ARMY RESEARCH LABORATORY

Analysis of Burning Rate Phenomena and Extinguished Solid Propellants From an Interrupted Closed Bomb With Plasma Igniter

by Robert J. Lieb, Pamela J. Kaste, Aviezer Birk,
Amy Kinkennon, Rose Ann Pesce-Rodriguez,
Michael A. Schroeder, and Miguel Del Güercio

ARL-TR-2561 August 2001

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-2561 **August 2001**

Analysis of Burning Rate Phenomena and Extinguished Solid Propellants From an Interrupted Closed Bomb With Plasma Igniter

Robert J. Lieb, Pamela J. Kaste, Aviezer Birk,
Amy Kinkennon, Rose Ann Pesce-Rodriguez,
Michael A. Schroeder, and Miguel Del Güercio
Weapons and Materials Research Directorate, ARL

Abstract

Interrupted closed-bomb analyses of M30 and JA2 propellants have been performed with the goal of understanding the phenomena responsible for the apparent augmentation of closed-bomb burning rates when plasma, rather than black powder, ignition is used. Burning rates of the propellants during plasma injection and after the plasma (to blowout pressures of 100 Mpa) have been estimated from the grain regression measurements and the P-t traces. Characterization of the extinguished grains has been performed in order to understand the interaction of the plasma with the propellant, including scanning electron microscopy (SEM) and Fourier-transform infrared (FTIR) analyses.

Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

1. Introduction

A 129-cm^3 closed bomb capable of either plasma or conventional black powder ignition was previously used [1] to study the effect of electrothermal chemical (ETC) ignition on solid gun propellants. For M30, it was reported that a 33% increase in burning rate over the range of 100–220 MPa occurred with plasma ignition, relative to conventional ignition; the closed-bomb burning rate augmentation of JA2 was insignificant. Researchers in the international community have also reported plasma augmentation of the burning rate with nitramine-based composite propellant [2]. A goal of this work is to understand the phenomena responsible for the apparent increase in burning rate measured in the closed bomb when plasma, rather than black powder, ignition is used. The approach was to repeat key experiments from [1] using granular, 7-perf M30 and JA2, but interrupt the burning at 35, 75, and 100 MPa, and determine if there is an increase in the intrinsic burning rate of the propellant, or if other phenomena (e.g., fracture [3], porous burn, etc.) are involved.

The interrupted closed-bomb experiment offers a means of studying basic plasma-propellant interactions under well-defined conditions of plasma energy and power input, pressure profile, and proximity of the sample to the plasma. A second goal of this work is to characterize extinguished grains from both plasma- and conventionally ignited samples, in order to begin to understand the basic mechanisms of plasma-propellant interaction. Scanning electron microscopy (SEM) was performed to assess fracture, erosive burning, gas evolution, and melt layer thickness, and Fourier-transform infrared (FTIR) spectroscopy was used to detect and identify decomposition products and component depletion.

2. Experimental

2.1 Closed-Bomb Firings

Samples for closed-bomb analysis consisted of 7-perforated grains of M30 and JA2 with a diameter, length, and perforation diameter of approximately 0.75, 1.5, and 0.07 cm, respectively. Closed-bomb analyses of M30 and JA2 were performed in a 3.81-cm inside diameter (ID) closed bomb of 129 cm^3, with a typical propellant charge weight of 32 g, with both conventional and plasma ignition. Details of the bomb configuration can be found in [1] and are only briefly described here. (In addition to the polyethylene capillaries used in [1], polyethylene terephthalate (mylar) capillaries have been used in this study.) For extinguished propellant measurements, the addition of the interface of the bomb to the evacuation chamber yields a total closed-bomb volume of 150 cm^3 (Figure 1). The expansion chamber consists of a 240-L tank with a 2.5-cm-diameter blowout area interfaced to the closed bomb.

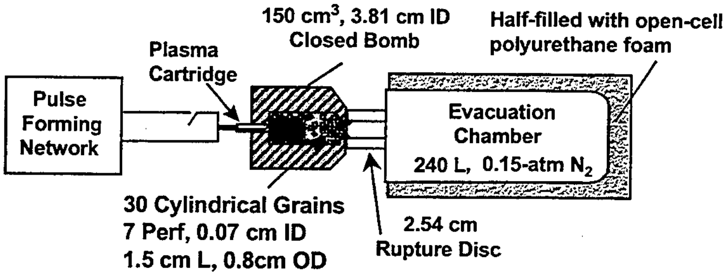


Figure 1. Experimental apparatus for extinguished closed-bomb experiments.

Rapid extinguishment of the propellants occurs due to the sudden expansion into the evacuated chamber. Soft capture of the propellant is achieved with a lining of thermally resistant polyurethane foam. In the case of plasma ignition, the plasma is channeled through a straw that is perforated to resemble a piccolo tube with 24 holes to enable uniform distribution of the plasma around the propellant. The plasma is generated by an electrical pulse to a nickel fuse wire that rapidly vaporizes. This results in ionization of the polyethylene liner, and a high-current discharge is sustained. The electrical pulse is generated with a 400-kJ capacitor-based pulse-forming network, with a charging voltage of 4 kV and output energy of up to 29.3 kJ. Acceptable firings yielded a power curve with a smooth rise and 1.2-ms duration; the peak power was typically 25–29 MW, and the plasma energy varied between 24–29 kJ. In the conventional mode, an electric match is used to ignite 0.6 g of black powder confined in a plastic straw with the propellant distributed concentrically in two tiers around the straw.

2.2 FTIR Spectroscopy

Microreflectance FTIR was used to obtain spectra of the propellant surface (i.e., about top 10 µ) with no modification of the sample. FTIR analyses were performed using a Mattson Polaris spectrometer operating at a resolution of 4 cm^{-1}. The reflectance spectra were obtained using a Spectra-Tech* microreflectance attachment with 32-µ IR objective and a signal averaging over 200 scans. Aluminum foil was used to collect the background spectra.

2.3 SEM

Micrographs of virgin and extinguished grains were examined to establish any morphological differences between grains ignited by conventional and plasma

---

* Thermo Spectra-Tech, 2 Research Dr., Shelton, CT 06484-0869.

sources. The grains were selected and cold fractured along the longitudinal grain axis to expose the burning surface of the perforations and a cross section of the burning surface and the propellant below this surface. The prepared specimens were sputter coated with gold-palladium. The lateral exterior burn surface was also examined for any differences.

3. Results

3.1 Closed-Bomb Firings

The P-t curves for the M30 and JA2 samples ignited with the plasma are shown in Figure 2, for blowout pressures of nominally 35 and 100 MPa. P-t curves for conventionally ignited M30 are also shown, and are evident from the longer time-to-burst of about 10 ms at 60 MPa. Also apparent is the uniform curvature due to the regular mass generation of the conventionally ignited propellant. In contrast, propellants ignited by plasma show a sharp increase in pressure within the first 1–2 ms due to the sudden plasma impulse, followed by a lower rate of pressure increase when normal propellant burning takes over.

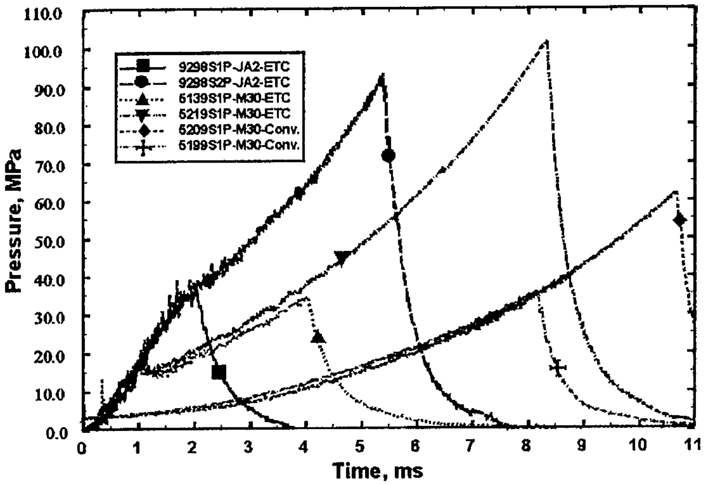


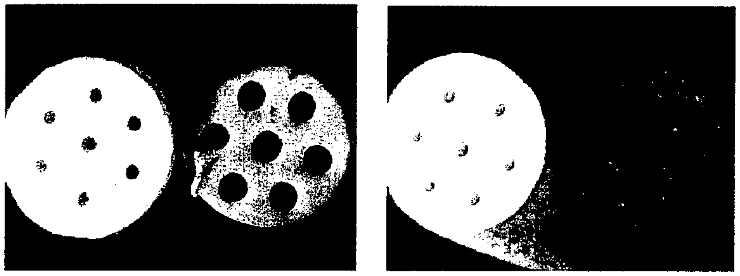
Figure 2. P-t curves for trials used in assessing post-plasma burning rate.

Originally, it was hoped that a propellant burning rate could be determined for each closed-bomb trial using the P-t curves and the changes in the grain dimensions of extinguished samples of plasma and conventionally ignited M30 and JA2 [4]. However, the fact that the P-t curves of the plasma-ignited grains show an initial rapid pressurization made the analysis more complicated.

With the interrupted burning tests, the approach used was to consider identical propellants, fired under similar plasma power conditions, for which the pressure-time histories were comparable, with the exception that they were extinguished at two different pressures. The recovered grains were measured to determine the extent of regression between the two blowout pressures. Typically, during the plasma pulse, the pressure would rise to about 30 MPa; therefore, comparison of the calculated regression (using conventional burn-rate parameters over the experimental pressure interval) with the measured propellant regression between two pressures beyond 30 MPa yielded the extent of the intrinsic post-plasma burn-rate augmentation.

For both M30 and JA2, no evidence was found of increased burning rate after the plasma event, i.e., the measured grain regression is consistent with those predicted using conventional burning rates. For both M30 and JA2, grain regression at 35 MPa was consistently slightly greater than predicted based on conventional burning rates, suggesting that there is burning-rate augmentation during the plasma event. Thus, it appears that the post-plasma burn rates are not intrinsic [5].

Burning occurred to a greater extent in the samples ignited with black powder than with the plasma, because plasma-ignited samples had a significant fraction of the total pressure caused by the plasma injection. Thus, conventionally ignited samples are exposed to a longer burn time. This is reflected by the extent of grain regression. Average perf diameters of conventionally ignited samples of M30 and JA2 were 1.15 mm and 1.07 mm, respectively, while for plasma-ignited samples, the perf diameters were 1.07 mm and 0.98 mm, respectively. Another indication that burning had progressed to a greater extent in the conventional samples was apparent with the color change of the white virgin M30 grains to a golden-brown color in the samples extinguished after conventional ignition (Figure 3a). Most recovered grains from the plasma ignition were blackened (Figure 3b). However, on surfaces where the propellants were shielded from the direct blast of the plasma, the M30 grains from plasma-ignited samples (100 MPa) appear as a lighter cream color than golden-colored conventionally ignited samples (75 MPa) even though grain regression was comparable. This suggests a difference in chemical mechanism between the conventional and plasma ignition.

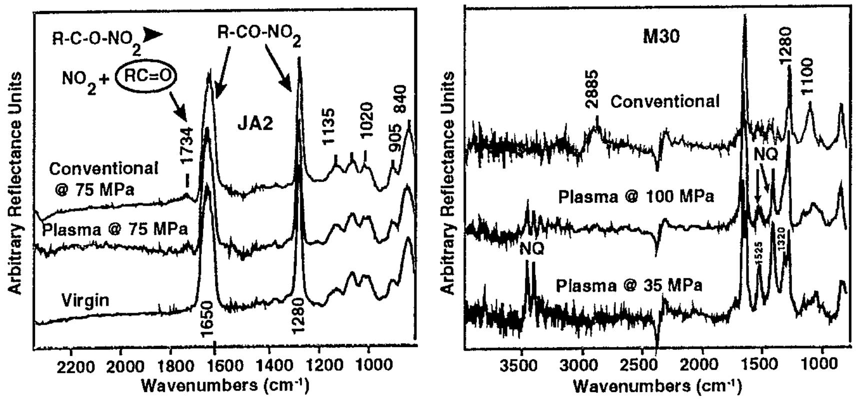


(a) Black powder ignition (b) Plasma ignition

Figure 3. Photograph of M30 propellant samples extinguished at 75 MPa. A virgin (white) grain is shown with each.

3.2 FTIR Analysis

The IR spectra of virgin and extinguished propellant samples are shown in Figures 4a and 4b (JA2 and M30, respectively). Dominant bands in the spectra of both propellants at 1650 cm^{-1} and 1285 cm^{-1} are due to the nitrate-ester (O-NO_2) absorption. The JA2 microreflectance spectra show a slight shoulder at 1734 cm^{-1} due to aldehyde formation. Samples that visually appeared altered, as though reaction had occurred, exhibited the aldehyde band more so than surfaces that were not noticeably changed. Extinguished samples from either plasma or conventional ignition, microtomed to a depth of about 50 µm, yielded spectra virtually identical to the virgin material (not shown). Thus, decomposition appears to be limited to surfaces less than this depth.



(a) JA2 (b) M30

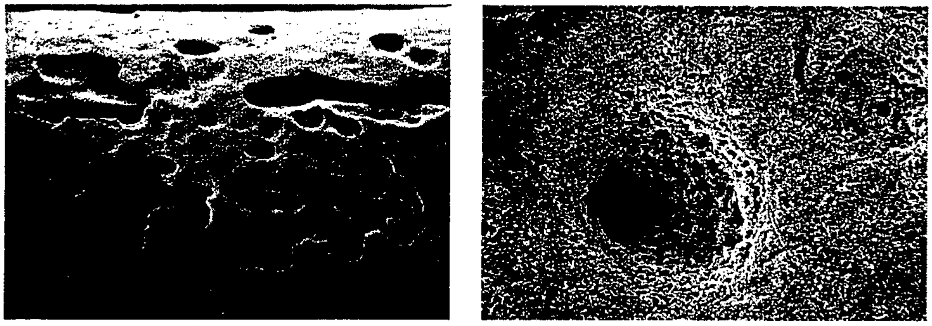
Figure 4. Microreflectance spectra of virgin, plasma- and conventionally ignited propellants.

In addition to the nitrate-ester bands, the spectrum of M30 has bands from nitroguanidine (NQ) as well. Bands due to NQ diminish after either plasma or conventional ignition, although the effect is significantly greater with conventional ignition, probably due to the greater extent of burning. The microreflectance spectra of the perforated regions of M30 grains were also obtained (not shown) for plasma-ignited samples extinguished at 35 and 100 MPa. The results are consistent with those from the outer surfaces of the samples, i.e., that at increased pressures (i.e., increased extent of burning), the NQ level is diminished. No difference in the NQ level within the perforated region was detected between the plasma and conventionally ignited samples. Also, in M30, a band at 1100 cm^{-1} (Figure 4b) from an unknown source becomes more distinct in the spectra of the extinguished grains, and is more prominent in spectra from conventionally ignited samples. This molecular species may also contain the aliphatic (-CH_2) and (-CH_3) groups, as evidenced by bands at 2885 cm^{-1} and 2975 cm^{-1}. Analysis by liquid chromatography-mass spectroscopy (LC-MS) could be helpful to isolate and identify the product.

3.3 SEM

Extinguished surfaces have been studied previously [6], and it has been noted that many combustion features are preserved on surfaces that undergo this manner of rapid pressure reduction. The flame is rapidly blown away from the surface, which quickly solidifies, leaving most of the burning surface features intact.

SEM micrographs revealed several interesting features. The exterior lateral surfaces of the extinguished grains from both the ignition sources appeared very similar except for one feature. In plasma ignition the grains showed evidence of burning caused by hot particles being sprayed onto the grain surface, as shown in Figure 5.



(a) 5×

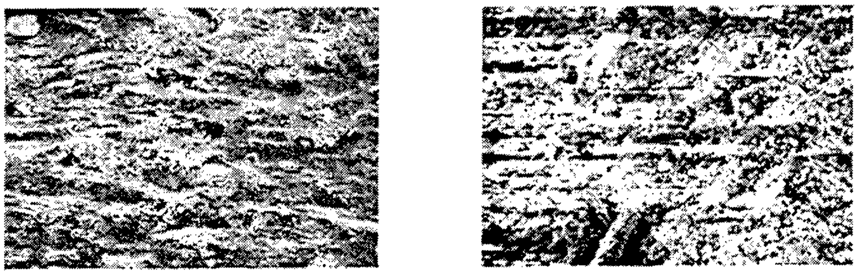
(b) 90×

Figure 5. Micrographs of extinguished grain exterior showing evidence of hot particle spray from the plasma igniter (100 MPa).

These features seemed to have further developed as the extinguishing pressures were increased. At higher extinguishing pressures, the grains burn for a longer period of time, so the progression of the burning can be followed. This indicates that perhaps the hot particles were projected through the surface and burning took place under the surface along the line of travel.

This phenomenon would tend to augment the surface area available and would give the appearance of a higher burning rate during the early portion of the propellant combustion. However, since the augmentation is caused by increased surface area, the apparent burning rate will be lowered in later stages of burning, as the resulting surface area is reduced due to the intersection (burn through and crossing) of burning surfaces.

Another interesting feature was noted on the burning surfaces within the perforations. Most burning surfaces of extinguished propellant appear as shown in Figure 6a, which depicts the conventionally ignited extinguished surface. Note that the surface is smooth, indicating melting. However, in Figure 6b there seems to be no indication of melting. There also appears to be a series of grooves

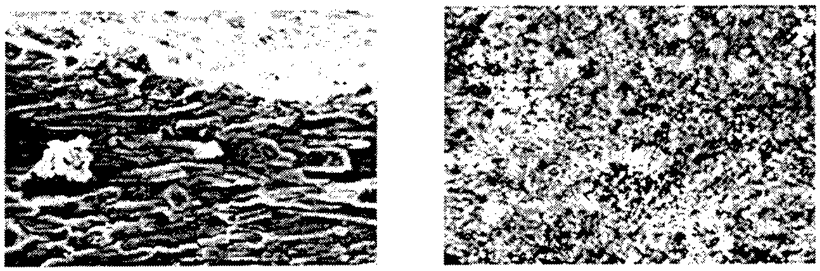


(a) Conventional Ignition
(70 MPa, 850×)

(b) Plasma Ignition
(35 MPa, 850×)

Figure 6. Micrographs of the burning surface of the extinguished grain perforation showing different features between ignition methods.

that conform to the size of NQ particles, which appear at the same magnification in Figure 7a. Stereoscopic pictures that were taken and analyzed confirmed that the features being observed were grooves. This indicates a different combustion process is in effect for the plasma-ignited samples that cause the NQ crystals to vacate the matrix. Note that in Figure 7b the grooves are much less prominent at higher pressure (100 MPa) and the surface appears more like the conventional. This is consistent with the burning mechanisms returning to similar processes at higher pressures. One other observation on the morphology of the M30 propellant is worth noting. While most propellants have measurable melt layers that range from 2–30 μm in thickness, the melt layer for M30 is so thin that it was not able to be measured. The evidence for a melt layer is shown in Figure 6a, as noted there. However, when a cross section of that surface is made and the thickness measurement is attempted, no thickness can be determined because it is so thin. The propellant goes from the outer surface to a structure identical to the unburned structure regardless of the ignition source without any measurable transition depth(<0.2 μm).



(a) Virgin (850×)

(b) Plasma Ignition (15 Kpsi, 850×)

Figure 7. Micrographs of the burning surface of the extinguished grains showing different features between ignition methods perforation.

4. Conclusions

The goals of this work were twofold: (1) to assess whether the plasma augmentation of propellant burning rate with plasma ignition is real or related to increased mass generation due to increased surface area (e.g., propellant fracture [3]) and (2) to study the mechanisms of plasma-propellant interaction using analytical techniques of SEM and FTIR spectroscopy. For either M30 and JA2, no evidence was found of increased burning rate after the plasma event, i.e., the measured grain regression of the extinguished propellants is consistent with that predicted using conventional burning rates. For both M30 and JA2, grain regression at 35 MPa was consistently slightly greater than predicted based on conventional burning rates, suggesting that there is burning rate augmentation during the plasma event. Work is in progress to assess the vivacity curves for the conventional P-t data obtained in this work, and to simulate the effects of fracture on these curves [3, 5].

The goal of understanding the interaction of plasma with M30 and JA2 propellants, as well as early combustion events with conventional ignition, is only beginning to be realized by this effort, although some important lessons on how to proceed in the future have been learned. For propellants such as JA2 and M30 which contain high levels of plasticizer (e.g., diethylene glycol dinitrate [DEGDN], nitroglycerin [NG]) that migrate, analysis is complicated by the fact that, even if the reaction at the surface is appreciable, the bulk of the propellant remains unreacted and diffusion of the remaining plasticizers after extinguishment is rapid which masks the effects of decomposition. It is noted that in previous studies of these propellants, no significant change in the Akardite II or plasticizer level was detected for grains extinguished from either plasma or conventional ignition [7]. For recent extinguished closed-bomb studies of JA2 and M30 with mylar capillaries, propellant surfaces were sampled immediately for analysis of decomposition products by the more-sensitive LC-MS (work in progress).

Extinguished M30 grains (conventionally ignited, 75-MPa blowout) burned to a greater extent than those ignited with the plasma. Moreover, M30 grains appear almost white in the case of plasma ignition (except for areas that received the direct blast of the plasma, which were blackened), and a golden-brown color for samples that were conventionally ignited, even in samples for which grain regression was comparable. Extinguished grains of M30 show that the NQ diminishes in plasma-ignited samples but is virtually eliminated with conventional ignition. Moreover, an unidentified decomposition product, apparently with aliphatic C-H, is evident in extinguished grains of conventionally ignited M30, which is less apparent when plasma ignition is used.

Extinguished JA2 grains (75-MPa blowout), ignited with either plasma or black powder, both show evidence of aldehyde formation due to denitration of the nitrate esters. Thus, under these conditions, denitration appears to be the result of burning, as opposed to direct interaction of the plasma with the propellant. It is noted that in other experiments, exposure to only plasma radiation resulted in denitration and plasticizer depletion due to subsurface reaction of the propellant [8].

The SEM micrographs revealed that differences exist between the morphology of the burning surfaces ignited by conventional means and by the plasma. The plasma sprays hot particles into the surface exposed to the plasma blast, which results in unprogrammed surface combustion. In addition, the surface features within the perforations indicated that different combustion mechanisms were active there. In the conventional ignition, a melt layer was indicated (smooth surface), whereas in the plasma ignition it appears that in some regions NQ crystals near the surface appeared to be absent and there was no indication of a smooth melt surface. The main conclusion from the morphology investigation was that the burning process at lower pressures appears to have differences. However, as the pressures increase the perforation surfaces are observed to become more and more alike.

The extinguished closed bomb has provided a system for assessing propellant burning rates during and after exposure to plasmas, and for studying plasma-propellant interactions under well-controlled conditions of plasma power, energy, and proximity to the propellant, and propellant temperature and blowout pressure.

INTENTIONALLY LEFT BLANK.

5. References

1. Del Güercio, M. "Propellant Burn Rate Modification by Plasma Injection." *34th JANNAF Combustion Meeting*, vol. 1, pp. 35–42, October 1997.
2. Woodley, C. R., and S. Fuller. "Apparent Enhanced Burn Rates of Solid Propellants Due to Plasmas." *16th International Symposium on Ballistics*, pp. 153–162, September 1996.
3. Kooker, D. E. "A Mechanism for ETC-Augmented Burning Rate of Solid Propellant Consistent with Closed Chamber Experiments." 18th International Ballistic Symposium on Ballistics, San Antonio, TX, November 1999.
4. Oberle, W., and D. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program." ARL-TR-36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, January 1993.
5. Birk, A., M. Del Güercio, A. Kinkennon, D. E. Kooker, and P. J. Kaste. "ETC Closed-Chamber Interrupted-Burning Tests with JA2 and M30 Solid Propellants." *36th JANNAF Combustion Meeting*, vol. II, pp. 105–117, October 1998.
6. Lieb, R. J. "Morphology of Extinguished Monolithic JA2 Grains Fired in a 30-mm Solid Propellant Electrothermal-Chemical (SPETC) Gun." ARL-TR-606, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, November 1994.
7. Kaste, P. J., R. A. Pesce-Rodriguez, M. A. Schroeder, G. L. Katulka, K. J. White, M. G. Leadore, and A. E. Kinkennon. "ETC Plasma-Propellant Interactions." *Proceedings of the Annual Conference of the ICT*, pp. 125-1–125-14, Karlsruhe, FRG, 1998.
8. Kaste, P. J., R. A. Pesce-Rodriguez, M. A. Schroeder, G. L. Katulka, and K. J. White. "Chemical Characterization of Plasma-Treated Solid Gun Propellants." ARL-TR-1798, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, September 1998.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	DARPA SPECIAL PROJECTS OFFICE J CARLINI 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH MAJ HUBER THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR DA OASARDA SARD SO 103 ARMY PENTAGON WASHINGTON DC 20310-0103
1	DPTY ASST SECY FOR R&T SARD TT THE PENTAGON RM 3EA79 WASHINGTON DC 20301-7100
1	COMMANDER US ARMY MATERIEL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA ASF PICATINNY ARSENAL NJ 07806-5000

NO. OF
COPIES ORGANIZATION

1 COMMANDER
US ARMY ARDEC
AMSTA AR QAC T C
C PATEL
PICATINNY ARSENAL NJ
07806-5000

1 COMMANDER
US ARMY ARDEC
AMSTA AR M
D DEMELLA
PICATINNY ARSENAL NJ
07806-5000

3 COMMANDER
US ARMY ARDEC
AMSTA AR FSA
A WARNASH
B MACHAK
M CHIEFA
PICATINNY ARSENAL NJ
07806-5000

2 COMMANDER
US ARMY ARDEC
AMSTA AR FSP G
M SCHIKSNIS
D CARLUCCI
PICATINNY ARSENAL NJ
07806-5000

1 COMMANDER
US ARMY ARDEC
AMSTA AR FSP A
P KISATSKY
PICATINNY ARSENAL NJ
07806-5000

2 COMMANDER
US ARMY ARDEC
AMSTA AR CCH C
H CHANIN
S CHICO
PICATINNY ARSENAL NJ
07806-5000

1 COMMANDER
US ARMY ARDEC
AMSTA AR QAC T
D RIGOGLIOSO
PICATINNY ARSENAL NJ
07806-5000

NO. OF
COPIES ORGANIZATION

1 COMMANDER
US ARMY ARDEC
AMSTA AR WET
T SACHAR
BLDG 172
PICATINNY ARSENAL NJ
07806-5000

9 COMMANDER
US ARMY ARDEC
AMSTA AR CCH B
P DONADIA
F DONLON
P VALENTI
C KNUTSON
G EUSTICE
S PATEL
G WAGNECZ
R SAYER
F CHANG
PICATINNY ARSENAL NJ
07806-5000

6 COMMANDER
US ARMY ARDEC
AMSTA AR CCL
F PUZYCKI
R MCHUGH
D CONWAY
E JAROSZEWSKI
R SCHLENNER
M CLUNE
PICATINNY ARSENAL NJ
07806-5000

5 PM SADARM
SFAE GCSS SD
COL B ELLIS
M DEVINE
W DEMASSI
J PRITCHARD
S HROWNAK
PICATINNY ARSENAL NJ
07806-5000

1 US ARMY ARDEC
INTELLIGENCE SPECIALIST
AMSTA AR WEL F
M GUERRIERE
PICATINNY ARSENAL NJ
07806-5000

NO. OF COPIES	ORGANIZATION
2	PEO FIELD ARTILLERY SYS SFAE FAS PM H GOLDMAN T MCWILLIAMS PICATINNY ARSENAL NJ 07806-5000
12	PM TMAS SFAE GSSC TMA R MORRIS C KIMKER D GUZIEWICZ E KOPACZ R ROESER R DARCY R KOWALSKI R MCDANOLDS L D ULISSE C ROLLER J MCGREEN B PATTER PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WEA J BRESCIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC PRODUCTION BASE MODERN ACTY AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY TACOM PM ABRAMS SFAE ASM AB 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM AMSTA SF WARREN MI 48397-5000
3	COMMANDER US ARMY TACOM PM TACTICAL VEHICLES SFAE TVL SFAE TVM SFAE TVH 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFVS SFAE ASM BV 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM AFAS SFAE ASM AF 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM RDT&E SFAE GCSS W AB J GODELL 6501 ELEVEN MILE RD WARREN MI 48397-5000
2	COMMANDER US ARMY TACOM PM SURV SYS SFAE ASM SS T DEAN SFAE GCSS W GSI M D COCHRAN 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	US ARMY CERL R LAMPO 2902 NEWMARK DR CHAMPAIGN IL 61822

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY TACOM PM SURVIVABLE SYSTEMS SFAE GCSS W GSI H M RYZYI 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFV SFAE GCSS W BV S DAVIS 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM CHIEF ABRAMS TESTING SFAE GCSS W AB QT T KRASKIEWICZ 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER WATERVLIET ARSENAL SMCWV QAE Q B VANINA BLDG 44 WATERVLIET NY 12189-4050
2	TSM ABRAMS ATZK TS S JABURG W MEINSHAUSEN FT KNOX KY 40121
3	ARMOR SCHOOL ATZK TD R BAUEN J BERG A POMEY FT KNOX KY 40121
14	COMMANDER US ARMY TACOM AMSTA TR R R MCCLELLAND D THOMAS J BENNETT D HANSEN AMSTA JSK S GOODMAN J FLORENCE K IYER D TEMPLETON A SCHUMACHER AMSTA TR D D OSTBERG L HINOJOSA B RAJU AMSTA CS SF H HUTCHINSON F SCHWARZ WARREN MI 48397-5000
14	BENET LABORATORIES AMSTA AR CCB R FISCELLA M SOJA E KATHE M SCAVULO G SPENCER P WHEELER S KRUPSKI J VASILAKIS G FRIAR R HASENBEIN AMSTA CCB R S SOPOK E HYLAND D CRAYON R DILLON WATERVLIET NY 12189-4050
2	HQ IOC TANK AMMUNITION TEAM AMSIO SMT R CRAWFORD W HARRIS ROCK ISLAND IL 61299-6000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY AMCOM AVIATION APPLIED TECH DIR J SCHUCK FT EUSTIS VA 23604-5577
1	DIRECTOR US ARMY AMCOM SFAE AV RAM TV D CALDWELL BLDG 5300 REDSTONE ARSENAL AL 35898
2	US ARMY CORPS OF ENGINEERS CERD C T LIU CEW ET T TAN 20 MASS AVE NW WASHINGTON DC 20314
1	US ARMY COLD REGIONS RSCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	SYSTEM MANAGER ABRAMS ATZK TS LTC J H NUNN BLDG 1002 RM 110 FT KNOX KY 40121
1	USA SBCCOM PM SOLDIER SPT AMSSB PM RSS A J CONNORS KANSAS ST NATICK MA 01760-5057
2	USA SBCCOM MATERIAL SCIENCE TEAM AMSSB RSS J HERBERT M SENNETT KANSAS ST NATICK MA 01760-5057
2	OFC OF NAVAL RESEARCH D SIEGEL CODE 351 J KELLY 800 N QUINCY ST ARLINGTON VA 22217-5660
1	NAVAL SURFACE WARFARE CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR TECH LIBRARY CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CRANE DIVISION M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
8	DIRECTOR US ARMY NATIONAL GROUND INTELLIGENCE CTR D LEITER M HOLTUS M WOLFE S MINGLEDORF J GASTON W GSTATTENBAUER R WARNER J CRIDER 220 SEVENTH ST NE CHARLOTTESVILLE VA 22091
2	NAVAL SURFACE WARFARE CTR U SORATHIA C WILLIAMS CD 6551 9500 MACARTHUR BLVD WEST BETHESDA MD 20817
2	COMMANDER NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R PETERSON CODE 2020 M CRITCHFIELD CODE 1730 BETHESDA MD 20084

NO. OF COPIES	ORGANIZATION
8	US ARMY SBCCOM SOLDIER SYSTEMS CENTER BALLISTICS TEAM J WARD W ZUKAS P CUNNIFF J SONG MARINE CORPS TEAM J MACKIEWICZ BUS AREA ADVOCACY TEAM W HASKELL AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019
9	US ARMY RESEARCH OFC A CROWSON J CHANDRA H EVERETT J PRATER R SINGLETON G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
8	NAVAL SURFACE WARFARE CTR J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 E ROWE CODE G33 T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448
1	NAVAL SEA SYSTEMS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NAVAL SURFACE WARFARE CTR M LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448
2	NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR BETHESDA MD 20054-5000
1	EXPEDITIONARY WARFARE DIV N85 F SHOUP 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750
1	AFRL MLSS R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
1	WATERWAYS EXPERIMENT D SCOTT 3909 HALLS FERRY RD SC C VICKSBURG MS 39180
5	DIRECTOR LLNL R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL L COULTER 7278 4TH ST BLDG 100 BAY D HILL AFB UT 84056-5205

NO. OF COPIES	ORGANIZATION
1	OSD JOINT CCD TEST FORCE OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
1	DEFENSE NUCLEAR AGENCY INNOVATIVE CONCEPTS DIV 6801 TELEGRAPH RD ALEXANDRIA VA 22310-3398
3	DARPA M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
2	SERDP PROGRAM OFC PM P2 C PELLERIN B SMITH 901 N STUART ST STE 303 ARLINGTON VA 22203
1	FAA MIL HDBK 17 CHAIR L ILCEWICZ 1601 LIND AVE SW ANM 115N RESTON VA 98055
1	US DEPT OF ENERGY OFC OF ENVIRONMENTAL MANAGEMENT P RITZCOVAN 19901 GERMANTOWN RD GERMANTOWN MD 20874-1928
1	DIRECTOR LLNL F ADDESSIO MS B216 PO BOX 1633 LOS ALAMOS NM 87545
1	OAK RIDGE NATIONAL LABORATORY R M DAVIS PO BOX 2008 OAK RIDGE TN 37831-6195
3	DIRECTOR SANDIA NATIONAL LABS APPLIED MECHANICS DEPT MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969
1	OAK RIDGE NATIONAL LABORATORY C EBERLE MS 8048 PO BOX 2008 OAK RIDGE TN 37831
1	OAK RIDGE NATIONAL LABORATORY C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831
5	NIST J DUNKERS M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899
1	HYDROGEOLOGIC INC SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170
3	NASA LANGLEY RSCH CTR AMSRL VS W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001
1	NASA LANGLEY RSCH CTR T GATES MS 188E HAMPTON VA 23661-3400
1	FHWA E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101

NO. OF
COPIES ORGANIZATION

3 CYTEC FIBERITE
R DUNNE
D KOHLI
R MAYHEW
1300 REVOLUTION ST
HAVRE DE GRACE MD 21078

1 USDOT FEDERAL RAILRD
M FATEH RDV 31
WASHINGTON DC 20590

1 MARINE CORPS
INTLLGNC ACTVTY
D KOSITZKE
3300 RUSSELL RD STE 250
QUANTICO VA 22134-5011

1 DIRECTOR
NATIONAL GRND INTLLGNC CTR
IANG TMT
220 SEVENTH ST NE
CHARLOTTESVILLE VA
22902-5396

1 SIOUX MFG
B KRIEL
PO BOX 400
FT TOTTEN ND 58335

2 3TEX CORPORATION
A BOGDANOVICH
J SINGLETARY
109 MACKENAN DR
CARY NC 27511

1 3M CORPORATION
J SKILDUM
3M CENTER BLDG 60 IN 01
ST PAUL MN 55144-1000

1 DIRECTOR
DEFENSE INTLLGNC AGNCY
TA 5
K CRELLING
WASHINGTON DC 20310

1 ADVANCED GLASS FIBER YARNS
T COLLINS
281 SPRING RUN LANE STE A
DOWNINGTON PA 19335

NO. OF
COPIES ORGANIZATION

1 COMPOSITE MATERIALS INC
D SHORTT
19105 63 AVE NE
PO BOX 25
ARLINGTON WA 98223

1 JPS GLASS
L CARTER
PO BOX 260
SLATER RD
SLATER SC 29683

1 COMPOSITE MATERIALS INC
R HOLLAND
11 JEWEL CT
ORINDA CA 94563

1 COMPOSITE MATERIALS INC
C RILEY
14530 S ANSON AVE
SANTA FE SPRINGS CA 90670

2 SIMULA
J COLTMAN
R HUYETT
10016 S 51ST ST
PHOENIX AZ 85044

2 PROTECTION MATERIALS INC
M MILLER
F CRILLEY
14000 NW 58 CT
MIAMI LAKES FL 33014

2 FOSTER MILLER
M ROYLANCE
W ZUKAS
195 BEAR HILL RD
WALTHAM MA 02354-1196

1 ROM DEVELOPMENT CORP
R O MEARA
136 SWINEBURNE ROW
BRICK MARKET PLACE
NEWPORT RI 02840

NO. OF COPIES	ORGANIZATION
2	TEXTRON SYSTEMS T FOLTZ M TREASURE 1449 MIDDLESEX ST LOWELL MA 01851
1	O GARA HESS & EISENHARDT M GILLESPIE 9113 LESAINT DR FAIRFIELD OH 45014
2	MILLIKEN RSCH CORP H KUHN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC J SANTOS PO BOX 1425 COVENTRY RI 02816
1	BATTELLE NATICK OPNS B HALPIN 209 W CENTRAL ST STE 302 NATICK MA 01760
1	ARMTEC DEFENSE PRODUCTS S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
1	NATIONAL COMPOSITE CENTER T CORDELL 2000 COMPOSITE DR KETTERING OH 45420
3	PACIFIC NORTHWEST LAB M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
2	AMOCO PERFORMANCE PRODUCTS M MICHNO JR J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944

NO. OF COPIES	ORGANIZATION
8	ALLIANT TECHSYSTEMS INC C CANDLAND MN11 2830 C AAKHUS MN11 2830 B SEE MN11 2439 N VLAHAKUS MN11 2145 R DOHRN MN11 2830 S HAGLUND MN11 2439 M HISSONG MN11 2830 D KAMDAR MN11 2830 600 SECOND ST NE HOPKINS MN 55343-8367
1	SAIC M PALMER 1410 SPRING HILL RD STE 400 MS SH4 5 MCLEAN VA 22102
1	SAIC G CHRYSSOMALLIS 3800 W 80TH ST STE 1090 BLOOMINGTON MN 55431
1	AAI CORPORATION T G STASTNY PO BOX 126 HUNT VALLEY MD 21030-0126
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174
1	CUSTOM ANALYTICAL ENG SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
3	ALLIANT TECHSYSTEMS INC J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	OFC DEPUTY UNDER SEC DEFNS J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202

NO. OF COPIES	ORGANIZATION
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
5	AEROJET GEN CORP D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296
3	HEXCEL INC R BOE PO BOX 18748 SALT LAKE CITY UT 84118
1	HERCULES INC HERCULES PLAZA WILMINGTON DE 19894
1	BRIGS COMPANY J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443
1	ZERNOW TECHNICAL SERVICES L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
1	GENERAL DYNAMICS OTS L WHITMORE 10101 NINTH ST NORTH ST PETERSBURG FL 33702
3	GENERAL DYNAMICS OTS FLINCHBAUGH DIV E STEINER B STEWART T LYNCH PO BOX 127 RED LION PA 17356
1	GKN AEROSPACE D OLDS 15 STERLING DR WALLINGFORD CT 06492

NO. OF COPIES	ORGANIZATION
5	SIKORSKY AIRCRAFT G JACARUSO T CARSTENSAN B KAY S GARBO MS S330A J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	PRATT & WHITNEY C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
1	AEROSPACE CORP G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806
1	UDLP G THOMAS PO BOX 58123 SANTA CLARA CA 95052
2	UDLP R BARRETT MAIL DROP M53 V HORVATICH MAIL DROP M53 328 W BROKAW RD SANTA CLARA CA 95052-0359
3	UDLP GROUND SYSTEMS DIVISION M PEDRAZZI MAIL DROP N09 A LEE MAIL DROP N11 M MACLEAN MAIL DROP N06 1205 COLEMAN AVE SANTA CLARA CA 95052
4	UDLP R BRYNSVOLD P JANKE MS 170 4800 EAST RIVER RD MINNEAPOLIS MN 55421-1498

NO. OF COPIES	ORGANIZATION
1	UDLP D MARTIN PO BOX 359 SANTA CLARA CA 95052
2	BOEING DFNSE & SPACE GP W HAMMOND S 4X55 J RUSSELL S 4X55 PO BOX 3707 SEATTLE WA 98124-2207
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
1	BOEING DOUGLAS PRODUCTS DIV L J HART SMITH 3855 LAKEWOOD BLVD D800 0019 LONG BEACH CA 90846-0001
1	LOCKHEED MARTIN SKUNK WORKS D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	LOCKHEED MARTIN R FIELDS 1195 IRWIN CT WINTER SPRINGS FL 32708
1	MATERIALS SCIENCES CORP G FLANAGAN 500 OFC CENTER DR STE 250 FT WASHINGTON PA 19034
1	NORTHRUP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090

NO. OF COPIES	ORGANIZATION
2	GDLS D REES M PASIK PO BOX 2074 WARREN MI 48090-2074
1	GDLS MUSKEGON OPERATIONS W SOMMERS JR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD G WALKER 991 ANNAPOLIS WAY WOODBRIDGE VA 22191
6	INST FOR ADVANCED TECH H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
2	CIVIL ENGR RSCH FOUNDATION PRESIDENT H BERNSTEIN R BELLE 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613

NO. OF COPIES	ORGANIZATION
1	UCLA MANE DEPT ENGR IV H T HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RESEARCH INST R Y KIM A K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UMASS LOWELL PLASTICS DEPT N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RSCH INST GA INST OF TCHNLGY P FRIEDERICH ATLANTA GA 30392
1	MICHIGAN ST UNIV MSM DEPT R AVERILL 3515 EB EAST LANSING MI 48824-1226
1	UNIV OF WYOMING D ADAMS PO BOX 3295 LARAMIE WY 82071
2	PENN STATE UNIV R MCNITT C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801

NO. OF COPIES	ORGANIZATION
1	PURDUE UNIV SCHOOL OF AERO & ASTRO C T SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS S TSAI DURANT BLDG STANFORD CA 94305
1	UNIV OF MAIN ADV STR & COMP LAB R LOPEZ ANIDO 5793 AEWC BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LABORATORY NEWARK DE 19716
1	DEPT OF MATERIALS SCIENCE & ENGINEERING UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN J ECONOMY 1304 WEST GREEN ST 115B URBANA IL 61801

NO. OF COPIES	ORGANIZATION
1	NORTH CAROLINA STATE UNIV CIVIL ENGINEERING DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908
1	UNIV OF MARYLAND DEPT OF AEROSPACE ENGNRNG A J VIZZINI COLLEGE PARK MD 20742
3	UNIV OF TEXAS AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VA POLYTECHNICAL INST & STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	DREXEL UNIV A S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
1	SOUTHWEST RSCH INST ENGR & MATL SCIENCES DIV J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY P DIETZ 392 HOPKINS RD AMXSY TD APG MD 21005-5071
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP AP L APG MD 21005-5066

ABERDEEN PROVING GROUND (CONT)

NO. OF COPIES	ORGANIZATION
91	DIR USARL AMSRL CI AMSRL CI H W STUREK AMSRL CI S A MARK AMSRL CS IO FI M ADAMSON AMSRL SL BA AMSRL SL BL D BELY R HENRY AMSRL SL BG AMSRL SL I AMSRL WM J SMITH AMSRL WM B A HORST AMSRL WM BA D LYON AMSRL WM BC P PLOSTINS J NEWILL S WILKERSON A ZIELINSKI AMSRL WM BD B FORCH R FIFER R PESCE RODRIGUEZ B RICE AMSRL WM BE C LEVERITT AMSRL WM BF J LACETERA AMSRL WM BR C SHOEMAKER J BORNSTEIN AMSRL WM M D VIECHNICKI G HAGNAUER J MCCAULEY AMSRL WM MA L GHIORSE S MCKNIGHT AMSRL WM MB B FINK J BENDER T BOGETTI R BOSSOLI L BURTON

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

K BOYD
S CORNELISON
P DEHMER
R DOOLEY
W DRYSDALE
G GAZONAS
S GHIORSE
D GRANVILLE
D HOPKINS
C HOPPEL
D HENRY
R KASTE
M KLUSEWITZ
M LEADORE
R LIEB
E RIGAS
J SANDS
D SPAGNUOLO
W SPURGEON
J TZENG
E WETZEL
A FRYDMAN
AMRSL WM MC
  J BEATTY
  E CHIN
  J MONTGOMERY
  A WERECZCAK
  J LASALVIA
  J WELLS
AMSRL WM MD
  W ROY
  S WALSH
AMSRL WM T
  B BURNS
  M ZOLTOSKI
AMSRL WM TA
  W GILLICH
  T HAVEL
  J RUNYEON
  M BURKINS
  E HORWATH
  B GOOCH
  W BRUCHEY
  M NORMANDIA

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMRSL WM TB
  D KOOKER
  P BAKER
AMSRL WM TC
  R COATES
AMSRL WM TD
  A DAS GUPTA
  T HADUCH
  T MOYNIHAN
  F GREGORY
  M RAFTENBERG
  M BOTELER
  T WEERASOORIYA
  D DANDEKAR
  A DIETRICH
AMSRL WM TE
  A NIILER
  J POWELL
AMSRL SS SD
  H WALLACE
AMSRL SS SE DS
  R REYZER
  R ATKINSON

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	SMC SCOTLAND P W LAY DERA ROSYTH ROSYTH ROYAL DOCKYARD DUNFERMLINE FIFE KY 11 2XR UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTERNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	DEFENSE RESEARCH ESTAB VALCARTIER F LESAGE COURCELETTE QUEBEC COA IRO CANADA
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND
1	DYNAMEC RESEARCH AB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN

NO. OF COPIES	ORGANIZATION
1	ISRAEL INST OF TECHNOLOGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO AMRL WEAPONS SYSTEMS DIVISION N BURMAN RLLWS SALISBURY SOUTH AUSTRALIA 5108 AUSTRALIA
1	ECOLE ROYAL MILITAIRE E CELENS AVE DE LA RENAISSANCE 30 1040 BRUXELLE BELGIQUE
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BOULEVARD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	INSTITUT FRANCO ALLEMAND DE RECHERCHES DE SAINT LOUIS DE M GIRAUD 5 RUE DU GENERAL CASSAGNOU BOITE POSTALE 34 F 68301 SAINT LOUIS CEDEX FRANCE
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND

NO. OF
COPIES ORGANIZATION

1 TNO PRINS MAURITS
LABORATORY
R IJSSELSTEIN
LANGE KLEIWEG 137
PO BOX 45
2280 AA RIJSWIJK
THE NETHERLANDS

2 FOA NATL DEFENSE RESEARCH
ESTAB
DIR DEPT OF WEAPONS &
PROTECTION
B JANZON
R HOLMLIN
S 172 90 STOCKHOLM
SWEDEN

2 DEFENSE TECH & PROC AGENCY
GROUND
I CREWTHER
GENERAL HERZOG HAUS
3602 THUN
SWITZERLAND

1 MINISTRY OF DEFENCE
RAFAEL
ARMAMENT DEVELOPMENT
AUTH
M MAYSELESS
PO BOX 2250
HAIFA 31021
ISRAEL

1 TNO DEFENSE RESEARCH
I H PASMAN
POSTBUS 6006
2600 JA DELFT
THE NETHERLANDS

1 B HIRSCH
TACHKEMONY ST 6
NETAMUA 42611
ISRAEL

1 DEUTSCHE AEROSPACE AG
DYNAMICS SYSTEMS
M HELD
PO BOX 1340
D 86523 SCHROBENHAUSEN
GERMANY

INTENTIONALLY LEFT BLANK

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

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** August 2001	**3. REPORT TYPE AND DATES COVERED** Final, July–October 1999

4. TITLE AND SUBTITLE Analysis of Burning Rate Phenomena and Extinguished Solid Propellants From an Interrupted Closed Bomb With Plasma Igniter	**5. FUNDING NUMBERS** 1L162618AH80
6. AUTHOR(S) Robert J. Lieb, Pamela J. Kaste, Aviezer Birk, Amy Kinkennon, Rose Ann Pesce-Rodriguez, Michael A. Schroeder, and Miguel A. Del Güercio	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRL-WM-MB Aberdeen Proving Ground, MD 21005-5069	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-2561
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)	**10.SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT*(Maximum 200 words)*

Interrupted closed-bomb analyses of M30 and JA2 propellants have been performed with the goal of understanding the phenomena responsible for the apparent augmentation of closed-bomb burning rates when plasma, rather than black powder, ignition is used. Burning rates of the propellants during plasma injection and after the plasma (to blowout pressures of 100 MPa) have been estimated from the grain regression measurements and the P-t traces. Characterization of the extinguished grains has been performed in order to understand the interaction of the plasma with the propellant, including scanning electron microscopy (SEM) and the Fourier-transform infrared (FTIR) analyses.

14. SUBJECT TERMS ETC, M30, JA2, interrupted closed bomb, propellant, extinguished	**15. NUMBER OF PAGES** 32
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	**18. SECURITY CLASSIFICATION OF THIS PAGE** UNCLASSIFIED	**19. SECURITY CLASSIFICATION OF ABSTRACT** UNCLASSIFIED	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number/Author ARL-TR-2561 (Lieb) Date of Report August 2001

2. Date Report Received____________________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ____________________

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.)____________________

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate.____________________

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.)____________________

CURRENT ADDRESS

Organization

Name E-mail Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)

(DO NOT STAPLE)

DEPARTMENT OF THE ARMY

OFFICIAL BUSINESS

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO 0001,APG,MD

POSTAGE WILL BE PAID BY ADDRESSEE

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL WM MB
ABERDEEN PROVING GROUND MD 21005-5069