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Title: Summaries of FY12 LANL Experimental Campaigns at the OMEGA Laser Facility

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Summaries of FY12 LANL experimental campaigns at the OMEGA Laser Facility

Overview

In FY 2012, Los Alamos National Laboratory (LANL) executed 244 total shots on OMEGA. LANL experiments contributed to the National Ignition (NIC) campaign in the following ways:

- Measured the x-ray ablative Richtmyer-Meshkov growth of isolated defects on plastic ablators
- Studied branching ratios in DT fusion plasmas
- Continued neutron imaging and radchem scintillator development for NIF

High-Energy-Density (HED) campaigns included:

- Studied shear in a counter-propagating flow geometry and reshock driven turbulent mixing
- Backlit defect implosion experiments to study effect of trench defect and polar direct drive
- Measured effect of capsule asymmetries on neutron yield and ion temperature
- Imaging x-ray Thomson scattering platform development for dense plasmas and warm dense matter equation of state
- Measurement of a supersonic radiation wave and foam aerogel EOS

CHaRM

The CH ablative Richtmyer-Meshkov (CHARM) campaign had two shot days in FY12. The goal of these experiments was to measure the oscillation frequency of small perturbations on CH ablators driven by the x-ray ablation Richtmyer-Meshkov effect. With this knowledge we would have a better understanding of how isolated defects behave during the first shock transit stage of a NIF ignition attempt, which could then provide methods for minimizing perturbations at the onset of Rayleigh-Taylor.

Our experiments used 15 beams inside large Au half-hohlraums, which were staggered in time to produce a 7.5 ns radiation drive with radiation temperature of 70 eV (see Fig. 1). Targets with 2-D arrays of 5 micron tall, 17 micron FWHM Gaussian bumps on them were attached over the opposite laser entrance hole with the defects facing inside the halfraum. During the experiment the bump arrays were backlit with Y and Ta backlighters (~2.2 keV emission) and imaged at 37x magnification into an x-ray framing camera.

Fig. 1: Schematic of CHARM platform where a Au halfraum is heated to 70 eV driving an ablation front into an array of isolated gaussian bump defects. Bumps are radiographed along the axis of the halfraum

Radiation hydrodynamics simulations running with Equation of State (EOS) tables for CH predict these small bumps decay for our experimental conditions as shown in Fig. 2 (green curve). The trend in our data supports this prediction even though the data lies somewhat above the simulation curve, which we think is either due to systematic errors in the data analysis or errors in the models. Nevertheless, this decay in amplitude occurs at a rate that is much slower than under direct-drive conditions measured at NRL. This has to do with the differences in absorption, transport, and ablation mechanisms between x-ray and laser drive. Under our conditions only very narrow bumps (<20 microns) exhibited this decay while wider bumps (>30 microns, FY11 data) only saturated. Contact: Eric Loomis, loomis@lanl.gov

Fig. 2: Summary of long drive duration data showing the saturation of bumps with width >30 microns and ablative RM decay for those with width less than <20 microns

Shear

In FY12 the Shear campaign focused on developing a counter-propagating flow platform for studying shear-driven turbulent mixing. These experiments use Be tubes containing low-density CH foam semi-cylinders separated by Al tracer layers. The counter-propagating flow is created by inserting Au “plugs” in front of each foam semi-cylinder at opposite ends to hold back the shock in each foam at one end (see Fig. 3). With the plugs in place the Be tube ends are irradiated with 10^{15} W/cm² laser intensity to initiate the counter-propagating flow. When the shocks cross they establish a shear layer in the Al, which then grows due to turbulent mixing.

Fig. 3: Geometry for counter-flowing Shear platform. Simulations with BHR mix model also shown

Over the course of the year we improved the target design by extending the length of the Al tracer so that shocks from one end could not penetrate into the adjacent foam. This created a longer duration, cleaner shear flow for studying the turbulence. We used x-ray radiography along two orthogonal lines-of-sight (edge-on and plan view of the tracer layer) to image the evolving turbulent structure at $>20\times$ magnification. In the edge-on view (see Fig. 4) the growing mix layer was imaged at times from 6 to 16 ns and in relatively good agreement with the LANL BHR turbulent mix model. The same data times were used (on the same shot) for the plan view radiography, which appears to show a transition to turbulence around the 10 ns point where 3-D structures begin to form out of the initially homogeneous flow. Contacts: Eric Loomis, loomis@lanl.gov

Hemi-cylinders of 60 mg/cc CH foams held together inside Be tube.
Separated by 20 micron Al foil

Fig. 4: Radiographs at two different times showing development of counter-flowing shear and mixing

ABEX

In laser driven implosions, of importance to inertial confinement fusion and stockpile stewardship, the cold shell is known to mix into imploding nuclear fuel. Yet there are no direct observations of just where, and at what rate, shell material migrates into the fuel. In June 2012 experiments at OMEGA facility in Rochester, LANL's ABEX (asymmetric-burn-experiment) campaign, in collaboration with the University of Nevada-Reno group of Prof. Roberto Mancini, has made advances towards providing time-resolved images of shell mix into fuel. Emission from titanium dopant in the shell is used to make quasi-monochromatic images. Temperature, and ultimately a crude estimate of chord-integrated titanium, has been extracted (see Fig. 5). Three separate such views, each at multiple times, were obtained each shot.

Fig. 5: Ti originally in the shell has mixed into the fuel (typical false-color map is used, i.e. red corresponds to increased signal).

A capsule with pre-imposed perturbations (Fig. 6) showed images similar to those obtained with perfect spheres--but to just what depth the Ti has penetrated remains ambiguous. The team is now focused on advanced analysis and refinement of the target design in order to address the long-standing absence of mix images in laser-driven implosions. Contacts: Rahul Shah (rcshah@lanl.gov) & John Benage (benage@lanl.gov)

Fig. 6: Photograph of a machined PAMS mandrel with ± 10 mm amplitude perturbation. The axis of symmetry is horizontal in this photograph.

RadChem

On 6 Aug. 2012, the Los Alamos National Laboratory prompt radchem development team successfully tested new assay system designs on the Omega Laser. Prompt radiochemical signatures generated in high energy density experiments provide insight into a variety of physical phenomena including late time hydrodynamic performance of the implosion as well as particle stopping within the plasma. These signatures are created through charged and neutral particle nuclear interactions within the imploded capsule materials. Often the resulting radioactive products undergo beta decay with end point kinetic energies approaching 14 MeV and half-lives as short as 20 milliseconds. The short half-lives necessitate deploying an assay system within the target chamber which will withstand the harsh, prompt radiation environment, but will readily assay the high end point energy beta decays that immediately follow. Further the detector must have minimal sensitivity to the flux generated by background sources.

During the August campaign the LANL based team fielded a new 4 element scintillator telescope, to measure beta decay from various elements with different end point energies ranging from 3 MeV up to 14 MeV and half-lives from 20 ms to several minutes. Figs. 7 illustrate the strategy employed by the detector. The red curves represent the electron spectrum expected from decays of ^{16}N and $^{9,10}\text{B}$. The colored vertical lines approximately represent the threshold sensitivity of the individual elements within the telescope detector, e.g. the first element will register hits from electrons above about 1 MeV, the second above ~ 2 MeV, etc. By requiring a coincidence between the elements of the telescope detector, not only is the background flux outside the solid angle of the detector acceptance reduced, but a threshold cut is placed on the electrons depositing energy within the telescope.

Fig. 7: Beta-decay spectrum with approximate detector element thresholds. (Left) ^{16}N beta spectrum, (right) $^{9,10}\text{B}$ beta spectrum

To test these concepts, the detector was fielded on the Omega target chamber during a set of high-yield implosions of DT filled glass and plastic capsules. Activation targets, including a polytetrafluoroethylene (Teflon) puck, were located in front of the telescope yielding the data shown in Figs. 8. Fig. 8 (left) shows the coincidence rate of the first two scintillator elements shortly after a shot. A fit to the distribution clearly shows half-life contributions from ^{16}N and ^{19}O decays, as expected from $^{19}\text{F}(n,\alpha)^{16}\text{N}$, and $^{19}\text{F}(n,p)^{19}\text{O}$ reactions. Fig. 8 (right) shows the coincidence rate using the first three elements, thus requiring a ~5 MeV threshold. This higher threshold eliminates the ^{19}O contribution, and significantly reduces the ^{16}N to the lower intensity, higher energy decay. The fit shown in Fig. 8 (right), using an exponential and no background, and gives a half-life measurement of, $t_{1/2}(^{16}\text{N}) = 7.11 \pm 0.14$ sec, in excellent agreement with the published value of 7.13 sec.

Fig. 8: Prompt decay data from a high-yield Omega implosion. (Left) Two element coincidence rate, (right) three element coincidence rate

Future experiments are planned at Omega, where the telescope will be moved closer to the imploding capsule to test the robustness of detector to prompt radiation, as well as to provide the opportunity for other activation measurements. Contacts: Andi Klein, aklein@lanl.gov; Gary Grim, pggrim@lanl.gov

DPEOS

The purpose of the DPEOS project is to measure the equation of state (EOS) of material in the warm dense matter regime. To accomplish this, we are developing an experimental platform to do this at Omega. Our experimental platform utilizes the Omega laser to drive a very strong shock into an aluminum or graphite sample. The shock is then released into 0.2 g/cm³ aerogel foam which is used as a pressure standard. A shock breakout measurement is used to determine the shock velocity and pressure in the foam. We have also developed an imaging x-ray Thomson spectrometer to measure Compton scattered x-rays from the released sample. This information can be used to determine the temperature and density of the released material, providing the necessary measurements to determine the EOS.

Our experimental plan for FY12 was to test and measure the shock and release conditions produced in the aluminum sample, get our new imaging x-ray Thomson spectrometer (IXTS) approved, test its operation, and obtain the first x-ray scattering measurements of WDM aluminum and/or carbon. We were successful in reaching these goals. We completed a total of 24 shots in two days at Omega. On the first day, we successfully fielded the IXTS for the first time and did obtain scattering data. However, our signals were contaminated by background x-ray signals from our x-ray backlighter. Our shielding and target design were improved for the second shot day in August and we obtained our first detailed x-ray scattering measurements from warm dense matter carbon. These measurements enabled a determination of the temperature of the shock and released carbon. In addition, we verified the shock conditions for both carbon and aluminum, which were consistent with our previous measurements. An example of the IXTS data we obtained is shown in Fig. 9. This figure contains the analyzed x-ray scattering signal along with a series of fits to the data. Two shot days are planned for FY13 in which we will perfect our target design to obtain better signal to noise for this data and in addition will carry out x-ray radiography measurements to pin down the density of the material. This will provide a complete EOS measurement for these warm dense matter conditions and be used to test EOS models in this regime. Contact: John Benage, benage@lanl.gov

Fig. 9: X-ray Thomson scattering measurements from shock and released warm dense matter graphite target. The elastic peaks correspond to scattering from bound electrons while the inelastic peak is due to scattering from free electrons. The measurements indicate a temperature of ~ 10 eV and density near 2 g/cm^3 .

NIF-5

The purpose of the NIF5 project is to test both diagnostics and physics ideas important for facilitating our understanding of important radiation flow experiments being carried out at the NIF. In the past, this project has focused significantly on diagnostic development and testing and experimental platform development. This fiscal year we changed the focus of the project to address an important physics issue for these experiments, namely the equation of state (EOS) of the foams used in these experiments. Foams exhibit sometimes significantly different material behavior than normal materials, both in their response to shocks and in their relatively high specific heats at moderate energy density.

To address these concerns, we carried out two days of experiments and a total of 28 shots on Omega in FY12. These experiments built on the platform development of other shock physics experiments at Omega, including target geometries and diagnostics. This enabled us to be relatively successful right away. Our specific purpose for these experiments was to measure the temperature of shocked aerogel foam in the few Mbar range. The foam would have an initial density of 0.2 g/cm^3 , which has the advantage that the principal

Hugoniot for this foam is well known, requiring only a measurement of the shock velocity to determine the state. We were very successful obtaining both good shock velocity measurements and SOP measurements for a wide range of pressures. A brief analysis of the shock velocity and SOP data is given in Fig. 10. We found that the temperature dependence on the shock velocity was weak for a wide range of shock velocities, indicating a very high specific heat and also indicating the important energy density range where ionization and dissociation is occurring. We also see a saturation of the SOP temperature at higher shock pressures. We believe this is either a limitation of the diagnostic or more likely radiative heating at the shock front that is confusing the measurement. As the two shot days were quite close together, few modifications were done to the target design and so this effect could not really be further investigated. We expect to learn more about this effect through a series of double shock experiments to be carried out in FY13. Contacts: John Benage, benage@lanl.gov

Fig. 10: Temperature and shock velocity measurements for 0.2 g/cm^3 aerogel foam targets. The straight line fit is based on Hugoniot measurements for this foam and the horizontal dashed line corresponds to a pressure of $\sim 4.4 \text{ Mbar}$.

DTRat

On Aug 9, 2012, LANL's ICF Gamma Ray Physics team conducted ongoing DT Ratio Campaign experiments at OMEGA. Yongho Kim and Hans Herrmann led the collaborative effort including participation from LLNL, AWE, MIT, Colorado School of Mines, Cornell and LLE. The capsules consisted of $\text{D-}^3\text{He}$, $^3\text{He-}^3\text{He}$

and D-T fills for the primary purpose of characterizing the D- ^3He γ -ray spectrum. D- ^3He γ -ray measurements have been used by Kim, et al. [1], as a cross-calibration for the recently published D-T gamma-to-neutron branching ratio (BR) inference under the assumption that ^5He from D-T & mirror nucleus ^5Li from D- ^3He generate virtually identical γ -ray spectra. This shot day was intended to test this assumption.

Figure 11 shows preliminary data taken by Gas Cherenkov Detector (GCD) during a Cherenkov threshold scan indicating the primary peak from D- ^3He fusion gammas decreases with increasing energy threshold as expected. More quantitative analysis is awaiting the results of CR-39 based proton yield measurements. However, one interesting feature is what appears to be a secondary peak (~ 0.2 ns), which is not reduced as readily by thresholding, implying that it is from photons of higher energy than the 16.6 MeV D- ^3He fusion gammas. The peak remains when the capsules contain no D (i.e., ^3He - ^3He implosions). Since there is no expectation of a fusion gamma from the unbound and thus extremely short-lived ^6Be , the current speculation is that this peak is the result of extremely high energy laser plasma instability (LPI) x-rays (>20 MeV) coming from the Two Plasmon instability. This mechanism is known to be amplified for thin walled glass capsules in which fusion bang time occurs before the end of the laser pulse. Over the past 2 years we have observed that this secondary peak becomes more pronounced with capsule thinness. It is now clear that this secondary peak must be accounted for when measuring the D- ^3He gamma yield and cross-calibrating D-T γ/n BR to D- ^3He γ/p BR. Doing so will have the result of making the cross-calibrated BR value more consistent with the previously determined absolute BR value published in Y.H. Kim, et al. [2]. This discovery may also lead to greater insight into LPI mechanisms leading to ultra-hot electrons having deleterious effects on ignition. Contacts: Yong Ho Kim, yhkim@lanl.gov

Fig. 11: Data from GCD showing fusion gamma decreasing with increasing energy threshold

[1] Y. Kim, J. M. Mack, H.W. Herrmann, C. S. Young, G. M. Hale, S. Caldwell, N. M. Hoffman, S. C. Evans, T. J. Sedillo, A. McEvoy, J. Langenbrunner, H. H. Hsu, M. A. Huff, S. Batha, C. J. Horsfield, M. S. Rubery, W. J. Garbett, W. Stoeffl, E. Grafel, L. Bernstein, J. A. Church, D. B. Sayre, M. J. Rosenberg, C. Waugh, H. G. Rinderknecht, M. Gatu Johnson, A. B. Zylstra, J. A. Frenje, D. T. Casey, R. D. Petrasso, E. K. Miller, V. Yu Glebov, C. Stoeckl, and T. C. Sangster, *D-T gamma-to-neutron branching ratio determined from inertial confinement fusion plasmas*, Physics of Plasmas **19**, 056313 (2012)

[2] Y. Kim, J. M. Mack, H.W. Herrmann, C. S. Young, G. M. Hale, S. Caldwell, N. M. Hoffman, S. C. Evans, T. J. Sedillo, A. McEvoy, J. Langenbrunner, H. H. Hsu, M. A. Huff, S. Batha, C. J. Horsfield, M. S. Rubery, W. J. Garbett, W. Stoeffl, E. Grafel, L. Bernstein, J. A. Church, D. B. Sayre, M. J. Rosenberg, C. Waugh, H. G. Rinderknecht, M. Gatu Johnson, A. B. Zylstra, J. A. Frenje, D. T. Casey, R. D. Petrasso, E. K. Miller, V. Yu Glebov, C. Stoeckl, and T. C. Sangster, *Determination of the D-T Branching Ratio based on Inertial Confinement Fusion Implosions*, Physical Review C **85**, 061601 (2012)

DIME

The DIME campaign had two shot days in 2012 at OMEGA. For the first, we used symmetric 60-beam illumination with $\sim 800\text{-}\mu\text{m}$ -spot phase-plate-smoothing for 1 ns to drive spherical implosions. The objective was to measure the mix depth of an embedded Ti layer (1% by atom) in the spherical capsule wall. The variable was the separation of the 2- μm impurity layer from the inner wall of the 435- μm radius capsule for the ten targets. The embedded depth was 0, 1.4, 3.0, or 4.8 μm . The 19- μm wall thickness was sufficient to prevent burn through by the laser drive. Therefore, we collected data for the 4π mix. A **first look** at normalized data is shown in Fig. 12.

Fig. 12: Correlation of mix parameters for 60-beam drive

Neutron yield data were provided by Vladimir Glebov (LLE). Barukh Yaakobi (LLE) facilitated the spectral analysis of the Ti Ka absorption feature and Ti line emission from the x-ray spectrographic data. One calculates the ρr of Ti from the transmission T of the continuum at 4.5 keV: $\rho r = -\ln T/s$ where s is the x-ray attenuation coefficient cm^2/gm of cold Ti. The line emission of Ti, heated by mix with the hot deuterium fill gas, peaks at zero depth and damps quickly with burial depth, thus corroborating this picture of mix. The curved lines are to 'guide the eye'. The anticorrelation between yield and the Ti spectral data, which indicates a mix depth of $\sim 1.5 \mu\text{m}$ is consistent with expectations. A similar campaign, identical in every respect for targets, was executed for polar direct drive later in the year. The objective for this campaign was to assess how PDD altered the mix depth and the spatial variations inherent with PDD. Steps in the inner CH wall layer were smaller. Data analysis is pending. Contacts: Jim Cobble, cobble@lanl.gov

Colliding Shock

The LANL Colliding Shock Campaign had nearly 30 shots on the Omega 60 laser in November, 2011; March and July, 2012. Radiographs of the colliding shocks were obtained on two cameras looking on orthogonal axes and at 2 ns delays with respect to each other. Excellent quality images were obtained, and a series of 3 are shown in Fig. 13 from 6, 12, and 18 ns. The experimental target is shown in the top of Fig. 13, which consists of a Be tube filled with foam, and a 20 micron Ti foil tracer on one side. The target is driven from both ends (with a slight delay to the beam opposed to the foil). At 6 ns the foil is just beginning to be driven into the foam, at 12 ns the foil has propagated into the foam and is just meeting the oncoming shock, and at 18 ns it has been recompressed and stalled by the counter propagating shock passing through it. The Be tube and shocks are visible in the radiographs as faint outlines perturbed by the propagating shock at the walls and in the foam. At 18 ns the tube is almost completely unrecognizable. The information from the turbulent mixing of the Ti layer in the reshocked area is contained in the width of the Ti layer. This width can be compared to our BHR-2 mix model in hydrodynamic simulations to understand how turbulence can affect the mixing of materials at material boundaries. Contact: Kirk Flippo, kflipppo@lanl.gov

Temporal Evolution of Ti foil layer

Fig. 13: The temporal evolution of a 20 micron Ti tracer foil inside a Be shock tube filled with foam. The laser pushes a shock into the tube from both ends, with a resultant recompression and stall of the shocked layer