Progress in Inertial Fusion Energy Technology: February – May 2003

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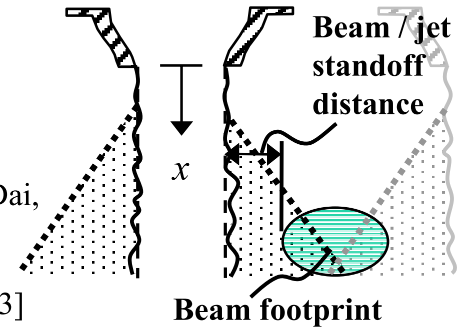
Progress in IFE Technology: February - May 2003

Thick-Liquid Protection — Georgia Institute of Technology

S.G. Durbin, M. Yoda, S.I. Abdel-Khalik



Tasks accomplished:

- Quantified rate of droplet formation due to hydrodynamics (turbulent breakup)
  - Mass collection experiments at *Re* = 130,000
  - Compare with empirical correlations from literature for round and annular jets [Sallam, Dai, and Faeth 2002]
- Design and fabricate liquid sheets nozzle with boundary layer cutting
  - Drastically reduces droplet formation in round jets [Wu *et al.* 1995; Pemberton *et al.* 2003]

Empirical predictions:

- Without adequate flow conditioning, empirical correlations indicates up to 3% of flow would be ejected as droplets in RPD.
  - Correlation based on fully developed turbulent flow at exit (*i.e.*, no flow conditioning, contraction/nozzle, or BL cutting)
- Droplets travel beyond beam / jet standoff distance
  - Typical RPD-2002 jet with dia. d = 4.61cm shown in Fig. 1

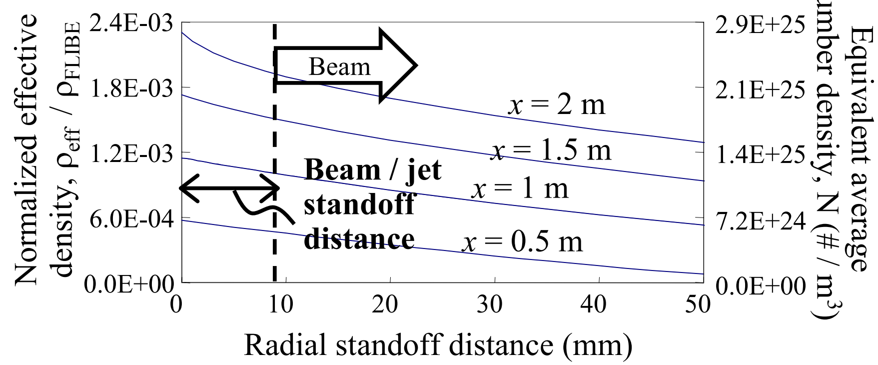


Figure 1. Empirical droplet density predictions

Droplet collection (Fig. 2):

- Mass flux of droplets measured for *Re* = 130,000, *We* = 19,000
  - Function of x and cuvette standoff distance, Δz_s
  - Standoff distance normalized by local standard deviation, $\sigma_z(x)$
  - Significant increase in mass flux below ~$9\sigma_z(x)$
- Measurements give 10^3–10^5 times lower droplet flux than predictions
  - Flow conditioning and contracting nozzle have significant impact
  - Try BL cutting next to reduce droplets further

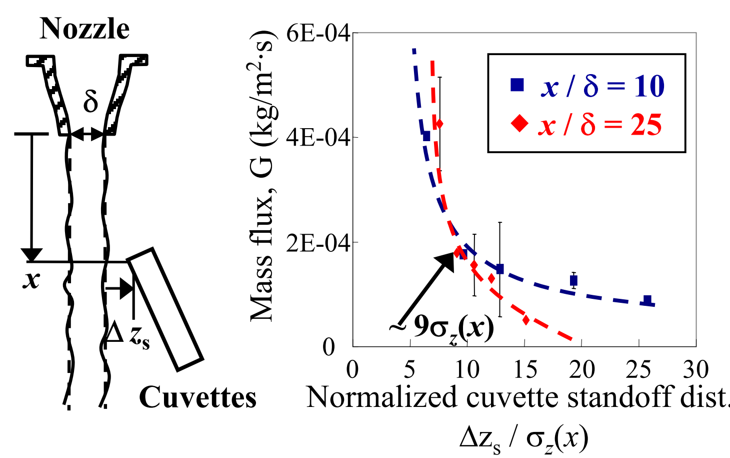


Figure 2. Droplet collection vs. cuvette stand-off distance

Publications and Presentations

[1] S.I. Abdel-Khalik, S.G. Durbin, and M. Yoda (2003) "Chamber clearing: The hydrodynamic source term", ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.

[2] S.G. Durbin, M. Yoda, S.I. Abdel-Khalik and D. L. Sadowski (2003) "Turbulent liquid sheets for protecting IFE reactor chamber first walls," to appear in *Fusion Science and Technology.*

Progress in IFE Technology: February - May 2003 (Cont'd.)

IFE Chamber Dynamics Modeling and Experiments— University of California, San Diego (http://aries.ucsd.edu/IFE)
M. S. Tillack, F. Najmabadi, A. R. Raffray, S. S. Harilal, C. V. Bindhu, A. C. Gaeris, M. R. Zaghloul, D. Blair, J. O'Shay, K. Sequoia

- Magnetic diversion studies have been extended to include axial fields (see Figure 1). Plume collimation and jet-like behavior are observed along the field direction. We are exploring techniques to obtain high field strength in a cusp configuration.
- A soft x-ray diagnostic is currently under development to help measure the early time (≤ 50 ns) behavior of the expanding plasma "fireball." Fast x-ray photodiodes combined with aluminum thin film filters will allow us to deduce the radiation spectrum of the plasma and infer its temperature as a function of time.
- We have started the design of an in-situ, time-resolved diagnostic for measuring the size and velocity of sub-micron aerosol ejected from liquid surfaces due to pulsed energy deposition. Design and fabrication of a new vacuum chamber has begun.
- Several publications are in preparation or have been submitted. A journal article on laser propagation was submitted to Journal of Physics B. Articles are in preparation on condensation physics and magnetic diversion. A PhD was awarded to D. Blair for his work entitled: "Mechanisms of particulate formation in laser ablation plumes". That work demonstrated the dominant effect of ionization on condensation in ablation plumes (see Figure 2).

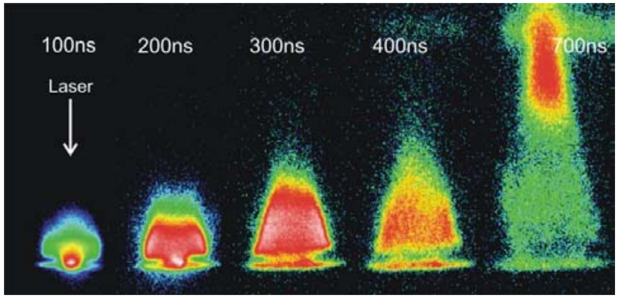
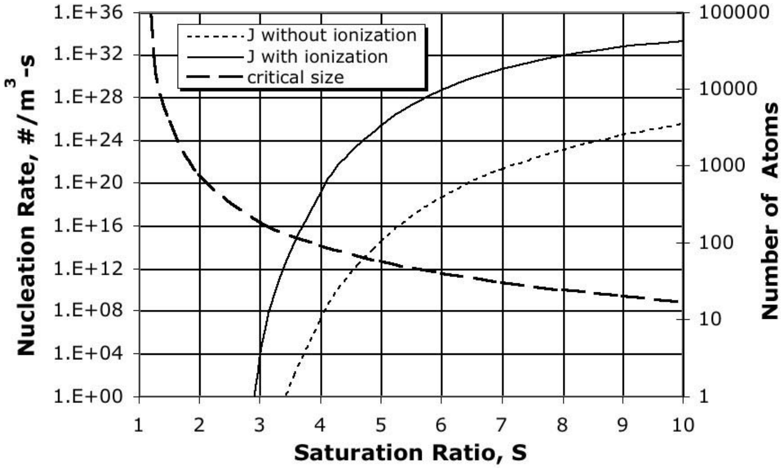


Figure 1. Images of ablation plume expansion along the magnetic field

Figure 2. Homogeneous nucleation rate for Si at 2000 K and $n=10^{20}/cm^3$ compared with the same conditions but including ionization fraction of 1%



Publications and Presentations

[1] Xueren Wang, Mark Tillack and S. S. Harilal, "2-D Magnetic Circuit Analysis for a Permanent Magnet Used in Laser Ablation Plume Expansion Experiments," UCSD-LPLM-02-04 December 5, 2002.

[2] C. V. Bindhu, S. S. Harilal, M. S. Tillack , F. Najmabadi, and A. C. Gaeris, "Energy Absorption and Propagation in Laser Created Sparks," submitted to Journal of Physics B.

[3] D. Blair, "Mechanisms of particulate formation in laser ablation plumes," UCSD PhD thesis, May 2003.

[4] M. S. Tillack, "The effect of ionization on condensation in ablation plumes," ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.

[5] A. R. Raffray and M. R. Zaghloul, "Liquid wall ablation under IFE photon energy deposition," ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.

Progress in IFE Technology: February - May 2003 (Cont'd.)

IFE Liquid Wall Chamber Dynamics / High Z equation of state and opacities for PbLi – University of Wisconsin – Madison

J. Yuan, G. A. Moses, Z. Gui, D. A. Haynes and G. L. Kulcinski

- Using the RSSUTA parallel code running on our 32-nodes linux cluster and JATBASE, we have completed calculations of equation of state and opacity tables for several high Z materials including Ge, Nb, W, Pb and U.

- Validation of our atomic data has been carried out further by comparing our results with the Busquet method. Assuming steady and using the average rate coefficients, the non-LTE equation that determines the densities of the charge states are solved to calculate the non-LTE high-Z opacities.

- Efforts continue for the database development in order to collect the massive atomic data generated from the code and also for the graphical user interface development. In parallel with JATBASE development, a web database is under construction aiming to provide easy access to our available atomic data. It is designed to accumulate our calculated data into a central data store which is for our future use or for other research groups if they desire.

- A suit of codes including the graphical user interface and underlying atomic data computing package ("Visual Opacity") is under heavy development. The goal is to provide a flexible, graphical user interface for spectroscopy analysis and opacity calculations. Visual Opacity uses the powerful HDF (High performance Data Format) data format. The VisAD package(a Java component library) is used for interactive and collaborative visualization and analysis of numerical data. The atomic physics model in Visual Opacity is the relativistic configuration-interaction Hartree-Fock model. The work done for this year includes the electron configuration selection, the configuration state function generation for all elements up to uranium, the self-consistent potential calculations and the fine energy structure calculations.

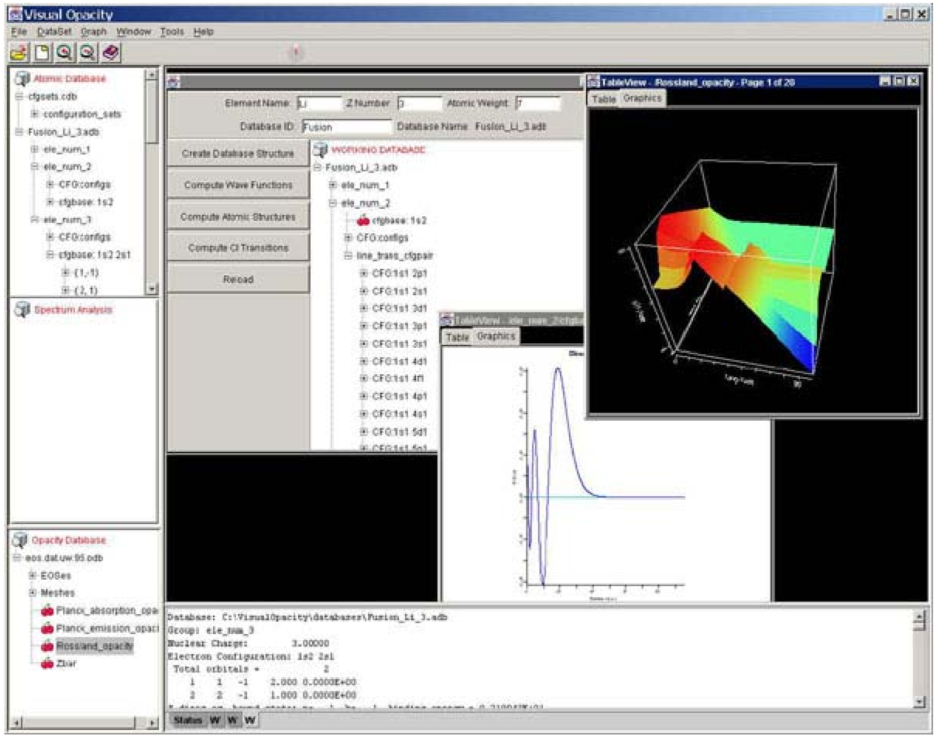


Figure 1. A sample screenshot of Visual Opacity which displays the electronic wave function and the opacities.

Publications and Presentations:

[1] J. Yuan, D.A. Haynes, R.R. Peterson and G. A. Moses, "Flexible Database-driven Opacity and Spectrum Calculations," accepted by Journal of Quan. Spect. & Rad. Trans, Sept. 16, 2002

[2] J. Yuan, G. Rochau and G.A. Moses, "A Graphical Tool for Computing Opacities for ICF Applications," accepted by International Journal of Modeling and Simulation, vol. 23 No. 4, 2003.

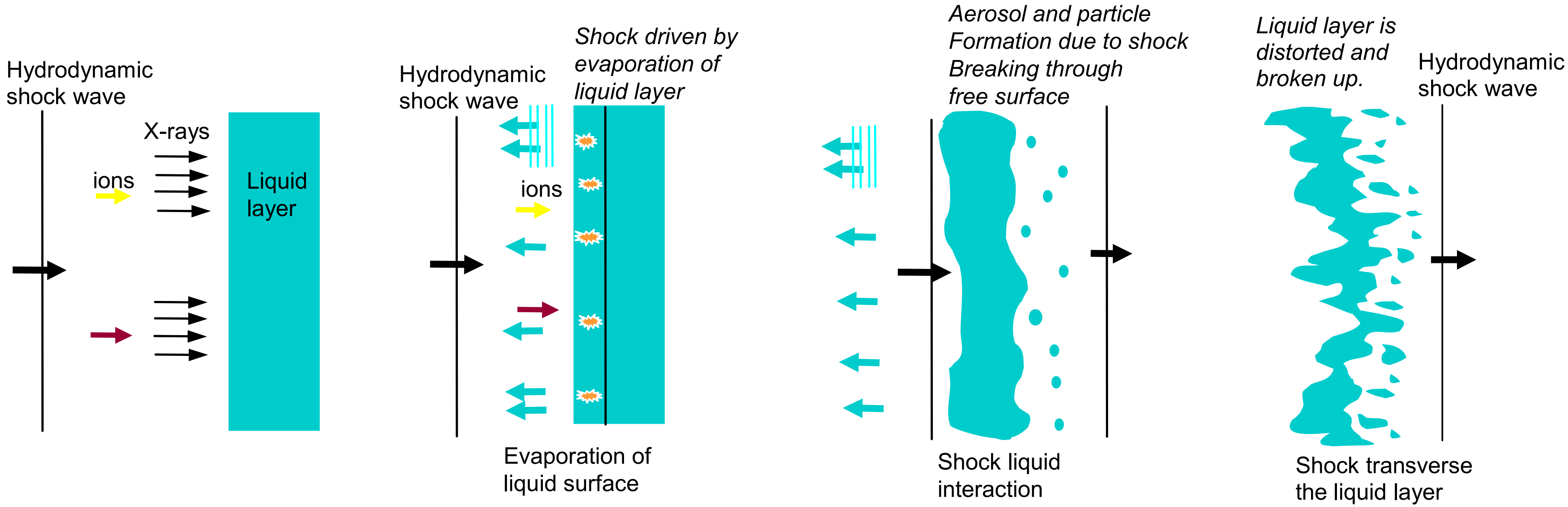
[3] J. Yuan, G.A. Moses, Z. Gui, "Web Accessibility to the Atomic Database Computing System," presented in the APS meeting, Nov. 6, 2002.

Progress in IFE Technology: February - May 2003 (Cont'd.)

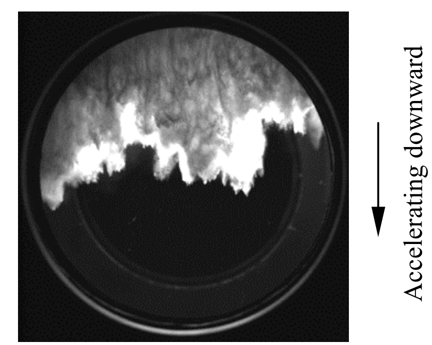
Liquid Layer Protection — University of Wisconsin – Madison

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

Hydrodynamic shocks will keep reverberating inside the reactor chamber long after the other disturbances have died out. A large vertical shock tube is used to study shock-liquid layer interactions at this time scale. Below is a schematic representation of the sequence events that occur after target ignition.



After X-rays and high energy particles interact with the liquid layer (causing an ablation front possibly resulting in a shock front propagating through the liquid layer), a hydrodynamic shock consequent to the initial target chamber ambient pressure will reach the liquid layer and cause further distortion and break-up. Our work is focused on the effects that a planar shock wave has on an initially flat, stationary liquid layer. The photograph on the right shows a cross-sectional image of the distortion and break-up of the back surface of a water layer struck on its front surface by an M=2.14 shock wave. We plan to quantify the break-up of the layer using a array of photodiodes.



Publications and Presentations:

[1] P. Meekunnasombat, J. Oakley, M. Anderson and R. Bonazza, "Experimental Investigation of A Shock-accelerated Liquid Layer with Imaging and Pressure Measurement," presented at the 15th Topical Meeting on the Technology of Fusion Energy, Washington DC, November 2002.

[2] R. Bonazza, J. Oakley, M. Anderson, P. Meekunnasombat, S. Wang, P. Brooks, "Experimental Hydrodynamics Model for First Wall Protection in IFE Reactors," presented at the High Average Power Lasers Meeting, General Atomics, La Jolla CA, April 2002.

Progress in IFE Technology: February - May 2003 (Cont'd.)

Target Fabrication, Injection, and Tracking – GA/LANL

D. Goodin, A. Nobile, R. Petzoldt, B. Vermillion, G. Besenbruch, James Maxwell, John Sheliak, and Jim Hoffer

- Diagnostic systems for target injection were brought online, including target profile at exit of barrel and gas pressure at various points in the system; designs were prepared for a rifled barrel for indirect-drive targets to be added to the target injection and tracking system.
- DT layering experiments at LANL have shown smoother DT ice surface with a foam underlay, using native beta-layering
- Studies of DT cooldown to 16K have shown the capability to retain a smooth DT ice surface to 16K - providing higher DT strength for injection
- We hosted the US/Japan Workshop on Target Fabrication and Injection at GA, with attendees and presentations from GA, Schafer, LANL, UCSD, and several institutions in Japan

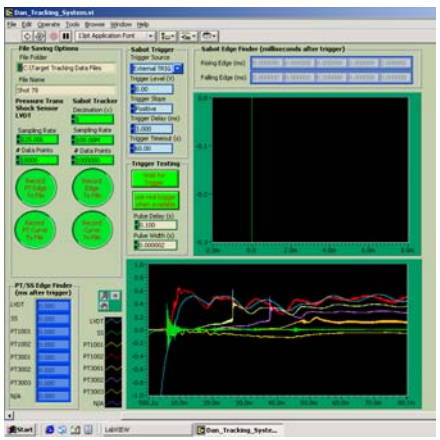


Figure 1. Example operator's screen for target injection diagnostics

Figure 2. Target injection and tracking system is undergoing shakedown testing

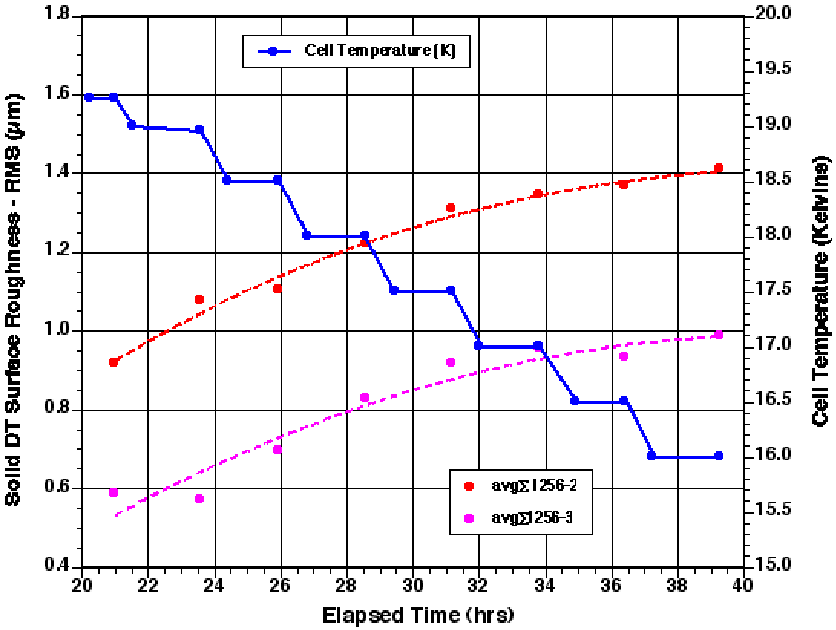


Figure 3. Measurements of DT ice surface finish during stepped cooldown to 16K

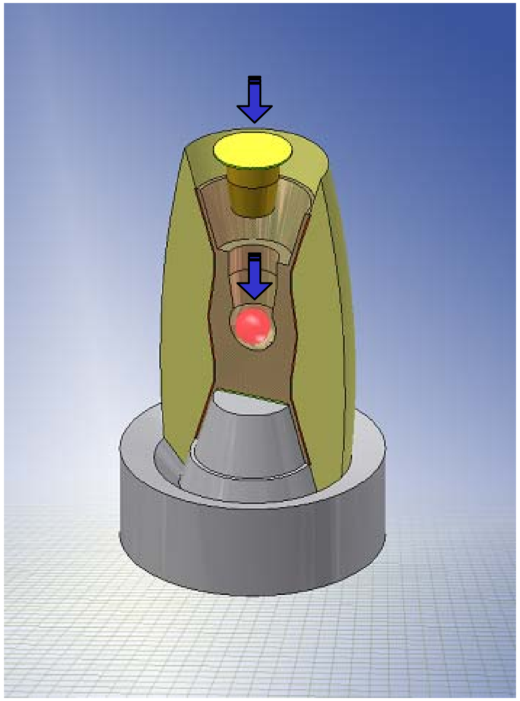
Publications and Presentations

[1] US/Japan Workshop/Osaka, Dan Goodin, "Overview of IFE Target Activities in the US" and "Summary of Target Fabrication and Injection Workshop"

[2] ARIES, Ron Petzoldt, "Summary of Target Factory Labor Assumptions and Mitigation of Target Assembly Step Failure", "Target Materials Selection and Constraints on Material Selections"

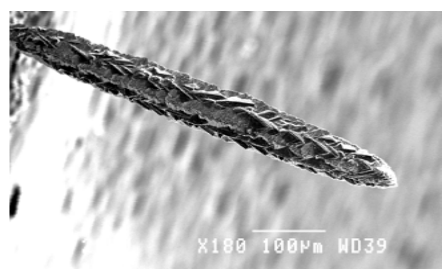
Hohlraum materials research– LANL/GA

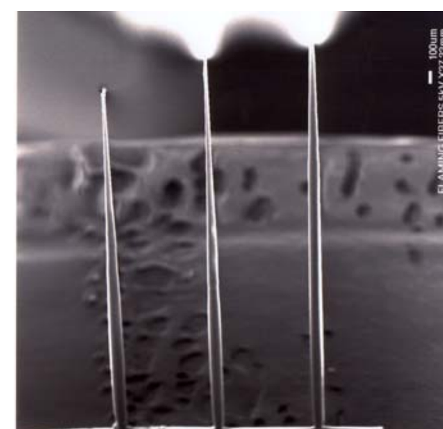
J. Maxwell, A. Nobile, D. Goodin



- **Quarterly Progress:**
  - Conceived New Concept for Integrated Manufacturing of Hohlraums
  - Demonstrated the growth of Boron and Carbon Fibers—and the sequential growth of fiber arrays (useful for some low-density hohlraum regions)
  - Put together a 2nd Laser CVD apparatus to speed progress in High-Z hohlraum Development, Installed Ti:Sapphire Laser
  - Developed a New Concept for Depositing Tungsten Alloys, at low temperatures: "Field-emission, High-Pressure Discharge, Laser Chemical Vapor Deposition."

- **Current Work**
  - Growth of Tungsten Fibers, Optimizing Growth, and Progressing to Tungsten-Alloys
  - Testing New "Glass Vial" Chamber for Tungsten Alloy Experiments





Progress in IFE Technology: September 2002 - January 2003 (Cont'd.)

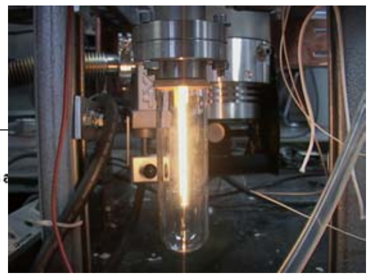
Vapor Dynamics and Condensation and Free Surface Flow Studies - University of California, Los Angeles

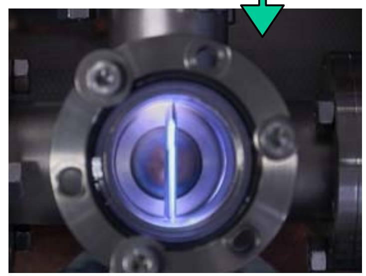
M. Abdou, A. Ying, P. Calderoni, T. Sketchley, N. Morley, A. Konkachbaev, A. Elias, M. Ni

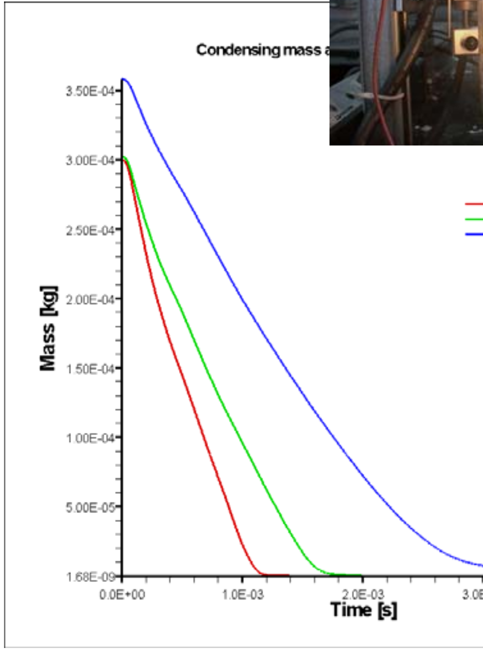
Experimental effort:

- Continued the investigation of lithium fluoride vapor condensation. Eliminate the presence of non-condensable impurities in the excited vapor - independent initial bakeout procedure and air-lock system designed for the source and the chamber
- Development of a spectroscopic diagnostic system for late stages of condensation (low pressure). Testing an electrical arc mechanism to locally re-excite the condensing vapors for density (or temperature-TBD) and chemical composition measurement

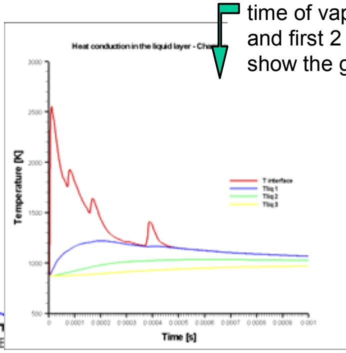
Test of the vacuum heating system developed to bake in situ the LiF material before ablation





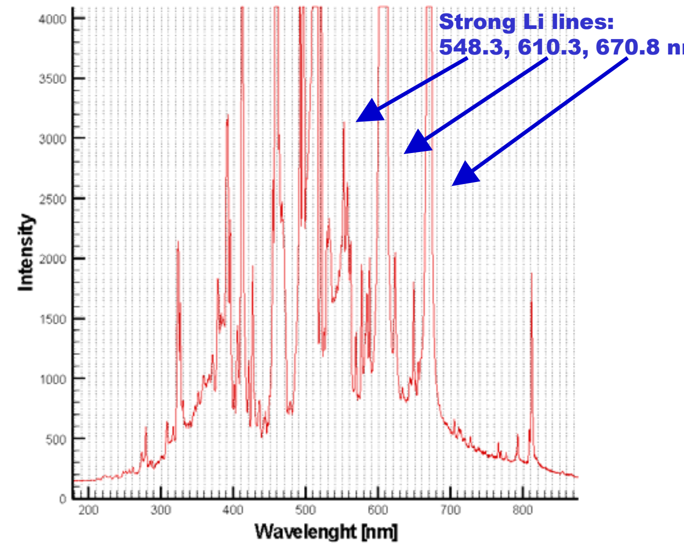


Condensing mass as a function of time for different wall temperature



Temperature distribution as a function of time of vapor and liquid at the interface and first 2 cells of the liquid layer to show the generalized module capability

LiF excited vapor emission spectroscopy



Other dominant lines are copper ions emission from triggering wire vaporization and electrodes sputtering - Low excitation potential of Li (and Be) atoms results in clear signature well suited for spectroscopy

Modeling:

- Generalized condensation boundary condition module to account for heat conduction in the liquid layer on the chamber wall - Performed Tsunami simulations of flibe condensation for comparison with experimental results
- Begin the analysis of vapor condensation enhancement by droplet spray - The goal is to develop a free surface incompressible heat and mass transfer module that accounts for mixing inside the droplet to couple with a gas dynamics code, such as Tsunami - the software program Truchas developed at LANL to simulate solidification manufacturing processes for phase change is being used

Publications and Presentations:

[1] P. Calderoni, "Experimental Study of Flibe Vapor Condensation," ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.

[2] P. Calderoni, "Modeling Effort on Chamber Clearing for IFE Liquid Chambers at UCLA," ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.

Progress in IFE Technology: February - May 2003 (Cont'd.)

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

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

- LLNL and the ARIES-IFE project hosted a meeting on liquid wall chamber dynamics. Presentations were given on all aspects of the problem including threats from the target, constraints on target injection and beam focusing, vaporization, aerosol and drop formation, condensation, response of the liquid to vapor and neutron induced shocks, and reforming the liquid protection. Current efforts on modeling various aspects of the problem and experiments to address the key issues were discussed. The talks are posted online at http://aries.ucsd.edu/ARIES/MEETINGS/ under the listing for the Town Meeting.

- Assessed the use of the LLNL's ABLATOR code as a predictive capability to assess liquid wall response to x-ray emission from IFE targets. Debugged the code and generated an enhanced version with useful features for IFE modeling (added new materials to data base, implemented IFE target spectra, generated multi-material version of the code)

- Benchmarking of ABLATOR against UCB's TSUNAMI flibe calculations, resulted in good agreement between the two codes (see Table I).

- Developed a parametric CAD model of the RPD-2002 target chamber demonstrating new capabilities for periodic replacement of internal components (Figure 1)

- This model will be used as a flexible platform for future target chamber mechanical design updates.

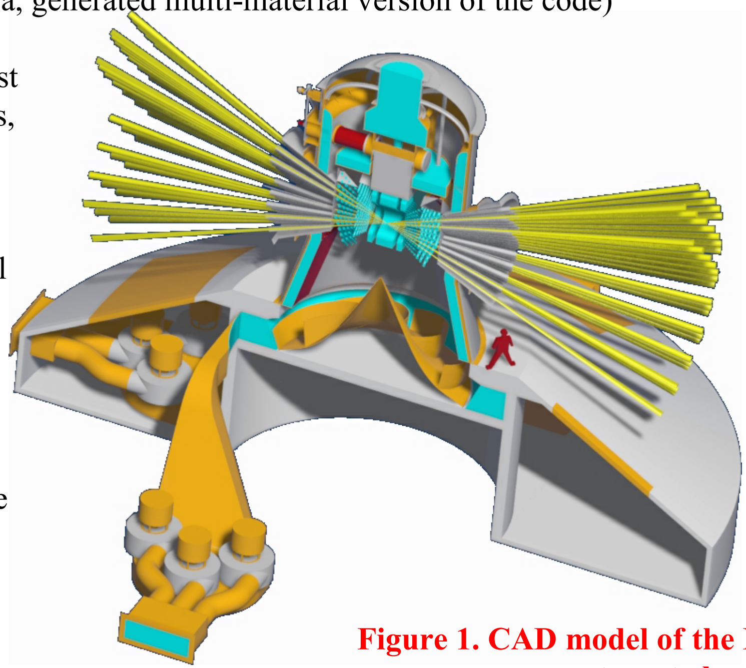


Figure 1. CAD model of the HYLIFE-II RPD-2002 target chamber

Fluence (J/cm2)	Thickness vaporized: Tsunami (microns)	Thickness vaporized: Ablator (microns)
1	0.19	0.15
2	0.24	0.20
5	0.30	0.27
10	0.35	0.32
20	0.40	0.37
30	0.43	0.40

Table 1. Estimation of vaporized flibe thickness in a 40 ns pulse at normal incidence for a single 113 eV line

Publications and Presentations

[1] S. Reyes, "ABLATOR modeling of X-ray Effects on Liquid Walls," ARIES Town Meeting on Liquid Wall Chamber Dynamics, May 5-6, 2003.
[2] R. Abbott, "Conceptual Design for HYLIFE Maintenance," ARIES meeting, Livermore, CA, May 6, 2003.
[3] R. Moir, "A "PCA" Version of 304 SS for HYLIFE," ARIES meeting, Livermore, CA, May 6, 2003.
[4] J. Latkowski, "Waste Disposal Assessment for the Final Focusing Magnets in the RPD-2002," ARIES meeting, Livermore, CA, May 6, 2003.
[5] W. Meier, "Application of Inertial Fusion to Energy Production," Seminar at LLNL.

Progress in IFE Technology: February - May 2003 (Cont'd.)

Thick-Liquid Protection—University of California at Berkeley

P. F. Peterson, J. Freeman, P. Bardet, C. Debonnel, G. Fukuda, D. Olander

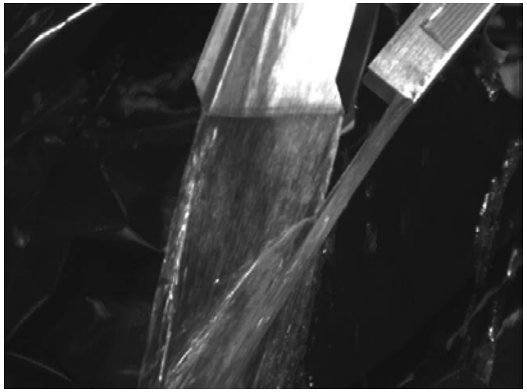


Figure 1. Two sheet jets collide, creating "rooster-tail"

- UCB continued its study of the fluid dynamics of colliding liquid jets. Currently, each of the jet types (cylindrical, sheet, slab, vortex) required to create HYLIFE-type thick-liquid pockets has been generated in scaled experiments, so the most important fluid mechanics issues relate to the subsequent interactions of multiple jets during collisions. Figure 1 shows to turbulent sheet jets exiting from inclined troughs. These experiments confirmed the Bernoulli model for jet collisions, which was shown to predict, within experimental uncertainty, the shape of the "rooster tail" created by the collision.

- A key issue for thick-liquid chamber protection is the reliability of nozzle and other components operating with high-temperature flibe or flinabe. Testing for reliability will require a high-velocity molten salt flow loop. Because the beryllium in flibe creates laboratory safety issues, UCB has been investigating surrogate salt mixtures. Analysis for the solubility of key structural materials has been done for zirconium-based (Figure 2 shows silicon solubility, a component of some advanced composites) showing that zirconium based salts would be more aggressive, making experiments with zirconium conservative in predicting performance with flibe. A natural-circulation zirconium salt test loop is already operating at ORNL.

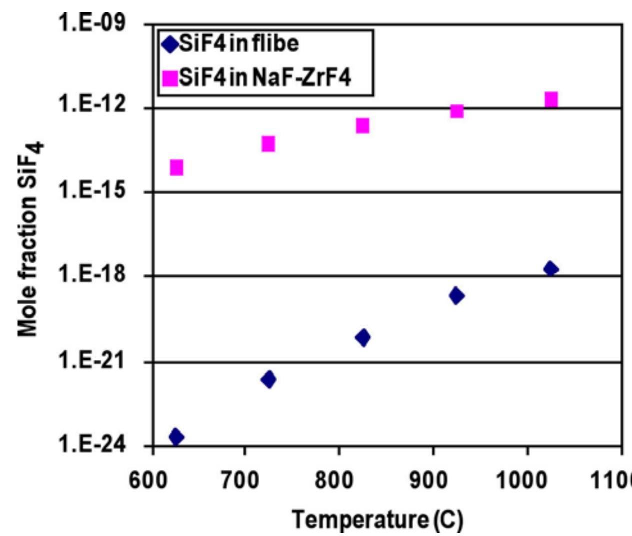


Figure 2. Silicon solubility in flibe and NaF-ZrF_4

Publications and Presentations

[1] W. Meier, D. Callahan, J. Barnard, J. Latkowski, S. Yu, and P.F. Peterson, "Updated Point Design for a Heavy-Ion-Driven, IFE Power Plant," *Fusion Science and Technology*, in press.

[2] S. Pemberton, R. Abbott, and P.F. Peterson, "Thick-liquid blanket configuration and response for the heavy-ion point design," *Fusion Science and Technology*, in press.

[3] C. Debonnel, G. Fukuda, P.F. Peterson, and S. Yu, "X-ray ablation and debris venting for the heavy-ion point design," *Fusion Science and Technology*, in press.