IFE TARGET FABRICATION PLANS AND PROGRESS

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Princeton Plasma Physics Laboratory

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OUTLINE

- **Purpose Of This Talk – ARIES Workscope:**
  "Integrate …… target fabrication activities into ARIES activity
  (Goal: begin to show a credible pathway for target fabrication)
  - **Propose preliminary fab, assembly, fill, and layering pathways"**

- **Indirect Drive Targets**
  - **Materials Manufacture (Metallic Foams)**
  - **Target Supply Process Flow Diagrams (OMEGA, NIF IFE)**
  - **"Warm Assembly"**
  - **"Cold Assembly"**

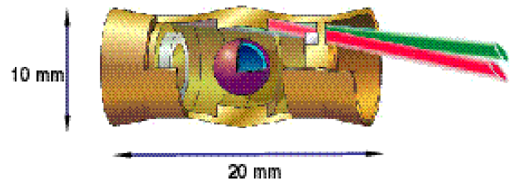
- **Direct Drive Targets**
  - **Materials Manufacturing Technologies**
  - **Development Issues and Pathways**
  - **Mass-Production Methods**

GENERAL ATOMICS

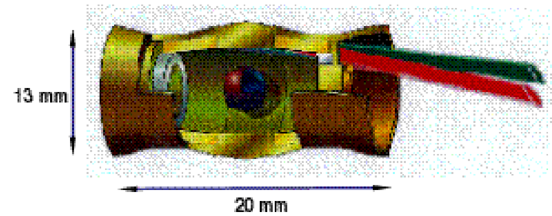
INDIRECT DRIVE TARGET MATERIALS

- Applies to both Close-Coupled and Full-Size Designs

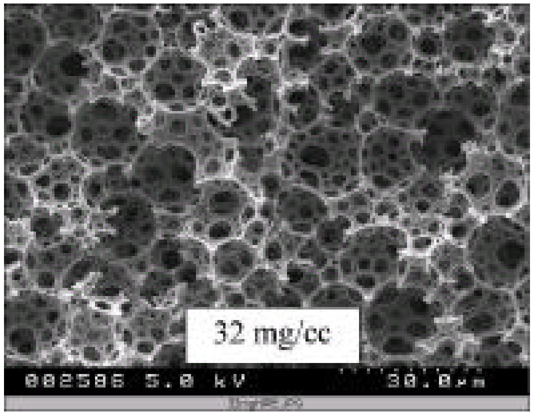
Close-Coupled



Full-Sized



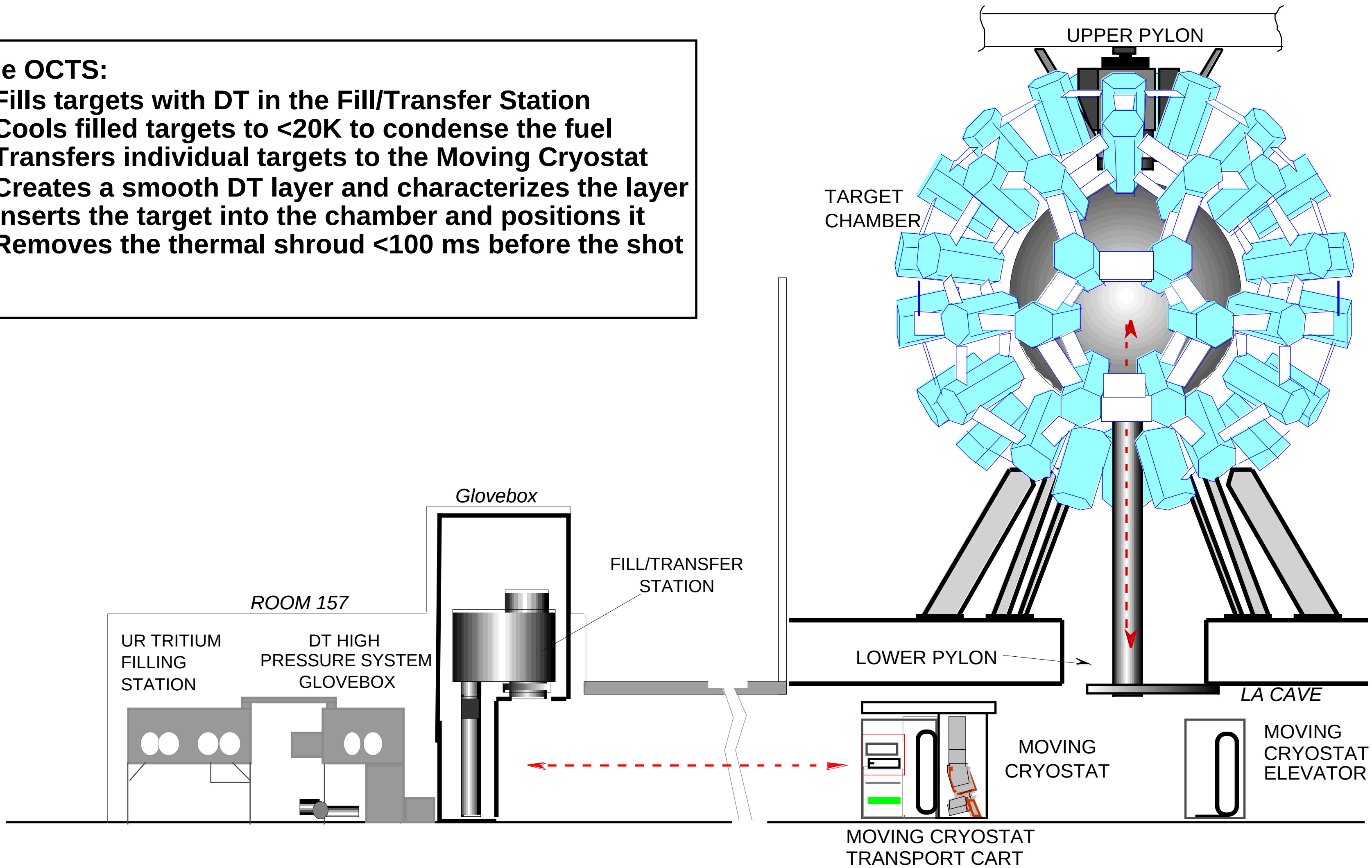
- LANL is investigating methods to fabricate the very low density metallic foams
- Current focus is on the development of metal-doped organic foams with densities down to 10 mg/cc
- Near term goals:
  - Synthesize foams with densities meeting requirements, and to develop a simple method for metal doping of the foams
  - Demonstrate the metal doping of foams with various metals (Au, W, Ta, Hf, Re, and Bi) using a simple wet impregnation technique



Synthesized Polystyrene Foam at 32 mg/cc

GA, LANL, AND UR/LLE HAVE JOINTLY DESIGNED AND CONSTRUCTED THE OMEGA CRYOGENIC TARGET SYSTEM

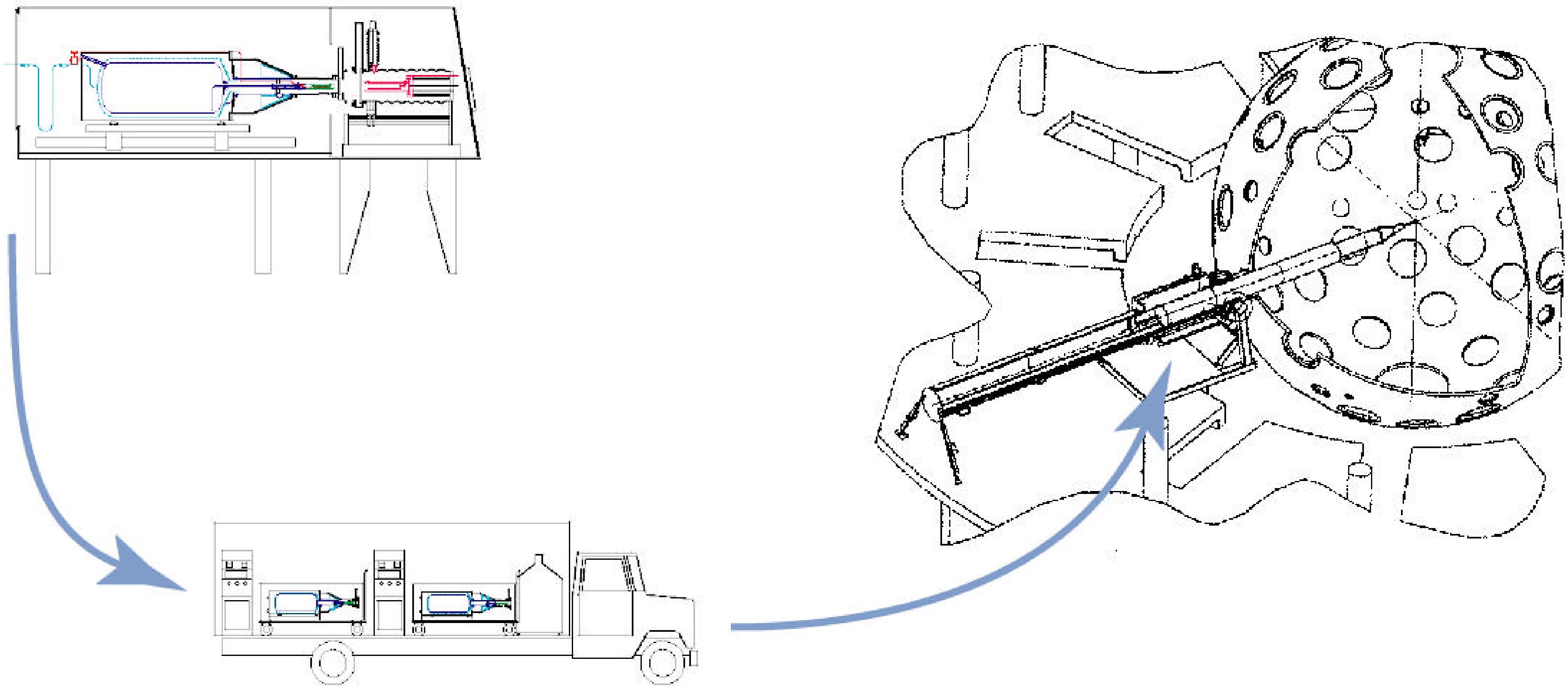
The OCTS:
- **Fills targets with DT in the Fill/Transfer Station**
- **Cools filled targets to <20K to condense the fuel**
- **Transfers individual targets to the Moving Cryostat**
- **Creates a smooth DT layer and characterizes the layer**
- **Inserts the target into the chamber and positions it**
- **Removes the thermal shroud <100 ms before the shot**



GENERAL ATOMICS

INDIRECT DRIVE TARGET FIELDING FOR NIF

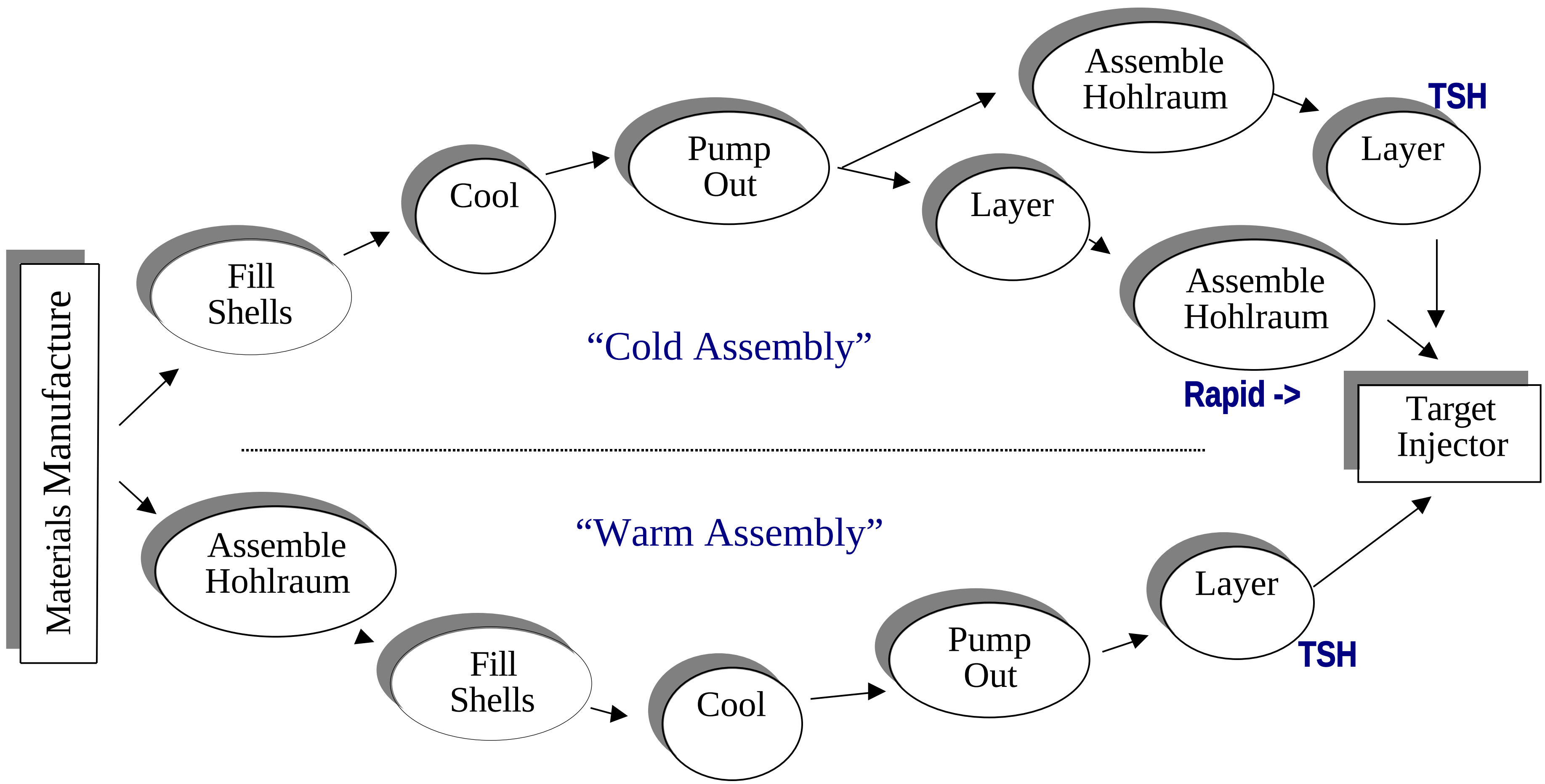
- The NIF Cryogenic Target System (NCTS) is Being Designed to Deliver Both Indirect and Direct Drive Targets
- Target are Individually Handled and Processed



GENERAL ATOMICS

INDIRECT DRIVE TARGET FIELDING OPTIONS FOR IFE

- **Two Fundamentally Different Process Flows**
  - **Room Temperature Assembly and Temperature Shimmed Hohlraum (TSH)**
  - **Cyogenic Assembly and Rapid Injection or TSH**

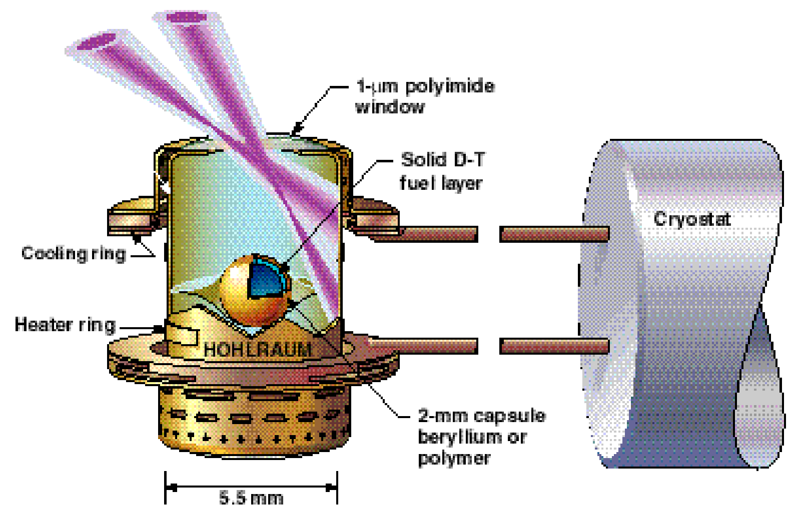


"WARM ASSEMBLY" SIGNIFICANTLY SIMPLIFIES THE HOHLRAUM PRODUCTION PROCESS

- **Precise Assembly Process Is Conducted at Room Temperature**

- **Warm Assembly and TSH Was Selected for NIF**
  - Simplicity of the Process
  - Avoids last second motions at target chamber center

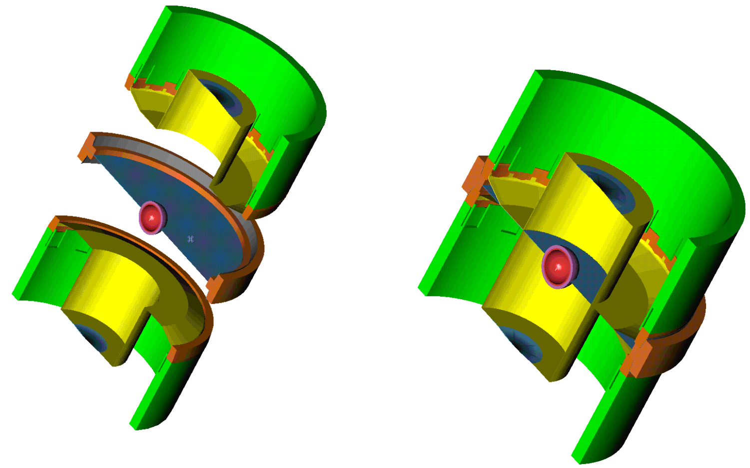
- **NIF Temperature Shimmed Hohlraum Method**
  - Pre-assembled, filled capsule and hohlraum
  - Impose temperature profile on the hohlraum wall to provide spherical isotherms on capsule inside
  - NIF system uses heater and temperatures sensors on each hohlraum (~$1000 for each hohlraum)



NIF Temperature Shimmed Hohlraum (TSH) Configuration

GENERAL ATOMICS

COLD ASSEMBLY HAS SOME CRITICAL PROCESS ADVANTAGES



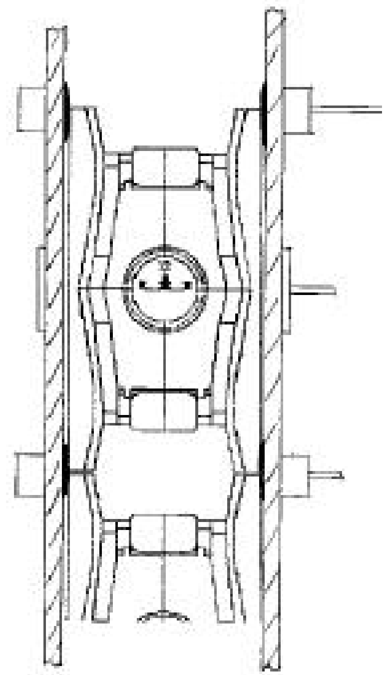
The hohlraum parts (yellow) are being assembled onto the capsule's mounting ring by the press anvils (green) of the cryogenic assembler.

- **Cold Assembly Significantly Reduces the Required Tritium Inventory**
- **Only Capsules are Placed in the Permeation Cell versus Entire Hohlraum (for warm assembly)**
- **Full-Sized Target Requires 30 Times More DT in Permeation Cell for Entire Hohlraum**
- **Close-Coupled Target Requires 13 Times More DT in Cell for Entire Hohlraum**
- **More Details Are In Jeff Latkowski's ANS Park City Paper "Preliminary Safety Assessment for an IFE Target Fabrication Facility"**

GENERAL ATOMICS

APPLICATION OF THE TSH METHOD TO IFE WILL REQUIRE A MASS-PRODUCTION METHOD

- **TSH Method Could Avoid a Complex Cryogenic Assembly Step**
  - Unless tritium inventory requires it anyway
  - Does reduce time constraints on cryogenic assembly
- **Propose to Stage the Hohlraums in Cryogenic Layering Tubes**
  - Allow temperature sensors to be on tube
  - Tubes would have a repeating, controlled temperature distribution to result in an isothermal condition at the filled capsule boundary
- **Use Multiple Tubes to Support 6 Hz Operation**
  - 300 tubes for 6 Hz operation (50 s for each tube)
  - Requires resonable floor space
- **Will Evaluate Thermal Profiles and Sensitivities of this Approach**
  - Grant Number DE-FG03-00ER54595, “ A New Layering Method for Indirect Drive IFE Targets”

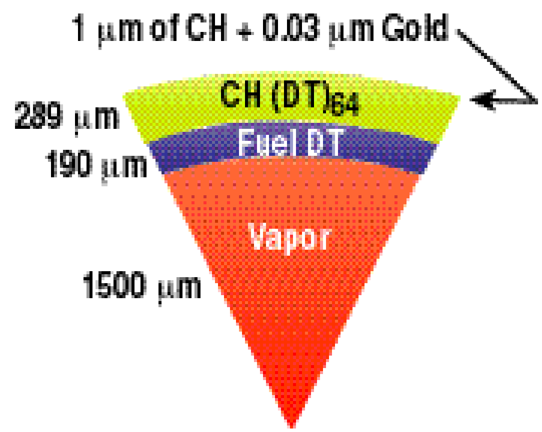


Layering of IFE Targets In A Staging Tube

GENERAL ATOMICS

ISSUES FOR DIRECT DRIVE TARGETS HAVE FOCUSSED ON INJECTION - FABRICATION TECHNOLOGIES ARE BETTER UNDERSTOOD

- **The NRL radiation preheat target consists of:**
  - a central area of DT vapor
  - a pure DT layer
  - a low density foam filled with DT
  - a thin CH seal coat to prevent DT evaporation
  - a very thin high-Z overcoat (e.g., gold)
- **Relevant fabrication technologies have been developed as part of the US and international programs**
- **Applicable fabrication technologies include:**
  - Foam shell by microencapsulation
  - Seal coat by interfacial polycondensation
  - Gold overcoat by physical vapor deposition
  - DT filling by permeation at room temperature
  - Fuel layer formation by cryogenic native β-layering or IR-enhanced layering

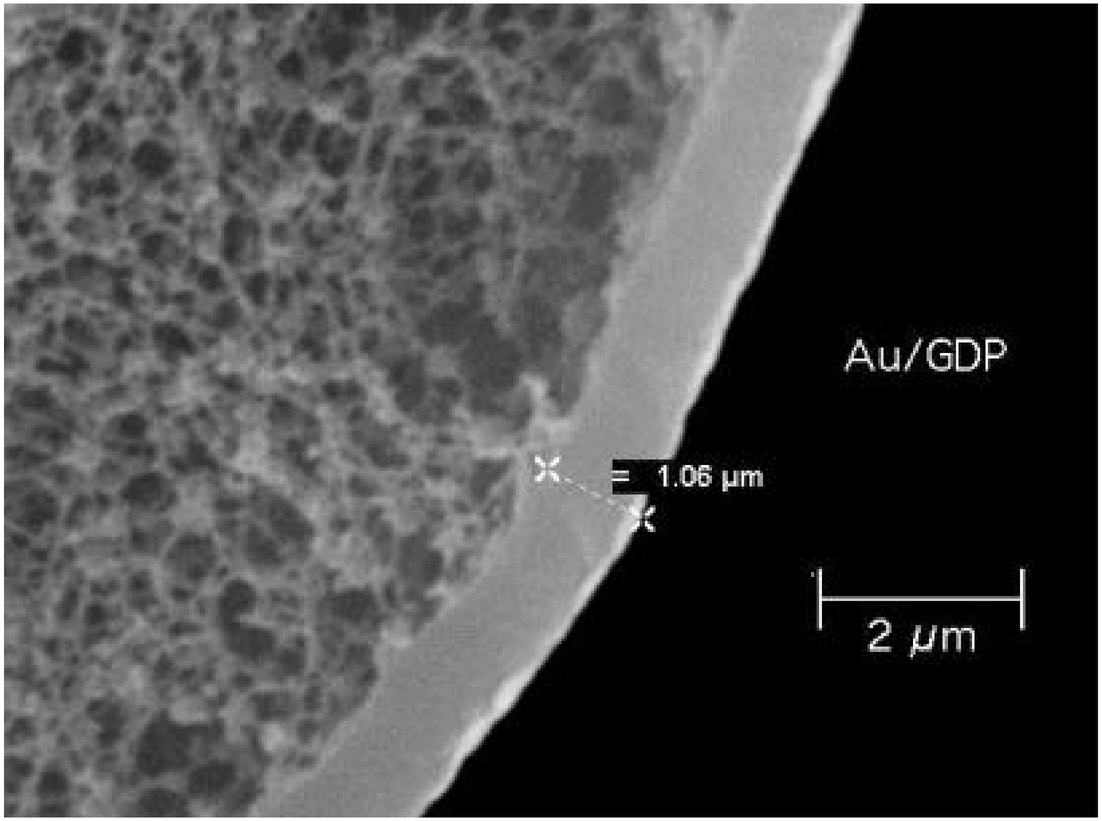


Target Diameter	4 mm
Foam Thickness	289 μm
Foam Density	~ 10 mg/cc
Foam Pore Size	<1 μm
Out-of-Round, Non-concentricity	<1 %
Seal Coat Thickness	~ 1 μm
High-Z Coat Thickness	~300 A
Surface Finish	~500 A

Key Specifications

THE BASIC FEASIBILITY OF BUILDING A RADIATION PREHEAT TARGET HAS BEEN DEMONSTRATED BY RECENT EXPERIMENTS

- **Starting point of trimethylolpropane trimethacrylate (TMPT) foam shells fabricated by microencapsulation at LLNL and overcoated with a thin (~0.5 μm) hydroxyethylcellulose (HEC) interfacial polycondensation seal**
- **The smooth HEC surface was overcoated at GA with GDP to bring the seal to ~ 1 μm**
- **Approximately 300 A of gold was added by physical vapor deposition and presence confirmed by energy dispersive analysis of x-rays**

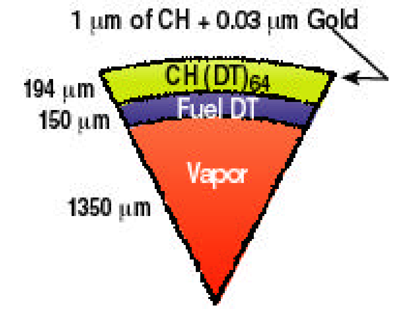


Trimethylolpropane trimethacrylate foam shell with ~1 μm hydroxyethylcellulose seal coat plus GDP, with ~300 Angstroms of gold

GENERAL ATOMICS

NIF ANALOG TO IFE RADIATION PREHEAT TARGET WILL DEMONSTRATE THE TARGET PHYSICS

- **NIF Analog is Very Similar to IFE Target for Fabrication Purposes**
  - Technical requirements similar
  - Plan prepared for materials development for NIF target[(1)]
  - Early materials development identical for NIF and for IFE target

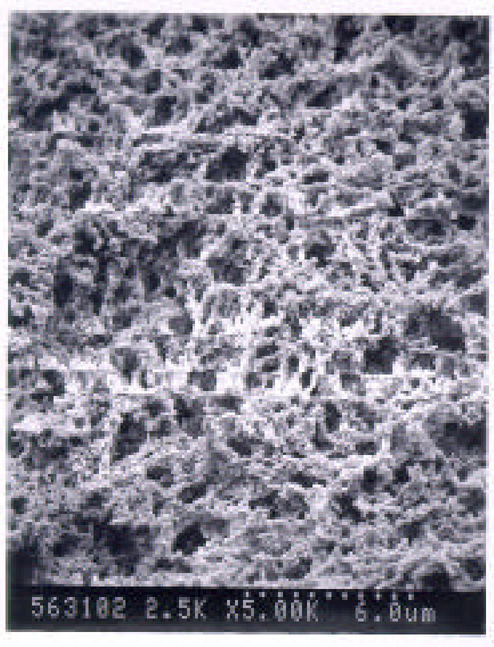


NIF Analog to IFE Radiation Preheat Target

- **Materials Issues to be Addressed:**
  - Maintaining <1 μm pore size & reducing density to ~10 mg/cc
  - Capability to meet geometric specifications for the foam shell
  - Ability to tolerate oxygen in the foam
  - Development of suitable characterization methods
  - Seal coat surface finish
  - Handling of ultra low density shells

- **Pathway Identified = Development of DiVinyl Benzene (DVB) Foam Shells**
  - Contains only carbon/hydrogen
  - Fabricated in bricks at ~10 mg/cc with pore sizes < 1 μm
  - Microencapsulation yet to be demonstrated

SEM of 10 mg/cc DVB Foam

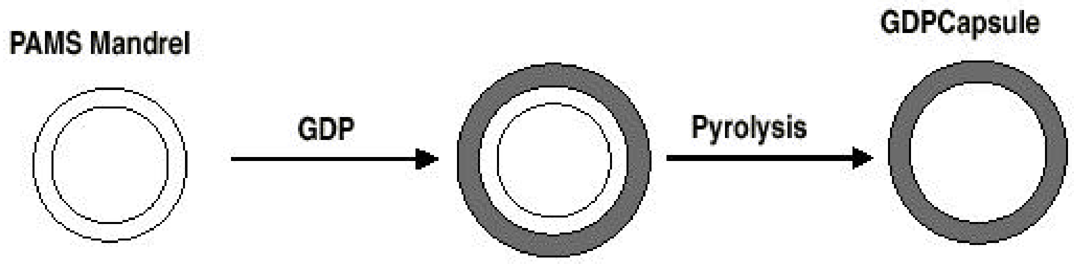


[1] *"Development Plan for Fabrication of the NRL Radiation Preheat Target for Fielding on NIF"*

GENERAL ATOMICS

EVALUATION OF FLUIDIZED BED AS AN IFE MASS-PRODUCTION METHODOLOGY

- **Historically, Scaleup of Capsules Has Required Evolving Methodologies**
  - Drop tower method was used up to about 0.5 mm OD (Nova) before sphericity and non-concentricity degrade
  - Microencapsulation was used up to about 1 mm OD (OMEGA), but thin walls difficult
  - Decomposable mandrel technique used to overcome non-concentricity and provide thin walls – but "bounce pan" GDP technique limited to few shells

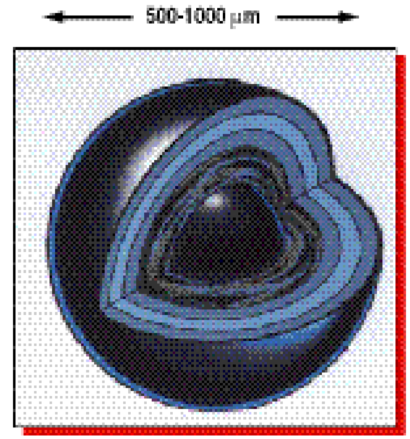


- **Fluidized Bed Has Potential for Mass-Production**
- **Three Potential Applications for IFE:**
  - Direct Drive: Seal coat for radiation preheat target (overcoating)
    Alternate capsules (non-foam)
  - Indirect Drive: Polymer capsule to replace Be in current design

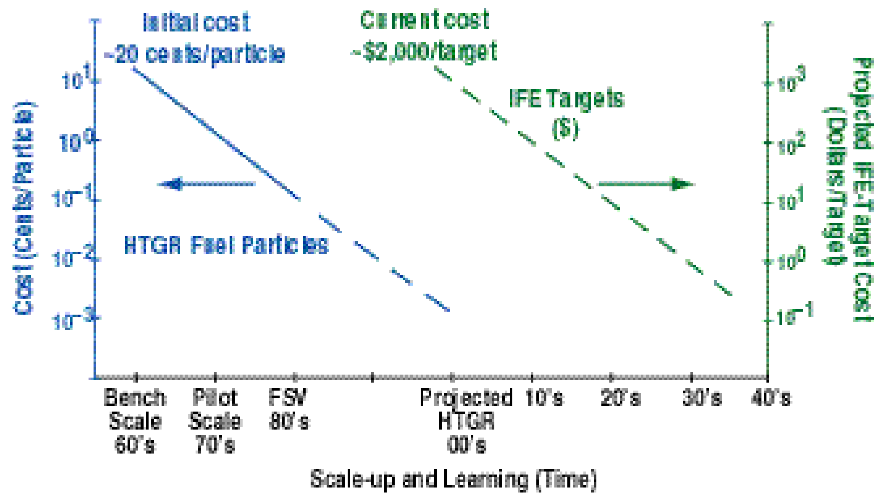
10^4 REDUCTION IN HTGR FUEL PRODUCTION COST IS ENCOURAGING FOR IFE

- High-temperature gas-cooled reactor (HTGR) fuel has similarity to IFE capsules
  - Multiple layers of high and low density coatings
  - Stringent quality requirements (but ~10X IFE)
- Over 10^{11} fuel particles have been produced in a small commercial production facility for Fort St. Vrain reactor
- Quality control was carried out by statistical means
  - Production yield was ~90%
- Cost reduction was ~10^4 due to scale-up
  - Bench scale 20¢ per particle
  - FSV was less than 0.2¢ per particle
  - Projected commercial 0.002¢ per particle

. . . Indicates that low cost IFE targets are not out of reach, but greater precision will be required



HTGR fuel particle with
4 different coating layers



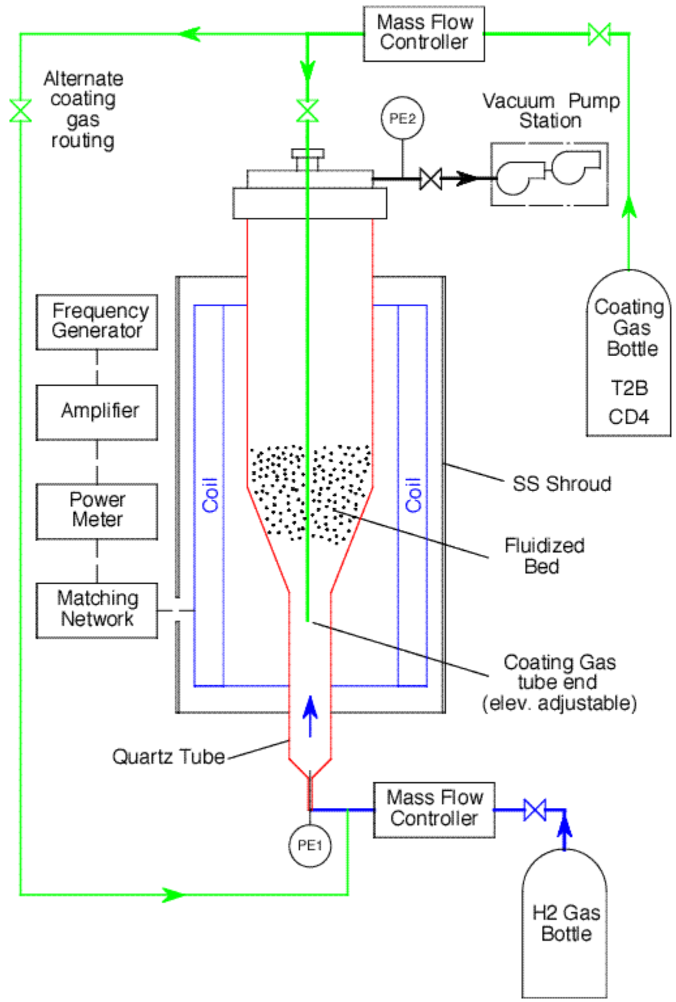
GENERAL ATOMICS

EVALUATION OF FLUIDIZED BED AS AN IFE MASS-PRODUCTION METHODOLOGY

- **Goal Is To Determine Viability of Replacing "Bounce Pan" with Fluidized Bed**

- **Approach Is To**
  - **Determine bed fluidization conditions for 1-2 mm PAMS mandrels**
  - **Perform initial runs with trans-2-butene**
  - **Evaluate lower-cost coating gases**
  - **Determine scaling to larger diameter mandrels**
  - **Project cost based on efficiency and coating times**

- **Funded by Grant DE-FG03-00ER54596, "Evaluation of Fluidized Beds for Mass-Production of IFE Targets"**



GENERAL ATOMICS

CONCLUSIONS

- Work Has Begun to Provide a Credible and Detailed Pathway for IFE Target Fabrication
- Working with Target & Chamber Designers in Iterative Fashion
- Experiments Are Underway to Define Processes for Fabrication of Low Density Metallic Foams
- Experience from NIF and OMEGA is Being Used to Define Process Flow Options
- ES&H and DT Inventories are being Used to Guide Process Selections
- Analytical Evaluations of Methods to Layer in Hohlraums are Beginning
- Experimental Evaluations of Fluidized Bed Mass-Production Techniques are Beginning

A DIRECT-DRIVE HEAVY ION FUSION TARGET

- *Max Tabak at LLNL earlier developed direct-drive HIF target designs*
  - *While the results are preliminary and stability is not assured, they do look interesting:*
  - *Modest driver requirements: ~1.8 MJ absorbed, ~100-200 TW*
  - *Good performance: 250-300 MJ yield, G ~150*
- *Target looks interesting: R ~ 3 mm, ~1750 µm DT gas, ~300 µm DT ice, ~900 µm DT ice + 5% CH foam, ~ 50 µm Pb outer shell*
  - *May be quite robust mechanically and thermally*
- *There are potential drawbacks:*
  - *Large tritium inventory, recirculation*
  - *Thick lead shell a concern for dry wall chamber (wetted wall?)*
  - *Beam transport for direct drive HIF may be a challenge….*