LA-UR- 10-02619

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Title: Sub-sonic Thermal Explosions Investigated by Radiography

Author(s): Laura Smilowitz
Bryan Henson
Blaine Asay
Jerry Romero
Gary Grim, Andy Saunders, Frank Merrill, Chris Morris,C.Schwarz, W. McNeil, the pRad Collaboration

Intended for: Defense Science Quarterly

Los Alamos
NATIONAL LABORATORY
EST. 1943

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Form 836 (7/06)

SUB-SONIC THERMAL EXPLOSIONS INVESTIGATED BY RADIOGRAPHY

L. Smilowitz, B. F. Henson, B. W Asay, J.J. Romero, G.P. Grim, A. Saunders, F. Merrill, C. Morris, C. Schwartz, W. McNeil, and the pRad collaboration.

Understanding the thermal response of an explosive such as the HMX based formulation PBX9501 is critical to the accurate prediction of its behavior in an accident scenario. Despite our detailed knowledge of detonation in this material, we cannot now predict such response as a function of the details of heating. The response to a particular heating scenario can span the full range between a relatively benign pressure burst and a high violence explosion or even steady state detonation. Radiographic imaging of super-sonic detonation has been informing that field for over 60 years. However, sub-sonic events present particular challenges that had precluded their observation by radiography. We have developed techniques to overcome those technical difficulties that have enabled the study of sub-sonic burning in thermal explosions of PBX 9501 and PBXN-9 using proton radiography for the first time.

Radiography provides a measure of the evolution of density caused by material flow and decomposition during heating up to ignition and then a measure of the rapid consumption of material during burn propagation subsequent to ignition. The ability to perform these experiments was predicated on several developments: the control of the ignition location in a thermal explosion, the prediction of ignition time for a given boundary condition, in some cases the synchronization of the ignition event, and the triggering of external diagnostics synchronous with the breakout of ignition. We have performed a series of thermal explosion experiments at the proton radiography (pRad) facility at Los Alamos National Laboratory exploring two different geometries, two case confinements, and two different HMX based formulations.

The results of these experiments are sequences of proton transmission images which can be calibrated into material density images and used to study the mechanism by which deflagration occurs. The image below shows one sequence of frames during a thermal explosion in a 1" diameter by 1" tall cylinder of PBX 9501 which is encased in 1/8" thick aluminum and subjected to a thermal boundary temperature on the cylindrical case wall of 205 C. At this temperature, the time to ignition is approx-

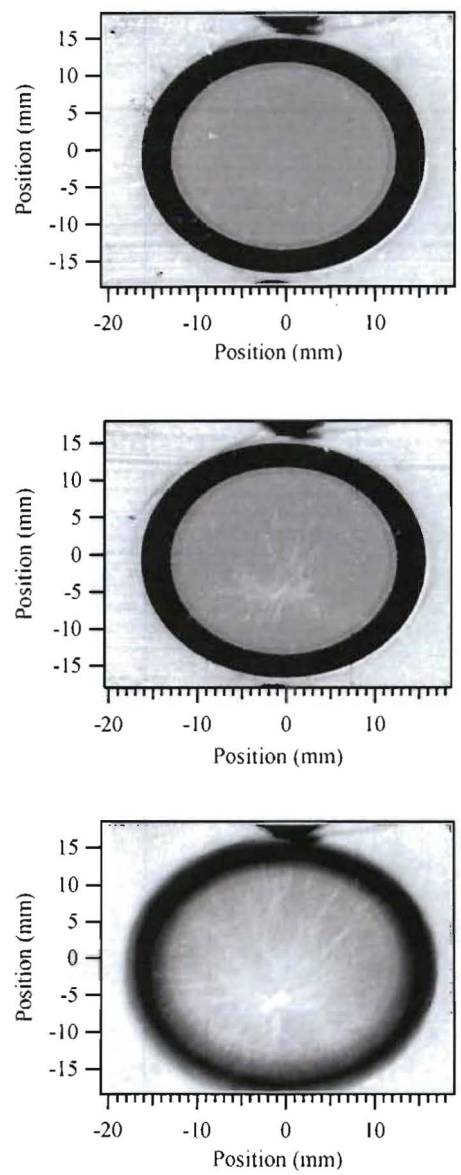

Figure 1: frames taken just after onset of ignition, and 20 and 40 microseconds later.

imately 30 minutes. At a time within 1 minute of ignition, a laser pulse is applied to the central ignition volume, synchronizing the onset of ignition to within the 1 ms duration proton pulse window. The onset of ignition is observed by a thermocouple at the center of the explosive and this is used to trigger the acquisition of proton transmission images.

Figure 1 shows proton transmission images taken 20 microseconds apart illustrating the early onset of ignition, the propagation of cracks from the ignition volume outwards to the radial case confinement, and the consumption of the PBX 9501. The grey scale used shows high density (such as the outer aluminum case) in black and lower density in white. The images of density evolution during thermal explosions in PBX 9501 have been used to develop a model for deflagration. The event observed includes an initial ignition volume of approximately 1 mm radius at the center of the HE. Subsequent to the breakout of ignition, the radial case begins to expand and cracks appear propagating from the central ignition volume out to the case walls. These cracks propagate to the walls ½" away within approximately 10 microseconds. A convective burn propagates outward from the central ignition volume at approximately 200 m/s lighting the material and consuming 10-15% of the explosive. Following the convective lighting, the material is consumed over the following tens of microseconds by a slower conductive consumption. These observations and measured velocities are captured in a model used to simulate the radiographic data.

Proton radiography of thermal explosions has yielded a mechanism for deflagration propagation which consists of both convective and conductive processes. Further work is underway to image the phenomena involved in the deflagration to detonation transition.

References

(1) Smilowitz, L.; Henson, B. F.; Sandstrom, M. M.; Romero, J. J.; Asay, B. W. *APPLIED PHYSICS LETTERS* **2007**, *90*.

(2) Smilowitz, L.; Henson, B. F.; Romero, J. J.; Asay, B. W.; Schwartz, C. L.; Saunders, A.; Merrill, F. E.; Morris, C. L.; Kwiatkowski, K.; Hogan, G.; Nedrow, P.; Murray, M. M.; Thompson, T. N.; McNeil, W.; Rightley, P.; Marr-Lyon, M.; pRad, C. *PHYSICAL REVIEW LETTERS* **2008**, *100*.

(3) Tringe, J. W.; Molitoris, J. D.; Smilowitz, L.; Kercher, J. R.; Springer, H. K.; Henson, B. F.; Glascoe, E. A.; Greenwood, D. W.; Garza, R. G.; Wong, B. M.; Batteux, J. D.; Maienschein, J. L. Time-sequenced X-ray observation of a thermal explosion. In *APS Shock Compression of Condensed Matter*; AIP: Nashville, TN, 2009.