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High-Speed Laser Imaging, Emission and Temperature Measurements of Explosions

by Thuvan Piehler, Barrie Homan, Rachel Ehlers, Richard Lottero, and Kevin McNesby

ARL-RP-137 **September 2006**

A reprint from the *2006 Insensitive Munitions & Energetic Materials Technology Symposium Proceedings*, Bristol, UK, 24–28 April 2006.

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14. ABSTRACT
This presentation reports results of laser high brightness imaging, optical temperature, emission and heat flux measurements of explosive combustion products by explosives. High brightness images were recorded by a high-speed camera synchronized to the output of a Cu-vapor laser (510 nm, 12 kHz). Time resolved measurements of temperature and heat flux of fireballs produced by open-air detonation of explosives were made using three-color pyrometry and high-speed heat flux gauges, respectively. The emission measurements (visible region) were performed using a grating-based, modular, spectrograph.

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Abstract:

This presentation reports results of laser high brightness imaging, optical temperature, emission and heat flux measurements of explosive combustion products by explosives. High brightness images were recorded by a high-speed camera synchronized to the output of a Cu-vapor laser (510 nm, 12 kHz). Time resolved measurements of temperature and heat flux of fireballs produced by open-air detonation of explosives were made using three-color pyrometry and high-speed heat flux gauges, respectively. The emission measurements (visible region) were performed using a grating-based, modular, spectrograph.

Introduction:

The main goal of this work is to investigate how changes in formulation can affect the time rate of delivery of energy onto a target or dynamic energy management. This set of experiments was designed to measure relative proximities of blast fireballs and leading shock fronts, to determine if different explosive formulations exhibited unique, wavelength dependent optical emission, to determine temperatures of gas and solid phase species near the fireball surface, and to measure the time change of heat emission following explosive initiation. All of the results reported here are for explosives functioning in an unconfined area.

Experimental Setup

<u>High Brightness Imaging</u>

Figure 1 shows the high brightness imaging experimental setup. High brightness images were recorded by illuminating a region near the edge of the fireball with the expanded beam output of a copper (Cu) vapor laser running at 12 kHz (12 W output power). This expanded beam was focused onto a sheet of reflective material placed behind the fireball region. The image produced on the reflective material was recorded by a camera (Vision Research) synchronized to the laser rep rate and filtered to see light at the laser wavelength (510nm). The images produced are shadowgraphs of the fireball edge as the fireball contact surface interrupts the expanded laser beam. Figure 2 shows an example of high brightness imaging measurements.

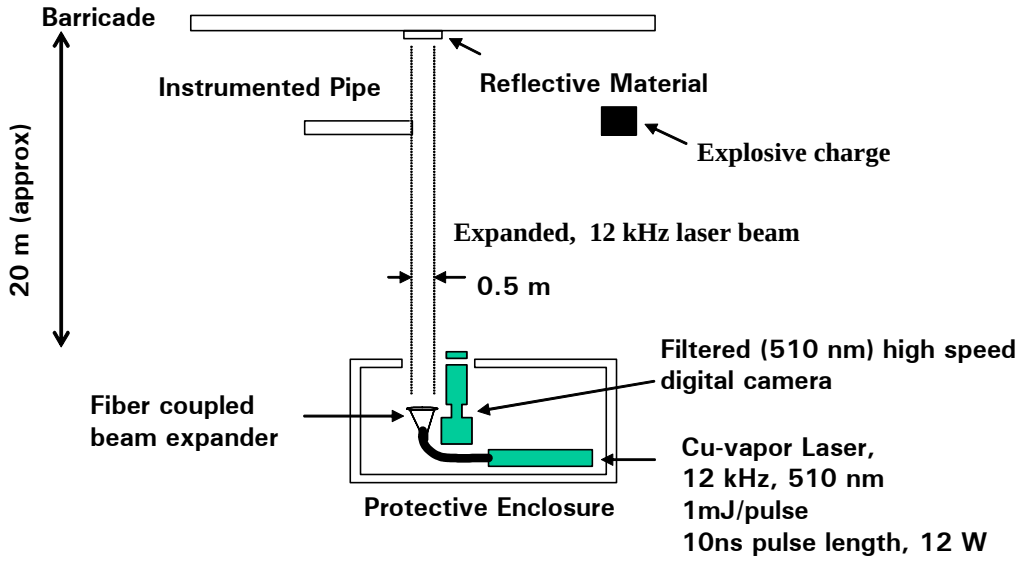

Figure 1: High brightness imaging experimental setup

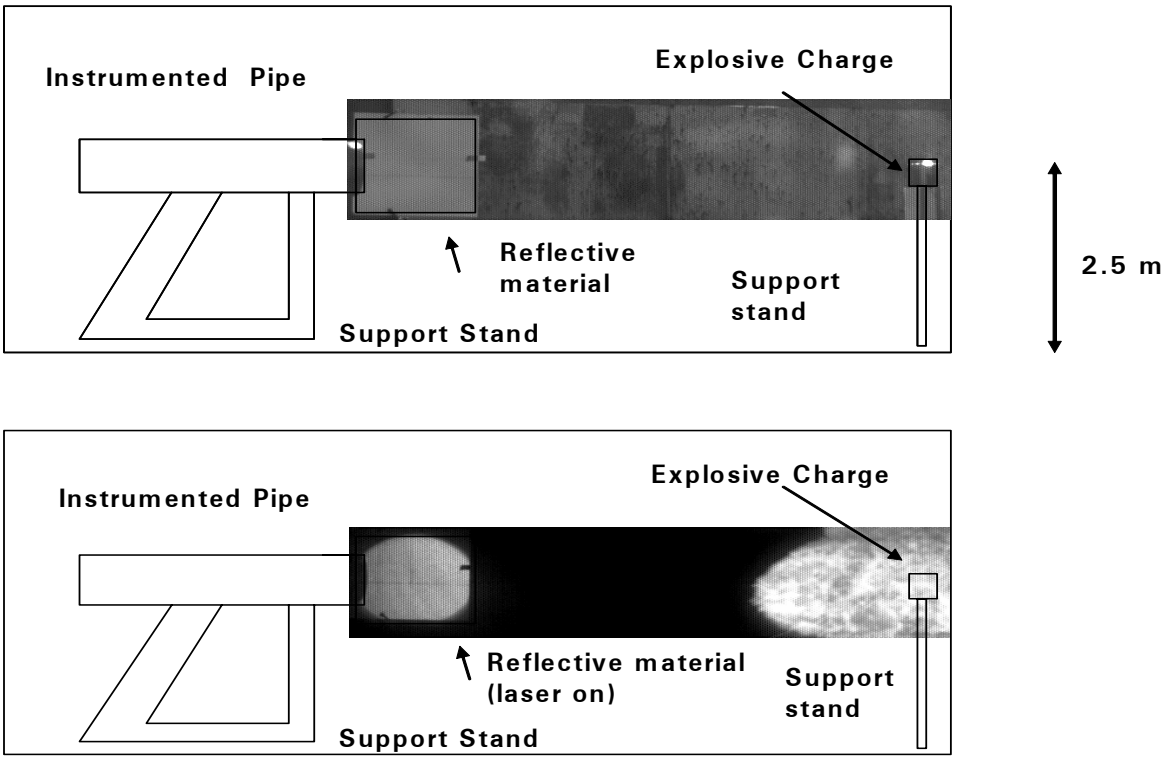

Figure 2: High brightness imaging measurements

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Broadband Emission

A 600-micron diameter core silicon-silicon (Si-Si) optical fiber, tipped by a collimating optic, was positioned so that the line-of-sight defined by the optical fiber/collimating optic assembly passed through the center of the explosive charge. The distance from the collimating optic to the explosive charge was approximately three meters. Light entering the optical fiber was transported through the fiber to a barricaded control room (fiber length approximately 30 meters). In the control room, light from the fiber was connectorized (SMA union) to a fiber bundle consisting of seven 125-micron core Si-Si optical fibers. Each of these optical fibers illuminated the entrance slit of a dedicated Ocean Optics model HR-2000 spectrograph. The seven spectrographs were modified by Ocean Optics, Inc., to allow simultaneous triggering and control by a laptop computer. For each measurement, the seven-spectrograph array began measuring light at the same time that a high voltage pulse was used to initiate the explosive. Figure 3 shows a schematic diagram of fiber optic to modular spectrograph.

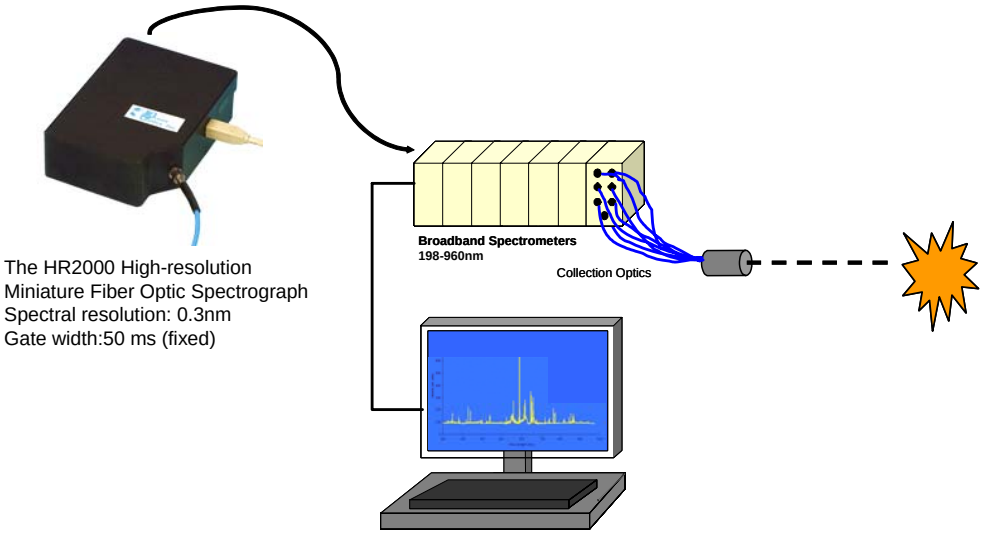


Figure 3: Schematic diagram of fiber optic to modular spectrograph. It measures light at the same time that a high voltage pulse was used to initiate the explosive.

High Speed Pyrometry

A three-channel, high speed, optical pyrometer (as shown in Figure 4) was built and used to measure the gray body temperature of the fireball produced during explosive testing. Each optical channel consists of a separate narrow bandpass filter, fiber optic, and a photodiode detector. The three filters are mounted in the open air approximately one inch from each other and

approximately 6 meters from the geometrical center of the charge. In this configuration, each channel integrates the light from all regions of the fireball due to the large acceptance angle of the bare fibers. Electrical signals from each detector were transported to the control room using a BNC electrical cable, and recorded on a digital oscilloscope (Hewlett-Packard). The spectral response of the system was calibrated using an ARC Model XS432 Xenon lamp. Time resolution is approximately 12 microseconds.

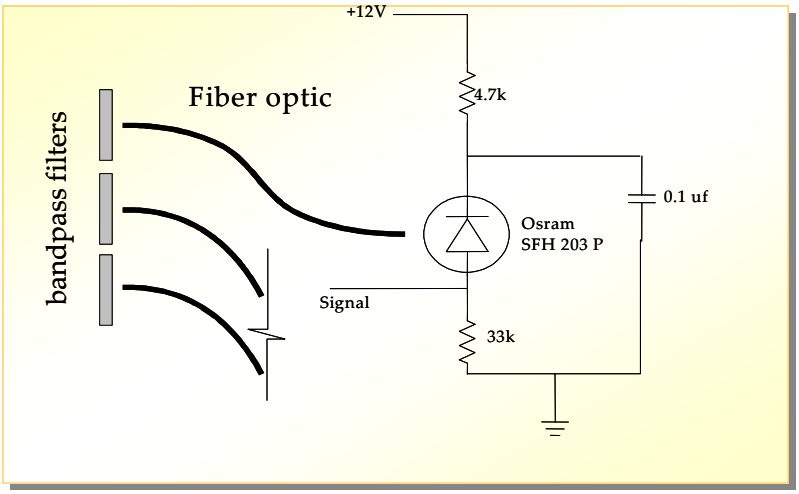
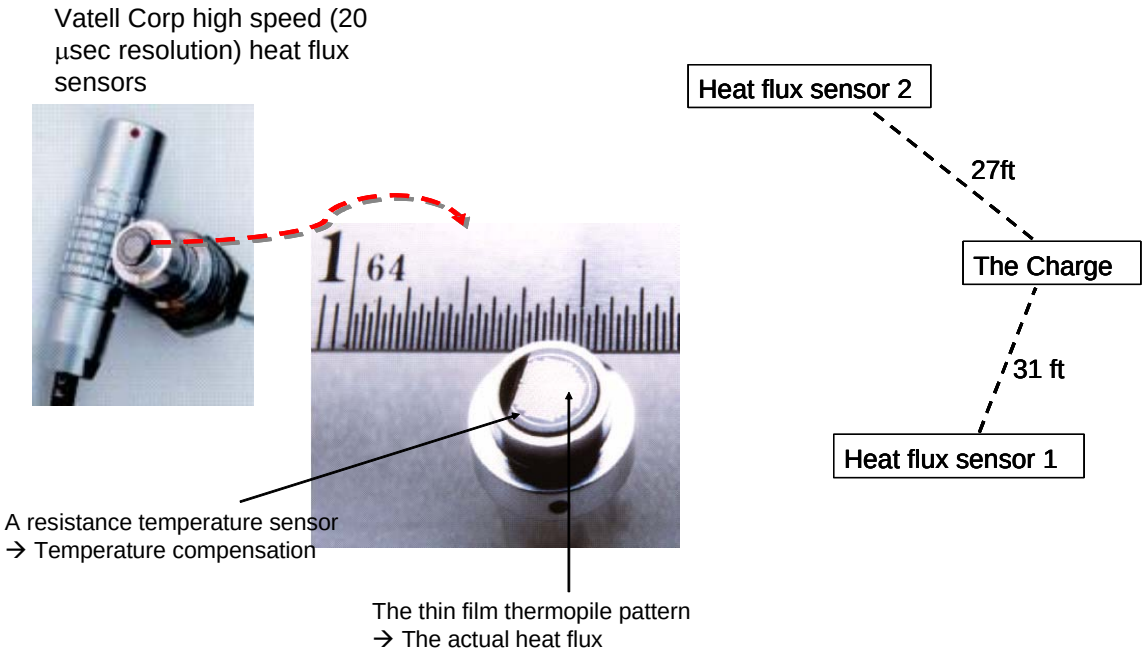


Figure 4: Pyrometry apparatus

Heat flux sensors

Two heat flux sensing systems (HFM-8, Vatell Corporation) have been implemented to measure heat flux of the fireball produced during explosive testing. Heat flux sensors are mounted in the open air approximately 9-10 meters from the geometrical center of the charge. Time resolution is approximately 16 microseconds. Figure 5 shows the schematic diagram of heat flux measurement setup.



http://www.sensorsmag.com/articles/0199/flu0199/main.shtml

Figure 5: Schematic diagram of heat flux measurement setup

All experiments were conducted at an outdoor experimental facility located at the Aberdeen Proving Ground in Maryland (as shown in Figure 6).

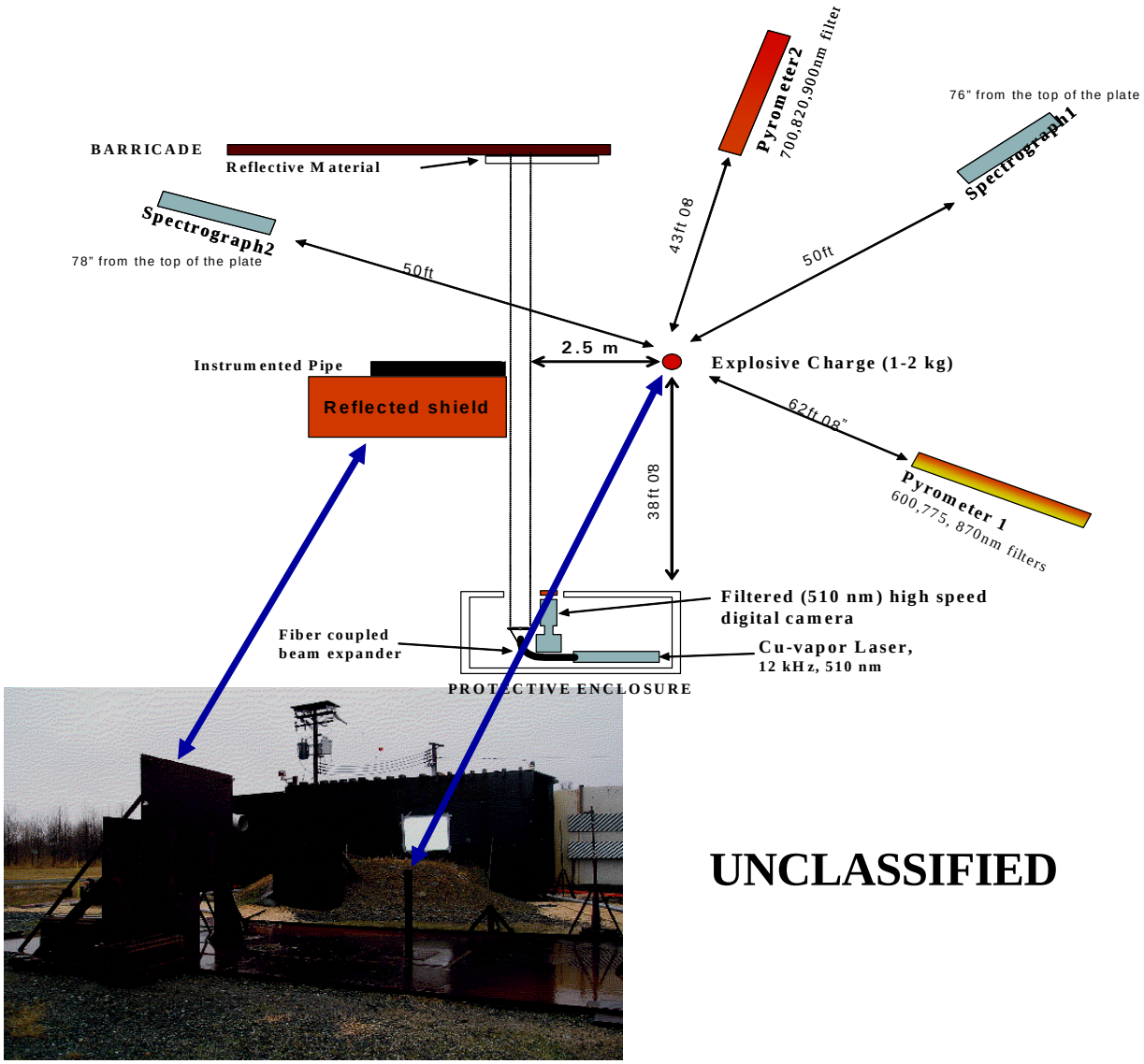


Figure 6: ARL facility experimental setup.

Results

Figure 7 shows a series of high brightness images following initiation of an explosive. Figure 8 is a plot of the reported intensity at each pyrometer wavelength and the calculated graybody temperature as a function of time for the explosive Comp B. The three filter wavelengths used by the pyrometer are 560nm, 678nm, and 820nm (10 nm bandwidth). The large peak at time zero is attributable to the initial flash from the onset of detonation. Temperature remains fairly constant during the first 50 ms of the explosion.

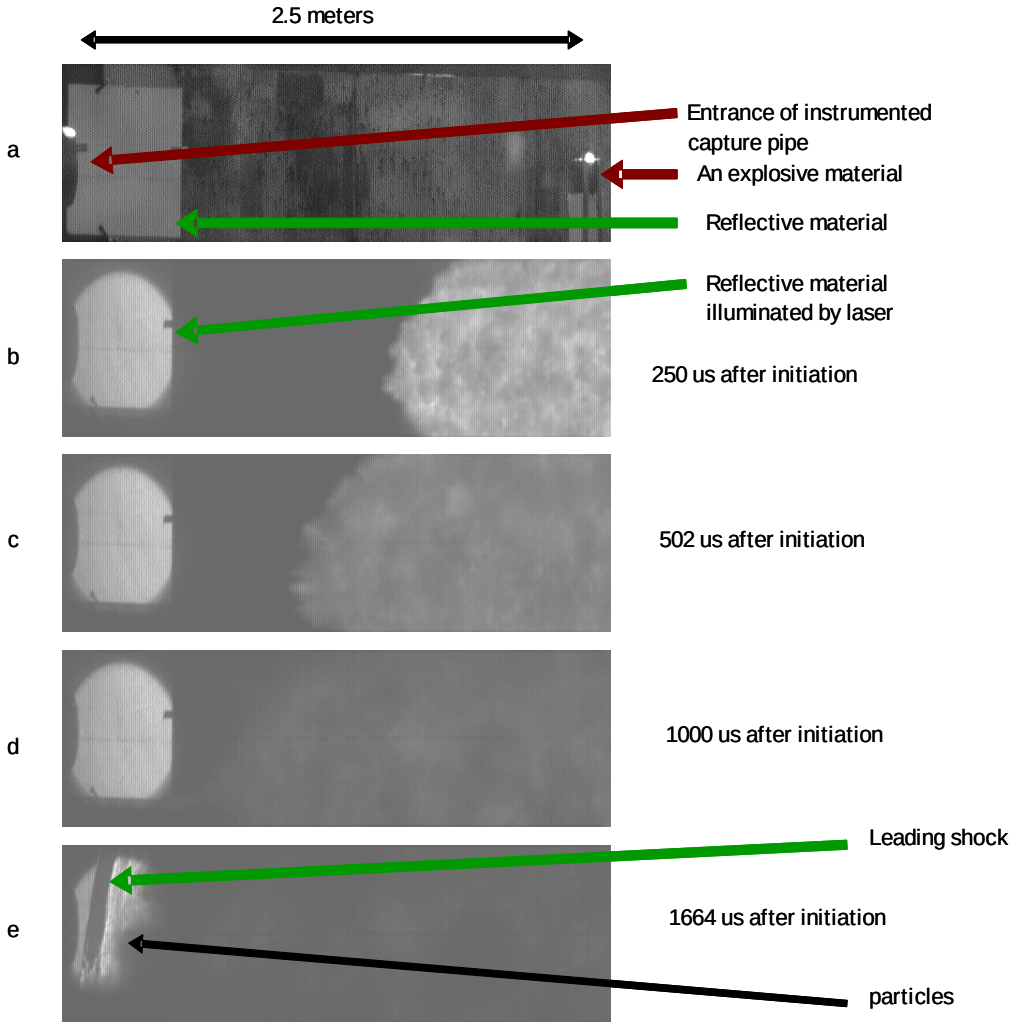


Figure7. High brightness images following initiation of an explosive

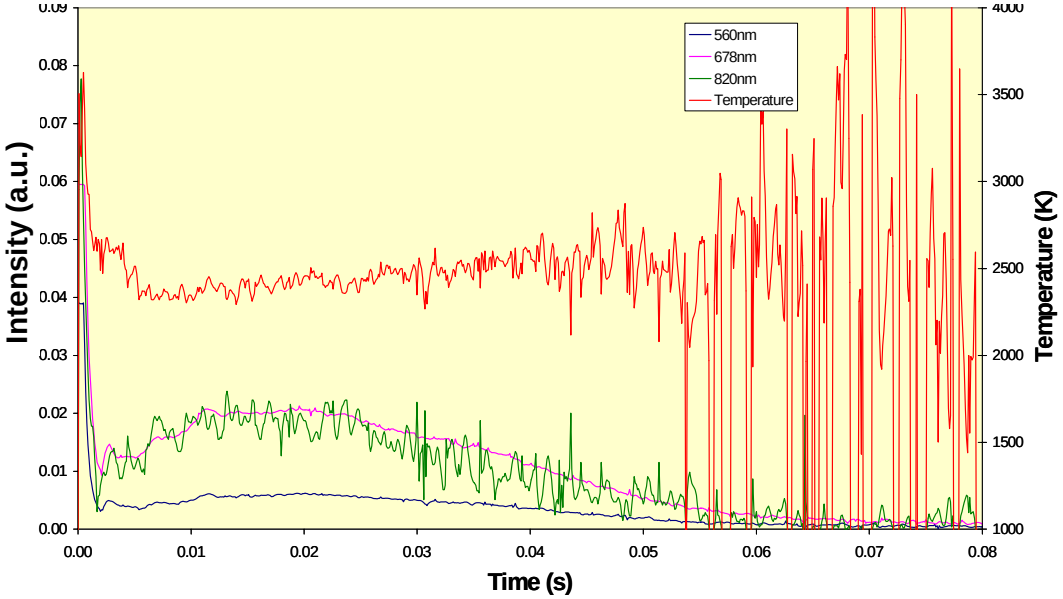


Figure 8: Intensity of fireball at the three pyrometer wavelengths and calculated temperature for Comp B (1kg)

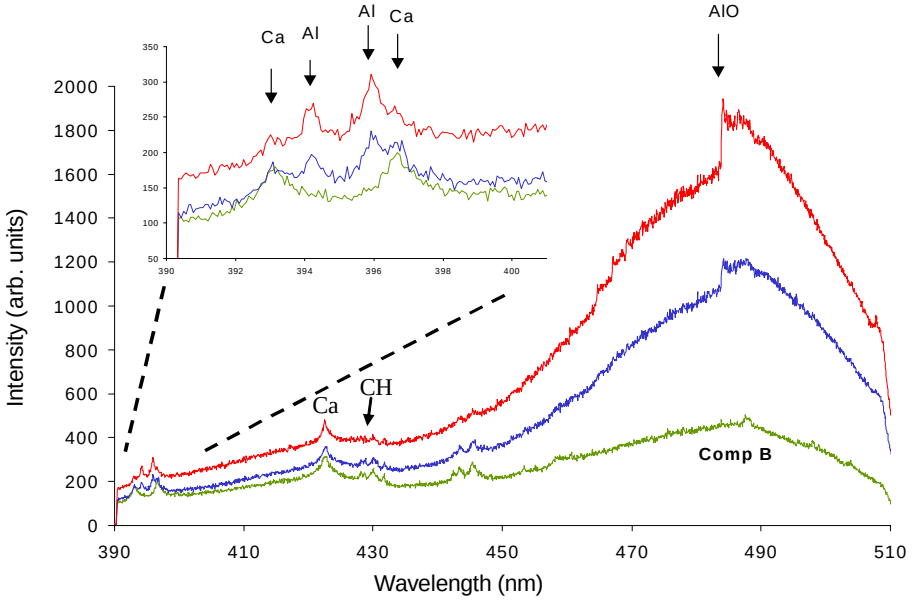


Figure 9: Broadband emission for measurements of Al/AlO

Figure 9 shows the broadband emission spectra of explosions (first 50 milliseconds) of Comp B, and aluminized explosives between 390 and 510 nm. This figure shows that only the aluminized explosives exhibit spectral features of Al and AlO. The peak near 422 nm and the group near 430 nm are from Ca and CH, respectively.

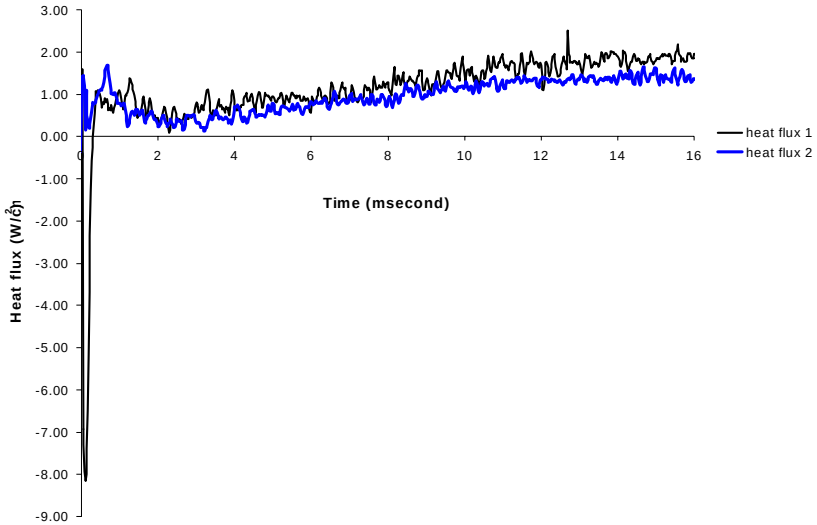


Figure 10: Heat flux measurements of Comp B

Figure 10 shows a typical plot of heat flux output of Comp B (1kg). The heat flux output from the fireball slowly increased from the first 5 ms up to 15 ms. This is agreeable with the pyrometer results (Figure 2). Hence, high-speed heat flux measurements may provide a prediction about the actual effectiveness of the formulations.

Conclusions:

Although each explosive tested produced fireballs of different peak temperatures, after approximately 5 ms after initiation, fireball temperature remained nearly constant. Single channel pyrometer signals and heat flux gauge measurements typically peaked about 15 ms after initiation, suggesting that the fireball may burn as a collection of flamelets until burn-out. High brightness imaging suggests that the fireball reaches near full volume and then burns towards maximum flux. Spectral features near 394nm and 396nm from gas phase aluminum emission and a band at 484nm from gas phase AlO emission are used as an indicator of Al combustion in the fireball and are also used as a secondary source of temperature information.

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