Summary of High Average Power Laser Workshop
Held at the Naval Research Laboratory on Dec 5 and 6, 2002

By John Sethian

This is a capsule summary of the results presented at the recent High Average Power Laser (HAPL) workshop held on December 5 and 6 at Naval Research Laboratory. This document gives the advances reported at the workshop. These are grouped by major research task, along with a brief description of the Phase I goals of that task. This meeting was particularly noteworthy as we had several significant advances to report. These are highlighted below as ### .

It turns out that one of the participants at the workshop was a major snowstorm. Even though area schools were closed, the government was on liberal leave, and the mail was delayed, over **60 participants from 25 institutions showed up at the workshop**. Evidently nothing could stop this group from presenting and discussing their recent advances.

Background on HAPL program: The High Average Power Laser Program (HAPL) is a national program to develop Inertial Fusion Energy (IFE) with lasers, direct drive targets and solid wall chambers. The program is funded by the US Department of Energy/NNSA/Defense Programs. One of the principles of the program is to develop the primary components together as a coherent system, as this is the most efficient approach to realizing a viable power fusion energy source. The components under development are: the lasers, target design, target fabrication, target injection, final optics, chambers, and relevant materials. The laser part of this program started in FY 1999, the other components in 2001.

The HAPL Program will develop Laser Fusion Energy in three distinct phases:

1. **Phase I** *(1999 to about 2005):* The present "Proof of Principle" research program.

2. **Phase II** (*approx 2006-2012*): The Integrated Research Experiments (IRE). These bring together the key components. There will be two facilities, a laser facility and a target facility, experiments and modeling in target design, a full-scale power plant study, plus material evaluation.

3. **Phase III** *(2012 to about 2020)*: The Engineering Test Facility (ETF). This full-scale laser facility (1.5-2.5 MJ) would demonstrate repetitive high fusion yield. The ETF would also evaluate components and demonstrate fusion power in burst mode.

Workshop format: The HAPL team meets periodically (3 times/year) to discuss their progress in a community setting. At this last meeting we had 30 oral presentations and 15 posters. To foster a workshop environment, ample time was left for discussion. A complete copy of the meeting presentations can be found on the HAPL web site: http://aries.ucsd.edu/HAPL/.

Presented below are the scientific and technological advances announced at the workshop. These are grouped by major component. To put these in context, we also list the Phase I goals for each component, and a brief description of our approach.

1: LASER DEVELOPMENT

Phase I Goals:

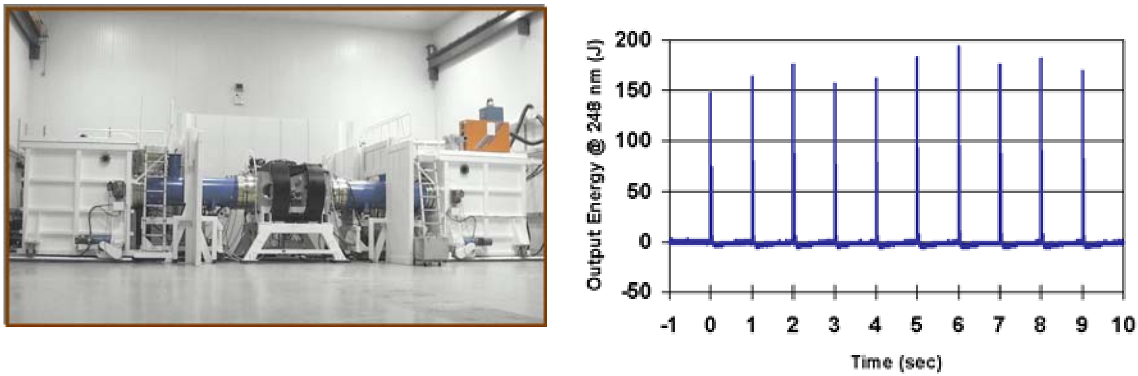
1. *Develop technologies that can meet fusion energy requirements for efficiency (> 6%), repetition rate (5-10 Hz), and durability (> 100,000,000 shots continuous).*
2. *Demonstrate required laser beam quality and pulse shaping.*
3. *Laser technologies employed must scale to reactor size laser modules and projected to have attractive costs for commercial fusion energy.*

Approach:

We are developing two laser approaches. One is a krypton fluoride (KrF) laser which uses electron beams to excite the laser gas, the other is a Diode Pumped Solid State Laser (DPSSL) that use high power solid state diodes to pump a Yb:S-FAP crystal. These architectures were chosen because they both have the potential for meeting the fusion energy requirements for rep-rate, durability, efficiency, beam uniformity and cost. Prior to this meeting neither system had operated as a laser.

Progress reported at workshop:

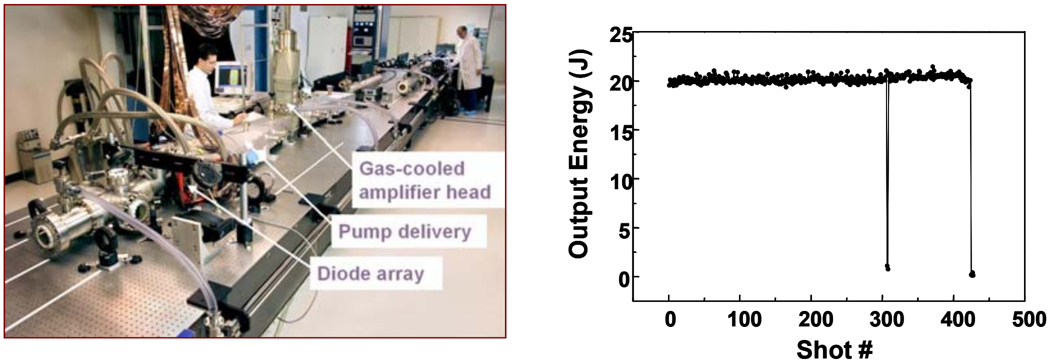
1-1 KrF Laser achieved first light: The Naval Research Laboratory announced that the “Electra” Krypton Fluoride (KrF) laser has achieved “first light” in a rep-rate mode. The system produces 400 Joules single pulse and 300 Joules repetitively. The Electra group has also demonstrated high electron beam deposition efficiency (>75%, vs. < 40% achieved in previous systems) and eliminated an electron beam instability that has plagued large area electron beams for decades.



Left: Electra Laser Facility. Right: First data showing laser output in rep- pulsed mode

1.2 DPSSL Laser achieved first light: Lawrence Livermore National Laboratory announced that the “Mercury” Diode Pumped Solid State Laser (DPSSL) has also achieved “first light” in a rep-rate mode, producing 31.6 Joules in a single pulse and 20.6 Joules in 20 ns at 10 Hz. This is the highest energy ever achieved by a DPSSL in nanosecond pulses. Four diode arrays producing up to 320 kW of peak power were

operated and significant advances were made in the growth of large, high quality laser crystals needed for present and future systems.



Left: Mercury Laser Facility. Right: Data showing laser output in at 5 Hz

2. HIGH GAIN TARGET DESIGN

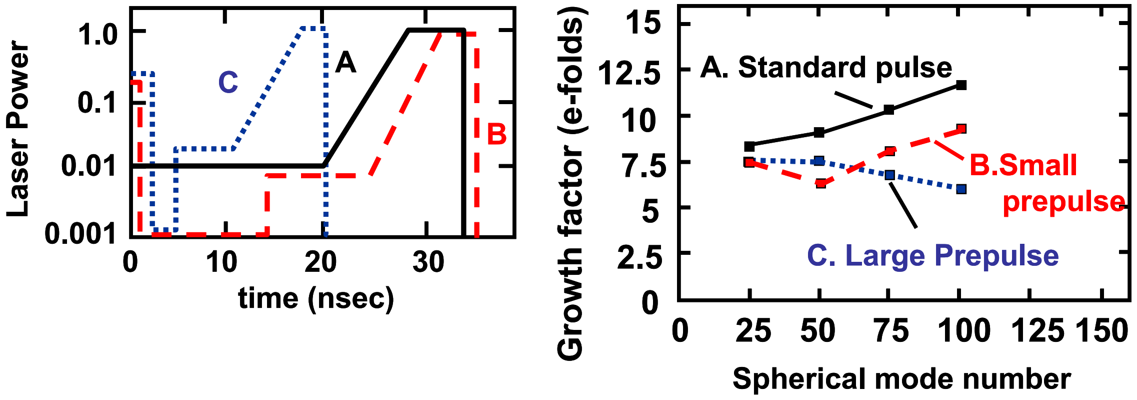
Phase I goals:

1. *Develop credible target designs, using 2D and 3D modeling that have sufficient gain (> 100) and stability for fusion energy.*
2. *Benchmark underlying codes with experiments on Nike & Omega.*
3. *Integrate design into needs of target fabrication, injection and reactor chamber.*

Approach:
This is carried out primarily through the NRL direct drive target design work carried out as part of the ICF program. The basic design has been shown in 1-D to have gains of over 100, which is adequate for fusion energy. We are starting to get corroboration of those gains with 2-D calculations. We are pursuing a suite of target designs that are evaluated not just for gain and stability, but also for their suitability for IFE (fabrication, injection, tritium inventory, low waste, etc). All the designs share some features in common:

1. *The laser pulse has a low intensity "foot" followed by a rise to maximum intensity.*
2. *The ablator is composed of a low density foam with DT wicked into it. The foam can significantly increase the laser absorption.*
3. *The design preheats the ablator by some means (shock, x-rays, or a combination). This raises the isentrope of the ablator, and hence lowers the growth rate of the Rayleigh Taylor instability. In some designs the ablator is preferentially heated, while the fuel remains on a lower isentrope. This increases the stability without materially reducing gain.*
4. *The laser is "zoomed:" the spot size is decreased in radius to match the compressing target. (This reduces the amount of light lost to refraction and/or absorbed far away from the ablation surface, and thus increases the absorption and coupling efficiency of the design.)*
5. *The designs include a thin high Z layer (such as Pd) outside the target. This has been shown experimentally to significantly reduce the imprint of laser non-uniformities, and hence mitigates the seeding of hydrodynamic instabilities.*

Progress reported at workshop:
2-1 “Picket fence” pulse shape stabilizes target and reduces imprint: In the areas of target design, Lawrence Livermore National Laboratory reported that a high intensity spike, or “picket”, at the leading edge of the laser pulse can significantly enhance the target stability with an acceptable reduction in yield. The University of Rochester presented similar results. The Naval Research Laboratory reported the “picket” may have the added benefit of reducing imprint of the laser beam. (The NRL and Rochester work are funded through the ICF program in DP, the LLNL work is funded through HAPL). **This work benefits NIF as well as IFE.**



Effect of varying laser pulse shape. Left: Three different laser pulse shapes. Right: Large prepulse offers significant enhancement in target stability as indicated by decrease in total number of e-folds.

3. TARGET FABRICATION

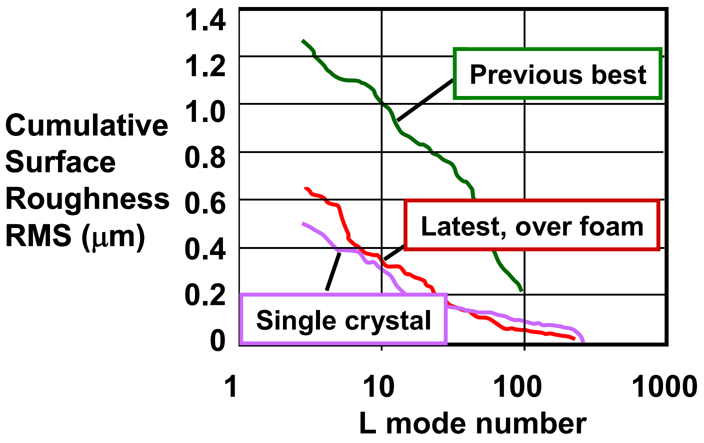
Phase I Goals:

1. *Develop mass production methods to fabricate cryogenic DT targets that meet the requirements of the target design codes and chamber design. Includes characterization.*
2. *Combine these methods with established mass production costing models to show targets cost will be less than $0.25.*

Approach

The work is concentrating on developing techniques to fabricate the target described above. This is a low density foam shell, about 4 mm diameter with a 400 micron wall. The DT fills the foam and extends inward another 200 microns or so. The outer layer of the target has a thin (6 μm) seal coat, and possibly a high Z-layer as described above. We will first make high quality targets on a single shot basis, using techniques that lend themselves to mass production. Then we will proceed to develop the mass production methods. At previous workshops we announced we had developed the chemistry for an appropriate foam, and we had demonstrated that an Au-Pd coating has both the high DT permeability needed to rapidly fill the targets and the high IR reflectivity to help protect the target in the chamber.

Progress reported at workshop:
<u>###</u> **3-1 Developed ultra-smooth DT ice layers on foam:** Los Alamos National Laboratory has produced ultra-smooth deuterium-tritium (DT) ice layers by growing the DT ice on a foam base. This arrangement replicates the current fusion energy target designs. The liquid DT is wicked into a low-density plastic foam, frozen at 19.7 degrees above absolute zero, and then slowly cooled to equilibrate at 19.25 above absolute zero. With this approach Los Alamos observed less than 0.6 microns variation in the DT ice surface finish, which is about 2 times better than what has been achieved before. This is a significant advance; as the inner surface of the shell must be very smooth in order maximize the fusion energy released from the target. **This result benefits not only the IFE program, but the fielding of cryogenic targets on the NIF as well.** Schafer Corporation produced the foams used in these DT layering experiments.



Cumulative reverse spectral RMS surface roughness. Single crystal results are best observed to date, but would be difficult to field in an actual target

3-2 Produced DVB foam shells in batch mode. Schaffer Corporation has developed overcoated divinyl-benzene (DVB) foam shells using microencapsulation, a process well suited to mass production. Up to 300 shells with the proper diameter, density, and wall thickness have been produced in a single batch. The material was chosen because it meets the requirements for low oxygen content and straightforward over coating. Tasks for the coming year include addressing concentricity, reproducibility, and the surface finish of the over-coating.

3-3 Methods to develop target mass production under development. General Atomics (GA) reported on their work with fluidized beds to both apply an overcoat to the foam shells. They showed they can produce external coatings on plastic shells that are on the order of 30 nm surface roughness. This meets the target requirements. This approach is also a possible method for enhanced cryo layering. GA also reported on their developments in microencapsulation. This is how the DVB shells are made now, but considerable work needs to be done to adapt this process to true mass production.

3-4 Direct drive targets projected to cost 16 cents each. Although not a new result at this meeting, it bears repeating as this meets one of the Phase I goals. GA has submitted this study for peer review.

3-5 Fielding cryogenic targets on Omega. The University of Rochester, Laboratory of Laser Energetics, presented their results on fielding direct drive cryogenic targets on the Omega laser facility. Although not an "official" participant in the High Average Power Laser Program, Rochester's experience is of interest to this program, particularly in the formation and deterioration of the ice layer. For example, in preliminary experiments it was observed that applying the heat to the outside of the target (as would be the case when it is injected) causes melting at the plastic/ice interface, and thus doubles the time required for the ice to melt. The morphology of that interface has not been determined, but if it is liquid with no gas bubbles, the result would not affect the target physics and would be encouraging for target survival.

4. TARGET INJECTION

Phase I Goals

1. *Build an injector that accelerates targets to a velocity to traverse the chamber (~6.5 m) in 16 milliseconds or less.*
2. *Demonstrate target tracking with sufficient accuracy for a power plant (+/- 20 microns).*
3. *Develop, in conjunction with the target design and chamber activities, a method to successfully inject the target into the chamber environment.*

Approach:

We are building a target injector based on gas gun technology. The injector will sequentially accelerate a batch of twelve targets at the proper repetition rate, and with prototypical acceleration to prototypical velocity. This research includes development of techniques to track the target with the required accuracy and hit the target on the fly with a low power laser beam. The injector design is flexible, and can be used for direct drive as well as indirect drive targets.

This task also includes research and development on "target survival." Establishing a chamber design that allows both target survival and long term first wall integrity is one of the bigger challenges in this program. The relevant issues are straightforward: The cryogenic target, at 18 degrees K, will be injected into a chamber, with a wall at around 1300 degrees K. The high wall temperature is required for both efficiency and first wall material survival. The chamber will most likely have some type of background gas for additional wall protection. The hot wall and gas will apply a heat load on the target. Yet, according to conventional wisdom the interior of the target can warm up no more than a few tenths of a degree without cracking the interior ice layer. Thus target survival depends on how fast the interior of the target warms up in response to this rapid heat load. As the target is in the chamber for only 16 msec, it is critical to understand the dynamic thermal and mechanical properties of the plastic/foam+DT/pure DT target. We are addressing this issue by performing *appropriate experiments, and using modeling to investigate alternate target and chamber designs. We have established a possible operating window for the lower fusion output energy targets, but we need this better understanding of the underlying physics to both confirm and extend this window. We have established close links between the chamber physics, target physics and target fabrication activities to facilitate this.*

Progress reported at workshop:

4-1 Fabrication of components for the target injection system is nearly complete. GA reported that their new IFE Target Development Facility, "Building 22", is nearly complete. (This was built on internal GA funds...thanks!). The main parts of the injector are here, and the target tracking system shows excellent repeatability for stationary targets. Tracking will be done by both backlighting the target and by interferometry.

4-2 Target survival scenarios under evaluation. Survival of the target into the hot chamber is still a challenge, however at this workshop several solutions were proposed. The University Of California San Diego (UCSD) presented a range of options, including an empty foam on the outside of the target, and letting the outer layer of the target melt. Based on thermal calculations, these appear to be viable, and are not inconsistent with the high gain target design. A splinter meeting was held on "target survival" in which the target designers met with those who are building and injecting the targets. Participants came from General Atomics, The Naval Research Laboratory, LLNL, The University of Rochester Laboratory for Laser Energetics, UCSD, The University of Wisconsin, Georgia Tech, and Los Alamos.

5. FINAL OPTICS

Phase I Goals

1. Meet laser induced damage threshold (LIDT) requirements of more than 5 Joules/cm^2, in large area optics.
2. Develop a credible final optics design that is resistant to degradation from neutrons, x-rays, gamma rays, debris, contamination, and energetic ions.

Approach:

The final optic steers the laser beams to the target. It is the only optical component that lies in direct line-of-sight of the target emissions, and hence is subject to the x-rays, ions, neutrons. It is also subject to intense laser light, as well as dust and contaminants. Our approach is to determine, through experiments, modeling, or both, the effect of each of these threats. Three types of final optics are being pursued:

1. *Grazing Incidence Metal Mirror (GIMM) on a stiff, neutron transparent, cooled substrate. This is our front runner approach, as it appears to have very high damage threshold is relatively easy to field, and works with both type of lasers.*
2. *Transmissive optics: We have found that a transmissive quartz optic could be suitable for the DPSSL approach if it is operated at elevate temperatures (500*

degrees C). However the optical absorption is too high at the KrF wavelength. This fact, plus the issues in fielding a thin, heated, large area optic, has led us to give more attention to the GIMMs.

3. *Dielectric Mirrors (reflective optics). These were abandoned in earlier studies because it was claimed that they degraded under intense neutron flux. We have some questions about these earlier claims, and are revisiting this approach at a low level.*

Progress reported at workshop:

5-1 Laser induced damage threshold tests completed with KrF laser…grazing incidence metal mirror (GIMM) still ok. UCSD had shown previously that grazing incidence aluminum mirrors exposed to green light (from a YAG laser) could survive over 10,000 shots at fluences better than 25 J/cm^2. Recently UCSD repeated these runs with a KrF laser at 248 nm. This of course is the wavelength of interest. The results showed a drop in the tolerable fluence to about 10 J/cm^2, which is still above our requirement. The damage threshold was critically dependent on the quality of the optic. This is in contrast to the longer wavelength results. Also, unlike at the longer wavelengths, the environment was quite critical, and the exposures needed to be performed well below atmospheric pressure (as would be the case in a power plant). Another interesting observation was that the UV light can condition the optic by removing impurities from the surface. In fact, a deliberately oiled surface was cleaned by the UV light. Bottom line: optics need to be higher quality, must be in a vacuum or low pressure environment, but contamination is less of an issue than originally thought.

5-2 Neutron irradiation of Final Optics: Los Alamos presented their results on the effect of neutron irradiation of transmissive final optics. Various optics candidates were exposed to 14.7-MeV neutrons at fluences up to 1.1 x 10^{15} neutrons/cm^2. Single crystal CaF_2 is unsuitable due to the large concentration of induced F centers; the dielectric mirror showed no effects, and the jury is still out on quartz. It should be noted, however, that the fluences expected in an actual power plant will be much larger. Thus this method serves as a first cut filter but not the ultimate test. The CaF_2 results are similar to those previously presented by LLNL who used fission neutrons for the exposure. It should also be pointed out that at a previous HAPL workshop LLNL reported that SiO_2, if operated at an elevated temperature, could have acceptable losses at the DPSSL wavelength of 350 nm. However the high optical absorption at 248 nm precludes the use of SiO_2 as a transmissive optic for KrF systems. In those studies the optic was exposed to fission neutrons at reactor relevant fluences of up to 8 x 10^{19} neutrons/cm^2. In a related program, LLNL and Oak Ridge National Laboratory (ORNL) are exposing dielectric mirrors, to be used as a reflective optic, with IFE-relevant fluences. These are done with fission neutrons, but are believed to be valid in the range of interest.

6. CHAMBERS

Phase I goals:

1. *Develop a viable first wall concept for a fusion power plant.*
2. *Produce a viable "point design" for a fusion power plant*

Approach:

We are pursuing the solid first wall chamber approach because if it can be made to work, it is the simplest approach both to field and upgrade. The issues with the first wall are short term degradation (either roughening or outright ablation) due to the instantaneous heat loading from the ions and x-rays from the target, and long term erosion due to helium retention. The short term heat loading is mitigated by the time of flight dispersion of the emissions from the target, which temporally spreads out the energy absorbed by the wall. A background gas in the chamber spreads this even further. The ideal first wall material would have a high melting/ roughening threshold as well as high thermal conductivity. The front runner candidates are either carbon-carbon composite, tungsten on SiC, or as investigated most recently, tungsten on ferritic steel.

Chamber physics is a complex phenomenon. To establish operating windows requires determining the energy spectra of each of the species produced by the target output, establishing how these species propagate through the chamber background gas to determine the "threat spectra" seen by the first wall, and then applying a material response code to determine the effect of this spectra.

The chamber conditions used in the above calculations are for shot number one. To determine the chamber conditions for shot #2 and beyond, we are developing a chamber dynamics code. This will eventually be coupled into the chamber models to get an integrated picture.

It is important to note that in an IFE Chamber most of the "action" takes place in the first 100 um. Behind the first wall the conditions are essentially steady state. Thus it should be straightforward to adapt the blanket technologies developed for MFE.

Progress reported at the workshop:
6-1 Helium retention in first wall may not be a problem for IFE: One of the biggest challenges with the solid wall chamber approach is long term survival of the first wall. High energy helium ions from the exploding target will be driven into the wall. The helium cannot move easily inside the material, and thus after many shots coalesces into bubbles which eventually cause the wall surface to fracture. This has been documented with tungsten, a prime candidate for the wall material. Those experiments were performed with tungsten at 800 degrees C. At this meeting, experimenters from Oak Ridge National Lab (ORNL) reported that if the tungsten is cyclically heated to the higher temperatures (> 2000 degrees C) expected in an IFE chamber, the amount of helium retained can be reduced by a factor of two or more. Moreover the amount of helium retained was strongly determined by the tungsten microstructure. CVD tungsten retained three times as much helium as polycrystalline tungsten. This work is preliminary and more experimental verification is needed--for example the effects of neutron irradiation on helium mobility need to be evaluated.

In addition to these experimental results, researchers from the University of California at Santa Barbara reported that their modeling shows the bubble formation could be reduced to the point that there may be no problem at all. This is because the ions produced by an IFE target have a wide spectrum of energies, and thus the helium will be driven to a range of depths into the first wall, rather than into just one location. The predicted exfoliation, or loss, rate from the first wall would be .078 cm per year. This result needs to be explored further and appropriate experiments conducted. So even though we are not out of the woods yet, at least we can now walk between the trees.

6-2 Established chamber operating window with ferritic materials: The University of Wisconsin has established a chamber operating window with a first wall composed of tungsten armor over an Oxide Dispersed Steel (ODS) base. The purpose was to establish if we could make a "first generation" IFE chamber work with existing or near future materials. The answer is yeas, based on coupling BUCKY runs of the target spectra with ANSYS runs of the temperature. (But making this particular two component first wall has yet to be demonstrated, as discussed below.) Wisconsin also has completed a thorough mapping of operating windows with graphite first walls. The operating windows were established in the three dimensional parameter space of temperature, density and radius. The whole process was expedited with the use of "Condor" flocks that allow them to tie into 450 computers on the University of Wisconsin network. The Condor flocks allow 100's of complex and detailed cavity dynamics runs to be completed overnight vs. only a few per night under the previous computing arrangements.

6-3 First version of chamber dynamics code completed. University of California San Diego (UCSD) announced the completion of the SPARTAN chamber dynamics code. This will become a very powerful tool to determine how the chamber "clears itself" and the conditions for shot #2 and beyond. The code is a ground up, fully modular package, so new physics can be incorporated to allow improvements and upgrades. An example simulation of the post-shot pressure history in the chamber and a representative beam tube was shown demonstrating the current capabilities of this 2D code.

6-4 Facility for chamber dynamics /material exposure experiments nearing completion. This is under development at UCSD. The facility uses an ND:YAG Laser (2 Joule output) to test the real time behavior and evolution of the wall material. UCSD has shown with modeling that a tuned laser beam can replicate the temperature profile in the first wall. A laser, of course, gives added flexibility with high rep-rate and adjustable energy profile. The facility is complete, but is awaiting final development of a Multi-Color Fiber Optical Thermometer (MCFOT) which will enable very accurate real time measurements of the wall behavior.

6-5 Magnetic deflection: If ion implantation turns out to still be a problem (i.e. the recent good results cited above don't pan out) we are evaluating the use of magnetic fields to deflect the ions to engineered sinks. Even if it is not needed for wall protection, it could be used to protect the final optics. Even though the fluxes at the optics are lower, the damage thresholds are significantly lower. LLNL reported results of their work with MRC. Although not yet complete, it looks like a field of 1 T should be sufficient for wall protection. LLNL Plans to field supporting experiments on LAPDU (Large Area Plasma Device Upgrade) at UCLA.

6-6 Safety analysis of graphite wall safety completed, shows oxidation is not a concern: This issue was discussed in a series of talks several workshops ago. While graphite data used in the calculations performed by LLNL and Idaho National Engineering and Environmental Laboratory (INEEL) suggested that there was a runaway oxidation problem, Wisconsin expressed concerns about the extrapolation of reaction data to such low temperatures. In response, INEEL measured the reaction rates for a modern carbon-fiber composite (NB31) at temperatures in the range of 525 to1000 degrees C. The results showed that NB31 is quite oxidation resistant, and that the initial temperature transient can be tolerated without bulk oxidation of the chamber/blanket structures. This is an excellent example of how process is supposed to work: 1) Analysis identifies the issue, 2) Capabilities improved to confirm the result, 3) Experiment conducted using newly available material. 4) New analysis performed to address issue.

7. MATERIALS DEVELOPMENT

Phase I goals:

Develop materials in support of chamber and first wall concepts

Approach:

Materials development is carried out as an integral part of the chambers and optics tasks. We are concentrating on experimentally validating the effects of the various threats on both optics and chamber components. These are coupled to modeling to ensure we have an appropriate predictive capability. We are also looking at advanced or engineered materials that can give improved performance, and are developing and evaluating advanced fabrication techniques that are critical to our first wall concepts.

Progress reported at the workshop:

7-1 XAPPER pulsed x-ray facility is operational at LLNL XAPPER is a gas z-pinch based x-ray source that will be used to study the effects of repeated x-ray exposure to materials. Of particular interest are the thermal fatigue and the gradual degradation (as manifested by roughening) caused by dislocation of line defects (progressive extrusion from the surface as a result of fatigue cycles). The latter has been modeled by UCLA for laser damage testing of aluminum mirrors. Time-temperature and stress-strain modeling will be carried out with the LLNL ABLATOR code. The facility should produce 7 J/cm^2 in a 3 mm focal spot at energies of 113 eV. The dose resulting from such fluences exceeds that expected from IFE targets, and hence will be a valuable test. The XAPPER facility has been installed and brought to full operation. LLNL is awaiting a new optical element to better focus the x-rays.

7-2 Materials exposure continues on RHEPP and Z machines at SANDIA. RHEPP produces ions, Z produces x-rays. These produce fluences and spectra that are typical of the anticipated threats on the chamber first wall. Both graphite and tungsten have been exposed, and the results compared with analytical modeling and BUCKY code predictions. The modeling agrees with the observed ablation thresholds in most case within 20%, but in some cases the difference can be as much as a factor of three. Obtaining accurate thermal properties, particularly of molten tungsten is important in achieving this agreement. From these results the threats from the x-rays do not appear to be a problem, if the chamber has no background gas, but the ions may pose a threat. The threat is not so much ablation as roughening of the surface, which appears to grow on each shot. The roughening is likely due to thermo-mechanical stress. Previous work thought ablation would be the upper limit, but if it is roughening, the threat to the wall from the ions is more serious. This is why most of the operating windows require some sort of background gas. Further exposures need to be performed at elevated temperatures, and we need to make sure we are taking into account the proper spectrum at the wall and the proper pulse shape.

7-3 Advanced engineered materials explored. UCLA pointed out that the ideal wall material would have high melting temperature, and be composed of small ligaments to both allow the material to “breathe” under cyclic thermal stress, and to allow the entrapped helium to get out. The ideal structure would also allow x-rays and ions to deposit their energy deeper into the first wall. UCLA proposed a solution that uses tungsten foam on an ODS (Oxide Dispersed Steel) base. (Although this tungsten foam has not been fabricated, foams with 1 micron ligament width have been made of Nb-Ti, and it is thought that the same technique could apply to tungsten.) It is estimated that the helium residence time can be less than 45 msec (about 1/5 the intershot time) if the temperature is at 1400 degrees C. One big issue with this foam is thermal conductivity and diffusivity, and that will be investigated. In addition to the foam, UCSD proposed another engineered material based on nano-composited tungsten. Development of such a material by PPI is the focus of a current DOE/OFES SBIR proposal. For our purposes it would also have to have some microstructure to allow thermo-mechanical cycling and helium desorption characteristics.

7-4 Mechanical fatigue in first wall structure should be manageable. UCLA also reported that if the first wall uses coolant tubes and are made of curved surfaces, the mechanical fatigue in the first wall should be manageable.

7-5 First work in bonding two component first wall reported. As most of the heat is deposited in a very thin layer (<100 um), we have the option to separate the functions of the first wall into two components: A thin armor, that is resistant to the target emissions, and an underlying substrate, to providing the supporting structure and interface with the blanket. (Note that the blanket sees effectively steady-state conditions.) This approach was first proposed by UCSD. At this meeting, ORNL reported first results of using a plasma arc lamp to bond a titanium layer onto a SiC substrate. This technique produced a layer with strength considerably higher than conventional techniques (CVD, PVD, etc.) Attempts to bond tungsten to steel were less successful, and additional work is needed. In both cases the durability of the bond under radiation damage and cyclic stress remains to be demonstrated and will be one of the upcoming areas of research.

7-6 Common methodology for evaluating materials under development With four different material exposure facilities, it was decided to establish a methodology for evaluating materials so that we will have a common database. The materials will be supplied by one source (ORNL) and will be chosen, after consultation with the community, for ease of modeling (i.e. its properties are well known) and relevance. The samples will be prepared by ORNL, and a common mounting, handling, and characterization procedure will be defined. This ensures that we are all working with the same material and are evaluating it the same way.

THE NEXT WORKSHOP WILL BE IN APRIL.