Progress in Inertial Fusion Energy Technology: February – May 2003
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 \((i.e., \text{no flow conditioning, contraction/nozzle, or BL cutting})\)
• Droplets travel beyond beam / jet standoff distance
  – Typical RPD-2002 jet with dia. \( d = 4.61 \text{cm} \) shown in Fig. 1

Droplet collection (Fig. 2):
• Mass flux of droplets measured for \( Re = 130,000, \ We = 19,000 \)
  – Function of \( x \) and cuvette standoff distance, \( \Delta z_s \)
  – Standoff distance normalized by local standard deviation, \( \sigma_x(x) \)
  – Significant increase in mass flux below \( \sim 9\sigma_x(x) \)
• Measurements give \( 10^5 \text{--} 10^6 \) times lower droplet flux than predictions
  – Flow conditioning and contracting nozzle have significant impact
  – Try BL cutting next to reduce droplets further

Publications and Presentations
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)

- 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](image1)

![Figure 2. Homogeneous nucleation rate for Si at 2000 K and n=10^29/cm^3 compared with the same conditions but including ionization fraction of 1%](image2)

Publications and Presentations
• 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.

Publications and Presentations:


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 an array of photodiodes.

Publications and Presentations:
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.

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

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


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

• 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

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Modeling:

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Publications and Presentations:

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

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


- 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/](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.

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

<table>
<thead>
<tr>
<th>Fluence (J/cm²)</th>
<th>Tsunami (microns)</th>
<th>Ablator (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>0.24</td>
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<tr>
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<tr>
<td>30</td>
<td>0.43</td>
<td>0.40</td>
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</tbody>
</table>

**Publications and Presentations**

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

• 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.

• 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.

Publications and Presentations