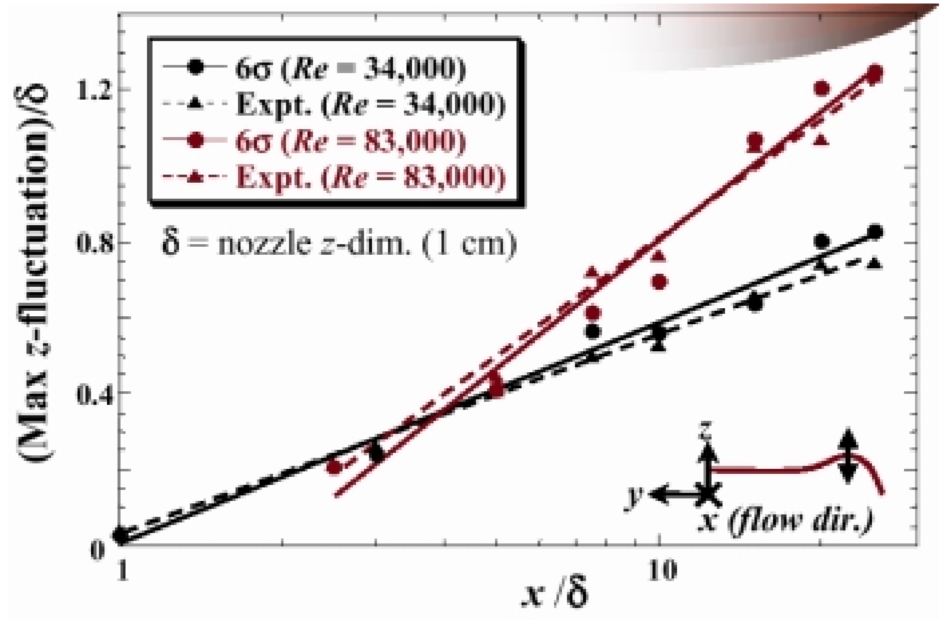
# ***Progress in Inertial Fusion Energy Technology: November 2000 – February 2001***

Compiled by J. F. Latkowski
Please direct comments and/or contributions to latkowski1@llnl.gov

**Thick-Liquid Protection:**

*J. A. Collins, D. Sadowski, M. Yoda and S. I. Abdel-Khalik*—Georgia Institute of Technology

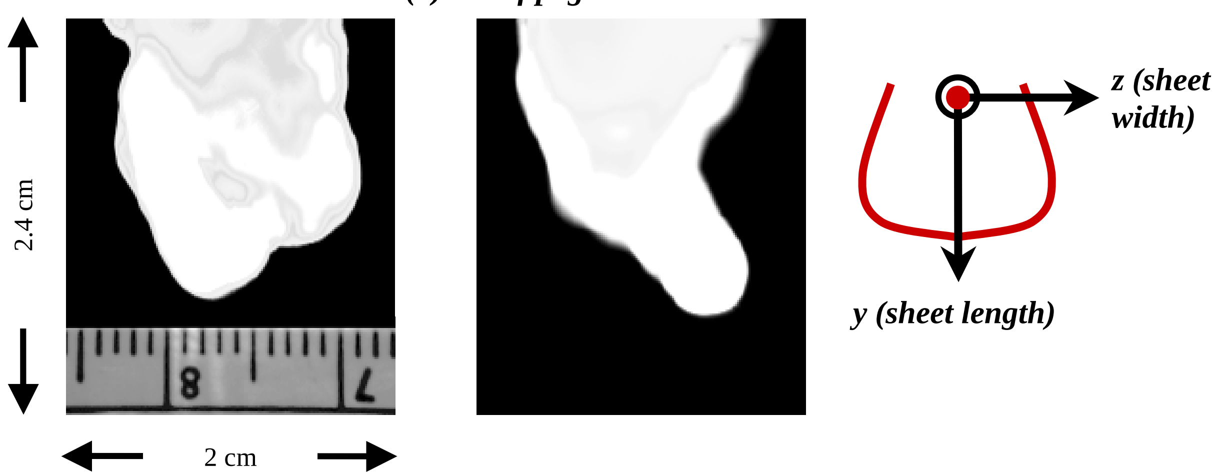
- Study of liquid sheets at Re > 80,000 and We > 8500:
  - Maximum surface ripple still grows logarithmically with downstream distance at 40% prototypical HYLIFE-II Reynolds numbers
  - Focus on corner regions of liquid sheets → regions with greatest surface ripple
  - Sheet stability strongly affected by initial conditions




*Experiment with Re = 84,000:*

- Two typical images of corner regions 25 cm (25δ) downstream of nozzle:
  - $\Delta t$ = 0.74 s
  - exposure = 0.4 ms
- Fluctuations at sheet edge up to 0.5 cm along *y* and *z*

***Flow direction (x) out of page***



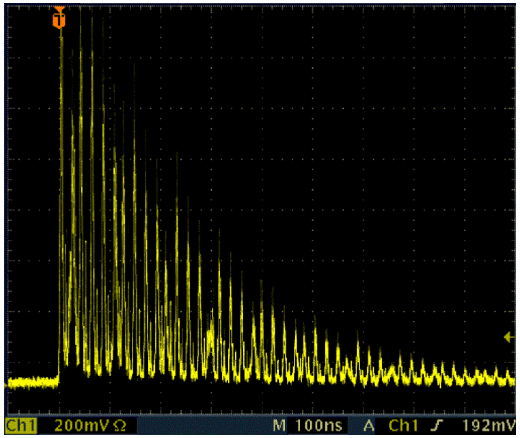
# Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)

**Laser Interactions and Final Optics Studies:**

*M. S. Tillack, F. Najmabadi, M. Zaghloul, T. K. Mau, X. Wang*—University of California, San Diego

- The ringdown reflectometer was assembled and tested. Detailed measurements are ongoing.
- Superpolished fused silica flats were obtained from Wave Precision Inc. (surface smoothness less than 2 Å, l/10 flatness) and sputter coated at General Atomics with 75 nm of Al. 1" round and 1.5x15 cm rectangles were fabricated from highly pure Al by diamond turning (to be compared with the Al-1100 mirrors previously tested).
- The 4-layer Fresnel model was used to examine the effect of impurity layers on coated Al mirrors.
- Modeling of beam scattering from rough surfaces is underway.
- Abstracts for papers on optics damage have been sent to IFSA and ICFRM.

One of the Al mirrors currently under examination




Example oscilloscope trace for the optical cavity reflectometer

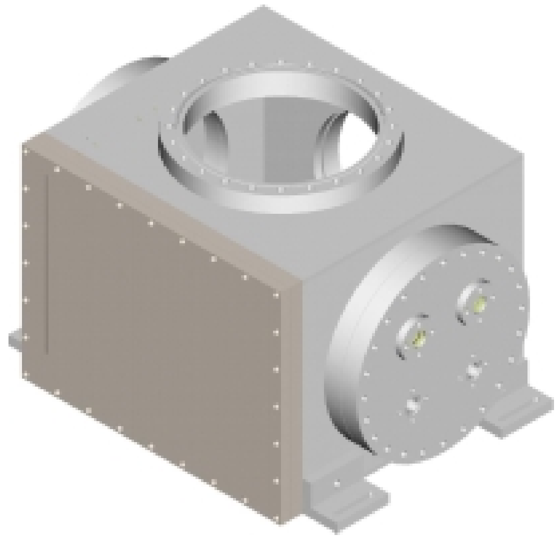
# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

**Laser Interactions and Final Optics Studies (Cont'd.):**

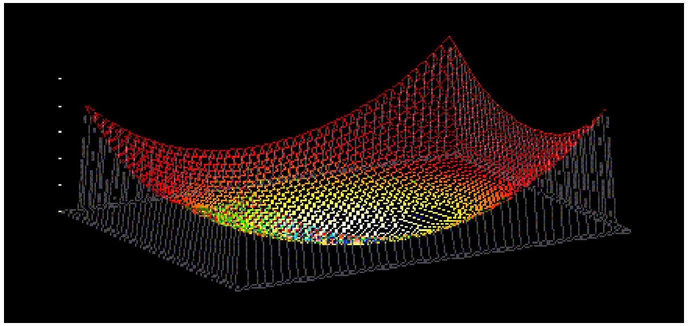
*M. S. Tillack, F. Najmabadi, M. Zaghloul, T. K. Mau, X. Wang*—University of California, San Diego

- The final design for the chamber physics vacuum chamber was completed and parts ordered. The design allows for interchangeable optical breadboards inserted through the side of the chamber. Interlocks and pneumatically-operated valves will be used to protect the turbopump.

- The Shack-Hartmann sensor was installed and used to characterize both the nanolaser and the 2-J YAG laser beams.



Final design of the vacuum chamber



Shack-Hartmann sensor: example wavefront emerging from a pinhole

**Publications and Presentations:**

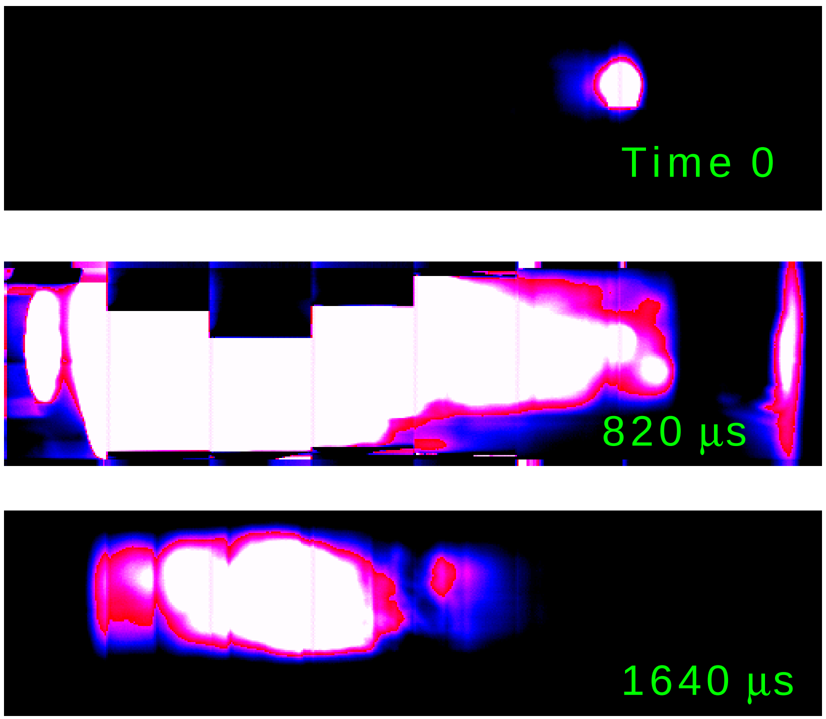
- NRL Laser-IFE Meeting (See: http://aries.ucsd.edu/MEETINGS/NRLworkshop/program.html), Feb. 6-7, 2001:
  - M. S. Tillack, "Laser Damage and Effects of Debris."
  - F. Najmabadi, R. Raffray, M. S. Tillack and A. Hassanein, "Chamber Dynamics and Clearing."
- T. K. Mau, "Laser Final Optics Analysis," ARIES Project Meeting, Dec. 5-6, 2000. See: http://aries.ucsd.edu/ARIES/DOCS/MINUTES/0012/
- Abstracts submitted to Second Int'l Conference on Inertial Fusion Sciences and Applications:
  - M. S. Tillack, S. A. Payne, and N. M. Ghoniem, "Damage threats and response of final optics for laser-fusion power plants." See: http://ashley.ucsd.edu/PUBLIC/IFSA2001/Tillack.html
  - N. M. Ghoniem and M. S. Tillack, "Theory and Measurements of Laser-Induced Damage of Reflective Metal Mirrors in IFE Environments." See: http://ashley.ucsd.edu/PUBLIC/ICFRM2001/Ghoniem.pdf

## Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)

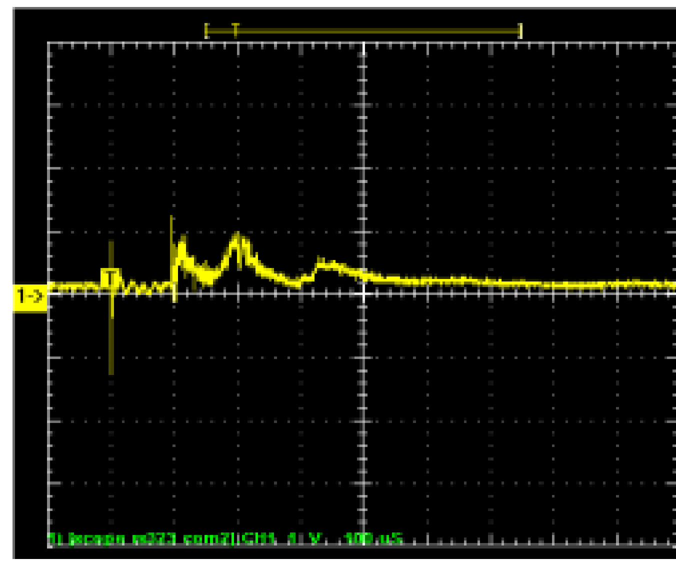
**Thick-Liquid Protection:**

*P. Calderoni, G. Turri (students), A. Y. Ying, T. Sketcheley, M. Abdou, and N. B. Morley*—University of California,Los Angeles

- Replaced spark gap with high-current ignitron switch for reliability and repeatability of discharge operations
- Obtained a 5.12 kJ discharge by charging a bank of capacitors (160 mF) to 8 kV, with a 24 kA current peak
- Collecting coupons placed inside the chamber to analyze composition of the ionized vapor jet




Colorized pictures of the glowing discharge with a fast acquisition digital camera. The black squares in the second frame are due to local saturation of the digital image that the software doesn't process. The acquisition is triggered together with the current switch. Each frame is exposed for 500 μs with 820 μs delay between each.



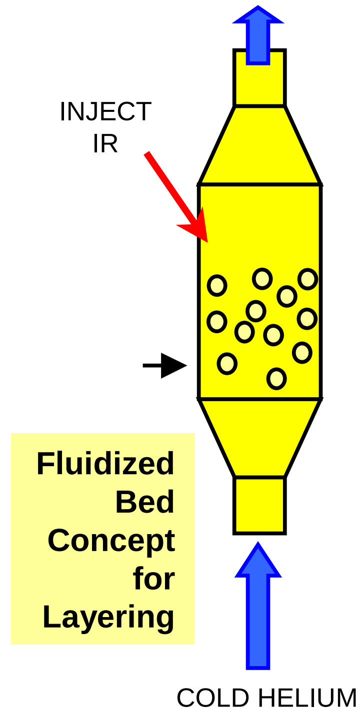
Oscilloscope trace of the pressure transducer reading. Time scale is 100 μs per division (1 ms overall) and 1V (= 10 psi) per division vertically, corresponding to a pressure peak of 0.69 bar.

# *Progress in IFE Technology: November 2000 – February 2001 (Cont’d.)*

## Target Fabrication, Injection and Tracking:

*D. Goodin, A. Nobile, N. Alexander, W. Steckle, A. Schwendt, and G. Besenbruch*—General Atomics and Los Alamos National Laboratory

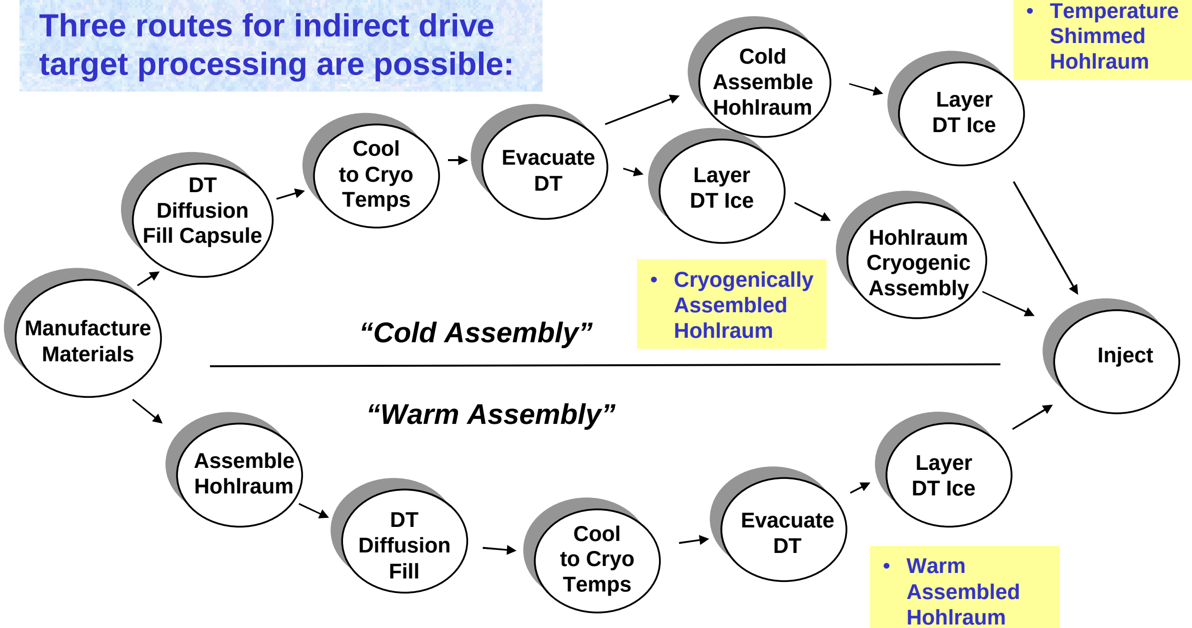
- Evaluated Target Fabrication Facility (TFF) tritium inventories for indirect drive target process flows; cryogenic assembly will be required to avoid high tritium inventories arising from hohlraum void volume
- Initiated thermal analyses of in-hohlraum layering; this method allows storage of final/prepared targets prior to injection - easing the time constraints on cryogenic assembly
- Developed concept for high-volume layering of IFE capsules using a cryogenic fluidized bed
- Prepared tungsten doped foam by incorporation of nanosized powder into the foam polymerization




### Publications and Presentations

- D.T. Goodin et al, “Developing Target Injection and Tracking for Inertial Fusion Energy Power Plants”, paper accepted for publication in *Nuclear Fusion*.
- “Update on Target Fabrication”, December ARIES Meeting, http://ashley.ucsd.edu/ARIES/DOCS/MINUTES/0012/
- “IFE Target Fabrication and Injection”, presented at the Third US/Japan Workshop on Laser Driven IFE, January 25-27, 2001 Livermore, California.
- Several presentations at the Laser IFE Program Workshop, February 6-7, 2001, Naval Research Laboratory.

**Three routes for indirect drive target processing are possible:**



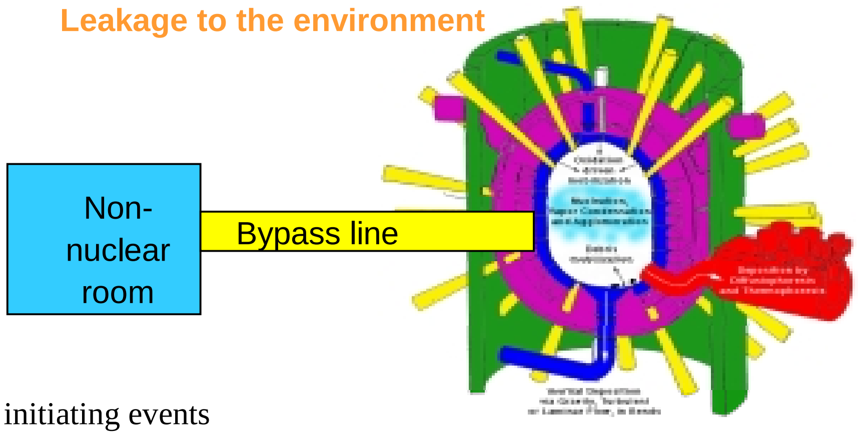

Undoped 30 mg/cc PS foam

2% W-doped 30 mg/cc PS foam

# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

## Safety and Environment:

*D. A. Petti, L. C. Cadwallader, B. J. Merrill and R. L. Moore*—Idaho National Engineering and Environmental Laboratory




- Minimization of radiological inventories through ES&H-conscious materials selection and careful design

- Implementation of radiological confinement in IFE systems recognizing the large number of penetrations in the chamber → contamination spread and confinement boundaries:
  - Spread of contamination up the beamlines?
  - Contamination "boundary" could be very large
  - Confinement buildings are subject to regular testing

- Identification of accident scenarios in IFE systems:
  - Master Logic Diagram being developed; will be used to identify initiating events
  - Hydrogen safety issues → deflagration and/or detonation

- Operational questions and issues:
  - If IFE targets require long fill times, plant start-up and recovery from forced outages may be difficult
  - Events such as loss of offsite power and loss of heat sink are relatively frequent events (0.1 to 0.01/year and 0.1/year, respectively)
  - Recycling of unusable targets (due to build-up of $^{3}He$) will carry an economic penalty
  - Effect and frequency of "rogue" (or dud) targets being explored

- Safety analysis of some of these events based existing designs (e.g., SOMBRERO, HYLIFE-II) → Effect of carbon whisker on LOVA analysis

- Waste management assessments of different configurations focusing on both volume and hazard of waste (e.g., final focus magnets

**Publications and Presentations:**

- D. Petti, "Status of ARIES-IFE Safety and Environmental Activities," Presented at the ARIES Project Meeting, Dec. 5-6, 2000. See: http://aries.ucsd.edu/ARIES/DOCS/MINUTES/0012/

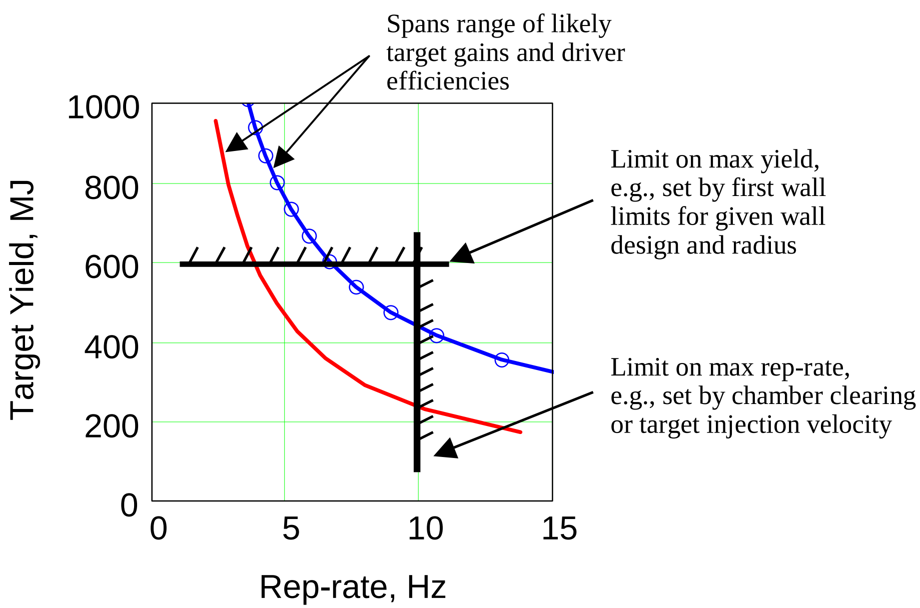
- D. Petti, "Fusion Safety and Technology Activities at the Idaho National Engineering & Environmental Laboratory," Presented at the University of California, Berkeley, Nov. 27, 2000.

# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

## Integration, Systems Studies, Safety & Environment and Driver-Chamber Interface:

***W. R. Meier, J. F. Latkowski, R. W. Moir, and S. Reyes***—Lawrence Livermore National Laboratory

- Elements evaluated for safety & environmental performance if used in IFE targets. Material assumed to be recycled on weekly basis:
  - Results summarized in table according to three criteria: (1) contact dose rates, (2) waste disposal ratings, and (3) accident dose
  - Future work to focus on derivation of contact dose rate limits that do not artificially restrict the ability to recycle target materials
- IFE systems codes have been used to identify operating windows as illustrated below for direct-drive, laser IFE.
- Safety assessments for a baseline target fabrication facility are ongoing.




*Illustrative example, actual constraints will depend on design details.

| Element | Code | Element | Code | Element | Code |
|---|---|---|---|---|---|
| Li | **P** | Be | **P** | B | **P** |
| C | **P** | N | W | O | **P** |
| F | **P** | Ne | **P** | Na | C |
| Mg | C | Al | CW | Si | P |
| P | **P** | S | **P** | Cl | W |
| Ar | W | K | W | Ca | W |
| Sc | C | Ti | C | V | C |
| Cr | C | Mn | C | Fe | C |
| Co | CA | Ni | CWA | Cu | C |
| Zn | C | Ga | **P** | Ge | C |
| As | C | Se | CW | Br | CWA |
| Kr | W | Rb | C | Sr | C |
| Y | C | Zr | C | Nb | CW |
| Mo | CW | Ru | CW | Rh | CW |
| Pd | CW | Ag | CW | Cd | CW |
| In | C | Sn | P | Sb | C |
| Te | CWA | I | C | Xe | C |
| Cs | C | Ba | C | La | **P** |
| Ce | C | Pr | **P** | Nd | C |
| Sm | CW | Eu | CWA | Gd | W |
| Tb | CW | Dy | W | Ho | W |
| Er | CW | Tm | CW | Yb | **P** |
| Lu | C | Hf | C | Ta | C |
| W | C | Re | CW | Os | CW |
| Ir | CW | Pt | W | Au | C |
| Hg | **P** | Tl | C | Pb | **P** |
| Bi | CW | | | | |

C = failed contact dose rate criterion (dose < 30 MGy for 30 years, continuous exposure);
W = failed waste management criterion (WDR < 1);
A = failed accident dose criterion (early dose < 5 mSv for 0.3% release);
**P** = passed all criteria.

### Publications and Presentations:

- ARIES Project Meeting, Dec. 5-6, 2000. See: http://aries.ucsd.edu/ARIES/DOCS/MINUTES/0012/
  - J. F. Latkowski et al., "Scoping Study Results of Safety and Environmental Attractiveness of Target Materials."
  - W. R. Meier, "Possible Operating Space for Laser IFE."
  - W. R. Meier, "Heavy Ion Driver Model Update."
- W. R. Meier, "Chamber Studies," Presented at the NRL Laser-IFE Meeting, Feb. 6-7, 2001.

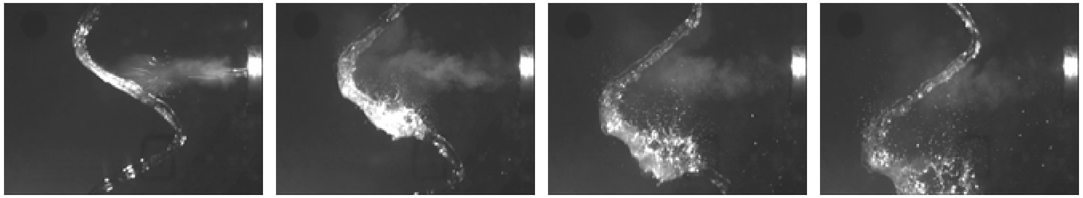
# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

## Thick-Liquid Protection:

*P. F. Peterson, S. Pemberton, C. Debonnel , C. Jantzen, R. Abbott*—University of California, Berkeley

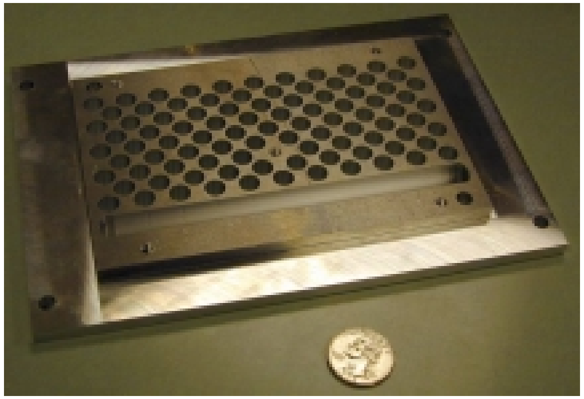
- Multiple disruptions of a single 10.3-Hz oscillating liquid jet have been performed in the Vacuum Hydraulics Experiment, confirming that multiple disruptions can be timed precisely. A multiple-jet nozzle block is nearing completion, so that studies of shock propagation through jet arrays can commence in April.

- A liquid vortex has been created using an extremely simple array of small holes drilled into the wall of a vortex tube. The holes inject flow tangential to the inside wall, at a 45° angle from the tube axis to give equal axial and aximuthal velocities. Excellent vortex quality was observed. Upcoming work will refine models for the layer thickness and design a slot system to extract the liquid at the tube ends (currently it exits as cone-shaped fans). The use of liquid vortexes around beams in the shielding structure for heavy-ion beam arrays can greatly improve the protection of final focus magnets.



Second of four disruptions of a 10.3 Hz single jet in vacuum shows droplets traveling downward away from clean jet forming above

First liquid vortex created for HI-IFE shielding conditions demonstrates a smooth vortex surface and layer thickness ~50% of tube radius



Multiple-jet nozzle block created with numerically controlled machining

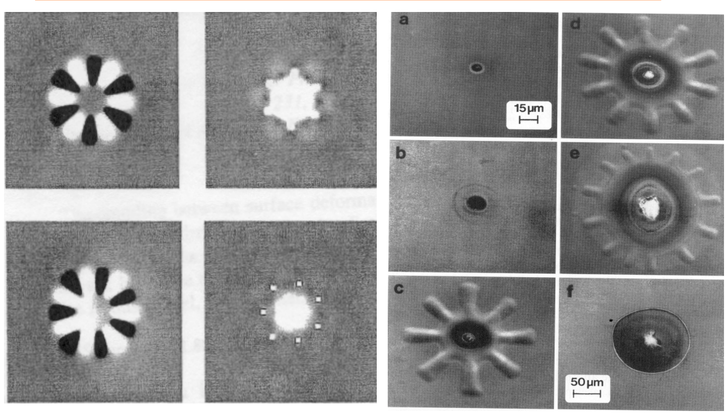
# Progress in IFE Technology: November 2000 – February 2001 (Cont’d.)

**Laser Damage to Optics:**

*N.M. Ghoniem, Z. Wang and Q. Hu*—University of California, Los Angeles (see: http://puma.seas.ucla.edu/web_pages/)

- Completed development of the surface roughening model by laser-induced deformation instabilities.
- Finished applications of the model to thin metallic coatings for both focused and uniform laser illumination.
- Laser-Induced Damage Threshold (LIDT):
  - Acquired and classified database on type of damage threshold.
  - Reviewed experimental set-up and aluminum damage results at UCSD.
- Participated in a mini-workshop on laser damage at UCSB with M. Tillack, F. Najmabadi, T. Mau (November 2000).
- Completed development of Dislocation Dynamics (DD) computer simulations for dislocation interaction with mirror surfaces.
- Continued international collaboration with Professor Daniel Walgraef (Free Univ. Brussles, Belgium) on extending the surface instability model to covalent materials.

**Focused Laser-induced Surface Deformation**




**Computer Simulation** **Experiment**

**Publications and Presentations:**

- D. Walgraef, N.M. Ghoniem, and J. Lauzeral, “Deformation Patterns in Thin Films Under Uniform Laser Irradiation,” *Phys. Rev. B*, **56, No. 23**: 15361-15377 (1997).
- Lauzeral, D. Walgraef, and N.M. Ghoniem, “Rose Deformation Patterns in Thin films Irradiated By Focused Laser Beams,” *Phys. Rev. Lett.* **79, No. 14**: 2706-2709 (1997).
- L. J. Perkins, B. G. Logan, M.D. Rosen, M.D. Perry, T. Diaz de la Rubia, N.M. Ghoniem, T. Ditmire, S.Wilkes and P.T.Springer, "The Investigation of High-Intensity-Laser Driven Micro Neutron Sources for Fusion Materials Applications at High Fluence", *Nuclear Fusion*, (2000).
- N.M. Ghoniem and J. Huang, « Computer Simulations of Mesoscopic Plastic Deformation with Differential Geometric Forms for the Elastic Field of Parametric Dislocations : Review of Recent Progress, » Fifth Euroconference on the Mechanics of Materials, Delft, Nethrlands, March 5-9, 2001. Invited paper to be published in *J. de Physique*.
- N.M. Ghoniem, « Laser Effects on IFE Final Optics, » Presentation at the Naval Research Laboratory (NRL), Feb. 6, 2001.

# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

**Gas Dynamics, X-Ray Ablation and ARIES-IFE:**

***R. R. Peterson, G. L. Kulcinski, D. A. Haynes, and L. El-Guebaly***—University of Wisconsin-Madison

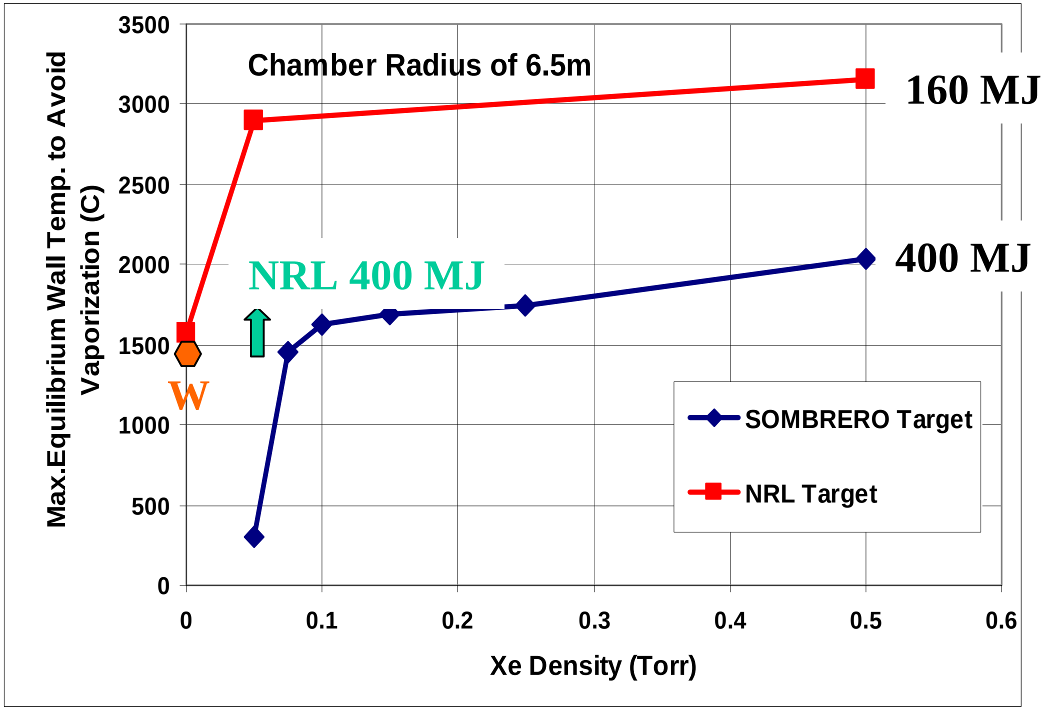
- The thermonuclear burn in the BUCKY computer code is being compared with calculations by Fraley in the 1970's and recent results with the LILAC code at the University of Rochester for some idealized problems. This has already lead to changes that will have some impact on target out put calculations with BUCKY.

- BUCKY calculations have been performed for Z experiments that are designed to study the generation of debris ions in hot plasmas. The work is relevant to IFE target output.

- A series of BUCKY calculations have been performed of the response of a 6.5 m radius graphite wall to the explosions of SOMBRERO and NRL targets. Time-of-flight dispersion of debris ions is important, especially for low gas density.

- The gas density and equilibrium wall temperature have been varied to find the highest wall temperature that avoids vaporization at a given gas density.

- Activation of target debris on the chamber wall has been considered.




**Publications and Presentations:**

- ARIES Project Meeting, Dec. 5-6, 2000. See: http://aries.ucsd.edu/ARIES/DOCS/MINUTES/0012/:
  - D. A. Haynes, "Parametric Results from Gas-Filled Chamber Analysis."
  - L. El-Guebaly, "Chamber Nuclear Performance."
  - L. El-Guebaly, "Activation Analysis for Gold Coating/Hohlraum."
- G. L. Kulcinski, R. R. Peterson, and D. A. Haynes, "Dry-Wall Target Chambers for Direct-Drive Laser Fusion," Presented at the NRL Laser-IFE Meeting, Feb. 6-7, 2001.

# *Progress in IFE Technology: November 2000 – February 2001 (Cont'd.)*

**Materials Irradiation Experiments:**

*L. Snead*—Oak Ridge National Laboratory

- Mapping Elevated Temperature Swelling (METS) Experiment:
  - Purpose: There is currently no high temperature irradiation data on the high quality graphite composites being considered for laser IFE. This experimental program will yield data on swelling and thermal conductivity following neutron irradiation to high temperature and neutron fluence.
  - Materials

| Materials | Kth(@RT) | Kth(1000°C) |
|---|---|---|
| Mitsubishi Kasei MKC 1PH (unidirectional CFC) | >700 | ~250 |
| Fiber Material Inc. FMI-222 (balanced CFC) | >450 | ~220 |

  - Irradiation in HFIR Core Region:

| Irradiation in HFIR Core Region: | | Temperature (C) | Dose (dpa) |
|---|---|---|---|
| MET S-1 Capsule | 9 zones in range of | 600-1500 | 2 |
| MET S-2 Capsule | " | 600-1500 | 4 |
| MET S-3 Capsule | " | 600-1500 | 10 |

- Status:
  - All pre-irradiation measurements completed.
  - Capsules fabricated and awaiting irradiation in HFIR.
  - Irradiation planned to begin this FY. Duration 1, 2, and ~7 months.
  - Post-irradiation examination to include thermal conductivity and swelling.