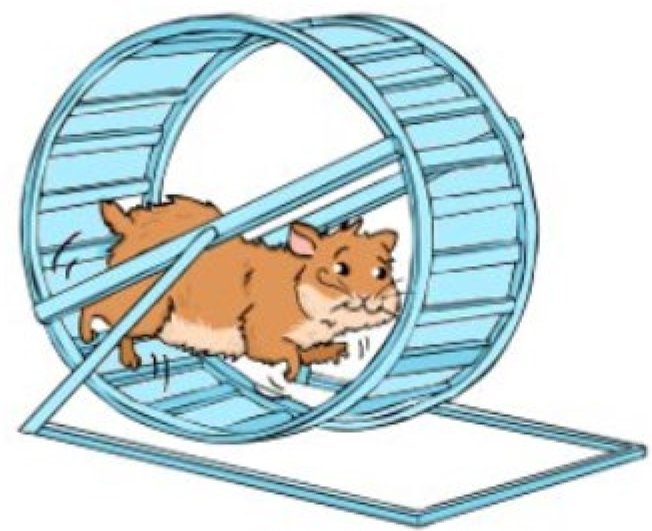
Target Fabrication Capability at Los Alamos National Laboratory

Tana Cardenas, Tom Day, Patrick Donovan, Stephanie Edwards, Frank Fierro, Lynne Goodwin, Chris Hamilton, Christina Hanson, Hans Herrmann, Lindsey Kuettner, Matt Lee, John Lamar, John Martinez, John Oertel, Brian Patterson, Theresa Quintana, Blaine Randolph, Derek Schmidt, Alexandria Strickland, Igor Usov, Doug Vodnik, Chris Wilson

April 23, 2019

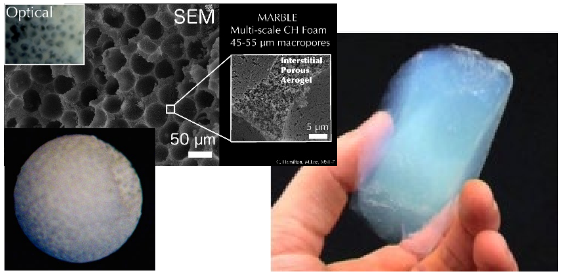
Overview

- LANL Capability
- Collaboration is key to our success
- Overview of what we do
  - Chemical Synthesis
  - Thin Films and Coatings
  - Micro-machining
  - Characterization
  - Precision Assembly
- Overview of Campaigns
- Summary

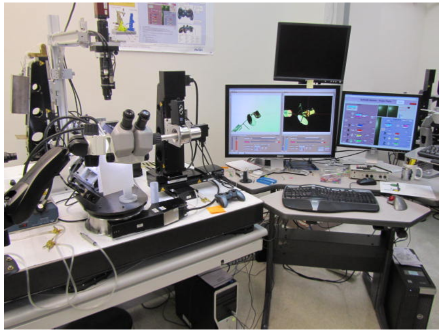


LANL Target Engineering is comprised of 5 pillars

Many of our experiments require highly specialized **Foams**

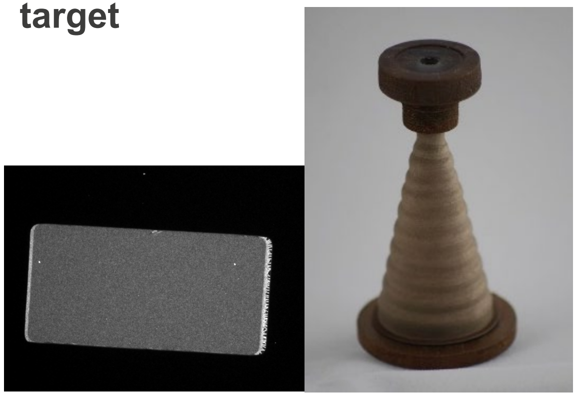


Precision Assembly is critical for all targets, particularly ones of greater complexity

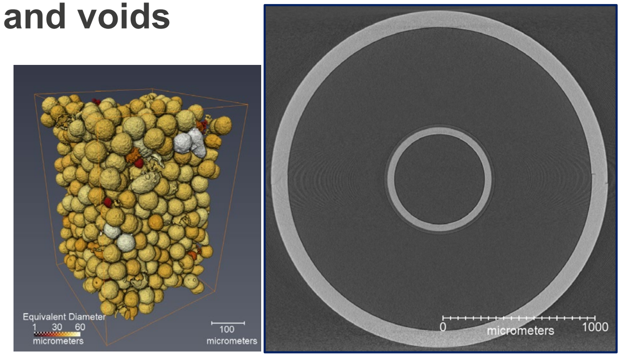


Micro-Machining of mm scale parts to um precision

Thin Films and Coatings are present at multiple levels of the target



Double-Shell targets require **Characterization** of centering, density and voids



We are a small team of efficient individuals!

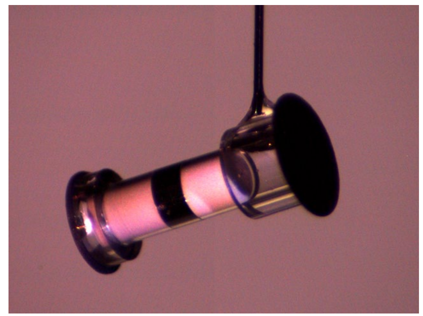
- 6 machinists
- 4 target coordinators
- 2 assembly technicians
- 3 part time chemists
- 2 part time coating support
- 2 part time radiography support

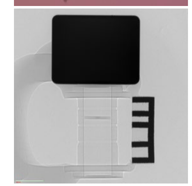
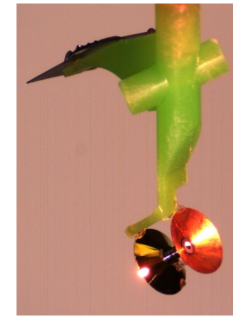
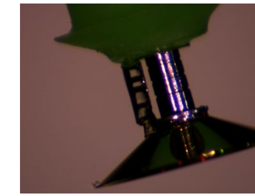
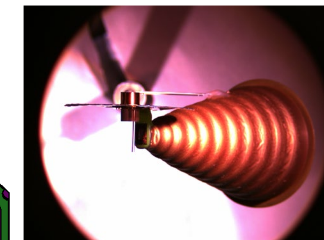
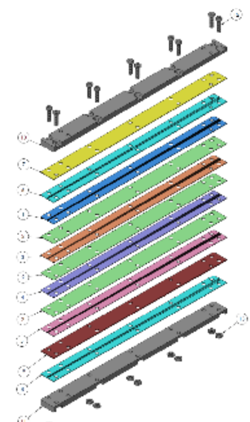
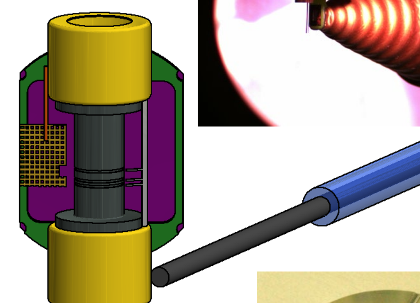
"A team is a small number of people with complementary skills who are committed to a common purpose, performance goals and working."-
Katzenbach & Smith

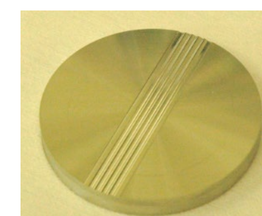
Because we are such a small team, we rely on the expertise of our colleagues at LLNL, General Atomics and LLE

Every year our team builds a wide variety of target types at a fast pace, we often deliver 3-4 target sets in one month!

- 800 Omega Targets
  - Complex spool, planar and gas filled targets, backlighters
- 44 shots on NIF
  - Mshock & DRV
  - Opacity
  - Double Shell Capsules
  - CylDRT
  - Marble Capsules
  - Revolver (ABLE)
- 23 sets of large targets
  - multiple complex target package assemblies
  - saw tooth and sine wave explosive packages
- NIF Neutron Imaging Aperture
  - 13 layers of penumbras and pinholes, 4 months fabrication time

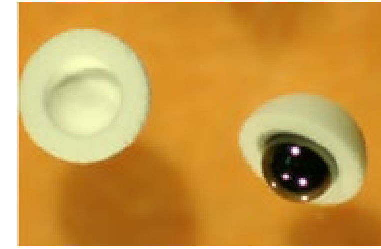


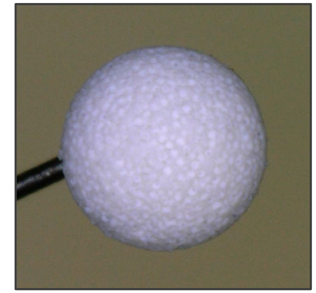


Synthesis of Foams and Doped Plastics

- CH Foams, HIPE and Divinylbenzene
  - Engineered pore size and densities as low as 16mg/cc are machinable.
  - Low density 98% deuterated DVB
- Polyimide Aerogels
- Tantalum Oxide Aerogels
  - High Z, machinable low density material
- SiO2 Aerogels and doped aerogels
  - 1:5 Ti-SiO_2 as low as 50 mg/cc are uniform and machinable
- Doped Plastics
  - including iodine and silicon

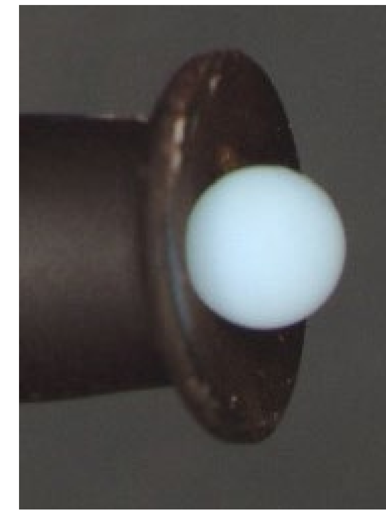


DS CH foam hemis



Engineered DVB sphere

Cast Polyimide Aerogel

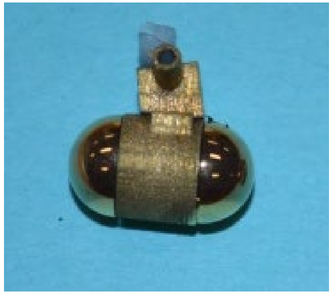


Tantaum Oxide NIF sized Sphere

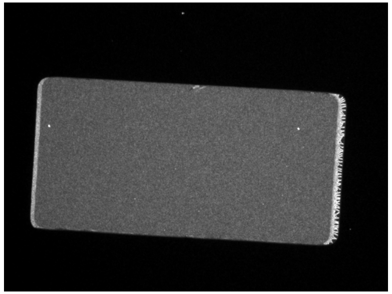
See Wednesday poster by C.J. Hanson “Materials Synthesis and Alternative Casting and Drying Methods of Polyimide Aerogels for Future Target Development” and Thursday poster “Advancements in Low Density Foam Capabilities” by S. Edwards

Thin metal PVD & CVD

- Physical vapor deposition (PVD) methods:
  - Electron beam and resistive evaporation
  - Magnetron and ion beam sputtering
  - Ion beam assisted deposition
  - Targets for Opacity on Z and NIF are co-deposited with electron beam resistive evaporation
  - Specialized sample holders and fixtures including planetary coatings for shields
- Chemical vapor deposition (CVD) method:
  - Parylene conformal for hot electron insulation
- Characterization methods:
  - RBS, XRF (chemical composition)
  - Profilometry, X-ray CT, SR (thickness)
  - AFM, OM (surface morphology)
  - SEM (microstructure)



Au coated sapphire half spheres



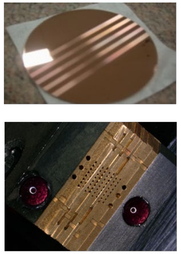
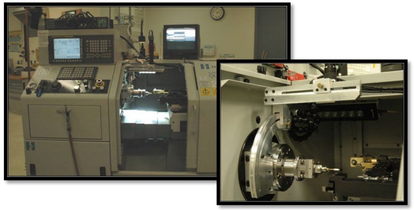
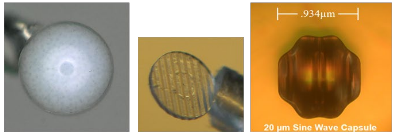
FeMg Coating for Opacity on NIF

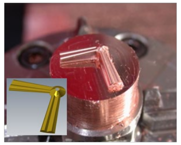
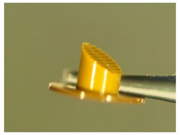
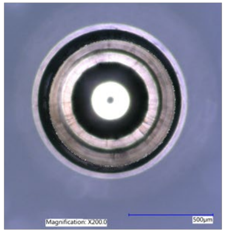
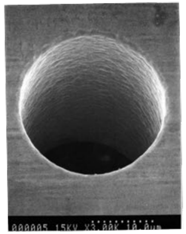
Mask For Opacity targets and NIF VISAR Cone

See "Opacity Foils Areal Density Uniformity and Uncertainty Analysis" D.R. Vodnik, B.L Bennet, I.O. Usov

Micro-machining

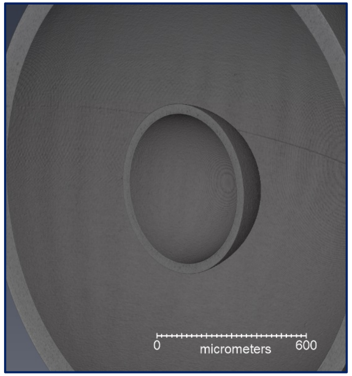
- We employ Erowa repeatable mandrel base systems
  - See Wednesday Poster by Randolph “Repeatable Mandrel Base Systems used for Micro Machining Complex Target Components for the Inertial Confinement Fusion (ICF) Program”
- Diamond Turning
  - Used for planar targets as well as Double Shell
- Precision CNC turning
  - Our workhorse machines do most foams
- 5 axis Micro Milling
- Dedicated Be Machining Capability
  - Plunge CNC EDM and diamond turning lathe
  - In the early phases of a $2M expansion

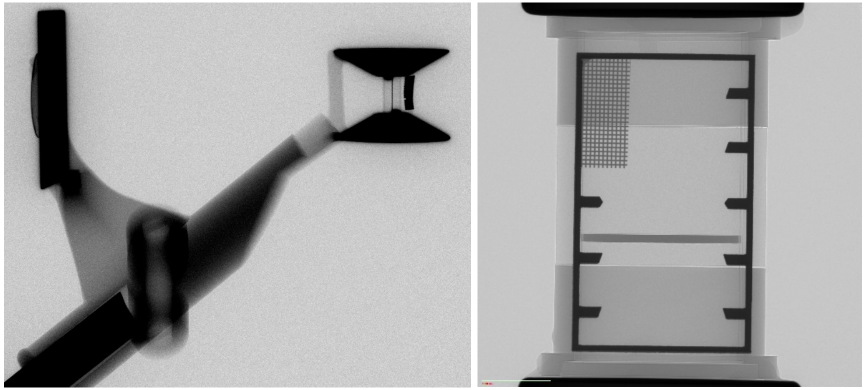

Characterization

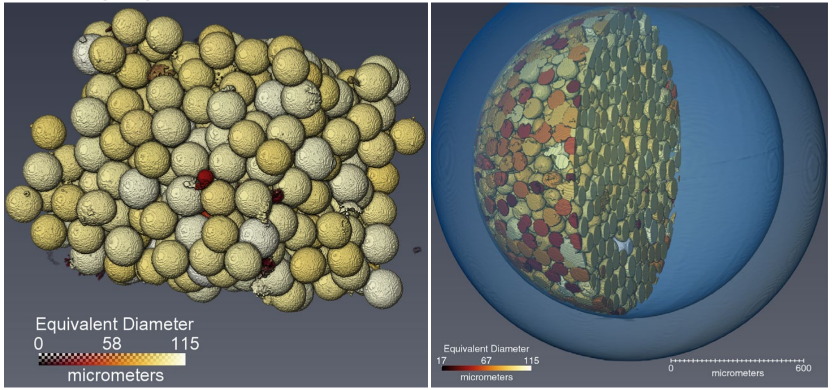
- We employ a plethora of dimensional tolerancing tools as well as DCS, SEM, NMR during and after target assembly
- Radiography & Micro Tomography are used often
  - Micro and nano-scale X-ray CT
  - Suite of analysis software to measure 2D and 3D morphological features
- Confocal Micro X-ray Fluorescence is used to identify impurities in targets



Reconstruction of DS capsule

See posters “Nondestructive Characterization of MARBLE and Double Shell Targets Using X-ray CT” and “Target Metrology using 3D X-ray tomographic and confocal imaging”


Radiographs of Omega and NIF Shear/Shock targets



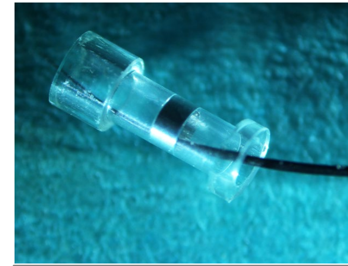
Void analysis and reconstruction of Marble capsule

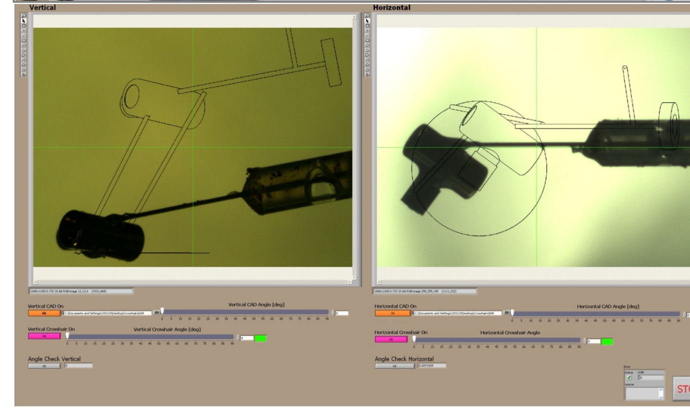
Precision Assembly

- Delicate Hand Assembly
  - Employ custom made fibers and manipulators
  - Make fixtures for stuffing spools by hand under microscope

See Thursdays Poster “Novel Manual Assembly Techniques for Target Component Assembly” by T. Quintana & L. Goodwin

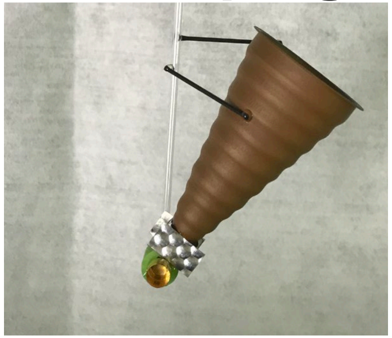
- Precision Robotic Assembly
  - Breadboard design utilizing off-the-shelf Newport stages
  - Control system programmed using LabView software
  - Each axis has readouts with zero, absolute, and relative motion controls
  - Joystick controls
  - Robotic stations are not automated, but become accurate extensions of operator



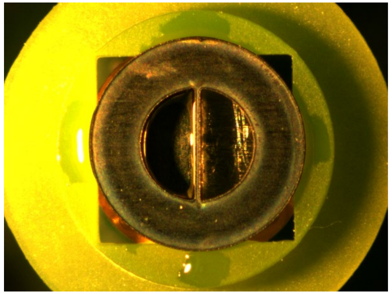


NIF Mshock & DRV are part of the Shear/Shock Campaign

- Mshock target studies hydro-instability
  - An ablator is indirectly driven by the hohlraums
  - Multi part shock tube is machined out of Be and CH
  - Tracer Layer is machined with an imposed high mode on top of a low mode power spectrum
- Mshock DRV studies EOS shock breakout of relevant materials
  - Dual End Target for dual study of Indirect/Direct Laser Feedback
  - Package compares reference materials and new materials
  - Behavior is observed on VISAR using a mirror

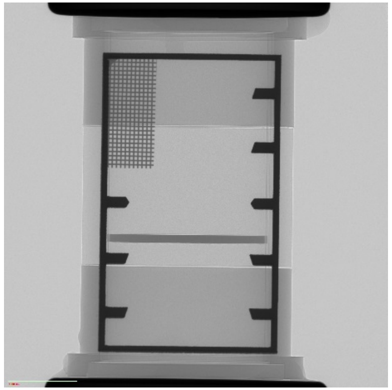


Top View of Mshock target

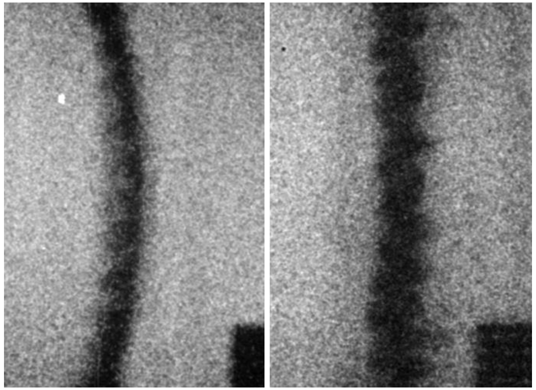


Physics package

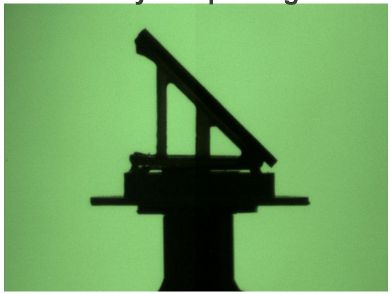
Original Shear target



Radiograph of spool



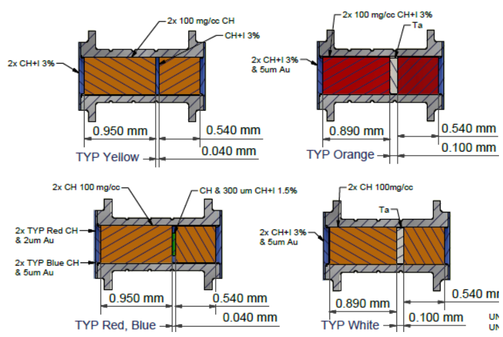
Post shock and post re shock data



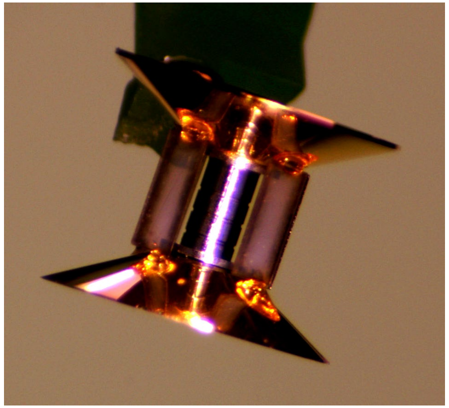
Mirror assembly

Omega Multi shock

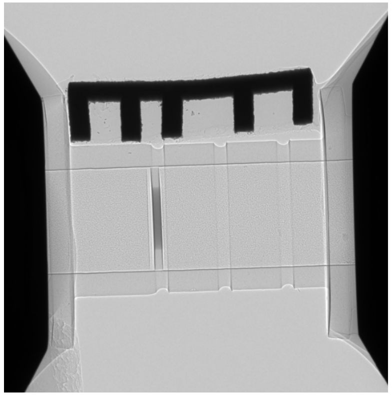
- Omega multi shock experiments provide platform development for NIF due to high shot rate.
- Pre-heat characterization/mitigation experiments to advance the development of a multiple shock drive platform for the NIF MShock hydro-instability campaign
- Single or dual drive target w/ gold cylindrical heating shield
- Be spool targets with various doped plastic tracer disks and foams



Cross section of spool types



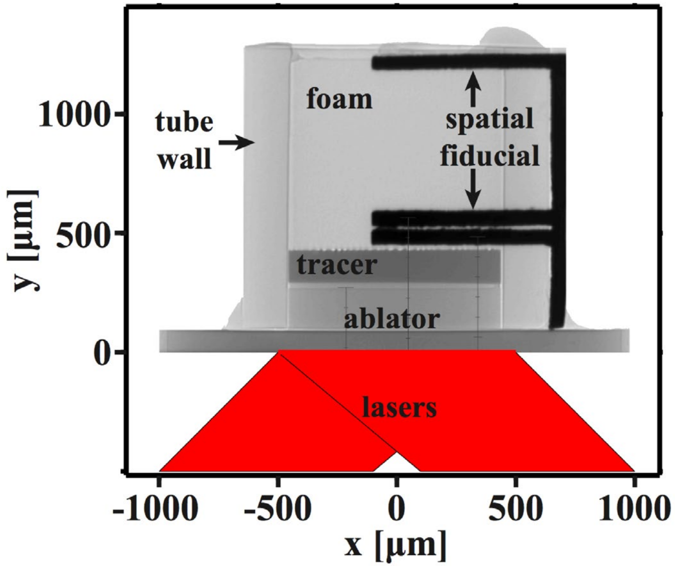
Spool with heater shields



Radiograph of spool

ModCon/DVMEP

- EP-Omega Platform part of Shear/Shock Campaign previously Oblishock
- Produce measurements of multimode perturbations for application to transitional modal model.
- Iodine doped CH tracer layer inserted and glued into PAI plastic ablator
- Desired profile machined into surface
  - In the past has been sine waves and multimode
  - The upcoming shot will be stair steps
- 60-300 mg/cc foam fills the shock tube

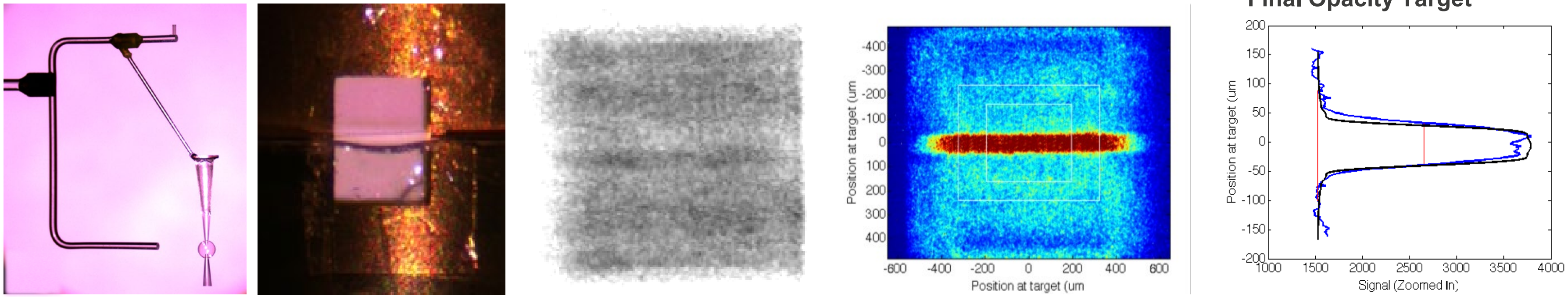


Mock up of drive on radiograph of tube

NIF Opacity targets

- A national strategy has been developed to replicate the iron opacity experiments on the NIF
- The opacity sample is trapped within a laser heated hohlraum and consists of a binary compound thin film, between two parylene-n layers
- There is a proton backlighter mounted beneath the hohlraum and an aperture plate, the collimator, is placed between the capsule and hohlraum
- A new cone in capsule design is being tested
- 50 targets have been shot on the NIF since 2016

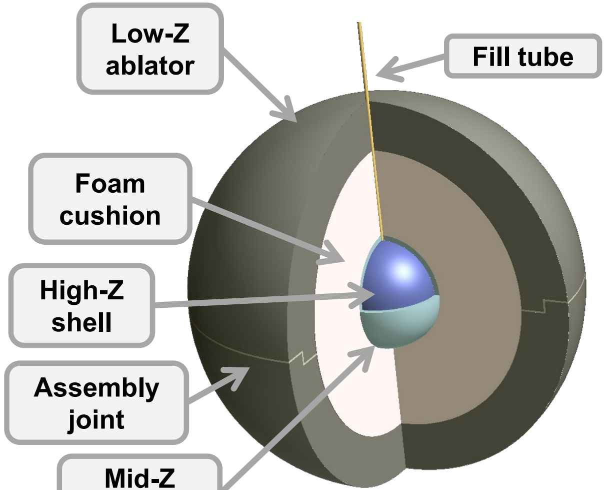
Final Opacity Target



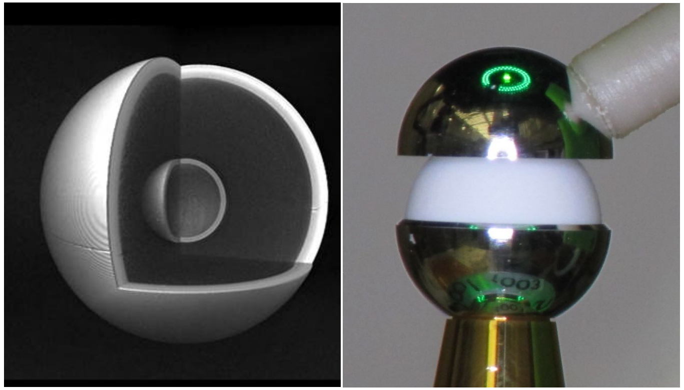
From left to right: Test cone-in-cap target, Image of slot covers, signal without slot covers, signal and plot with slot covers

Double shells support the NNSA mix and burn mission

- Double shell capsules are challenging to fabricate due to their multiple layer, multiple material design
- We have been working with LLNL and GA to fabricate imaging shells and keyhole targets to address:
  - Drive coupling, symmetry
  - Hard x-ray preheat
  - Collision physics, momentum transfer
  - Mix mitigation, fill tubes, joints
- A DS Target Fabrication Workshop took place at LANL in March to discuss R&D efforts needed to achieve high yield targets



DS Point Design

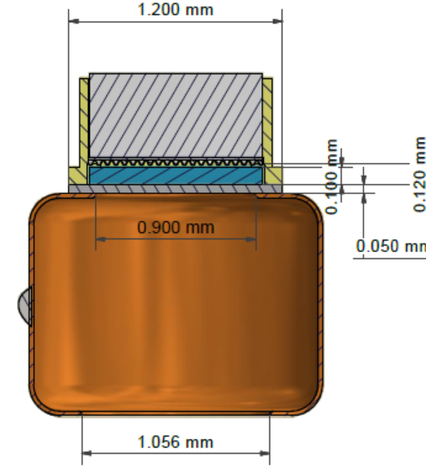


CT reconstruction of Imaging DS and Keyhole during assembly

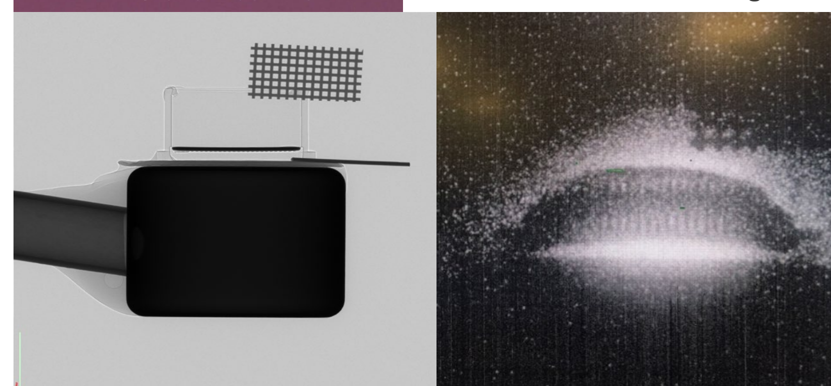
DS Planar

- Investigate key Double Shell physics issues in a scaled planar geometry
- Study perturbation growth in the inner shell
  - 0.8 atm neopentane filled halfraum
  - 50 um thick Al ablator
  - 100 um thick foam cushion
  - 20 um Zr/Be graded and bilayer coatings with machined sine waves
  - 900 um ID shock tube
- Previous shot days have studied joint-imprinting of various morphologies

XTVS chamber view



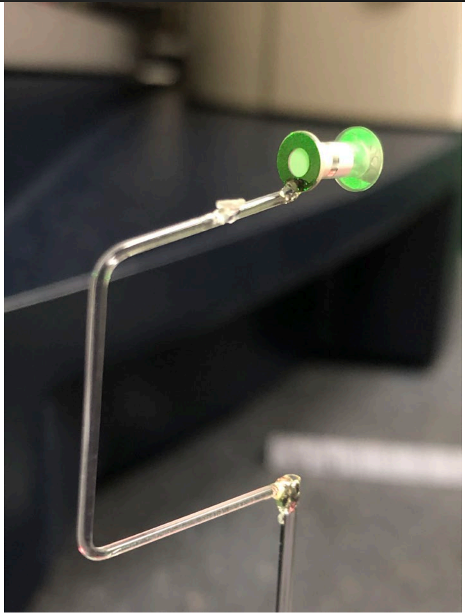
Cross section of target



Radiograph of diagnostic view and side on radiography data

CylDrt on Omega and the NIF

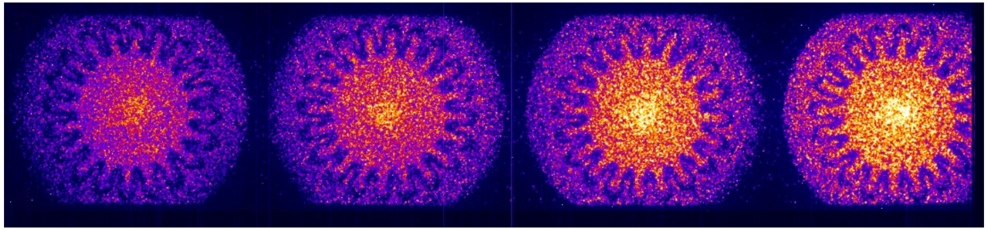
- Cylindrical implosion platform designed to study deceleration phase Rayleigh-Taylor instability in convergent geometry.
- The target is an EPON spool that has a metal band embedded concentrically
  - 24 um thick Aluminum band
  - Perturbations machined on the inside of the aluminum band using a Fast Tool Servo (FTS) tool post on a Moore diamond-turning lathe.
  - Cast EPON spool is machined on a copper mandrel and then leached



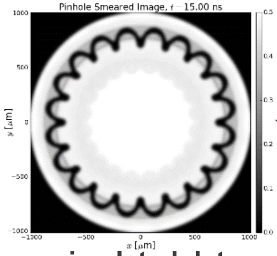
NIF direct drive target

See poster on Tuesday "CylDrt Machining Process and Fast Tool Servo Programming" by C.T. Wilson et.al

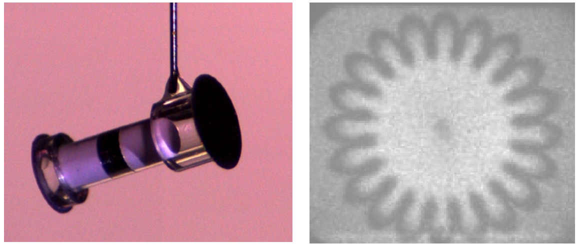
Talk on Friday "Manufacturing Process and Characterization Overview of a Cylindrical CH ablator with seamlessly embedded thin aluminum band for use in Omega and NIF Experiments" by T.day



NIF data



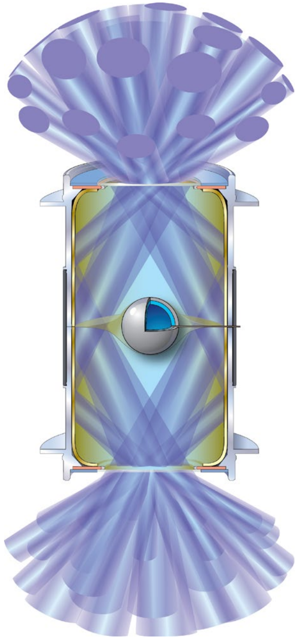
simulated data

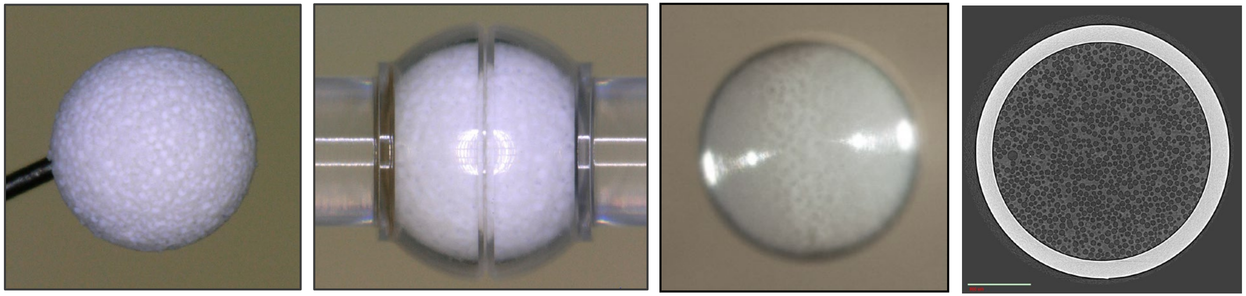


Omega March 2019 target and data

Marble was developed to quantify the influence of heterogeneous mix on fusion burn

- Highly developmental campaign has driven R&D in many areas of production
- The target consists of a machined plastic capsule filled with deuterated plastic foam.
  - Machined hemispheres 120um and 20 um wall have a step joint capable of holding more than 20 atm of gas
  - Capsules are stuffed with deuterated, engineered pore foam
  - Full metrology is done at every stage of the production process
  - Marble taught target fabrication and physicists what we didn't know!





The engineered foam sphere is stuffed into the CH ablator and back machined before tomography

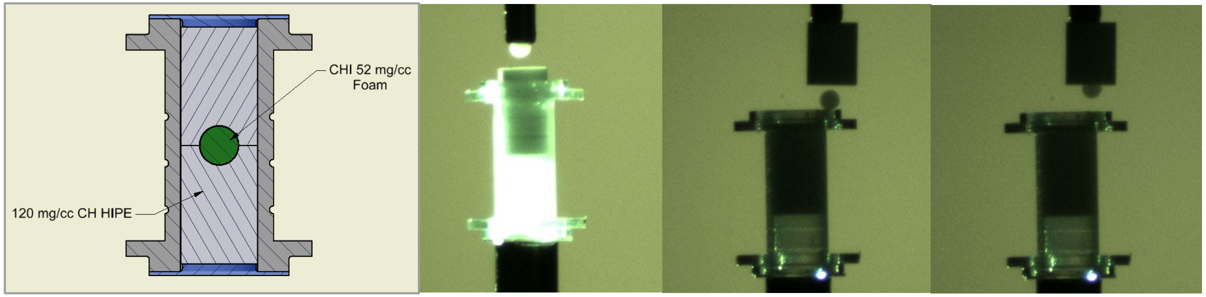
The finished capsule is characterized and turned into a CFTA and sent to LLNL for assembly into a hohlraum

Marble VC on Omega was developed to explore physics issues of Marble in a cylindrical geometry

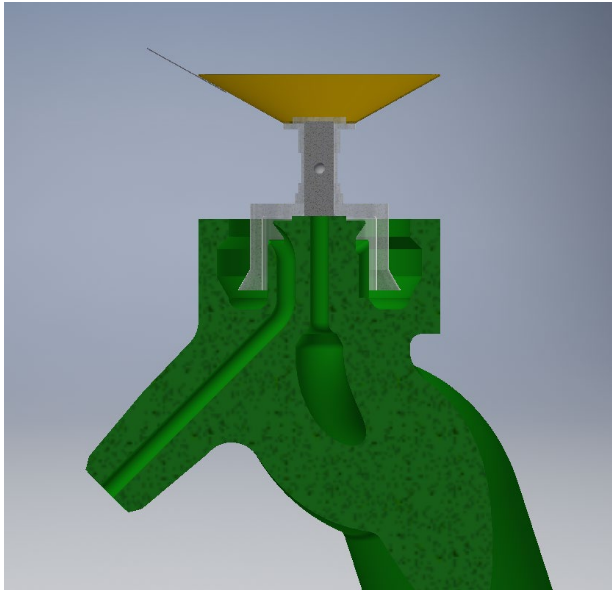
- Be or CH shock tube with void in foam
- Study the evolution of foam or gas filled void by incoming shock
- Gas filled target has highest fill pressure ever attempted in this geometry
- Previous targets investigated preheat of

as well as shock speed of various densities

and pore sizes



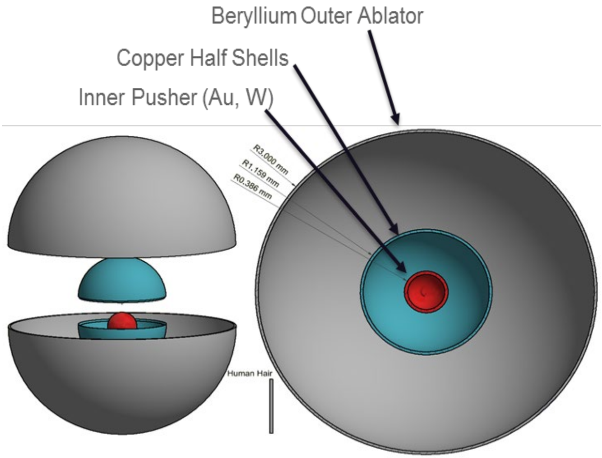
Void collapse target and robotic assembly of foam void



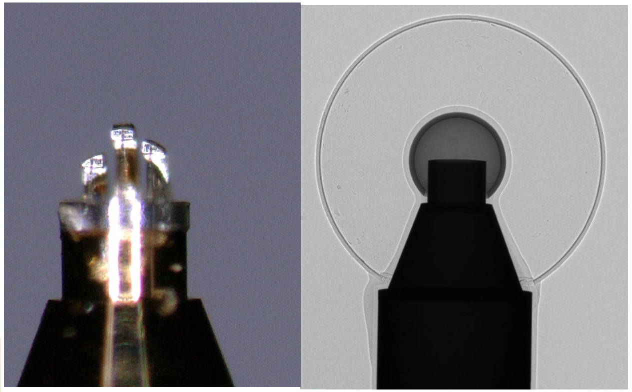
Gas filled target

Revolver

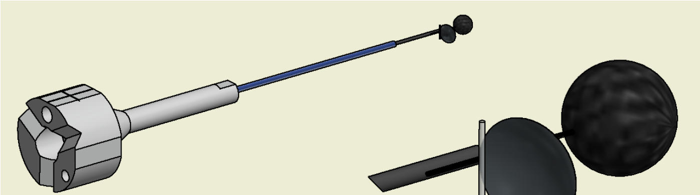
- Purpose is to validate the controlling physics (ablator energetics, collision energetics, and feature mitigation) for direct-drive multi-shell targets
- The point design is a triple shell with 50 um thick outer ablator a 50 um thick Cu middle hemi shells and the inner pusher is gold, foam or tents are proposed to support the shells
- NIF Able target is scheduled for June 2019
  - 5mm Beryllium Shell with spherical Fe backlighter
- Recent keyhole shots on omega tested new diagnostic principles
  - VISAR Finger Targets made from 2PP
  - Fiber Optic Targets



Revolver Point Design



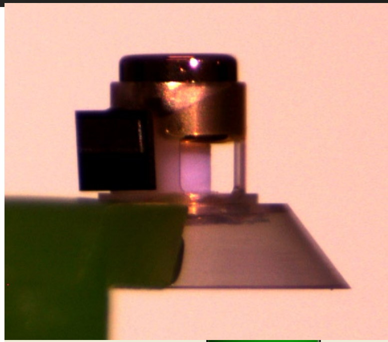
Finger (left) & Fiber Optic Target

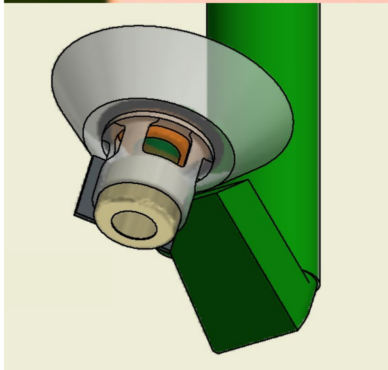


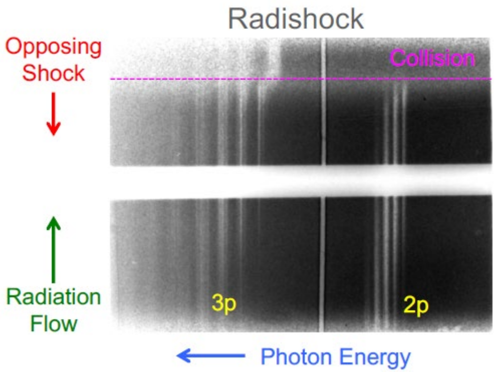
NIF Able Target

Radishock

- Part of the LANL Radflow campaign
- Objective to use high fidelity temperature and density data to constrain computational models in a system where a radiative wave flows across a counter propagating shock
- Target is comprised of
  - Gold halfraum
  - Plastic spool with attached cone and windows
  - Ti doped SiO2 Aerogel
  - Kr Backlighter capsule
- All foams require DCS because the experiment is highly sensitive to density variations

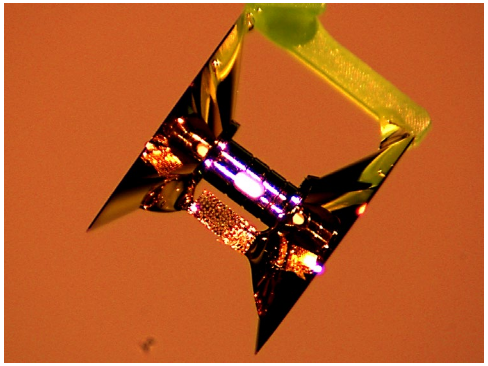




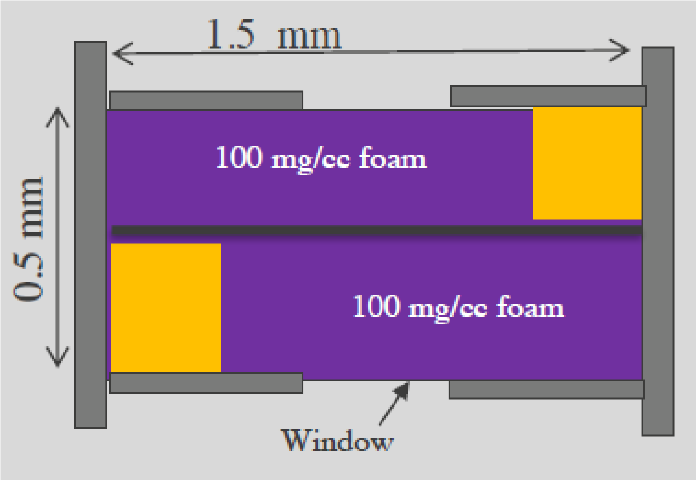


HEDB

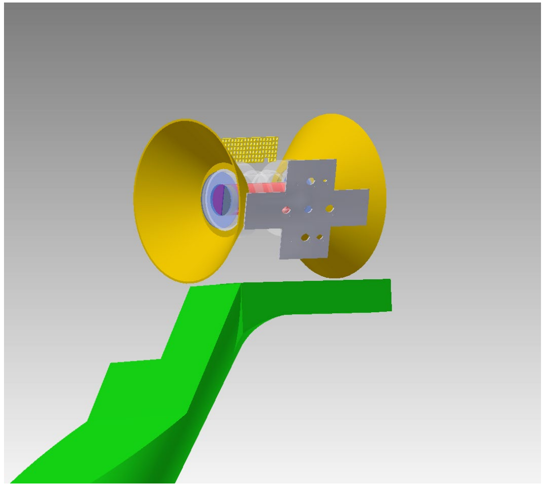
- LDRD to study the effect and strength of HED shock-driven B-field generation in ICF relevant HED condition
- Complex target is a shock tube with Plunge EDM "milled" proton window
  - Stuffed with foam and thin laser machined foil



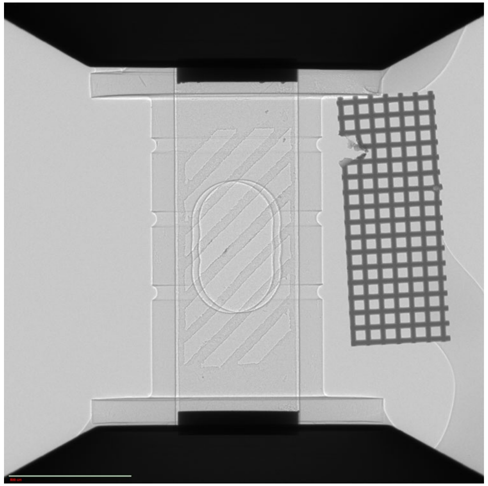
Side view of target



Cross section of target



Target design for May 2019

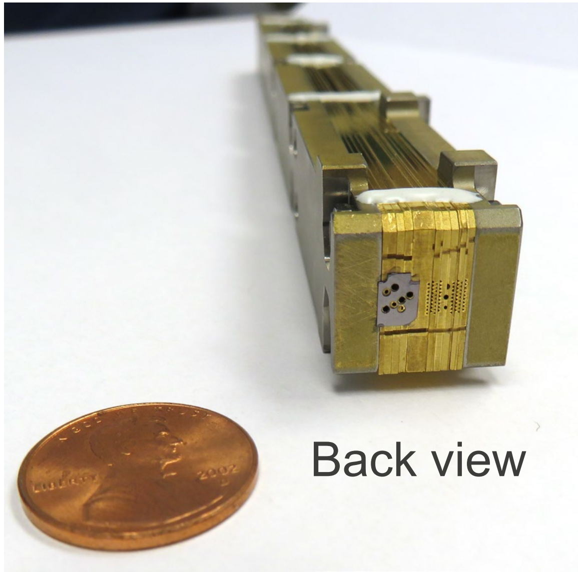


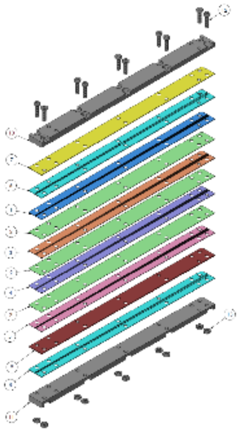
Radiograph of the grated target

Neutron Pinhole

- LANL has designed, machined and characterized 3 generations of Neutron pinhole on NIF
- Consists of 14 gold layers and 2 outer tungsten layers. 15 circular and 72 triangular openings were machined into the layers
- Machining took 62 weeks
- Full characterization on the OCMM, White light interferometer as well as a confocal white light interferometer.
- Metrology took 2 months
- The addition of characterization information provides a broad understanding of the neutron imaging system and image data.
- The initial qualification shot of the Second Equatorial Neutron Imaging System (NIS3) was a success

See talk "Three-dimensional Characterization of the Third Line-of-Site Neutron Imaging Pinhole at NIF" by L. Goodwin et. al



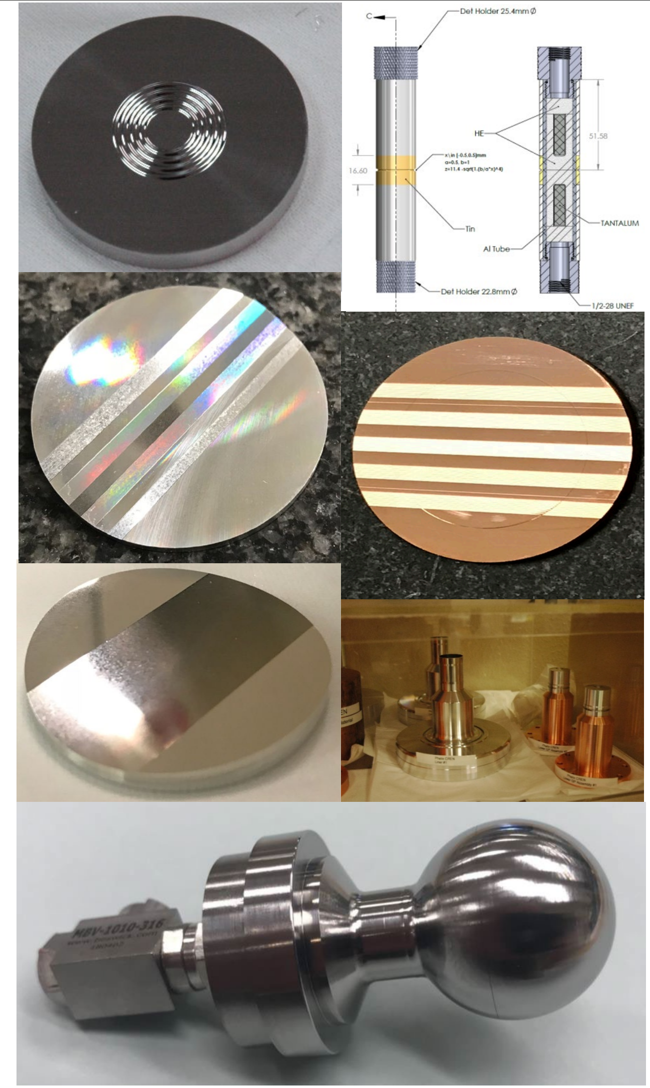


Large Targets

- We fabricate multiple complex target assemblies every year for PRAD-LANCE ancho canyon, UCSB and Z machine on Sandia
- Precision Titanium Spheres for Phelix on PRAD
- Cerium and Zinc saw tooth targets
- pRad Linear and Axial sine wave Profiles
  - 4 different sine wave profiles on one target cylinder
- Ejecta Targets, saw tooth profiles on non planar faces

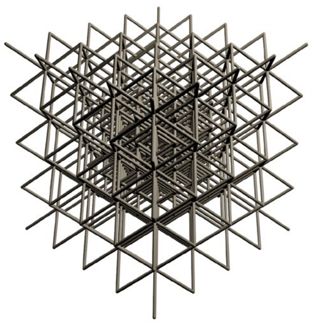
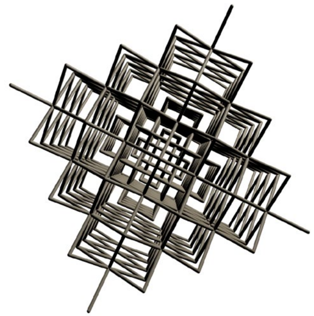
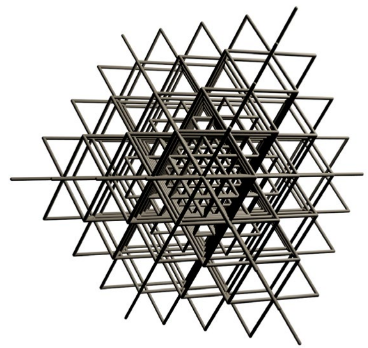
See Tuesday poster “Research & Development of Precision Machined Titanium Spheres at Los Alamos National Laboratory: Phase 1” by J.C. Lamar et. al

See Wednesday posters “Various Diamond Machining Processes and Implementation at Los Alamos National Laboratory” by P.M. Donovan et. al and “Fabricating of large targets” by J.I. Martinez et. al



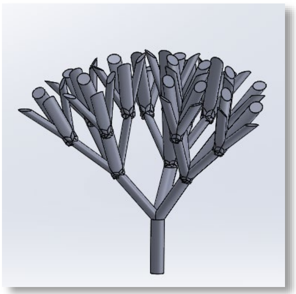
Next-Generation Foams and Aerogels

- Recent developments: graded density metallic foams via templating

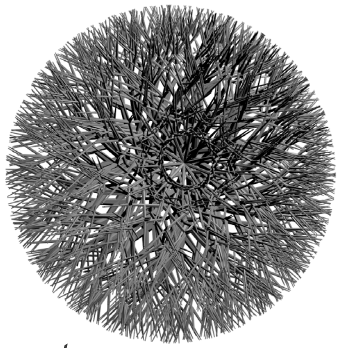
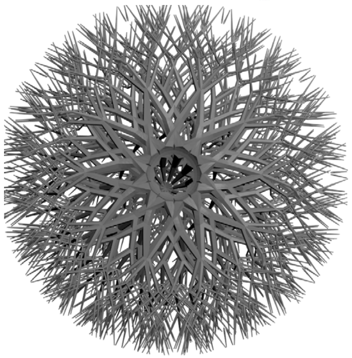




Current R&D

- We have successfully fabricated a ~3mm diameter 3-D printed Au sphere with *graded radial density*



Fractal tree concept

Future R&D

- *Comprehensive* characterization is needed (density = f(r), porosity)
- Higher resolution needed to achieve target-sized objects
- How should density change in a given direction?

Summary: We delivery a myriad of complex target designs every year concurrent with development

- Complex Omega Targets (not including capsules)
  - 800 targets for 19 shot days
- NIF Warm Targets
  - 11 Mshock/DRV
  - 18 Opacity
  - 10 Double Shell Packages
  - 3 Cyl Drt
  - 4 NIF Marble
  - 2 ABLE
- Large Target Fabrication (pRad, UCSB)
  - 16 different high complexity target packages
  - 60 sawtooth and sine wave explosive packages
- NIF Neutron Imaging Aperture
  - 13 layers of penumbras and pinholes, 62 weeks fabrication time

Adaptive Sample Preparation and Target Fabrication for High-Throughput Materials Science May 14-16 at Texas A&M University

Questions?