 - to obtain quantitative mix data for cryogenic fuel imploded on a convergent geometry
- Direct-drive implosions potentially have higher gain on the NIF than indirect-drive (2.5 times).
- Direct-drive provides a second path to demonstrate ignition on the NIF.

Summary

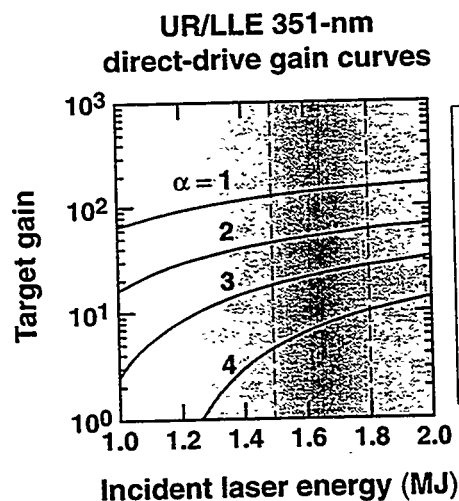
The LLE direct-drive program will determine the laser and capsule requirements for achieving ignition and gain using direct drive on the NIF



- Rayleigh-Taylor instability
 - control/reduction of linear growth rates
 - understanding of saturation and weakly nonlinear regime
- Laser-irradiation smoothing techniques
 - reduction of “laser imprinting”
 - reduction of laser-plasma instabilities
- Power/energy balance $\leq$ few % rms
- High-precision, moderate-contrast-ratio pulse shaping
- Cryogenic DT capsules
 - finish requirements for all surfaces
 - layer uniformity
 - layer homogeneity

TC3979a

Direct drive offers the potential of higher gains (~2–3 times) on the NIF than indirect drive



Hydrodynamic and laser-plasma instability constraints will determine the performance of NIF ICF capsule implosions.

Instabilities

Direct drive	Hydrodynamic	Laser-plasma
Indirect drive	Hydrodynamic	Laser-plasma

Sources of Implosion Nonuniformities

Heuristically, there are four sources of perturbations a direct-drive capsule must tolerate to ignite and burn



$$\left(\frac{\sigma_{\text{rms drive symmetry}}}{\text{Max allowed value drive symmetry}} \right)^2 + \left(\frac{\sigma_{\text{rms laser imprinting}}}{\text{Max allowed value laser imprinting}} \right)^2$$

$$+ \left(\frac{\sigma_{\text{rms DT ice}}}{\text{Max allowed value DT ice}} \right)^2 + \left(\frac{\sigma_{\text{rms outside capsule finish}}}{\text{Max allowed value outside capsule finish}} \right)^2 < 1$$

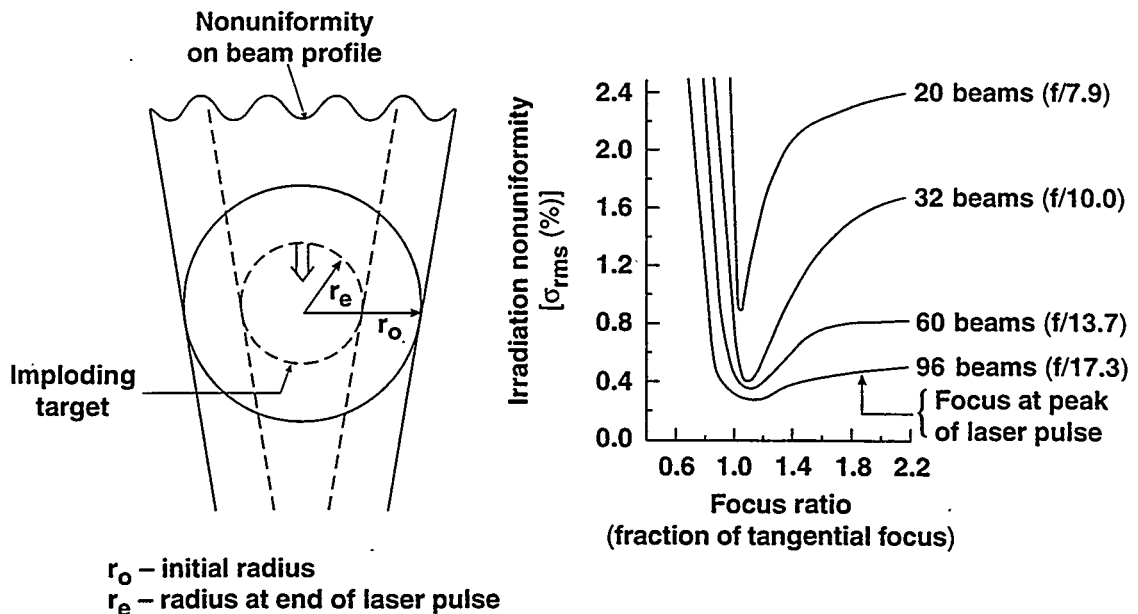
- Laser-irradiation-related issues
- Target-fabrication-related issues

Detailed numerical simulations show that these sources are not truly independent and, therefore, must be carefully balanced/controlled.

TC4113d

Drive Symmetry

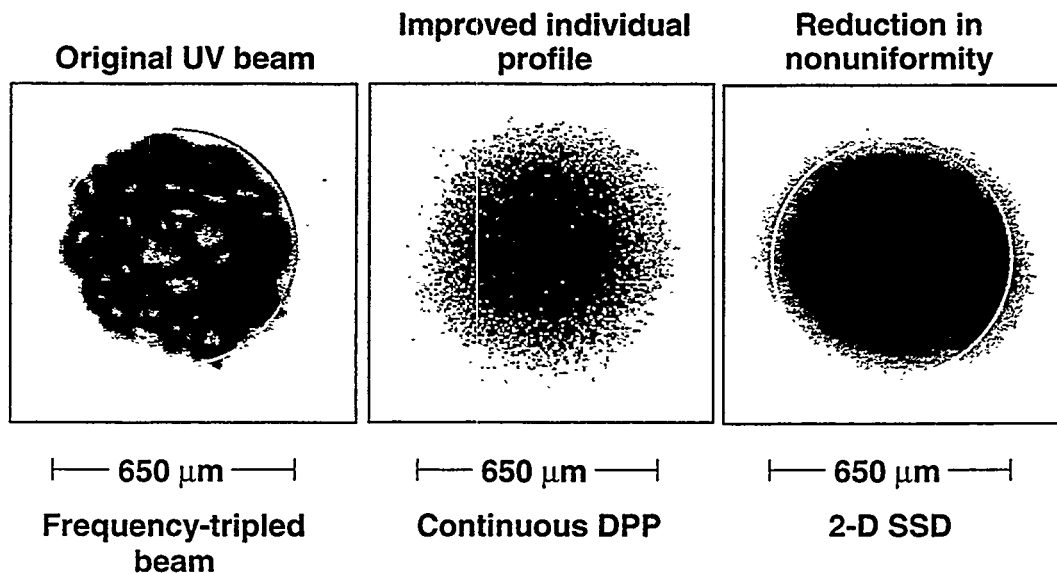
A sufficient number of beams provide adequate long-wavelength uniformity throughout the implosion



Laser Imprint

Improvements in irradiation uniformity can be broken into two steps:

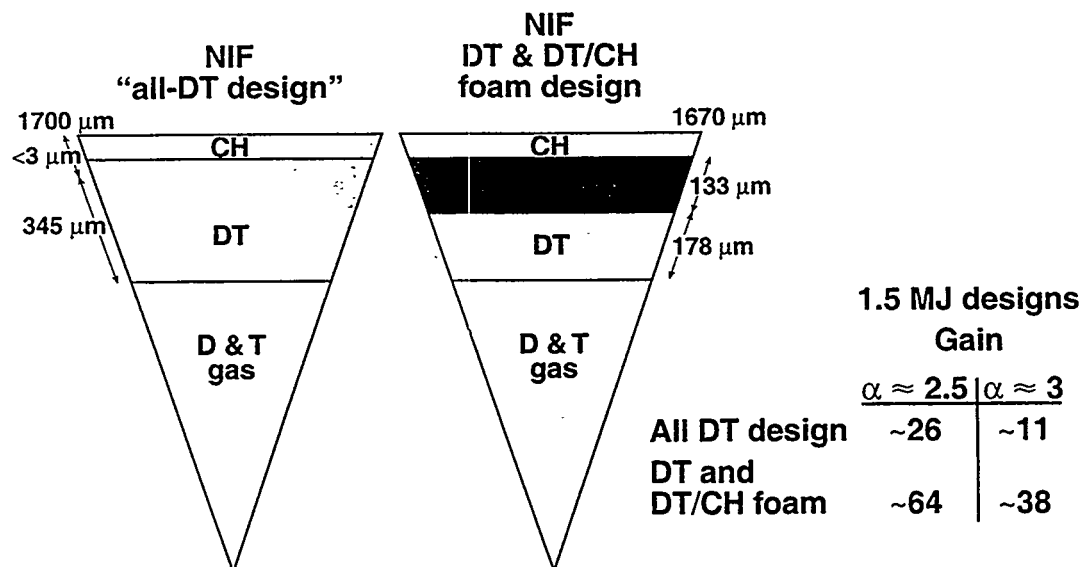
1. improved individual beam profile
2. reduction in individual beam nonuniformity



E7846f

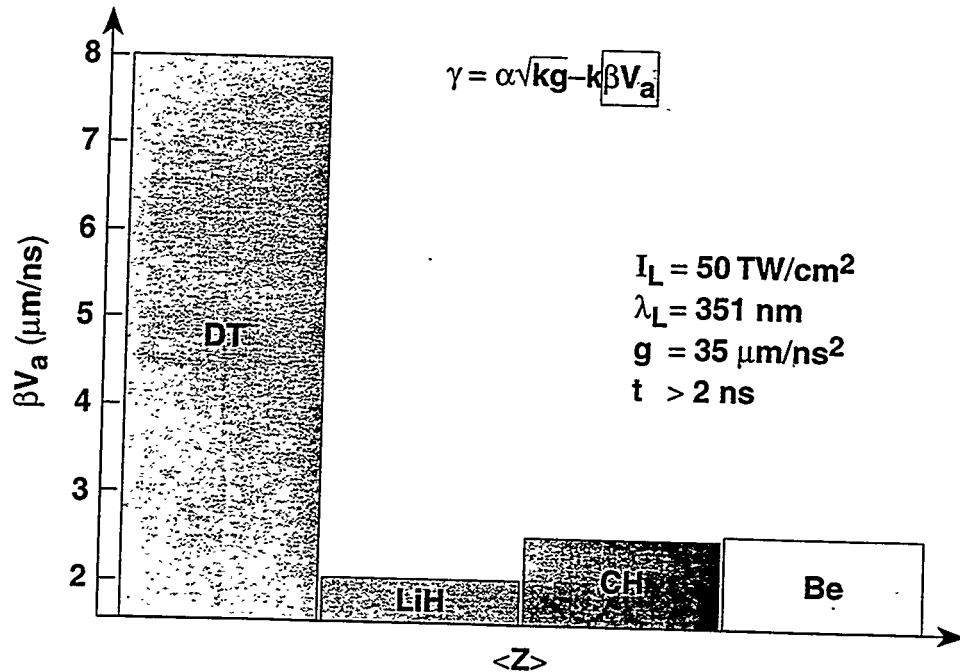
Advanced Capsule Design

DT/CH foam targets have improved laser absorption efficiency resulting in higher capsule performance at a given laser energy



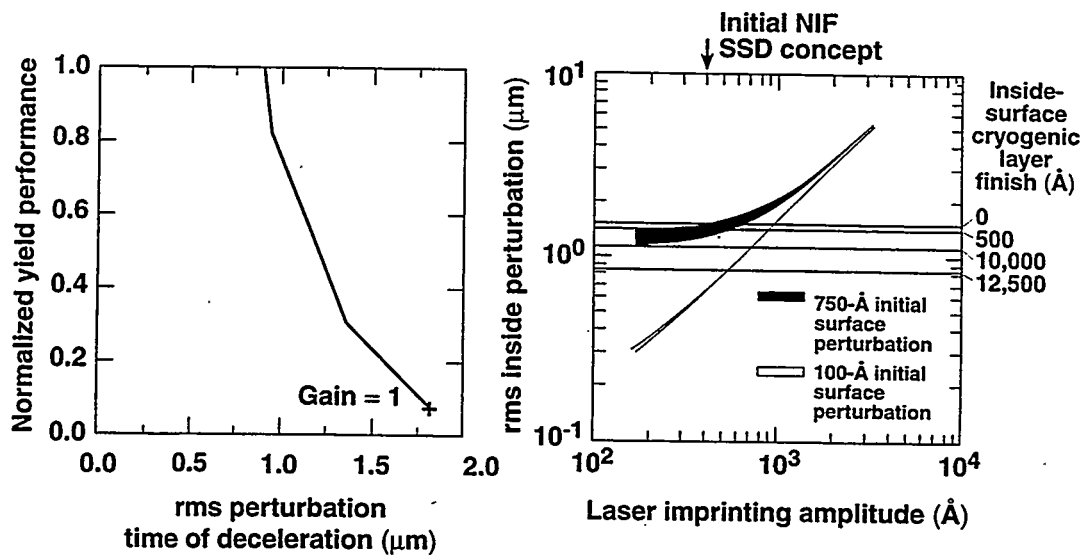
- Hydrodynamic stability is similar for both designs however issues related to foam "perturbations" need to be addressed. The OMEGA cryogenic program will examine this issue.

For relevant direct-drive ablator materials DT shows the highest growth-rate mitigation



TC4408

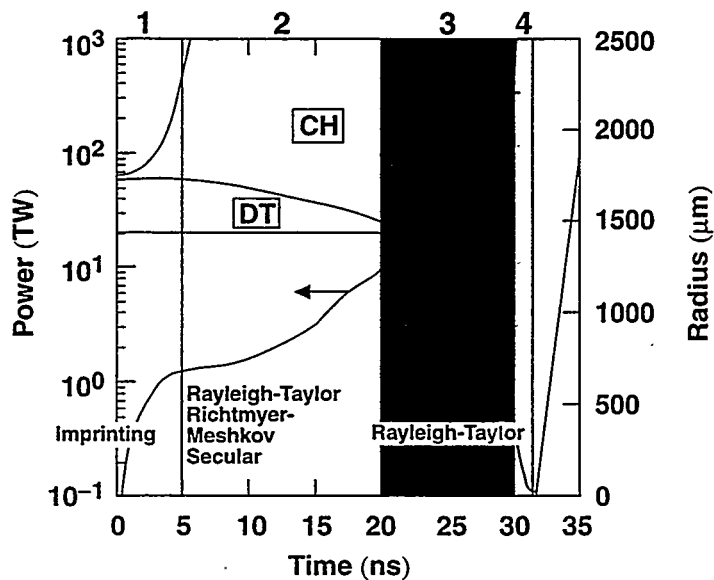
For the 1.5-MJ (DT $\alpha = 3$) capsule design the rms perturbation on the inside surface of the fuel at the time of deceleration must be below $\approx 1.5 \text{ } \mu\text{m}$



TC4326

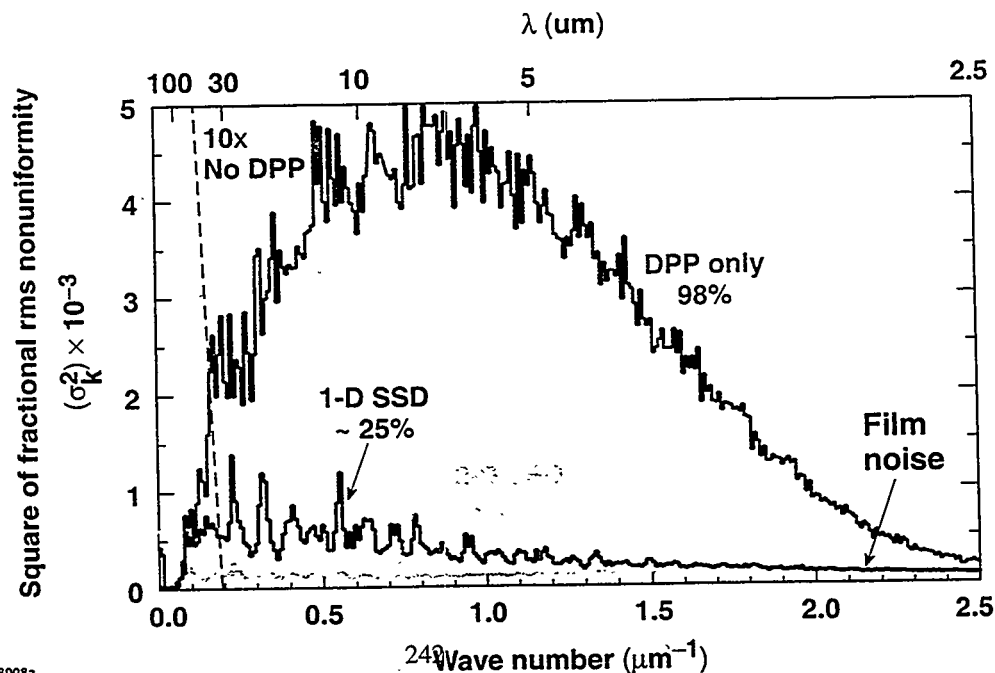
The development of hydrodynamic instabilities during a direct-drive capsule implosion can be broken into four stages

1. Laser-plasma interaction and imprinting
2. Rayleigh-Taylor, Richtmyer-Meshkov, and Secular (t^2)
3. Rayleigh-Taylor
4. Rayleigh-Taylor



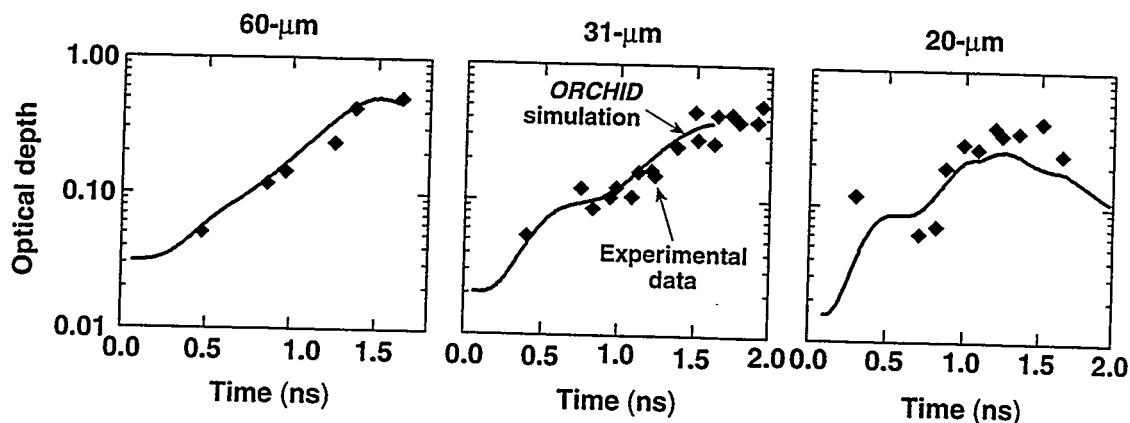
TC3376h

Single-beam nonuniformities are reduced by smoothing by spectral dispersion (SSD)



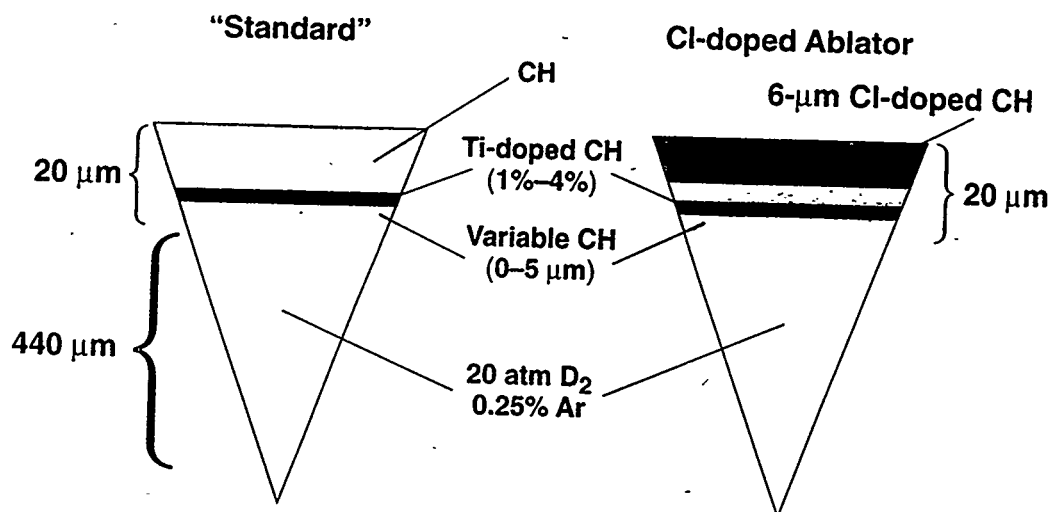
EB008a

Experimentally measured RT amplitudes are in agreement with results from 2-D hydrodynamic simulations



E8736

We are probing the hot-spot and main-fuel-layer regions using a series of Ar and Ti-doped targets



- 30 kJ, 60 beams, 1-ns square, and 1-ns Gaussian
- Both targets have a 1000-Å overcoat as a shinerthrough barrier/gas retention layer.

E8797

LOS ALAMOS OMEGA TARGETS: Direct Drive Cylinders and Tetrahedral Hohltraums

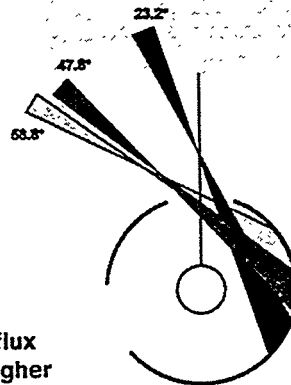
P.L. Gobby, H. Bush, Jr., J. E. Moore, V. G. Gomez, S. Dropinski, K. Gifford, R. Manzanares, G. Rivera, N. E. Elliott, C.W. Barnes, D. Tubbs, T. J. Murphy, and K. Klare.

Los Alamos National Laboratory

Two new targets take advantage of Omega's special properties.

- **Tetrahedral hohltraums** use all 60 Omega beams, where Nova style cylindrical hohltraums cannot. A more symmetrical radiation drive is expected.
- **Direct drive cylinders** use Omega's smooth beams for hydrodynamic instability studies. Cylinders are inherently easier to diagnose than are spheres.
- Work supported by the U.S. Department of Energy under contract number W7405-ENG36.

"tetrahedral hohlraums" are spherical hohlraums with a tetrahedral arrangement of laser entrance holes



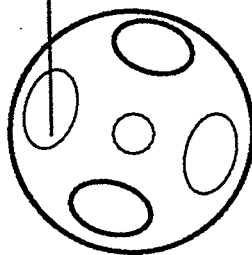
Ideally, Y_{32} is the lowest-order mode in the flux asymmetry, and a hohlraum smooths higher orders better

There is no P_2 in this geometry

Scale-1 tetrahedral hohlraum:
300 μm diameter; same surface area as
scale-1 Nova hohlraum

Phillion & Pollaine, Phys.
Plasmas 1, 2963 (1994).

tetrahedral hohlraum campaign has already motivated
3-D visualization tools and simulation methods

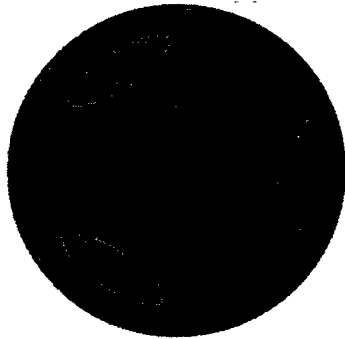


Beam pointing dictated
by geometry:

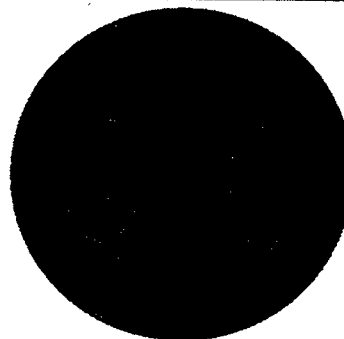
- Don't hit the LEH
- Don't pass through another LEH
- Don't hit the capsule
- Keep the intensity near desired levels

Three-dimensional design was required to allow a
tetrahedral hohlraum to be designed.

Mounting of the capsule requires the hohlraum to be split at the equator. We considered two ways of doing this.



Los Alamos

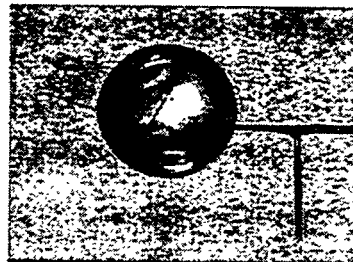


Our Choice

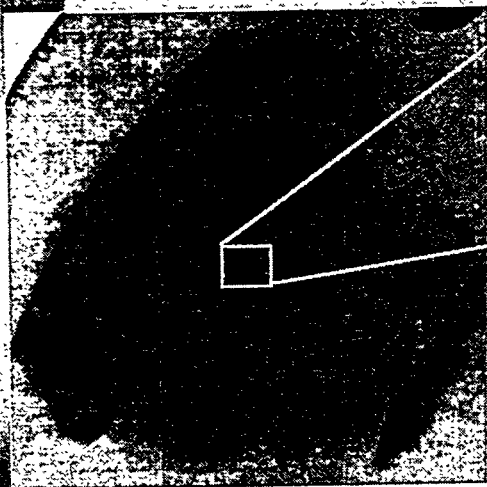
Equator is in the plane of the slide.

Guaranteeing that all 60 Omega beams are "on target" is a challenge.

- LEH's are not an inherent part of the mandrel.
- Hohlraum halves distort when removed from the mandrel.
- Assembly station precision is about 20 microns.
- Tetrahedral hohlraum is not mounted "square" in the Omega target chamber.
- Resulting final LEH positions were in error by as much as 50 microns.



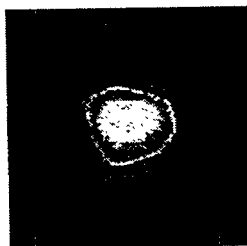
In the first campaign, tetrahedral hohlraums yielded angular implosion images



- 1 ns sq
- 30 kJ
- Standard capsule
- Scale-1 tetrahedral hohlraum

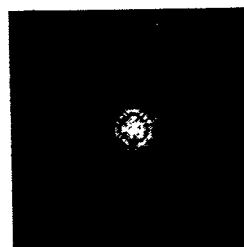
In the second tetrahedral campaign, larger hohlraums, smaller LEHs, and a different pulse yielded round implosions.

March 1997



Scale-1
900 μm diam LEHs
1 ns square
Analysis of data implies 3.6% rms flux asymmetry in Y_3^2

August 1997



Scale-1.2
700 μm diam LEHs
PS 22
Analysis of data implies 1% rms flux asymmetry in Y_3^2

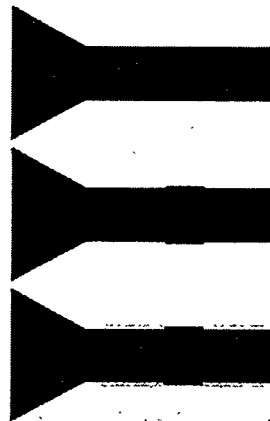
Precision Machining

- Turning operations were conducted on a Moore M-18 with 1 micro-inch resolution.
- A fast tool servo - made for us by PEC at NC State - was used to produce all the azimuthal perturbations on the direct drive cylinder. It served as a "third axis" on the M18.

Los Alamos

Fabrication of the cylinders requires 3 machining and 3 coating steps.

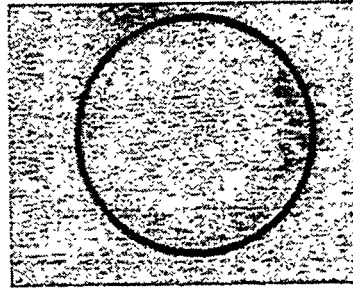
- Turn aluminum mandrel.
- Dip coat with CI-PS, anneal and machine to 4 micron thickness.
- Parylene coat to 1.5 microns.
- Dip coat with PS, anneal, machine final dimensions and anneal again.



Los Alamos

The fabrication procedure resulted in round cylinders with uniform walls.

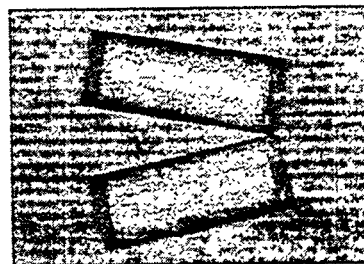
- 900 micron diameter
- 20 micron wall
- Wall uniformity is determined by precision of re-centering, = 0.25 micron.



Los Alamos

Foam filled the interior of the Direct Drive Cylinders

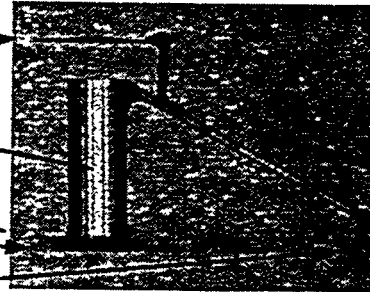
- 60 mg/cc Polystyrene
- 2-3 micron cells
- Backfilled with Brij, machined and leached with methanol.



Los Alamos

Direct Drive Cylinder Target

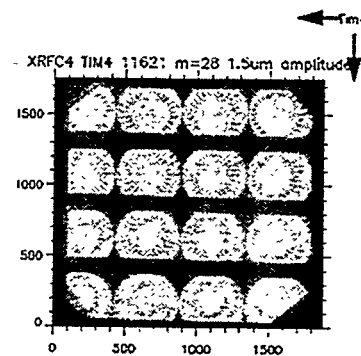
- Titanium/Be Backlighter
- 0.05 micron Al
- XYZ Fiducial
- Pb-CH Shield
- Azimuthal Fiducial



Los Alamos

Outstanding radiographic images obtained of symmetric cylindrical implosions using direct drive on OMEGA

- Images obtained at 1.2X magnification using leaded-plastic aperture of 750 μ m ID (and 1500 μ m OD) and XRFC4 (FXI-like camera).
- Both perturbed ($m=28$, 1.5 μ m initial sinusoidal amplitude) and unperturbed targets shot.
- Axial implosion spike seen at 2.8-3.0nsec.
- 2.5nsec linear ramp pulse provides ~ 1.5 ns of suitable backlighter intensity.
- "Plumes" caused by perturbations along entire length of cylinder



Axial Implosion Spike

UR
LE

Both tetrahedrals and direct drive cylinders are scheduled for this summer at Omega

- Tetrahedrals will focus on high drive symmetry, with the larger 2800 micron hohlraums and 700 micron LEH's. Capsules will include some double shells.
- The direct drive cylinders will smaller perturbations, internal perturbations and deuterated foam. Perturbations will only cover the chlorinated marker layer.

Los Alamos

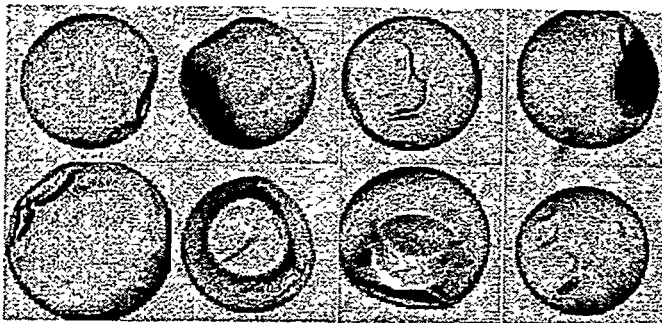
Enlargement of Glass and Plastic Shells to 2 mm in Size

Abbas Nikroo
David Steinman
Annette Greenwood

12th Target Fabrication Specialists' Meeting
April 1998
Jackson Hole, Wyoming



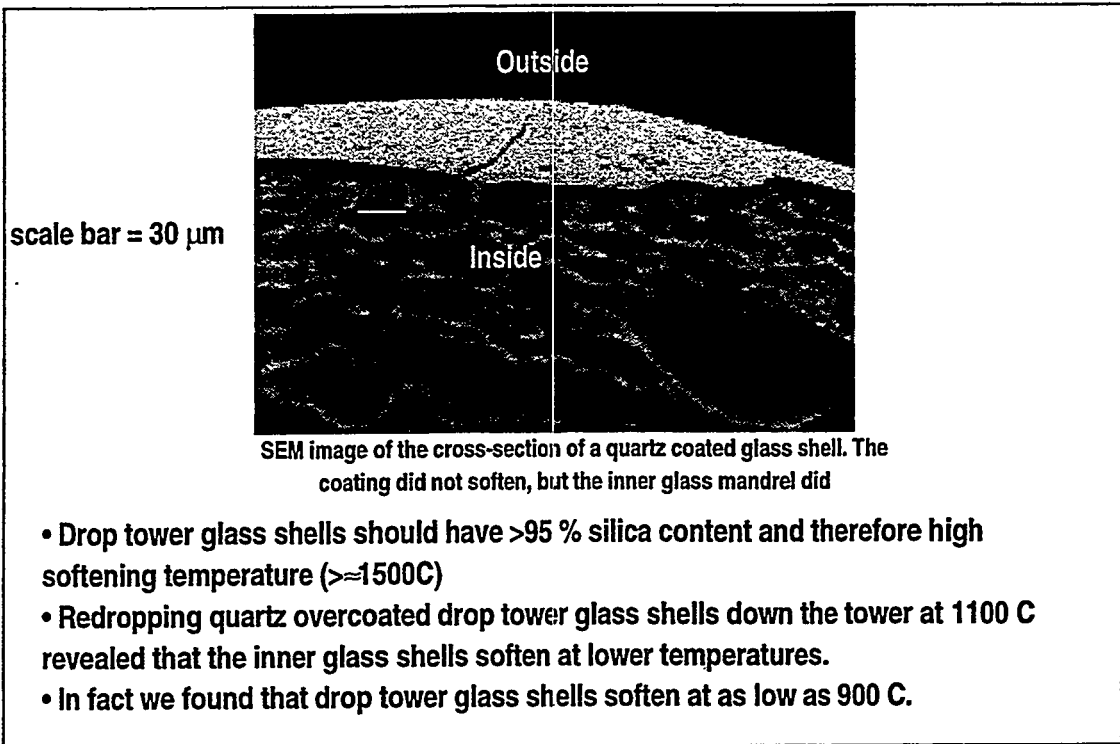
$\geq 1500 \mu\text{m}$ glass shells are needed for NIF cryogenic layering experiments



Most 1300-1500 μm drop tower glass shells are puckered or wrinkled

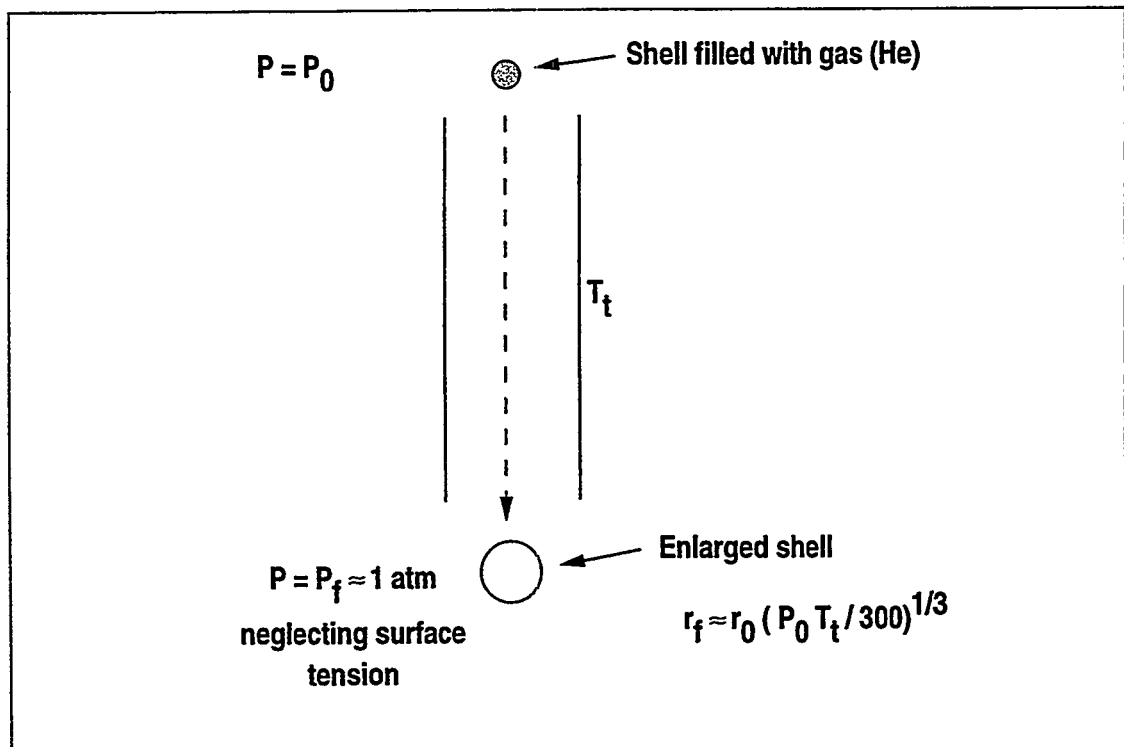
- Large ($\geq 1300 \mu\text{m}$) glass shells produced by the traditional drop tower are mostly puckered or wrinkled. Currently, shells larger than 1500 μm cannot be made by this technique.
- These features are undesirable for layering experiments.
- Therefore, substantial culling of glass shell batches needs to be done to choose acceptable shells in the 1300-1500 range.

Drop tower glass shells soften at <1200 C !!

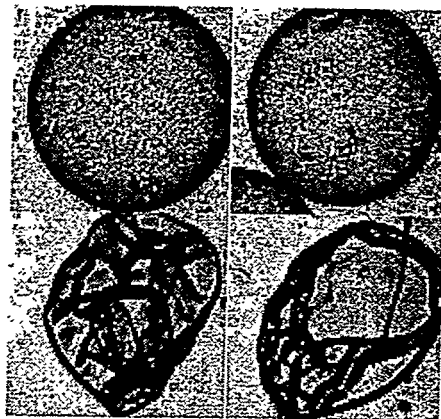


 **GENERAL ATOMICS**

Smaller shells can be enlarged by filling them with gas and redropping them through a hot tower



The 18 foot drop tower was too long for redropping shells



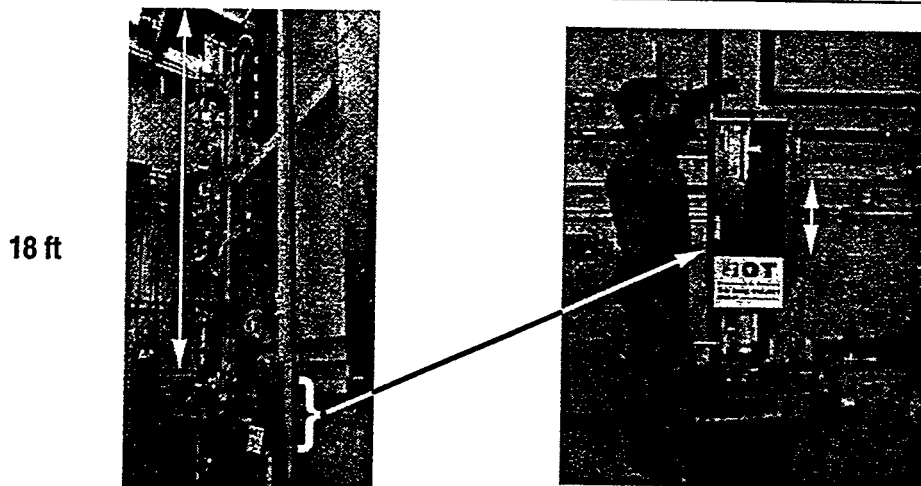
Before drop

After Drop

- Helium leaked out after the shell had enlarged while dropping down the tower.
- A shorter tower was needed or less permeable gas.
- Deuterium still exited the shell faster than the shell could exit the tower.



A short hot zone allows rapid freezing of the expanded shell



18 ft

- A 3 zone furnace stood up on end was used as the short tower.
- Only the center zone (about 1 foot long) was used at 950 C
- Shells were collected in a Petri dish.

Expanding shells are susceptible to bursting and buckling

- Filling the shell with gas places a tensile stress on the shell given by:

$$\sigma = P r / 2 t$$

P = Pressure

r = radius of shell

t = thickness of shell

- As the shell expands, the stress remains the same!

Since : $P \rightarrow P \beta^{-3}$; $r \rightarrow r \beta$ and $t \rightarrow t \beta^{-2}$ with β = expansion factor

- Therefore, if the shell does not burst immediately, it will never burst as it falls through the tower.

- As the shell cools, however, it will experience as high as 1 atm buckle pressure.

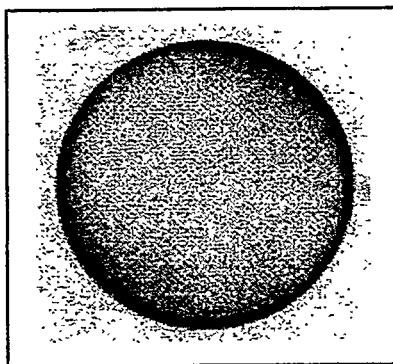
- The aspect ratio of the shell decreases by β^3 , and its buckle strength by β^6 .

- Only shells with a buckle strength of β^6 can survive expansion by β .

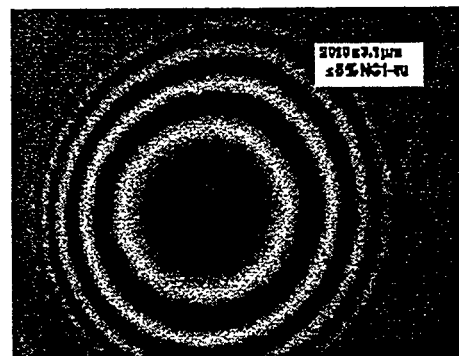
- Therefore, thick walled shells are needed for this technique.



Good > 1500 μm glass shells were made using the redropping technique



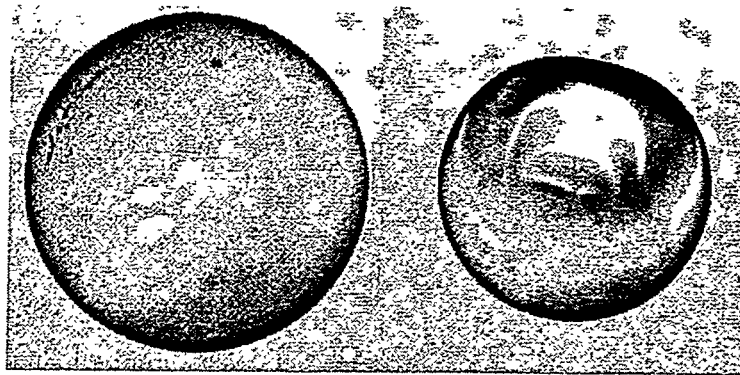
Optical image of a 1740 μm diameter shell



Interferometric image of a 2002 μm shell showing smooth fringe patterns

- The surviving expanded shells were typically >3 μm thick and very fragile.

Glass shells that were originally dimpled could be repaired with this technique as well



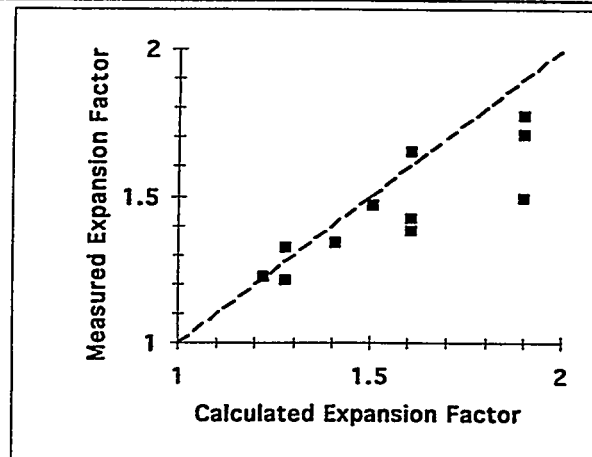
1600 μm diameter shell
After drop

1200 μm diameter shell
Before drop

- The outward gas pressure could undimple and unwrinkle shells while enlarging them



The observed expansion of shells correlated closely with the expected values



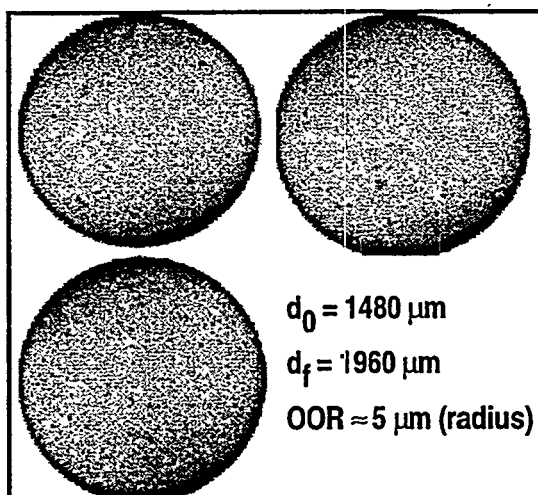
- Surface tension was neglected when calculating the expected expansion of shells.
- At higher expansions (> 1.5) most shells buckled and broke lowering the average diameter of the final group of shells.

Plastic shells could also be expanded by dropping through a heated tower

- 2 mm PAMS shells that survived could not be made by microencapsulation at the time.
- Smaller (1-1.6 mm) PAMS could be made.
- We used the redropping technique to expand these shells to 2 mm .
- A tower heated to 150 to 220 C had to be used depending on the starting PAMS batch
- Nitrogen was used as the fill gas, since He permeates out of plastic too fast.
- For small enlargements, no gas fill was necessary.
- This also allowed us to quickly determine the effect of wall non-uniformity of the starting shells on the roundness of the final shells.



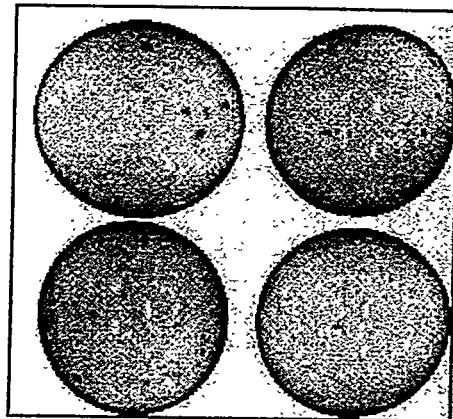
2 mm PAMS shells were made using 1.6 mm shells



Expanded shells

- The starting shells had very good wall uniformity
- The out-of-roundness (OOR) of the final shells was similar to that of the starting shells.

Non-uniform wall thickness of starting shells led to oblate final shells

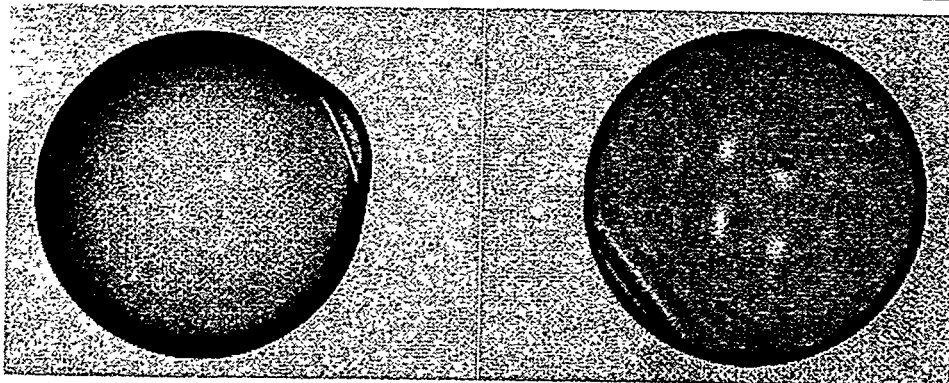


Final oblate shells

1450 μm shells expanded to 2025 μm diameter
The out-of-round increased from 1.7 μm to 46.9 μm



Uniform shells with gross non-sphericity could be made more spherical



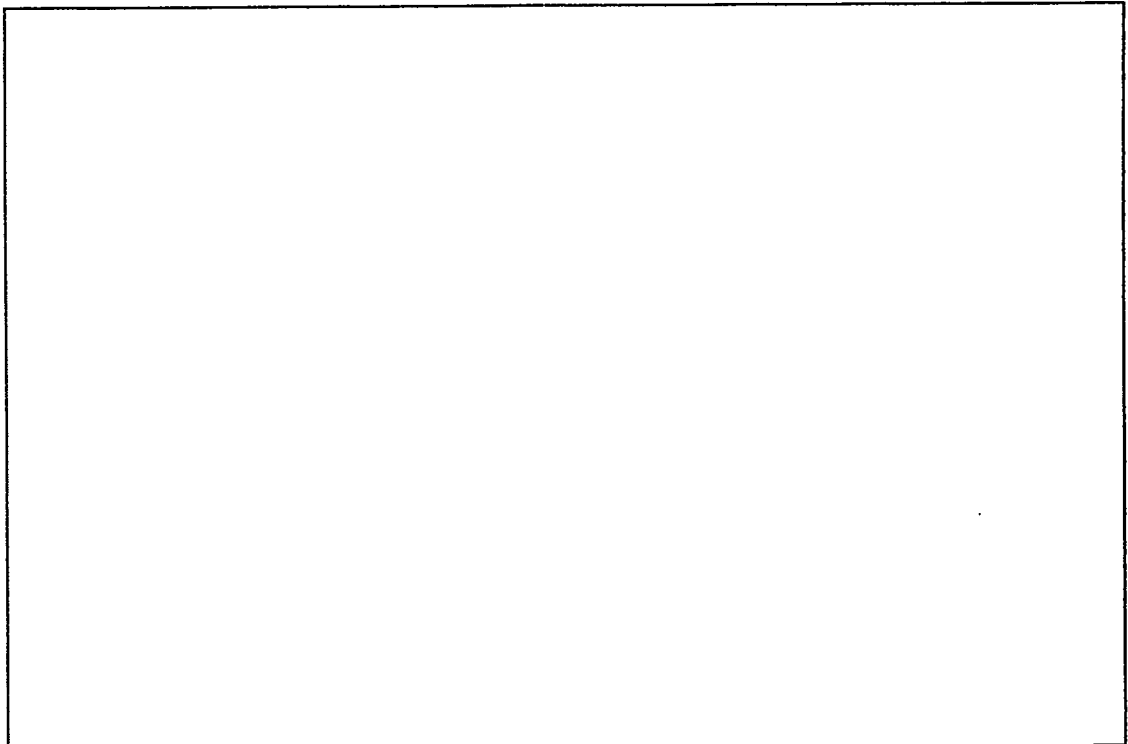
Before

After

- 1 mm shells were intentionally deformed by a soldering iron.
- They were then expanded to 1.2 mm by the redropping technique.
- The gross non-sphericity was repaired, but optically visible "stretch marks" were left behind

Gas filled glass and plastic shells can be enlarged by dropping them through a heated tower

- We were able to make glass shell larger than 1.5 mm by filling them with helium and redropping them down a short zone (1 foot) heated to only 950 C.
- A longer heated zone will result in the collapse of the shells because of loss of gas pressure in the shells by permeation.
- The expanded shells are very much susceptible to buckling because of their lowered aspect ratios.
- Thick, uniform starting shells are needed for this technique.
- This technique can be used on PAMS or GDP shells as well at lower temperatures.



Subsurface Damage in Metals Induced by the Ploughing Component of Precision Machining Processes

Robert D. Day, Rob Dickerson, Carl Maggiore, Paul Brooks,
Robert Springer, Barry Carter, Douglas Hatch
Los Alamos National Laboratory, Los Alamos, NM 87545
Phillip E. Russell
North Carolina State University, Raleigh, NC 27606
Tracy Woodward, Terry Stark
Materials Analytical Services, Raleigh, NC 27606

MOTIVATION

- Ploughing Dominates Energy Partition in Ultraprecision Material Removal Process
- Fabrication Induced Damage may be Significant Fraction of Wall Thickness
- Gain Better Understanding of Ploughing Process and how it Affects Surfaces of Precision Components

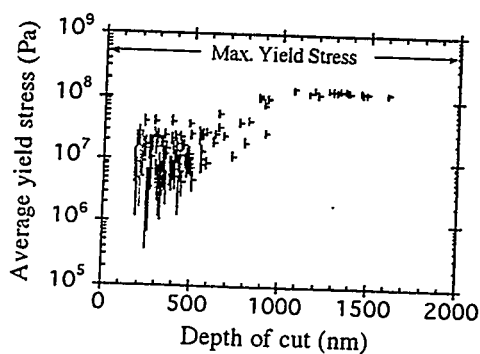
SINGLE CRYSTALS OF GOLD AND IRIDIUM USED AS SAMPLES

- Noble Metals Eliminate Effects Caused by Surface Oxides
- These Two Elements Represent Extremes in Mechanical Properties for FCC Metals
- Known Crystallographic Orientation Enables Crystallographic Effects to be Analyzed
- Insight Gained at Specific Orientations Allows Basic Understanding of Ploughing Process

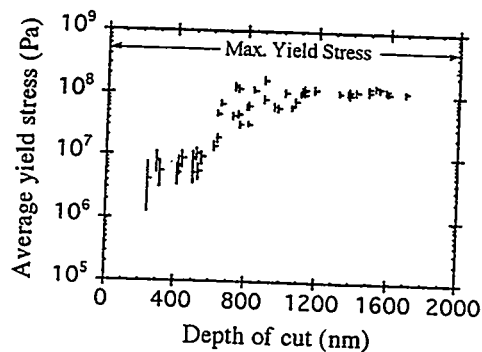
EXPERIMENTAL ARRANGEMENT

- Single Crystal Diamond STM Tip used as Indentor
- Stand-alone STM Controlled Depth and Length of Plough
- Sample Mounted on Microbalance so Vertical Ploughing Force Could be Recorded as the Plough was Generated
- Force Uncertainty was $\pm 1 \mu\text{N}$
- Ploughs were $13 \mu\text{m}$ in Length
- Depth of Ploughs were Measured with SFM

YIELD STRESS VS DEPTH OF GOLD

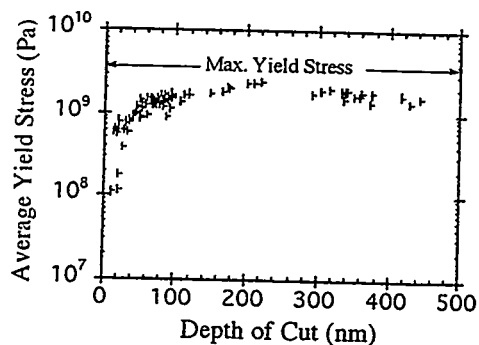


{100} Surface Yield Stress



{111} Surface Yield Stress

YIELD STRESS VS DEPTH OF IRIDIUM {111} SURFACE



SUMMARY OF YIELD STRESS RESULTS

- 20x to 30x Increase in Yield Stress with Increasing Depth for both Materials
- Implication that Average Strain is Increasing as Depth Increases
- Yield Stress Rises Much More Sharply for Iridium than Gold
- Constant Yield Stress Closer to Estimated Maximum Value for Iridium than Gold
- Appears that Iridium Reached a Strain Hardening Limit
- Appears that Gold Reached an Average Strain Limit

CONCLUSIONS

- Strain Hardening in Ploughing Even for Small Volumes
- Strain Hardening Theory Helps Explain Results
- Severe Strain Gradients are Present
- Yield Stress and TEM Data are in Good Agreement
- Appears that Iridium Reached a Strain Hardening Limit
- Appears that Gold Reached an Average Strain Limit



Thermal description of a cryogenic shell

Application to the "Liquid layer" concept and thermal specifications for cryogenic targets

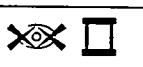
Ph. BACLET

TFM , 18-23 April 1998 Jackson Hole



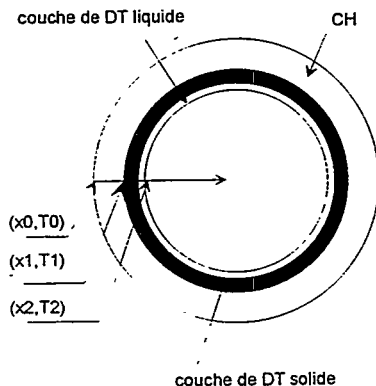
SUMMARY

- 1 / Thermal description of a cryogenic μ -shell
-1D model
- 2 / Liquid layer concept
- description
- evaluation
- 3 / Thermal specifications for cryogenic targets.
- 3D model
- evaluation
- 4 / Concluding remarks.



"Liquid layer" Concept

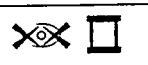
- * Reduction of the inner DT surface roughness by creating a liquid layer maintained by capillarity.
- * Liquid layer thickness must be :
 - higher than 1 μm (value of the residual solid surface roughness)
 - less than 10 μm to be maintained by capillarity



$$T_0^{y_2} - T_0^{y_1} = \frac{q}{2 \cdot k_{DT}} [y_1^2 - y_2^2]$$

Depends on internal heating source

VAORMOS
Laboratoire Micro-cibles

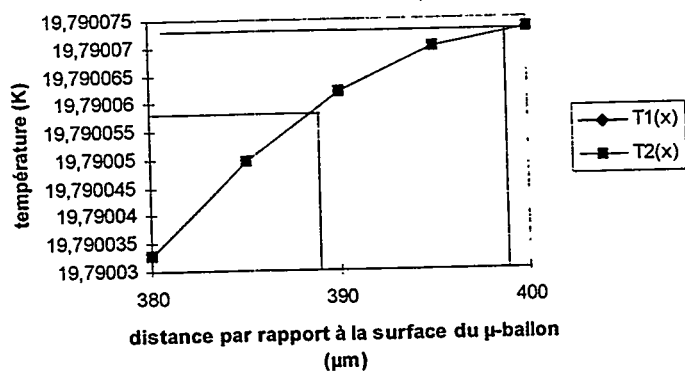


L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

couljacb ppt 3

Liquid layer : β -layering redistribution

Thermal gradient of 10 μK
to obtain a liquid layer thickness between 1 μm and 11 μm



10 μK : Impossible to obtain with classical cryostat

VAORMOS
Laboratoire Micro-cibles



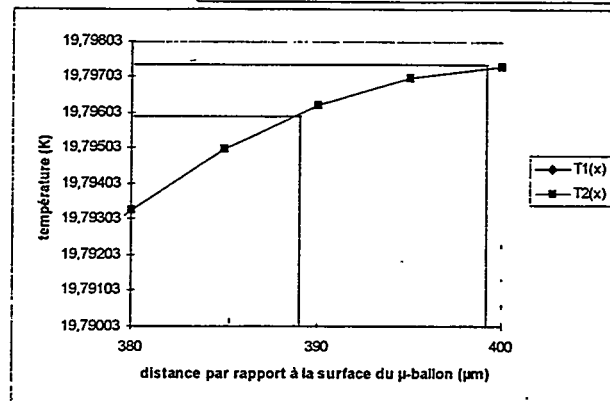
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

couljacb ppt 4



IR absorption of 5mW/cm³

Thermal gradient of 1 mK
to obtain a liquid layer thickness between 1µm and 11µm



IR heating stabilizes the "liquid layer"

Possible to obtain with classical cryostat



Assumptions :

- equilibrium
- mass conservation

$$T_2^{(side a)} = T_2^{(side b)}$$

$$\delta_a = -\delta_b$$

$$\delta = \frac{\Delta T}{2 \dot{q} \left(\frac{e_p}{k_p} + \frac{e_{DT}}{k_{DTp}} \right)}$$

Difference of thickness depends on :

- geometrical factor
- heating source
- Uniformity of temperature outside the shell





Indirect driven-target :

- polymer thickness : 200μm
- DT layer thickness : 200μm
- β-layering redistribution : 180μK (Very hard to achieve)
- IR heating : 1.95mK

IR heating improves the thermal stability of the cryogenic shell

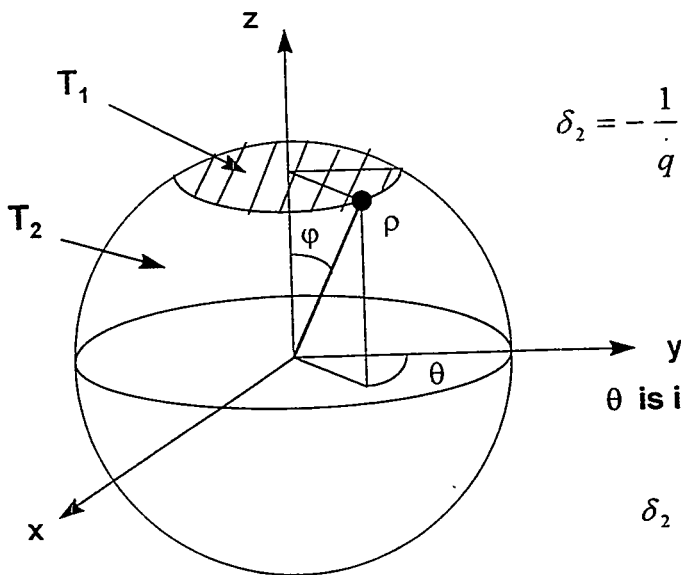
Direct driven-target :

- polymer thickness : 30μm
- DT layer thickness : 130μm
- β-layering redistribution : 80μK
- IR heating : 865μK

geometric factor is unfavourable for direct driven -targets



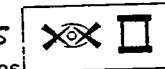
3 D model : influence of the surface of the non uniform temperature zone



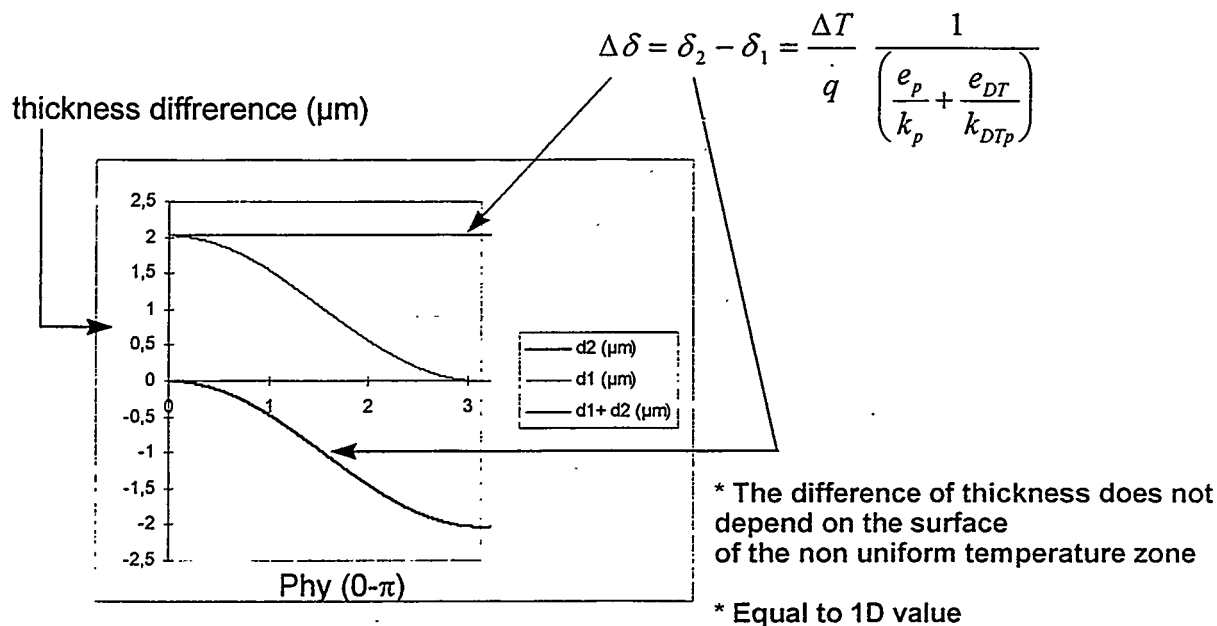
$$\delta_2 = -\frac{1}{q} \frac{1}{\left(\frac{e_p}{k_p} + \frac{e_{DT}}{k_{DTp}}\right)} \frac{\theta (1 - \cos(\Phi)) \Delta T}{4\pi}$$

θ is integrated between 0-2π

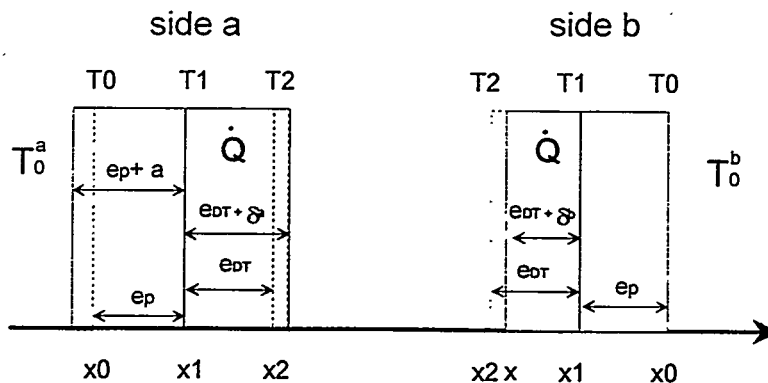
$$\delta_2 = -\frac{1}{q} \frac{1}{\left(\frac{e_p}{k_p} + \frac{e_{DT}}{k_{DTp}}\right)} \frac{(1 - \cos(\Phi)) \Delta T}{2}$$



3 D model : influence of the surface of the non uniform temperature zone

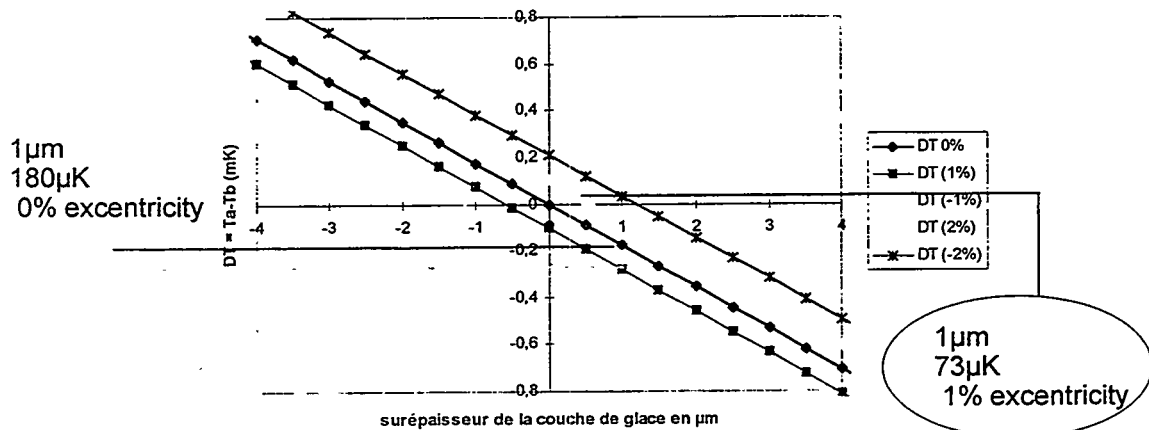


1 D model : influence of the concentricity of the polymer shell



shell non concentricity factor

$$\Delta T = T_0^a - T_0^b = -2 \dot{q} \delta_a \left(\frac{e_p}{k_p} + \frac{e_{DT}}{k_{DTp}} \right) - a \dot{q} \left(\frac{e_{DT} + \delta}{k_p} - \frac{a}{2k_{DT}} \right)$$



LMJ indirect driven target

The worst must be taken into account



* 1D, 2D and 3D model to specify the homogeneity of temperature outside the polymer shell needed to obtain a concentric DT layer

* Application to :

- "Liquid layer" : stabilized by infrared heating, almost zero rugosity.

- Thermal specifications for cryogenic targets :

	β -layering	β -layering + IR	β -layering	β -layering + IR
concentricity defect	0	0	1%	1%
Indirect driven target	180 μ K	1.95mK	73 μ K	0.8mK
Direct driven target	79 μ K	863 μ K	63 μ K	686 μ K

- + No influence of the surface of the non uniform temperature zone.
- + Great influence of concentricity of the polymer μ -shell
- + IR stabilization of the thermal behaviour of the cryogenic μ -shell
- + Give specification for 3D simulations.



STRENGTHENING LARGE THIN GLASS SHELLS BY OVERCOATING WITH GDP

Plus: An idea for filling beryllium NIF capsules with DT

Presented by: Dave Steinman (GA)

**Co-authors: Abbas Nikroo and
David Woodhouse (GA)**

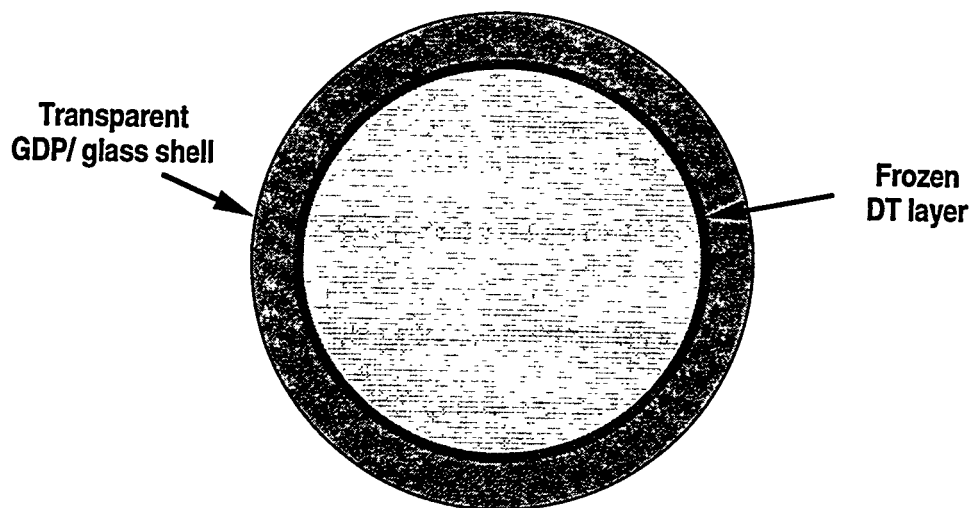
Twelfth Target Fabrication Specialists' Meeting

Jackson Hole

April 20-23, 1998

WHY STRENGTHEN LARGE GLASS SHELLS?

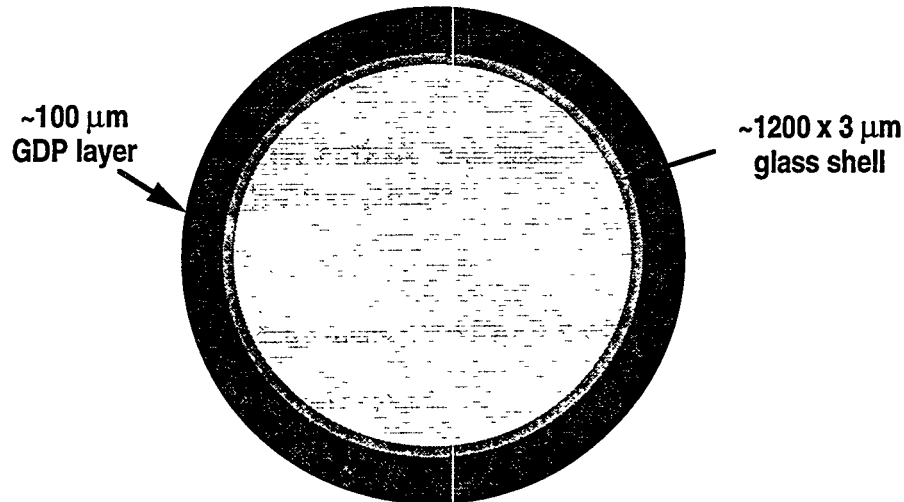
**Because..... Beta-layering experiments on NIF-size capsules
need to be done without fill-tubes**



A fill-tube disrupts the Beta-layering process

WE STRENGTHENED GLASS SHELLS BY COATING THEM WITH GLOW DISCHARGE POLYMER (GDP)

- The best glass shells were $\sim 1200 \times 3 \mu\text{m}$ in size
- see Abbas Nikroo's talk on how to make glass shells bigger
- We coated these glass shells with $\sim 100 \mu\text{m}$ of GDP



THEN WE TESTED SHELL STRENGTH WITH HIGH PRESSURE HELIUM FILLS

- Helium fills were fast, each was done in a day
- We filled the shells @ 280°C (hotter degrades the GDP; colder makes DT-filling impractically long)
- We used 20 atm fill steps (versus ~ 2 atm steps for bare large glass shells) with a 30 minute hold time at each step
- Weighing and interferometry techniques confirmed that the surviving shells were gas filled
- Weighing was the simplest technique but it was tricky
 - GDP decomposed during the fill and lost mass
 - GDP picked up oxygen after the fill and gained mass
- So, we weighed the shells immediately after the fill; stored them in vacuum between weighings; and re-weighed them periodically to determine leak rates and the initial fill pressure

MODELING SAYS THAT A THICK GDP LAYER CAN SIGNIFICANTLY STRENGTHEN A GLASS SHELL

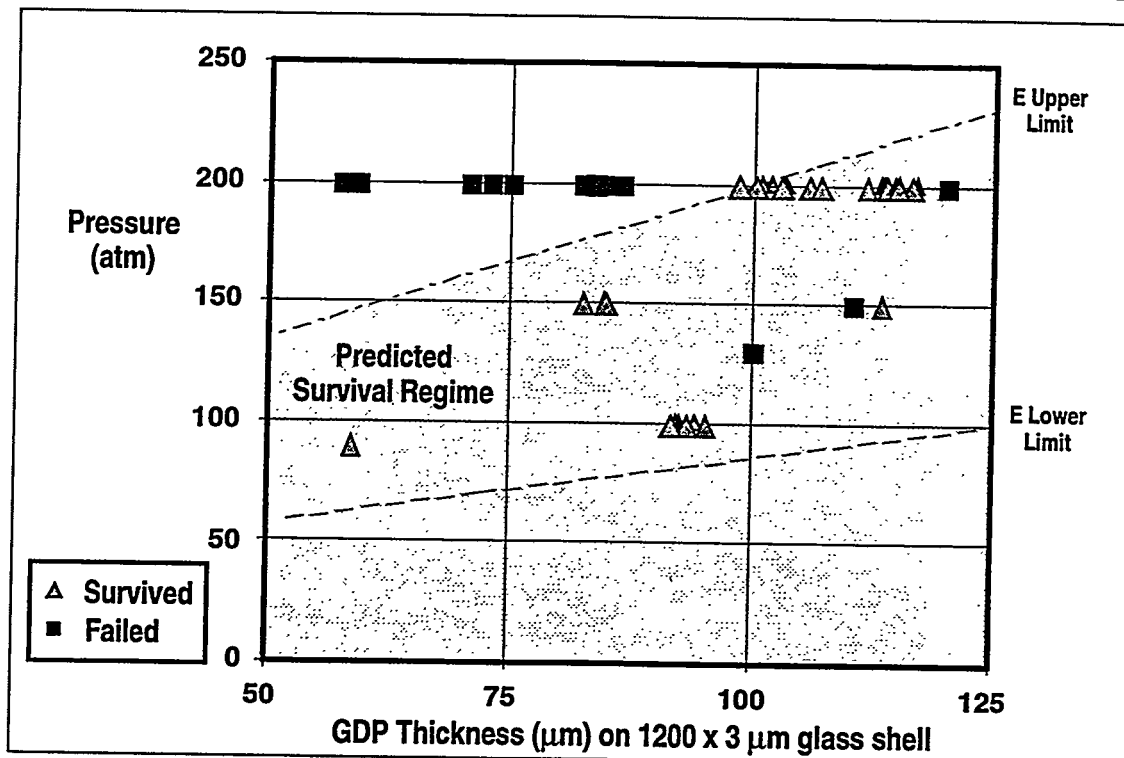
Pressure felt by glass:
$$P_{\text{glass}} = \frac{P_{\text{GDP/glass}}}{1 + \alpha}$$

where:
$$\alpha = \frac{(t_{\text{GDP}} / t_{\text{glass}})}{(E_{\text{glass}} / E_{\text{GDP}})}$$

for a 1200 x 3 μm glass shell coated with 100 μm GDP:

Strength of GDP/ glass shell $\approx 2.5 \times$ Strength of glass shell

GDP/GLASS SHELL FAILURE WAS PREDICTED BY OUR MODEL

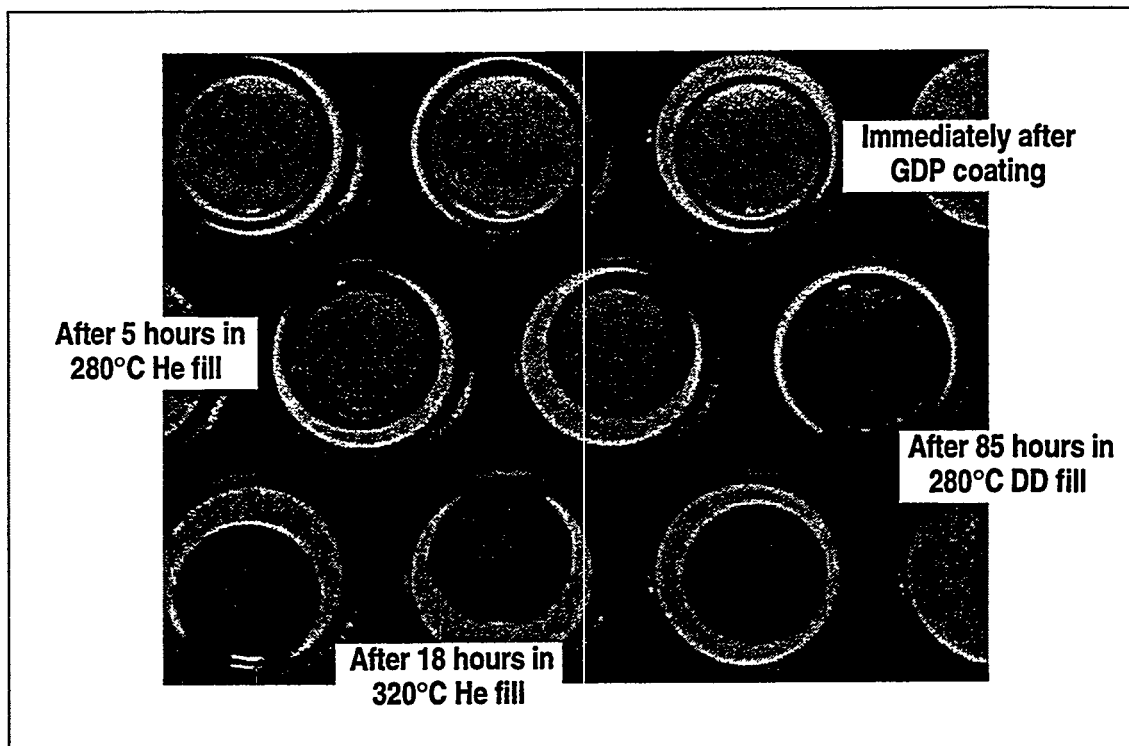


WE CONFIRMED THAT THE SHELLS COULD BE FILLED WITH DEUTERIUM

It took a week to fill the shells with 90 atm of deuterium

- filled @ 280°C
- 20 atm "driving" pressure
- 6 atm steps
- 2 hour hold time at each step with overnight soaks

THE SHELLS SURVIVED THE DEUTERIUM FILL BUT HAD DARKENED CONSIDERABLY



SOME OF THE HELIUM-TESTED GDP/GLASS SHELLS WILL SOON BE FILLED WITH DT

- **Art Nobile will fill the shells at LANL**
- **We'll learn if DT adversely affects shell strength**
- **Jorge Sanchez will see if the shells can be Beta-layered at LLNL**

WE ARE NOW TESTING LARGER GDP-COATED GLASS SHELLS MADE USING THE NIKROO "RE-BLOWING" TECHNIQUE

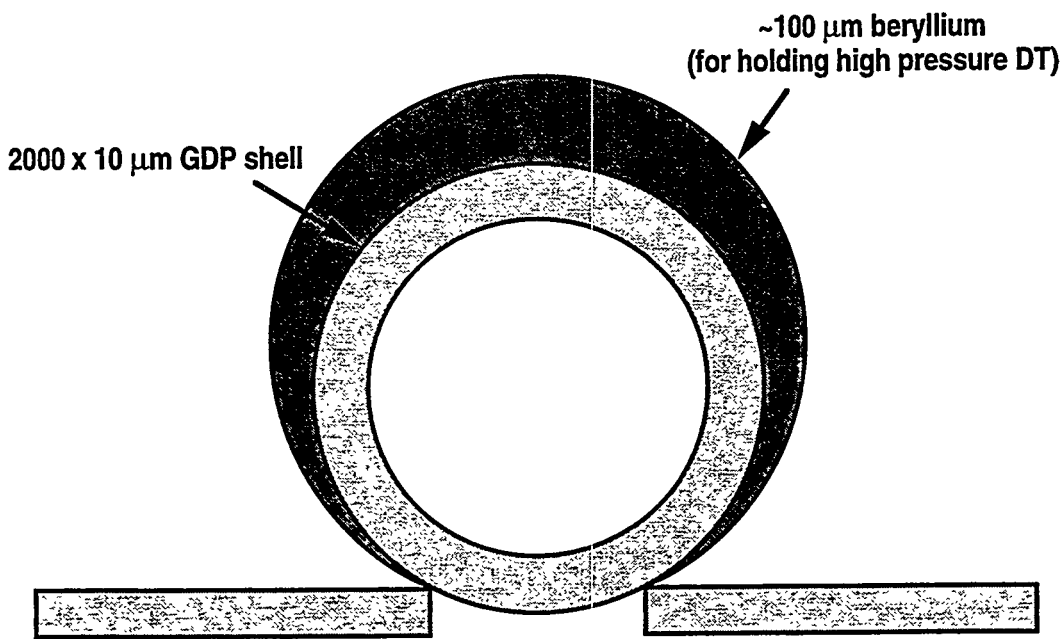
- **1500 to 2000 μm glass shells are being used**
- **Shells were coated with up to 200 μm of GDP**
- **Initial helium testing @ 50 atm showed a lower survival rate than expected (1 of 6 shells tested held gas)**
- **Defects in the glass walls may have caused the failure rather than the high shell aspect ratio.....more testing needs to be done**

UNFORTUNATELY, GDP-STRENGTHENED GLASS SHELLS ARE NOT SUITABLE NIF FUEL CAPSULES

- Beryllium is the leading NIF capsule material candidate
- Filling a beryllium capsule with high pressure DT is a challenge
 - Drill, fill and plug techniques are not trivial
 - a fill tube is not an option
 - a permeable beryllium shell is in the development stage
- How will we fill beryllium capsules with DT?

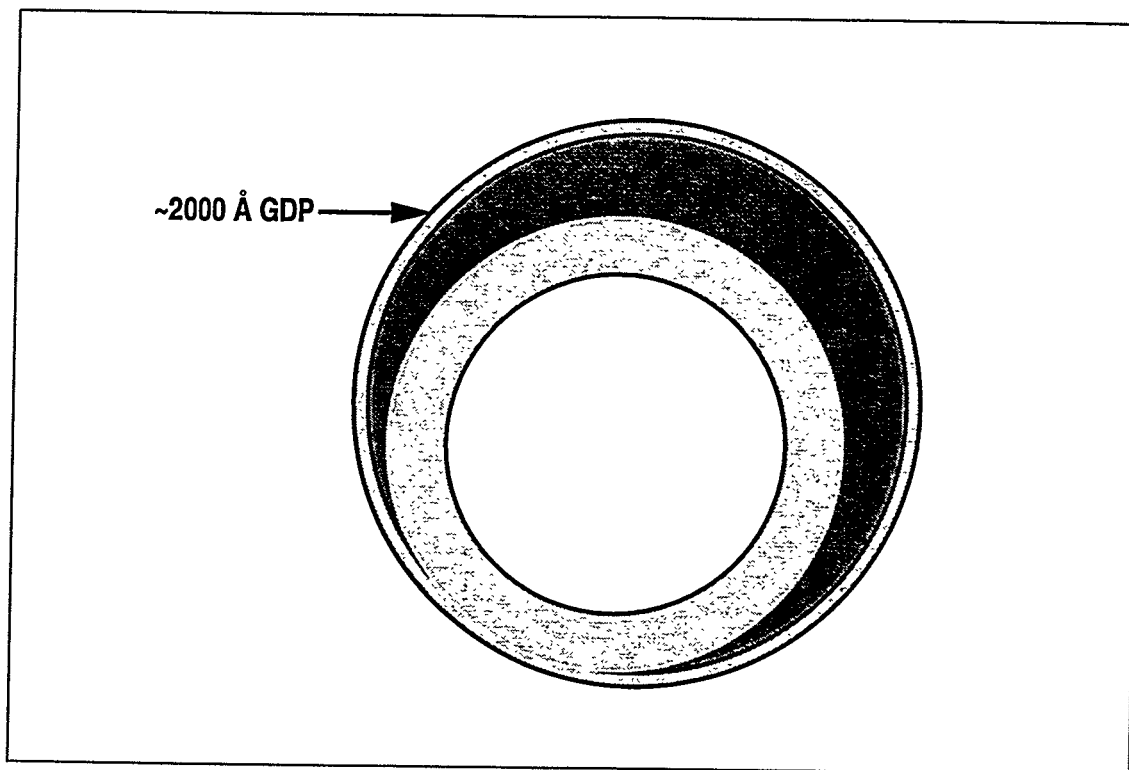
Here's an idea.....

TAKE A GDP SHELL MADE FROM A PAMS MANDREL AND COAT ONE SIDE WITH BERYLLIUM

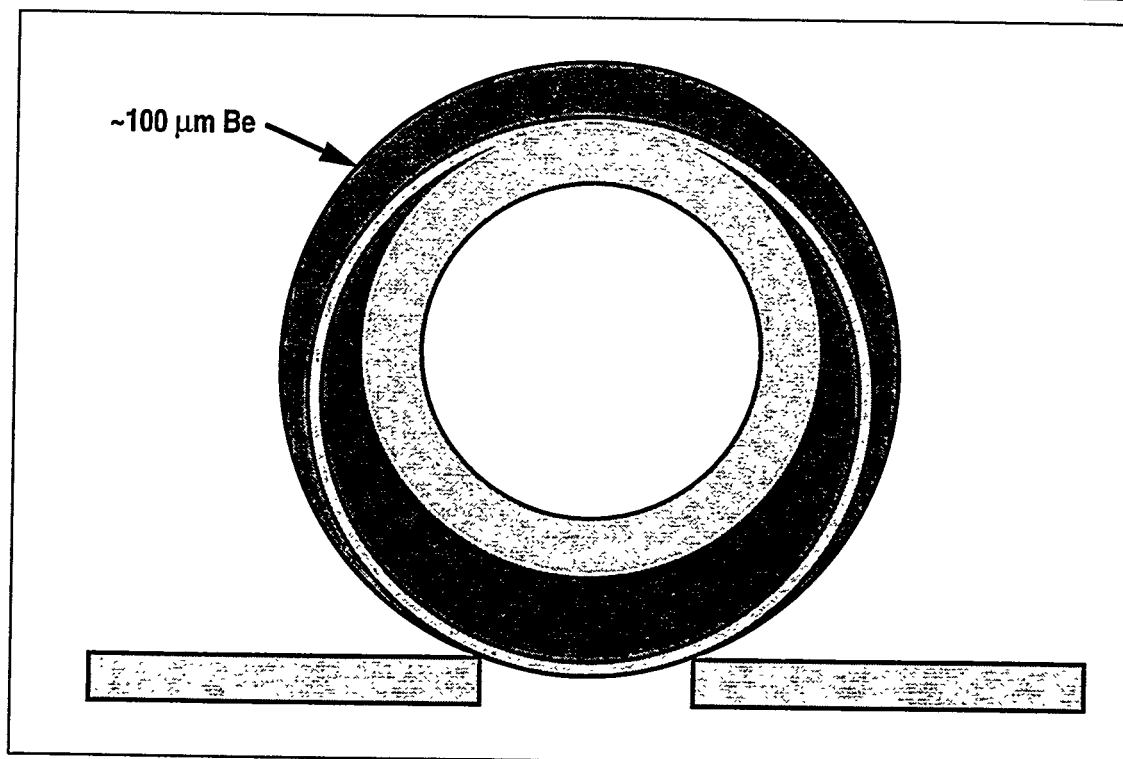


Note: Coating a stationary shell gives excellent surface finish

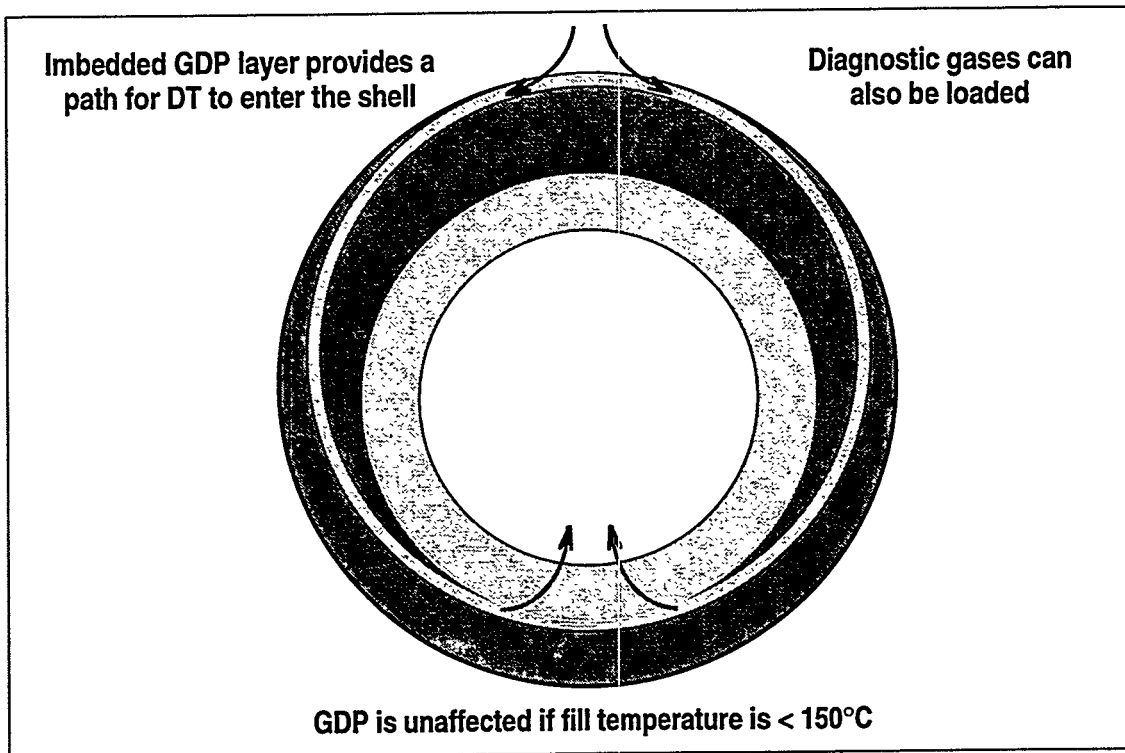
NEXT, BOUNCE-COAT THE SHELL WITH ~ 2000 Å OF GDP



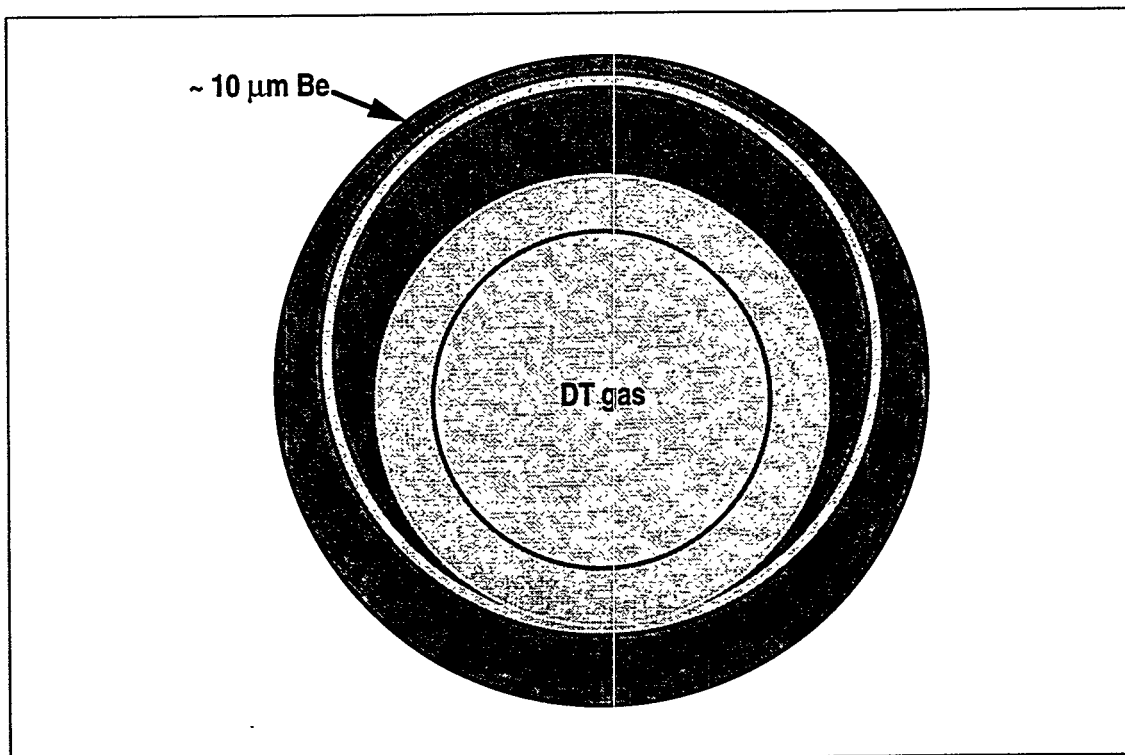
BERYLLIUM-COAT THE "THIN-WALLED" SIDE OF THE SHELL



FILL THE SHELL WITH DT AT A "LOW" TEMPERATURE



A LITTLE MORE BERYLLIUM ENTRAPS THE DT



FABRICATION STUDIES OF LARGE PAMS TARGET MANDRELS USING MICROENCAPSULATION

Don Czechowicz
Richard Stephens

General Atomics
San Diego, CA

**GOAL: DEVELOP A PROCESS TO PRODUCE
LARGE 2.0mm PAMS TARGET MANDRELS
THAT CAN MEET NIF REQUIREMENTS**

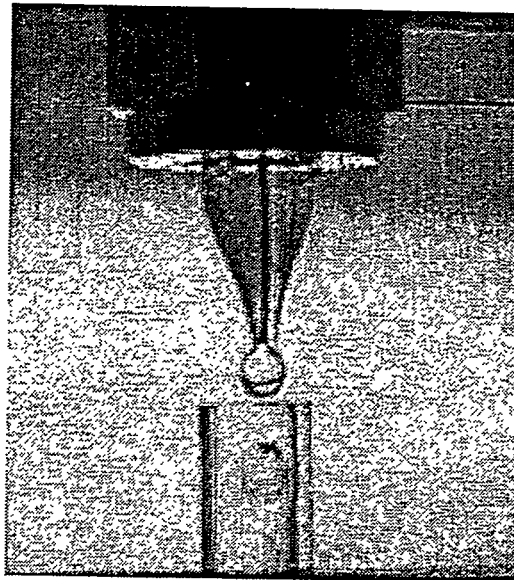


APPROACH: USE OF GA DROPLET GENERATOR

Large 2.0 mm Shells

Conditions:

- Oil-1/Water-1 = ~ 2:1
- Working Towards Density Matching
- Enhanced Tumbling During Curing
- > Aggressive Stirring



Large 2.0 mm Beads

Conditions:

- Water-1 = 0
- Density Matching
- Gentle Stirring

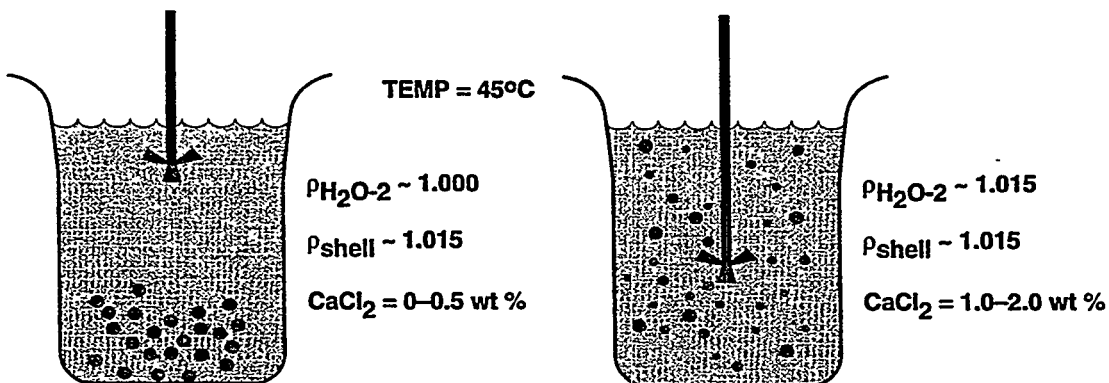


FABRICATION ISSUES:

<u>ISSUE</u>	<u>SHELLS</u>	<u>BEADS</u>
1) Size	X	
2) Survivability (cracks)	X	
3) Agglomeration	X	X
4) Nonconcentricity (centering of W-1)	X	
5) Out-of-Round (OOR)	X	X
6) Difficulty working w/ 15-20 wt% 404k PAMS		X
7) Time to get to dry PAMS Target Mandrel	X	
8) Unknown Performance of Bead as GDP Mandrel		X



SHELL CURING

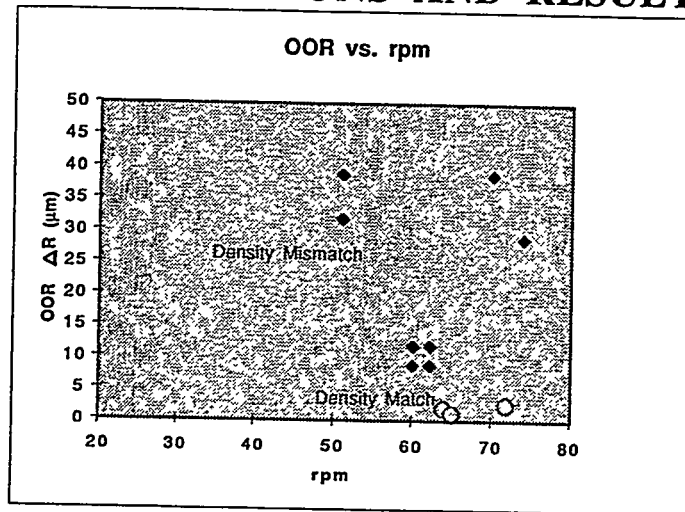


With Shell/Water-2
Densities Mismatched

With Shell/Water-2
Densities Matched



SHELL STIR CONDITIONS AND RESULTS



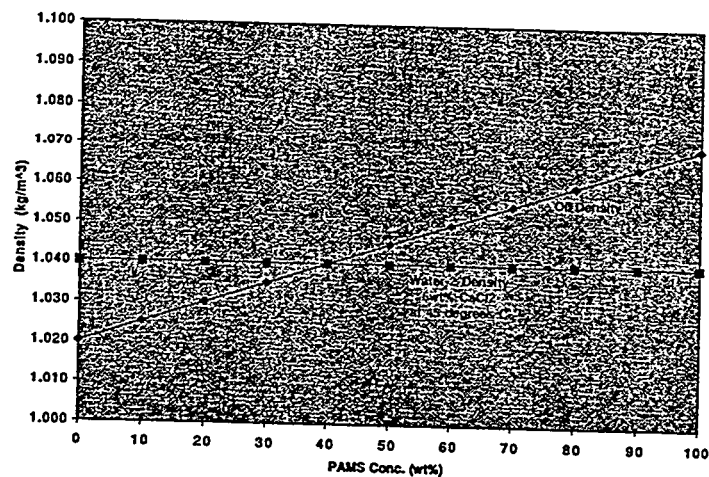
Shells Produced using Density Matching Conditions were 1850-1950 μm



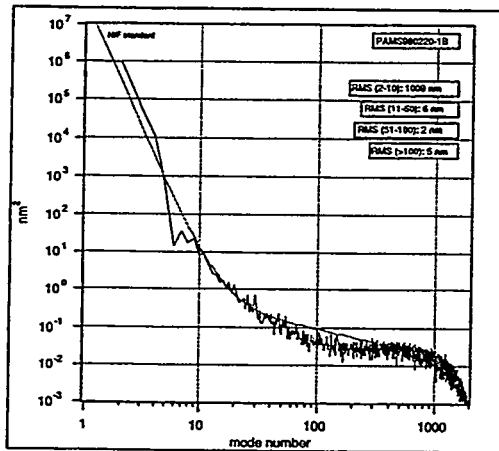
BEAD CURING CONDITIONS AND RESULTS

Density vs. PAMS Concentration

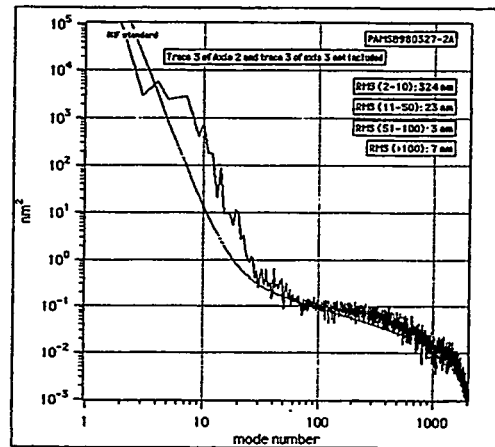
<u>Batch</u>	<u>Density Stir Match</u>	<u>rpm</u>	<u>Size (μm)</u>	<u>OOR Δr (μm)</u>
213-1	No	62	2053	1.3
213-2	No	52	2010	3.0
213-3	No	71	2002	2.0
327-2	Yes	61	2052	1.4



1855 μm PAMS shell
 37 μm wall thickness
 Near Density Match Conditions
 (1.0 wt% CaCl_2)



2114 μm PAMS bead
 Density Match Conditions
 (6.0 wt% CaCl_2)



 **GENERAL ATOMICS**

SUMMARY:

- Have a Process to Fabricate Near 2.0 mm PAMS Shells and Beads with OOR $\Delta R < 3 \mu\text{m}$
- Production of Highly Spherical 2.0 mm Shells a Challenge
- Stirring Conditions are Important for Shell Survival and Centering of Water Droplet in Shell Preforms
- Density Matching is Critical for Producing Spherical Shells, and may be Less Critical for Producing Spherical Beads

FUTURE EFFORTS:

- Optimization of Stirring Schemes while at Density Match Conditions
- Use of Oil-1/Water-1 System with Higher Interfacial Surface Tension

 **GENERAL ATOMICS**

The Use of CaCl_2 and Other Salts to Remove Vacuoles and Improve Surface Finish in PAMS Omega Shells

Barry McQuillan

Fred Elsner

Rich Stephens

Lloyd Brown

General Atomics

The Problem: Vacuoles in Shell Wall Lead to Surface Roughness
The Solution: Add Salt to the PVA W2 Solution!

■ **Presumed model for vacuole formation:**

WATER MOVES INTO THE POLYMER/SOLVENT WALL DURING CURING, and eventually nucleates a small water ball. The shell wall cures and solidifies around the water ball, the water leaves, and a vacuole remains.

■ **To eliminate the vacuoles, PREVENT THE FLOW OF WATER INTO THE POLYMER/SOLVENT WALL DURING CURING.**

The simple solution: ADD SOME SALT TO THE WATER, so the water wants to remain with the water, and not go into the oil phase.

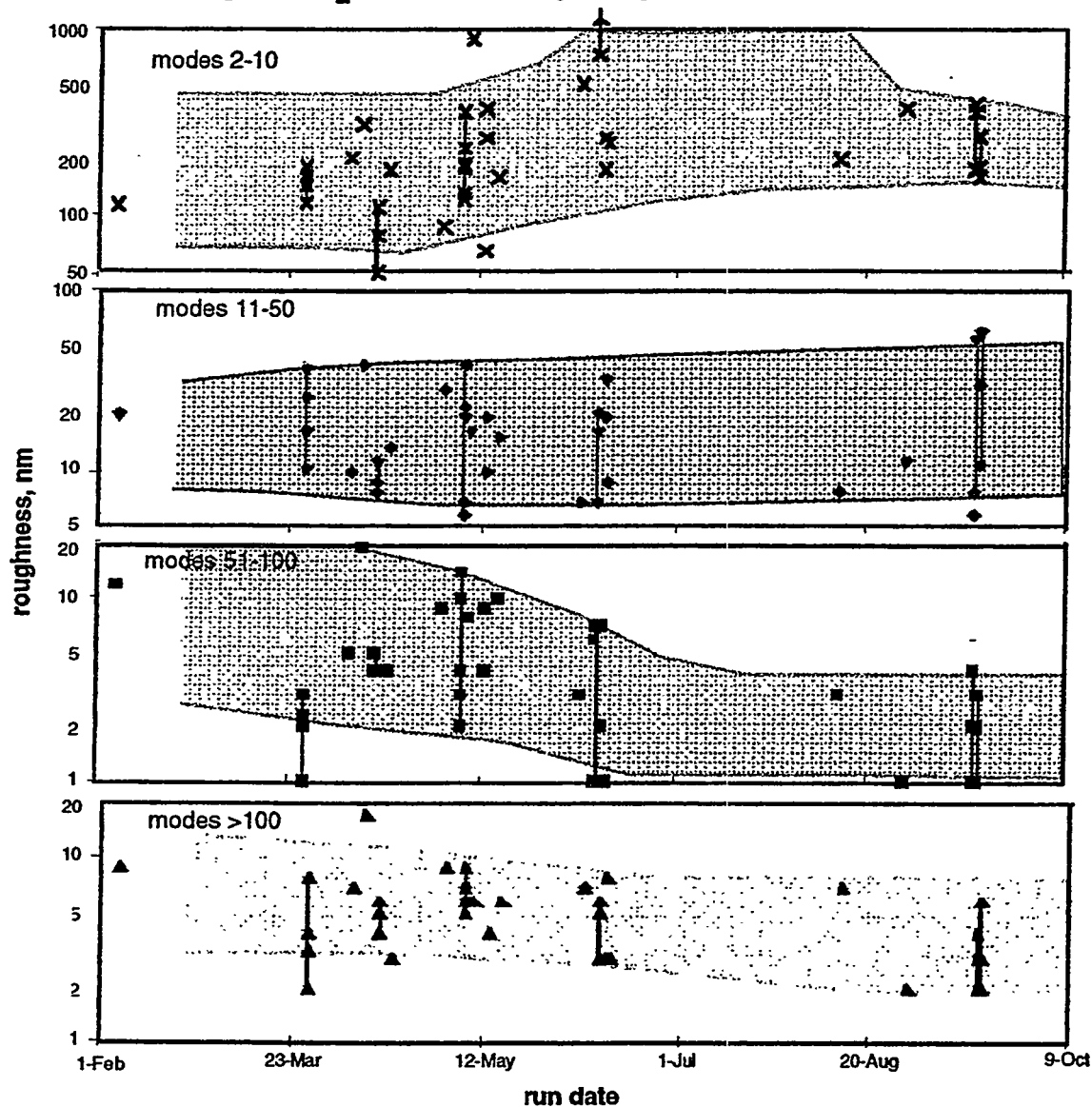
Salt shouldn't dissolve into the oil phase.

Salt should be compatible with PVA solution.

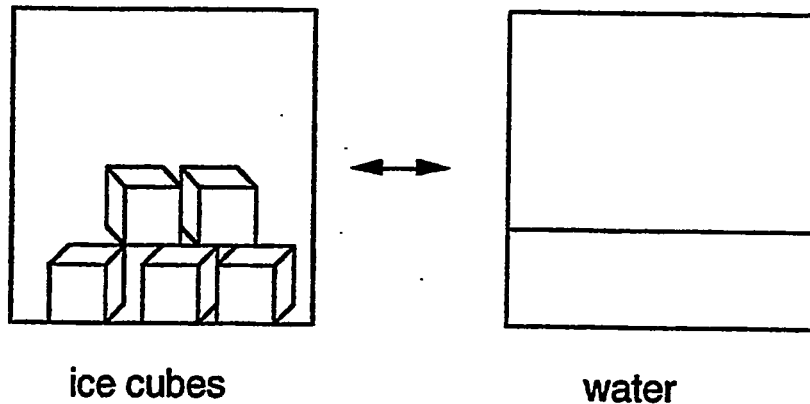
The complex understanding: adding salt decreases the water ACTIVITY. Activity can be understood in terms of relative vapor pressure, chemical potential, salt concentrations, etc.

Adding Salt Improves AFM Surface Roughness Modes 50-100

Start Adding CaCl_2 ↓ early May

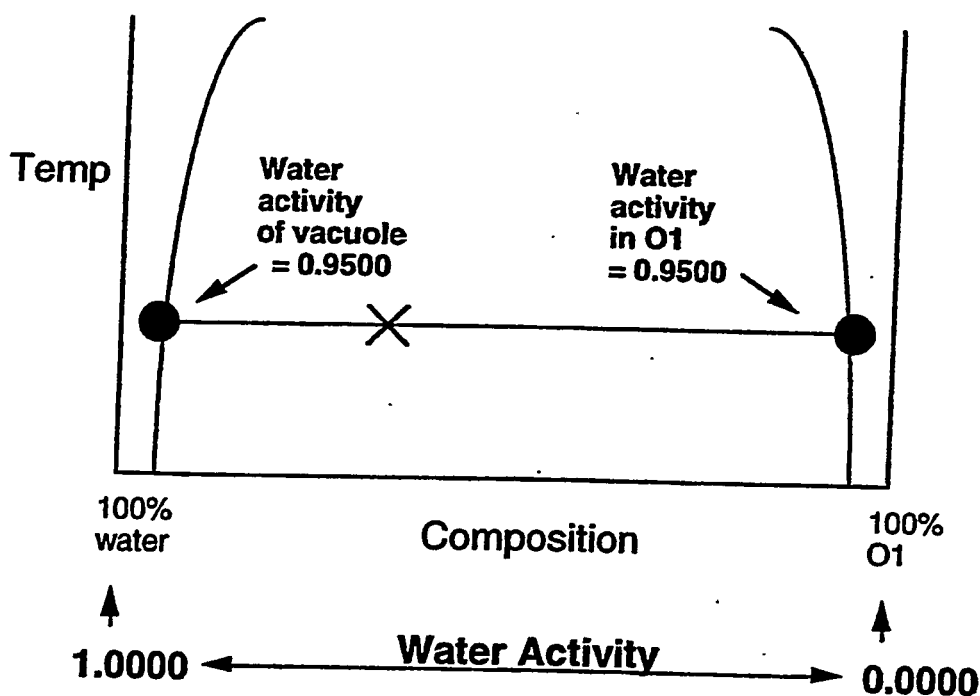


A Chemical Change Results from a Material Moving From a State of High Activity to Low Activity



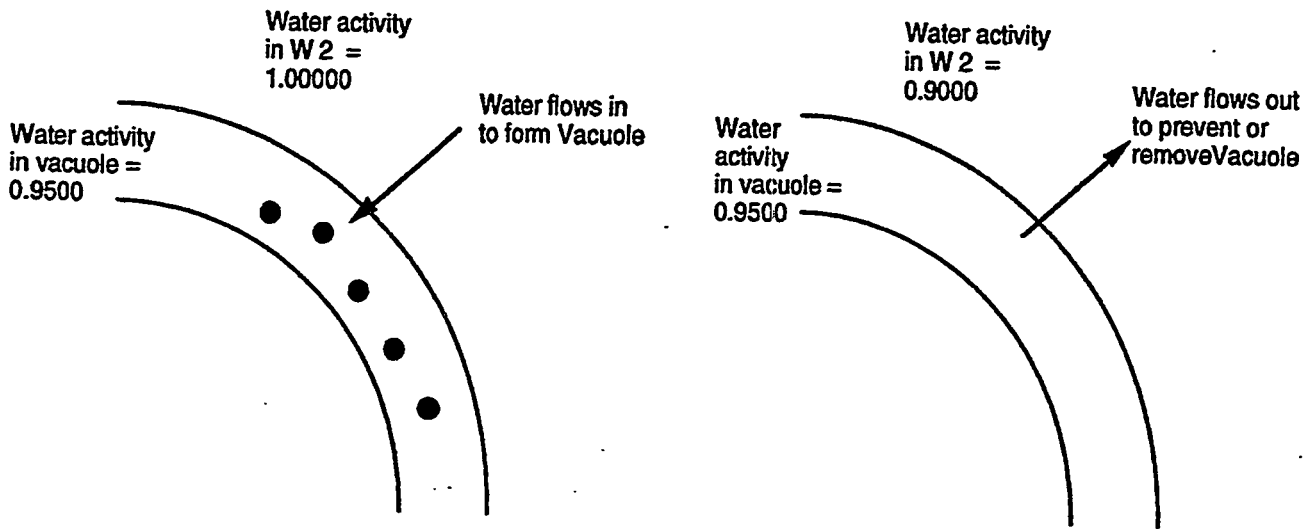
	ICE			WATER	
	Vapor Pressure mm Hg	Activity		Activity	Vapor Pressure mm Hg
-1 C	4.217	1.000	←	1.010	4.258
0 C	4.579	1.000	↔	1.000	4.579
1 C	4.941	1.003	→	1.000	4.926

A Polymer Phase Diagram Implies Activities of the Components



- To form vacuole, the water activity of O1 must reach the necessary level.

To Prevent Formation of Vacuoles, Use Water (W2) With Activity Lower Than Activity of Water Vacuole



- **Key Point-I don't know a priori the water activity of the vacuole state!**

How Much Salt Should I Add To Lower Activity?

- * I don't know the activity of the water in the vacuole, so I don't know how much salt to add.
- * By definition, pure water has an activity = 1.00000000...
- * For the water activity of 0.1 wt% PVA,

Use Flory-Huggins equation, $\chi = 0.5$, X = volume fraction water:

$$\ln X + (1-X) + \chi(1-X)^2 = \ln(P/P_0) + (P_0-P)V/RT$$

Temperature	20 C	60 C
Water activity	0.9999999567	0.9999999995

Water activity of 0.1 wt% PVA solution is virtually the activity of pure water! PVA does not decrease water activity sufficiently.

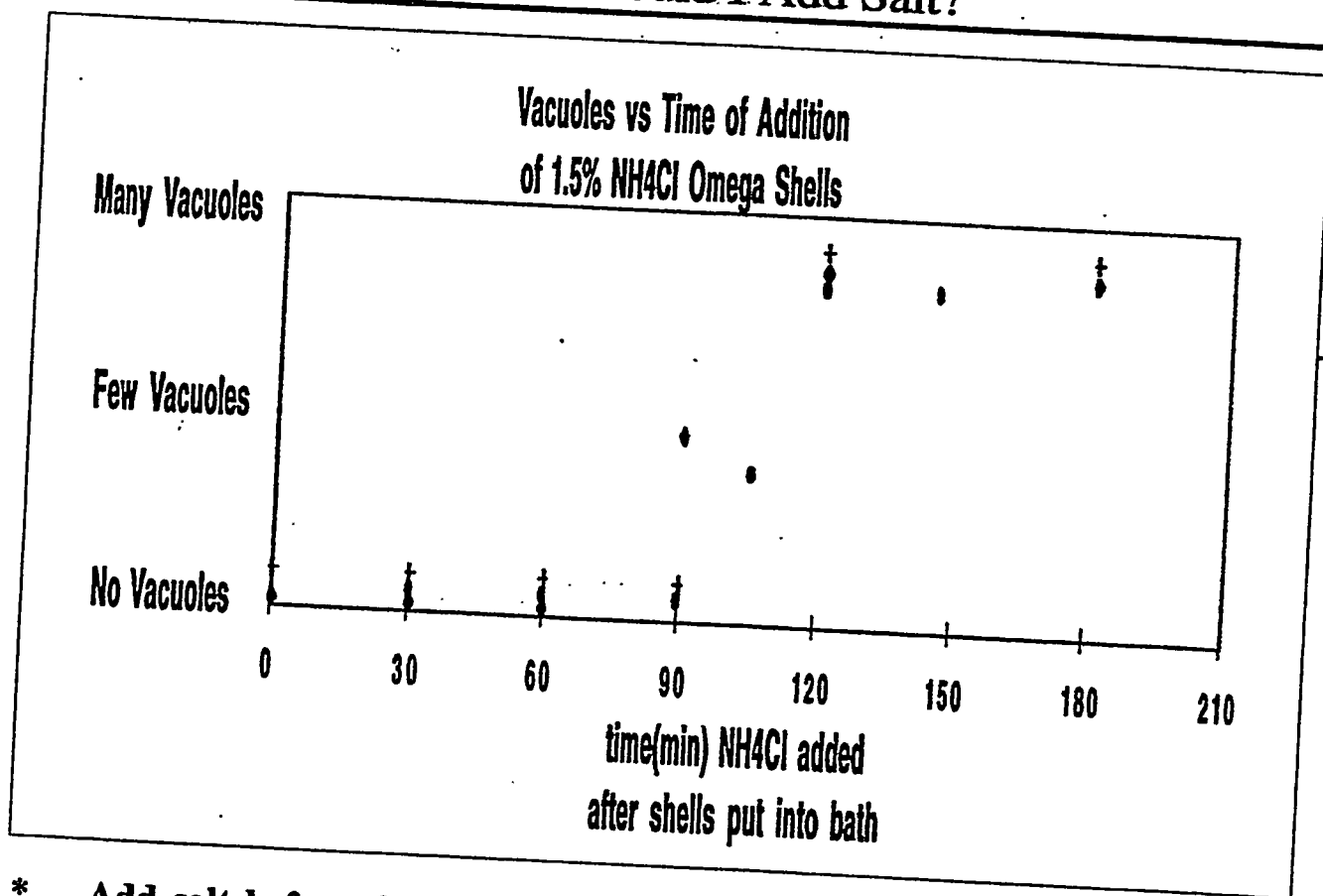
How Much Salt Should I Add To Lower Activity-2?

* R.A. Robinson and R.H. Stokes, Electrolyte Solutions, (1959) has tables of water vapor pressures over salt solutions at 25 C. One can plot their data for CaCl_2 , and interpolate to the following values:

wt% $\text{CaCl}_2 \cdot 2 \text{H}_2\text{O}$	water activity P/P_0	Vacuoles?
0.5	0.9972	yes
1.0	0.9944	maybe
1.5	0.9915	no
2.0	0.9885	no
2.5	0.9855	no
3.0	0.9822	no

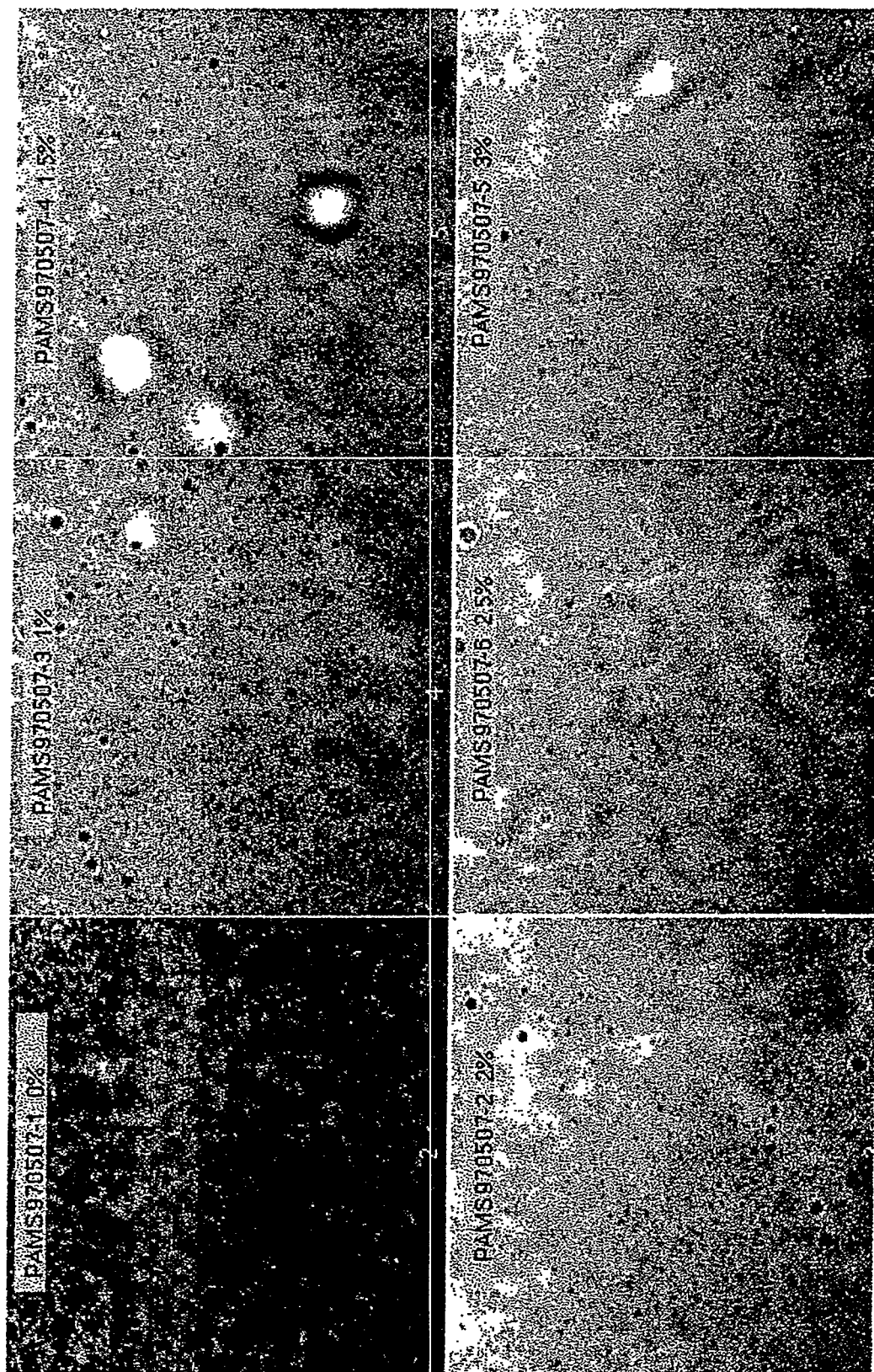
* These values are at 25 C. The shells are made at 60 C. The activity values at higher temperatures are nearly the same.

When Should I Add Salt?



* Add salt before the 90 minute mark !

With Increasing CaCl_2 Concentration, Vacuoles Disappear in Omega PAMS Shells:



With Every Good Idea (Adding Salt) Comes
A Recognition of Other Issues/Problems

- 1) CaCl_2 is found on the inside of PAMS shells.

Apparently it diffuses through the O1 shell wall. We cannot remove the CaCl_2 from the final GDP shell!!

The Solution: REPLACE CaCl_2 WITH NH_4Cl SOLUTION, (1.5 wt% is sufficient). NH_4Cl decomposes to gases under the pyrolysis conditions.

- 2) Any impurity in the O1 solution, which will want to attract water, will grow a vacuole in spite of adding salt.

PAMS from the manufacturer has some residual LiOMe from the polymerization, which is soluble in PAMS solvents. Water reacts with LiOMe to make LiOH and methanol, and the LiOH will want to draw water to itself. We have found that shells made with salt, but with PAMS which we have not reprecipitated, can be hazy-vacuoles!

The Solution: ONE MUST REPRECIPITATE THE PAMS, TO REMOVE THE LITHIUM METHOXIDE/HYDROXIDE.

With Every Good Idea (Adding Salt) Comes
A Recognition of Other Issues/Problems-2

- 3) Sphericity (OOR) Goes Nuts!

Before using salt, we could get OOR below 1 micron for Omega shells. Once we used CaCl_2 , the OOR went to 2-4 microns, out of specification!

Ultimately, we found that by adding CaCl_2 , we were changing the W2 solution density by about 0.01 g/cc. This change resulted in a worse OOR.

Bob Cook has estimated:

$$\text{max OOR} = (\Delta\rho)r^3/\gamma$$

With a $\gamma \sim 10$ dyne/cm, we could explain most of this increase in OOR.

The Solution: CHANGE THE CURING BATH TEMPERATURE FROM 60 C, DOWN TO ABOUT 43 C FOR CaCl_2 , AND TO 48 C FOR NH_4Cl SOLUTIONS. The density⁸⁹ match between O1 and W2 is closer to zero at these new temperatures.

Summary: Add Salt (NH_4Cl) To W2 PVA Solution

- * Adding salt to W2 eliminates vacuoles in PAMS shells**

1.5 wt% NH_4Cl in W2 is sufficient.

- * Beware of other effects on shell specifications:**

Water soluble impurities in PAMS polymer and O1 solvent

Density mismatch and OOR

Potential for diffusion of salt into shell



THE NATIONAL PLAN FOR IGNITION

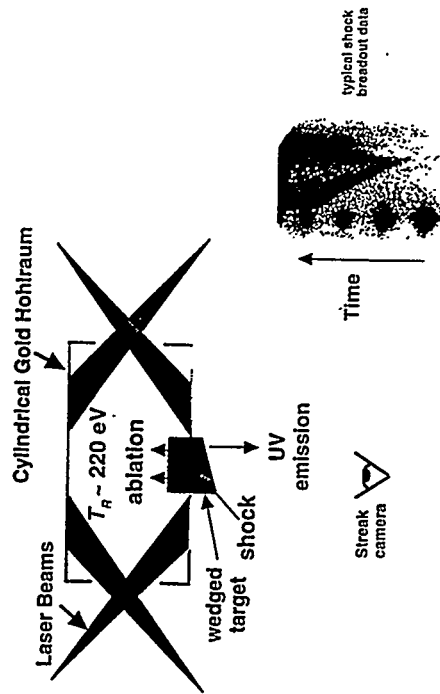
Thomas P. Bernat
Lawrence Livermore National Laboratory

During approximately the past year, the ICF laboratories and the Department of Energy Office of Inertial Fusion have structured a national plan to prepare for and execute experiments that will lead to the ignition campaigns on the National Ignition Facility (NIF). This plan includes both direct and indirect drive, and is coordinated with the schedule for completion and activation of the NIF to take full advantage of the facility capabilities as they become available. Under this plan, the first indirect drive ignition campaign could commence as early as the last quarter of 2005, approximately one year after the NIF is at full power from all beams. This ambitious schedule will require the steady development and, starting at the end of 2001, production of indirect-drive targets for experiments in hohlraum energetics and laser-plasma interactions, hohlraum drive symmetry, capsule physics and optimization, and the ignition implosions themselves. An analogous set of targets to prepare for direct-drive ignition implosions in the 2008-2009 timeframe will also be needed.

We are constructing a multi-lab National Ignition Plan

- Provides for early use of NIF requires experiments and development on other facilities
- A self-consistent, integrated plan
- ✓ What has to be done
- ✓ When (schedule - constrained by budgets)
- ✓ Who - coordinated, institutionally divided tasks and responsibilities

On Nova, we measure shock strength by observing shock breakout through a wedged or stepped target



It has been formally decided that NIF will do indirect drive first

Two options were considered

Ongoing experiments

direct-drive experimental results available
NIF configuration and startup

start ignition and weapons physics expts.

A single indirect drive target campaign

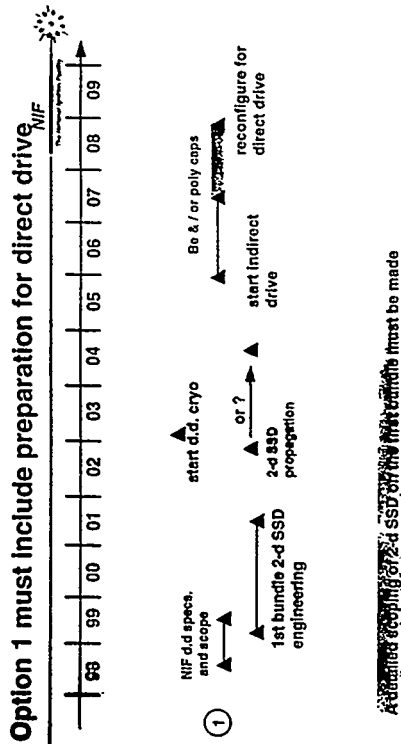
or

Two consecutive indirect drive target campaigns

Initial NIF configuration and experiments for direct drive

start direct drive (or tetrahedra)

start indirect drive
reconfigure for direct drive



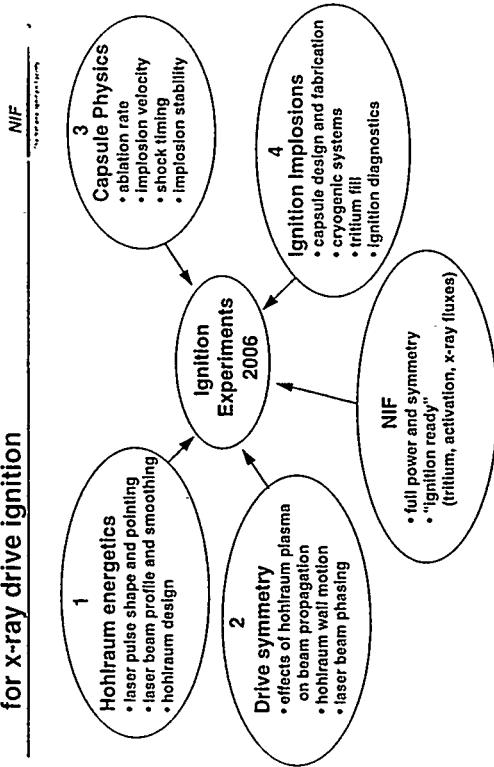
Excerpts from Program Manager's Memo

... This plan should bring the NIF up in the x-ray drive configuration and then should reconfigure the NIF for direct drive about 2008 (assuming the present schedule for completion and initial operation). In this plan, the hohlraum illumination configuration available in this direct drive configuration should be identified and optimized for non-ignition user groups.

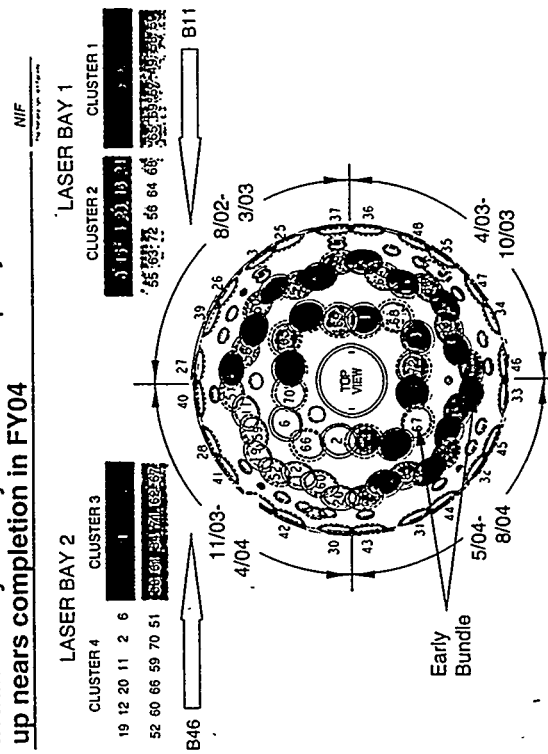
... a detailed plan that better identifies the resource implications for various direct-drive options is required.

... The Ignition planning group should be tasked to develop a detailed plan for direct drive for implementation on the NIF.

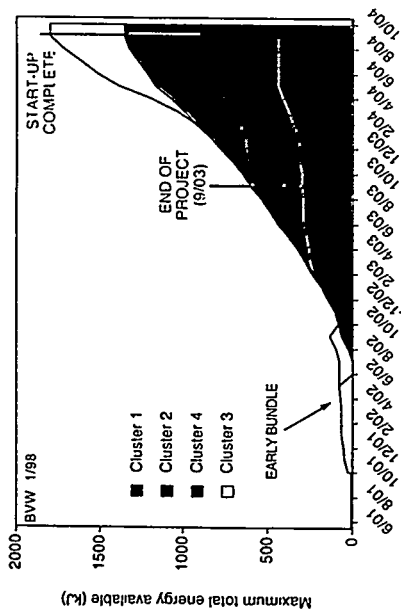
The National Ignition Plan includes preparation for x-ray drive Ignition



Irradiation symmetry increases rapidly as start-up up nears completion in FY04

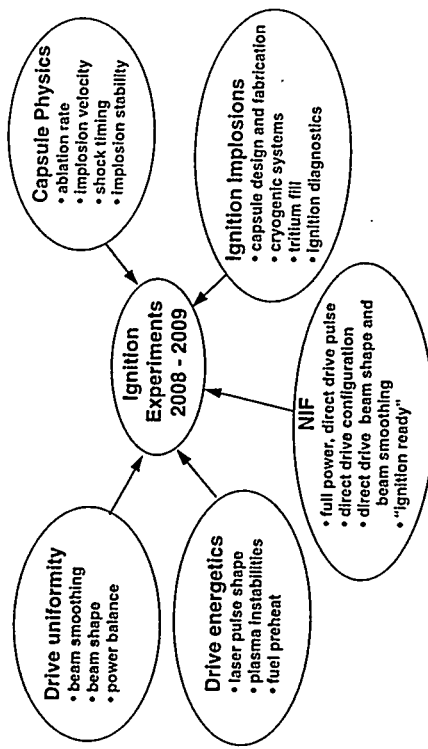


Maximum energy available for experiments increases as bundle-by-bundle start-up proceeds

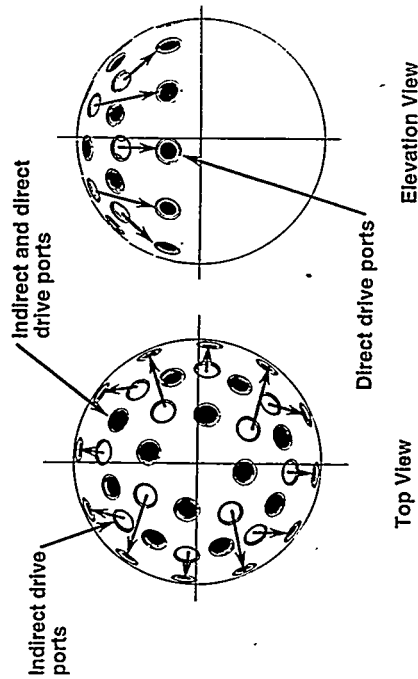


NIF

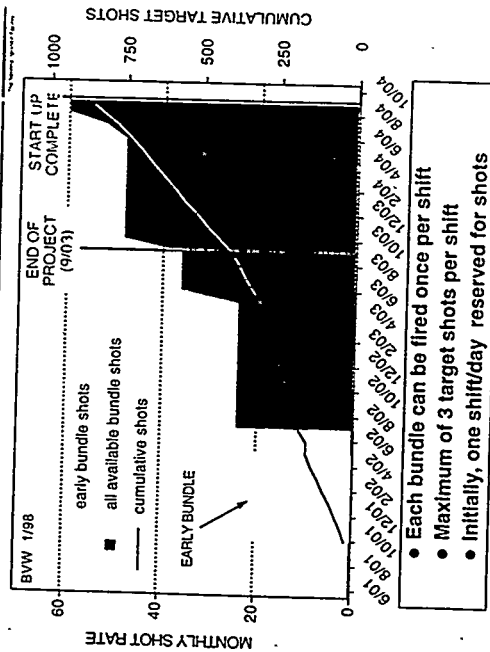
The National Ignition Plan also includes direct drive



For direct drive, half of the beams in each ring are moved to a new ring at the lower latitude

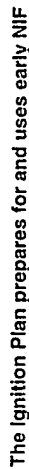


Initial target shot rates are limited by concurrent equipment installation and start-up activities

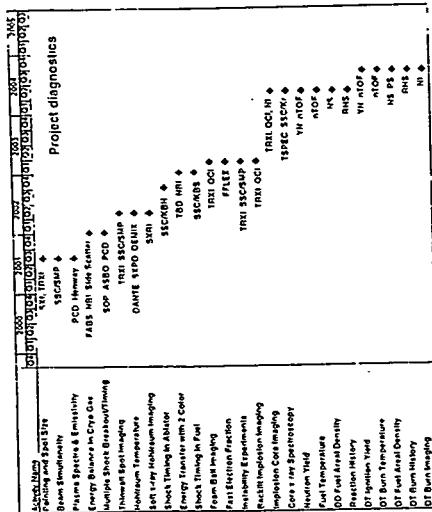


- Each bundle can be fired once per shift
- Maximum of 3 target shots per shift
- Initially, one shift/day reserved for shots

NIF



FIN



US/Canadian Physics diagnostics have yet to be included in this schedule

AME

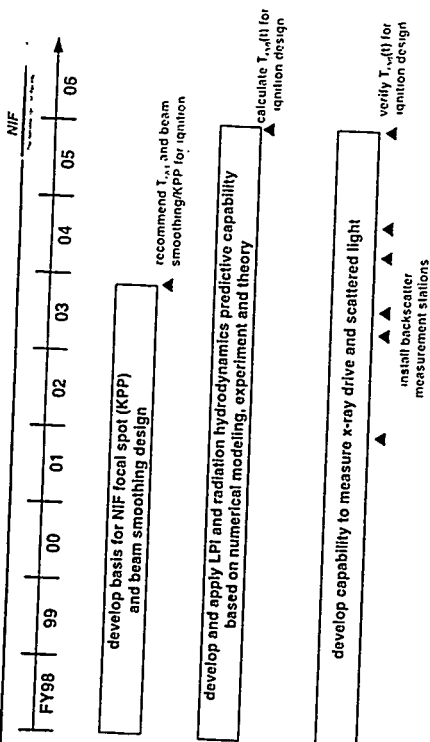
How long has the business been in operation?

- A prioritized set of indirect and direct drive activities, milestones, and schedules for getting to Ignition on the NIF
- A work breakdown structure (WBS)
- A "first cut" experimental plan coordinated with the NIF start-up schedule
- A proposed distribution of involvement from the ICF labs

The Plan will be completed with:

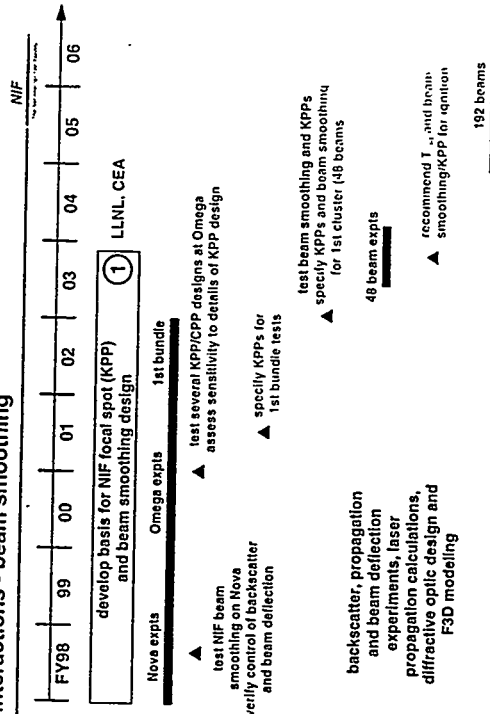
- A lab-by-lab list of tasks and responsibilities
- An estimation of resources to carry out the plan.
- An assessment of NIF shots, coordinated with other users, especially Weapons Physics (first-order schedule assumes equal split on average)
- A disciplined method of managing changes to the baseline; e.g. a change control board consisting of the ICF Program Managers, coordinated with other users through a top level management group

WBS 1 Hohlraum energetics and laser plasma interactions

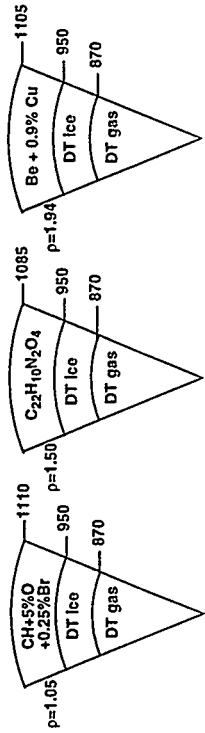


WBS 1.1 Hohlraum energetics and laser plasma interactions - beam smoothing

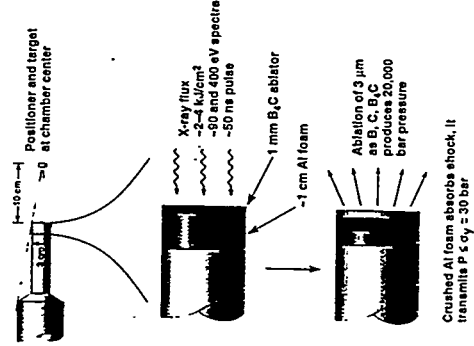
WBS 1.1 Hohlraum energetics and laser plasma interactions - beam smoothing



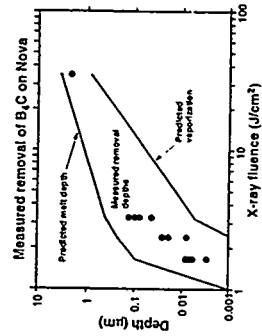
WBS 1.1 Hohlraum energetics and laser plasma interactions - beam smoothing



We have developed a concept for protecting diagnostics and the target positioner from x rays and debris



- B₄C removal at 2-4 kJ/cm² extrapolated from melt-depth model, benchmarked on Nova
- Predicted x-ray fluence and spectra from Lasnex
- Al foam and B₄C mechanical response from CALE and DYNA
- A 3-cm-diam. disc of B₄C at 10 cm would ablate less than 100 mg. This is less than the cryotarget mass.



20-05-0187-00817

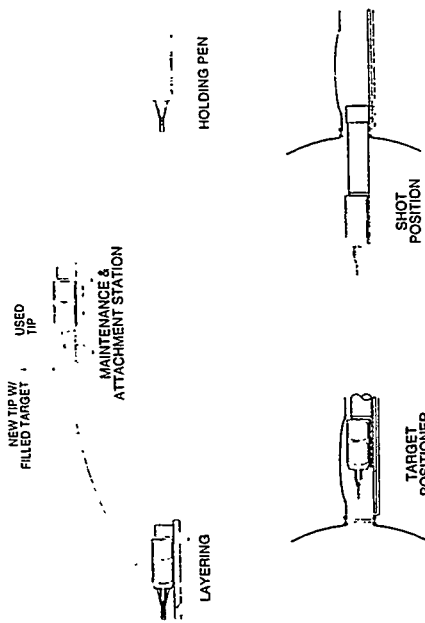


Figure 4-1. Overview of Concept B target filling cycle

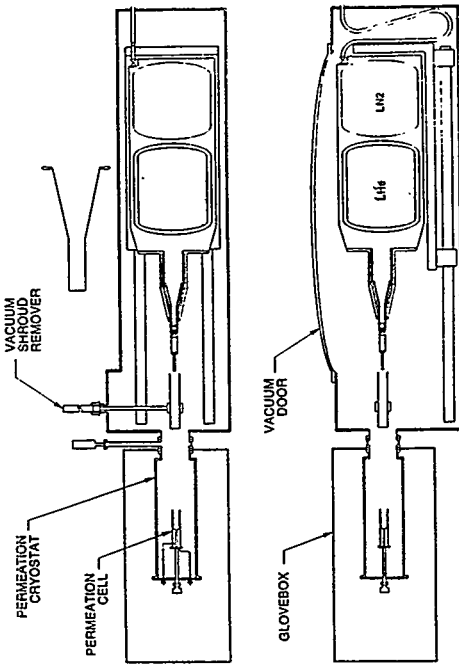


Figure 5-3 Fill Station

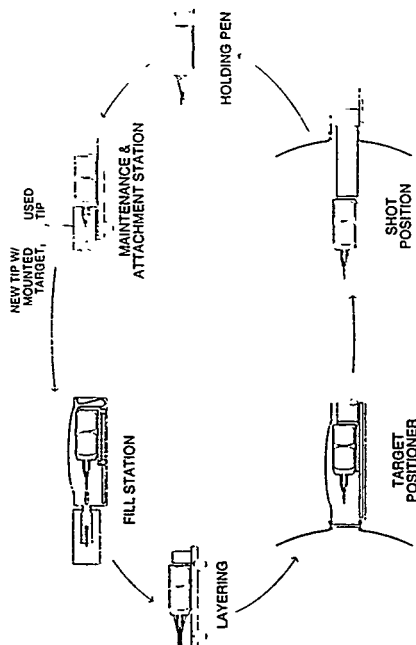


Figure 5-1. Overview of Concept A target filling cycle

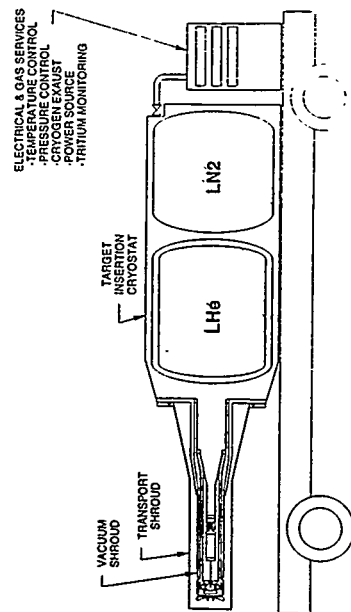


Figure 6-5 Target Insertion Cryostat and Cart

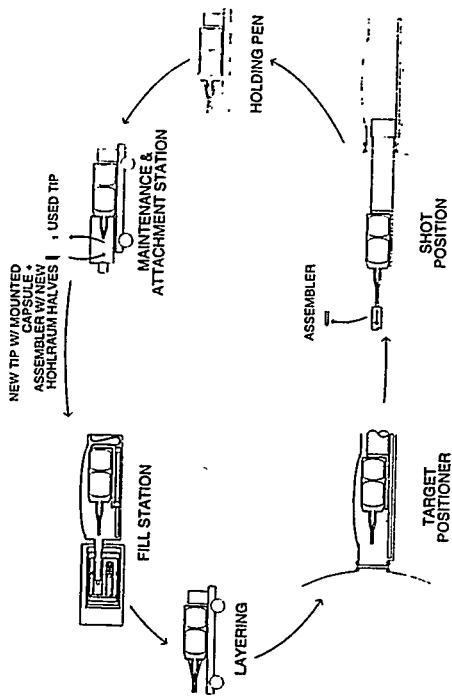


Figure 6-1. Overview of Concept E target fielding cycle.

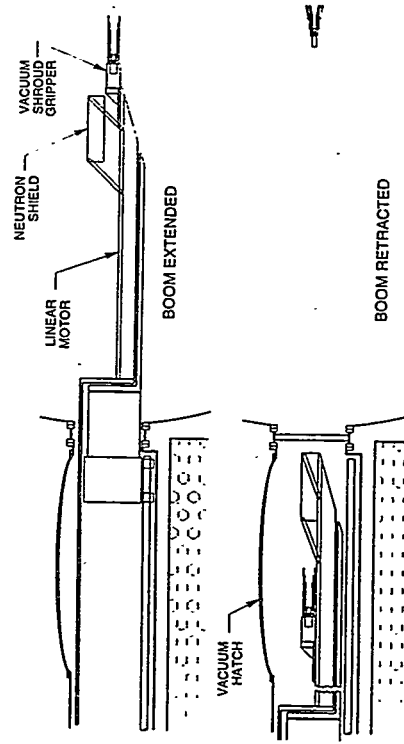


Figure 6-9. The Shroud Retractor on NIF Target Chamber is attached to the chamber port opposite the Target Positioner

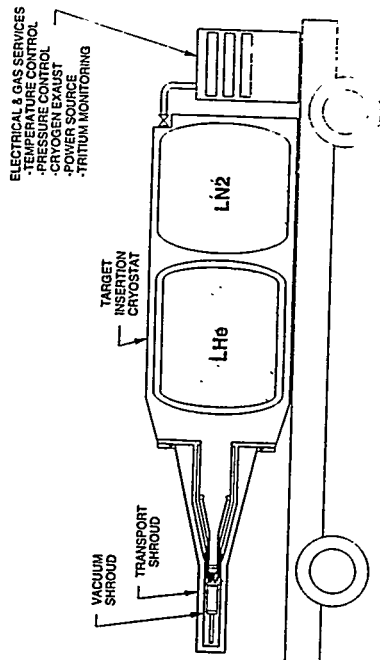


Figure 4-4. Target Insertion Cryostat and Cart

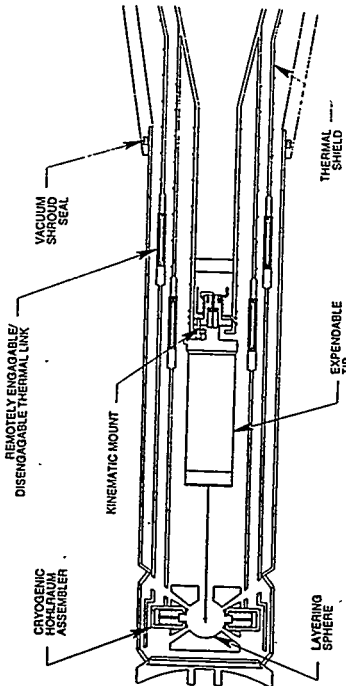
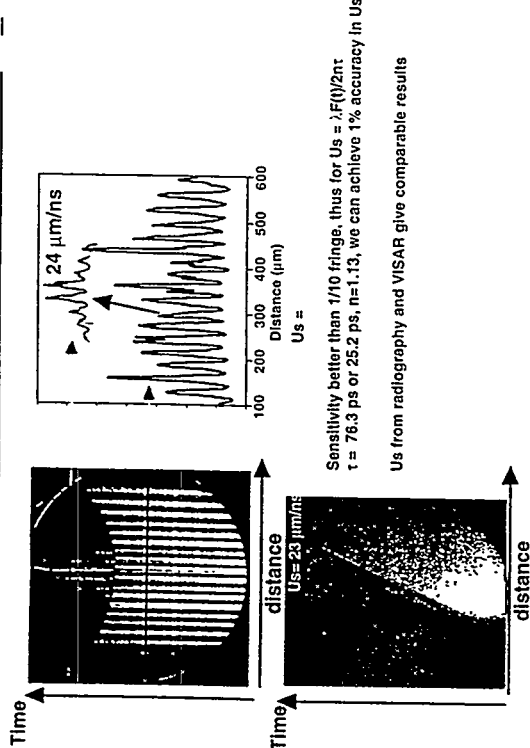
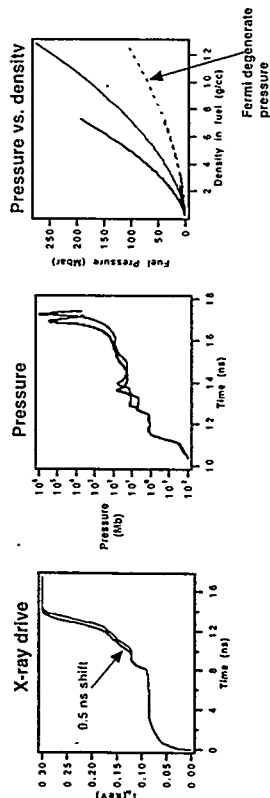


Figure 6-6. Tip of Target Insertion Cryostat

Shock velocity in D_2 is determined with VISAR by measuring fringe shifts



NIF target performance depends critically on shock timing

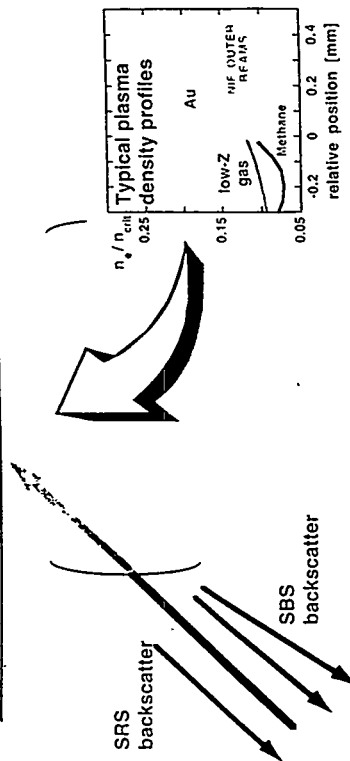


Blue drive profile gives neutron yield of 0.2 MJ

Red drive profile gives neutron yield of 10 MJ

Require shock timing to 10 ns

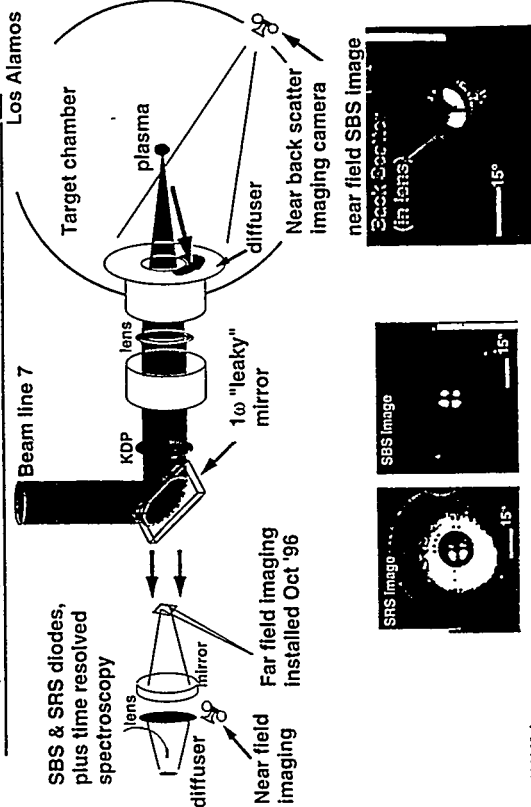
Lasers heating gas filled hohlraums encounter low-Z and Au plasmas with which they can interact



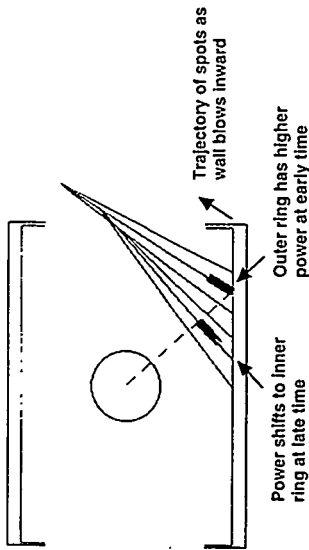
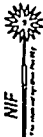
Lasers can stimulate waves in plasmas from which they can scatter or reflect. The plasmas in Nova and NIF have the potential for saturated levels of backscatter by Stimulated Brillouin Scattering (SBS - off ion sound waves), and/or Stimulated Raman Scattering (SRS - off electron plasma waves).

Scattered light affects energy balance and symmetry in hohlraums

One Nova beamline is configured to measure time and spectrally resolved scattered laser light



Beam phasing maintains centroid of spot emission at fixed angle to avoid symmetry swings at capsule



• Two ring irradiation also reduces 4th order Legendre distortion

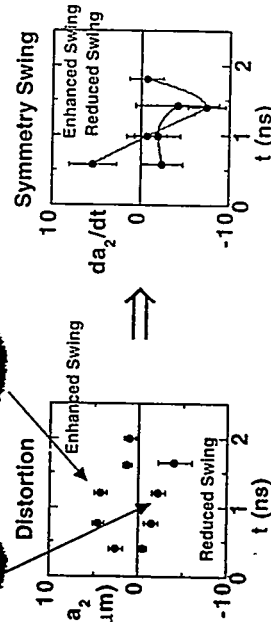
Backlit imploding foam balls* provide detailed evidence of time-dependent symmetry control

Omega Backlit foam ball images at $t \approx 1\text{ ns}$



Continuously measures:

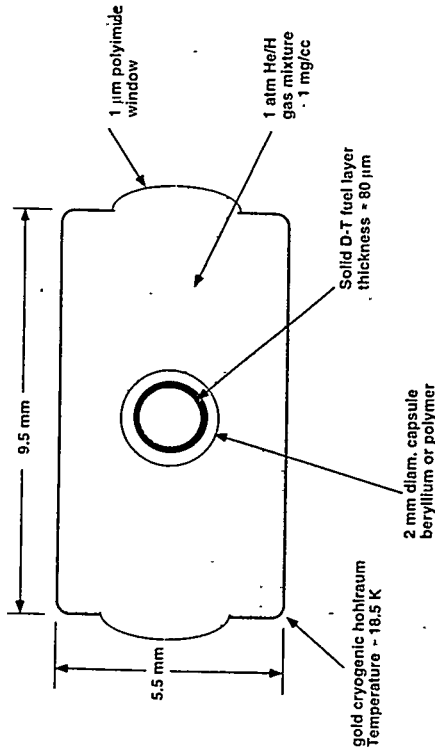
$$a_2(t) \propto \int_0^t P_2(t') dt'$$



*P. Amendt, S.G. Glendinning et. al. PoP (1997)

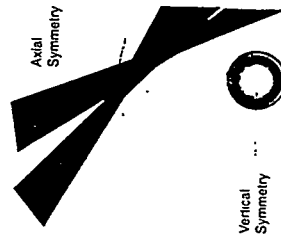
04JUN99/427

Indirect drive ignition targets have several parts



Characteristics of cryogenic hohlraums for the National Ignition Facility (NIF)

- Capsules: 2 mm ID with 160 μm wall CHX plastic or Be ablator
- DT layer: 80 μm thick uniform ice layer Layer thickness uniformity 1% Surface finish 0.5 - 1.5 μm rms
- Hohlraum: Gold 9.5 mm long 5.5 mm O. D. Thickness: 15 μm < t < 40 μm Windows: 1 μm polyimide film He + H₂ gas 1:1 atomic% mix Gas density of 0.8 - 1.5 mg/cc
- Temperature: 18.5 K nominal DT layer ΔT - 0.5 mK Layer ΔT uniformity 1% rms



1.1.54e-02 1.1.54e-02

Characterization of low density RF foams using optical (visible-UV) imaging

*O.J. Glembocki, S.M. Prokes, J.D. Sethian,
M.L. Rebbert, and C.R.K. Marrian*
Naval Research Laboratory, Washington, DC

T. Lehecka and Y. Chan
Science Applications International, Inc, McLean, VA

D.Schroen-Carey and C. Hendricks
Schafer Corporation, Livermore, CA

e-mail: glembocki@bloch.nrl.navy.mil

Introduction

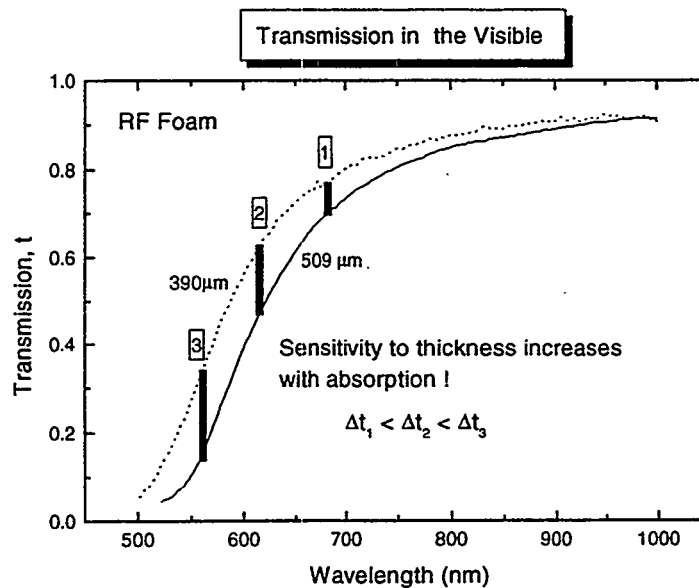
- **Key Issues:**
 - Direct drive target designs require low density foams in the ablator
 - NRL using RF foams for targets.
 - Require high degree of uniformity in
 - mass density and thickness
 - impossible to attain from simple inspection
 - because the foams are delicate, contact probes such as AFM and stylus thickness tools are destructive
 - Can optics probe target uniformities?
 - Optics are nondestructive
 - And can give rapid feedback

Methodology

- Optical absorption is directly proportional to:
 - density of electronic states
 - density of vibrational states
 - both are directly related to the mass density
- Light passing through absorbing medium is exponentially attenuated:
 - $I_t = I_0 e^{-\alpha x}$
 - I_0 = incident intensity
 - α = absorption coefficient
 - x = distance into absorbing medium
- Therefore measuring optical transmission through the target should give us a measure of the variation in the product of mass density with thickness

Methodology continued

- Sensitivity to thickness increases with absorption coefficient: $\Delta I_t / \Delta d = -\alpha I_0 e^{-\alpha d}$



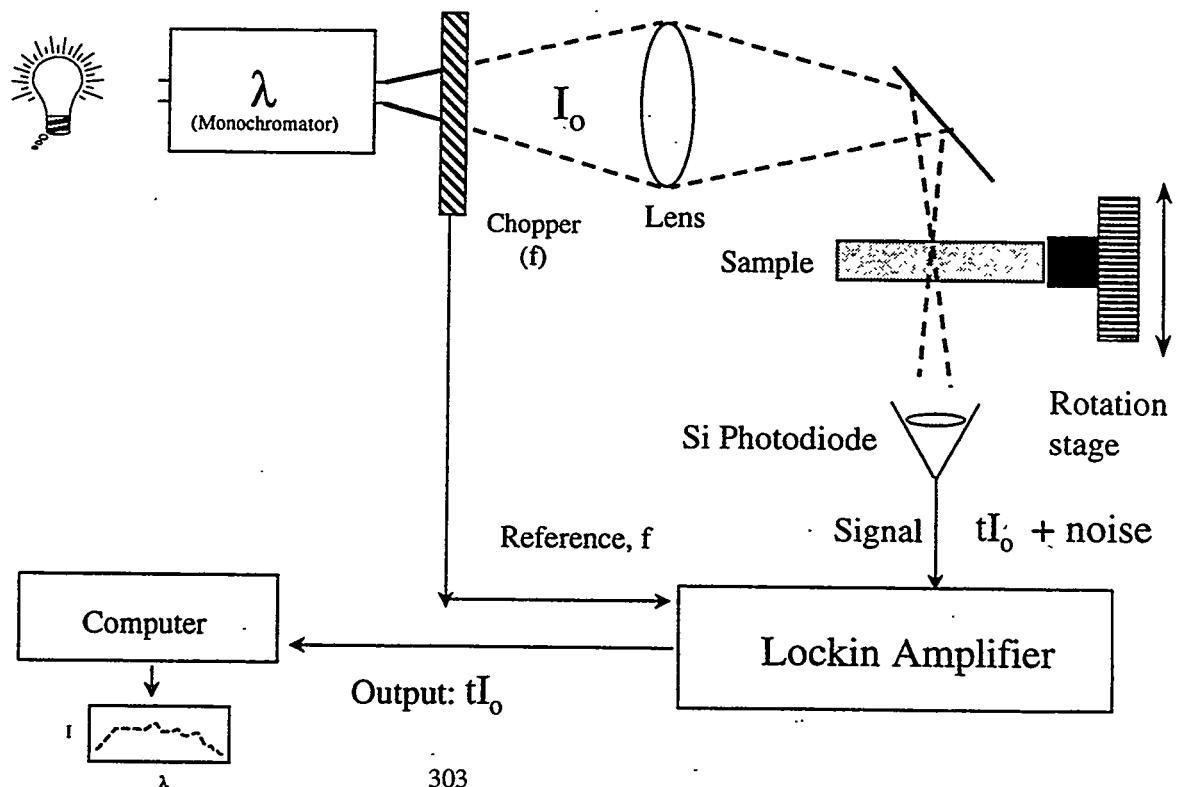
Methodology continued

- CCD camera technology allows us to image transmission over a large area.
- By combining the CCD with a microscope and monochromator, we can perform spatial maps of the optical absorption. This should give us a measure of the target uniformity.

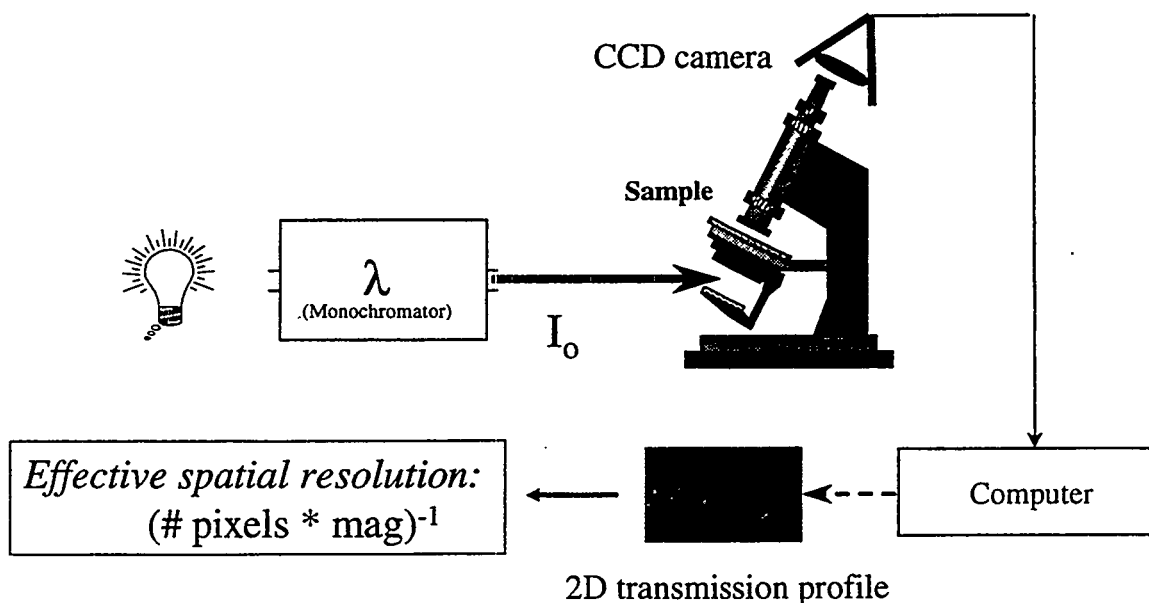
Issues

- What is the spatial resolution?
- What is the sensitivity to:
 - mass density variations?
 - thickness?

Transmission spectrometer



Imaging system for visible light



- For UV imaging we must use quartz optics and UV sensitive detectors

Experimental details

- Optical absorption:
 - Spex 1/4m double spectrometer
 - Si UV-enhanced photodiode
 - Halogen lamp
- Visible imaging
 - Bausch and Lomb 1/10m spectrometer set to 510nm
 - Halogen lamp
 - Olympus microscope
 - Quick Cam-2 CCD camera with adjustable gain and exposure time. 640x480 active area with 8bit intensity resolution.
- UV- imaging:
 - Hg lamp with pass band filter set to 351nm
 - Triple lens imaging optics
 - Star-1 CCD camera: 1024x1024 active area with 12 bit resolution

Foam thickness

foam
↓

← mold

- Microscopy

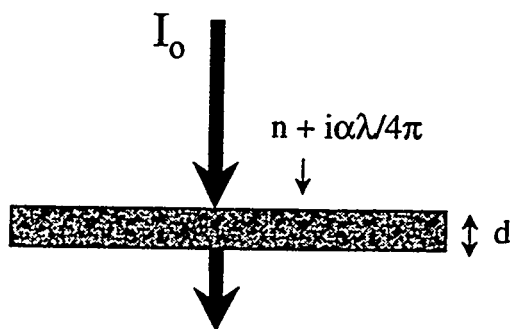
- Nikon microscope equipped with eyepiece micrometer
- Peel away mold
- Compare mold thickness to sample

	<u>Mold</u>	<u>Foam</u>
Microscope	230μm	60μm
Micrometer	200μm	na

	<u>Mold</u>	<u>Foam</u>
Microscope	300μm	275μm
Micrometer	355μm	na

- White light interferometry was also used as a check.

Calibrate sensitivity to thickness variations



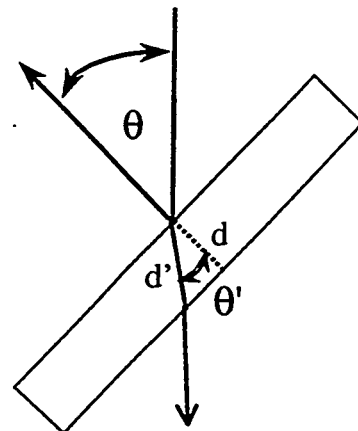
$$I_t = I_0 (1-R)^2 e^{-\alpha d} / (1-R^2 e^{-2\alpha d})$$

$$R = (n-1)^2 / (n+1)^2$$

For our foams:

$$n=1.3 \text{ \& } R \sim 0.02$$

$$I_t = I_0 e^{-\alpha d}$$



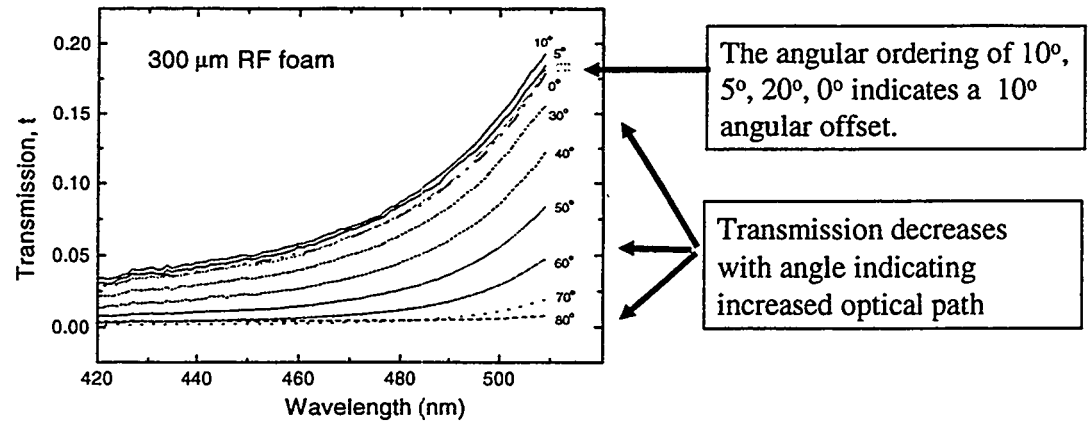
$$n \sin \theta' = \sin \theta$$

$$d' = d / [1 - (\sin \theta / n)^2]^{1/2}$$

$$I_t = I_0 e^{-\alpha d'}$$

transmission as a function of angle

- Let's vary angle of incidence to increase thickness



- We can easily discern 5° angular variations.
- This corresponds to a 2.2% change in thickness or 6.6 μm for a 300 μm thick.

Thickness variations from transmission data

- Varying angle has 3 effects.

The optical path increases:

$$d(\theta - \theta_0) = d / [1 - \sin^2(\theta - \theta_0) / n^2]^{1/2}$$

Area sampled by probe beam changes:

$$A(\theta - \theta_0) = A / \cos(\theta - \theta_0)$$

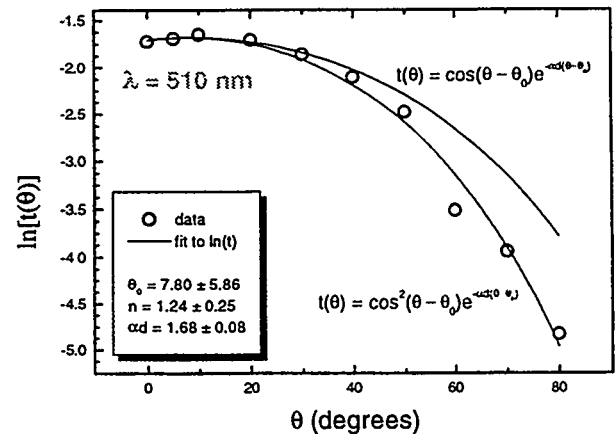
Area of absorbers changes (?)

$$A(\theta - \theta_0) = A / \cos(\theta - \theta_0)$$

- Transmission as a function of angle becomes:

$$t(\theta) = \cos^m(\theta - \theta_0) e^{-\alpha d(\theta - \theta_0)}$$

$$m = 1, 2$$



- Data agrees well with calculated behavior using reasonable values for index of refraction if we assume that area changes as $\cos^2$.

Thickness • mass density variations

- General case where α and d vary

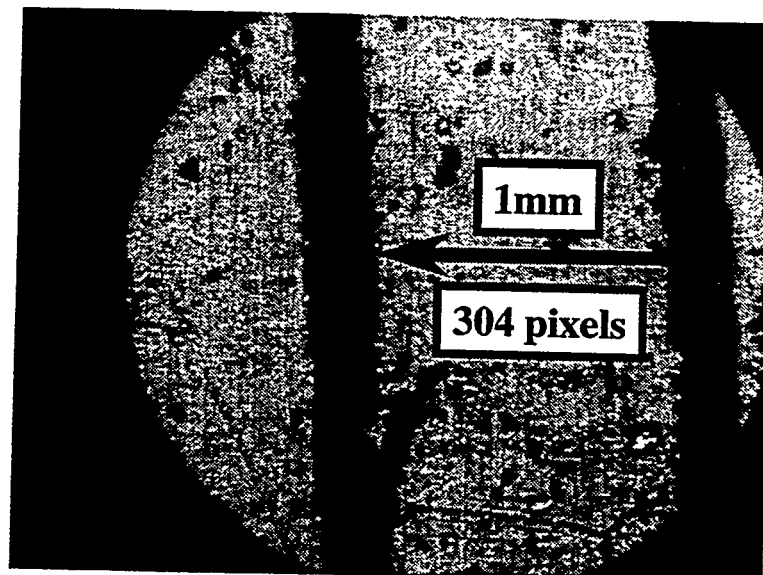
$$t_1 = e^{-(\alpha d)_1} = e^{-u_1} \quad t_2 = e^{-(\alpha d)_2} = e^{-u_2}$$

$$\ln\left(\frac{t_2}{t_1}\right) = -\Delta u = u_1 - u_2$$

$$\frac{\Delta u}{u} = \frac{\ln\left(\frac{t_2}{t_1}\right)}{\ln(t_2)} = \frac{\Delta \alpha}{\alpha} + \frac{\Delta d}{d}$$

Sensitivity governed by the absorption coefficient because $\ln(t_2) \sim \alpha$

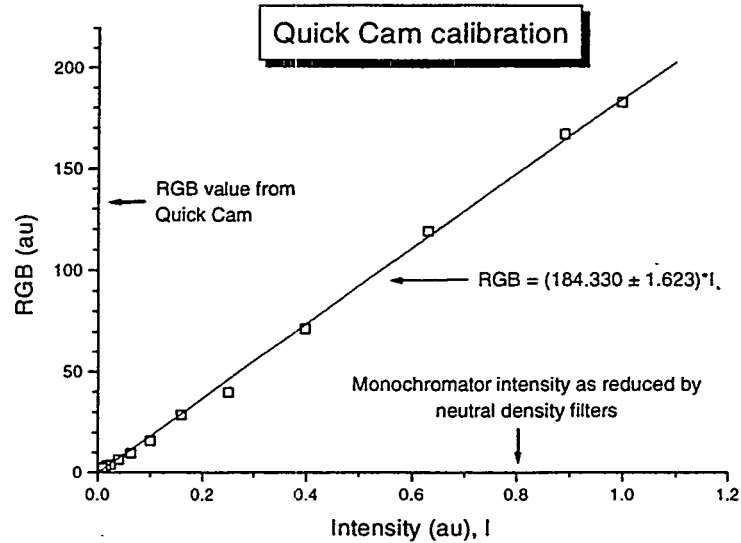
Lateral spatial resolution @ 16X magnification



Spatial resolution is : 3.28 μm

Quick Cam intensity calibration

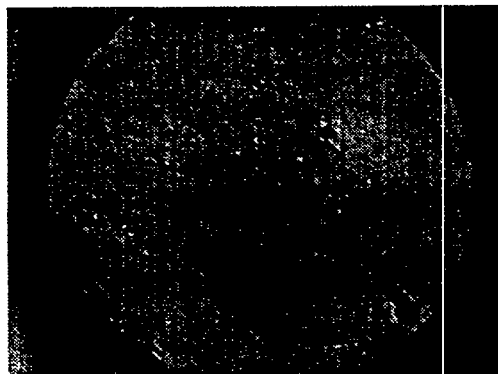
- Take images through microscope
- Use neutral density filters to reduce incident intensity



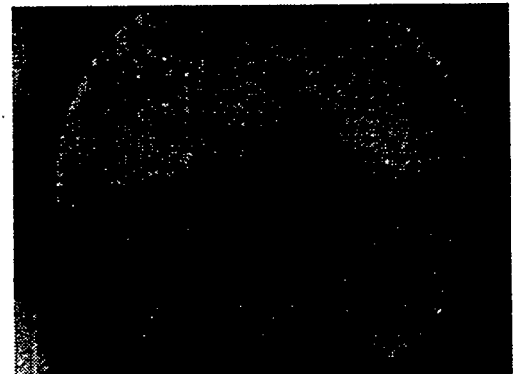
- RGB values are linear over 2 decades in incident intensity.

Transmitted light image using Quick Cam

- Wavelength = 510nm
- Intensity range of QC(RGB value) = 1 to 255
1 = black and 255=white

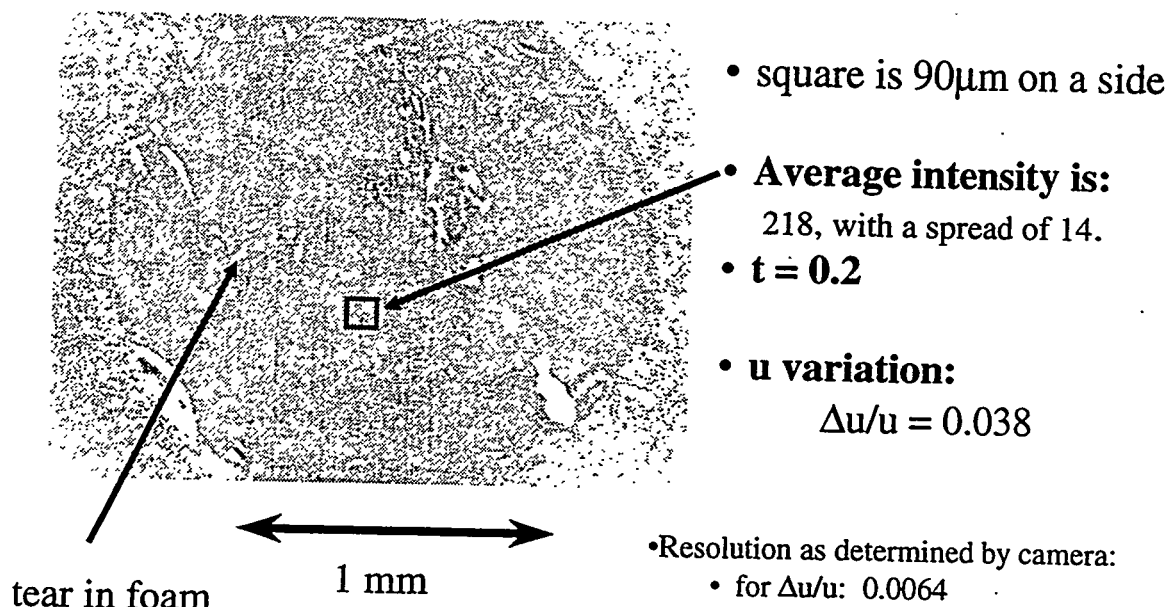


300 μ m foam

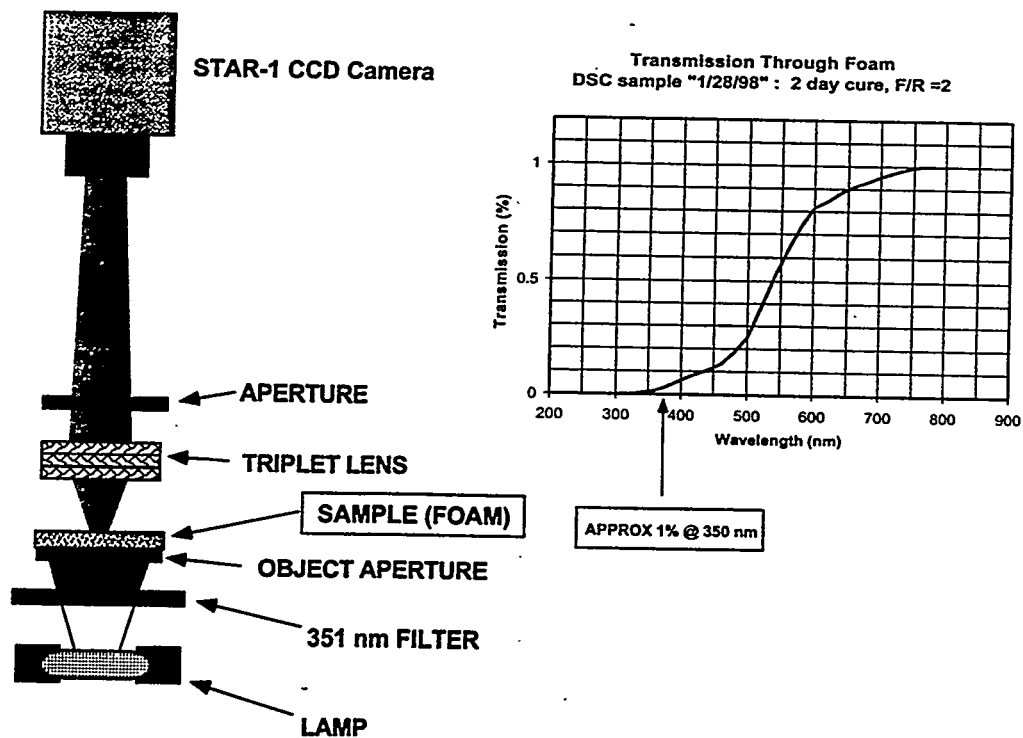


reference light (no foam)
attenuated by 100

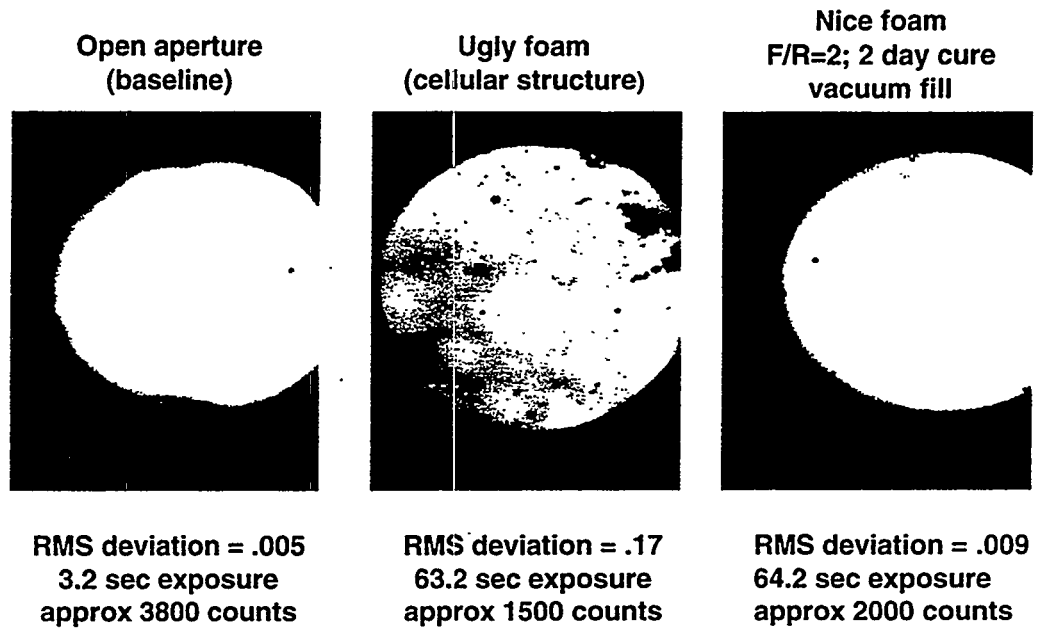
transmission profile



SETUP TO MEASURE UV TRANSMISSION THROUGH FOAMS



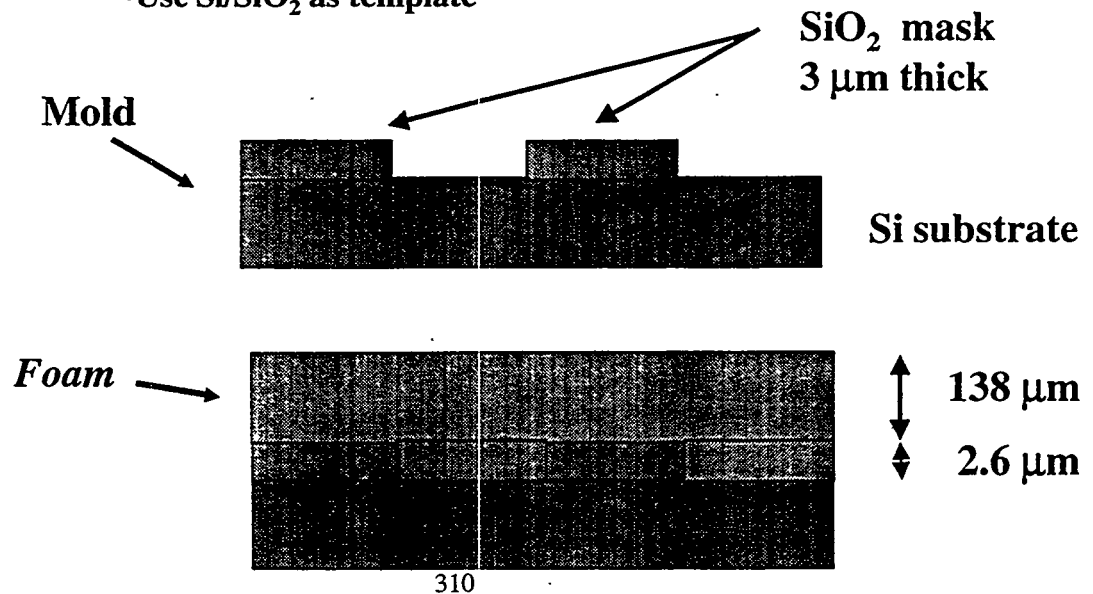
UV transmission through foams



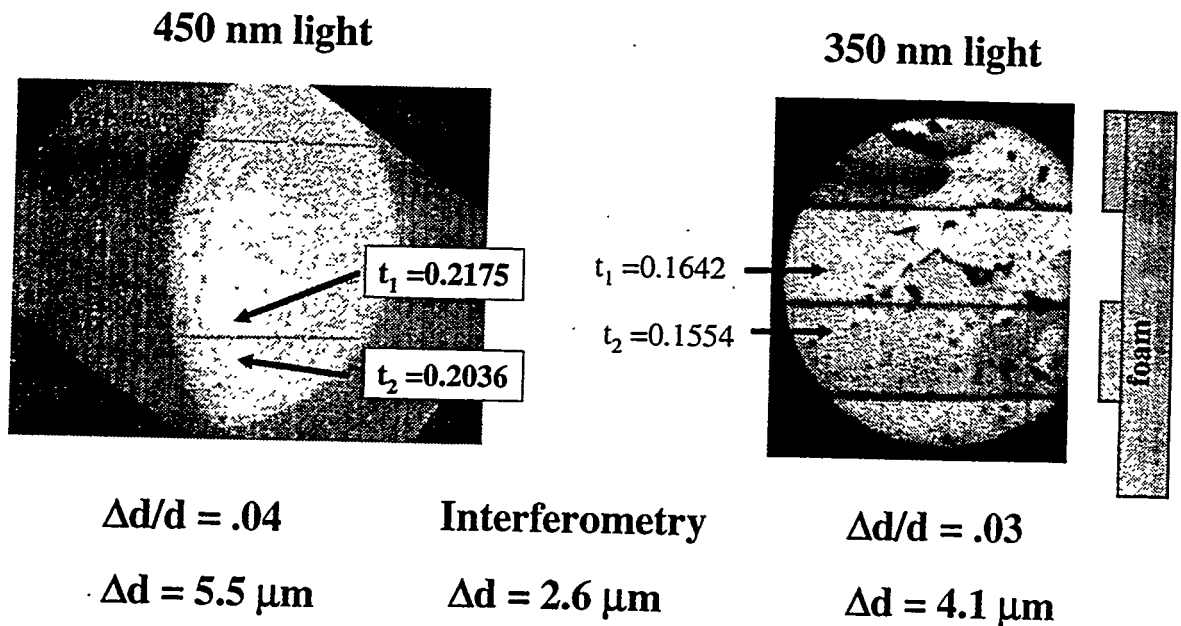
Still to be determined: Attenuation coefficient (I.E. calibration)

Calibration of thickness to transmission

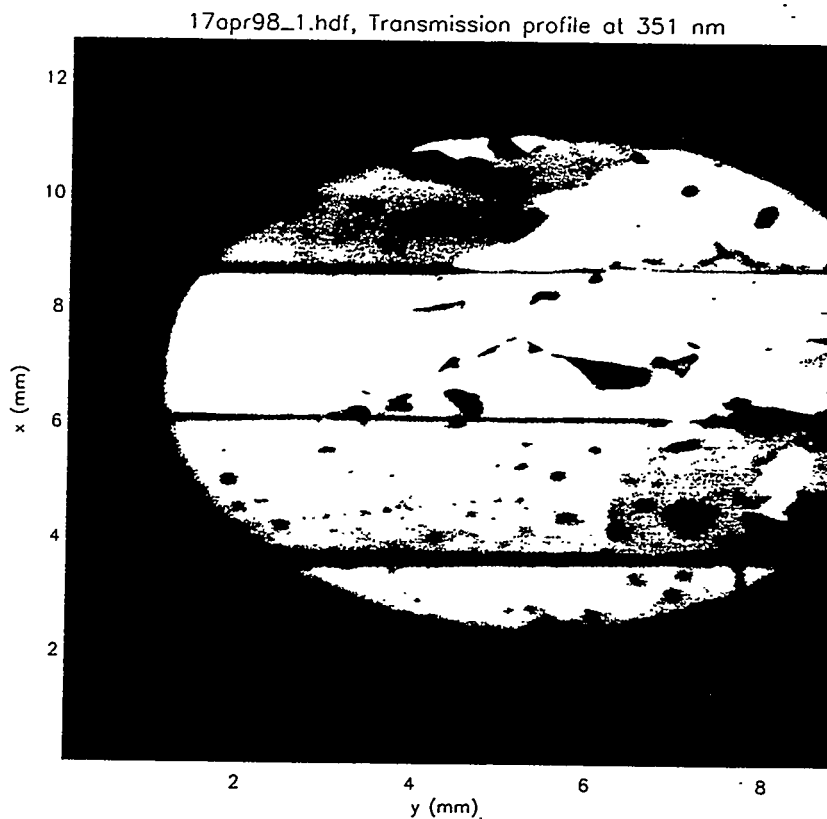
- Use a mold with a square wave pattern:
 - 3 μm amplitude
 - 400 nm period
 - Use Si/SiO₂ as template



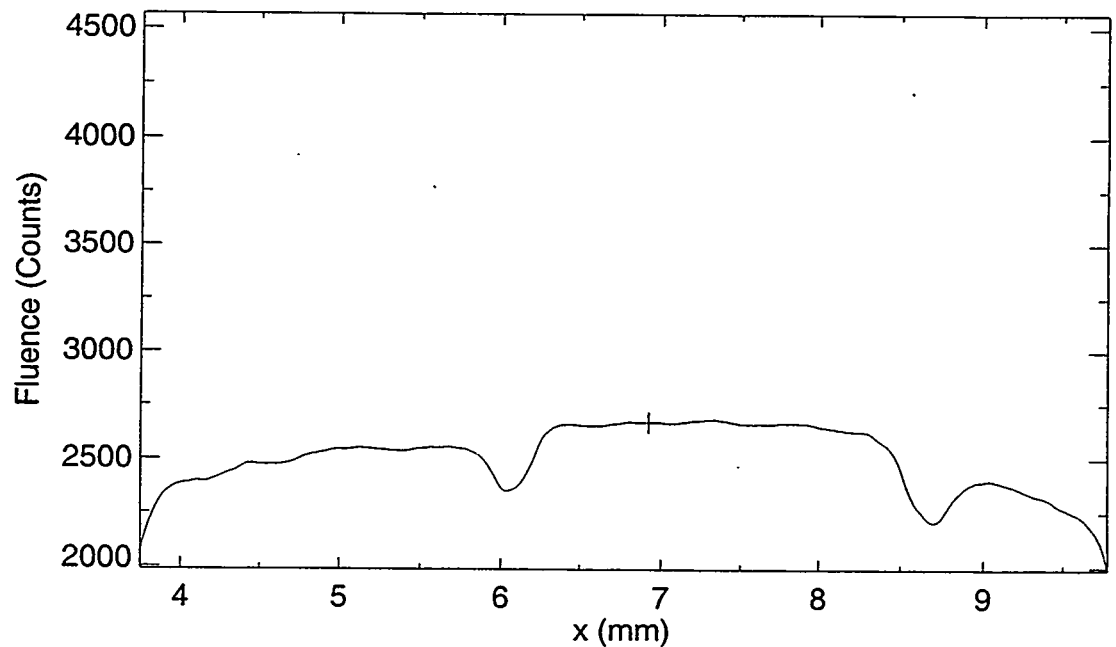
Results for 140 μm thick foam



- Our results agree with expected values for the step
- Contrast is much better for UV light.



ipr98_1.hdf, Transmission profile at 351 nm Model: Photometrics Star 1 X
 00e-05 m X0cal: 2.300000e-05 m X1start: 5.750000e-05 m X1cal: 2.300



wdisp:xval=6.92300,yval=2669.27,vval=2.34600(mm),hsmo=11,vbin=1

Conclusions

- Transmission is sensitive to (mass density)*thickness (u)
 - Sensitivity increases with absorption
 - Can easily detect several % variations in thickness
- Optical imaging of RF foams has been performed in visible and UV
 - We have calibrated the transmission with a square wave with a $3\mu\text{m}$ amplitude in a $140\mu\text{m}$ thick foam.
 - Theoretically, we can see variations of $0.02/\ln(t)$ in u in visible and $0.0025/\ln(t)$ in UV
 - Our foams range in $\Delta u/u$ from 0.009 to 0.17
 - UV imaging reveals cellular structure in non vacuum filled foams
 - Vacuum filled foams show best uniformity

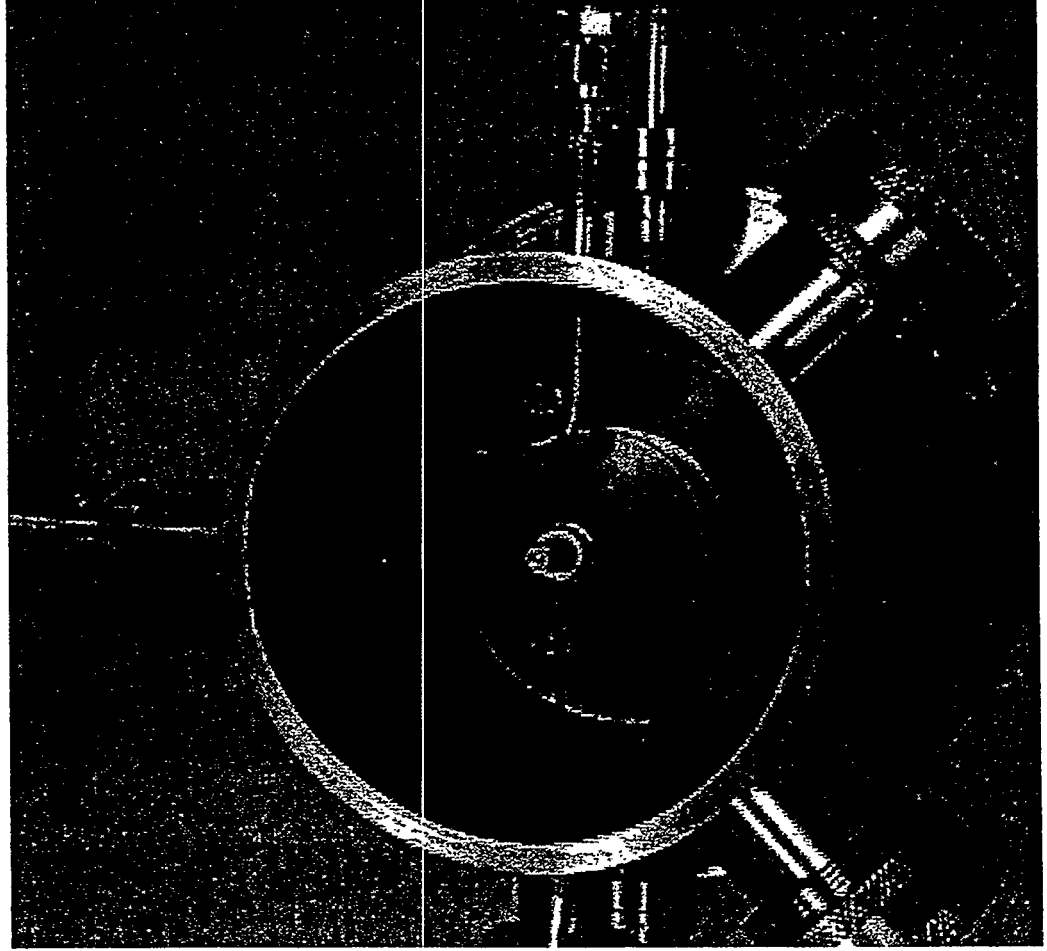
Spinning Pan Modification To GDP Coater For Improving Surface Quality

**D. Woodhouse, A. Nikroo
Fusion Group, General Atomics
P.O.Box 85608, San Diego, CA 92186-9784**

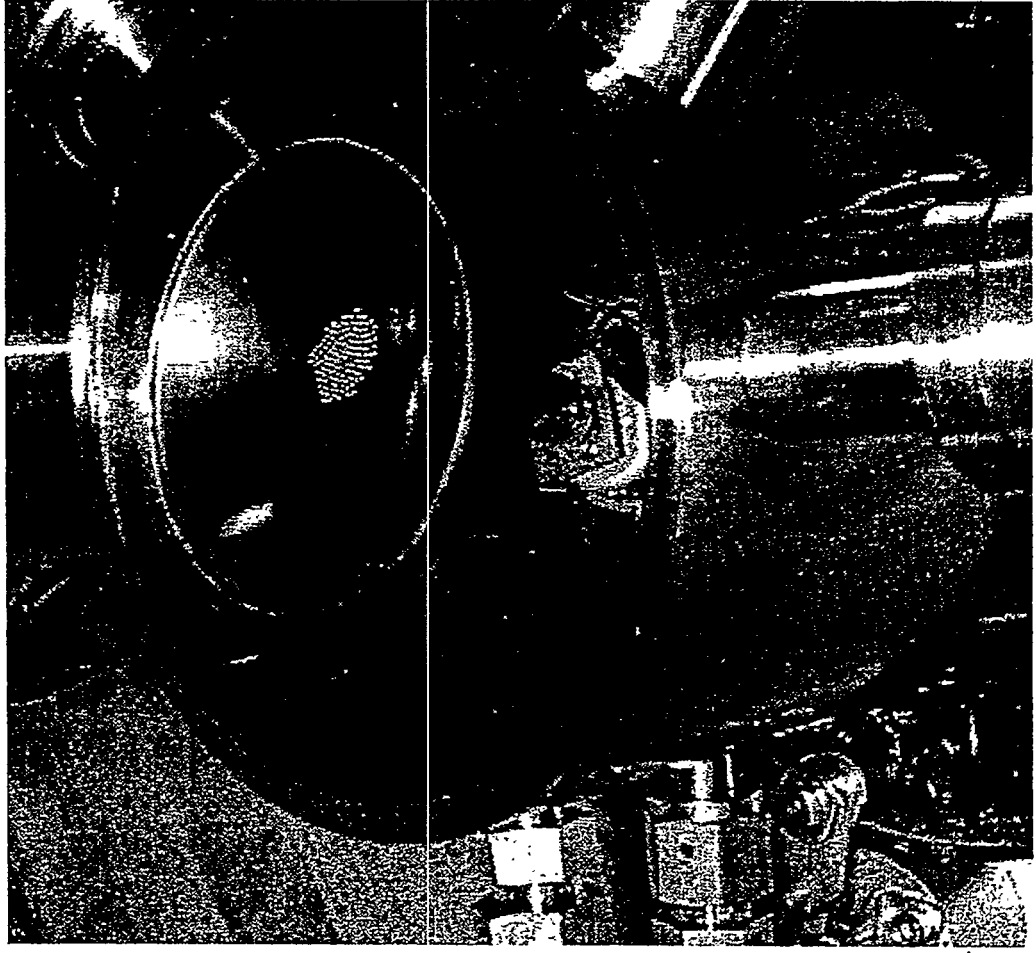
The surface finish of large size (greater than 1 mm diameter) ICF targets coated with GDP is influenced greatly by the method used to agitate the shells. The piezo electric bounce pan works well for small shells of low mass or a small number of larger shells. When coating production size batches of large diameter shells, however, the bouncer induces shell to shell collisions of sufficient force to knock off small chips of GDP coating. These chips initiate the growth of domes on the shell, resulting in poor surface quality. This poster shows that by placing the large shells in a spinning pan that is slightly tilted, a gentle rolling motion is induced that reduces the number and intensity of collisions caused by bouncing while exposing the entire shell surface evenly to the coating plasma. Utilizing the spinning pan allows a larger number of shells to be coated, while increasing the surface quality of the shells produced.

**This poster describes
modifications to the GDP coater
that, by
changing the method of shell
agitation, allow a larger number
of shells to be coated without
surface quality degradation.**

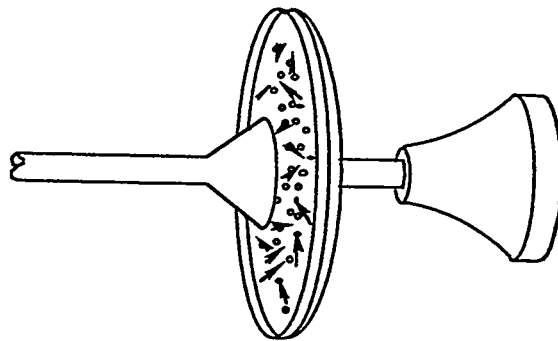
Existing Bouncer in GDP Coater
(Pan Removed)



Spinning Pan Installed in GDP Coater



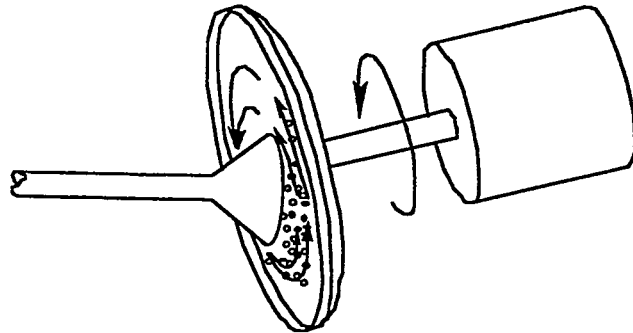
The Current System yields poor surface finish in large batches of large diameter shells



The piezo crystal actuated bouncer used in GDP coaters agitates the shells by small vertical movement of the coating pan. This action works well for shells of small size and low mass. As the shell size increases, collisions with other shells cause tiny flakes of recently deposited GDP to separate from the shell surface. These loose particles become growth sites for domes and beads resulting in a poor surface finish on large shells.



Why the spinning pan yields better surface finish



The spinning pan is tilted slightly from the vertical axis. As the pan rotates, gravity causes shells to constantly roll 'downhill', seeking the low point in the coating pan directly under the plasma tube. This exposes the entire shell surface evenly to the coating plasma. The shells also roll smoothly in one direction, reducing the intensity of shell to shell collisions.



Two Possible Approaches

We have been able to improve the surface finish of large shells coated with the bouncer pan by reducing the bouncer agitation strength which tends to produce non-uniform coatings. Reducing the number of shells per batch to very few also improves surface quality but is not cost effective given the length of coating runs required for NIF size targets.

Experiments using the spinning pan have shown that surface finishes as shown in the right hand photo can be expected, even though the batch contains many times the number of shells. This approach appears to be more efficient.

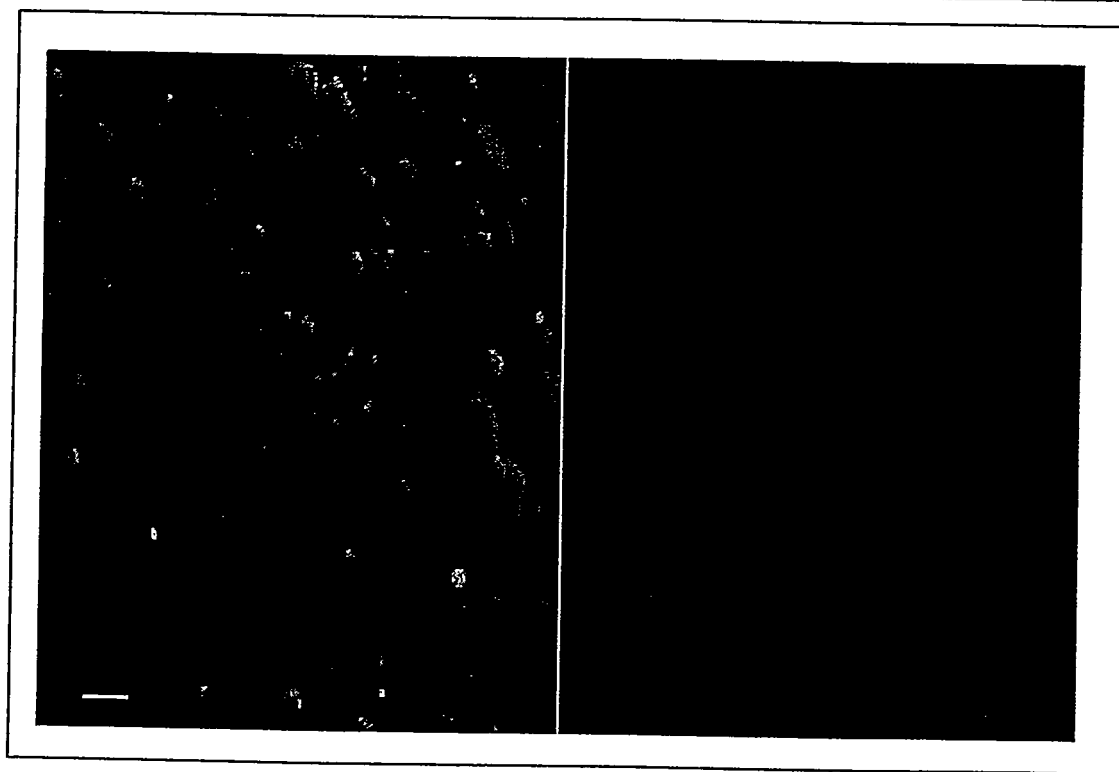


Spinning Pan Hardware

The spinning pan hardware consists of a small electric motor and gear reduction unit located entirely within the base of the coating chamber. Power is supplied by an external DC variable voltage power supply enabling the rotational speed to vary in order to provide sufficient agitation for the shells.

The motor assembly is mounted on a support rod, formerly used as the tapper in the bouncer equipped GDP coater. The support rod enables the coater operator to make angle and position adjustments during a coating run and can also be tapped to dislodge shells that may be sticking to the pan.

Surface Finish Comparison



Scale Bar = 10 microns



The SEM photographs above show surface features of similar batches of 2mm PAMS shells coated with 12 microns of GDP. In the left hand photo, 12 shells were coated in a bounce pan. The right hand photo is from a batch of 12 shells coated in a spinning pan.

The shells coated in the bounce pan are covered with domes while the spinning pan coated shells remain nearly free of domes while having a very uniform coating thickness around the shell.

Concerns with the modification

Rotational speed of the pan is critical to the process. The pan must turn rapidly enough to overcome the tendency of shells to resist rolling, but not so fast as to cause shells to be ejected from the pan. Required speed may vary as the shells gain mass and size and must be monitored throughout the coating run.

We have experienced a few cases of the motor siezing during coating runs of long duration due to running the motor above recommended current levels. New motors of higher capacity have been ordered and are expected to eliminate this problem.



Conclusions

The spinning pan modification allows a larger number of shells to be coated at one time while improving the surface finish quality. As we move toward production of larger diameter (NIF size) targets, the spinning pan may contribute to cost reduction in the coating process without compromising product quality.

RECENT PROGRESS IN THE AREA OF MICROENCAPSULATION AT LLNL

Masaru Takagi, Steve Buckley and Robert Cook

**Lawrence Livermore National Laboratory
P.O. Box 808 L-474
Livermore CA 94550**

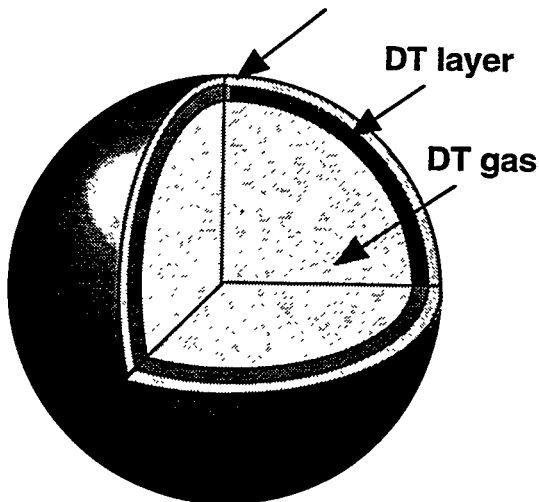
**12th Target Fabrication Meeting
Snow King Resort
Jackson Hole, Wyoming
April 19-23, 1998**

**Work performed under the auspices of the US Department of Energy
by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.**

Current NIF Target Specifications for Capsules



Ablator ; Polyimide, Cu-doped Be



**Material : Polyimide
Cu-doped Be**

Diameter : 2 mm

Wall thickness : 150-200 μ m

Sphericity : > 99.95 %

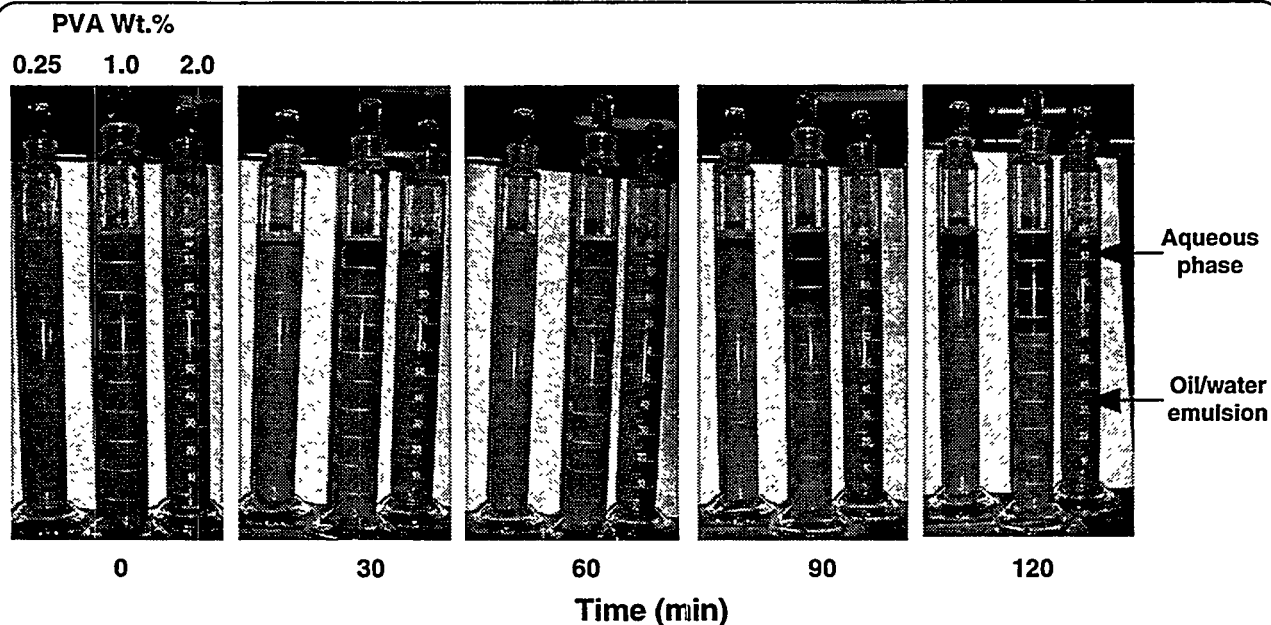
Relative Interfacial Tension can be Approximately Determined



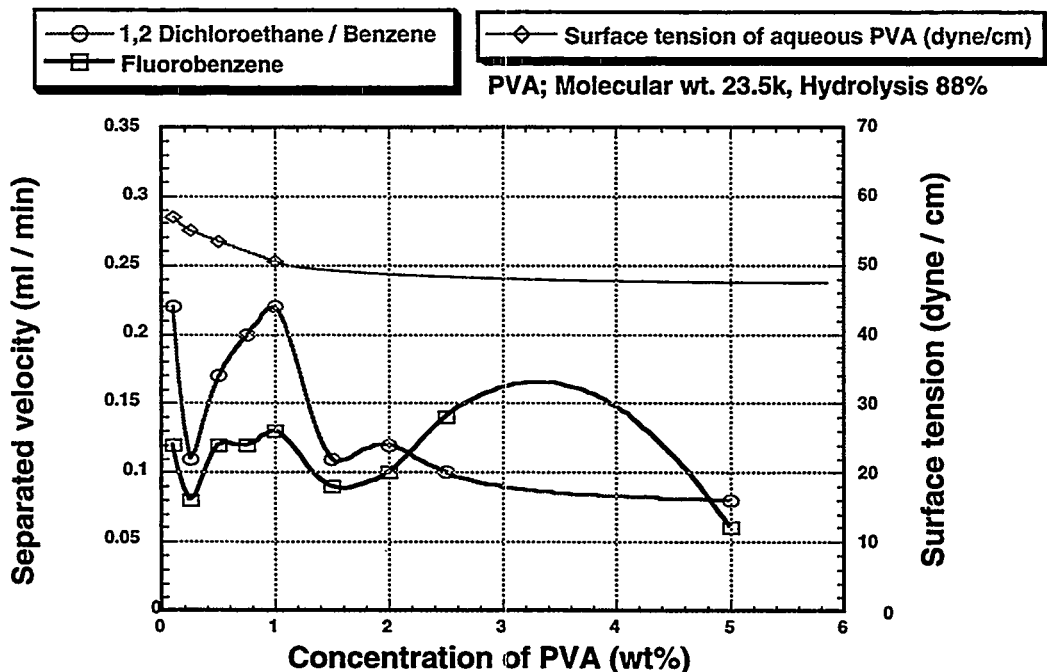
Method: Aqueous and oil phases are mixed and the time dependence of their separation is measured.

Faster separations are due to larger interfacial tensions

- We find that 1,2-dichloroethane / benzene has a greater interfacial tension than fluorobenzene



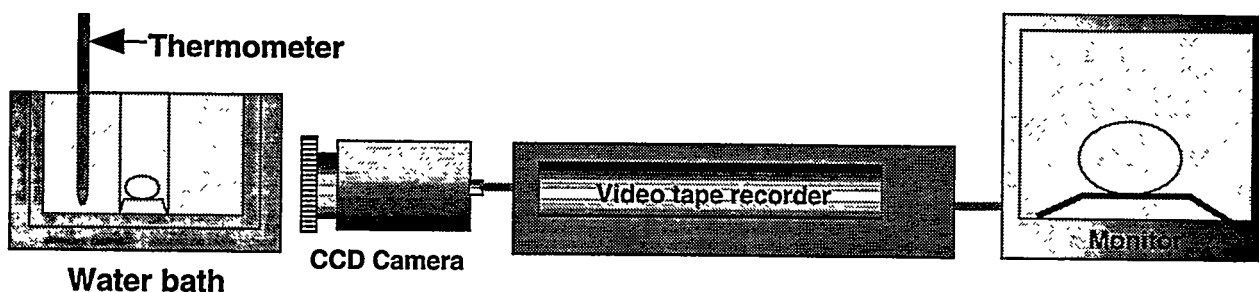
Separation Velocity of W Phase Changes with the Concentration of PVA



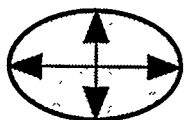
A Direct Measurement of Interfacial Tension uses Gravitationally Induced Droplet Deformation



Experimental method



Calculation method



$$\text{m.o.o.R.} = 2\left\{(r+\epsilon) - \frac{r^3}{(r+\epsilon)^2}\right\} = \frac{2\delta\rho g r^3}{\gamma}$$

Where

m.o.o.R.; difference between maximum and minimum ellipsoid (cm)

r; radius (cm)

ϵ ; positive deformation $\epsilon = \frac{\delta\rho g r^3}{3\gamma}$

$\delta\rho$; density difference between droplet and surrounding bath (g/cm^3)

g; gravitational constant (cm/sec^2)

γ ; interfacial tension (dyne/cm)

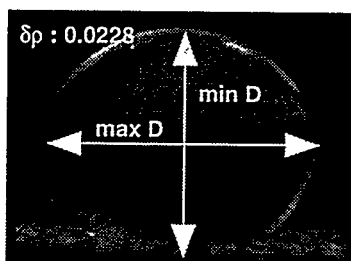
The Interfacial Tension of Mixture Solvents with 1,2Dichloroethane and Benzene is Higher than Fluorobenzene



The interfacial tension measured using sessile drop method.

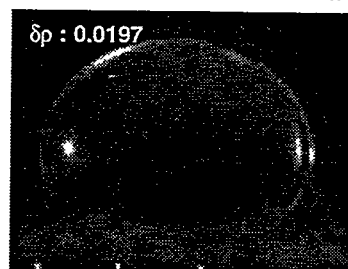
Fluorobenzene

In Water



Interfacial tension γ ; 6.8 dyne/cm

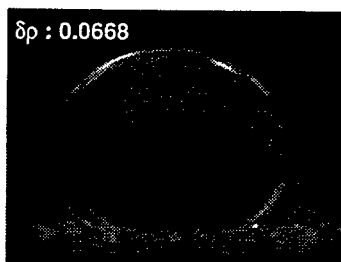
In 2.5 wt% PVA Solution



Interfacial tension γ ; 2.9 dyne/cm

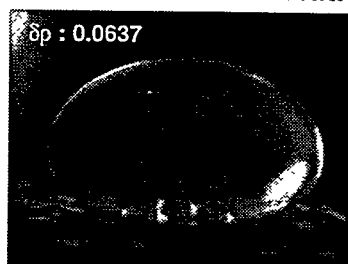
1,2Dichloroethane / Benzene

In Water



Interfacial tension γ ; 34.8 dyne/cm

In 2.5 wt% PVA Solution

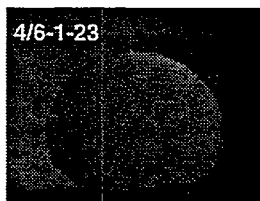


Interfacial tension γ ; 11.9 dyne/cm

Interfacial Tension is Dependent on Solvent System and Temperature



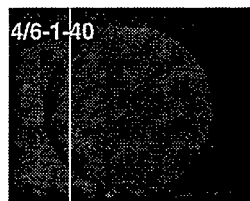
1 wt% PVA, 1.5wt % NH_4Cl Vs Fluorobenzene



$\delta\rho$; 0.0155, γ ; 4.0



$\delta\rho$; 0.012, γ ; 7.4

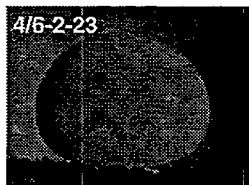


$\delta\rho$; 0.0045, γ ; 11.9

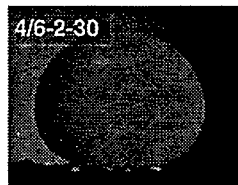


$\delta\rho$; 0.001, γ ; -

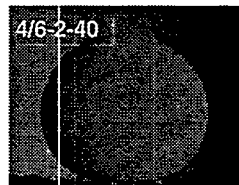
1 wt% PVA, Vs Fluorobenzene



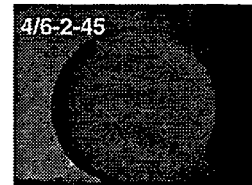
$\delta\rho$; 0.02, γ ; 4.0



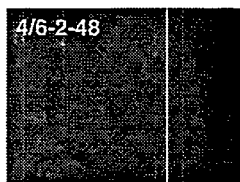
$\delta\rho$; 0.0145, γ ; 5.0



$\delta\rho$; 0.009, γ ; 8.3



$\delta\rho$; 0.0055, γ ; -

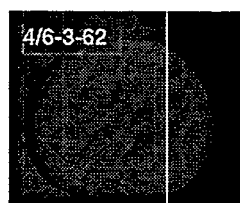
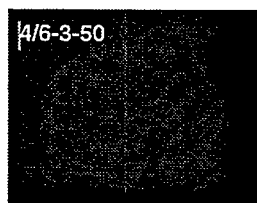
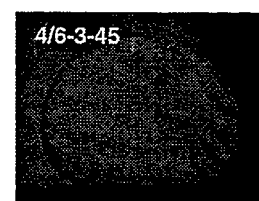
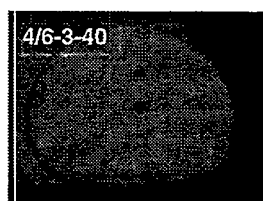
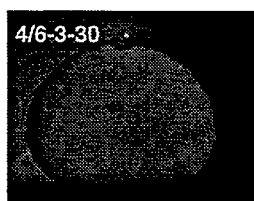


$\delta\rho$; 0.003, γ ; -

Interfacial Tension is Dependent on Solvent System and Temperature



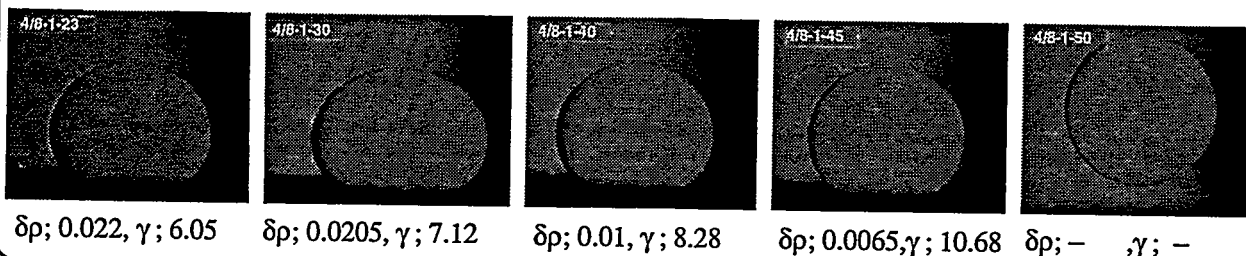
1 wt% PVA, 1.5 wt% NH_4Cl Vs 11wt% PAMS dissolved in Fluorobenzene



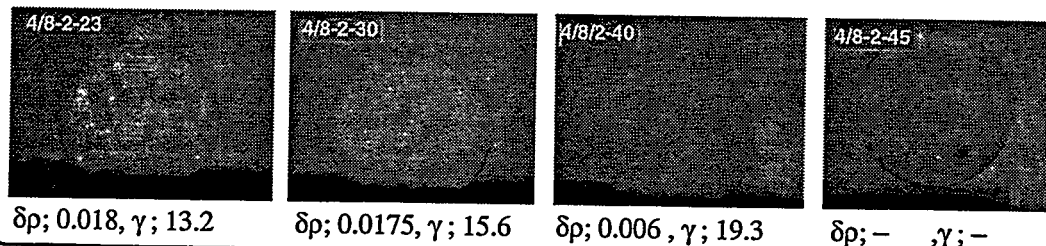
Interfacial Tension is Dependent on Solvent System and Temperature



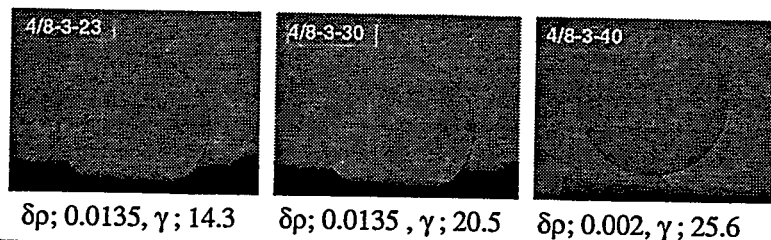
0.1 wt% PVA Vs Fluorobenzene



0.1 wt% PVA, 1.5 wt% NH_4Cl Vs Fluorobenzene



0.1 wt% PVA, 1.5 wt% CaCl_2 Vs Fluorobenzene



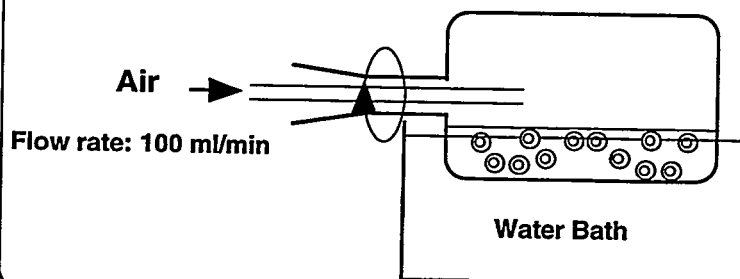
Stirring Methods for Achieving High Wall Thickness Uniformity and High Sphericity



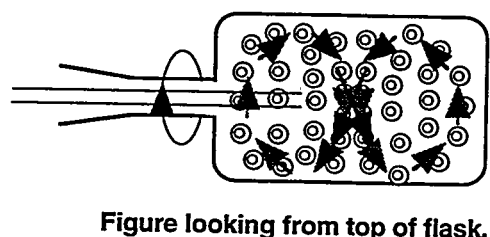
Key is stirring of null gravitational state.

Using Cylinder type flask

100 revolutions per minute



Motion of emulsion



Result;

- The centering of O/W emulsion to make uniform O phase is quicker than the propeller stirring method.
- Drying time is less.
- O / W emulsion isn't damage by a propeller.
- Yield of shells is good.

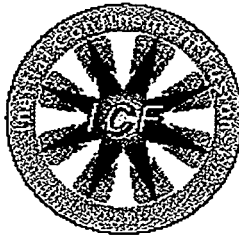
PAMS Using 1,2-Dichloroethane/Benzene Solvent System

Run Conditions		Data		Calculations	
polymer	wt%	Major Axis μm	Minor Axis μm	Angle In deg	Ave Diam μm
26K PAMS	20wt%	2568.0	2566.1	0	1.9
1,2DCE/Benzene	Core water intact	2569.9	2566.5	-45.95	3.4
PVA		2569.2	2566.9	0	2.3
		2525.3	2520.4	-58.75	4.9
		2523.9	2521.8	0	2.1
		2523.2	2519.2	-32.71	4.0
		2537.3	2536.6	0	0.7
		2538.9	2536.7	0	2.2
		2538.2	2536.3	0	1.8
		2558.7	2557.1	0	1.6
		2559.0	2556.1	-52.95	2.9
		2560.2	2557.1	-57.89	3.1
		2581.7	2578.9	79.87	2.8
		2580.8	2580.1	0	0.7
		2582.2	2578.9	-30.81	3.2
		2567.7	2566.1	0	1.6
		2568.0	2566.2	0	1.8
		2567.8	2566.4	0	1.4
		2564.8	2563.7	0	1.1
		2567.7	2565.8	0	1.9
		2575.3	2573.3	0	1.9
		2579.1	2568.0	-35.8	11.1
		2538.7	2536.7	0	2.0
		2537.8	2535.5	0	2.2
		2566.2	2564.1	0	2.2
		2566.3	2564.5	0	1.8
					0.0
Group Ave=					#DIV/0!

PAMS Using Fluorobenzene Solvent System

Run Conditions		Data		Calculations	
polymer	wt%	Major Axis μm	Minor Axis μm	Angle In deg	Ave Diam μm
26K PAMS	20wt%	2153.713	2152.816	0	1.1
Fluorobenzene	Core water intact	2272.748	2269.625	-79.1921	3.1
PVA		2169.449	2148.875	78.3855	19.6
		2401.293	2365.399	-24.2911	35.9
		2397.392	2374.23	12.0384	23.2
		2381.374	2378.92	5.1988	2.8
		2529.396	2522.311	54.41981	7.1
		2567.239	2563.843	-8.302339	3.4
		2563.804	2555.475	-24.36371	8.3
		2513.039	2485.623	86.688	27.4
		2512.54	2506.282	-65.0795	6.3
		2501.613	2499.561	0	2.1
		2478.984	2463.996	43.4722	15.0
		2525.783	2483.013	-43.8911	42.8
		2491.801	2466.144	40.295	25.7
		2343.353	2341.871	0	1.5
		2343.055	2340.779	0	2.3
		2340.505	2339.886	0	0.8
		2304.784	2302.975	0	1.6
		2307.238	2305.499	51.5302	1.7
		2305.035	2304.013	-20.3661	1.0
		2129.203	2127.212	0	2.0
		2130.778	2122.538	0	8.2
		2127.933	2123.982	-42.1185	4.0
		2085.577	2084.516	-34.5197	1.1
		2085.721	2084.286	-14.8319	1.4
		2087.071	2084.713	0	2.4
		2106.287	2101.437	-34.5197	4.8
		2105.873	2103.177	-14.8319	2.7
		2105.831	2104.275	0	1.6
Group Ave=					#DIV/0!

Strength Measurements of Polyimide Coatings

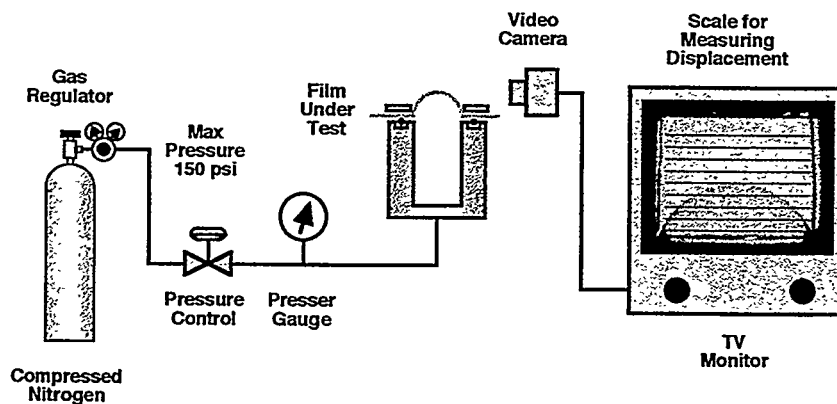


Mike Saculla, Ed Hsieh, Steve Letts,
Chad Roberts and Greg Rogers

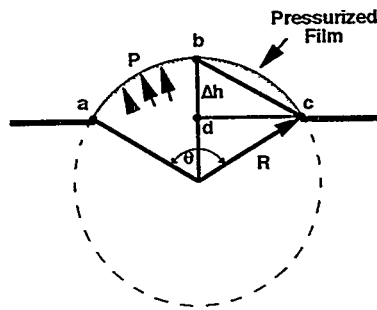
University of California
Lawrence Livermore Nat'l Lab
P.O. Box 808
Livermore, CA 94550

Target Fabrication Meeting 1988
Jackson Hole, Wyoming
April 20 - 23, 1988

Gas burst tensile test apparatus



By recording the pressure and the radius of curvature at burst, we obtain the tensile strength of the film



$$\sigma = \frac{P R}{2 t}$$

where σ = tensile stress in film
 R = radius of curvature
 P = pressure on film
 t = thickness of film

Δh = displacement
 $a - c$ = window diameter

Presently we measure Δh to calculate R .

Procedures have been established to determine R from freeze frame recording, simplifying the calculation.

Derivation of pressure/stress equation on film



$$\begin{aligned} F &= \int_0^\delta f'_\theta \\ &= \int_0^\delta P 2 \pi R^2 (\cos \theta)^2 \sin \theta \Delta \theta \\ &= \frac{2}{3} P \pi R^2 (\cos \delta)^3, \end{aligned} \quad \text{Equation 1}$$

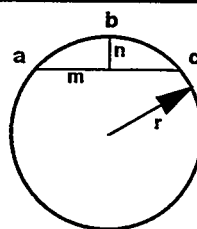
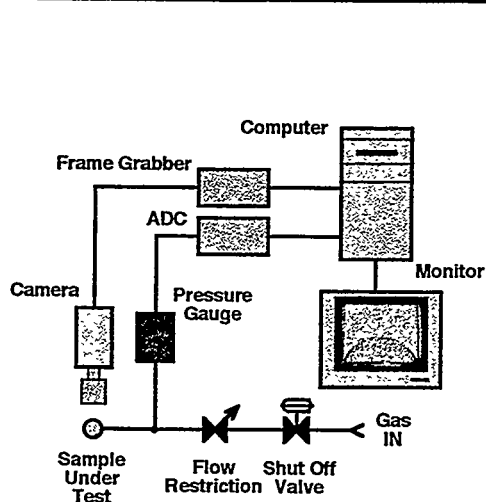
where $\delta = \cos^{-1} \left(\frac{R - \Delta h}{R} \right)$.

$$\sigma_\theta = \frac{P_\theta R}{2 t},$$

σ_θ = tensile stress at points with angle θ to verticle

$P_\theta = P \cos \theta$, and P is from Equation 1

Automated method of recording film burst



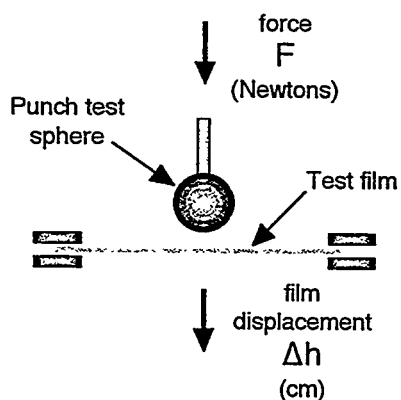
$$r = \frac{n^2 + (m^2 / 4)}{2 * n}$$

The radius (r) of a circle can be defined by selecting three points (a,b,c) along it's curvature. Computer codes allow a user to select three points on the saved image of a deformed film. The radius is then calculated. The pressure at burst time is also recorded by the computer.

Punch test was performed using Instron instrument for tensile stress measurement

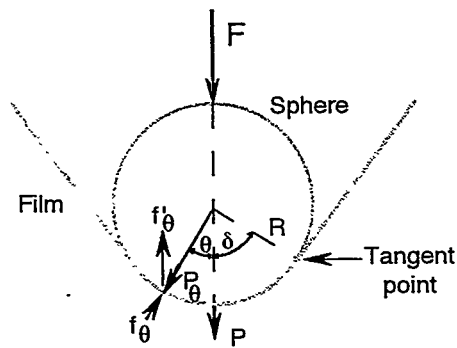


Instron model 4201
stress / strain
instrument



F and Δh are continuously monitored by the Instron machine

Pressure and force on film and sphere



F = total force pushing on sphere

P = pressure on film at the highest penetration point ($\theta = 0$)

P_θ = pressure at point θ degrees from verticle
= $P \cos \theta$

f_θ = reaction force from film pushing against the sphere, always pointing toward the center of the sphere
= $P_\theta * (\Delta \text{area})$
= $P \cos \theta * (2\pi R^2 \sin \theta \Delta \theta)$

f'_θ = verticle component of f_θ
= $f_\theta \cos \theta$

δ = angle at burst pressure between the tangential point at the film with the verticle

Basic assumptions in calculating tensile stress from Instron measurements



- ◆ Using a lubricated punch test sphere there is negligible friction between the surfaces of the sphere and film.
- ◆ The pressure exerted by the sphere on the film at angle θ from the direction of force is $P \cos \theta$, where P is pressure at $\theta = 0$.

Influence of Blowing Agent Concentration on Large (2mm) Polystyrene Shells Formation.

Yuriy A. Merkul'ev, Aleksander A. Akunets, Valeriy M. Dorogotovtsev, Sergey A. Startsev, Aleksander P. Turivnoy, Lebedev Physical Institute, Moscow, Russia,

Abstract. Influence of blowing agent concentration on polystyrene shell formation from solid granules in drop tower furnace are discussed. The concentration of blowing agents (solvent) has typically been 2 to 5 mass %, and under these conditions high temperature and low pressure in the furnace is necessary for polymer shells formation. We have found both computationally and experimentally that increasing of blowing agent concentration allows us to produce a high yield of large shells at lower furnace temperatures. An important benefit of the lower furnace temperature is a reduction in thermally induced polymer degradation which results in fragile shells. In our report we will discuss both the experimental results and the agreement of these results with our computational modeling studies.

The laser fusion national projects of different countries have goal of creation of laser with 0.2-2.0 MJ pulse. The polymer capsules with high pressure of DT-fuel are basis of targets for laser experiments. The shells – capsules with 1-3 mm diameter must have high sphericity, small wall thickness deviation and smooth surface. The scientific group of the Department of Neutron Physics at the Lebedev Physical Institute has been involved in the production of targets for ICF experiments for more than 25 years. During 20 years LPI target group had been using the method of polymer shell formation from solid granules containing the blowing agents. High quality polystyrene shells with diameter up to 1.5 mm have been fabricated in drop tower furnace and in ballistic furnace. Besides mathematical model and simulation codes for shell formation processes description were created.

Unfortunately, large shell fabrication requires technological condition which gives rise to complicated processes: hot zone temperature raising leads to polymer degradation, increased granule diameter is connected with numerous nucleation and foam formation etc. Besides good shells' yield goes down because of appearance of asymmetric particles, which cannot be explained in one-dimensional model. The blowing agent concentration rise is one of the ways to achieve hot zone temperature decreasing.

The primary activity was experimentation with drop tower furnace with new 1.5 m hot zone, focusing on producing of polystyrene shells with maximum diameter from solid granules, similar produced early granules. Optimal temperature and pressure (He-Ar mixture) gas were found for formation of large (about 2 mm) shells at 1.5 m hot zone. The shells with diameter up to 2.3-2.5 mm were fabricated, but its had not target quality. The good shells had diameter to 1.9 mm, but had dust on surface.

The basic defect of the technology of large (diameter 0.7-0.8 mm) solid granules blowing was high (1100°K - 1200°K) temperature of polystyrene shell formation. We began to experimentally and computationally research a influence of high (8-16 mass %) concentration of blowing agents on technological conditions of polystyrene shell formation. The experiments have been fulfilled on the drop tower furnace, because statistical errors were small (shells quantity was significant).

The results of this experiments is nest:

1. Solvent concentration increasing from 4 mass % to 8 mass % was raised the good shell yield to 3-4 times,
2. Shells with diameter up to 3.3-3.5 mm were fabricated, but its had not target quality. The good shells had diameter to 2.2 mm,
3. Optimal temperature of the polystyrene shell formation was decreased on 100°K - 150°K at solvent concentration increasing,
4. Computational results have been agreed qualitatively with experimental dependence and predicted decreasing of optimal temperature of the polystyrene shell formation up to 800°K and mass loss reduction at solvent concentration increasing to 16-20 mass %.

Summarizing obtained result, we can affirm that goal results - production conditions of good 2mm shells are real at solvent concentration increasing to 12-16 mass %.

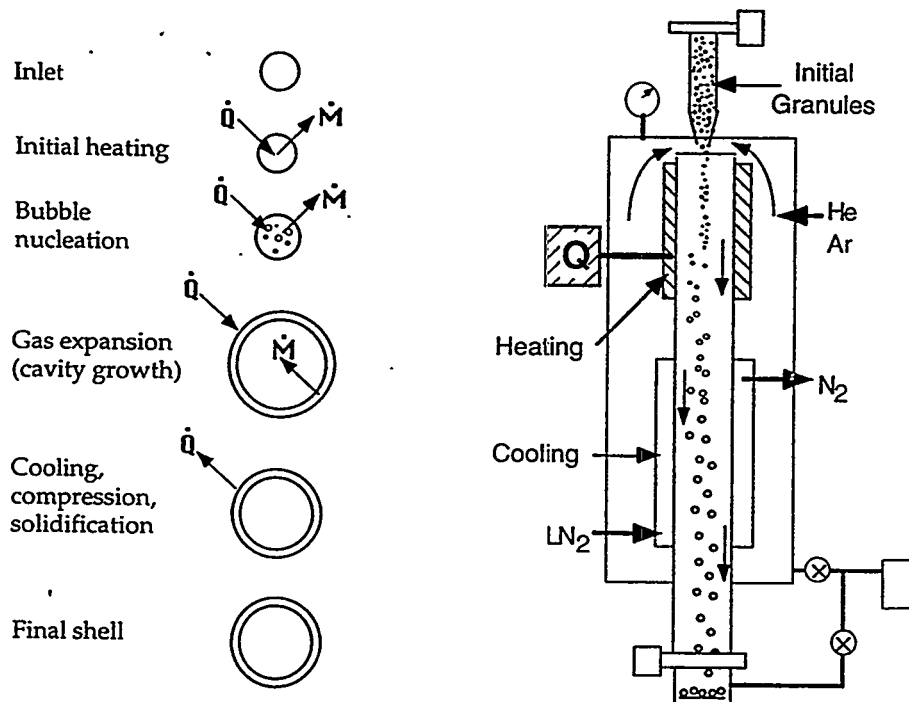
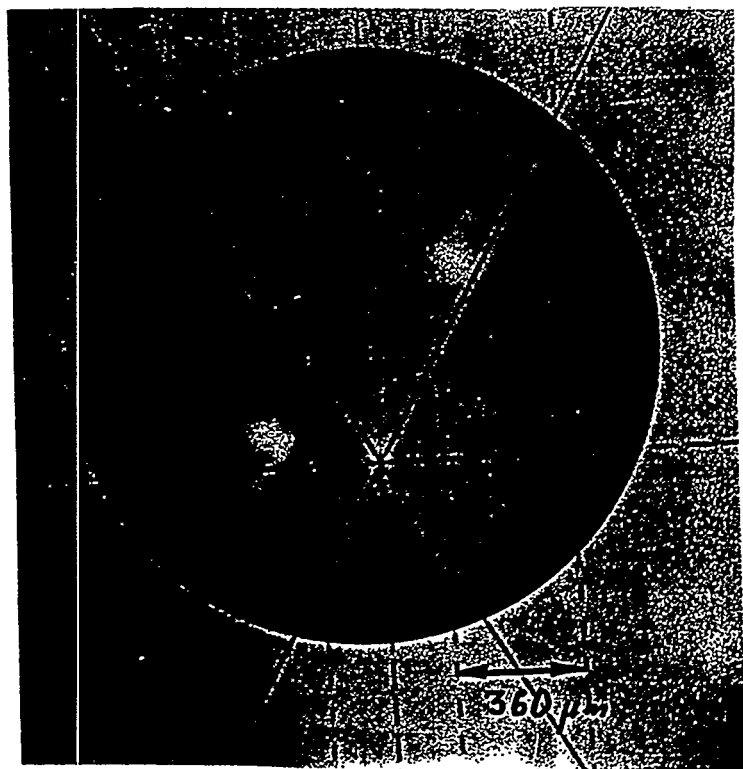
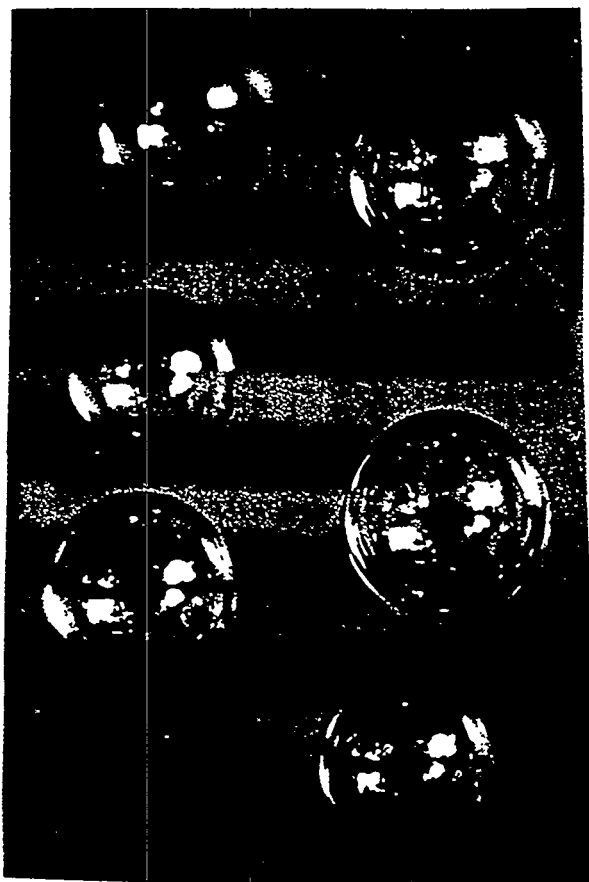


Figure 1. Sketch of physical process of shell blowing (left) and current vertical drop tower configuration.

Typical shells



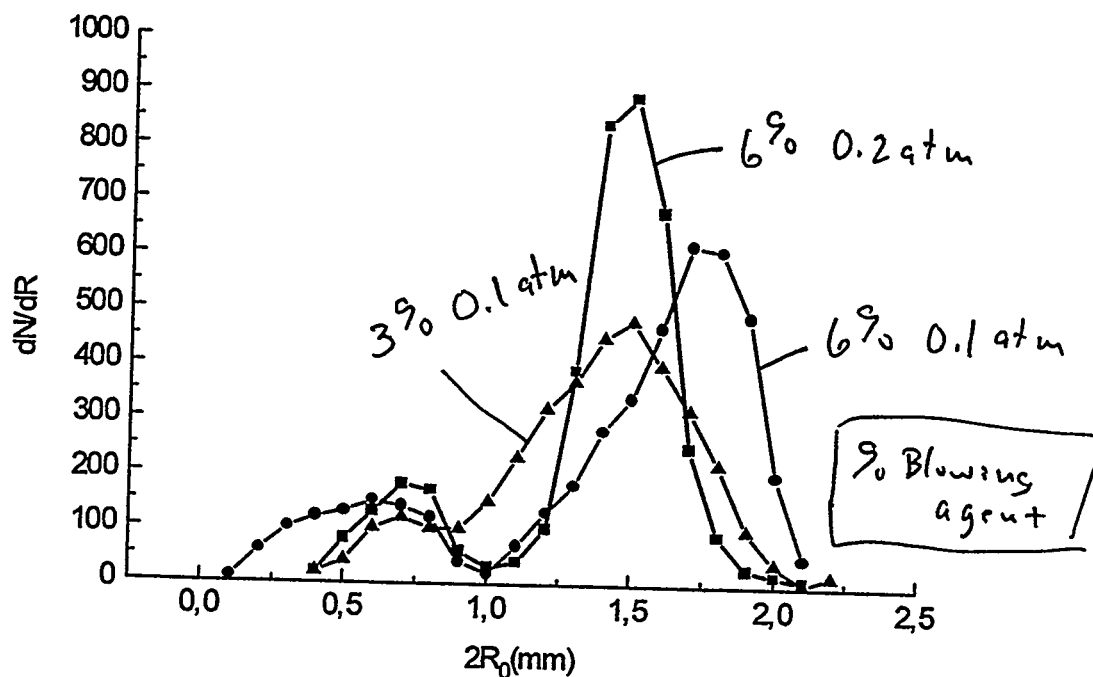


Fig. 2. Dependence of microspheres quality in relation to total number of monoshells from radius. $T=800^{\circ}\text{C}$, size of initial particles - 0.74mm , length of the hot zone is 1 m , pressure - 0.2 atm. , He+Ar.

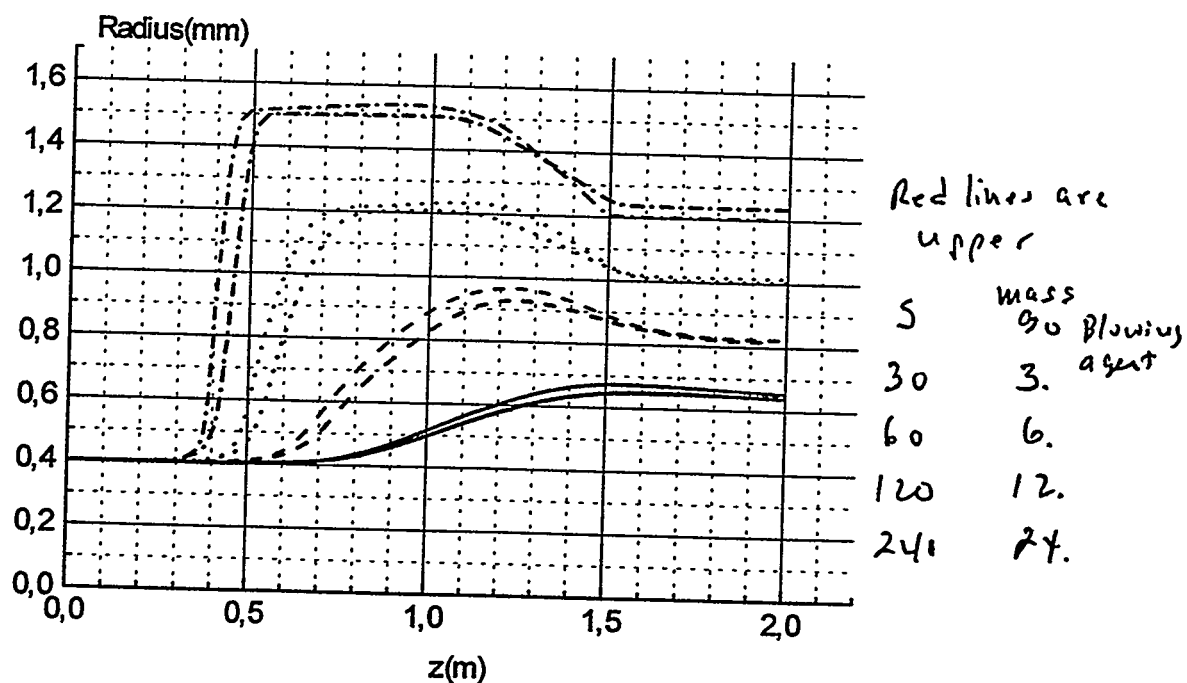


Figure 3. Shown is radius as a function of coordinate in furnace. Furnace pressure is $0.2 \times 10^5\text{ Pa}$. Red lines denote hot zone temperature 1073 K (800°C). Blue lines denote hot zone temperature 873 K (600°C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

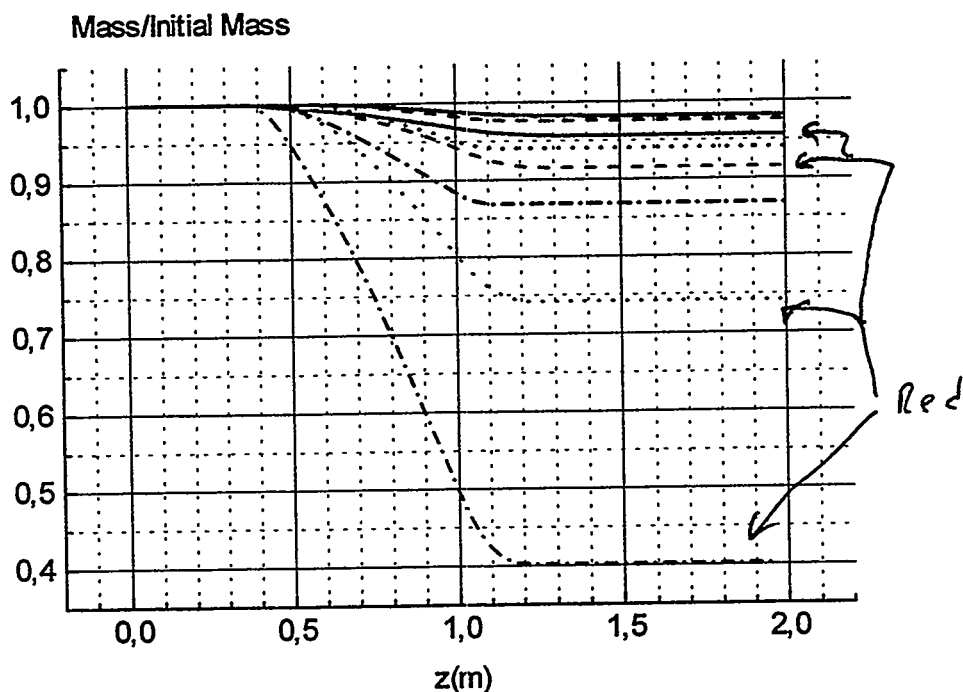


Figure 4. Shown is mass of microspere as a function of coordinate in furnace. Furnace pressure is 0.2×10^5 Pa. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

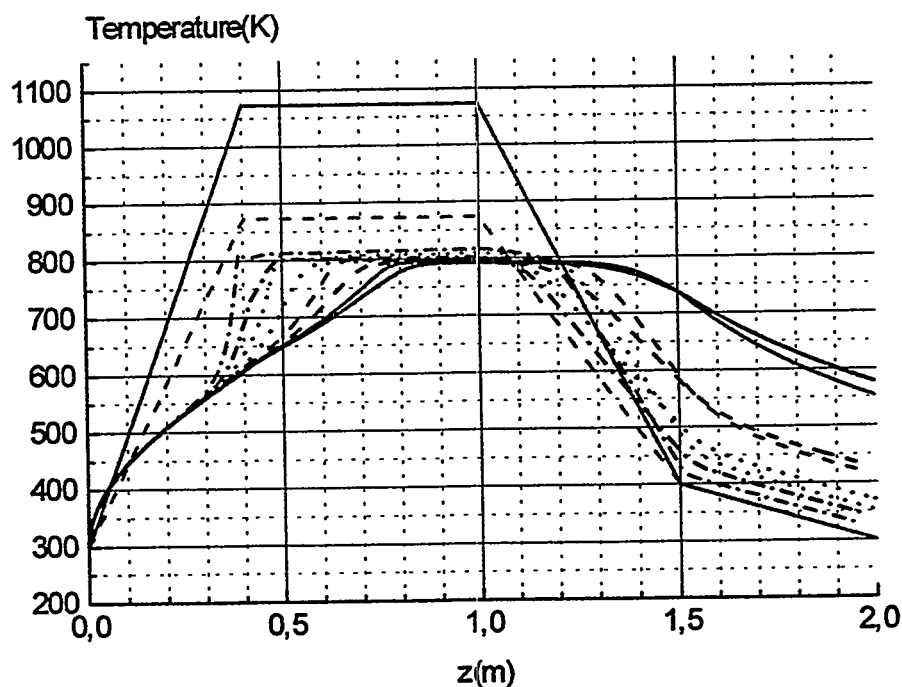


Figure 5. Shown is inner temperature of microspere as a function of coordinate in furnace. Furnace pressure is 0.2×10^5 Pa.

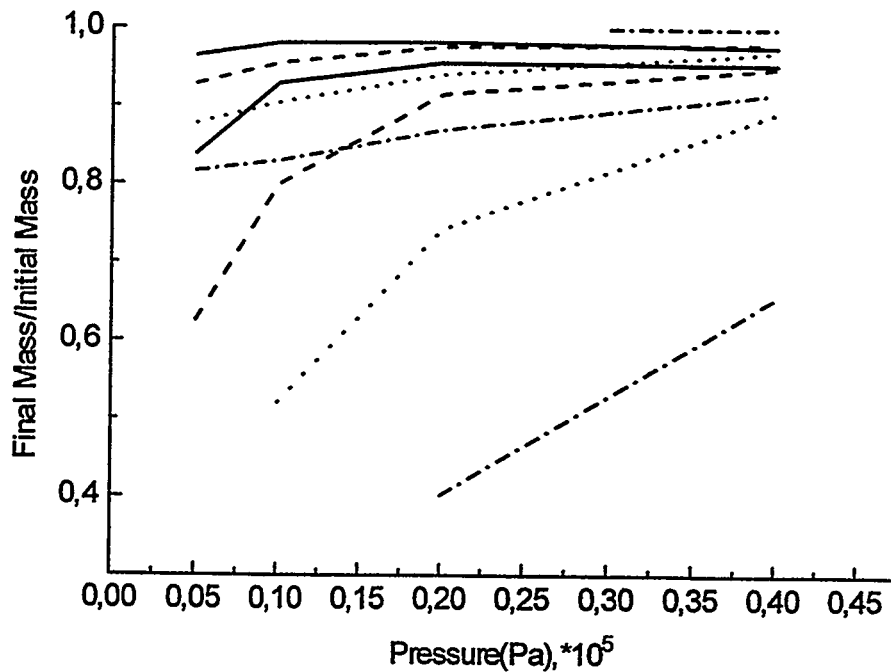


Figure 6. Shown is ratio Final Mass/Initial Mass as a function of pressure. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

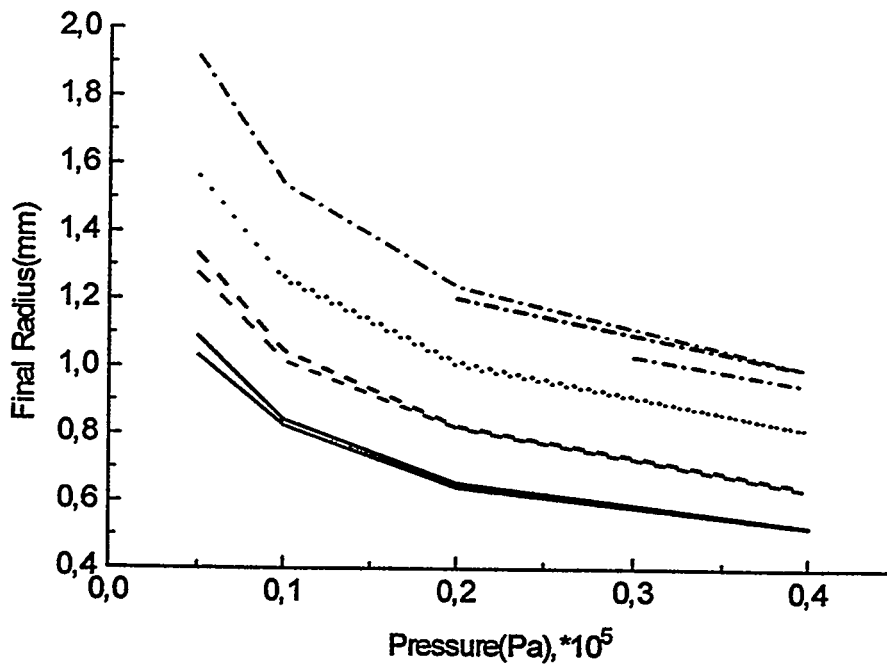


Figure 7. Shown is final radius as a function of pressure. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

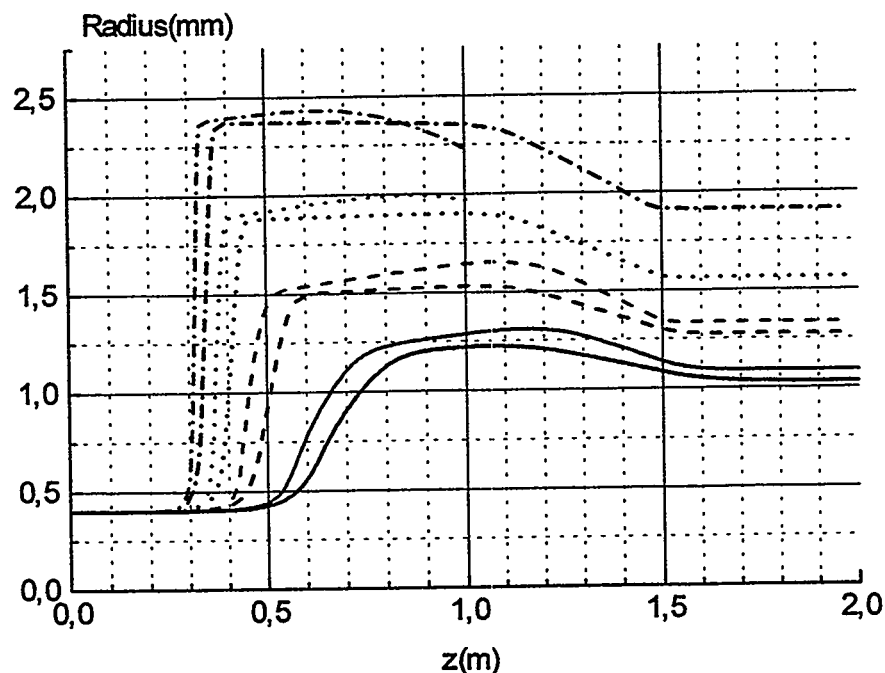


Figure 8. Shown is radius as a function of coordinate in furnace. Furnace pressure is 0.05×10^5 Pa. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

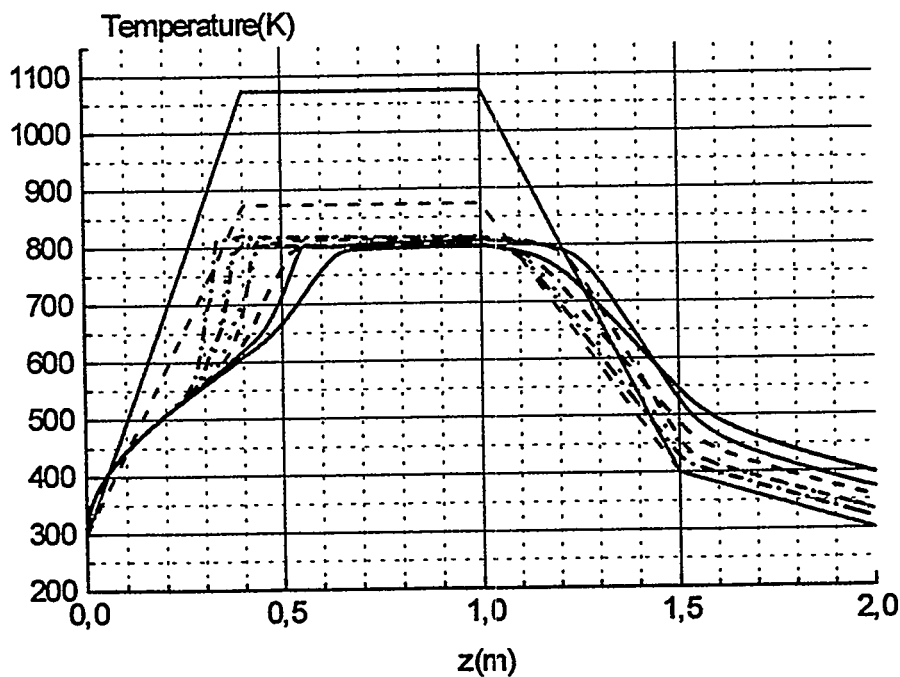


Figure 10. Shown is inner temperature of microsphere as a function of coordinate in furnace. Furnace pressure is 0.05×10^5 Pa. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

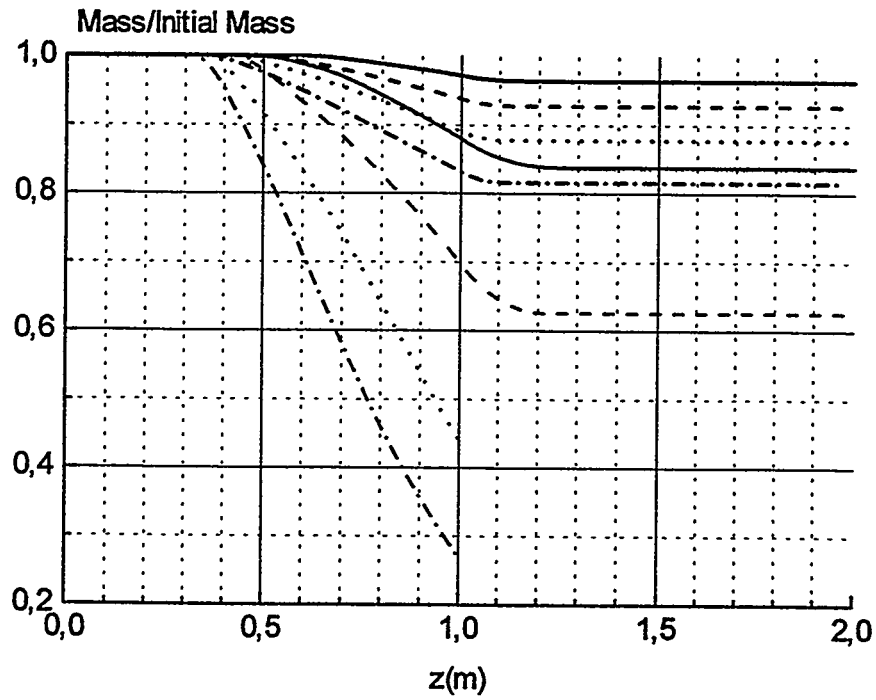


Figure 9. Shown is mass of microspere as a function of coordinate in furnace. Furnace pressure is 0.05×10^5 Pa. Red lines denote hot zone temperature 1073 K (800 °C). Blue lines denote hot zone temperature 873 K (600 °C). Oversaturation values $S = 30, 60, 120, 240$ are denoted by solid, dash, dot and dot-and-dash lines respectively.

Fabrication of a thin-walled plastic shell using emulsion technique

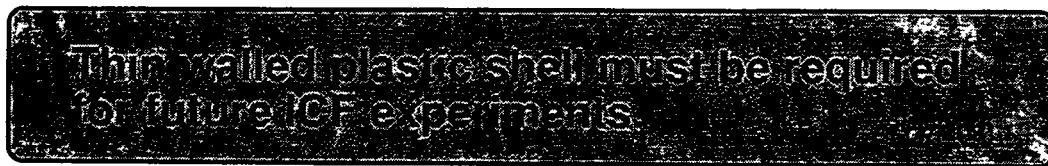
Hitoshi Nakano and Tsuyoshi Fukuda

**School of Science and Engineering,
Department of Electrical
Engineering,
KINKI University**

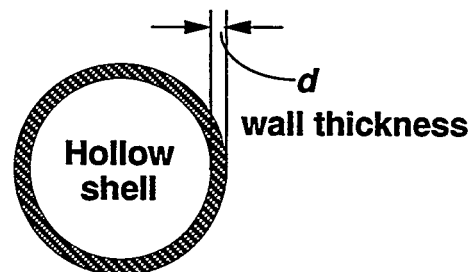
Target Fabrication Meeting '98

**April 19-23 1998
Snow King Resort, WYO, USA**

**Fabrication of a thin-walled plastic shell using
emulsion technique**



We have modified and extended the direct encapsulation technique (the emulsion technique) in order to produce the plastic shell of thin wall layer.



Method: Emulsion technique

**Shell materials: Polystyrene (PS),
Co-polymer of acrylonitrile and styrene (AS)**

A Polystyrene (PS) and a co-polymer of acrylonitrile styrene (AS) are used as the shell material.

A PS is the one of the candidate for the ICF experiments and an AS would be also accepted by several ICF experiments.

The AS was designed such that it has a slightly lower permeability to hydrogen isotopes than PS usually used in ICF experiments while maintaining the same resistance to damaging effect of beta radiation from tritium as PS. The tensile strength and flexural rigidity of AS are 750 and 1000 kg/cm², respectively, which are approximately two times higher than that of PS. AS is advantage to produce the thin-walled shell.

Microencapsulation processes for producing plastic shell

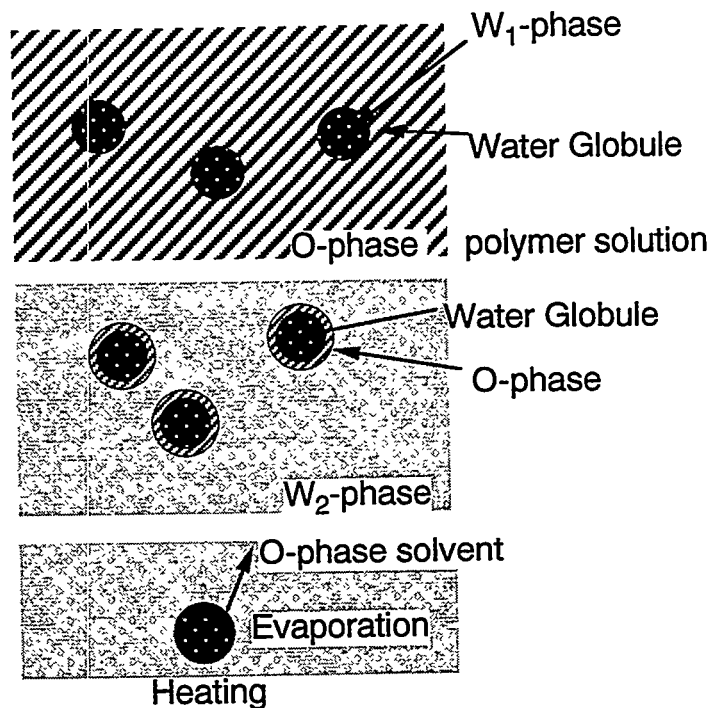
1st emulsification

W_1/O emulsion

2nd emulsification

$W_1/O/W_2$ emulsion

Underwater drying



Experimental parameters for producing thin-walled plastic shells

Emulsion technique employs three different solutions.

W_1 phase: Water with surfactant

O phase: PS or AS dissolved in organic solution

W_2 phase: PVA or gelatin solution

Experimental parameters for producing thin-walled shells

Concentration of plastics in
O phase

1 ~ 8 wt%

Temperature at underwater
drying

50 ~ 95°C

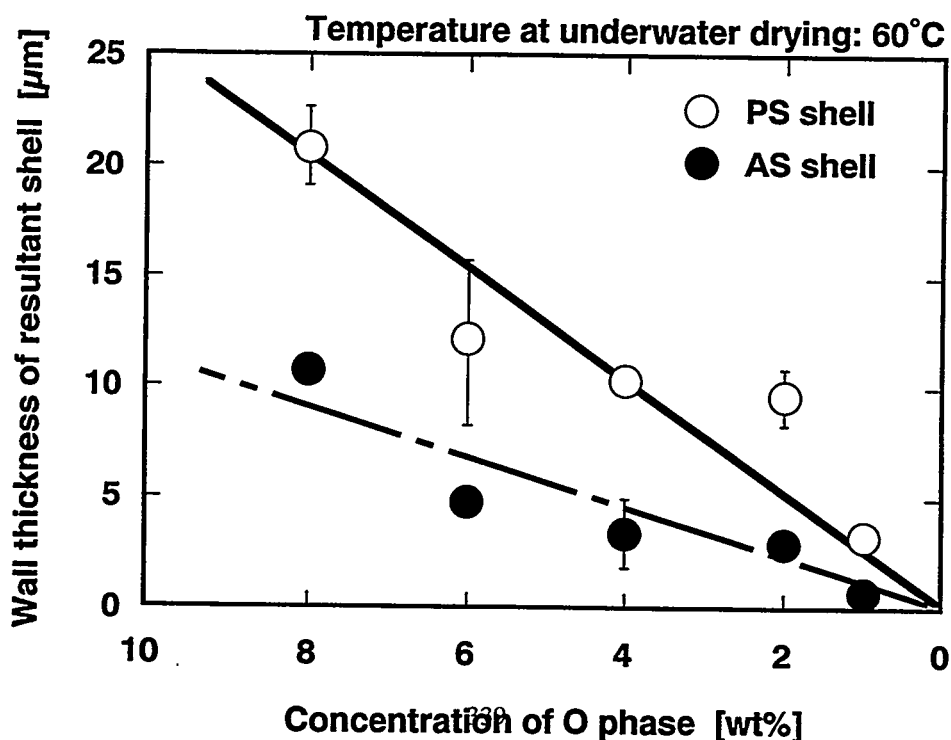
Concentration of O phase: 4 wt%

Molecular weight

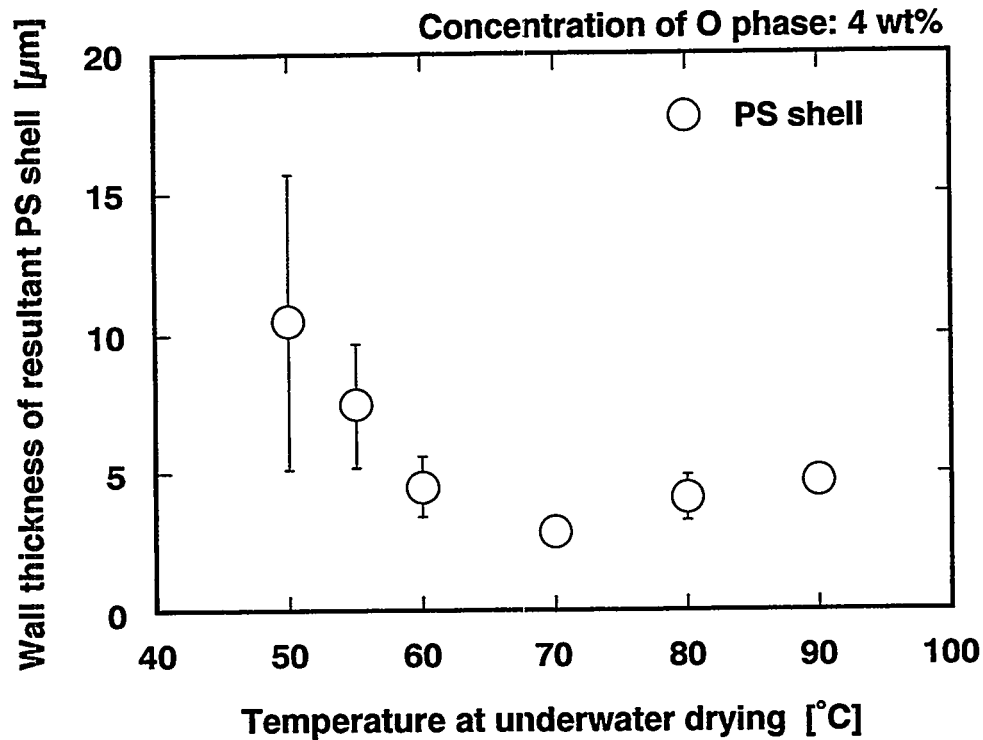
230,000 290,000 400,000

Concentration of O phase: 4 wt%

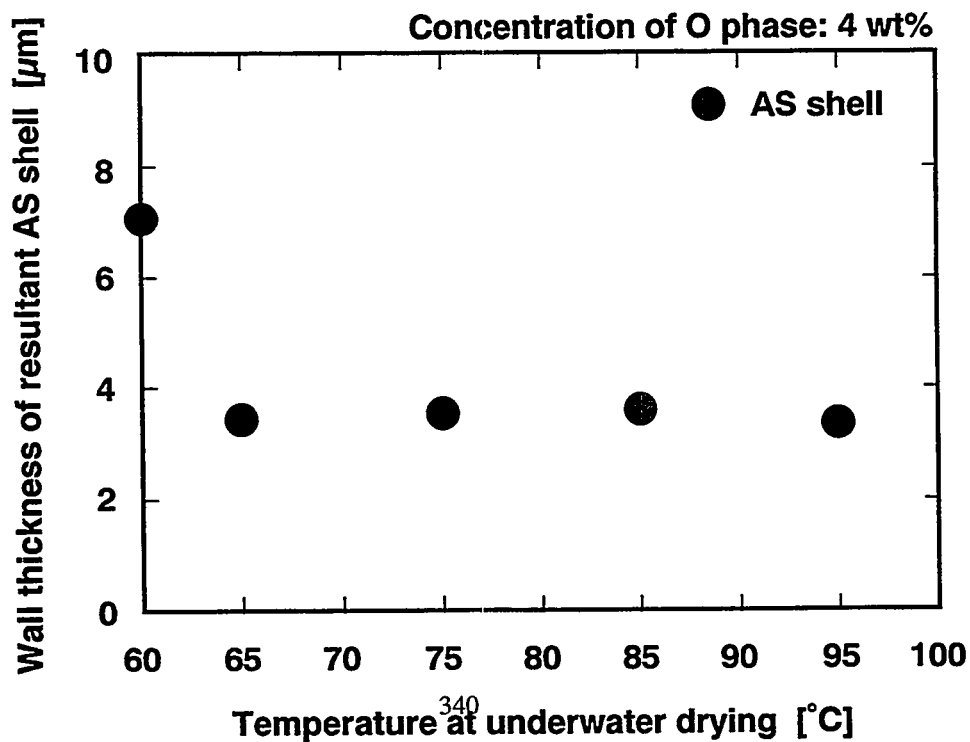
Wall thickness is found to be reduced at low-concentration.



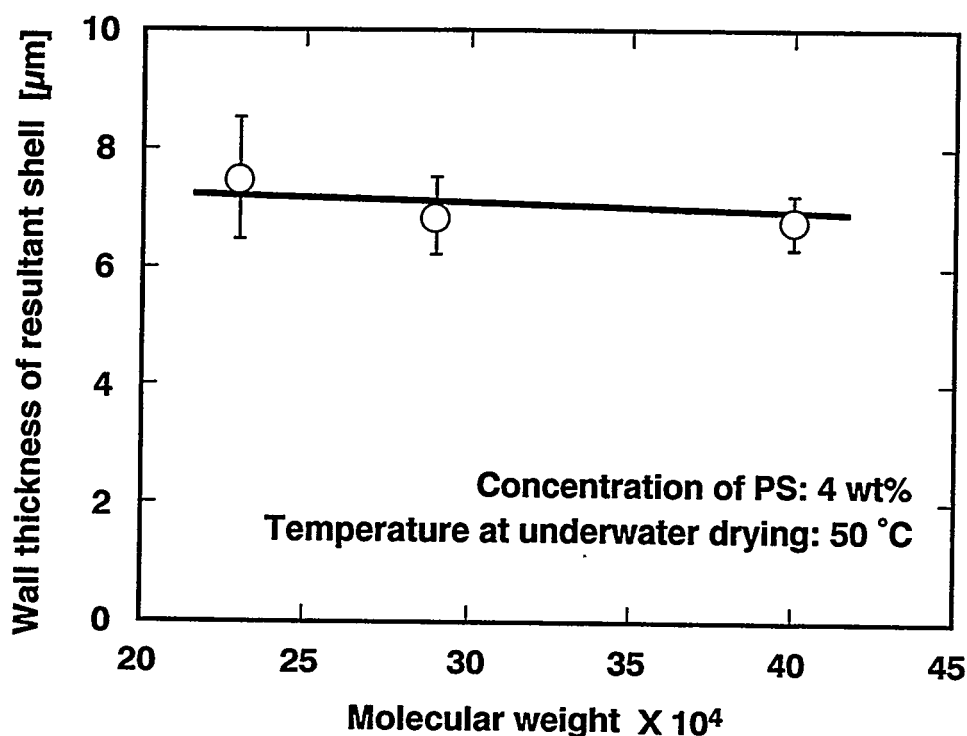
Higher temperature at underwater drying results in thin wall thickness.



Higher temperature at underwater drying results in thin wall thickness.



Wall thickness is independent on molecular weight of PS



The wall thickness reduction at high temperature drying may be caused by annealing effect

The reduction of the wall thickness has not analyzed what happens during the underwater drying.

In the underwater drying at lower temperature, a PS or an AS molecule in the O phase solvent deposits with insufficient binding force when the solvent is removed. Thus the shell has the micro-spaces between molecules in the wall.

In addition, the PS or AS molecules would be shrieked its carbon chain. These result in relatively wide wall thickness.

In contrast, if the temperature reaches or exceeds to PS or AS softening point, the molecules may initiate to stretch its chain. The spaces between molecules would disappear and the molecule would make tough network.

The wall thickness reduction at high temperature would be caused by annealing effect.

Summary

Thin-walled plastic shells has been fabricated using conventional emulsion technique.

Low-Concentration of plastics has produced thin-walled plastic shells

Higher temperature has produced thin-walled plastic shells.

Molecular weight was not essential to produce thin-walled plastic shells

Two experimental parameters for producing the shells are completely independent with each other. Wall thickness could be expected to reduce with the combination of each parameter demonstrated by present experiments.

Design, Fabrication and Testing of Be Capsule for Resonant Ultrasound Experiments

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Los Alamos National Laboratory/UC/DOE

Los Alamos, New Mexico, U.S.A.

LA-UR-98-1326

This work is supported by the U.S. Department of Energy under contract number W7405-ENG36

ABSTRACT

ICF requires smooth and well-characterized Beta layered DT ice inside the ICF target. One of our researchers is developing Resonant Ultrasound Spectroscopy or RUS1 a means of measuring internal pressure of DT. This technique also is capable of measuring various aspects of surface roughness and figure using acoustic methods.

This capsule is intended to be the experimental capsule for the acoustic tests. These experiments require a Beryllium capsule with an inside radius of 1mm and an outside radius of 3 mm. These Be capsules have various contours machined into their interior surfaces up to mode 12. The capsules are filled to ~4kpsi (kpsi=1000pounds with Helium or Deuterium gas, and joined using an epoxy adhesive.

This paper describes the adhesive joint design, machining techniques, figure measurements. It also describes the fixtures needed to assemble and fill this high-pressure capsule and the testing of this type of capsule.

INTRODUCTION

The design of the interior of the capsule is dictated by the acoustic experimenter so that the figures he desires to investigate are machined into the interior of the Be capsule. These contours must be describes mathematically so that they can be machined by Computer Numerical Control (CNC) techniques.

CNC machining of the Be components is a critical and developing technique in the fabrication of experimental capsules. Developing tooling and cutting technology for precision contours is an ongoing process. Measurements of these fine contours are taking place on our new sphere mapper.

The design of the capsule has a unique joint design that precludes adhesive from intruding into the interior and ruining the desired contours. This joint provides alignment of the capsule in radial and axial directions. This large area joint provides structural integrity to the capsule under high-pressure loads.

A capsule filled to 270 atmospheres requires that many things happen in a sequence that assures the safety of the operating personnel and the integrity of the capsule. Assembly

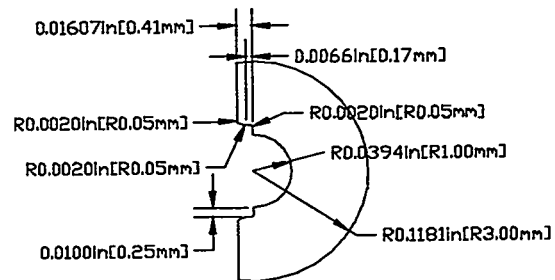
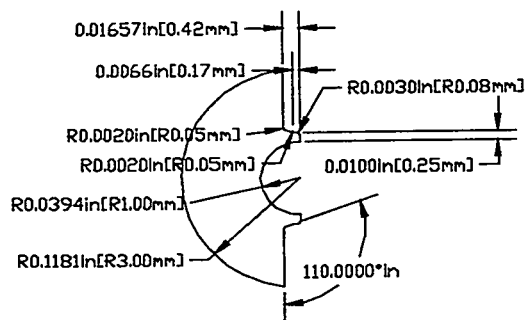
operation timing² must be consistent with the fixture time of the adhesive. The device therefore must be quickly assembled into a gas tight device.

The filling fixture/vessel design is a versatile device that provides safe gas handling, part separation, and part closure. This design can be adapted to insert plugs, assemble cylinders, and other shapes under pressures as high as 10ksi.

Test units with only spherically machined interiors have been constructed with fill tubes and tested to verify the assembly process and structural integrity of the gas filled capsules. Some of the acoustic test items have been assembled with gas and experiments have begun.

CAPSULE DESIGN

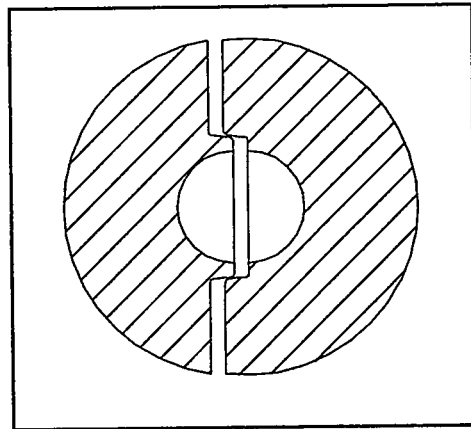
This capsule is intended to be the experimental capsule for the acoustic tests. These Be capsules have various contours machined by CAM into their interior surfaces up to mode 12.



This capsule is intended to be the experimental capsule for the acoustic tests. These Be capsules have various contours machined by air bearing CAM into their interior surfaces up to mode 12.

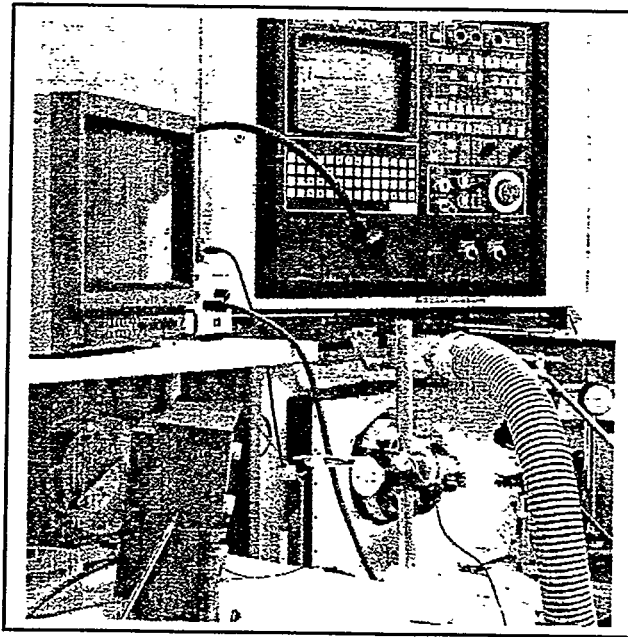
The joint design is self-aligning so the problem of tolerance build up is lessened. We have very accurate machining capabilities and it is wise to use this capability to its fullest. Self-aligning joints take advantage of the fact that the Be is CNC machined in an air bearing lathe for all final cuts. This accurate machining assures self-alignment. This makes the fixture problem much easier as the fixtures can be machined in conventional machines to relatively loose tolerances.

As the hemi-shells are brought together in the fixture the alignment portion of the joint becomes very tight before the parts are at final height. This very close fit ensures the alignment of the parts and keeps adhesive from squeezing into the interior of the capsule. Several test parts have proven this technique of adhesive exclusion to work quite well.



AIR BEARING CNC MACHINING OF HEMISPHERES

The hemispheres³ were machined on a Pnuemo Ultra 2000 computer numerically controlled diamond turning machine. This machine has very smooth roller ways in the X and Z axes so it is capable of producing a high quality mirror surface on the parts machined. The laser interferometer positioning feedback system allows 25 nm linear resolution. Its air bearing spindle provides a very smooth and accurate axis of rotation so axis-symmetric contours can be machined to a very high precision. This Ultra 2000 had previously been retrofitted with a beryllium dust collection system so it could safely produce beryllium parts. This combination of features made this the machine of choice for machining the spherical harmonic functions into the small beryllium hemispheres.

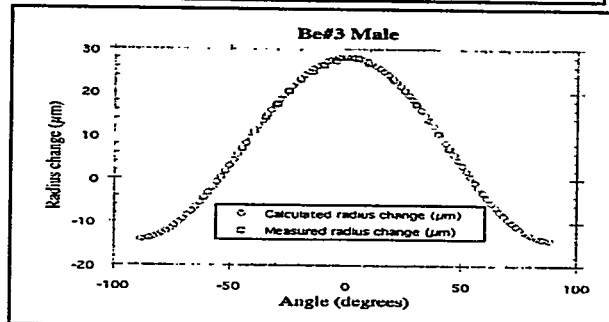
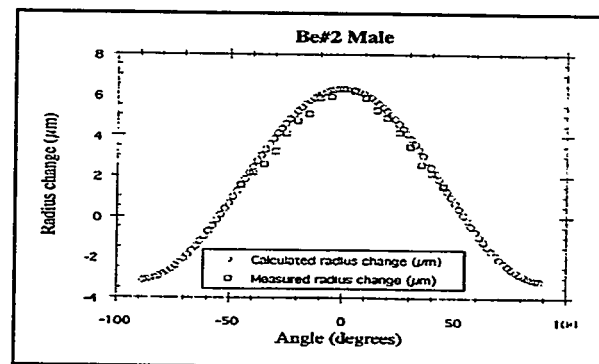


To produce the parts the spherical harmonic functions were incorporated into a computer program written in the BASIC programming language. This program generated a series of X and Z coordinate values which corresponded to the location of the cutting tool as it machined the hemispheres. These coordinate positions were downloaded into the Ultra 2000 controller via a floppy disk. After the cutting tool was located with respect to spindle to an accuracy of 0.5 μm , the part cutting program was initiated, and the hemisphere was machined.

INSPECTION OF THE SPHERICAL HARMONIC

The contours were inspected on an air bearing roundness gauge. Since they were so small (nominally 1 mm in radius) conventional probes associated with a normal roundness gauges could not be used. To be able to probe inside the shells and detect the changing contour caused by the spherical harmonic functions, a very small diameter probe stylus must be used. Some 150 μm diameter glass spheres were available so one was mounted on the end of a 100 μm diameter copper wire. This was a very fragile stylus assembly, therefore an air bearing linear variable differential transformer (LVDT) with less than 1 gram of probing force was used as the probe. This combination worked very well for measuring the targets.

To measure the contours accurately, the absolute radius must be known. So the null point



of the LVDT was set to a specific radius using a calibrated master sphere of a known diameter that was centered on the rotary table. A micrometer was then used to move the LVDT's null point to the nominal radius of the part. This null point was located to an accuracy of $\pm 2.5 \mu\text{m}$. The part was then centered on the rotary table and the pole of the part was positioned so it was at the theoretical radius. Radius versus angle data was then taken about the pole in 5-degree increments. At angles greater than $\pm 47^\circ$ the equator of the hemisphere would hit the stylus so radii at angles greater than $\pm 45^\circ$ were not measured. After the data was recorded, a best fit to the contour was performed to reduce alignment errors. The final measurement error was estimated to be within $\pm 0.5 \mu\text{m}$. The inspection data and the theoretical contour data are shown for two of the hemispheres in figures.

MATERIALS PREPARATION

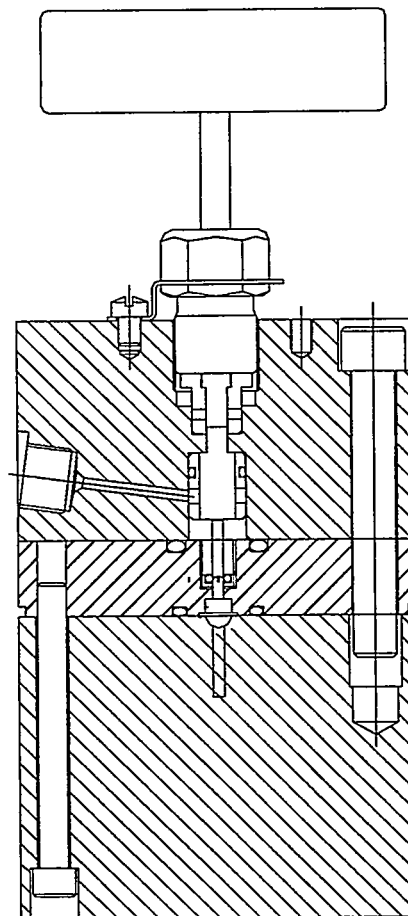
We have found that changes in the process can have very large and unexpected results. Careful preparation of the Beryllium and the adhesive is key to the integrity of the bonded assembly of the joint.

STEM DESIGN

Stainless steel stems are cut to the outside radius of the hemi-shells and to a length that matches to the bonding fixture height. The stems are bonded with a low strength adhesive to the hemi-shells in a fixture that assures perpendicularity. This step is important as this gives us the handle to hold the parts and contributes to the closing height. The low strength adhesive allows easy removal of the stems after bonding.

BONDING FIXTURE DESIGN and FILLING OPERATIONS

The heights have previously been measured and the stems carefully fitted to ensure closure of the joint. The adhesive is prepared as described in the end note paper. The adhesive is applied by hand carefully and in limited quantity. The hemi-shells with the attached stems are inserted into the fixture. The fixture components are then assembled and bolted together. The fixture holds the hemi-shells apart by means of the bonded stem and a non-sealing o-ring while the gas fill system is purged and filled to the desired pressure. The design of the plunger drive mechanism and its parts are borrowed from the highly reliable Autoclave Engineers Inc. valve 60VM-4071. This is done to ensure sealing of the mechanism and avoid custom-built parts.

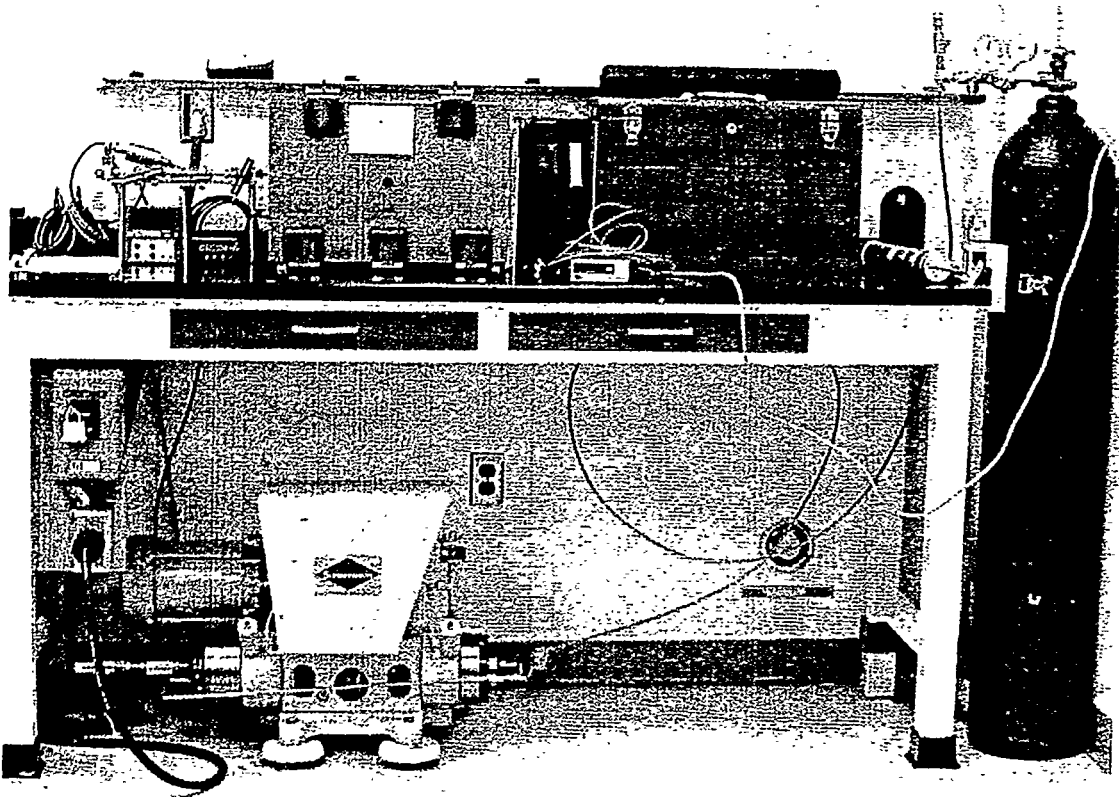


When the desired pressure is achieved, the rotating handle is turned. This drives the plunger forcing the two hemi-shells together. The large plunger lands on the upper part of the upper aluminum section of the fixture at the same time the joint of the hemi-shells closes.

The system is allowed to remain at pressure and room temperature for 16 hrs. The adhesive will cure in this time. An elevated temperature post cure finishes the cycle while the fixture is still mechanically holding the parts together. The gas pressure is relieved and the part removed from the fixture.

PRESSURE TESTING

Test units of the above design are machined, and assembled using the same process as the acoustic experimental parts. After manufacturing, these units are tested in a high-pressure gas facility. This test facility consists of a 2kpsi helium supply, a Newport Scientific two-stage diaphragm pump, high-pressure manifolds, digital pressure transducers and a shrapnel containment box.



Proof tests of these units indicate that if processed correctly the failure pressure for this design is in excess of 25kpsi. 25kpsi is the limit of pressure for our test facility.

CONCLUSIONS

Gas filled high strength adhesive bonded capsules can be made using careful design, high strength adhesives, and precision machining.

This capability can be used for a variety of capsules of varying geometry and a variety of gases.

The pressure capacity for this fill/fixturing system is 10 ksi depending on the size of the capsule being filled.

Joint geometry and adhesive strength determine the pressure holding capacity of the capsule.

Air bearing CNC machining is a key element in the design and fabrication of any Be capsule or target.

References

¹ Resonant Ultrasound Spectroscopy or RUS Tom Asaki

² TEST RESULTS OF EPOXY ADHESIVE ON ALUMINUM AND BERYLLIUM FOR FABRICATION OF CAPSULES AND TEST APPARATUS Mike A. Salazar

³ Machining of Be Spheres for Ignition Capsule Applications L. Salzer

Progress in Enhanced Layering Engineering for the OMEGA Cryogenic Transport System

D. Bittner, J. Sater, J. Burmann

Schafer Corp., 303 Lindbergh Ave., Livermore, CA. 94550

Schafer

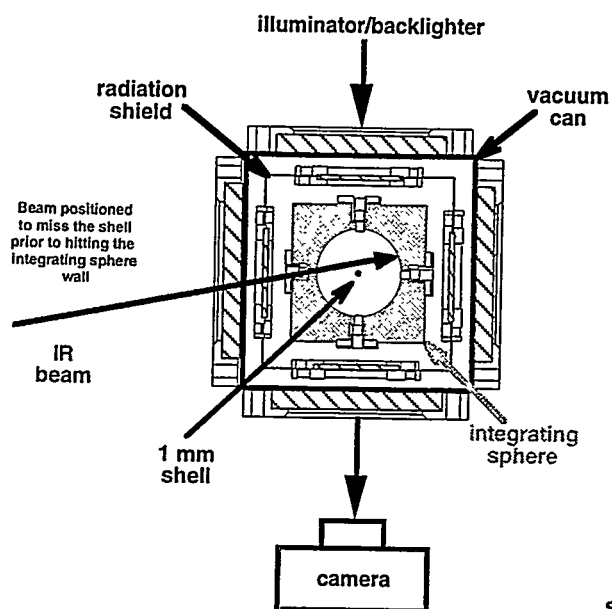
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ABSTRACT

The first cryogenic target experiments will begin within two years at the University of Rochester/Laboratory for Laser Energetics. Initial experiments will be conducted using non-tritiated hydrogen layered by IR heating. Approximately one year later, UR/LLE plans to begin using DT targets with layers smoothed by Joule heating. We are currently involved in integrating these enhanced layering capabilities into the UR/LLE cryogenic system. Our current conceptual design, schedule, and progress will be presented.

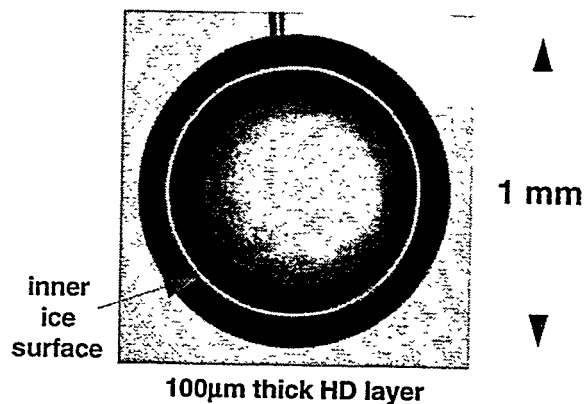
Schafer

IR heating experiments, using 1 mm O.D. shells with attached fill tube, are in progress.



In current experiments, an IR beam is injected into an integrating sphere containing an HD filled shell.

The dimensions of the shell and integrating sphere are comparable to the dimensions for a OMEGA layering shroud.



Schafer

We are in the process of designing an IR heating layering shroud.

There are four major components necessary to implement IR heating:

- **IR source**

3.2µm radiation is required to pump the D₂ line. An IR laser provides a convenient means of producing the desired light in a narrow bandwidth. The laser currently in use at LLNL is no longer manufactured, therefore, another laser must be identified.

- **Uniform shell illumination**

This is an issue being addressed by the current experiments. An integrating sphere is being used to generate uniform shell illumination and various IR injection schemes are being investigated.

- **IR beam transport**

The IR light must be transported from the IR source and coupled into the layering shroud. Current experiments use an open space laser. To transport the beam in the moving cryostat, a flexible light guide, optical fiber, is necessary.

- **Shell material**

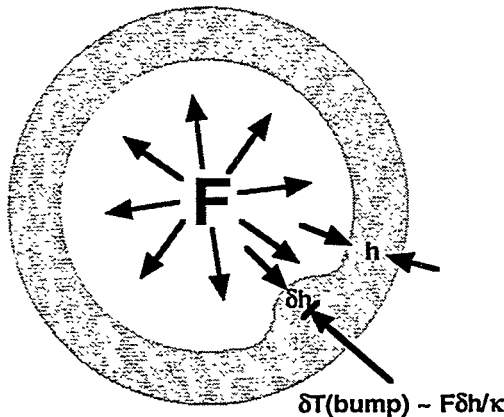
CD shells developed for the IR experiments will be required for OMEGA experiments.

Schafer

After a shakedown period, OMEGA will start shooting DT targets augmented by Joule heating.



Solid layers can be smoothed by applying a heat flux to the surface.



Tritium decays producing a low energy beta particle, an electron.

By applying an electric field to couple to the electrons in the gas, a heat flux, F , can be generated for smoothing the inner solid surface.

Schafer

Joule heating has its own set of issues which must be addressed.

Among the requirements are some analogous to those for IR heating:

- **rf source**

A standard power amplifier should work well for this application.

- **rf coupling**

A suitable means of coupling the rf into the cavity needs to be devised. This is an issue being addressed by the current experiments. A variable coupler has been designed and tested to allow for in situ adjustment.

- **Uniform electric field**

Nonuniformities in the electric field will produce nonuniformities in the final DT layer. The layering shroud must be a polished spherical cavity which minimizes perturbations to the electric field. This includes minimizing the size of openings in the shroud.

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Status

IR heating:

- An IR source has been identified. Aculight Corp. manufactures a compact and self-contained optical parametric oscillator (OPO) laser which covers the range 1-5 μ m with a power of about 300 mW at 3 μ m.
- Typical silica glass optical fiber does not transmit well beyond about 2 μ m. Fluoride glass optical fiber has good transmission characteristics in the 3 μ m range. We have acquired a 2m length of the fluoride glass fiber from Infrared Fiber Systems, Inc. for testing.
- Design of the IR heating shroud has commenced. It will essentially be an integrating sphere version of the beta heating shroud.

Joule heating:

- Experiments are being conducted using a geometry consistent with OMEGA dimensions.
- Design of the layering shroud will commence next fiscal year.

Schafer

DESIGN AND TESTING OF THE VERSATILE CRYOGENIC HOHLRAUM TEST APPARATUS (CHTA)

D. T. Goodin, W.A. Baugh, W. Egli, J. Sanchez*, and R.W. Stemke
General Atomics, San Diego, California
*Lawrence Livermore National Laboratory

General Atomics has designed and fabricated a Cryogenic Hohlraum Test Apparatus for Lawrence Livermore National Laboratory (LLNL). The CHTA provides a versatile platform to allow LLNL scientists and engineers to test the effects of differing thermal, radiation, pressure, compositional and mechanical environments on cryogenic hohlraum targets.

The CHTA consists of a vacuum vessel for carrying out cryogenic experiments, a cryogenic stage for cooling the hohlraum during the experiments, and a gas handling system to provide various cooling and fill gas mixtures to the hohlraum. The vacuum vessel has multiple windows and ports to allow experimental access to the hohlraum experiments at the vessel center. Four of these windows are reentrant and allow very close optical access to the hohlraum. An XYZR positioner allows precise manipulation of the hohlraum without opening the vacuum vessel. The cryogenic stage provides supercritical helium cooling to the hohlraum. The gas handling system can provide H₂, D₂ and He gas in any mixture to both the interior of the hohlraum and to a capsule mounted inside the hohlraum.

The CHTA was designed, fabricated and tested at GA and after passing acceptance tests was delivered to and installed at LLNL.

*Work supported by Lawrence Livermore National Laboratory under Subcontract B310613.

PURPOSE OF THIS WORK

-Provide a versatile, cryogenic test bed for development of an Inertial Confinement Fusion Temperature Shimmed Hohlraum (TSH)

BACKGROUND/SUMMARY

-Supports development of ICF targets by allowing testing of the effects of differing thermal, pressure, compositional, and mechanical environments on cryogenic hohlraums

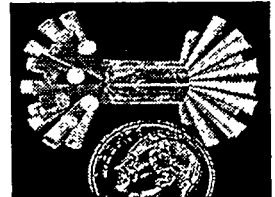
-Although originally conceived for use with supercritical helium cooling of the hohlraum, the versatile system is also well suited for studies with conduction cooling via sapphire rods

-Also could be adapted for testing of the Cryogenically Assembled Hohlraum (CAH) fielding method

-Designed and constructed by General Atomics for Lawrence Livermore National Laboratory

INDIRECT DRIVE INERTIAL CONFINEMENT PROCESS

- Uses the heating of a radiation cavity (hohlraum) to produce x-rays that result in a radiation implosion of the capsule



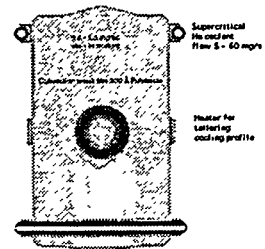
THE HELIUM COOLED TEMPERATURE SHIMMED HOHLRAUM

-Supercritical (100 atm) helium cooling fluid to minimize cooling system mass

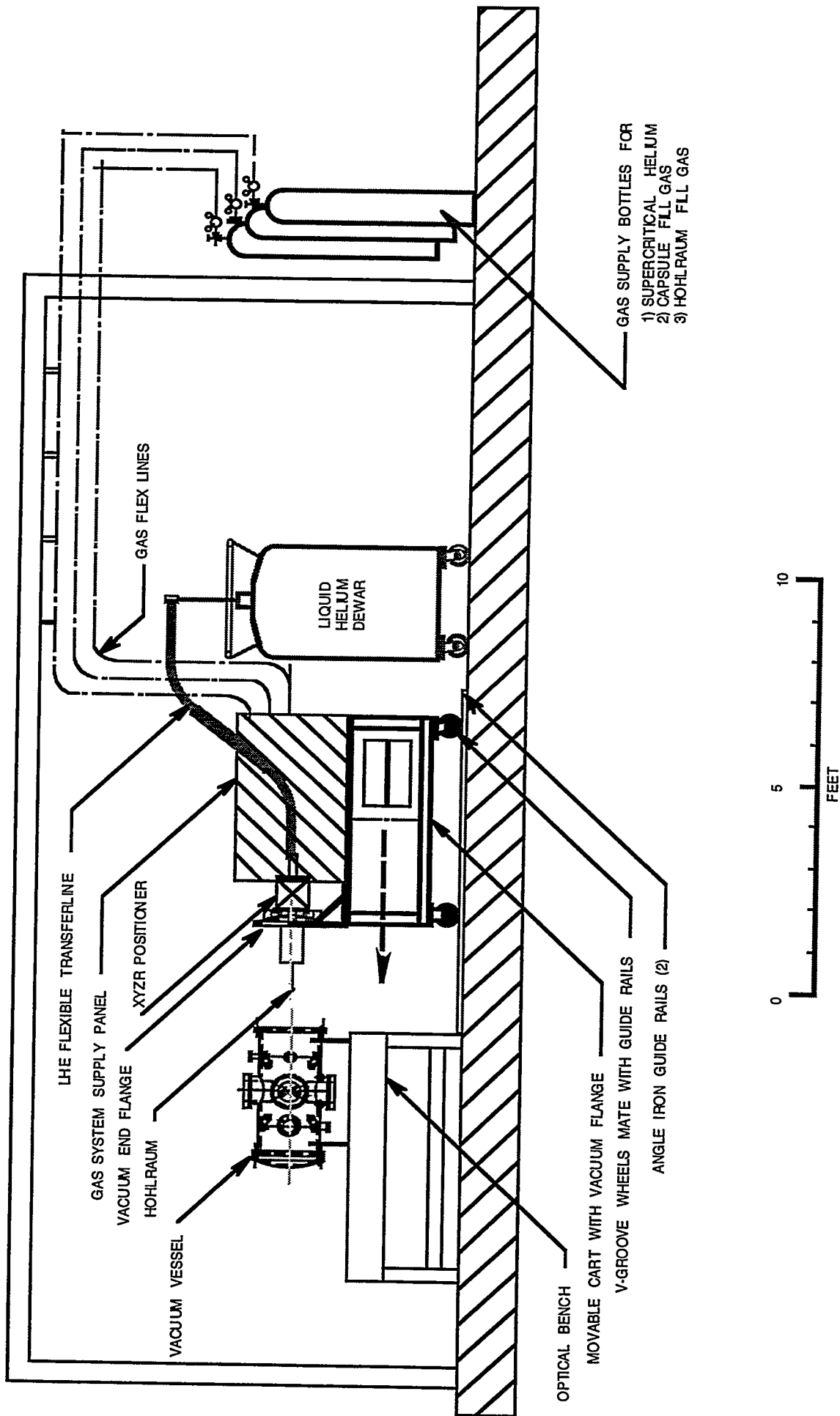
-Helium flow of 10 - 60 mg/s total, on two cooling loops

-Central heating ring to generate spherically symmetric temperature isotherm

-Polyimide windows on laser entrance holes contain tamping gas mixture



OVERVIEW OF THE CHTA EQUIPMENT AND INSTALLATION



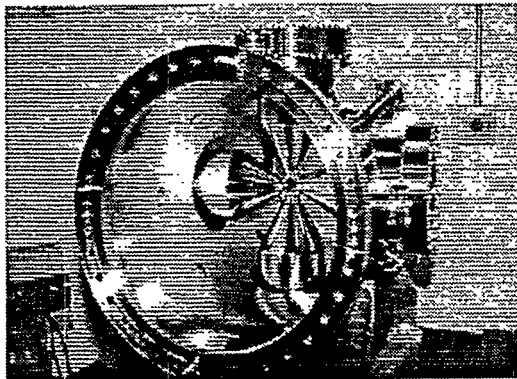
VACUUM SYSTEM AND TARGET CHAMBER

Requirements

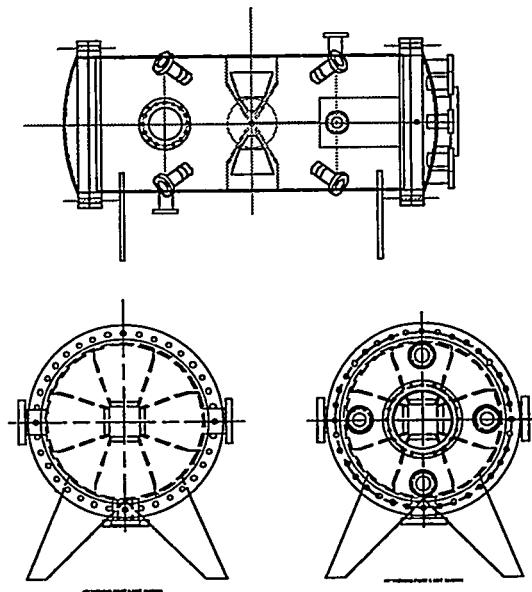
- Pumpdown from dry nitrogen in 2 hours and from air in 4 hours
- Physical and optical access (re-entrant windows for hohlraum viewing)

Design

- Welded stainless steel high-vacuum chamber, 40" long by 16" diameter
- Volume of 130 liters and surface area of 1.6 square meters
- All metal seals - Conflat flanges and copper wire sealed door flanges
- 250 liter/s turbomolecular pump
- Speed sensor interlock automatically closes gate valve if turbo shuts down
- Pressure Measurement
 - Cold cathode gauge
 - Pirani gauge



Interior view of target chamber
showing viewing windows



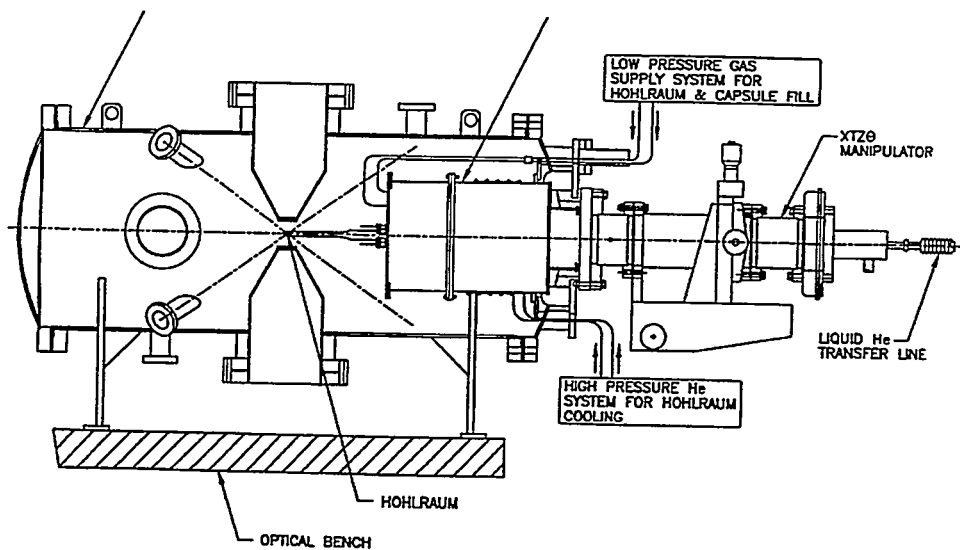
CRYOGENIC SYSTEMS

Requirements

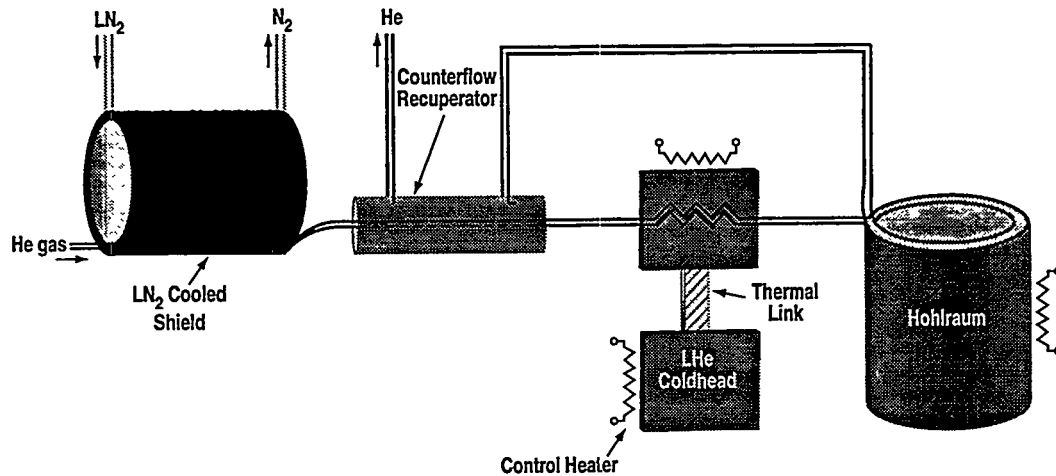
- Cool ≤ 60 mg/s of supercritical helium from room temperature to 8K
- Cooldown time of < 6 hours
- Temperature Stability
 - Coldhead, ± 10 mK
 - Hohlraum, ± 5 mK

Design

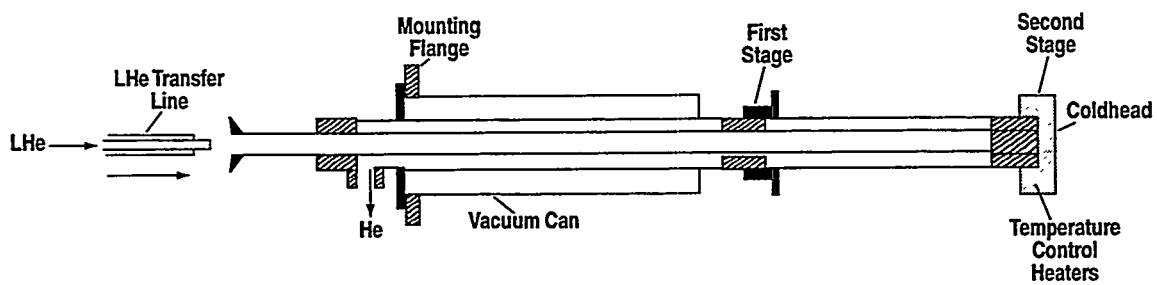
- Liquid helium powered coldhead for heat removal
- Liquid nitrogen radiation shield, intercepts, and pre-cooling
- Supercritical helium once-through cooling fluid to transfer heat from hohlraum
- He flow of 5-60 mg/s in two cooling loops
- Counterflow recuperators to maximize LHe usage efficiency



SIMPLIFIED SCHEMATIC OF SUPERCRITICAL HELIUM COOLING SYSTEM (ONE OF TWO LOOPS SHOWN)



LIQUID HELIUM POWERED CRYOCOOLER



HOHLRAUM AND CAPSULE FILL SYSTEMS

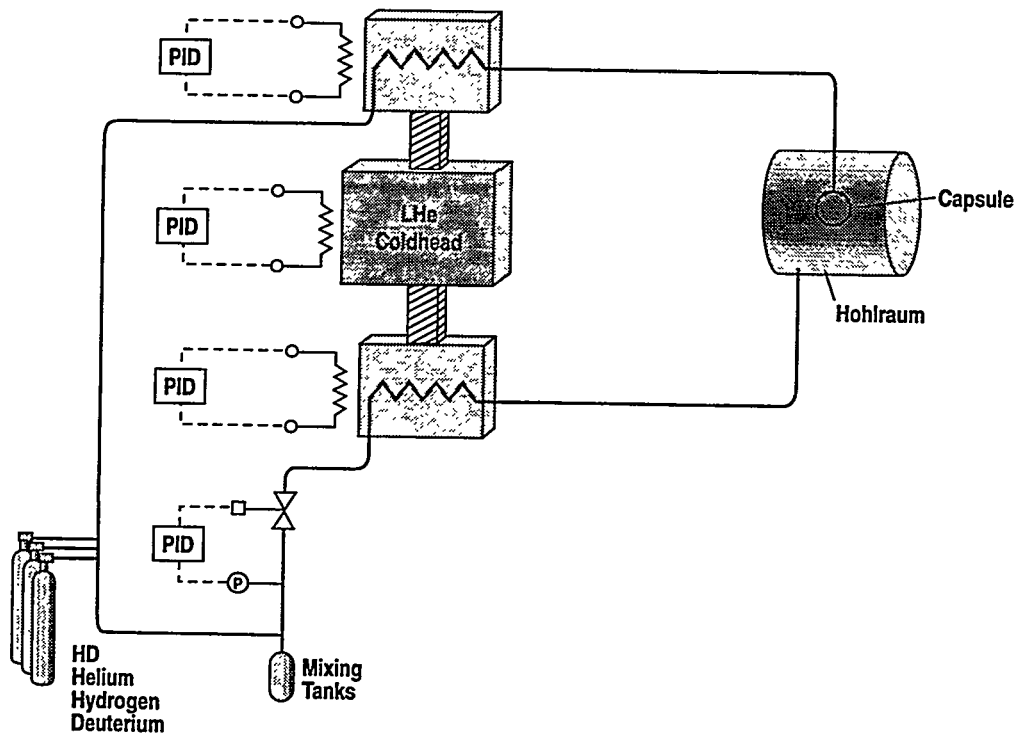
Requirements

- Pressures of less than 3 atm
- Pressure controller for hohlraum fill
- Leak rate of $< 1\text{E-}08$ torr-l/s at 18K

Design

- Gas heat exchangers thermally linked to LHe coldhead
- Granville-Phillips pressure controller

SIMPLIFIED SCHEMATIC OF HOHLRAUM AND CAPSULE FILL SYSTEMS



INSTALLATION AND TESTING RESULTS

-Vacuum System

- Pumpdown from dry nitrogen, 51 minutes
- Pumpdown from air, 55 minutes

-Cryogenic System

- Achieved hohlraum temperatures of $< 8\text{K}$ at 32-60 mg/s He flowrates
- Cooldown times as low as 2 hours from room temperature
- Temperature stability of $\pm 10\text{ mK}$ on coldhead, $+ 1\text{mK}$, $- 3\text{ mK}$ on cold gas to hohlraum
- Liquid He use met criteria

-Hohlraum and Capsule Fill System

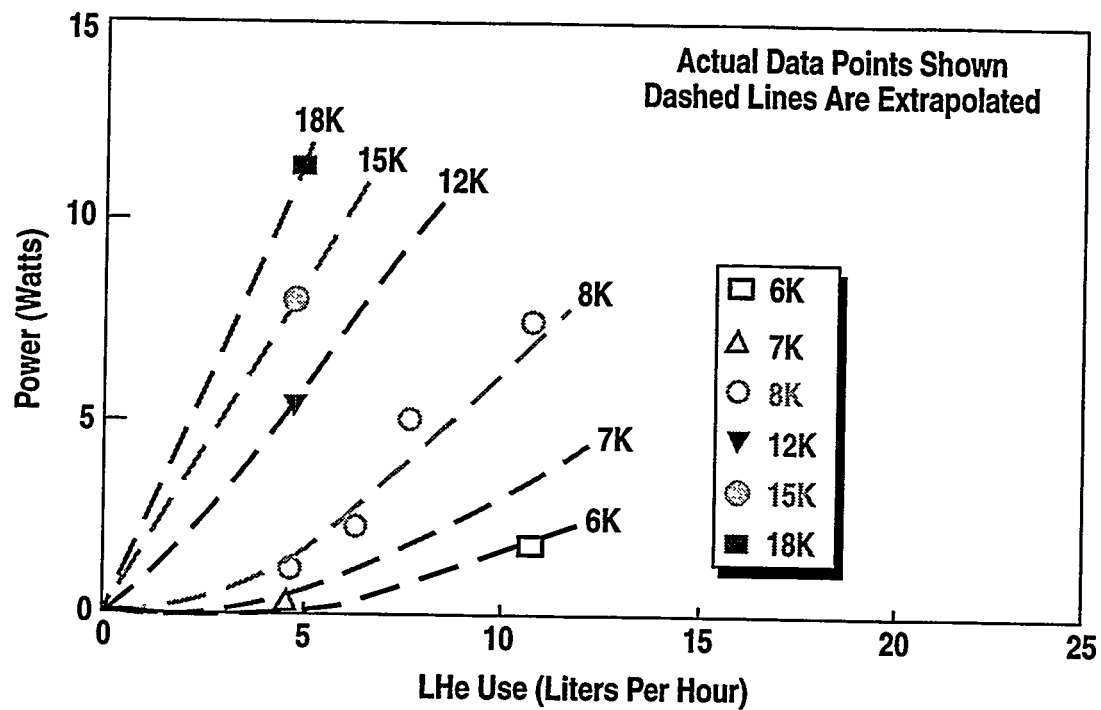
- Leak rate of $9\text{E-}09\text{ torr-l/s}$ with both systems pressurized

All technical acceptance criteria were met

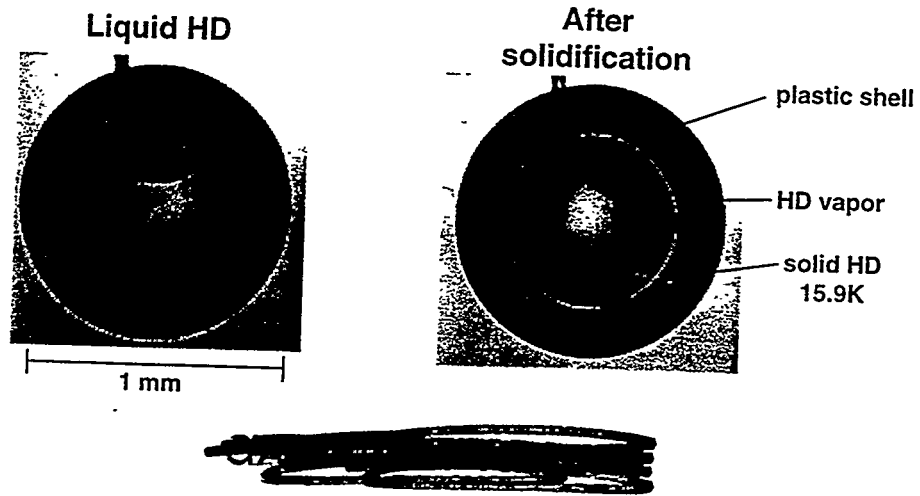
System	Test	Criteria	Measured Value	Comments
Vacuum	Pumpdown	2×10^{-6} torr $< 2\text{h}$ from N_2 5×10^{-6} torr $< 4\text{h}$ from air	51 minutes 55 minutes	Criteria greatly exceeded.
Cryogenic	Cooldown	300K to 13-20K in 6h	2 hrs 22 min to 10.5K 2 hrs 02 min to 10.0K (repeat) Lowest Temp was 7.8K	Criteria greatly exceeded.
		$< 5\text{ LPH LHe}$ use	Variable depending on imposed heat load.	At 4.6 LPH: 0.22 W at 7K 1.3 W at 8K 5.3 W at 12K 8.0 W at 15K
	Stability	30 mg/s He flow: - $\pm 50\text{mK}$ on coldhead - $\pm 5\text{mK}$ on hohlraum	Coldhead $\pm 10\text{mK}$ Cold gas to hohlraum $+1\text{mK}$, -3mK	
		3 mg/s He flow: - $\pm 50\text{mK}$ on coldhead - $\pm 5\text{mK}$ on hohlraum		
Gas Handling	Hohlraum Fill	0.5 atm P control	Demonstrated control ability to $\pm 3\text{ torr}$ (indicated) with bypass flow (HV311) set to "g".	Not optimized
		$< 1 \times 10^{-8}\text{ torr-l/s}$ leak at 18K	$9 \times 10^{-9}\text{ torr-l/s}$ with both hohlraum and capsule fill lines pressurized	
	Capsule Fill	$< 1 \times 10^{-8}\text{ torr-l/s}$ leak		



SUMMARY OF COLDHEAD PERFORMANCE



Infra-Red heating forms and smooths HD layers

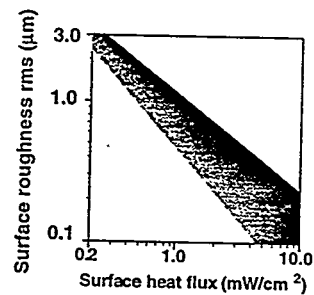
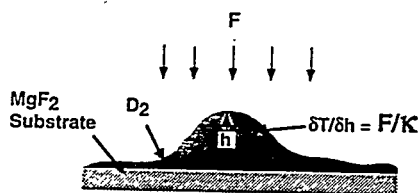


G. Collins, D. Bittner, G. Moll, E. Monsler, W. Unites, R. Stephens, D. Tiszauer, M. Feit, J. Burmann, J. Sanchez, E. Mapoles, and T. Bernat

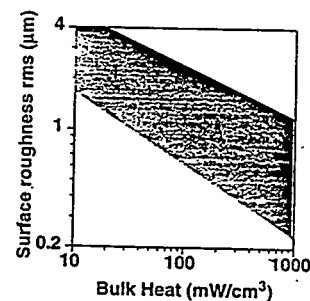
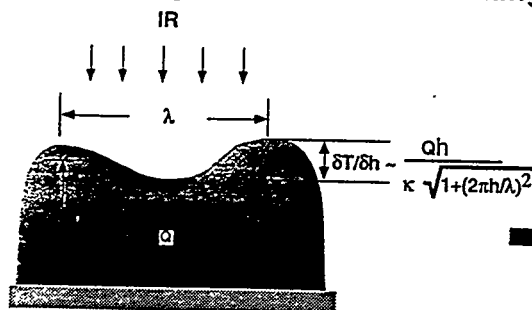
Experiments on flats show surface temperature gradients, $\delta T/\delta h$, reduces roughness



(1) Heat flux across the gas/solid interface

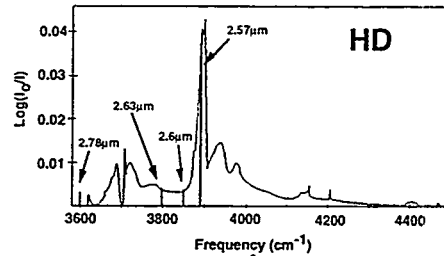


(2) Bulk heat generated with IR heating

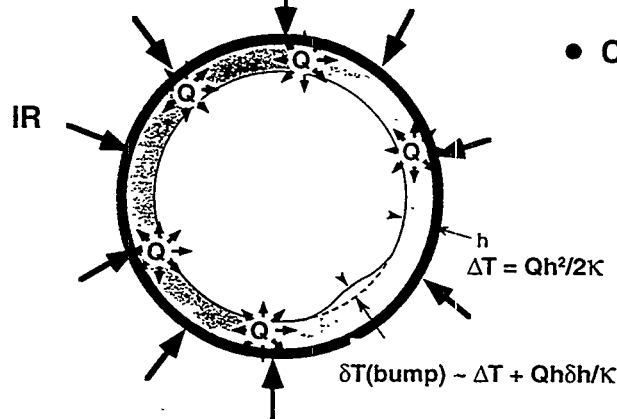


Objective:

Form smooth HD or D₂ layers in a CD shell
by pumping molecular absorptions



- Absorption of IR light generates volumetric heating, Q_{IR}
- Need uniform illumination
- Cannot heat plastic too much

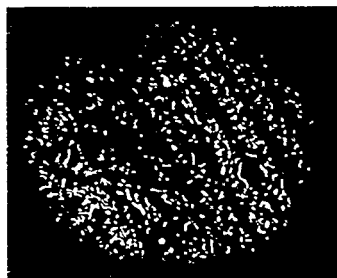


We have shown
Q_{IR} can be 30 Q_{DT}

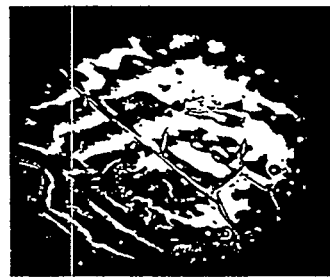
IR illumination can significantly modulate surface structure



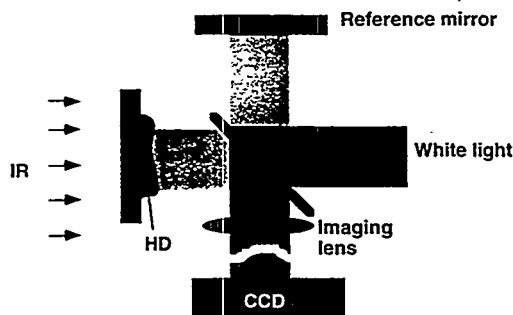
surface with spatially
coherent illumination



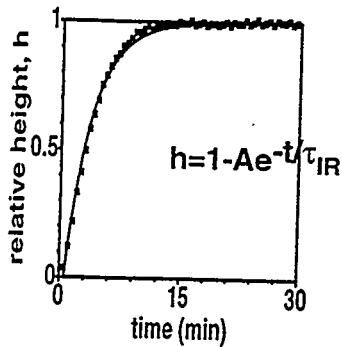
14 % coherent
illumination



<3% coherent
illumination



The conversion efficiency of IR into bulk heat is determined by the redistribution time constant 



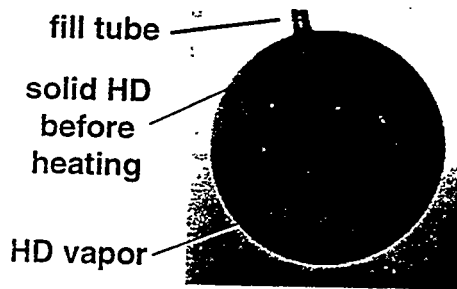
$$\tau_{IR} = L\rho/Q_{IR} \sim 3 \text{ min} \sim 1/10 \tau_{D-T} \Rightarrow Q_{IR} = 10 Q_{D-T}$$

ρ = density

L = latent heat

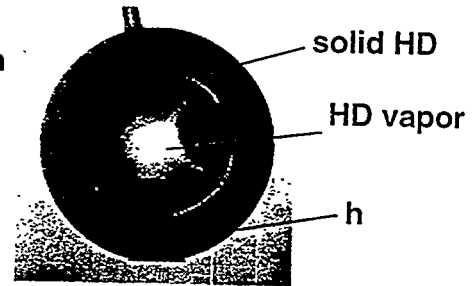
Q_{IR} = power absorbed/volume

Laser power limited Q_{IR} in these experiments

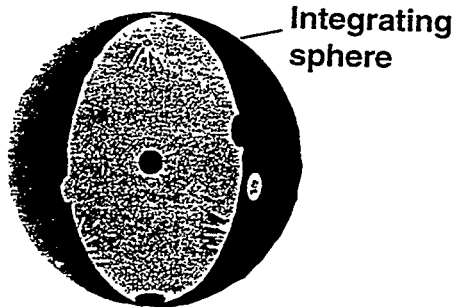


uniform IR illumination

$\Rightarrow$



Modeling shows IR illumination can easily be better than 99% uniform



6 windows and 4 IR beams which miss shell on first pass yield uniformity > 99%

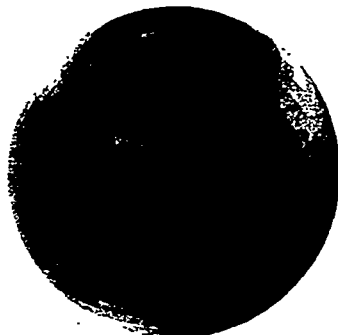
To generate $Q_{IR} = 4 Q_{DT}$ we need

$P = 21 \text{ mW (HD)}$

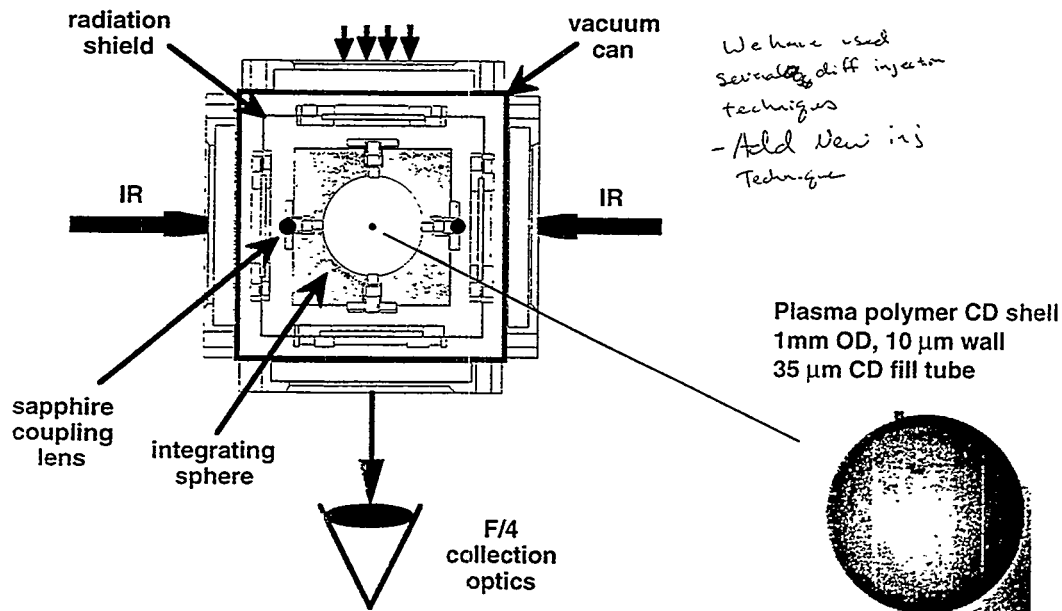
$41 \text{ mW (D}_2\text{)}$

160 mW (DT)

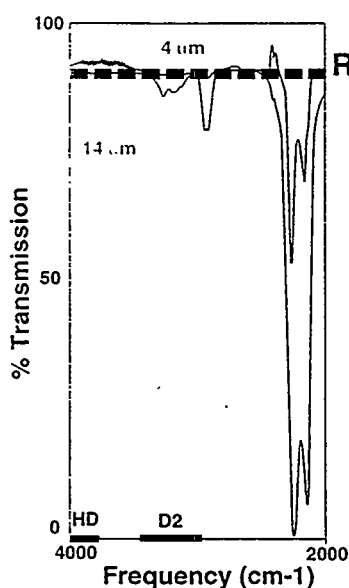
low intensity regions are from low reflection windows



Integrating sphere generates uniform spatially and modulated IR illumination



Our polymer shell was designed
to minimize absorption in the shell

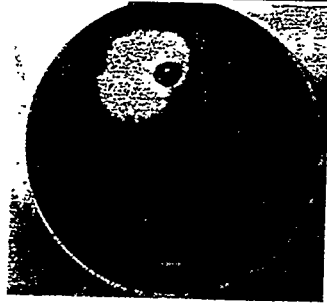


$$R = \left(\frac{n-1}{n+1} \right)^2 \sim 11\%$$

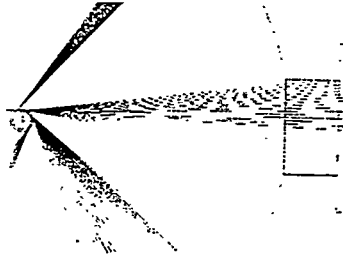
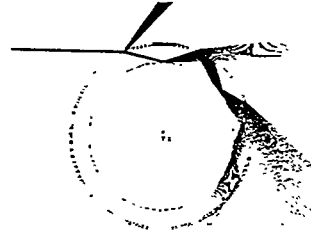
- Plasma polymer from deuterated p-Xylene
- Using the shift in T_{TP} we have set the maximum baseline absorption at $\alpha < 4 \text{ cm}^{-1}$
- Plastic absorption sets the IR uniformity requirements for NIF
- DT does not effect the relevant transmission spectrum of plasma polymer at room temperature

use to set plastic spec

The bright band is due to reflections off the ice-gas interface

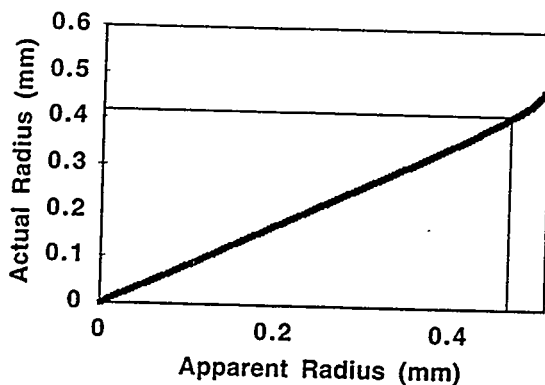
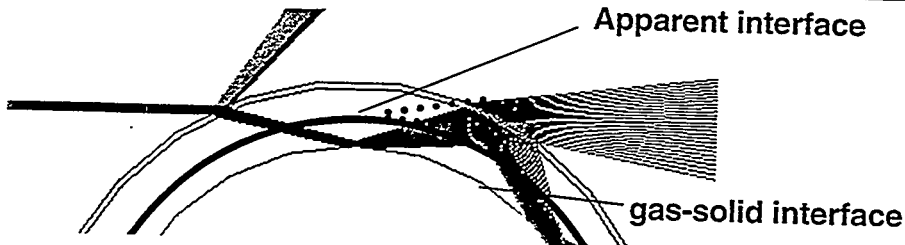


- Bright band is due to internal reflection off the gas-liquid or gas-solid interface



- Bright band is enhanced by slow input and collection optics
- Bright band is used to measure surface roughness

The apparent layer thickness and uniformity are shifted from actual values



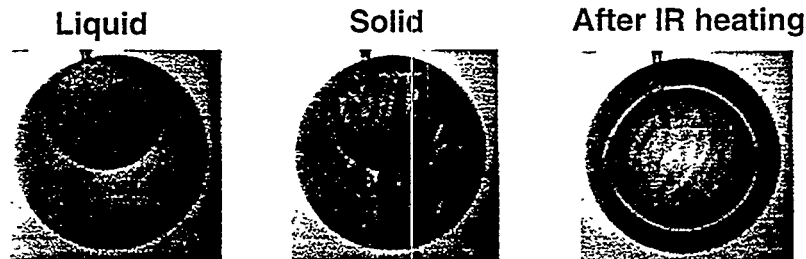
- Apparent image for $\sim 100\mu\text{m}$ layer is shifted $\sim 10\%$
- Apparent image is more distorted for thin layers

Add Chart UG.
369

Various cooling techniques were used for generating a uniform layer

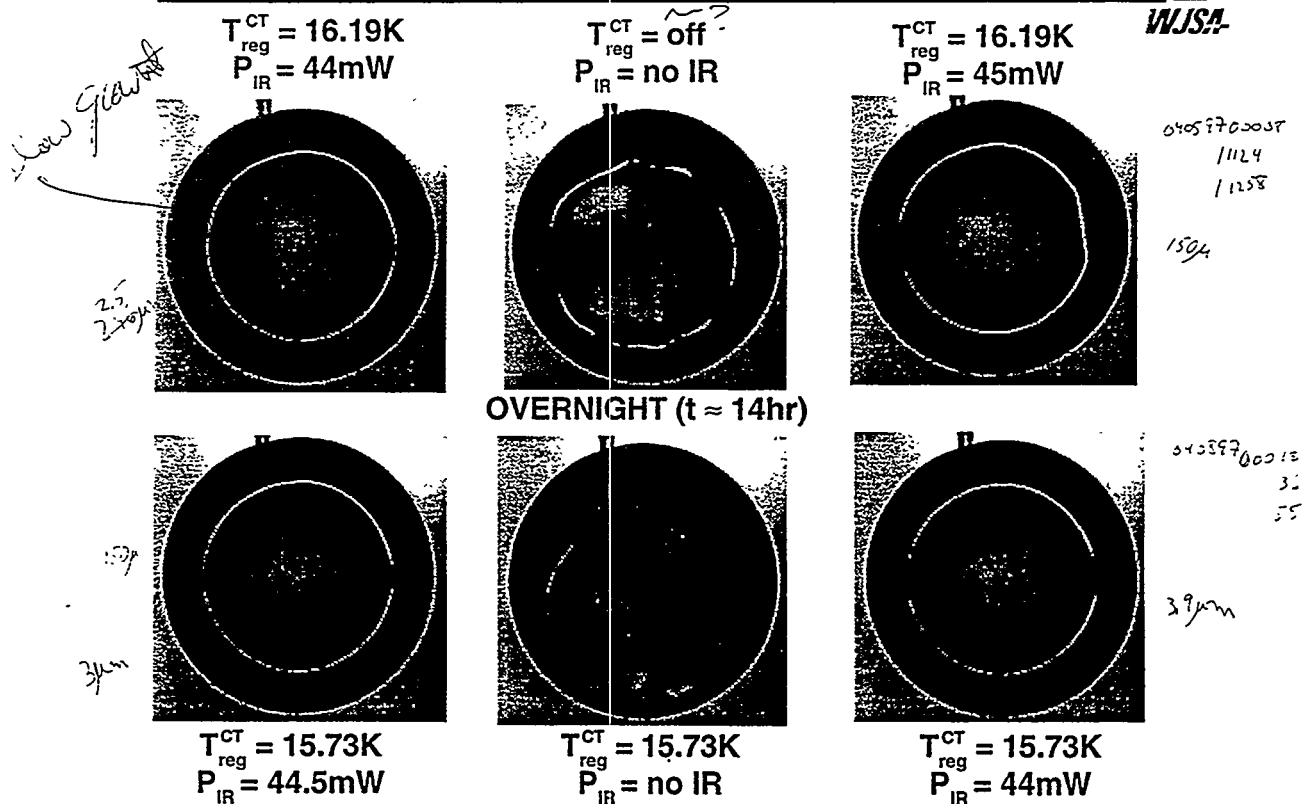


- Fast freeze from liquid state, then apply IR to solid
- Technique used for mass redistribution and surface roughness experiments
- Fast freeze from liquid state, apply IR to solid, then warm up slowly to near melting point
- Apply IR to liquid, then very slowly cool down to solidify
- Had difficulty preventing a quick freeze



Distinguish w/ cylinders //

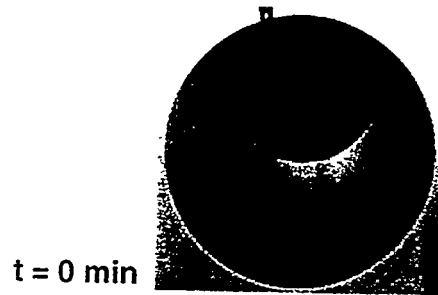
Degraded layers can be regenerated



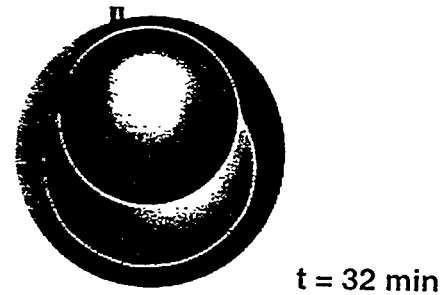
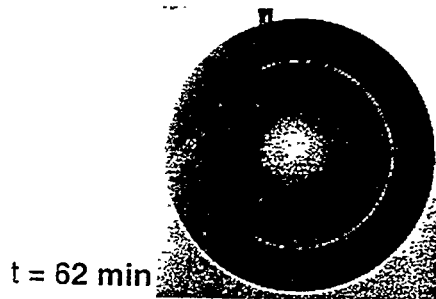
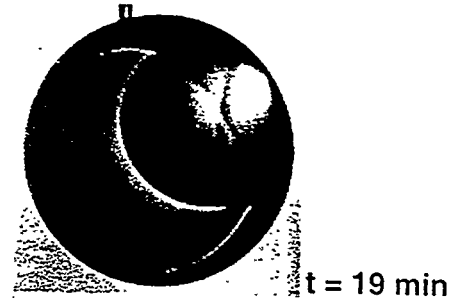
Gradual melting and cooldown resulted in significantly improved layers



- Apply IR to solid, warm up to melt solid, cool down to freezing onset (about 100mK), then hold



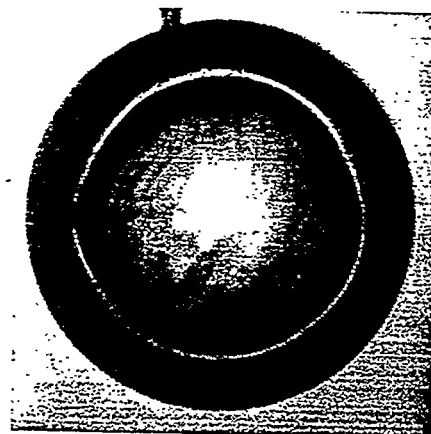
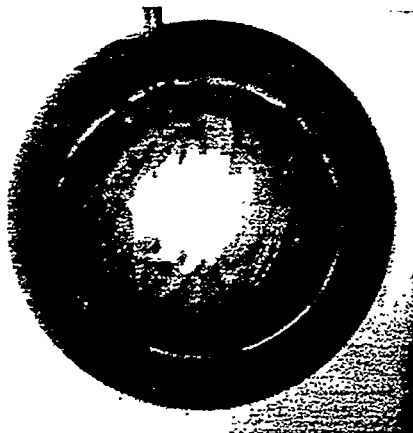
$T = 15.73\text{K}$
 $P_{\text{IR}} = 44.5\text{mW}$
 $\text{rms} = 3.0\ \mu\text{m}$



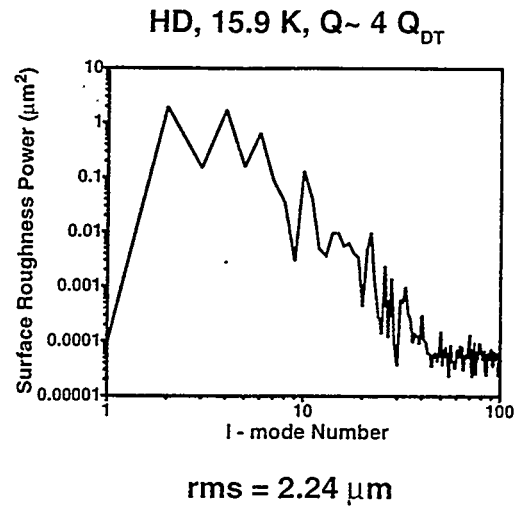
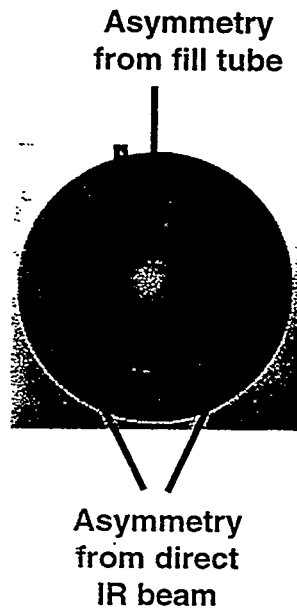
We find a huge temperature dependence on surface roughness in a curved geometry



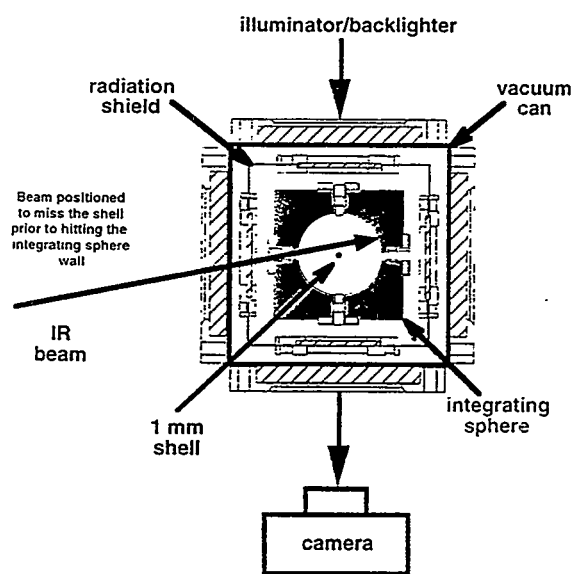
- HD, 15.3 K $\Delta T = 2$
- Same layer after warming to 15.5 K



One can readily make a relatively uniform layer of HD with IR heating

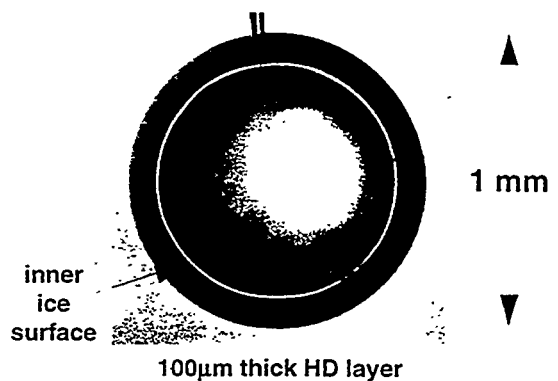


IR heating experiments, using 1 mm O.D. shells with attached fill tube, are in progress.

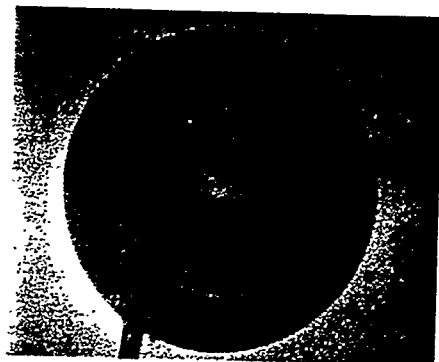
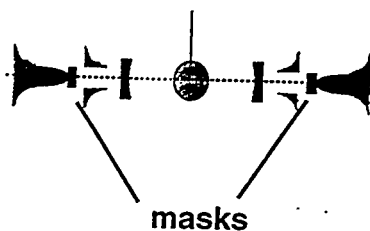


In current experiments, an IR beam is injected into an integrating sphere containing an HD filled shell.

The dimensions of the shell and integrating sphere are comparable to the dimensions for a OMEGA layering shroud.

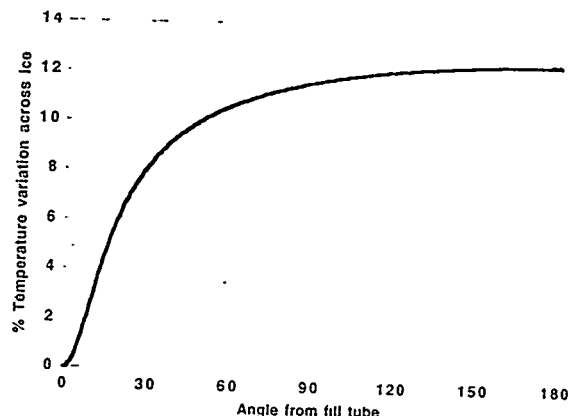


After optimizing the IR masks, fill tube induced defects limited RMS roughness



P=24 mW
16K
 $\sigma = 3.7 \mu\text{m}$

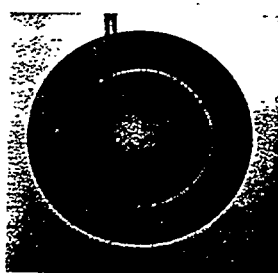
COSMOS modeling showed the fill tube causing a 10 % distortion of the isotherms



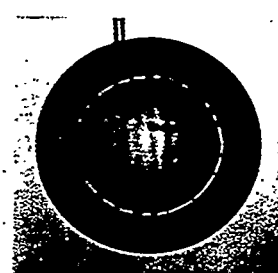
Layers degraded after turning the IR off at thick layers and high power



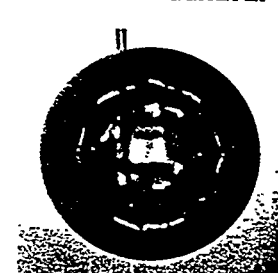
PIR = 50 mW
15.7K
no masks



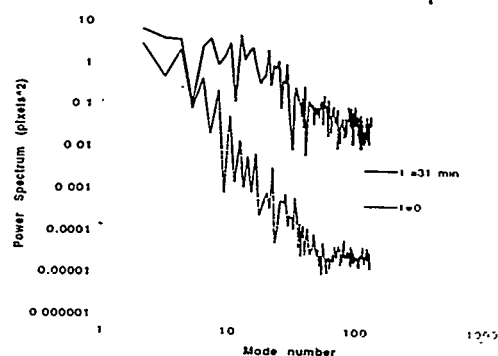
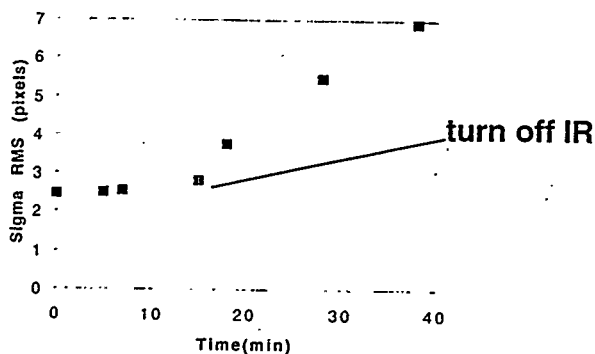
$\delta t = 0$ $\sigma = 2.5 \mu\text{m}$



$\delta t = 12 \text{ min}$ $\sigma = 5.6 \mu\text{m}$



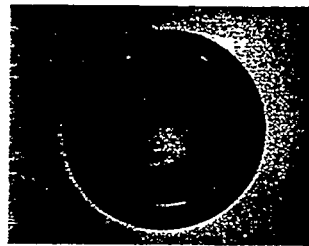
$\delta t = 31 \text{ min}$ $\sigma > 7.9 \mu\text{m}$



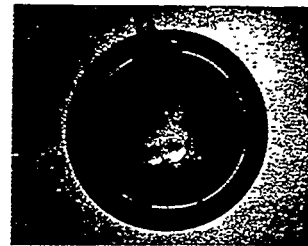
Layers degraded more slowly after turning off the IR for thin layers at low power



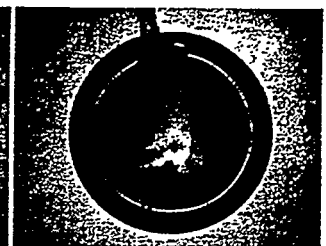
PIR = 12 mW
16.0K
with masks



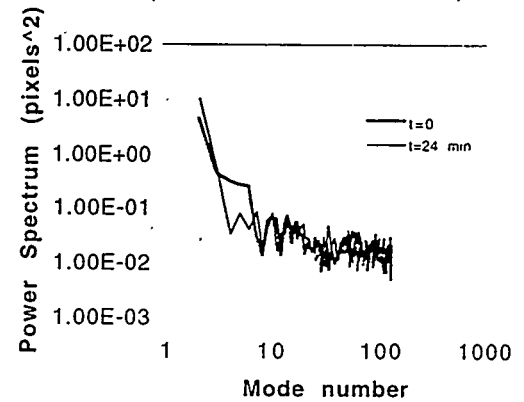
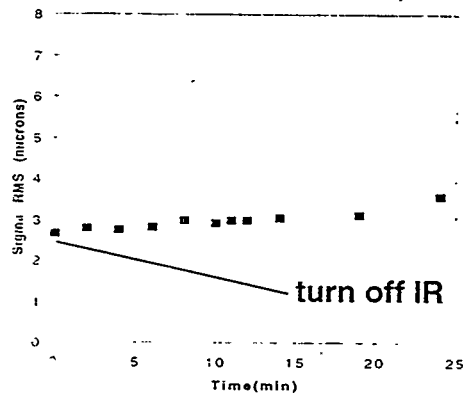
$t=0$ $\sigma = 2.6\mu\text{m}$



$t=12$ min $\sigma = 3.1\mu\text{m}$



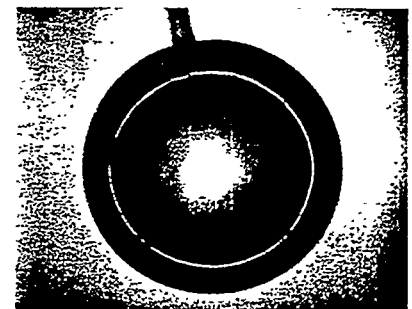
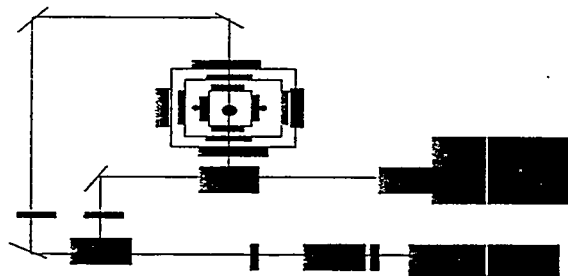
$t=24$ min $\sigma = 3.6\mu\text{m}$



First interferometric images have been taken



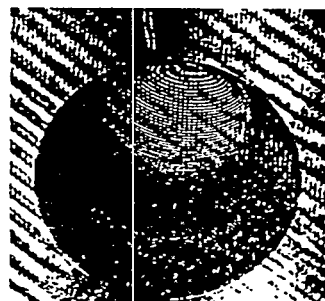
Interferometry measures layer uniformity



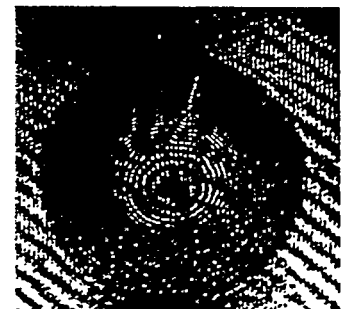
13 mW, dots, 16.1K



Empty shell



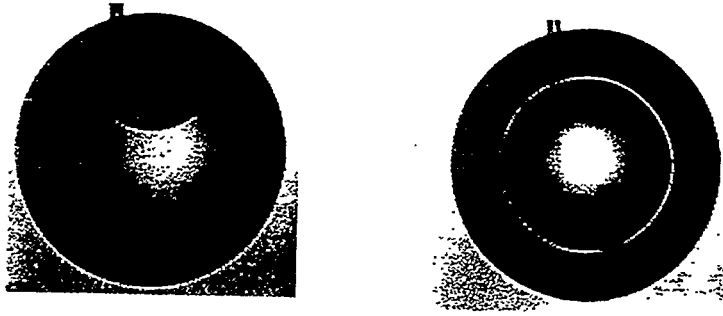
Liquid



Solid

Conclusions:

- IR heating forms and smooths HD layers in thin plastic shells:



- Progress has been made in removing asymmetries in the layer due to illumination nonuniformities
- More work is needed to better characterize hydrogen layers in spheres
- IR layering provides a simple no risk option for testing T, Q, and impurity effects on a layer as well as developing characterization techniques

PRECISE MEASUREMENT OF SHELL DIAMETERS

General Atomics, San Diego, California

J. Gibson, M. Hoppe, A. Greenwood,
D. Steinman and R. Stephens

Until recently we have not had the capability for accurately determining shell diameters for shells larger than 1 mm. We have developed two new techniques for accurately measuring shells with diameters of up to 2.5 mm.

One method makes use of a longer focal length telecentric lens with a larger field of view that reduces our focusing error by at least a factor of two over our previous set up. This method makes use of "Image", a NIH (National Institute of Health) free-ware program and its "wand" tool. The method depends on calibrating with a NIST-traceable ball for each set of measurements and unique lighting conditions. Using this method, the measurement error for the diameter of a 1000 μm shell is about $\pm 0.2 \mu\text{m}$ ($\pm 0.02\%$). The use of the "wand" tool also provides a measure of the OOR of shells to 0.3 μm for a 1 mm size shell (as confirmed by AFM spheremapping).

The second method incorporates a new z-translation laser stage mounted on our Nikon interferometer which is capable of positioning within 0.1 μm over a range of about 3 mm. This capability allows for very efficient and precise measurement of capsule diameters. The measurement error for a 1000 μm shell is less than $\pm 0.2 \mu\text{m}$ ($\pm 0.02\%$).

Work supported by U.S. Department of Energy under Contract NO. DE-AC03-95SF20732.

1. PRECISE OUTER DIAMETER MEASUREMENTS

The need for capability to measure capsules larger than 1 mm in diameter and increased accuracy requirements for the determination of diameters of capsules have led to the development of an improved technique to quickly measure capsule diameters and out-of-roundness (OOR).

We define OOR to be half the difference between the major and minor axes of the best-fit ellipse to a capsule silhouette:

$$\text{OOR} = \frac{(\text{Ellipse major axis} - \text{Ellipse minor axis})}{2}$$

2. PREVIOUS METHOD FOR MEASURING CAPSULE DIAMETERS

Previous O.D. measurements relied on a planar square grid NIST traceable standard and a mouse controlled line measurement tool in the National Institute of Health (NIH) *Image* program.

This method required the operator to place the cursor on one edge of the capsule and stretch a line to the opposing edge. The length of the line was automatically recorded by the "Image" program.

Measurement accuracy and precision by this method was limited to about 0.2% (500 μm shell) due to operator accuracy in choosing the two pixels with the mouse for measuring the diameter and the pixel size of the video camera ($\sim 0.5 \mu\text{m}$).

The available optics we were using with our former method limited our ability to measure capsules larger than 1mm.

3. NEW METHOD RELIES ON SPHERICAL STANDARDS AND MEASUREMENT OF THE CAPSULE PERIMETER

Our new method encompasses the following enhancements:

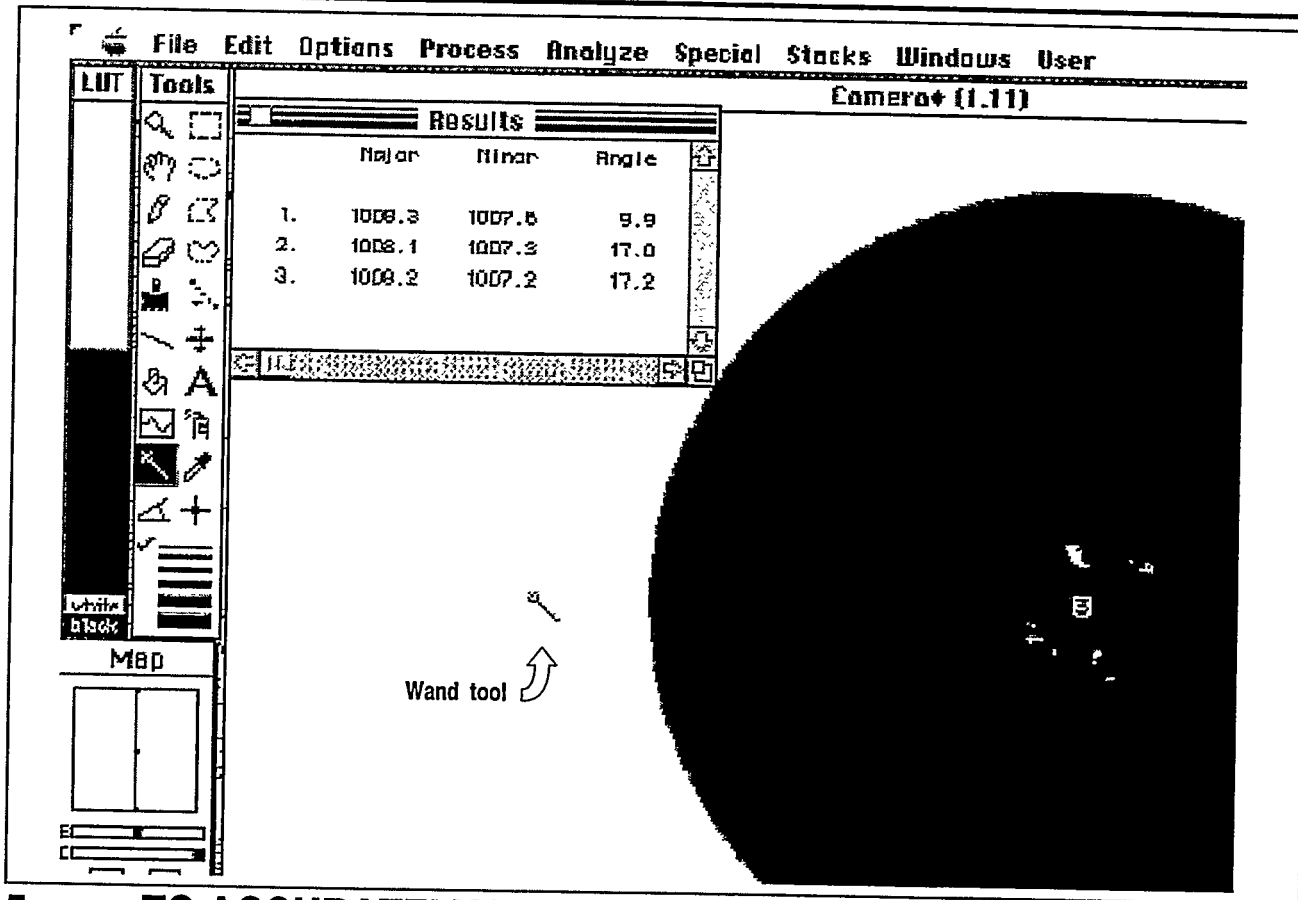
Tungsten carbide or sapphire balls with NIST traceable diameters ($\pm 0.2 \mu\text{m}$) and sphericity ($< 0.2 \mu\text{m}$) are used to calibrate the built in "wand" tool in the GA enhanced NIH *IMAGE* program for both pixels per micron and pixel aspect ratio.

When employing the wand tool, the computer program uses image analysis to find the ellipse that best fits the capsule image and records the major and minor axes. (This technique thus eliminates the major source of operator error when picking the two pixels for measuring the diameter with the "line" tool.)

Because the capsule silhouette is two dimensional, the pixel size limitation is greatly reduced resulting in increased precision for both the diameter and OOR measurements.

We now use a longer focal length telecentric lens so focusing is much less critical. Our present optical set up has a larger field of view that can accommodate capsules up to 2.5 mm in diameter.

4. THE GA MODIFIED "IMAGE" PROGRAM AS IT APPEARS ON THE COMPUTER SCREEN WHEN MEASURING CAPSULE DIAMETER AND OOR



5. TO ACCURATELY DETERMINE OOR, IT IS ESSENTIAL TO CORRECT FOR SCREEN DISTORTION

The image program corrects for screen distortion by using a parameter called the aspect ratio (A.R.) factor, a constant applied to the y-axis to make it agree with the x-axis.

Formerly the operator measured a length on a NIST-traceable micrometer scale in the horizontal direction, then again in the vertical direction. The ratio between the two measurements gave us the A.R. The accuracy by this method is pixel size limited.

Our new method utilizes the "magic wand" and a NIST-traceable calibration ball. The calibrated ball is first measured with the wand tool with the A.R. set to 1.0000. The values for the major and minor axes are entered on the Excel work sheet (light gray cells on Poster 6). The ratio of the measured minor and major axes gives the true A.R. which is then entered in the *Image* program. The calibrated ball is certified to be round; the aspect ratio forces the major and minor axes to have the same value.

6. EXCEL WORKSHEET FOR DETERMINING CAPSULE DIAMETERS AND OOR

Operator: JBG
Date: 3/25/98

Aspect Ratio Derivation

MAX	MIN
1001.1	988.5
1001.1	988.6

Aspect ratio = 1.0127

	Meas.	TRUE
STD OD:	1001.0	1000.2
	1001.2	1001.1
	1001.0	1000.7
	1001.1	1000.9

Shell No.	True Avg OD	OOR	Max OD	Min OD	Comments
Standard Ball	1000.3	0.1	1001.2	1001.1	1000.2 μ m std tungsten carbide ball
Standard Ball	1000.1	0.2	1001.0	1000.7	
Standard Ball	1000.2	0.1	1001.1	1000.9	
1	901.2	0.3	902.2	901.7	
2	898.9	0.1	899.7	899.6	
3	1003.5	3.7	1008.0	1000.7	
4	976.9	1.0	978.7	976.7	
5	988.9	1.1	990.8	988.6	
6	928.6	1.0	930.3	928.3	
7	973.9	1.1	975.7	973.6	
8	901.1	0.2	902.0	901.6	
9	899.1	0.1	899.9	899.7	
10	1003.5	3.7	1008.0	1000.7	
11	977.2	1.0	978.9	977.0	
12	989.3	1.1	991.1	989.0	
13	928.8	0.9	930.4	928.6	
14	974.0	1.1	975.8	973.7	
15	901.2	0.2	902.1	901.7	
16	899.4	0.1	900.2	900.1	
17	1003.5	3.8	1008.1	1000.6	
18	977.1	1.0	978.8	976.9	
19	988.8	1.2	990.8	988.4	
20	928.5	0.9	930.1	928.3	
21	973.9	1.2	975.8	973.5	
Avg =	953.2	1.2			
St Dev =	40.7	1.1			

Max =	1003.5	3.8
Min =	898.9	0.1
Median =	973.9	1.0

7. A NIST-TRACEABLE BALL IS USED TO CALIBRATE THE "IMAGE" PROGRAM FOR PIXELS PER MICRON

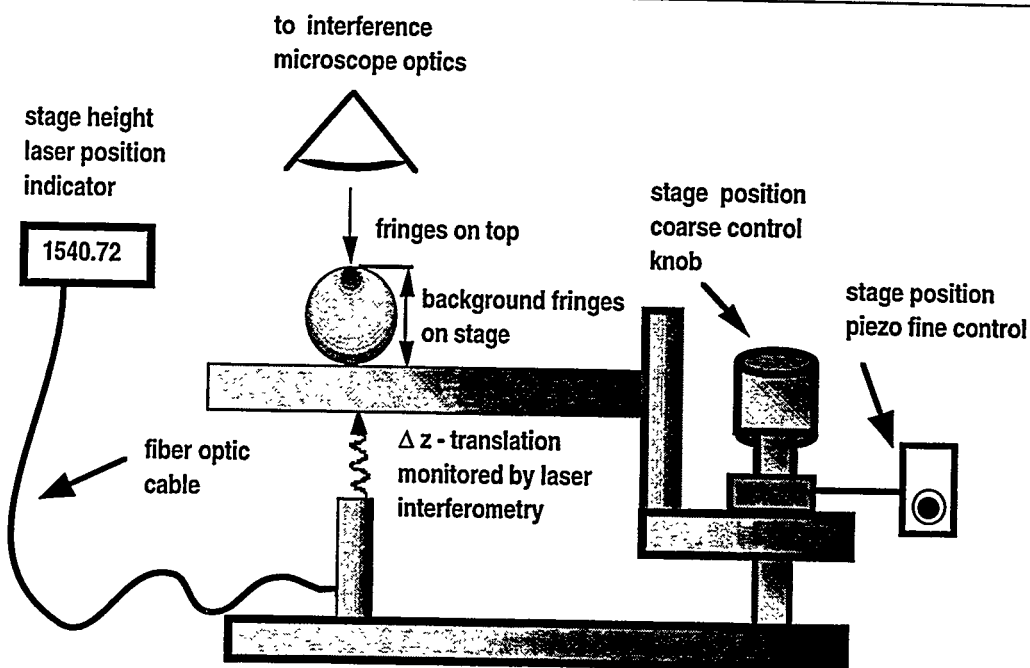
The true value of a NIST-traceable calibrated ball is entered in the dark gray cell of the worksheet shown in Poster 6. It is essential that the calibrated ball be close to the same size as the samples to be measured.

The micron to pixel scale in the Image program is set to a previously determined approximate value.

The standard ball is measured with the wand tool three times refocusing between each measurement. The values for the major and minor axes are copied into the medium gray cells shown in Poster 6. The ratio of the measured diameter to the true diameter is applied to all subsequent measurements.

Finally the samples are measured with the wand tool and the values for the major and minor axes are copied from Image into the Excel worksheet. The illumination, microscope and computer settings must be strictly maintained once the system is calibrated since the measured OD is very sensitive to the illumination.

8. WE CAN ALSO MEASURE LARGE SHELLS USING A NEW Z-TRANSLATION LASER STAGE ON A NIKON INTERFEROMETER



Our z-translation laser stage is capable of positioning within $0.1\mu\text{m}$ over a range of $\sim 2.5\text{ mm}$. The stage can be translated as fast as $50\mu\text{m/s}$ to slower than $0.1\mu\text{m/s}$. This capability allows for very precise interferometric measurement of capsule diameters and layer thicknesses.

9.

OD MEASUREMENT COMPARISON OF METHODS

Technique	Precision (μm)	% error (1000 μm shell)	OOR / error (μm)	Size limitations	Speed
Old method	$\pm 1 \mu\text{m}$	0.1%	yes / $\pm 1 \mu\text{m}$	1000 μm	set up ~15 min 30 seconds /shell
New method long f lens	$\pm 0.2 \mu\text{m}$	0.02%	yes / $\pm 0.3 \mu\text{m}$	~ 2500 μm	set up ~10 min 10 seconds /shell
Interferometer * old z stage	$\pm 1 \mu\text{m}$	0.1%	no	1000 μm	set up ~15 min 1 minute / shell*
Interferometer * new z stage	$\pm 0.2 \mu\text{m}$	0.02%	no	~ 2500 μm	set up ~15 min 1 minute / shell

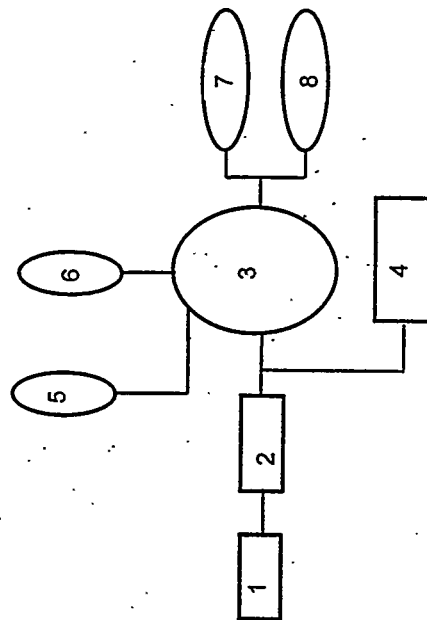
* Also used to measure wall thickness and layer thicknesses

Overcoating glass microspheres in electric discharge by evaporation of tetraethoxysilane

Yu.V.Andramanova, A.A.Aushev, N.L.Zolotukhina,
V.M.Izgorodin, T.V.Karelskaya, A.F.Kovyllov,
N.A.Lisovenko, G.P.Nikolaev, E.G.Orlikova, T.V.Serova
and I.V.Sevrugin

Russian Federal Nuclear Centre
All-Russia Research Institute of Experimental Physics
Sarov, Russia

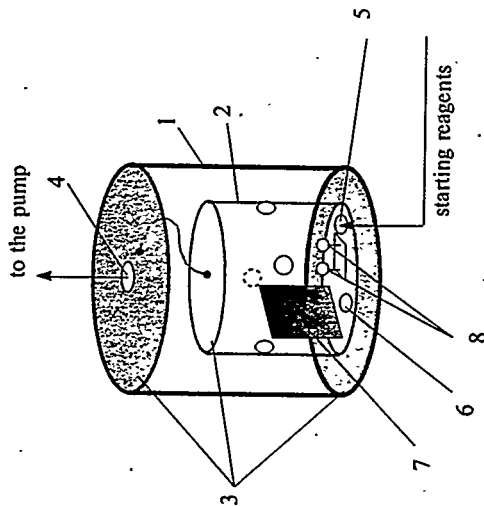
Fig. 1. Schematic representation of the plasmochemical vacuum setup for depositing films in flowing regime with application of gas discharge of alternating current at the frequency of 18-19 kHz



1. vacuum pump; 2. diffusion pump; 3. reaction chamber;
4. micromanometer; 5. vacuum meter; 6. power source; 7, 8. Initial reagent.

Fig.2. Schematic representation of the reaction chamber 3 for deposition of SiO_2 films.

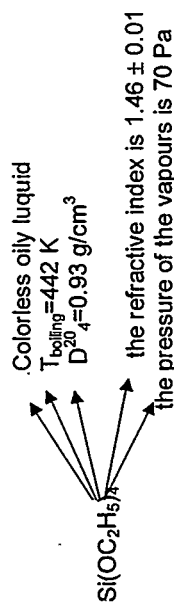
Work parameters: the pressure is 14 - 1400 Pa,
the voltage is 230 - 240 V,
the frequency is 18 - 19 kHz,
the power is 400 W.



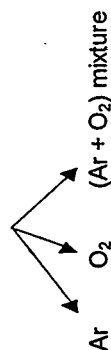
1. the outer casing of the setup constituting a cylinder of quartz glass with a diameter of 86 mm and height of 80 mm;
2. the inner reaction chamber with a diameter and height of 40 mm ; it is provided with four ports for removing volatile reaction products;
3. flat steel electrodes;
4. ports for evacuating the reactor;
5. a port for starting reagents inlet, being dosed through special cans;
6. a port for measuring pressure in the reactor;
7. a "witness" substrate, which is a 30x20x1.5 mm glass plate;
8. glass spherical substrates.

Initial reagent

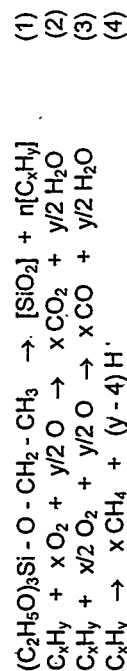
1. Siliconorganic compound with a high pressure of the vapours - tetraethoxysilane



2. Gases for electric discharge



Schematic representation of chemical reaction



Overcoating order

1. To evacuate down the setup to a pressure of 0.1 Pa
2. To admit the plasmas gases to chamber 3 (Fig. 1) up to a pressure of 27 Pa and to ignite the discharge
3. 5 min. later to fill the reaction chamber 3 of tetraethoxysilane vapour up to 27 Pa and to deposit the silica film
4. after finishing coating to use the bombardment of the layer by plasma particles during 5-10 min.

Fig. 3. Dependence of the SiO_2 film thickness on the deposition time.

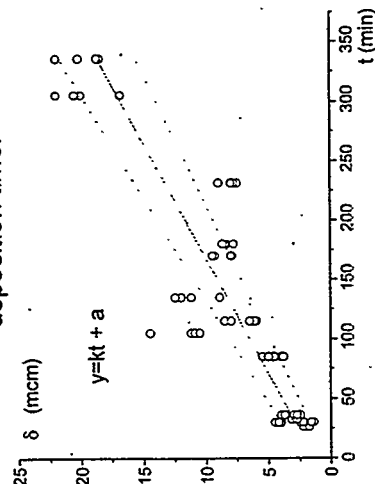
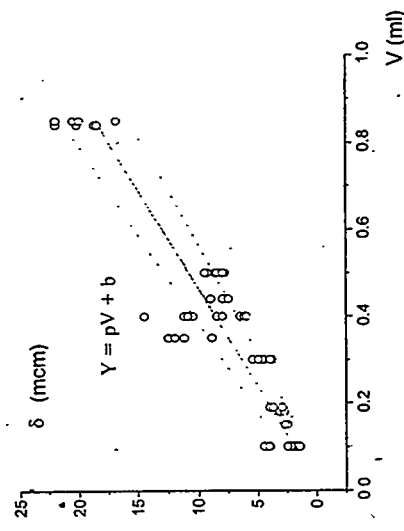


Fig. 4. Dependence of the SiO_2 film thickness on the utilization of tetraethoxysilane.



Physic-chemical and structural properties of the film

properties	Coating in the Ar-atmosphere	Coating in the Ar+O ₂ atmosphere
Outward appearance	Looked transparent with a light brown shade	Looked transparent with a light brown shade
X-ray crystal structure analysis	amorphous	amorphous
Elemental composition	Si.....29.67 % mass O.....35.33 % mass C.....29.50 % mass H.....2.30 % mass Na, K, Ca, Al...."traces"	Si.....30.00 % mass O.....38.33 % mass C.....28.60 % mass H.....2.20 % mass Na, K, Ca, Al...."traces"
UR-spectroscopy	Abs.line (sm ⁻¹) 3400 1640 2900 1720 960 890	Abs.line (sm ⁻¹) 3400 1640 2900 1720 960 890
	group Ads. H ₂ O Def. O-H Val. C-H Val.C=O Val.C-C Val. C-C	group Ads. H ₂ O Def. O-H Val. C-H Val.C=O Val.C-C Val. C-C
Density	1.55 ±0.07	1.55 ±0.07
Refractive index	1.46±0.01	1.46±0.01

The example of increasing the wall thickness of glass target by means of plasm-chemical method for laser fusion experiments on the Iskra-5 facility

Fig.5. The interferogramm of a glass microsphere with D-T gas coated by the silica layer. The thickness of microsphere wall is 1 mcm; the film thickness is 10 ^{nm}



In-Situ Polymerisation Technique For The Production Of Foam Filled Laser Targets

A Review

Wigen Nazarov

Chemistry Department, University of Dundee,
Dundee DD1 4HN, Scotland

In-Situ Polymerization - Procedure

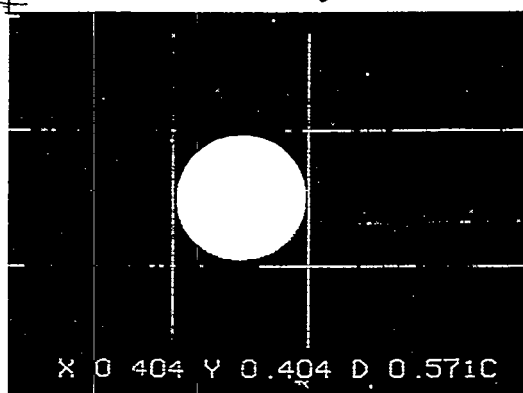
University of Dundee



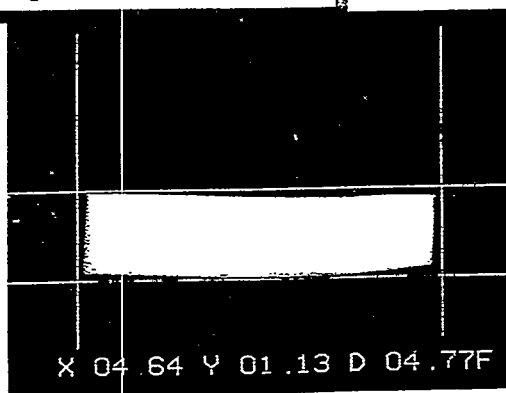
- In-situ polymerization technique is used for the production of foams in difficult to reach areas of a laser target. Briefly, this involves the following steps:
 - ◆ A monomer (Trimethylol Propane Triacrylate (TMPTA) is the preferred monomer) is dissolved in a suitable solvent and a suitable initiator added to the solution.
 - ◆ The monomer solution is injected into the required position in the target, so that it fills it completely.
 - ◆ The monomer solution is then polymerized to a gel using a UV light source.
 - ◆ The target containing the gel is then placed in a non-solvent (e.g. methanol) to precipitate the foam.
 - ◆ The target, containing the wet foam, is then dried using a critical point dryer.

Examples of Free Standing Foams and Films Made by In-Situ Polymerization Technique

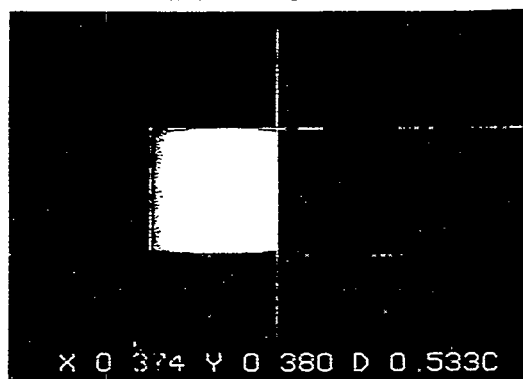
University of Dundee



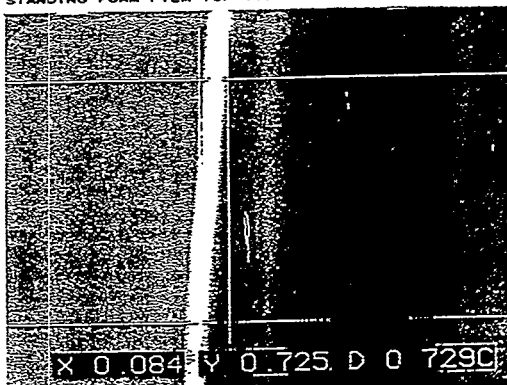
A FREE STANDING FOAM LOOKING FROM THE TOP



A FREE STANDING FOAM FILM TOP VIEW



A FREE STANDING FOAM SIDE VIEW



A FREE STANDING FOAM FILM SIDE VIEW

Advantages of In-situ polymerization

University of Dundee



- It is possible to produce foams in inaccessible areas of a laser target.
- Density range from 10 mg cm^{-3} to full density (sometimes lower than 10 mg cm^{-3} depending on target geometry).
- Foams as low as 3 mg cm^{-3} have been produced by this technique.
- High Z elements can be loaded in the foam:
 - ◆ Chlorine, Bromine, Fluorine: up to 50%, can be loaded in the foam structure.
 - ◆ Silicon oxide, Aluminium oxide: up to 30%, can be loaded as dispersion.

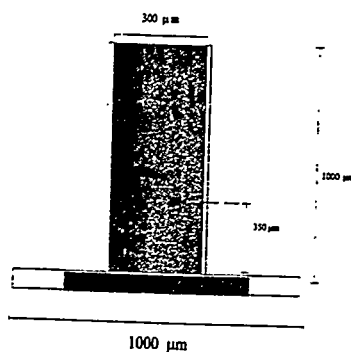


Examples of Targets Made by in-situ Polymerization Technique

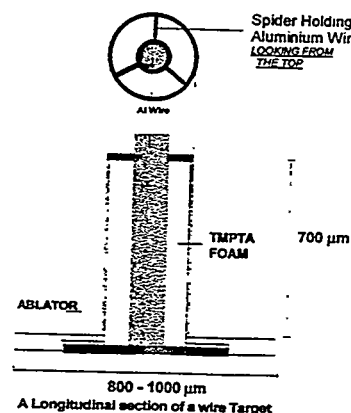
- **EOS (Equation of State) targets:**
 - ◆ **Aluminium Step Targets:** Embedded aluminium step in foams.
 - ◆ **Washer type targets:** for laser shock experiments carried out at LULI laboratories.
- **Free standing foam:** Foams without moulds.
- **Free standing films:** Free standing films can also be made by this technique.



Sphere and Wire Targets



Sphere drag targets: These targets were designed to show the effect of a shock wave in a low density medium passing a higher density particle.



Wire targets: Wire targets were devised to investigate Kelvin-Helmholtz instability. These targets were designed with an aluminium wire placed along the axis of a foam filled cylinder. Targets of a similar nature have been made before by our colleagues at LANL.



Acknowledgments

Atomic Weapons Establishment:

This work was carried out under contract to Atomic Weapons Establishment, Aldermaston, England.

AWE Fabrication Team:

Barrie Lewis	Section Leader
Tony Tyrrell.....	Deputy Section Leader
Colin Horsfield.....	Senior Scientist
Peter Hobbs.....	Design Engineer
Gerry Eatwell.....	Film production/Electroplating
Jim Lockyer.....	Micromachining
Debbie Hadley.....	Characterization
Marilyn Mertens.....	Microassembly
Julie Bolton.....	Microassembly

Characterization of Deuterium-Foam Targets for NIKE*

L. Y. Chan,

Science Applications International Corporation, McLean, VA

J. D. Sethian,

Plasma Physics Division, Naval Research Laboratory, Washington, DC

The NIKE laser facility at NRL has been fielding planar deuterium-foam targets in accelerating foil experiments to study the hydrodynamic instability growth in fusion-like target material designs. The present deuterium foil design consists of a polyimide thin-film and deuterium-wetted resorcinol-formaldehyde (RF) foam, enclosed in a cryogenic cell. Target fabrication issues that are being addressed under cryogenic conditions include: (i) bowing of the polyimide vapor barrier due to the deuterium vapor pressure, (ii) changes in foam target thickness when wetted by liquid deuterium and (iii) surface uniformity of the rear surface of the wetted foam. Characterization methods to resolve these issues and their results will be presented.

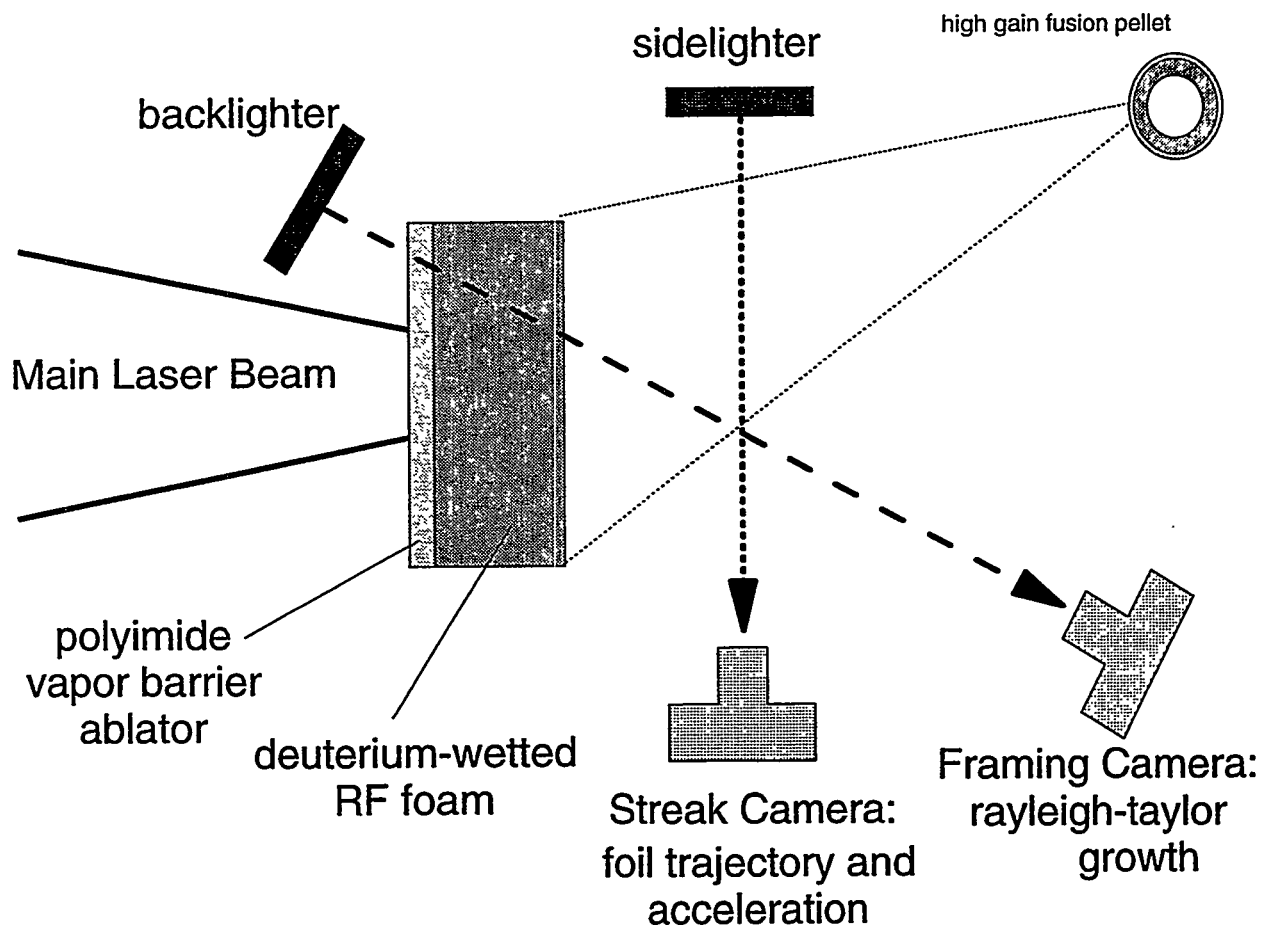
* This work is supported by the U. S. Department of Energy

NIKE KrF Laser

- Gas Laser: $1/4\ \mu\text{m}$ wavelength (248nm), 2 kJ on target, 4ns main pulse with 8ns low intensity foot, $10^{14}\ \text{W}/\text{cm}^2$ intensities.
- ISI Beam Smoothing: intensity fluctuations of 1% rms in single beam and 0.3% for 44 overlapped beams, $3/4\ \text{mm}$ top-hat spatial profile at focus.
- Direct drive isentropic acceleration and compression of planar foil targets.

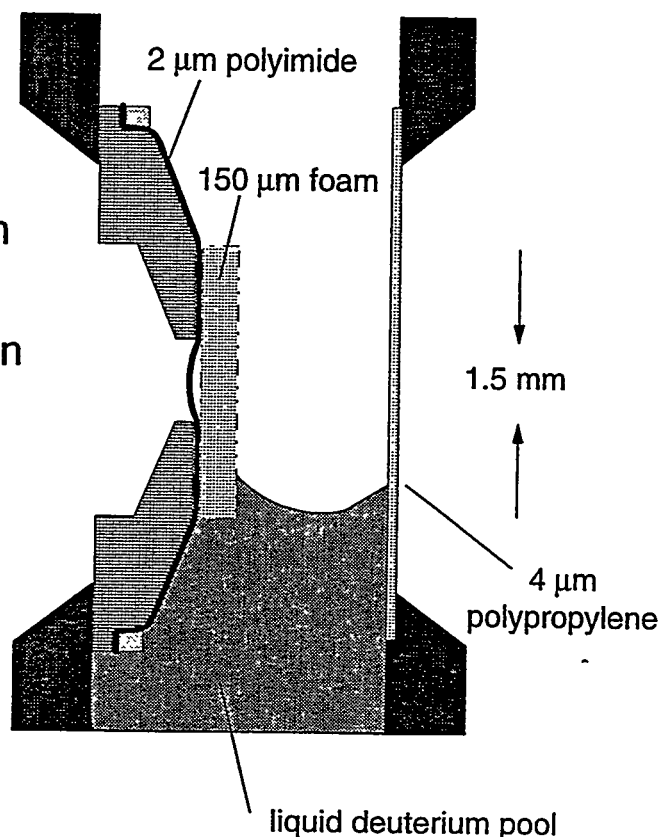
Deuterium Foil Acceleration

- Acceleration of high gain direct drive target consisting of fusion-like materials for realistic compression and radiation effects.
- Measure hydrodynamic (Rayleigh-Taylor) instability growth and evaluate different ablator schemes to control and stabilize this instability.

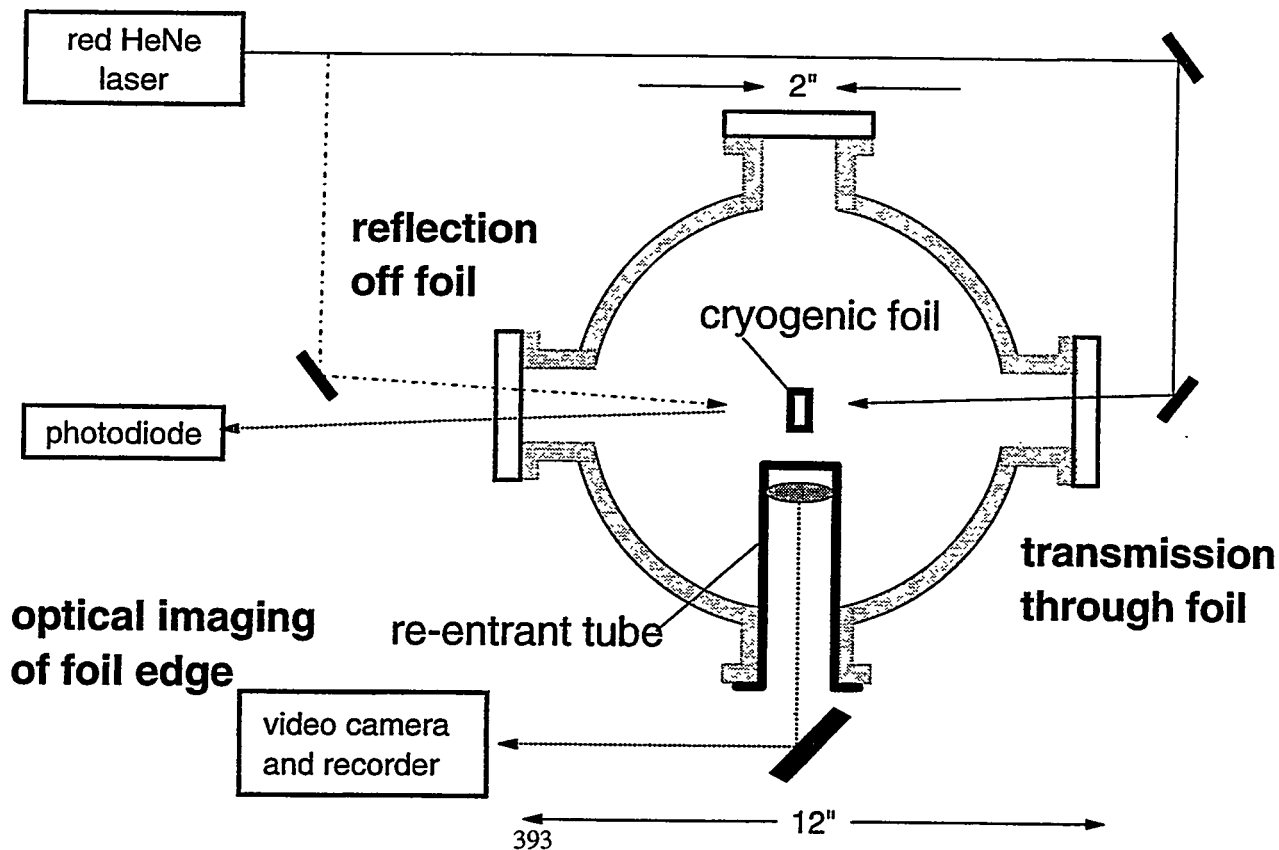


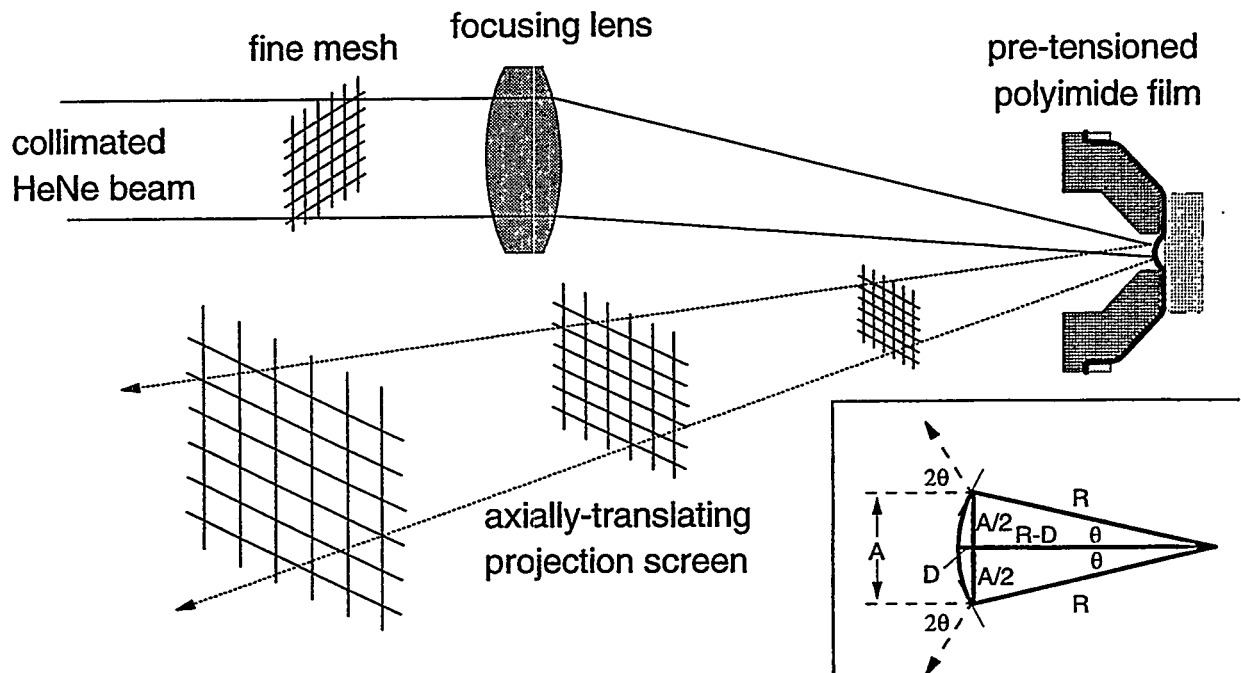
Side View of cryogenic cell and deuterium foil target

1. Bowing of polyimide film from deuterium vapor pressure.
2. Liquid deuterium gap between bowed polyimide and wetted foam.
3. Thickness change in foam when wetted.
4. Surface uniformity of wetted foam and meniscus shape.



Cryogenic Test Chamber





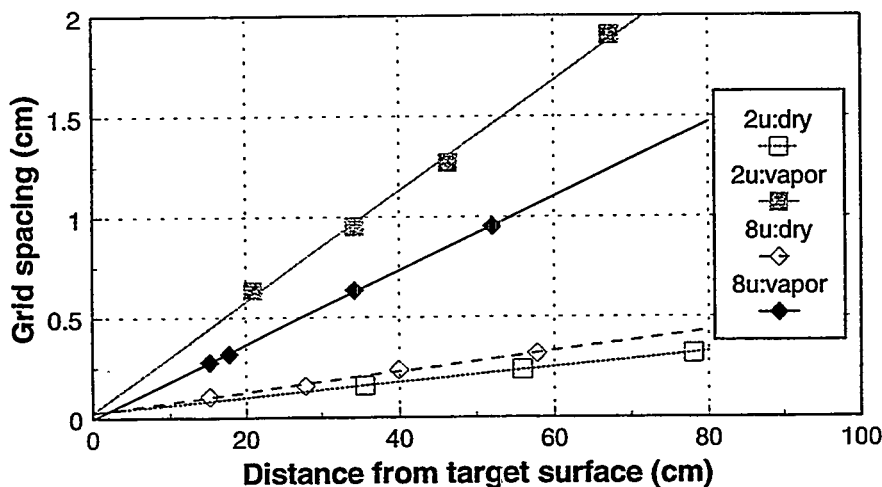
- position fine mesh for image of gridlines (near field), rather than 2D diffraction pattern (far field).

For small angle bowing:

$$R = A/2\theta$$

$$D = A^2/8R = A\theta/4$$

Probe Expansion Results for 2μ / 8μ Polyimide film + 150μ RF foam



- liquid deuterium vapor pressure at 20K is ~200 torr.

- spherical stress on thin membrane:
 $\sigma = PR/2t$
 $R = (2\sigma/P) t$

Source of Polyimide Film:

Bow Radius: R(mm)

Bow Displacement: D(μm) [A=1.5mm]

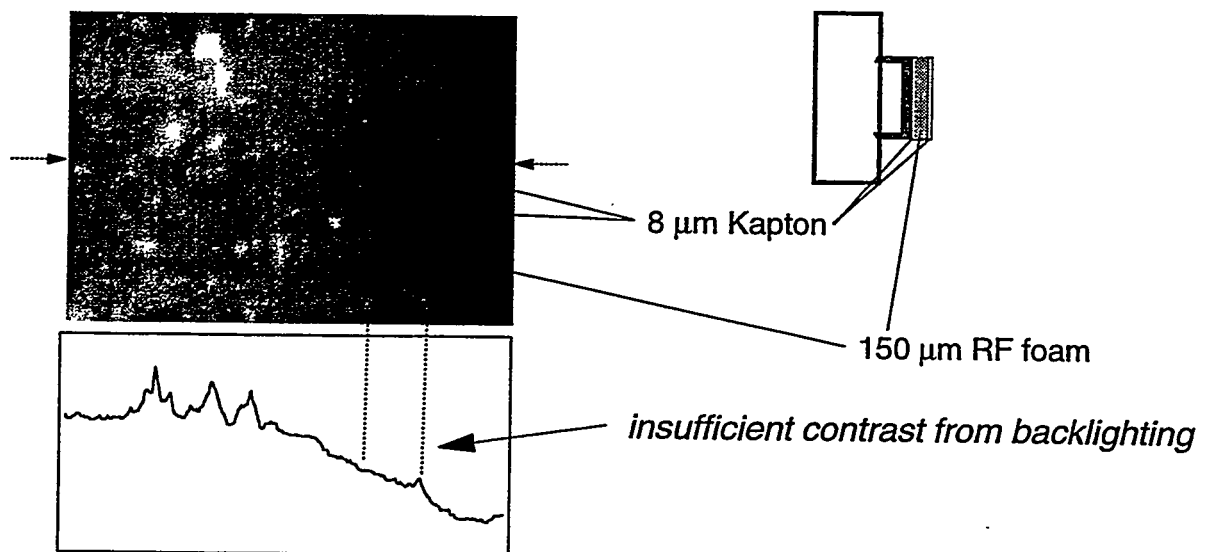
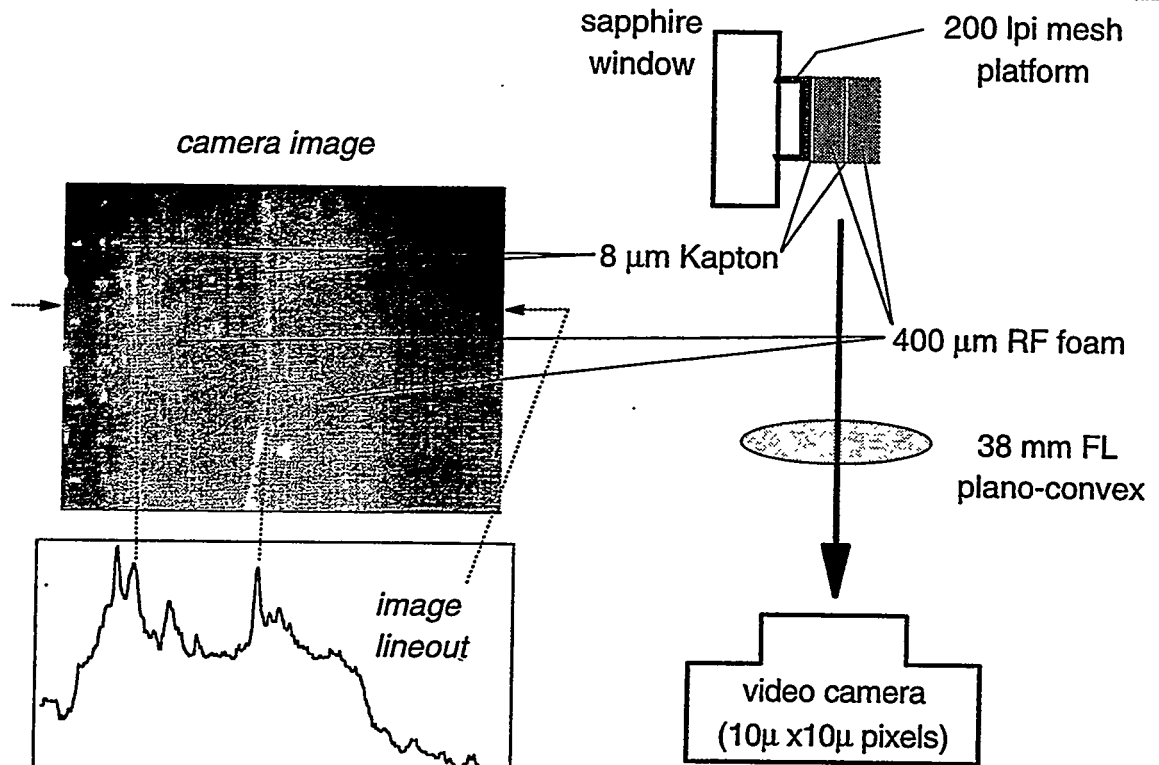
Probe Beam Spot: A_p(mm) [+/- 20%]

Target Bow: D_t (μm) [A=800μm]

	2μm	8μm
Rebberit	23.0	38.2
	12.2	7.4
	0.28	0.25
	3.5	2.1

Measurement of Wetted Foam Thickness via Edge Imaging

NRL



	400 μ m	150 μ m
Mesh Spacing (pixel)	58	110
Spatial Scale (μ m/pixel)	2.2	1.1
Dry Foam Width (pixel)	194	110
Wetted Foam Width (pixel)	194	140
Uncertainty Estimate (pixel)	2-3	10

1. High resolution image scanning of wetted foam edge

- Image of edge of backlit wetted foam appears shiny and smooth compared to that of dry foam.
- Current cryogenic cell does not permit sufficient access to observe meniscus of liquid deuterium on wetted RF foam.
- Improvements in spatial resolution, scanning capability and brighter backlighting are being pursued.

2. Large angle reflection of probe beam off rear surface of wetted foam

- Reflection at incident angles is very low for RF foams.
- Scattering from non-uniformity at the surface of the wetted foam might cause additional divergence in reflected beam that could be measured to determine the level of surface nonuniformity.
- A new cryogenic cell is being designed to permit sufficient access for large angle reflective probing.

A COMPARISON OF PROCESSES FOR THE FABRICATION OF FLAT R/F FOAMS FOR ICF TARGET MODELING

M. REBBERT, O. GLEMBOCKI, C. MARRIAN, S. PROKES, J. SETHIAN

GOAL

**THE GOAL WAS TO DEVELOP A PROCESS THAT PRODUCES
FLAT R/F FOAMS FOR USE AS ICF TARGETS.**

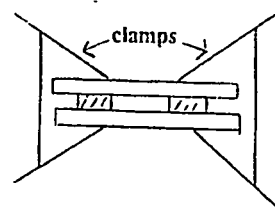
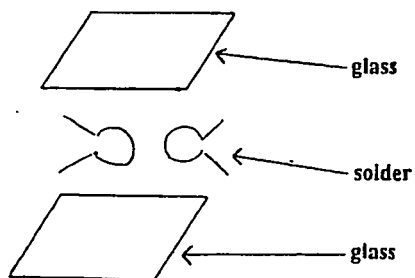
**THE PROCESS NEEDS TO PRODUCE FOAMS IN QUANTITY THAT
ARE FLAT, UNIFORM, AND WITH A CONTROLLED THICKNESS
BETWEEN 120 TO 300 μm AND DENSITIES RANGING BETWEEN
25 TO 100 mg/cm^3 .**

CHEMISTRY OF R/F FOAM

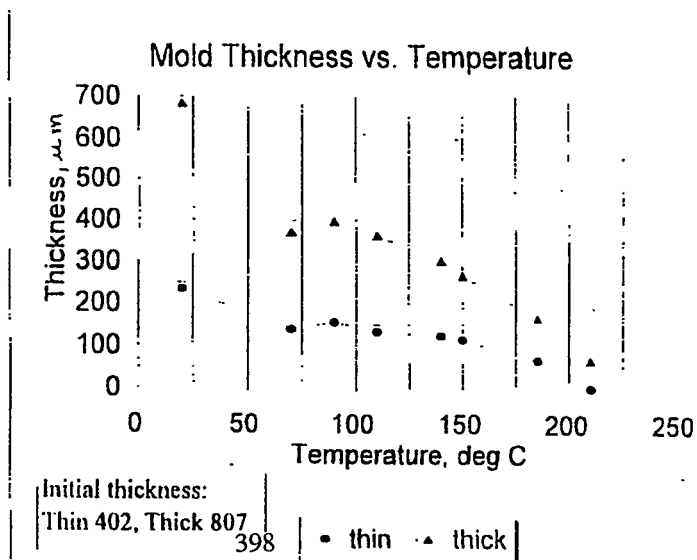
THE CHEMISTRY FOR PRODUCING THE R/F FOAMS IS BASED
ON THE PROCESS DEVELOPED AT LLNL.

FOAMS THAT WERE MADE FOR THIS STUDY HAD AN F/R
RATIO OF 2 AND A R/C RATIO OF 200.

MOLDS



- GLASS SLIDES ARE TREATED WITH A RELEASE AGENT

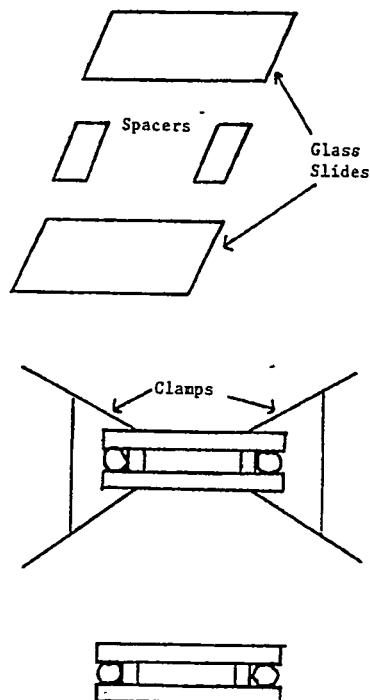


THE FOAM SOLUTION IS PIPETTED INTO THE MOLDS AND THE GLASS SLIDES ARE CLAMPED TOGETHER.

THE MOLD SLIDES ARE FIRST BAKED IN AN OVEN TO GEL THE FOAM. THEY ARE THEN SWITCHED TO A WATER BATH FOR THE FULL CURE.

AFTER THE CURE, THE MOLD SLIDES ARE PLACED IN IPA, WHERE THE GLASS SLIDES ARE REMOVED LEAVING THE FOAM FILLED MOLDS FOR SOLVENT EXCHANGE.

AFTER SOLVENT EXCHANGE, THE FOAMS ARE DRIED BY CRITICAL POINT DRYING.



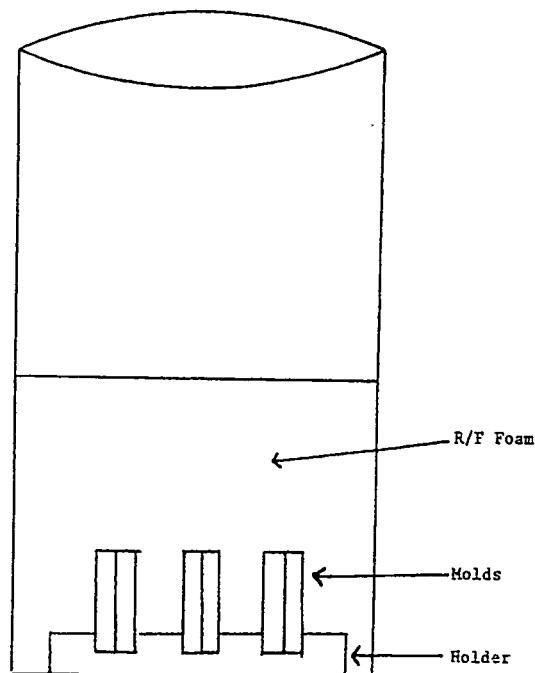
THE GAP BETWEEN THE SLIDES THAT DETERMINES THE FOAM THICKNESS IS MADE BY SPACERS.

TYPICAL MATERIAL FOR THE SPACERS IS GLASS OR ALUMINUM.

THE SLIDES AND SPACERS ARE CLAMPED TOGETHER AND GLUE IS APPLIED TO THE EDGES.

AFTER THE GLUE SETS, THE CLAMPS ARE REMOVED AND THE MOLD IS READY FOR FILLING.

VACUUM FILLING



THE MOLDS ARE PLACED IN A BEAKER. THEY ARE HELD ON EDGE BY A HOLDER. RF FOAM SOLUTION IS POURED INTO THE BEAKER TO COVER THE MOLDS. THE BEAKER IS PLACED IN A VACUUM CHAMBER. THE AIR IS PUMPED OUT OF THE CHAMBER AND FOAM SOLUTION AND THE FOAM FILLS THE EVACUATED VOIDS.

CURING

- THE BEAKER OF FOAM IS REMOVED FROM THE VACUUM CHAMBER AND PUT IN A WATER BATH FOR PRESCRIBED CURE TIMES.

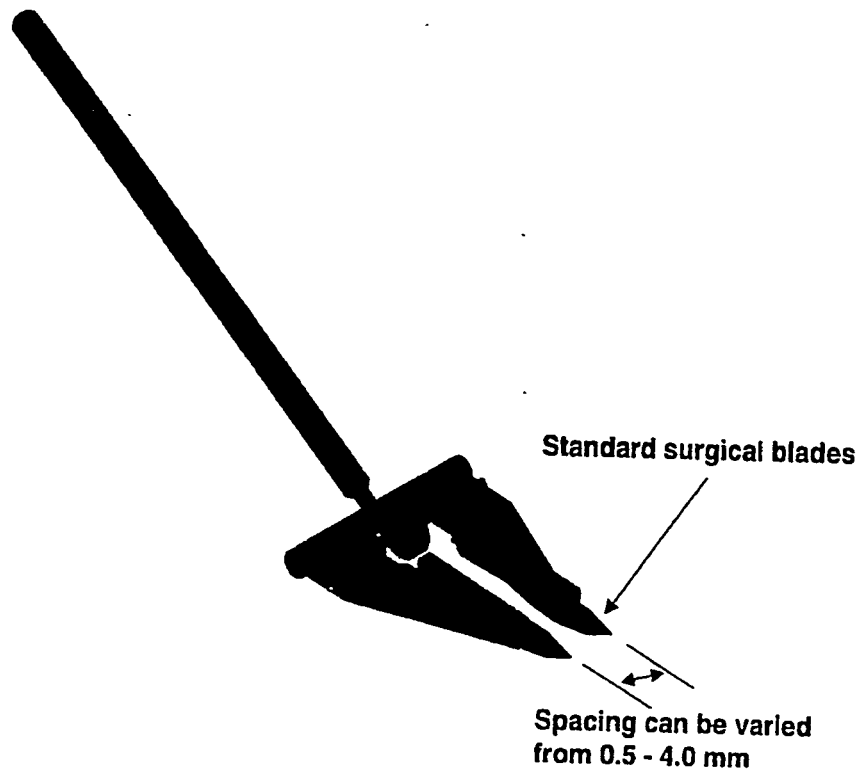
EXCHANGE

- AFTER THE CURE, THE GLASS MOLDS ARE DUG OUT OF THE FOAM MASS AND ARE PLACED IN IPA FOR SOLVENT EXCHANGE. IN THE IPA THE SLIDES SEPARATE LEAVING THE SHEET FOAM FLOATING IN IPA.

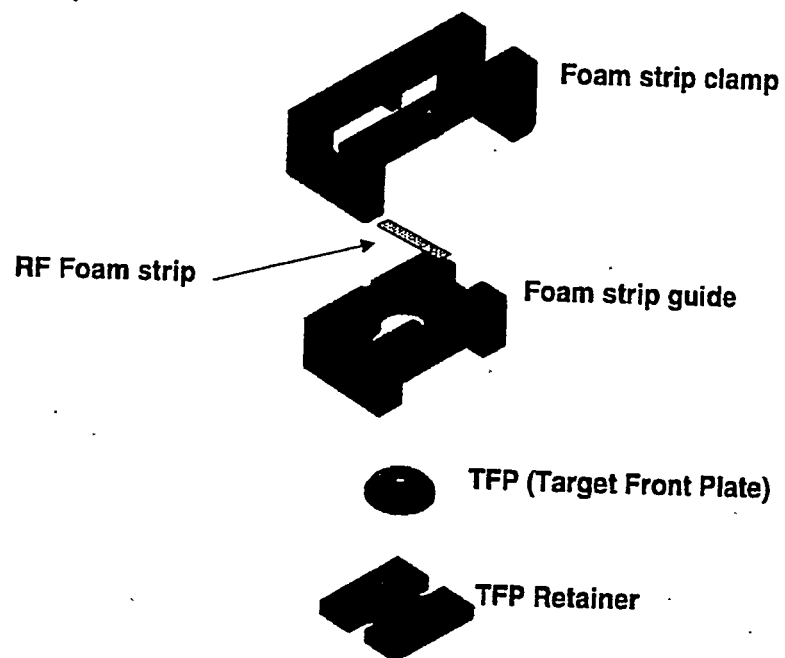
DRYING

- THE WET FOAM IS CUT INTO STRIPS, MOUNTED IN A DRYING FIXTURE AND DRIED BY CRITICAL POINT DRYING WITH CO₂.

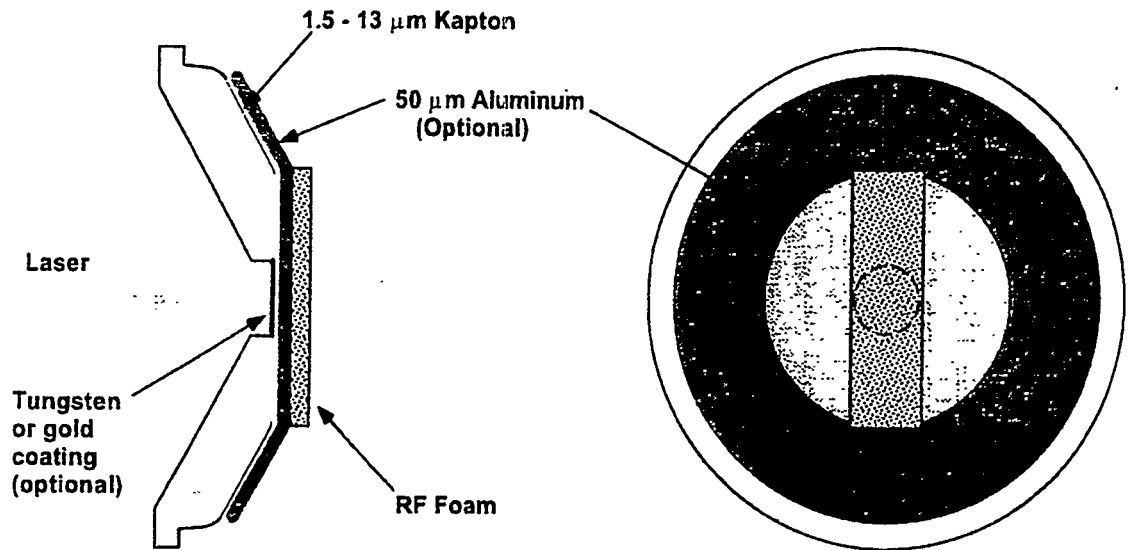
CUTTER USED TO CREATE FOAM STRIPS



FIXTURE TO HOLD FOAM STRIPS ON TFP WHILE DRYING

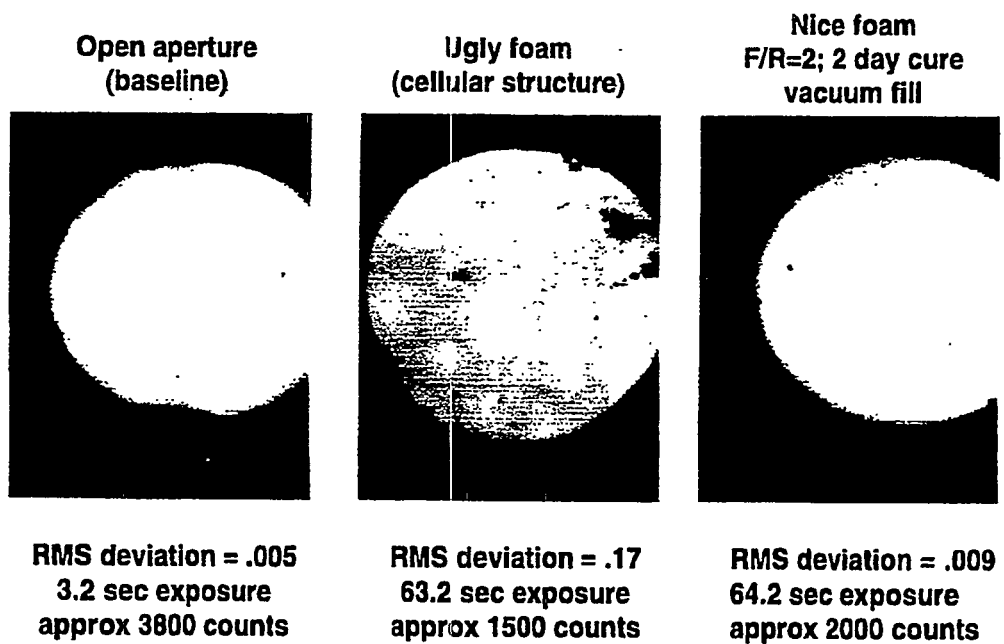


Standard Nike Target Front Plate (TFP) with Foam



D2-EOS.CVS

UV transmission through foams



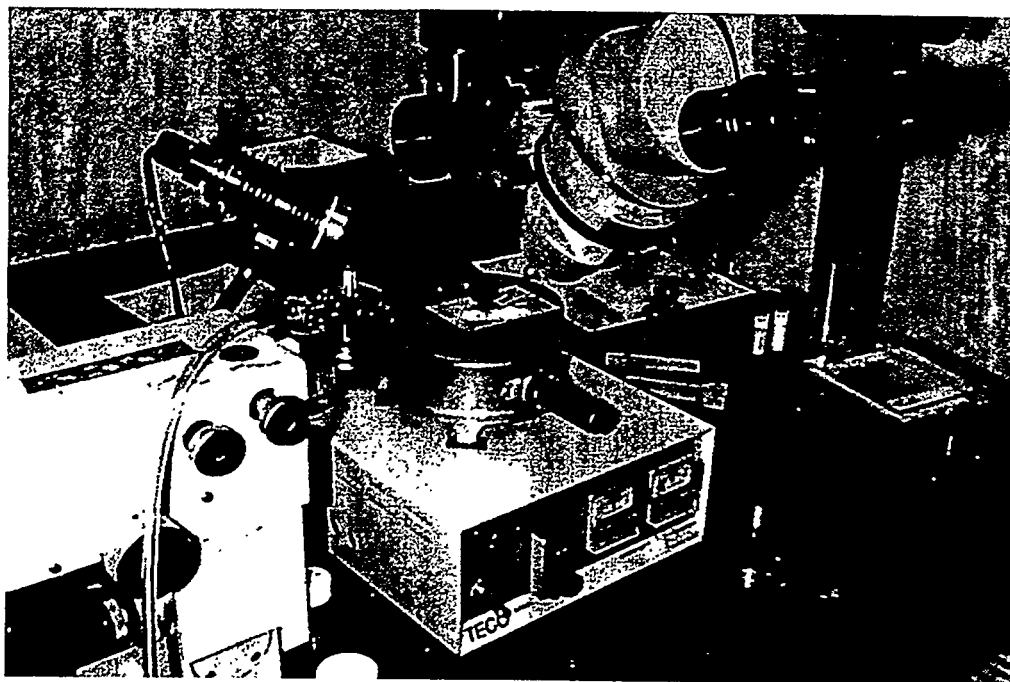


John Burmann
Schafer Corp.
303 Lindbergh Ave.
Livermore, CA 94550

Steve Letts and Mike Saculla
Lawrence Livermore National Laboratory
7000 East Ave. Livermore, CA 94551

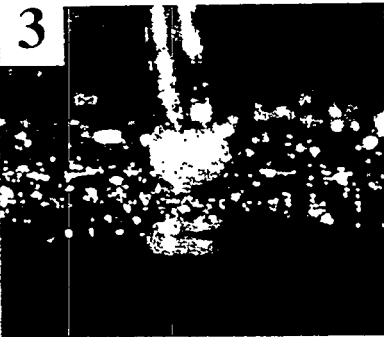
- We have recently developed a technique to make plasma polymer shells with integral fill tubes.
- Mark Whitman from UR/LLE, was the first person to make a shell and fill tube in one piece.
- We had trouble successfully duplicating his procedure, but instead have developed an alternate technique that has proven reliable.
- They can be constructed with small (30 μm OD) fill tubes and are easier to make than capsules with the fill tube glued directly to the shell.
- These shells have been a valuable asset for recent cryogenic experiments at LLNL and at LANL.

*
"This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48."

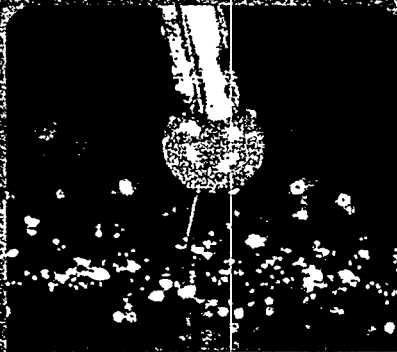
**Schafer**

19k molecular weight P α MS is ground into a powder and placed on a gold coated microscope slide. It is then heated to $\approx 140^\circ\text{C}$ to create small molten puddles. The gold adheres to the P α MS⁴⁰³ better than the plain glass slide.

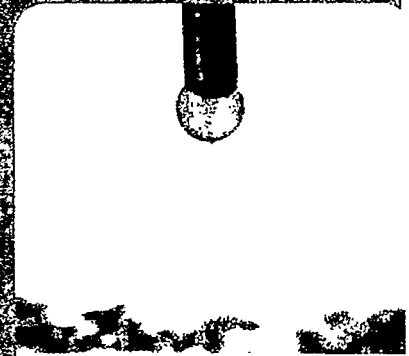
3



STEP 1



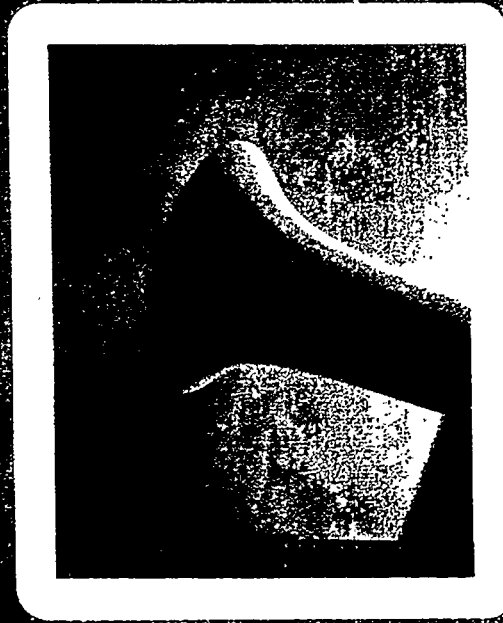
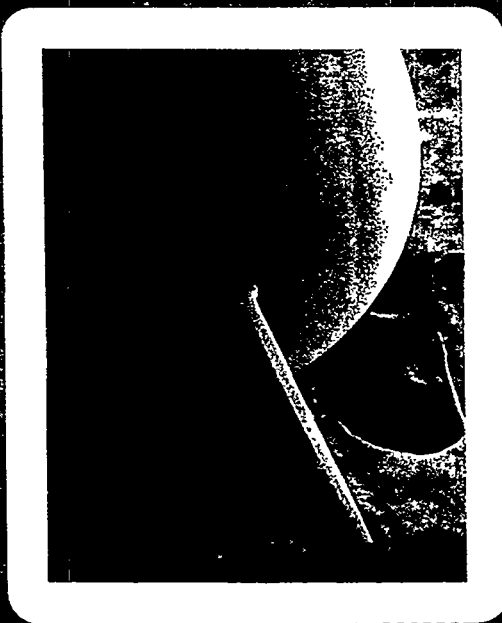
STEP 2



STEP 3

A shell is being held with a vacuum chuck in a micro manipulator and brought down to touch a small molten puddle of PαMS, then pulled away slowly to draw a fiber. The fiber is trimmed to $\approx 1.5 - 2$ mm in length before being coated with "CH" or "CD" plasma polymer.

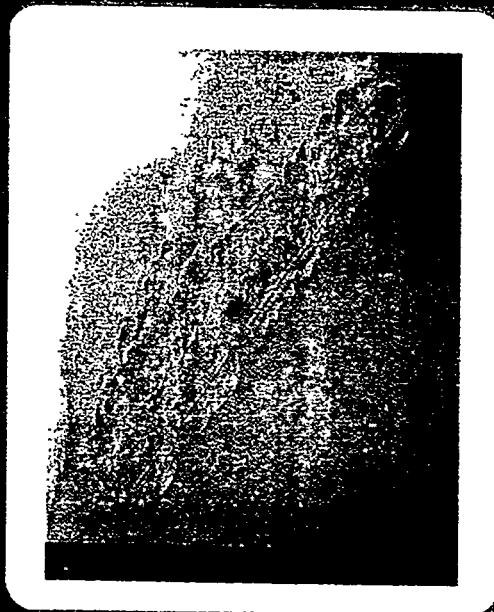
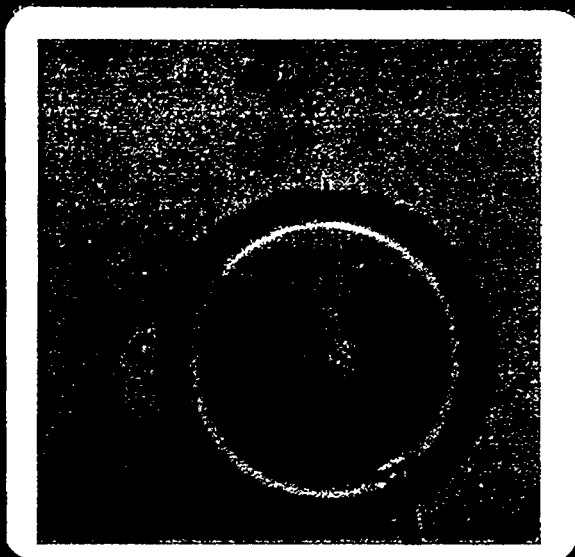
4



SEM photos by Derek Coker, Schaffer Corp.

This is an S.E.M. photo of a 1 mm diameter PαMS mandrel with a 19k molecular weight PαMS stalk.

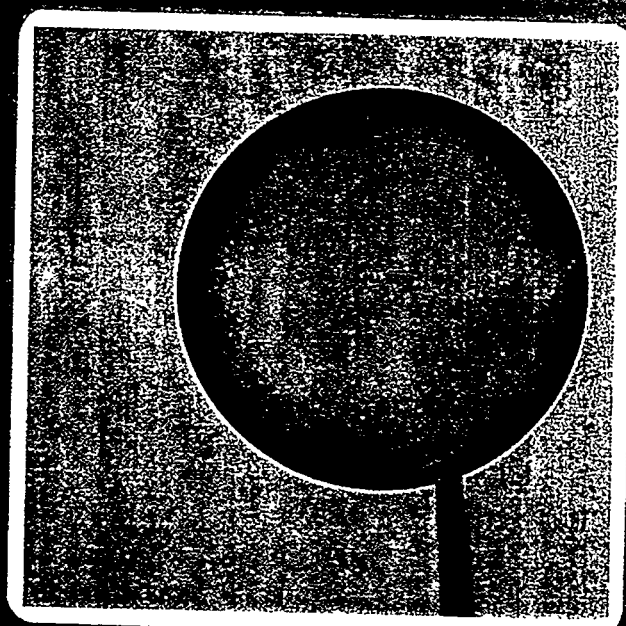
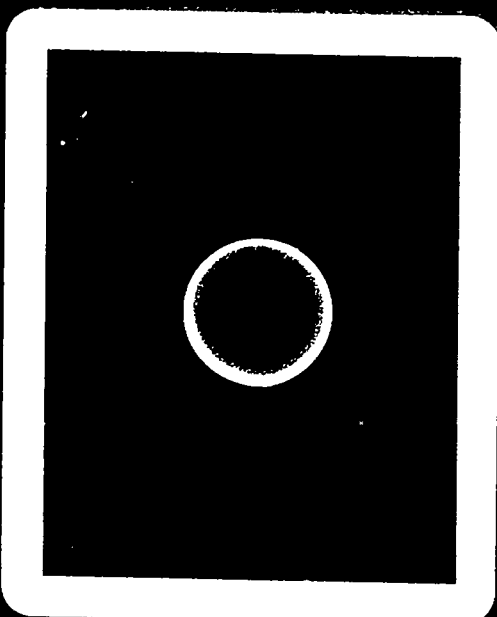
5



We had problems with the thinner shells ($\approx 10\text{-}12\ \mu\text{m}$) sticking to the pan after pyrolysis, as shown in these photographs. Gas flow was slightly increased, which lowered the shell temperature, until there was no adhesion to the pan.

6

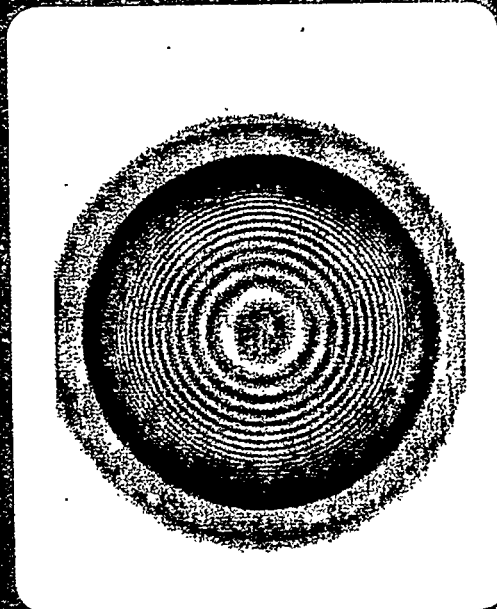
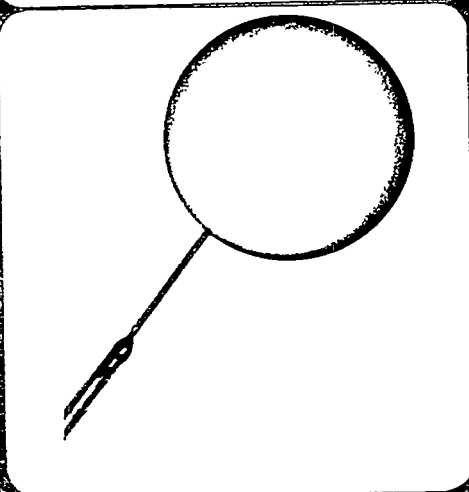
We have found that putting no more than 5 shells at a time in the GDP coater gives a more uniform coating.



Radiography and other characterization have shown a slight non-uniform wall, due to the fact that the "tail" ⁴⁰⁵ limits movement of the shell while coating.

7

The shell/fill tube is then epoxied into a small glass capillary tube and leak checked at room and LN₂ temperatures.



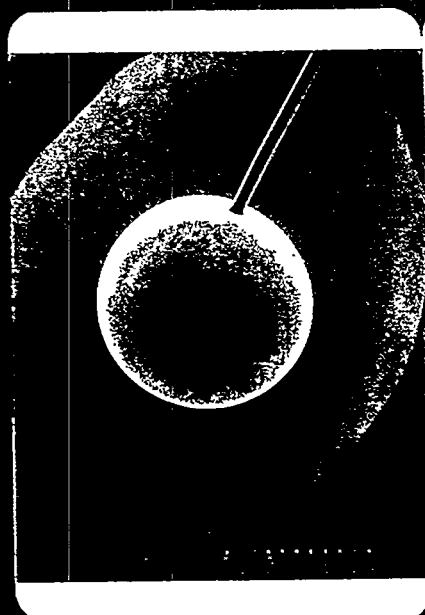
The shell is checked by interferometry to insure an open fill line. Air is evacuated from the shell causing a fringe shift due to a change in index of refraction. If there is no fringe change, the fill tube is plugged.

8

Complete shell with fill tube at 50X magnification.

500X magnification at fill tube to shell transition.

View from inside shell at fill tube, 500X magnification.



SEM photos by Derek Coker, Schafer Corp.

Here are S.E.M. photos of a "CD" plasma polymer completed shell.

MACHINING BERYLLIUM SPHERES FOR IGNITION CAPSULE APPLICATIONS*

**L. Salzer, R. Day, N. Elliot, L. Foreman,
R. Margevicius, M. Salazar and
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**Materials Science and Technology
Division
Los Alamos National Laboratory
Los Alamos, New Mexico**

This work is supported by the U.S. Department of Energy under contract number W7405-ENG36

Introduction

As part of an initiative to produce capsules for the National Ignition Facility (NIF), we machined spheres with a diameter of 2.2 mm. The major challenge is relocating the second side after the first side is completed. This was done with our Quick Flip Locator (previously reported) and explained in figs. 1 through 7. Scanning electron micrographs and Wyco interferometer data are shown.

This poster deals with machining and finishing the outside diameter of the sphere. The previous operations (the inside cavity and joint) were machined into cylindrical components using similar part-holding fixtures and machining operations.

Machining operations

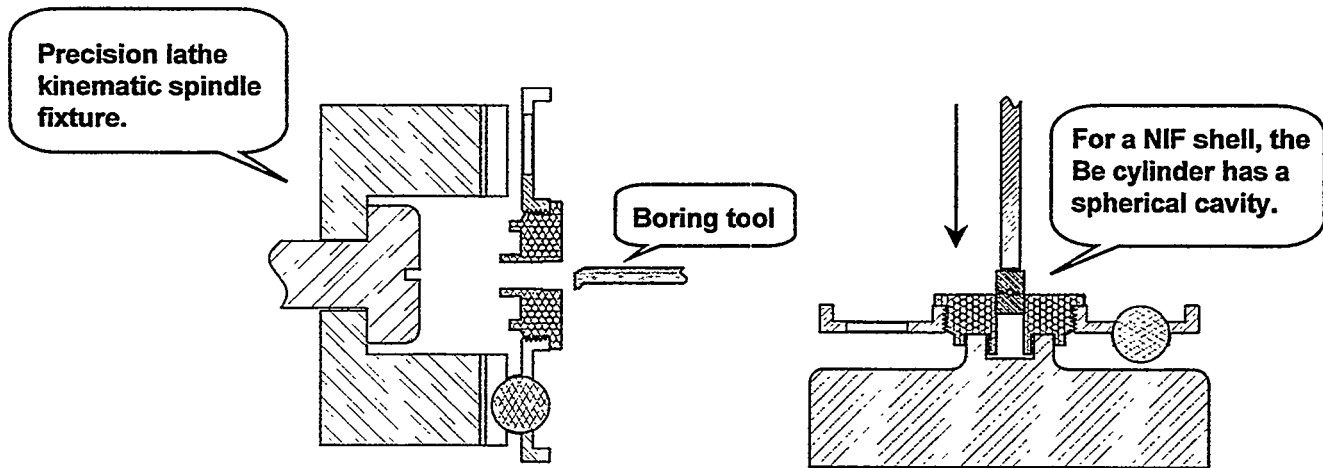


Fig. 1

Fig. 2

Boring the ID of part holder while on kinematic mount on precision lathe. A larger diameter lead area aligns Be cylinder when inserted as shown in Fig. 2.

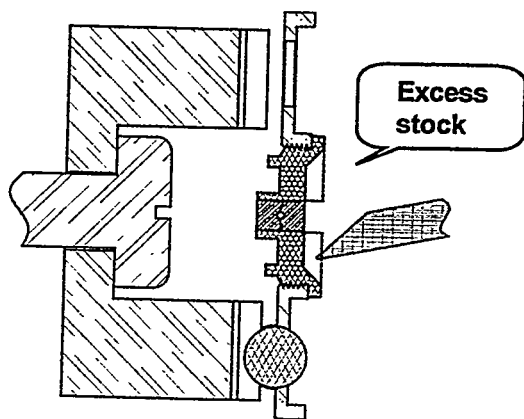


Fig. 3

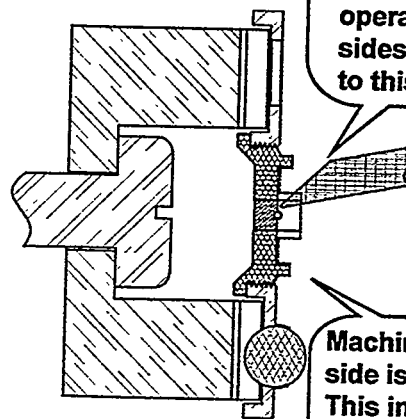


Fig. 4

Removing excess stock on Fig. 3 is done on a conventional Hardinge lathe. Fig. 4 shows the reversible locator positioned on the magnetic kinematic mount of the Pnuemo precision lathe for a final turning operation on the first side.

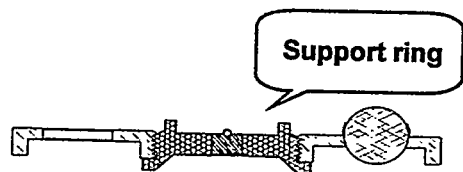


Fig. 5

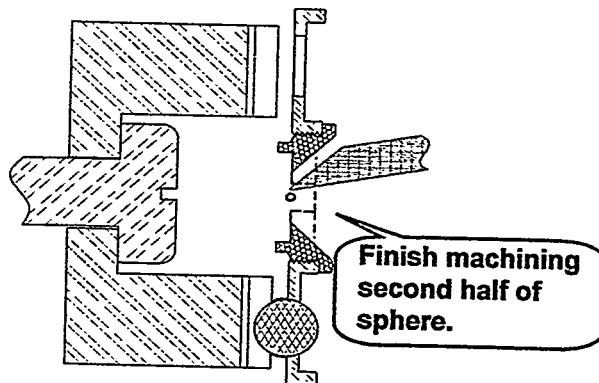


Fig. 6

Part support ring is secured with epoxy in Fig. 5. Fig. 6 shows the second finish machining operation. Note: the reversible locator is reversed relative to Fig. 4.

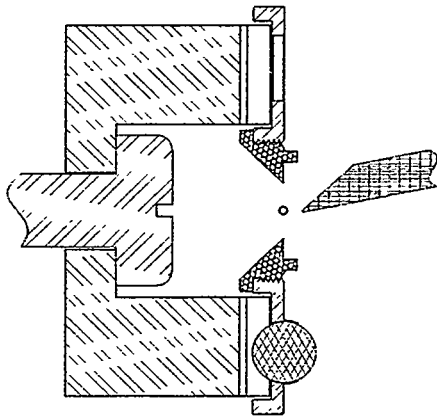
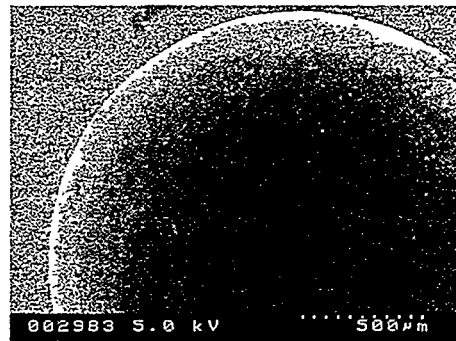
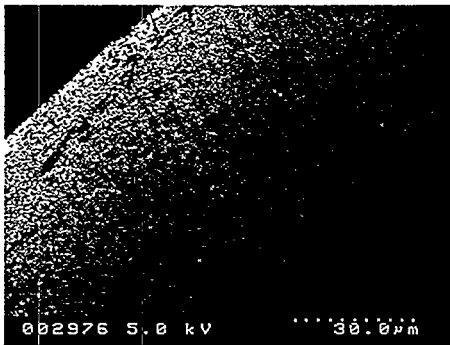


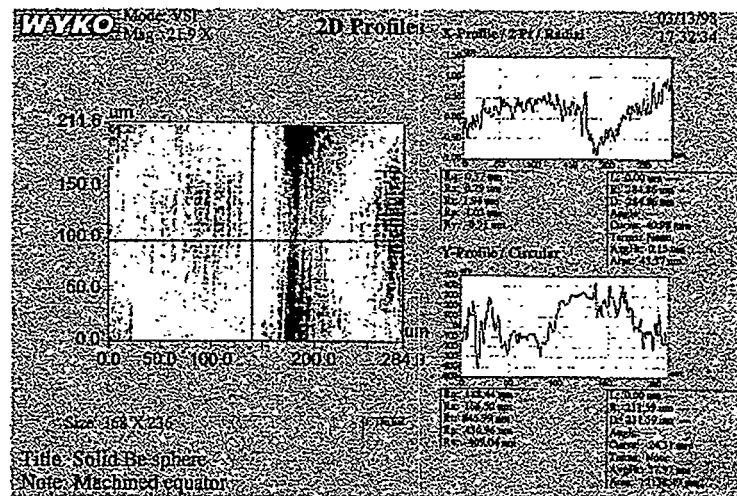
Fig. 7

In Fig. 7 only enough support ring material is removed to expose epoxy for easier part removal.

Machined surface data



Scanning electron micrographs of S200D Be sphere shows registration of the spherical surface at the equator of $< 1.0 \mu\text{m}$.



Wyko data shows the equator area. The tool path machining program overlapped at the equator by $12 \mu\text{m}$ in both directions. This may explain the undercut (or groove).

Finishing the outside surface

Top polishing plate

Sphere

Drive plate

Bottom polishing plate

The diagram illustrates a spherical polishing machine. It features a central sphere mounted on a drive plate. The sphere is surrounded by a top polishing plate and a bottom polishing plate. The drive plate is shown in a cross-section view at the bottom, indicating its role in rotating the sphere. The top and bottom plates are designed to finish the outside surface of the sphere.

WAYKO Map: 823.X Date: 03/24/99
Mode: PSI Time: 11:35:53

Surface Data

Surface Statistics:
Ra: 9.32 nm
Rq: 13.34 nm
Rz: 52.47 nm
Rt: 72.22 nm

Set-up Parameters:
Size: 368 X 236
Sampling: 206.61 nm

Processed Options:
Terms Removed:
Curvature & Tilt:
Filter(s):
Median:

56.3 μm

40.0
30.0
20.0
10.0
0.0

0.0 10.0 20.0 30.0 40.0 50.0 60.0 75.8 μm

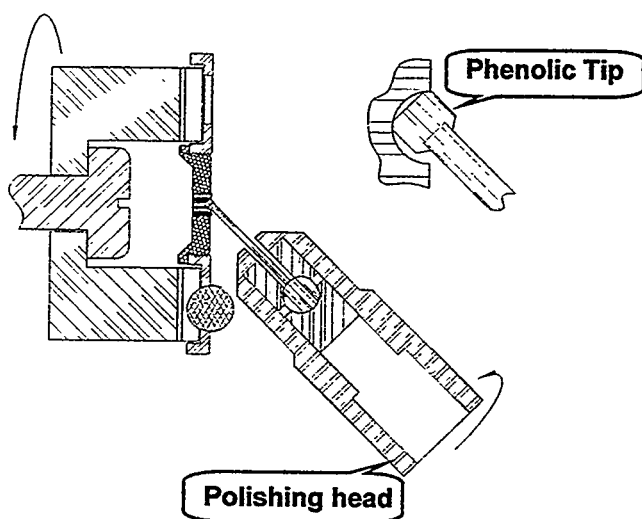
37.002
25.000
10.000
5.000
20.000
35.223

0.0 μm

Title: Be Solid NH
Note: 15 Min Turn Back

411

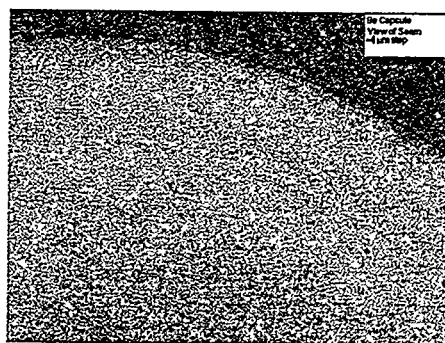
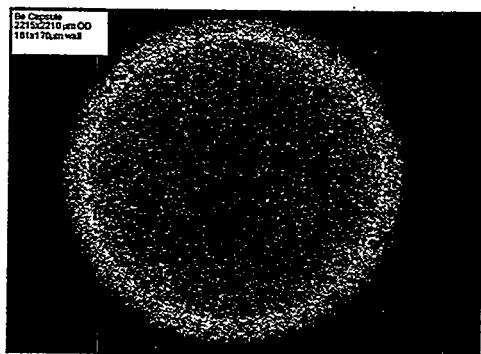
Polishing the cavity



Two stations of our three station Finish Lapping Machine were used to polish the cavity surface. The adjusted angle between the two stations is 135 degrees. This machine uses compressed-air-operated polishing head holders to vary the polishing head contact pressure.

Spindle rotation on the two stations was in opposite direction. We used BaikaloX as the polishing medium.

Radiographs of first machined and fused Be shell



Acknowledgment: The authors would like to thank Martin Hoppe and David Steinman of General Atomics for the radiographs and sphere maps of Be shell #1.

Fabrication of polyimide shells by vapor phase deposition for use as ICF targets



**E. L. ALFONSO, S. H. CHEN, R. Q. GRAM,
D. R. HARDING, and F. Y. TSAI
University of Rochester
Laboratory for Laser Energetics**

**Target Fabrication Meeting
Jackson Hole, WY
April 19-23, 1998**

Introduction

Polyimide meets the material requirements for future designs of ICF targets

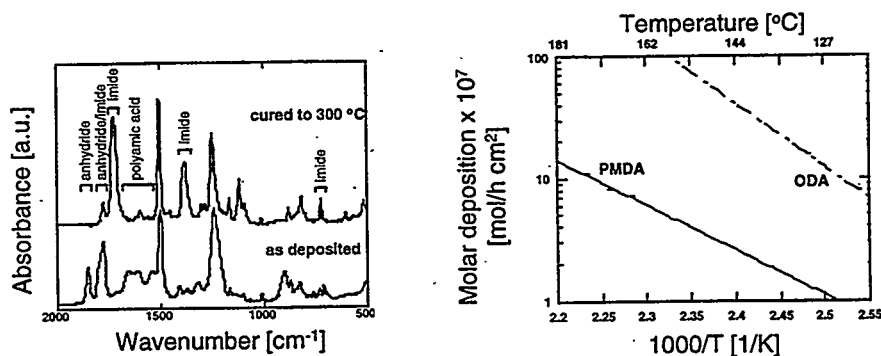


- ICF targets must have high sphericity, concentricity, smoothness, and uniformity.
- Additionally, greater tensile strength, elastic modulus, room temperature permeability, radiation resistance, and thermal conductivity of the target material benefit future ICF designs.
- OMEGA requires high aspect ratio targets; the goal is a 920 μm target with a negligibly thick wall.

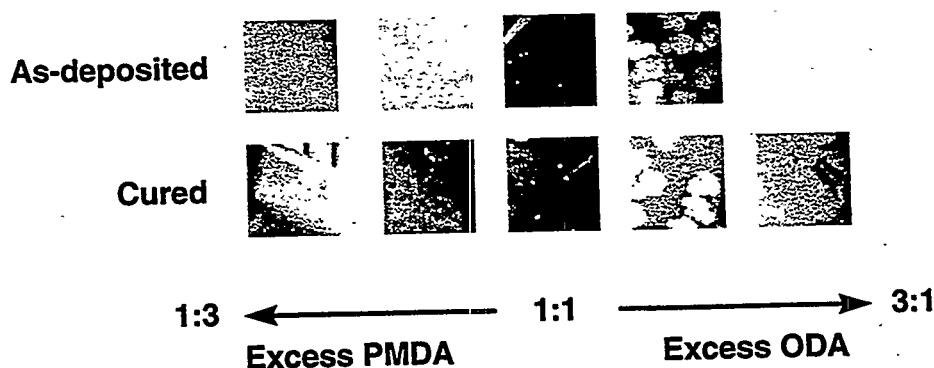
Polyimide precursors were vapor-deposited onto flat substrates to characterize the uniformity of the deposition process and properties of the material



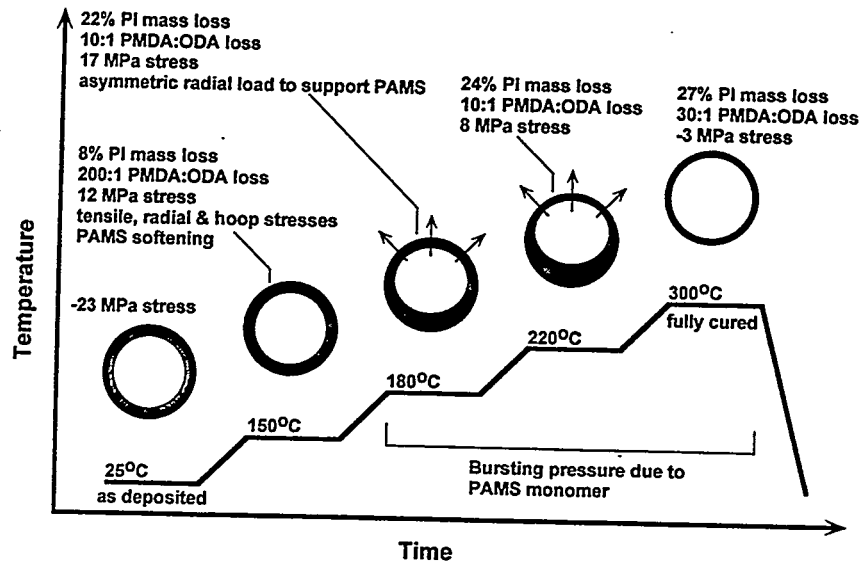
- The chemical composition was obtained from the FTIR spectra.
- The relative composition of the monomers in the film was adjusted by first calibrating the molar flux of each source.
- The stress in the polyamic acid film was measured at discrete temperatures through the imidizing cycle.



The stoichiometric ratio of the monomeric precursors affects the opacity and survivability of the film



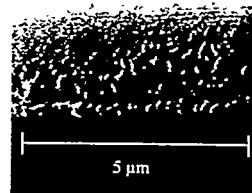
Competing factors during the imidizing and mandrel-removal temperature cycle affects the survivability of the polyimide shell



Deposition onto bounced depolymerizable PAMS mandrels leads to polyimide shells



High aspect ratio
polyimide target

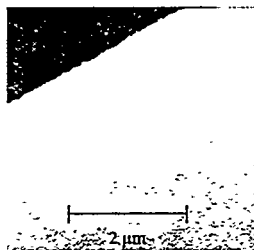


Wall cross section

- Deposition rates are ~ 0.3 to $1.0 \mu\text{m h}^{-1}$.
- Outer diameters range from 700 to $950 \mu\text{m}$.
- Wall thicknesses are 2 to $13 \mu\text{m}$.

Polyimide surface and structure affected by deposition environment

- Deposited at 10^{-6} Torr.



Inner surface and wall cross section



Outer surface

- Plasma-assisted (10^{-3} Torr) polyimide shells had a nodular structure.

The permeation time constant of polyamic acid/polyimide is a function of cure temperature

Condition	τ_{D_2} [min]	D ₂ permeability at 25°C [10 ¹⁷ mol m/m ² Pa s]	N ₂ permeability at 25°C [10 ¹⁷ mol m/m ² Pa s]
PAMS mandrel	1.2	470	16
PAA + PAMS mandrel	74	7.4	-
PAA/PI cured to 100°C	17	32	-
PAA/PI cured to 150°C	8.5	64	-
PI cured to 300°C*	0.3	2000	850

*measured on VDP flat film (according to ASTM Designation D1434-82)

- The vapor-deposited material had a permeability 7 times greater than commercially available Kapton-H film.
- No pinholes or cracks are seen in the film.

The strength and room-temperature permeability of polyimide targets offers the possibility of: more durable thin wall targets; shorter fill times; and more rapid cooling times for OMEGA Cryogenic Experiments



- Polyimide targets (3 μm wall) have survived pressurization to 750 psi at a rate of 75 psi s^{-1} , and depressurization to atmosphere at 250 psi s^{-1} , without fracturing.
- For OMEGA Cryogenic Experiments, the time to fill the target to 1100 atm would be 3.6 min (A 3 μm plasma polymer capsule would require 18 h).
- By contrast, current plasma polymer shells, with equivalent dimensions, cannot be pressurized greater than $\sim 1 \text{ psi s}^{-1}$, or survive an overpressure of $\sim 120 \text{ psi}$.
- With a burst pressure of 50 atm, a cryo-polyimide target can withstand a temperature 40 K (the critical point of DT).

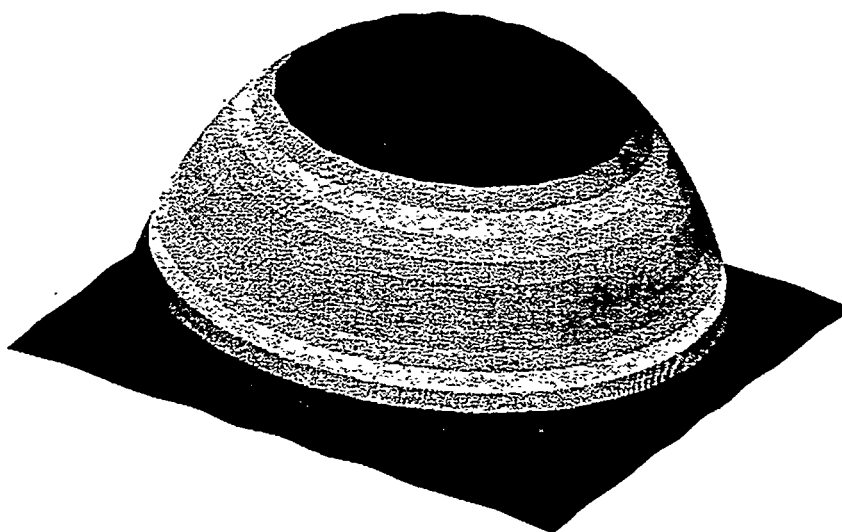
Summary

Thin wall, high aspect ratio polyimide capsules have been successfully fabricated at LLE



- Stoichiometric ratio of the vapor-deposited monomers affects the quality of the film.
- Several competing mechanisms in the imidizing and mandrel-removal phase of processing reduce the yield of fully cured polyimide shells.
- The final cured temperature of vapor-deposited polyamic acid/polyimide film determines its room temperature permeability.
- High aspect ratio targets have survived rapid pressurization and depressurization in nitrogen.

Characterization of Thick Cryogenic Layers Using an Interferometric Imaging System



P. W. McKenty and M. D. Wittman
University of Rochester
Laboratory for Laser Energetics

Target Fabrication Meeting
Jackson Hole, WY
19-23 April 1998

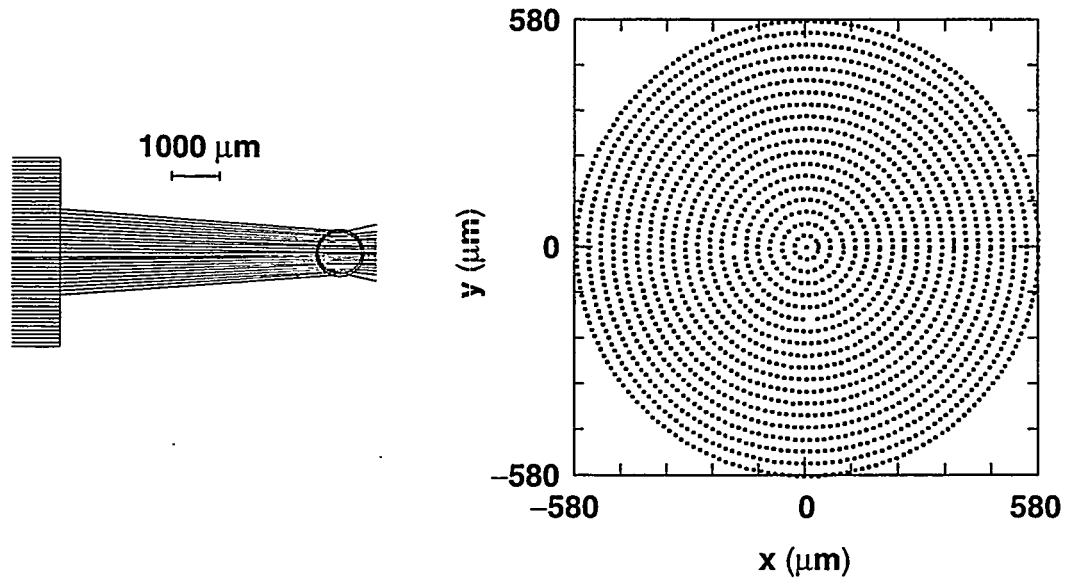
Summary

Numerical models of the interferometric imaging technique indicate qualitative agreement in recovering a variety of spherical harmonic perturbations on the inner ice surface



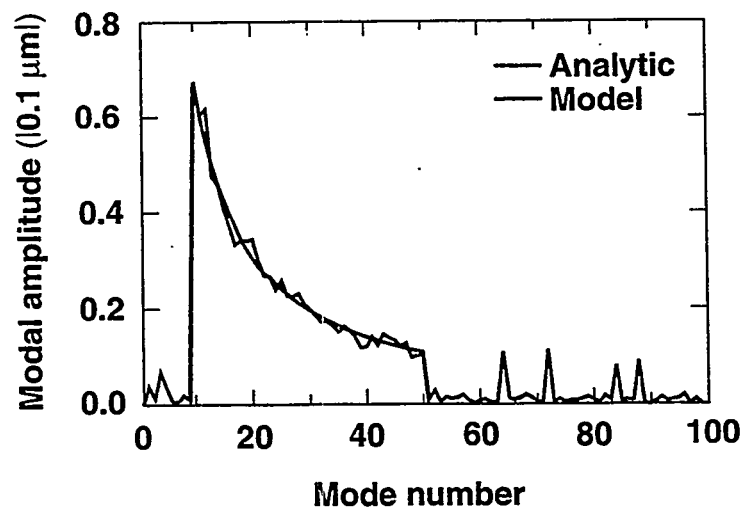
- The computer code *RINGS* has been adapted to simulate the OPD due to $f/5$ ray tracing through single-shell, surrogate cryogenic capsules.
- Initial results indicated that spectral analysis of the OPD near the referenced target equator was able to replicate pure sinusoidal perturbations.
- Many acquired great-circle, 1-D power spectra are averaged together and transformed to yield the desired 2-D power spectrum of the inner ice surface.
- Analysis of individual, single-mode Legendre perturbations does not recover the applied distortion.
- Modeling of perturbations with a wide spectrum of spherical harmonics displays an oscillatory behavior that must be understood.

Characterization studies simulate probing a cryogenic target with f/5 optics utilizing a cylindrical probe grid



TC4443

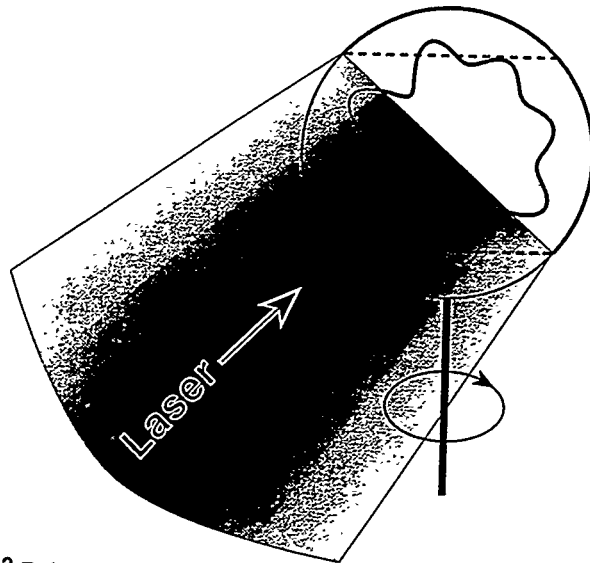
Method has been shown to recover a spectrum of applied modes with reasonable accuracy



$$R_1 = R_0 + \sum_{m=10}^{50} a_0 m^{-1.1} \cos[m(\phi + 2b(m)\pi)] \text{ with } a_0 = 0.739 \mu\text{m} \text{ and } b(m) - \text{random \#}.$$

TC4451

The method^{2,3} used to analyze LLNL's measurement of outside surface roughness can be applied by averaging many (>10) acquired great circles



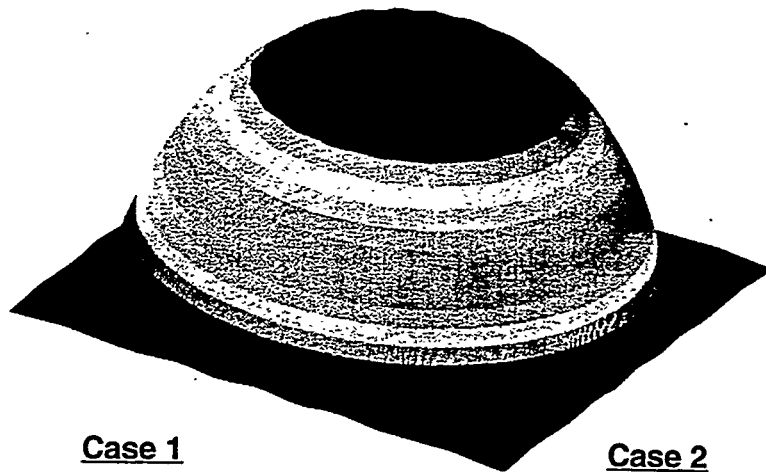
$$P_{1D}(\ell_{avg}) = \frac{(an)^n \ell_{avg}^{n-1}}{(n-1)!} e^{-an\ell_{avg}}$$

$$P_{2D}(\ell) = -\frac{d}{d\ell} \int_0^\infty P_{1D}(\sqrt{j^2 + \ell^2}) dj$$

² R. L. McEachern, C. E. Moore, and R. J. Wallace (to be published).
³ S. M. Pollaine *et al.*, *ICF Quarterly Report '94*, 87 (1994).

TC4446

Recent studies examine perturbations with single and wide spectral Legendre content over a range of amplitudes and spectral dependencies



Case 1

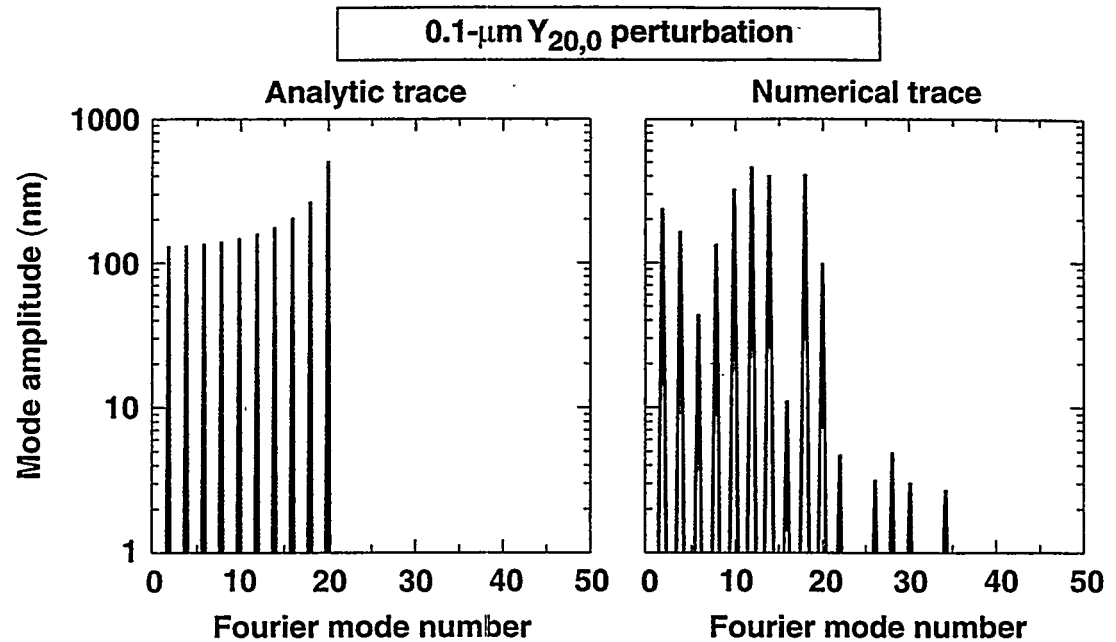
Case 2

$$R_1 = R_0 + \frac{\ell}{400} \mu m Y_{\ell,0}$$

$\ell = 10, 20, \text{ and } 40$

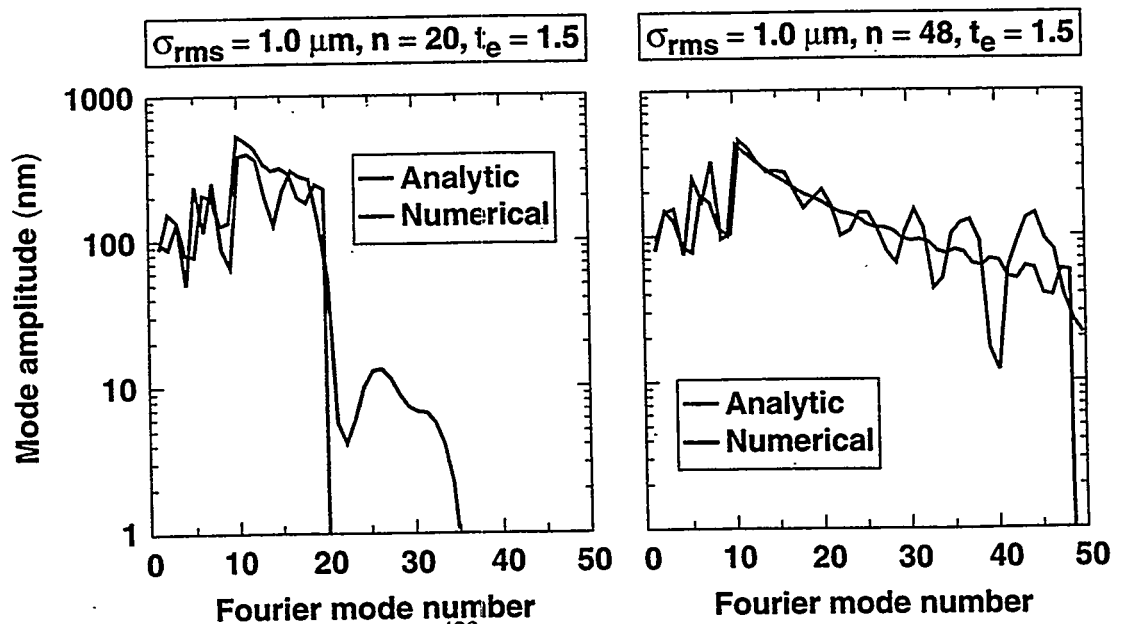
$$R_1 = R_0 + \sum_{\ell=10}^n \left(\sum_{m=-\ell}^{\ell} \frac{a_0^{-\ell}}{\sqrt{2\ell+1}} Y_{\ell m} \right)$$

The numerical method does not do a good job resolving a single Legendre mode due probably to the highly longitudinal structure of the interior surface



TC4684

Analysis of perturbations with a wide spectral content yields reasonable qualitative results, but oscillatory nature of the spectral content must be understood

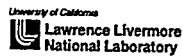


TC4685

Science of Polyimide Film Deposition



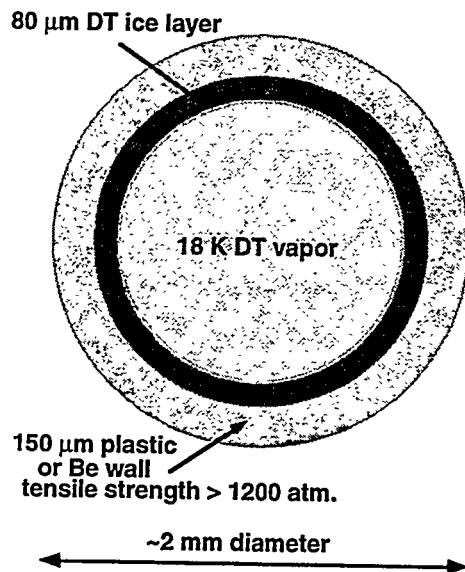
Target Fabrication Meeting 1998
April 19-23, 1998
Jackson Hole, Wyoming



Chad Roberts, Mike Saculla
Steve Letts and Bob Cook

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.

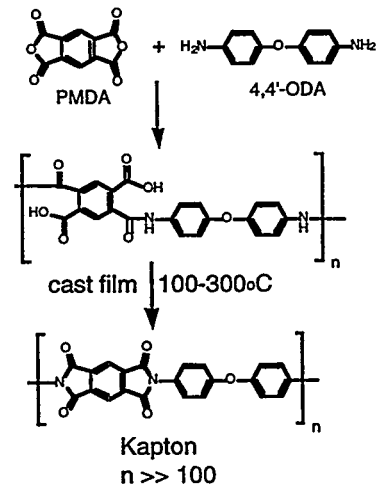
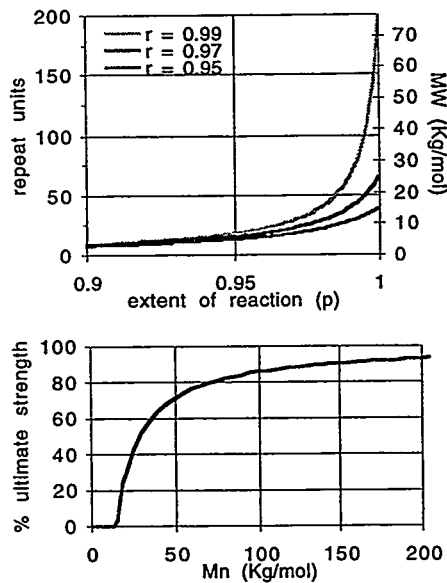
The development of high strength ablator materials suitable for capsule coating is essential.



- Room temperature transport of a filled capsule adds significant fielding flexibility while cutting costs by \$10-20M
- At 25 C the internal gas pressure is ~350 atm.
- Literature strength values (atm):

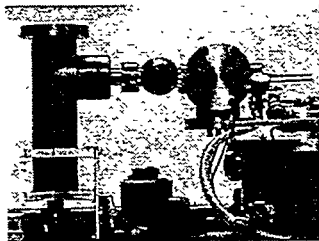
Polystyrene	800
Kapton	2370
Hitachi L-100	3100
Uplex	3350-4180
Be	1700-4500
- Advantages of Polyimide:
 - Diffusion fillable
 - Optical access to frozen fuel
 - Solid DT layer enhancement by IR or joule heating

Molecular weight and strength are determined by the stoichiometry and efficiency of the reaction.

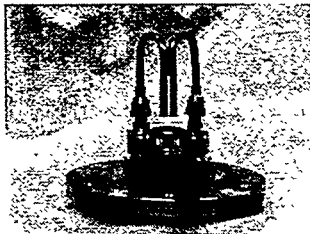


Our coating technology has continuously evolved.

Old Polyimide Coater



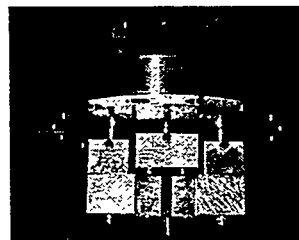
Old Source Chambers



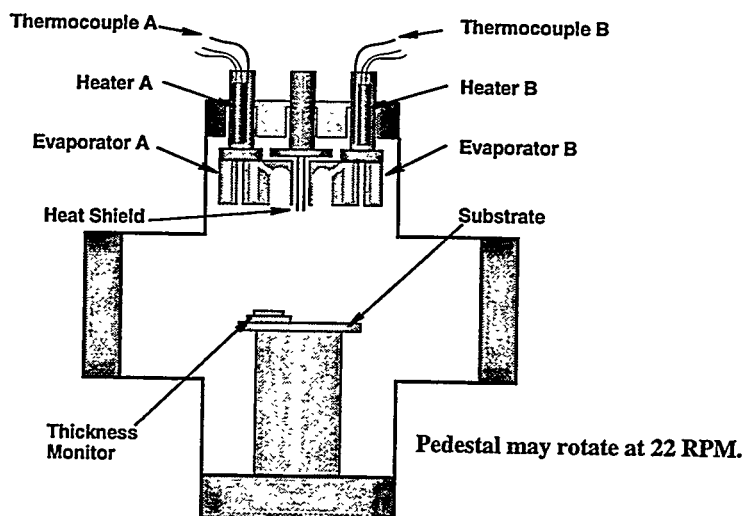
New Polyimide Coater



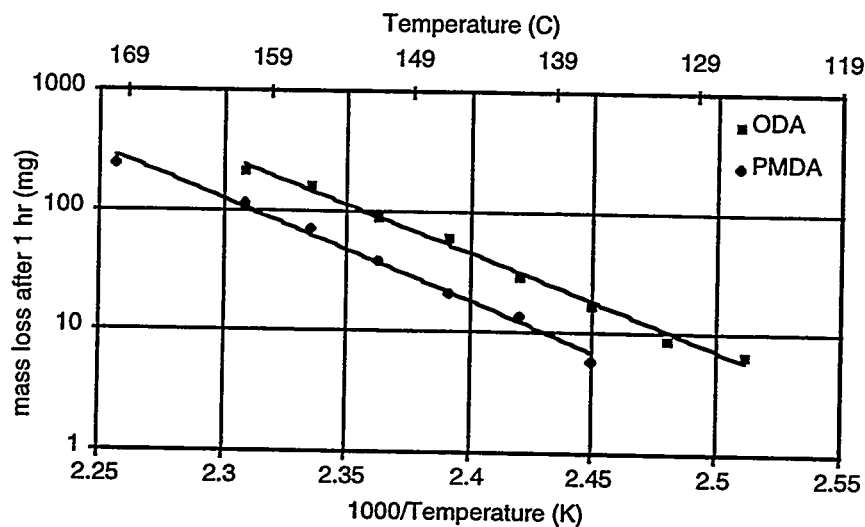
New Source Chambers



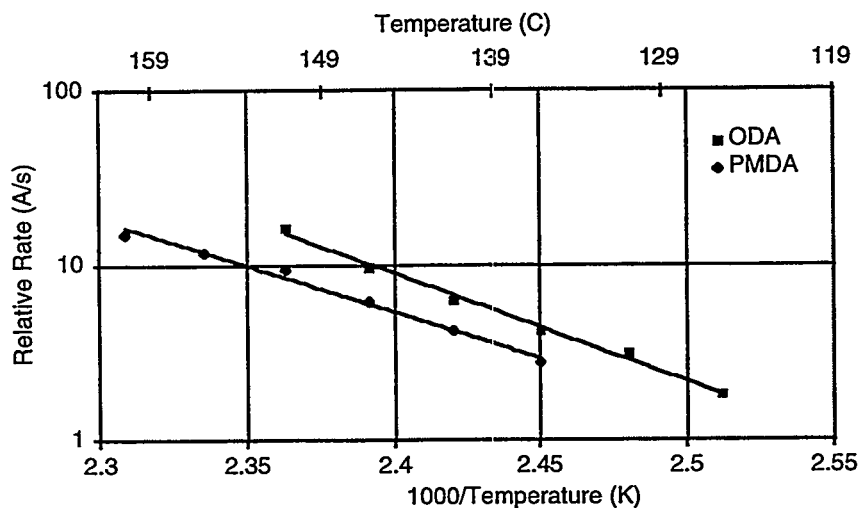
The deposition process was monitored through the mass loss and deposition rate.



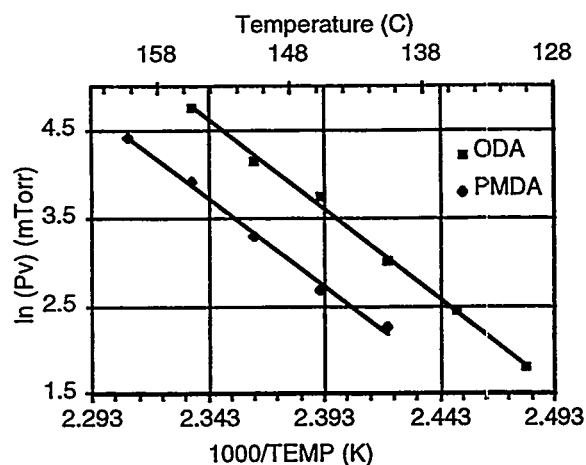
The mass loss from the monomer sources as a function of temperature was determined.



Using a quartz crystal microbalance, the deposition rate as a function of temperature was determined.



Vapor pressure as a function of temperature was calculated using the geometry of the evaporators.



* Data follows the Clausius-Clapeyron equation
 $\ln P = -\Delta H/RT + C$

DH = 170 & 165 kJ/mol,
 ODA and PMDA.

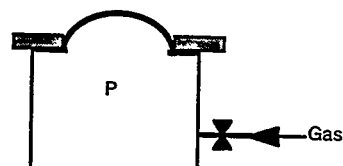
* Monomer vapor pressures can be matched at high and low deposition rates.

Our present vapor deposited films are close to minimum requirements for NIF.



Current Films	at least 900-1100 atm*
Minimum for NIF	1200 atm
Kapton (literature)	2300 atm
Uplex (literature)	4000 atm

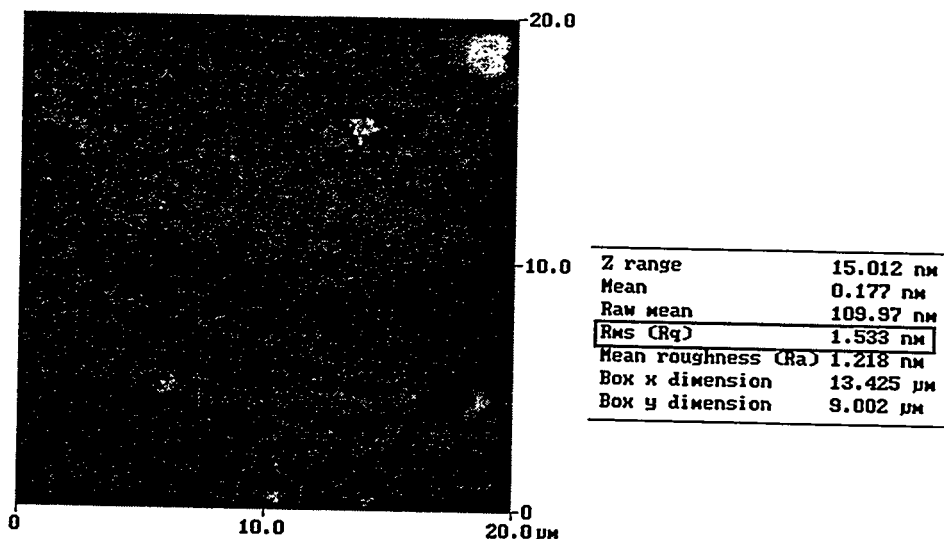
Film biaxial tensile



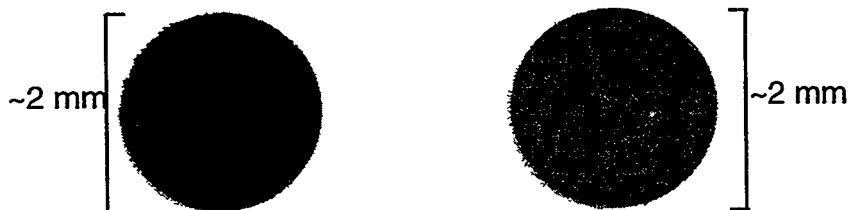
Our immediate goal is to optimize the film burst strength by varying the source temperatures (relative vapor pressure of PMDA & ODA).

* Leaking during burst test due to defects in film.

Vapor deposited polyimide films are typically smooth.



Deposition on NIF size mandrels was recently accomplished.



PAMS bead coated with CH and overcoated with PMDA/ODA

PAMS bead overcoated with PMDA/ODA

Deposition onto mandrels was performed using a standard bounce pan with a charged tungsten filament to prevent surface charging of the beads.

Summary

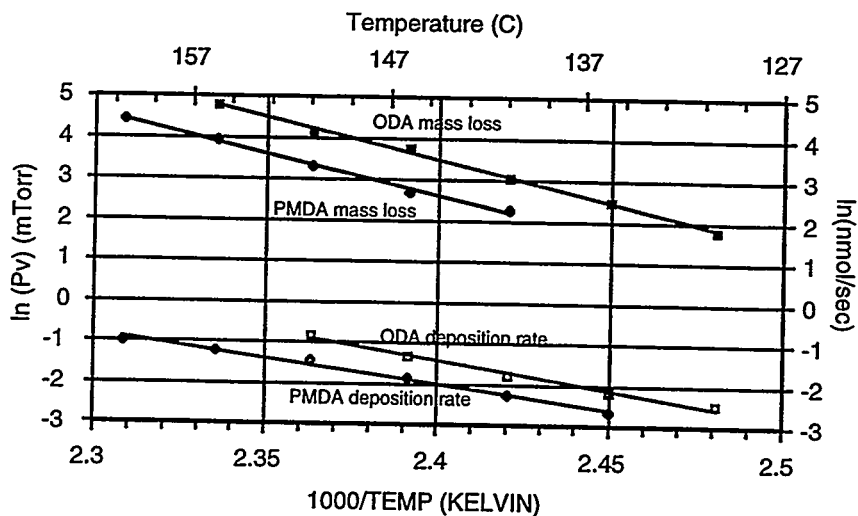


1. The dual monomer evaporator system was designed to allow for the formation of a uniform coating over a 50 mm radius area.
2. Stoichiometry or ratio matching at various deposition rates is now possible using deposition rate monitor and mass loss data.
3. Strength of current films is adequate for minimum NIF requirements, but a reasonable safety margin is desired.

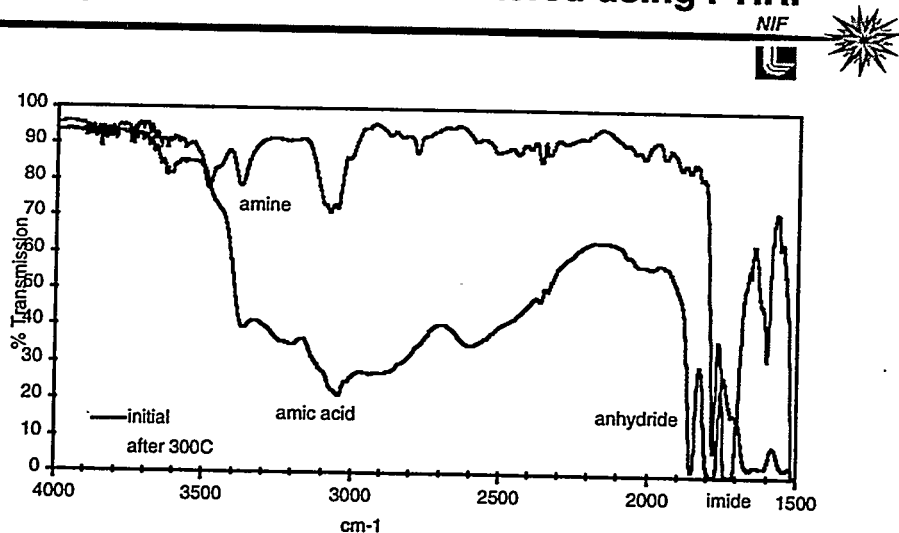
and Future Work

1. Deposition chamber will be slightly modified to allow for longer runs and production of thicker coatings.
2. Correlation of tensile strength and deposition parameters will be refined.
3. Emphasis will be shifted toward coating of shells.
4. Switch to higher strength polyimide monomers.

Deposition rate data correlates with mass loss data and demonstrates mass balance.



Thermal conversion of the initial PMDA/ODA coating to a Kapton-like film was monitored using FTIR.



Some Aspects of the Hydrodynamics of the Micro-Encapsulation Route to NIF Mandrels

P.M. Gresho
R.C. Cook

*Lawrence Livermore National Laboratory
for*

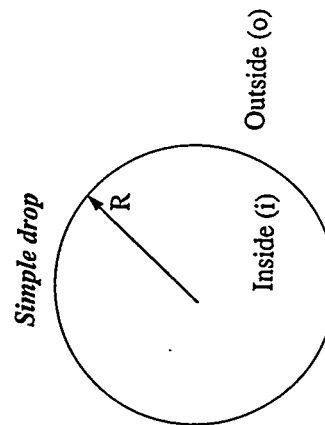
*"Target Fabrication '98"
19-23 April 1998*

Introduction

- There is lots of 'hydrodynamics' involved in target-fab from liquids...
- Ancillary processes are also important: diffusion/mass transfer, surfactant effects, solidification, ...
- This is merely a progress report; final understanding of the physics—and how to use it to advantage—are not yet here
- Terminology: w/o/w, etc.
 - * (i) Simple drop (inside/outside fluids)
 - * (ii) Compound/encapsulated drop: core/shell/host
 - * (iii) Surface tension/interfacial tension (γ)—our important 'friend'

Outline of Presentation

- Introduction/Terminology
- Hydrostatics/Droplet Shapes
- Hydrodynamics/Navier-Stokes
 - * Droplet Shapes
 - * Drag and Terminal Velocity
 - * Capillary Waves
 - * Potential Flow Aspects/Thin Shell Effects
 - * Dynamics/Equation of Motion
 - * More Thin Shell Effects
- Non-Newtonian Aspects
- Future Work
- Summary and Conclusions

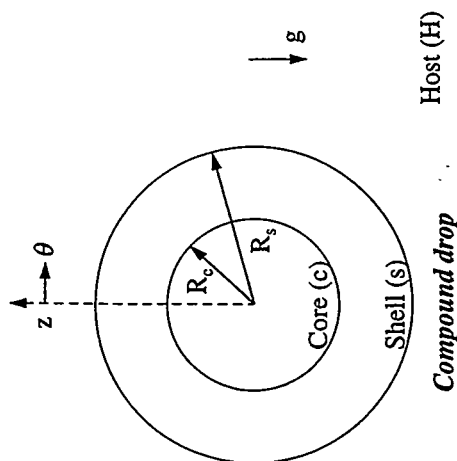


Hydrostatics: The Young-Laplace Equation (cont.)

- For a static compound drop, core pressure can be large:

$$\begin{aligned} P_s &= P_H + 2\gamma_s/R_s \\ P_c &= P_s + 2\gamma_c/R_c \\ &= P_H + 2\gamma_s/R_s + 2\gamma_c/R_c \end{aligned}$$

- If density matched, $P_H = P_0 - \rho g z$, etc.



Hydrostatics: The Young-Laplace Equation

- If $u = 0$, static shape of simple drop determined by

$$\Delta P \equiv P_m - P_{out} = \gamma \left(\frac{1}{R_1} + \frac{1}{R_2} \right) = \gamma \nabla_s \cdot \mathbf{n}$$

- If ΔP is constant (zero gravity, or small), the shape must be a sphere $R_1 = R_2 = R$, and

$$\Delta P = 2\gamma/R$$

- This result also follows from thermodynamics and a variational principle (minimum free energy)
- $u = 0$, strictly, requires density matching

A 'Density Column' can keep $u = 0$ in 1 g

A simple droplet in a density column, 'given' by $\rho_H = \rho_0(1 - \beta z)$ for $z \uparrow$ and $g \downarrow$, can suspend a droplet of density ρ_0 at $z = 0$

The price for no motion is no sphericity

The Young-Laplace equation can be solved, for small perturbations from a sphere (R):

$$r(\theta) \approx R \left[1 - \frac{\rho_0 \beta g R^3}{12\gamma} P_2(\cos \theta) \right],$$

Hydrostatics: The Young-Laplace Equation (cont.)

$$P_2(\cos\theta) = \frac{1}{2}(3\cos^2\theta - 1) \Rightarrow \text{oblate spheroid}$$

$$\text{for } B_0 \equiv \frac{\rho_0 \beta_g R^3}{12\gamma} \ll 1.$$

For 'typical' values, $\rho_0 = 1$, $\beta = 10^{-3}$, $g \approx 10^3$, $R \approx 0.1$, $\gamma = 1-100$, get

$$B_0 \approx 10^{-6} - 10^{-4}$$

$$\text{Thus } MOOR \approx 2[\tau(\pi/2) - \tau(0)] = 3B_0 \cdot R \\ = 0.003 - 0.3 \mu m$$

Hydrostatics: The Young-Laplace Equation (cont.)

■ For a compound droplet,

* (i) $u = 0 \Rightarrow$ need $\rho_c = \rho_s$

* (ii) Then get same shell deformation as for simple drop

* (iii) And, a *spherical* core

Hydrodynamics: The Navier-Stokes Equation

For $u \neq 0$ we must face

$$\partial u / \partial t + u \cdot \nabla u + \frac{1}{\rho} \nabla P = \nu \nabla^2 u + g$$

$$\text{and } \nabla \cdot u = 0$$

to conserve momentum and mass.

If $Re \equiv u_c R / \nu \ll 1$ the much simpler (linear) Stokes equations apply; omit $u \cdot \nabla u$

$$\text{For 'typical' case } Re \approx \frac{1 \times 0.1}{0.01} = 10 \dots \text{oops}$$

Hydrodynamics: The Navier-Stokes Equation

If $Re \ll 1$, even a moving (simple) drop remains spherical (God is good). To O (Re), get

$$MOOR \approx \rho u^2 R^2 / \gamma, \approx 10 \mu m \text{ for } u = 1 \text{ cm/sec } (\gamma = 10)$$

For compound drop, need $\rho_c = \rho_s$ for guaranteed containment—and can *still* have perfect spheres—for $Re = 0$

For a thin shell, the viscosity drives the flow (in the limit) to zero, in both core and shell. It behaves more like a solid sphere

Terminal Velocity ($Re \ll 1$)

Balancing net Buoyancy against drag, for a *solid sphere*, gives

$$\frac{4}{3}\pi R^3 \rho_s g = \frac{4}{3}\pi R^3 \rho g + 6\pi\mu R U_T^s;$$

(Stokes law)

$$U_T^s = \frac{2gR^2}{9\mu}(\rho_s - \rho),$$

downward for $\rho_s > \rho$.

For finite Re , U_T^s is larger than from Stokes law;

Terminal Velocity ($Re \ll 1$) (cont.)

For a 'typical' case ($\Delta\rho = 0.02, \mu = 0.01$) get $U_T \approx 4\text{cm/sec}$

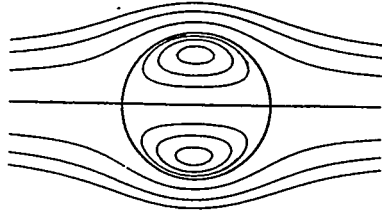
For a simple droplet, Stokes law 'changes,' with the result

$$U_T = U_T^s \cdot \frac{1 + \mu_i/\mu_o}{\frac{2}{3} + \mu_i/\mu_o}$$

For

$$\mu_i/\mu_o = 0, 0.1, 1, 10, \infty, \text{ get}$$

$$U_T/U_T^s \approx 1.5, 1.4, 1.2, 1.03, 1$$



Simple Drop
Steady Streamlines

Terminal Velocity ($Re \ll 1$) (cont.)

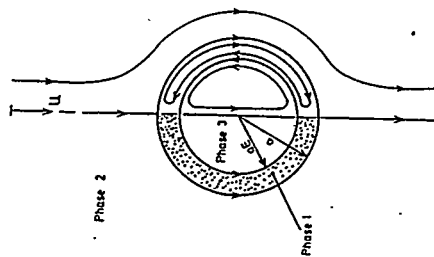
For a compound droplet, with $\rho_c \equiv \rho_s$, U_T is bounded above and below—in fact, for equal $\Delta\rho$,

$$\frac{2}{3}U_{\text{bubble}} = U_{\text{solid}} < U_{\text{compound}} < U_{\text{simple}} < U_{\text{bubble}} = \frac{3}{2}U_{\text{solid}}$$

For $\rho_c \neq \rho_s$, a compound drop may still be 'stable'; i.e., core remains in the shell... and concentric is only metastable, with preferred orientation eccentric

This is the (Stokes) theory!! In practice, our compound droplets are remarkably stable/robust...

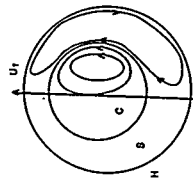
Some relevant physics seems still to be eluding us



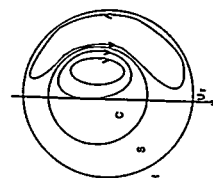
Streamlines for a Compound Droplet

Rising/Falling Compound Droplets— at U_T

- Rising droplet: $\rho_c v_c + \rho_s v_s < \rho_H (v_c + v_s)$
* Needed for stability: $\rho_c > \rho_s$ Result:



- Falling droplet: $\rho_c v_c + \rho_s v_s > \rho_H (v_c + v_s)$
* Needed for stability: $\rho_c < \rho_s$ Result:



Big Drops are Bad—Big Surface Tension is Good

- For $Re \leq 10$ or so, the shape of a translating droplet is no longer spherical. Rather, it is given by

$$r(\theta) \equiv R \left[1 - \frac{1}{4} \frac{\rho u^2 R}{\gamma} P_2(\cos \theta) \right]$$

so that

$$MOOR = 2 \left[r(\pi/2) - r(0) \right] = \frac{3}{4} \frac{\rho u^2 R^2}{\gamma}$$

- * For typical values and $u = 1 \text{ cm/sec}$ ($Re \approx 10$), get $MOOR \approx 7.5 \mu\text{m}$

Big Drops are Bad—Big Surface Tension is Good (cont.)

- * For Stokes law settling, for example,

$$u = \frac{2}{9} \frac{g R^2}{\mu} (\rho_s - \rho) \quad \text{so that}$$

$$MOOR = \frac{1}{27} \frac{\rho}{\gamma} \left(\frac{g \Delta \rho}{\mu} \right)^2 R^6$$

- * For 'typical' values ($\Delta \rho = .02$, $\mu = .01$, $\gamma = 10$), get $MOOR \approx 140 \mu\text{m}$! ($\Delta R/R \approx 1/7$)
(For $R = .05 \text{ mm}$, $MOOR = 140/2^6 \approx 2 \mu\text{m}$)

- Keep the drop speed down! [For $MOOR \leq 1 \mu\text{m}$, need $u \leq 3.7 \text{ mm/sec}$]

Capillary Waves

- For deformed droplets, surface tension again helps us; larger curvature (smaller R_1 , R_2) generates high pressure, causing flow that reduces the deformation

- For a simple, inviscid drop, $e^{i\omega t}$ behavior gives

$$\omega_l^2 = \frac{\gamma}{\ell \rho_0 + (\ell + 1) \rho_i} \cdot \frac{\ell(\ell + 1)(\ell - 1)(\ell + 2)}{R^3}$$

* $\ell = 2$ is oblate spheroid mode:

$$\omega_2^2 = \frac{24\gamma}{(2\rho_0 + 3\rho_i)R^3} \equiv \frac{4.8\gamma}{\rho R^3} \text{ for } \rho_0 \approx \rho_i$$

Capillary Waves (cont.)

- * For 'typical' case ($\gamma = 10$), $\omega_2 \approx 220 \text{ sec}^{-1}$ (35Hz) a period ($2\pi/\omega$) of ~30 millisec.

- For a simple viscous drop, $e^{i\omega t} \cdot e^{-t/\tau}$ behavior gives

$$\omega_l = \omega_l(\text{inviscid}) - \frac{(2\ell + 1)^2 \sqrt{\omega_l^2 \mu_i \mu_o \rho_i \rho_o}}{2\sqrt{2R}[\ell \rho_o + (\ell + 1)\rho_i][\sqrt{\mu_i \rho_i} + \sqrt{\mu_o \rho_o}]}$$

- * For mode 2 and $\rho_i \approx \rho_o$,

$$\begin{aligned} \omega_2 &= \omega_2^i - \frac{2.5\sqrt{\omega_2^i \mu_i \mu_o}}{\sqrt{2\rho R}(\sqrt{\mu_i} + \sqrt{\mu_o})} \\ &\approx \omega_2^i - \Delta\omega \end{aligned}$$

Capillary Waves (cont.)

- * For the same typical case with

$$\mu_i = 1 \text{ and } \mu_o = 0.01,$$

$$\Delta\omega \approx 2.4 \text{ (small effect)}$$

$$*\tau^{-1} = \Delta\omega +$$

$$\frac{(2\ell + 1)(2(\ell^2 - 1)\mu_i^2 \rho_i + 2\ell(\ell + 2)\mu_o^2 \rho_o + \mu_i \mu_o [\rho_i(\ell + 2) - \rho_o(\ell - 1)])}{2R^2[\ell \rho_o + (\ell + 1)\rho_i][\sqrt{\mu_i \rho_i} + \sqrt{\mu_o \rho_o}]^2}$$

Capillary Waves (cont.)

and for $\ell = 2$ and $\rho_o = \rho_i$

$$\tau^{-1} = \Delta\omega + \frac{[6\mu_i^2 + 16\mu_o^2 + 3\mu_i \mu_o]}{2\rho R^2(\sqrt{\mu_i} + \sqrt{\mu_o})^2}$$

and for the same typical values,

$$\tau \approx \frac{1}{2.4 + 248} = 4 \text{ milliseconds (big effect)}$$

Capillary Waves (cont.)

* For $T \equiv 2\pi/\omega$ of 30 msec and τ of 4msec, any mode 2 oscillation is very quickly damped owing to viscosity—and the damping is faster for higher modes, as is the frequency.

* Capillary waves on a viscous drop are very short-lived...

■ For an *inviscid compound* drop, even a potential flow analysis gave... a mess!!

$$\omega_{\pm}^2 = \frac{\frac{\gamma_c \gamma_s}{R_c^3 R_s^3} \cdot \frac{(\ell-1)\ell(\ell+1)(\ell+2)}{(2\ell+1)\rho_s} [A \pm \sqrt{B}]}{\left(1 + \frac{\ell(\rho_H - \rho_s)}{(2\ell+1)\rho_s}\right) \left(1 + \frac{(\ell+1)(\rho_c - \rho_s)}{(2\ell+1)\rho_s}\right) \left(\frac{R_s}{R_c}\right)^{\ell+1/2} - C \left(\frac{R_c}{R_s}\right)^{\ell+1/2}}$$

Capillary Waves (cont.)

where

$$A = \frac{1}{2} \left[\frac{R_c}{R_s} \sqrt{\frac{\gamma_s R_c}{\gamma_c R_s}} m_i + \frac{R_s}{R_c} \sqrt{\frac{\gamma_c R_s}{\gamma_s R_c}} m_o \right],$$

$$\text{where } m_i = \left[1 + \frac{(\ell+1)(\rho_c - \rho_s)}{(2\ell+1)\rho_s} \right] \left(\frac{R_s}{R_c}\right)^{\ell+1/2} - \frac{(\ell+1)(\rho_c - \rho_s)}{(2\ell+1)\rho_s} \left(\frac{R_c}{R_s}\right)^{\ell+1/2},$$

and $m_o = m_i$ with ρ_c replaced by ρ_H ,

$$B = 1 + \frac{1}{4} \left[\frac{R_c}{R_s} \sqrt{\frac{\gamma_s R_c}{\gamma_c R_s}} m_i - \frac{R_s}{R_c} \sqrt{\frac{\gamma_c R_s}{\gamma_s R_c}} m_o \right]^2$$

Capillary Waves (cont.)

$$\text{and } C = \frac{(\ell+1)(\rho_c - \rho_s)}{(2\ell+1)\rho_s} \cdot \frac{\ell(\rho_H - \rho_s)}{(2\ell+1)\rho_s}.$$

ω_+ is the bubble mode; core and shell are 'in-phase'

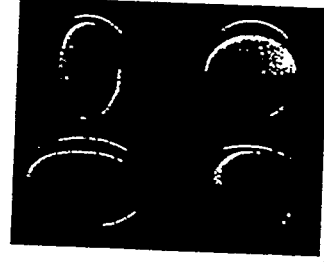
ω_- is the slosh mode; out-of-phase

For a 'typical' case, with $\ell = 2$, $\Delta\rho/\rho = 0.02$, $R_c/R_s = 0.9$,

$\gamma_c = \gamma_s = 20$, we get

$$m_i = m_o = 1.31,$$

$A = 1.33$, $\sqrt{B} = 1.02$, and $C \equiv 10^{-4}$, and



Bubble Mode

Sloshing Mode

O/W/O Compound Drop

Capillary Waves (cont.)

$\omega_+ = 303 \text{ sec}^{-1}(48H_z)$; $T = 21 \text{ msec}$
and $\omega_- = 40 \text{ sec}^{-1}(6.4H_z)$; $T = 0.16 \text{ sec (slow)}$

* Assume (not known) viscous damping is again 'large'...

* The thin-shell 'limit' frequency is given by

$$\omega_\ell^2 = \frac{\gamma_c + \gamma_s}{R^3} \cdot \frac{(\ell - 1)\ell(\ell + 1)(\ell + 2)}{\ell\rho_s + (\ell + 1)\rho_c},$$

giving, for 'our' parameters,

$$\omega_2 \approx 440 \text{ sec}^{-1}(70H_z); \quad T = 14 \text{ msec}$$

* Again, we shall assume that viscous damping is large.

* ~Bottom line on capillary waves: Too evanescent to matter much.

Potential Flow for a Special Case

■ For the special case of a concentric core, it is useful to find the pressure forces on core and shell for specified acceleration (uni-directional) of core, shell, and host fluids. Later, the results will be used in the equations of (bulk) motion for core and shell—to help understand compound droplet dynamics.

■ Consider u_c , u_s , u_H as given/prescribed bulk velocities at the boundaries of the core and shell, and are time-varying. The (instantaneous) potential flow is as follows.:

$$(1) \quad u_c = \nabla \phi_c \text{ with } \nabla^2 \phi_c = 0; \quad \phi_c \text{ finite at } r = 0, \quad \frac{\partial \phi_c}{\partial r} = u_c \cos \theta \text{ at } r = R_c$$

Potential Flow for a Special Case (cont.)

$$(2) \quad u_s = \nabla \phi_s \text{ with } \nabla^2 \phi_s = 0; \quad \frac{\partial \phi_s}{\partial r} = u_s \cos \theta \text{ at } r = R_s,$$

$$\frac{\partial \phi_s}{\partial r} = u_s \cos \theta \text{ at } r = R_s, \text{ and}$$

$$(3) \quad u_H = \nabla \phi_H \text{ with } \nabla^2 \phi_H = 0; \quad \frac{\partial \phi_H}{\partial r} = u_H \cos \theta \text{ at } r = R_s,$$

$$\text{and } \frac{\partial \phi_H}{\partial r} \rightarrow u_H \cos \theta \text{ for } r \rightarrow \infty.$$

Potential Flow for a Special Case (cont.)

■ The solutions are

$$\phi_c = u_c r \cos \theta \quad (= u_c z)$$

$$\phi_s = \frac{(u_s R_s^3 - u_c R_c^3) r + \frac{R_c R_s^3}{2} (u_s - u_c) \left(\frac{R_c}{r}\right)^2}{R_s^3 - R_c^3} \cos \theta$$

$$\phi_H = \left[u_H r + \frac{R_s}{2} (u_H - u_s) \left(\frac{R_s}{r}\right)^2 \right] \cos \theta$$

Potential Flow for a Special Case (cont.)

- These are used in Bernoulli's equation to get P :

$$\frac{\partial \phi}{\partial t} + \frac{1}{2} q^2 + P/\rho = \text{const, gives}$$

$$P/\rho = \text{const} - \frac{1}{2} q^2 - \partial \phi / \partial t, \text{ where}$$

$$q = |\mathbf{u}| = |\nabla \phi|.$$

- * Neither the constant term nor the potential flow velocity contribute to a drag force, but $\partial \phi / \partial t$ definitely does.
- * We will evaluate P at the surfaces of the core and shell and integrate them over the surface to get the inviscid/potential flow drag forces.

Potential Flow for a Special Case (cont.)

- *Remarks:
- (1) The terms involving differences of accelerations are manifestations of the so-called "added mass" effect.
 - (2) The remaining terms correspond to "free stream acceleration" or, equally accurate, to "solid body acceleration."
 - (3) The force from P_s will be seen to be very important for the *thin shell* case ...

*Integration of the component of pressure that acts in the direction of motion ($P \cos \theta$) and integration over the total surface areas gives the pressure/acceleration drag forces.

$$(1) F_c = \frac{4}{3} \pi \rho_c R_c^3 \dot{U}_c \text{ on shell inner surface}$$

Potential Flow for a Special Case (cont.)

$$(1) P_c = -\frac{\partial \phi_c}{\partial t} \Big|_{r=R_c} = -\rho_c \dot{U}_c R_c \cos \theta$$

an external force on the shell's inner surface.

$$(2) P_s = -\frac{\partial \phi_s}{\partial t} \Big|_{r=R_c} = -\rho_s \dot{U}_s R_s \cos \theta \cdot \frac{(\dot{U}_s R_s^3 - \dot{U}_c R_c^3) + \frac{1}{2} R_s^3 (\dot{U}_s - \dot{U}_c)}{R_s^3 - R_c^3}$$

an external force on the core's surface.

$$(3) P_H = -\frac{\partial \phi_H}{\partial t} \Big|_{r=R_s} = -\rho_H R_s \cos \theta \left[\dot{U}_H + \frac{1}{2} (\dot{U}_H - \dot{U}_s) \right],$$

an external force on the shell's outer surface.

Potential Flow for a Special Case (cont.)

$$(2) F_s = \frac{4}{3} \pi \rho_s R_c^3 \cdot \frac{(\dot{U}_s R_s^3 - \dot{U}_c R_c^3) + (\dot{U}_s - \dot{U}_c) R_s^3 / 2}{R_s^3 - R_c^3}$$

on the surface of the core, and

$$(3) F_H = \frac{4}{3} \pi \rho_H R_s^3 \left[\dot{U}_H + \frac{1}{2} (\dot{U}_H - \dot{U}_s) \right]$$

acting on the shell outer surface.

Potential Flow for a Special Case (cont.)

* For $R_c \rightarrow R_s$ the acceleration force on the core is quite large:

$$F_s \equiv \frac{4}{3} \pi \rho_s R_c^3 \left[\frac{\dot{U}_s - \dot{U}_c}{2} \cdot \left(\frac{R_c}{\delta R} \right) \right],$$

where $\delta R \equiv R_s - R_c \ll R_c$. This helps keep the core contained in the shell.

Simplest Equation of Motion for Rigid Sphere

* For uni-directional motion of a solid sphere (we must, again, start 'simple') falling (slowly) in an unbounded quiescent fluid with $Re = 0$ (or $Re \ll 1$), the equation of motion is

$$\frac{4}{3} \pi R^3 \left(\rho_s + \frac{1}{2} \rho \right) \dot{U} = \frac{4}{3} \pi R^3 (\rho_s - \rho) g - 6 \pi R \mu \left[U + R \int_0^t \frac{\dot{U}(\tau) \tau}{\sqrt{\pi \nu (t-\tau)}} d\tau \right]$$

in which the last term is called the (Basset) history integral. It 'compensates' for the use of the *Steady* Stokes drag term ($6 \pi \mu R U$) in a time-varying situation. Note that the recent past is more heavily weighted in the convolution integral—a manifestation of viscous diffusion.

Simplest Equation of Motion for Rigid Sphere (cont.)

* This 1st-order integro-differential equation can be converted to a simpler (?) 2nd-order ODE:

$$\left[\frac{\frac{4}{3} \pi R^3 \left(\rho_s + \frac{1}{2} \rho \right) \right]^2 \ddot{U} + 2 \left[\frac{4}{3} \pi R^3 \left(\rho_s + \frac{1}{2} \rho \right) - 3 \pi R^3 \rho \right] \dot{U} + 6 \pi R \mu U =$$

$$\frac{4}{3} \pi R^3 (\rho_s - \rho) g + \frac{R}{\sqrt{\pi \nu t}} \left[6 \pi R \mu U_0 - \frac{4}{3} \pi R^3 (\rho_s - \rho) g \right]$$

* Two remarks are relevant here:

(1) An analytical solution is available—of the form

$$U = c_1 + c_2 e^{\lambda_1 t} \left(1 + c_3 \operatorname{erf} \sqrt{\lambda_1 t} \right) + c_4 e^{\lambda_2 t} \left(1 + c_5 \operatorname{erf} \sqrt{\lambda_2 t} \right)$$

Simplest Equation of Motion for Rigid Sphere (cont.)

* (2) The ODE is actually *unstable* if the coefficient of $\dot{U}$ becomes negative. This occurs if

$$\frac{4}{3} \pi R^3 \left(\rho_s + \frac{1}{2} \rho \right) < 3 \pi R^3 \rho, \text{ or } \rho / \rho_s > 4/7$$

* Thus, the 2nd-order ODE is *not* amenable to any numerical integration procedure for 'our' case of interest ($\rho \approx \rho_s$)!!

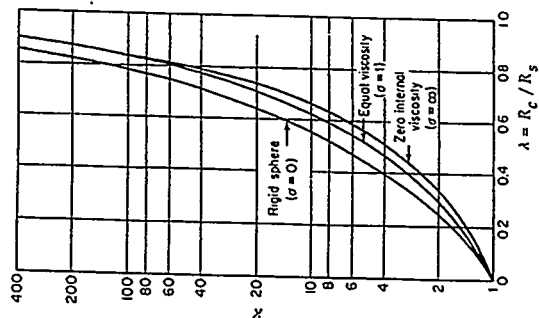
Special Equation of Motion of Core and Shell

- * The overall/total equation of motion for the core and the shell are not yet available for the 'general' case.
- * After seeing the equation of motion for a *solid* (no-slip) outer shell wall (R_s) you will see why!

Core:

$$\frac{4}{3} \pi R_c^3 \rho_c \dot{u}_c = \frac{4}{3} \pi R_c^3 (\rho_c - \rho_s) g + \frac{4}{3} \pi R_c^3 \rho_s \left[\frac{\dot{u}_s R_s^3 - \dot{u}_c R_c^3 + \frac{R_s^3}{2} (\dot{u}_s - \dot{u}_c)}{R_s^3 - R_c^3} \right] - 6 \pi \mu_s R_c K \cdot \frac{1 + \frac{2}{3} \frac{\mu_s}{\mu_c}}{1 + \frac{\mu_s}{\mu_c}} \left[u_c - u_s + R_c \int_0^t \frac{\dot{u}_c(\tau) - \dot{u}_s(\tau)}{\sqrt{\pi \nu_s(t-\tau)}} d\tau \right],$$

where $K \equiv f(\mu_s/\mu_c, R_c/R_s)$ and goes from 1 to ∞ for $R_c \rightarrow R_s$



Stokes' Law Correction Factor

Special Equation of Motion of Core and Shell (cont.)

Shell:

$$\begin{aligned} \frac{4}{3} \pi (R_s^3 - R_c^3) \rho_s \dot{u}_s &= \frac{4}{3} \pi [\rho_c R_c^3 + \rho_s (R_s^3 - R_c^3) - \rho_H R_s^3] \\ &+ \frac{4}{3} \pi R_s^3 \rho_c \dot{u}_c + \frac{4}{3} \pi R_s^3 \rho_H [\dot{u}_H + \frac{1}{2} (\dot{u}_H - \dot{u}_s)] \\ &+ 6 \pi \mu_s R_c K \cdot \frac{1 + \frac{2}{3} \frac{\mu_s}{\mu_c}}{1 + \frac{\mu_s}{\mu_c}} \left[u_c - u_s + R_c \int_0^t \frac{\dot{u}_c(\tau) - \dot{u}_s(\tau)}{\sqrt{\pi \nu_s(t-\tau)}} d\tau \right] \\ &- 6 \pi \mu_H R_s \left[u_s - u_H + R_s \int_0^t \frac{\dot{u}_s(\tau) - \dot{u}_H(\tau)}{\sqrt{\pi \nu_H(t-\tau)}} d\tau \right] \end{aligned}$$

Special Equation of Motion of Core and Shell (cont.)

Remarks:

- (1) The equation only applies instantaneously at $t=0$ because of concentric assumption. Also, at $t=0$, need $U_c = U_s = 0$.
- (2) It might apply for eccentric motion if K could be found for such a case—and it could, with some effort.
- (3) For $R_c \rightarrow R_s$ the thin-wall effect for both the potential flow (acceleration terms on RHS) and the (new) viscous terms will dominate; recall that the core acceleration term goes like

$$\frac{4}{3} \pi R_c^3 \rho_c \cdot \frac{\dot{u}_s - \dot{u}_c}{2} \cdot \left(\frac{R_c}{\delta R} \right). \text{ The } K\text{-factor}$$

is even *stronger*; it goes like

$$K \cdot \frac{1 + \frac{2}{3} \frac{\mu_s}{\mu_c}}{1 + \frac{\mu_s}{\mu_c}} \rightarrow \frac{1}{3} \left(\frac{R_c}{\delta R} \right)^3 \text{ for } \delta R = R_s - R_c \rightarrow 0.$$

- (4) Thus, thin shells strongly favor 'robustness'; i.e., $U_c \approx U_s$ —the core 'follows' the shell. And we see this in the laboratory.

Concluding Remarks

- Non-Newtonian shell behavior is still TBD
- The true equations of motion are still TBD
- Mass transfer from shell to host is still TBD
- The physics of 'core centering,' while not yet fully understood, has been partially resolved via the thin-wall phenomena
- We should keep Re as small as possible to help preserve sphericity
- Capillary waves are not much of an issue

FIGURE 10

Techniques for Making Flat Film Targets Using Si-Doped GDP

*Katie Strube, Thom Bahrs,
Sue Carter, Charles Hendricks,
Brian Motta, Tom Walsh*

Schafer Corporation

Schafer

Si-Doped Polymeric Targets

- Made for the Omega laser program at the University of Rochester, LLE
- Poly- α -methylstyrene (PAMS) film is cast at Schafer on patterned substrate
- PAMS film (60-80 μm thick) is sent to General Atomics in ring holder to be coated with Si-doped GDP (<20 μm thick)
- Coated film is sent back to Schafer so the PAMS layer can be removed

Schafer

PAMS Coated with Si-Doped GDP in Ring Holder



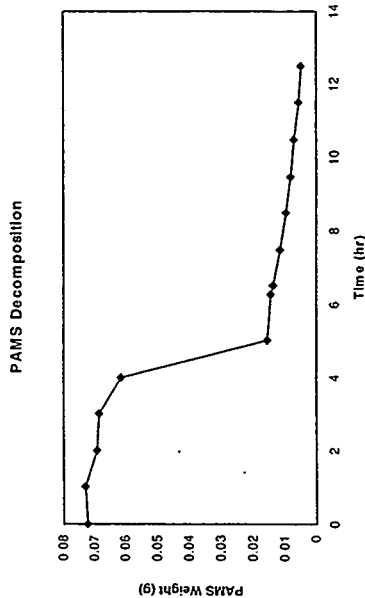
Schafer

PAMS

- Acts as the patterned substrate for deposition of Si-doped GDP
- Prevents Si-doped GDP from flaking away
- Decomposes at a lower temperature than Si-doped GDP
- Residue dissolves easily in toluene

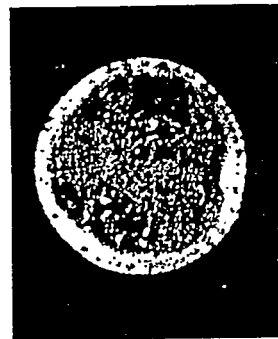
Schafer

Experiment #1 - PAMS



Schafer

PAMS Film Before and After Heating to 225 °C



Schafer

Experiment #2 - PAMS with Si-Doped GDP Layer

- PAMS coated with Si-doped GDP heated slowly
 - Began at 50 °C
 - Ramped up 20 °C every 20 minutes
- Integrity of film maintained up to 210 °C
- Film began bubbling between 210 °C and 225 °C
- About 80% of film mass was lost

Schafer

Next Steps

- Find the precise temperature between 210 °C and 225 °C at which PAMS begins bubbling
- Use other methods such as vaporization to remove PAMS layer
- Look into other methods of casting Si-doped polystyrene

Schafer

Microencapsulation Process Factors Which Influence Sphericity in Omega PAMS Shells

Barry McQuillan
Annette Greenwood

General Atomics

What Process Variables Control Omega PAMS Sphericity (OOR)?

- * For Omega shells, $r = 470$ micron, the production specification is
batch (4π OOR) = average $[2^{1/2} (r_+ - r_-)] < 1$ micron
- * We have identified/confirmed 3 process variables which influence the shell OOR:
 - Density mismatch between O1 and W2
 - Stirring rate
 - Fluorobenzene saturation of W2

* With careful control of these three parameters, we can consistently obtain

batch (4π OOR) $\sim 0.5 \pm 0.2$ micron



Density Matching is Critical for Low OOR !!

- OMEGA shells were originally cured in a 60 C water bath, using only PVA solution as W2. We could obtain 4π OOR $\sim 0.4-0.6$ micron with this system. However, they had vacuoles.

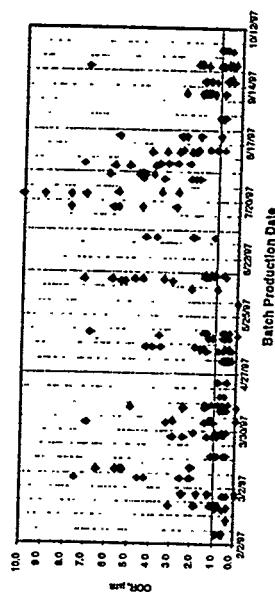
When we discovered addition of CaCl_2 to W2 could eliminate vacuoles, we made wonderful clear shells, but we consistently made 4π OOR $\sim 2-5$ micron !!

- Bob Cook (memo 11-96) showed that for a simple droplet of O1 (no core W1):

$$\Delta P = (\Delta \rho) g R = -\gamma [\max \text{ OOR}] / R^2$$

$$\max \text{ OOR} = R^3 (\Delta \rho) / \gamma$$

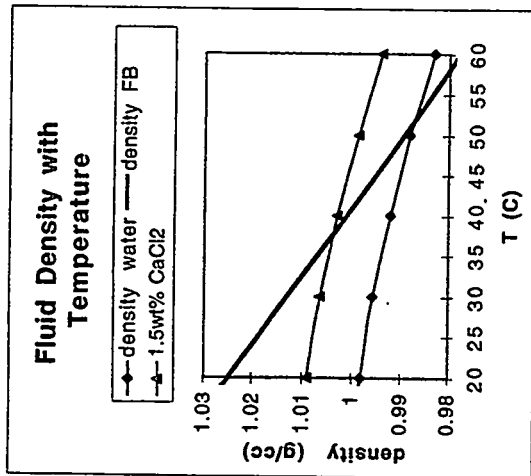
Adding CaCl_2 to W2 at 60 C Increased OOR !



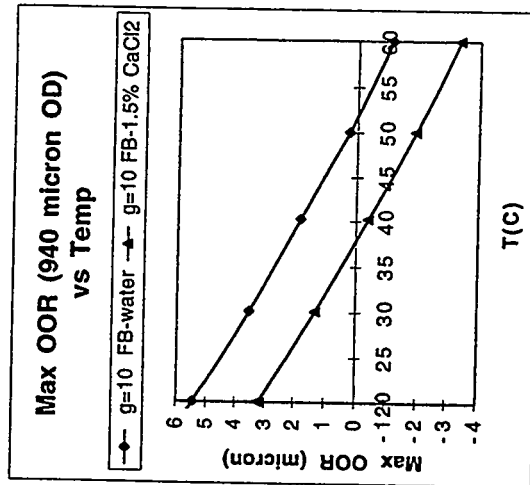
Began adding CaCl_2 -60 C $\uparrow$

Began adding CaCl_2 -43 C $\uparrow$

Look at Density Mismatch O1/W2 -
Cure Shells at Lower Temperature!



4 Cook Max OOR vs Density Mismatch-With and Without CaCl₂



Caveats to Density & Max OOR Plots

- * Fluorobenzene density vs temperature was used, not density of O1.
Fluorobenzene density vs temperature curve was 2 point linear extrapolation.
- * 1.5 wt% CaCl₂ density vs temperature was approximate, based on shifting the water density vs temperature curve to match 1.5 wt% CaCl₂ at 20 C.
- * Max OOR equation used $\gamma = 10 \pm 3$ dyne/cm, estimated by Rich Stephens at room temperature, for starting composition.
 γ may change with temperature
 γ may change with O1 composition change
- * Radius of shell used is "final dry shell" 470 micron

Shells are Stirred in Beaker During Curing-Shear Effects OOR

Cook estimated

$$\text{max OOR} = 4\eta(2\pi f)^2/r^2\gamma$$

where

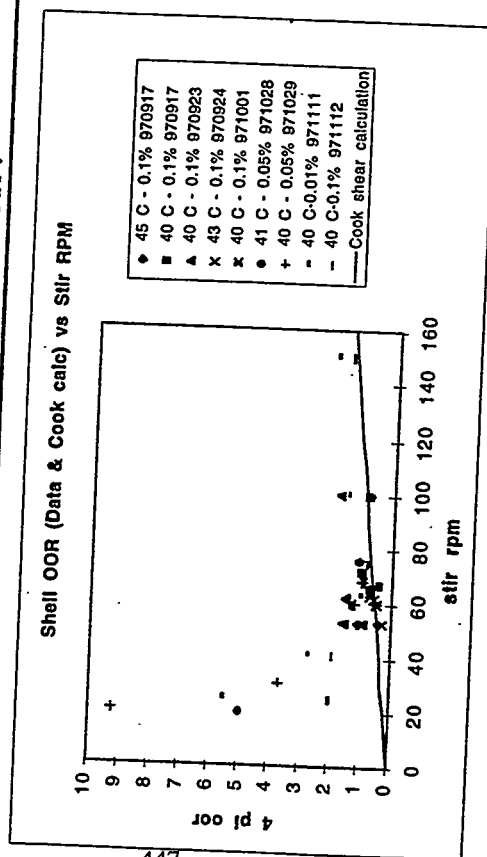
η is the viscosity (0.014 poise for 0.1 wt% PVA)

f is the stirrer frequency (Hz = rpm/60)

r is the droplet radius (470 microns)

γ is the interfacial surface tension (10 dyne/cm)

Beaker Stirrer RPM Affects Shell OOR !

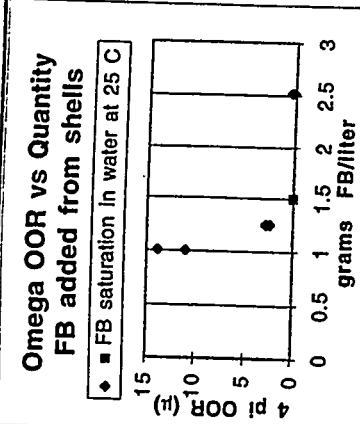
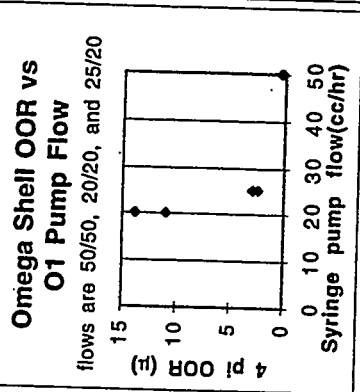


* At high rpm, Cook equation seems to describe OOR.

* At low rpm, (and especially W2 PVA < 0.1 wt%), something else occurs.



Density Match & Stir Rate Are Optimized- Now the Quantity of Fluorobenzene is Significant!



* Looks like good OOR requires the quantity of fluorobenzene in beaker must exceed the solubility of fluorobenzene.

* Exceeding the solubility means the shells cannot dry, until fluorobenzene evaporates from the solution: a longer drying time, giving time for the shell to become spherical and concentric.

Summary of Process Variables Which Effect OOR

* Density match between O1 and W2 is critical.

Use curing bath temperature to control density match.

Get to the curing temperature as quickly as possible, before shell is dry.

Use of fluorobenzene rather than binary solvent O1 keeps the O1 density change with composition/time at a minimum.

* There exists a stir rate for minimum OOR, which is a compromise between shear and shell tumbling.

Perhaps some improvements in stirring and tumbling are required to improve OOR further.

* Saturate the W2 phase with the O1 solvent, to ensure shells go into a saturated W2 system and drying time is extended at temperature.

SPLIT THE DIFFERENCE BETWEEN SURVIVAL AND DESTRUCTION

- Ultimate tensile strength found by fitting the function,
 $Pressure = \sigma_{ult} \cdot 4 (Wall_{capsule}/Diameter_{capsule})$, and minimizing the least squares error to the data. This yields:
Destruction Limit Data: $\langle \sigma_{ult} \rangle = 200 \text{ MPa} \pm 0.5$ (S.D.)
Survival Limit Data: $\langle \sigma_{ult} \rangle = 140 \text{ MPa} \pm 0.5$ (S.D.)

Average : $\langle \sigma_{ult} \rangle = 170 \text{ MPa} \pm 30 \text{ MPa}$
For GDP from 35 K to 54 K

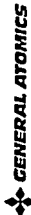
- At room temperature $\langle \sigma_{ult} \rangle = 77 \text{ MPa}$; private communication with R. Q. Gram (URLLE)
- There is no clear temperature dependence evident in the data between 35 K and 54 K



IMPLICATIONS FOR OMEGA AND NIF

Capsule Diameter	Capsule Wall Thickness	DT Layer Thickness	Fill Pressure at 300 K	Max Cryogenic Survival Pressure	Max Survival Temperature
1000 μm	5 μm	100 μm	14,000 psi 100 MPa	490 psi 3.4 MPa	43.8 K 36.0 K (Pmax/3)
1000 μm	1 μm	100 μm	14,000 psi 100 MPa	98 psi 0.68 MPa	32.5 K 27.4 K (Pmax/3)
2000 μm	150 μm	80 μm	5100 psi 35 MPa	6000 psi 41 MPa	at least 54 K 220 K if σ_w linear from Cryo to Room Temperature 105 K (Pmax/3)

- Omega requires transporting filled capsules (1 μm) at under 30 K
- Transporting filled NIF Capsules may be possible in a liquid nitrogen cryo-system





Crystal Growth And Surface Energy Of Hydrogen Crystals:

Application to Target Surface Roughness

**Bernard Kozioziemski
Gilbert Collins
Thomas Bernat**

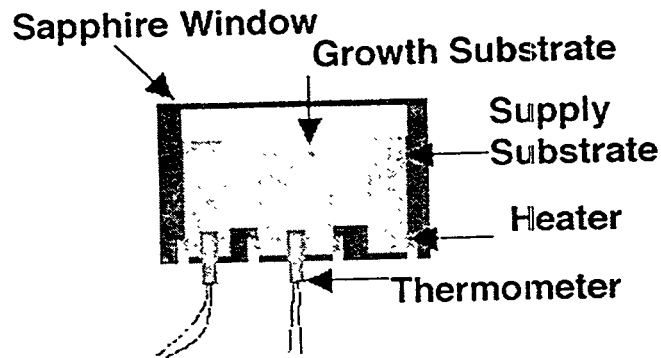
April 22, 1998

Predictions of D-T ice layer roughness depend on surface energy



- **We use Tom's model to predict smoothing of ice surfaces with applied heat flux and bulk heating**
 - We assume large, mismatched crystal facets are the source of roughness
 - Heat flux and bulk heating techniques must overcome surface energy increases before a surface can be smoothed
- **The surface energy must be known to predict the effectiveness of smoothing techniques**
 - Surface energy can be determined by measuring the roughening temperature
 - We need to know if facets exist and what the crystal orientation is to obtain the surface energy
- **We apply these results to crystals grown in spheres**
 - Experiments in shells show multi-crystalline surfaces
 - Grain boundaries may reduce surface energy in a curved geometry

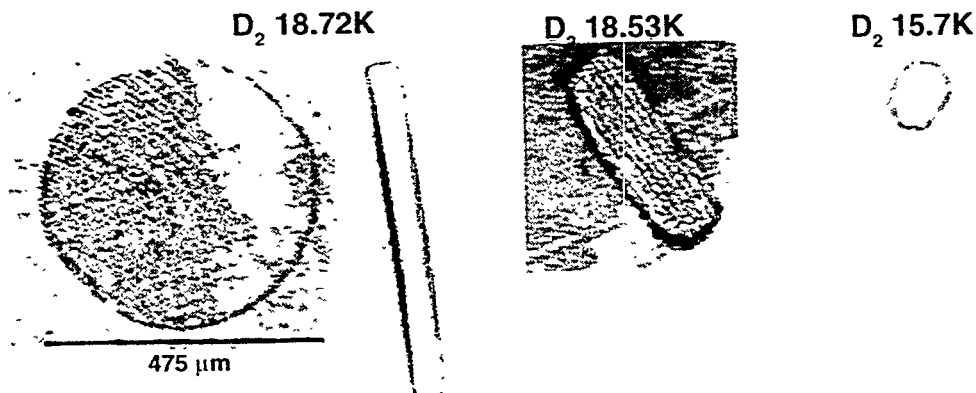
To measure surface energy
we grow single crystals from the saturated vapor



T_{TP} for $D_2 = 18.7K$
 $HD = 16.6K$
 $H_2 = 13.8K$

- D_2 is deposited on the supply substrate
- Lowering the temperature of the growth substrate relative to the supply substrate enables controlled growth from the vapor
- The bottom of the cell is connected to a liquid helium cooled copper block

We observe a number of common crystal growth shapes
with facets



- Interferometry and sharp edges locate crystal facets.

Two perpendicular facets have been observed on crystals growing near T_{TP}



- The hexagons appear much less frequently near T_{TP} than the bars or circles
- We have not been able to hold a crystal near T_{TP} for extended periods

J=0 D₂ 18.65K



nD₂ 18.71K



HD 16.45K



- Because facets exist at the triple point temperature, we can set a lower bound for the surface energy

The atomic roughening transition temperature is proportional to the surface energy



$$T_r^i = \frac{2\gamma_t(\varphi)d_i^2}{\pi k_b}$$

$$\gamma(\varphi) = \gamma_0 + \gamma_1 |\tan(\varphi)|$$

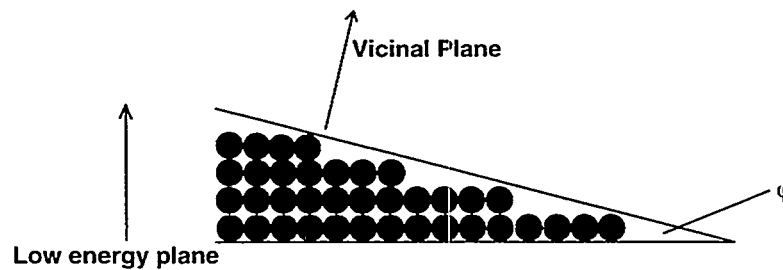
$\gamma(\varphi)$ is the orientation dependent surface energy
 d is the spacing between parallel planes

- Each crystal plane has a different T_r^i
- Measuring T_r^i determines the surface energy
- Hydrogen crystals have at least one facet at the melting temperature
- We find $\gamma_0 = 1.5 \text{ ergs/cm}^2$ for the (0001) direction, and $\gamma_0 = 1.0 \text{ ergs/cm}^2$ for the (10 $\bar{1}$ 0) direction

Steps increase the energy of a surface



- The number of steps increases with increasing angle
- For low angles, we model the surface energy of a tilted surface as $\gamma = \gamma_0 + \gamma_1 |\tan(\phi)|$
- Heat flux and bulk heating must overcome the step energy to smooth a facet



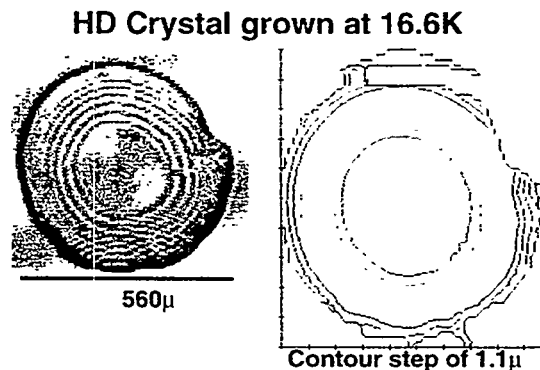
The step energy is found from the crystal curvature near the facet



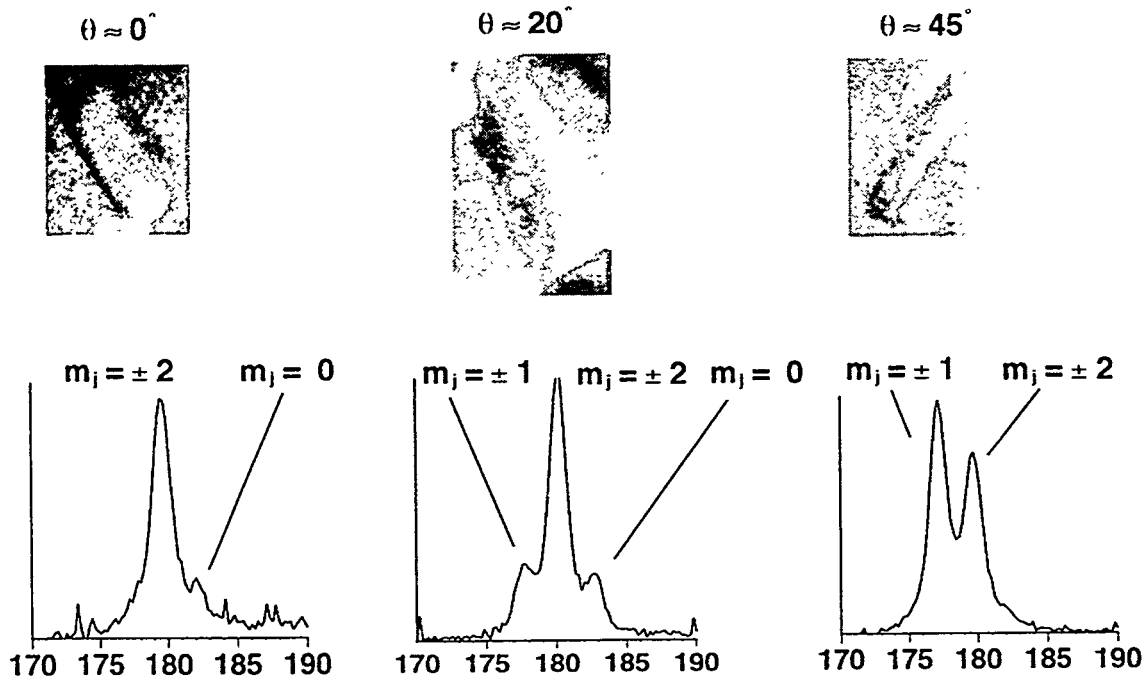
- Landau's theory for the equilibrium crystal shape is matched to the phase map of a crystal profile

$$\text{Surface Energy} = \int \gamma(\phi) \sqrt{1 + y'^2}$$

- We find $\gamma_1/\gamma_0 = 1/4$



Orientation of the c-axis is characterized by the raman spectrum



We model layer roughness using our values for the surface energy



- Layers seek out minimum free energy

$$\int (\underbrace{\gamma(\varphi)}_{\text{Surface Energy}} \sqrt{1 + y'^2} + \underbrace{K_F y^2(x)}_{\text{Heat Flux}} + \underbrace{K_B y^3(x)}_{\text{Bulk Heating}}) dx$$

$$K_F = c_p F / (2k)$$

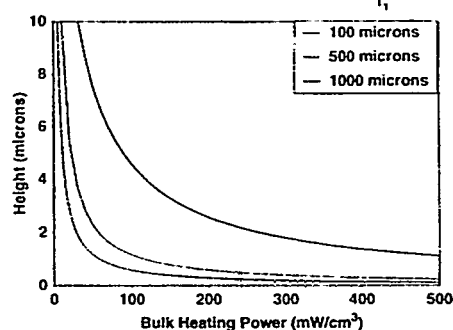
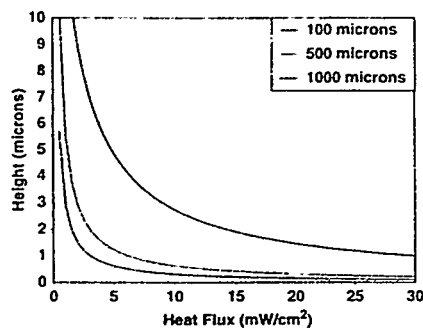
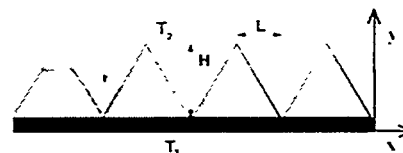
$$K_B = c_p Q / (3k)$$

$$\gamma_0 = 1.5 \text{ ergs/cm}^2$$

$$\gamma_1 = 0.35 \text{ ergs/cm}^2$$

- To first order $\gamma(\varphi) = \gamma_0 + \gamma_1 |\tan(\varphi)|$

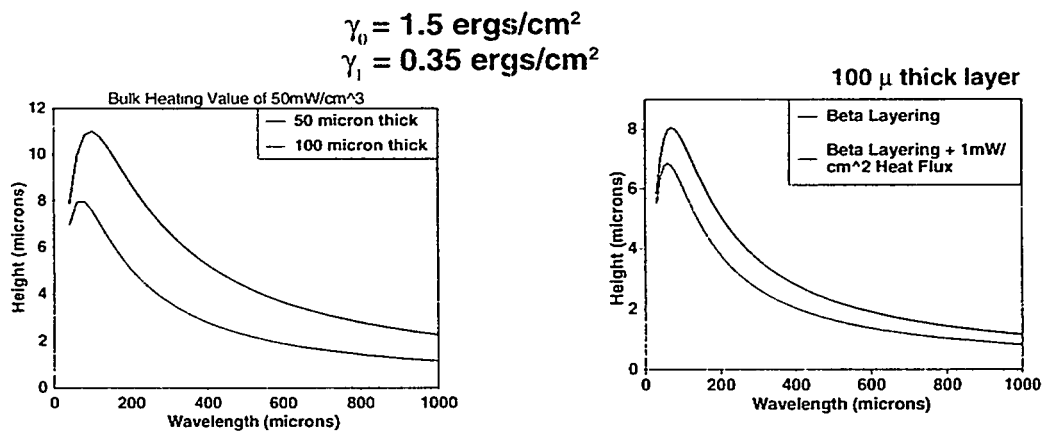
- γ_0 and γ_1 determine a minimum surface roughness



Smoothing of crystal is wavelength dependent



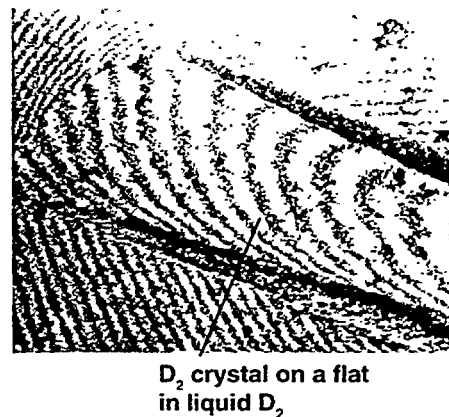
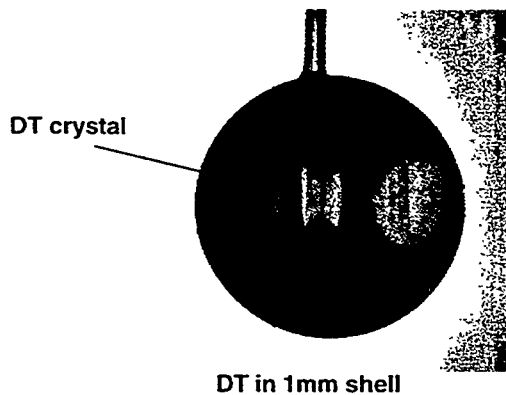
- Short wavelength crystals are harder to smooth than long wavelength.
- Bulk heating can smooth thicker layers easier than thin



Crystal growth in shells looks similar to growth on flats



- The surface structure minimizes the total energy, including surface, grain boundary, and thermal energy
- Initial nucleation of crystals strongly influences the surface roughness

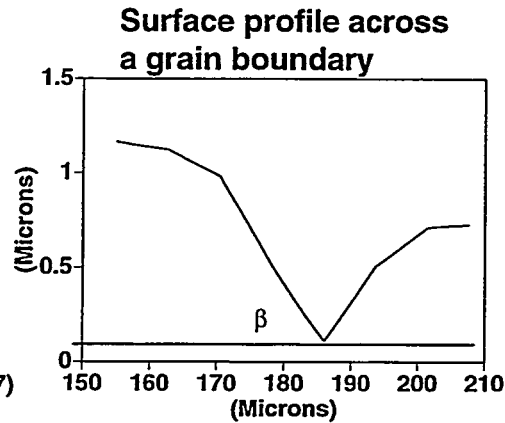


A cusp is formed where crystals meet



- Two surfaces meeting at a grain boundary form a cusp
- Grain boundaries cost energy to create
- The energy of the grain boundary is¹ $\gamma_b = 2 \gamma_s \sin(\beta)$
- We find $\beta = 3^\circ$
 $\gamma_b = \gamma_s / 10$

• Recrystallization of ice layers is limited by grain boundary energy



¹W.W. Mullins *Journal of Applied Phys.* 28, 333 (1957)

Conclusions



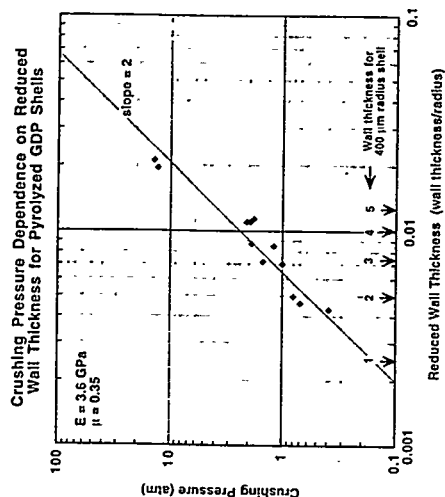
- Facets are observed on hydrogen crystals at the triple point temperature
- We set a lower bound for the surface energy for two crystal orientations
 $\gamma_0 = 1.5 \text{ ergs/cm}^2$ for (0001), and $\gamma_0 = 1.0 \text{ ergs/cm}^2$ for the (1010) directions
- Tom's smoothing model predicts roughness of multi-crystalline surfaces
- Growing crystals on flats helps us understand growth in shells

Filling Polymer Targets at Low Pressurization Rates

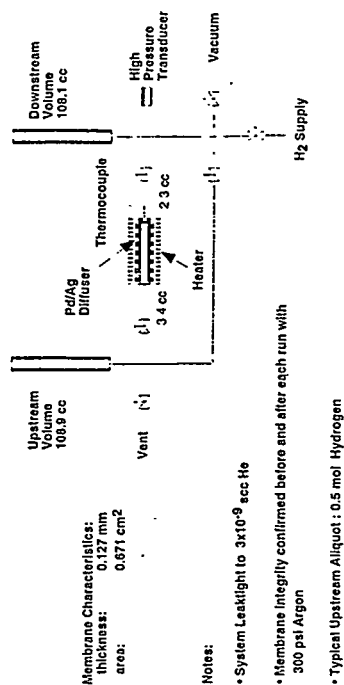
W. T. Shmayda, N. P. Kherani, D. Harding[†], R. Graham[†]

Presented at: Target Fabrication Meeting
April 19-23, 1998

Ontario Hydro Technologies, Toronto, Ontario, Canada
[†]LLE, University of Rochester, Rochester, NY, 14623



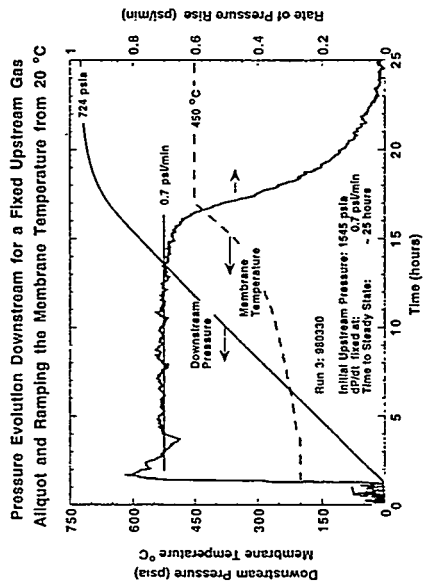
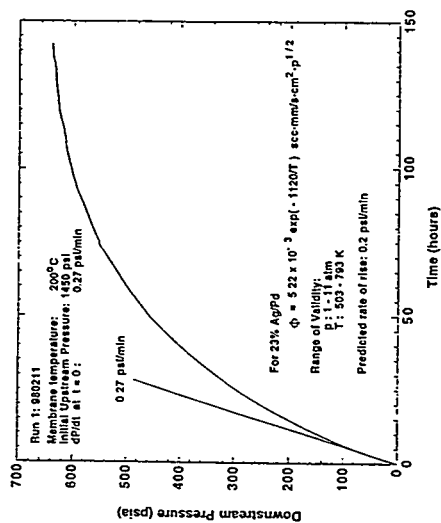
Schematic of the Permeation Test Apparatus



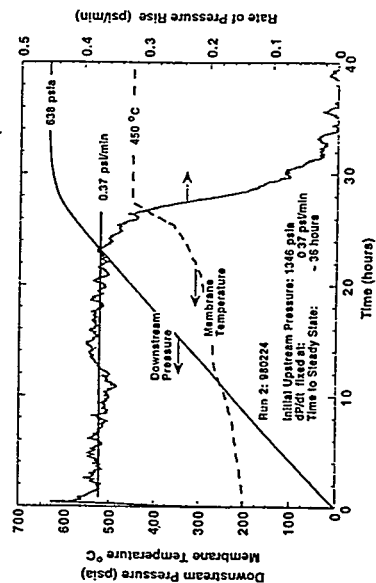
Background

- U of R plan to charge targets with DT using a 3 stage process
 - Transfer gas from storage to a condensation tube
 - Inject gas into the compressor and permeation cell at a controlled rate
 - Pressurize the permeation cell to ~22,000 psi
- Constraints:
 - Gas Inventory: 0.33 mol
 - $dp/dt < \text{a few psi/min}$
- Four low pressure filling options have been considered:
 - Compressor + sequencing pairs of valves
 - Pressure controller + demand settable regulator
 - Temperature ramping of the condensation cell
 - Diffuser

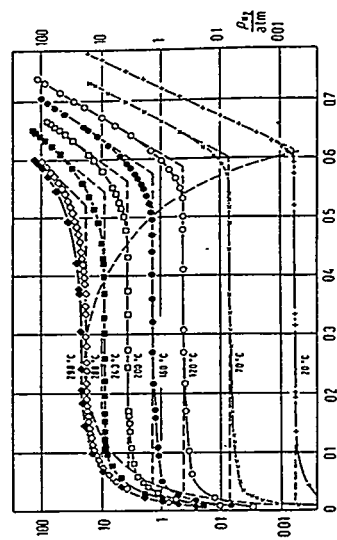
Pressure Evolution in the downstream Chamber for a Fixed Amount of Gas Upstream and a Constant Membrane Temperature



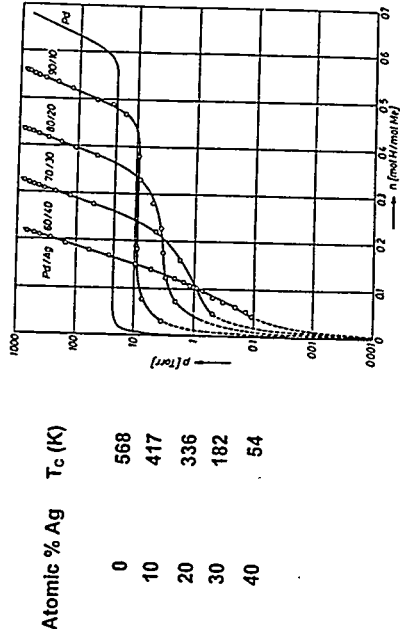
Pressure Evolution Downstream for a Fixed Upstream Gas Aliquot using a Ramped Membrane Temperature



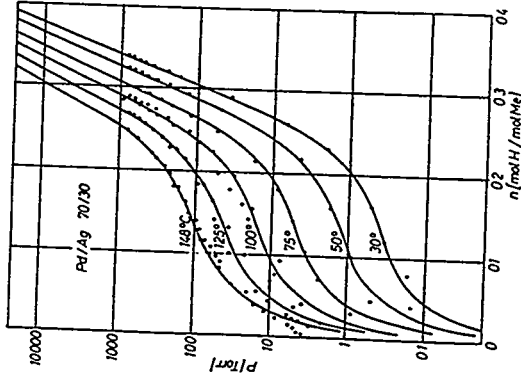
Pressure/composition Isotherms for the Pd/H System
ref: Wicke & Brodowsky, 1978



Isotherms for Hydrogen Solubility in Pd and Pd/Ag Alloys at
 50°C & Critical Temperature Dependence on Ag Content
 ref. Brodowsky 1965

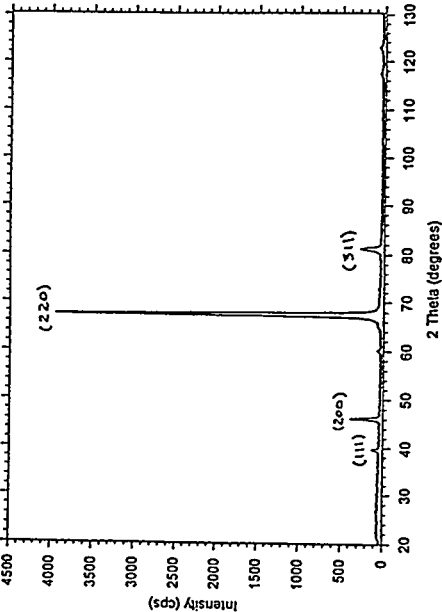


Isotherms for Hydrogen Solubility in 30% Ag/Pd
 ref. Brodowsky, 1965

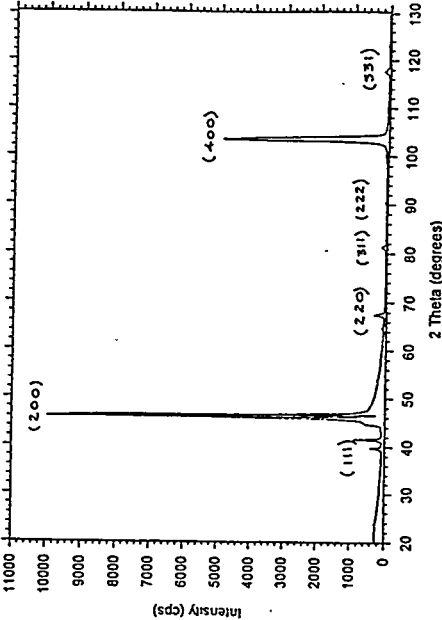


X-ray diffraction measurements do not show any
 obvious hydriding effects.

Virgin sample (rolled)



Following test (annealed cubic)



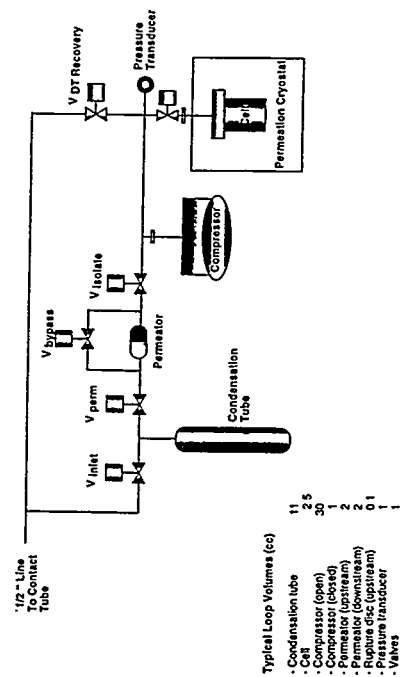
Tebus et al. Studied the Effects Exposing 15% Ag/Pd foil to Tritium

- Exposure Conditions: 350 °C, 4 -> 4.5 atm T, up to 2004 hours
 - T/Pd-Ag ~ 0.04, He = 480 appm
- > Helium-3 dose to metal ~ 9000 atm-hrs
- Observations
 - Embrittlement noticeable once He concentration exceeds 330 appm (5830 atm-hrs)
 - Helium vacancies migrate to coalesce into bubbles O(nm)
 - Bubble distribution uniform through grains NOT at grain boundaries or dislocations

Conclusions

- Diffuser offers excellent rate of rise control, compactness, inherent fail safe operation
- Helium Effects:
 - Typical charging operation: 30 hrs, up to 130 atm -> 3900 atm-hrs per run
 - > 2 - 3 charging operations feasible
 - > He induced changes to permeability, solubility, mechanical strength ???
- Hydride Effects:
 - Select 30%Ag/Pd alloy for low pressure filling function
 - Select 40%Ag/Pd alloy for 'cryovalve' function

PERMEATION SYSTEM FOR LOW PRESSURE FILLING OF TARGETS



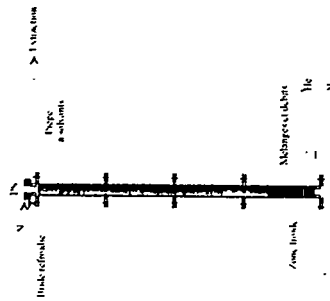
The Drop-Tower Technique for Micro-Shells Fabrication

Ph. BACLET - R. COLLIER, E. FLEURY

TFM 98, 18-23 April 1998, Jackson Hole

CONTENT

- 1 / First column design and results :
- 2 / Second column design and results :
- 3 / Mechanism of formation of the microspheres
- 4 / Influence of the parameters of injection in the column
 - 4.1 / Pressure inside the column
 - 4.2 / Temperature of the hot zone
 - 4.3 / Temperature of the cold zone
 - 4.4 / Atmosphere of the column
- 5 / Buckling of the bigger microshells.
- 6 / Conclusions and future work



Column design :

* Hot zone :

height : 6 m
T° max : 650°C
5 independent zones

* Cold zone :

height : 1 m
T° : -10 à 25 °C

* The drop tower runs under air

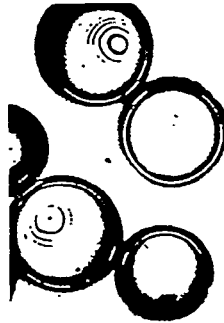


Shells :

- * Diameter up to 700µm
- * Eccentricity of about 30%
- * Problems of sphericity of the inner bubble.
- * Bad reproducibility.

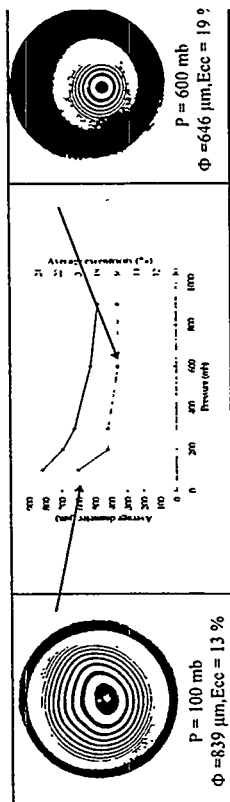
Qualitative influence of experimental parameters :

- * Higher T → larger diameter
- * Better reproducibility with granule injector than with gas stripper injector
- * Benefic effect of the atmosphere (He flow) on concentricity and diameter



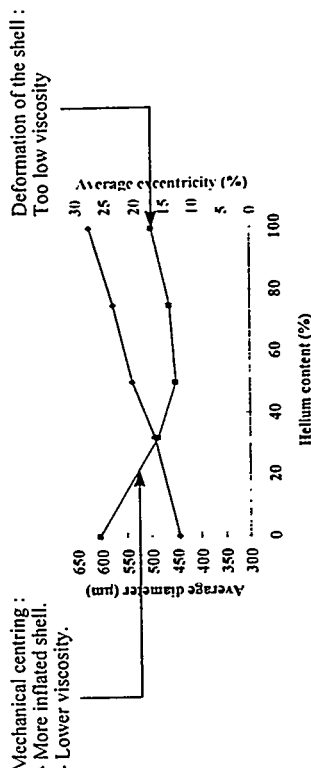
Useful information for the designing of the second column





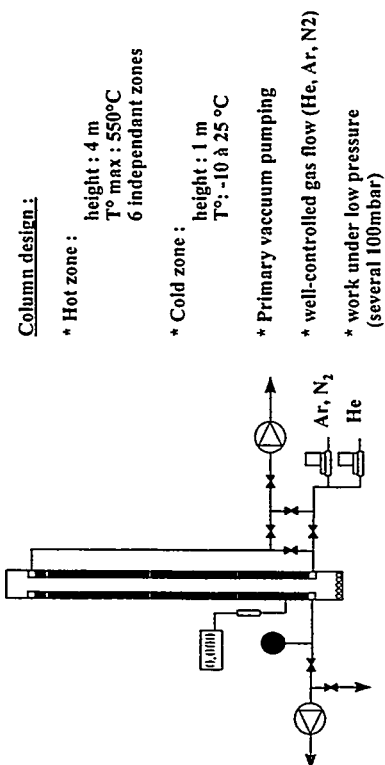
The lower the pressure, the higher the diameter.

Deformation of the inner bubble for very low pressure



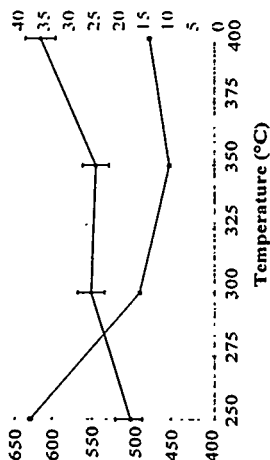
The higher the He content, the larger the diameter.

Heat flow on the inflating shell more important



Initial conditions	Evolution of the initial granule
3/150°C The granule angles grow, but decrease in size and the first bubbles appear inside the polymer matrix.	3/150°C No modification of the initial granule.
4/110°C The bubbles continue to grow, but decrease in size and the first bubbles appear inside the polymer matrix.	4/110°C The bubbles are more numerous and larger. Their size is homogeneous. The grain becomes round.
5/70°C The granule is inflating because of the decrease of the decomposition gas inside the shell.	5/70°C The granule grows to the detriment of the other, leading to its complete disappearance.
6/20°C The granule is inflating because of the decrease of the decomposition gas inside the shell.	6/20°C During the last stage of the process, the granule partially enters the size of the initial granule of about 25 μm has to be compared to the diameter of the expanded shell (diameter).

Influence of the temperature of the hot zone



The higher the temperature, the larger the diameter.

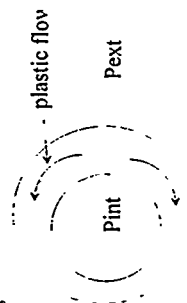
The higher the temperature, the higher the concentricity

Influence of the temperature of the hot zone

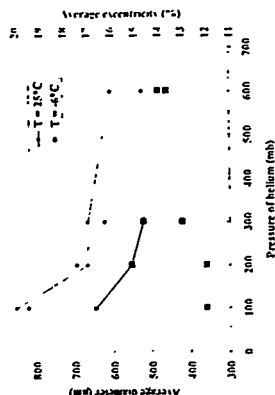
DIAMETER :

- * Closed system (n=Cte)
- * T inside the shell increases : P increases : V increases.

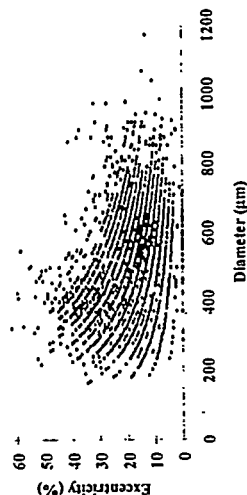
CONCENTRICITY : mechanical centring



Influence of the temperature of the cold zone

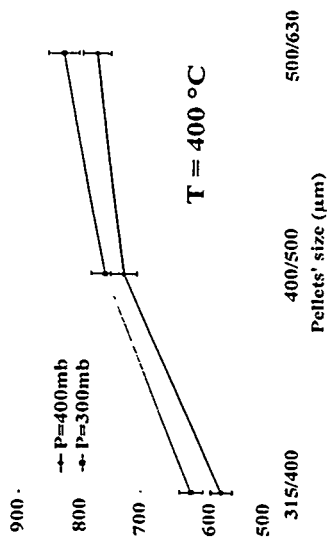


Correlation between Diameter and concentricity



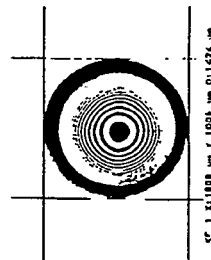
The larger the diameter, the best the concentricity

Influence of the pressure on the injected pellets



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Results obtained with the second Drop Tower



Micro-structure

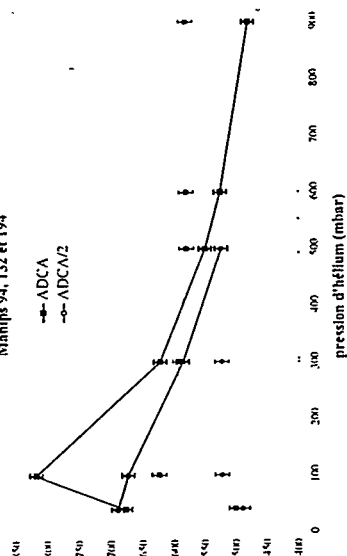
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

Structure of the micro-shells



L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

Conditions expérimentales: T = 400°C; C = 315/400 µm

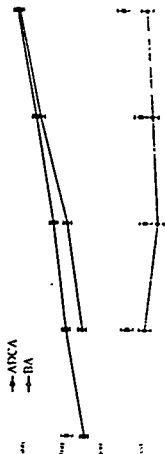


Concentricity is better (16% to 11%) with a lower quantity of blowing agent

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Décomposition température	ADCA 180°C exothermic	BA 20 - 130°C endothermic
------------------------------	-----------------------------	---------------------------------

Conditions expérimentales : $G = 315/400 \mu m$
 $T = 400^\circ C$; $P = 300 mb$
 Manip : 97, 100, 163 et 178

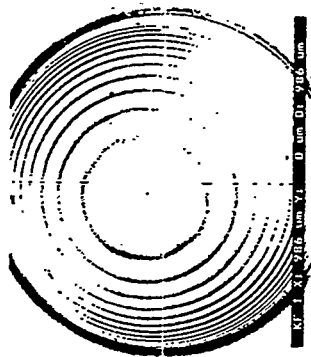


bicarbonnate is better than ADCA for concentricity

Direction des Applications Militaires ——— L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

DIRECTION DES APPLICATIONS MILITAIRES

Grains obtained with Libbey-Olin Institute granules

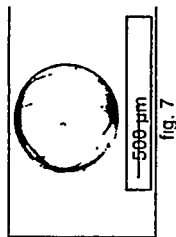


Big Diameter can now be obtained : $1972 \mu m$ - Improve the concentricity (13%)

Direction des Applications Militaires ——— L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

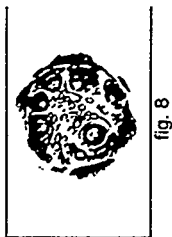
Initial granule :

Spherical shape.



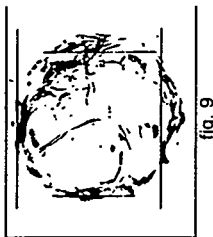
400°C :

bubble nucleation from the surface to the center of the PS



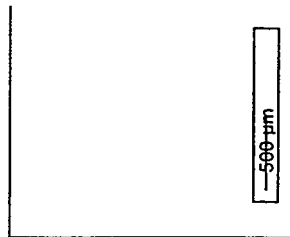
500°C :

coalescent behaviour of the growing bubbles



600°C :

The shell formation is completed



Mechanism is different



DIRECTION DES APPLICATIONS MILITAIRES

USI ONS

First column :

- * under air, gas-stripper injector, 350°C.
- * 700µm, 30% eccentricity, deformation of the inner bubble, bad reproducibility.
- * Useful informations for the designing of the second column.

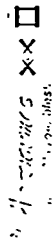
Second column :

- * Run under reduced atmosphere, controlled flow rates, granules injection, 350°C.
- * Up to 1500µm with 4% eccentricity (larger possible), dense structure of the wall, smooth surface (SEM).

Proposal of explanation of the non concentricity by the mechanism of formation.

Proposals of explanation of the influence of the column parameters.

The limits of the technique are far to be reached.



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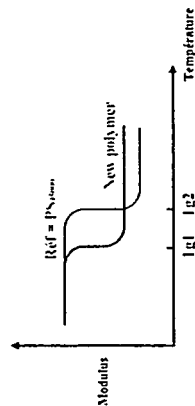


DIRECTION DES APPLICATIONS MILITAIRES

Futur e work

Modification of the material parameters :

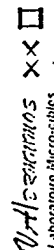
- * Blowing agent
- * Polymer :



Modification of the process parameters :

- * Optimization of the parameters described in this work
- * Thermal gradient.
- * Permeation device to avoid buckling

PAMS mandrels for PAMS/GDP coatings



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Status of the Design of the Tritium Handling Systems for the Omega Cryogenic Target System

A. Nobile and J.E. Nasise
Tritium Science and Engineering Group
Los Alamos National Laboratory, Los Alamos, NM

C. Gibson, G. E. Besenbruch, and D. T. Goodin
Fusion Group
General Atomics, San Diego, CA

D. Harding, and L. Lund
Laboratory for Laser Energetics
University of Rochester, Rochester, NY

The Omega Laser Facility at the University of Rochester Laboratory for Laser Energetics (UR/LLE) will begin laser implosion shots on cryogenic DT ICF targets in the year 2000. The OMEGA Cryogenic Target System (OCTS) that fills plastic ICF targets to high pressure, cools them down to cryogenic temperatures, layers and characterizes the targets, and then transports them to the center of the Omega Target Chamber where they are shot, is being designed and constructed by General Atomics. Although the quantities of tritium being handled are relatively small (<1 g), the design of the tritium handling systems to support the OCTS operation is a significant challenge. The gloveboxes that provide secondary containment of the tritium handling equipment are quite large and must support a 1700 kg cryostat vessel, contain the vacuum and gas handling systems, and yet allow for access to the vessel for maintenance and repair after it becomes tritium contaminated. There are two major vacuum systems to support the OCTS operation. These were designed to be tritium compatible, relatively compact, easy to maintain, and yet provide high vacuum and roughing vacuum to a number of vessels having a wide range of tritium contamination levels. Finally, a Tritium Removal System (TRS) is being designed to provide cleanup of the glovebox atmosphere, vacuum system effluents, and equipment associated with the Target Chamber. The TRS must perform in a manner to support a yearly tritium release limit of 400 mCi of tritium, which is a significant challenge. This paper describes the current status as well as some of the challenges encountered in the design of the gloveboxes, the vacuum system, and the TRS.

The OMEGA Cryogenic Target System will field cryogenic DT ICF targets on OMEGA

- **Laser illumination of first cryogenic DT targets on OMEGA at the University of Rochester Laboratory for Laser Energetics (UR/LLE) will occur in 2001**
- **Tritium release limits are low**
- **Several systems will play a role in the tritium handling aspects of the OCTS**
 - **Gloveboxes**
 - **Vacuum System**
 - **DT High Pressure System**
 - **Tritium Removal Systems**
- **DT experiments are planned with a small scale cryostat at LANL**

Los Alamos

UR/LLE will have a 1 g tritium inventory with stringent tritium release limits

- **1 g tritium inventory is licensed by State of New York**
- **Current tritium release limits are low**
 - **Tritium Fill Station room: 200 mCi/yr**
 - **Target Chamber bay: 2-3 Ci/yr**
- **Increase in release limit in Tritium Fill Station room is an option**
- **A high degree of tritium containment is necessary**

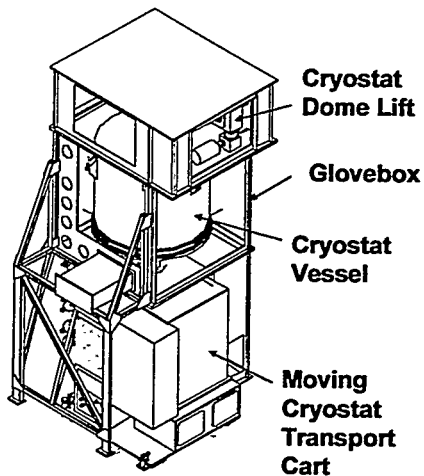
Los Alamos

OCTS equipment will be contained within four gloveboxes

- Tritium Fill Station Glovebox (existing)
- DT High Pressure Glovebox (new)
- Fill/Transfer Station Glovebox (new)
- Vacuum Pump Glovebox (new) ...

Los Alamos

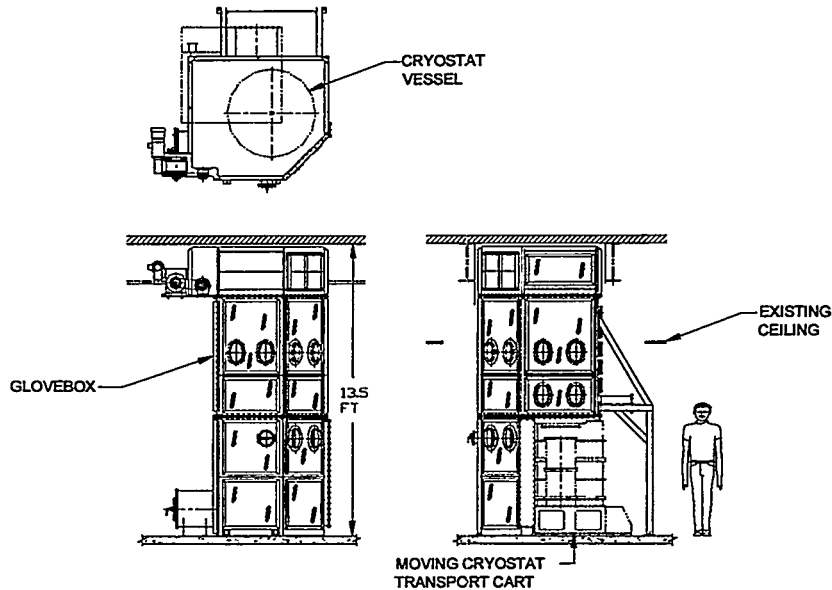
Fill/Transfer Station Glovebox



- Overall height approx. 13 ft.
- Supports 1700 kg cryostat
- Provides access for docking of the Moving Cryostat Transport Cart below the cryostat
- Contains support systems for cryostat, such as cryocoolers and vacuum system
- Allows for opening of the cryostat and maintenance of cryostat components
- Must be assembled in a relatively small room

Los Alamos

Fill/Transfer Station Glovebox is under construction



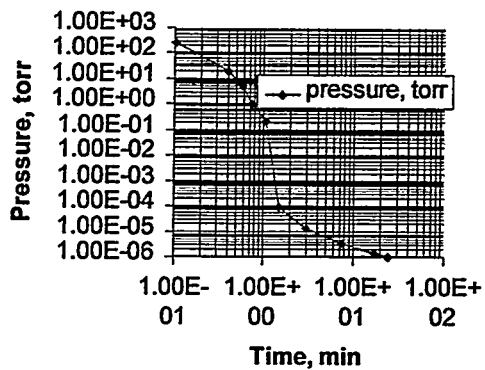
Design of the vacuum system required close coordination with other system designs

- Vacuum pumpdown calculations performed with Vacuum Designer II code
- Approach involved use of small turbo pumps and small diameter backing lines
- Tritium "hardened" turbomolecular pumps not needed in all locations
- Tritium compatible pumps used on systems with relatively high tritium concentrations
- Conventional pumps with elastomeric seals used in systems with low tritium concentrations

Los Alamos

Vessel pumpdown times were evaluated with Vacuum Designer II code

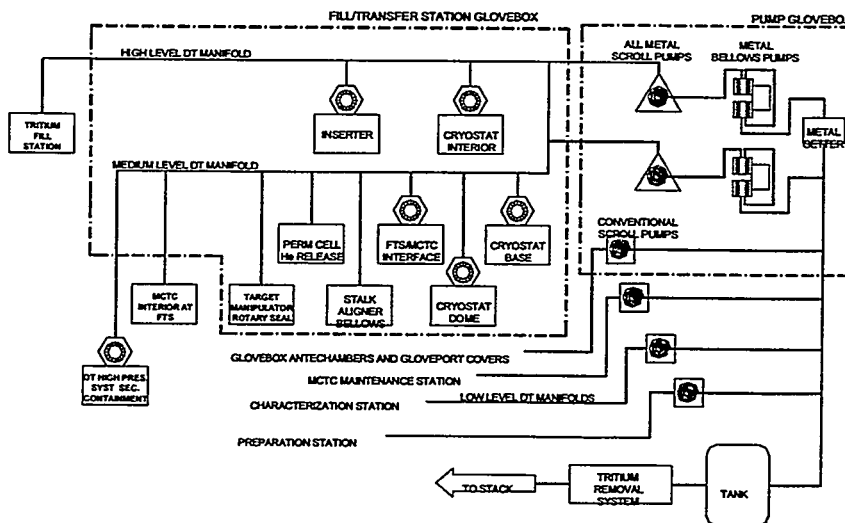
Insertion Pumpdown from Atmospheric Pressure



- Stainless steel rate = $1.0\text{E-}08 \text{ tL/cm}^2\text{sec}$; total = $8.6\text{E-}05 \text{ tL/sec}$
- O ring length = 6'
- Volume = 17 L
- 240 L/s turbo with 2" of 3.83" dia. Tubing
- PV-12 scroll pump in series with a MB 601 bellows pump

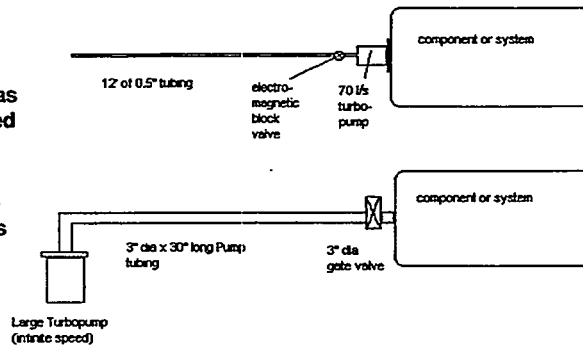
Los Alamos

OCTS vacuum system



Approach involving turbo pumps directly connected to vessels was chosen

- Small pump, mounted directly on the component, has the same pumping speed as a large pump connected to the component with large diameter tubing
- The former is easier to fit in a glovebox and is cheaper



Los Alamos

Vacuum pumps were not tritium hardened except where high tritium levels are expected

- Turbopumps are hybrid mag-bearing, dry film lubricated ceramic bearing types. Full mag-bearing, hardened seal and connector design would add substantially to cost.
- Roughing pumps, used for passboxes and for backing some turbopumps are not tritium hardened when only trace tritium levels are expected (Edwards Scroll pump uses elastomeric seals and teflon tip seals)
- Roughing pumps which evacuate and back turbopumps in known high tritium areas are tritium hardened. These pumps are all metal and use metal seals (Metal Bellows and Normetex Scroll pumps)

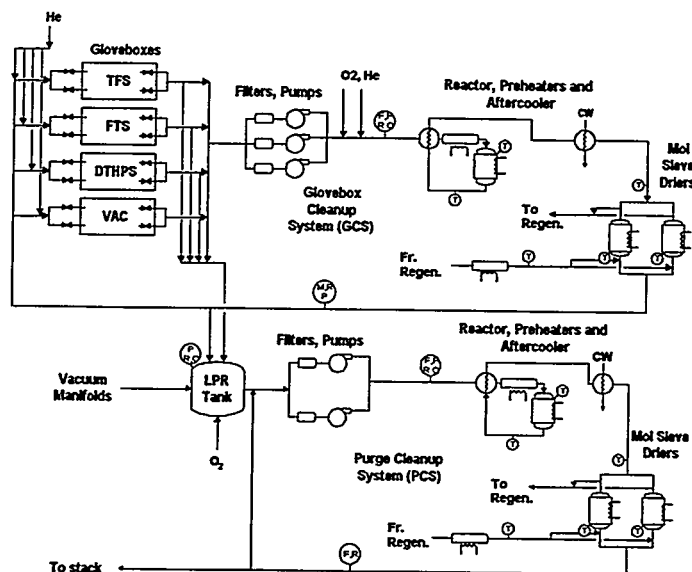
Los Alamos

Tritium cleanup systems are needed for operation of the OCTS and OMEGA Target Chamber

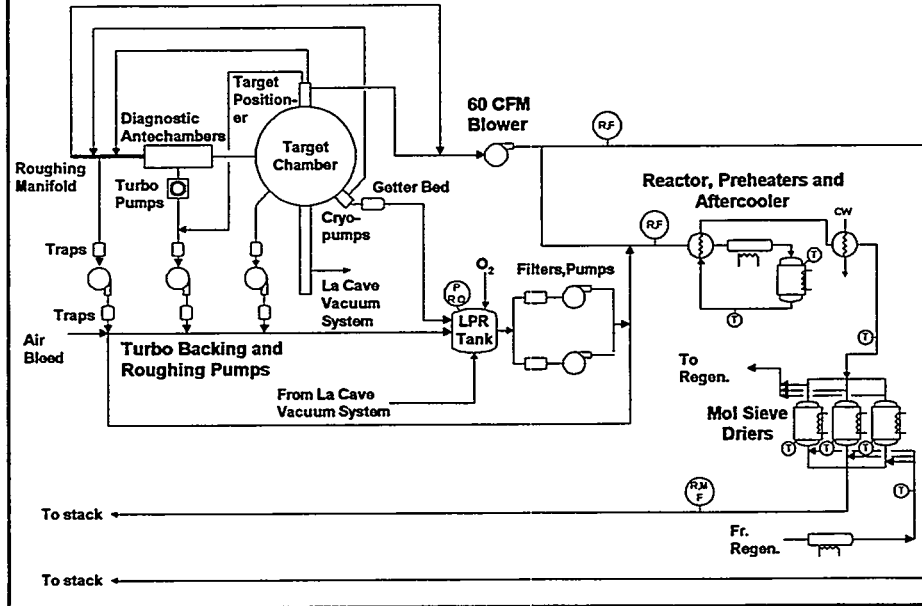
- OCTS equipment in Tritium Fill Station room
 - Four gloveboxes
 - Pumping manifolds
- Target Chamber
 - Tank purging during maintenance
 - Rough pumpdown of Target Chamber
 - Purging of diagnostic antechambers
 - Rough pumpdown of diagnostic antechambers
 - Target Chamber cryopump regeneration gas

Los Alamos

Rm. 157 Tritium Removal System (TRS)



Target Chamber TRS



Summary

- Safe handling of tritium will be critical to the successful operation of the OCTS
- The system must operate under stringent tritium release constraints
- A number of tritium handling systems have been designed to meet the operating objectives

Los Alamos

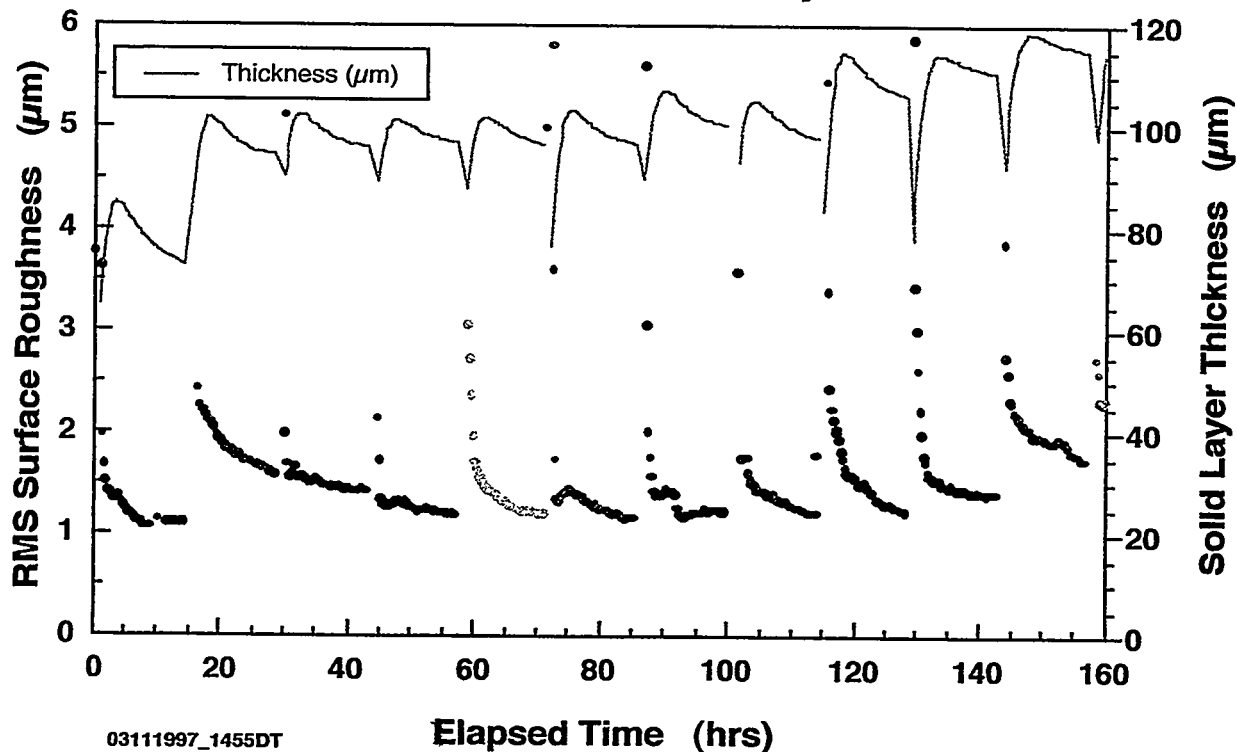
D-T Surface Roughness Statistics and Temperature-Step Stress Effects for Solid Layers Equilibrated Inside a 2 mm Beryllium Torus

John D. Sheliak
General Atomics
Los Alamos, New Mexico

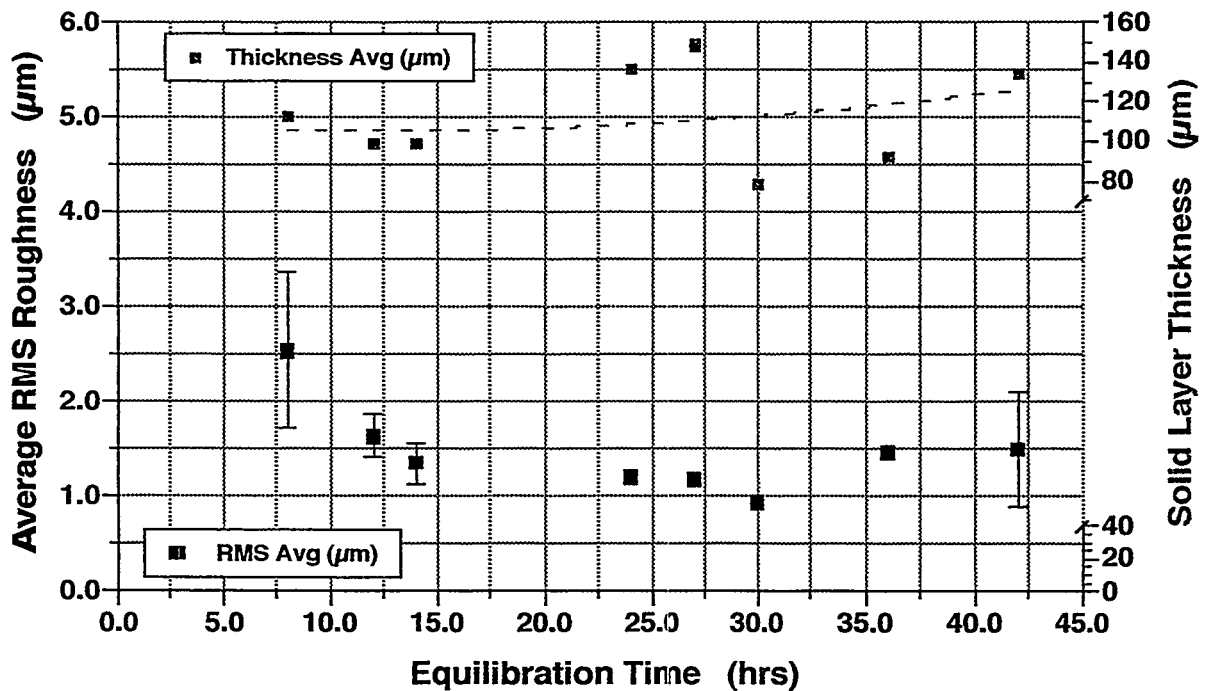
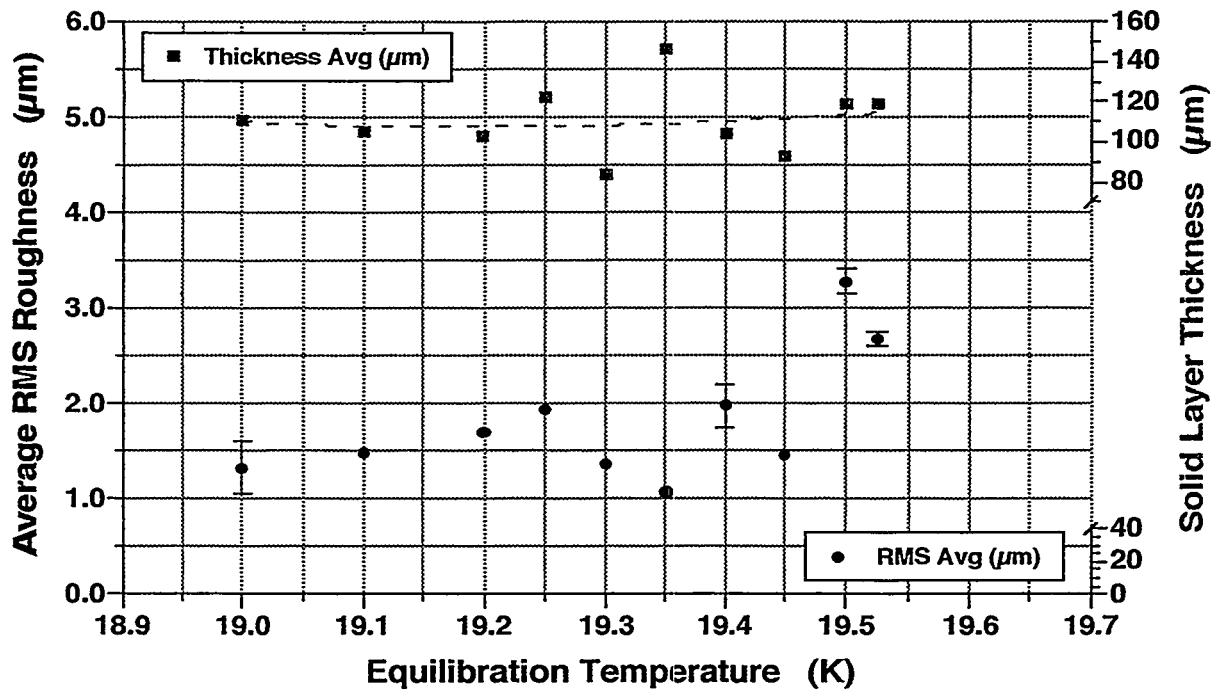
James K. Hoffer
Los Alamos National Laboratory
Los Alamos, New Mexico

12th Target Fabrication Specialists Meeting
Jackson, Wyoming
April 20 – 23, 1998

DT Freeze - Thaw Cycling @ 19 K in 2 mm Beryllium Torus with 14 hr Equilibration Cycles



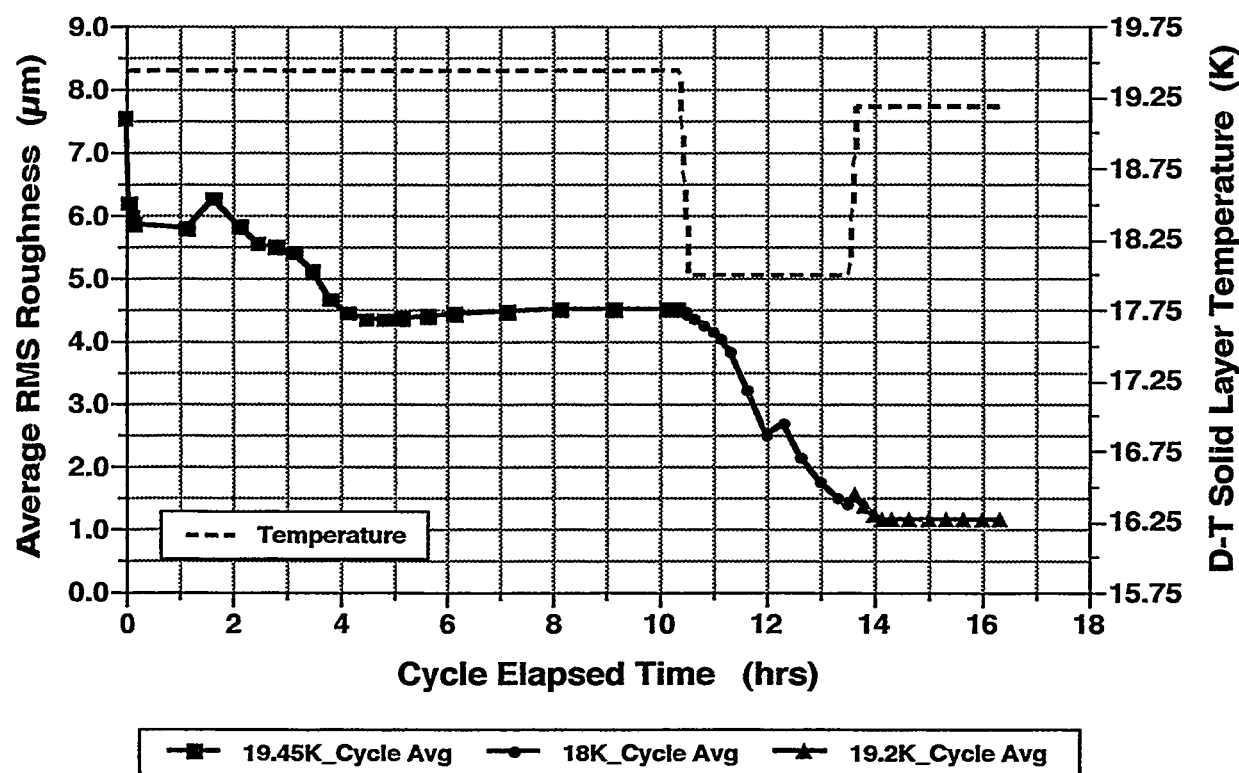
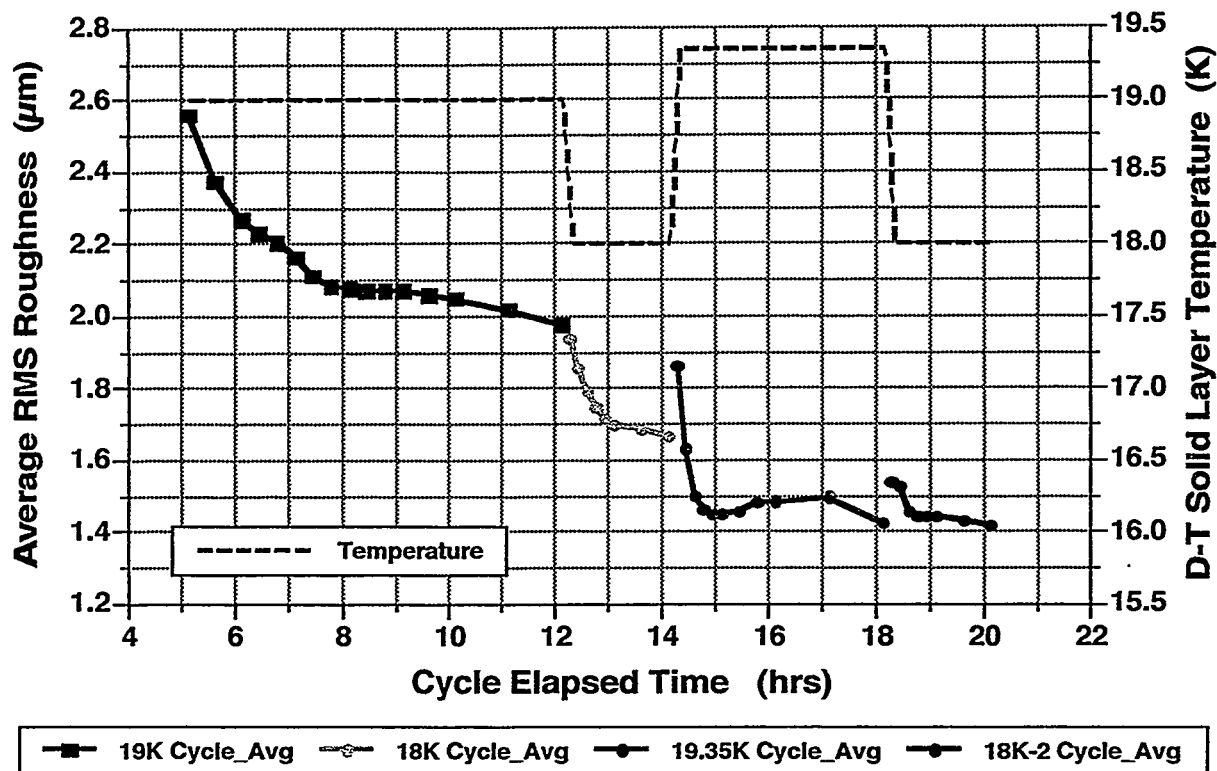
Temperature and Time Dependence of DT Solid Surface Roughness for Freeze/Thaw Equilibration Cycling Inside 2 mm Beryllium Torus



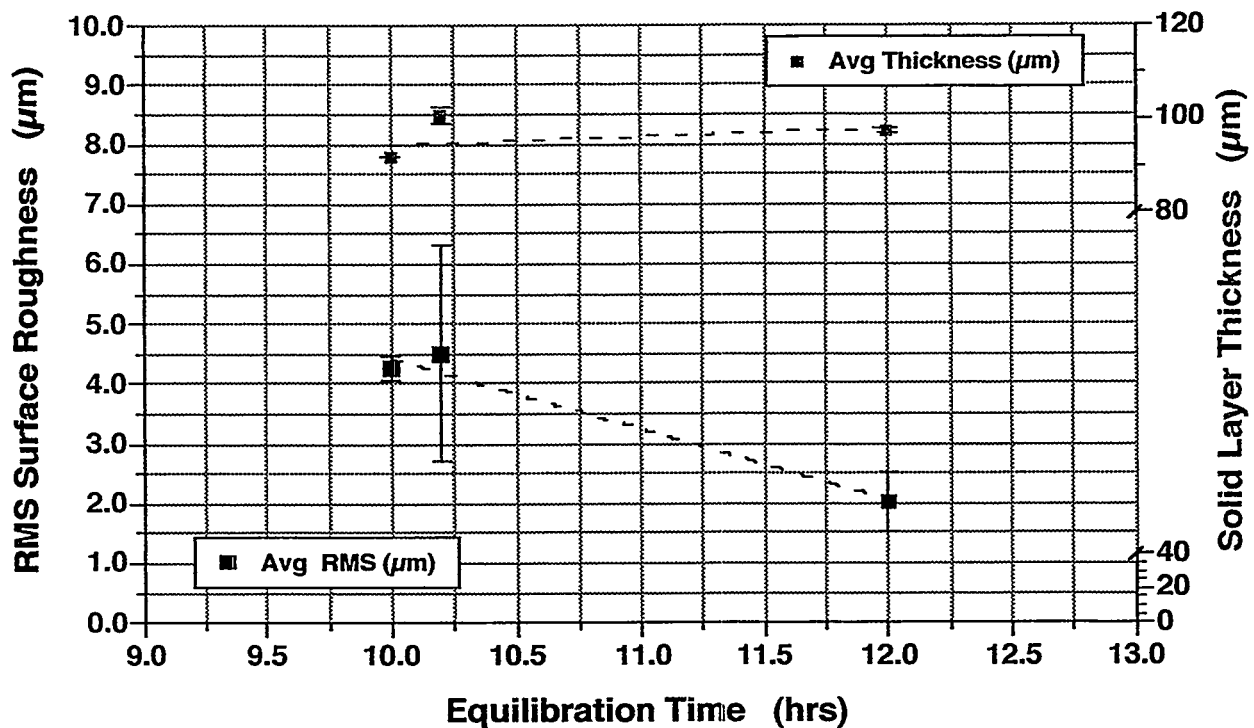
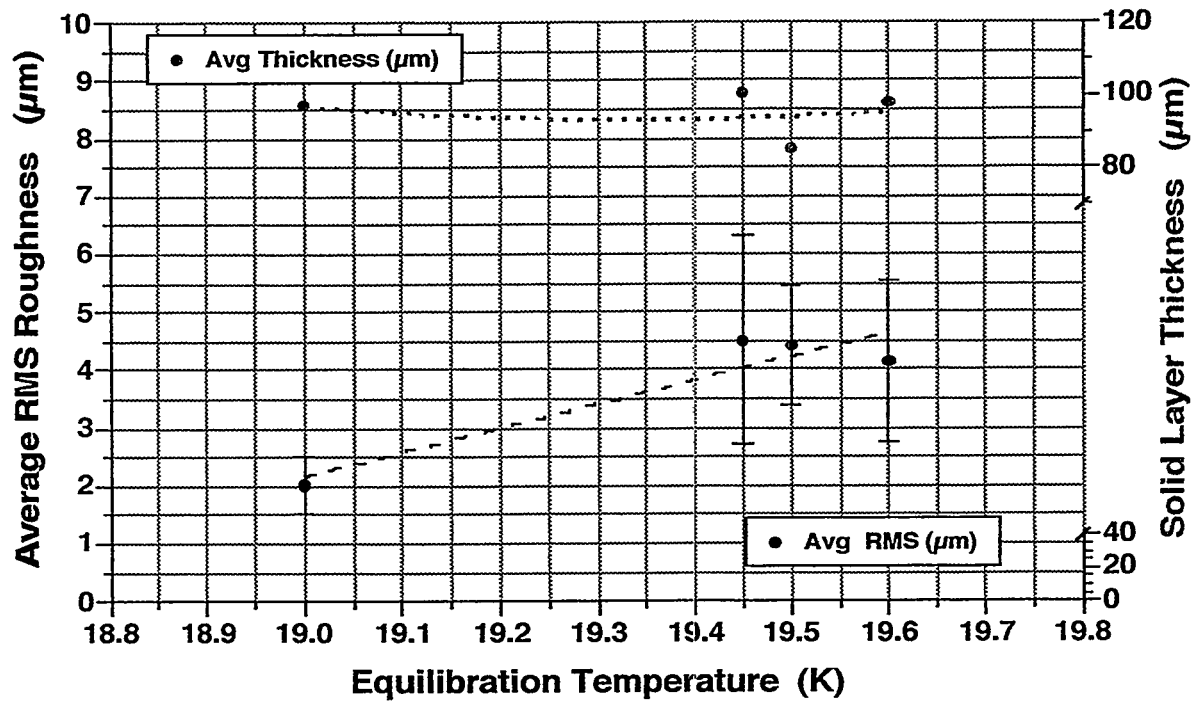
The average equilibrated solid D-T surface roughness was 1 - 2 μm for all these data, excluding the higher equilibration temperature and lower equilibration time regimes

We then attempted to reduce surface roughness by slow-freezing at 3 mK/min & 5 mK/min

Average Surface Roughness per Cycle for D-T Solid Layer with a Slow-Freeze Cycle and Follow-on Temperature Steps



Temperature and Time Dependence of D-T Surface Roughness for Slow-Freeze Cycling Inside 2 mm Beryllium Torus

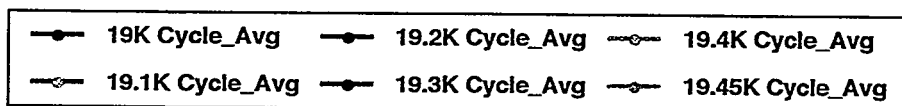
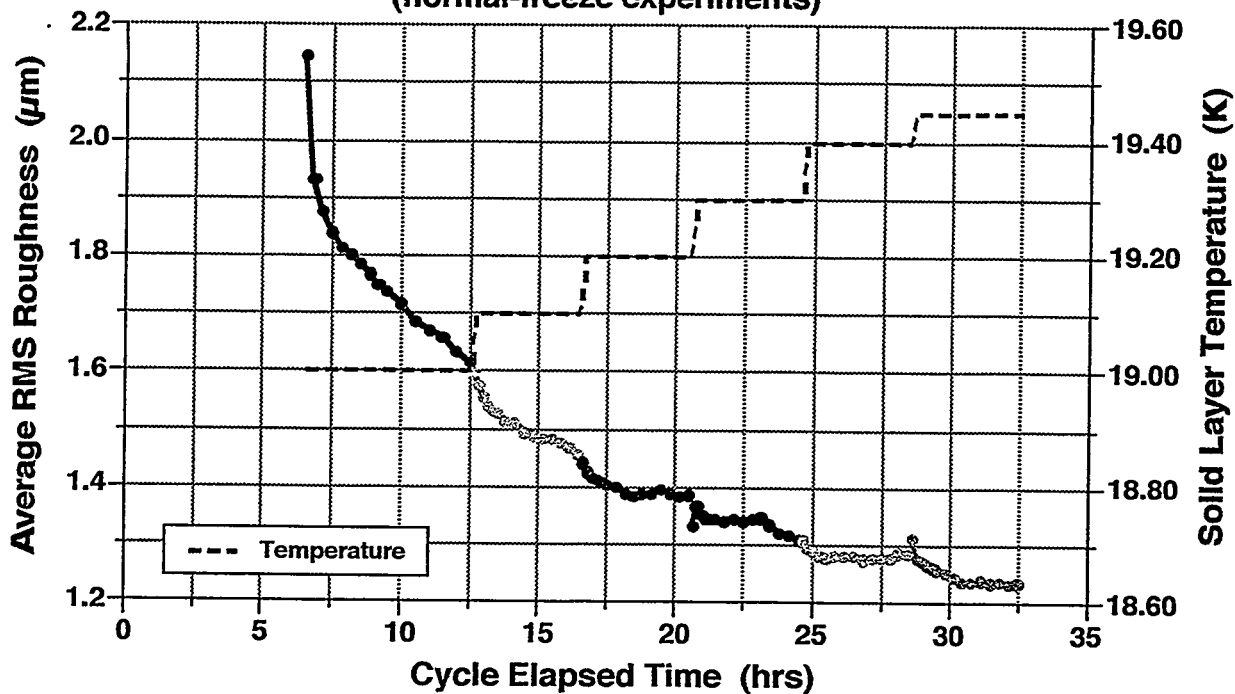


The 19.0 K and 12 hr equilibration data showed an average RMS roughness of $2 \mu\text{m}$; above 19.4 K and below 12 hrs, the surfaces were rougher

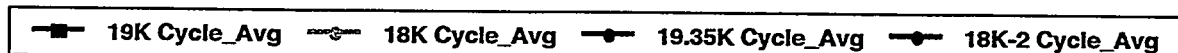
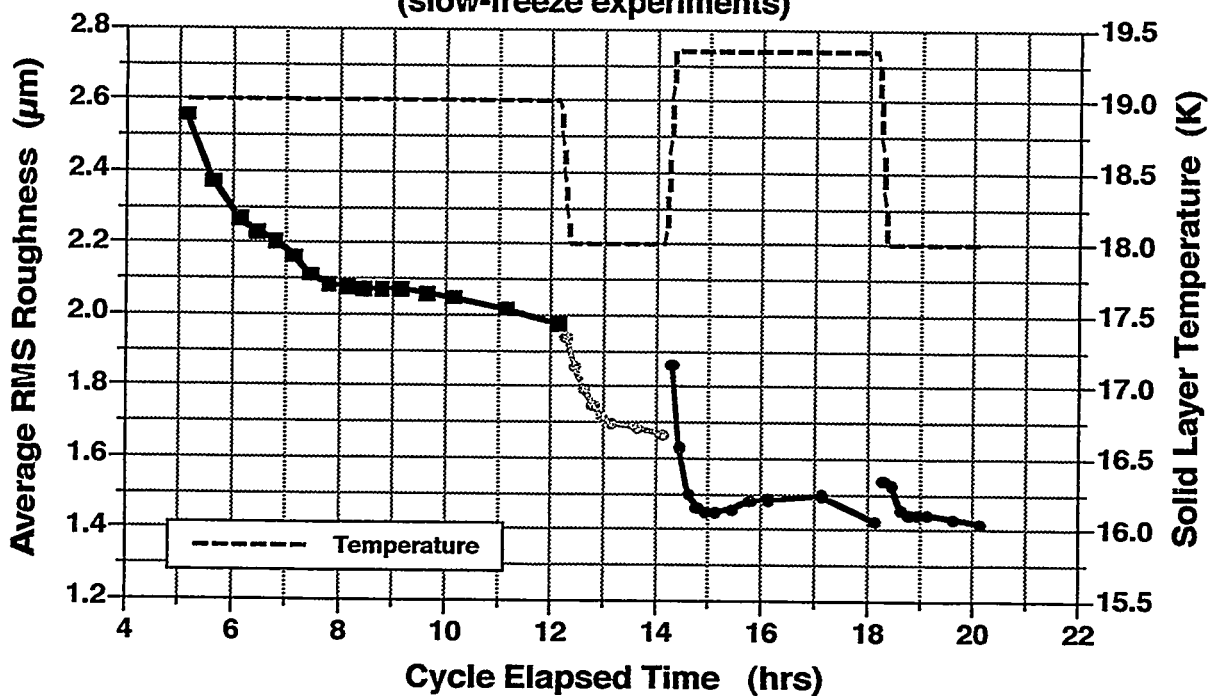
This residual surface roughness can be smoothed by subjecting the solid layer to sudden temperature excursions

Average RMS Roughness for D-T Equilibrations with Follow-On Temperature Stepping

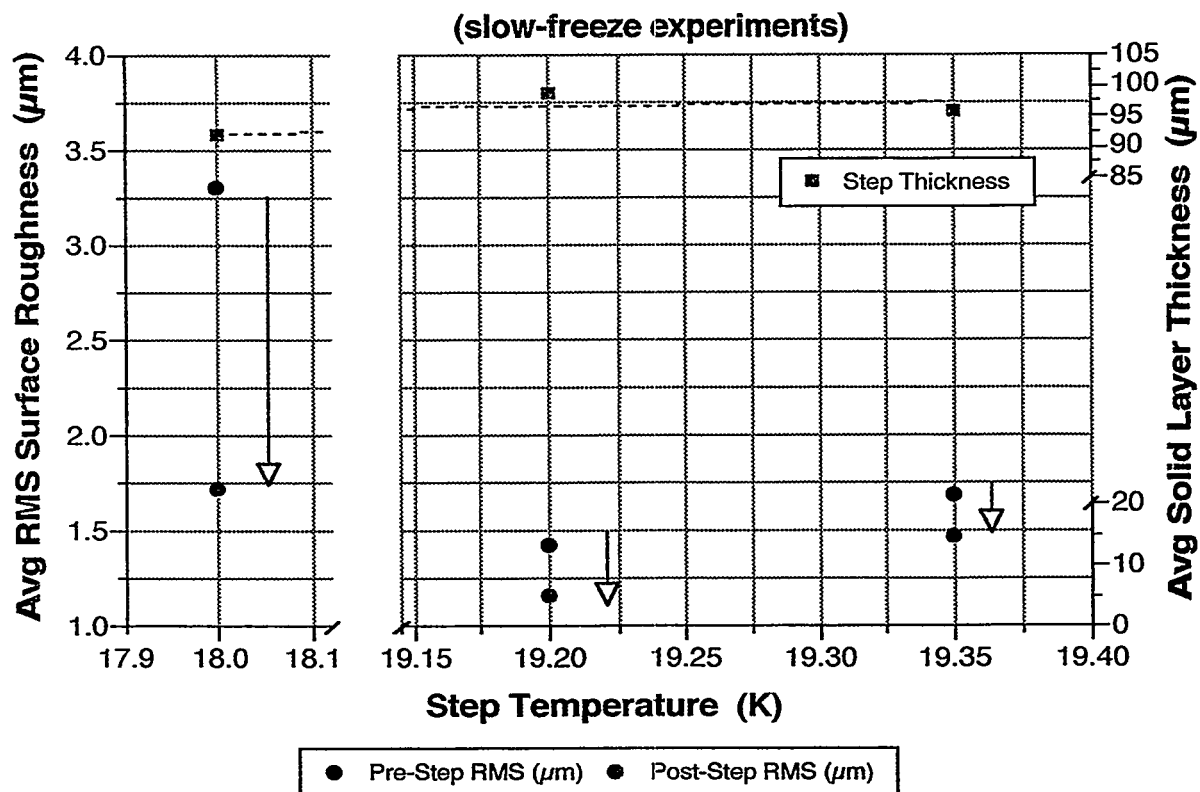
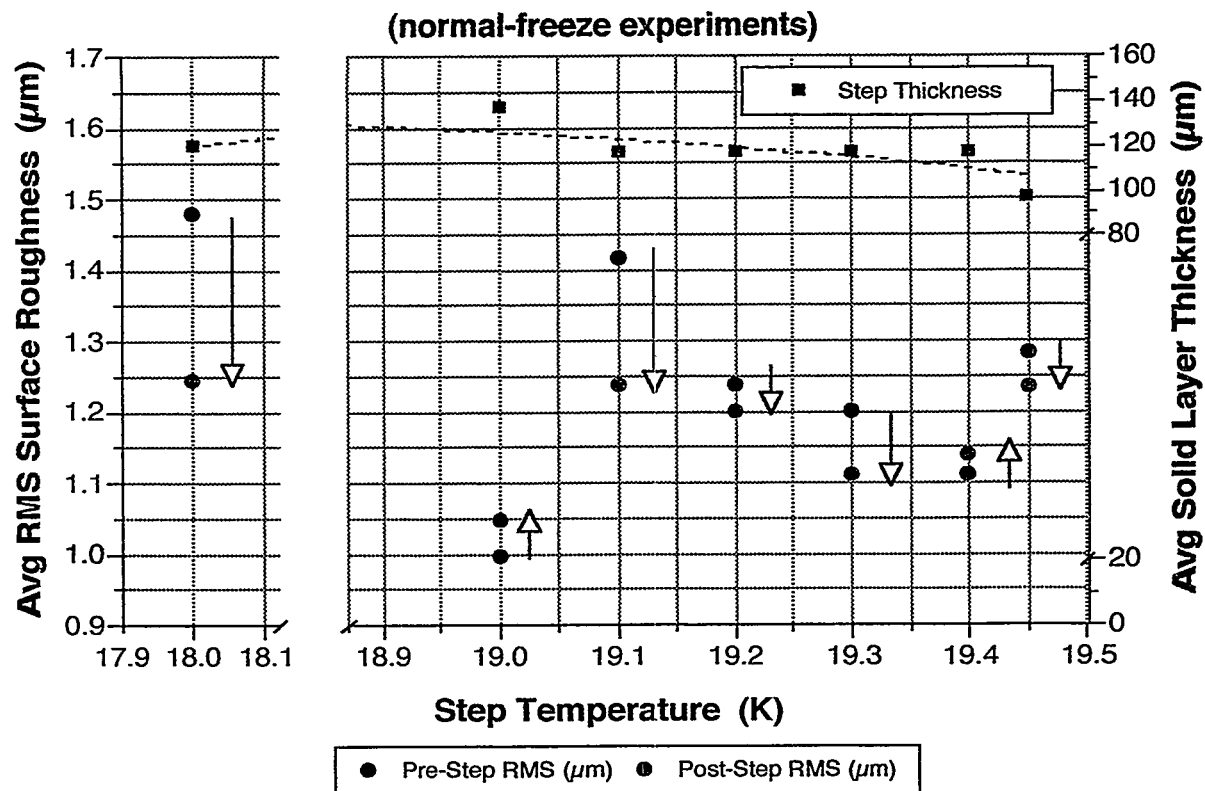
(normal-freeze experiments)



(slow-freeze experiments)



Effects of Sudden Temperature Changes on Equilibrated D-T Solid Layer Inside 2 mm Beryllium Torus



Conclusions

- Equilibrated surface roughness for normal freeze/thaw cycling at 19.0 K averaged $1.3 \pm 0.3 \mu\text{m}$, with a low value of $0.81 \mu\text{m}$
- Temperature stepping consistently produces a final layer as smooth as, or smoother than the initial equilibrated D-T solid layer
- Slow-freezing generally resulted in rougher D-T solid layers; but temperature stepping reduced roughness close to that observed in normal freeze experiments
- Residual layer roughness resulted from l - modes 60 and below, although very rough layers were smoothed by reducing l - modes 20 and below

7



Thermal Simulations of a Cryogenic Indirect Driven Target

Ph. BACLET - S CHARTON

TFM 98, 18-23 April 1998, Jackson Hole

U.A. DRACINOS
Laboratoire Micro-cibles



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simiac3.ppt



SUMMARY

1 / Introduction

2 / 3 D Thermal modelisation

3 / First order optimization : more than 10, or several tens of mK

- thermal shield.
- Convecting effect of the gaz in the holraum.

4 / Second order optimization : less than 1mK.

- Variable thickness hohlraum
- Sapphire rings position.

5 / Conclusion

U.A. DRACINOS
Laboratoire Micro-cibles



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sunjac3.ppt



Geometry

Hohlraum

- gold
- 6mm diameter - 10mm long
- thickness : constant 50 μ m or varying 15-75 μ m
- filling gas : low pressure helium (no convection)
- windows : 4000 Å polyimide film- diameter 3mm

Cooling system

- Al₂O₃ rings : 8mm OD
- distance from hohlraum center : 6 - 8mm
- Al₂O₃ connecting rods 100mm long - 1mm diameter

Capsule

- 2mm diameter
- 200 μ m CH layer - 180 μ m DT uniform layer
- temperature : 19.5 K nominal



Thermal Modeling

3D Mesh

- Mesh generation : CASTEM 2000 (gibiane)
- Finite elements : 6-nodes prisms
4-nodes tetrahedrons
- Total of 55,000 elements for 1/4th of the geometry

Boundary Conditions

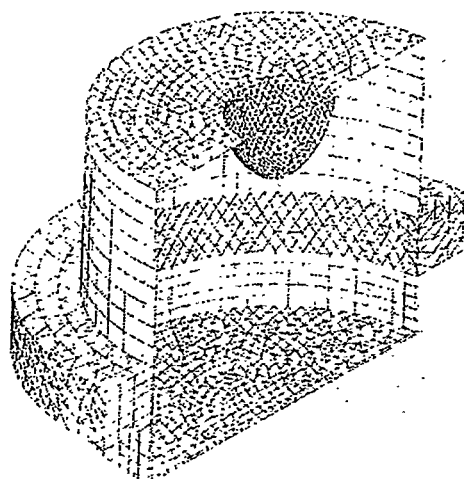
- Black body thermal radiation at 300K, 80K, or
Cryogenic Rod Temperature
- DT ice layer : β -decay heat 0.05 W/cm³
- Fixed temp. at the bottom of the cryogenic rods

Finite Element Solver

- THERMX 96
- Steady-state resolution
- Non-linear diffusion equation
- Cholesky decomposition algorithm



3D mesh



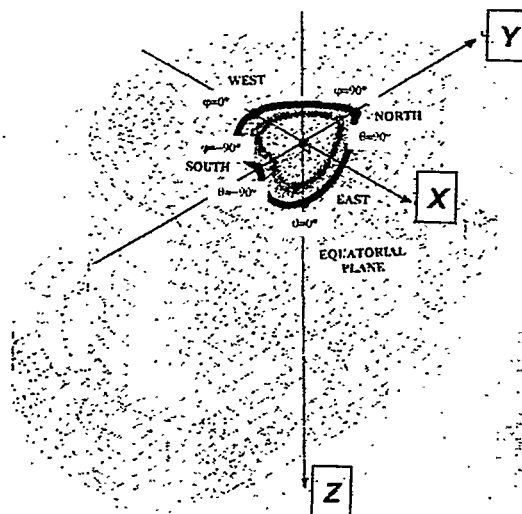
cryogenic hohlraum with sapphire rings

10 cm sapphire rod

cryogenic hohlraum with sapphire rings, and sapphire rod:



Description of the thermal gradients

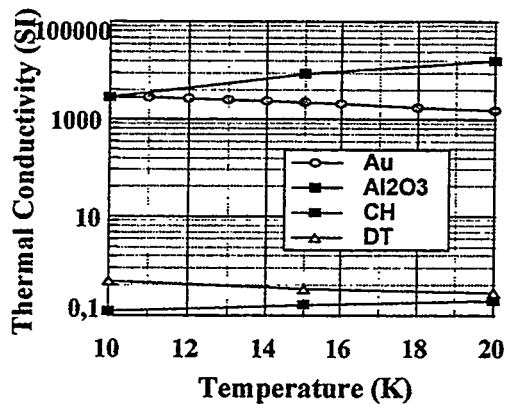




Materials Properties

Y.S. Touloukian and D.T. DeWitt,
Thermophysical Properties of Matter, 1970

Thermal Conductivities



Total Hemispherical Emissivities

Gold : 0.05

Al₂O₃ : 0.07

Polyimide : 0.4

extrapolated values
measurements planned

VA/DRMOS
Laboratoire Micro-cibles

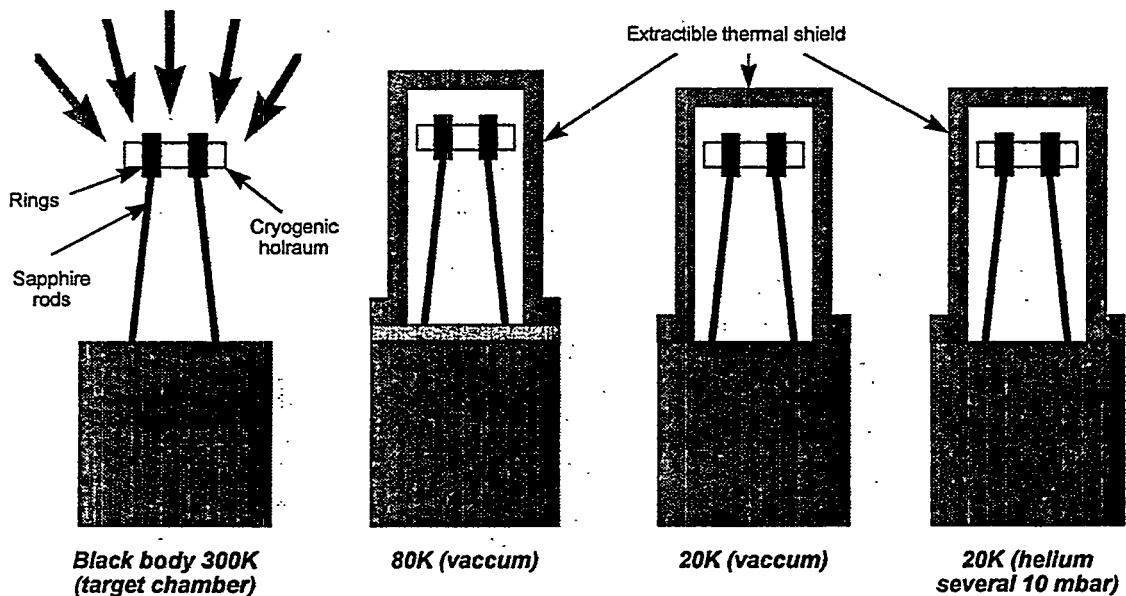


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simjac3.ppt



Different configurations of thermal shield for cryogenic indirect drive target

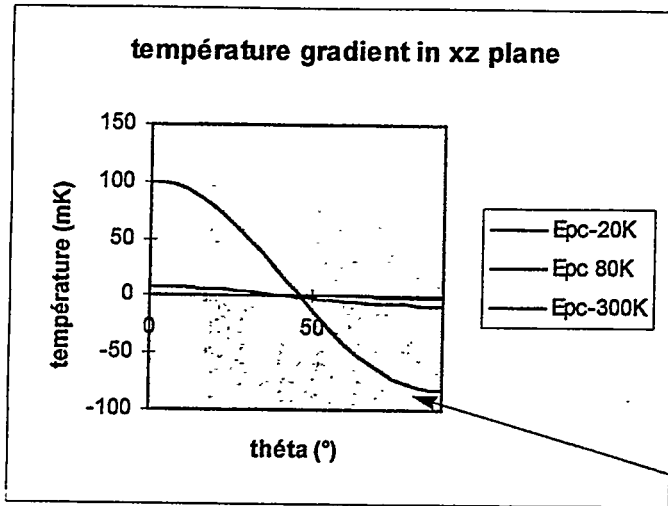


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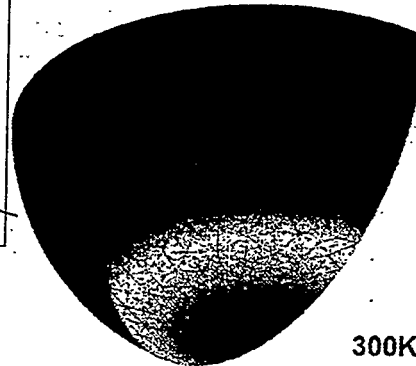


Around the PS shell :

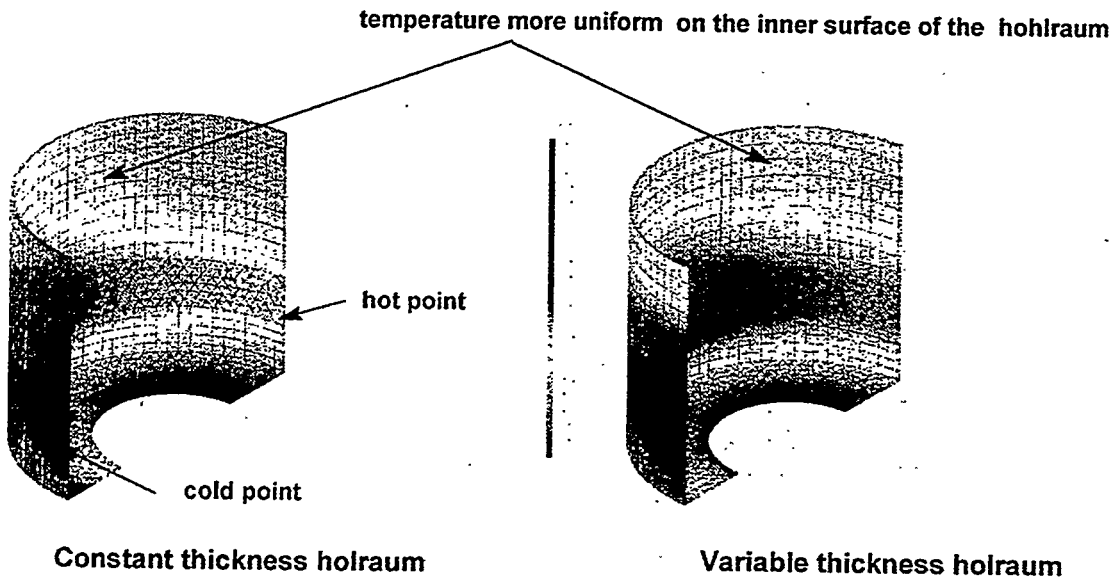
$$\Delta T_{xz} (300k) = 182.3 \text{ mK}$$

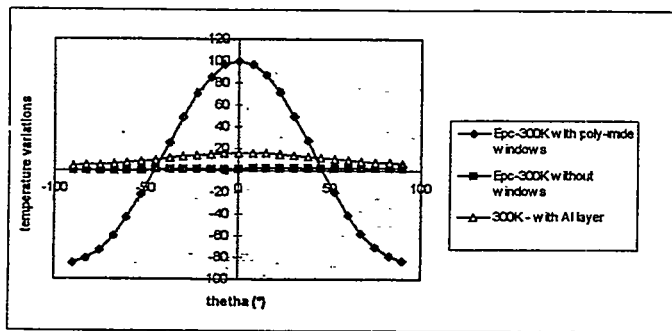
$$\Delta T_{xz} (80k) = 15.6 \text{ mK}$$

$$\Delta T_{xz} (20k) = 0.82 \text{ mK}$$



Influence of variable thickness hohlraum





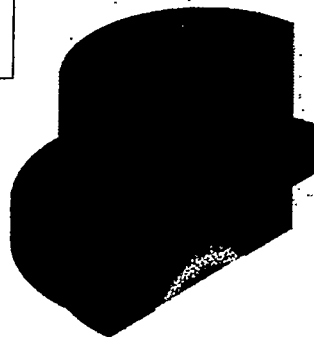
y-z plane

Great influence of Al coating

$$\Delta T_{xz} \text{ (without windows)} = 2.7 \text{ mK}$$

$$\Delta T_{xz} \text{ (with A/CHON windows)} = 10.5 \text{ mK}$$

$$\Delta T_{xz} \text{ (with CHON windows)} = 183 \text{ mK}$$



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L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

simjac1.ppt



Compatibility between implosion Physics and thermics of the cryogenic target

* Implosion Physics (gas hohlraum) : (50% He/H₂)

- Minimal pressure to avoid the expansion of gold plasma
- Maximal pressure to minimize the development of plasma instabilities

about 1 bar He/H₂ (20K)

* Thermics of the target:

- Low pressure inside the hohlraum to avoid convection
- Pure conduction desired.

several 10 de mbars He/H₂ (20K)

* Filling of the hohlraum :

- Low pressure with the target in the middle of the laser chamber.
- Increase the pressure several seconds before the laser shot

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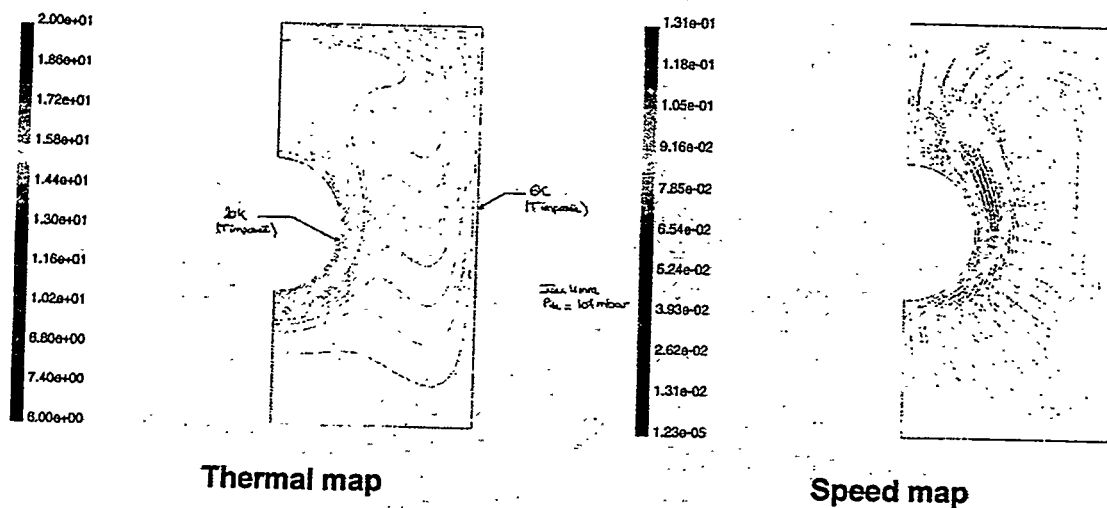


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simjac6.ppt



First results for convection effects



V.A. DRONIMOS
Laboratoire Micro-cibles



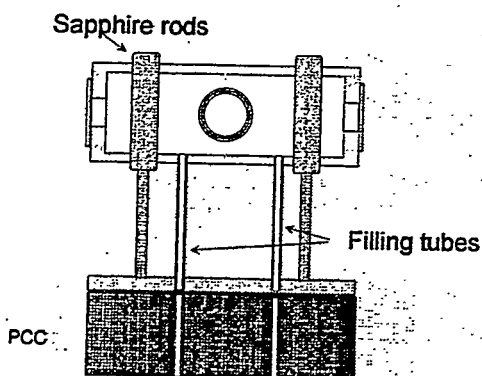
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

simjac6.ppt

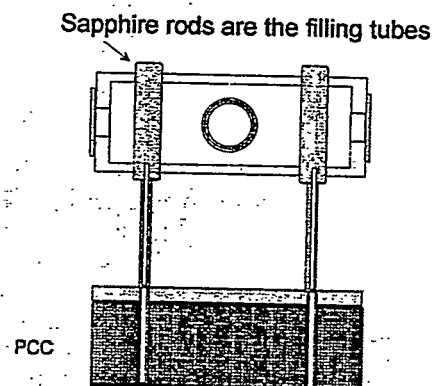


Compatibility between implosion Physics and thermics of the cryogenic target

First option



Second option



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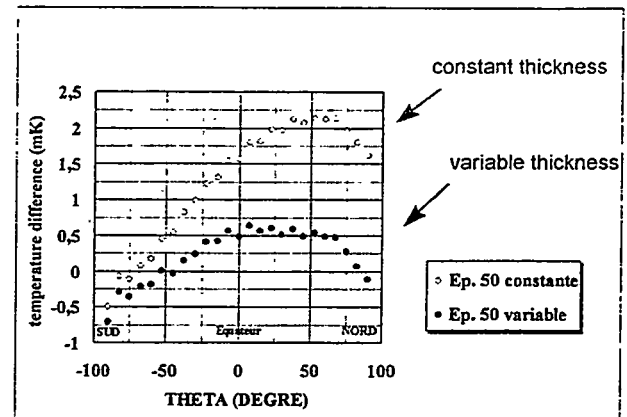
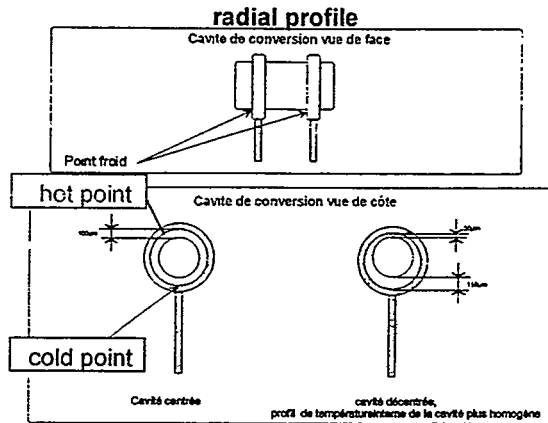


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Temperature variations in the y-z plane for radial variable thickness holhraum



Constant thickness : 50µm >> $\Delta T = 2.65$ mK
Variable thickness : 20µm -70µm >> $\Delta T = 1.3$ mK

Radial profile improve the uniformity for 300K configuration only
(with polyimide aluminium layer)

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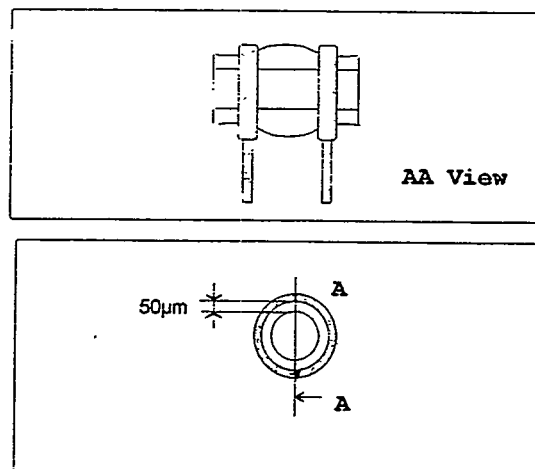
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

vinyac2.ppt slmyac.ppt

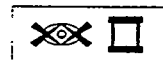


Variable thickness hohlraum : longitudinal profile

- Second order optimization : below than 1mK for the homogeneity on the outer shell surface
- Must be compared to optimization of rods position.
- Make the temperature on the inner surface of the holraum hotter in the middle.



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Laboratoire Micro-cibles



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vinyac2.ppt



Conclusions



* **Specification** : homogeneity of temperature on the outer surface of the PS shell better than 0.2mK.

* **First order variations** : several 10 of mK

- Thermal shield :

+ 300K : 180mK :

. Not consistent with the specification

. Evaluation of aluminium layer to reflect the black body radiation of the chamber

+ 80 K : 16mK

. Not consistent with the specification

. No specific advantage

+ 20K (conduction through sapphire rods) : 1.5mK

. Consistent with a first order optimization

. No need of gas (technology more easy)

+ 20K (He) : 1.5mK

- Convection effects : study in progress

* **Second order variations** : below 1mk :

- Variable thickness hohlraum (radial, longitudinal)

- sapphire rods position,...

ARMAMOS
Laboratoire Micro-cibles



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simyaz.f.opt

Neutronics and Activation Analysis for the National Ignition Facility Cryogenic Target Positioner



by

Jeff Latkowski

Jorge Sanchez

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.

NIF operations will be subject to several radiological requirements



- **Individual workers will receive doses ≤ 500 mrem/year**
- **Total occupational dose will be maintained at or below 10 person-rem/year**
- **Target insertion & characterization will be allocated ~ 0.5 person-rem/year**
- **Several subtasks have been identified:**
 - general access at the target chamber
 - nosecone/foam removal
 - general inspection & seal replacement
 - target installation, cryogen fill, pump down, and layering

Time-Motion studies have been completed



<u>Subtask</u>	<u>Start time after a 20 MJ shot</u>	<u>Duration</u>	<u>Dose Rate Goal (mrem/hour)</u>	<u>Contributors</u>
General access at the target chamber	5 days	6 person-hr	1.25	TB equipment & cryostat
Nosecone/foam removal	6 days	0.5 person-hr	0.33	Cryostat, foam, & nosecone
General inspection & seal replacement	14/30 days	4 person-hr	0.04	Cryostat
Target installation, cryogen fill, pump down, & layering	14/30 days	12 person-hr	0.04	Cryostat

The above subtasks would result in an occupational dose of 0.3 person-rem/year

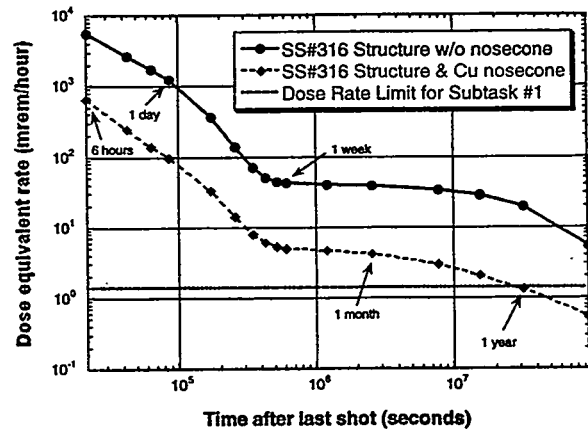
NIF-xxxxxx
JFL 4/22/1998

4

Neutron activation will prohibit use of traditional materials



- Without shielding nosecone, use of SS #316 would result in dose rates that would prohibit routine access to the transport cryostat for unacceptably long times (several years)
- With copper nosecone, routine access would still be impossible for 1 year
- Dose rates only include contributions from nosecone, transport cryostat, and foam



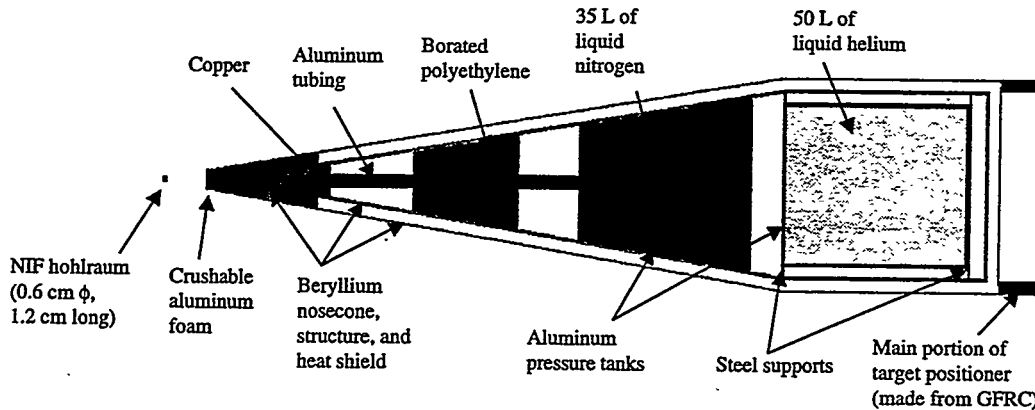
NIF-xxxxxx
JFL 4/22/1998

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The cryostat will combine features that result in a low-activation design



- Design utilizes a borated polyethylene insert (25 cm long)
- Cryogen tanks could be made from an aluminum alloy
- Beryllium structure may need to be coated with $\sim 1\text{-}10\text{ }\mu\text{m}$ of Ni, Cr, or Al to deal with x-rays and unconverted light



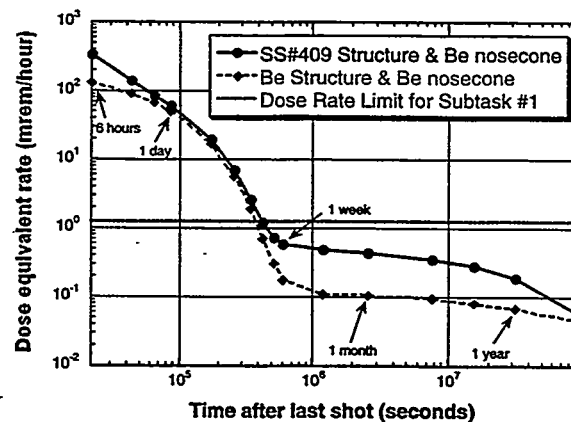
NIF-xxxxxx
JFL 4/22/1998

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With a Be nosecone and structure, the cryostat dose rates would nearly meet the limits



- At 5 days after a 20 MJ shot, other equipment would contribute 1.17 mrem/hr* to the 0.15 mrem/hr from the transport cryostat**
- By $t=6$ days, dose rate has fallen to 0.30 mrem/hr (worker is only exposed to the cryostat & foam)
- At 30 days, dose rate exceeds 0.04 mrem/hr goal by $2\times$, but is dominated by Cu tubing (conservatively estimated 1 kg)



* Assumes that the polyethylene plug is implemented to reduce activation of the Final Optics Assemblies

** Assumes that a shielding cover is placed over the aluminum foam

NIF-xxxxxx
JFL 4/22/1998

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ES&H issues related to the use of beryllium



- Beryllium is hazard when it is in a particulate form that may be inhaled (3-4% of the population is allergic to Be)
- According to LLNL policy, an Operational of Facility Safety Procedure would be required as the possibility of generating Be particulates
- The crushable aluminum foam is intended to reduce the shock imparted to the target positioner
 - the foam will also “shadow shield” the nosecone from soft target x-rays, which may ablate beryllium
 - depending upon the temporal and spatial emission of the x-rays, the foam may need to be enlarged/supplemented to ensure that beryllium is not ablated (see *Considerations for the Preliminary Design of the NIF Target Insertion Cryostat* by Pittenger, et al. at this meeting)

NIF-xxxxxx
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Conclusions and future work



- Due to neutron activation, traditional structural and cryogenic materials may only be used sparingly in the NIF transport cryostat
- By using a beryllium nosecone & structure, residual dose rates may be decreased to acceptable levels (dose would be 0.56 person-rem/yr)
 - quantity of copper tubing should be minimized
 - steel supports for the cryogen tanks should be reduced/eliminated
- The ES&H issues related to the use of beryllium need to be fully addressed

NIF-xxxxxx
JFL 4/22/1998

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**Charles D. Hendricks, Thom Bahrs, Sue Carter, Scott Faulk,
Earl Hodges, Ed Hsieh, Brian Motta, Katie Strube, Tom Walsh**
Schafer Corporation
303 Lindbergh Avenue
Livermore, California 94550

We present here the evolution of NIKE LASER targets, not as physics design changes, but from the fabrication point of view. The evolutionary modifications of the laser target designs are, of course, dictated by the physics to be studied in the irradiation experiments. The physical realization and production of the targets falls to us as target fabrication specialists.

In FY93, at Schafer Corporation, we began to work seriously on the production of targets for the Naval Research Laboratory (NRL) NIKE Laser Program. Initially, the targets were flat, smooth films to be made from a pure CH polymeric material. The mounts on which the target foils were to be supported went through several iterations before a final design was produced. The physical dimensions of the foils, diagnostic considerations, mechanical stability and, of course, convenience of insertion into the NIKE target chamber were important considerations in the target mount designs. An initial version of the target mount is shown in Fig. 1 and in Fig. 2 we see the current canonical NIKE flat film target mount.

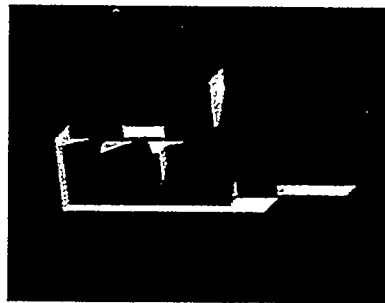


Fig. 2

SMOOTH, FLAT TARGET FOILS

SMOOTH, THIN, SINGLE FILM TARGETS

- Surface morphology: P-V roughness <100Å
Film curvature: 4 μm / mm
Volume quality: Mass integral < Equivalent surface variations

Fig. 4 Double film target

SMOOTH, FLAT, DOUBLE FILM TARGETS

- Surface morphology, film curvature and volume quality are the same as those for single smooth film targets
- Films must be parallel to within 0.5% (to within 1/4 degree)

To provide targets with well-characterized, known wavelength and amplitude surface patterns for Rayleigh-Taylor experiments, we began producing flat foil targets with $\sin(x)$

5

patterns on one face of the foil and a surface as smooth and flat as possible on the opposite face. A schematic diagram of a $\sin(x)$ foil is shown in Fig. 5. Other required characteristics of the foils are not changed. That is, the foil curvature, volume quality, and material uniformity requirements continued as for flat, smooth foils. Other surface patterns were also generated for Nike experiments and included "step-ramp" functions to provide a square edge which can be Fourier analyzed into a series of harmonic functions

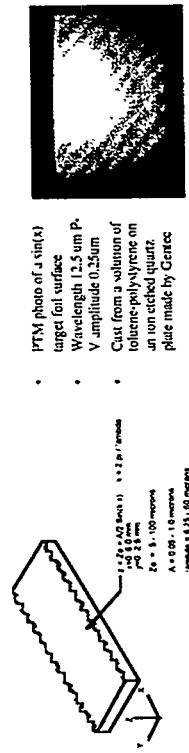


Fig. 5 Sin (x) target diagram

with broad wavelength and amplitude ranges. Figure 6 shows a PTM photograph of the surface of a film with a $\sin(x)$ pattern on one surface.

MODIFIED SURFACE AND VOLUME QUALITY SPECIFICATIONS

As the NIKE laser pulses were studied and the exceptionally high spatial quality of the wavefronts became apparent, it was recognized that higher quality targets could lead to better experimental results. Consequently, modifications were made in the target foil specifications. The critical changes in foil characteristics for NIKE targets as of 1998 are:

SMOOTH, THIN, SINGLE FILM TARGETS

- Surface morphology: P-V roughness < 50Å
- Film curvature: 1 μ m / mm
- Volume quality: Mass integral < Equivalent surface variations

Permissible surface roughness has changed from ten nanometers to five nanometers peak-to-valley and the foil curvature permitted has changed from four microns/mm to one micron/mm. Volume quality specifications changed to match the equivalent surface variations specifications.

MORE COMPLEX TARGET TYPES

As the targets became more complex, they also became more challenging to produce. Because they consist of several individual parts, the production of the parts themselves has its own unique set of difficulties. Figure 7 shows a series of targets designed to study

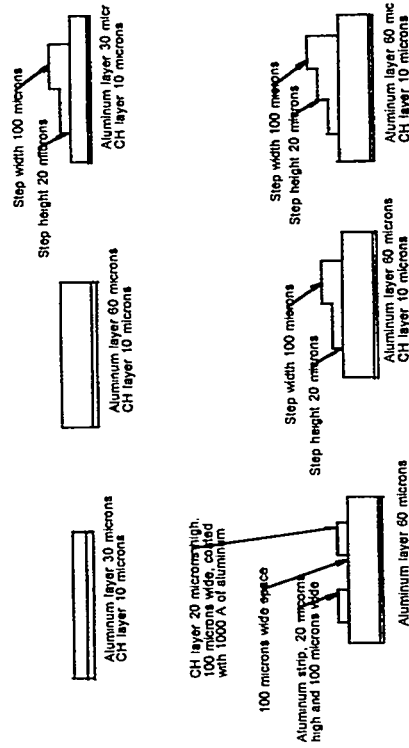


Fig. 7 Shock and material physics targets

various physics issues including shock propagation in the target materials. Even some of the smooth, flat foil targets became more difficult to produce. Requests came for polymer foils doped with high percentages of materials such as tungsten. Layers of aluminum and gold on the polymer foils became commonplace. The added layers ranged from ten nanometers to tens of microns. Some of the thin films of aluminum, for example, were applied by thermal evaporation from an aluminum coated tungsten filament in a vacuum. Thick aluminum and tungsten layers on a polymer film were made by applying the metal films onto the polymers which were still tacky after being cast.

One of the most difficult problems to solve has been the tendency of composite films to curl because of film shrinkage after casting or because of oxidation, thermal changes, or water vapor absorption with time after the films are formed. Thermal annealing of simple films can alleviate some warpage problems. However, thermal annealing of a multilayer foil of tungsten and polystyrene layers is difficult if not totally impossible because of the differing coefficients of thermal expansion.

CRYOGENIC TARGETS AND THEIR PRECURSORS

It was inevitable that we would become involved in the production of the parts and assembly of complete cryogenic targets for NIKE experiments. The base of the cryo targets is called a TFP -- Target Front Plate. These parts are made for us by Micro Machining & Mfg in Scotts Valley, California. Figure 8 shows a computer rendition of the TFP as received from the supplier.

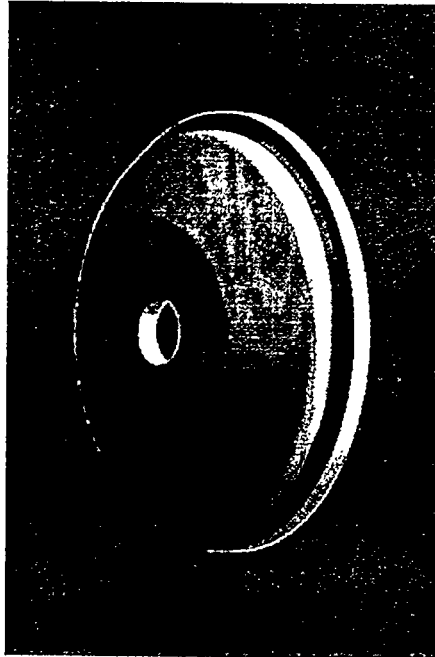
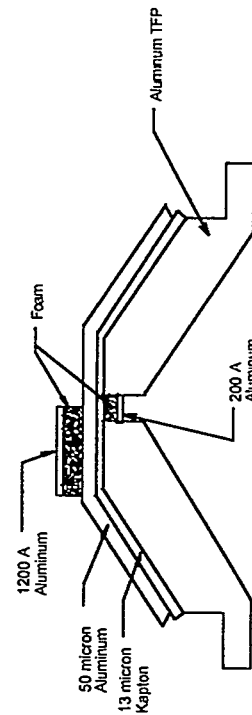


Fig. 8 A computer rendition of an aluminum Target Front Plate

Figure 9 is a diagram of one version of a complete cryo target. The assembly of a NIKE cryo target of this type is difficult and often frustrating and disappointing. The first step is the



NRL Cryo-target
(Several versions, each slightly different)

Fig. 9.

application of a stretched layer of polyimide (Kapton) to the pedestal of the TFP. The laser beam irradiates the target through the 1.5 mm diameter hole from the hollow cone side of the target. Kapton film (1.5 microns to 13 microns thick) is stretched over the pedestal (as shown in Fig. 10) after a thin layer of "3 minute" epoxy is spread over the outside conical surface. When the epoxy cement has cured sufficiently, a layer of aluminum foil is stretched over the Kapton and another layer of epoxy cement. In this particular design, the

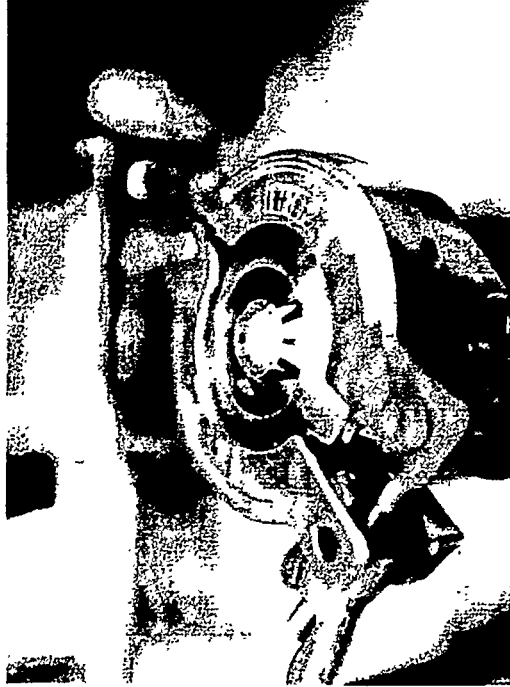


Fig. 10 Initial assembly steps in fabrication of a target as shown in Fig. 9

aluminum foil is nominally 60 microns thick as it is attached and is subsequently diamond turned to a thickness of 50 or 40 microns depending on the particular target design. The upper low density RF foam, about 100 microns thick and aluminized (120 nanometers thick) on one surface, is attached to the aluminum film. The foam is machined into a strip one mm wide which ends at the mid-line of the 1.5 mm hole in the TFP. Another piece of RF foam is to be inserted into the laser side of the 1.5 mm hole, cemented in place and coated with 20 nanometers of aluminum.

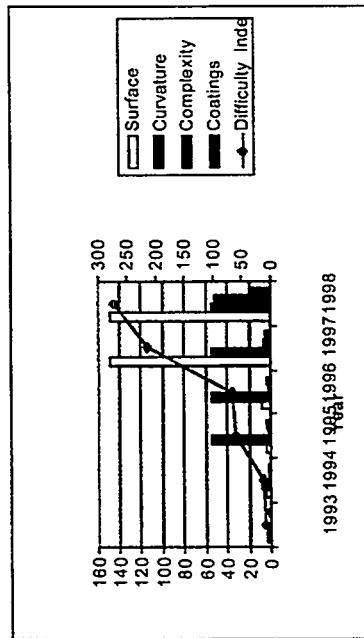
John Sethian (NRL) has developed many of the techniques we use to assemble these targets and Milt Rebbert (NRL) and Diana Schroen-Carey (Schafer) have been our primary foam suppliers.

We have recently begun the application of aluminum, gold, and tungsten films of 10, 30, 50, 60 and 100 nanometers to either or both of the Kapton surfaces on the TFPs.

NIKE TARGET FABRICATION DIFFICULTY INDEX

We have put together a phantom number we call the DIFFICULTY INDEX as an indication of how hard it is to put together the various NIKE targets and how the difficulty has changed over the last few years. The low value of the index in the years 1993 and 1994 is certainly in retrospect. It didn't seem that easy at the time! The index is composed of numbers assigned to various aspects of the target fabrication process. The functionality of the various aspects of the target design and specifications of quality was arbitrarily assigned but was consistent throughout the chronology of the NIKE task. Whether or not a change in surface quality required was an exponential function of difficulty or a square or a cube is not

so important as the fact that to achieve a two nanometer surface finish is significantly more difficult than it is to achieve a ten nanometer finish. To assemble six or eight parts into a target is more difficult than to assemble two parts with the same precision. We have just tried, for our own amusement, to see if we could generate a number which reflects the change in difficulty of



500

Fig. 11 Target Assembly Difficulty Index

assembling targets as specifications and complexities of targets are changed. Figure 11 shows our first fumbling efforts to quantize a Target Assembly Difficulty Index. It may not be the first such effort and probably won't be the last but it is an indication that this job doesn't seem to be getting any easier --**BUT WE ALREADY KNEW THAT.**

Overview of Fabrication for the Los Alamos High Energy Density Physics Program

Los Alamos National Laboratory
MST-7 Group
Los Alamos, New Mexico
University of California/DOE/USA

This work is supported by the
U.S. Department of Energy
under contract
number W7405-ENG36

Wally Anderson

Acknowledgements:

Visuals - Mike A. Salazar

MST-7 Precision Machining - Jake Bartos, Fino Armijo, Bob Day, Felix Garcia, Dough Hatch, Matt Martinez, Blaine Randolph, Gerry Rivera, Lee Salzer

MST-7 Target Assembly - Pete Gobby, Harry Bush, Steve Dropinski (Shafer), Norm Elliot, Veronica Gomez, Vivian Gurle, Ruben Manzanares, Joyce Moore, Mike A. Salazar.

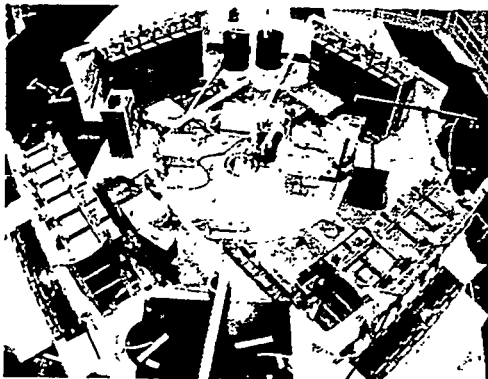
MST-7 Foams - Joe Duke, Matt Bush

MST-7 PVD Coatings - Chris Adams, Gary Reeves, Bob Springer, John Townsend

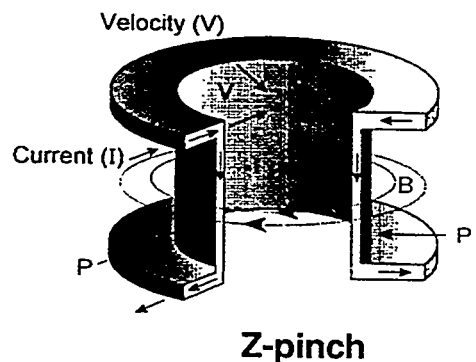
MST-7 Electroplating - Mike Brooks

Los Alamos National Laboratory
MST-7 Group
Los Alamos, New Mexico
University of California/DOE/USA

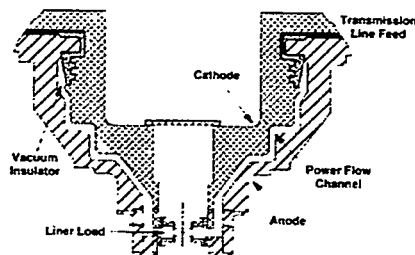
Liner Z-pinch



Pegasus II

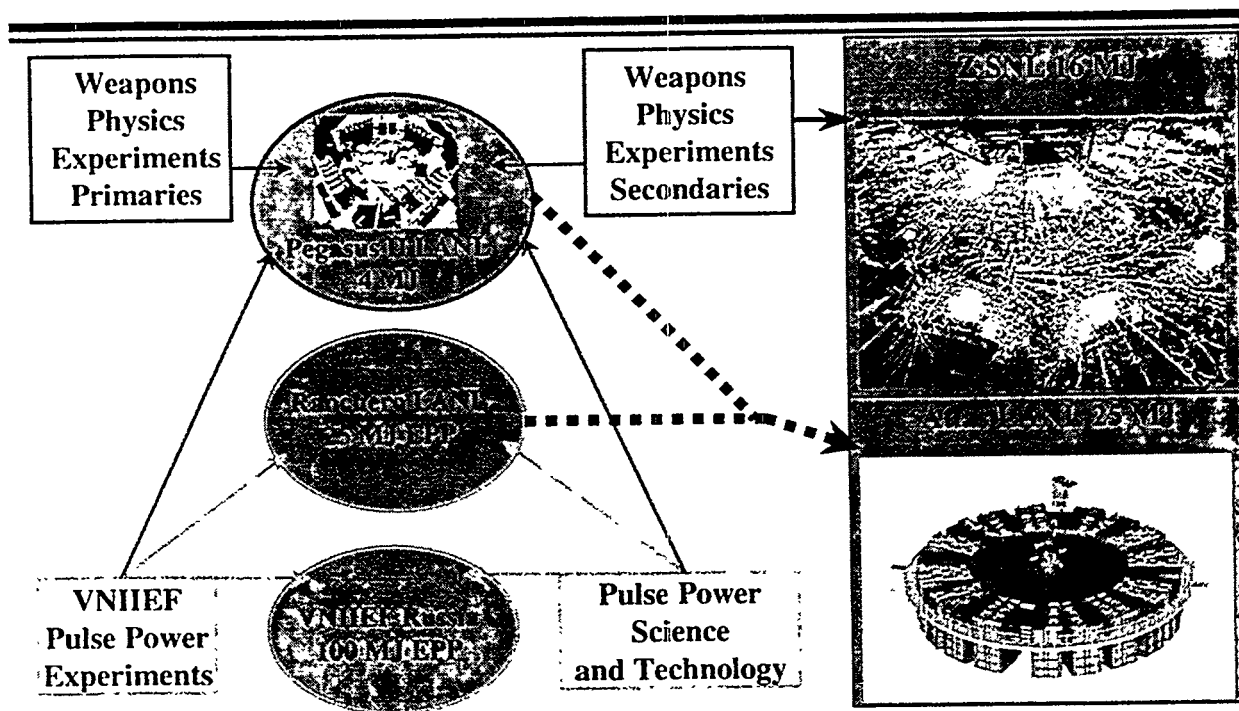


Z-pinch

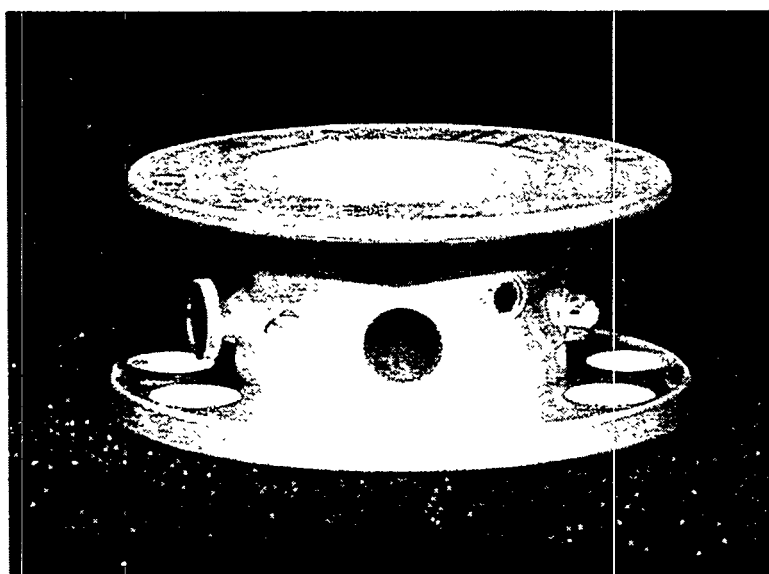


Pegasus Power
Flow Channel

High Energy Density Physics Program

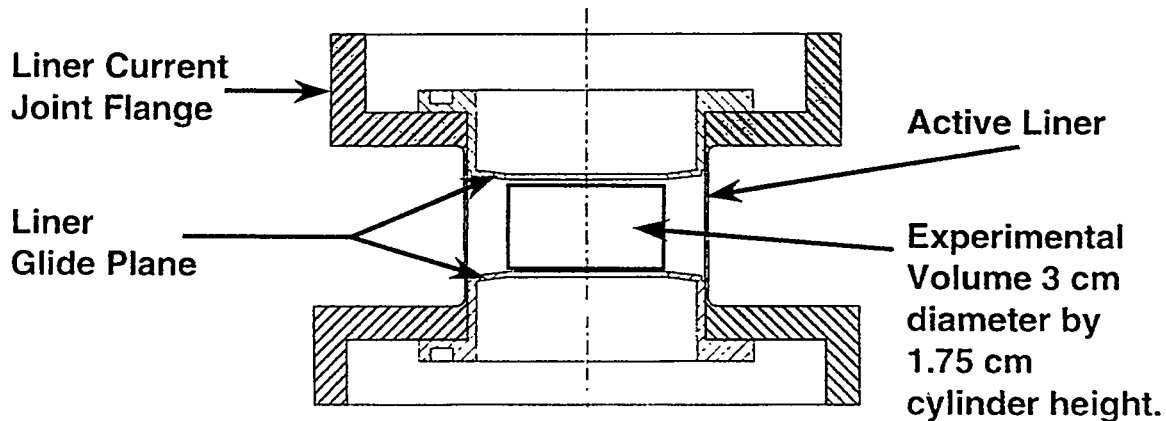


Radiation Driven Physics Experiments Z at SNL



- Electroformed secondary hohlraums and radiation transport tubes.
- Parylene and CH foam tamped aperture experiments.

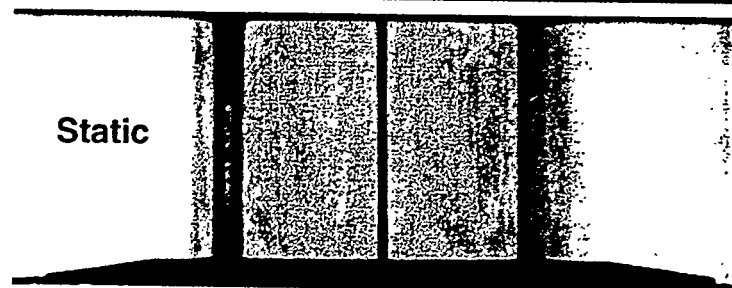
Shock Driven Physics Experiments Pegasus Precision Liner



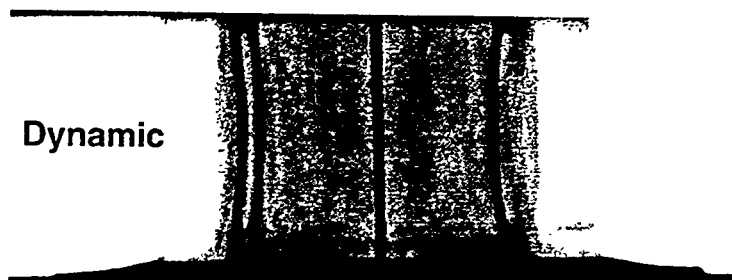
Liner Specifications:

- 4.722 cm i.d.
- 406 μm wall thickness
- 5 μinch rms surface finish

Shock Driven Physics Experiments LLNL-1 Radiograph



- Nominally 0.8 mm diameter wires embedded in 17.5 mm bore holes in Al.
- Wires bend as Al flows dynamically.
- Unexpected features in experiment have resulted in modifications to calculation code physics.



Flash X-ray Source R-2

Flash X-ray Source R-3

Imploding O Liner

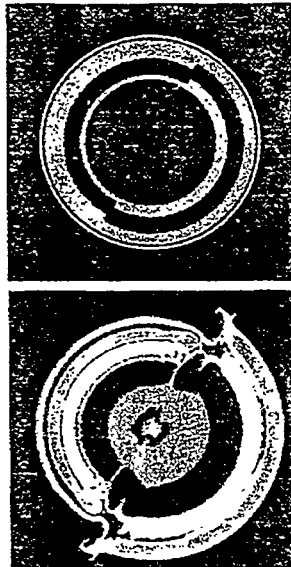
Flash X-ray Source R-1

PEGASUS Top View

Shock Driven Physics Experiments DH Series

Our most recent Pegasus experiments in collaboration with AWE have verified the generation of vorticity predicted by 2D Eulerian calculations

Calculations
Density contours



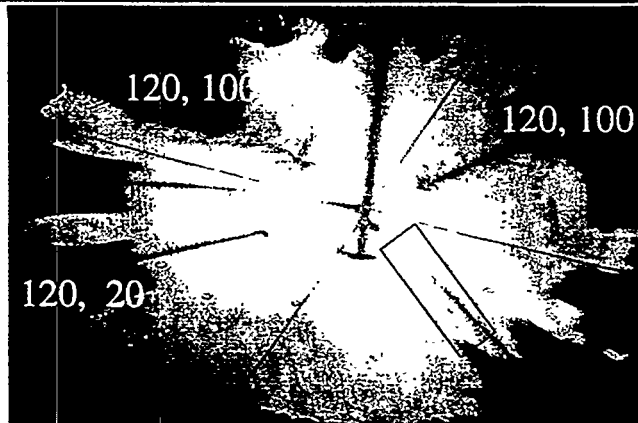
Static

Experimental radiographs

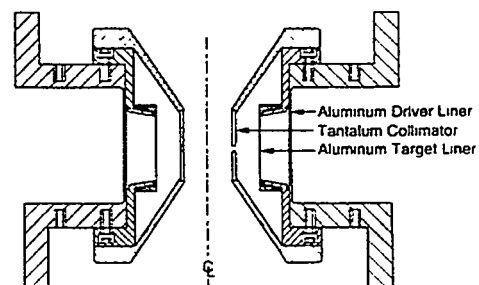
Dynamic
12.3 μ s



Shock Driven Physics Experiments Ejecta



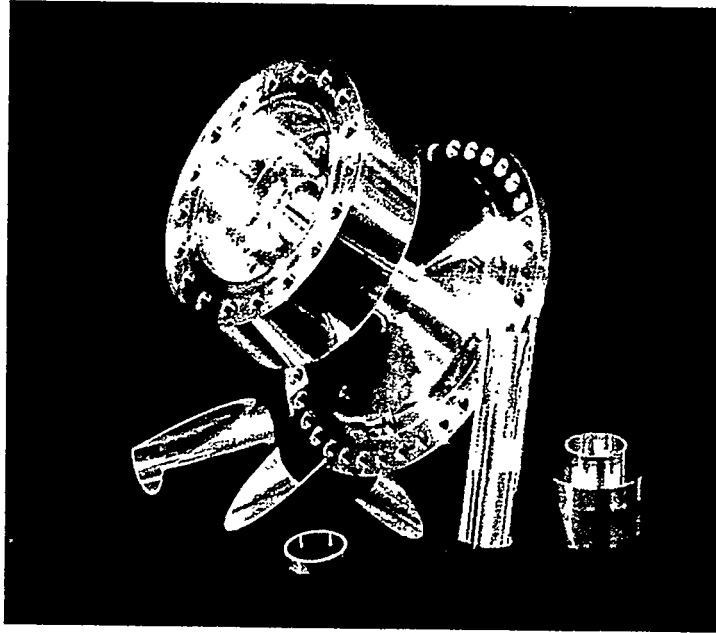
Liner Ejecta Experiment



Axial holography to measure distribution of ejecta from the target liner.
Triple axis x-radiography to measure motion of driver liner.

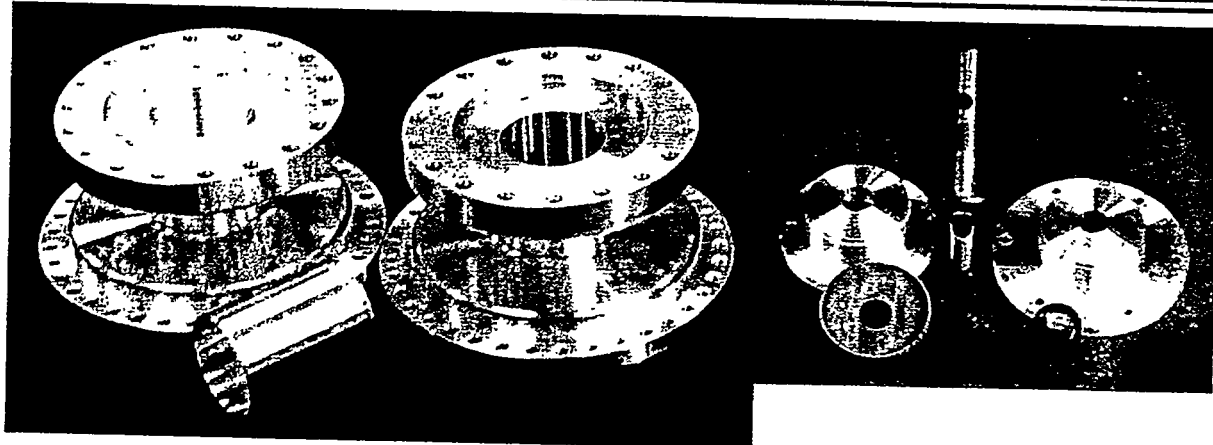
- Axial shadow graph shows ejecta plumes from a Sn surface.
- Ejecta density and velocity are a function of surface finish and features micromachined into the Sn surface.
- Narrow, fast ejecta plumes are from conical voids, cone angle and depth are indicated on shadow graph.
- Low density volume ahead of dense plumes can be analyzed holographically for ejecta particle size distributions, inset box is an example of a candidate region.

Special Liners for Physics Experiments Composite Liners for RT&E Mix Experiment



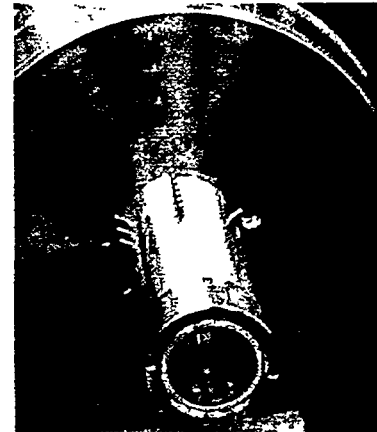
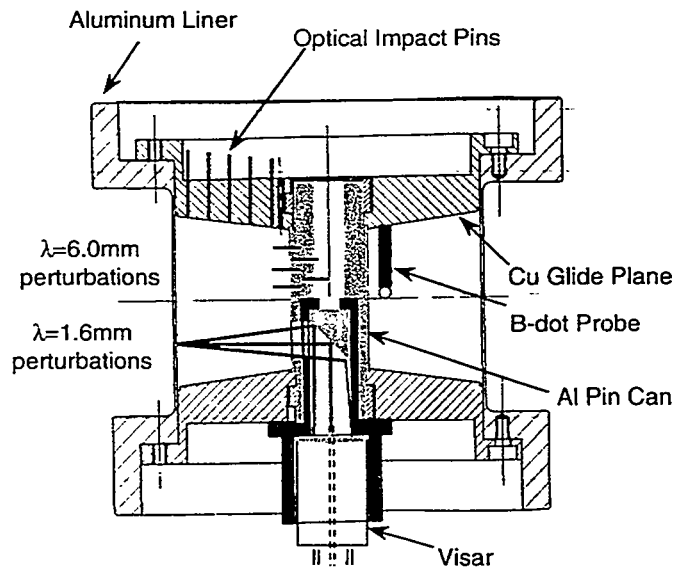
- 200 μm thick Cu impactor in 800 μm thick Al liner.
- Liner and impactor cylinders machined with excess wall thickness and for interference fit interface at thermal equilibrium.
- Liner surfaces finished after impactor insertion.
- Sinusoidal perturbations machined into surface of RT&E Mix-2 Cu impactor.

Special Liners for Physics Experiments Composite Liners for High Strain Rate (HSR) Experiments



- 400 μm thick Al 6061T6 impactor in 700 μm thick 1100 Al liner.
- Liner and impactor cylinders machined with excess wall thickness and for interference fit interface at thermal equilibrium.
- Liner surfaces finished after impactor insertion.

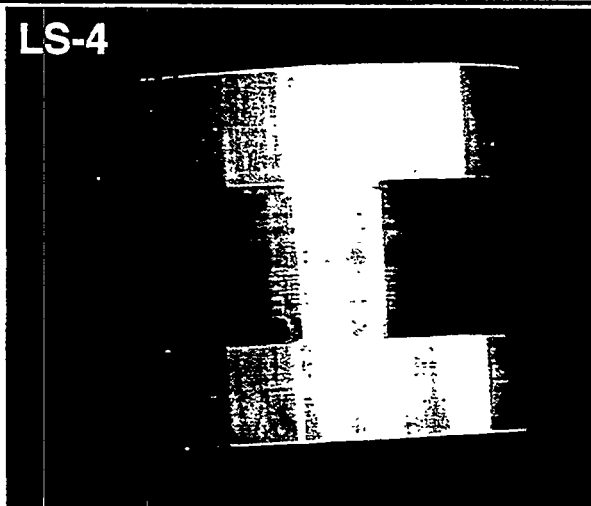
Pulse Power Science and Technology Liner Performance Measurements



- Axial and Radial X-radiography
- Optical Impact Pins
- Visar
- B-dot Probe
- Diamond Raman
- Ruby Fluorescence
- Foil Strain Gauge

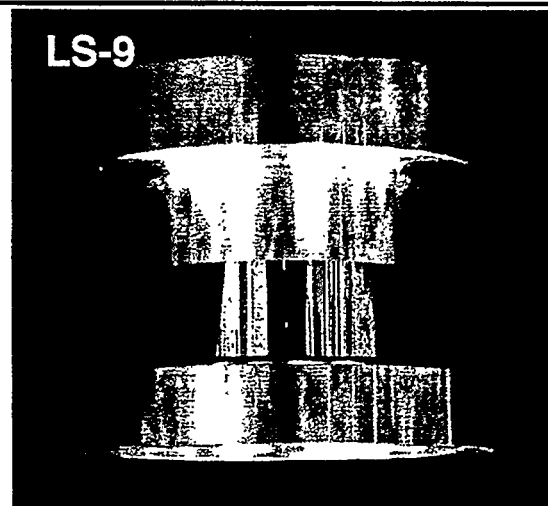
Pulse Power Science and Technology Machined Perturbations for Liner Stability Experiments

LS-4



- 5 μinch rms surface finish
- 2 mm wavelength, 100 μm peak to valley sinusoid

LS-9



- 44 μinch rms surface finish
- 0.7 μinch rms surface finish, diamond turned

Pulse Power Science and Technology Machined Perturbations LS-6 & LS-9 Radial Radiographs

Los Alamos National Laboratory
MST-7 Group
Los Alamos, New Mexico
University of California/DOE/USA



Static
LS-6



7.50 μ s



8.25 μ s



9.00 μ s

- Top: 2 mm wavelength, 25 μ m p-v amplitude
- Bottom: 0.5 mm wavelength, 25 μ m p-v amplitude



Static
LS-9



8.90 ms



9.61 ms

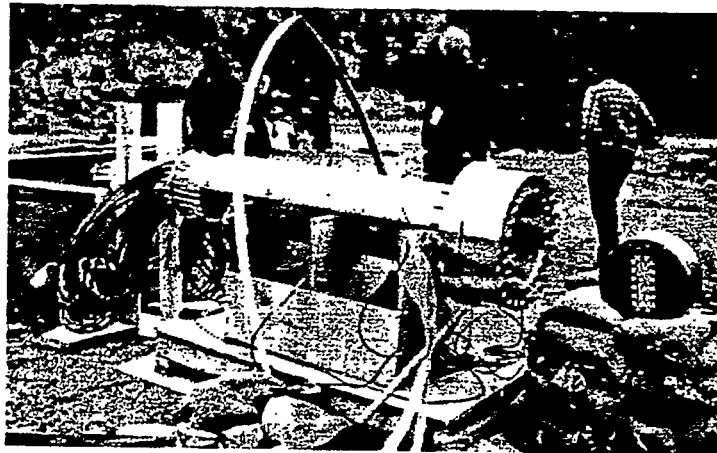


10.82 ms

- Top: 44 μ inch rms surface finish
- Bottom: 0.7 μ inch rms surface finish, diamond turned

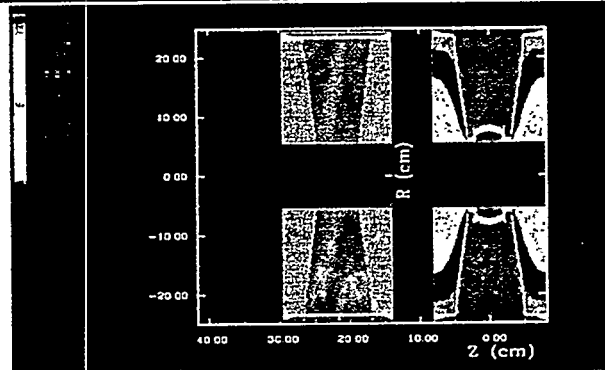
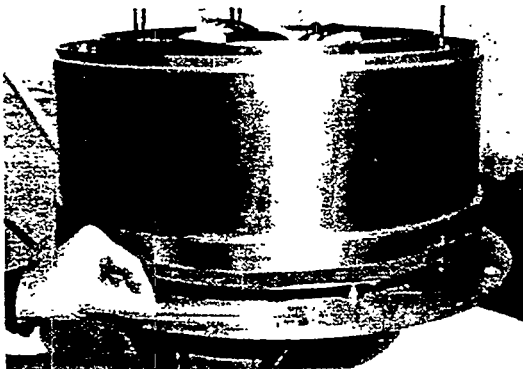
Pulse Power Science and Technology Ranchero Explosive Pulse Power Driver

Los Alamos National Laboratory
MST-7 Group
Los Alamos, New Mexico
University of California/DOE/USA



- Shown in 25 MJ, 25MA configuration without liner power flow channel or pulse shaping elements.
- Atlas liner design verification experiments in FY-98.
- Basic Atlas radiography design verification in FY-98.
- Weapons physics experiments at Atlas parameters in FY-99.

Pulse Power Science and Technology VNIIEF High Energy Liner HEL-1



- 48 cm o.d by 10 cm cylinder height liner, 4 mm wall thickness.
- 1 kg liner of a Russian Aluminum alloy, fabricated by VNIIEF.
- False color image calculations by LANL group X-PA, courtesy R. Faehl.
- Both Los Alamos and VNIIEF diagnostics agreed with the calculated dynamic performance.
- Liner motion was not perfect but indicated an Al liner in a 100 MJ system can remain intact. This is 4x to 5x the energy of available US drivers.

Conclusions

- MST-7 has a five year history of fabricating solid liner driven Weapons Physics Experiments and Pulse Power Technology Experiments for the Los Alamos 4 MJ Pegasus II driver in support of the SBSS Laboratory Mission.
- Program transitions toward the 25 MJ Atlas facility under construction at Los Alamos have begun.
- Radiation driven Los Alamos HEDP Program pulse power experiments are now done at the Sandia Albuquerque Z facility.
- The Los Alamos Ranchero explosively driven pulse power generator will be used first to verify Atlas liner design and dynamics, and then for preliminary Atlas weapons physics experiments.

Modeling of the emulsion process to make uniform ICF capsules

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Presented at Target Fabrication Meeting 98
April 20-23, 1998
Jackson, WY, USA

Abstract



ILE, Osaka

In the emulsion method with a stirring propeller in the dry process, deformations of emulsions are an important key to make uniform shells. On the other hand, such deformations may leave permanent out-of-roundness after the shell is completed. In order to make high quality shells, it is necessary to understand the process in which a uniform layer is formed.

We formulated the centering force by which a nonuniform compound emulsion turns to be uniform.

We think that the centering force consists of hydrodynamic forces and thermodynamic force based on interfacial surface tension.

Resultant centering force can move the water globule in a compound emulsion to the center before the emulsion lost the fluidity.

What is the centering force?

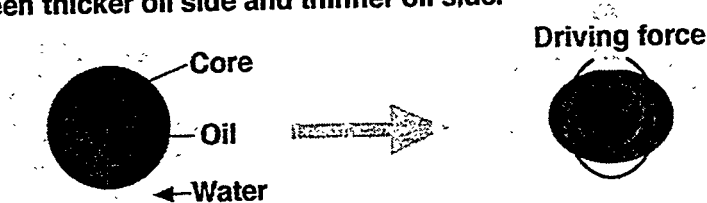


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We consider that the centering force based on the Tayler Wang's process consists of hydrodynamic forces and a thermodynamic force based on the free energy on the inner surface.

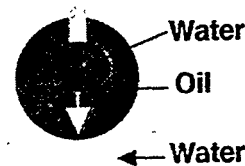
1. Hydrodynamic force

When low frequency vibrational modes are set up in the oil phase, off-set sphere moves to the center. This is due to the pressure difference between thicker oil side and thinner oil side.



2. Thermodynamic force

When an inner water globule is pushed by something, the globule moves due to increase in the free energy (=interfacial tension times surface area) on the inner surface.



Final equation of motion for the water globule



ILE, Osaka

$$\frac{4\pi R_i^3}{3} \left(\rho_w + \frac{R_i^3 + R_o^3/2}{R_o^3 - R_i^3} \rho_o \right) = \text{Inertial} + \text{Buoyancy} + \text{Frictional} + F_{free}$$

$$\begin{aligned} \text{Inertial term} &= \alpha_o \rho_o \frac{R_o^3 - R_i^3}{R_i^3} \left[\left(\frac{AvDt^+}{10^{-4}} \right) V_{o/2}^+ - \left(\frac{AvDt^-}{10^{-4}} \right) V_{o/2}^- \right] \left(\frac{R_i}{R_o} \right)^2 \\ &\quad + \pi \alpha_o \rho_o \frac{R_o^3 + R_i^3}{2R_i^3} \cdot \left(-2x_w R_i^2 + \frac{2}{3} x_w^3 \right) \end{aligned}$$

$$\text{Buoyancy term} = 980(\rho_o - \rho_w) V_w$$

$$\text{Frictional term} = 6\pi \mu_o R_i \left[v_o \left(0.6 + \left(\frac{R_i}{R_o} \right)^2 \right) \frac{AvDt^+ - AvDt^-}{10^{-4}} \frac{R_o^3 - R_i^3}{R_i^3} - v_w \right] \frac{1 + \frac{2\sigma}{3}}{1 + \sigma} K$$

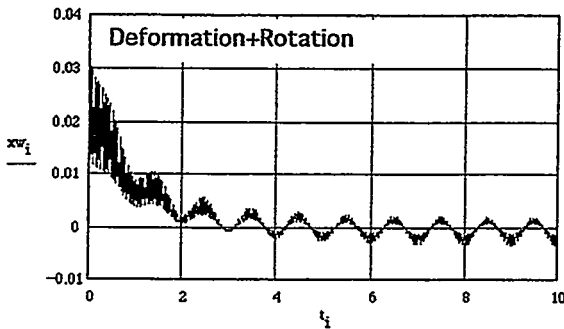
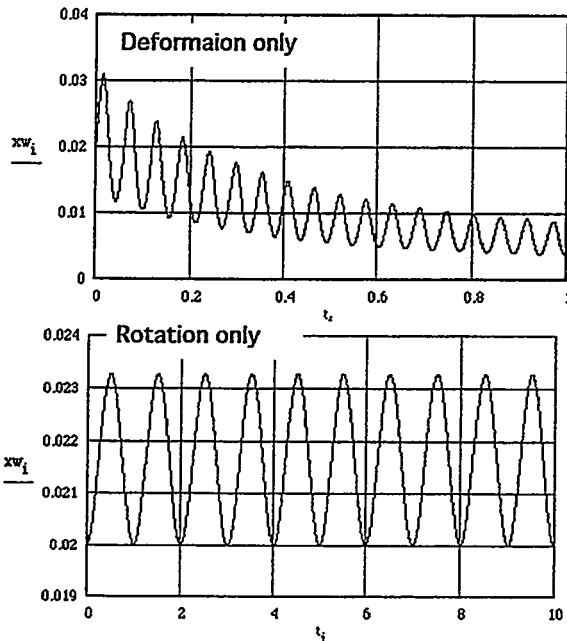
$$\begin{aligned} F_{free} &= \frac{\partial \Delta E_{free}}{\partial x} \\ &= \frac{-4\pi \gamma (30R_i^4 x_w + 40R_i^2 x_w^3 + 6x_w^5)}{R_o^6} \varepsilon_o^2 \end{aligned}$$

With rotation of the emulsion, a water globule moved to the center.



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Even if the centering force is too small to counter balance the gravitational force, a water globule in a rotating emulsion moved to the center.

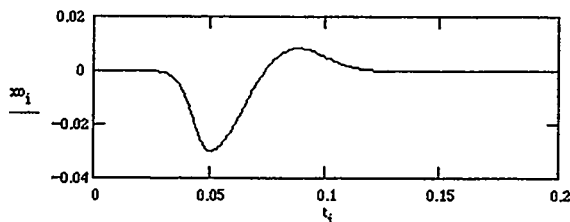


Diameter of shell 6 mm
Deformation frequency 13 Hz
Deformation amplitude 10% of R_0

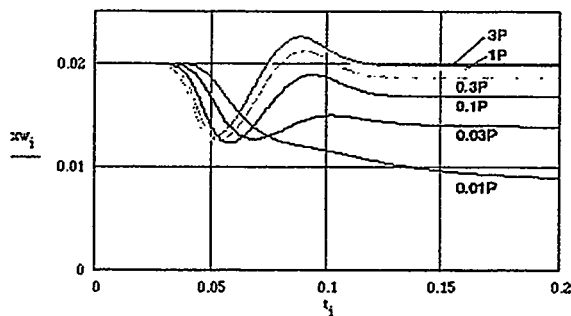
A step induced by pulse deformation strongly depends on the viscosity of the oil phase.



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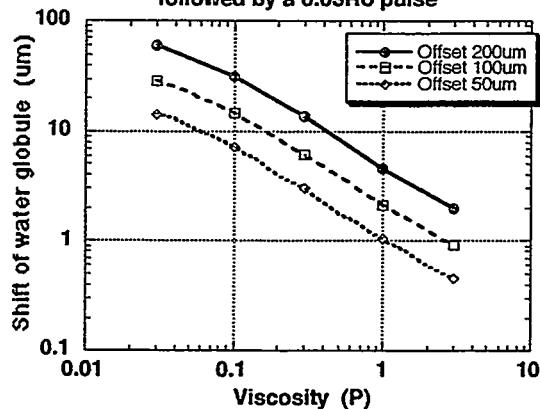


Applied deformation on the outer surface



Motion of inner water globule

Shift of water globule induced by a 0.1Ro pulse followed by a 0.03Ro pulse

Scaling law for shift ($\mu < 1$ P)

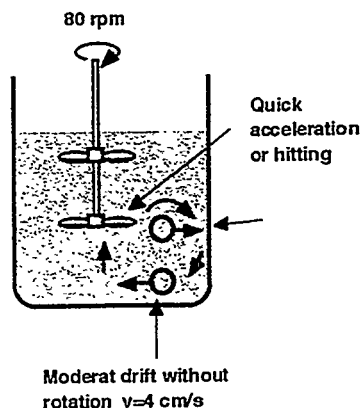
$$\Delta x_w = 2 \times 10^{-4} \left(\frac{3}{\mu_o} \right) \left(\frac{X_w}{0.02} \right) \left(\frac{A}{0.03} \right)^2$$

A ; amplitude of deformation on the outer surface (cm)
 X_w ; offset of water globule (cm)
 μ_o ; viscosity of oil phase (P)

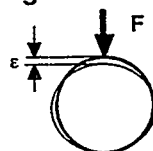


I.L.E. Osaka

Deformation was estimated from
observed velocity change and the
interaction time.



Relation of deformation with the momentum
change



$$F\Delta t = M\Delta v$$

$$F = \frac{\partial E_{free}}{\partial \epsilon}$$

$$= 8\pi\epsilon\gamma$$

The interaction time is given by the blade width divided
by the blade velocity.

$$M=0.12g, \gamma=15 \text{ dyn/cm}$$

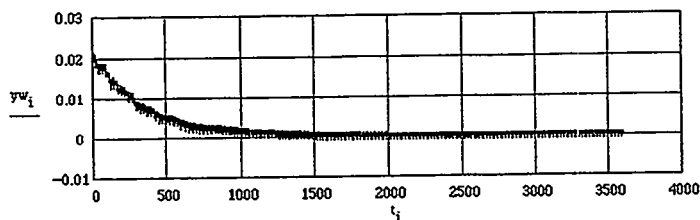
Stirring speed (rpm)	δv (cm/s)	δt (ms)	Expected deformation (μm)	Frequency of the event (1 / min)
80	4	50	230 (7.7% of R_0)	3
120	7	30	680 (23% of R_0)	5



I.L.E. Osaka

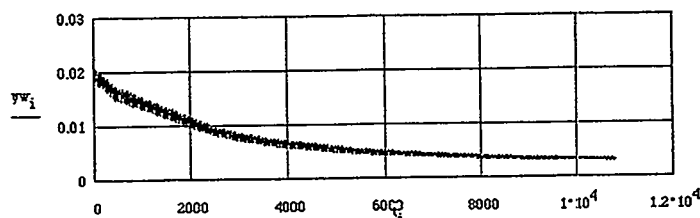
Terminal thickness uniformity depends on
the deformation amplitude (stirring rate).

$0 < A < 22\%$ of R_0 , Deformation rate=1/12 sec



Thickness uniformity
after 1 hr is 99.97%.

$0 < A < 22\%$ of R_0 , Deformation rate=1/60 sec



Thickness uniformity
after 3 hr is only 80%.

Experimental conditions and estimated parameters for NIF class emulsions.

Stirring speed (rpm)	δv (cm/s)	δt (ms)	Expected deformation (mm)	Frequency of the event (1 / min)
190	11	19	64 (6.4% of Ro)	8

For smaller shells, deformation ε can not be expected because of smaller mass.

$$\varepsilon = \frac{\delta v \cdot m}{8\pi \cdot \gamma \cdot \delta t}$$

Diameter; 2 mm

Thickness of oil; 133 μm

$m=4.2$ mg

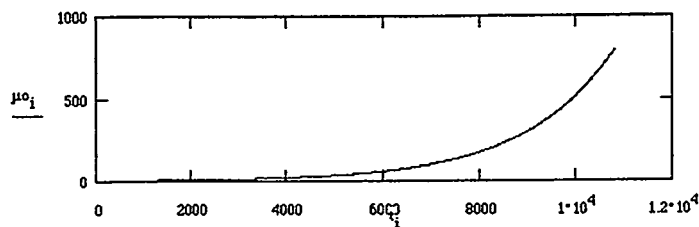
$\gamma=15$ dyn/cm

$\rho_w=0.9718$

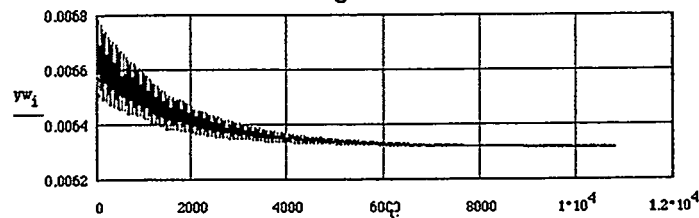
$\rho_o=0.997$

Viscosity of oil

ILE, Osaka



Motion of water globule in emulsion



In this calculation, the oil phase lost fluidity before centering. The terminal thickness uniformity was only 52 %.

The density matching is more important for smaller shells.

Summary



Centering of water globule in a compound emulsion was formulated basing on Taylor Wang's process.

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- The centering force consists of hydrodynamic forces and thermodynamic force.

By repeating pulse deformations uniformity of the compound emulsion is improved. Since the centering force is not so strong to support density mismatched emulsion, rotation of emulsion is always necessary.

- Our calculation basing upon the experimental stirring rate and the drying rate indicates that our emulsion method has feasibility to fabricate shells with uniformity >99.9%.
- To improve the shell uniformity, deformation-induced centering is necessary before the emulsion loses the fluidity. After the centering, the emulsion must be rotated to keep the uniformity until the emulsion loses the fluidity and fix the water globule at the center.

Fabrication of large shells using a rotating dry bed in emulsion process

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Presented at Target Fabrication Meeting 98
April 20-23, 1998
Jackson, WY

Abstract



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To understand the emulsion process, large shells were fabricated with controlled rotation speed and deformation rate using a rotating bed. Key points of this experiment is as follows;

1 Counter balance the gravitational deformation by centrifugal force

In conventional emulsion process stirred with a propeller, gravitational sagging of oil phase takes place because of bad density matching between W1 and O.

2 Eliminate middle mode nonsphericity

Middle mode (3-50) nonsphericity would be attributed to collisions of emulsion with the stirring propeller.

3 Improve the thickness uniformity

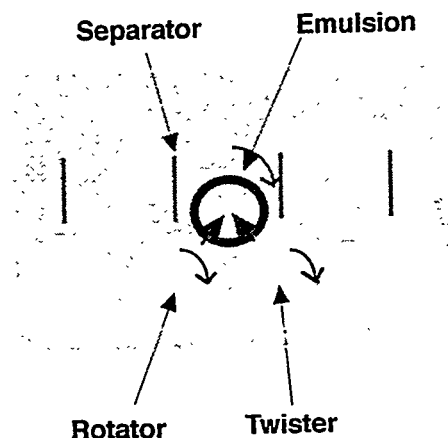
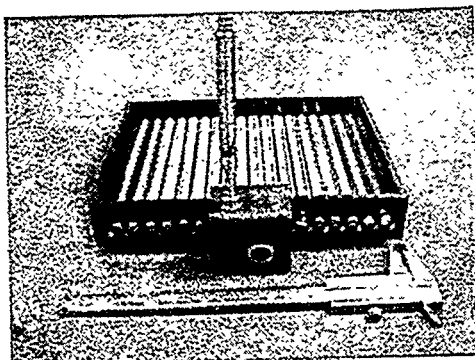
The thickness uniformity will be improved by continuously rotating the emulsion around the horizontal axis.

A rotating bed was newly used in drying process of emulsion method.



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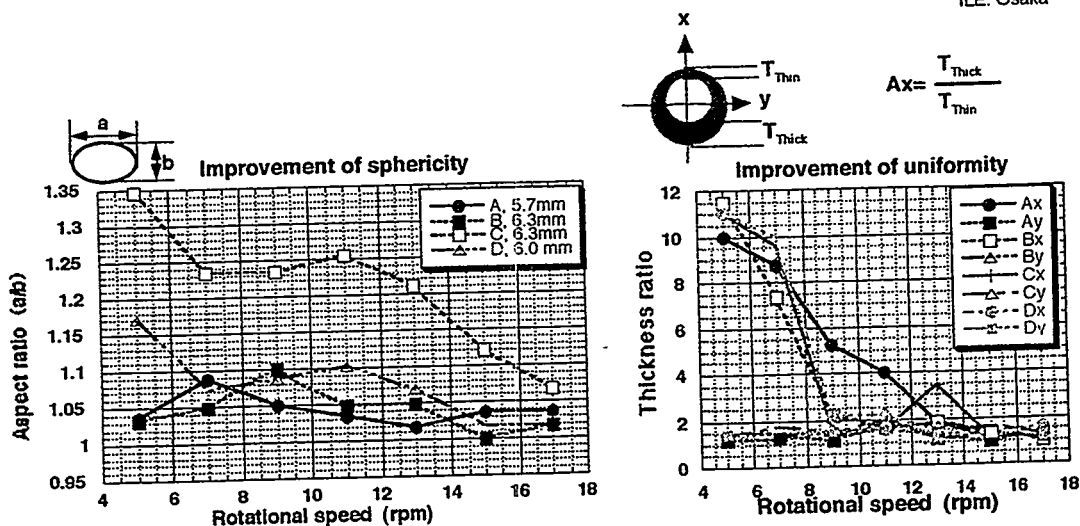
Point support of emulsions provides the centering force.
Continuous rotation eliminates gravitational sagging.



Rotation around the horizontal axis improved the sphericity and uniformity of emulsion.



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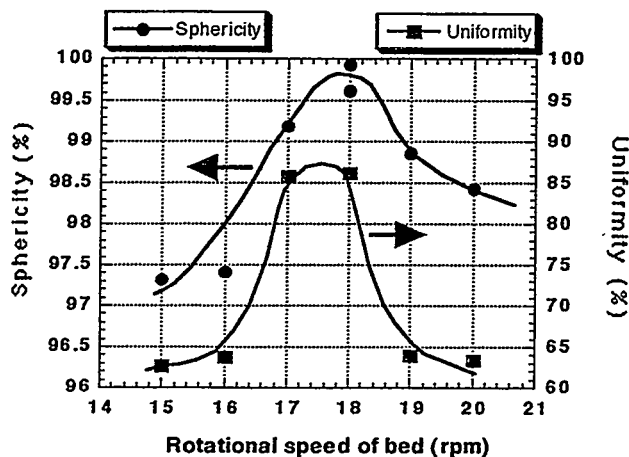


Sphericity of shells fabricated on a rotating bed



The rotating bed showed good performance in sphericity but poor in uniformity. ILE. Osaka

"Rugby football"-like shell



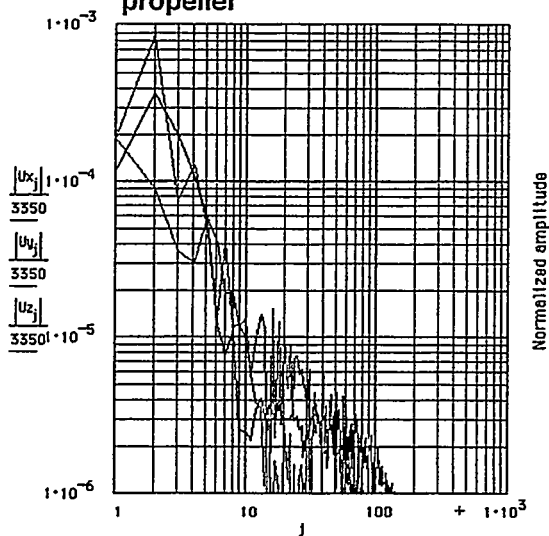
"Pancake"-like shell



Rotating bed showed good performance in the low mode range except for mode 3.

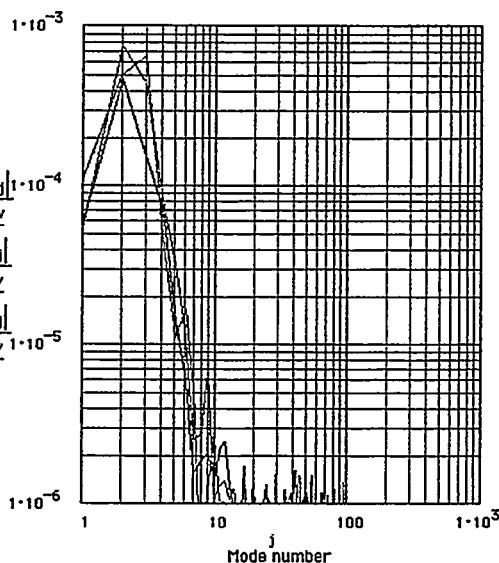


Dried in a bath stirred with propeller



Higer middle mode is attributed to collisions of the emulsion with the propeller.

Dried on the rotating bed



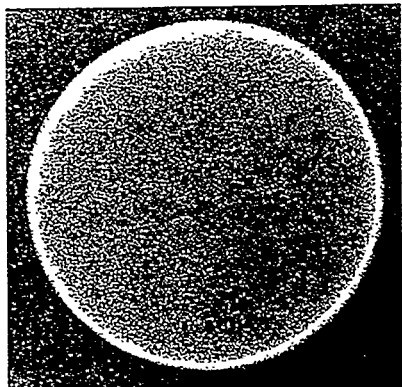
Large mode 3 was induced by curvatures of rotating bars. (current guess)

Why is the uniformity bad?

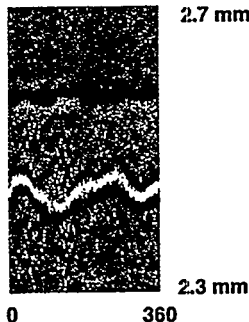


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Because the rotation was one dimensional and the deformation is continuous.



X ray image of a 6.15-mm-diameter shell
(Rotation speed of bed; 18 rpm)



The best uniformity was only 86%.

This can be attributed to;

1 One dimensional rotation

There is no centering force in the axis direction.



No centering force

2 Centering force in the equator plane is also weak because $dE/dx = 0$.

In case of continuous rotation, the free-energy change on the inner surface is zero.

3 Deformation induced by point contact was small.

When an emulsion lost solvent, it begins to float.

Summary



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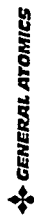
The rotating dry bed showed good performance in the sphericity but poor in the wall thickness uniformity.

- By counter balancing the gravitational deformation with centrifugal force, sphericity of 99.93% was achieved.
 - The sphericity can be further improved if the accuracy of rotating bars is improved.
- The thickness uniformity was only 86 %. Currently we think this low uniformity is attributed to no centering force in the axis direction.
- The uniformity is improved if the rotation axis is changed or additional vibrational mode is applied on the emulsion.

Production of titanium-doped glow discharge polymer containing targets for experiments at OMEGA

Abbas Nikroo
Martin Hoppe
Annette Grenwood

12th Target Fabrication Specialists' Meeting
April 1998
Jackson Hole, Wyoming

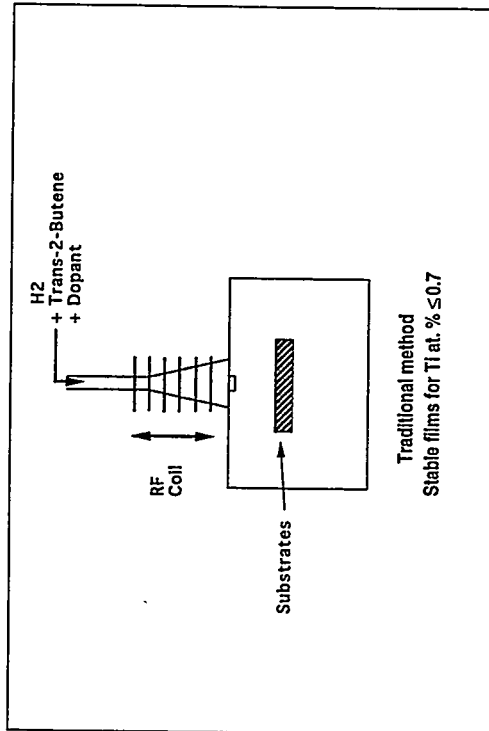


Titanium-doped GDP was needed for LLE experiments

- Shells containing thin titanium doped GDP (Ti-GDP) layers were needed for experiments at OMEGA
- Films containing ≥ 2 atomic % Ti were desired.
- Ti Cl_4 was used as dopant
- This allowed co-doping with chlorine if needed
- Pyrolysis of films at 300 C removes virtually all Cl
- Ti atomic % was measured by X-ray Fluorescence
- Ti containing organics react with moisture quickly and degrade. Ti-GDP was no exception



Films made using the traditional dopant delivery scheme were stable only if they contained ≤ 0.7 atomic % titanium



The Ti doping level in stable films made the traditional way was not sufficient for LLE experiments

- Films containing ≥ 0.7 atomic % Ti made using the traditional dopant introduction method turned oily and broke apart in less than a minute
- Ti is incorporated into the films as TiCl_x
- Oxidation of Ti and release of HCl was probably responsible for films breaking up
- Films with lower (< 0.7 at. %) Ti content were more stable
- Ti at. % was irreproducible. Consecutive runs using the same coating parameters led to coatings with 0.1 and 1 at. % Ti.
- This was mainly due to the low dopant flows (≈ 0.02 sccm) needed to keep the Ti atomic % in the desired range.
- This doping level was too low for LLE needs. ≥ 2 at. % Ti was desired
- We had to find a different way to make stable films with ≥ 2 at. % Ti.



Films deposited onto the coating tubes were more stable

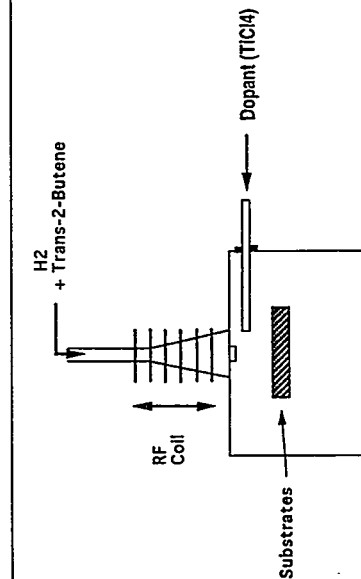


Coating tube used for a Ti-GDP coating
left - after 24 hrs right - after 2 hrs
In air

- We had noticed that films deposited within the coating tubes remained stable for hours
- This suggested that $TiCl_4$ dissociated into more stable species in the active plasma region

◆ GENERAL ATOMICS

Ti-GDP dopant delivery scheme was changed



- Dopant was introduced from the side of the coating chamber into the plasma plume directly over the shells

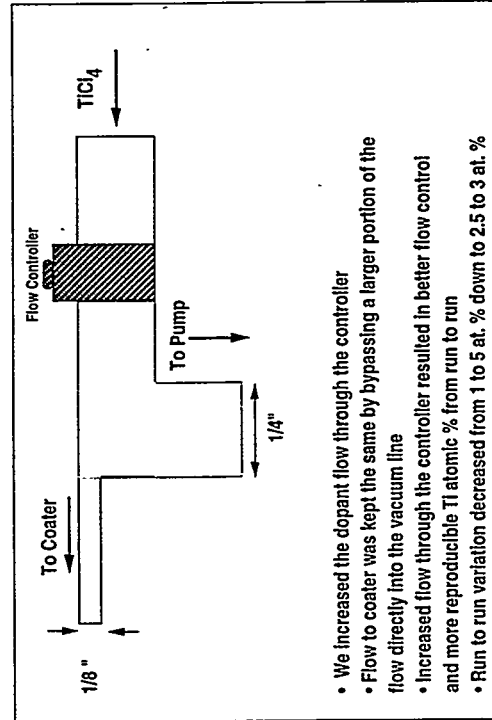
◆ GENERAL ATOMICS

With the modified dopant delivery scheme stable films with up to 5 at. % Ti could be made

- Films with up to 5 atomic % Ti did not turn oily or break up
- This eliminated the need for any special sample handling procedures or equipment
- Reproducibility of the Ti atomic% from run to run was still a problem
- Introducing the dopant from the side led to a natural lateral non-homogeneity of the Ti atomic %

◆ GENERAL ATOMICS

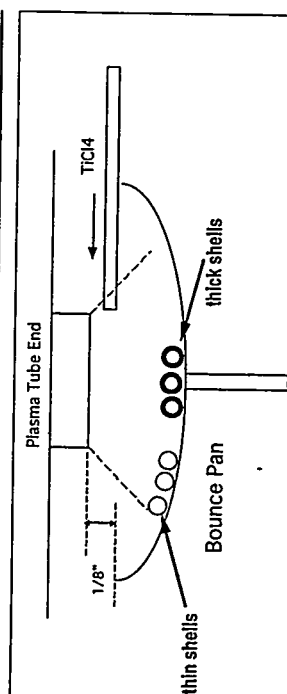
Modifications to allow increasing the dopant flow led to improved reproducibility of the Ti atomic percent



- We increased the dopant flow through the controller
- Flow to coater was kept the same by bypassing a larger portion of the flow directly into the vacuum line
- Increased flow through the controller resulted in better flow control and more reproducible Ti atomic % from run to run
- Run to run variation decreased from 1 to 5 at. % down to 2.5 to 3 at. %

◆ GENERAL ATOMICS

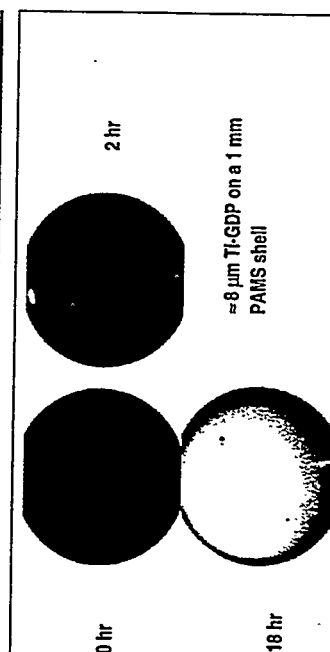
Dopant introduction from the side resulted in lateral non-uniformity of the Ti atomic %



- Introducing the dopant from the side results in lateral non-homogeneity of the Ti concentration.
- For thin walled shells ($< 10 \mu\text{m}$) this leads to different Ti concentrations and coating rates for shells of different wall thicknesses:
(e.g. $\approx 20\text{-}40\%$ difference for 4 versus 6 μm thick shells)
- If PAMS mandrels are not pyrolyzed prior to coating then the problem is minimal (PAMS mandrels are typically $> 16 \mu\text{m}$ thick).

GENERAL ATOMICS

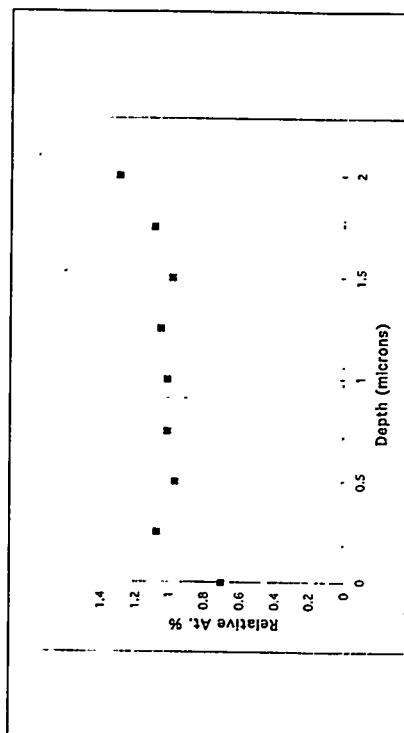
Ti-GDP coatings become lighter as they oxidize



- Ti-GDP films change color from almost black to light brown overnight
- The initial dark color is probably due to $(\text{TiCl}_3)_x$ or $(\text{TiCl}_2)_x$ Initially in the coating
- Formation of TiO_2 lightens the coating

GENERAL ATOMICS

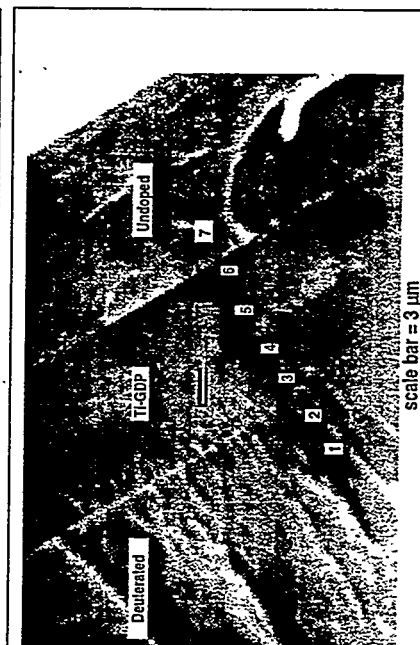
Scanning Auger spectroscopy of Ti-GDP films indicated good homogeneity of the Ti concentration



- Auger scan of a $\approx 4 \mu\text{m}$ thick Ti-GDP film containing $\approx 3\%$ atomic % Ti (by XRF)
- The atomic percent at each depth is normalized to the XRF value

GENERAL ATOMICS

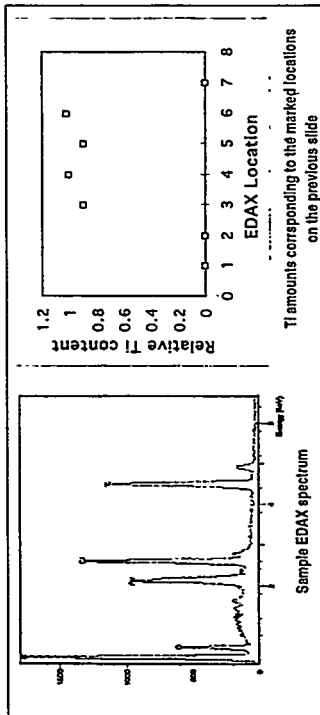
Cross-section EDAX measurements were made to examine diffusion of Ti from a Ti-GDP layer to adjacent non-Ti-GDP layers



- SEM image of a shell containing a Ti-GDP layer sandwiched between an undoped layer and a deuterated GDP layer

GENERAL ATOMICS

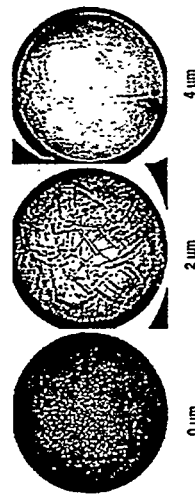
Cross-sectional EDAX measurements also indicated good homogeneity of the Ti concentration and no observable diffusion into adjacent layers



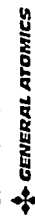
- Cross-sectional EDAX on multi-layer films (see previous slide) showed no observable diffusion of Ti into adjacent undoped layers.
- It also indicated rather homogeneous distribution of Ti in the Ti-GDP layer



Films containing greater than 5 atomic % Ti had to be overcoated with undoped GDP immediately after the Ti-GDP coating



- Ti-GDP layers with ≥ 5 at. % could be deposited if overcoated with undoped GDP without exposure of the Ti-GDP film to air
- After pyrolysis of the PAMS mandrel, Ti layers containing ≥ 5 atomic % cracked
- The degree of cracking reduced if the Ti-GDP layer was supported with thick undoped GDP underlayers



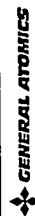
Pyrolysis of the Ti-GDP layer increased the Ti atomic % in the films

- Pyrolysis resulted in the removal of most of the Cl
- It also increased the Ti at. %
- More Cl and hydrocarbons are lost than Ti during pyrolysis
- Ti-GDP layer thickness shrinks by 20 % compared to $\approx 10\%$ for undoped GDP
- Freestanding 1 mm Ti GDP shells as thin as 2 μm with ≈ 4 at. % Ti were made
- Immediate pyrolysis of Ti-GDP coated shells was essential in obtaining free standing Ti-GDP shells
- Longer pyrolysis hold times (at 300 C) of 10-14 hours are needed to remove the PAMS from inside a Ti-GDP layer



Stable Ti-GDP films containing ≤ 5 atomic % Ti suitable for LLE experiments were made

- By changing the dopant delivery method to the coating system we were able to make stable Ti-GDP films containing up to 5 atomic % Ti.
- This provided spectroscopically observable Ti signals in diagnostic experiments at OMEGA.
- Using TiCl_4 as the dopant allowed co-doping films with both chlorine and titanium
- Pyrolysis of the films removes the chlorine leaving films doped with only Ti.
- The Ti concentration appears to be homogeneous in the bulk of the coating.
- Ti-GDP layers containing ≥ 5 atomic % Ti can be deposited, but they need to be overcoated with an undoped GDP layer before the film is exposed to air.



High Energy Density Physics Loads

By

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Los Alamos, New Mexico, U.S.A.

This work is supported by the U.S. Department of Energy under contract number W7405-ENG36

LA-UR-98-1326

ABSTRACT

The LANL Pegasus II Pulse Power Facility is uniquely capable of long pulse, Z-pinch experiments, favorable for driving solid phase heavy cylindrical liners and advantaged for hydrodynamic compression experiments with superior symmetry. The facility can conduct experiments in a classified environment. The facility is being used by the LANL HEDP program for hydrodynamic experiments of interest to both primary and secondary weapons physicists. The use of this facility is international as Lawrence Livermore National Laboratory/USA, United Kingdom/AWE, France/CEA, and Russia/VNIIEF are also using this facility.

Pegasus II generates approximately 10 MA at 90 kv. The Precision Liner, as used in HEDP experiments (5 MA, 40 kv), produces a 300 lb shock in cylindrically convergent geometry. The HEDP experiments at Pegasus II are an early step toward producing shock pressures and experimental diagnostics relevant to weapons physics issues. Current experiments use compressible media to simulate thermally ionized materials. This work will be continued on the LANL Atlas driver, which is designed to deliver 20 MA, at 240 kv, with 38 MJ of stored energy, and 20 MJ delivered to the target.

There is a requirement in this program for variety of loads for various experiments. The requirements for structural components increase, as it becomes apparent to our designers that the flexibility of our design/manufacturing capabilities allows great variations of design.

This paper describes some of the design and methods used to construct complex composite loads. These loads contain liquid Gallium, polymer foams, metal, and various gases at pressures of vacuum to 5 atm.

ADHESIVE BONDED JOINTS

There is a requirement in this program for variety of plastic loads for various experiments. The requirements for structural plastic components increase, as it becomes apparent to our designers that the flexibility of our design/manufacturing capabilities allows great variations of design.

We are required; to keep excess adhesive from being pushed into various working areas of the targets; to have optically transparent joints for diagnostic purposes; and to have joints capable of handling gas pressure. In order to achieve

these objectives a unique family of adhesive joints has been designed.

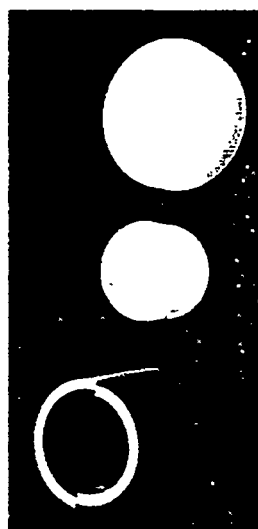
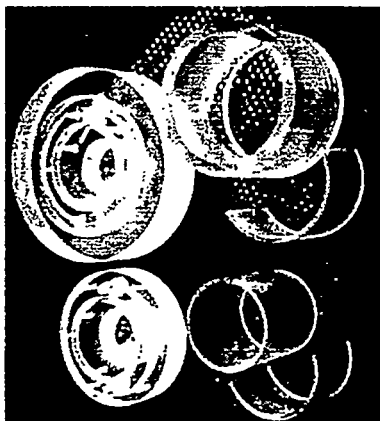
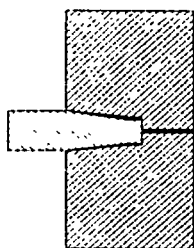
The design of these joints is such that as the parts are assembled excess adhesive is squeezed out of holes and vents at designated points. Trapped air is also vented as the parts are brought together. The mating parts are made with a slightly diverging taper that reduces in clearance to almost zero as the joints begin to close. This feature forces the adhesive to flow toward the vents and keeps adhesive from flowing into undesirable areas. When done carefully, no air is trapped in the joint and no adhesive is displaced to the interior. We use an ultra-violet curing acrylic adhesive that is a good optical, x-ray, and chemical match.

PLASTIC COMPONENTS UK/AWE DH-1

Conventional machining, CNC machining and CNC air bearing machining are used to provide the precision plastic parts needed for this type of load. Shown are the plastic load components for a Pegasus experiment. Thermoplastic materials must be stress relieved at various stages of machining to avoid distortion.

FIXTURE PARTS

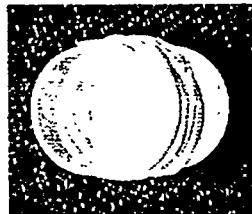
Conventional machining, CNC machining and CNC wire EDM machining are used to provide the fixture parts needed for the assembly of the various components. These special and unique fixtures are indispensable to assembly of these unique and unusual designs. Many of these tools are used only once and it is our rapid machine capabilities that make these unique tools possible.



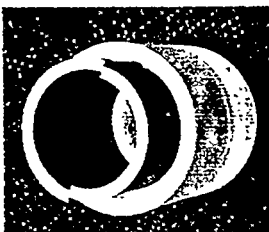
BONDING SUBASSEMBLIES DH-1

Subassemblies are joined using various means to fixture the various components. Innovation and flexibility are the keys to these difficult assembly problems. The UV cured adhesive is of great advantage in these operations. One can assemble adjust and clean parts before the curing process.

Fixturing can be as simple as a rubber band. In this case the rubber band holds the half cylinder to the full cylinder for adhesive bonding.



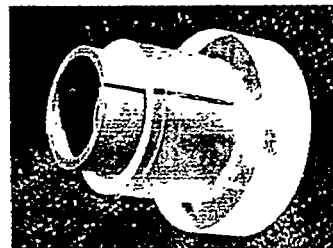
CNC wire EDM fixture holds a half cylinder to interior of a full cylinder for adhesive bonding.



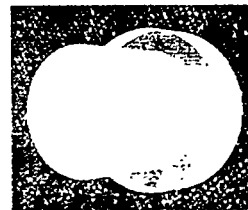
The small press is important to various stages of assembly as it provides perpendicularity and constant pressure. The open design allows access for the UV light source.



The EDM fixture used previously holds inner and outer cylinders in rotational and axial alignment with each other and the plastic end cap. The press is used for this operation and for the final operation to bond the other end cap.

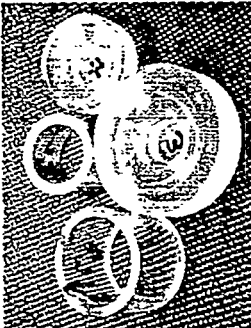


This is the bonded assembly before final machining in a CNC air-bearing lathe. This lathe can achieve optical finishes of 1-2 micro inches RMS.



LLNL-1

Components of experiment LLNL-1 were designed, manufactured and assembled in the same manner as above except that the cavity has an Aluminum cylinder with imbedded wires of various materials. The Al cylinder also has an Aluminum stripe electroplated onto its interior.

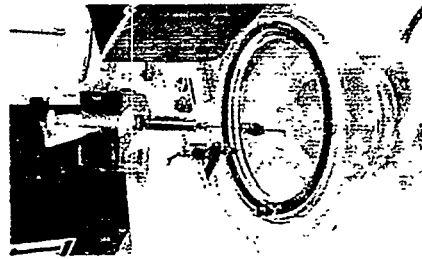


The second picture shows a finished LLNL-1. It has CNC air-bearing lathe turned optical surfaces, Au stripe, Al cylinder, and imbedded wires all bonded into a gas tight assembly.

GALLIUM FILLING OPERATIONS

Gallium is one of the few materials that expand when solidified. Parts must be maintained at 100°F to keep the Gallium liquid. Preheated parts and hand type heat gun are used to maintain the proper temperature.

Gallium filling operations are conducted in a vacuum. The part to be filled with Gallium is placed into a vacuum chamber. A syringe with a long hypodermic tube is inserted through a special vacuum tight fitting into the fill cavity in the plastic part. A vacuum is pulled on the chamber and Gallium is slowly injected to completely fill the cavity. A slow fill is necessary because Gallium has a very high surface tension and it does not flow or readily wet the plastic.

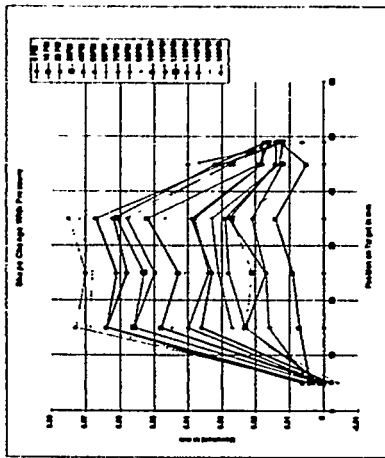


After the filling operation liquid UV curing adhesive is floated on top of the Gallium in the fill hole and cured with UV light. This fills the hole and seals in the Gallium. The entire part is now placed into an UV light-curing station for 2 hours and heat cured for at least 12 hrs. at 50°C. We have found through experimentation that this prolonged heat cure is necessary to achieve full cure and therefore structural integrity.



WALL DISTORTION POLYSTYRENE TEST

This is a graph of wall distortion as a function of pressure as measured at various points on a test part. The very curious shape of the distortion is probably due to the distortion of the plastic during machining because of tool pressure creating a non-uniform wall thickness.



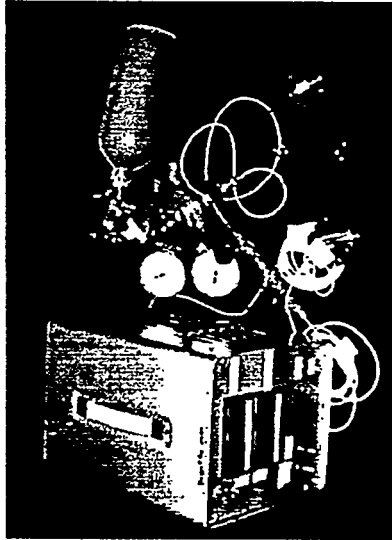
Most of our loads are made with acrylic. Acrylic generally behaves like polystyrene so one could believe that similar behaviors would occur with similar parts.

PEGASUS GAS FILL SYSTEM

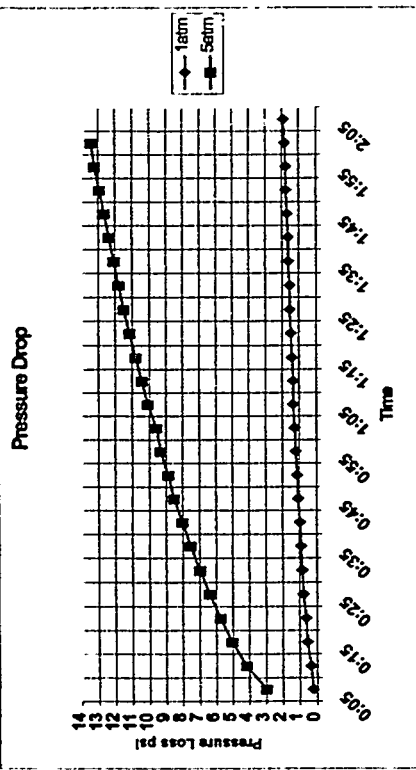
The gas fill system is a simple system utilizing the vacuum of the experimental chamber to evacuate the load. Components of the fill system include valve manifold, pressure transducer, digital read out.

Conflat port feed through, polyurethane tubing, target, and gas supply with regulator.

Parts are pressure tested and leak rates established. Xenon leaks readily through tubing and target so it is important to know at a given time after fill what the pressure will be after removal of the digital readout. The digital readout is not EMP safe so that it must be removed just prior to a Pegasus experiment.



The chart below is the leak rate established for LLNL-1, with the load in a vacuum. It shows a drop in large pressure occurs early in the pressurized cycle. The electronic pressure transducer readouts are not EMP hardened and must be removed from the experimental area prior to shot time. The timing of the shot must be anticipated and the monotonic drop in gas pressure must be accounted for when filling the target with gas. If the time pressure relationship drops below pre-established minimums, then the experiment must be aborted and the target refilled.



CONCLUSION

Using a wide range of capabilities, MST-7 supplies sophisticated target engineering, materials, and manufacturing.

Our high technology manufacturing capability in the areas of precision machining, electroplating, physical vapor deposition, chemical vapor deposition, polymer synthesis/fabrication, and target assembly allow complex and complete target assemblies to be manufactured and characterized in our facilities.

We develop new materials, and manufacturing techniques to satisfy the needs of the target design community. These advanced and adaptable capabilities often drive the theoretical design.

We have developed multi-chamber loads which can be filled with liquids in our assembly laboratories. These loads can be filled with various gases at the experiment site.

We have developed gas and liquid tight, optically clear, fillet free, structural adhesive joints for experiments.

Development of a Cryostat to Pressure Load and Evaluate Cryogenic ICF Targets

Peter S. Ebey, James K. Hoffer, Arthur Nobile, Jr.

Los Alamos National Laboratory, MS-K764, Los Alamos, NM 87545

This work is supported by the U.S. Department of Energy under contract number W7405-ENG36

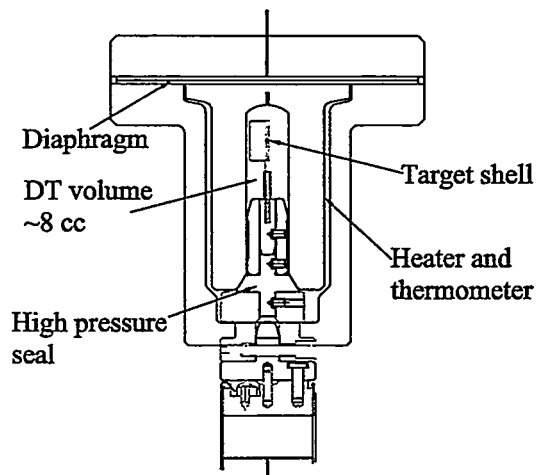
Capabilities and Design Features of LANL Cryogenic Pressure Loader (CPL)

- Permeation loading of either Omega or NIF sized plastic targets
- Serve as a test bed for future target concepts
- Measure DT Equation of State (EOS) at high densities
- Beta Layering of DT shell to determine effects of mount/hohlraum geometry on layer uniformity
- Observation of Layered Sample surface
 - ⇒ Real time video monitor and CCD camera for roughness analysis of stored images
- Ability to rotate layered sample to obtain multiple views
- Space exists to accommodate future experimental apparatus
 - ⇒ Cryogenic valve; Resonant ultrasound spectroscopy (Asaki, LANL); Joule heating apparatus (LLNL)
- Spare feedthroughs
 - ⇒ Spare signal, heater, and coax leads
 - ⇒ One spare gas feedthrough tube could actuate a bellows
 - ⇒ Several blanked-off openings for future applications
- Inserter and mechanical support of the cryostat are coaxial to avoid misalignment due to thermal contraction
- Cryocooler is mechanically decoupled from the cold can to lessen vibrations
- Heat load up inserter minimized: To permit operation with one cryocooler
 - ⇒ Exchange gas path is severely constricted across thermal gradient
 - ⇒ Inserter post is evacuated and filled with radiation baffles to minimize conduction and radiation transfer from 300 K to the target
- Copper Layering Hemispheres driven in from two sides to form an isothermal layering environment

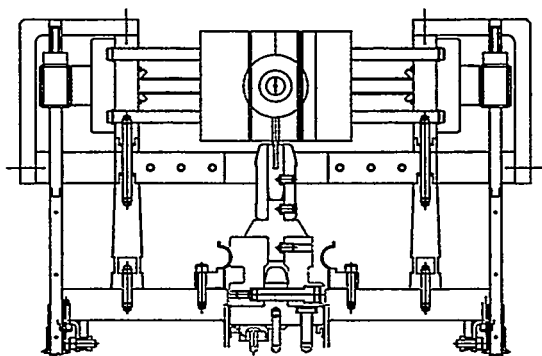
LANL CPL Will Test Elements of the Omega Cryogenic Target System (OCTS)

- Permeation cell is an exact copy of the OCTS cell
 - ⇒ Test operation of high pressure breechlock seal
 - ⇒ Evaluate pressure loading procedures
 - ⇒ Test the effects of warm ballast volume in the DT plumbing
- Target shells are identical to Omega plastic targets
- Tritium Migration Tests
 - ⇒ Determine amounts of residual tritium in permeation cell
 - ⇒ Measure rates of tritium migration within cryostat to estimate rates in the OCTS
- Layering environment and target mount geometry are similar to OCT
 - ⇒ Evaluate post-filling steps, including beta-layering
 - ⇒ Test whether mount wire distorts the thermal profile at the target shell
- Inserter Z and rotation manipulators similar to OCTS: from the same vendor

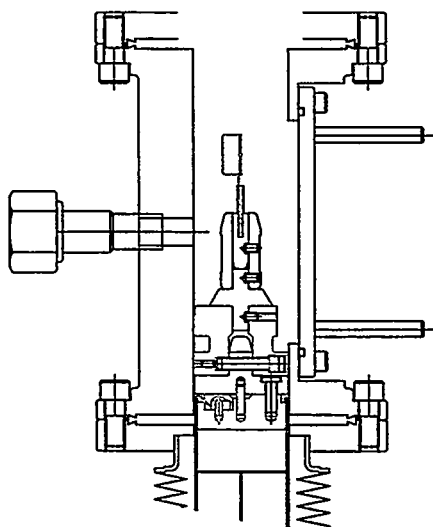
Cryostat Details



Target shell in place
in PERMEATION CELL.
This cell is an exact
copy of the GA design
for the Omega CTS

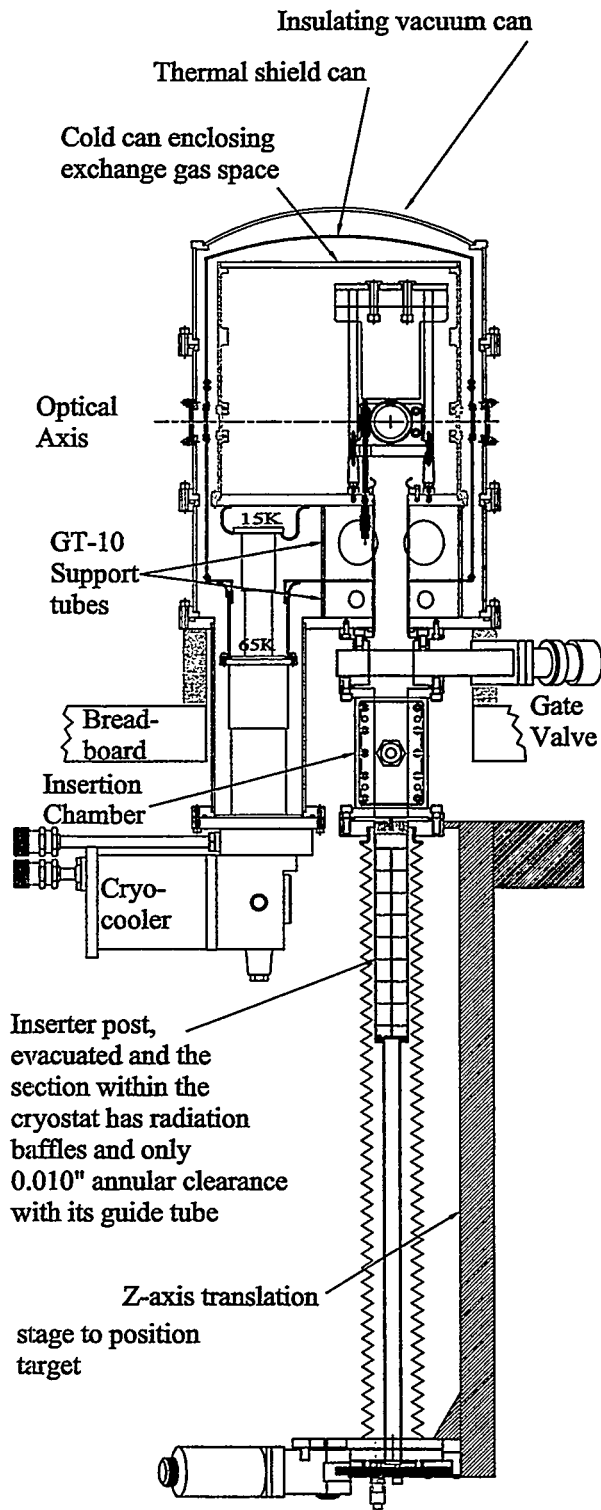


Target shell in place
in LAYERING SPHERE,
formed by two gear
driven copper hemi-
spheres

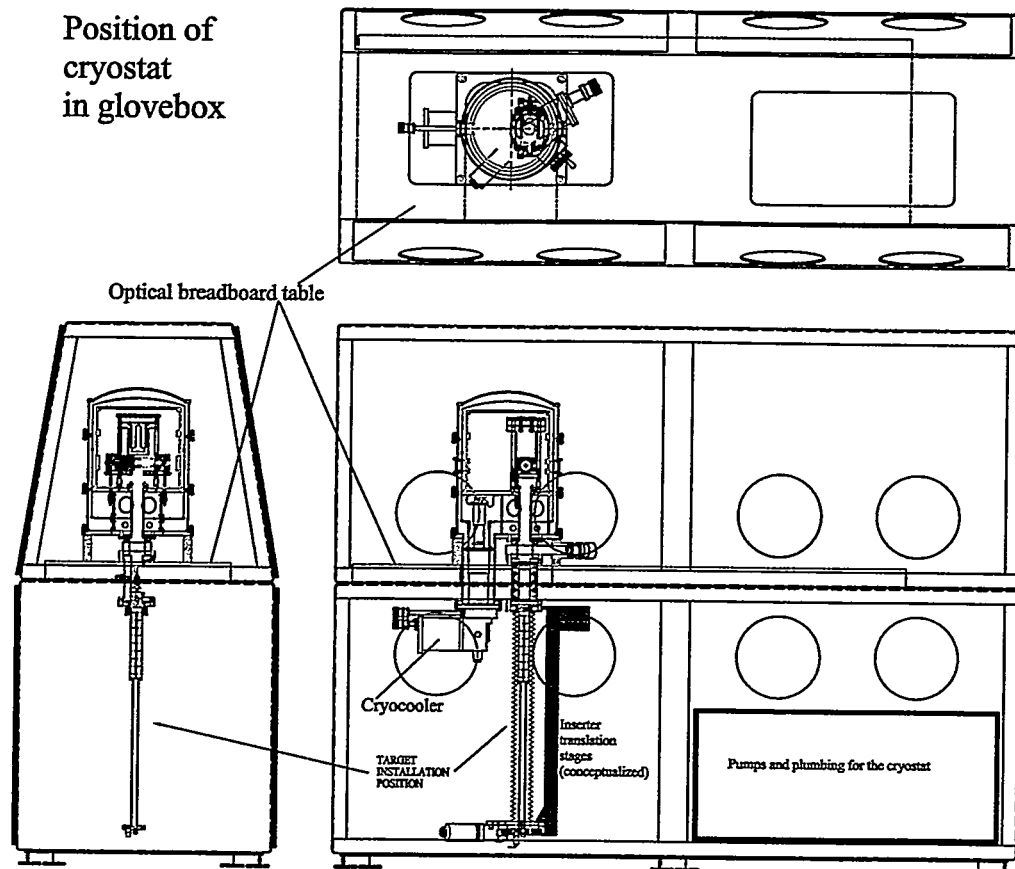


Newly loaded target
in INSERTION CHAMBER

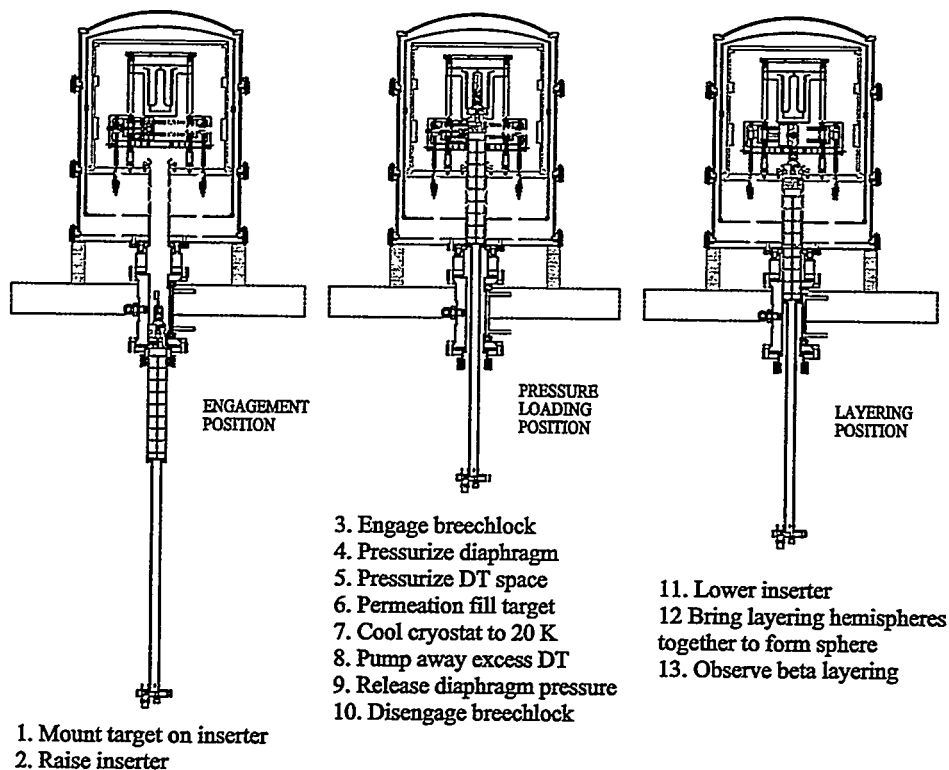
Cryostat Front View

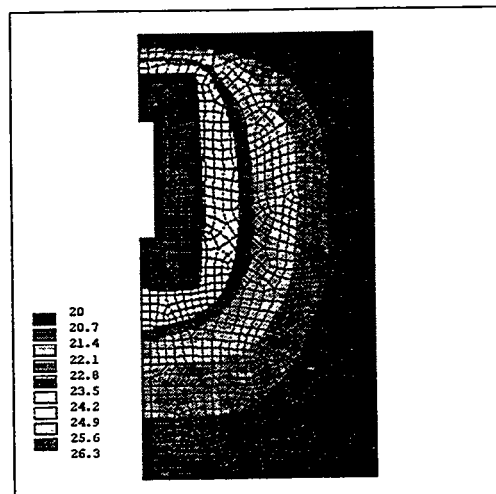
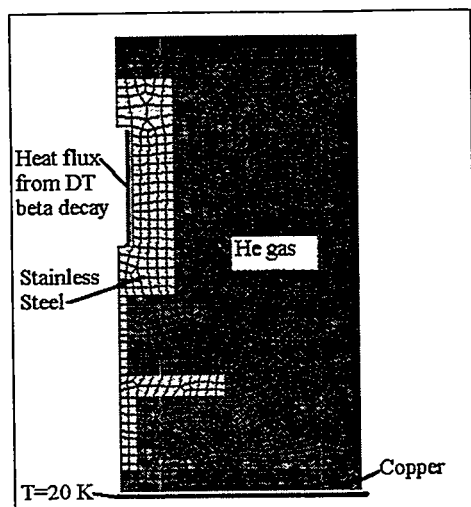


Rotation Stage to rotate
insertion post to actuate
breechlock and give multiple
views of the layered target

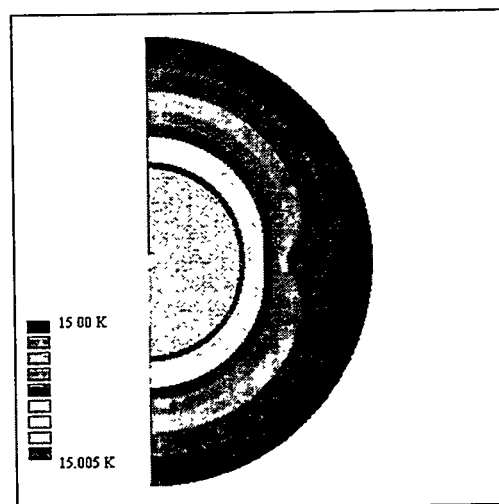
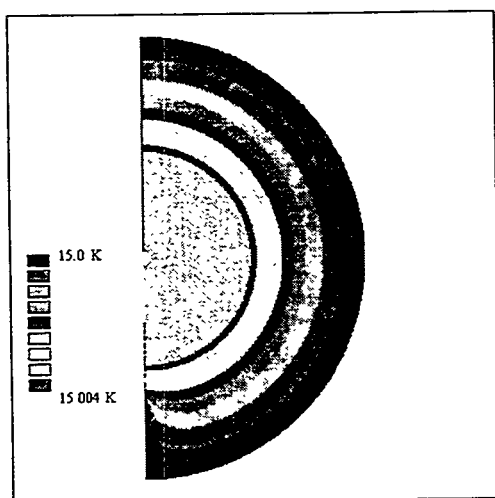


Major steps in CPL operation





Simulation of effect of beta heating on the cooldown of the DT filled permeation cell: The left figure shows the model used for an axisymmetric finite element analysis of the steady state temperature contours within the cold can and permeation cell. The right figure gives the result for the conditions that the coldplate is regulated at $T=20$ K and the permeation cell is warmed by beta heating of the DT. In this model the actual cryostat design is simplified somewhat to maintain axisymmetry, but the model thermal paths have essentially the same thermal characteristics as the actual paths.



Simulation of the effect of target mount geometry on spherical isotherms in the layering sphere: These two figures show the resulting temperature contours from two axisymmetric finite element analyses for a 1 mm diameter, 100 μ m thick spherical shell of solid DT (self heated due to beta decay) suspended in helium exchange gas in the center of a 25 mm diameter isothermal (15 K) spherical cavity. In the left figure there is a (~ 4.6 mm long, 200 μ m dia.) copper wire thermally anchored to the isothermal wall. This causes a temperature gradient of 0.9 μ K on the inner surface of the DT shell. In the right figure there is a ring (7.8 mm dia., ~ 250 μ m cross sectional dia.) held isothermally at 15 K. Even with this perturbation, the inner surface of the DT shell is within 0.02 μ K of being isothermal. (The gray regions in the figures correspond to temperatures warmer than the color scales.)

Tritium Systems for the OMEGA Cryogenic Target System

**Target Fabrication Specialists Meeting
April, 1998**

**A. Nobile, J.E. Nasise, E. N. Schmierer, and C. R. Walthers
Tritium Science and Engineering Group
Los Alamos National Laboratory, Los Alamos, NM**

**N. B. Alexander, G. E. Besenbruch, C. Gibson, and D. T.
Goodin
Fusion Group
General Atomics, San Diego, CA**

**D. Harding, and L. Lund
Laboratory for Laser Energetics
University of Rochester, Rochester, NY**

Los Alamos

The OMEGA Cryogenic Target System will field cryogenic DT ICF targets on OMEGA

- **Laser illumination of first cryogenic DT targets on OMEGA at the University of Rochester Laboratory for Laser Energetics (UR/LLE) will occur in 2001**
- **Tritium release limits are low**
- **Several systems will play a role in the tritium handling aspects of the OCTS**
 - **Gloveboxes**
 - **Vacuum System**
 - **DT High Pressure System**
 - **Tritium Removal Systems**
- **DT experiments are planned with a small scale cryostat at LANL**

Los Alamos

UR/LLE will have a 1 g tritium inventory with stringent tritium release limits

- 1 g tritium inventory is licensed by State of New York
- Current tritium release limits are low
 - Tritium Fill Station room: 200 mCi/yr
 - Target Chamber bay: 2-3 Ci/yr
- Increase in release limit in Tritium Fill Station room is an option
- A high degree of tritium containment is necessary

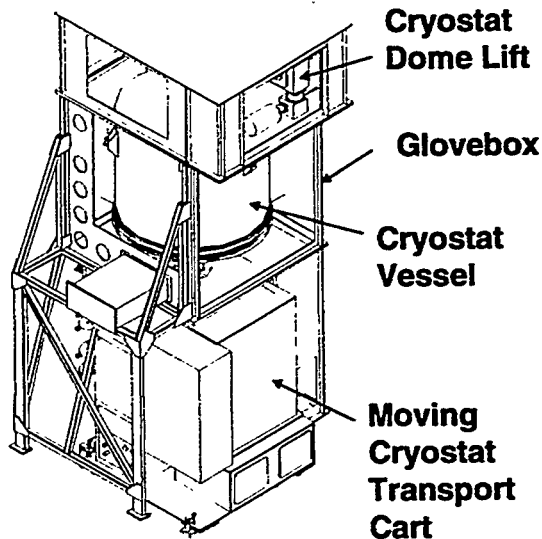
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OCTS equipment will be contained within four gloveboxes

- Tritium Fill Station Glovebox (existing)
- DT High Pressure Glovebox (new)
- Fill/Transfer Station Glovebox (new)
- Vacuum Pump Glovebox (new)

Los Alamos

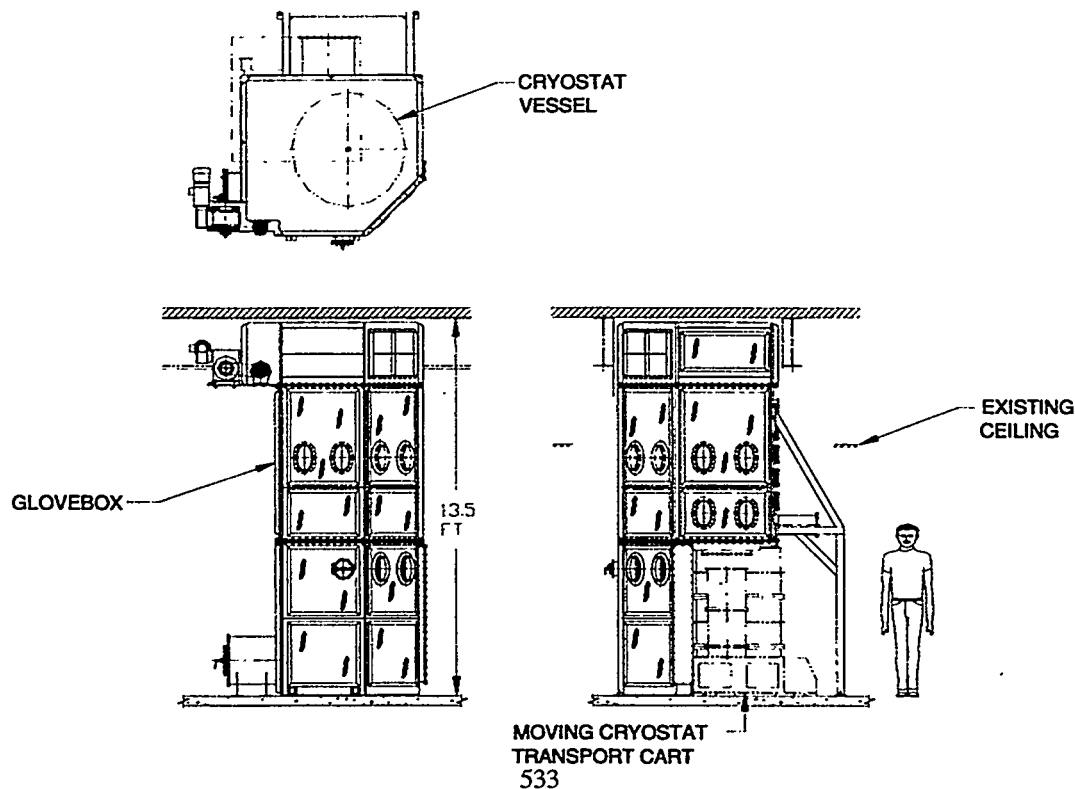
Fill/Transfer Station Glovebox



- Overall height approx. 13 ft.
- Supports 1700 kg cryostat
- Provides access for docking of the Moving Cryostat Transport Cart below the cryostat
- Contains support systems for cryostat, such as cryocoolers and vacuum system
- Allows for opening of the cryostat and maintenance of cryostat components
- Must be assembled in a relatively small room

Los Alamos

Fill/Transfer Station Glovebox is under construction



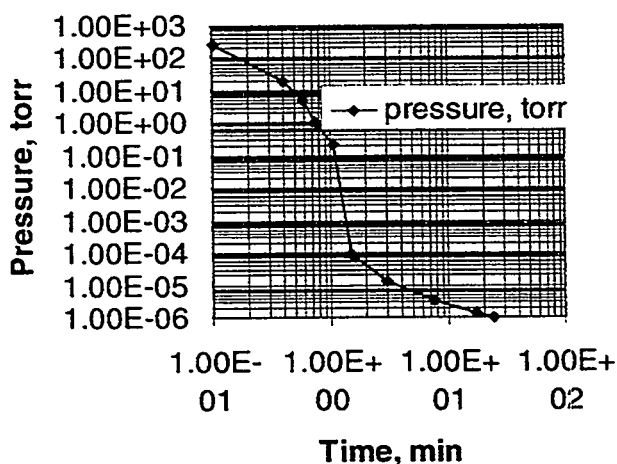
Design of the vacuum system required close coordination with other system designs

- Vacuum pumpdown calculations performed with Vacuum Designer II code
- Approach involved use of small turbo pumps and small diameter backing lines
- Tritium "hardened" turbomolecular pumps not needed in all locations
- Tritium compatible pumps used on systems with relatively high tritium concentrations
- Conventional pumps with elastomeric seals used in systems with low tritium concentrations

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Vessel pumpdown times were evaluated with Vacuum Designer II code

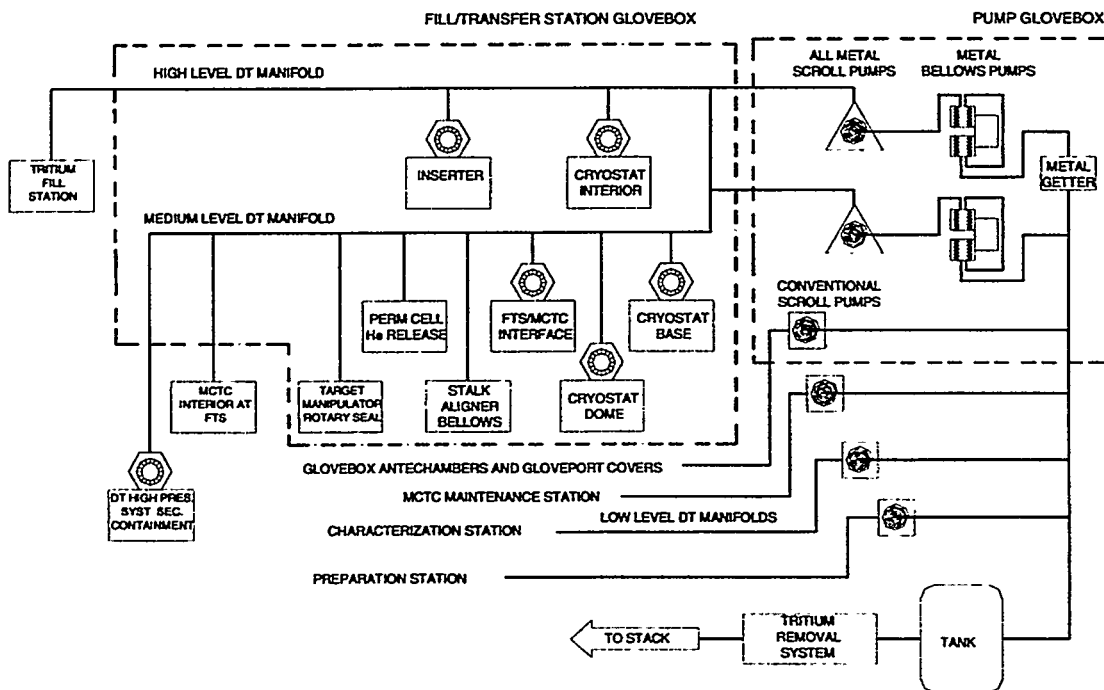
Inserter Pumpdown from Atmospheric Pressure



- Stainless steel rate = $1.0\text{E-}08$ tL/cm²sec; total = $8.6\text{E-}05$ tL/sec
- O ring length = 6'
- Volume = 17 L
- 240 L/s turbo with 2" of 3.83" dia. Tubing
- PV-12 scroll pump in series with a MB 601 bellows pump

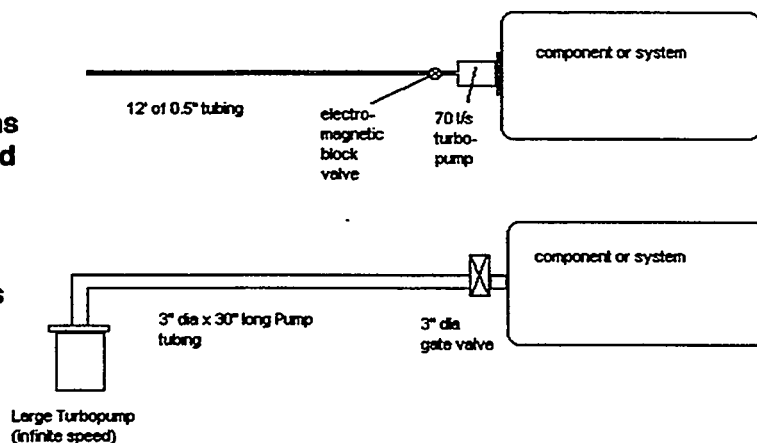
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OCTS vacuum system



Approach involving turbo pumps directly connected to vessels was chosen

- Small pump, mounted directly on the component, has the same pumping speed as a large pump connected to the component with large diameter tubing
- The former is easier to fit in a glovebox and is cheaper

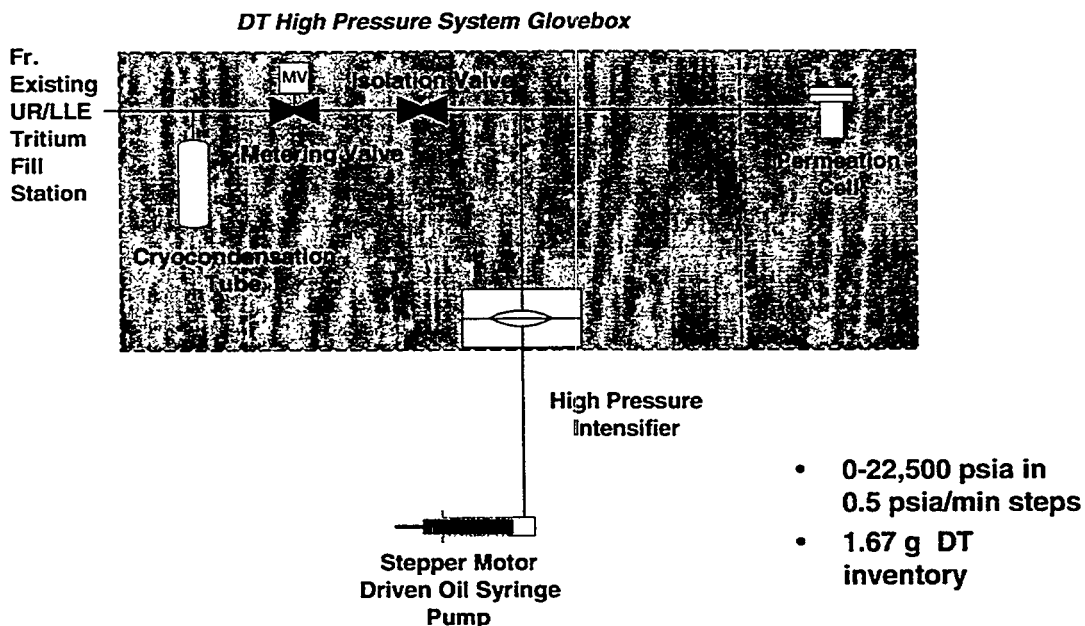


Vacuum pumps were not tritium hardened except where high tritium levels are expected

- Turbopumps are hybrid mag-bearing, dry film lubricated ceramic bearing types. Full mag-bearing, hardened seal and connector design would add substantially to cost.
- Roughing pumps, used for passboxes and for backing some turbopumps are not tritium hardened when only trace tritium levels are expected (Edwards Scroll pump uses elastomeric seals and teflon tip seals)
- Roughing pumps which evacuate and back turbopumps in known high tritium areas are tritium hardened. These pumps are all metal and use metal seals (Metal Bellows and Normetex Scroll pumps)

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The DT High Pressure System must safely compress DT at a very slow and uniform rate



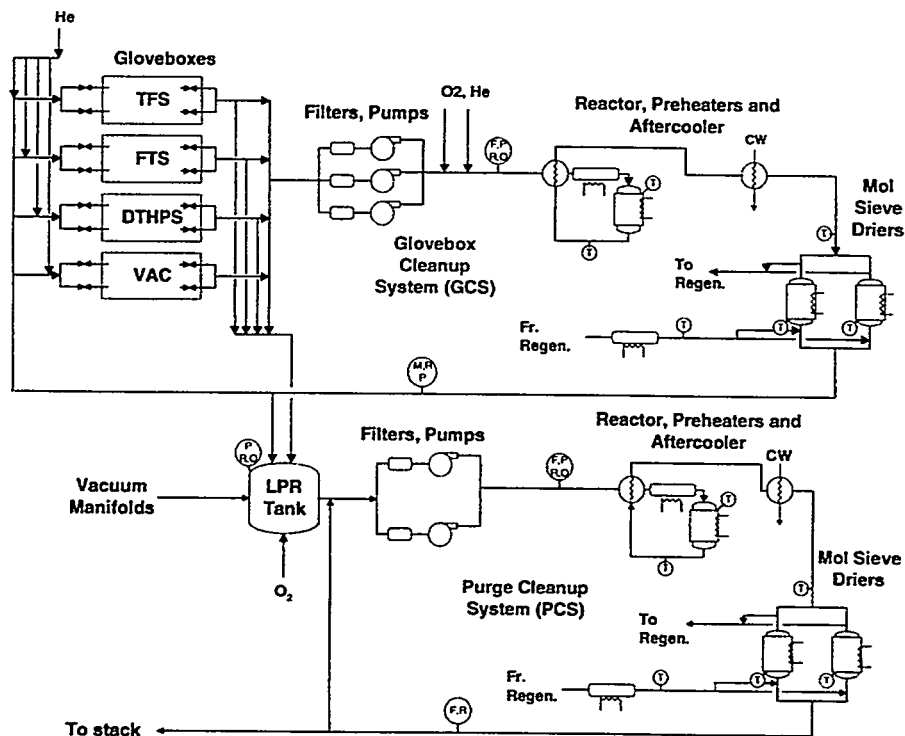
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Tritium cleanup systems are needed for operation of the OCTS and OMEGA Target Chamber

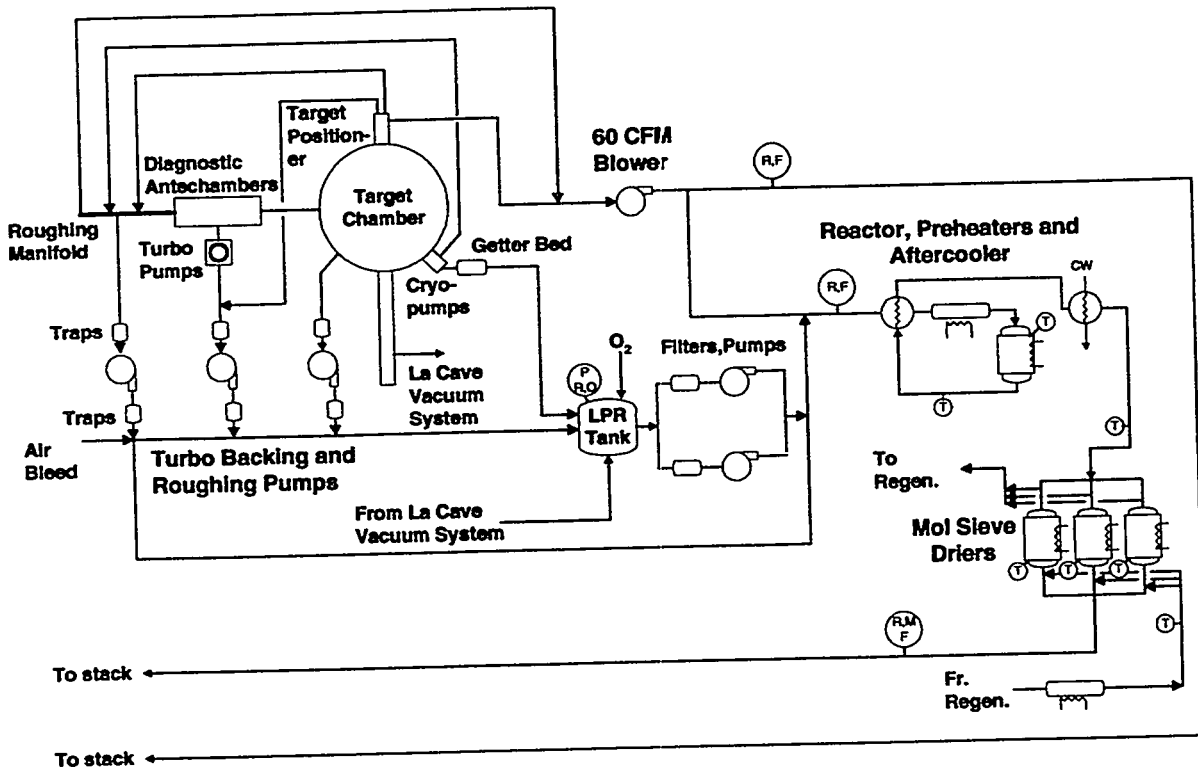
- OCTS equipment in Tritium Fill Station room
 - Four gloveboxes
 - Pumping manifolds
- Target Chamber
 - Tank purging during maintenance
 - Rough pumpdown of Target Chamber
 - Purging of diagnostic antechambers
 - Rough pumpdown of diagnostic antechambers
 - Target Chamber cryopump regeneration gas

Los Alamos

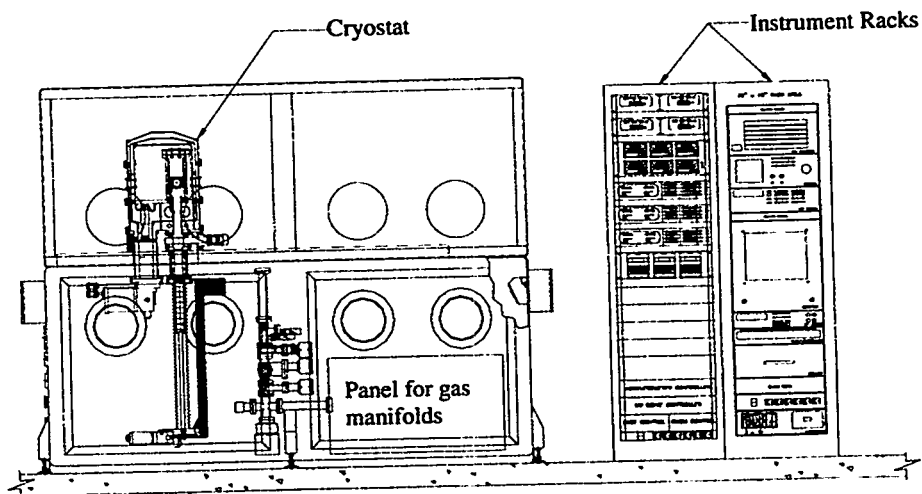
Rm. 157 Tritium Removal System (TRS)



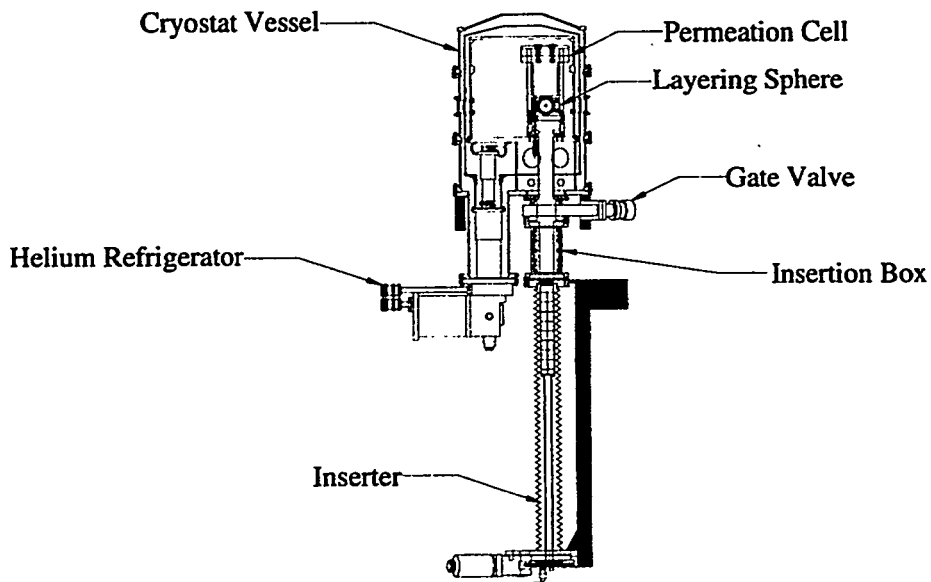
Target Chamber TRS



DT experiments will be performed with a small scale cryostat at WETF



The cryostat will perform many of the same operations as the OCTS Fill/Transfer Station



Los Alamos

Summary

- Safe handling of tritium will be critical to the successful operation of the OCTS
- The system must operate under stringent tritium release constraints
- A number of tritium handling systems have been designed to meet the operating objectives

Los Alamos

A FLEXIBLE CRYOGENIC TEST BED

W.A. Baugh

General Atomics, P.O. Box 85608, San Diego, California 92186-5608

The Flexible Cryogenic Test Bed consists of five major components: A cryogenic refrigeration system, a vacuum chamber, a vacuum pumping station, an instrumentation process control panel, and a Helium Leak detector.

A cryogenic refrigeration system consists of three major components: a Cryogenic Helium Compressor is a single-stage, water-cooled, rotary compressor, a two-stage Helium closed cycle cryogenic refrigerator, with a cold head and with the ability to reach temperatures of $<20K$, and flexible stainless steel supply and return lines that connect the refrigerator to the compressor.

A vacuum chamber (18" diameter by 18" high) with a 77K thermal shield and twelve interface flanges ranging from 1/2" to 7" on the sides, top and bottom, used for instrumentation, vacuum pumps, vacuum gauge, viewports, RF power and motion feedthroughs.

A vacuum pumping station consists of turbo pumping station (Verian Turbo-V250), multi-gauge controller to operate up to three ion gauges and eight silicon diodes gauged simultaneously.

The instrumentation and process control panel consists of a high performance temperature controller designed for use with most cryogenic temperature sensors. It also has two standard outputs that can be configured as a heater control to control the cryogenic system set point to within 0.01K.

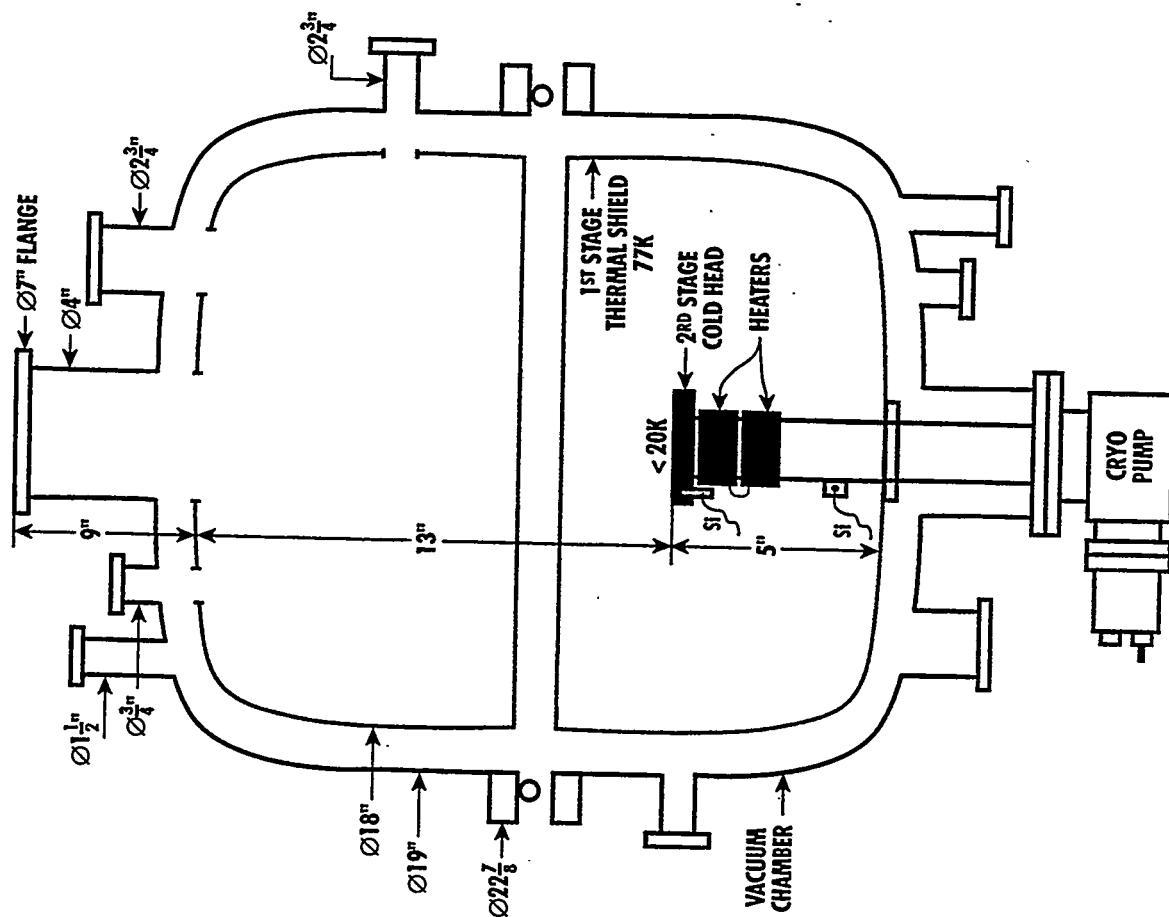
FLEXIBLE CRYOGENIC TEST BED

The purpose of the Flexible Cryogenic Test Bed is to test the conceptual design of subassemblies going into the Omega Cryo Target System

The Flexible Cryogenic Test Bed has the capability to test conceptual design of parts and subassemblies at cryo temperatures and sub-atmospheric pressures

The Flexible Cryogenic Test Bed can be altered or combined together with other vacuum chambers in various configurations to meet a wide variety of needs

A FLEXIBLE CRYOGENIC TEST BED



PERMEATION CELL

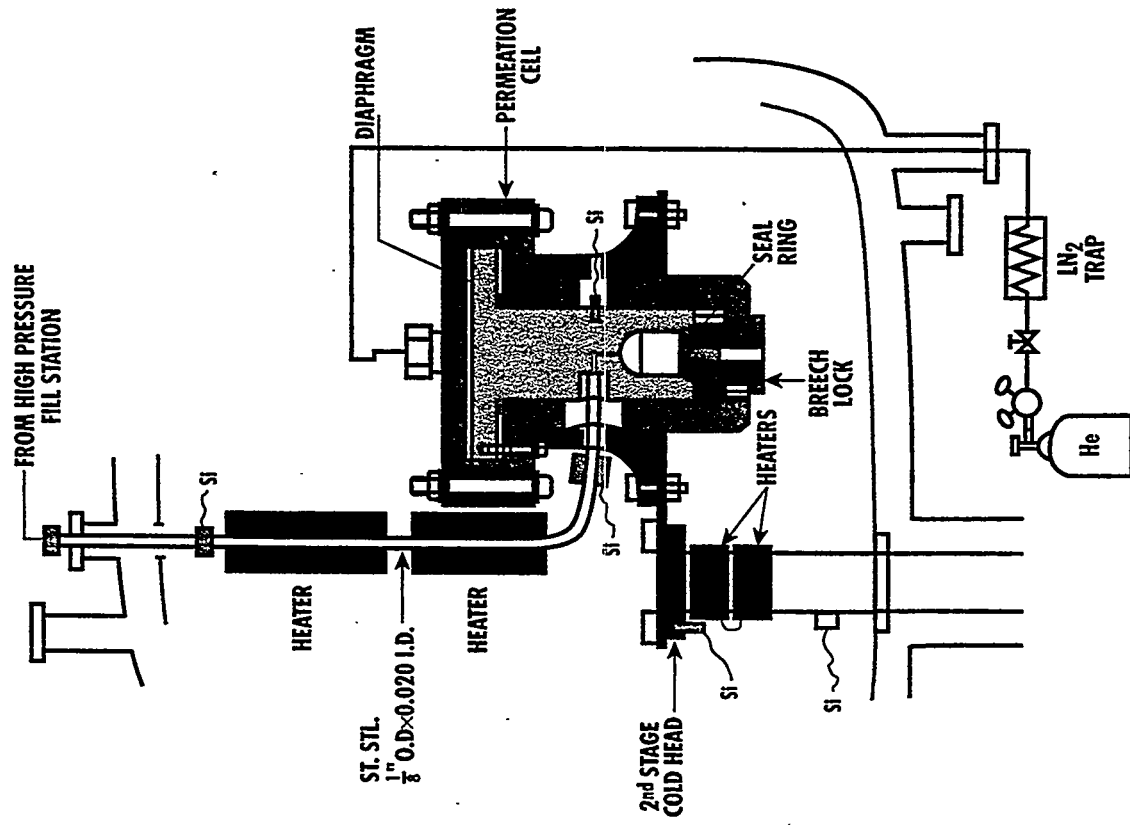
PURPOSE OF TEST

Supports Omega Cryo Target System (OCTS) and Fill / Transfer Station (FTS)

TEST OBJECTIVES:

1. Verify — Cell Design
2. Proof Test — 27,500 psi
3. Helium Leak — $<10^{-8}$ st cc atm/s
4. Mechanical Operation — 13K
5. 50 Cycles
6. Cryo Sealing — sealing against a surface that is at cryo temp

PERMEATION CELL



INFLATABLE SEAL TEST

PURPOSE OF TEST

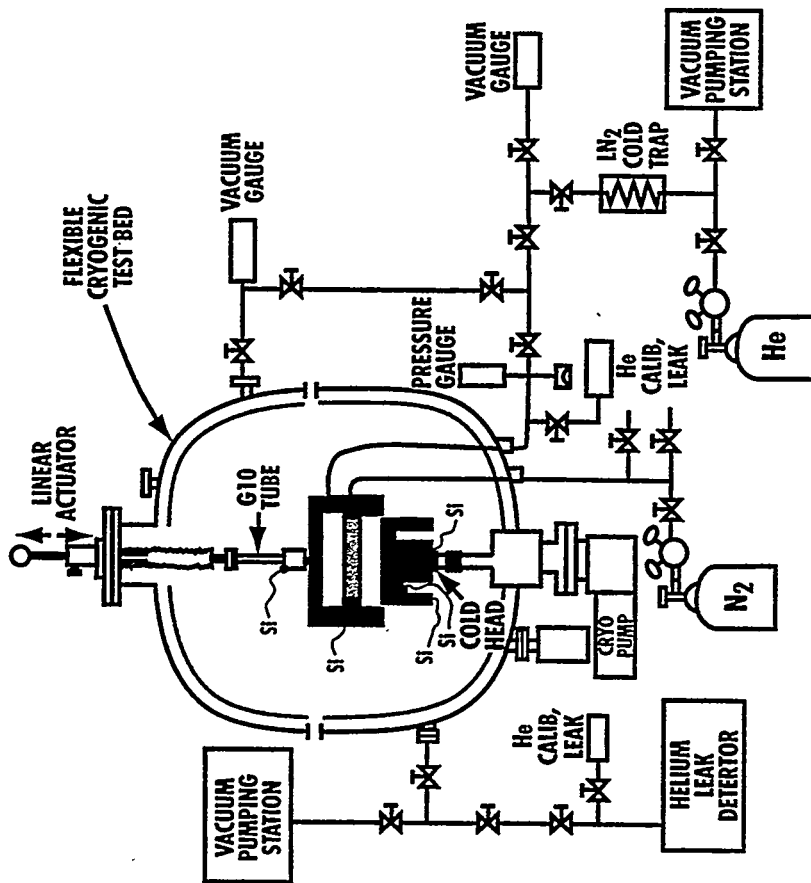
Supports Omega Cryo Target System (OCTS)

OCTS Requires Moving Cryostat Shroud Seal

TEST OBJECTIVES

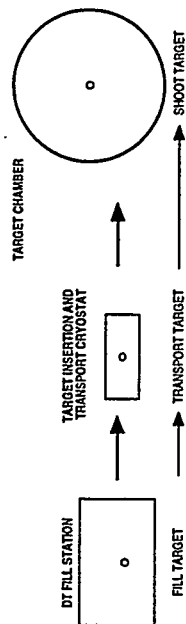
1. Sealing — with N₂ inflation gas, He challenge gas
2. Diffusion — with He inflation gas
3. Cryo Sealing — sealing against a surface begins at cryo temperature
4. Life Cycle — verify expected number of cycles
5. Thermal Transient — LN₂ immersion
6. Fit and Alignment of the Components — ease of separation

INFLATABLE SEAL TEST



INTRODUCTION

- With the ultimate tensile strength (σ_{ult}) of GDP capsules, the temperature at which the capsule will burst can be calculated for the fill gas density
 - Pressure in capsule = $\rho \cdot z(\rho, T) R T$
 - Burst Pressure = $\sigma_{ult} \cdot 4 (\text{Wall}_{\text{capsule}} / \text{Diameter}_{\text{capsule}})$ (for thin walled spherical shells)
- High density capsules will be filled with DT at a location separate from the fusion target chamber



- Temperature requirements for the cryogenic system, that transfers capsules/targets from the fill station to the target chamber, are set by the maximum required experimental fill density, the capsule σ_{ult} , and the required size range of capsule dimensions (outside diameter and wall thickness).

GENERAL ATOMICS

ABSTRACT

The burst strength of GDP capsules was measured at cryogenic temperatures for the first time. This was done over the temperature range from 34 K to 54 K. The thin walled, GDP capsules were made coating PAMS mandrels and pyrolyzing away the mandrels to leave the GDP capsule. The capsules were found to burst at a pressure that was proportional to aspect ratio (capsule wall thickness to diameter). The resulting ultimate tensile strength is 170 MPa. The tensile strength showed no clear temperature dependence in this temperature range. However this strength is approximately 2 times the room temperature tensile strength.

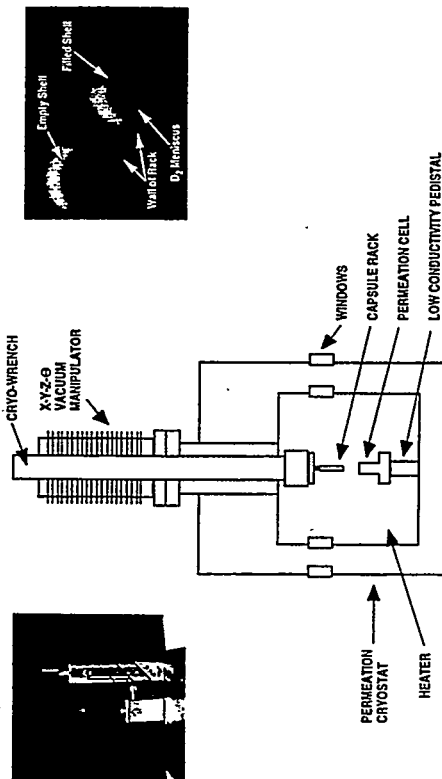
The experiments were performed by filling sets of capsules to high density with deuterium (16,070 psi at 293K). The capsules were then cooled to cryogenic temperatures in their permeation pressurization cell. At cryogenic temperature they were removed from the cell and observed inside of the cryostat through windows to determine which targets were filled. The capsule were then placed back inside of the cell and the temperature of the cell raised and equilibrated. The capsules were removed from the cell and again observed to determine which had burst and which remained filled. The cycle of placing the capsules back into the cell, raising the cell's temperature, and removing the capsules for observation was repeated until all of the capsules had burst. The burst pressure was calculated from the fill density and the temperatures at which the capsules were last observed filled and first observed to be burst.

* THIS WORK SUPPORTED BY U. S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC03-95SF20732.

GENERAL ATOMICS

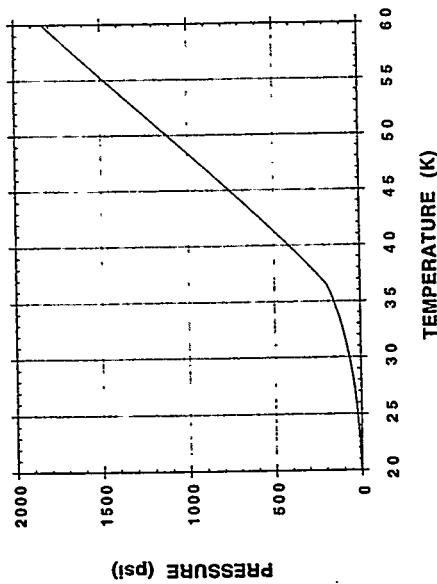
EXPERIMENTAL APPARATUS

- The gas intensifier system, permeation cryostat and cryo-wrench of the proto-type for OMEGA Cryogenic Target System were used.

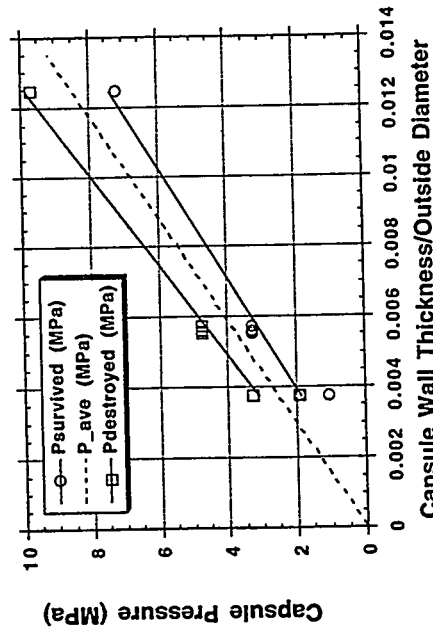


GENERAL ATOMICS

DEUTERIUM AT A CONSTANT DENSITY WITH 16,070 PSI AT 293K



PRESSURES DERIVED FROM TEMPERATURE AND FILL DENSITY



EXPERIMENTAL PROCEDURE

1. Load a set of capsules into individual holes of a rack
2. Seal rack into a high pressure cell in a cryostat at room temperature
3. Slowly fill cell with deuterium to 110.8 MPa (16,070 psi), permeating the capsule
4. Cool cell to cryogenic temperatures and evacuate the excess condensed D2 from cell
5. Open cell in cryostat and raise rack to level of cryostat viewing windows, note which capsules are filled by presence of meniscus
6. Put rack back in cell, raise temperature of cell to a desired fixed point, wait
7. Raise rack to level of cryostat windows, note which capsules are intact (survived) and which are missing (destroyed, burst, shattered)
8. If capsules remain, go to step 6.



RESULTS

Capsule Outside Diameter (µm)	Capsule Wall Thickness (µm)	Survived Filling ?	Highest Observed Survival Temperature (K)	Lowest Observed Destruction Temperature (K)
882	3.3	NO		
882	3.3	YES	35	38
882	3.3	YES	38	41
882	3.3	YES	38	41
882	3.3	YES	38	41
882	3.3	YES	38	41
882	5.1	YES	41	44
916	5.1	YES	41	44
921	5.1	YES	41	44
10.1	811	YES	49	54
10.2	786	YES		*
10.7	918	YES		*

* Remained intact up to room temperature. This implies that they failed in an unobservable manner (e.g. small pin hole or crack) at an unknown temperature. The other targets failed by a global catastrophic shattering into small shards.



A HIGH PRESSURE FILL AND BURST TESTING STATION*

Lloyd Brown, Martin Hoppe, and Stephen Grant
Fusion Group, General Atomics
P.O. Box 85608
San Diego CA 92186-5608

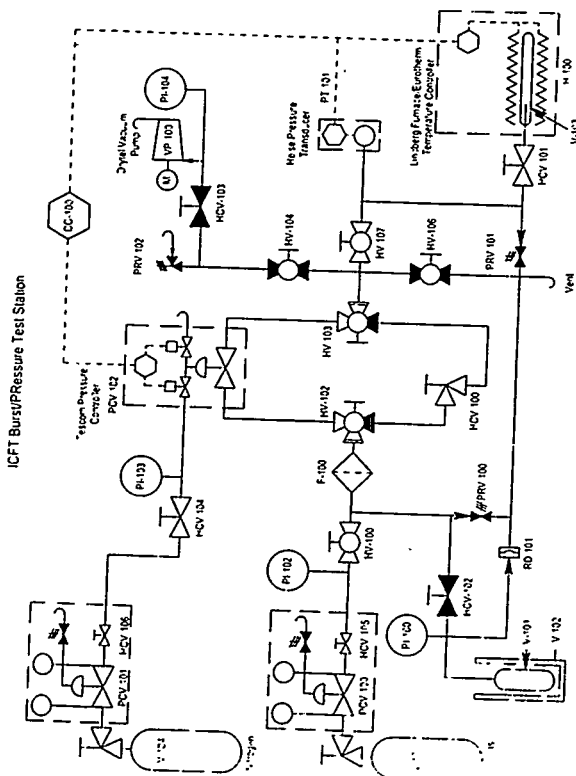
HIGH PRESSURE FILL & BURST TESTING STATION

We have built a new gas permeation system that is considerably smaller, more reliable and allows automated operation by computer with the potential ability to conduct multiple fills of a variety of gases at different pressures. The previous fill station required considerably more operator labor in slowly stepping up the pressure and at the end of the fill slowly decreasing the pressure. This new system requires negligible operator labor due to automatic operation and electronic control provides increased reliability.

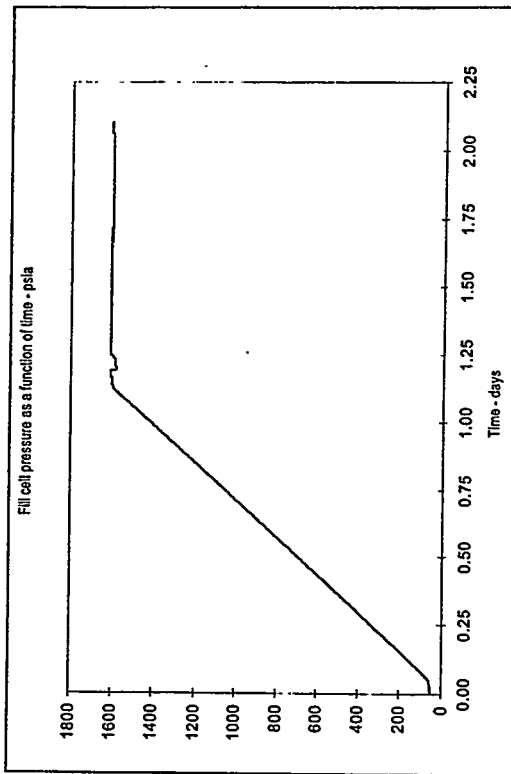
APPLICATIONS AND COMMUNICATIONS

This new station will generally be used to supply gas pressures up to 2,000 psia as well as utilizing a cryogenic intensifier with a volume of ~60 cc for an increased maximum pressure of 6,000 psia (400 atm) at 400° C (room temperature equivalent @ 180 atm). Fills are filled in the computer data base and can be retrieved in graph form showing the programmed ramp, step, and dwell of the fill.

*Work supported by U.S. Department of Energy under Contract No. DE-AC03-95SF20732.



DATA FROM TYPICAL 50 ATMOSPHERE FILL



COMPUTER PROGRAM

COMPUTER PROGRAMMED INTERFACE
WITH MICROSOFT VISUAL BASIC...
SOFTWARE TO ALLOW AUTOMATIC
CONTROL OF FILL TEMPERATURE,
RAMP & DWELL FILL PRESSURES

Date: 4/1/98 Time: 4:55:00 PM Data File: Undefined

Temperature Controller		Pressure Controller	
Fill Temperature	380	Fill Pressure	1588
Temp Set Point	20	Press Set Point	20
23			
Hold Time (min)	30	Prop Band (%)	25

Sequence Controller	
Elapsed Time (min)	not started
Load shells, evacuate and leak check	Press when done
Temperature ramp to fill temperature	Start Heat
Pressure ramp to fill pressure	
Holding at fill condition	
Isolate fill cell	
Cooling	

MOUNT / BLAST SHIELD

1/2 INCH LEXAN UTILIZED FOR PANEL
MOUNTING OF VALVES,
AND ENHANCED SAFETY FOR
PERSONAL PROTECTION

PERMEATION CELL

EFFECTIVE FRACTION OF CELL VOLUME HEATED TO
FURNACE TEMPERATURE IS ~98% AT 360°C
- ELIMINATES THE NEED FOR PRESSURE RELIEF
DURING COOL DOWN PHASE

TESCOM[™] COMPUTER CONTROLLED REGULATOR

THE ER 3000[™] ELECTROPNEUMATIC CONTROLLER
PROVIDES A TRUE DISTRIBUTED PRESSURE
CONTROL OF GAS FROM VACUUM TO 10,000 PSIG
GIVING THE SYSTEM CLOSED
LOOP FEEDBACK CONTROL WITH EXCEPTIONAL
ACCURACY AND RESPONSE TIME

CRYOGENIC INTENSIFIER

PROVIDES FOR DOUBLING OF THE FILL
GAS PRESSURE

FURNACE CONTROL

SYSTEM FURNACE IS COMPUTER
CONTROLLED AND INCLUDES AN
OVERTEMP SHUTOFF IN THE EVENT OF
FURNACE FAILURE



APPLICATION OF OPTICAL PROFILOMETERY TO ICF TARGET COMPONENTS*

**A comparison of "tried and true" techniques and those
using a Computer Aided Optical Profilometer**

by: Charlotte M. King

Acknowledgments:

**S. Buckley
D. Coker (WJSA)
E. M. Fearon
R. McEachern
M. Saculla
R. Wallace**

***This work was performed under the auspices
of the U.S. Department of Energy by Lawrence
Livermore National Laboratory under contract
no. W-7405-Eng-48.**



Introduction

**Optical Profilometry allows non-contact surface
measurements of parts that may be damaged by
a typical stylus profilometer. Additionally, the tip
geometry of a stylus profilometer is limiting even
on parts where damage is not a concern.**

**These advantages led to the acquisition of a
commercially available Computer Aided Optical
Profilometer (CAPO).**

The following is a comparison of methods.

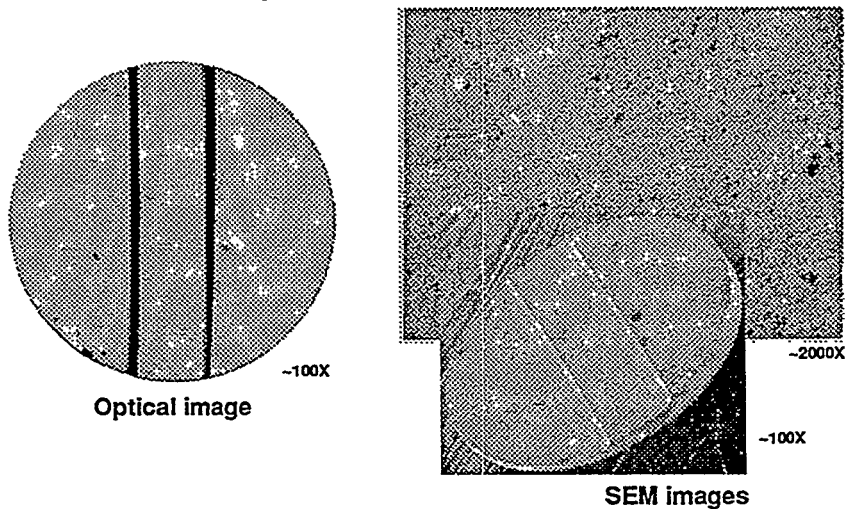
Computer Aided Optical Profilometer specifications

- Vertical resolution
 - 3Å (Phase Shift Interference)
 - <1nm (Vertical Scanning Interference)
- Maximum vertical range
 - 500µm
- Magnification
 - 2.5 to 97.7X
- Accuracy / repeatability
 - ±1%

Limitations of Computer Aided Optical Profilometer

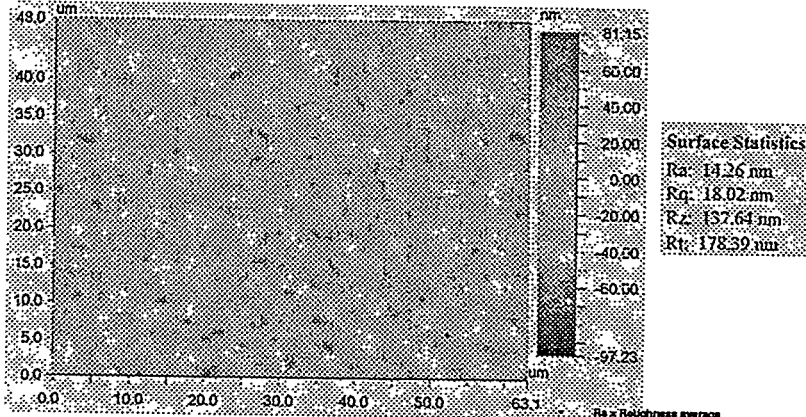
- When viewing large dynamic range subtle details are lost
- Data drops out on rough surfaces and steep slopes

Typical ICF aluminum stepped witness plate micrographs



- Difficulty in quantifying physical characteristics

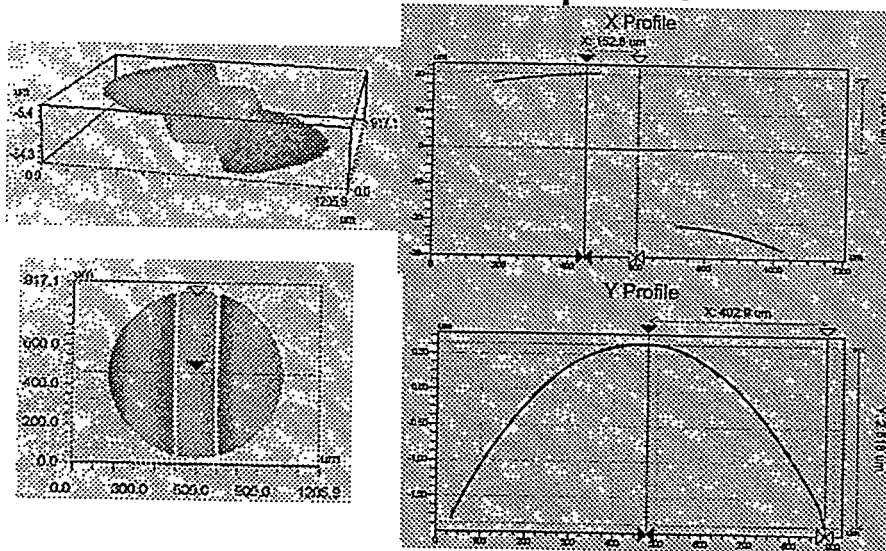
Typical example of CAOP data from aluminum witness plate surface



- With one measurement, CAOP gives both quantitative and qualitative information

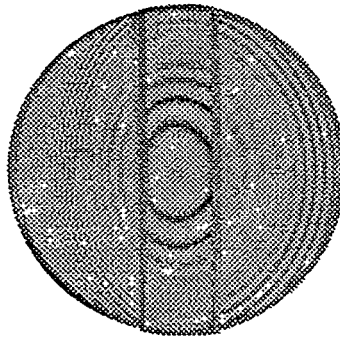
- Ra = Arithmetic average
 - mean height as calculated over the entire measured array
- Rq = Root mean square roughness (RMS)
 - rms average of the measured height deviations taken within the evaluation area
- Rt = Maximum height of the profile
 - vertical distance between the highest and lowest point
- Rz = Average maximum height of the profile
 - average of successive values of Rt within the sampling length

Example of CAOP data from aluminum witness plate showing large scale features and X and Y profiles

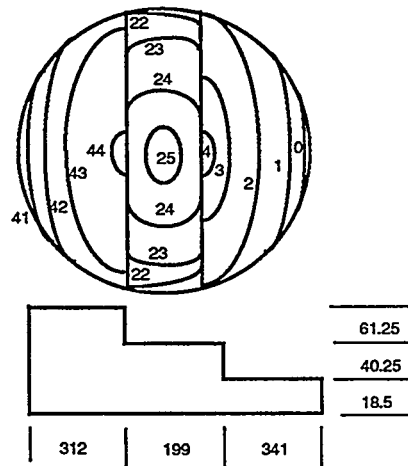




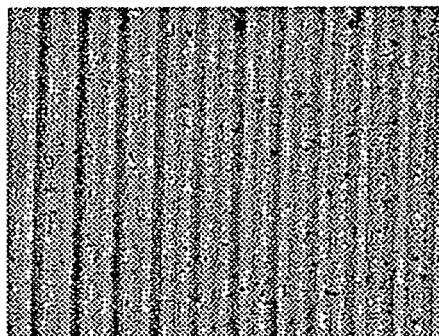
Traditional labor intensive approach to characterizing witness plates



- Profiled by hand mapping
 - This approach takes 5 times longer than CAOP



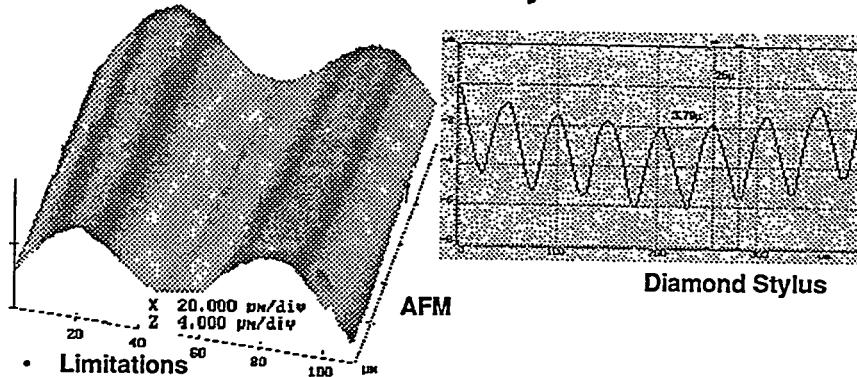
Typical ICF Rayleigh-Taylor package micrograph



100X

Optical Micrograph:
limited qualitative data
(some x-y data)

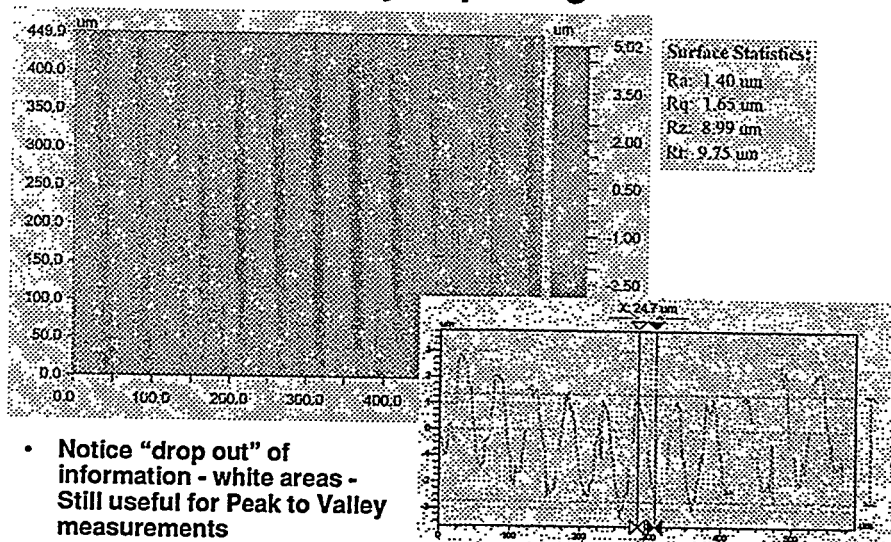
Profiles of Rayleigh-Taylor package from AFM and diamond stylus contact profilometry



• Limitations

- Requires surface contact
- Stylus tip distorts Peak and Valley data
- Maximum height difference (with current LLNL technology) each system can work with
 - AFM 5μ
 - Diamond Stylus 160μ

Example of CAOP data from Rayleigh-Taylor package

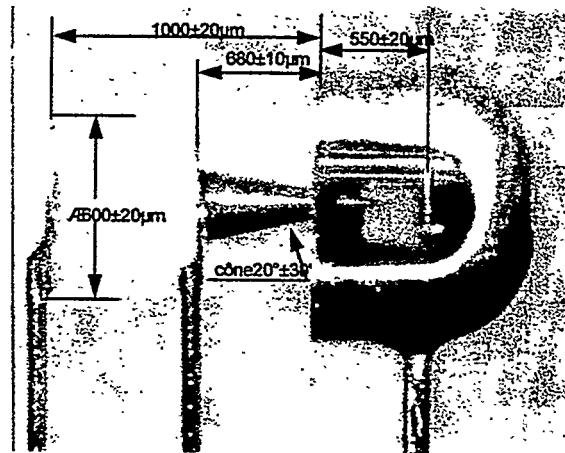


- Notice “drop out” of information - white areas - Still useful for Peak to Valley measurements



Target Assembly and Metrology at CEA Limeil Valenton

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fax. 01 43 86 74 38



TFSM 98 Jackson Hole



Direction des Recherches en Ile-de-France

DRIF - 17/04/1998 - 1

Target Assembly and Metrology at CEA/Limeil Valenton

Abstract

At the heart of laser driven Inertial Confinement Fusion experiments are tiny targets. Their size, constituting materials and fabrication processes have evolved to meet the demands of doing experiments on high-powered lasers such as *Phébus*, an operating facility at CEA/Limeil-Valenton or the future *Laser MégaJoule (LMJ)* facility.

Within the numerous targets designed and fabricated at CEA/Limeil-Valenton are, for instance, those for electronic temperature measurements in gas-filled target or those for debris generation and effect measurements for *LMJ* target chamber dimensioning studies. The uniform high temperature environment and the density conditions are provided by the use of small millimeter-sized hohlraums driven by the current *Phébus* laser (2 * 3 kJ energy of 0.351 µm wavelength in a nanosecond pulse regime).

Based on such examples, the proposed paper will present both the assembly and metrology methods and advanced capabilities developed at CEA/Limeil-Valenton to produce the targets.

Debris production measurements on Phébus facility are critical for target chamber dimensioning of the LMJ project

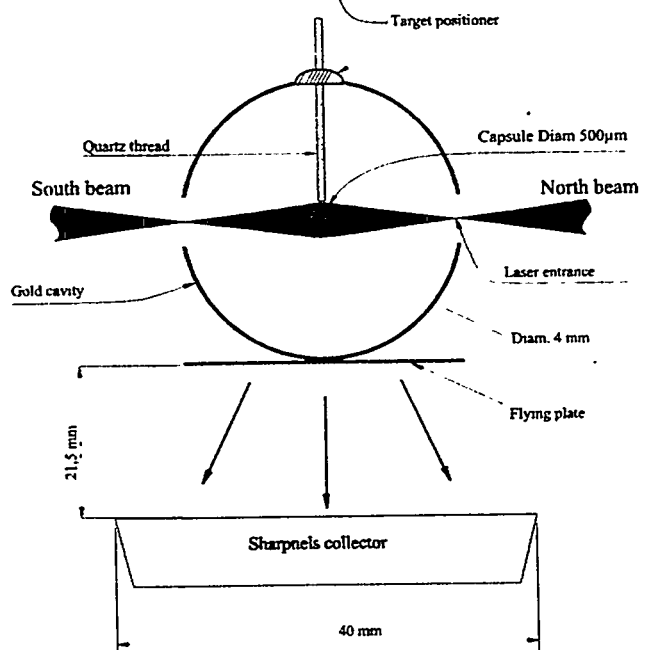
Numerical and experimental studies to :

- produce debris impacts onto different materials to address debris rate determination,
- evaluate debris effects onto materials of the LMJ target chamber.

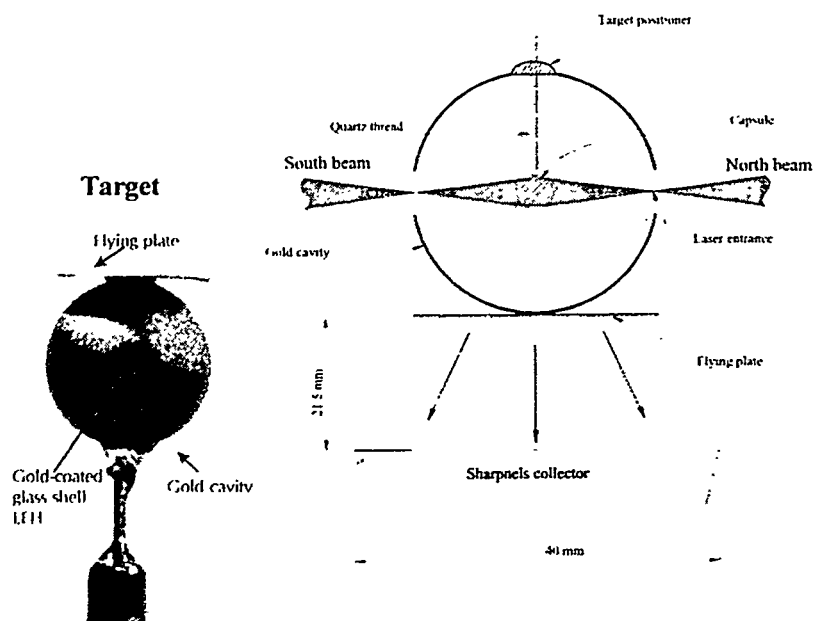
Debris production experiments on Phébus facility

Conditions of the experiment

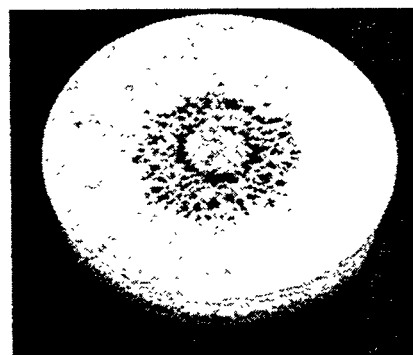
- Laser energy :
3 kJ / beam
Pulse duration : 1,3 ns
- Flying plates :
stainless steel, aluminium, copper
- Collector materials :
polyethylene, glass, B₄C, SiO₂



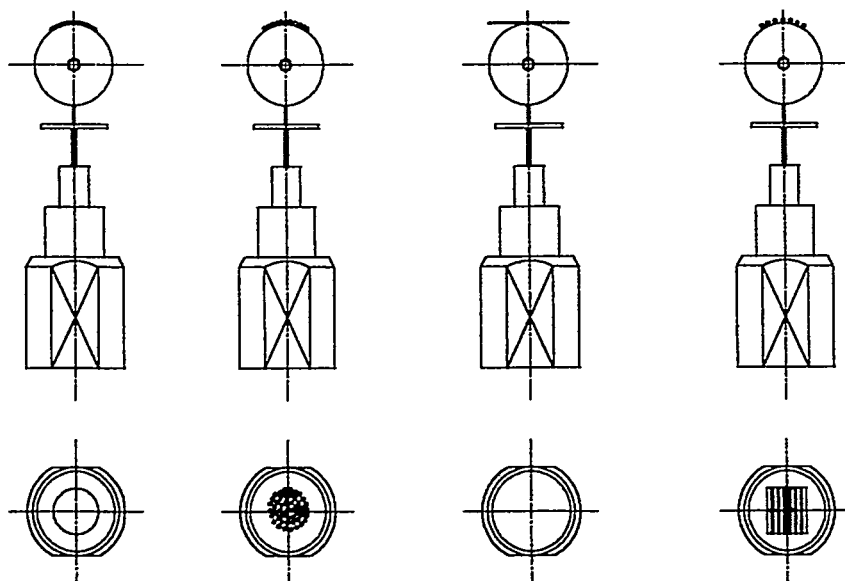
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Polyethylene collector



Different debris production targets





ASSEMBLY STATION

Target positionner

- 3 translations
- 2 rotations

Resolution : $1\mu\text{m}$, 10^{-30}

Part positionner

- 3 translations
- 3 rotations

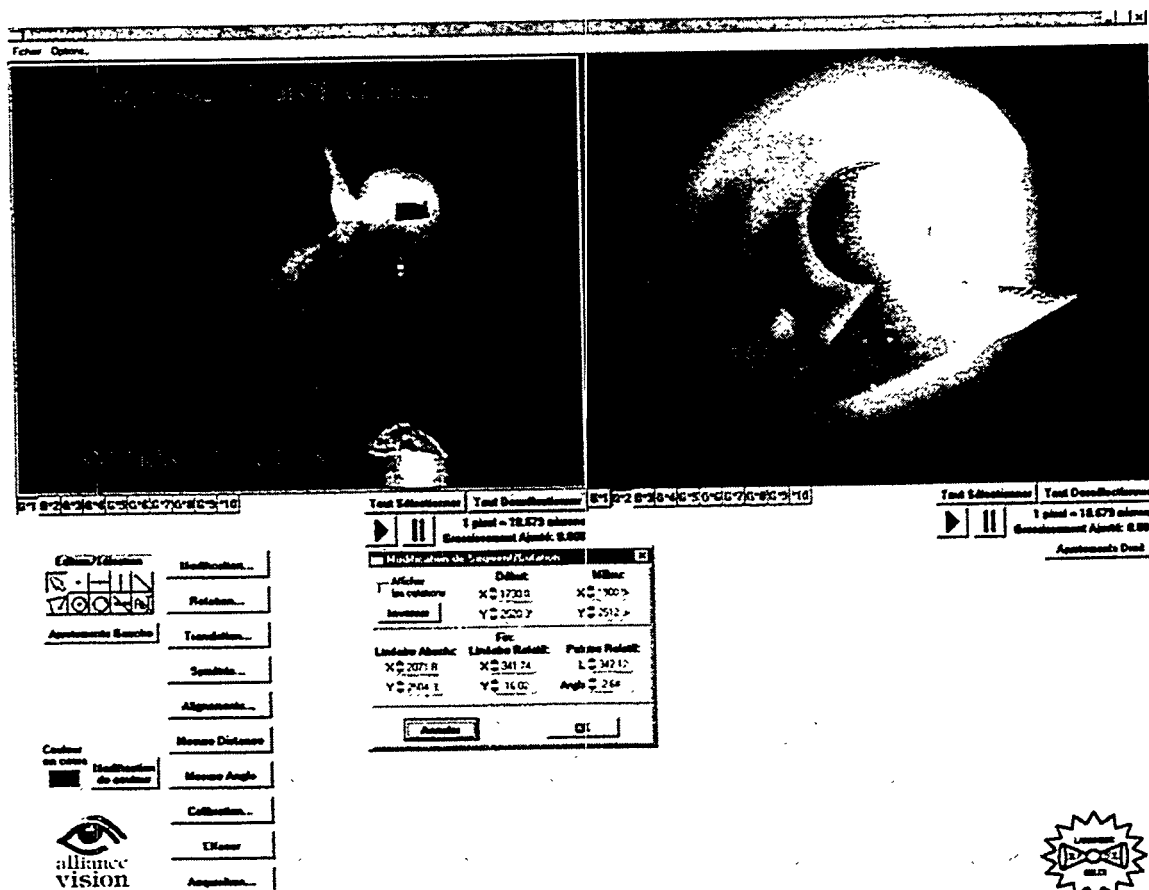
Resolution : $5\mu\text{m}$, 10^{-20}

1 motorised displaceme
(5 soon)

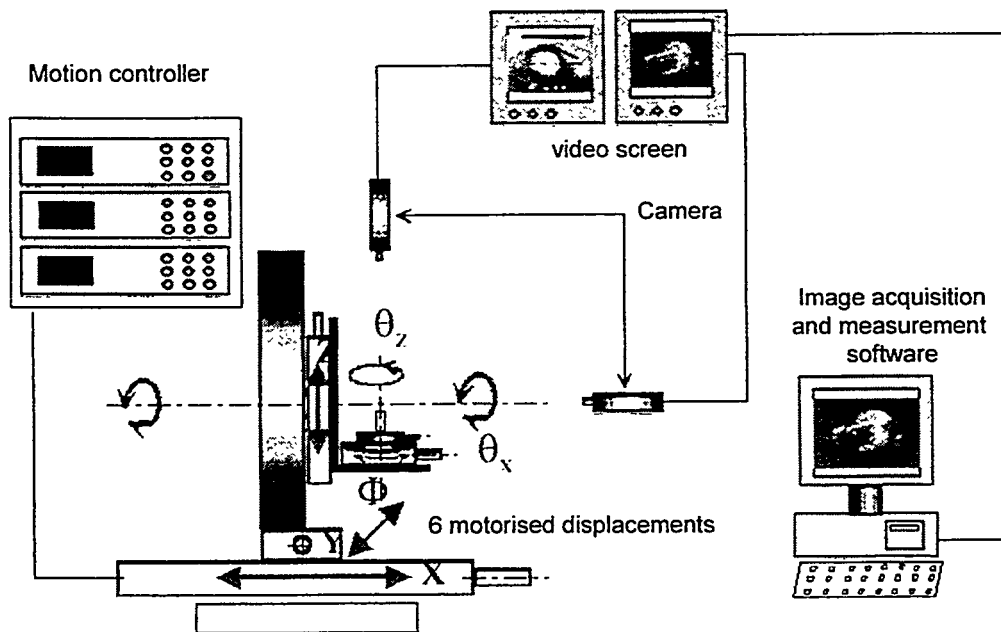


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Metrology station



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DRF 17041200 1

Metrology station



Accuracy : $> \pm 10 \mu\text{m}$

Microscope



Accuracy : $> \pm 3 \mu\text{m}$

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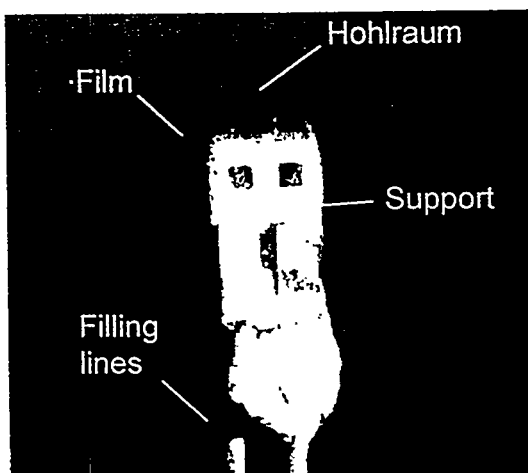
Gas-filled target experiments on Phébus facility

Use of gas-filled hohlraum is considered for the indirect drive ignition and burn of capsule containing DT mixtures on the LMJ facility.

Main issues :

- high precision assembly of the different constituting target parts
- durable and tight assembly of LEH and diagnostic membranes

Gas-filled target assembly

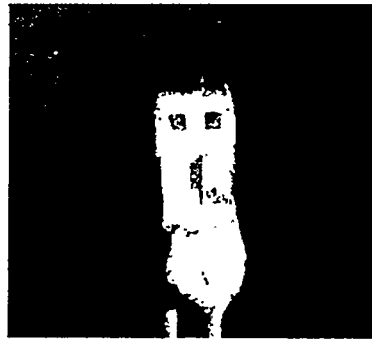
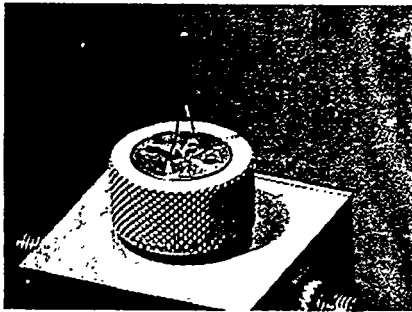


Main stages of assembly operation

- Cu lines welded on brass support
- hohlraum positionning and gluing on brass support
- window gluing on hohlraum
- leak measurements

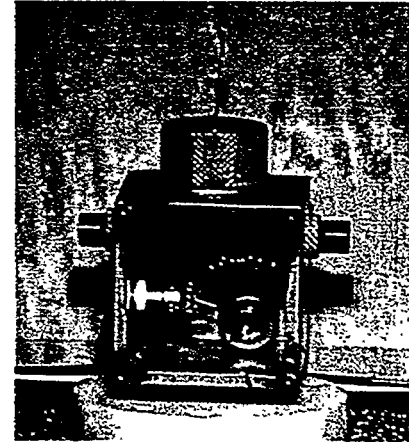
Gas-filled target experimental set up

Target above the
sensor box

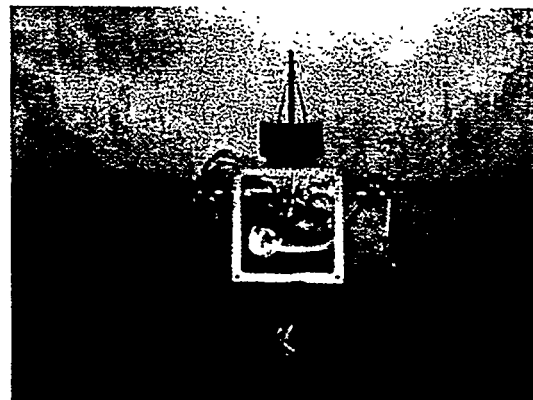
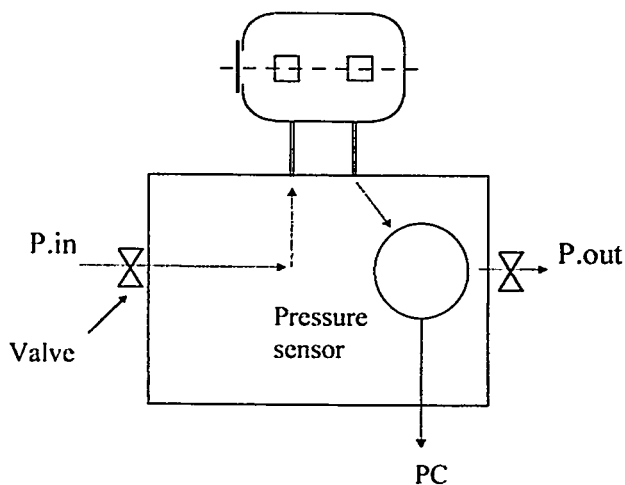


Gas-filled target

Sensor box

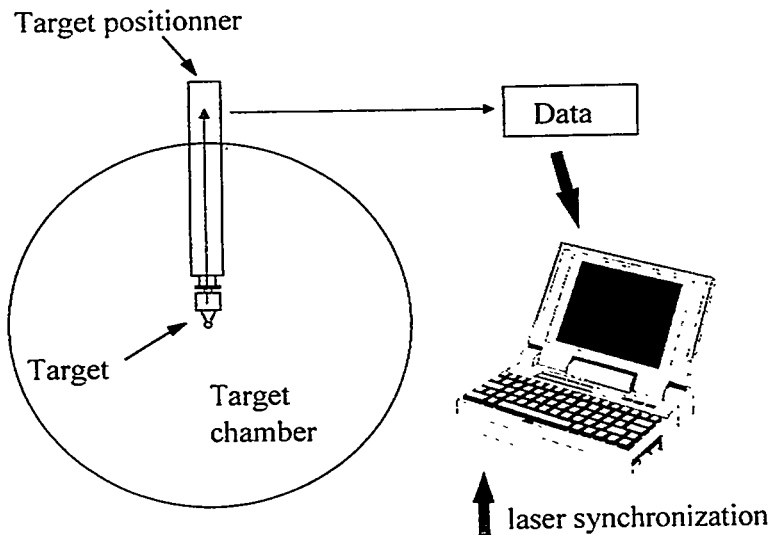


Pressure sensor box



Gas-filled target and both
the filling system
and the pressure sensor

Implementation of gas-filled target experiments in the target chamber



Measurement is made using :

- a pressure sensor
- an amplifier
- with an accuracy : $\pm 1\%$

Data acquisition :

- I/O device
- Labview software

Fabrication of Miniature Targets for Nova

**Anthony Demiris, Hedley Louis, Larry Logory,
and David Farley**



***Lawrence Livermore National Laboratory
Livermore, California 94551***

**Target Fabrication Meeting, April 1998
Jackson Hole, Wyoming**

Work performed under DOE by LLNL under Contract No. W-7405-Eng-48.

Introduction to miniature target fabrication



Millimeter-scale shock tubes with precision-machined submillimeter features have been fabricated for experiments conducted on the Nova Laser facility

Materials used in these experiments often require precision machining of features as small as 1 μm

The ability to conduct quantitative experiments depends critically on the precision with which these targets can be constructed

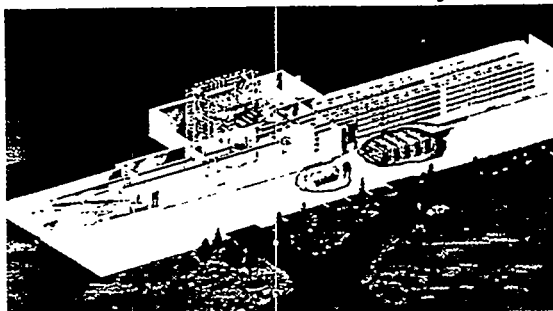


**Target fabrication
requires precision
diamond turning
machines operated by
skilled and dedicated
workers**

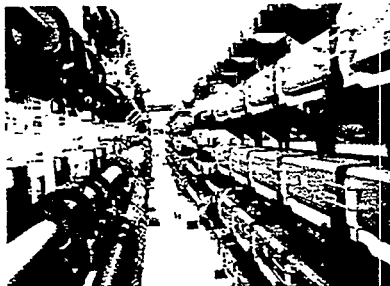
Our experiments are performed at the Nova laser facility



The Nova Laser Facility



Laser Bay

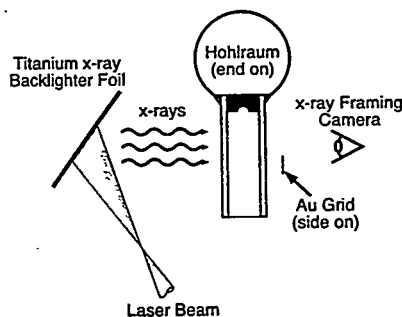
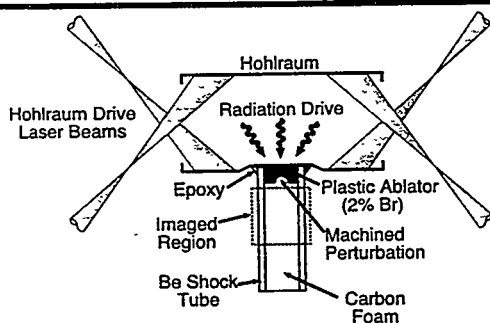


Target Chamber



We use Nova to provide over 22 trillion watts of power to drive our experiments

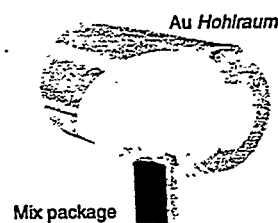
Nova is used as a driver to send a strong shock down a miniature shock tube



1. Eight of Nova's beams heat the hohlraum to 2,000,000 °K
2. Ablation drives a shock down the miniature shock tube
3. The flow is backlit using a titanium backlighter foil
4. The flow is imaged with a gated 2-D x-ray framing camera

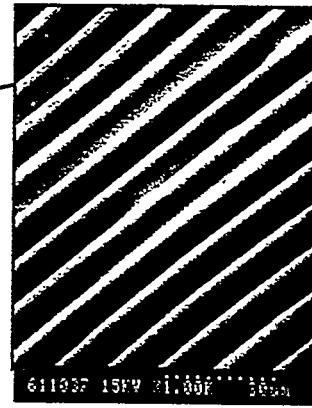
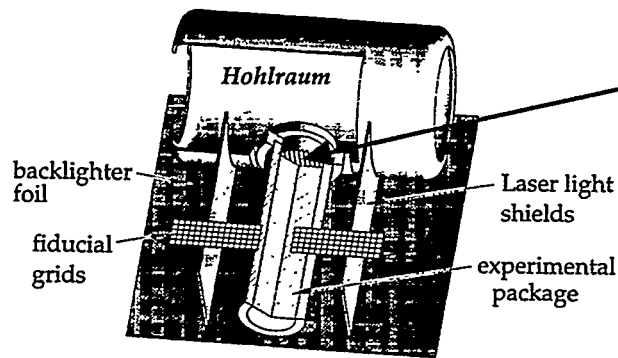


Target shown with US dime for size comparison

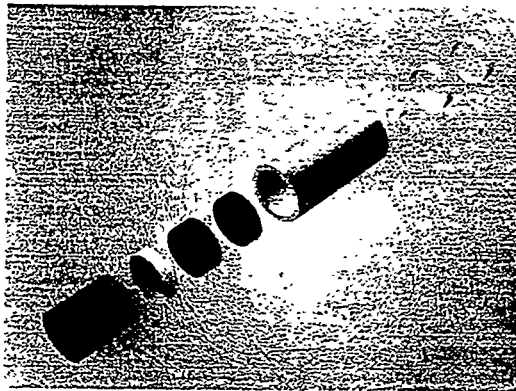


Cut-away view of package mounted to the hohlraum

Target designs typically incorporate several precision machined parts



linear grooves, $\lambda = 10 \mu\text{m}$

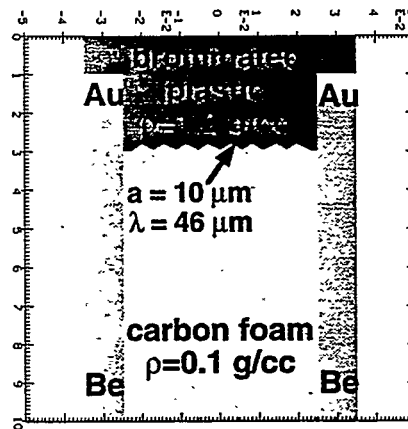


Some targets are assembled from many precision machined parts

Numerical simulations guide the investigation, and the results are confirmed by experiment

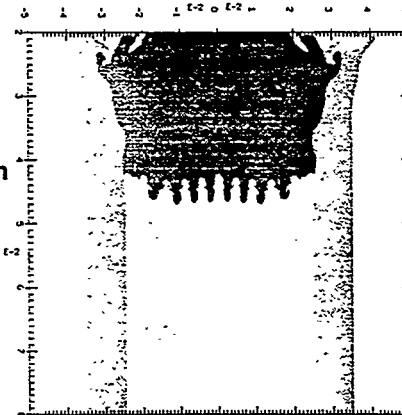


Numerical Simulations

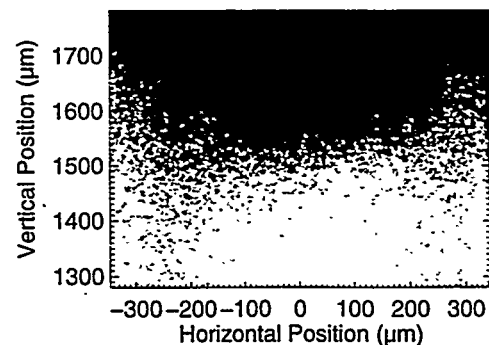


Shock
Propagation

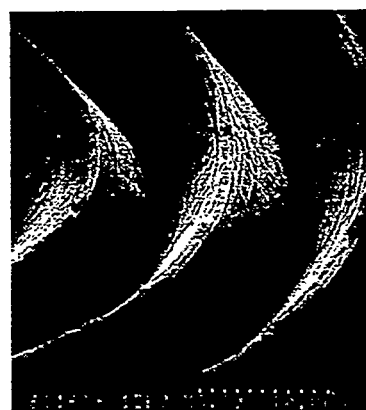
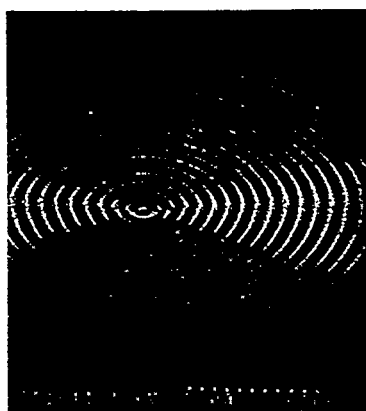
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Experimental Data



Circular sawtooth perturbations have also been investigated



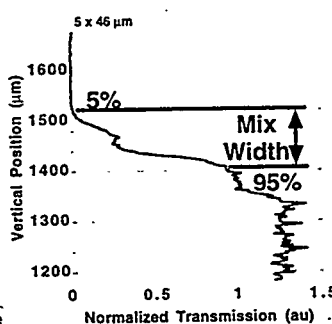
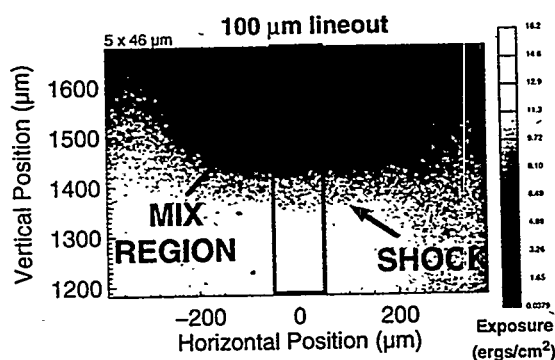
These SEM images illustrate the precision of the machining process and the quality of the surface finish

amplitude = $10\ \mu\text{m}$
wavelength = $23\ \mu\text{m}$

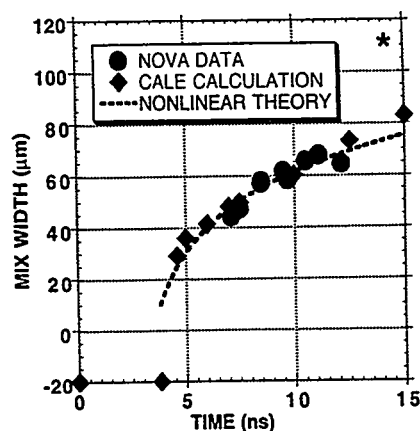
The experimental data is analyzed, and the results are compared with simulations and theory



The experimental data is determined from analysis of gated x-ray framing camera data



Measured data agree well with computer simulation and theory

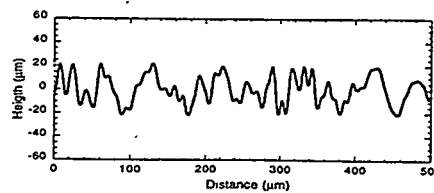


A surface profile consisting of the superposition of 100 sinusoidal waves was machined and the assembled target was shot



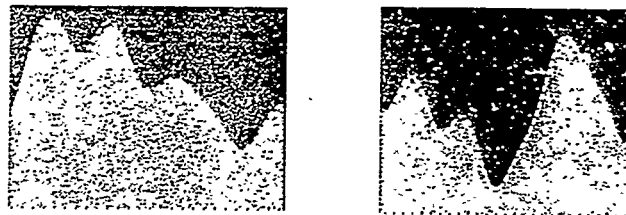
Desired surface profile

Constant Amplitude Ratio Machined Surface
100 modes (10 - 100 μm) ; $a_p/\lambda = 0.05$

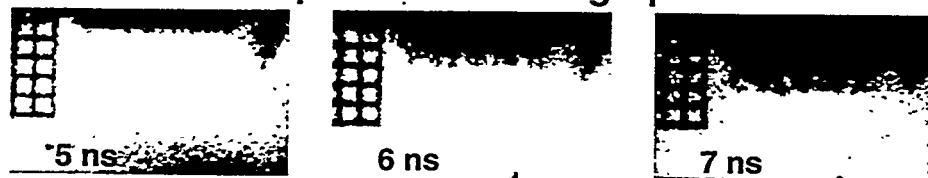


The machined profile matches the desired mathematical function (dashed line)

SEM images of profile



Experimental radiographs



A hemispherical perturbation has been machined to serve as the source of a high-speed jet flow



Two plastic ablator configurations were used:

- brominated plastic, or
- brominated plastic with a 2 μm -thick layer of scandium coating as a tracer

side view
brominated plastic ablator



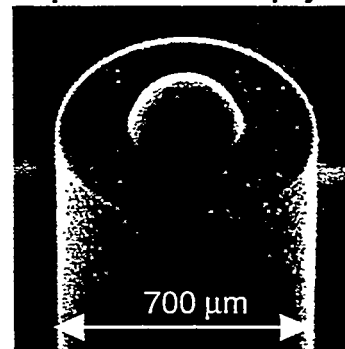
side view
Sc-coated brominated plastic



Brominated plastic ablator :
Density = 1.22 g/cm^3
Surface finish $\approx 0.1 \mu\text{m}$

Foam payload :
Density = 0.1 gm/cm^3
Surface finish $\approx 2 \mu\text{m}$
Cell size $< 0.1 \mu\text{m}$

Oblique view of foam payload

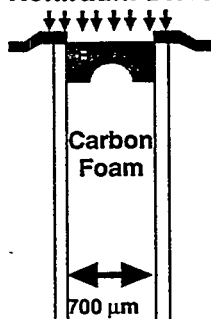


(All parts micromachined with diamond tools)

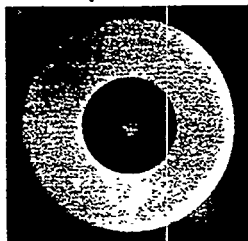
The hemispherical perturbation was uniformly coated with a 2- μm -thick layer of scandium metal



Experiment Schematic Hohlraum Drive



Plain plastic ablator



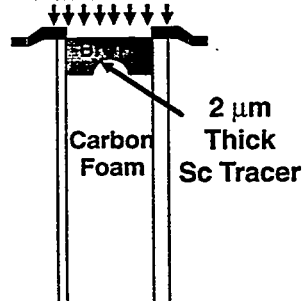
End View

Scandium metal is vapor deposited onto the inner surface of the hemisphere

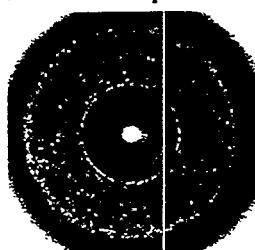


SEM images of scandium-coated ablator prior to final machining

Hohlraum Drive



Scandium coated plastic ablator

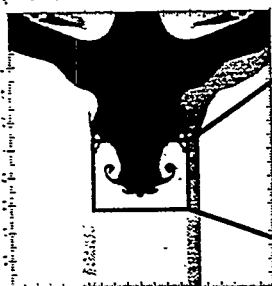


End View

Comparison of simulations and experimental data indicate good agreement for the high speed jet flow



simulated material Plots

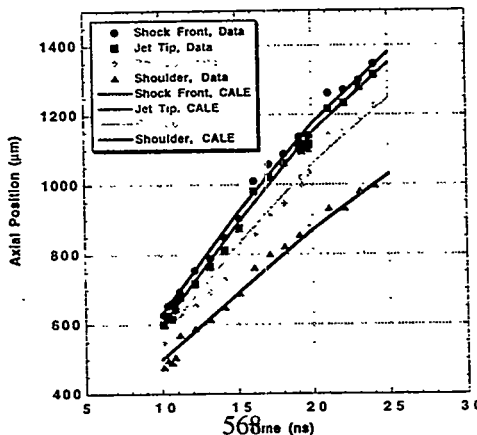


$t = 25 \text{ ns}$

simulated radiographs

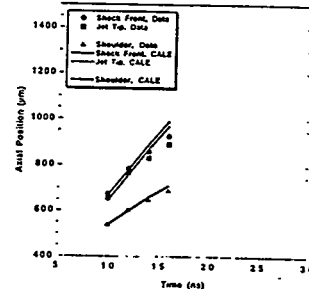
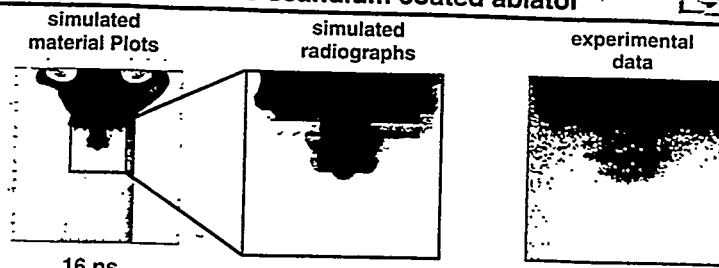


experimental data



Comparison of jet feature locations as a function of time from experiment and simulations indicates good agreement

Comparisons indicate poor agreement for the high speed jet flow with the scandium coated ablator



This data from the scandium-coated ablator design indicates that additional simulation development is required

Computer Aided Optical Profilometry has increased productivity



- Current stage allows for larger parts
- Minimal environment requirements needed
 - Modest vibration and temperature controls
- Data Outputs
 - Color topographic "map"
 - Profiles of area of Interest
 - Calculated surface properties (Ra, Rq,...)

Summary

Optical profilometry allows non-contact measurements with increased quantification and productivity, although it does have limitations.

The Fabrication of Three-Dimensional Laser Target Microstructures

Robert P. Keatch and Brian Lawrenson

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The University of Dundee, Scotland, UK Tel: +44(0)1382 344778*

Abstract

This paper describes the processes developed for "micromachining" novel, three-dimensional structures into silicon wafer substrates and other mediums. The structural detail and dimensions required are similar to those encountered in the manufacture of integrated circuits and consequently, the techniques of oxidation, photolithography, wet, dry and photo-enhanced etching, and vacuum deposition all have the potential for use in this area of microfabrication. Although the techniques described are primarily directed towards new processes for the production of miniature free-standing laser targets with varied surface profiles, these techniques are not limited to this, and can be applied to areas such as microsensors and biomedical technology

51 The use of silicon within the microelectronics industry relies heavily on the surface finish of the substrate. To this end, the surface flatness of the polished wafer is paramount to the subsequent fabrication stages when producing integrated circuit devices. Any abnormality in the surface would manifest itself during coating and photolithographic processing leading to device failure. However, in the field of microengineering, the surface itself, rather than the underlying substrate, may be the active element of the device. Examples of this can be found in various applications including optical devices such as diffraction gratings and phase shift photomasks as well as mechanical devices such as ink-jet nozzles, atomic force microscope stylus, microsensors, and laser target components.

Since surface topography is of paramount importance to the final target device manufactured, techniques have been developed to create reproducible surface profiles. These profiles include

sawtooth, trapezoidal, square-groove, blazed, and sinusoidal waveforms with varying amplitudes and wavelengths. The techniques for producing these profiles can rely either on the substrate material chosen (which may exhibit certain surface characteristics), or the method by which a profile is directly imaged into the surface. The complete fabrication process involves a combination of selective removal (known in general as etching) to generate the desired topography and then subsequent deposition to reproduce the desired structure in the chosen material. Other substrate materials including free-standing films have also been employed. These include amorphous silicon, polyimide, carbon, nickel foil, copper coated laminates, fused quartz, and glass slides. Techniques such as electroplating, sacrificial release, x-ray transparency, and u-v transparency have all influenced the choice of substrate material.

Figure 1 shows a flat silica disc supported on a tall pillar of silicon produced by means of a combination of plasma etching and conventional wet etching. Very high sidewall definition may also be realised by utilising crystallographic etching. This involves the selective exposing of <111> planes and if the correct orientation is chosen, they may be used to form v-grooves or square groove profiles with very smooth sidewalls. Subsequent incorporation of these profiles into the microstructure by employing several fabrication stages provides a substrate for the production of corrugated targets. Under high magnification as shown in figure 2, the ability for mass-production and excellent quality of the surface and edges of the released target becomes apparent. These are the hallmarks of microfabrication technology.

Research Facility

The microfabrication facility at Dundee University was first established some 15 years ago with the intention of providing the capability for fabrication of discrete solid state electronic devices, a variety of transducers and sensors, and complete MOS integrated circuits. Building on our expertise in these areas we have been expanding our capability into the new field of microengineering. The

equipment for producing the photomasks enables us to produce structures having features down to about 0.8 microns in size with a very fast turnaround time. We understand that this section of the laboratory is matched by few, if any, other UK universities. The equipment is housed in a cleanroom having a total area of 240 square metres, plus an additional general laboratory area of 98 square metres. The cleanrooms are maintained at positive pressure, and the intake air is filtered to Class 10,000. Further filtration is provided by laminar cabinets local to the equipment and this provides a working environment of better than Class 100. Vacuum, de-ionised water, compressed air and nitrogen services are distributed from a central plant room.

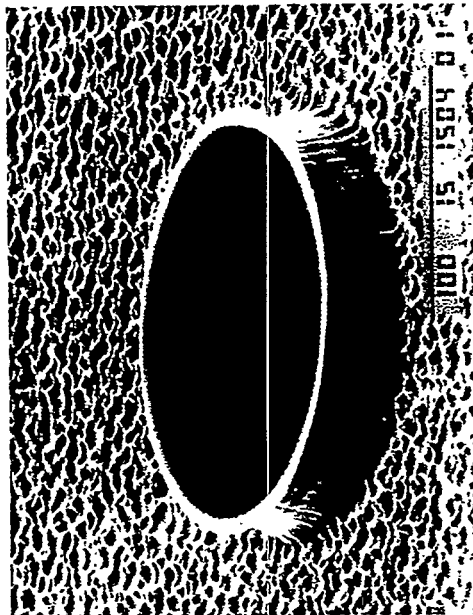


Figure 1 SEM of microstructure produced on silicon substrate

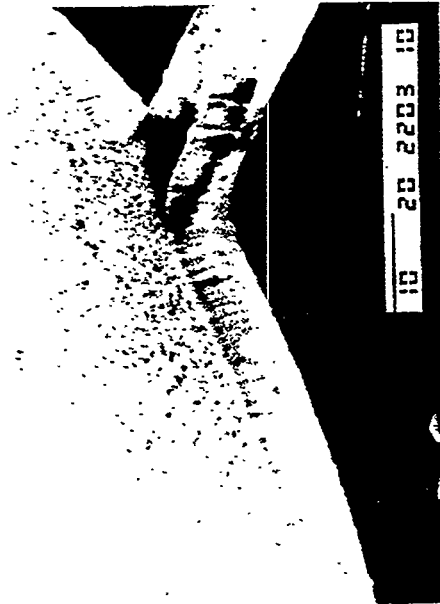
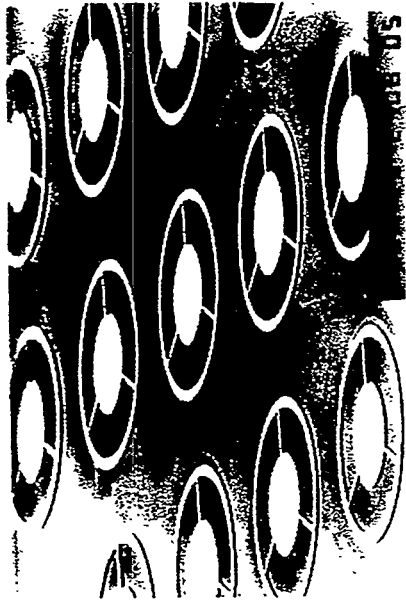


Figure 2 SEM showing microstructures and final gold laser target

Acknowledgements

We would like to thank the Target Fabrication Division at the Atomic Weapons Establishment UK, for access to analytical expertise and deposition facilities. This work was performed by the University of Dundee under an extra-mural research agreement.

Steve Lettis, Steve Buckley, Evelyn Fearon, Mike Saculla, and Robert Cook

Lawrence Livermore National Laboratory

Abstract

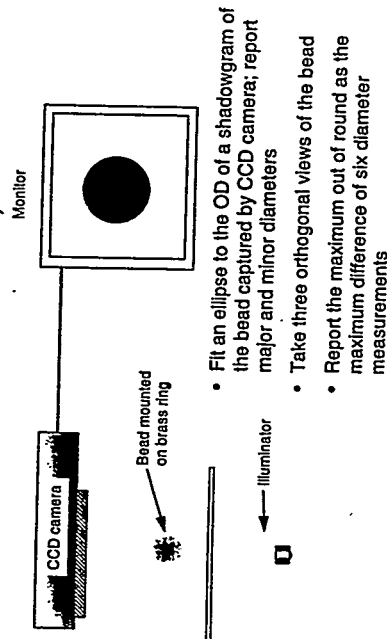
The "decomposable mandrel" approach, as currently practiced for preparing both Nova and Omega scale capsule mandrels, involves producing poly(α-methylstyrene) (PαMS) shells by microencapsulation, overcoating them with plasma polymer, and then thermally processing to decompose the underlying PαMS shell. This technique was originally developed using solid PαMS beads, however the ease with which tightly size controlled microencapsulated shells could be prepared with excellent sphericity at Nova and Omega scales led to the abandonment of the bead work in favor of shells. The extension of the microencapsulation approach to NIF scale shells has proved challenging with respect to maintaining excellent sphericity, and thus we have begun to reexamine the intrinsically simpler bead formation processes.

We will report on work in two areas. First we will present results on beads prepared in batch mode by heating highly plasticized commercial PαMS beads in a continuous bath. Using this technique beads with maximum out-of-rounds (MOOR) less than 5 μm have been produced. Second, we will discuss results obtained using density gradient columns to suspend single bead experiences due to the mixing of water baths during batch processing methods. Using various diol/glycerol mixtures, relatively stable density gradient columns can be prepared at temperatures as high as 150 °C. At these temperatures the commercial beads become fluid and spherical, however loss of the plasticizer and very low molecular weight components of the bead due to limited solubility in the column fluid leads to surface finish problems.

Work performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

Fast spherical characterization of large shells and beads is done on RACI

(Rapid Asphericity Characterization Instrument)

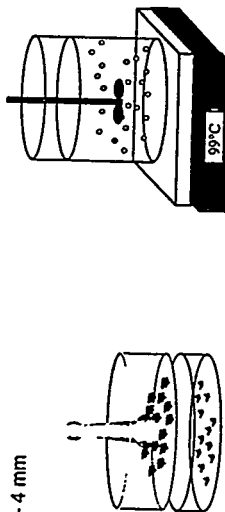


Smooth spherical PαMS beads are made in batch mode using an aqueous thermal treatment

Broad dispersity 19k Mw PαMS

Large beads

2 - 4 mm



Grind

Sieve cut

H₂O/PVA
Stir 8 hours
99°C

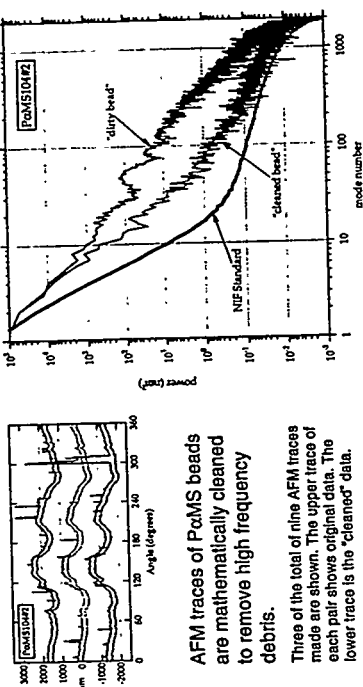
Beads spherulized in hot water have maximum out-of-round as low as 2-3 μm.

shell num	major axis μm	minor axis μm	MOOR μm	ave diam μm	MOOR μm
1X	2051	2048	3	2049	6
1Y	2052	2048	4	2049	6
1Z	2048	2046	2	2049	6
2X	1901	1899	2	1901	3
2Y	1901	1899	2	1901	3
2Z	1902	1901	1	1901	3
3X	1903	1901	2	1902	4
3Y	1904	1900	4	1902	4
3Z	1903	1901	2	1902	4
4X	1930	1927	3	1929	3
4Y	1930	1928	2	1929	3
4Z	1930	1929	1	1929	3
5X	2088	2080	8	2084	9
5Y	2088	2080	9	2084	9
5Z	2089	2080	9	2084	9
6X	1858	1856	2	1858	4
6Y	1859	1855	3	1858	4
6Z	1860	1857	3	1858	4
7X	2170	2168	2	2170	3
7Y	2171	2168	3	2170	3
7Z	2171	2169	2	2170	3
8X	1862	1861	1	1862	3
8Y	1863	1862	1	1862	3
8Z	1863	1862	1	1862	3
9X	2081	2079	2	2080	2
9Y	2080	2079	1	2080	2
9Z	2081	2079	2	2080	2

Group Ave: 1982 4.1

Improvement to < 1 μm out-of-round is necessary for NIF.

The power spectrum of the "cleaned" bead shows the need for more improvement to match the NIF goal.



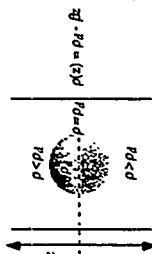
AFM traces of PαMS beads are mathematically cleaned to remove high frequency debris.

Three of the total of nine AFM traces made are shown. The upper trace of each pair shows original data. The lower trace is the "cleaned" data.

VO-33 4/21/90

Effect of Density Gradient on Sphericity.

Consider a fluid droplet with density ρ_d suspended in a linear density gradient column $\rho(z) = \rho_d - \beta z$.



We will assume a symmetric ellipsoidal deformation so that the equation of the deformed droplet can be expressed as

$$\frac{x^2 + y^2}{(r + \epsilon)^2} + \frac{z^2}{\left(\frac{r^3}{(r + \epsilon)^2}\right)^2} = 1$$

where ϵ is the positive deformation of the droplet radius r , in the xy plane.

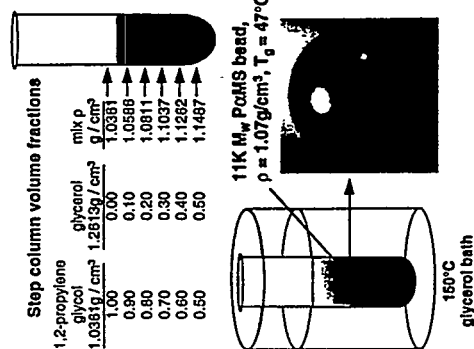
The buoyancy corrected gravitational potential energy of a mass unit, dm , of volume dV , in the droplet can be expressed as

$$d(G.E.) = dm \times g z = (\rho_d - \rho(z)) dV \times g z = \beta g z^2 dV,$$

thus the total buoyancy corrected gravitational potential energy of the droplet is

$$G.E. = \beta g \int_V z^2 dV = \frac{4}{15} \beta g \pi \frac{r^5}{(r + \epsilon)^3}$$

Spherical beads of PαMS are produced using a density gradient column.



• Step-column is heated to blend steps.

• A PαMS bead is suspended at 150°C (fluid state) for 4 h, then cooled.

• Distortion due to gradient is calculable ($\propto \Delta\rho/\Delta z$).

• Primary problem is slight solubility of bead plasticizer in column solvents.

• Single bead diameter variations of 3 to 5 μ m have been achieved.

VO-3 4/2/90

The surface energy, S.E. of the ellipsoid is the interfacial surface tension, γ times the surface area, thus the total energy, T.E. is given by

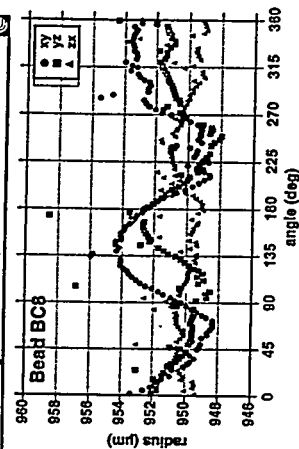
$$T.E. = S.E. + G.E. = \frac{4}{3} \pi \gamma (r + \epsilon)^2 + \frac{2\pi^3}{(r + \epsilon)} + \frac{4}{15} \beta g \pi \frac{r^5}{(r + \epsilon)^3}$$

and ϵ can be evaluated by minimizing T.E. with respect to ϵ with the result that

$$\epsilon = \frac{2\beta g r^4}{15\gamma} \left[\frac{1}{1 + 4\frac{\epsilon}{r} + \text{terms of } O\left(\frac{\epsilon^2}{r^2}\right)} \right] \text{ and higher} \approx \frac{2\beta g r^4}{15\gamma}$$

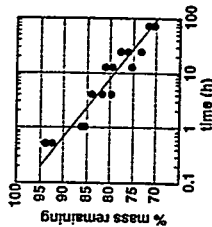
This expression allows us to evaluate what values of β , which characterizes the density gradient, are acceptable. If we want the shell to be less than 1 μ m out of round then ϵ must be less than 1/6 μ m or 0.16 $\times$ 10⁻⁴ cm. Using 0.1 cm for r and a conservative 10 dyne/cm for γ , we find that β must be no greater than 0.012 g/cm³cm. Thus on a 10 cm high column the density at the top must be no greater than 0.12 g/cm³ more than the density on the bottom.

Beads less than 10 μm out of round have been produced in a relatively crude density column.



MOOR (μm)	
BC8	6.3
BC9	14.5
BC10	6.3
BC12	4.1
BC13	16.2
BC14	10.5
BC15	14.0
BC16	10.6

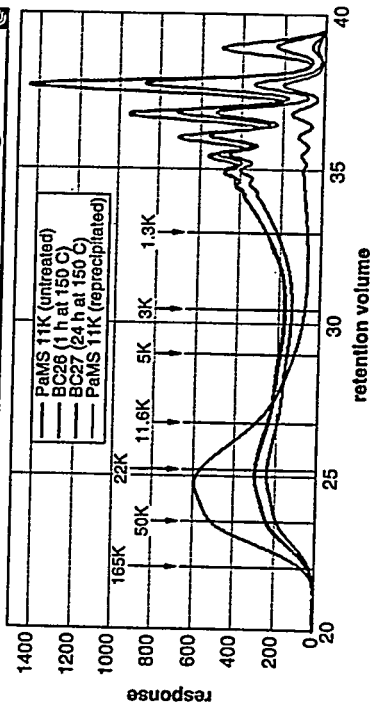
• Column gradient not less than about $0.03 \text{ g/cm}^3\text{cm}$. Predicted out of round at least $3 \mu\text{m}$



• Primary problem is solubility of some portion of bead material at elevated T. Significant mass loss is observed. When the column is cooled the solubilized material redeposits on the bead surface.

VO-5 4/21/88

GPC measurements confirm the loss of low molecular weight material from the beads during heating



The red curve is the original untreated PaMS bead material. The blue and green traces are for the PaMS bead material treated for 1 h and 24 h, respectively, in the 150°C column. The pink trace is for a sample of the PaMS material that was reprecipitated once, a method for removing low molecular weight components.

VO-5 10/18/87

Considerations for the Preliminary Design of the NIF Target Insertion Cryostat

Lee C. Pittenger, Jeff Latkowski, Jorge Sánchez
Lawrence Livermore National Laboratory

4/19/98

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.

NIF-0004579
LCP/inh- 1

General Design Considerations

NIF

The National Ignition Facility

- **Compatibility with NIF Target positioner**
 - Horizontal insertion
 - Payload limits assumed for positioner design and stability analysis
 - 200 kg mass
 - 2 m length (target to positioner boom interface)
 - 0.5 m diameter
- **Cryogenic refrigeration loads**
 - Heat transfer from surroundings
 - target
 - other exposed cold surfaces
 - thermal control inputs
- **Effects of yield target neutrons**
 - Heating of cryogenics
 - Activation

NIF-0004579
LCP/inh- 2

General Design Considerations (continued)

NIF

The National Ignition Facility

- X-ray and debris considerations
 - Shock absorption by crushable material - Testing of Al foam has demonstrated its suitability.
 - B₄C layer prevents ablation of Al sheet foam facing
- Size and placement of protective foam affect access for diagnostics and depend on:
 - effective size of the radiating source (the expanding *Hohlraum* material for indirect drive targets)
 - the distance from source beyond which ablation of unprotected material can be tolerated, which in turn depends upon the material (Al, Be, ?)

NIF-0004579
LCP/inh- 3

Cryogenic capacity

NIF

The National Ignition Facility

- The NIF target positioner design anticipates that the cryostat will be filled prior to mounting and will require only exhaust connections for spent (and heated to ambient temperature) cryogens.
- Supercritical He may be preferred to LHe as a refrigerant to avoid the disturbances of two-phase flow.
- After some iteration, we find that a tank containing 30 litres (2.57 kg. @ 2.5 atm.) of supercritical He @ 5.2 K will provide 1000 mW•days of refrigeration of a cold sink @ 8 K.
- The radiant load on a 6 mm dia X 12 mm high *Hohlraum* from a 300 K vacuum shroud is ≈ 23 mW; the estimated power for *Hohlraum* temperature profiling is ≈ 50 mW; and the β -decay load is negligible.
- A LN₂-shielded tank of the above size will receive ≤ 100 mW of radiant and conductive load with good cryogenic design practice.
- Taking, conservatively, the sum of the above loads to be ≈ 200 mW, such a tank would provide for 5 days' capacity.
- Such a tank also fits conveniently into the size envelope of the assumed positioner payload.

NIF-0004579
LCP/inh- 4

Cryogenic capacity (continued)

NIF

The National Ignition Facility

- **RECAP:** A 30 litre dewar will provide for 5 days refrigeration by supercritical He.
- This capacity would be reduced by any surface area in addition to that of the *Hohlraum* which may have to be maintained at ≈ 8 K.

Capacity (days)	Added load	Area ($\epsilon = .2$, source @ 300K)
5	0 mW	0 cm ²
4	33	4
3	133	16
2	300	36
1	800	95

- (If a 77 K shield is employed until shot time the *Hohlraum* radiation load, as well as the load on chilled surface areas which can also be so shielded, becomes negligible.)
- Under the assumption that a holding time in the range of 1 - 5 days will be operationally acceptable, a supercritical He capacity of 30 litres is taken as a preliminary estimate.
- (The same volume of LHe will provide $\approx 2X$ the refrigeration at the cost of dealing with 2- ϕ flow.)

NIF-0004579
LCP/inh-5

Layout of tanks in the cryostat

NIF

The National Ignition Facility

- The cryostat exterior configuration is assumed to be that of the business end of the current NIF positioner:
 - a truncated cone subtending a 10° half angle at the target center, transitioning to
 - a cylinder of 500 mm dia.
- At the expense of requiring longer transfer plumbing for the He, the He tank is placed outboard of (further from center than) the LN₂ tank, thus gaining a reduced flux of 14 MeV neutrons by virtue of:
 - reduced solid angle
 - shielding by the LN₂ tank and its contents

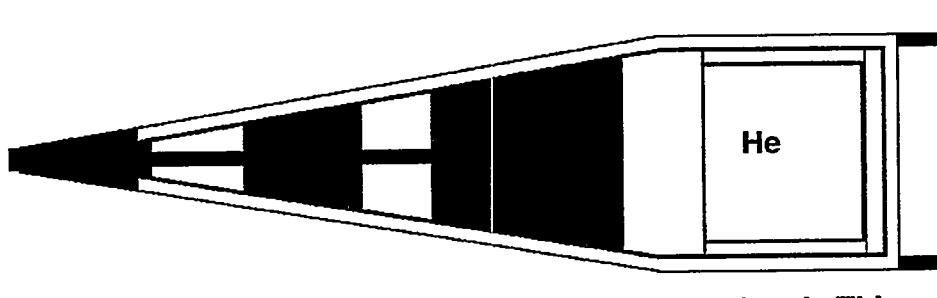
NIF-0004579
LCP/inh-6

Layout of tanks in the cryostat (continued)

NIF

The National Ignition Facility

- A workable layout of the tanks is below; the He tank volume is ≈ 50 litres as shown; thus there exists the possibility of providing somewhat more refrigeration capacity than we have here estimated.



- A volume of LN_2 of > 50 litres can also be accommodated. This allows for a time between LN_2 fills of > 5 days, compatible with the longest hold time afforded by the 30 litres of He.

NIF-0004579
LCP/inh- 7

Beryllium offers advantages for cryostat construction

NIF

The National Ignition Facility

- Be acts as a neutron moderator, shielding the cryogens (particularly the He), the positioner mechanisms, and the surroundings.
- In Be, 14 MeV neutrons produce:
 - a very short-lived product, ^8Be (with a half life of $< 10^{-16}$ s (quicker than we can extract the positioner)),
 - orders-of-magnitude lower yields of ^9Li and ^6He , both with sub-second half lives and,
 - a low yield of ^{10}Be (with a half life of $1.6 \cdot 10^6$ yr, thus of low activity).
- Be as a structural material has a very high stiffness/mass ratio
- A cryostat vacuum shell of the assumed truncated cone + cylinder configuration, made of Be and having a factor of safety of 10 against buckling under 1 atm of pressure, will have a wall thickness of 2.4 mm, and a mass of 8.8 kg.
- By comparison, a similar Al shell would be 4.6 mm thick, and have a mass of 25.6 kg. (Al is also less desirable from an activation standpoint.)

NIF-0004579
LCP/inh- 8

Problem of expanding *Hohlräume*

NIF

The National Ignition Facility

- The cryostat can be cushioned from the sharp impact of ablation recoil caused by < 100 eV x-rays with a disc of crushable material (Al foam has been tested and found suitable.)
- The disc can be coated with B_4C , as a relatively benign ablator.
- The mass of ablated material depends to first order on the area presented to the source by the disc, and the flux of x-rays (thus, for a point source on the solid angle subtended by the disc).
- The area of the disc depends upon the distance from the target to which it is necessary to prevent ablation of the cryostat material, and the effective size of the radiating target (the expanding *Hohlraum*).
- In order to shield from a distributed source, the disc must subtend a larger conical angle than the cryostat proper. The shadow cone of the disc is also a cone of inaccessibility for diagnostic viewing of the target.
- The effective sizes of the radiating *Hohlräume* for different targets is currently being investigated. Some consequences of source geometry are quantified on the next page.

NIF-0004579
LCP/inh- 9

Problem of expanding *Hohlräume* (continued)

NIF

The National Ignition Facility

- For a range of effective source sizes (here assumed spherical and of uniform strength), the resulting disc diameter and shadow cone half-angle for protecting the entire conical section of the cryostat with a disc 10 cm from the target center are given below, along with the number of NIF target chamber ports denied line-of sight to the target center.

Effective source radius (cm)	Disc radius to shield cryostat cone section (cm)	Shadow cone half angle with disc at 10 cm from target center ($^{\circ}$)	Number of NIF ports denied line-of sight (cumulative)
0.67 (unexpanded <i>Hohlraum</i>)	2.31	13	1
2.75	4.24	23	6
3.66	5.10	27	13
5.70	7.00	35	16

NIF-0004579
LCP/inh- 10

Cryogenic capacity (EXTRA VIEWGRAPH)

NIF

The National Ignition Facility

- Rad load on 6mm dia X 10 mm high *Hohlraum* from 300K vacuum shroud, assuming $\epsilon \leq 0.2$ 20 mW
(If a 77 K shield is employed until shot time, this load becomes negligible.)
- Power for *Hohlraum* temperature profiling 50 mW
- β -decay load 0.1 mW
- From the above, we conservatively take as a starting point a 100 mW direct refrigeration requirement. To provide this for 5 days at 8 K would require (if there were no other heat sources)
 - 8 litres of LHe @ 4.2 K or
 - 15 litres of supercritical He @ 5.2 K
- Doubling the latter volume to allow for an additional 100 mW, the radiant load on a roughly spherical, chromium plated 30 litre dewar with a 77 K shield is found to be 65 mW. Thus, there remains an allowance for an additional load through conductive supports of 35 mW, which is more than adequate for tensile supports of Kevlar, *e.g.*

PRODUCTION OF LOW DENSITY FOAM TARGET COMPONENTS FOR SANDIA Z-PINCH EXPERIMENTS

Scott Faulk

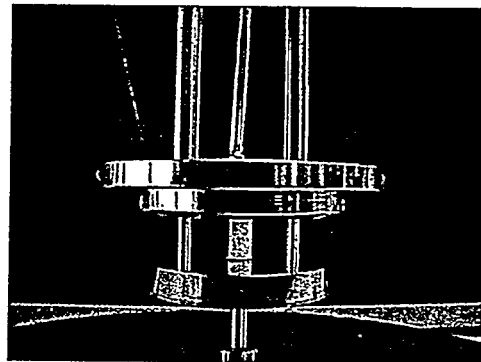
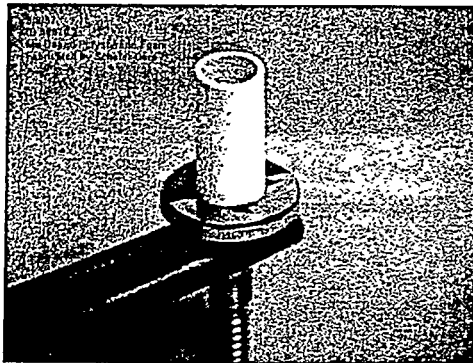
Diana Schroen-Carey

Kelly Youngblood

Schafer Corporation, 303 Lindbergh Ave., Livermore CA. 94550 (510) 447-0555

SANDIA USES FOAMS ON THE Z-PINCH TO MODULATE THE PLASMA

- Sandia's z-pinch machine is being used for pulsed power experiments.
- Stored electrical energy is carried down a cylindrical array of fine tungsten wires, resulting in a burst of x-rays lasting several nanoseconds.
- These experiments pave the way for:
 - testing of radiation effects on materials
 - weapons effects simulations
 - studying the physics of inertial confinement fusion.



Schafer

 **GENERAL ATOMICS**

THE FOAMS ARE PRODUCED AT SCHAFER'S LIVERMORE SITE

- Equipment includes:
 - emulsion forming syringe pump
 - computer controlled oven (SNL loan)
 - critical point drier
 - freeze drier
 - single point diamond turning lathe
 - Hardinge precision lathe
 - CNC mini-mill
 - Nikon Measurescope with computer analysis system
 - interference microscope
 - photon tunneling microscope
 - laser micrometer
 - Kodak DC120 digital camera
- Key personnel
 - Scott Faulk, precision micromachinist
 - Diana Schroen-Carey, polymer chemist
 - Kelly Youngblood, chemist

Schafer



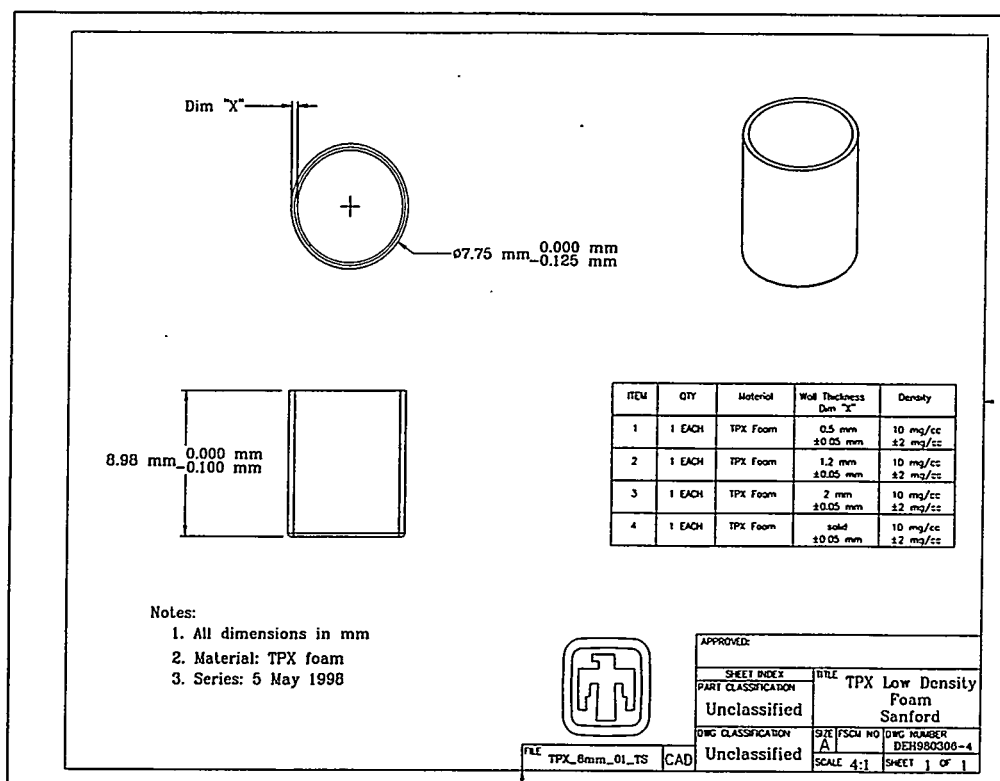
OUR GOAL IS TO MAKE FOAM PRODUCTION ROUTINE

- Orders are e-mailed in Autocad format
 - Foam designs have gotten more complex, and this ensures that the design is understood
 - E-mail expedites the process
- We map out a strategy
 - Molds reduce labor hours and increase reproducibility, while some designs require machining
 - Decide on foam type (usually polystyrene or TPX)
 - Cast or machine and evaluate product
 - Create new molds or modify machining process to improve quality and tighten dimensional tolerances
- When order is complete, a detailed QC package is made
 - Excel file containing dimensional tolerances and density calculations
 - Digital images of foams are created
 - All data is sent on CD

Schafer



ORDERS COME ON EMAIL IN AUTOCAD FORMAT

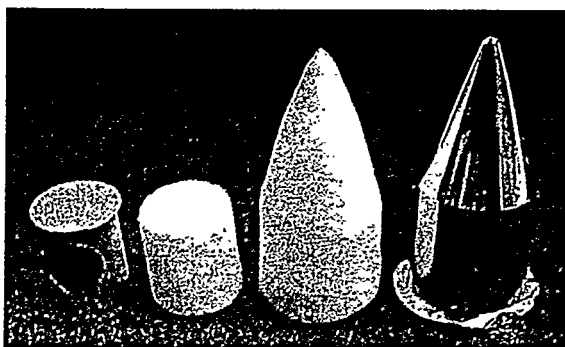


Schafer

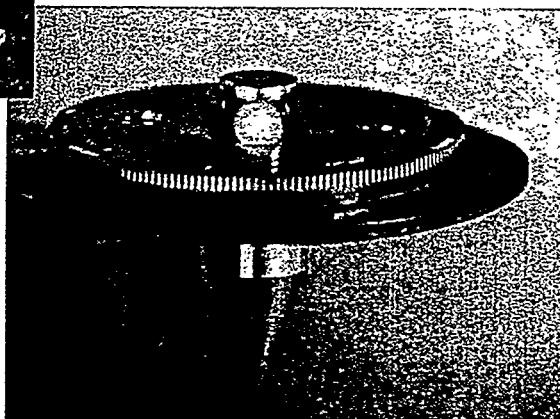
GENERAL ATOMICS

NEW FOAM DESIGNS HAVE GOTTEN MORE COMPLEX

- Tight tolerances and new geometries



Target Components
Gold hohlraum machined at GA
Foam inset is 10 mg/cm³ TPX



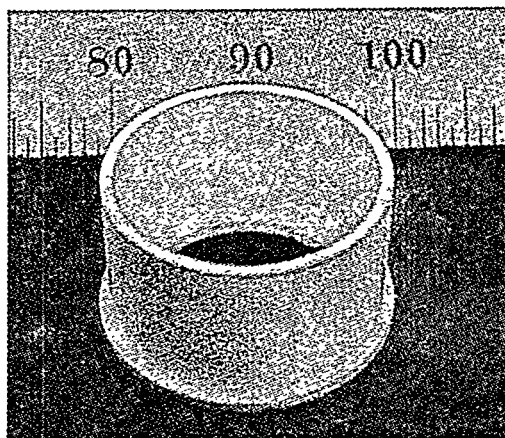
Finished Target
Assembled at Sandia
By Schafer personnel

Schafer

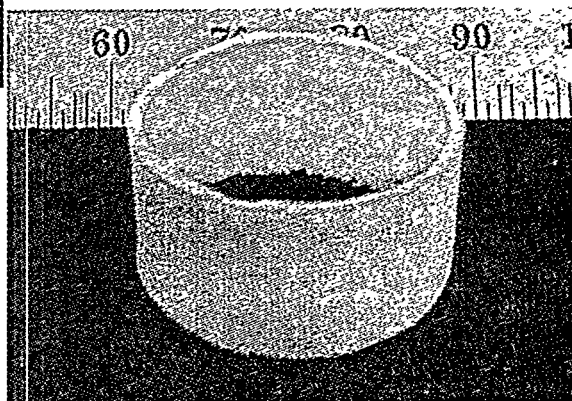
585

GENERAL ATOMICS

... MORE DESIGNS



PS Annulus 40 mg/cc
17 mm OD

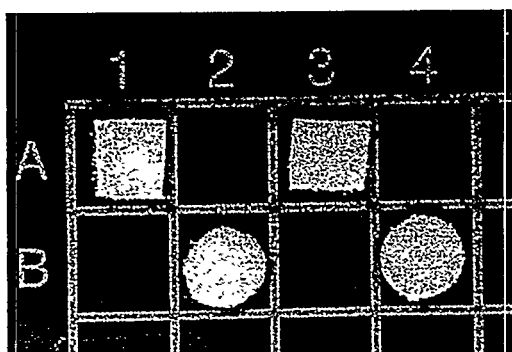


TPX Annulus 10 mg/cc
24 mm OD

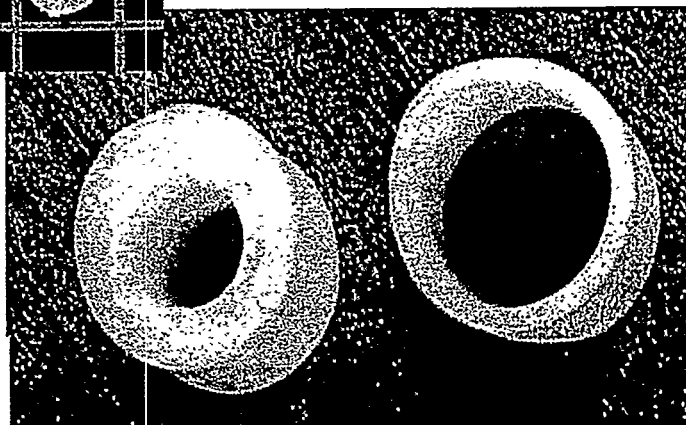
Schafer

 **GENERAL ATOMICS**

... MORE DESIGNS



Hole closure foams



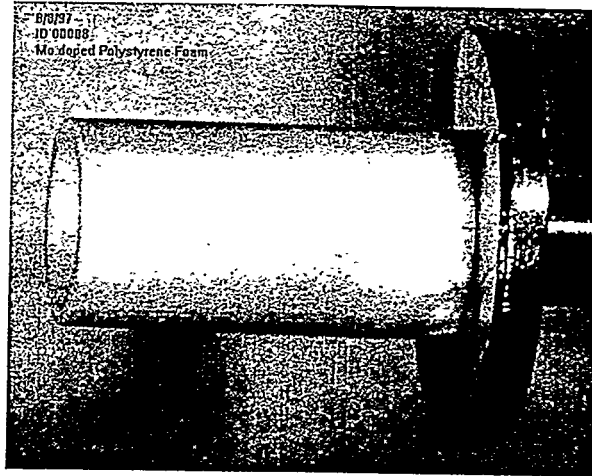
Annuli with various wall
thicknesses and same OD

Schafer

 **GENERAL ATOMICS**

WE ARE ALSO BEGINNING TO "DOPE" THE FOAMS

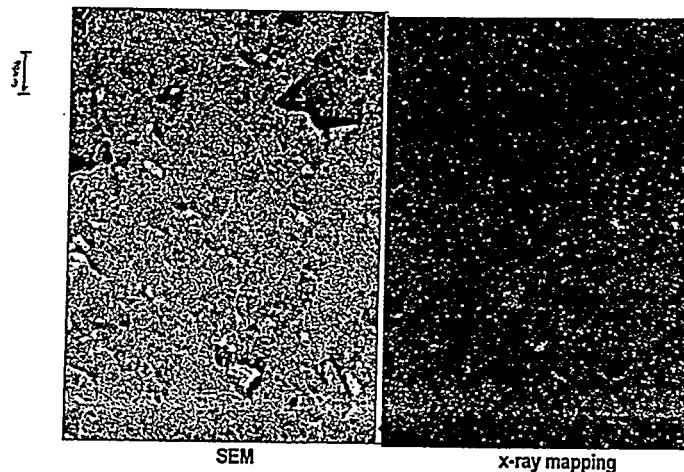
- We were asked to add molybdenum to polystyrene
 - Short lead time (5 weeks notification)
 - Custom synthesis was not an option
 - We used a technique analogous to dispersing pigment in a water based paint
 - Resultant foam dried without shrinkage and machined well.



Schafer

GENERAL ATOMICS

ANALYSIS INDICATED MOLYBDENUM DISPERSED WELL BUT AT 1/3 THE EXPECTED LEVEL



- The results suggest we had incorporated only the smaller particles (Goodfellow, Mo_2C , mean diameter 3.8 microns).
- XRF result 2.9 mg/cc Mo, 7.8 wt %.

We made an excess of organic solution, then removed an aliquot while stirring briskly.

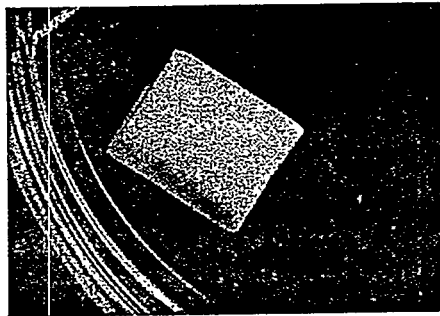
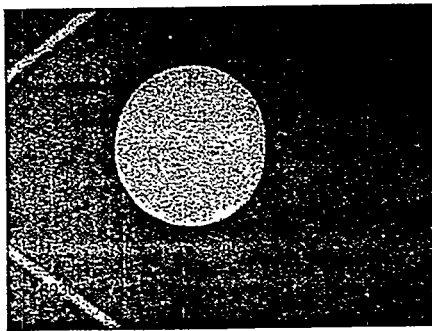
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GENERAL ATOMICS

WHEN ORDER IS COMPLETE, A QC PACKAGE IS MADE

- Includes data in excel format and photos and is sent on CD
- Photos are in JPEG format

sample ID	weight in mg	height in cm	OD in cm	volume	density mg/cc
80305T-1A	1.649	0.674	0.580		
		0.684	0.566		
		0.646	0.569		
Average	1.649	0.668	0.572	0.17	9.6



Schafer

 **GENERAL ATOMICS**

SANDIA HAS USED ION MICROTOMOGRPHY TO FURTHER CHARACTERIZE THE FOAMS

- Characterization done by Arlyn Antolak, SNL-CA.
 - non-destructive, high resolution, elemental analyses.
 - Internal voids can be identified.

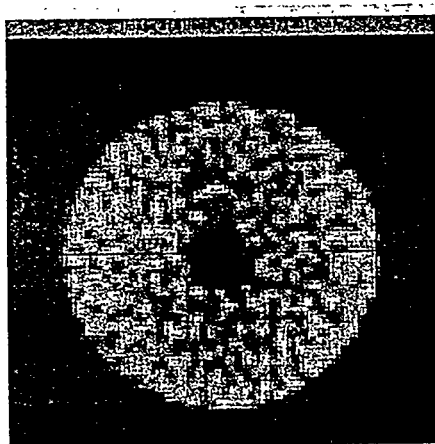


Image of foam with internal void

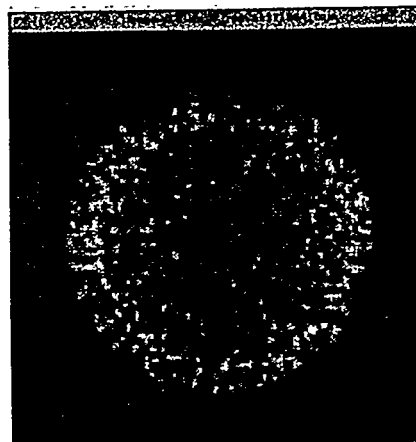


Image of uniform foam

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 **GENERAL ATOMICS**

WE HAVE DELIVERED 120 PRECISION PIECES SO FAR THIS FISCAL YEAR

- Three foams are currently being produced, polystyrene-divinyl benzene (polystyrene), poly(4-methyl-1-pentene) (TPX), and resorcinol-formaldehyde (RF).
- We are developing a production method for silica aerogel.
- Density from 150 mg/cm³ to 7 mg/ cm³.
- Geometries include:
 - cylinders, diameters 4 to 24 mm
 - annuli, diameters 4 to 24 mm, walls 2 to 0.5 mm
 - flats, circles and squares, 0.7 to 0.3 mm thick

Schafer

 **GENERAL ATOMICS**

A NEW INTERFEROMETER BASED PROFILOMETER FOR ROUGHNESS AND THICKNESS MEASUREMENTS OF ICF TARGETS

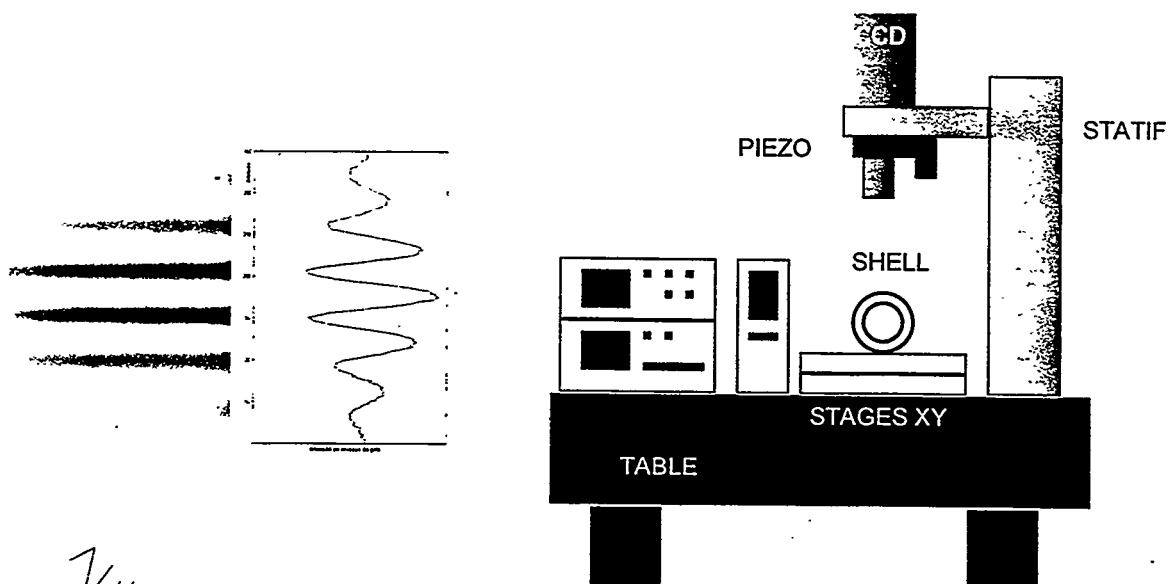
P. LOINTIER

**Aim: Measure the thickness, the outer and inner
surface roughness of a complete shell**

Valduc
DRMN - MDS
Laboratoire de Mécanique

L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

VERTICAL SCANNING INTERFEROMETRY EXPERIMENTAL SETUP



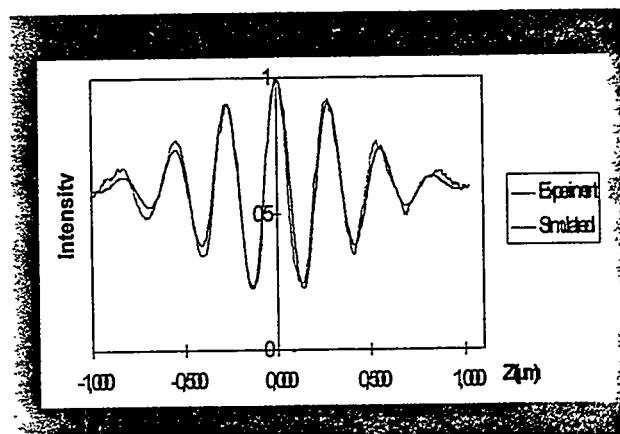
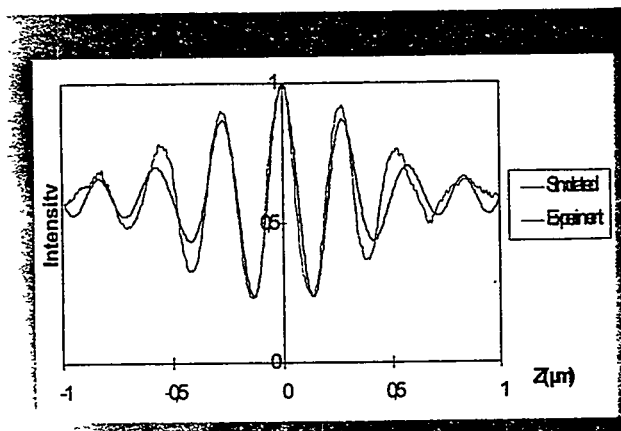
Valduc
DRMN - MDS
Labo Mécanique Froid et

L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

COMPARISON EXPERIMENT - SIMULATION

$$I(Z) = I_0(\lambda) \cdot \Sigma(1 + \cos(4\pi Z/\lambda))$$

$$I(Z) = I_f + I_0(\lambda) \cdot \exp(-k(Z-Z_0)^2) \cdot \cos((4\pi(Z-Z_0))/\lambda)$$

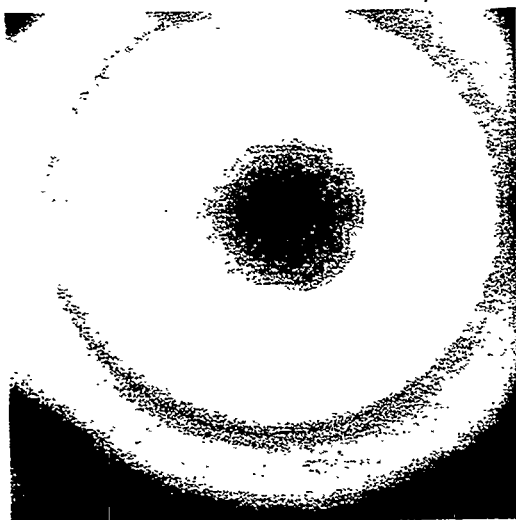


Valduc

DRMN · MOS
Labo Métallurgie Froide et

L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

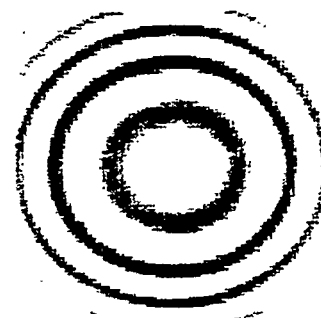
RESULTS ON SHELL



Outer surface topography of a
shell of 0.5 mm diameter
(area 30 x 30 μm)

Fringe pattern of
outer surface

Fringe pattern of
inner surface



Valduc

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Labo Métallurgie Froide et

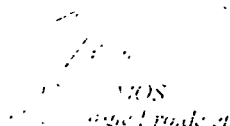
L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

CONCLUSIONS

- ✓ Modelization of the fringes intensity curve versus z
- ✓ Utilization of an autocorelation function to fit experimental data with modeled function

PERSPECTIVES

- ✓ Setting up a z displacement for thickness measurement and a precision rotary air bearing for the target rotation



L'ATOME, DE LA RECHERCHE A L'INDUSTRIE

The Fabrication of Double Shell

Targets for Nova

Joe Duke, Norman Elliott, Veronica Gomez,
Joyce Moore, Ruben Manzanares, Gerald Rivera,

Bob Watt, Bill Varnum, and Pete Gobby
Materials Science and Technology Division,

Los Alamos National Laboratory

Introduction

At scales appropriate to the National Ignition Facility, calculations indicate double shell capsules reach ignition conditions with room temperature fuel. Los Alamos is laying the groundwork for these double shell ignition targets with a preliminary campaign on Nova.

The Target

The target design features an inner glass capsule 260 μm OD centered inside a machined polymer shell 550 μm OD. The central shell is centered in two ways. In one technique a pair of machined foam hemispheres are sized to fit the inner diameter of the outer shell and the outer diameter of the inner shell. Alternatively, a pair of Formvar[®] polymer films, approximately 800Å thick, are formed to the inner capsule and captured in the equatorial joint of the outer shell.

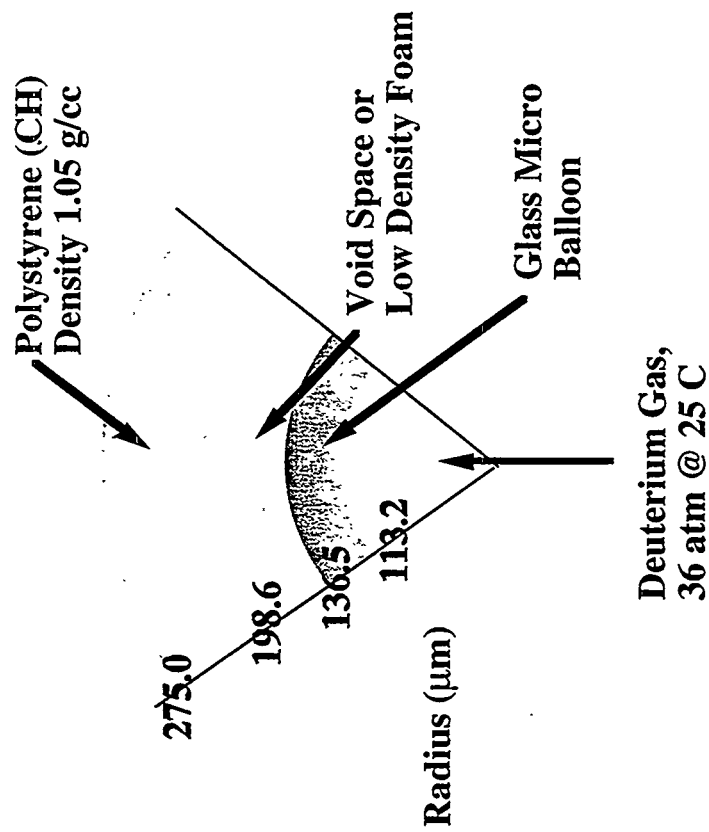


Figure 2. SEM of the polystyrene high internal phase emulsion foam (30 mg/cc) used to center the glass sphere in the plastic sphere. The surface finish on the foam hemispheres was measured at 2 μm rms.

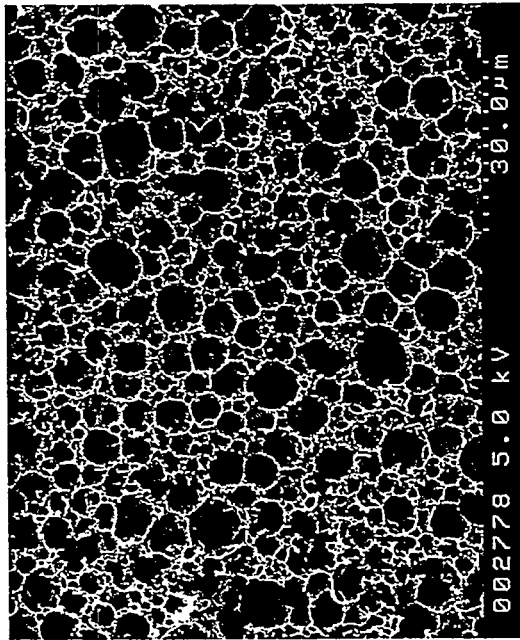


Figure 1. Pie view of the Double Shell Targets for Nova. The radius of the surfaces from the center of the target are given.

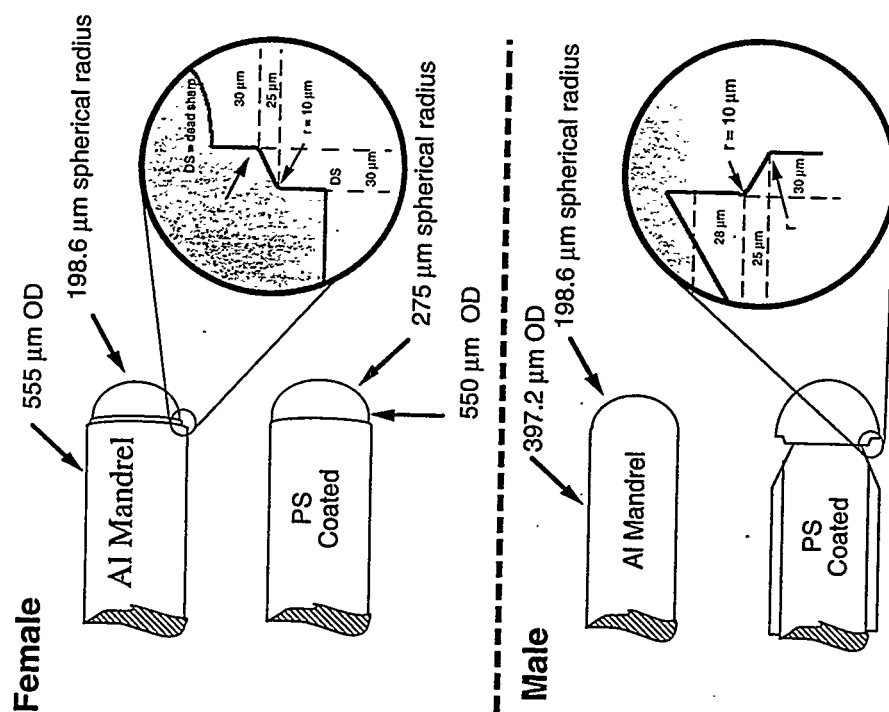


Figure 3. Mandrels used to machine the outer polystyrene hemispheres.

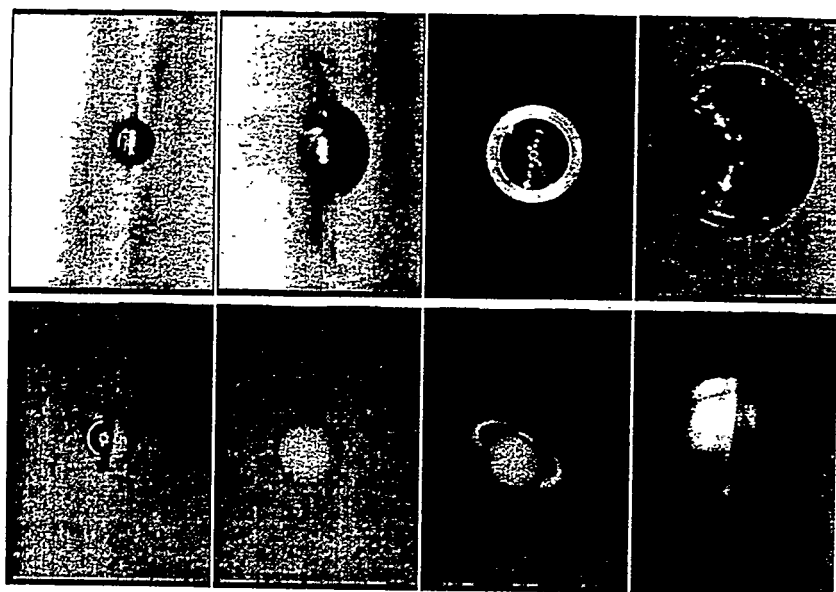


Figure 4. Foam (left) and film (right) assembly processes.

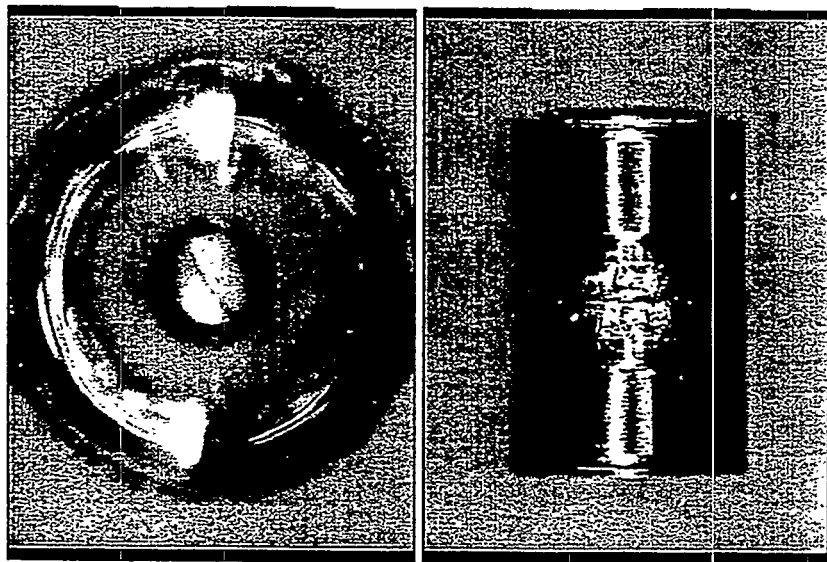


Figure 5. Double shell foam design inserted into hohlraum.

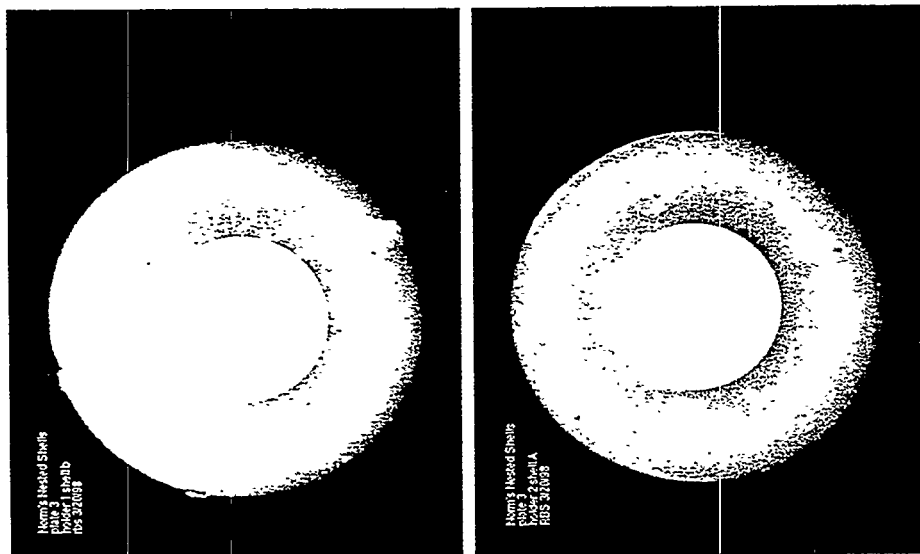


Figure 6. Radiography of foam (top) and film(bottom) designs, performed at General Atomics.

Results

Only the foam centered design had been shot as of April 13th, 1998. The Formvar® targets were to be shot last Friday, April 17, 1998. The foam shot came in at about 1.5% of a clean 1D calculation. This is essentially what we expected based on the last ICF double shells in 1980+ on Shiva. The shells were decentered a bit, 6.7 and 10.7 μm for the foam and film designs, respectively. We monitored mostly neutron activities like yield and bang time. No imaging of the core could be done since no radiation from the D-D Bremsstrahlung could escape the 30 μm thick Si capsule. In general, at a convergence ratio of 38, the results looked at least as good as single shell data obtained at that convergence ratio. Therefore the possibility of a non-cryogenic NIF ignition capsule using the double shell concept is still alive. We go to Omega in August to shoot with much better symmetry and hope to get much better results.

Acknowledgements

This work was supported by the U. S. Department of Energy under contract number W7405-ENG36.

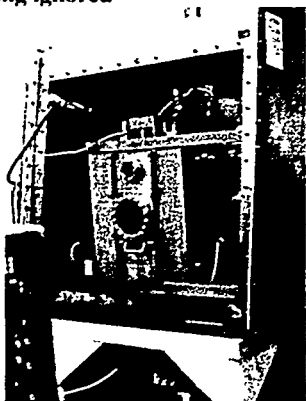
Be and Be-alloy PVD at Los Alamos in Support of Weapons Physics and ICF Experiments*

Chris Adams, Bob Henneke, Norm Elliott, and Larry Foreman
Materials Science and Technology Division, MST-7
Los Alamos National Laboratory, Los Alamos, NM

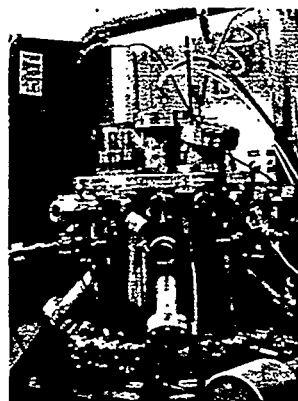
* This work is supported by the U. S. Department of Energy under contract number W7405-ENG36

Current Be and Be-alloy PVD Capabilities

- Current capabilities include both RF/DC sputter deposition and electron beam evaporation of Be and Be-alloys
- Can make use of:
 - Substrate heating
 - Gas pulsing
 - Substrate biasing
 - Ion cleaning/ bombardmentin either deposition system
- Current focus is on electron beam evaporation of Be and Be-alloys, although sputtering is not being ignored

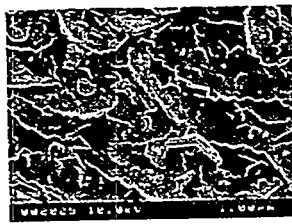


Electron Beam Evaporation System



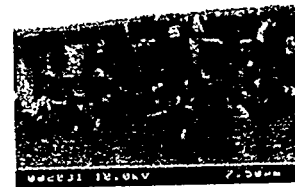
Sputter Deposition System

Typical DC Sputtered Be Surface Morphologies and Microstructure



No gas pulsing

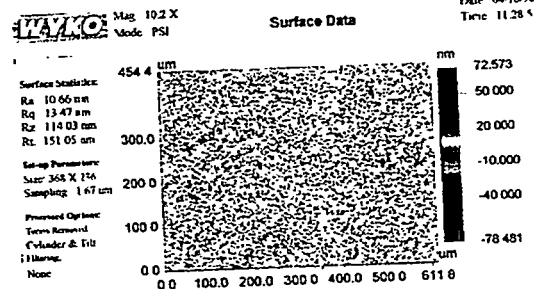
- Typical DC sputter deposited Be
- Si substrate (~1.2nm RMS)
 - 600W, no applied bias (-24V, substrate floating)
 - ~ 2.3 μ m/hr, ~10 μ m
 - Target-substrate: 3 in.
 - No substrate heat applied



Typical columnar structure

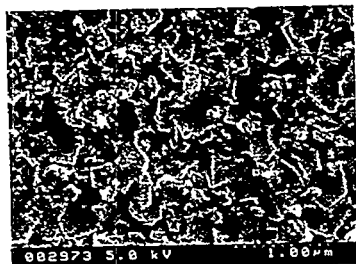


N₂ gas pulsing

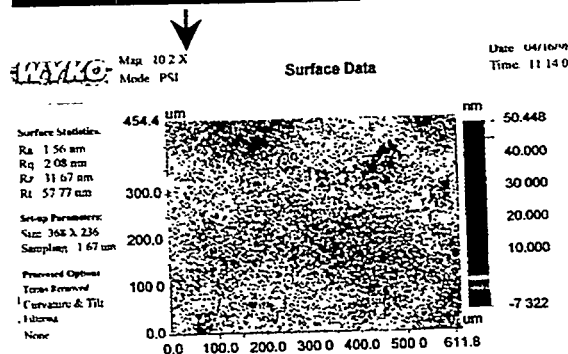
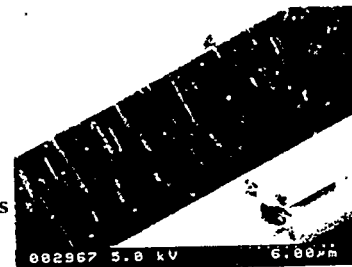


Title: DC Sput Be
Note: 12/19/96, 10 mic on Si

Typical Electron Beam Evaporated Be Surface Morphology and Microstructure



- Typical electron beam deposited Be
- Si substrate (~1.2nm RMS)
 - ~ 5.4 μ m/hr, ~9 μ m
 - Source-substrate: 6 in.
 - No substrate heating
 - No gas pulsing or applied bias



Title: E-beam Be, 1/12/98
Note: 10 mic. on Si

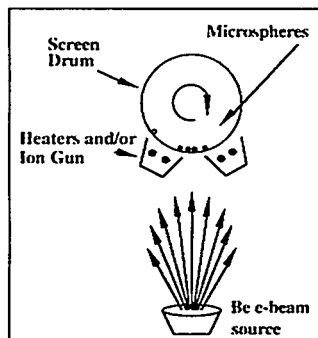
E-beam evaporated
Be film smoother
than a DC sputtered
film at this film
thickness

Advantages/ Disadvantages of Electron Beam Deposition of Be and Be-Cu Alloys

- **Potential advantages of electron beam evaporation**
 - Typically a more rapid deposition process than sputtering (easily $36\mu\text{m/hr}$ on flats)
 - More compatible with implementation of flow-through ion gun
 - Gas pulsing more effective due to lower pressure during deposition
- **Potential disadvantages of electron beam evaporation**
 - Expend source material quickly
 - Difficult to produce alloys from a single source if constituent vapor pressures differ significantly
 - Fortunately, the vapor pressures for Cu and Be are nearly identical
 - Limited to evaporating upwards
 - Unwanted heating of substrates (PAMS) due to presence of molten source material

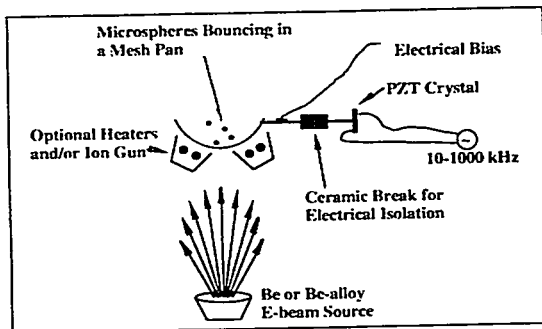
Barrel Coating of Microspheres

- Recently tried using the barrel coating arrangement shown below to coat hollow glass microspheres and hollow NIF scale PAMS shells.

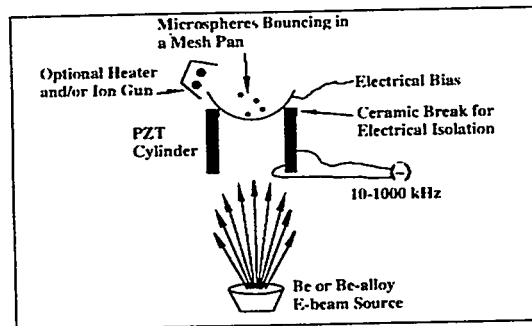


- Results to date have been disappointing due to static charge build-up on spheres during deposition resulting in striped spheres.
- Tried using a hot filament in vicinity of the barrel to provide electrons for charge neutralization. This has been ineffective so far.
- We also plan to try using the ion gun already in the chamber to bombard the substrates with positive ions during deposition.

Alternative Approaches to Fabrication of Be-Cu Coated NIF Targets also Being Considered



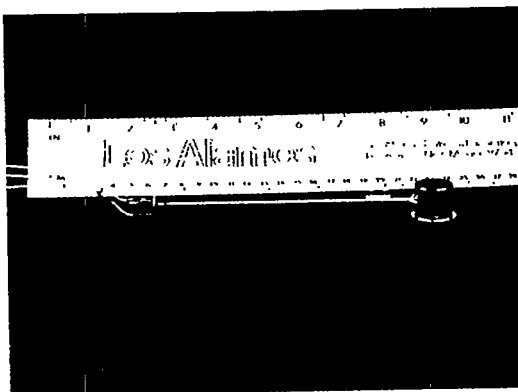
Method A



Method B

We are incorporating a vibratory pan driven by a PZT piezoelectric crystal. Two implementations will be considered, (methods A & B shown above). Method A offers two distinct advantages over B. The PZT crystal is removed from both the deposition flux and any potential heating sources used during deposition.

First Approach to Using a Vibratory Pan



The photo at the left shows our bench top first attempt at using a PZT crystal (from a Sonalert device) to vibrate PAMS micro-spheres. The stainless cup proved to be too heavy and excessively damped the system. We were able to vibrate the spheres when they were placed atop a lighter screen material

Bounce Coating Induced Domes on Glow Discharge Polymer Coated Shells

Abbas Nikroo

David Woodhouse

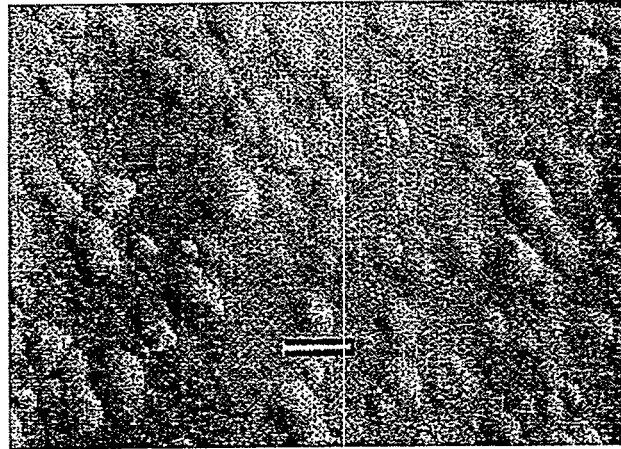
12th Target Fabrication Specialists' Meeting
April 1998
Jackson Hole, Wyoming



Bounce coating many large shells led to dome-filled surfaces

- Dome-filled coatings were encountered intermittently in 3 different coaters when bounce coating 1 mm shells.
- The poor surface finish correlated with number and size of shells bounce coated at once.
- Roll coating the shells in a spinning pan dramatically reduced the number of domes on the final coating.
- The seeds for the domes appear to originate from GDP chips produced in shell to shell collisions.

GDP coatings on pristine 1 mm PAMS shells were cluttered with domes

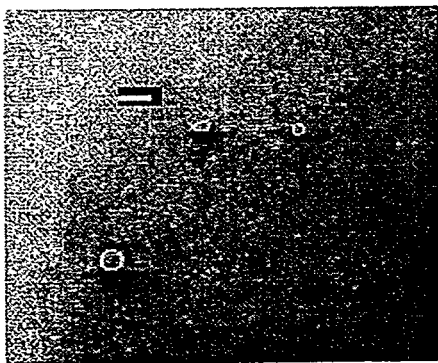


Scale bar = 10 μ m

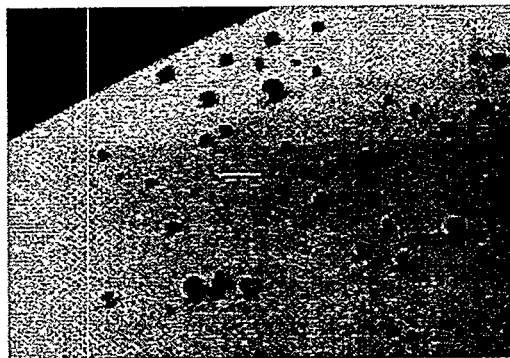
- Above is an SEM image of a coating thicker than 3 μ m on 1 mm PAMS shells
- 3 different coaters produced these poor surfaces on an intermittent basis.



Spherical beads were also produced in these coatings



a - Beads attached to shells after coating

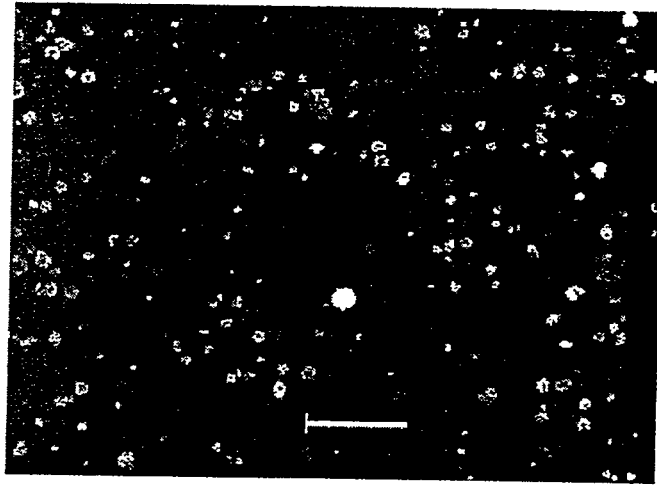


b - clean shell after rolling in pan used to coat shells in (a)

scale bars = 10 μ m

- $\approx$ 10 μ m beads were often loosely attached to the shells
- These beads could be knocked or washed off. They could also contaminate clean shells.

The bouncer pan was also littered with domes and beads



scale bar = 30 μm

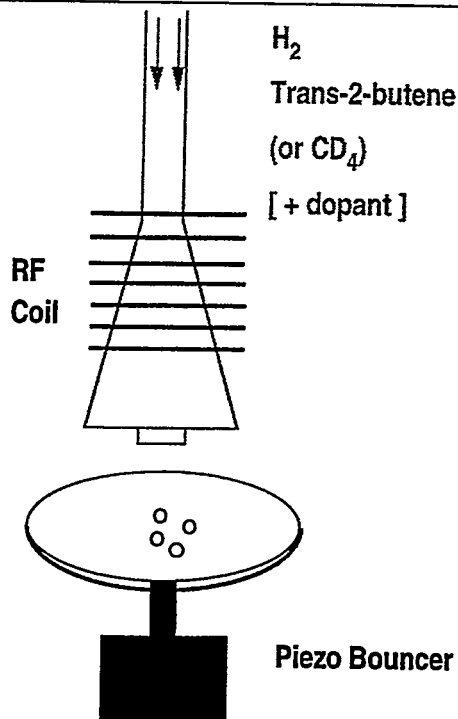
- SEM image of a portion of the bouncer pan used for a coating run that led to a dome-filled surface finish on the shells.



The different coaters in our lab have a number of items in common

Items coaters had in common :

- Gases
- Quartz Plasma Tubes
- Bouncer Pans
- Shells



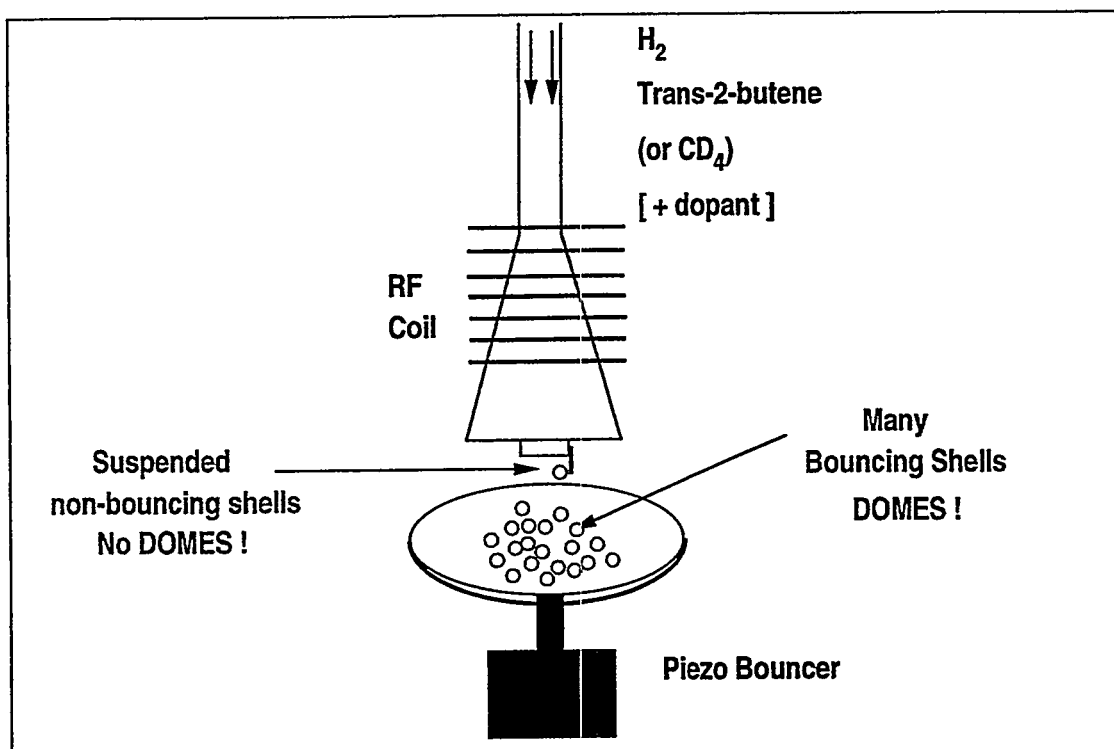
Systematic experiments showed a definite correlation between poor surfaces and the number of shells coated at once

- We performed a series of systematic experiments to determine the cause of this problem:

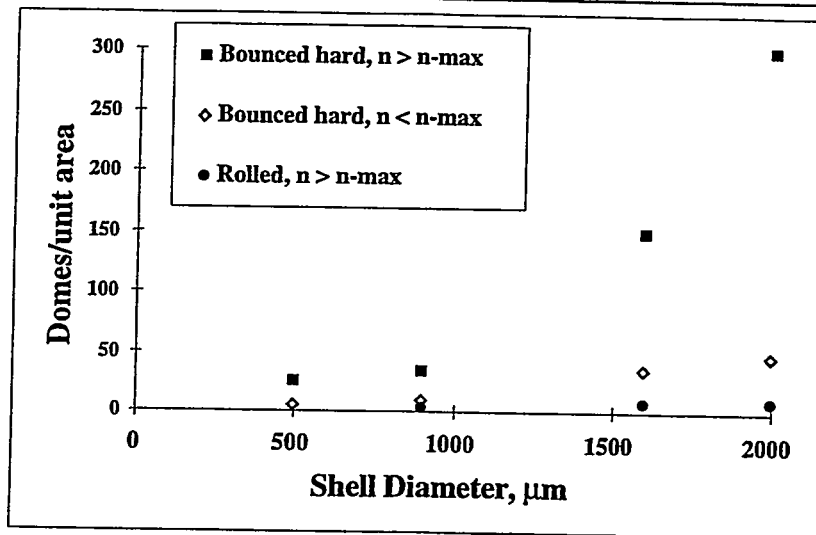
		<u>Tube 1</u>		<u>Tube 2</u>	
		Substrate	Domes	Substrate	Domes
Consecutive runs using two separate tubes	1st Run	Flat	No	10 shells	No
	2nd Run	200 shells	Yes	200 shells	Yes
	3rd Run	10 shells	No	Flat	No

- The poor surface finish correlated with the number of shells bounced coated together at one time.
- The final surface finish was dome-filled only when large numbers of shells were coated together.
- Reduction of the bouncing agitation improved the surface but led to non-uniform coatings.

Shells suspended above the bounce pan had a dome free coating



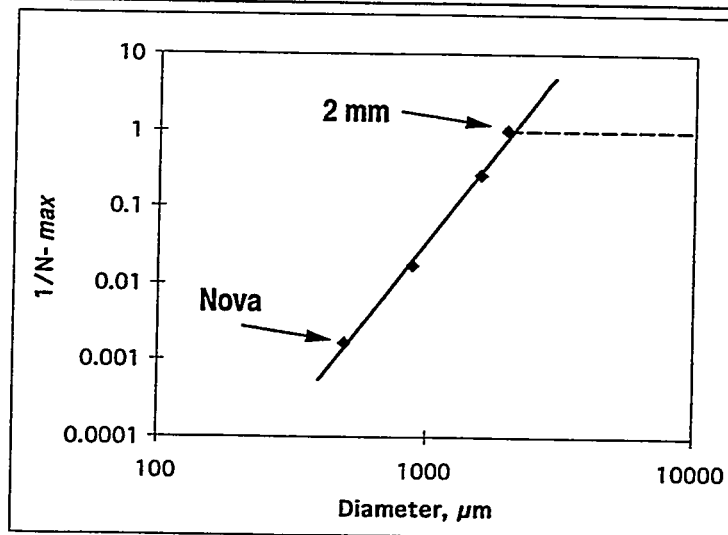
Larger shells had a higher density of domes



- 12 μm coatings on different diameter shells all with ≈ 20 μm wall thickness.
- For each size, when more than a critical number (n-max) of shells were coated together, the surface became filled with domes.
- Rolled shells were coated in a spinning pan.



The maximum number of shells that could be coated together for dome free coatings decreased with increasing diameter

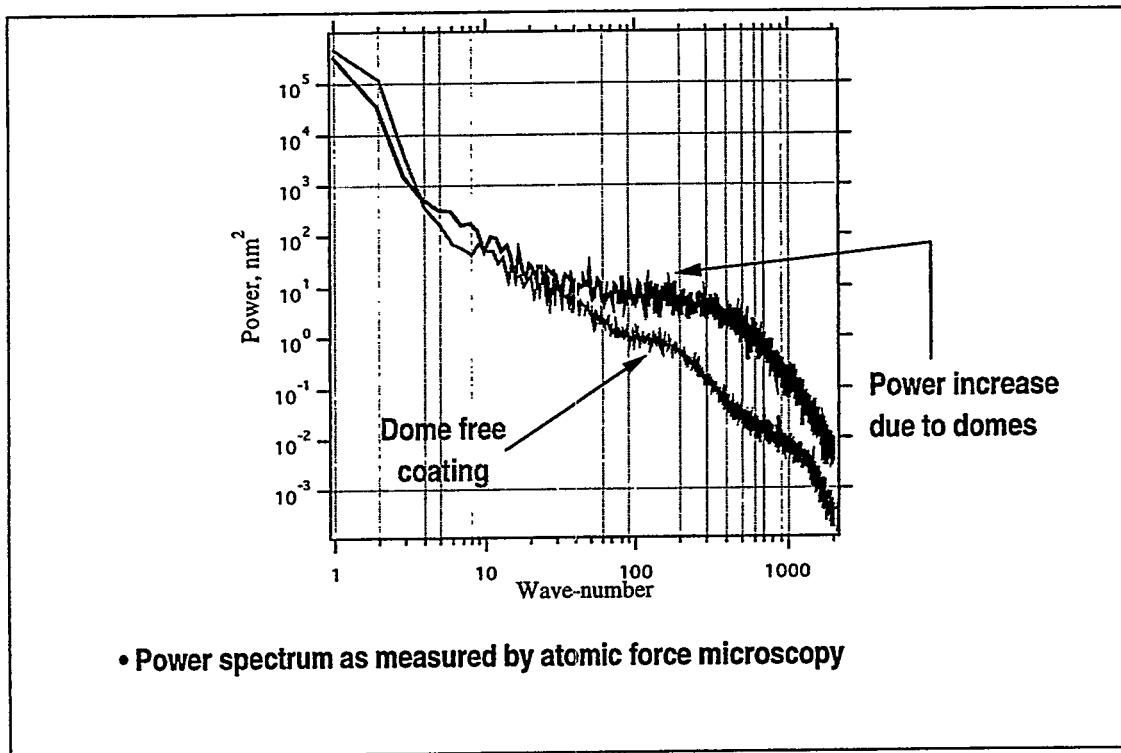


- n-max appeared to scale as :

$$\approx d^{-5}$$

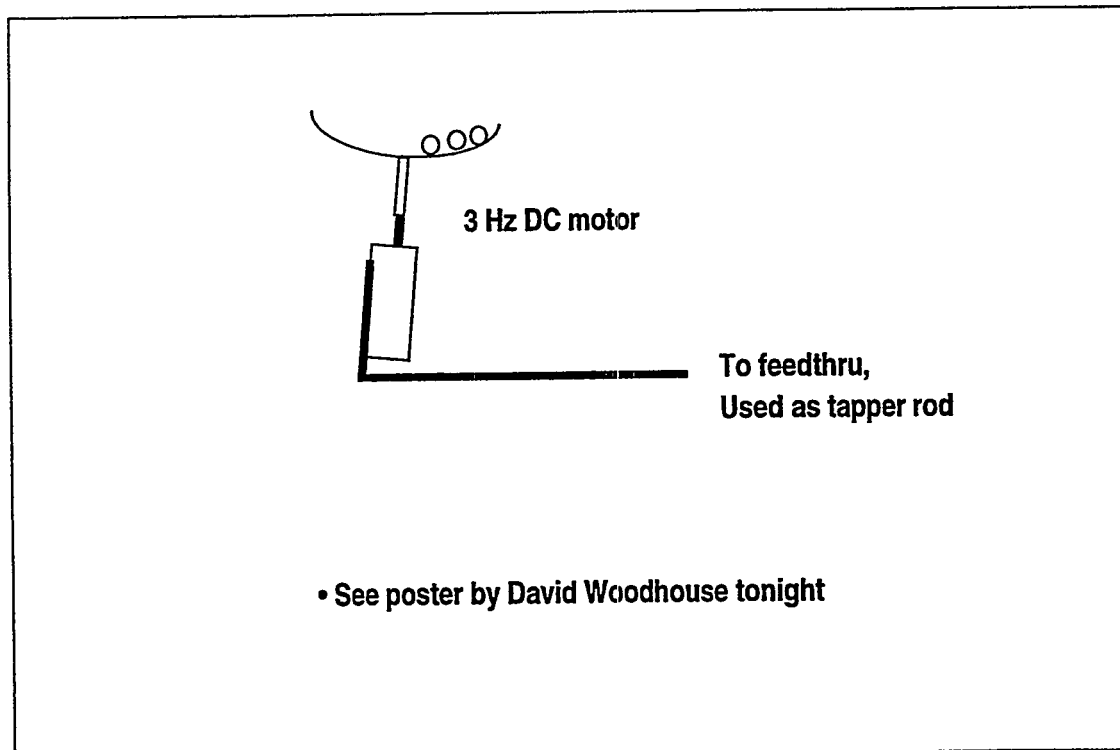
for $d \leq 2000 \mu\text{m}$

Dome filled surfaces increased the spectral power of modes ≥ 20

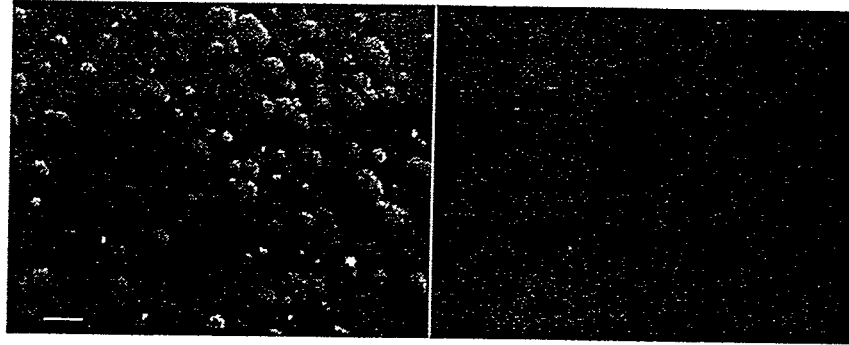


 **GENERAL ATOMICS**

Coating over a hundred LLE shells together in a spinning pan led to coatings with reduced number of domes



Coating 2 mm shells in a spinning pan produced virtually dome free coatings



Bounce coated

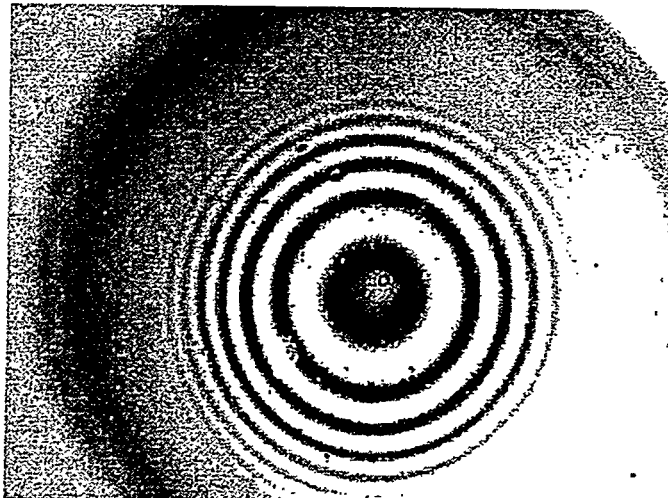
Roll coated

scale bar = 10 μ m

- 2 sets of 12 NIF size shells were coated. One was bounce coated, the other roll coated.
- Roll coated shells had a superior surface finish.



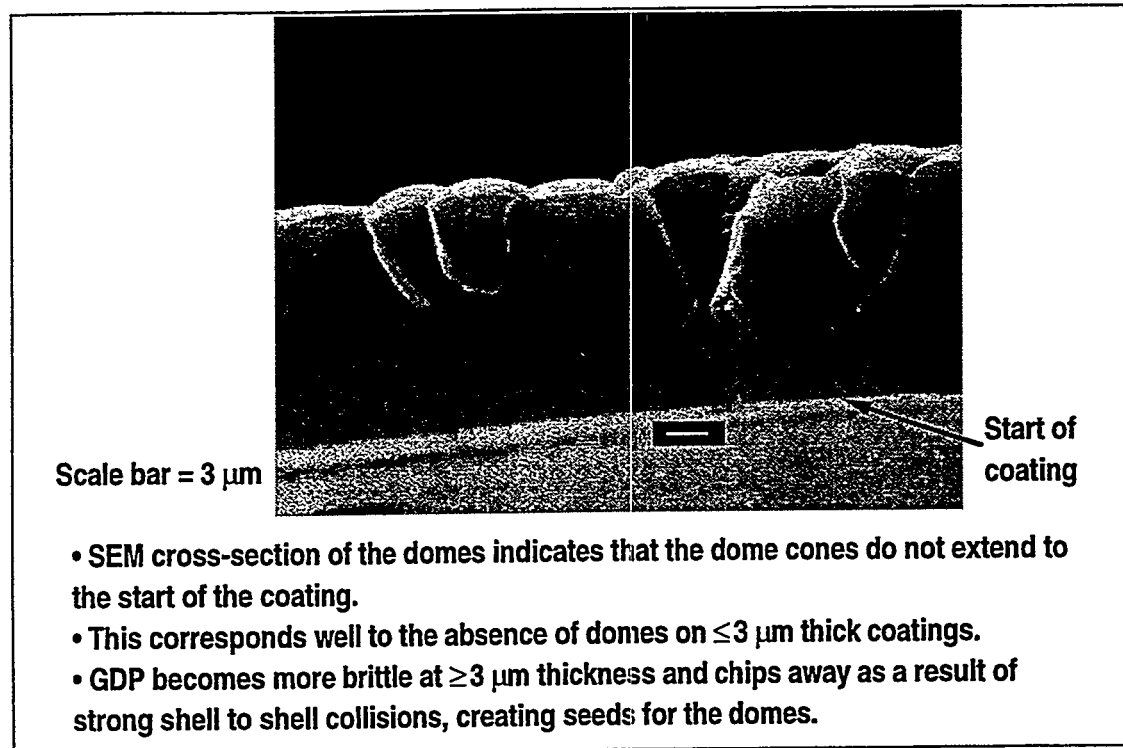
Roll coating shells does produce a uniform coating



Roll coated 2 mm shell

- The interferometric fringes are offset only very slightly from the center of the shell, indicating uniform walls.

The domes appear to originate at depths of $\geq 3 \mu\text{m}$ from the inner surface of coating



Conclusions

- Bounce coating large numbers of shells together results in dome-filled coatings.
- For NIF size shells only one shell can be coated at once, while for Nova shells ≈ 500 shells can be coated together.
- Reducing the bouncing agitation reduces the number of domes in the final coating, but leads to non-uniform coatings.
- Roll coating shells in a spinning pan dramatically reduced the number of domes on the final coatings while producing uniform coatings. This allows coating larger number of shells at once.
- The seeds for the domes appear to originate from GDP chips produced in shell to shell collisions after the coating becomes $> \approx 3 \mu\text{m}$ thick.

Properties of Films Generated with a Saddle-Field Plasma

W. T. Shmayda, N. P. Kherani, F. Gaspari [†], S. Zukotynski [†],
D. Harding ^{††}

Presented at: Target Fabrication Meeting
April 19-23, 1998

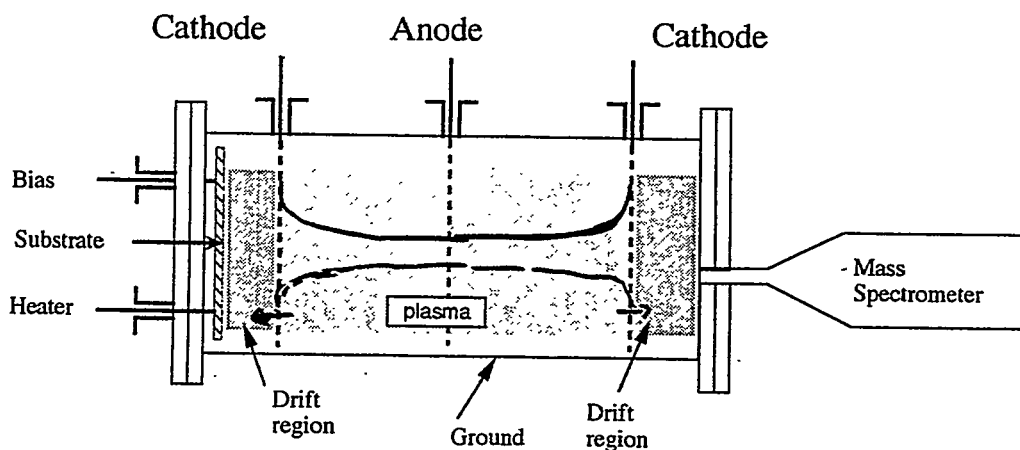
Ontario Hydro Technologies, Toronto, Ontario, Canada

[†]Elect. Eng. Dept., University of Toronto, Toronto, Ontario, Canada

^{††}LLE, University of Rochester, Rochester, NY, 14623

DC Saddle Field: *discharge fields*

ONTARIO HYDRO



Neutral fill pressures: 30 - 150 mTorr
Neutral particle density: $1 - 5 \times 10^{15}$ #/cc
Discharge current density: 56 - 170 $\mu\text{A}/\text{cm}^2$

The substrate is decoupled from the plasma. The ion energy, the ratio of neutral to ion fluxes and the substrate temperature can be controlled independently.

Ion energy:

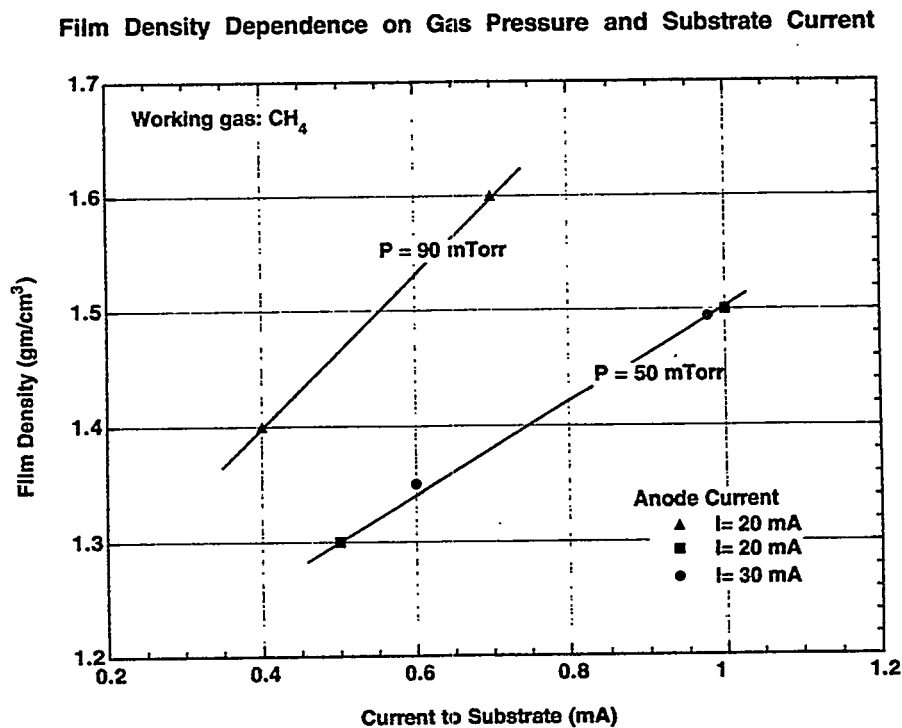
The potential of the substrate can be adjusted from ground to values above the floating plasma potential. The energy of the ions striking the film surface can reduce to zero.

Ratio of ion to neutral flux:

Both neutrals and ions irradiate the substrate. Their ratio can be altered by adjusting the substrate potential in addition to the plasma parameters.

Substrate temperature:

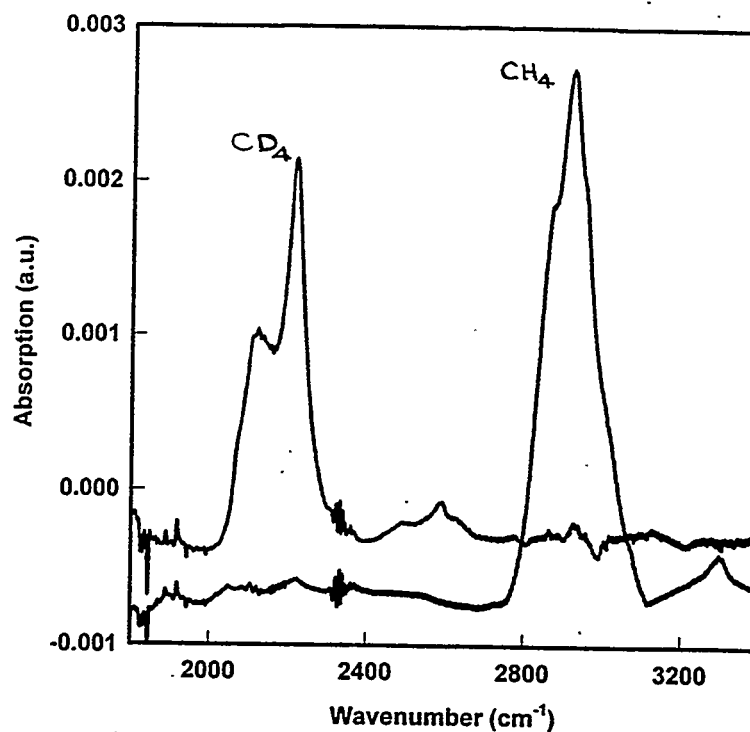
The substrate can be heated during the deposition to alter the morphology of the film as it is deposited.



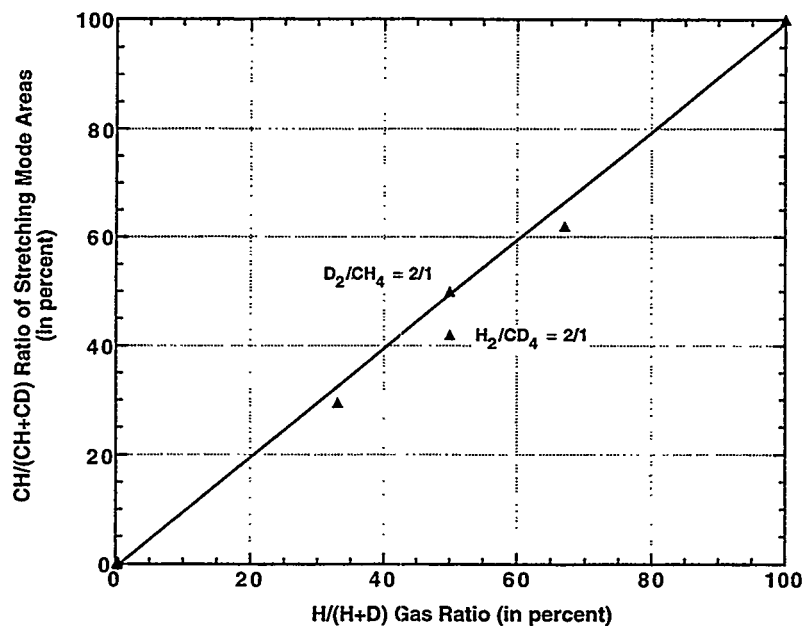
How do the hydrogen species mix in the plasma?
 How are these species incorporated in the solid phase?
 How does the isotopic ratios in the plasma affect film densities?

%CH ₄	%CD ₄	%H ₂	%D ₂	Isotopic Ratio (H/D)
50	-	-	50	2/1
33	-	-	67	1/1
100	-	-	-	1/0
-	50	50	-	1/2
-	33	67	-	1/1
-	100	-	-	0/1

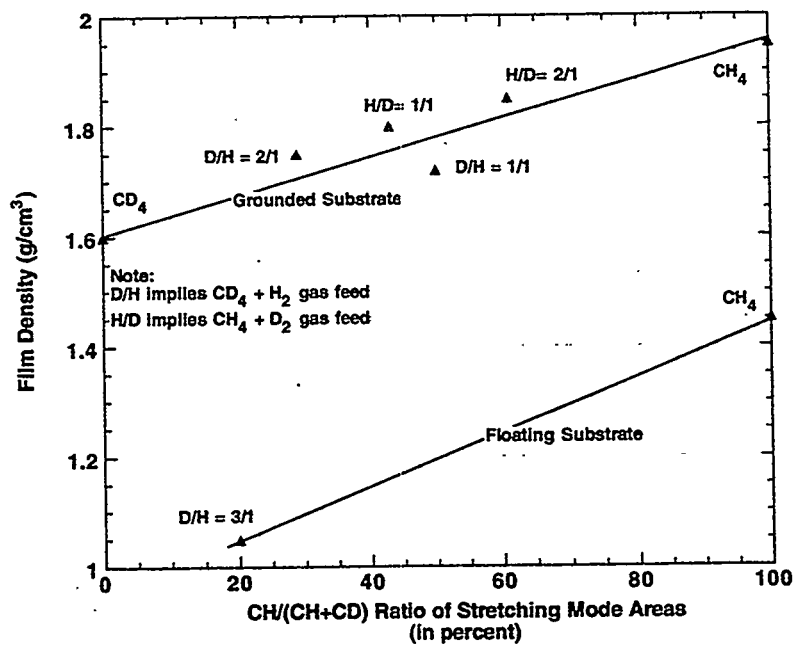
FTIR Absorption Spectra illustrating the Stretching Modes for films grown using CH₄ or CD₄ as the working gas



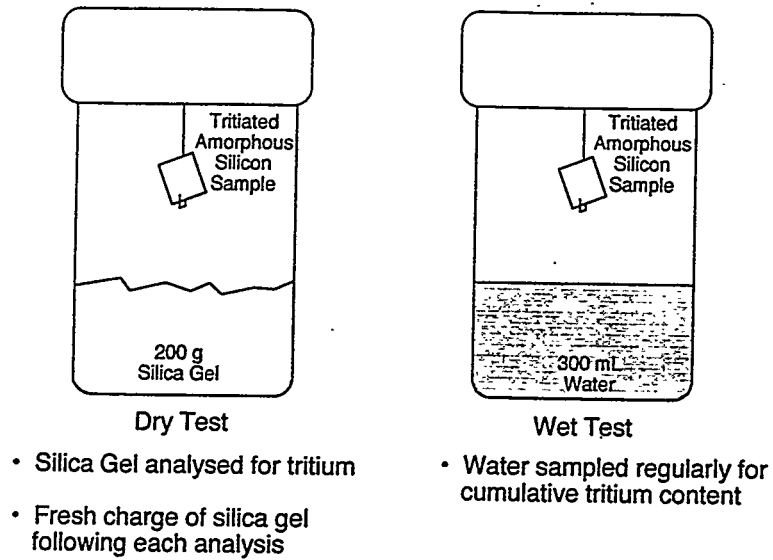
Correlation between Isotopic Ratio of Gas injected into the Plasma and that found in the films



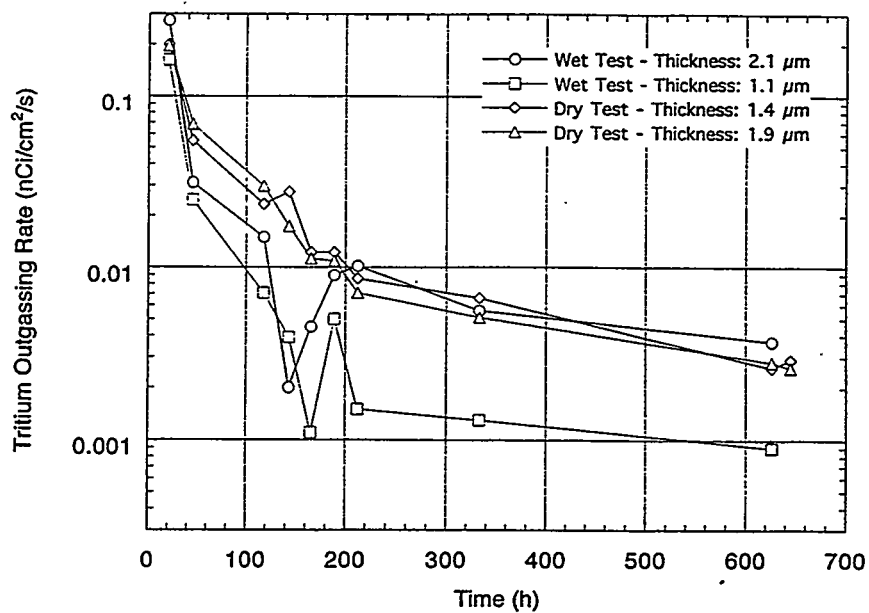
Correlation between Film Density and the Stretching Mode Area Ratios



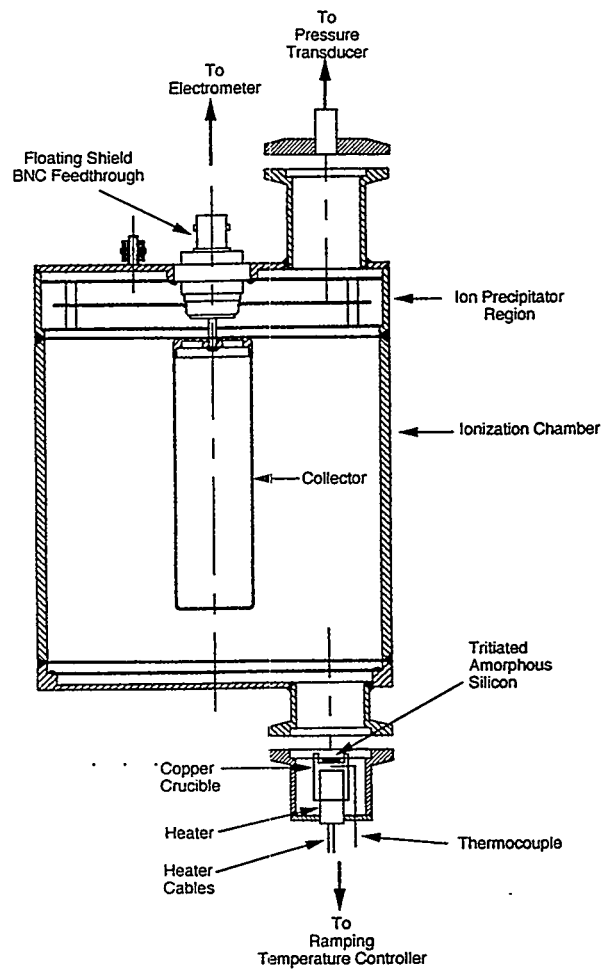
Apparatus for the measurement of tritium outgassing



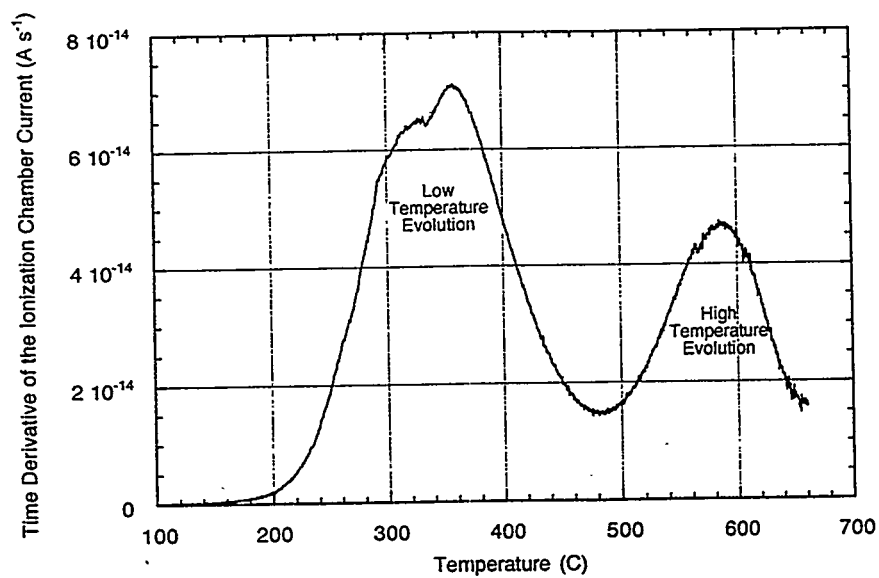
Tritium Outgassing Rate of Tritiated Amorphous Silicon Films



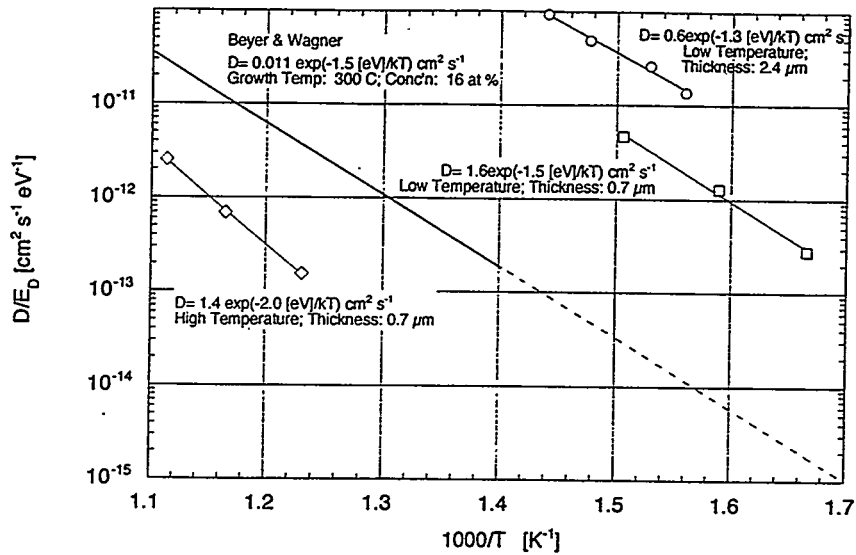
Measurement of Tritium Diffusivity using an Ionization Chamber Tritium Monitor



Typical measure of the rate of tritium evolution during linear temperature ramping of a tritiated amorphous silicon film



First Measurements of Tritium Diffusivity in Tritiated Amorphous Silicon (Growth Temperature: 150 C; Tritium Concentration: 17 at %; Si-Bonded Tritium: 6 at %)



Summary

- Film density can be controlled between 1.1(?) and 3 by:
 - substrate potential
 - operating pressure
 - ion/neutral flux blending
- Film density decreases with increasing atomic H mass
- Gas phase isotopic ratios of atomic hydrogen are reflected in the films
 - simplifies fabrication of C-DT films
 - use $\text{CD}_4 + \text{T}_2$ gas
- aC:H films are stable in air below 300°C

Organometallic Chemical Vapor Deposition of Beryllium*

Mitchell Trkula, Stevan G. Pattillo and Kenneth V. Salazar

Polymers and Coatings Group
Materials Science and Technology Division
Los Alamos National Laboratory

*This work is supported by the U.S. Department of Energy under contract number W7405-ENG36



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Why Beryllium?

OMCVD of Be

- Material Properties
 - density
 - low opacity
 - high tensile strength
 - high thermal conductivity
- Capsule Design and Fielding
 - hold DT fill at room temperature
 - more tolerant of DT ice surface finish
 - thermal environment for ice is easier to achieve



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Approach to Beryllium OMCVD

OMCVD of Be

- Looking to develop new routes to Beryllium CVD
 - old deposition chemistries were often high temperature
 - old, low temperature chemistries were
 - difficult to control
 - produced impure materials
- Looking toward low temperature depositions
 - gives one a wide choice of substrates
 - Be is refractory - expect very fine grain material at low T
- CVD well suited to 3-D coatings (fluidized bed)

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Beryllium Synthetic Chemistry Effort

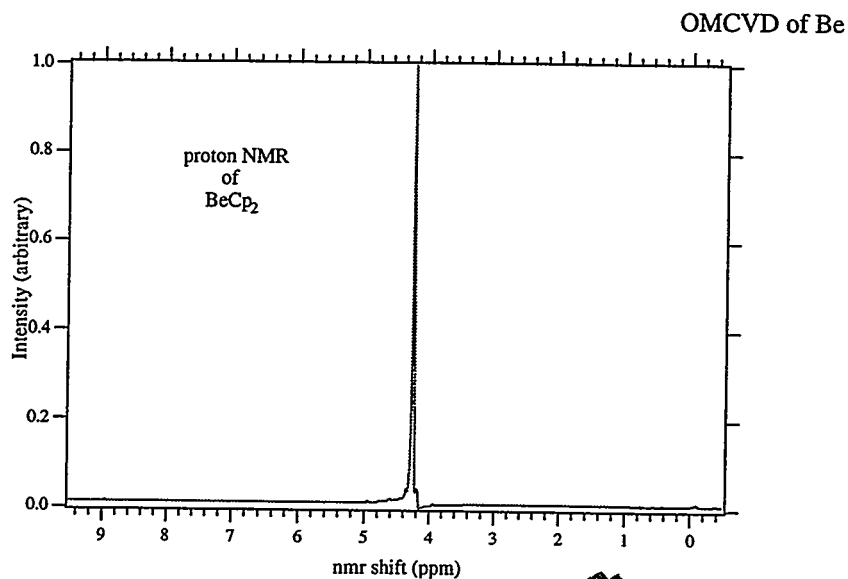
OMCVD of Be

Synthesis of Precursors:

- bis(cyclopentadienyl)beryllium
BeCp₂ - original precursor
 - $\text{BeCl}_2 + 2 \text{NaCp} \rightarrow \text{BeCp}_2 + 2 \text{NaCl}$
- bis(pentamethylcyclopentadienyl)beryllium
BeCp₂* - lower volatility
 - $\text{BeCl}_2^* + 2 \text{NaCp}^* \rightarrow \text{BeCp}_2^* + 2 \text{NaCl}$
- H₂Be:NR₃ - analog to alane amines
 - $\text{Et}_2\text{Be} + \text{NaH} \rightarrow \text{Et}_2\text{Be}_2\text{-NaH}_3$
 - $\text{Et}_2\text{Be}_2\text{-NaH}_3 \rightarrow 2 \text{NaBeH}_3 + \text{BeEt}_2$
 - $\text{NaBeH}_3 + \text{R}_4\text{NCl} \rightarrow \text{H}_2\text{Be:NR}_3 + \text{NaCl} + \text{RH}$

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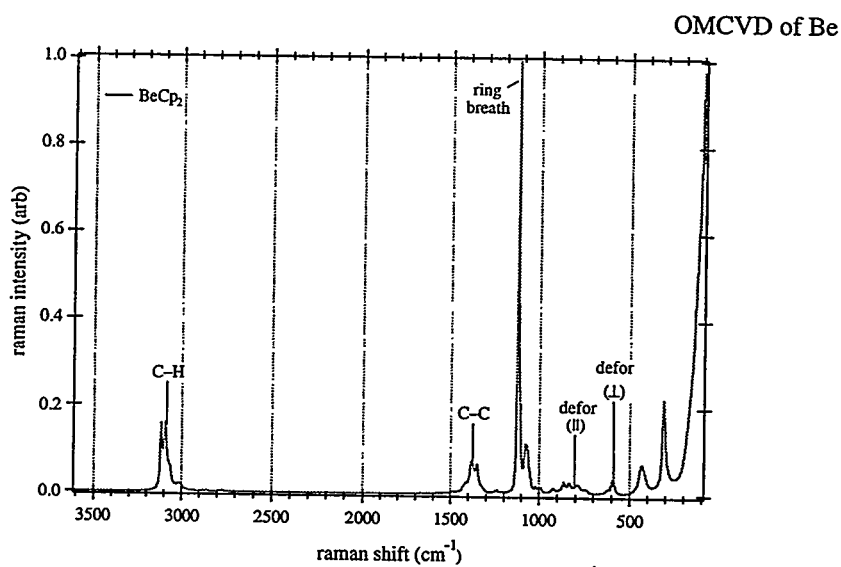
Proton NMR of BeCp₂ Made at LANL



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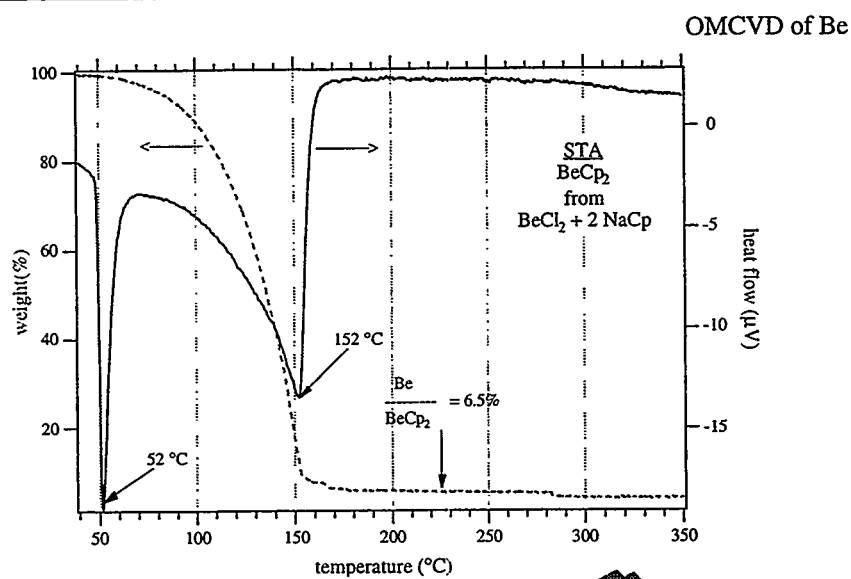
Vibrational FT-Raman of BeCp₂ Made at LANL



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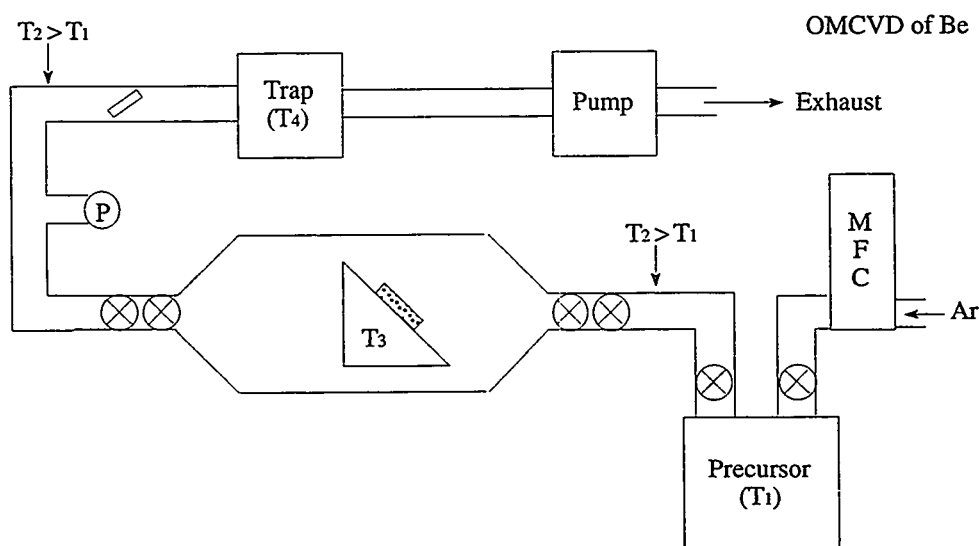
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Thermal Analysis of BeCp₂ Made at LANL



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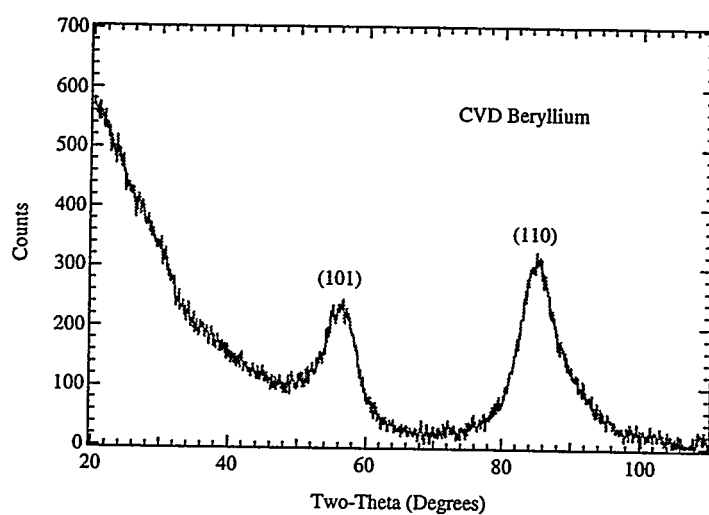
Apparatus for Deposition of 2-D Beryllium



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XRD of OMCVD Beryllium on Silicon

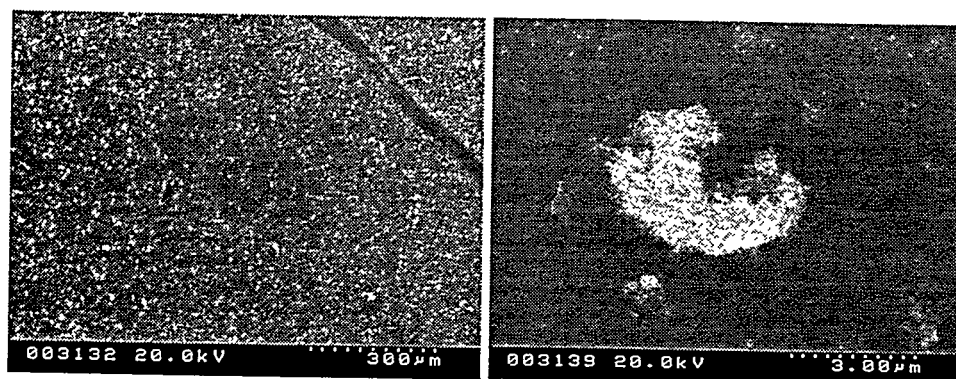
OMCVD of Be



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SEM of OMCVD Beryllium on Silicon

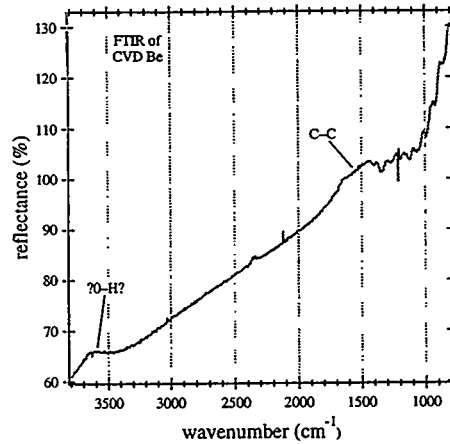
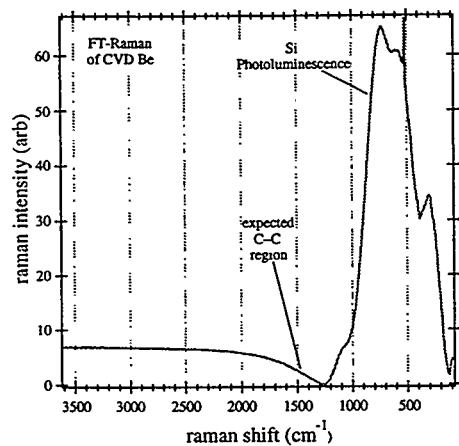
OMCVD of Be



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Infrared Analysis of OMCVD Be on Silicon

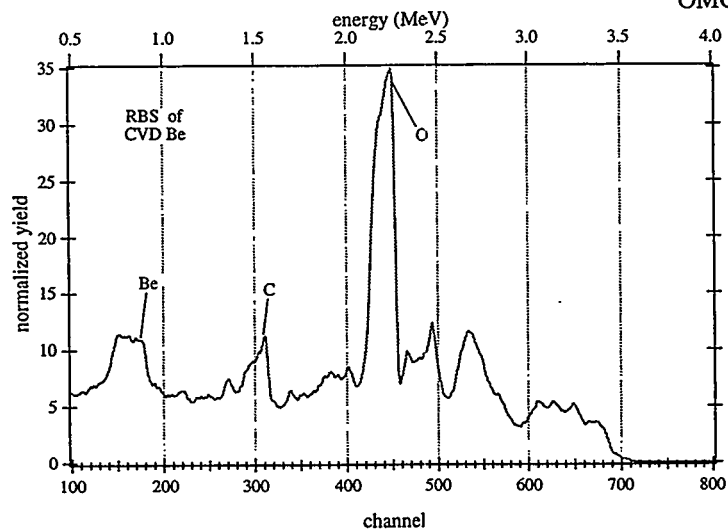
OMCVD of Be



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RBS Spectrum of CVD Beryllium on Silicon

OMCVD of Be



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Cu Doping of CVD Be

OMCVD of Be

- Appears (hfac)Cu(tmvs) is an ideal precursor
(hfac = hexafluoroacetylacetonato, tmvs = trimethylvinylsilane)
 - $\text{CuO}_2 + 4 \text{Hhfac} + 2 \text{tmvs} \rightarrow (\text{hfac})\text{Cu}(\text{tmvs}) + \text{H}_2\text{O}$
- High deposition rates
 - 165 C - 1000 Å/min
 - 200 C - 5000 Å/min
- High purity metal
 - 99.99 % Cu
 - 1.81 $\mu\Omega$ - cm
- Easy to deliver
 - yellow liquid with 1 torr vapor pressure at 60 C
 - can produce a cocktail for direct liquid injection

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Summary and Future Directions

OMCVD of Be

- OMCVD from BeCp_2
 - very fine grain Be with assortment of larger clusters
 - films contain C at ~10%
 - state of C still not known
 - precursor is very air sensitive
- Future Work
 - perform OMCVD from BeCp_2^*
 - prepare $\text{H}_2\text{Be:NR}_3$ and perform MOCVD
 - down select best process
 - convert process to fluidized bed

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Materials Science and Technology

First shells formation experiments with upgraded Ballistic Furnace.

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*Department of Neutron Physics, Lebedev Physical Institute
Moscow, Russia*

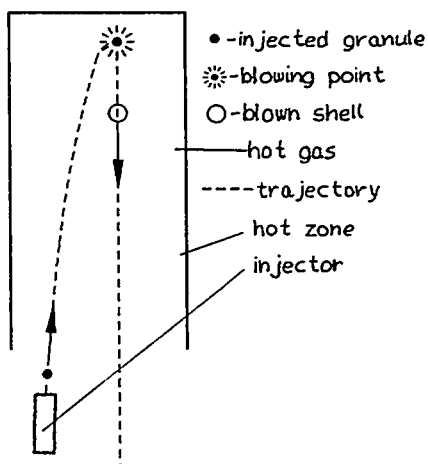
Robert Cook

Livermore, CA 94550, USA

Lawrence Livermore National Laboratory

1998

The concept of a "Ballistic Furnace".



- > The initial granules are propelled upwards into the hot zone along a ballistic trajectory. This approach allows one to sharply increase the time the granule spends in the hot zone of the furnace as well as allowing microshell formation to occur near the trajectory apex when its velocity is small.

Main parameters of the modern Ballistic Furnace configuration.

- Maximum hot zone temperature..... 900°C.
- Gas pressure.....0 - 1 atm.
- Height of hot zone.....1.56 m.
- Inner diameter of hot zone.....200mm.
- Maximum injection speed12m/sec.
- Maximum injection rate1 sec⁻¹.
- Controlled temperature profile in hot zone (13 channels).
- Computer controlled initial granules loading and injection.
- Forced water cooling of the cooling zone.

Goals of the first experiments with upgraded Ballistic Furnace

- To find operational conditions suitable for shell formation from 0.7-0.78mm initial granules.
- To compare results of shells formation experiments with previous ones obtained with 1m hot zone.
- To study dependence of shell's diameter and yield of good shells on operational condition and initial granule's size.
- To compare experimental results with modeling calculations.

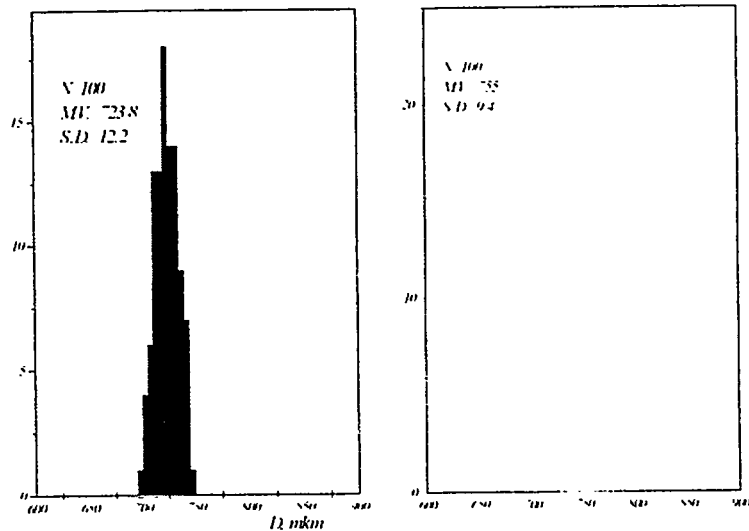
Initial granules for shells formation experiments

We are using LPI made initial granules - solid spherical polystyrene particles from 0.7 to 0.78 mm in diameter.

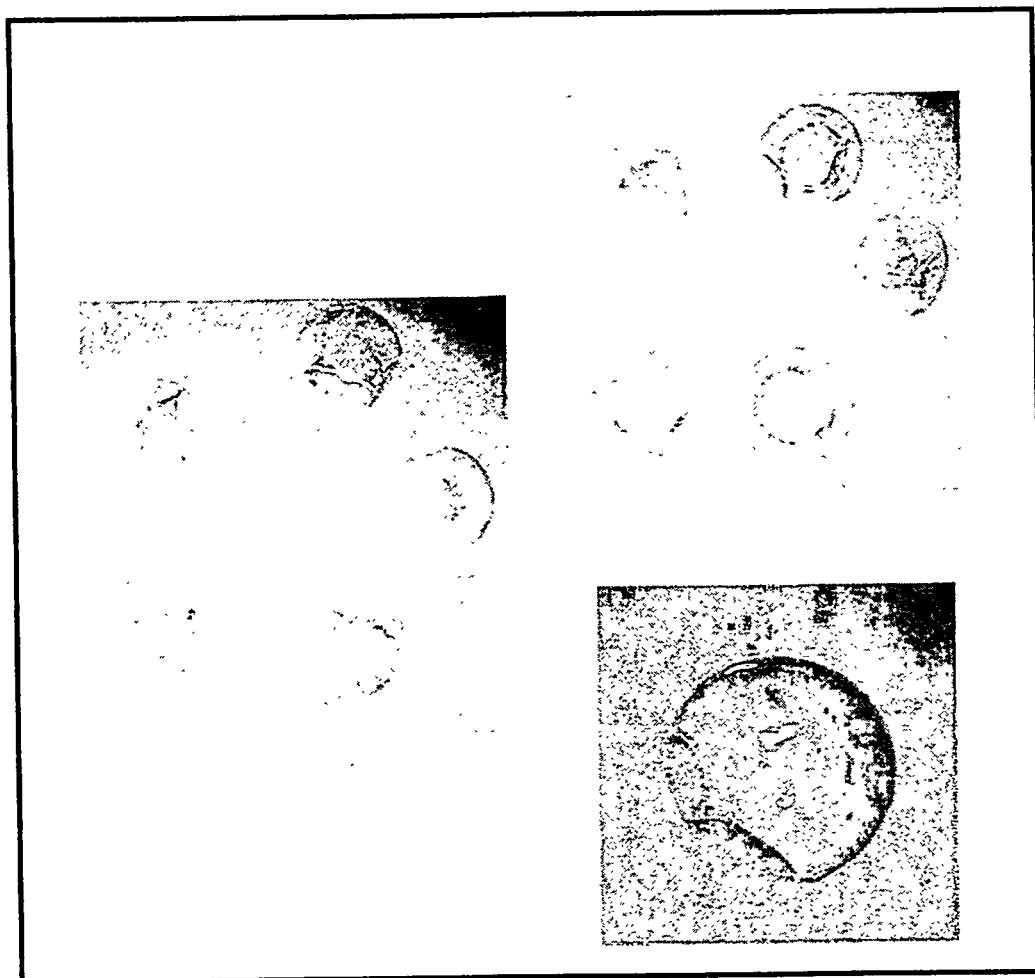
Average molecular mass of granules material ~ 60 000.

Polydispersion factor ~ 2.5

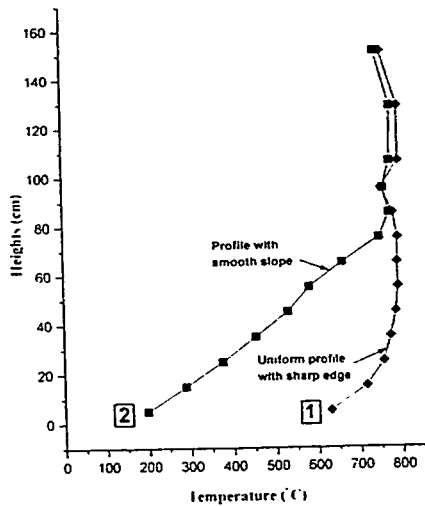
Foamer - ethylacetate, methylacetate 6-8 weight percent.



Typical initial granules size distribution.



Two types of hot zone temperature profile tested in our experiments.

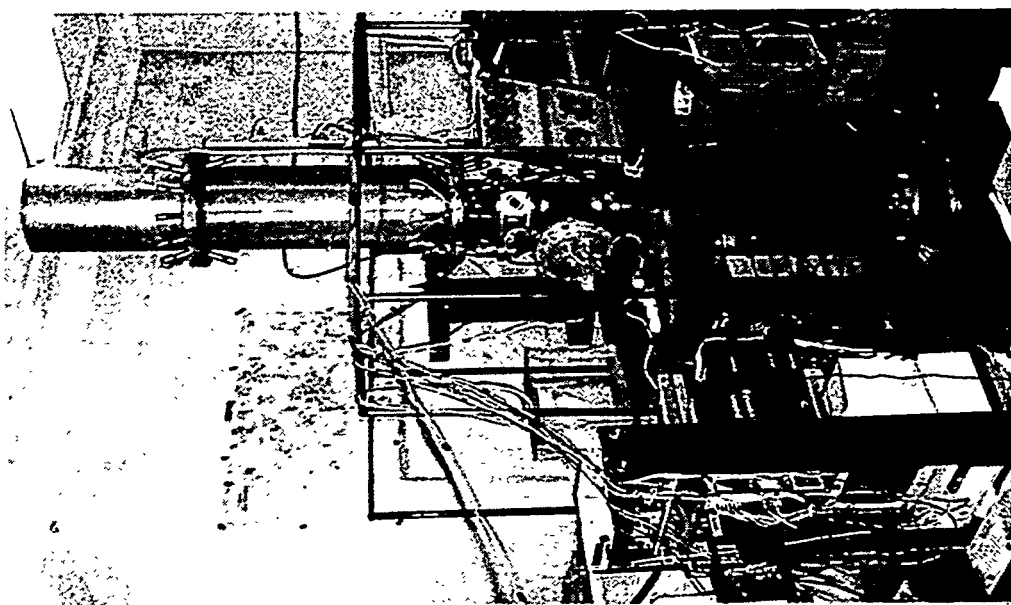


- Results of shell formation experiment are strongly depended on temperature profile in the hot zone.
- Experiment with 1-st profile: pure shell's yield, small size, a lot of deformed shells.
- Experiment with 2-nd profile: quite good yield, larger shells, a few of deformed shells.

Results of recent shells formation experiments

- Modification of the Ballistic Furnace configuration have led to significant changing in operational conditions suitable for shells production.
- Strong influence of temperature profile in the hot zone on shell's yield, size and quality has been found.
- Final size of formed shells and their quality weakly depends on other operational condition.
- First good quality shells up to 1.9mm have been produced with upgraded Ballistic Furnace from small (0.7-0.78mm) initial granules.

General view of the modern Ballistic Furnace



INVESTIGATION INTO A PRODUCTION METHOD FOR
SILVER DISC TARGETS REQUIRED FOR ABLATION
FRONT INSTABILITY STUDIES ON HELEN

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Radiation Physics Department
Atomic Weapons Establishment, United Kingdom

R P Keatch
Department of A.P.E.M.E.
University of Dundee, United Kingdom

Requirement

To produce planar/sinusoidal targets to meet the experimental requirements. These are two diameters of 300µm and 500 µm and with the sinusoidal pitch at 30µm with a height of 0.2 µm. discs flat on both sides we also required. The total thickness to be 3.0µm ± 1.5%.

Investigation

The first trials used sinusoidal surfaces on 500µ discs made by Dundee University in photoresist on a silicon mandrel. This had to be coated in copper to give a measurement on the Zygo New View 100.

Slide 1

These were quite satisfactory in profile and easy to remove the evaporated metal film using solvents; unfortunately, two problems remained to be solved - difficulty to measure thickness of the metal films and problems of machining the top surface flat (to meet requirements).

Therefore, from discussions with the AWE nanocentre using the ultra precision lathe an aluminium mandrel was made with sinusoidal profile cut in the top surface. Discs were evaporated through a mask, initially with copper, using electron beam physical deposition.

Slides 2 and 3

The thickness could be measured accurately on the Zygo New View and the top surface machined flat after deposition. Removal of the copper from the aluminium base was achieved using phosphoric acid which dissolves it but does not attack Cu.

The discs when removed did, unfortunately, suffer distortion due to strain in the evaporated copper.

Slide 4

The actual requirement for a silver target and from past experience this was known to have higher strain in the substrate compared to copper. Therefore, experiments were carried out evaporating silver in an attempt to reduce this strain problem but with not much success to date. These trials included electron beam and sputter source evaporations. Also, attempts were made to anneal the silver after evaporation, but subsequent experimental heating, on a wide range of substrates, caused the silver to adhere quite strongly to the substrates used to date.

It followed, therefore, that another method of production was required to meet the experimental requirement. The option considered was electroplating.

Following discussions with the AWE plating staff it was established that silver could be electroplated on aluminium using a "zincing" process, however this zinc deposit had a variable thickness from 0.1 to >1.0µ.

The technique established, following further discussions with the nanocentre staff produced a flat turned surface on a zinc plated aluminium mandrel.

The problem was then how to produce electroplated discs.

Further discussions with Dundee University established that a mask could be made on the zinc surface.

Initial experiments using photoresist gave unsatisfactory results as it peeled off in the silver electro plating bath. Therefore further experiments using polyimide coatings showed that cured polyimide would withstand electroplating.

A suitable mask was made on the zinc plated mandrel surface and discs of silver were electroplated.

The polyimide mask was dissolved using a special solvent and, after the thickness of the silver discs had been measured, sine waves were produced on the top silver surface using the ultra precision lathe.

Slide 5

The silver targets were dissolved from the zinc base using dilute hydrochloric acid and if handled carefully stayed flat.

Slide 6

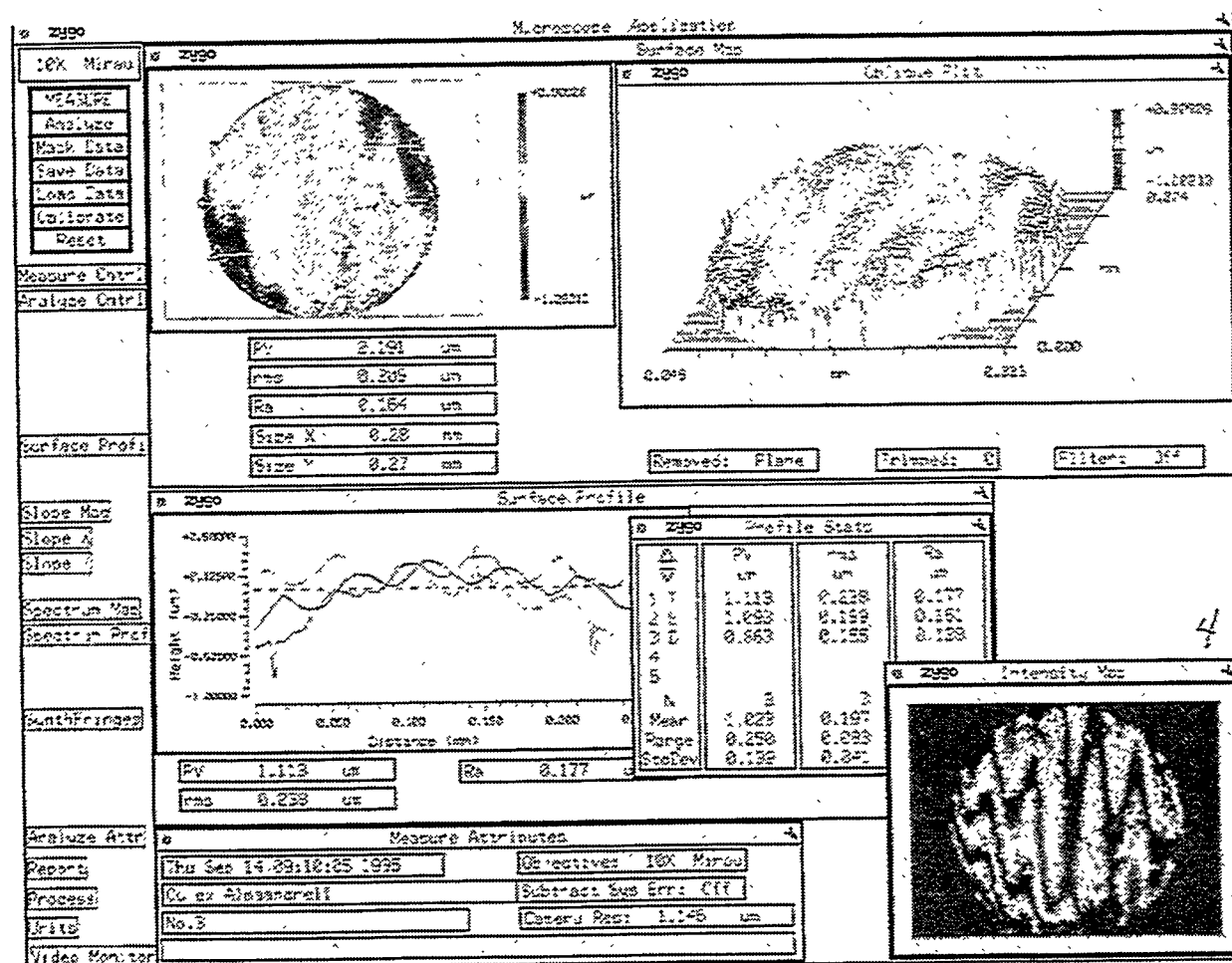
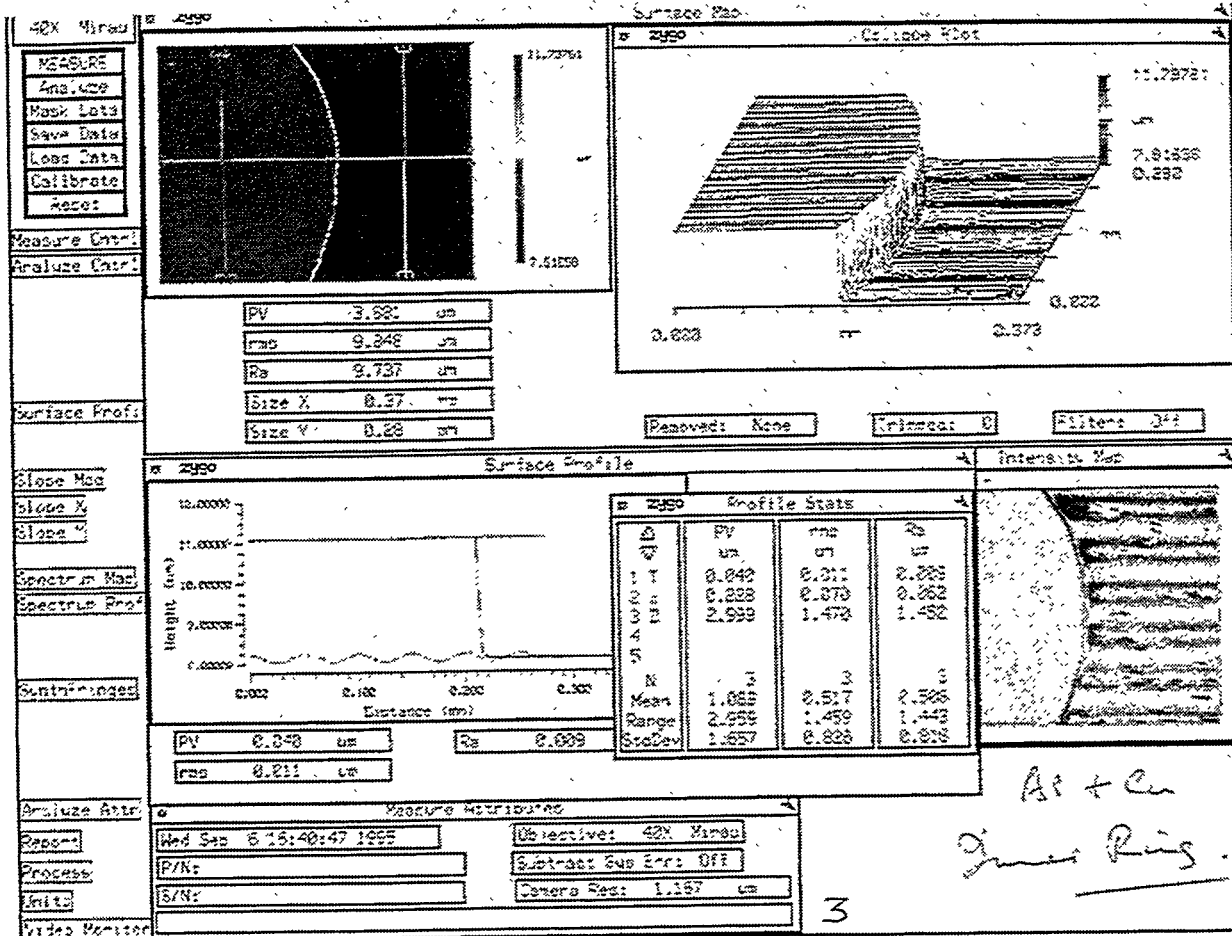
Conclusion

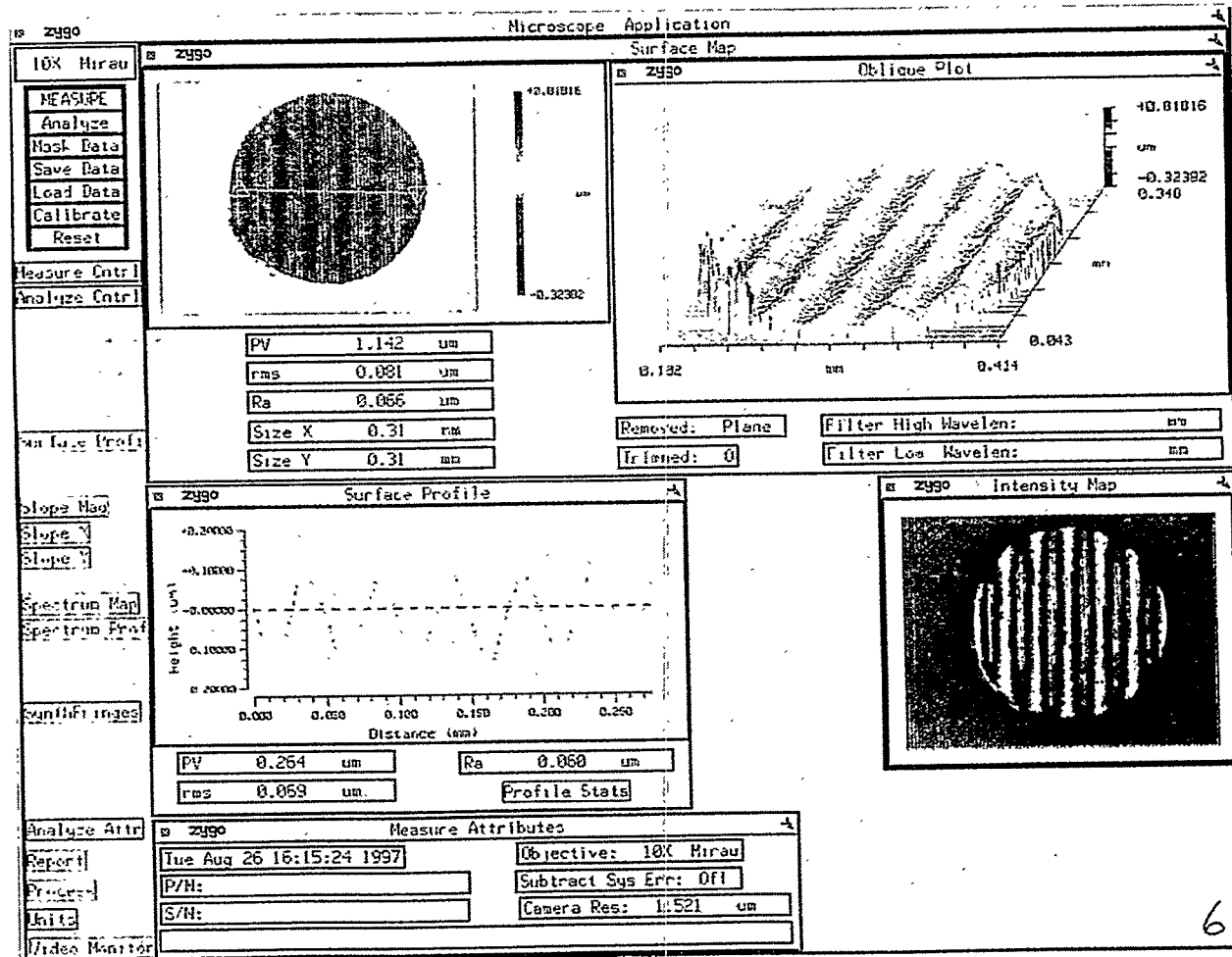
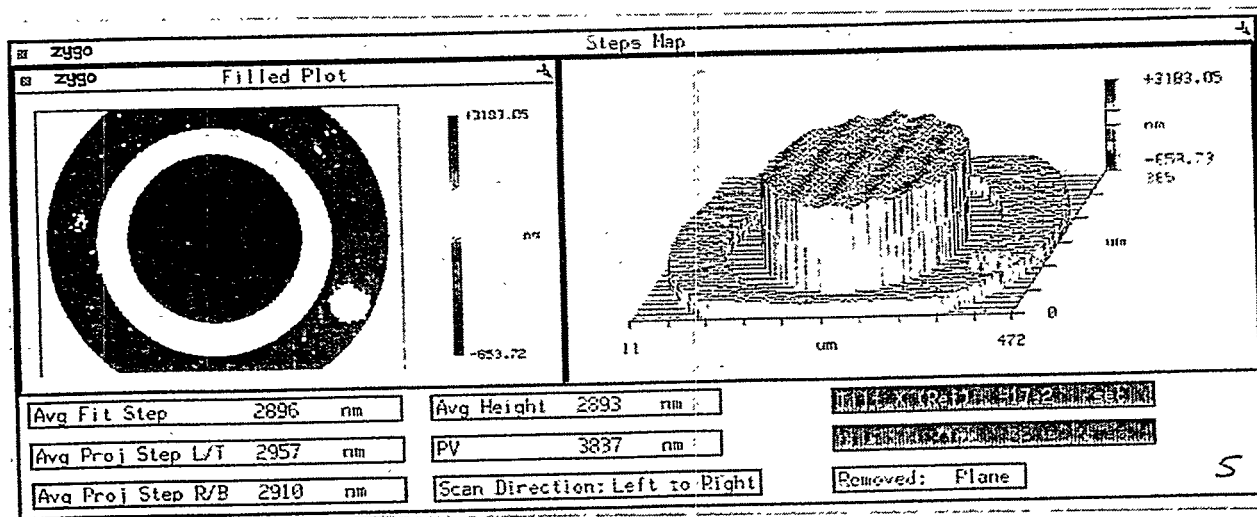
The technique using electroplated silver has given the most satisfactory results to date.

Acknowledgements

My thanks are due to J Lamb and S Wheeler for the advice and machining on the AWE ultra precision lathe.

My thanks are also due to C Lowe for advice and carrying out the electroplating and G Eatwell for his expertise in physical evaporation.





Richard B. Stephens, General Atomics

Reflection spectra of thin films (from <1 to >50 microns thick) show intensity oscillations which allow one to accurately calculate their thickness (Fig. 1). Optical distance between the front and back of the thin film surfaces put an oscillation in the reflection spectrum. The path difference between the two beams is twice the optical thickness of the film (optical thickness = physical thickness $\times$ index of refraction). Even (odd) multiples of $1/2$ give minima (maxima) in the reflected intensity. This is complicated a bit because the index, hence optical thickness is wavelength dependent. The resulting fringe frequency varies inversely with optical thickness.

We have recently used this technique to measure the thickness of ICF target walls using fiber-optics for illumination and detection.

The set up is compact, convenient, and fast, consisting of a fiber optic probe, a book-sized light source/spectrometer, and a portable computer (Fig. 2). In most cases, the probe does not need a focussing lens, and the position of the shell is not critical; the spot on the shell surface which reflects back to the detector is self-selected and can be as small as $50\mu\text{m}$ (Fig. 3). (The front and back surfaces must be parallel.) Measurements take only a few seconds, and compensation for variations in light intensity and detector sensitivity is not generally required.

Because so much of the illumination is lost, sensitive optics are required, and in some applications, lensing is needed to boost the optical efficiency (Fig. 4). In addition, the technique is sensitive to dispersion errors in the spectrometer; wavelength errors in the reflection curve will make analyses difficult.

For these measurements, it is necessary to know the index of refraction of the shell material(s). The value of the index for typically used materials has been determined; The index of GDP changes during processing (Fig. 5) and with the addition of dopants (Fig. 6), introducing an error of $\sim 1\%$ if the index of material in the shell as measured is not independently determined.

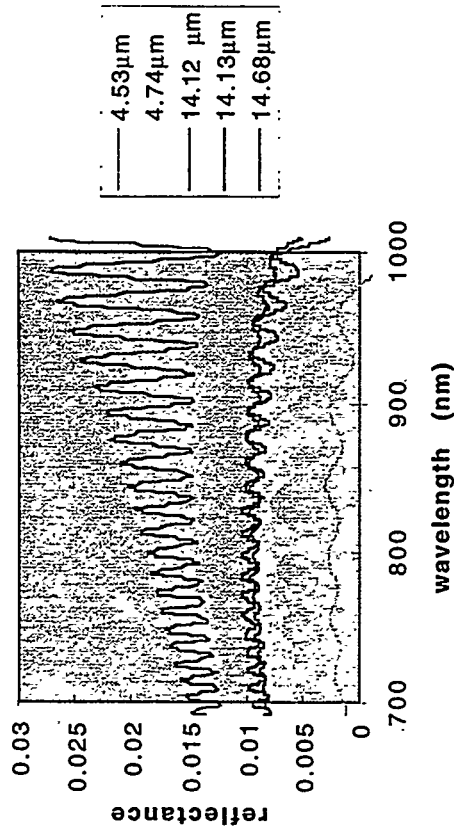
This setup has several potential niches for use in target fab operations.

- Measure thickness fluctuations around a shell in deliverables or DT ice inside a test Be hemishell (Fig. 7).
- Deposition check for GDP on PAMS, GDP on glass, or glass on GDP.
- Quick batch thickness determination for PAMS shells.

It is apparently not useful for measuring PAMS shell wall thicknesses. Possibly since the inside and outside walls are created independently, the walls are not quite parallel.

Figure 1: Reflections from thin GDP films from the bottom of the GDP coater bounce pan.

GDP films



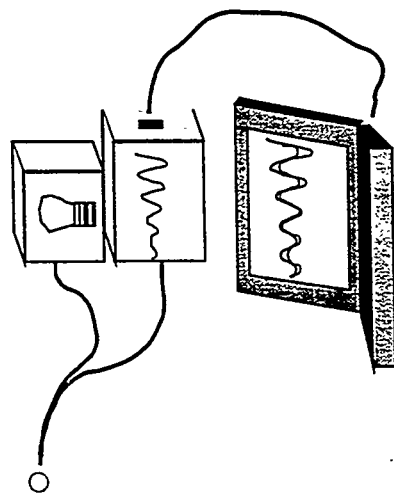


Figure 2: Measuring system consists of fiber optic probe, book sized light source/spectrometer, and portable computer

Figure 3: Schematic showing how fiber optic bundle illuminates and detects from the same point (The fibers have a $NA = 0.22$), and self-selects the reflecting spots. Note that the detected spot is smaller than illuminating optic (for positive curvature).

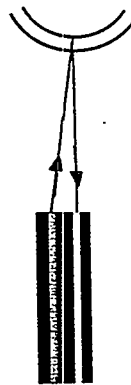


Figure 4: Schematic showing how a GRIN lens improves the light collection efficiency. This lens is 1 mm OD, and focusses 1 mm from end.



Figure 5: Index of refraction of PAMS and GDP after various exposures to the pyrolysis oven. The PAMS index increases a few % on heating.

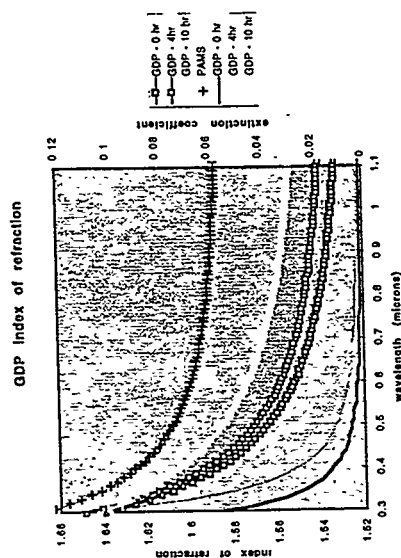


Figure 6: Index of refraction of germanium doped GDP. Compared to plain GDP, The Ge-GDP index changed much less, but dispersion of index (slope of the curve) much more.

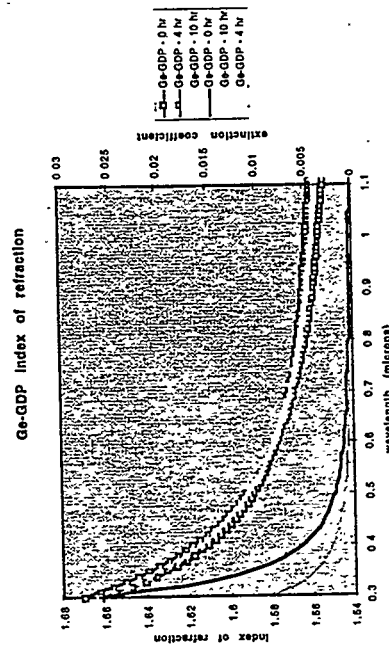


Figure 7a): Possible geometry for measuring DT low mode fluctuations in ice thickness. The sketch shows a glass fronted Be hemishell with the inside surface coated with DT (partially cut away to show the Be inner surface.

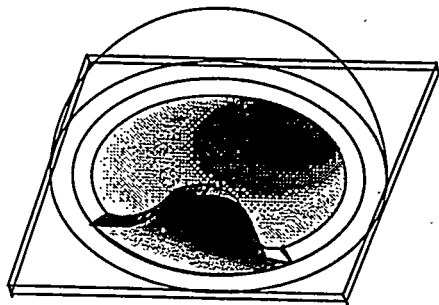
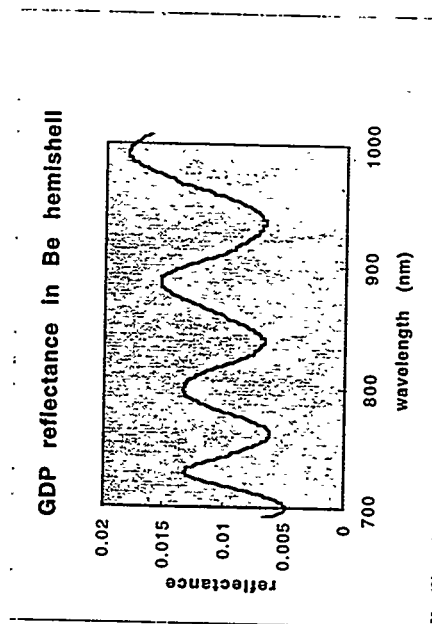


Figure 7b): This idea was tested with a hemishell cut from a GDP shell sputter coated with Be. The interference fringes were very large. DT has a much lower index of refraction, so the oscillation amplitude in the reflection would be correspondingly lower.



1

METHODS FOR MEASURING PARAMETERS OF THE ICF TARGETS SHELLS ALLOWING TO AUTOMATE THE PROCESS OF MEASURING.

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ABSTRACT

Methods for measuring of the shell diameter and wall thickness in liquid have been developed and investigated and the obtained results are presented. The passage of shells causes a change in the liquid column conductivity. The value of electrical signal depends on the shell diameter. This method allows to measure the diameter with an accuracy better than 0.5 micron. The speed with which shells are floating up in liquid is connected with the diameter and wall thickness. If the diameter is known, from the time of floating up the wall thickness can be determined with an accuracy of 3-10%.

These methods allow to automate the measuring process and may be used in an automated line for control and selection of high-quality shells for ICF targets.

INTRODUCTION

For inertial fusion energy (IFE) power plants considered in literature [1] and for experimental investigation of ICF as well as automated production, selection and control of shells for fusion targets are required.

It turned out that the idea of working with shells in liquid is very useful for their automated selection and control [2,3]. Liquid removes electrostatic charges, cleans the shells, protects them from dust and detrimental effect of vapors and gases, promotes motion of the shells in preset directions (floating up in guiding channels).

We have developed and investigated methods separation of shells according to their diameter [4,5] and wall nonuniformity [6], methods for measuring the diameter of shells and the wall thickness in liquid. In this paper we introduce the methods for measuring the diameter and the wall thickness in liquid.

MEASUREMENT OF THE SHELL DIAMETER

Scheme of the method

This problem is solved by method for measurement of conductivity of the liquid column in a capillary. The idea of the method is explained by Fig.1 and is the following. In the capillary 4, filled with liquid, there are two or more electrodes 1,2,3. The shell 5, floating in liquid inside the capillary, changes the cross-sectional area of the liquid column between two electrodes and accordingly the resistance of this column. The change of resistance is in direct connection with the shell diameter. Measuring the resistance it is possible to determine the shell diameter. Large-scale modelling with dimensions in units and tens of mm proved the method applicability.

Calculated estimations

For manufacturing a model for shells with diameters of 100 - 500 μm it is necessary to determine optimal relation between the diameter of a capillary, the diameter of shells and the distance between the electrodes.

For optimization of parameters we calculated the dependence of a resistance change on the sphere diameter. Calculations were done for two models. In the first variant it is supposed that the liquid column in the capillary is uniformly filled with current, and the sphere is substituted by a cylinder with the same radius. This substitution is correct if the distance between the electrodes is not more than 0.7 of the diameter of the sphere. With such assumptions the resistance will be inversely proportional to the sectional area of the liquid column. Let us consider the three variants of electrodes: a closed ring, a semiring from above or semiring from below. Calculations are carried out with dimensionless values. For three variants of electrodes we obtain the following dependence of the relative resistance change.

1. A semiring below

$$\frac{R_0}{R} = (1-p)^2 + \frac{2}{\pi} \left[(1-p)\sqrt{2p-1} + 2p \arcsin \frac{1-p}{p} \right] \quad (1)$$

2. A semiring above

$$\frac{R_0}{R} = (1-p)^2 - \frac{2}{\pi} \left[(1-p)\sqrt{2p-1} + 2p \arcsin \frac{1-p}{p} \right] \quad (2)$$

3. A closed ring

$$\frac{R_0}{R} = (1-p)^2 \quad (3)$$

where: R_0 - the resistance of a liquid column without a sphere

R - the resistance of a liquid column with the sphere presence

R_0/R - relative resistance

D - the diameter of the sphere

D_c - the diameter of the capillary

$p = D/D_c$ - the relative diameter of the sphere.

The results of calculations are represented at the graphs 1, 2, 3 of Fig. 2.

The other variant of calculation was carried out, when the distribution of the field and lines of current were taken in to account. The results of calculations for a closed ring are shown in Fig.2 curve 4. Analogous calculations but for a semiring from below are shown in Fig.2 curve 5. As it is evident from graphs of Fig.2 calculations, carried out by the two different methods, coincide well in quality. The calculations prove that in some cases the change of electrode forms may give increase of sensitivity.

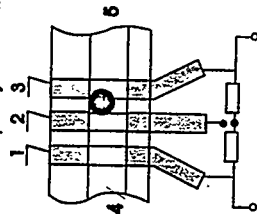


Fig. 1 Scheme of the device for measurement of diameter.

Experiment

Several variants of devices were accomplished and several kinds of liquids as electrolyte were investigated. One variant of the devices has three electrodes (Fig. 1). Voltage was fed on the electrodes 1, 3. Change of voltage on the electrode 2 was registered when the shell was passing between the electrodes (Fig. 3). Pure water and water with NaCl, pure alcohol and alcohol with NaCl were investigated as electrolytes. The most stable results are obtained with pure alcohol at the device with the distance between electrodes equal to $\sim 300 \mu\text{m}$.

Series of measurements with two shells with diameters of $435 \mu\text{m}$ and $492 \mu\text{m}$ were carried out. According to the results of measurements relative resistance change R_0/R was determined:

for the spere $D = 435 \mu\text{m}$ $R_0/R = 0.641$,
for the spere $D = 492 \mu\text{m}$ $R_0/R = 0.526$.

The results of the experiment, shown in Fig. 2 prove well the evaluation calculations, shown in the same figure. The sensitivity of this method with such electrode configuration, for shell range of $D = 400-500 \mu\text{m}$ is $0.5 \mu\text{m}$, when the relative change of resistance is 0.001 . When feeding voltage was stabilized, the accuracy in the series of 12 measurements became $\pm 0.0007 R_0/R$, and maxim error of one measurement was $\pm 0.002 R_0/R$; accordingly maximum error became $\pm 1.0 \mu\text{m}$ and average error in the diameter measurement was $\pm 0.35 \mu\text{m}$. Range of diameters is from several tens micrometres to several millimetres and the accuracy is $\Delta D/D \sim 0.1 \%$.

The described device for shell diameter measurement was patented [7].

MESUREMENT OF SHELL WALL THICKNESS

In work [8] it has been shown that the shell diameter can be measured from the ratio of velocities with which the shells are floating up vertically in a narrow and wide tube. The velocity of floating up depends both on the diameter and thickness of the wall of a shell. As the method for determining the shell diameter in liquid has been developed by us, then, knowing the diameter, the wall thickness can be determined from the time of floating up. Such experiments have been carried out by us. But it turned out that

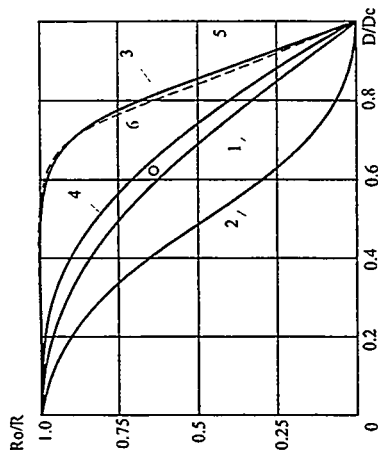


Fig. 2. Diagram of resistance depending on diameter of shell. 1, 4 - rings electrodes, 2 - semiring above, 3, 5 - semiring below, 6 - experimental points for $D = 435 \mu\text{m}$, $D = 492 \mu\text{m}$.

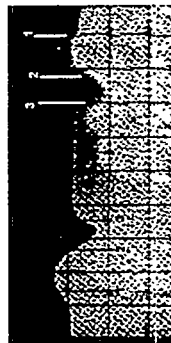


Fig. 3. Oscillogram of voltage variation by flotation of shell.

convection and cocurrent flows in liquid during floating up vertically cause a spread in the time of floating up. We succeeded in reducing significantly the effect of cocurrent and convection flows using floating up along an inclined tube instead of floating up in the vertical direction.

Scheme of the method and experiment

For investigation of possibilities and accuracy of the method a variant of a device for spheres flotation time measurement and wall thickness determination was assembled. It included an optical scheme and an electronic stop-watch start scheme (Fig. 4). Sphere 1, floating up the inclined tube 2, which makes angle to horizon, overlaps laser radiation from a fiber 3. The electric signal from photodiode 4 and impulse forming schemes 5 starts an electronic stop-watch 6. Having passed basic distance 1, the sphere overlaps laser radiation from the fiber 7. An impulse from photodiode 8 stops the stop - watch. The accuracy of registration of sphere passing time is hundredth shares of a second. Flotation time for different spheres with known diameter and wall thickness was investigated. The results of measurements are shown in the histogram

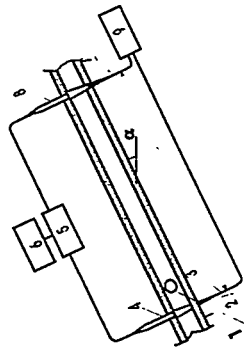


Fig. 4. Scheme of device for wall thickness determination

Fig. 5. Average values of all the measured ones and shells parameters are shown at the table

N of sph.	1	2	3	4	5
D μm	259	260	258	258	280
d μm	0.69	1.48	1.4	3.68	3.45
t sec	19.4 $\pm$ 0.19	46 $\pm$ 0.12	46 $\pm$ 0.31	52.1 $\pm$ 0.4	45.5 $\pm$ 0.45
V cm/sec	0.252	0.241	0.241	0.212	0.244
l cm	4.9	11.1	11.1	11.1	11.1

No special steps were made to make the device thermostatic. The temperature in the room was controlled. At the beginning of measurements with the sphere N 1 the temperature in the room was 27°C . At the end of a series of measurements - 26°C . Smooth change of the sphere velocity N 1 in the first series of measurements corresponds to temperature change and, consequently, to the liquid viscosity change. The further measurements with other spheres were conducted when the temperature in the room was $\sim 26^\circ\text{C}$.

The results of time measurements (Fig. 5) show that the difference between two nearly measurements is only 0.1-0.2 sec.

Evaluation of method accuracy

The shell velocity along the inclined tube is almost by an order of magnitude less than the free flotation velocity. It is caused by an expulsive force proportional to $S \sin \alpha$, by additional rolling resistance along the inclined tube and by liquid resistance during sphere rotation around its centre. All this reduces essentially the influence of cocurrent flows. As the rotation velocity is in direct connection with the flotation velocity, the resistance during rotation is proportional to the flotation velocity. Let us assume, that resulting resistance force F with some coefficient K is proportional to the Stokes law:

$$F = K \pi R h \eta V \quad (4)$$

where: R - is the shell radius, h - is the dynamical viscosity of liquid.

Expulsive force projection onto the motion direction F_I will be:

$$F_I = 4 \pi R^2 g (R/3 \rho_w - d \rho_m) S \sin \alpha \quad (5)$$

The force F is equal to F_I . Hence the flotation velocity is:

$$V = \frac{4 R g}{K h} \left(\frac{R}{3} \rho_w - d \rho_m \right) \sin \alpha \quad (6)$$

The results of floatation of shells with the well-known parameters allow to define the coefficient K . The floatation time dependence on wall thickness for the preset diameter is of the form:

$$t = l / (A - B d) \quad (7)$$

where: $A = 4 R^2 g \rho_w / 3 K h$, $B = 4 R g \rho_m / K h$.

The coefficients A, B are defined from the known diameter. Such, for shells with diameter of 258 μm dependence is of the form:

$$t = l / (2.6 - 127 d) \quad (8)$$

Here: l and d - mm; t - sec

Let us estimate the accuracy of the measurement method of the wall thickness from the time of surfacing on the example of spheres 3,4,5 and dependence 8. For the thickness of 1 - 4 μm , the method sensitivity is 0.3 - 0.4 $\mu\text{m/sec}$. Having the statistic floatation time range of 0.3 - 0.4 sec we get the wall thickness determination accuracy of 0.09 - 0.16 μm for the considered sphere diameter. If one take s measures to make the device thermostatic, or measures the temperature and takes in to account the viscosity change the statistic time range will decrease to 0.2 sec. And that increases the wall thickness measurement accuracy up to 0.06 - 0.08 μm .

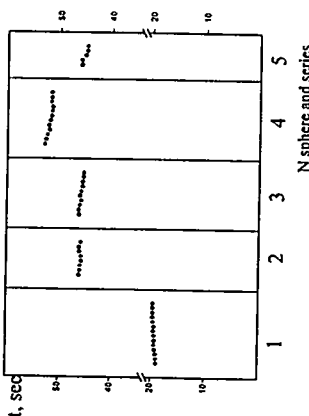


Fig.5. Histogram of floatation times of shells depending on wall thickness.

The conducted experiments and estimations of sensitivity and accuracy prove the possibility of applying the method for wall thickness determination, with accuracy of 0.1 μm , that is 3 - 10 % for the wall thickness of 1 - 4 μm .

CONCLUSIONS AND PERSPECTIVES

We have developed and investigated a method for measuring the diameter of shells in liquid, which provides the measurement accuracy better than 0.5 μm and a method for measuring the wall thickness with the measurement accuracy of 0.1 μm . The advantages of using a liquid are: liquid removes electrostatic discharges, cleans shells from dust, allows to move shells both inside measuring devices and from a device to device.

All these measurements can be easily automated and can find application in automated control and selection of high quality shells for ICF targets and for inertial fusion energy (IFE) power plants [1,2,3].

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DIRECTION DES APPLICATIONS MILITAIRES

**DEVELOPMENTS OF LOW-DENSITY CH FOAMS DOPED WITH
ORGANO-METALLIC PRECURSORS**

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Target Fabrication Meeting 1998
Snow King Resort
Jackson Hole, Wyoming
April 19-23, 1998

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DIRECTION DES APPLICATIONS MILITAIRES

Outline

- Introduction
- Needs
- Synthesis of organo-metallic precursors
 - Synthesis process
 - Characterization means
 - Structure of several molecules
- Synthesis of metal-doped CH foams
 - Synthesis process
 - Characterization means
 - Study of several parameters
- Concluding remarks

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Introduction

- Dopants are means of studying several plasma physics experiments
- We have a good knowledge of undoped or halogen-doped CH foams
- Implosion and radiochemistry experiments are interested in metals and rare earths as dopants such as titanium, aluminium, yttrium, ytterbium and erbium

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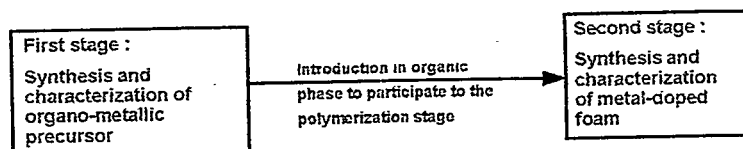
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DIRECTION DES APPLICATIONS MILITAIRES



Two stages to fabricate metal-doped CH foams



Criteria to fabricate suitable metal-doped foams :

- Organo-metallic precursors
 - Polymerizable ligands
 - Soluble in organic phase
 - Crystals or oil
 - Dopants : aluminium (Al), titanium (Ti), yttrium (Y), ytterbium (Yb), erbium (Er)
- Foams
 - Density ~ 50 mg/cc
 - Cell diameter < 30 μ m
 - Open porosity
 - Dopant % at. 0.5-1
 - Homogeneous distribution of dopant
 - Ability towards machining

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Synthesis of organo-metallic precursors

- Starting materials
 - Commercial metal alkoxydes and metallic nitrates
 - $\text{Ti}(\text{O}^i\text{Pr})_4$
 - $[\text{Al}(\text{O}^i\text{Pr})_3]_4$
 - $\text{M}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ $\text{M}=\text{Y}, \text{Yb}, \text{Er}$
 - Commercial polymerizable ligands toward metals

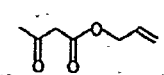
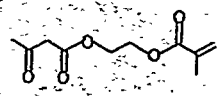
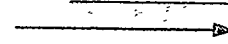
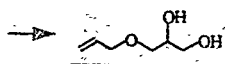
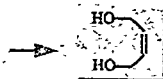
» Acetone

» 2-butane 1,4-diol

» HAAEMA

» APO_2H_2

» HAAA

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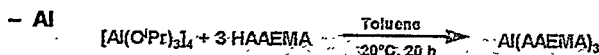
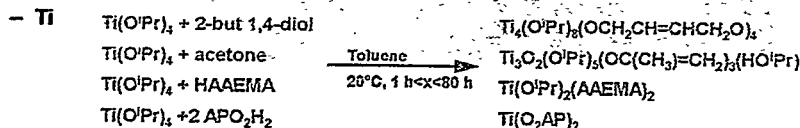
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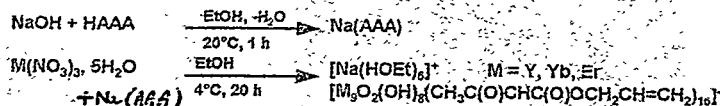
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Synthesis of organo-metallic precursors

- Sol-gel process : the challenge is to remain polymerizable function(s) (having crystals for X-ray investigations is the best)
- Main reactions (40 % < yields < 95 %)



- Y, Yb, Er

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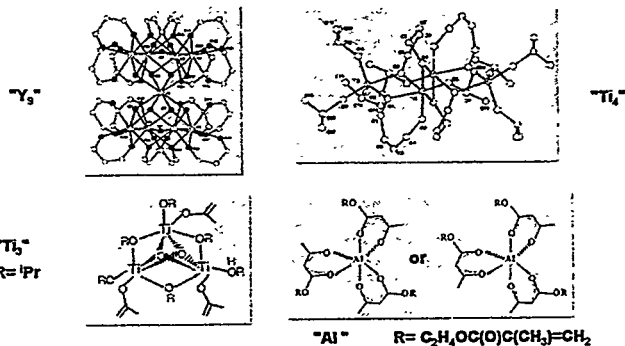
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Synthesis of organo-metallic precursors

- Characterization means of the structure

- Elementary analysis
- FTIR spectroscopy
- ^1H NMR
- X-ray diffraction

- Structures



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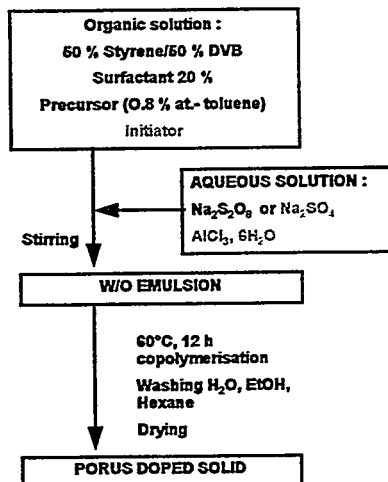
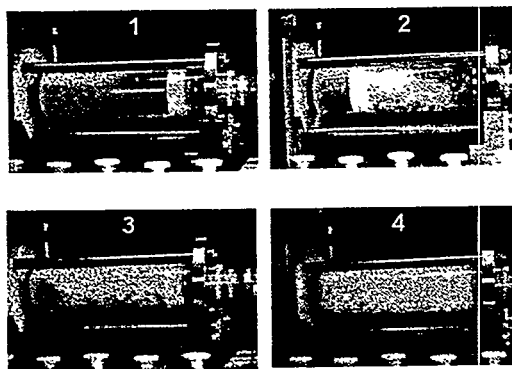
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DIRECTION DES APPLICATIONS MILITAIRES

Synthesis of metal-doped CH foams

- Experimental set up



"Low-density polystyrene foam materials for direct-drive laser inertial confinement fusion targets", F.-M. Kong, R. Cook, B. Haendler, L. Hair and S. Letts ; J. Vac. Sci. Technol. A6(3), May/Jun 1988, p.1894.

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DIRECTION DES APPLICATIONS MILITAIRES

Synthesis of metal-doped CH foams

- Main parameters set
 - Stirring process, washing and drying process
 - Time and temperature of copolymerization
 - Aimed density 50 mg/cc
 - Monomer distribution (50/50)
 - Aimed % at. dopant 0.8
 - Amount of initiator
- Main parameters studied
 - Surfactant (concentration)
 - Process of polymerization
 - » reference : without electrolytes
 - » I : $\text{AlCl}_3, 6\text{H}_2\text{O}$
 - » II : Initiator in the organic phase, Na_2SO_4 in the water phase
 - Precursors (type of metals and ligands, toluene)

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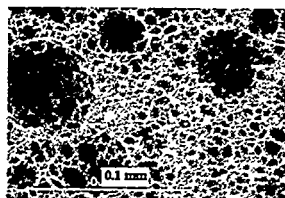


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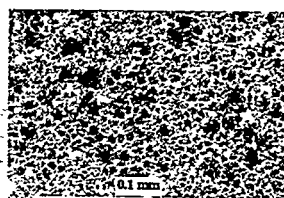
Synthesis of metal-doped CH foams

- Parameters studied
 - Amount of surfactant effects
 - » too much $\rightarrow$ destabilization of emulsion / weak foams
 - » not enough $\rightarrow$ not sufficient stabilization of emulsion / rigid foams / big cells
 - » 5% $\rightarrow$ distribution of cell diameters is more homogeneous
reduction of cell diameters

15 % wt.
surfactant



$\text{Ti}_4(\text{OPr})_4(\text{OCH}_2\text{CH}=\text{CHCH}_2)_4$
0.88 % Ti



20 % wt.
surfactant

0.7 % Ti

Optimum amount : 20 % wt. surfactant

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Characterization means of foams

- | | | |
|------------------------------|---|---------------------------------|
| • Elemental analysis | → | • Metal weight % |
| • FT-IR spectroscopy | → | • Organic residues |
| • X-ray analysis | → | • Metal distribution |
| • S.E.M. | → | • Morphology and microstructure |
| • mass/volume or picnometer | → | • Density |
| • Compressing test/machining | → | • Mechanical strength |

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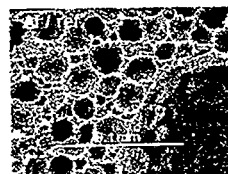
DIRECTION DES APPLICATIONS MILITAIRES

Synthesis of metal-doped CH foams



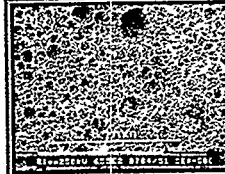
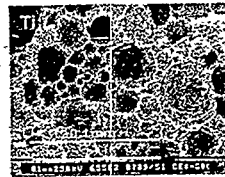
- Parameters studied (cont.)
 - Electrolyte effects (example)

» reference



Large cell diameter
distribution
Pores closed

» system I / reference



More homogeneous distribution
Reduces cell diameters
Open pores

» system II / reference



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Synthesis of metal-doped CH foams

Parameters studied (cont.)

Electrolyte effects (cont.)

system I

- Cell diameters seem to be smaller
- Wall thicknesses are thinner

system II

- Better opening of pores

Precursors	System I	System II
$Ti(O^iPr)_3(OCH_2CH=CHCH_2O)_4$	•	
$Ti_3O_2(O^iPr)_3(OC(CH_3)=CH_2)_3(HO^iPr)$		•
$Ti(O^iPr)_2(AEMA)_2$		•
$Ti(O_2AP)_2$		•
$Al(AEMA)_3$	•	
$[Pt(HOEt)_4]^+$	•	
$[Pt(O_2(CF_3)(CH_3)(O)CH(CF_3)CH_2CH=CH_2)_4]^+$	•	
$M = Y, Yb, Er$		

Toluene effects

» Depends on the type of precursor

- Good effects on Ti_3 and Ti_4 if no toluene
- Bad effects on Ti ($Ti(O^iPr)_2(AEMA)_2$) if no toluene (no emulsion)

Ligand effects

» Depends on the type of metal

» Only studied on Ti : preference according to foam criteria



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Synthesis of metal-doped CH foams

Parameters studied (cont.)

Metal effects

- » Not yet studied because of synthesis difficulties
- » Foam structure depends on the type of precursor (metal or ligand ?)

Metal concentration effects

- » Precursor introduction destabilize emulsion
- » Destabilization depends on the type of metal
 - $Ti : [Ti]$ increase $\longrightarrow$ cell diameters increase
 - Y, Yb, Er : no variation

» Metal loss

- Loss of metal depends on
 - Type of precursor
 - Toluene
 - Amount of surfactant
- Possible explanations
 - Partial polymerization of precursors
 - Alteration of precursors ...

Metal	Maximum % at. (0.8)	Maximum % wt.
Ti	0.2	1.5
Al	0.22	0.89
Y	0.06	0.79
Yb	0.04	1.10
Er	0.06	1.17

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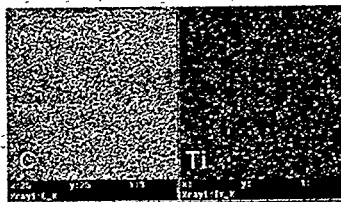
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DIRECTION DES APPLICATIONS MILITAIRES

Synthesis of metal-doped CH foams

- Metal distribution
 - Mapping analysis on 4 mm²
 - Good distribution



- Mechanical strength
 - Compressing test (20°C, cylinders)
 - » %metal → E (Young modulus) and Re (elastic resistance)
 - Machining has been obtained on best metal-doped foams : example (diameter=173 μm, height=380μm)



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DIRECTION DES APPLICATIONS MILITAIRES

Concluding remarks

- We succeeded in synthesizing metal-doped foams with titanium, aluminum, yttrium, ytterbium and erbium
- We managed to meet the foam criteria (50 mg/cc density, cell diameters < 30 μm, open porosity, homogeneous distribution of dopant, machining) but we still have to improve the knowledge of molecular mechanisms to increase the dopant concentration
- One possible way is to try to understand molecular mechanisms to fit the precursor into the organic phase
- We also plan to introduce precursors into polystyrene to synthesize metal-doped polystyrene microballoons

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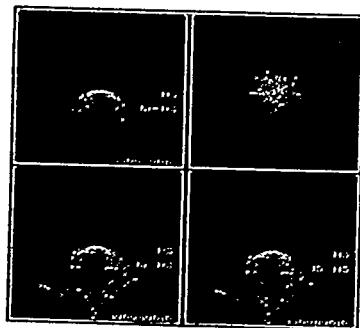


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Using Ion Beam Techniques to Determine the Elemental Composition of ICF Targets

UR
LLE



David R. Harding
University of Rochester
Laboratory for Laser Energetics

Target Fabrication Meeting
Jackson Hole, WY
19-23 April 1998

Ion beam analysis techniques provide 3-D quantitative elemental information about targets without requiring external calibration against NIST-traceable standards

UR
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OMEGA-relevant applications:

- Determine the elemental composition and density of plastic capsules (C, H, N, O, Si, Ti, Cl, Ge).
- Determine the elemental composition and areal density of multilayered flat foils (CH, KCl, Ti) used in plasma physics experiments.
- Determine the composition of Au-coated foam targets.

Techniques:

- **Rutherford Backscattering Spectroscopy:** Uses an energetically well-defined ion beam, the kinematics of backscattering (conservation of energy and momentum), and a surface barrier detector (15-keV resolution) to detect elements ($z > \text{Be}$).
- **Nuclear Resonance Analysis:** Uses the resonance reaction between $^{15}\text{N}^{++}$ (at 6.385 MeV) and H, and measures the resultant γ product (at 4.43 MeV).

71004

Resolution and sensitivity of the techniques

UR
LLE

Rutherford Backscattering Spectroscopy

- 2- μm spatial resolution
- 10-nm depth resolution
- 2- to 7- μm probe depth using ^4He ; up to 20 μm using ^1H beam
- Moderate sensitivity (10^{-4}) to mid-z elements in low-z matrices: i.e., Si; Cl $\sim 1 \times 10^{19}$ atom/cc
- Accuracy: $\pm 3\%$ for ρ density
 $< 1\%$ for average stoichiometries
 $\sim 25\%$ uncertainty for trace elements

Backscattering cross sections for ^4He (0.5 to 4 MeV) on all elements $> \text{Be}$ are nearly Rutherford and well characterized.

Nuclear Resonance Analysis:

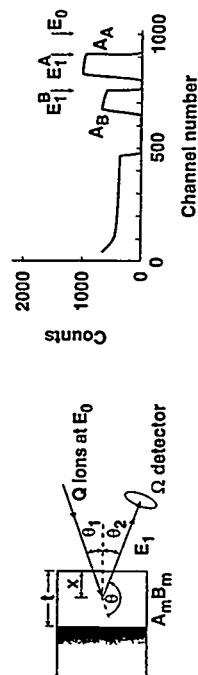
- Used to quantify hydrogen content
- Accuracy ~ 1 at. %
- Probe depth $\sim 1 \mu\text{m}$
- Depth resolution: 50 to 100 nm
- Uses known: stopping powers and nuclear cross section to calculate elemental compositions

71005

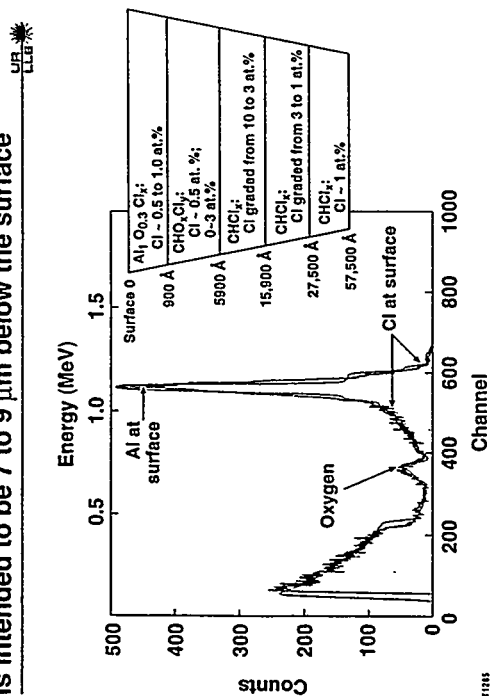
The RBS technique depends upon 4 physical concepts

UR
LLE

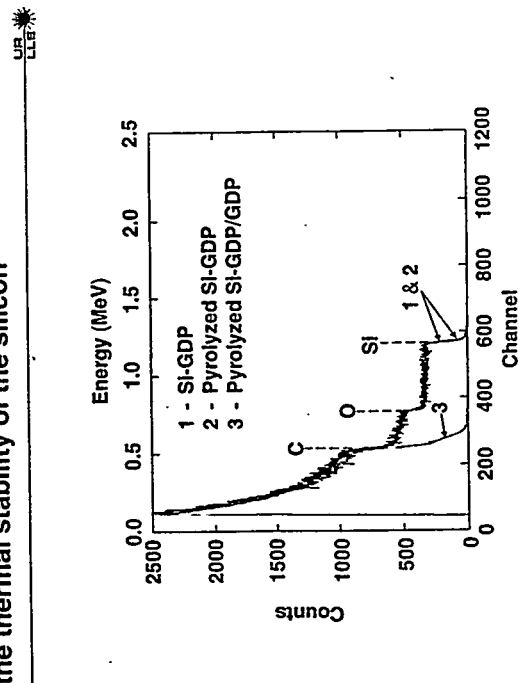
1. The kinematic factor describing energy transfer from the incident ion beam to a target nucleus in an elastic two-body collision.
2. The probability for scattering, given by the differential cross section.
3. The average energy loss of the projectile and recoiled target atom (given by the stopping powers) as they transverse the sample.
4. Energy straggling given by the statistical fluctuation.



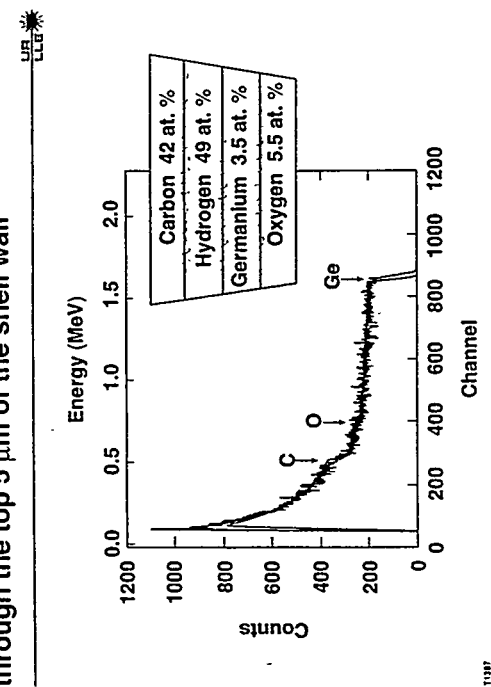
RBS spectrum from a 900 - μ m-diam target (5- μ m-diam spot size): Chlorine is present at the surface when it is intended to be 7 to 9 μ m below the surface



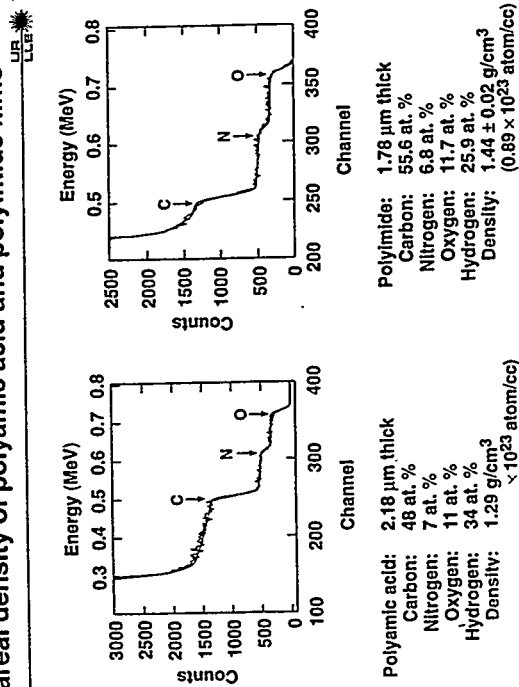
RBS spectra of 3 silicon-doped GDP films demonstrate the thermal stability of the silicon



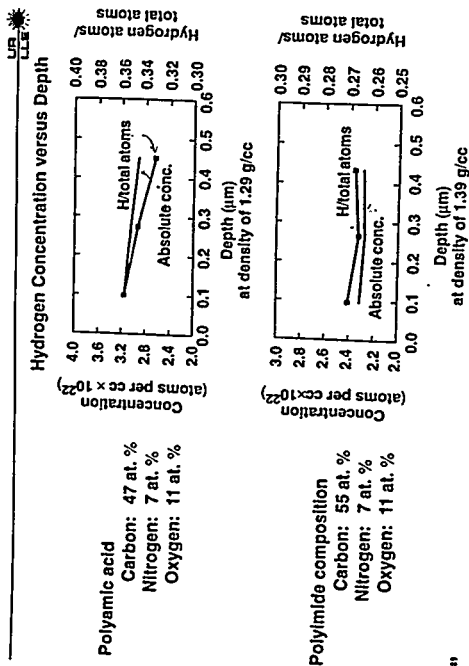
RBS spectrum of a Ge - doped OMEGA target (<P130-49): Ge is uniformly distributed through the top 5 μ m of the shell wall



RBS data provides the elemental composition and areal density of polyamic acid and polyimide films

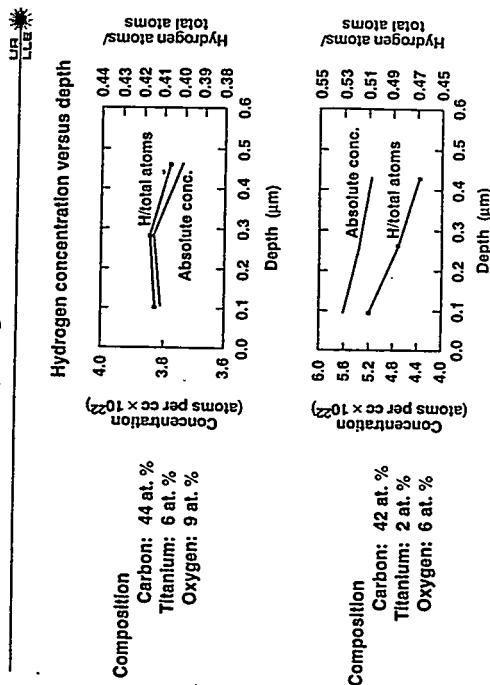


The hydrogen content of polyamic acid and polyimide, as determined by NRA, is consistent with the stoichiometric values



11388

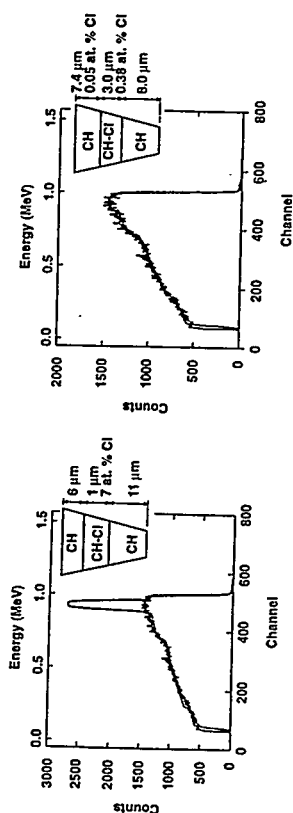
Different Ti-doped plastic films possess significantly different hydrogen concentrations



11390

A 1.4 MeV H^+ probe beam provides substantially greater depth information than a 2 MeV He^+ beam. The target is a 900 μm shell (P-69) with a Cl-doped layer in an 18 μm thick shell wall

UR
LLE



RBS data with an appropriate simulated fit that yields the structure shown.

11391

Summary of data obtained over the past 2 years shows the variability of the elemental compositions of targets

Plasma Polymer Targets:

Carbon: 40 to 46 at. % for all types of doped/undoped plastic targets
Hydrogen: 40 to 55 at. %; minor depth gradients (<3 at. % gradient over 0.5 μm)
Silicon: 6 at. %; uniform depth distribution and thermally stable
Germanium: 1 to 4 at. %; uniform depth distribution and thermally stable; minor variation within batch (<1 at. % variation)
Titanium: <1 to 8 at. %; recently ~ 6 at. %
Chlorine: <1 at. % on average if material heated to 300C; high Cl gradient at the surface; 1 to 4 at. % if material not heated
Oxygen: 2 to 10 at. % (saturation level); may depend upon how long target exposed to air

Polyimide Targets:

Polyimide: carbon 55 at. %; hydrogen 27 at. %; nitrogen 6 at. %; oxygen 12 at. %;
Polyamic acid: carbon 47 at. %; hydrogen 35 at. %; nitrogen 7 at. %; oxygen 11 at. %;
density 1.44 g/cm³ (nitrogen rich)
density 1.29 g/cm³

11392

Conclusion



- The composition of all the elements in a plasma polymer target varies significantly from batch to batch (and less significantly within a batch). Full analysis requires the following data:
 1. measured density;
 2. measured wall thickness; and then
 3. RBS and NRA data.
- RBS and NRA provide accurate and complementary methods for directly (and nondestructively) determining the composition of a single plastic target without the need for external calibration.
- The cost of these techniques prevents them from being used to routinely characterize targets; however, the technique can be appropriately used to periodically verify the analysis of other more-convenient analysis procedures (i.e., XRF).

T1413

Temperature control sensitivity variation of cylindrical hohlraums with capsule thermal conductivity



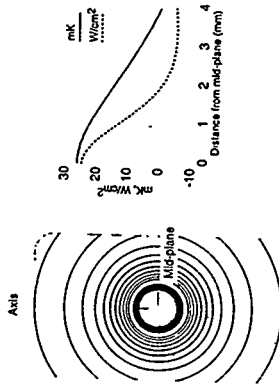
Jorge J. Sanchez & Warren H. Giedt

Target Area Technologies
Lawrence Livermore National Laboratory

presented at

Target Fabrication Meeting - 98 -- April 19-23, 1998

Ideal isotherms and wall temperature profile



- Uniform DT layer thickness produces spherically symmetric heat flow
- Ideally the temperature of the hohlraum wall must conform to the profile of the capsule isotherms for the DT layer to remain uniform
- Practically, a similar profile with 20% higher temperature rise compensates for the LEH's and yields sufficient uniformity

4/28/98

Hohlraum-target system thermal design

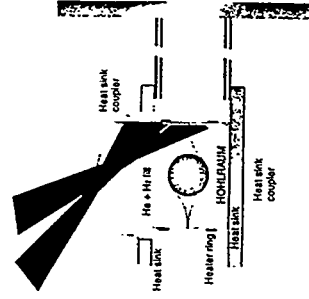


- Ideal isotherms and wall temperature profile
- Hohlraum support and cooling system
- System modeling & numerical solution procedure
- Ensuring conduction heat transfer through fill gas
- Capsule thermal conductivity effect on DT layer
- DT layer thickness sensitivity to control uncertainty
- Summary and future work

4/28/98

Hohlraum support and cooling system design

- Sapphire support/cooling rods
 - High tensile strength provides superior target assembly support
 - Single crystal rods have very high thermal conductivity and are not affected by handling stresses
 - Central location concentrates debris on the cryostat ablation shield
- Axial heat flow equalizer
 - Relocated from LEH area to remove interference with laser beams



4/28/98

Numerical solution procedure



- Assumptions
 - Azimuthal heat flow symmetry
 - Conduction >> convection
- Axi-symmetric model
 - tritium decay heat input
 - external heating of hohlraum wall
- Solution procedure
 - specify layer thickness & geometry
 - search for required heat flux distribution to hohlraum wall

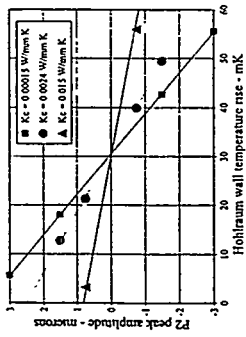


4/28/98

DT layer thickness sensitivity to temperature control uncertainty



- Layer thickness vs. angle is modified to create P2 defects of 1 to 3 microns at mid-plane
- Model run to find hohlraum wall temperature rise for uniform temperature along DT surface
- P2 defect amplitude vs. hohlraum hub to mid-plane temperature rise



4/28/98

Ensuring conduction heat transfer in fill gas



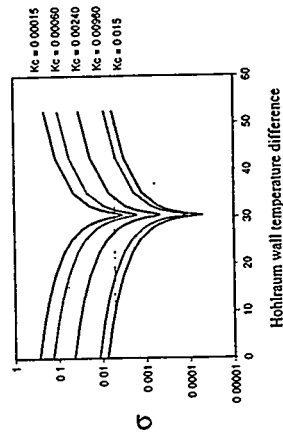
- Local temperature and heat flow variations introduced by free convection difficult to account for
 - $k_{\text{conv}} / k_s < 0.005$ -- for convection to be negligible
- For fill gas density of 1 mg/cm³ Rayleigh number is of order 400-600. Heat transfer due to convection is less than 0.05
- Techniques to reduce or restrict convection
 - Horizontal thin films, and if necessary:
 - Lower gas density until just before firing to decrease convection heat transfer to less than 0.5% of conduction

4/28/98

Capsule thermal conductivity and effect on DT layer sensitivity



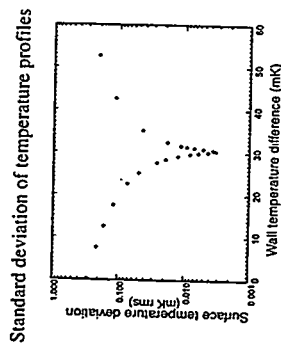
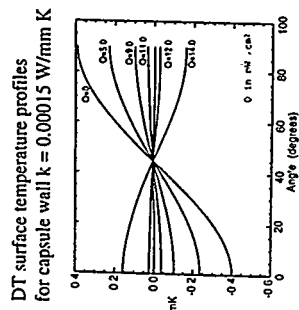
Standard deviation of calculated surface temperatures for a range of capsule thermal conductivities



Minimum values are all less than 5.0 μ K and can be considered to specify the wall temperature rise which will yield a uniform DT layer thickness

4/28/98

Surface temperature profiles and their standard deviations



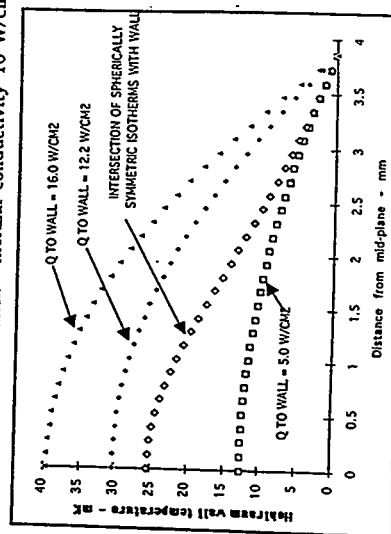
J/2898

11

Temperature distributions along hohlraum wall for uniform heat fluxes



hohlraum wall 30 microns thick - thermal conductivity 10 W/cm K



Future activities



- The design of a multiple heat-flow path cooling hub for minimizing circumferential temperature variations.
- Modeling and verification of the effect of free convection on heat flow in the fill gas.

J/2898

Summary

- It is estimated that the DT layer thickness variation can be held to within 0.2 to 0.4 micron by controlling the temperature rise along the hohlraum wall to about 3.0 mK for plastic capsules.
- The sensitivity of DT layer thickness variation decreases significantly with increase of the capsule wall thermal conductivity. For conductivity values characteristic of metals, maintaining layer thickness variation from 0.2 to 0.4 micron will require control of the temperature rise along the hohlraum wall only to within 10 mK.

Requirements:

Required to test 3D Hydrodynamic mix models of the RM instability and fully turbulent regimes

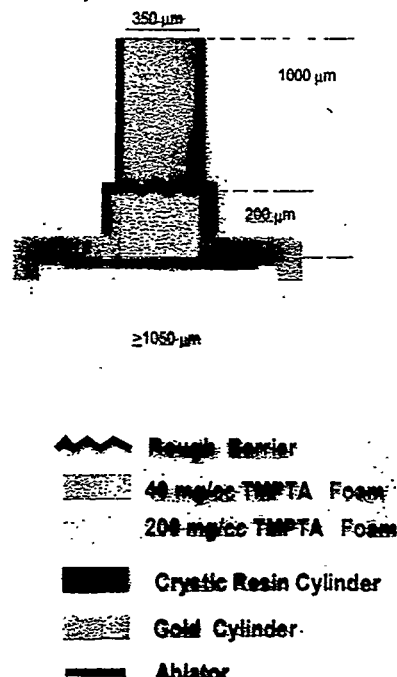


◆ Target design:

- A randomly rough interface
- Foam depants to allow the spectroscopic investigation of the mix.

◆ Target type:

- No barrier
- removable metal barriers
- Permanent plastic barriers
- Permanent plastic barriers with gold tracer layers.



In-Situ Polymerization of Foam Filled Laser Targets With Two Regions of Different Densities, Separated by a Thin Film.

*Presented at the 12th TFSM, Jackson Hole, Wyoming,
April 19 - 23, 1998*

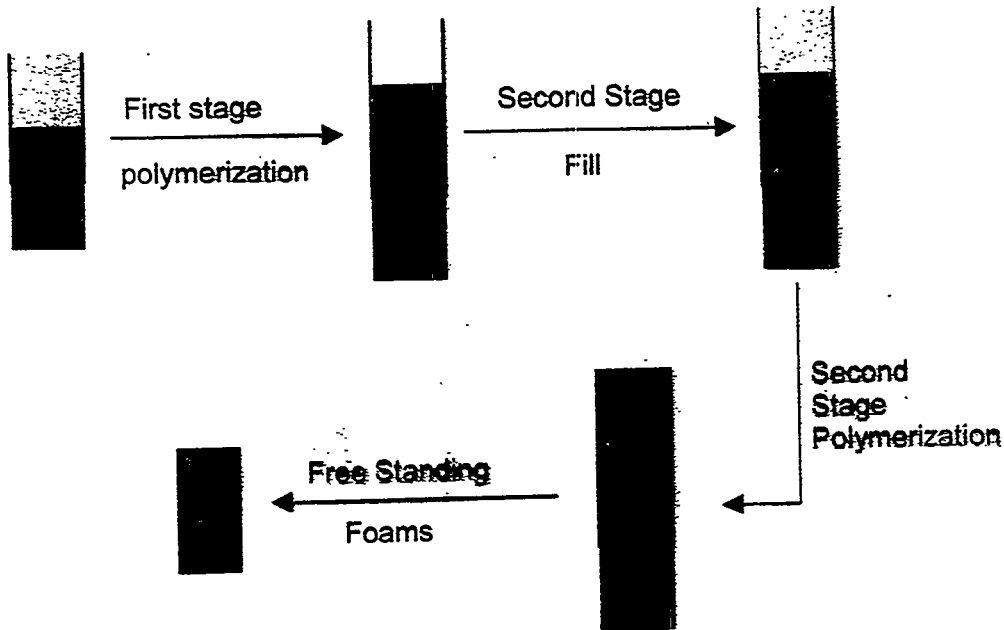
Colin J. Horsfield*, Wigen Nazarov** , Kevin Oades*

*Atomic Weapons Establishment, Aldermaston, Reading RG7 4PR, England.

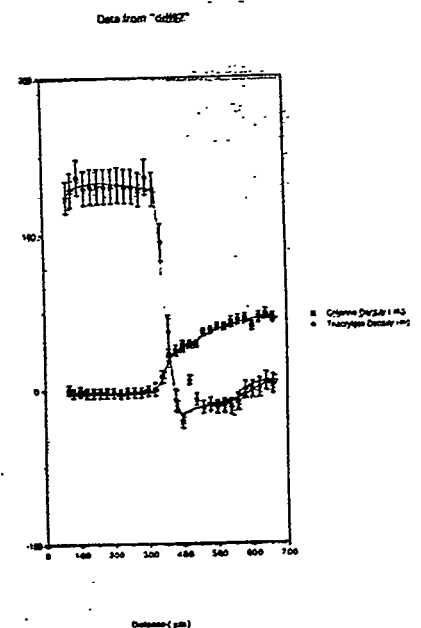
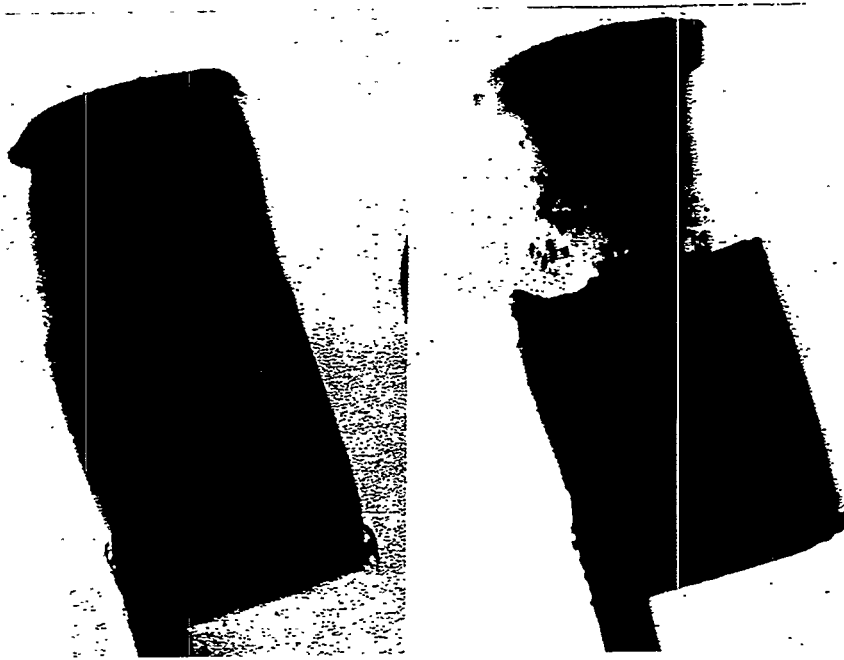
**Department of Chemistry, University of Dundee, Dundee DD1 4HN, Scotland.

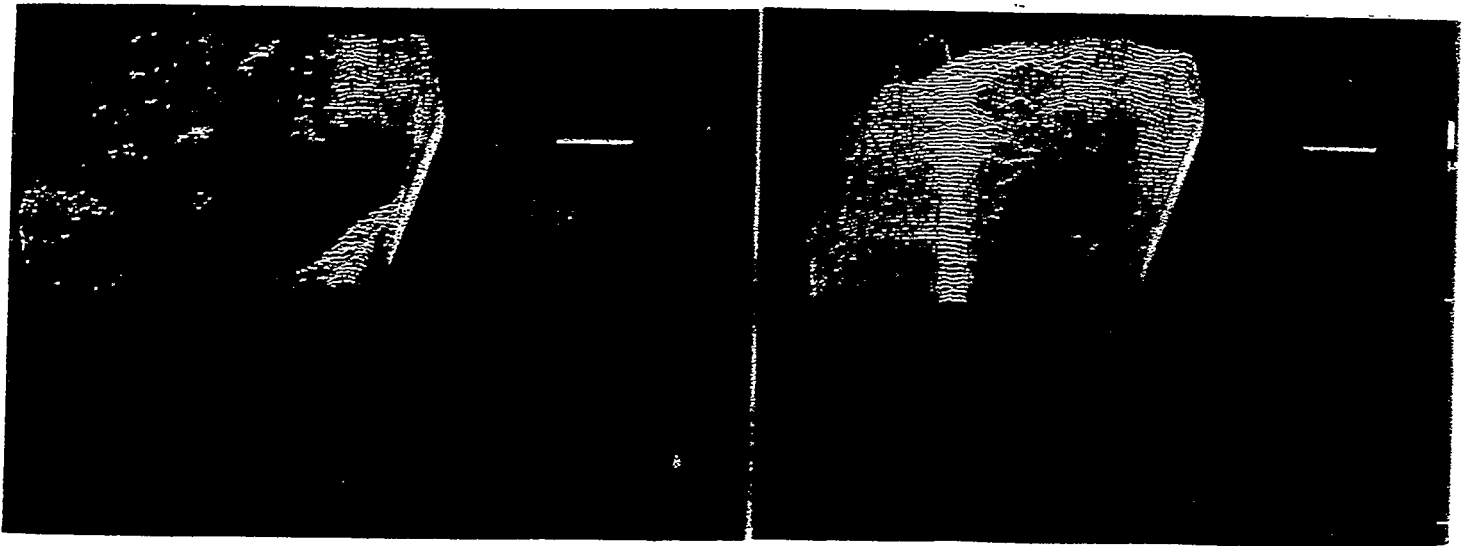


Two phase foams with no barriers



Differential radiography showed that the Cl monomer diffusion was greater than 100 μm and this was unacceptable.



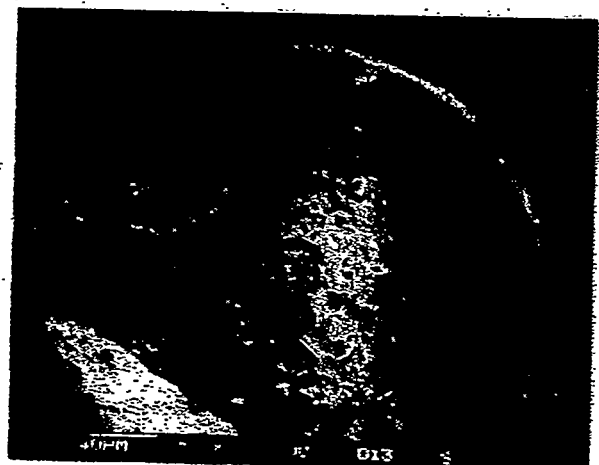


The surface of the foam facing the top cylinder appears to be similar roughness to that found on the rough foils. The lower surface is, however, much smoother than expected.

Removal of copper foil



- ◆ SEM showed there was a high density broken film on the surface of the top foam. Initially this was thought to be an effect associated with TMPTA foam. However, on dissolving the copper foil used in the interface, a plastic residue was observed. It is now believed that this is a layer of PMMA, highly crosslinked by the heat generated during the sputtering process. This renders the film insoluble.
- ◆ It was also observed that the copper foil buckled. This explains the smooth surface in the upper cylinder



Permanent barrier

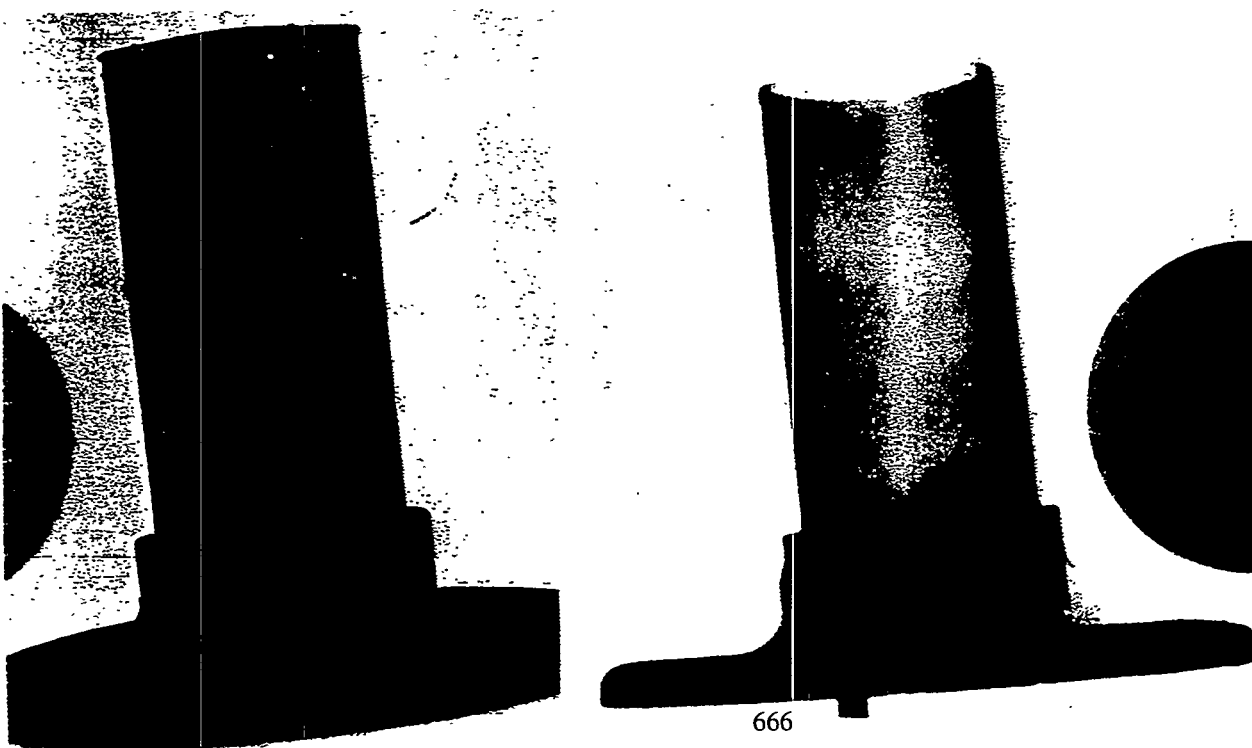
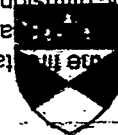


- ◆ At this stage it was decided that a permanent barrier would be acceptable.
- ◆ Rough PMMA surfaces were coated with Parylene C which was used as the interface.



Diffusion through barrier

When the targets were made the Parylene N layer was cut too close to the cylinder diameter. This caused leakage from the first fill (lower cylinder) into the upper cylinder. The results were not acceptable. By cutting the Parylene oversize by 40 micrometer in radius this folds classic diffusion meniscus.



Two phase foams with removable metal barrier



RADIOGRAPH OF TWO PHASE FOAM MADE WITH
A ROUGH CU BARRIER (CU REMOVED)



- ◆ A target with copper removed showed an apparent surface roughness. However, the interfaces were too confused by the boundary between the two cylinders.
- ◆ The cylinders were therefore separated and examined by CLSM.

Surface measurements



It has been shown that confocal laser scanning microscopy can be used to measure these surfaces on the scale of a laser target ($400\text{ }\mu\text{m}$).
Ref.: C. J. Horsfield, 9th TFSM, Monterey, 1993).

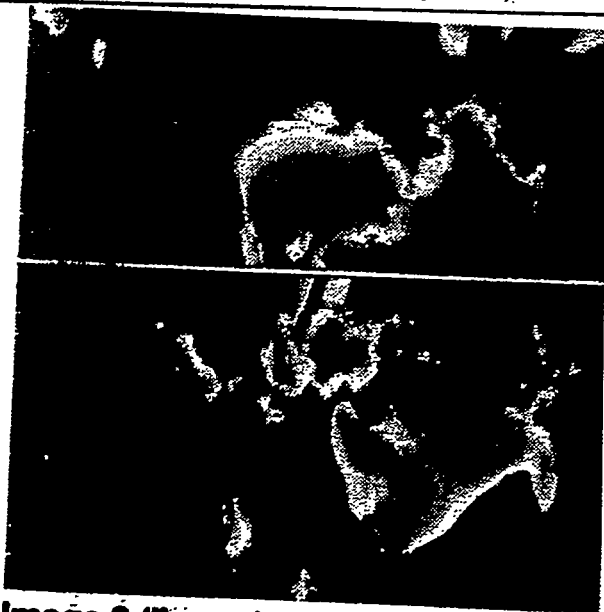


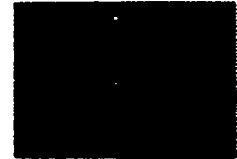
Image 2 (Jigsaw): 50x obj, 49x zoom
rms = $4.17\text{ }\mu\text{m}$



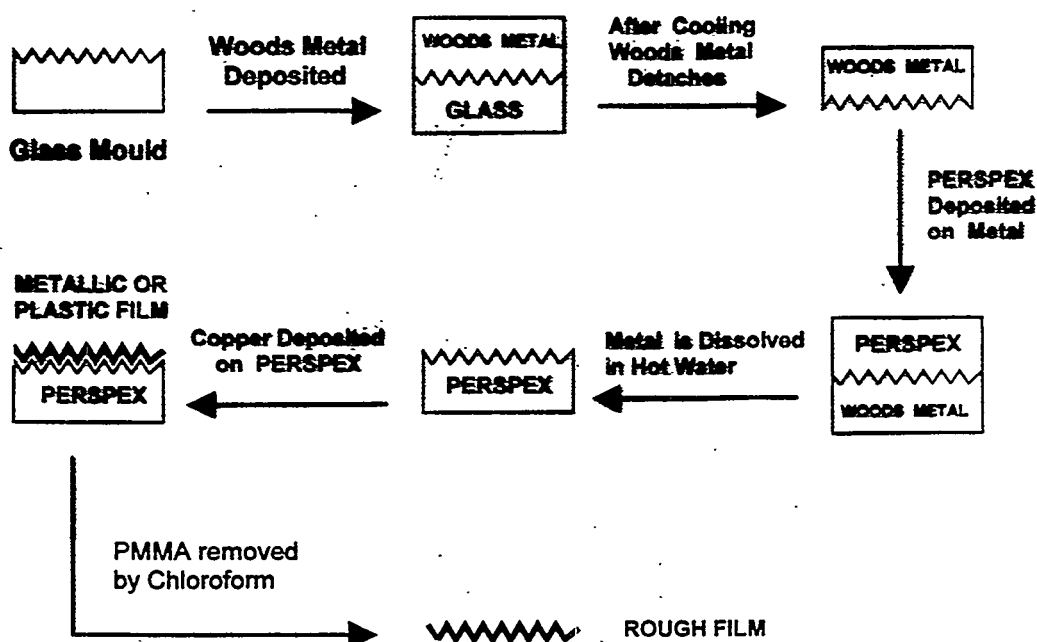
Immiscible solvent systems



- ◆ Foams produced from Immiscible solvent systems were considered. However, it was proposed that the solvent would wick in the rough surface of the first fill as it is the same order as the pore size. Therefore, this technique was never attempted.
- ◆ Targets were all plastic or gold. The obvious choice for the removal barrier was a metallic foil. Which could be removed by acids
- ◆ This foil had to have required surface roughness, 5 μm rms. The thickness was chosen to be $\leq 1 \mu\text{m}$ (pore size of the foam).



Production of Metallic and/or Plastic barriers



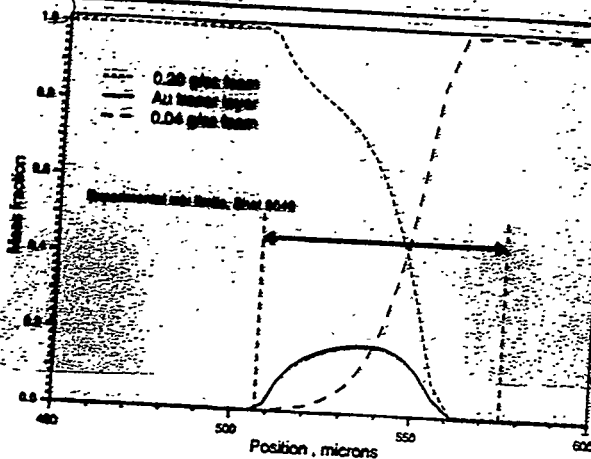
Experimental Shots

University of Dundee



1D simulations with the turbulent mix model predict the extent of the gold tracer layer to be 60 μm at 17ns for this target

Good quality experimental data clearly show a wide opaque region due to the tracer material being distributed through the mix region



Shot 0040
 $t = 17\text{ns}$

Conclusion

University of Dundee



- We have shown that the production of two phase targets to be a viable method of measuring mix effects, in laser driven experiments.
- We remain hopeful that these techniques can be further developed to produce barrier free targets. Although, this also requires development of suitable dopants for point projection as a diagnostic technique.

DEVELOPMENT OF THE DEVICE TO FABRICATE CRYOTARGETS WITH A THICK LAYER OF A FUEL

Elena R.Koresheva, Irena V.Aleksandrova, Igor E.Osipov,
Gennadiy D.Baranov*

Lebedev Physical Institute, Leninskyi Pr.53 Moscow, Russia
* "Red Star" State Enterprises, Moscow, Russia

The team-work between the Lebedev Physical Institute (LPI) and the "Red Star" State Enterprises (RSSE) has been started in the frame of a three-year Project #512 supported by the International Science and Technology Center (ISTC) over the period of 1996 - 1999 under the collaboration of W.J.Schafer Associates (Livermore), Los-Alamos National Laboratory and Laboratory for Laser Energetic of the Univ. Rochester.

The goal of the Project is to complete the physics and engineering base to create a new technology and its associated equipment capable of fabricating thick layered cryogenic fuel capsules for application to ICF. The Work Plan encloses:

- System analysis of the main technical requirements for a prototype of a device for the formation of cryotargets with a thick layer of fuel.
- Simulation code for modeling the filling regimes for polymer shells with gaseous fuel.
- Development, manufacture and testing the system for filling polymer shells with gaseous D₂-fuel and with H₂-D₂ mixture up to pressure of 1000 atm at room temperature.
- Research needed for the optimization of work characteristics of the fill system.
- Experimental research to determine the conditions of cryogenic layer formation inside a shell.
- Physical model for the formation of cryogenic targets with a thick fuel layer.
- Development, manufacture and testing a prototype of a device for the formation of cryogenic targets with a thick fuel layer.
- Development in the scope of a layer characterization system for a motionless spherical target.

The work on the Project for the 1st year has been completed according to the Work Plan. Problem #1 was solved for the preparation of a cryotarget with thick fuel layer, namely: (a) construction of a device for filling polymer shells with gaseous hydrogen isotopes up to the pressures of 1000 atm (at 300 K); (b) corresponding simulation code for the filling procedure calculation and shell unit depressurization without shells destruction.

A distinctive feature of the technical approach when solving this problem is the work with a batch of free-standing (unmounted) shells which answers the requirements of the ICF experiment for the minimization of the dead volume of gaseous fuel and the time of any procedure of cryogenic target preparation for its irradiation by a laser (filling, transport, layering, characterization and delivery).

The main difficulties which occurred at this period are the following:

- a lack of extensive experience in creation of a high pressure fill system
- delays (not all of the parts were delivered in time)
- search for manufacturers
- changes in the WP according to the recommendations of the US collaborators

The difficulties were successfully resolved during the project completion by means of:

- variety of design and mathematical approaches,
- ideas competition
- consultations with the leading specialists,
- independent expertise,
- staff changes, WP corrections,
- participation of students in the project to leave only the most important work to the specialists.

The correction of the WP makes it possible to optimize the research program which now includes all of the main tasks for the preparation of the cryotargets for the experiments on a power laser facility.

In this report the general results obtained according to the Technical Schedule over the period of September 1996 - April 1998 are presented.

TECHNICAL APPROACH TO THE ISSUE

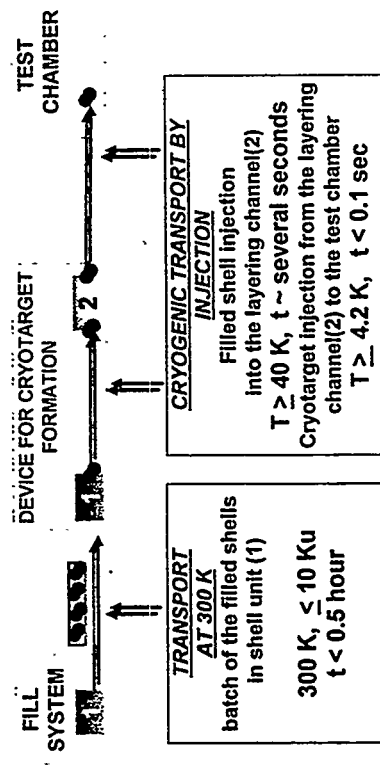
● CLOSED CYCLE FOR POLYMER SHELLS:
filling $\Rightarrow$ layering $\Rightarrow$ delivery

● FREE STANDING TARGETS USAGE
 $\Rightarrow$ basis of the approach

● RAPID FUEL FILLING OF TARGET BATCH
 $\Rightarrow$ ramp filling regime

● RAPID FUEL LAYERING $\Rightarrow$ Fall & Strike Technique

● TARGET TRANSPORT $\Rightarrow$ batch of filled shells
transport or single target injection



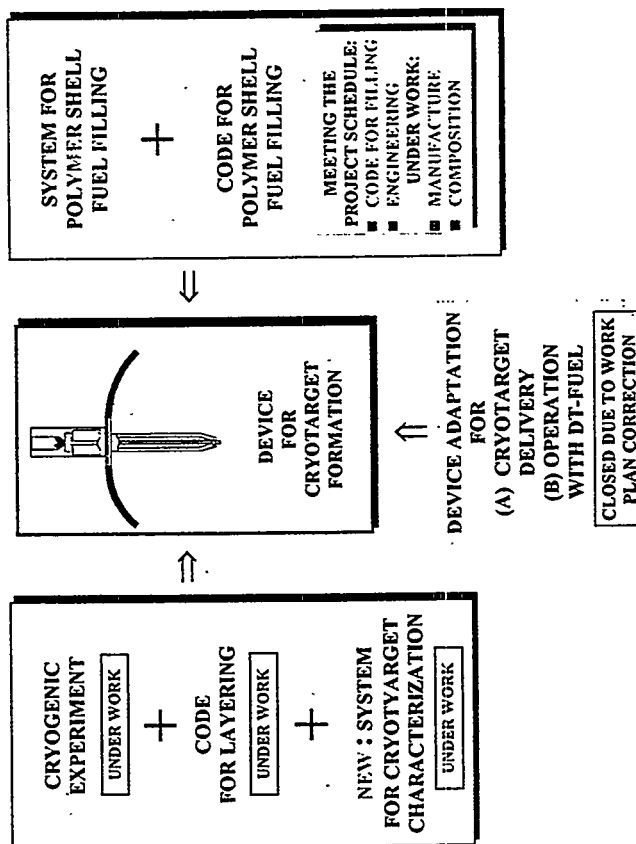
A distinctive feature of the technical approach is the work with a batch of free-standing shells which answers the requirements of the ICF experiment for the minimization of the dead volume of gaseous fuel and the time of any procedure of cryogenic target preparation for its irradiation by a laser (filling, transport, layering, characterization and delivery).

SCOPE OF ACTIVITY AND EXPECTED RESULTS

Scope of activity consists of 26 stages including

all key problems of cryptotarget production:

Target fuel-filling $\Leftrightarrow$ Fuel layering $\Leftrightarrow$ Cryptotarget characterization



RESULTS OBTAINED:

The work on the project for the 1st year has been completed according to the Work Plan. Problem #1 was solved for the preparation of a cryptotarget with thick fuel layer, namely: (a) construction of a device for filling polymer shells with gaseous hydrogen isotopes up to the pressures of 1000 atm (at 300 K); (b) corresponding simulation code for the filling procedure calculation and shell unit depressurization without shells destruction.

FIRST YEAR RESULTS (1)

FIRST YEAR RESULTS MEET THE PROJECT SCHEDULE

4 STAGES ARE COMPLETED:

- “Technical requirements to the fill system and to the device for thick fuel layered cryotarget formation”
- “Technical tasks for specialists according the project schedule”
- “Simulation code on the operation regimes of a system of filling polymer shells with gas fuel up to 1000 atm”
- “Design and engineering work for the system of filling polymer shells”

8 STAGES ARE UNDER WORK:

- “Feasibility study on the development of the characterization system”
- “Fill system manufacture and assembly”
- “Code for layering”
- “Creation and test of the layering channels”
- “Cryogenic experiments”
- “Apparatus to control working parameters of the fill system”
- “System for glass shell filling”
- “Shell production (Glass and Polystyrene)”

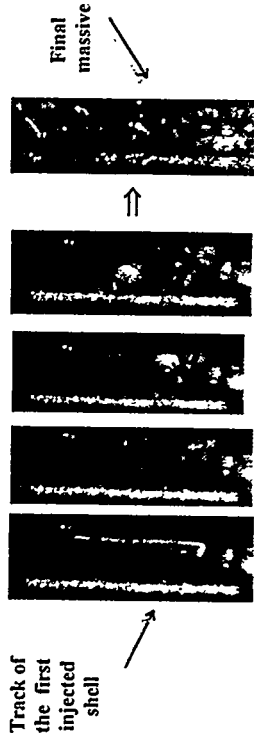
69 SPECIALISTS

ARE INVOLVED IN THE WORK UNDER THE PROJECT

- 20 specialists have degree of science: Ph.D, Dr.Sci, Corr-Mem. RAS
- 4 are the students
- 41 specialists have previous area of weapon expertise

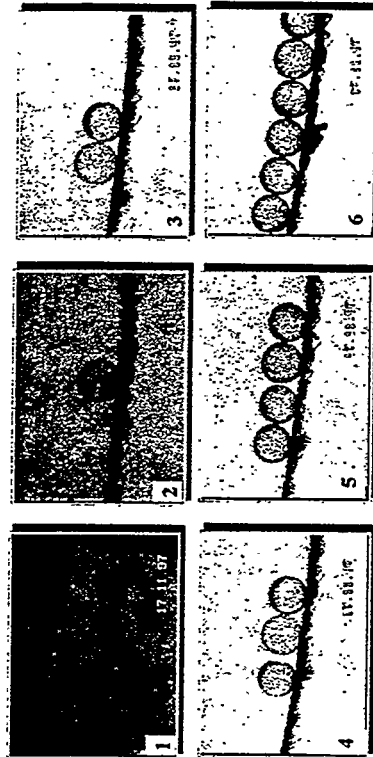
THE PASS-FUNCTION OF THE LAYERING CHANNELS WAS DETERMINED FOR THE GLASS AND POLYMER SHELLS

STEPWISE DELIVERY OF THE GLASS SHELLS FROM THE SPIRAL CHANNEL INTO THE TEST CHAMBER AT 300 K



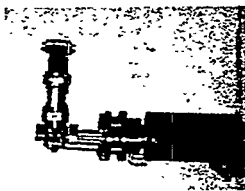
RESULT: The testing has shown good going: all of the 24 microshells passed through the channel and their appearance was observable in the test chamber. Conditions: 300K, vacuum in the channel 1 Torr, average shell diam. 500 μm .

STEPWISE DELIVERY OF THE GLASS SHELLS FROM THE "NARROW" CHANNEL INTO THE TEST CHAMBER AT 4.2 K

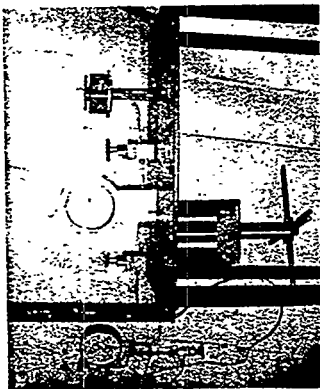


RESULT: 100% of the tested glass microshells (50) passed through the channel. Conditions: 4.2K chamber wall temp., 0.1 mTorr vacuum in the channel, average shell diam. 500 μm , H_2 fill pressure 20 - 40 atm

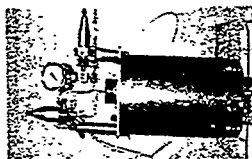
FILL SYSTEM MANUFACTURE AND ASSEMBLY



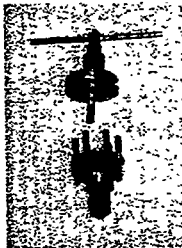
INTERMETALLIC
Ti STORE



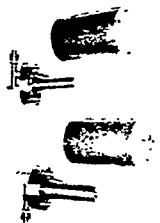
FACILITY FOR PREPARATION OF THE ELEMENTS
OF THE FILL SYSTEM



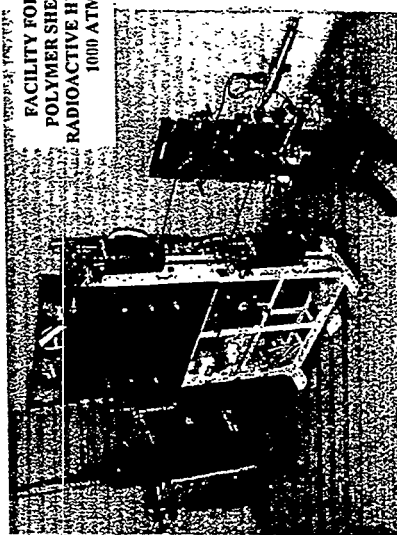
INTERMETALLIC
Zr-Cu-Fe STORE



TARGET FILM CHAMBER

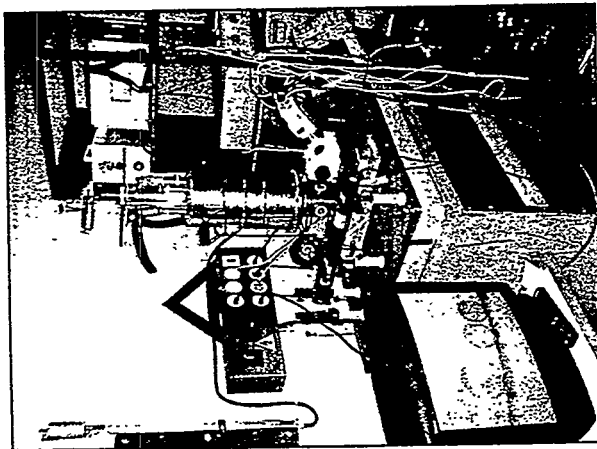


THERMOMULTIPLICATOR

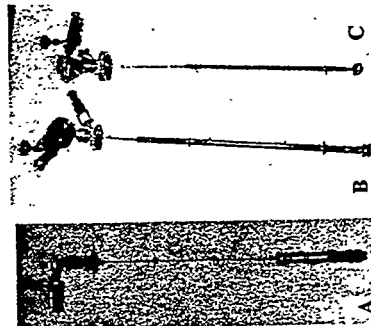


FACILITY FOR FILLING THE
POLYMER SHELLS WITH NON-
RADIOACTIVE HYDROGENS UP TO
1000 ATM AT 300 K

FACILITY TO CARRY OUT CRYOGENIC EXPERIMENTS



CREATION AND TEST OF THE LAYERING CHANNELS



A - SPIRAL
LAYERING
CHANNEL
B - "WIDE"
LAYERING
CHANNEL
C - "NARROW"
LAYERING
CHANNEL

TARGET SYSTEM OPERATION: FILLING and TRANSPORTING POLYMER SHELLS TO MODULE for CRYOGENIC LAYERING STUDY.*

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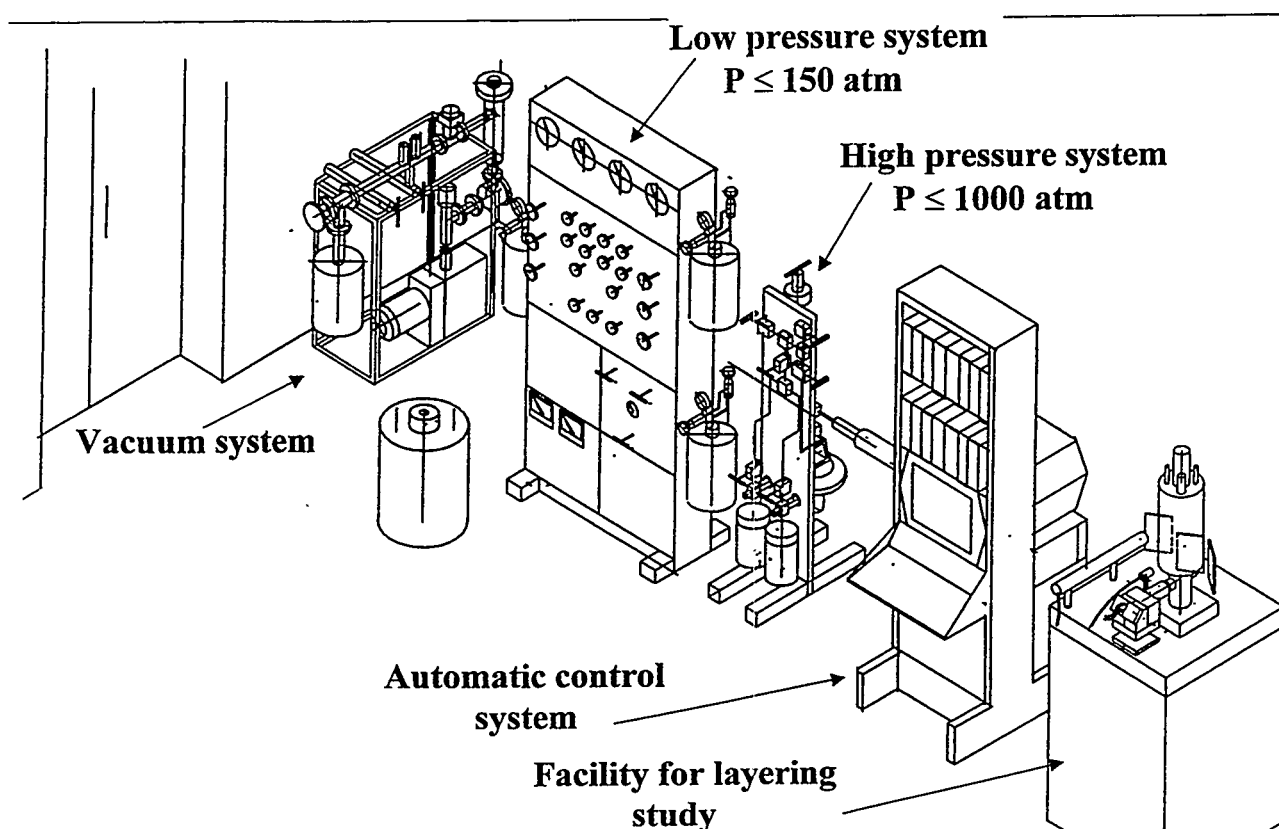
12th Target Fabrication Specialists' Meeting, April 19-23, 1998.

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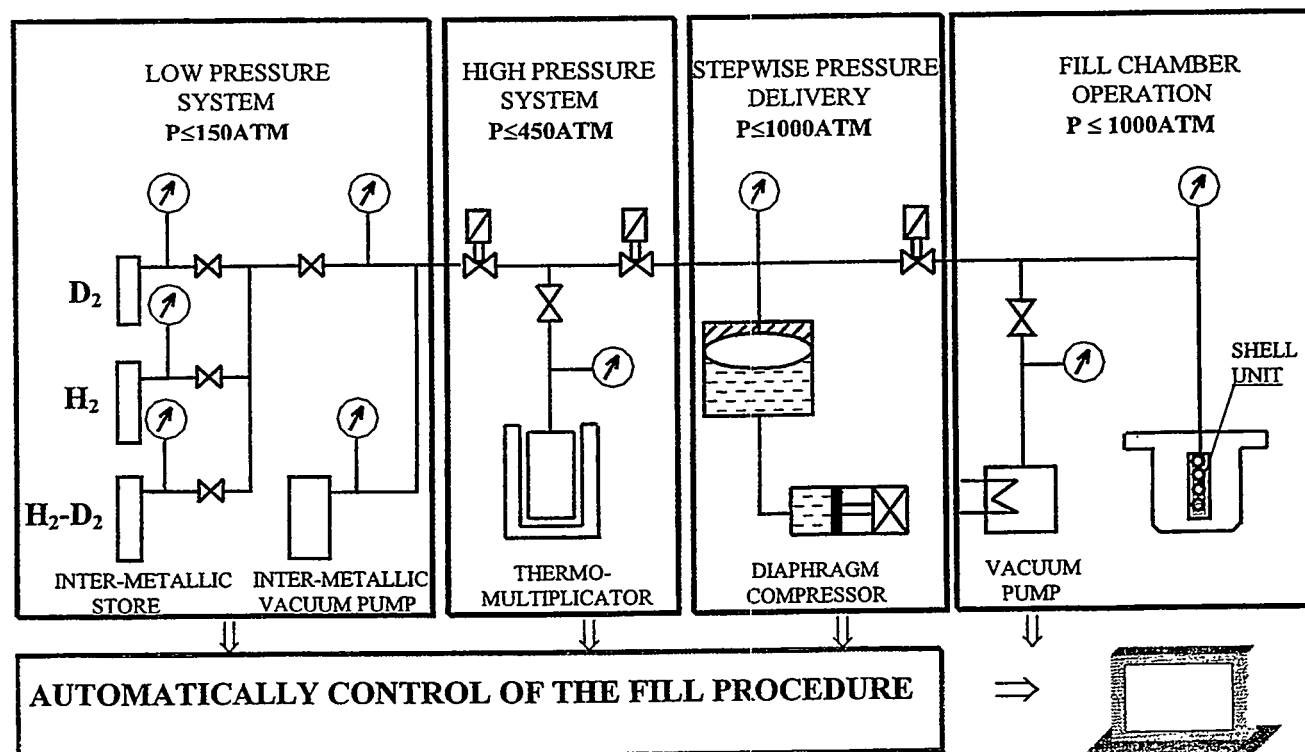
INTRODUCTION

- The Lebedev Physical Institute (LPI) and the "Red Star" State Enterprises (RSSE) have developed the fill and the transport systems of polymer shells designed to cryogenic target fabrication with a 100- μ m-layer thickness. The results of the design, engineering and construction are presented.
- The specifics of the system are the following:
 - work with a batch of free standing shells
 - diffusion ramp-filling procedure for minimizing the fill time
 - the transport of all the filled shells to layering module at 300 K.
- A system allows for filling of 10 to 25 polymer shells at one time with gas fuel (H_2 , D_2 , H_2 - D_2 -mixture) up to pressure of 1000 atm at room temperature. The calculated fill-time is less then 24 hours for millimeter-size capsules.
- The filled shells transport to the layering module is carried out in a special shell unit at room temperature. Under operation with D-T fuel, the radioactivity of the shell unit does not exceed 10Ku.
- At present we carry out a set of experimetns on the created system approbation.

EXPERIMENTAL SETUP FOR FUEL FILLING AND LAYERING

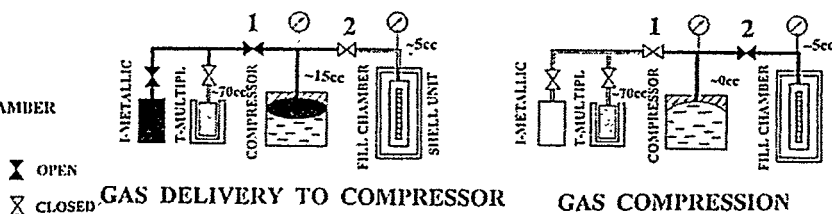


SCHEMATIC OF THE FILL SYSTEM

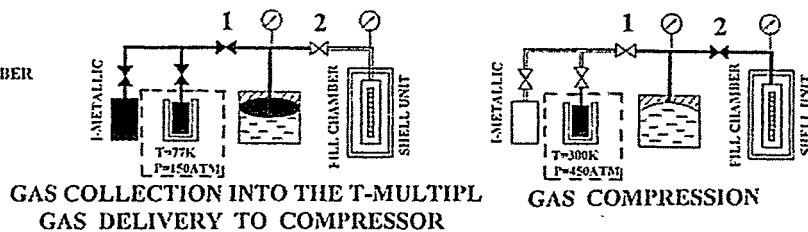


PHYSICAL LAYOUT

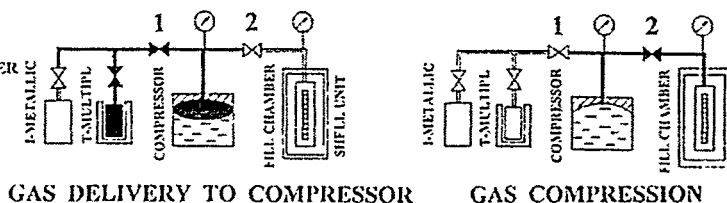
STAGE I
I-METALLIC $\Rightarrow$ COMPRESSOR $\Rightarrow$ FILL CHAMBER
P=1+150ATM



STAGE II
I-METALLIC $\Rightarrow$ COMPRESSOR $\Rightarrow$ FILL CHAMBER
I-METALLIC $\Rightarrow$ T-MULTIPLICATOR
P=150+450ATM



STAGE III
I-MULTIPLICATOR $\Rightarrow$ COMPRESSOR $\Rightarrow$ FILL CHAMBER
P=450+1000ATM



FILLING PROCEDURE

◇ WE USE RAMP FILLING PROCEDURE



$$\Delta P(t) = P_0 - P_{IN} = \text{CONST}$$

◇ ALLOWABLE PRESSURE DIFFERENTIAL ON THE SHELL WALL.

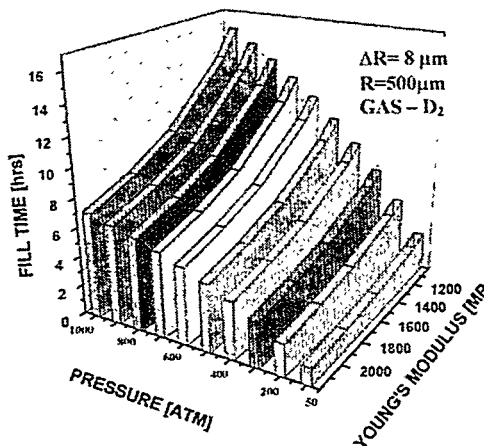
$$\Delta P(t) \leq 0.5P_c = \frac{2E}{\sqrt{3(1-\nu)^2}} (A_s)^{-2}$$

E - Young's modulus; ν - Poisson's ratio

$$A_s = \frac{R}{AR} \begin{matrix} \text{- external radius} \\ \text{- wall thickness} \end{matrix}$$

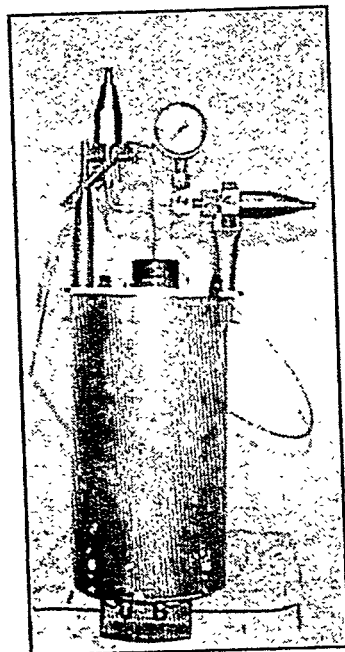
◇ ACCURACY OF PRESSURE DELIVERY $\leq 1\text{ATM}$

**RAMP FILLING REGIME:
TIME VS. YOUNG'S MODULUS**

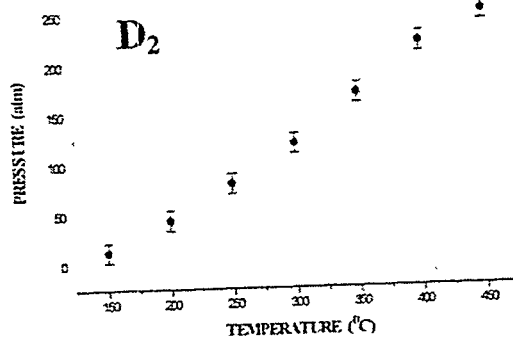


INTER-METALLIC COMPOUNDS

Propose to be achieved: collection, purification, and reversible storage of hydrogens.



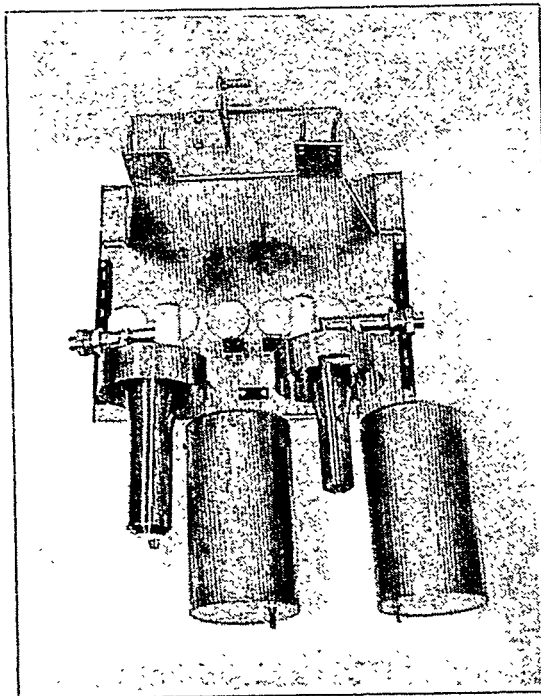
Zr-CR-Fe COMPOUND DISSOCIATION PRESSURE
VS. TEMPERATURE IN THE PLATEAU AREA



PARAMETERS

- MATERIAL ZrCrFe_x
- RESIDUAL PRESSURE 0,1-0,5ATM
- RESOURCE >1000 CYCLE
- GAS PURITY 99,9999
- PRESSURE DELIVERY ±1ATM
- WITH THE ACCURACY
- CAPACITY 4,5mol

THERMOMULTIPLICATOR



PARAMETERS

- 1 STAGE:
 - volume 60 cc
 - pressure 450 atm
- 2 STAGE:
 - volume 20 cc
 - pressure 600 atm
- TEMPERATURE: T = 77-300 K
- HEATER: N = 100 Wt
- TIME OF HEATING
 - (from 196K to 300K): τ= 0,9 – 1,57 hrs

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