

Progress in Inertial Fusion Energy Technology: March – May 2002

Compiled by S. Reyes

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Progress in IFE Technology: March - May 2002

Aerosol Production in the Post-shot IFE Chamber Environment – INEEL Fusion Safety Program

J.P. Sharpe, B.J. Merrill

- A preliminary assessment has been performed on the production of aerosol in a liquid-protected IFE chamber. Various models were assembled for the analysis: a 1-D radiative gas dynamics model, a wall condensation model, a wall thermal response model, and an aerosol nucleation and growth model.
- Conditions for the analysis included a chamber of 6.5 m in radius coated by a 1 cm layer of liquid Pb and a shot energy corresponding to the 458 MJ HIB target. For computational purposes, the chamber was discretized into nodes of equal volume (see Figure 1).
- Two cases were investigated. Case 1 assumed all shot energy was deposited only into the wall, vaporizing mass from the Pb film. All nucleation ceases by 1 ms; the average particle size in a region up to 1 m from the wall is $2.0\ \mu\text{m}$, and the number density $\sim 10^{13}\ \text{m}^{-3}$.
- A second case was examined using singular ($2\mu\text{s}$) chamber conditions predicted by the BUCKY code. The net vaporized mass at this time was 37 kg. In this case, nucleation ceases after 5 ms, and after 100 ms the aerosol population is roughly uniform in the chamber with a density of $\sim 10^{10}\ \text{m}^{-3}$ and an average size of $6\ \mu\text{m}$ (corresponding to $\sim 15\ \text{kg}$ of aerosol mass in the chamber). Time behavior of the aerosol is shown in Figure 2.
- Future work may include aerosol model refinements (addition of ion-induced nucleation, and model of multi-component aerosols) and coupling the aerosol model to more suitable chamber radiative gas dynamics codes (e.g. BUCKY).

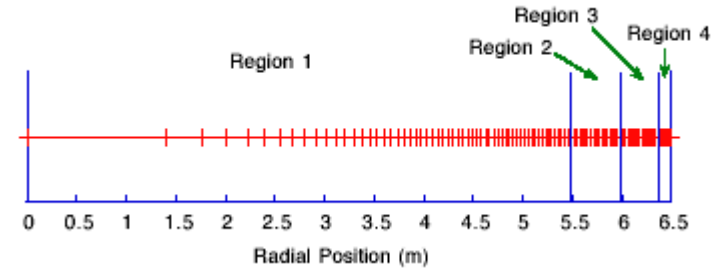


Figure 1. Equal-volume nodes used for calculations, and region definitions for averaging.

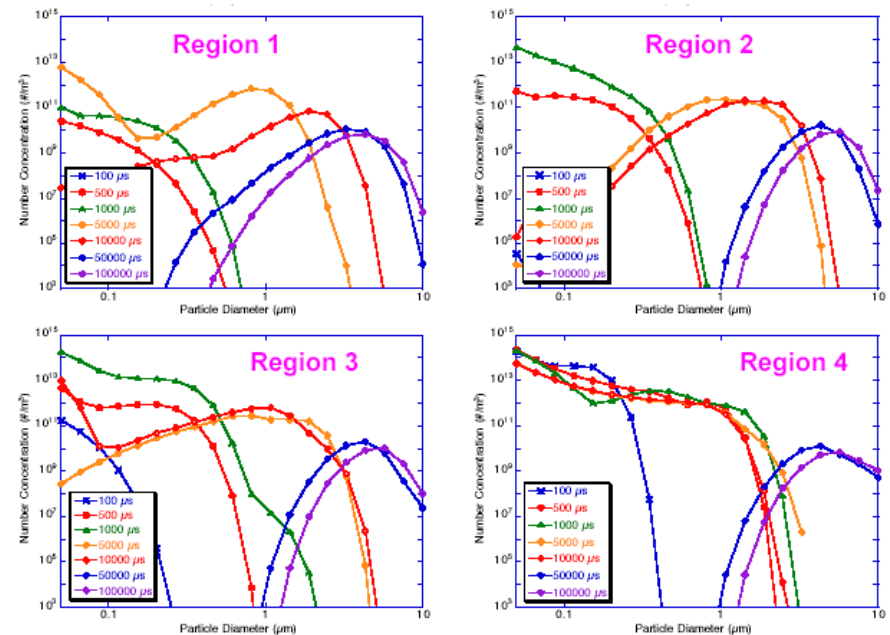


Figure 2. Regional evolution of the aerosol population for case 2 (number concentration [$\#/\text{m}^3$] versus particle diameter [μm]).

Publications and Presentations:

Presentation at the ARIES Program Meeting, Madison, WI, 22-23 April, 2002:

[1] J.P. Sharpe, "Preliminary Results on Aerosol Production in the Post-shot IFE Chamber Environment"

Progress in IFE Technology: March - May 2002 (Cont'd.)

CFC Chemical Reactivity for IFE Safety Analysis– INEEL Fusion Safety Program

T.D. Marshall, R.J. Pawelko, R.A. Anderl, B.J. Merrill, G.R. Smolik, R.M. Moore, D. A. Petti

- CFC-air reactivity tests have been performed to improve models used for safety analysis of fusion reactors utilizing carbon blankets (e.g. SOMBRERO).
- Lower-temperature regimes (525 –1000 °C) were explored to investigate regimes that chemical kinetics controls the oxidation reaction. These tests revealed:
 - Oxygen starvation at 1000 °C occurred due to low flow rate
 - Significant CO₂ production at both low and high specimen temperatures
 - Measured activation energy of 53 kcal shows the surface reaction $C + 1/2 O_2 \rightarrow CO$ is predominant at temperatures below 710 °C

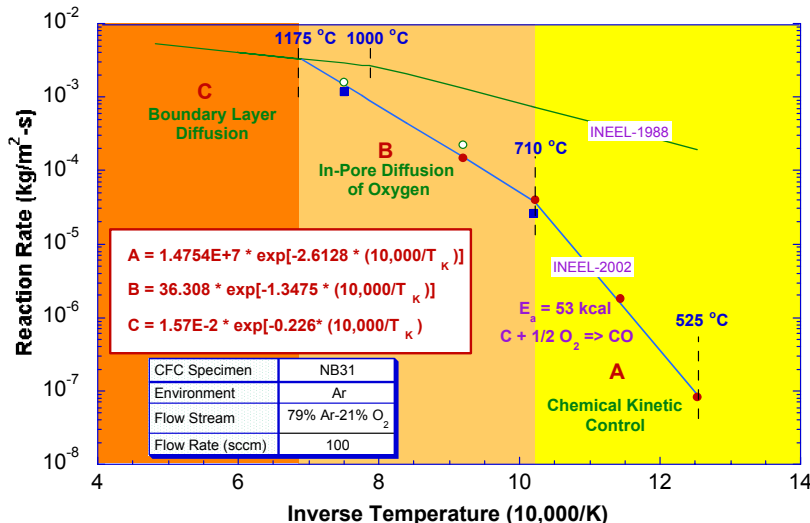


Figure 1. Oxidation reaction rate data and fits.

- Figure 1 shows the new data (INEEL-2002) and corresponding fits and clearly demonstrates over-prediction of rates from the older data (INEEL-1998) extrapolated to lower temperatures.
- Analysis of a LOVA event in SOMBRERO using the improved oxidation correlations revealed:
 - Lower reaction rates at the back wall allow more O₂ to transport to the front wall, increasing oxidation
 - Higher peak temperature but more rapid temperature decay with the new model (see Figure 2)
 - Oxidation mostly occurs in the transition regime between diffusion rate control and rate control via chemical kinetics; behavior in this regime strongly depends on the type of graphite used in the blanket

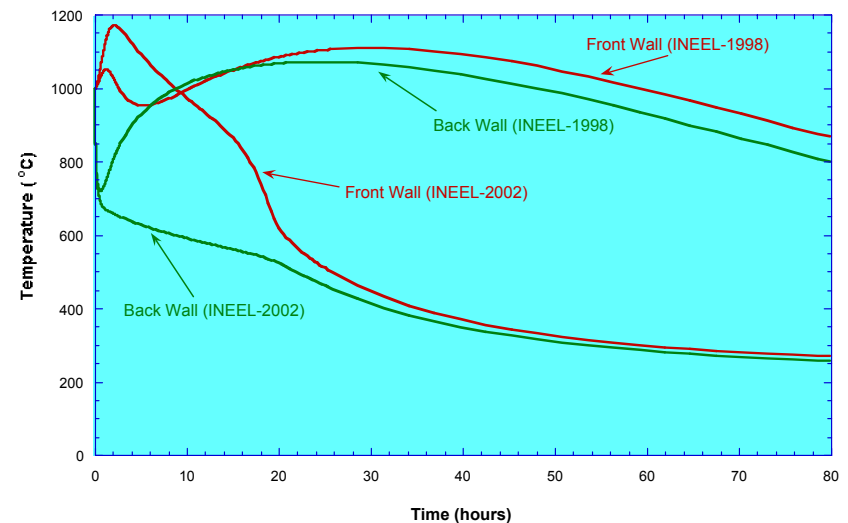


Figure 2. SOMBRERO LOVA analysis using the new data.

Publications and Presentations:

Presentation at the HAPL Program Review, San Diego, CA, 4-5 April, 2002:

[1] D.A. Petti, "CFC-Air Chemical Reactivity for IFE Safety Analysis"

Progress in IFE Technology: March - May 2002 (Cont'd.)

ARIES-IFE Nuclear Analysis - University of Wisconsin-Madison

L. El-Guebaly, P. Wilson, D. Henderson, and A. Varuttamaseni

Feasibility of Recycling Hohlraum Wall Materials:

- Addressed the recycling issues of candidate materials: Au/Gd, Au, W, Pb, Hg, Ta, Pb/Ta/Cs/, Hg/W/Cs, Pb/Hf, Hf, solid Kr, and solid Xe
- Hohlraum materials represent a very small waste stream, less than 1% of the total IFE waste, meaning recycling is not a “must” requirement for power plants unless materials have cost and resources problems (e.g., Au, Gd, and Pt). Other materials should not be excluded for failing to meet the recycling criteria.
- Recycling the candidate materials introduces problems. It produces high-level waste, requires remote handling, adds radioactive storage facilities, and increases the cost and complexity of the plant.
- Design solutions to the recycling waste and dose problems could be to remove transmutation products online, store materials for a cooling off period, and/or limit exposure time by using new materials.

Radiological Issues for Thin Liquid Wall Options:

- Assessed activation of the LiPb and Flibe breeders using ARIES operating conditions
- Recommend employing the same liquid breeder for the liquid wall to minimize the waste volume
- The worst activation case is no mixing of the liquid wall material with the breeder, and the best case is the mixing of the two coolant streams.
- For tangential injection with separate flows, the liquid wall will generate tons of high-level waste unless the in-chamber residence time and/or exposure time is limited. Lead or any lead compound is the worst.
- For porous wall injection with mixing of first wall coolant and breeder, the waste disposal rating is not sensitive to the in-chamber residence time of the liquid wall fluid, however LiPb is worse than Flibe.
- Small amounts (several cups) of transmutation products could be filtered out online and then the liquid metal can be reused or disposed of as low-level waste.

Publications and Presentations:

- [1] L. El-Guebaly, D. Henderson, P. Wilson, and A. Abdou, “Target Activation and Radiological Response of ARIES-IFE Dry Wall Chamber”, Presented at ISFN-T-6 Symposium in April 2002 and accepted for publication in *Fusion Engineering and Design*
- [2] L. El-Guebaly, P. Wilson, D. Henderson, and A. Varuttamaseni, “Feasibility of Recycling Hohlraum Wall Materials”, ARIES Project Meeting, April 22-23, 2002, UW-Madison
- [3] L. El-Guebaly, P. Wilson, and D. Henderson, “Radiological Issues for Thin Liquid Wall Options”, ARIES Project Meeting, April 22-23, 2002, UW-Madison

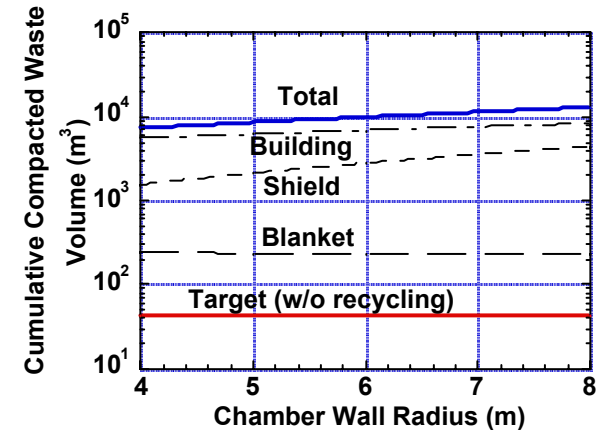


Figure 1. Cumulative compacted waste from different components of an IFE plant

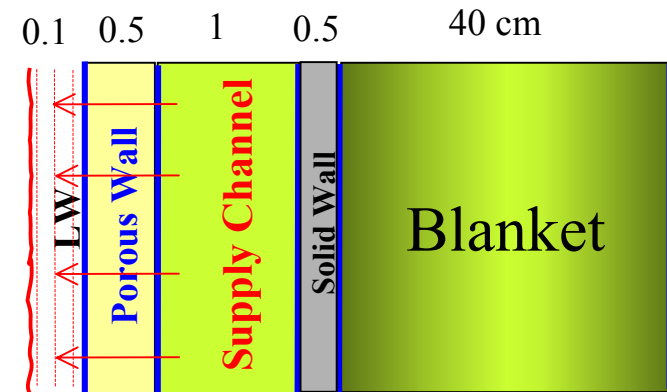


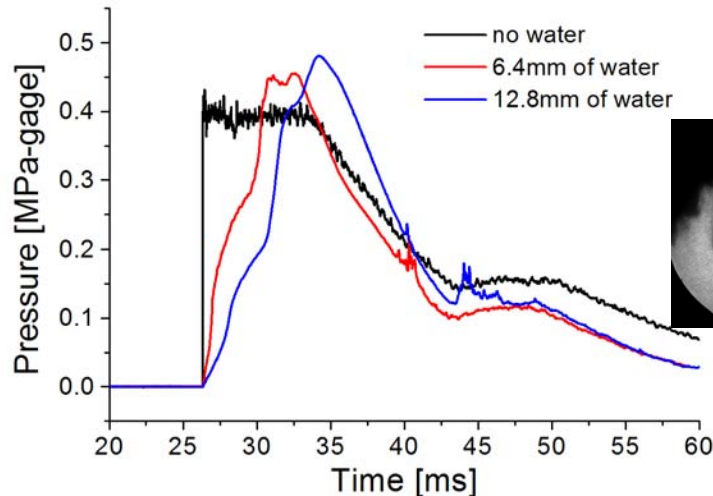
Figure 2. Schematic of a thin-liquid wall concept

Progress in IFE Technology: March - May 2002 (Cont'd.)

Liquid Layer IFE Chamber Protection Experiments - University of Wisconsin-Madison

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

- To study liquid wall protection for IFE chambers a shock tube is used to experimentally investigate 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 of the contact of the liquid sheet against the tube end wall is recorded for several initial liquid layer thicknesses.



The pressure measurements in the bottom wall of the shock tube provide a quantitative measure for comparing the role a liquid layer may play in protecting the first wall of the ignition chamber. Figure (A) is the pressure trace from a Mach 1.38 shock contacting different thicknesses of water suspended 1.04m above the tube end wall with a 0.94 μ m Mylar membrane. The pressure peak rises gradually as the thickness is increased and is spread out in time. The maximum pressure is similar to the test with no liquid water. The picture to the left of the pressure trace is a 0.63cm thick water layer 5.4 ms after shock interaction.

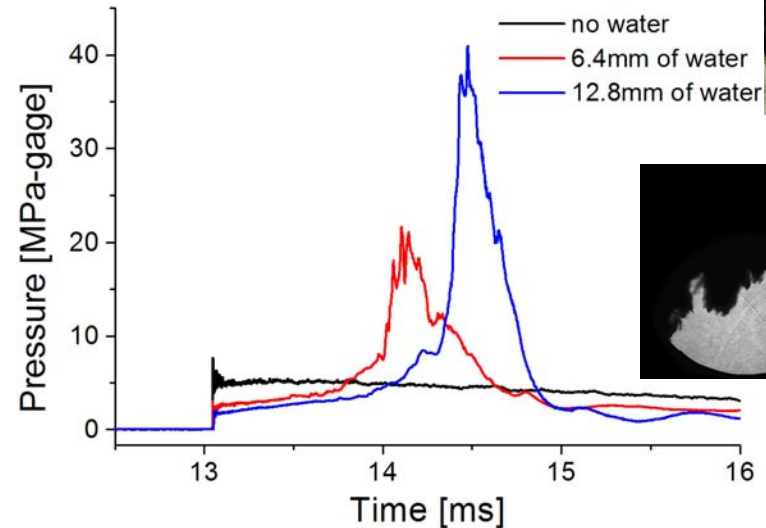
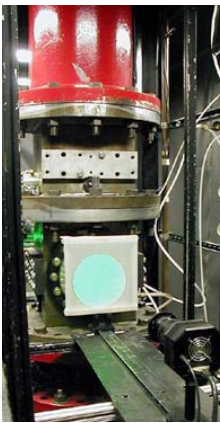


Figure (B) is the pressure trace from a Mach 2.85 shock wave with different amounts of water at 1.04 m above the end wall, at this Mach number the peak pressures from the contact of the accelerated water sheet are significantly (up to $\sim 10\times$) higher than with no water present. The picture to the left side of the pressure trace shows the interface of a the 1.23 cm thick water layer 1.8 ms after shock interaction. Numerical and theoretical models are being developed to model this phenomena.

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] Shock Interface and Shock Structure Interactions; J. Oakley, M. Anderson, S. Wang, R. Bonazza, R. Peterson, October 2001 [ARIES E-Meeting, 24 October 2001].
- [3] 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.

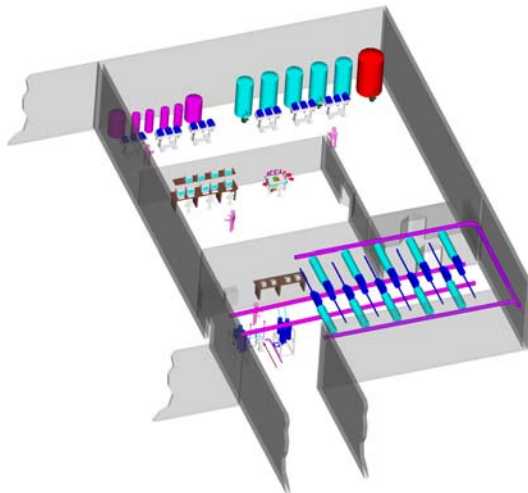


Progress in IFE Technology: March - May 2002 (Cont'd.)

Target Fabrication, Injection, and Tracking – GA/LANL

D. Goodin, R. Petzoldt, N. Alexander, A. Nikroo, L. Brown, G. Besenbruch, A. Nobile

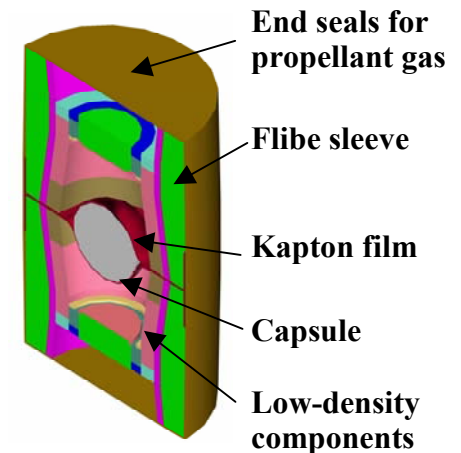
- Working with target designers we have identified, for the first time, potential manufacturing processes from beginning to end for the distributed radiator HIF target.
- The target manufacturing process steps were presented to the international community at the 14th International Symposium on Heavy Ion Inertial Fusion
- We conducted a survey of high-Z, low-density foam manufacturing methods for the absorber/radiators in the HIF target.
- We initiated a chemical engineering analysis of an “nth-of-a-kind” target fabrication facility for the HIF target. We completed cost estimates for fabrication of a polystyrene ablator, filled and layered with DT. The estimate of \$0.11 per target for these steps is an encouraging result (i.e. leaves cost margin for the hohlraum).
- We started upgrading Building 22 for IFE research including the Target Injection and Tracking experimental system.
- We are hosting the IAEA Technical Meeting on Physics and Technology of Inertial Fusion Energy Targets and Chambers to be held on 17-19 June 2002. <http://web.gat.com/conferences/iaea-tm/main.html>



Preliminary target fabrication facility layout



7200 ft² experimental space is being refurbished for use in IFE research



CAD model for HIF target assembly sequence

Publications and Presentations

- [1] R. W. Petzoldt, “Aerosol Limits for Target Tracking”, ARIES meeting in Madison, WI, 22-23, 2002
- [2] D.T. Goodin, “A Credible Pathway for Heavy Ion Driven Target Fabrication and Injection”, 14th International Symposium on Heavy Ion Inertial Fusion, Moscow, Russia May 26-31, 2002

Progress in IFE Technology: March - May 2002 (Cont'd.)

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

N.M. Ghoniem, R. Ungureanu and Q. Hu—University of California, Los Angeles (UCLA)

- Developed a new concept for segmented reflective grazing metal mirrors, which may eliminate the need for additional focusing mirrors in an IFE system.
- Held a University-Industry workshop on June 7, 2002, with MER corporation, represented by Dr. Wiold Kowbel, to explore various design and manufacturing options for reflective optics
- Performed solid modeling and thermal analysis for the proposed concept.

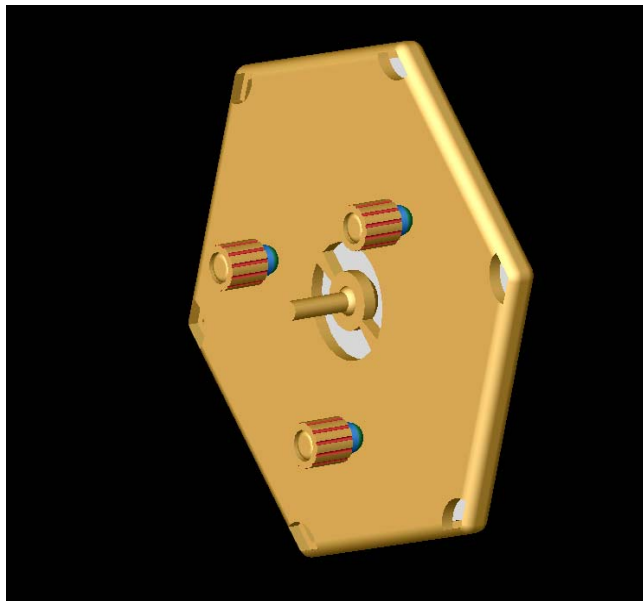


Figure 1. Basic Unit Design with Piezoelectric actuators

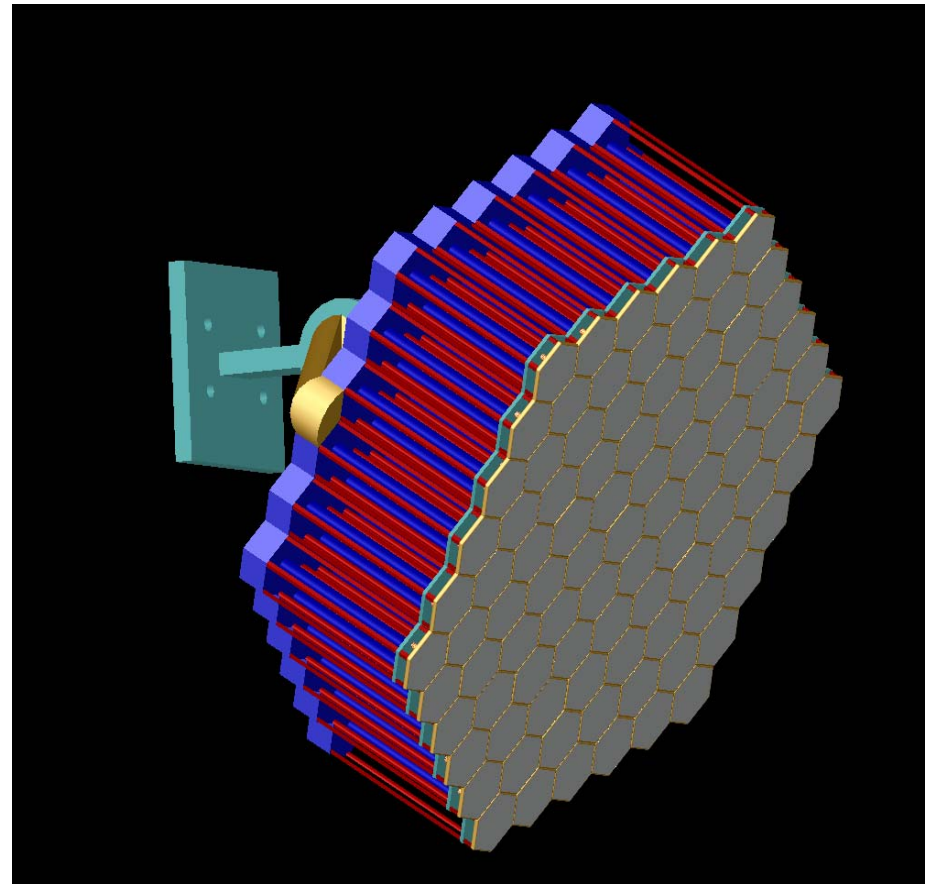


Figure 2. UCLA Segmented Mirror Design

Publications and Presentations

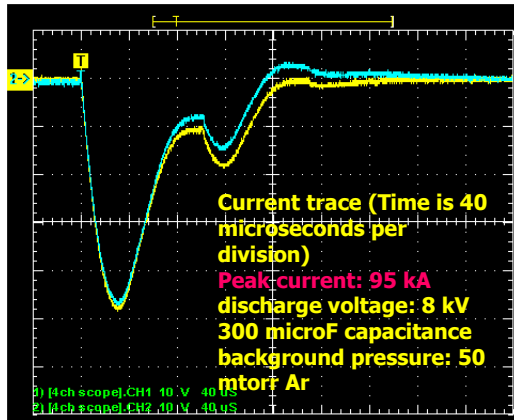
- [1] N.M. Ghoniem, Razvan Ungureanu, Matteo Cova, and Giacomo Po; “The UCLA Grazing Incident Metal Mirror Design,” Presented at UCLA, June 7, 2002, University-Industry workshop on Laser Mirrors at UCLA.

Progress in IFE Technology: March - May 2002 (Cont'd.)

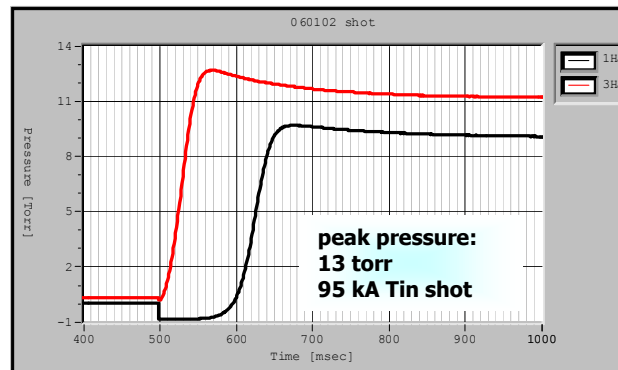
Vapor Dynamics and Condensation and Free Surface Flow Studies—University of California, Los Angeles (UCLA)

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

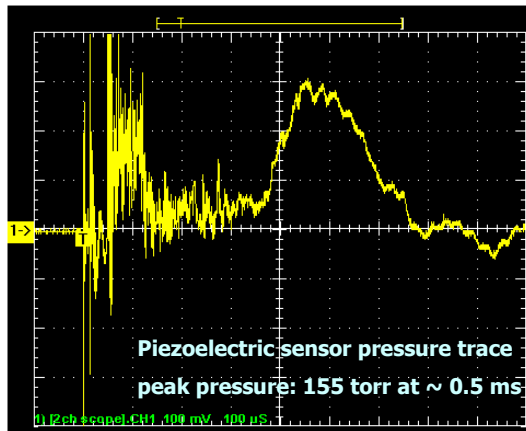
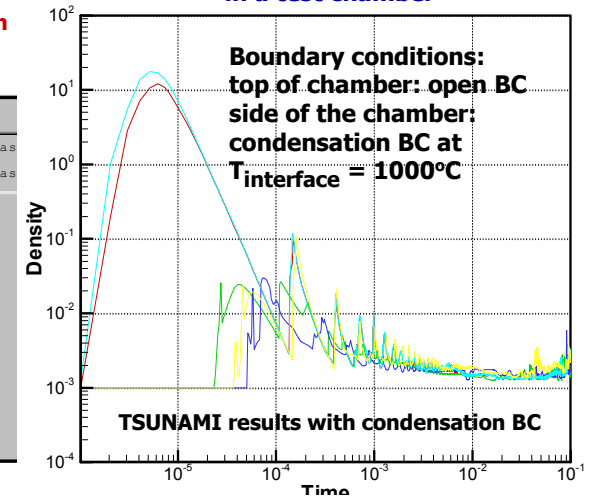
- Performed Tin shots and began to address the use of pressure diagnostics for condensation study
- Completed Flibe casting in quartz tubes, Flibe liner available for shots
- Implemented 1-D condensation module into TSUNAMI and performed test runs



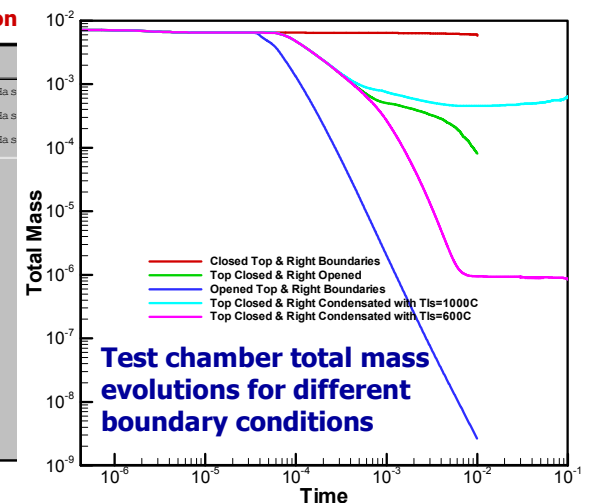
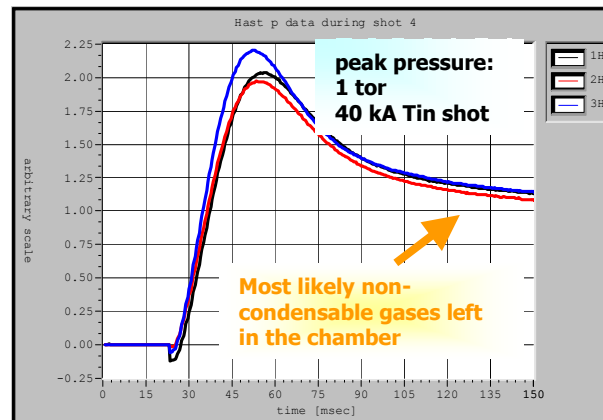
Hastings dual sensor pressure trace at cold trap region
 (Time delay between 2 readings might be due to temperature effect- needs to be fixed)



Density evolution at different locations in a test chamber



Hastings dual sensor pressure trace at cold trap region



Progress in IFE Technology: March - May 2002 (Cont'd.)

Thick-Liquid Protection — University of California at Berkeley

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

- Using the 500 frame-per-second video system loaned by UCLA, disruption data from the UCB Vacuum Hydraulics Experiment (VHEX) have confirmed that voided liquid structures compress as predicted by the “snowplow” model following strong impulse loading. The figure shows the motion of the array surface following impulse delivery. The surface decelerates until the liquid becomes fully compressed, and then travels with constant velocity after the shock emerges from the back side. Validation of the snowplow model is encouraging, because for full-scale IFE chamber conditions it predicts that shock emergence times are very long, greater than the shot repetition period.

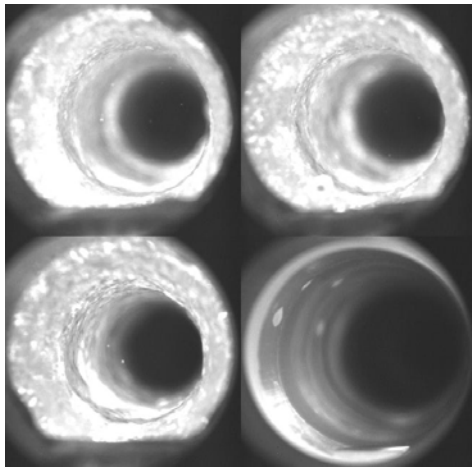


Figure 2. View down the UCB vortex experiment, at 2.5, 1.9, 1.4, and 0 liters/sec

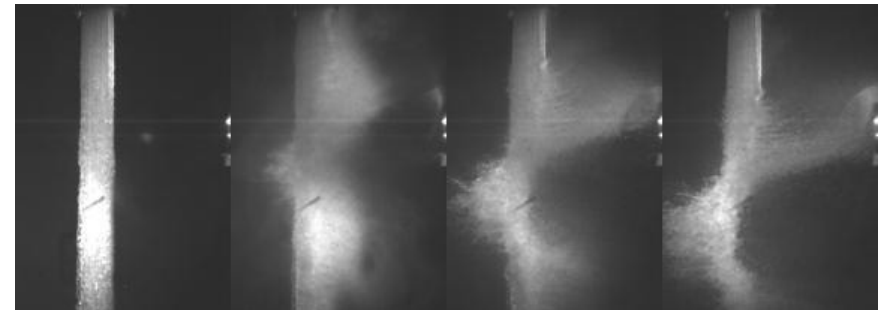
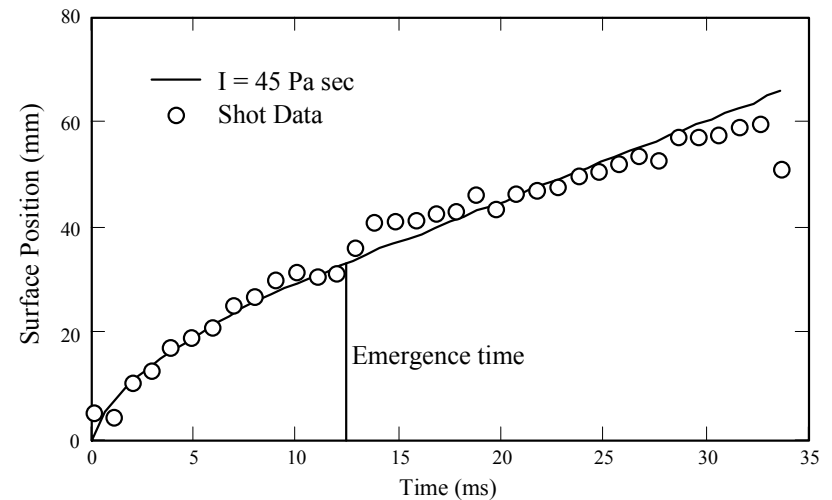


Figure 1. An impulse load propagates into voided liquid (8 msec intervals)

- Vortex thickness experiments, using a shadow projection method, have confirmed theoretical predictions that vortex thickness is not sensitive to the flow rate, suggesting that maintaining constant and precise thickness in HIF beam tubes is possible.

Publications and Presentations:

- [1] S.J. Pemberton, R.P. Abbott, and P.F. Peterson, “Abatement of shocks during disruption of porous thick-liquid blankets in HYLIFE type inertial fusion chambers,” 6th International Symposium on Fusion Nuclear Technology, San Diego, April 7-12, 2002.
- [2] C.S. Debonnel, G.T. Fukuda, P.M. Bardet and P.F. Peterson, “Control of the Heavy-Ion Beam Line Gas Pressure and Density in the HYLIFE Thick-Liquid Chamber,” 6th International Symposium on Fusion Nuclear Technology, San Diego, April 7-12, 2002.

Progress in IFE Technology: March - May 2002 (Cont'd.)

Thick-Liquid Protection — Georgia Institute of Technology

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

- Investigate behavior of liquid sheets issuing from nozzles with 3D contractions
 - Nozzles with (5th order polynomial) contractions in both y - and z -dimensions
 - Sheets show pronounced “axis switching” downstream of nozzle exit (Figure 2)
 - Measured crossover point (downstream location where y -, z -dimensions equal) at Reynolds numbers $Re = 26,000$ – $74,000$
- Starting to visualize and quantify drop ejection from high Reynolds number sheets ($Re > 100,000$) (Figure 3)

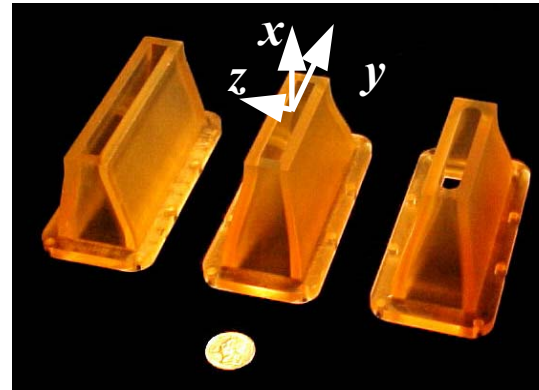


Figure 1. Nozzle geometry:
 A) 2D circular-arc contraction (only in z -dimension)
 D) 3-D 5th order polynomial contraction (contracts in y and z)
 E) Same as D with rounded corners at exit

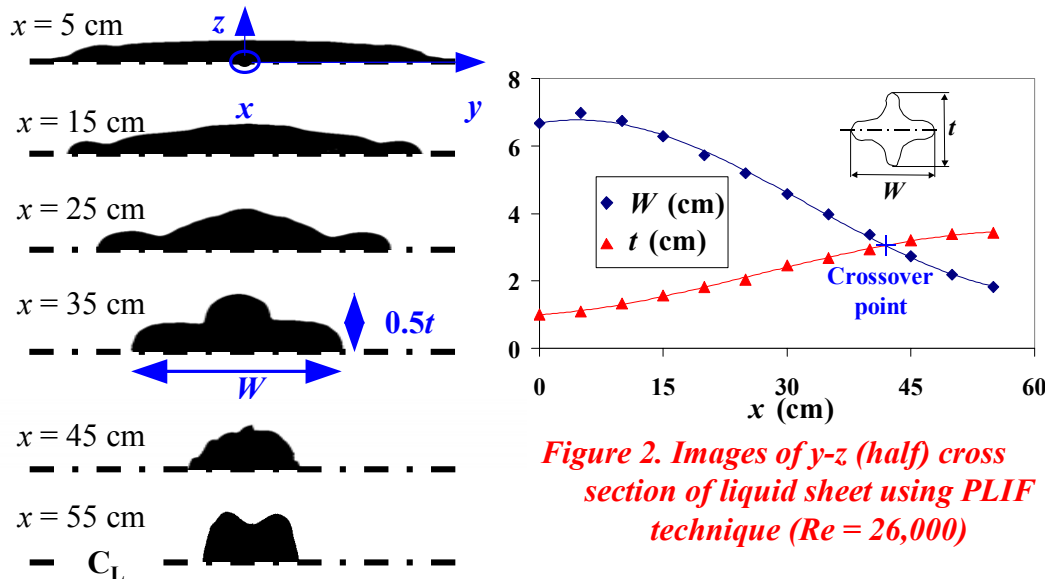


Figure 2. Images of y - z (half) cross section of liquid sheet using PLIF technique ($Re = 26,000$)

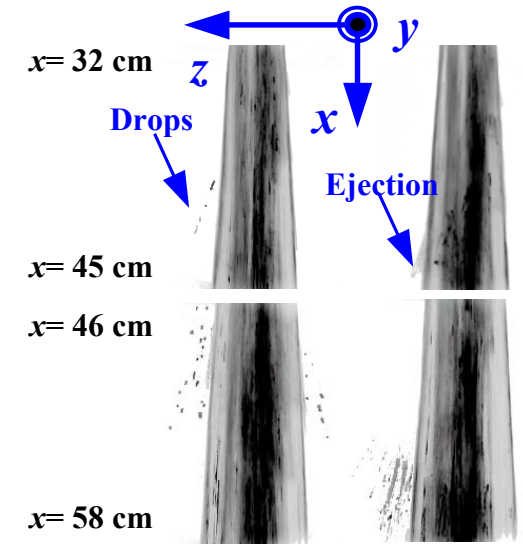


Figure 3. Drop ejection

Publications and Presentations

- [1] 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," submitted to Fusion Engineering and Design (2002) Also poster presentation at ISFNT-6 (San Diego, CA)

Progress in IFE Technology: March - May 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

- Safety and Environment:
 - Work on waste management options for IFE power plants continues to emphasize need for recycling and clearance.
 - Study of S&E characteristics and pumping power requirements of alternative liquid materials for a thick-liquid wall chamber concept (Figure 1).
- HIF Systems Modeling:
 - Work with the HIF Virtual National Laboratory to update the point design using the HYLIFE-II thick -liquid-wall chamber.
 - Updated the driver system code model to include new models (benchmarked to detailed PIC simulations) for the beam spot size on target (Figure 2).
 - This work is also providing input to the ARIES-IFE study.
- Preliminary assessment of final optics options for a Fast Ignition IFE power plant.
- Preparations are being made for IFE activities at the Snowmass summer workshop.

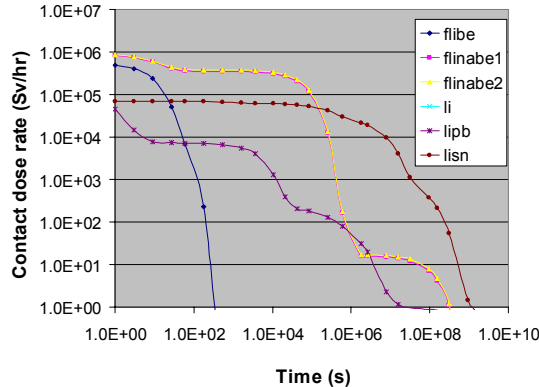


Figure 1. Regarding S&E, flibe, LiPb and flinabe stand as the most attractive options, however, required pumping power for LiPb and LiSn maybe too high

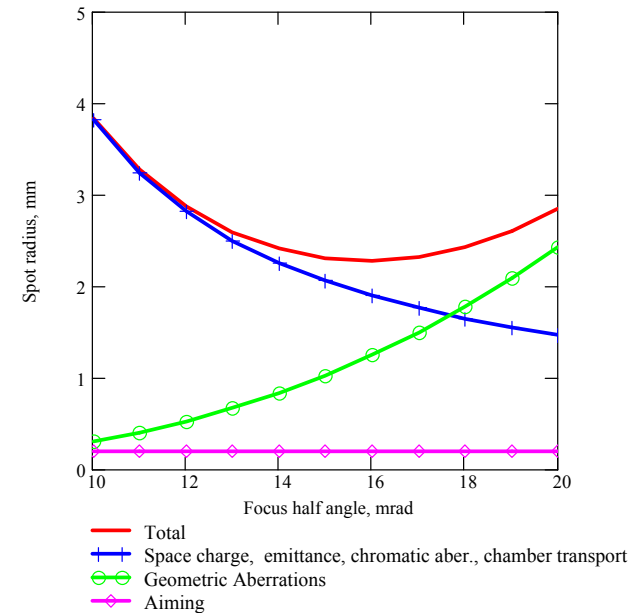


Figure 2. Results on spot size on target versus focus half angle for HIF

Publications and Presentations:

[1] S. Reyes, et al., "Safety Assessment for Inertial Fusion Energy Power Plants: Methodology and Application to the Analysis of the HYLIFE-II and SOMBRERO Conceptual Designs," submitted to the *Journal of Fusion Energy*.

ISFNT-6, San Diego, 7-12 April 2002: [2] W. R. Meier, et al., "Progress Toward Heavy Ion IFE," [3] S. Reyes et al., "Use Of Clearance Indexes To Assess Waste Disposal Issues for the HYLIFE-II Inertial Fusion Energy Power Plant Design," [4] S. Reyes, et al., "Liquid Wall Options For Tritium-Lean Fast Ignition Inertial Fusion Energy Power Plants"

4th High Average Power Laser Program Workshop, 4-5 April 2002: [5] S. Reyes, et al., "Update on Fast Ignition Laser IFE Activities," [6] J. F. Latkowski, W. R. Meier, "Progress in Alternate Chambers Activities," [7] S. Payne, J. F. Latkowski, "Transmissive Final Optic for Laser IFE"

ARIES Program Meeting, Madison, WI, 22-23 April, 2002: [8] S. Reyes, "S&E considerations for IFE Thick Liquid wall concepts," [9] W. R. Meier, P. F. Peterson, "Introduction to Thick-Liquid-Wall Chambers," [10] W. R. Meier "Heavy Ion Fusion Modeling Update - Spot Size Model Changes"

Progress in IFE Technology: March - May 2002 (Cont'd.)

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

M. S. Tillack, F. Najmabadi, A. Gaeris, S. S. Harilal, B. Harilal, J. Pulsifer, D. Blair, S. Chen (see: <http://aries.ucsd.edu/IFE/>)

- Two new projects were initiated in March 2002:
 - Experimental Studies of Magnetic Diversion Concept
 - Creation, Evolution and Transport of Vapor and Aerosol in IFE Chambers.
- Experimental studies of laser ablation plume dynamics were carried out in order to demonstrate our ability to generate reactor-relevant expanding plasmas. Ion energy of 600 eV was obtained in a plasma with electron density of $10^{18}/\text{cm}^3$ using $10^{10} \text{ W}/\text{cm}^2$ laser intensity. Studies are being carried out with increased intensity (up to $10^{14} \text{ W}/\text{cm}^2$) to fully characterize our capabilities before experiments with magnetic fields are attempted. See Figure 1.
- Analysis of the effect of ionization on homogeneous cluster formation were carried out. Even small amounts of ionization in the ablation plume can have a dramatic effect on aerosol generation (Figure 2).
- A high temperature target holder was designed and fabricated. It is capable of maintaining the target surface at a temperature up to 1000°C with an accuracy of 1°K (Figure 3).

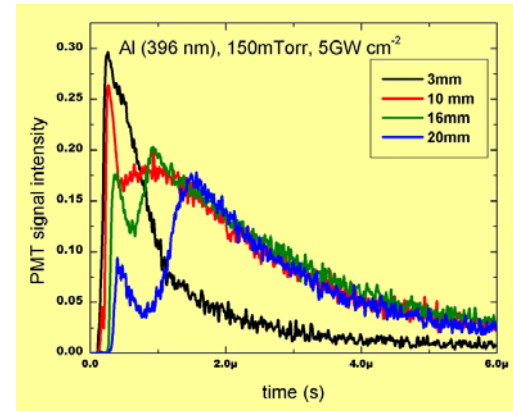


Figure 1. Time-of-flight spectroscopy in Al: slow peak (56 eV) and fast peak (600 eV)

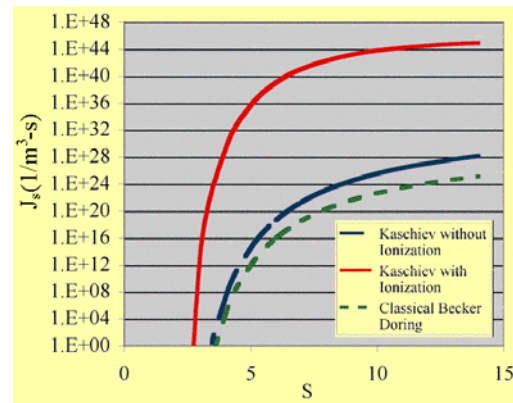


Figure 2. Effect of ionization on homogeneous cluster formation

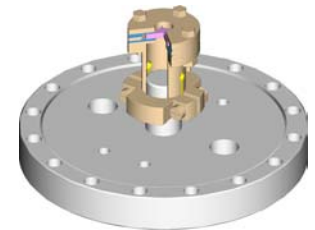


Figure 3. High temperature target holder

Publications and Presentations:

VLT Seminar, DOE Budget Planning Meeting, Gaithersburg, March 12, 2002:

[1] M. S. Tillack, "IFE Chamber Physics"

4th High Average Power Laser Program Workshop, 4-5 April 2002:

[2] M. S. Tillack, "Mirror damage studies - progress report" [3] A. R. Raffray and Z. Dragojlovic, "Chamber Dynamics Modeling," [4] F. Najmabadi, "Progress in UCSD Chamber Simulation Experiments," [5] T. K. Mau, "Status of Modeling of Damage Effects on Final Optics Mirror Performance"

US/Japan Workshop on Fusion Power Plant Studies, San Diego, 6-7 April 2002:

[6] M. S. Tillack, "Damage Mechanisms and Limits for Laser IFE Final Optics"

ISFNT-6, San Diego, 8-12 April 2002:

[7] M. S. Tillack and N. M. Ghoniem, "Performance and Lifetime of a Grazing Incidence Metal Mirror Used as a Final Optic for a Laser-IFE Power Plant"

Seminar at ILE (Institute for laser Engineering), Osaka Japan, 21 May 2002:

[8] M. S. Tillack, "Laser-Matter Interactions Near the Ablation Threshold"