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Target Requirements on the Path to Ignition

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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 ρr, 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 o f 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.

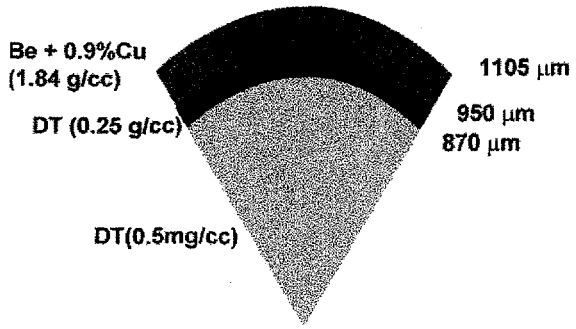
To explore computationally this feed-out/feed-in phenomenon, the addition payload, the unablated Be/Cu, can be changed or replaced in new capsule designs. Simply changing the copper dopant concentration from 0.9 atm% can change the amount of unablated Be/Cu, changing the capsule sensitivity to DT ice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

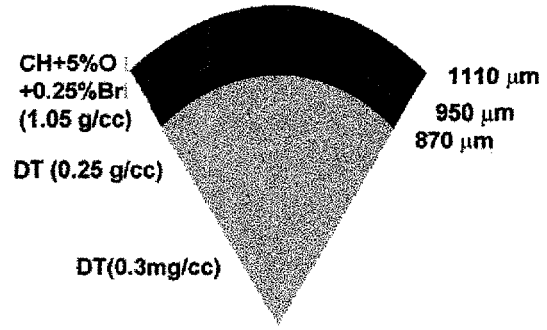
A glass and beryllium capsule might be designed by replacing the unablated beryllium with 10 μm at density 2.2 g/cm^3 . High strength glass (~200kpsi) might be able to contain the DT gas at room temperature, and the beryllium could be coated over it, avoiding the need for a joint. The pulse shape, yield 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 ρr 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.

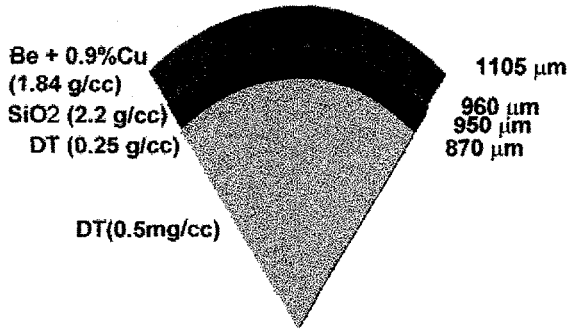
Be330



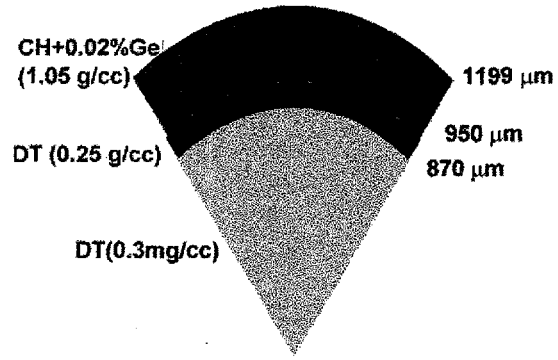
PT



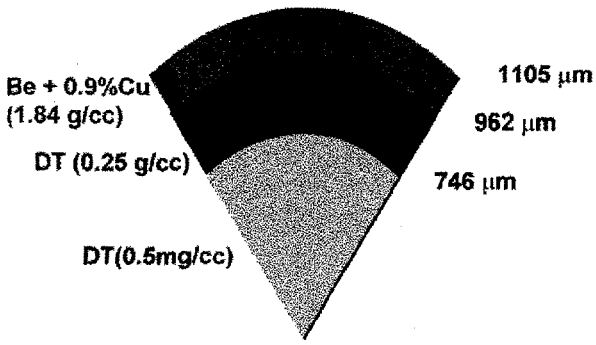
Be-glass

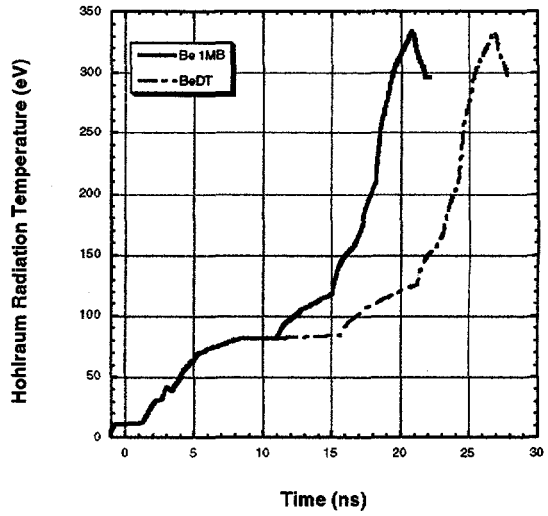


Pthick



Be330-2x

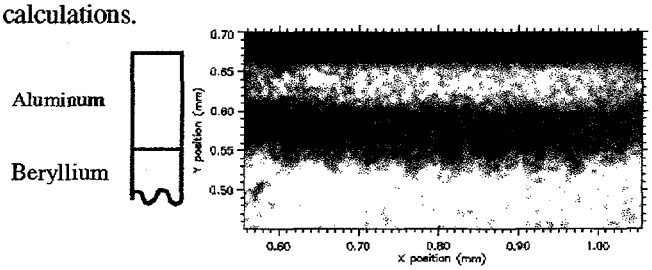




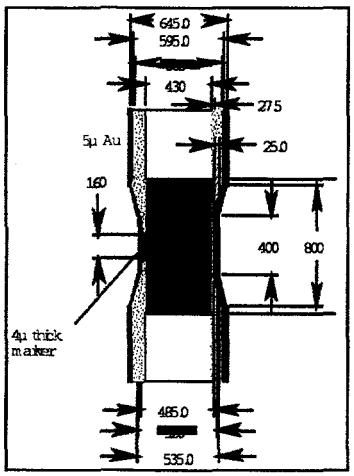
II. Instability Experiments

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.

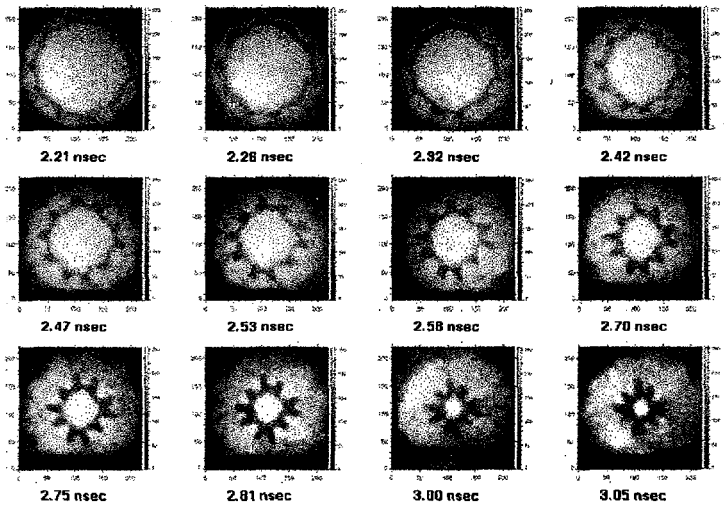
Nova experiments on aluminum/beryllium sandwiches are testing our understanding of the feed-out / feed-in process. Transmission radiography of the packages has proven quite successful in imaging the growth of perturbations placed on the surfaces away from the radiation drive. Side and backlighting measure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



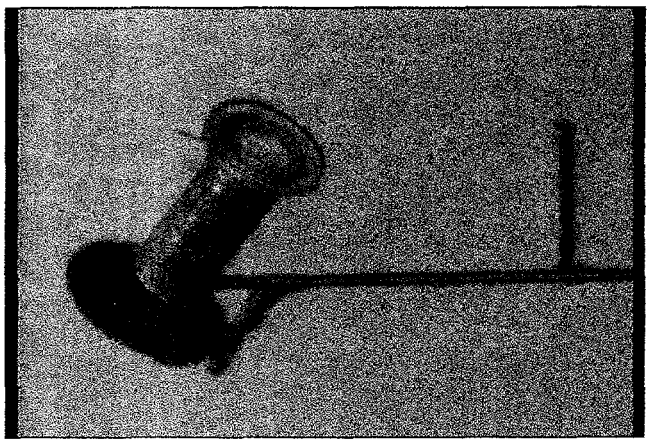
To study radiation driven instability growth in cylindrical geometry target fabricators built the complicated layered cylinders in hohlraums with sub-micron features show below using layers of brominated polystyrene on plain CH with chlorinated marker layers.



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



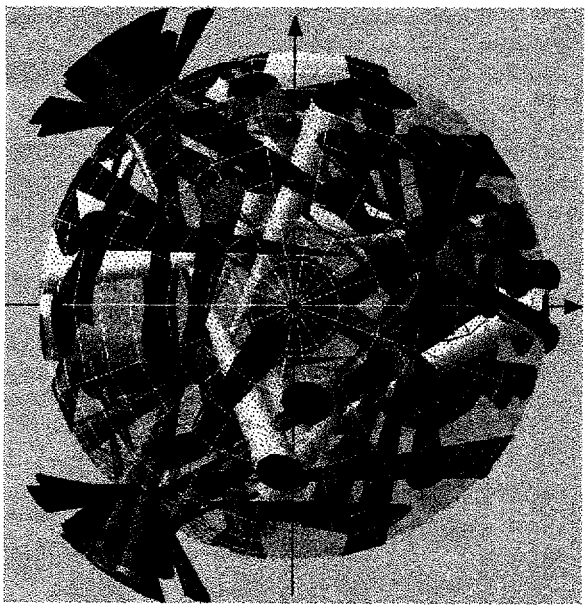
Recent (January 27-30, 1998) directly driven cylindrical implosion experiments on Omega were highly successful in creating higher convergence than those indirect drive experiments. Highly symmetric implosions were obtained using 50 drive beams and a ramped 2.5 ns pulse.



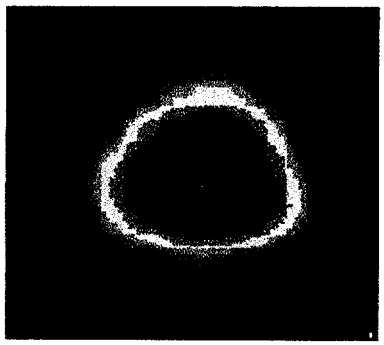
Future cylindrical targets will continue to stress fabrication capabilities. Directly driven cylinders for Omega will: 1) continue to study Rayleigh-Taylor growth from perturbations modes 10-40 with initial amplitudes of about 1 μm, 2) use perturbations on the shell inner surface, 3) study mixing of 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 lline

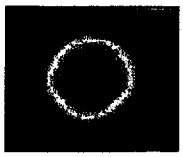
will produce X-rays on shock collapse and stagnation. Very high Z (e.g Au) layers 0.5 μm thick on the inner surface as well as buried CD, Ti, and Cl doped tracer layers will help diagnose mix. Cylindrical experiments will not stop with the Omega laser, we envision indirectly driven cylinders twice as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

We are beginning spherical implosion experiments at Omega using a tetrahedral holraum 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.

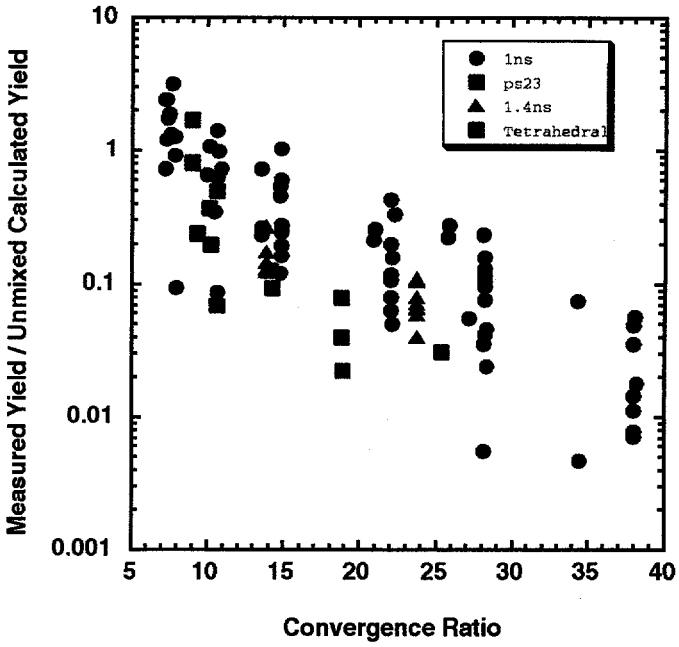


The symmetry in these tetrahedral hohlraums is better than in a NIF cylindrical hohlraum, without relying on beam phasing. Calculations show this, but we have also controlled the symmetry by varying the laser entrance hole and hohlraum diameters. In one case we had the tetrahedral shaped implosion core 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 (~3.3kBar) 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 ½ 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 0.2μm Cu, which diffuses into the beryllium, avoiding sharp boundaries. Cylindrical experiments can test our calculations of convergent effects using large defects. If may be possible to use ½ 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 perturbatons 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) cyrogenic 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 strenght (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).