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Imaging and measuring the evolution of solid density within a thermal explosion

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Explosives have been used for millennia. All materials are energetic, but high explosives have the ability to release their stored energy in a very short period of time- nanoseconds in the case of detonations. Many explosives have an as-designed behavior that is well understood and controlled. However, the off-nominal behavior, such as would occur in an accident scenario, is typically much less understood. The subject of our research has been the energy release mechanisms for secondary high explosives heated to thermal explosion. The study of thermal explosions poses several difficulties including extreme temperature, pressure, and rate of change. In addition, thermal explosions pose the difficulty of being spontaneous dynamic events with limited ability to predict the time of the event. Typically, event durations are tens of microseconds and timing jitter is tens of seconds- essentially a one in a million duty cycle. These difficulties have precluded the use of many standard laboratory diagnostics to the study of the phenomena. In the past years, we have developed diagnostics which can survive the extremes of the thermal explosion with sufficient response time and the ability to remain armed and be triggered by the onset of the spontaneous event. In addition to microsecond temporal resolution, the diagnostics need to be spatially resolved with 100 micron spatial resolution and centimeter field of view in order to capture the spatial heterogeneity of the event. Our work has focused on the important secondary high explosive PBX 9501 which is a formulation of the organic crystalline nitramine octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX). Our evolving understanding of this material has enabled us to develop a table-top x-ray imaging experiment providing millisecond time resolution with duration of minutes and sensitivity to density changes of better than 1%. This quasistatic regime provides images of material thermal expansion, phase transitions, and thermal decomposition leading to the onset of thermal ignition. A second technique provides microsecond scale time resolution with duration of milliseconds and contrast sensitivities of a few percent. This technique allows us to observe the propagation of ignition which determines the overall violence of the thermal explosion. In this talk, I will describe our current understanding of thermal explosions, and the evolution of the radiographic diagnostics that we have developed to study thermal explosions.