ARMY RESEARCH LABORATORY

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.

NOTICES

Disclaimers

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-RP-137 **September 2006**

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

Thuvan Piehler, Barrie Homan, Rachel Ehlers,
Richard Lottero, and Kevin McNesby
Weapons and Materials Research Directorate, ARL

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

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
September 2006	Reprint	February 2005–February 2006

4. TITLE AND SUBTITLE High-Speed Laser Imaging, Emission and Temperature Measurements of Explosions	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Thuvan Piehler, Barrie Homan, Rachel Ehlers, Richard Lottero, and Kevin McNesby	**5d. PROJECT NUMBER** AH80 DTRA T004 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-WM-TB Aberdeen Proving Ground, MD 21005-5066	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-RP-137
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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

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.

15. SUBJECT TERMS

high speed imaging, optical measurements, explosions

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Thuvan Piehler
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	22	**19b. TELEPHONE NUMBER** (*Include area code*) 410-278-0319

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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

Thuvan Piehler, Barrie Homan, Rachel Ehlers, Richard Lottero and Kevin McNesby
U.S. Army Research Laboratory
Aberdeen Proving Ground, MD 21005

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.

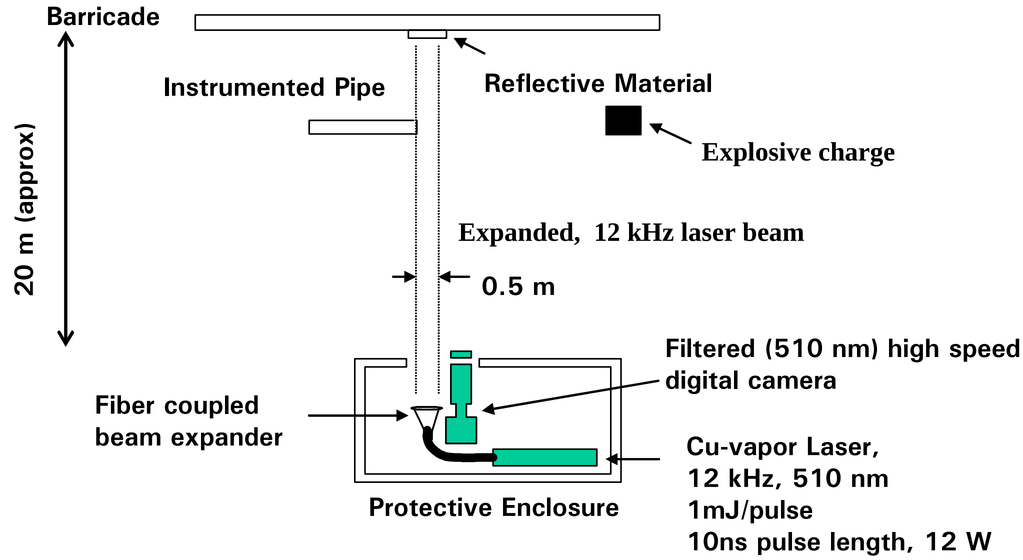


Figure 1: High brightness imaging experimental setup

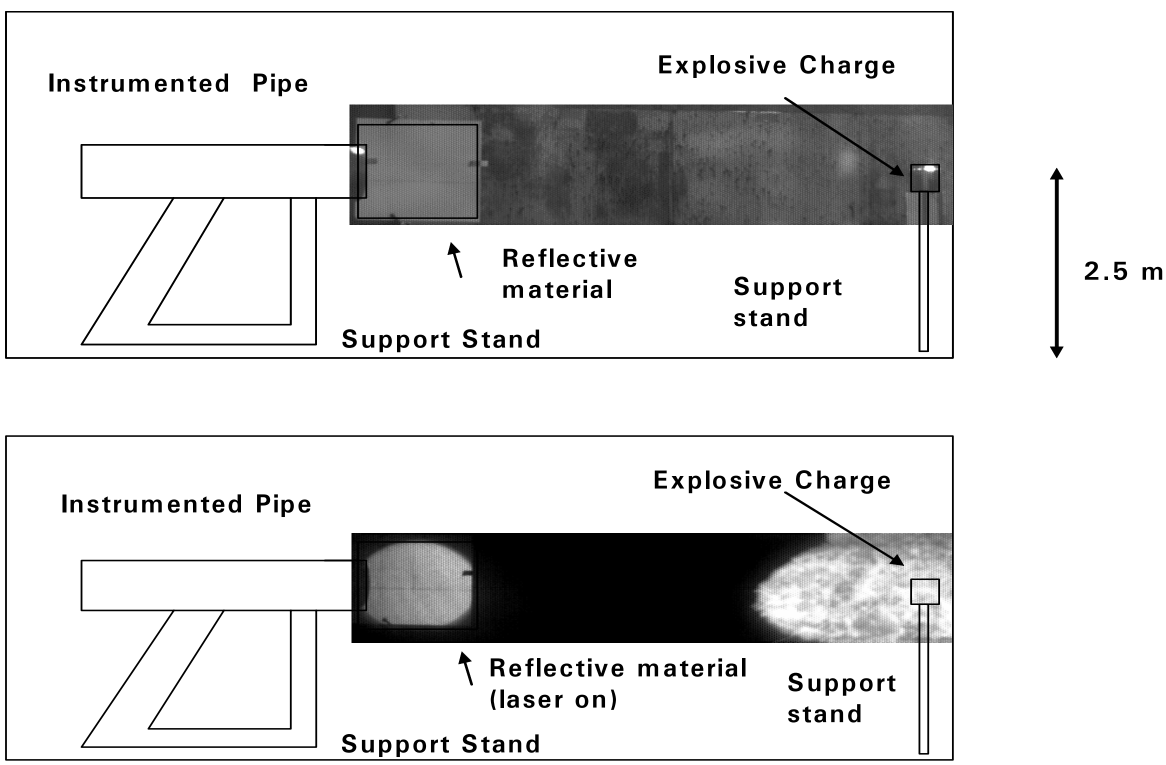


Figure 2: High brightness imaging measurements

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.

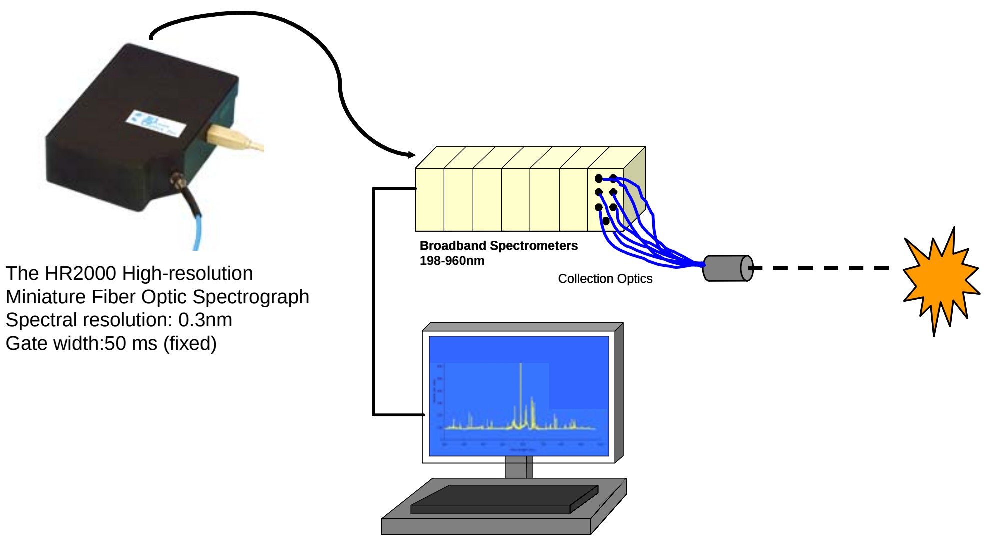


Figure 3: Schematic diagram of fiber optic to modular spectrograph. It measures light at the same time that a high voltage pulse was used to initiate the explosive.

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.

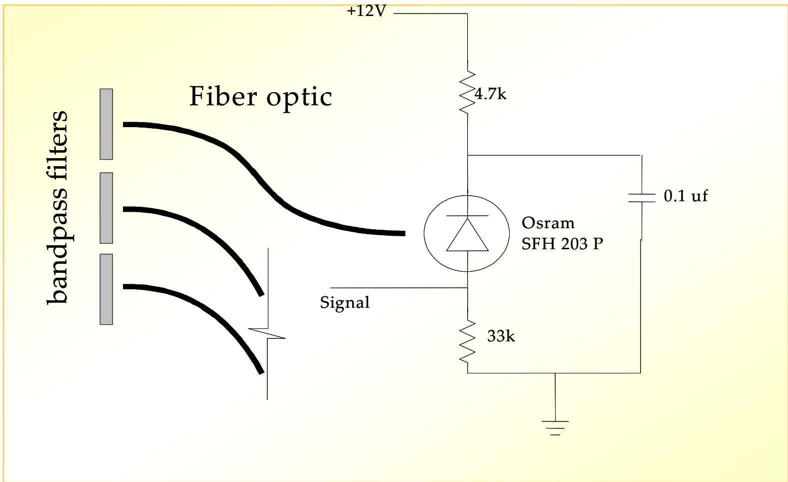
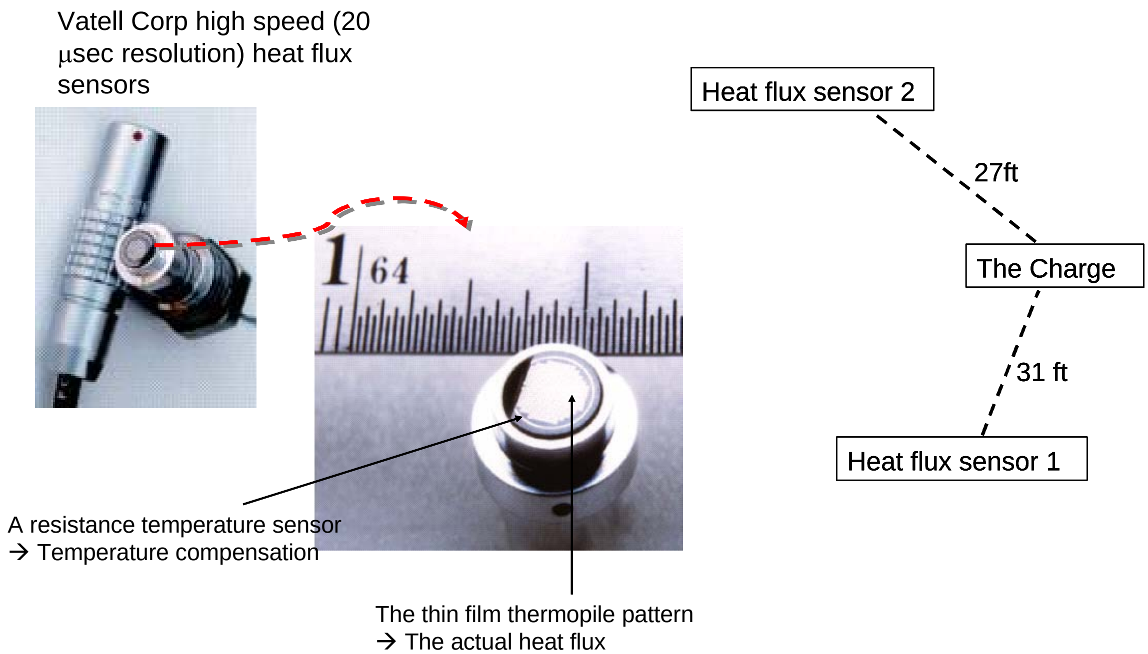


Figure 4: Pyrometry apparatus

Heat flux sensors

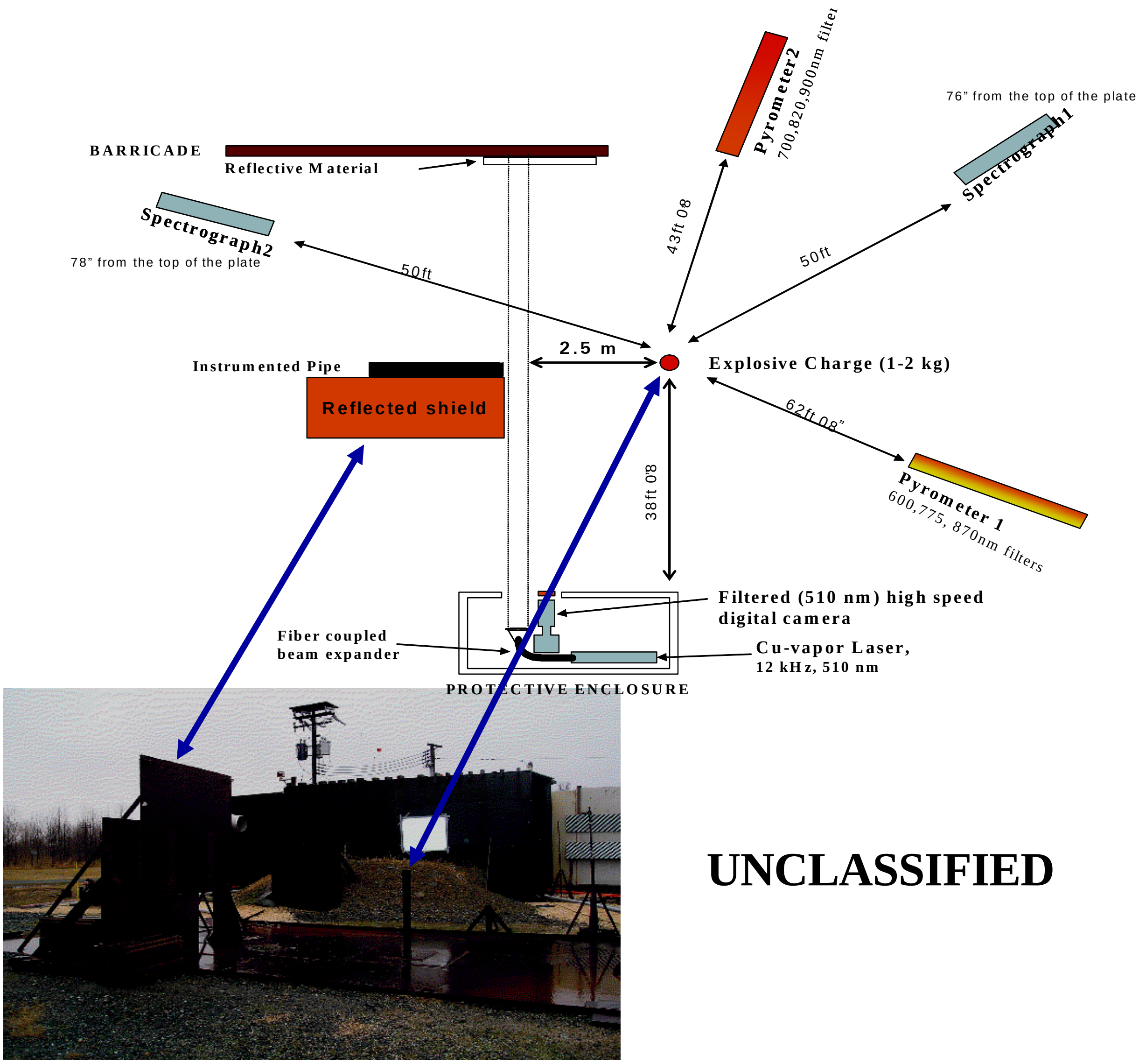
Two heat flux sensing systems (HFM-8, Vatell Corporation) have been implemented to measure heat flux of the fireball produced during explosive testing. Heat flux sensors are mounted in the open air approximately 9-10 meters from the geometrical center of the charge. Time resolution is approximately 16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



UNCLASSIFIED

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.

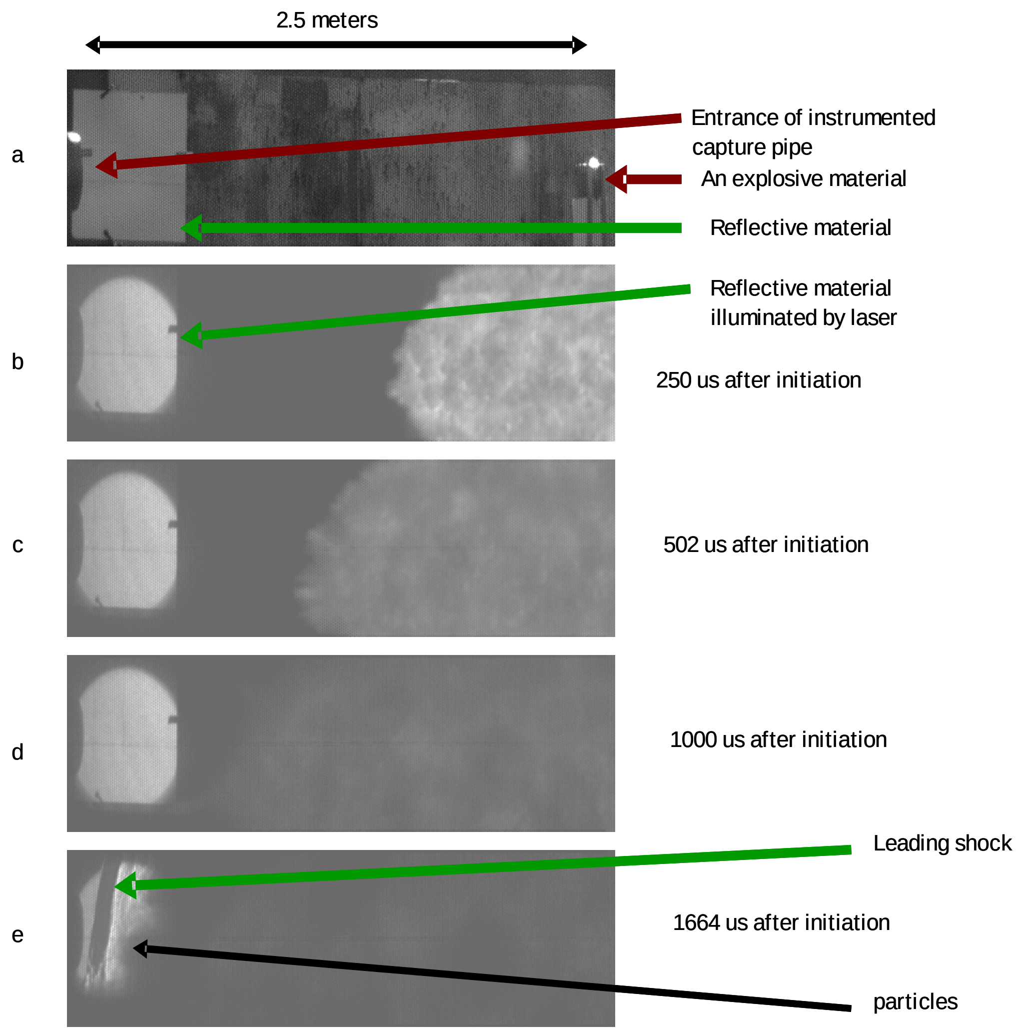


Figure7. High brightness images following initiation of an explosive

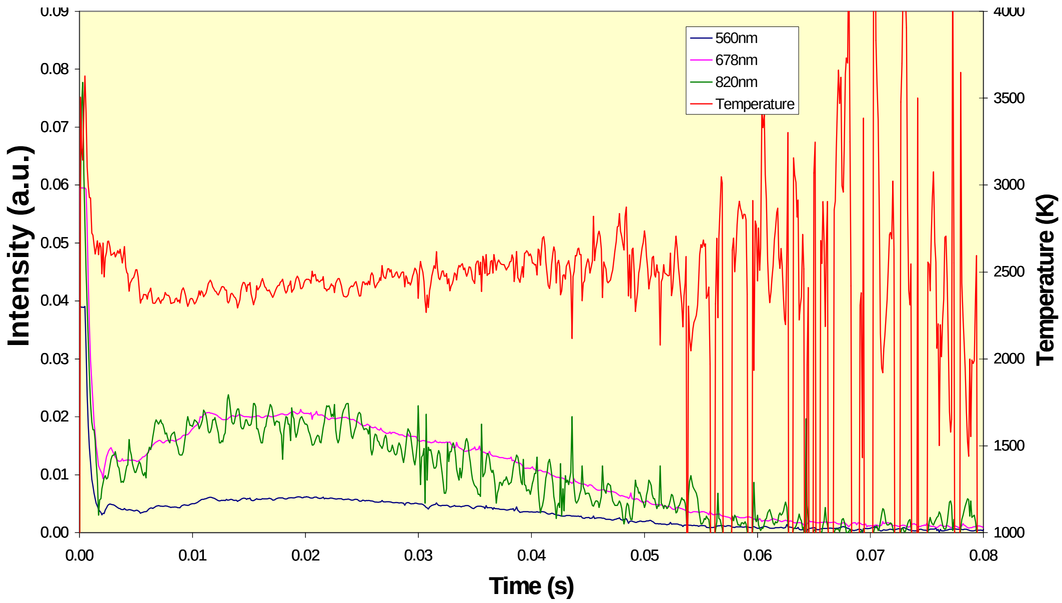


Figure 8: Intensity of fireball at the three pyrometer wavelengths and calculated temperature for Comp B (1kg)

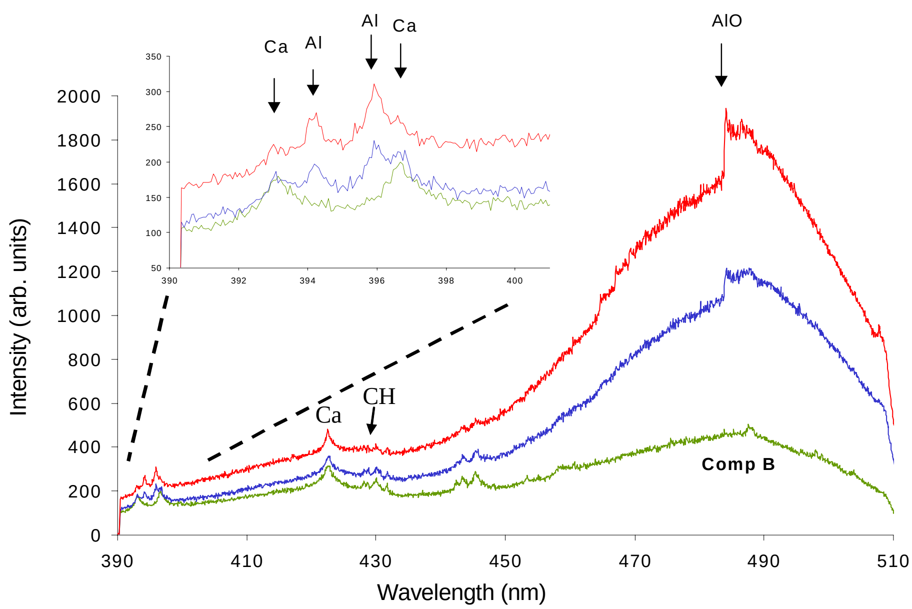


Figure 9: Broadband emission for measurements of Al/AlO

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.

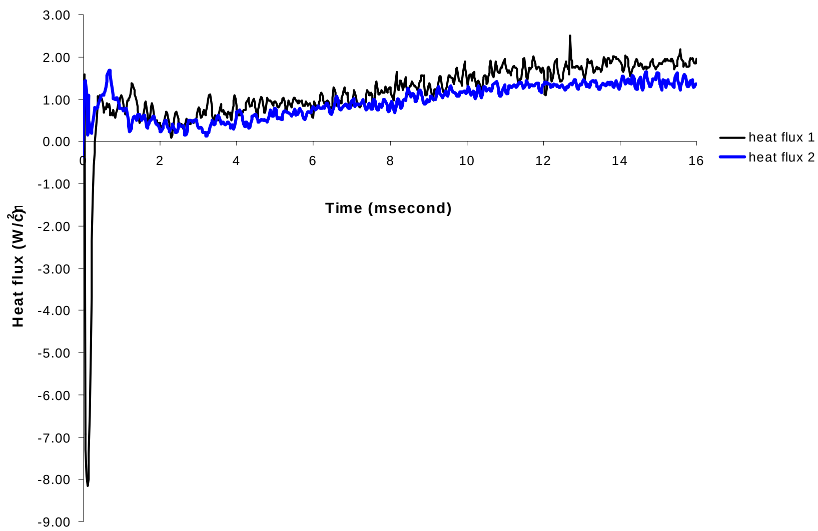


Figure 10: Heat flux measurements of Comp B

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.

NO. OF COPIES	ORGANIZATION
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	US ARMY RSRCH DEV & ENGRG CMD SYSTEMS OF SYSTEMS INTEGRATION AMSRD SS T 6000 6TH ST STE 100 FORT BELVOIR VA 22060-5608
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC IMS 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK TL 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

1	DIR USARL AMSRD ARL CI OK TP (BLDG 4600)

NO. OF COPIES	ORGANIZATION
3	AIR FORCE RSCH LAB FRL EDWARDS/USC ERC/AFRL K CRISTE 10 E SATURN BLVD EDWARDS AFB CA 93524
1	AIR FORCE RSCH LAB AFRL/PRSP BLDG 8451 G DRAKE 10 E SATURN BLVD EDWARDS AFB CA 93524
1	AIR FORCE RSCH LAB AFRL/MNME W COOPER 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MNME M FAJARDO 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MNAV S FEDERLE 101 W EGLIN BLVD STE 342 EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MN S KORN 101 W EGLIN BLVD STE 105 EGLIN AFB FL 32542-6810
1	AIR FORCE RSCH LAB AFRL/MNME M KRAMER 2306 PERIMETER RD EGLIN AFB FL 32542-6810
1	AIR FORCE RSCH LAB AFRL/MNAC J KUJALA 101 W EGLIN BLVD STE 334 EGLIN AFB FL 32542-6810
1	AIR FORCE RSCH LAB AFRL/MNME W R MAINES 2306 PERIMETER RD EGLIN AFB FL 32542

NO. OF COPIES	ORGANIZATION
1	AIR FORCE RSCH LAB AFRL/MNME T MCKELVEY 2306 PERIMETER RD EGLIN AFB FL 32542-5910
1	AIR FORCE RSCH LAB AFRL/MNME D W RICHARDS 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MNME C RUMCHIK 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MNME L STEWART 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE RSCH LAB AFRL/MNME K WALKER 2306 PERIMETER RD EGLIN AFB FL 32542
1	AIR FORCE AFOSR AFOSR M BERMAN 4015 WILSON BLVD RM 713 ARLINGTON VA 22203-1954
1	US ARMY ARDEC/WECAC AMSTA AR WEE D DOWNS BLDG 3022 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC P HAN BLDG 3022 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSTA AR WEE A L HARRIS PICATINNY ARSENAL NJ 07806

NO. OF COPIES	ORGANIZATION
1	US ARMY TACOM ARDEC AMSTA AR WEA D KAPOOR BLDG 355 PICATINNY ARSENAL NJ 07806
1	US ARMY TACOM ARDEC AMSRD AAR D J LANNON BLDG 1 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC AMSRD AAR AEE W S NICOLICH B3022 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC R PAWLICKI DOTC BLDG 3022 RM 222 PICATINNY ARSENAL NJ 07806-5000
1	US ARMY TACOM ARDEC V STEPANOV BLDG 3028 PICATINNY ARSENAL NJ 07806
1	US ARMY TACOM ARDEC R SURAPANENI BLDG 3022 PICATINNY ARSENAL NJ 07806-5000
1	CDR US ARMY TACOM ARDEC AMSTA AR WEE A T VLADIMIROFF PICATINNY ARSENAL NJ 07806
1	CDR US ARMY AMRDEC US AMCOM AMSAM RD PS PT R HATCHER REDSTONE ARSENAL AL 35989
1	CDR US ARMY AMRDEC US AMCOM AMSAM RD PS WF S HILL REDSTONE ARSENAL AL 35898-5247
1	CDR US ARMY AMRDEC US AMCOM AMSAM RD PS WF A STULTS REDSTONE ARSENAL AL 5989-5247

NO. OF COPIES	ORGANIZATION
1	CDR US ARMY AMRDEC US AMCOM AMSAM RD PS PT BLDG 7120 D THOMPSON REDSTONE ARSENAL AL 35989
1	US ARMY RSCH OFFICE D MANN PO BOX 12211 RSCH TRIANGLE PARK NC 27709-2211
1	NATL GROUND INTELLIGENCE CTR IANG GS MT/MS 306 C BEITER 2055 BOULDER RD CHARLOTTESVILLE VA 22911-8318
1	NATL GROUND INTELLIGENCE CTR IANG GS MT/MS 306 R YOBS 2055 BOULDER RD CHARLOTTESVILLE VA 22911-8318
1	CDR US ARMY SOLDIER SYS CTR AMSSB RIP B (N) M MAFFEO NATICK MA 01760-5019
1	CDR US ARMY SOLDIER SYS CTR AMSSB RIP B (N) J WARD NATICK MA 01760-5019
1	US ARMY SPECIAL OPRN CMD CAG COMBAT APPLCTN GROUP L BOIVIN PO BOX 70660 FT BRAGG NC 28307
1	US ARMY SPECIAL OPRN CMD CAG COMBAT APPLCTN GROUP G GEORGEVITCH PO BOX 71859 FT BRAGG NC 28307-5000
1	US ARMY SPECIAL OPRN CMD CAG COMBAT APPLCTN GROUP D JETER PO BOX 70660 FT BRAGG NC 28307
1	US MARINE CORPS CTR FOR EMERGING THREATS AND OPRTNTY C CURCIO 3087 ROAN AVE BLDG 3087C QUANTICO VA 22134

NO. OF COPIES	ORGANIZATION
1	US MARINE CORPS MARINE CORPS SYSTEMS CMD CESS PM NBC DEFENSE MEDICAL MCSC MED T EAGLES 20333 BARNETT AVE STE 315 QUANTICO VA 22134-5010
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV J BALDWIN CODE 477200D 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 4T4300D T BOGGS CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 4T4310D M CHAN CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 4T4200D R CHAPMAN CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 478400D P DIXON 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV T FOLEY 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV K HIGA 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100

NO. OF COPIES	ORGANIZATION
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 477200D B LORMAND 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 477200D M MASON 1 ADMINISTRATION CIRCLE CHINA LAKE CA 93555-6100
1	NAVAL AIR WARFARE CTR NAVAIR WEAPONS DIV CODE 4T4320D T PARR CHINA LAKE CA 93555-6100
1	NAVAL ORDNANCE SAFETY AND SECURITY ACTIVITY D PORADA 23 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL ORDNANCE SAFETY AND SECURITY ACTIVITY K TOMASELLO FARAGUT HALL BLDG D323 23 STRAUSS AVE INDIAN HEAD MD 20640-1541
1	US NAVAL RSCH LAB 4555 OVERLOOK AVE SW CODE 6189 R MOWREY WASHINGTON DC 20375-5342
1	US NAVAL RSCH LAB CHEMISTRY DIV CODE 6125 J RUSSELL 4555 OVERLOOK AVE SW WASHINGTON DC 20375-5342
1	CDR NAVAL SEA SYSTEMS CMD INDIAN HEAD CODE 910A W KOPPES 101 STRAUSS AVE INDIAN HEAD MD 20640-5035

NO. OF COPIES	ORGANIZATION
1	CDR NAVAL SURFC WARFARE CTR CODE 4023 BLDG 3347 S D ARCHE 300 HWY 361 CRANE IN 47522-5001
1	NAVAL SURFACE WARFARE CTR CODE G22 BLDG 221 R GARRETT 17320 DAHLGREN RD DAHLGREN VA 22448-5100
1	NAVAL SURFACE WARFARE CTR CODE G24 S HOCK 17320 DAHLGREN RD DAHLGREN VA 22448-5100
1	NAVAL SURFACE WARFARE CTR CODE G24 B KNOTT 17320 DAHLGREN RD DAHLGREN VA 22448-5100
1	NAVAL SURFACE WARFARE CTR E LACY 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CODE G22 S WAGGENER 17320 DAHLGREN RD DAHLGREN VA 22448-5100
1	NAVAL SURFACE WARFARE CTR CODE 910 W BLDG 600 V BELLITTO 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR BLDG 600 J CAREY 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 440C P CARPENTER 101 STRAUSS AVE INDIAN HEAD MD 20640

NO. OF COPIES	ORGANIZATION
1	NAVAL SURFACE WARFARE CTR CODE 910F J CHANG 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR D CICHRA 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR EXPLOSIVES TEST & DEVELOPMENT CODE 370 D COOK 101 STRAUSS AVE BLDG 695 INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR R CRAMER 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 90D R DOHERTY 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR M DUNN 101 STRAUSS AVE BLDG 695 INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR CODE ST A DUONG 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR BLDG 600 F FOROHAR 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR CODE 920J R GUIRGUIS 101 STRAUSS AVE INDIAN HEAD MD 20640-5035

NO. OF COPIES	ORGANIZATION
1	NAVAL SURFACE WARFARE CTR RSCH & TECHNOLOGY DEPT CODE 910O BLDG 600 J HARPER 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR R JONES 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR ENERGETIC MATERIALS RSCH CODE 920L BLDG 600 V JOSHI 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR RSCH AND TECH DEPT CODE 910R R JOUET 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR BLDG 490 ROOM 220 C KNOTT 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR BLDG 600 J MANNION 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR BLDG D 323 CODE 4210M R MCCALL 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 90 P MILLER 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 920D BLDG 600 S MILLER 101 STRAUSS AVE INDIAN HEAD MD 20640

NO. OF COPIES	ORGANIZATION
1	NAVAL SURFACE WARFARE CTR CODE 920 G PANGILINAN 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 920U BLDG 600 L PARKER 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 920P BLDG 600 S PEIRIS 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR D ROSENBERG 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 370JG BLDG 695 J ROGERSON 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR J SALAN 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE CSE BLDG 600 A STERN 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	NAVAL SURFACE WARFARE CTR CODE 4210D C WALSH 101 STRAUSS AVE INDIAN HEAD MD 20640
1	NAVAL SURFACE WARFARE CTR CODE 910X BLDG 600 A WARREN 101 STRAUSS AVE INDIAN HEAD MD 20640
1	OFFICE OF NAVAL RSCH C BEDFORD 800 N QUINCY ST ARLINGTON VA 22217

NO. OF COPIES	ORGANIZATION
1	NAVAL AIR SYSTEMS CMD PATUXENT (NAVAIR) HQ AIR 4 7 A GEHRIS 48150 SHAW RD BLDG 2109 RM 122 PATUXENT RIVER MD 20670
1	OFFICE OF SECRETARY OF DEFENSE ODUSD/S&T D TAM 1777 N KENT ST STE 9030 ARLINGTON VA 22209
1	PENTAGON LW&M LAND WARFARE & MUNITIONS D BAUM OUSD(AT&L)/DS/LW&M RM 3B1060 3090 DEFENSE PENTAGON WASHINGTON DC 20301-3090
1	OUSD(AT&L)/DS/LAND WARFARE & MUNITIONS S ROJAS RM 3B1060 3090 DEFENSE PENTAGON WASHINGTON DC 20301-3090
1	ARGONNE NATL LAB K CARNEY PO BOX 2528 IDAHO FALLS ID 83404
1	ARGONNE NATL LAB CHEMISTRY DIV J HESSLER 9700 SOUTH CASS AVE ARGONNE IL 60439-4831
1	LAWRENCE LIVERMORE NATL LAB A GASH PO BOX 808 L 092 LIVERMORE CA 94551
1	LAWRENCE LIVERMORE NATL LAB MS L 30 A KUHL PO BOX 808 LIVERMORE CA 94550
1	LAWRENCE LIVERMORE NATL LAB L 282 J MOLITORIS PO BOX 808 LIVERMORE CA 94551

NO. OF COPIES	ORGANIZATION
1	LOS ALAMOS NATL LAB MS P918 DX DO W DANEN LOS ALAMOS NM 87545
1	LOS ALAMOS NATL LAB MS E549 K HUBBARD LOS ALAMOS NM 87545
1	LOS ALAMOS NATL LAB MS C920 S SON LOS ALAMOS NM 87545
1	LOS ALAMOS NATL LAB GROUP DX 2 MS C920 B TAPPAN LOS ALAMOS NM 87545
1	SANDIA NATL LABS MS 0836 M BAER ALBUQUERQUE NM 87185-0836
1	SANDIA NATL LABS MS 0836 E HERTEL ALBUQUERQUE NM 87185-0836
1	SANDIA NATL LABS MS 1172 T HITCHCOCK PO BOX 5800 ALBUQUERQUE NM 87185-1172
1	SANDIA NATL LABS PO BOX 5800 MS 1452 B INGRAM ALBUQUERQUE NM 87185-1452
1	SANDIA NATL LABS PO BOX 5800 MS 1454 M KANESHIGE ALBUQUERQUE NM 87185-1454
1	SANDIA NATL LABS PO BOX 5800 MS 1452 B MELOF ALBUQUERQUE NM 87185-1452
1	SANDIA NATL LABS BOX 5800 MS 1454 A RENLUND ALBUQUERQUE NM 87185-1424

NO. OF COPIES	ORGANIZATION
1	DEFENSE THREAT REDUCTION AGENCY J KOLTS 8725 JOHN J KINGMAN RD STOP 6201 FORT BELVOIR VA 22060
2	DCI CTR FOR WEAPONS INTLLGNC NONPROLIFERATION AND ARMS CONTROL WINPAC M AGUILO J WALTON WASHINGTON DC 20505
1	J BACKOFEN 2668 PETERSBOROUGH ST HERNDON VA 20171-2443
1	US GOVERNMENT C LLOYD 47110 SOUTHAMPTON STERLING VA 20165
1	DEFENSE INTELLIGENCE AGENCY K CRELLING BLDG 6000 DWO 4 BOLLING AIR FORCE BASE WASHINGTON DC 20340-5100
1	AEROJET E LIU PO BOX 13222 SACRAMENTO CA 95813
1	ALLIANT TECHSYSTEMS INC C ZISETTE PO BOX 1 RADFORD VA 24141
1	APPLIED RSCH ASSOCIATES C NEEDHAM 4300 SAN MATEO BLVD NE STE A 220 ALBUQUERQUE NM 87110
1	ARGONIDE CORP F TEPPER 291 POWER CT SANFORD FL 32771

NO. OF COPIES	ORGANIZATION
4	ATK THIOKOL PROPULSION J AKESTER K LEE P BRAITHWAITE G LUND PO BOX 707 M/S 244 BRIGHAM CITY UT 84302-0707
2	ATK THIOKOL PROPULSION S GLAITTLI S LUSK PO BOX 707 MS 230 BRIGHAM CITY UT 84302-0707
1	BATTELLE MEMORIAL INST T BURKY 505 KING AVE COLUMBUS OH 43201
1	BOOZ ALLEN HAMILTON G ZUCCARELLO 3811 N FAIRFAX DR STE 600 ARLINGTON VA 22203
1	CACI INC M EGGLESTON 14151 PARK MEADOW DR CHANTILLY VA 20151
1	DE TECHNOLOGIES INC C FORSYTH 3620 HORIZON DR KING OF PRUSSIA PA 19406
1	ENERGETIC MATL APPLICATIONS L JOSEPHSON 300 DAWN CT RIDGECREST CA 93555
1	ENSIGN BICKFORD ARSPC & DEFNS A GARVEY 640 HOPMEADOW ST BLDG 46 SIMSBURY CT 06070
1	EXOTHERM CORP A LASCHIVER 1035 LINE ST CAMDEN NJ 08103
1	GENERAL SCIENCES INC P ZAVITSANOS 205 SCHOOLHOUSE RD SOUDERTON PA 18964

NO. OF COPIES	ORGANIZATION
1	GEO CTRS INC D PARITOSH BLDG 3028 PICATINNY ARSENAL NJ 07806-5000
1	HICKS & ASSOCIATES INC C KITCHENS JR 1710 SAIC DR STE 1300 MCLEAN VA 22102
1	NANOTECHNOLOGIES INC D HAMILL 1908 KRAMER LN AUSTIN TX 78758
1	NORTHROP GRUMMAN CORP/DTRA J COCCHIARO 6940 S KINGS HIGHWAY STE 210 ALEXANDRIA VA 22310
1	NORTHROP GRUMMAN IT M SEIZEW PO BOX 471 SAN PEDRO CA 90733-0471
1	PRATT & WHITNEY N TRIVEDI 600 METCALF RD SAN JOSE CA 95138
1	ST MARKS POWDER A GENERAL DYNAMICS CO J DRUMMOND PO BOX 222 ST MARKS FL 32355
1	SAIC W WAESCHE 4319 BANBURY DR GAINESVILLE VA 20155
1	SRI INTL J BOTTARO 333 RAVENSWOOD AVE RM PS 318 MENLO PARK CA 94025
1	TALLEY DEFENSE SYSTEMS G KNOWLTON 40512 N HIGLEY RD MESA AZ 85205

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND
30	DIR USARL AMSRD ARL WM BD W ANDERSON S BUNTE E BYRD B FORCH B HOMAN P KASTE A KOTLAR K MCNESBY M MCQUAID A MIZIOLEK B RICE R SAUSA R PESCE-RODRIGUEZ R BEYER A BRANT J COLBURN P CONROY C LEVERITT M NUSCA AMSRD ARL WM TB S AUBERT P BAKER E BUKOVKY R EHLERS D KOOKER B KRZEWINSKI N NAIK T PIEHLER B ROOS R SKAGGS E WILSON