Progress in Inertial Fusion Energy Technology: June – August 2002

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Progress in IFE Technology: June - August 2002

Laser Damage to Optics —University of California, Los Angeles (UCLA)

N.M. Ghoniem, R. Ungureanu and Q. Hu (**http://puma.seas.ucla.edu/web_pages/**)

- Completed thermal and structural analysis of the multi-layer reflective mirror concept.
- Initiated ray-tracing analysis for the focusing capabilities of the segmented reflective concept developed at UCLA.
- Completed the publication of an extensive article on laser-induced damage in Phys. Rev. B. (see publications below).

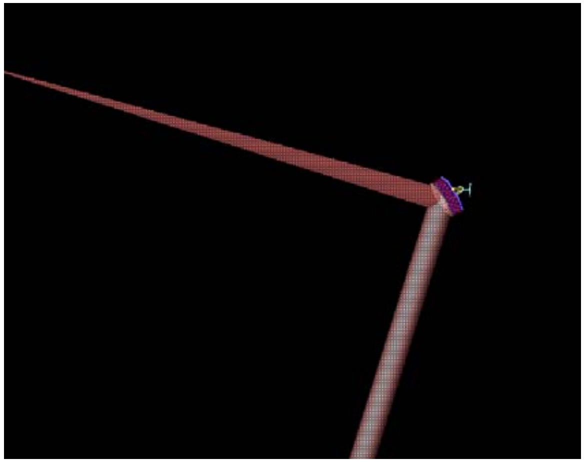


Figure 2. Ray-tracing modeling of the UCLA segmented mirror

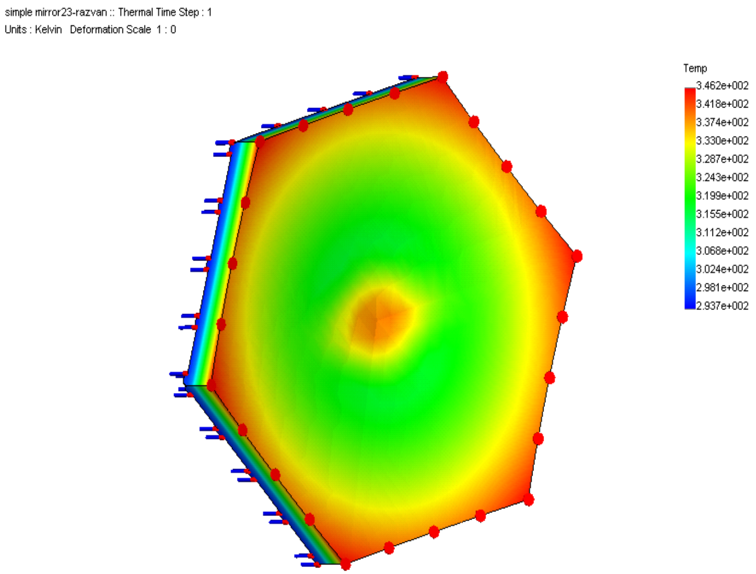


Figure 1. Temperature distributions on the face of a basic unit of the segmented mirror

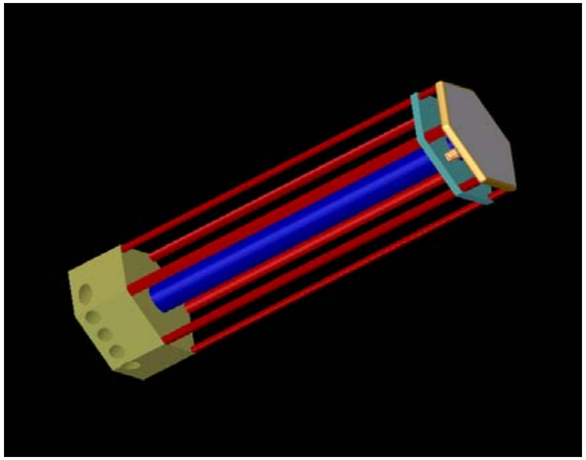


Figure 3. Piping and support structure of the basic unit of the UCLA segmented mirror. The diameter of the circle inscribing the hexagonal face is 6”

Publications and Presentations:

[1] D. Walgraef and N.M. Ghoniem, "The Effects of Crystal Anisotropy and Adherence Forces on Laser Induced Deformation Patterns in Thin Films," *Phys. Rev.*,**B 65** 1555304-1 to 1555304-10.

Progress in IFE Technology: June - August 2002 (Cont'd.)

IFE Chamber Dynamics Modeling and Experiments— University of California, San Diego

M. S. Tillack, F. Najmabadi, S. S. Harilal, C. V. Bindhu, A. R. Raffray, M. Zaghloul, A. C. Gaeris, J. Pulsifer, D. Blair, S. Chen (http://aries.ucsd.edu/IFE)

- Experimental study of laser ablation plume dynamics to simulate the interaction of IFE target emissions with the surrounding chamber medium. The plasma is generated by 10-ns, pulses at a power density ~10^{10} W/cm^2 and allowed to expand into air, helium and argon. Measurements were made with a 2-ns gated iCCD camera and space- and time-resolved emission spectroscopy (Fig. 1).

- Performed literature search in preparation for experiments on the effect of magnetic field on plume expansion dynamics. Magnetic fields have been used recently in the field of thin film deposition to control the transport of species (http://aries.ucsd.edu/LIB/BIB/db.cgi?uid=default&view_records=Search+Records&topic=mag-diversion).

- Fabricated Langmuir probe with high-frequency circuitry. Probe measurements provide better spatial resolution as compared with spectroscopy, and can be used to determine the ion density. Initial measurements were made in a silicon laser plasma. At this time, the circuit is being optimized to reduce noise.

- Used Becker-Döhring theory of nucleation to examine explosive mass ejection near the free surface of a liquid IFE chamber wall. Under very high heating rates typical of IFE indirect-drive x-ray energy deposition and laser-matter interactions (~10^{13} K/s), free surface vaporization and heterogeneous nucleation boiling play a relatively minor role in the overall boiling process. The high heating rate causes superheating of the liquid to a metastable state, which then decomposes explosively into liquid and vapor phases (Fig. 2).

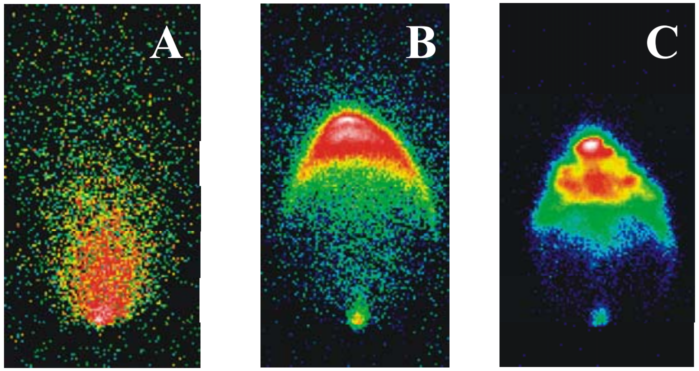


Figure 1. Al plume expanding into air: a) 10^{-6} torr at 300 ns, b) 150 mtorr at 370 ns, c) 1.3 torr at 370 ns after laser pulse

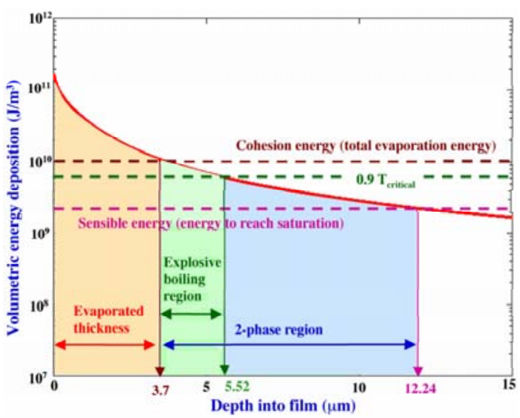


Figure 2. Flibe film under 458 MJ indirect drive target x-ray energy deposition

Publications and Presentations:

[1] S. S. Harilal, C. V. Bindhu, M. S. Tillack, F. Najmabadi and A. C. Gaeris, "Plume Splitting and Sharpening in Laser-produced Aluminum Plasma," submitted to Applied Physics Letters, June 2002. http://aries.ucsd.edu/LIB/REPORT/UCSD-ENG/UCSD-ENG-093.pdf

[2] S. S. Harilal, C. V. Bindhu, M. S. Tillack and F. Najmabadi, "Plume Splitting and Sharpening in Laser Produced Al Plasma," presented at the Gordon Conference on Laser Interactions With Materials, Jul 21-26, 2000, Proctor Academy, New Hampshire.

[3] A. R. Raffray and M. Zaghloul, "Scoping study of Flibe evaporation and condensation," ARIES IFE meeting, General Atomics, July 1-2, 2002.

Progress in IFE Technology: June - August 2002 (Cont'd.)

Laser IFE Materials — Oak Ridge National Laboratory

L. L. Snead

- Carbon Fiber Composite Radiation Effects--> the purpose of this task is to characterize the swelling and mechanical property performance of carbon fiber composites at very high temperatures.
  - Completed measurement of thermal conductivity of FMI-222 carbon fiber composite irradiated to 800°C at 8 dpa.
- Optics Irradiation Program--> the purpose of this task is to provide irradiation services for optical mirrors to LLNL for the HAPL program.
  - Sillica based diielectric mirrors obtained from LLNL and machined. Alumina substrate mirrors ordered.
  - Thermal analysis of irradiation vehicles begun.
- Refractory Armored Wall Materials--> the purpose of this task is to review the possibility of using refractory armored materials for wall materials in an IFE system.
  - Tungsten and molybdenum coating have been applied to SiC and SiC composites.
  - SEM, Optical and TEM characterization of refractory/SiC interface completed.
  - Mechanical property evaluation underway.
- Helium/Wall Interaction- the purpose of this task is to define whether a temperature regime exists to avoid exfoliation due to helium bubble formation in IFE tungsten (or other) walls.
  - High temperature helium irradiation and analysis system assembled. Irradiation begun.

Publications and Presentations:

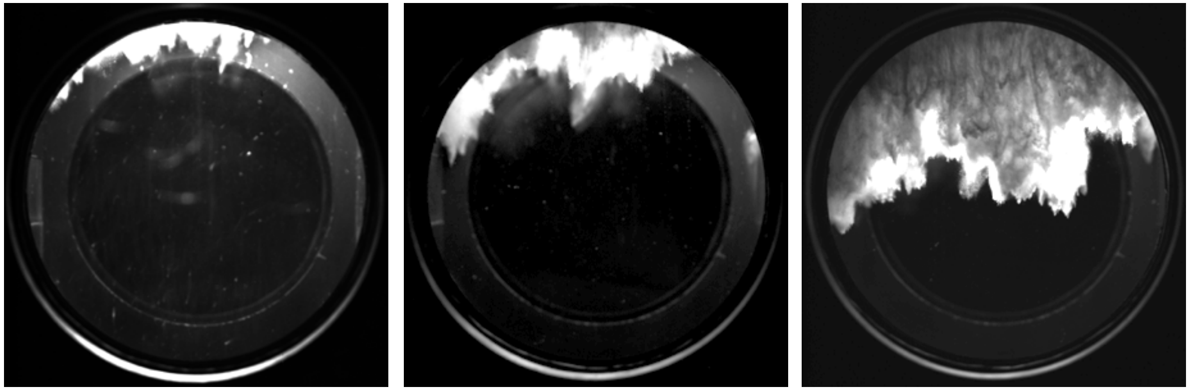
[1] L. L. Snead,T. D. Burchell, A. L. Qualls, "Strength of Neutron-Irradiated High-Quality 3D Carbon Fiber Composite," Journal of Nuclear Materials, 2002.

Progress in IFE Technology: June - August 2002 (Cont'd.)

Liquid Layer Protection – University of Wisconsin, Madison

P. Meekunnasombat, J. Oakley, M. Anderson, R. Bonazza

- The inertial fusion energy reaction results in a blast wave that emanates from the center of the reaction chamber to the first wall of cooling tubes. One proposed idea to protect the first wall from fusion debris and to remove the thermal energy is with a liquid sheet.
- To study this concept a shock tube is used to experimentally study a flat liquid layer subjected to a shock wave. The shock wave accelerates the shocked liquid layer down the shock tube where it is imaged in the test section. The pressure history is digitally recorded as well as the pictures of the breakup of the water layer.



2.12 ms *2.31 ms* *2.62 ms*

Figure 1. A liquid layer is placed on a 0.94 μm Mylar membrane at the interface section 0.46 m above the test section (where the shocked liquid is imaged.) The above images are of an initially flat 12.8 mm thick water layer accelerated by a Mach 2.14 planar shock wave. Each image is from a different experiment and the time series is obtained by adjusting the delay time of the laser pulse. The time indicates the age of the break-up from when the shock wave first contacts the liquid layer in the interface section. With the planar imaging technique, the thickness of the shocked liquid layer (indicated by the light area) and geometry of the break-up can be seen more clearly than with shadowgraph imaging.

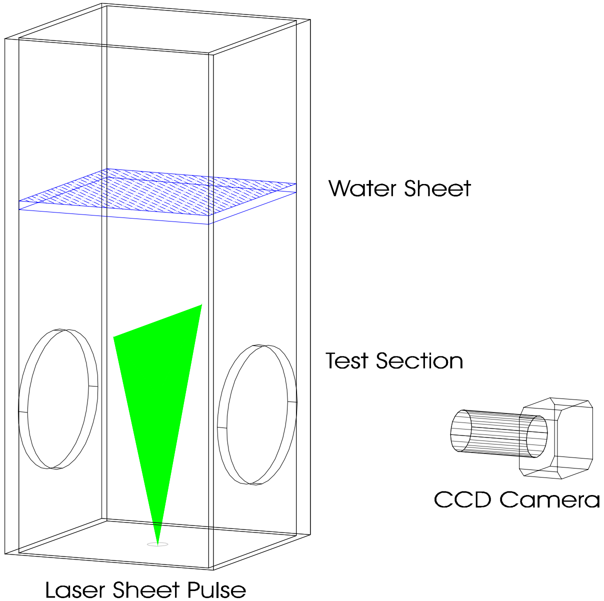


Figure 2. Schematic of the planar image setup in the shock tube. The camera shutter is left open during the test and a Nd:Yag laser sheet is pulsed according to the preset delay time to image the shocked liquid layer in the test section.

Publications and Presentations

[1] Experimental Hydrodynamics Model for First Wall Protection in IFE Reactors; Riccardo Bonazza, Jason Oakley, Mark Anderson, Phongsan Meekunnasombat, Shaoping Wang, Paul Brooks, April 2002 [presented at the High Average Power Lasers Meeting, General Atomics, La Jolla CA, 4-5 April 2002].

[2] J. Oakley, M. Anderson, S. Wang and R. Bonazza, "Experimental and Numerical Investigation of Shock Diffraction and Pressure Distribution Around Shocked Cylinder Banks," submitted to *Shock Waves*, October, 2001.

Progress in IFE Technology: June - August 2002 (Cont'd.)

Thick-Liquid Protection — Georgia Institute of Technology

S.G. Durbin, J.R. Reperant, M. Yoda, S.I. Abdel-Khalik

- Design and fabrication of liquid sheet nozzles from new transparent resins (DSM Somos® WaterShed™ and WaterClear™). See Fig. 1.
- Installation and testing of new single-component laser-Doppler velocimetry (LDV) system: quantify initial conditions by mean velocity and turbulence intensity profiles at nozzle exit (Fig. 2).
- Fabrication of new flow straightener section (Fig. 3) to easily change flow conditioning components (perforated plate, honeycomb, mesh screen).

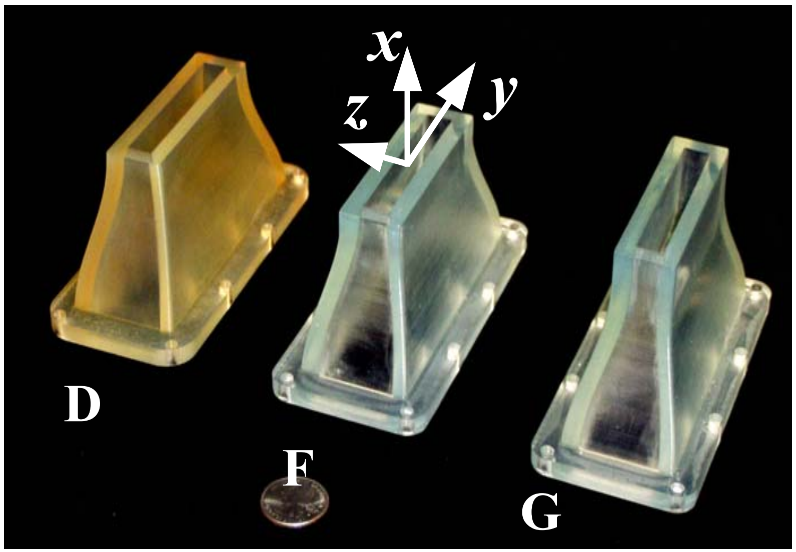


Figure 1. Transparent nozzles:
d) Inner contour 3-D 5th order polynomial contraction in DSM Somos® 7120
f) Same as D in DSM Somos® WaterShed™
g) Same as F with 1 cm flat channel at exit

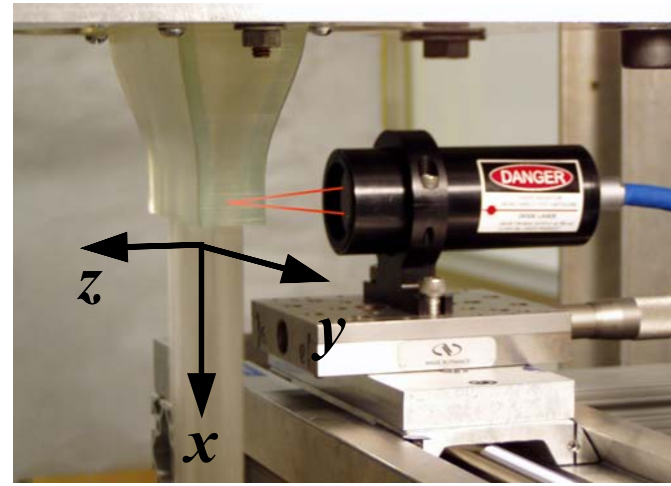


Figure 2. Laser Doppler velocimeter, shown with nozzle G and simulated laser beams

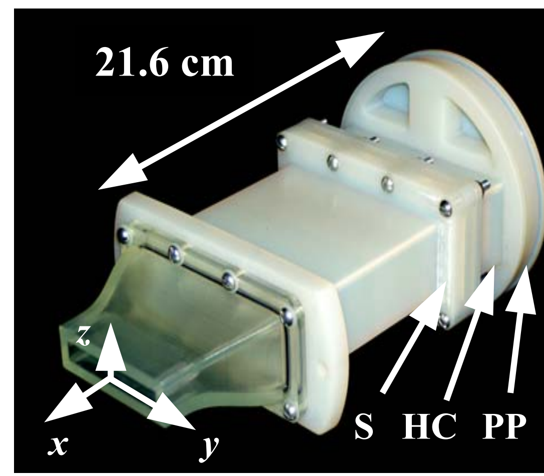


Figure 3. Flow straightener, shown with nozzle G. Sections hold perforated plate (PP), honeycomb (HC), and screen (S)

Publications and Presentations

[1] Anderson, J. K., Durbin, S. G., Sadowski, D. L., Yoda, M. and Abdel-Khalik, S. I., "Experimental studies of high-speed liquid films on downward facing surfaces", 2nd IAEA Technical Meeting on Physics and Technology of IFE Targets and Chambers (San Diego, CA); also submitted to *Fusion Science and Technology* (2002)

[2] Shin, S., Abdelall, F. F., Abdel-Khalik, S. I., Yoda, M. and Sadowski, D. L., "Fluid dynamic aspects of the porous wetted wall protection scheme for IFE reactors", *Ibid*.

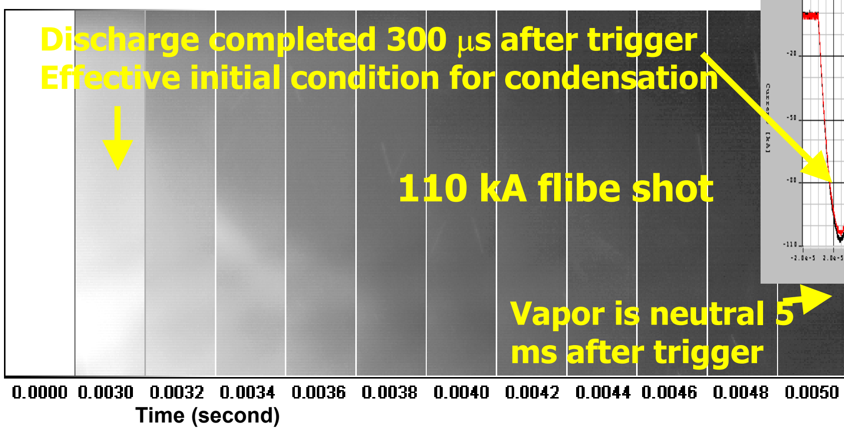
[3] Reperant, J. J. R., Durbin, S. G., Yoda, M., Abdel-Khalik, S. I. and Sadowski, D. L., "Studies of turbulent liquid sheets for protecting IFE reactor chamber first walls," originally presented at ISFNT-6 (San Diego, CA); to appear in *Fusion Engineering and Design* (2002)

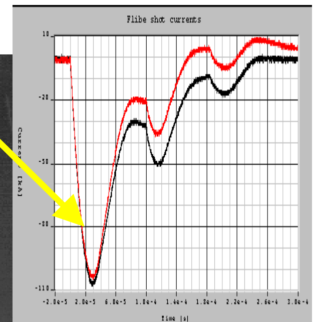
Progress in IFE Technology: June - August 2002 (Cont'd.)

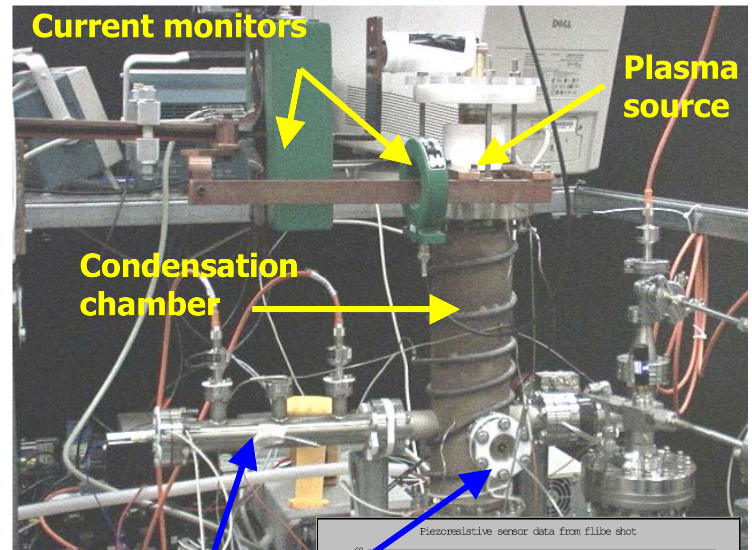
Vapor Dynamics and Condensation and Free Surface Flow Studies—University of California, Los Angeles (UCLA)

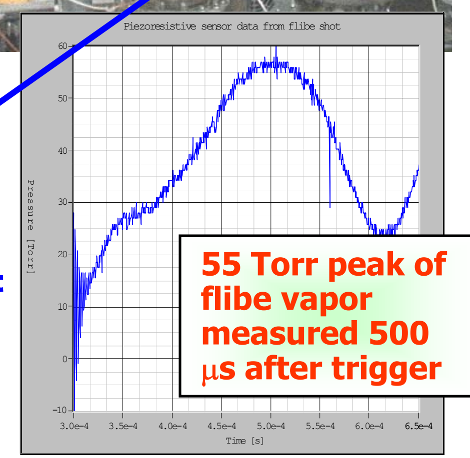
M. Abdou, A. Ying, N. Morley, P. Calderoni, A. Konkachabaev,A. Elias,, M. Ni, T. Sketchely

- Performed Flibe shots. Results were presented at the Second IAEA Technical Meeting on Physics and Technology of IFE Targets and Chamber.
- Continued to address and evaluate various diagnostics for condensation study.
- Identified a thin wire discharge mechanism which would eliminate the existence of the non-condensable gases.
- Performed 3D incompressible flow modeling to study jet corner deformation mechanisms.



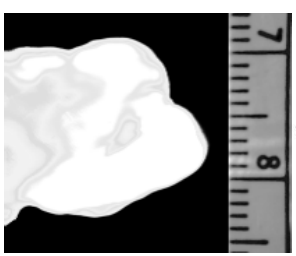


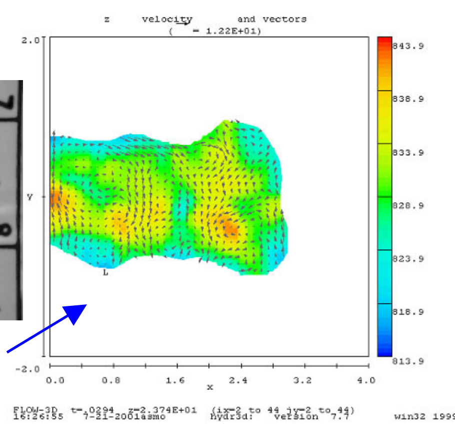




LIF Data From GT Water jet:

V = 8.4 m/s, δ = 1 cm
x/ δ = 25





3D Simulation with 5% initial turbulence seed: x/ δ = 25

Progress in IFE Technology: June - August 2002 (Cont'd.)

Target Fabrication, Injection, and Tracking – GA/LANL

D. Goodin, R. Petzoldt, N. Alexander, L. Brown, G. Besenbruch, A. Nobile, and Jim Hoffer

- We prepared a cost model framework for fabrication and assembly of the distributed radiator hohlraum. Detailed inputs to the model are still being defined.
- We hosted the "IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers" on 17-19 June 2002. http://web.gat.com/conferences/iaea-tm/main.html (The presentations are posted on the web site and a special issue of Fusion Science and Technology is being prepared for submitted papers). See Fig. 1.
- Target tracking system initial experiments with stationary targets demonstrated the ability to reproducibly detect positions to ±2.5 microns (A first step toward the ultimate goal of tracking moving targets with high precision).
- We setup an experimental system to evaluate scale-up of micro-encapsulation methods for production of polymer capsules, and produced our first set of capsules (Fig. 2).

Figure 1. Recent progress in IFE targets and chamber technology was presented at the IAEA meeting

Figure 2. Micro-encapsulation setup for target production scale-up studies

Publications and Presentations

IAEA meeting: **[1]** J. Dahlburg, "Target Fabrication - Its Role in High Energy Density Plasma Phenomena", **[2]** M. Shmatov, "Some Problems Related to Heating the Compressed Fuel through the Cone", **[3]** J. Hoffer, "Studies of DT in IFE Targets", **[4]** W. Rickman, "Filling and Layering Research of Inertial Fusion Targets in the LANL Cryogenic Pressure Loader", **[5]** E. Valmianski," Wake Shields for Protection of IFE Targets During Injection", **[6]** R. Petzoldt," Experimental Target Injection and Tracking System", **[7]** M. Shmatov, "Measures to provide Surviving Direct Drive Targets", **[8]** E. Stephens, "Palladium and Palladium Gold Alloys as High Z Coating for IFE Targets", **[9]** N. Alexander, "Layering of IFE Targets Using a Fluidized Bed", **[10]** W. Steckle, "Low Density Materials for use In Inertial Fusion Targets", **[11]** A. Greenwood, "Thickness and Uniformity Measurements of Thin Sputtered Gold Layers on ICF Capsules"
ARIES meeting: **[12]** D. Goodin, "Update on Target Fabrication, Injection, and Tracking.

Progress in IFE Technology: June - August 2002 (Cont'd.)

Integration, Systems Studies, Safety & Environment and Driver-Chamber Interface — Lawrence Livermore National Laboratory

W. R. Meier, J. F. Latkowski, R. W. Moir, and S. Reyes

- Updated self-consistent point design for HIF, working with the HIF VNL, target designers and liquid chamber designers. Progress reported at the ARIES Project Meeting and Snowmass Fusion Summer Study.
- Continued work on S&E, including toxicological issues of hazardous target materials such as Pb and Hg. Also, developed methodology to assess the effect of activation cross-section uncertainties on activation results.
- Visited vendor that is supplying rep-rated source for x-ray damage experiments (see figure). Source will be on-site by end of fiscal year.
- Initiated feasibility studies to irradiate liquid wall materials in z-pinch based x-ray source.

Figure 1. PLEX LLC is supplying a z-pinch based x-ray source for rep-rated materials damage studies (supported by the HAPL program)

Publications and Presentations:

Second IAEA Technical Meeting, 17-19 June 2002:

[1] S. Reyes, J. F. Latkowski, L. C. Cadwallader, "Safety and Environmental Aspects of Inertial Fusion Energy: An Overview of Recent Activities and Developments".

[2] J. F. Latkowski, S. Reyes, S. A. Payne, W. R. Meier, and J. A. Speth, "Rep-rated X-ray Ablation Experiments for Damage Studies of Inertial Fusion Energy and Inertial Confinement Fusion Components".

[3] J. Sanz, R. Falquina, J.F. Latkowski, S. Reyes, "Monte Carlo Uncertainty Analyses of Pulsed Activation in the NIF Gunite Shielding".

ARIES Project Meeting, 1-2 July 2002:

[4] W. R. Meier, P. Peterson, "Updated Heavy Ion Driver Parameters for Snowmass Point Design".

[5] J. F. Latkowski, "Updated Shielding Analysis for Final Focus Magnets".

Snowmass Fusion Energy Sciences Summer Study, 8-19 July 2002:

[6] W. Meier, et al., "Drivers for IFE" .

[7] J. F. Latkowski, "Overview of S&E" .

Progress in IFE Technology: June - August 2002 (Cont'd.)

Hohlraum Fabrication and Target Assembly- LANL/GA

A. Nobile, J. Maxwell, K. DeFriend, J. Young, D. Goodin

- Working with LLNL target designers, the number of candidate materials for the HIF target has been refined, and a new concept for a tailored, functionally-graded hohlraum has been developed using these materials. While details of the concept are still being defined, this will lower the cost of the HIF target (see Fig. 1).
- Five talks were given at the "IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers" on 17-19 June 2002.
- Laser chemical vapor deposition (CVD) routes to produce the functionally-graded hohlraum materials have been identified to produce the hohlraum materials. Important CVD precursors have been identified, and are beginning to be tested.
- An experimental laser CVD system to validate parallel laser chemical vapor deposition as a means to hohlraum production has been assembled, and is ready to begin growth experiments (see Fig. 2 below).
- Variables such as lattice spacing, fiber diameter, ion penetration depth, etc. were optimized to produce the necessary hohlraum material low densities.
- A concept has been developed for a production scale laser CVD reactor to produce HIF target (see Fig. 3 below).

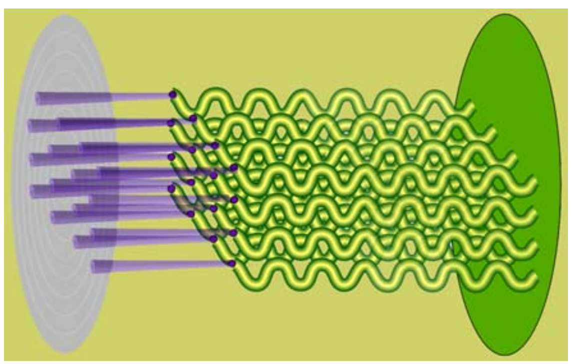


Figure 1. Recent progress and New Concepts in Hohlraum Manufacturing were Presented

Figure 2. Portion of Experimental Hohlraum Fabrication System

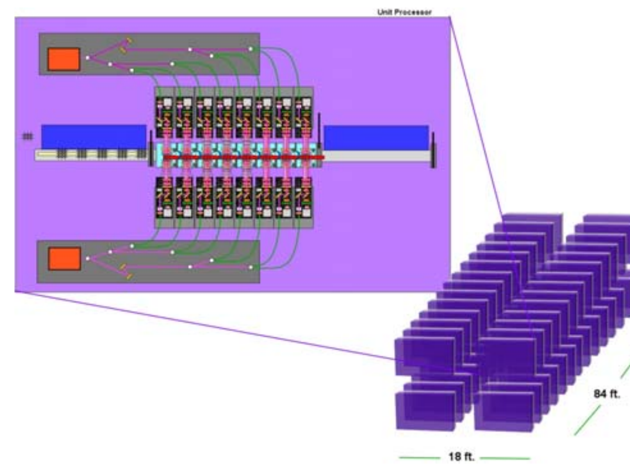


Figure 3. Concept development for Mass Production

Publications and Presentations

[1] A. M. Schwendt *et al.*, "Titium Inventory of Inertial Fusion Energy Target Fabrication Facilities: Effect of Foam Density and Consideration of Target Yield of Direct Drive Targets, *Fusion Science and Technology*, in press.

[2] A. Nobile *et al.,* "Tritium Inventory of IFE Target Fabrication Facilities", Presented at the Second IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers, June 17-19 2002.

[3] J. Maxwell *et al.*, "Synthesis of High Z Low Density Foams for Heavy Ion Fusion Hohlraums", Presented at the Second IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers, June 17-19 2002.

Progress in IFE Technology: June - August 2002 (Cont'd.)

Thick-Liquid Protection—University of California at Berkeley

P. F. Peterson, S. Pemberton, C. Debonnel, G. Fukuda, D. Olander

- UCB has been actively supporting chamber analysis for the HIF point design process now underway. Shown is the 9x9 beam arrangement that is emerging as from the design process, and recent TSUNAMI calculations showing venting through this 9x9 beam array.

- UCB completed extensive testing of it's cylindrical nozzle system to measure surface smoothness, and to study the effects of different flow-conditioning structures on pressure drop and smoothness. Shown here are 3 (out of 320) photos of a 9.0 m/s cylindrical jet at L/D = 27 and Re = 145,000. The standard deviation fluctuation of the top surface, compared to the radius, is 1.78 percent, and the bottom surface is 1.53 percent. This is small compared to the 10 percent value being used in the current HIF point design.

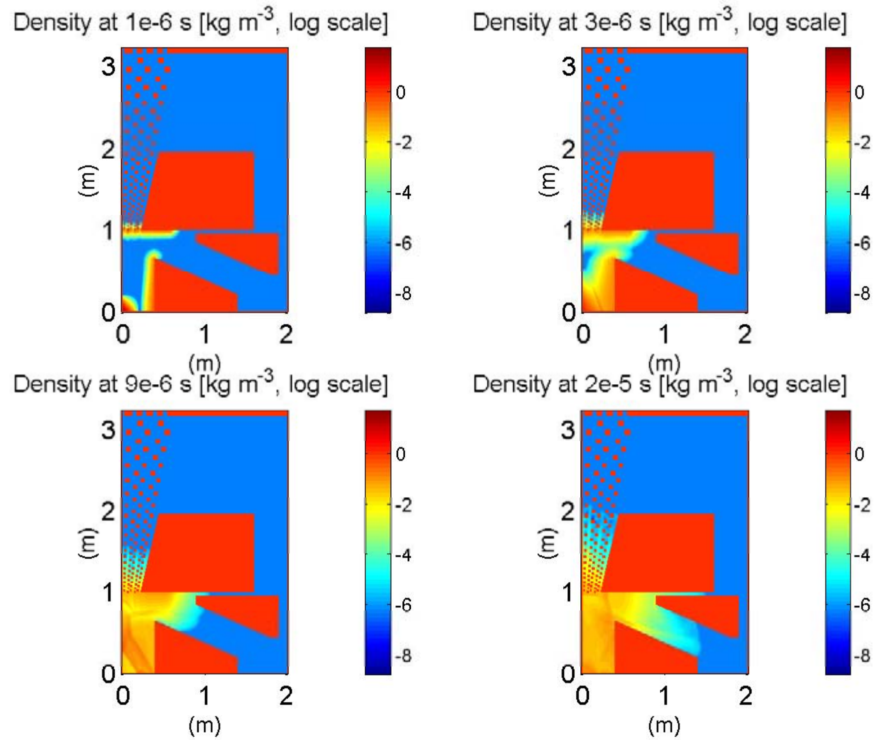


Figure 1. HIF Point Design Tsunami calculations

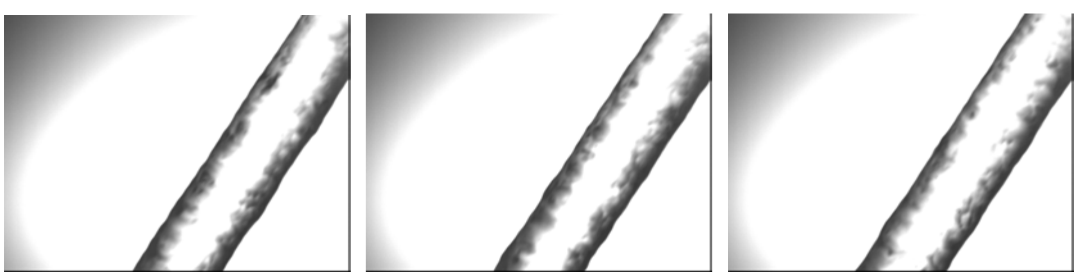


Figure 2. Three photos of the UCB cylindrical jet, used to obtain statistical information on jet smoothness