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Title: LANL and ANL Complete Ground-Breaking Shock Experiments at the Advanced Photon Source

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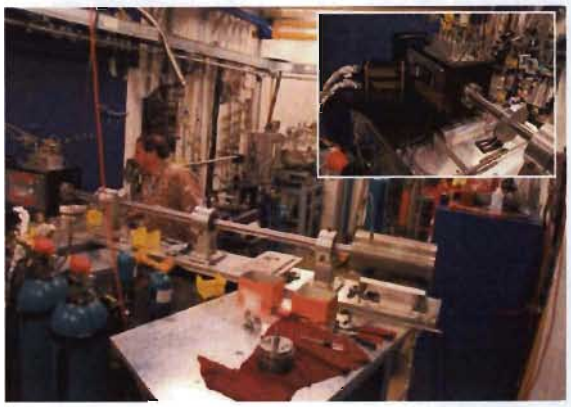
LANL and ANL Complete Ground-Breaking Shock Experiments at the Advanced Photon Source

When a projectile impacts a material, a shock wave (or compression wave) is formed creating high pressures states in very short timescales - typically within a few nanoseconds (or billionth-of-a-second). These "extreme" states of matter, found in nature as meteorite impacts or within the earth's core for example, can be created in the laboratory using explosives, lasers, and gun systems. For decades, scientists have studied the shock wave and how it propagates through a material to learn how materials fail or "break", to understand how materials transform from one phase to another (melting, freezing, etc.), or to generate conditions that are comparable to those found inside the planets. Although there has been much success in relating the shock wave profile to the material response, standard methods have difficulty when the processes and/or materials are heterogeneous. To study complex materials (such as foams, powders, high explosives, etc.) and/or complicated processes (hot-spot formation in explosives, formation of jets, phase transitions, etc.), more advanced diagnostics are required. Developments in synchrotron facilities (intense and coherent X-ray sources) and in detection methods provide unique opportunities for ultrafast, high-resolution, spatially resolved measurements to examine materials during impact loading.

The goal of a team from Los Alamos National Laboratory (LANL) in collaboration with scientists from Argonne National Laboratory (ANL) was to develop a mobile plate impact facility for use at synchrotron facilities, to install this gun in the beam at the beamline 32ID-B, and to perform ultrafast measurements of material subjected to impact loading. In October 2011, this team completed their first experimental run at the Advanced Photon Source (APS) using the Impact System for Ultrafast Synchrotron Experiments, or IMPULSE, a 12-mm launcher system designed specifically for use at synchrotron sources and capable of reaching moderate projectile velocities up to approximately 1 km/s. Figure 1 shows photos of the IMPULSE system inside the experimental beamline 32ID-B at the APS.

Two experimental methods were used to examine shocked materials including phase contrast imaging (PCI) and dynamic Laue diffraction. Figure 2 shows a diagram of the experimental configurations. PCI can be used to obtain high-resolution images with high contrast allowing one to resolve fine features/structures such as cracks, particles, interfaces, etc. Briefly, X-rays transmitted through the samples were converted to visible light (using a scintillator), and imaged onto a fast detector (detector to sample distance optimized for best contrast) to obtain a detailed 2D image of the event in real-time. The second method known as Laue diffraction,



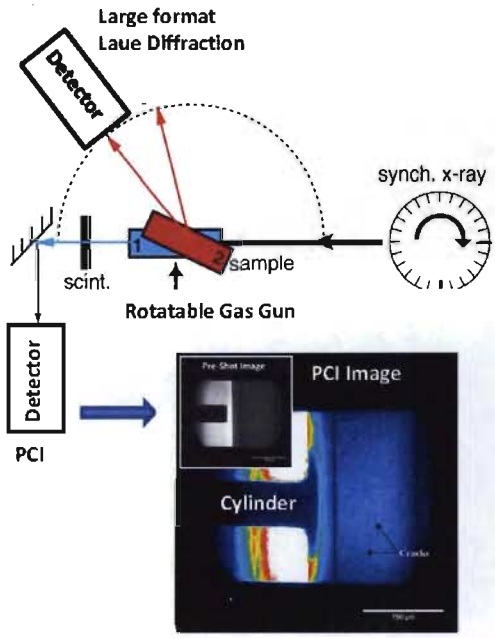


FIG. 1. The IMPULSE mini-gun system (12-mm bore) shown inside the experimental hutch at Sector 32 ID-B (top). A diagram of phase contrast imaging and dynamic Laue diffraction experiment along with an example image obtained from an experiment that impacted a 300-micron steel cylinder onto a boron carbide plate. The image was taken approximately 500-ns after impact (bottom).

provides information on a material's atomic structure to diagnose the phase of the material and/or to examine microscopic defects inside the sample. These diagnostics were used to examine various materials impacted by projectiles using the IMPULSE gun system that was inserted into the X-ray beam. The team successfully performed over thirty experiments on various materials to examine phenomena including jet formation in cerium

metal, dynamic compaction of borosilicate spheres, high strain-rate impact of steel cylinders onto various target materials, etc. Additional tests were performed using a new 3-frame silicon-CMOS (complementary metal-oxide-semiconductor) detector to obtain "shock movies." The team also successfully performed the first impact experiment to obtain dynamic Laue diffraction data (<153 ns) from iron single crystal. Example PCI data are shown in Figure 2 for a steel cylinder impacting a boron carbide plate.

These first-ever experiments done at a synchrotron were ground breaking. The 3-μm spatially resolved measurements reveal novel phenomena with the possibility of studying the rich underlying physics for materials subjected to high strain rate loading. "We have firmly established the dynamic phase contrast imaging technique at APS (Section 32ID), with a single X-ray bunch from the standard mode (24-bunch)," says Shengnian Luo from Los Alamos, "The preliminary experiments on dynamic Laue diffraction also showed promise for future success." This work is an important step in the development of future facilities including the Matter-Radiation Interactions in Extremes (MaRIE)-LANL's signature experimental facility concept-as well as the Dynamic Compression Sector experimental facility proposed to be built at the APS.

This was a collaborative effort between scientists and technicians from LANL's Physics Division (S. Luo, K. Kwiatkowski, T. Shimada), the Shock & Detonation Physics Group (B. Jensen, J. Esparza, C. Owens, D. Hooks, K. Ramos, J. Yeager, D. Fredenburg, T. Pierce, R. Saavedra), and the Weapons Test Engineering Group (R. Valdiviez); and Argonne National Lab (K. Fezzaa and A. Deriy).