Development and Performance of High Energy High Performance Co-Layered ETPE Gun Propellant for Future Large Caliber Systems

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Outline

- **Introduction**
  - Function/Purpose of the program
- **Background**
- **Propellant geometry and charge design**
- **Propellant formulations**
  - Slow burning
  - Fast burning
- **Characterization**
  - Closed bomb
  - Lamination bond strength test
  - Small scale sensitivity test
- **Interior Ballistic Predictions and Gun Firing**
- **Conclusion**

Introduction
Function/Purpose of the Program

Objective:

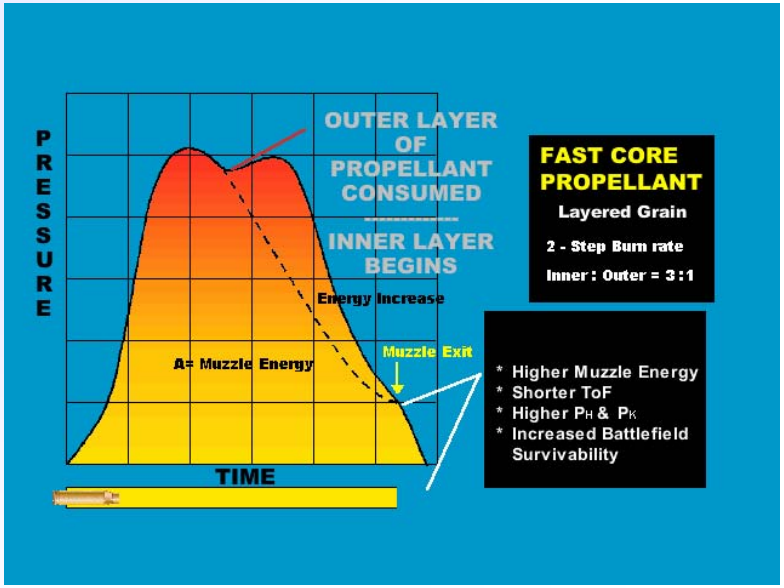
- ARDEC/Aerojet IPT formed to develop a pair of slow and fast burning ETPE based propellants to respond to FCS/Future Weapon System requirements.

Scope:

- ARDEC/Aerojet collaborated to develop formulations.
- Aerojet synthesized the BN7 binder and processed the molding powder at Sacramento Facility
- ARDEC processing propellant and finishing into co-layered radial strip configurations
- Finished product ballistically fired at UDLP

Background

- GEN2 Propellant Objectives
  - High Energy
    - Impetus ~1075 J/g (slow-burning) ~ 1250 J/g (fast-burning)
    - Burn-rate Ratio (fast-to-slow) ≥3:1
      - Achieved 1.7:1 ratio
  - High Loading Density
    - Co-layered Material
  - Vulnerability
    - Comparable To Standard JA2
  - Mechanical Properties
    - Comparable To Standard JA2
  - Ballistics
    - Muzzle Velocity Increase While Maintaining Muzzle Pressure (13.2 kpsi)
    - Temperature Dependency Comparable To Standard JA2



ETPE Background

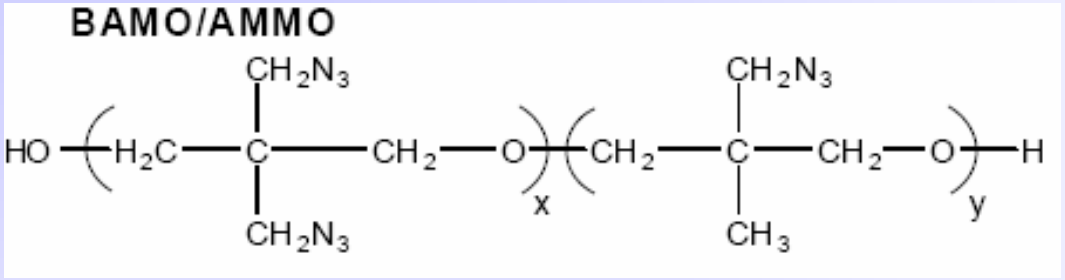


Figure 1: ETPE structure.

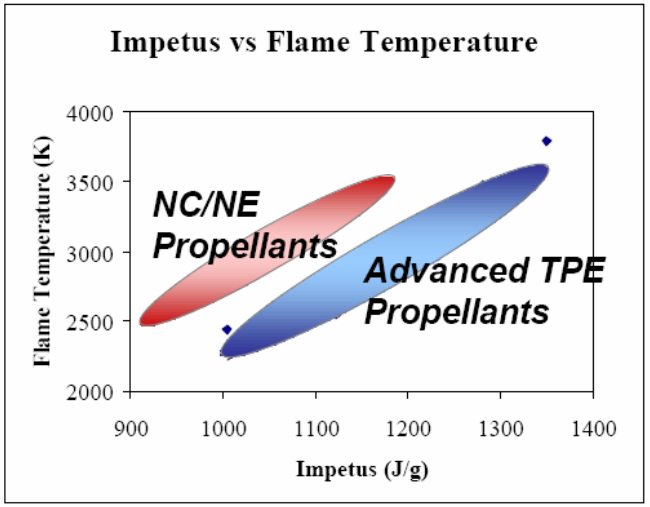


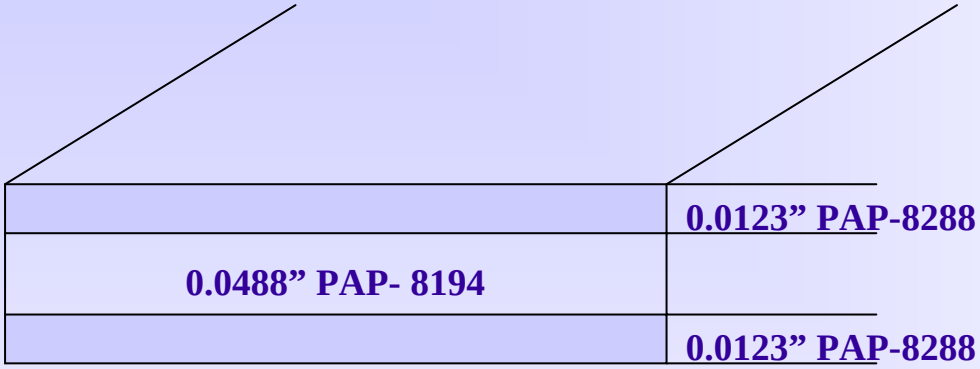
Figure 2: ETPE energy comparison.

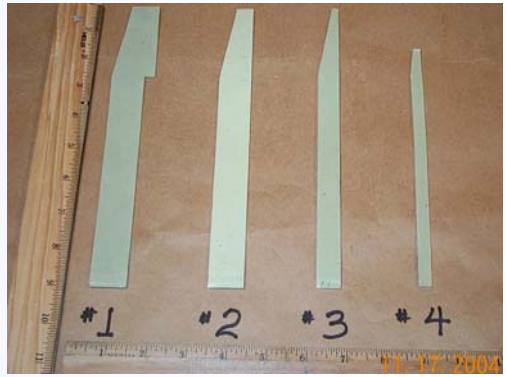
- **Advantages of ETPE gun propellants discussed in early 1980's.**
- **Early calculations indicated ETPE propellants had performance advantages compared to NC propellants.**
- **Feasibility studies were performed in coordination with Army Research Lab (ARL), Navy & others.**
- **Recent efforts have demonstrated ETPE propellants on a larger scale.**
- **Since 1998, > 5,000 lbs of ETPEs manufactured.**

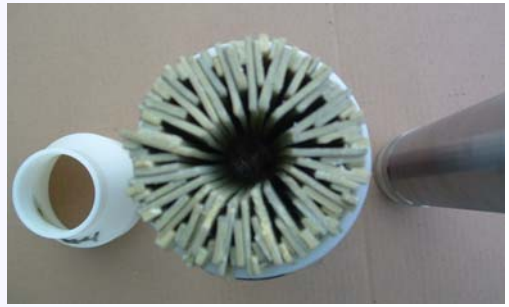
ETPE based propellant Advantages

- Do not require oxidizers ($BaNO_3$) or stabilizers (DPA).
- Can be warmed and re-extruded. → Recycle propellant.
- Provide greater energy density. → Less propellant.
- Advanced grain geometry capability.
- No plasticizer migration issues.
- Immune to moisture problems.
- Burn rate tailorability in propellants.
- Easily processed by twin screw extrusion.

Radial Strips for the 60 mm Chamber







60mm Cartridge Radial Strips
nominal thickness 0.0488 inches
deterred thickness 0.0123 inches
4 strip configurations 24 each
each round to hold a maximum of: 0.39 kg PAP-8288
and 0.76 kg PAP-8194

1440 Co-layered radial strips
15 rounds assembled
Projectile weight ~7.4 Kg
Propellant charge weight ~1400 g
Piccolo tube~ETC igniter

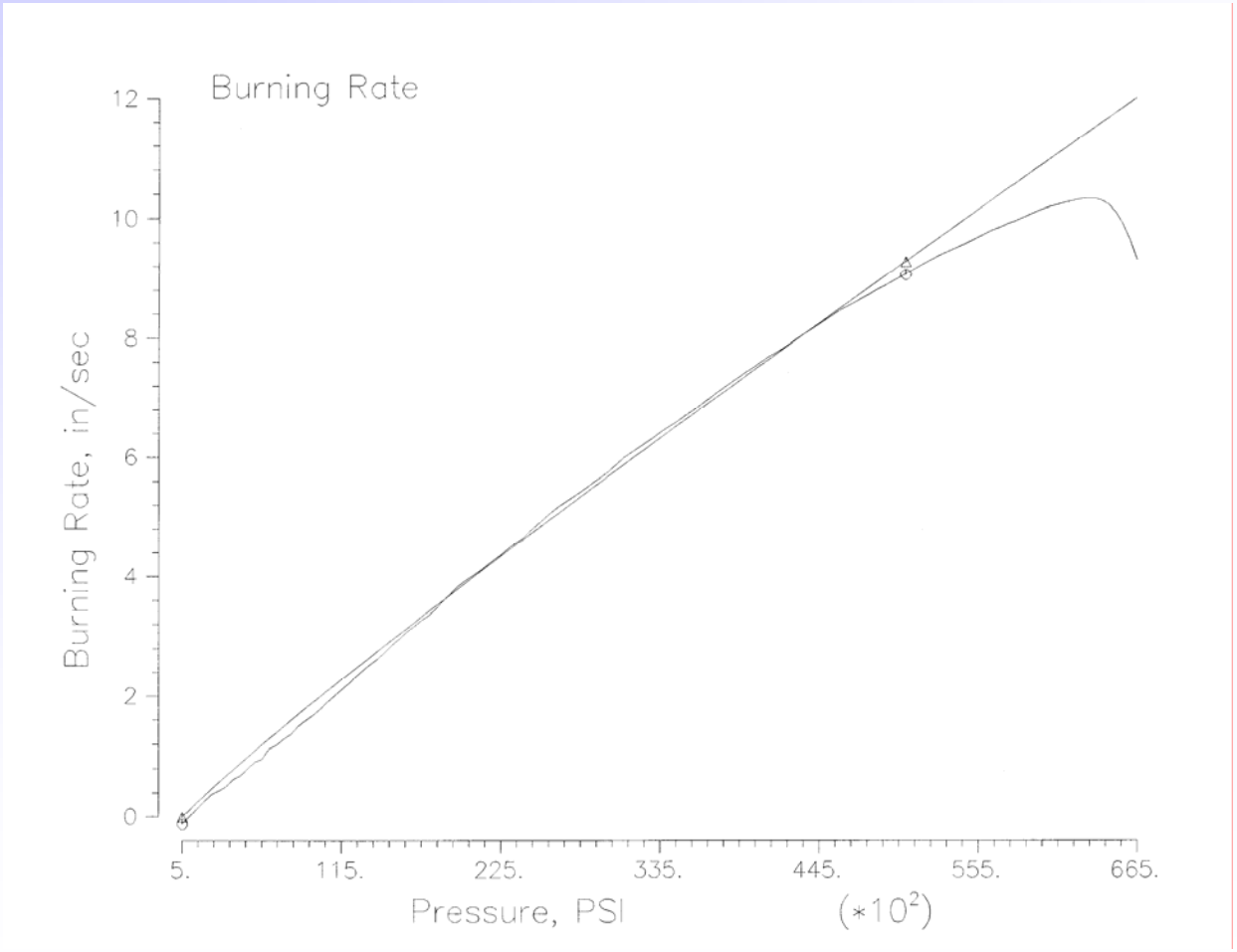
Fast and Slow Formulations

Ingredients	JA2	Fast Burning PAP-8194J (% by wt)	Fast Burning PAP-8194AA (% by wt)	Fast Burning PAP-8194BB (% by wt)	Fast Burning PAP-8289 (% by wt)	Slow Burning PAP-8233D (% by wt)	Slow Burning PAP-8287 (% by wt)	Slow Burning PAP-8288 (% by wt)
Impetus , J/g	**1164**	**1276.17**	**1276.17**	**1276.17**	**1276.17**	**1050.92**	**1050.92**	**1022.45**
Flame Temp, K	**3475**	**3252**	**3252**	**3252**	**3252**	**2543**	**2543**	**2473**
Density, g/cc	**1.580**	**1.6675**	**1.6675**	**1.6675**	**1.6675**	**1.6159**	**1.5945**	**1.6136**

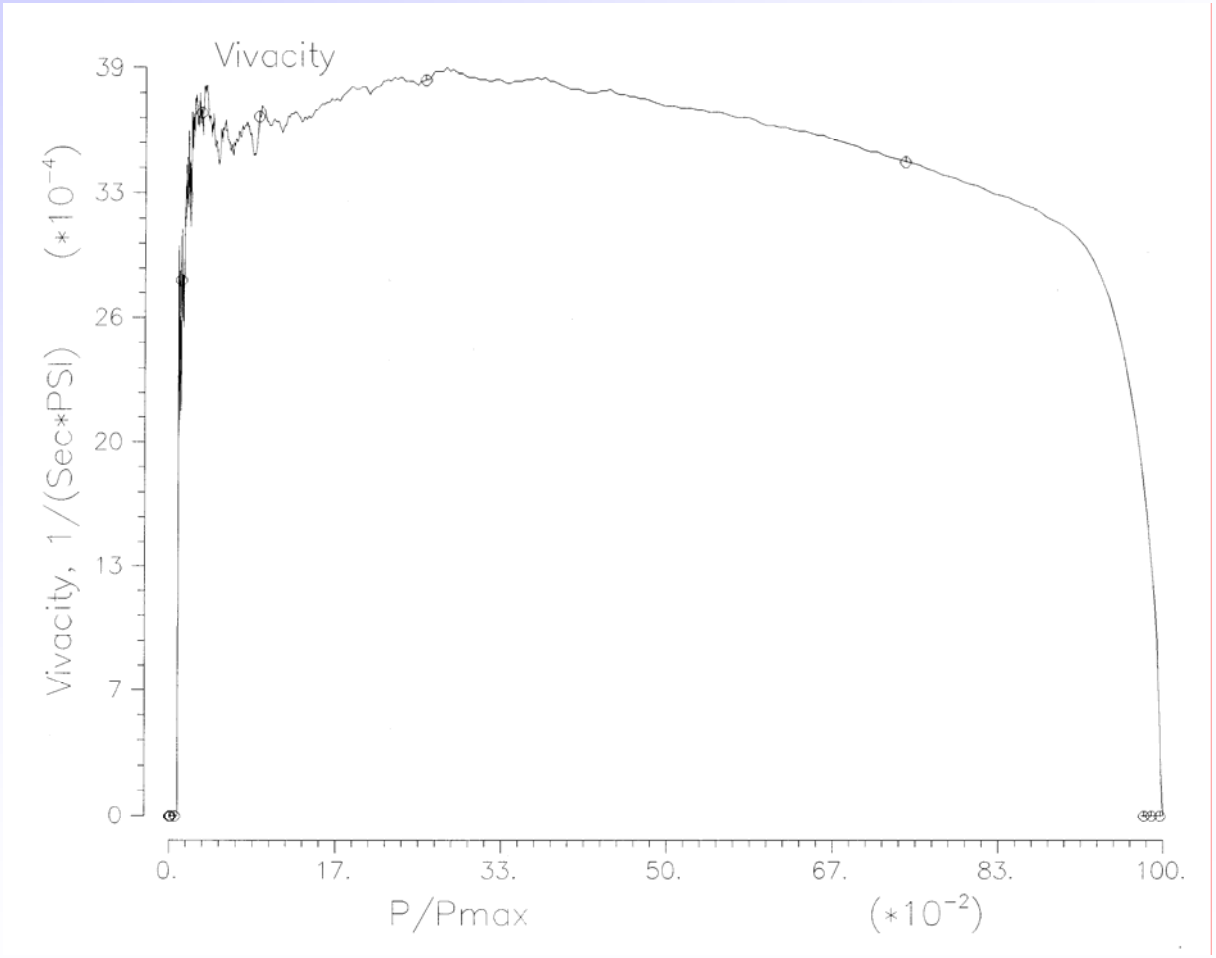
Fast and Slow Formulations

Ingredients	Fast Burning 8194J (% by wt)	Fast Burning 8194BB (% by wt)	Fast Burning 8289 (% by wt)	Slow Burning 8233D (% by wt)	Slow Burning 8287 (% by wt)	Slow Burning 8288 (% by wt)
Burn rate@40ksi	7.226	7.863	8.006	5.021	5.069	4.571
Coefficient	0.240736E-03	0.569389E-03	0.373879E-02	0.543665E-03	0.617472E-03	0.552724E-03
Exponent	.972903	.899642	.723735	0.861661	.850561	.851256

Burn Rate of Virgin Fast Formulation @+21°C

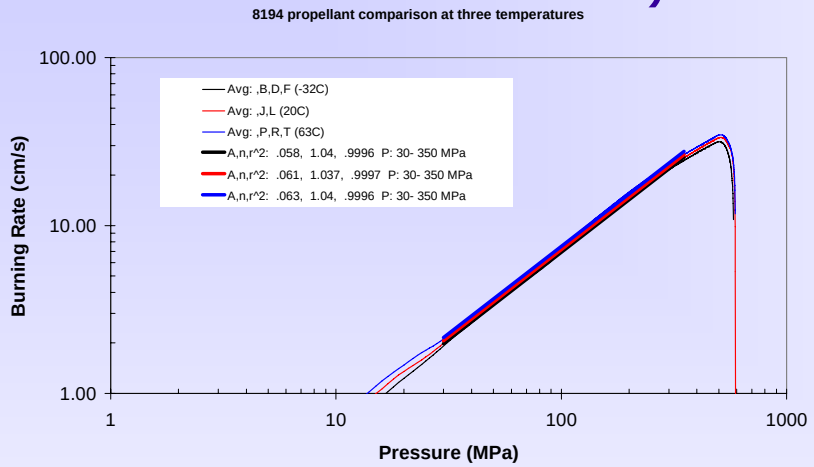


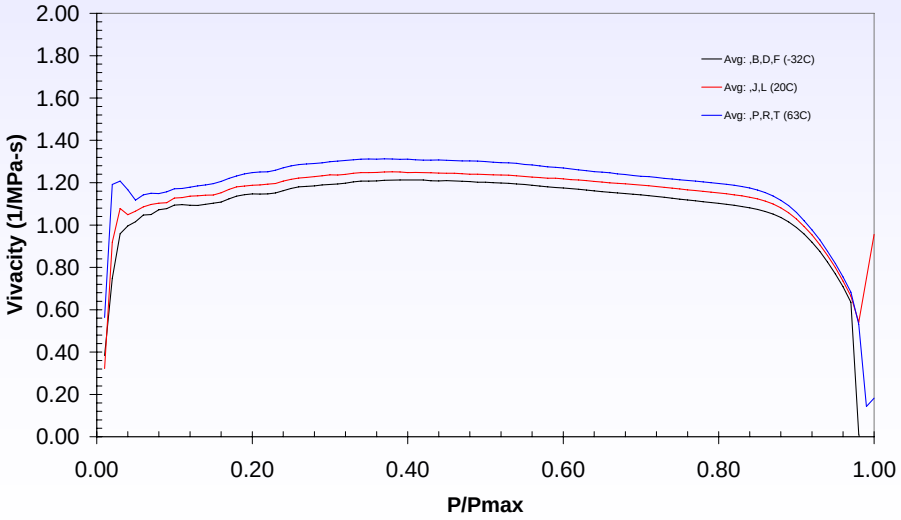
Vivacity Curve of Fast Formulation @+21°C

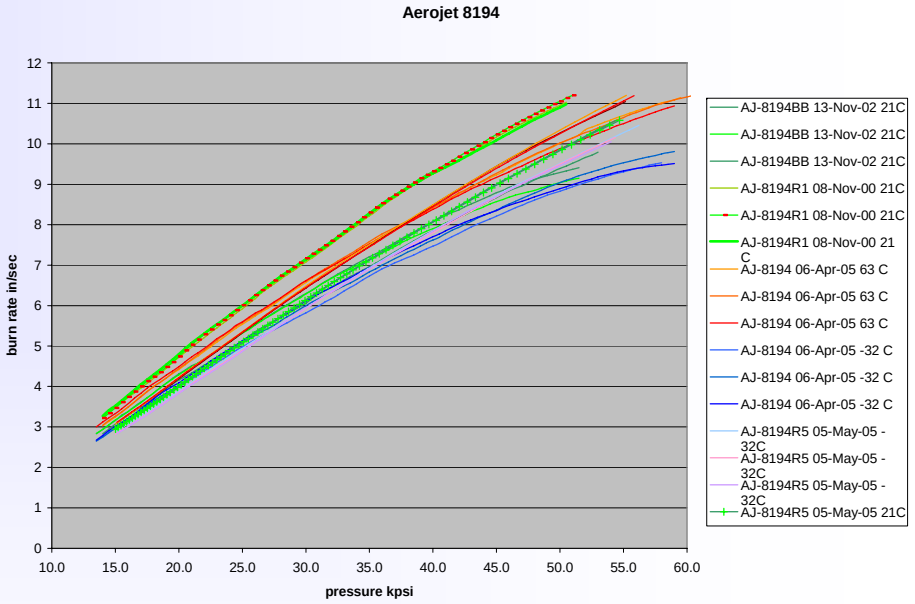


K.Klingaman, ARDEC
B. Homan, ARL

Burn Rate of Recycled Fast Burning Formulation @ +63ºC, +21ºC, -32ºC







Burn rates of all reworked batches

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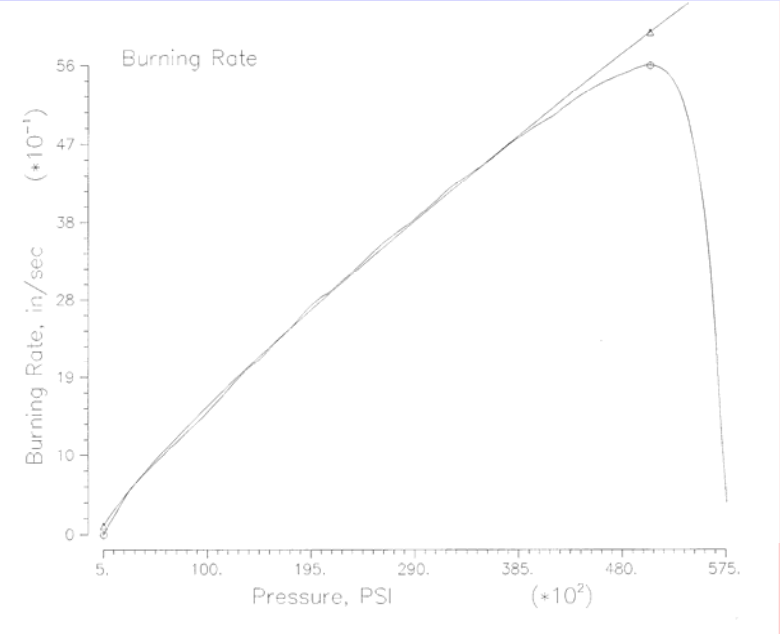
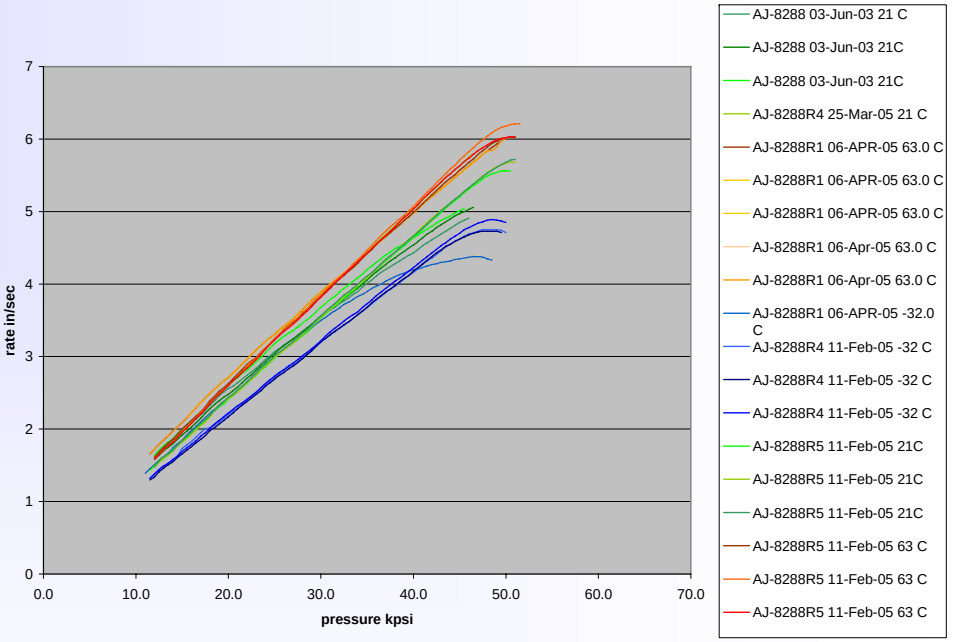
B. Homan, ARL

Burn Rate of Slow Burning Formulation @+63°C, +21°C, -32°C



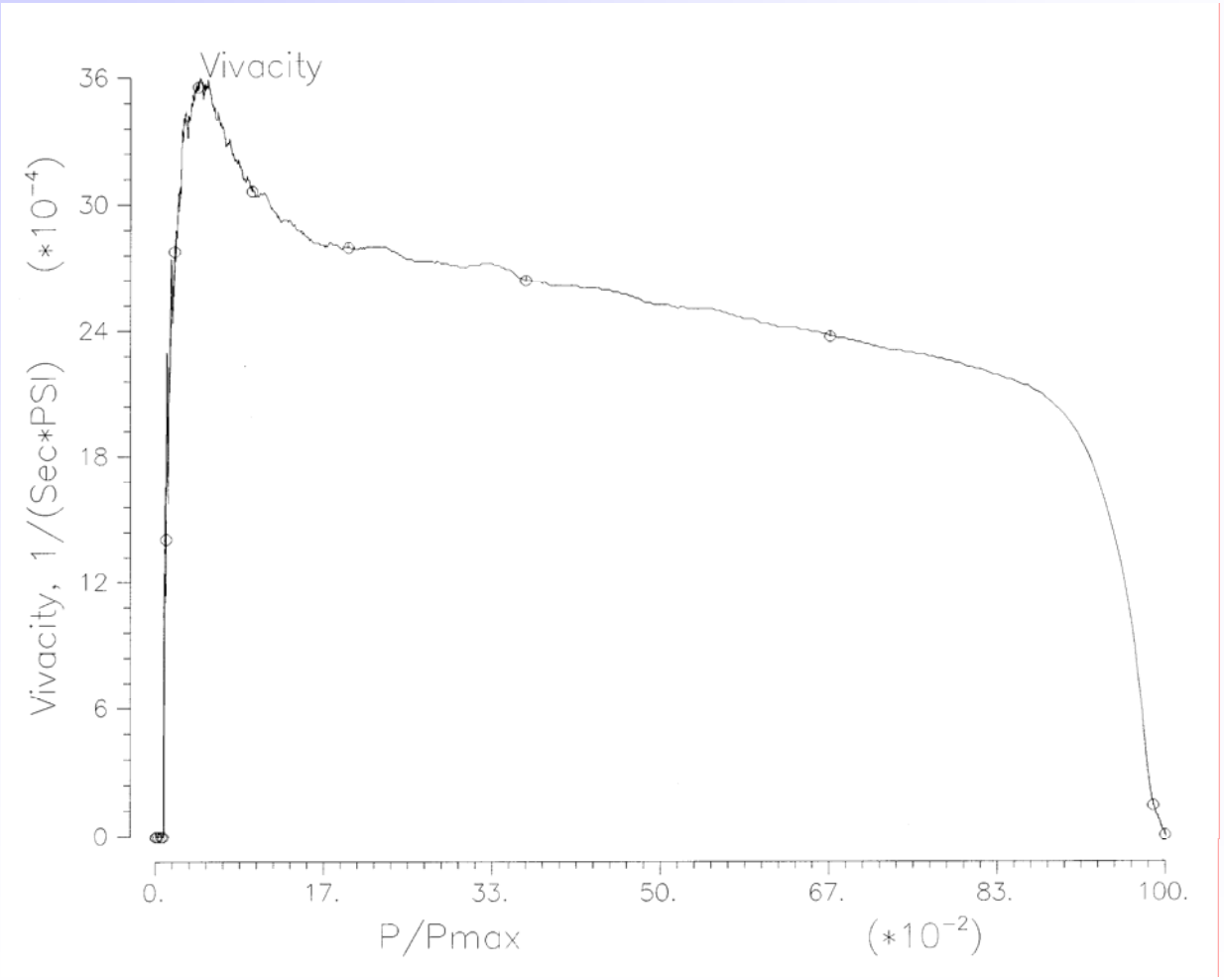


Burn rate of virgin propellant

Burn rate of recycled propellants

K.Klingaman, ARDEC
B. Homan, ARL

Vivacity Curve of Slow Formulation @ +21°C,

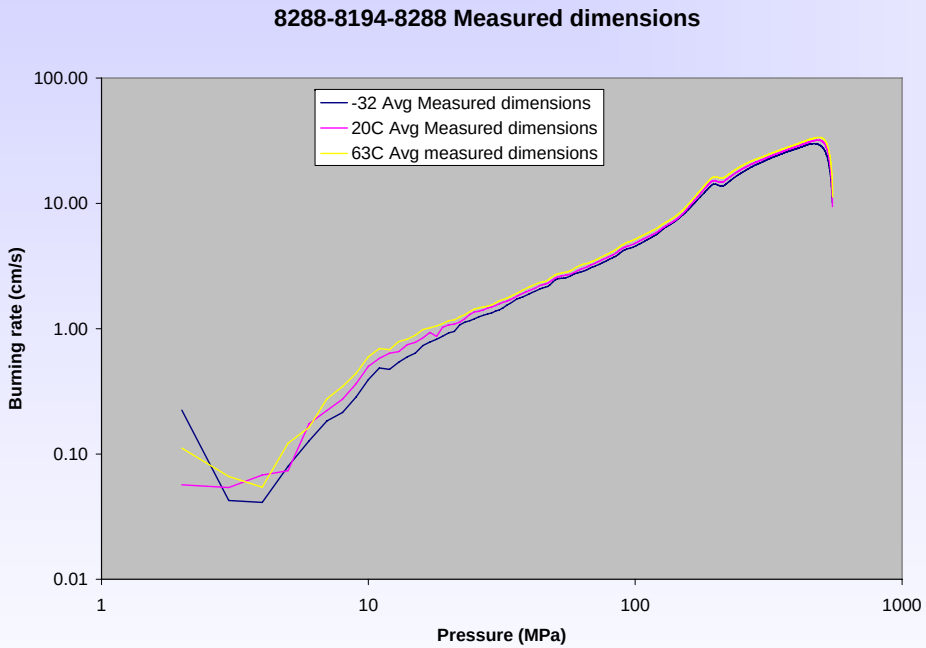


Burn Rate Differential

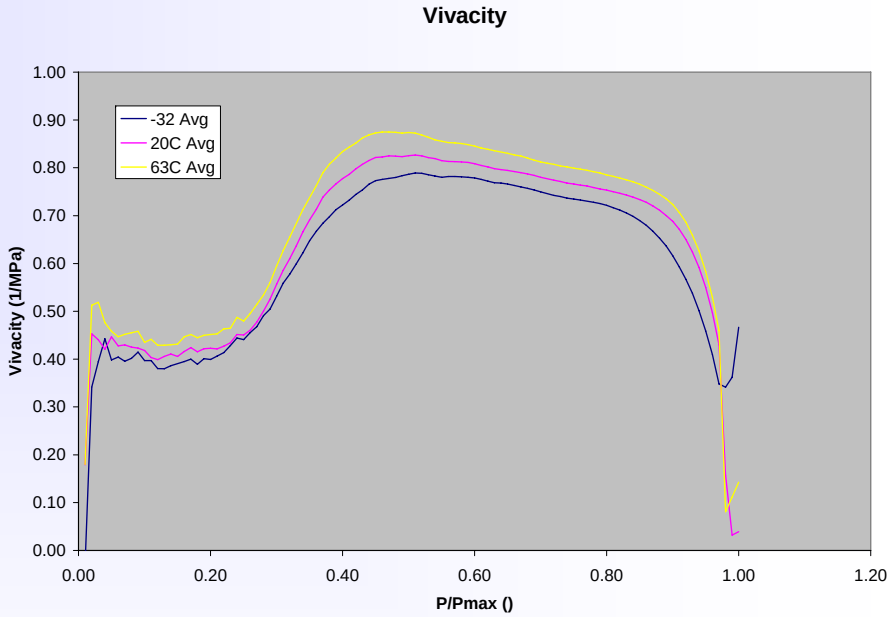
LOT 8288R1	63^0 C	21^0 C	-32^0 C
Pressure Coefficient	0.478722 E-03	0.552724E -03	0.873594E-03
Pressure Exponent	0.87300	0.851256	0.799747
20 kpsi, burn rate in/s	2.722	2.534	2.425
30 kpsi, burn rate in/s	3.8722	3.578	3.526
40 kpsi, burn rate in/s	4.985	4.571	4.19
Lot 8288R5			
Pressure Coefficient	.2069E-03	0.198347E -03	0.214117E-03
Pressure Exponent	0.953278	0.949800	0.932513
20 kpsi, burn rate in/s	2.6	2.413	2.195
30 kpsi, burn rate in/s	3.835	3.546	3.253
40 kpsi, burn rate in/s	5.046	4.661	4.238

Lot 8194R1	63^0 C	21^0 C	32^0 C
Pressure Coefficient	0.7544E-03	0.374174E-03	0.723218E-03
Pressure Exponent	0.877512	0.954209	0.871697
20 kpsi, burn rate in/s	4.486	4.755	4.059
30 kpsi, burn rate in/s	6.403	7.001	5.780
40 kpsi, burn rate in/s	8.332	9.213	7.428
Lot 8194R5			
Pressure Coefficient	.6497E-03	0.518E-03	0.427E-03
Pressure Exponent	0.806	0.838	0.863
20 kpsi, burn rate in/s	4.082	3.973	3.83
30 kpsi, burn rate in/s	6.41	6.114	5.9
40 kpsi, burn rate in/s	8.44	8.051	7.81
Burn Rate Ratio			
8194R1/8288R1@40 Kpsi	**1.6931**	**2.0155**	**1.7727**
8194R5/8288R5@40 kpsi	**1.6726**	**1.7273**	**1.8429**

Burn rates and Vivacity Curve for Co-layered Propellant @+63C, +21C and -32C



Burn rates for co-layered propellants



Vivacity curves for co-layered propellants

Lamination Bond Strength Tests

Co-layered propellant test specimen

Specimen Test Set Up

Lamination Bond Strength Tests

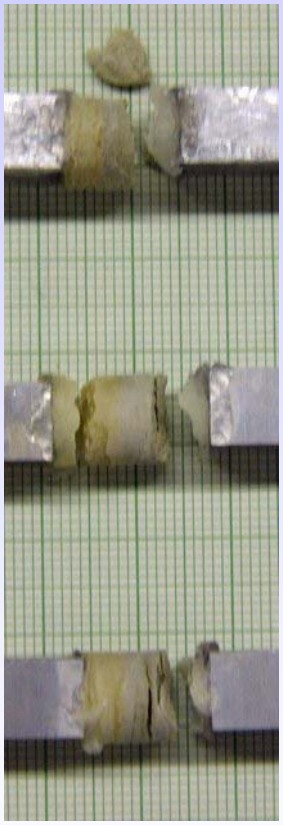


Figure 33. Tested Specimens of Co-Layered Material @21° C. Failure did not occur at layered seam.

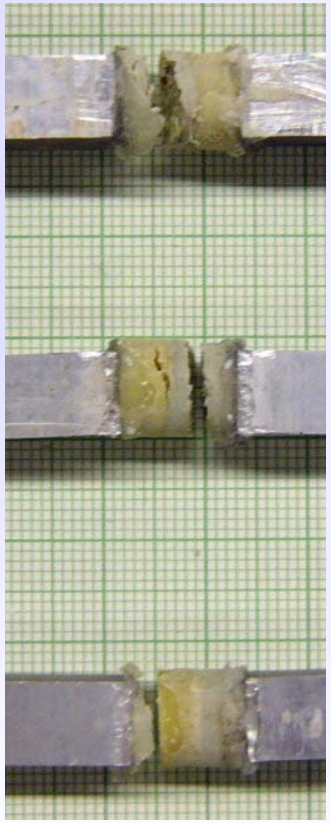


Figure 34. Tested Specimens of Co-Layered Material at @ 63° C. Failure did not occur at layered seam

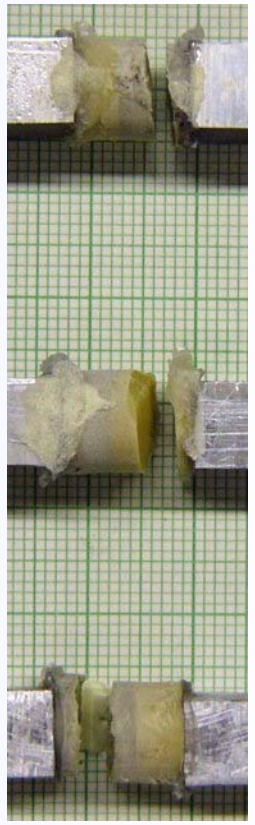
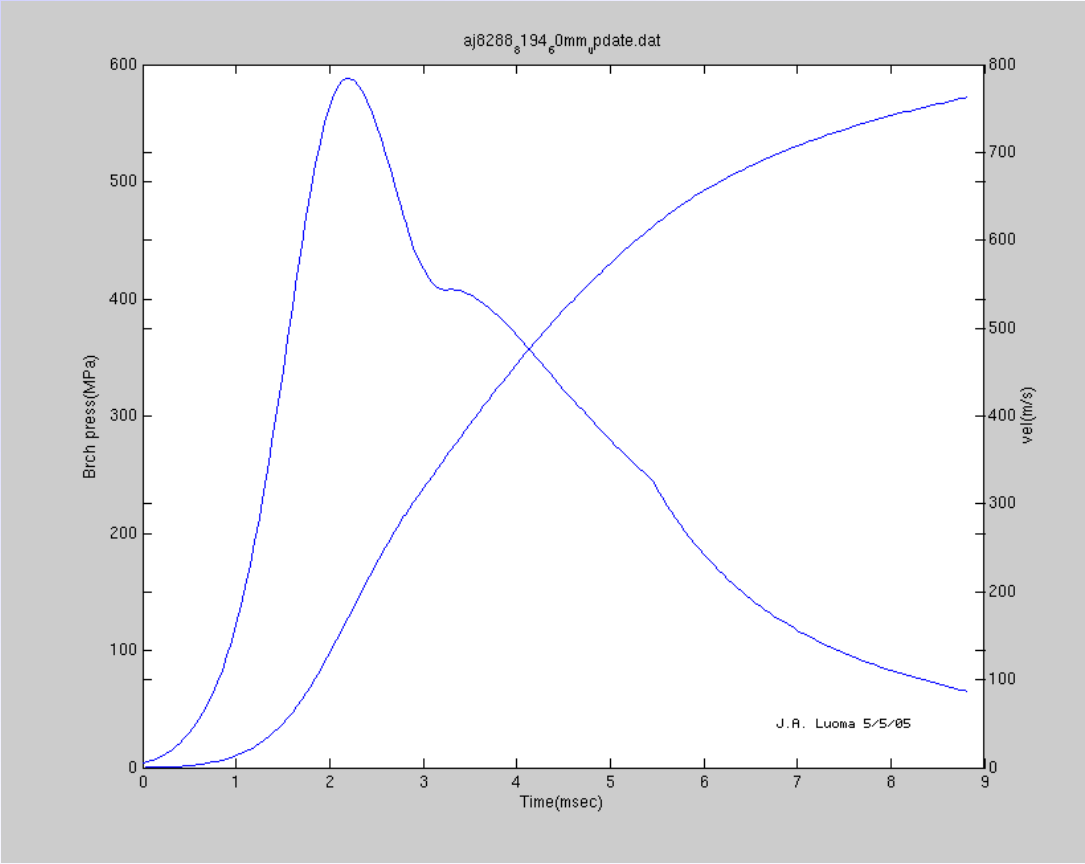


Figure 35. Tested Specimens of Co-Layered Material at @ -32° C. Failure did not occur at layered seam

Small Scale Sensitivity Screening Test

Propellant	ERL Type 12 Impact 50% point (cm)	Electrostatic Discharge Test (ESD)	BAM Friction (N)
RDX Lot # 21-18	24.8± 1.2 25.1± 1.7	-	212N reacted 188N 10/10 no go
JA2 Lot # PD-065-5	32.0± 1.4	NR 20 trials @ 0.25 Joules	212N reacted 188N 10/10 no go
Fast Burning Lot 8194	86±1.3	NR 20 trials @ 0.25 Joules	(R1)252N reacted (R1)360N 10/10 no go (R5)240N reacted (R5) 216N 10/10 no go
Slow Burning Lot8288	impact insensitive Reacted in 2 out of 10 trials @ 100 cm drop height.	NR 20 trials @0.25 Joules	(R1) 324N reacted (R1) 288N 10/10 no go (R5)252N reacted (R5) 240N 10/10 no go
Co-layered	64.8±1.2	NR 20 trials @0.25 Joules	240N reacted 216N 10/10 no go

Predicted Pressure and Velocity



Predictions for Co-layered Propellant in the 60 mm ETC Gun Test Fixture

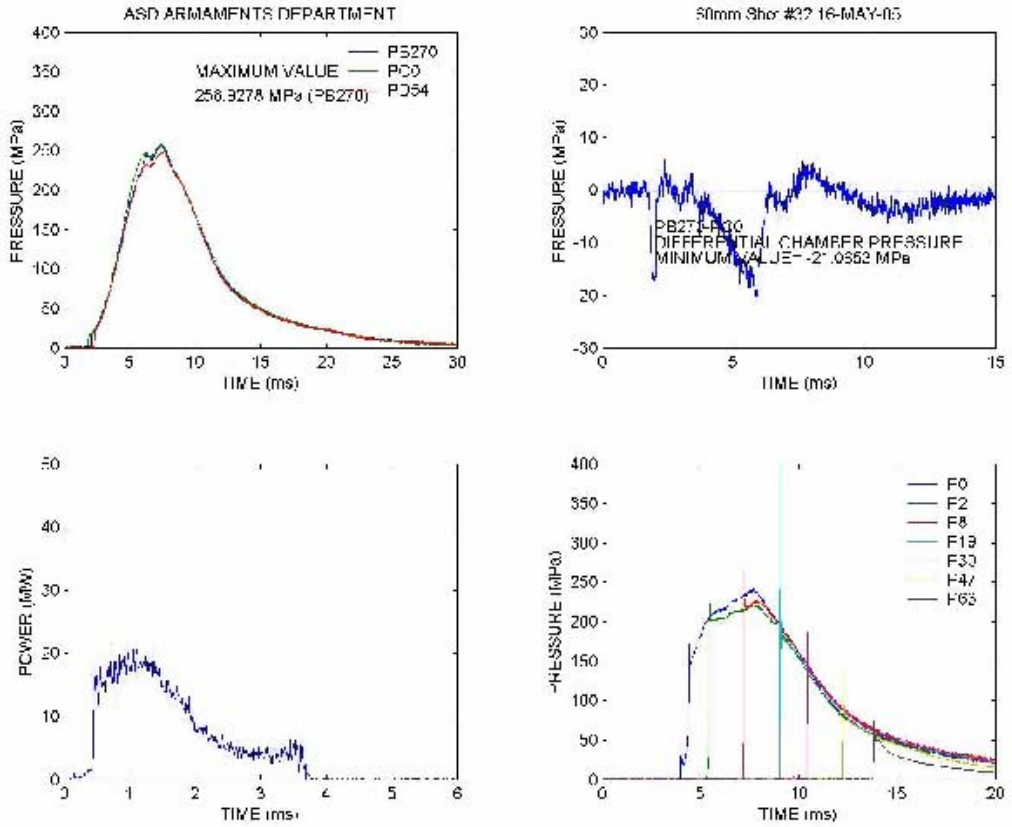
Predictions	***First***	***Second***
Slow Burning Layer Thickness,mm	***0.35***	***0.39***
Fast Burning Layer Thickness,mm	***1.129***	***1.15***
Estimate Velocity, m/s	***762.45***	***739.58***
Estimated Pressure, MPa	***590***	***570***

J.Luoma, UDLP

60mm ETC Gun Firing Data

Round Number	Charge weight, grams	Temp, C	Pmax MPa	Max dP MPa	Vmuzzle m/s
1	947	20	159	-12.762	533
2	1023.9	20	257	-21.0853	635
3	1100	20	320	-49.3577	682
4	1144.10	20	429.8	-71.8651	720
5	1125.8	20	390	-55.6482	713
6	1123.80	20	381	-11.4971	709
7	1127.4	63	390	-50.5527	689
8	1124	63	418	-47.7186	705
9	11128.6	63	409	-34.6392	697
10	1125.4	0	375	-22.276	705
11	1128.8	-10	426	-15.7317	725
12	1123.8	-20	401	-20.0931	717
13	1124.4	-32	540	-72.0385	752
14	1125.9	-32	503	-86.191	744
15	1123.6	-32	538	-114.9868	752

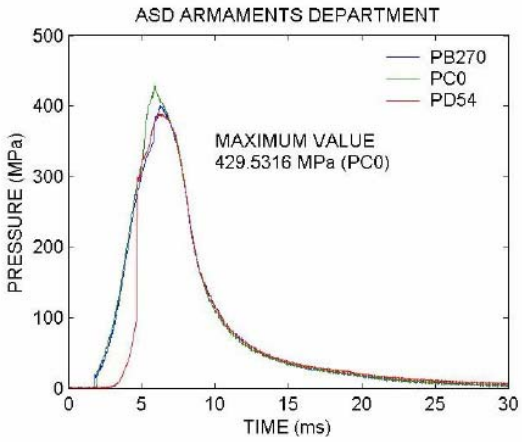
Pressure time trace at 20^{0}C, Shot # 32: V= 635 m/s, Pmax= 540 MPa, CW=1023.9

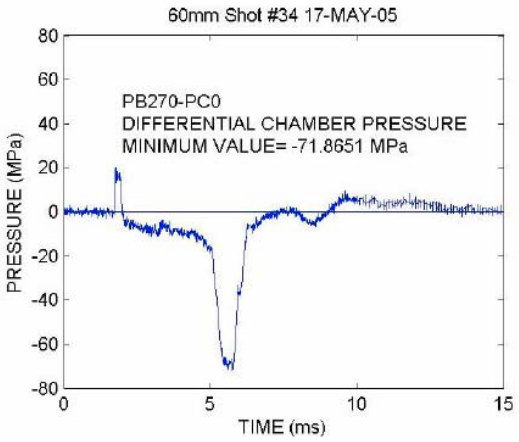


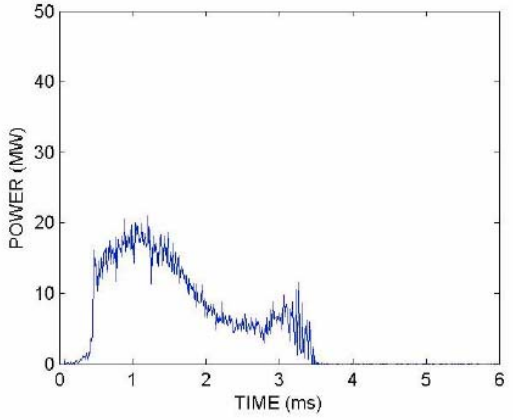
Committed to Excellence

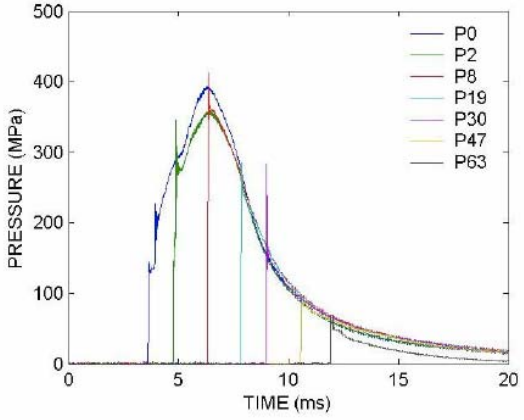
Shot #34 at 20^0 C

V= 752 m/s, Pmax= 540 MPa, CW=1124.4



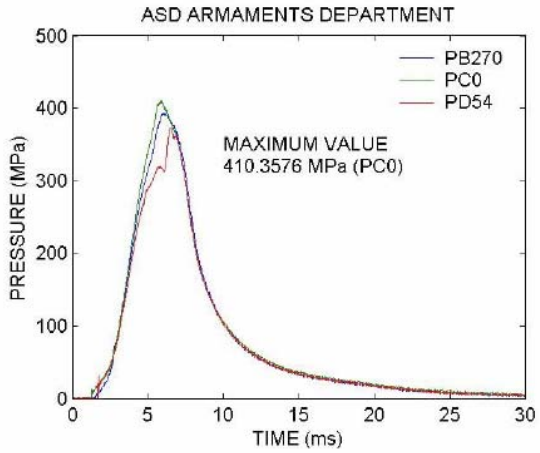


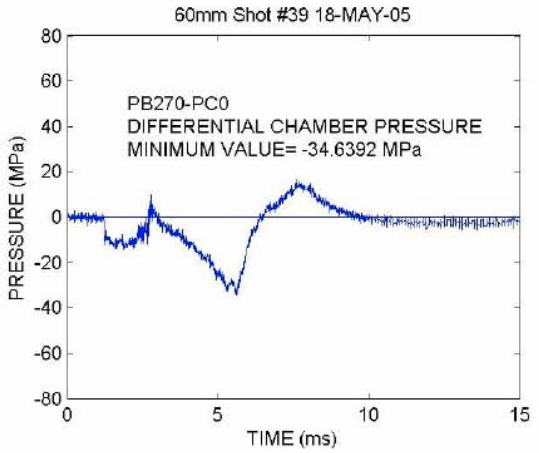


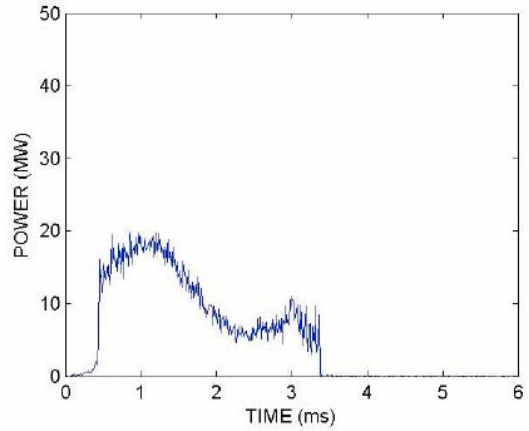


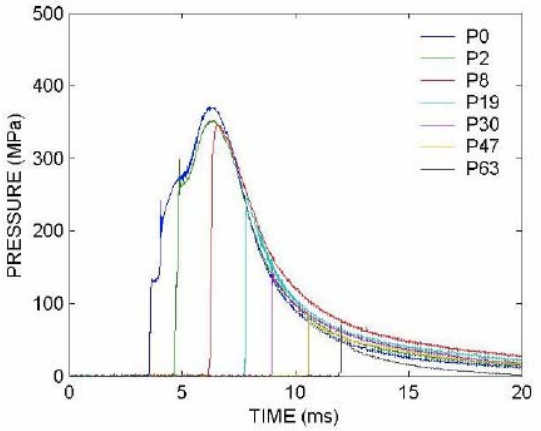
Shot #39 at 63^0 C

V= 697 m/s, Pmax= 409 MPa, CW=1128.6



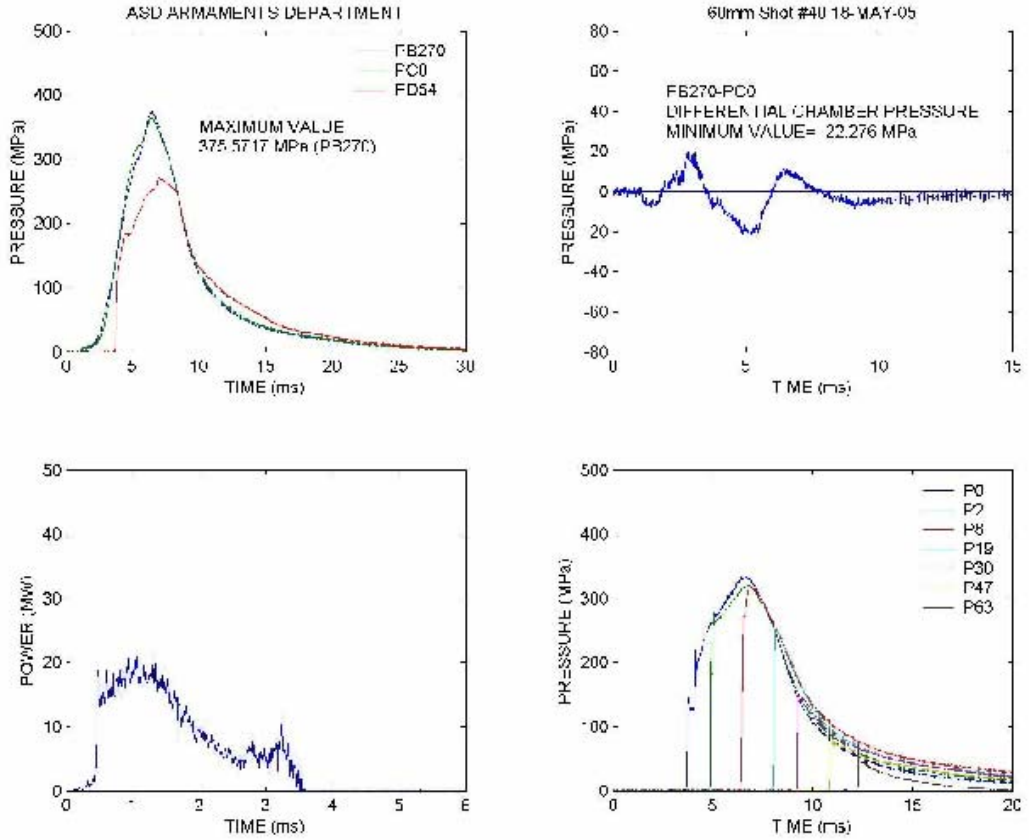






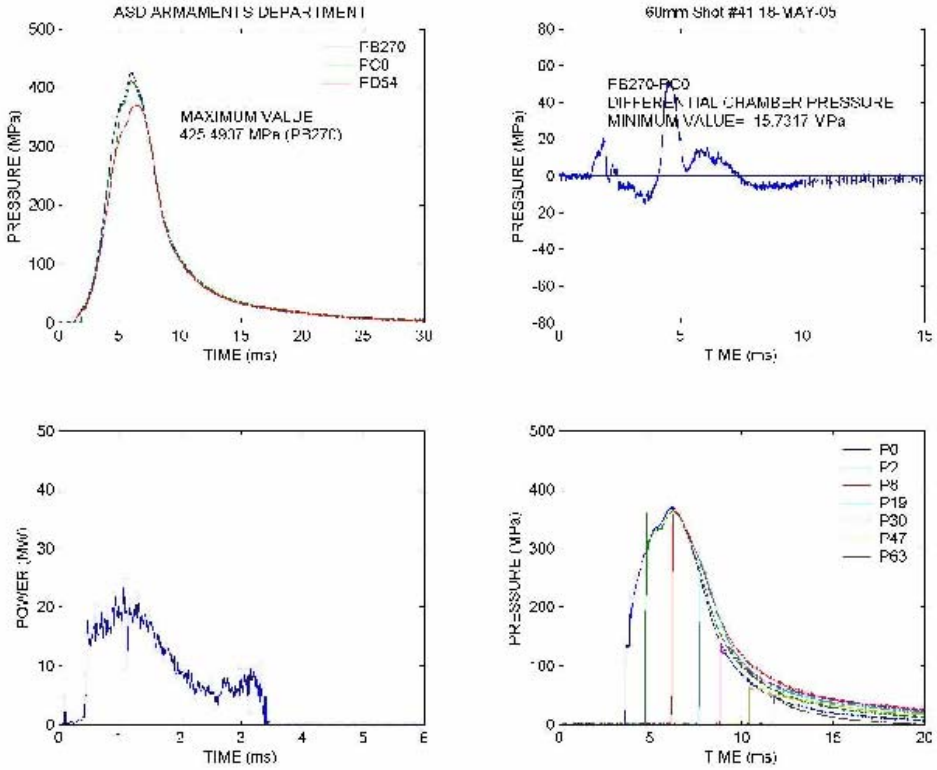
Shot #40 at 0^0 C

V= 705 m/s, Pmax= 375 MPa, CW=1125.4



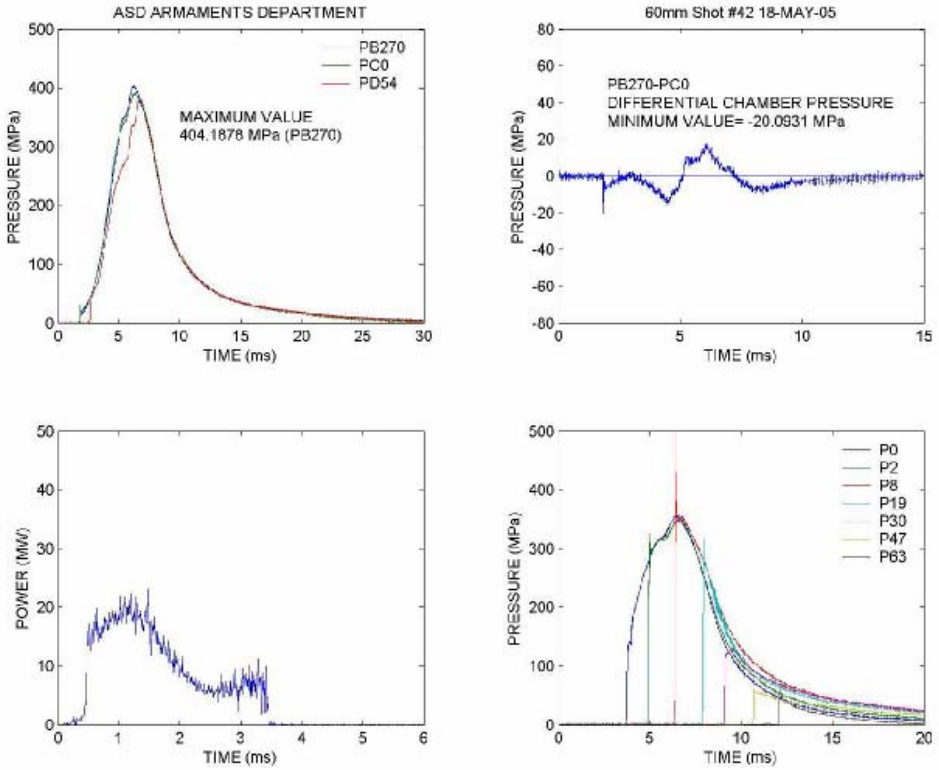
Shot #41 at -10^0 C

V= 725 m/s, Pmax= 426 MPa, CW=1128.8



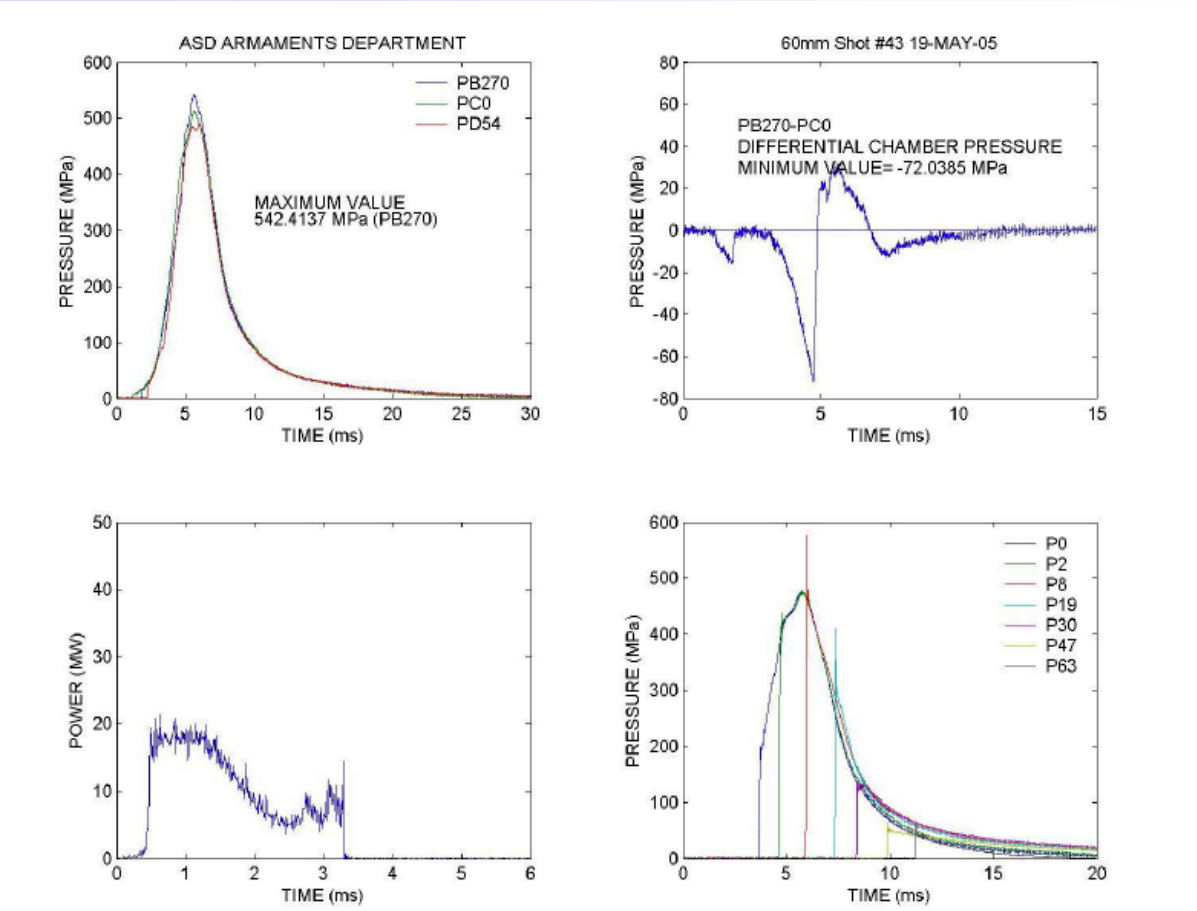
Shot #42 at -20^0 C

V= 717 m/s, Pmax= 401 MPa, CW=1123.8



Shot #43 at -32^0 C

V= 752 m/s, Pmax= 540 MPa, CW=1124.4



Conclusion and Summary

- Downselected Fast Burning Formulation and Slow Burning Formulation Burn Rate Differentials were as follows:

	+63C	+21C	-32C
• 8194R1/8288R1@40kpsi	1.6931	2.0155	1.7727
• 8194R5/8288R5@40kpsi	1.6726	1.7273	1.8429

- Lamination of the slow and the fast burning formulation in radial strip configuration did not delaminate at +63^{0}C, 21^0 C and -32^0 C, because the bond between the two formulations is stronger than the propellant.
- Reprocessing of propellants did not show significant changes in burn rates, rheological properties for the slow burning formulation and chemical composition. However, the mechanical properties deteriorated because of the presence of voids in the propellants for the last recycled propellants. The voids in the propellants can easily be eliminated by the use of a more advanced processing equipment like the Twin Screw Extruder.
- Gun firing in the 60 mm 60 ETC gun were completed and results are promising.
  - While all (15) 60 mm rounds of the layered ETPE were fired, the results were mixed. It is recommended that for any future work with radial strips, the strips be embossed to aid in flame spread and an alternate ignition system be considered.