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Application of New Techniques for EOS Data

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at Los Alamos National Laboratory (LANL). One area of great uncertainty as well as high physics leverage is that of the material properties of plutonium and other materials including zirconium, uranium-niobium, deuterium-tritium, tantalum, beryllium, and oralloy. These properties include plutonium Hugoniot and melt-curve data to 10 Mbars and the plutonium off-Hugoniot data. Our goal is a proof-of-principle experiment on the Los Alamos Trident laser that will determine the technical and logistical issues involved with performing an accurate equation-of-state (EOS) and melt-curve experiment with plutonium, as well as performing initial measurements on the plutonium Hugoniot. This method can also be used to gather data at relatively low cost for other materials as well. Such a capability would complement existing gas-gun facilities and laser-driven miniflyers.

Background and Research Objectives

There have been a number of basic experiments over the last twenty years using lasers to drive a strong shock in various materials [**1-4**]. In the last ten years, this method has been used to measure the equation-of-state (EOS) on the principal Hugoniot [**5**]. The initial experiments had inaccuracies of ~10% due to a number of factors: shock planarity and consistency in time, non-uniformity of the laser beam in directly driven targets, diagnostic resolution and edge effects due to target size, to name a few. Recent experiments at the Atomic Weapons Establishment (AWE) using the HELEN laser to produce x-rays via indirect drive into a hohlraum, coupled with very careful calibration of diagnostics, have produced measurements of the EOS of copper to an accuracy of within about 2 to 3% at pressures up to ~20 Mbars [**6**]. Thus the basic principle of accurate

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measurements using x-rays from a laser-driven hohlraum to generate an ablation-pressure-driven shock has been demonstrated, as well as the diagnostic technique of measuring the shock breakout with optical streak cameras.

We propose to use a similar geometry and methodology to make EOS measurements for plutonium and other materials of interest in the range of pressures of interest up to 10 Mbars. For the lower pressures, we will adapt two techniques developed and used in other experiments: an active shock breakout technique and high-resolution transverse radiography. The latter technique may allow, for the first time in these laser-driven experiments, the potential for absolute Hugoniot measurements (instead of the usual impedance technique) by measuring the particle velocity and density simultaneously with the shock velocity. For these proof-of-principle experiments, the pressure ranges will be lower, possibly to ~1 Mbar. It may be required to use a larger driver to achieve the higher pressure ranges with larger sample sizes of interest.

In the past, the non-smooth illumination by glass lasers made directly driven shocks very non-planar and unsatisfactory. Although more accurate measurements have been done with x-ray drive produced by a hohlraum, the tradeoff is a much lower energy efficiency due to conversion of laser light to x-rays. However, there have been recent advancements in beam-smoothing techniques as well as basic laser technology. Smoothing by foam buffering utilizes a preheat and thermal conduction layer to smooth the laser beam by transverse thermal conduction before the beam deposits energy into the material. Smoothing using random phase plates (RPP) to spread the beam profile (and defects) over a large area, smoothing by spectral dispersion (SSD), and other methods have been developed over the years for the inertial confinement fusion program.

There have also been published techniques to measure melt in a solid material using x-ray diffraction [7]. The idea here is to create an x-ray source with a laser and use the crystallographic properties of solids to Bragg-diffract the x-rays onto a detector. When a shock of sufficient strength passes through the material of interest and causes the solid to melt, the crystallographic structure is eliminated, and hence the detector no longer measures any diffracted x-rays. This can be used to accurately measure the melt curve of the

material. We propose to evaluate this method to measure the melt curve of plutonium in conjunction with the EOS measurements.

There are many advantages to utilizing these methods to study plutonium material properties. Some are elucidated here. First, both diagnostics and the methods of driving the shock are non-contact techniques. This means containment and ES&H issues are greatly reduced. A small chamber, ~12-in diameter, holding the plutonium can be constructed without requiring any physical contact with the driver (a laser beam) or the diagnostics (a laser beam or x-rays). Secondly, the quantities of plutonium required to perform the measurements are very small; even less than the accountable limits. Third, the experiment can be performed in a laboratory facility under carefully controlled and reproducible conditions. Fourth, the shot rate/data acquisition rate is relatively high, typically -6 shots a day. And fifth, the relative costs for the facility operations are low in comparison with other measurement methods: ~ $3k per shot is required, a negligible amount compared to other associated costs (experimentalists, target fabrication, etc.). Because the facility is shared with other programs and projects and the plutonium can be isolated in a containment vessel, there is no need for a dedicated facility to perform these measurements. Finally, there are no other proven laboratory methods to reach pressures in the ~10 Mbar regime.

Complementarity with Other Approaches

We have examined the approaches presently used to acquire such information and believe that our proposed approach is complementary; it offers features that other approaches do not have and couples well with information available from other facilities. The other facilities considered were LYNER, gas guns and laser driven miniflyers, as well as the diamond anvil technique. LYNER at present has the potential to acquire data on large sample sizes; this also simplifies diagnostics and can provide high accuracy data. However, due to the cost and quantities of material involved, there will be far fewer shots available than our technique could provide. Thus the differences due to size (i.e., grain structure) on LYNER can complement the larger quantity of data available with our technique. In addition, LYNER cannot reach the upper limit of pressure ranges of interest.

Gas guns also are a laboratory method of acquiring data. These have the potential benefits of large amounts of data and a proven technique. However, a dedicated facility is required and because of the contact method of producing the pressure, the entire apparatus must be contained and precautions taken in case of a breach. In addition, the pressures available with the present system are again below the upper limit of interest.

Laser-driven miniflyers can acquire data up to ~200 kbars. This technique is difficult to extend much past this due to laser absorption, planarity and other issues. Thus this technique is good for lower pressures; our technique is good at higher pressures, >100 kbars. There are other laser facilities potentially available. However, none of these offer the convenience of being able to handle plutonium and other hazardous materials. For proof-of-principle experiments, the cost of developing a remote plutonium- handling capability and transportation is not warranted.

In summary, our goal is a proof-of-principle experiment on the Los Alamos Trident laser that will determine the technical and logistical issues involved with performing an accurate EOS and melt-curve experiment with plutonium, as well as performing initial measurements on the plutonium Hugoniot. This method can also be used to gather data at relatively low cost for other materials as well. Such a capability would complement existing gas-gun facilities and laser-driven miniflyers.

Importance to LANL's Science and Technology Base and National R&D Needs

Having a facility that could provide large quantities of accurate EOS and melt data for many materials in a cost-effective manner would have a significant programmatic impact. The pressure ranges of interest are very difficult to calculate and model, thus requiring data. The present data set is both sparse and has large uncertainties in certain regimes. In addition, the present data acquisition rate is low due to cost considerations and other factors. Our proposed method, if proven, can fill the requirements in many regions and can be complementary to the other methods. It will also provide unique capabilities in terms of the pressure ranges > 2 Mbar and off-Hugoniot measurements that cannot be made with the current set of facilities.

Scientific Approach and Accomplishments

Our planned approach towards performing the proof-of-principle measurements was as follows. (1) Perform calculations on indirect drive requirements to generate a planar and constant shock in a reference (aluminum) material and surrogate. (2) Measure shock planarity and strength generated by a indirect driven hohlraum on Trident. (3) Determine and develop a procedure to fabricate plutonium targets, install them into a dedicated contained vacuum chamber, transport the chamber from the Plutonium Facility to Trident, shoot the targets within the chamber, and transport the chamber back to the Plutonium Facility for cleanup and reuse, all according to NEPA guidelines. The total amount of plutonium will be much less than 0.5 grams, the accountability limit. (4) Design and possibly fabricate the chamber, if results and data are available to do so. (5) Perform preliminary experiments on Trident with surrogates to further develop the melt technique measurements using dynamic x-ray diffraction.

During the project year, our activities included performing calculations on direct- and indirect-drive requirements to generate a planar and constant shock in a reference material and surrogate, measuring shock planarity and strength generated by an indirect-driven hohlraum on Trident, and performing preliminary experiments on Trident with surrogates to further develop the melt technique measurements using dynamic x-ray diffraction.

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