Moisture Resistant Black Powder Substitute and Its Application as Center-Perforated Pellets in Mortar Ignition Cartridges

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Leadership
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Organizational Climate

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Background

- **Black powder is still an important energetic used in many military applications**
  - The BP formulation is thousands of years old.
  - It is an important component in ignition, propulsion, and explusion trains of modern weapons systems.
    - ✓ **Over 100 military components distributed by JMC require BP.**
    - ✓ **Estimated annual consumption 100,000 lbs (75mm Saluting Charge, 155mm MACS Prop Charge, Grd Illum Signals, etc.)**
- **Certain limiting characteristics make it highly desirable to replace BP in some or all of these components, e.g.,**
  - Moisture absorption
  - Safety during its production
  - Reproducibility – lot to lot and charcoal variations

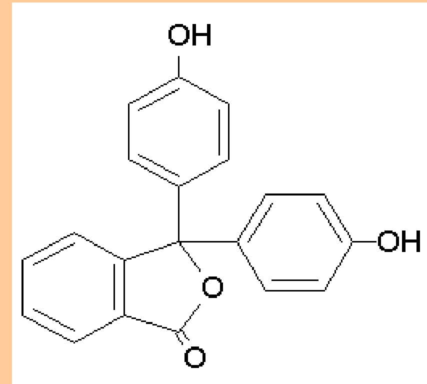
Background

Properties of a suitable BP replacement include:

- **Greater Resistance to Moisture Absorption**
  - ✓ Maintain ballistic performance
  - ✓ Minimize corrosion of nearby metallic components
  - ✓ Minimize loading and storage costs
    - Less stringent temperature and humidity controls
    - Decreased frequency of component inspections
- **Charcoal-Free**
  - ✓ Performance problems in BP have coincided with changes in production of the charcoal used therein. Variability may arise due to:
    - Wood type and growth history
    - Process creep in production parameters
    - Moisture absorption even at low relative humidity
- **Sulfur-Free**
  - ✓ BP combustion produces sulfur dioxide – toxic by inhalation, acid rain precursor
- **Processing Requiring Fewer Attended Operations**
  - ✓ Minimizes risk of operator fatalities during production
- **Drop-In Replacement**
  - ✓ Minimizes component redesign and qualification costs

Moisture Resistant Black Powder Substitute (MRBPS)

- Formulation does not contain charcoal or sulfur
- Principal Constituents of Formulation Family
  - Potassium Nitrate (KNO_3) is the Principal Oxidizer
    - ✓ The same as in black powder
  - Auxiliary Oxidizer is Potassium Perchlorate
    - ✓ Adds brisance to the MRBPS formulation
    - ✓ Allows an added degree of freedom for performance tailoring
  - Phenolphthalein replaces Charcoal as the Fuel
    - ✓ Structurally related to charcoal
    - ✓ Notable for promoting short rise times as a fine powder
    - ✓ Absorbs significantly less moisture than charcoal under comparable conditions
  - Ethyl Cellulose is added as a Process Aid/Binding Agent
    - ✓ As binder to hold fuel and oxidizers together
    - ✓ Additive allows remote continuous processing of MRBPS via twin-screw extrusion
      - Will provide lubrication lowering torque required for extrusion
      - Eliminates phase separation between MRBPS solids and the processing solvent, ethanol
    - ✓ Absorbs minimal moisture
  - Heat of Explosion (798 kcal/g) is comparable to that of black powder (810 kcal/g)
  - Pressure exponents are somewhat higher for MRBPS (»0.33) than BP (0.20)



Structure of Phenolphthalein

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Moisture Absorption Measurements

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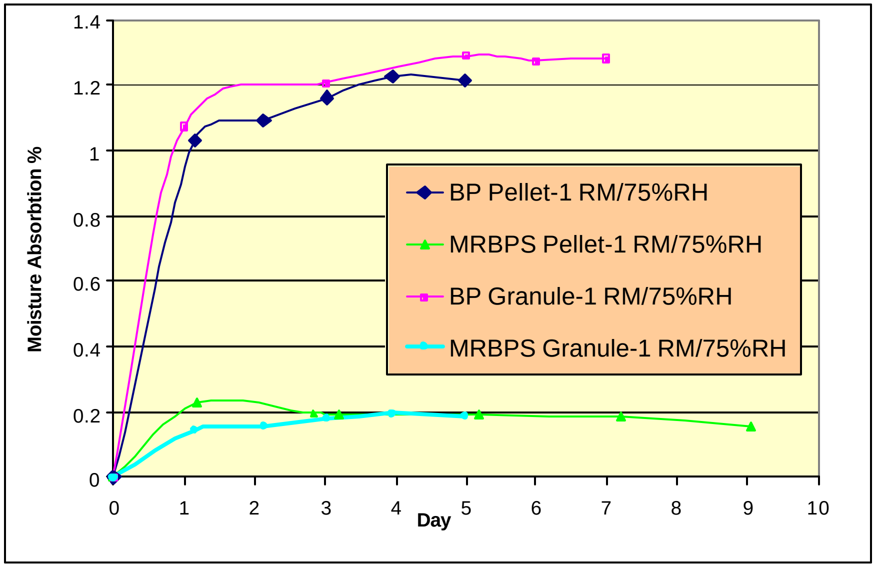
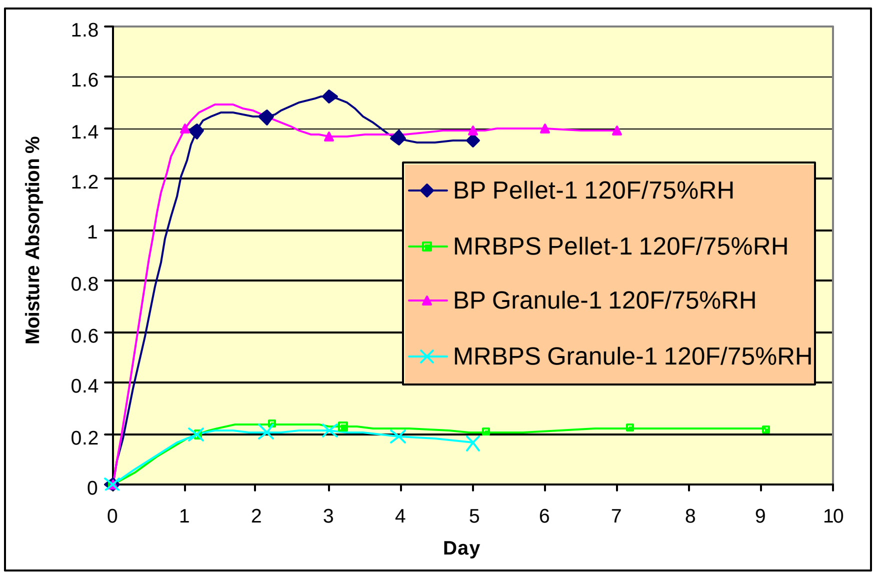


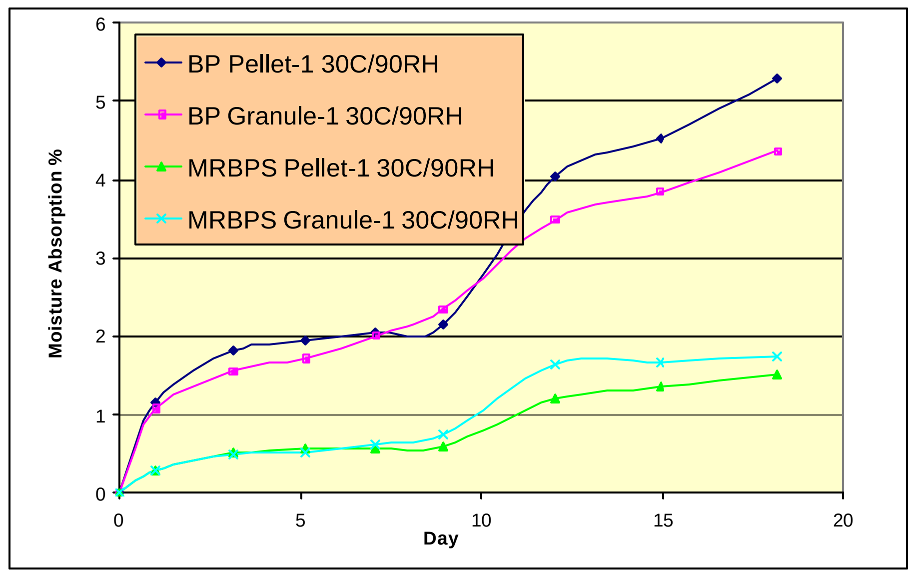
<u>75% RH/Ambient Temperature & 120 F</u>:

- **Ambient temperature- BP and MRBPS reached equilibrium at 1.2% and 0.2% respectively after 3 days.**
- **120 F- BP and MRBPS reached equilibrium at 1.4% and 0.2% respectively after 1 day.**
- **No significant difference in moisture absorption between pellets and granules.**

<u>90%RH/30C (Mil-STD-286 C, Part 503.1.3)</u>:

- **BP and MRBPS pellets absorbed 5.3% and 1.5% moisture respectively after 18 days. Similar moisture absorption pattern occurred for granules.**





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Potassium Perchlorate Increases Brisance of MRBPS

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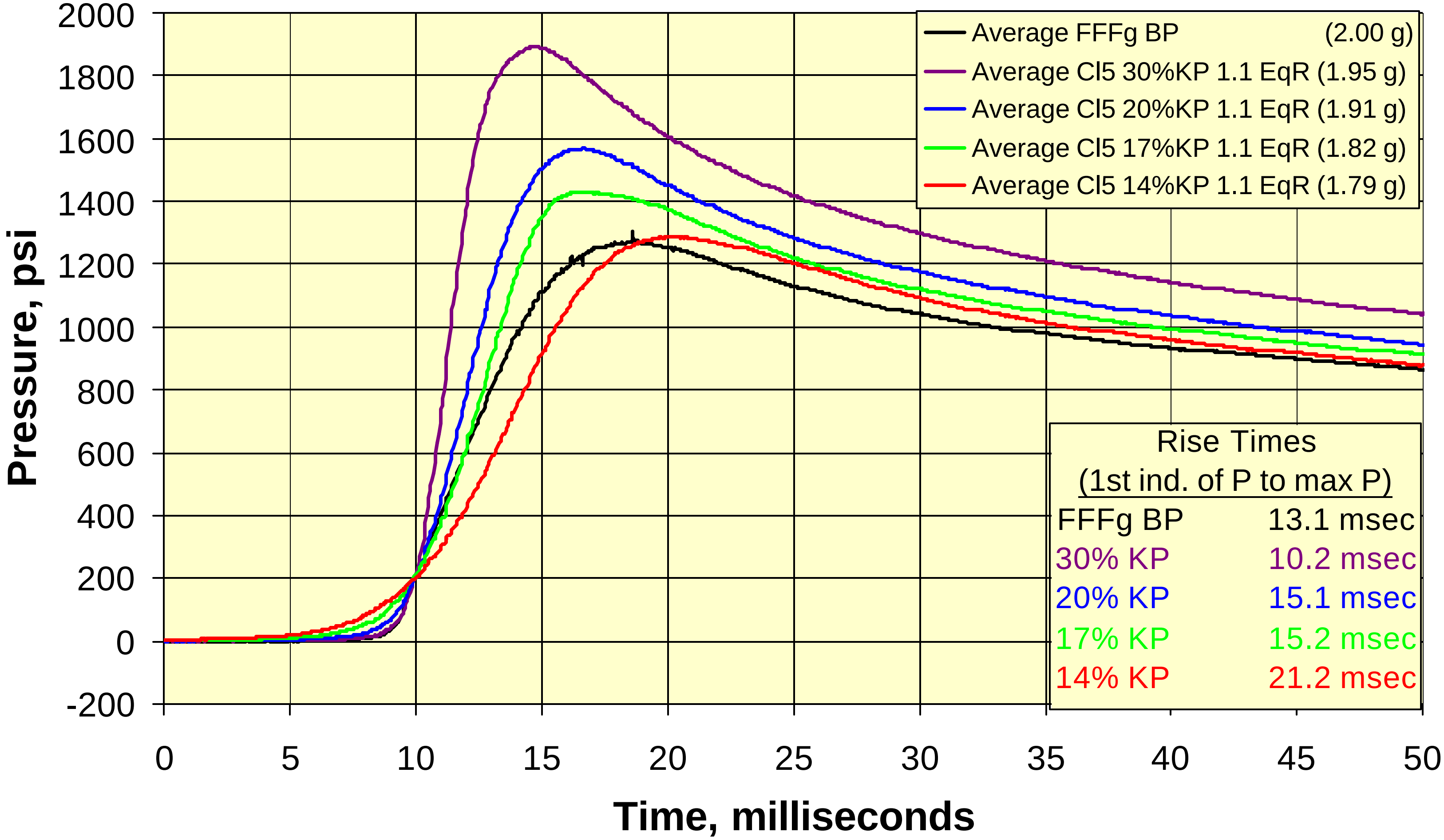
45-cc Closed Bomb Tests on Granules.
Class 5 MRBPS Granules with same Fill Volume as 2.00 g of Class 5 BP.
Averaged P vs. T Traces are Normalized for 200 psig at 10 ms.



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Simulation of Mortar Ignition Cartridge Pellet Ballistics (Single Pellet)

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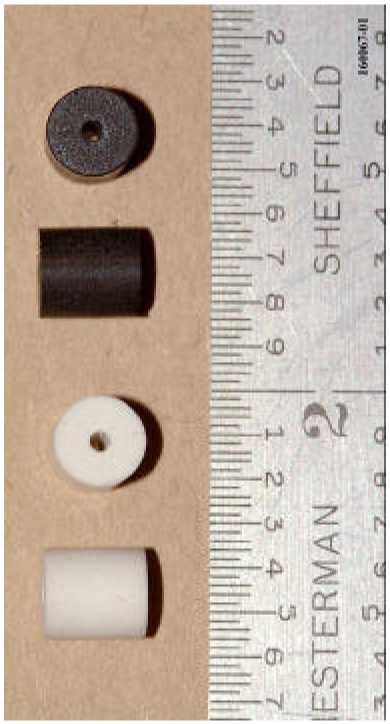
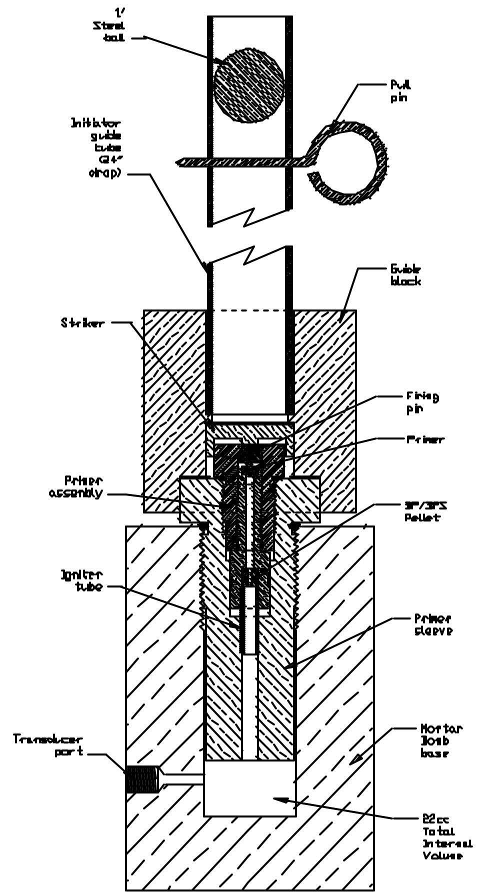
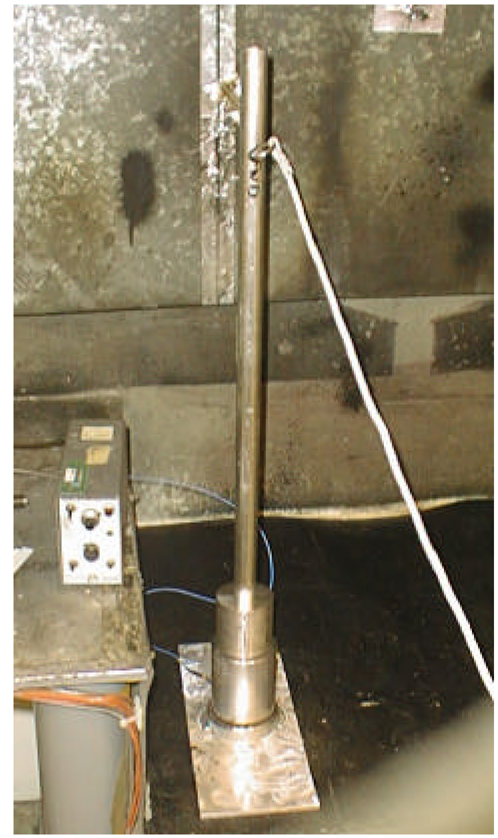
BP

MRBPS



Mortar Ignition Cartridge Pellets





"Primer Bomb" utilizing a portion of the M299 Ignition Cartridge (81mm Mortar)

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Lower Fuel Content Increases Rise Times
Primer Bomb Tests (Single Pellet)

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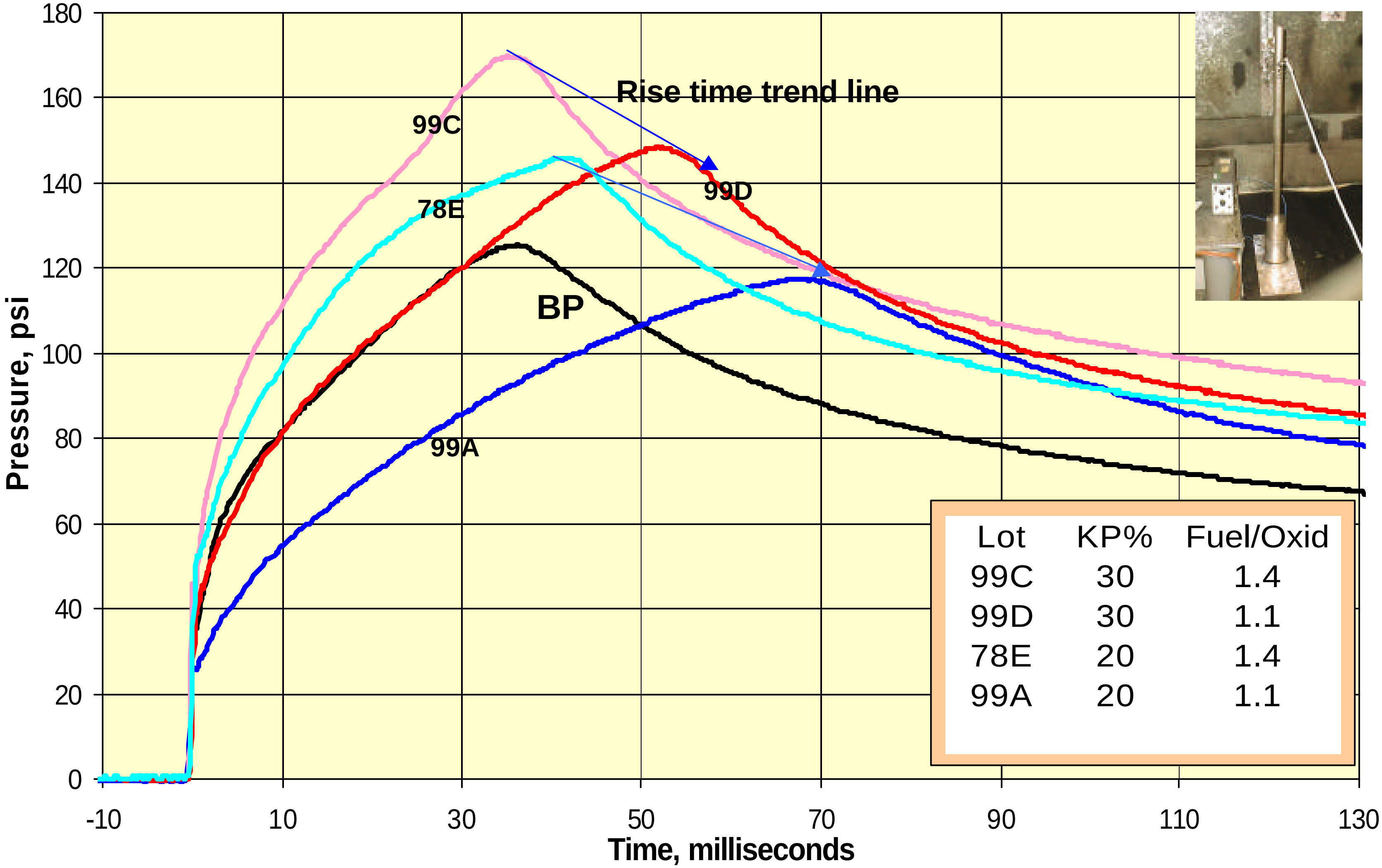

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Ballistic Reproducibility of Mortar Ignition Cartridge Pellets in the Primer Bomb (Single Pellet, 89% TMD)

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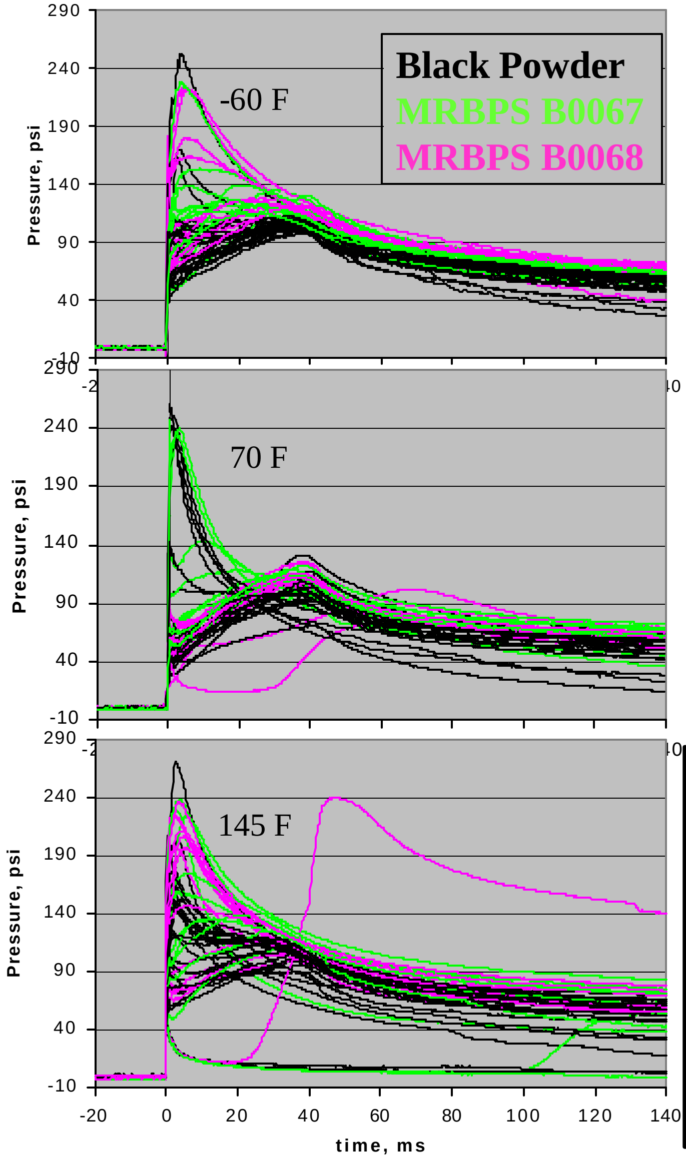

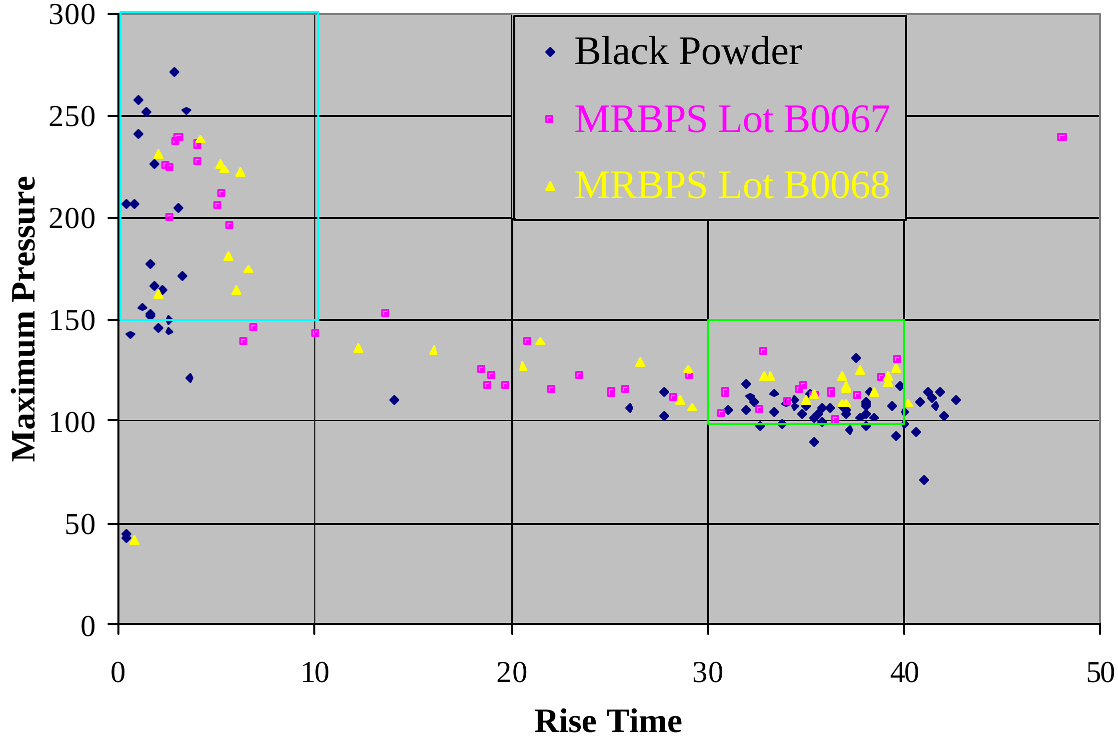

Two patterns of ballistic response are observed in primer bomb measurements :

Combustion of incomplete unbroken pellets-high density
- ✓ Rise times typically between 30-40 msec
- ✓ Maximum pressures between 100-130 psi

Combustion of shattered pellets-low density
- ✓ Rise times less than 10 msec
- ✓ Maximum pressures greater than 150 psi

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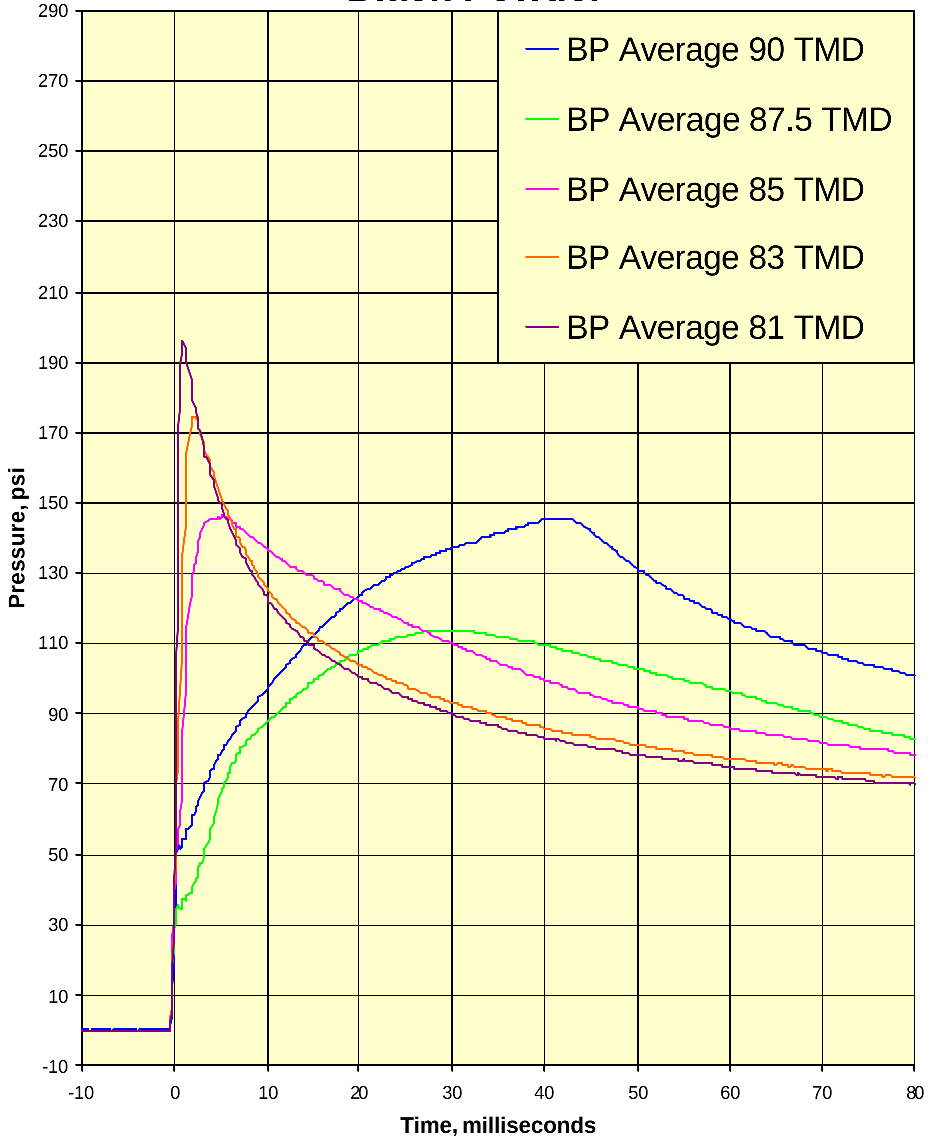
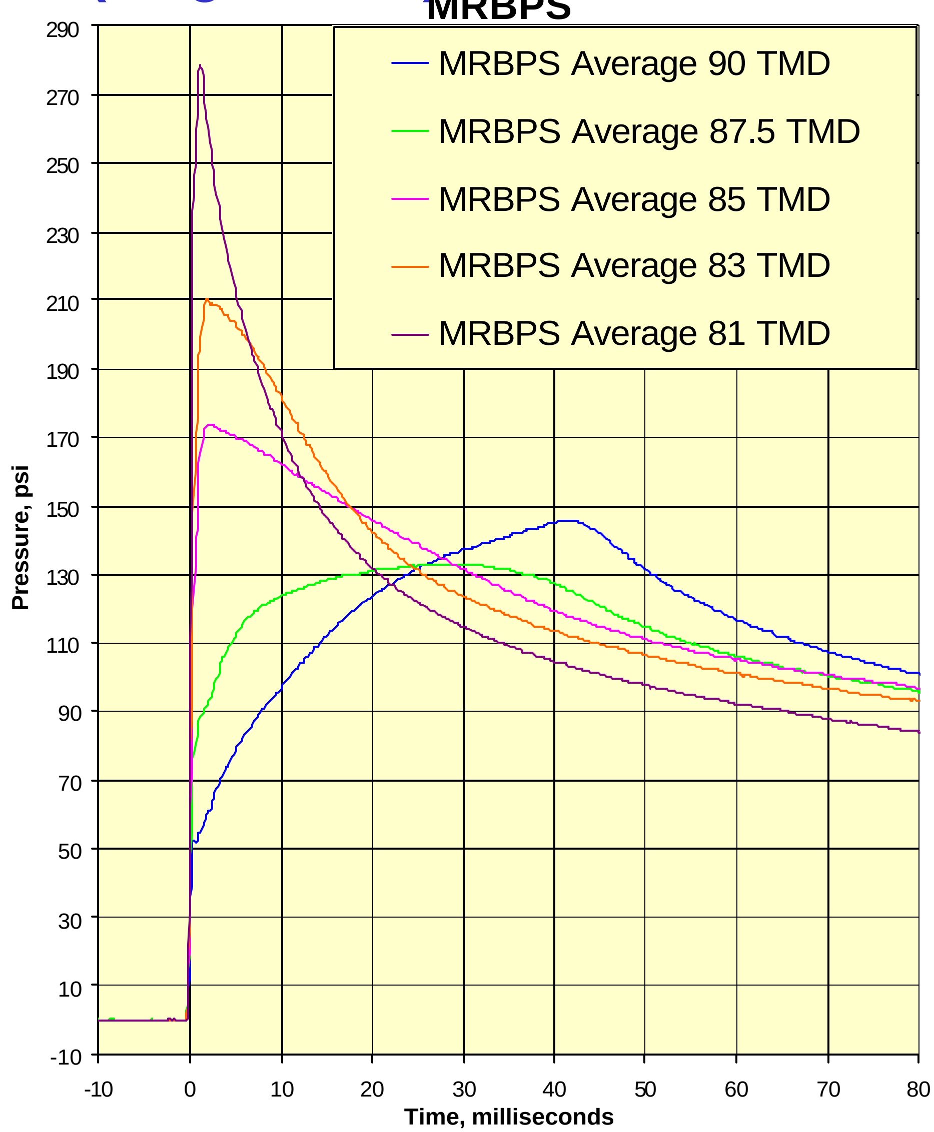
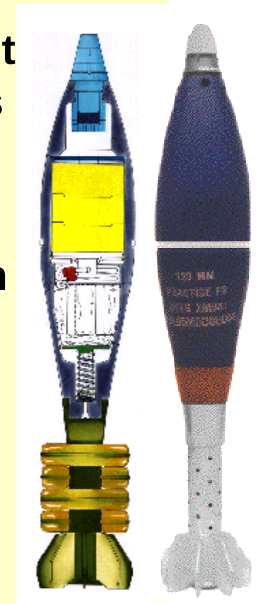
Effect of Pellet Density on Ballistics in Primer Bomb (Single Pellet)





A Paradigm Shift Occurred in Perceived Acceptable Performance of Mortar Ignition Cartridge Pellets

- **An investigation into 120 mm mortar short round issues was very informative.**
  - **120 mm mortars, e.g., M931 Full Range Practice, XM930 Visible Light Illuminating and M929 WP Smoke, did not meet range requirements (less than 80% of specification) due to fin separation.**
  - **The investigation determined that ignition cartridges containing black powder pellets with high densities caused over-pressurization in the cartridge and, consequently, fin separation.**
    - ✓ **BP pellets provided by ARDEC to ATK as a baseline for development of MRBPS pellets were "high density".**
      - **MRBPS was formulated to mimic performance of high density BP pellets (surface burning mechanism).**
      - **The same formulation is too brisant to mimic low density BP pellets.**
  - **BP pellets with low to medium densities yielded acceptable mortar performance.**
    - ✓ **Low/medium density BP pellets produce consistent and quick flame spreading across the whole length of the M1020 ignition cartridge flash tube. This is not the case for high density BP pellets.**



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Effect of BP Pellet Density/Crush Strength on Ballistics-M1020 Primer Bomb (5 Pellets)

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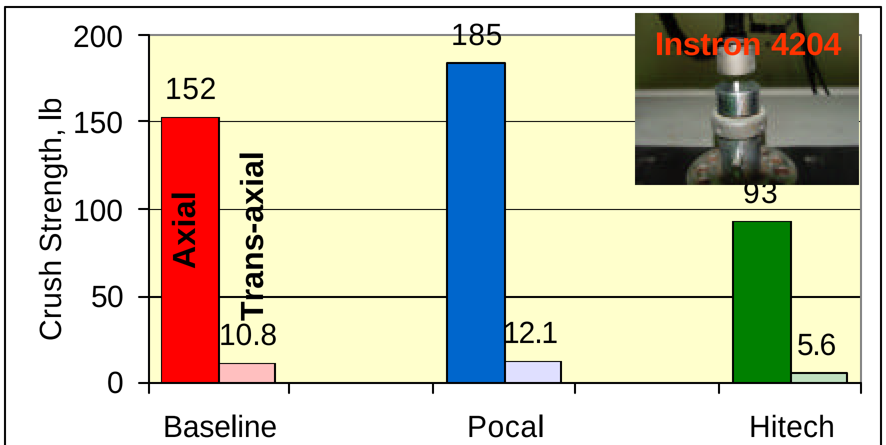
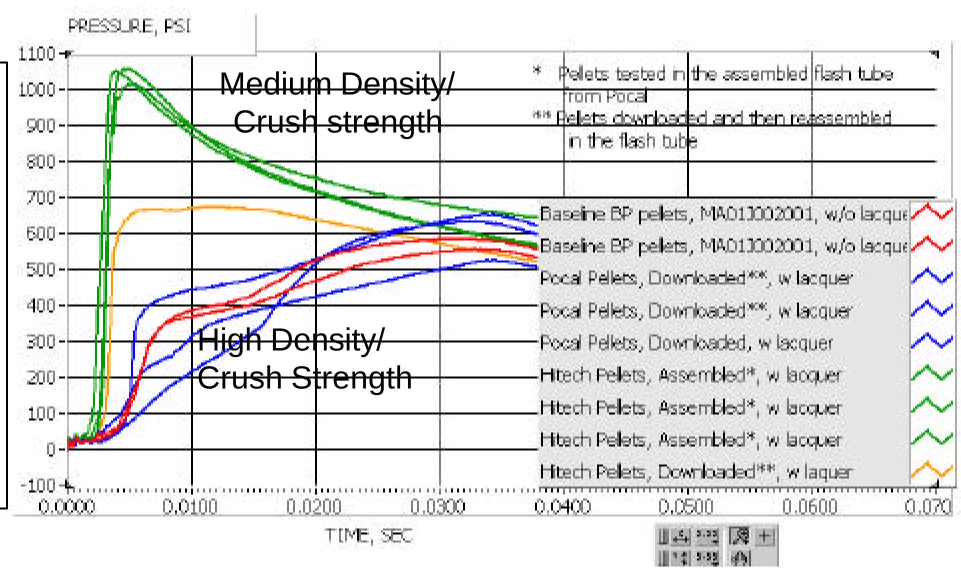
	Height	OD	Weight	ID	Density
	inch	inch	gram	inch	g/cc
Pocal (MA00M001002)- high density					
Average	0.222	0.200	0.192	0.049	1.791
Std Devc	0.0013	0.0004	0.0025	0.0007	0.0208
Hitech (MA99D002S699)- medium density					
Average	0.224	0.199	0.184	0.050	1.712
Std Devc	0.0008	0.0003	0.0018	0.0004	0.0174
Baseline (MA01J002001)- highdensity					
Average	0.223	0.200	0.192	0.048	1.778
Std Devc	0.0009	0.0003	0.0017	0.0009	0.0202

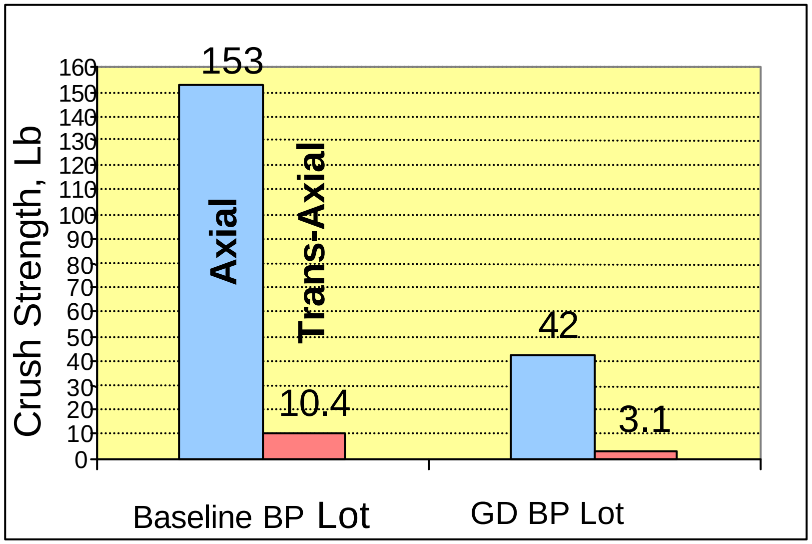
M1020 Primer Bomb

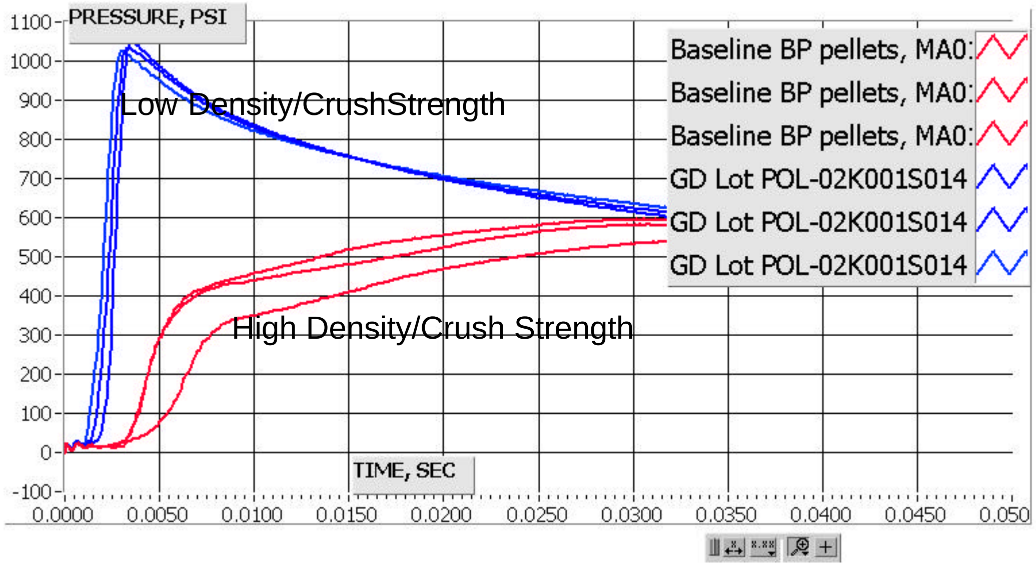
- **Utilizes M1020 ig ctrg components**
- **Solenoid electronically activates drop weight**
- **High density: slow rise/erratical (500-650 psi, approx. 35 ms rise)**
- **Medium density: quick rise/consistent (1000-1050 psi, approx. 5 ms rise)**





Effect of BP Pellet Density/Crush Strength on Ballistics- M1020 Primer Bomb (5 Pellets)





Pellet density/crush strength controlled by

- **Fill Volume: control the weight of pellet; depth of lower punch**
- **Load: control the height of pellet; distance between two punches at the end of press cycle**

BP functional density range for M1020

- **1.61-1.71 g/cc (low to medium)**

Low density pellets

- **1020-1050 psi peak/approx. 5 ms rise; prone to break-up**

GD Lot (POL-02K001S014)- low density					
	Height	OD	Weight	ID	Density
	inch	inch	gram	inch	g/cc
AVG	0.226	0.203	0.181	0.051	1.610
STD DEV	0.0024	0.0004	0.0030	0.0001	0.0312
Baseline (MA01J002001)- highdensity					
AVG	0.223	0.200	0.192	0.048	1.778
STD DEV	0.0009	0.0003	0.0017	0.0009	0.0202

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BP Ignition Flame Imaging
Kodak 500 FPS Motion Corder Analyzer, SR Series

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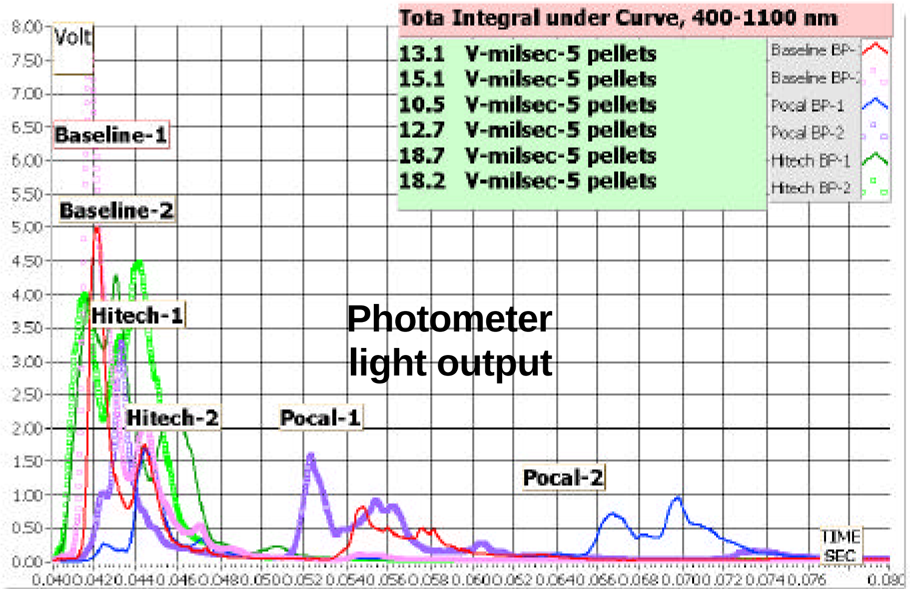

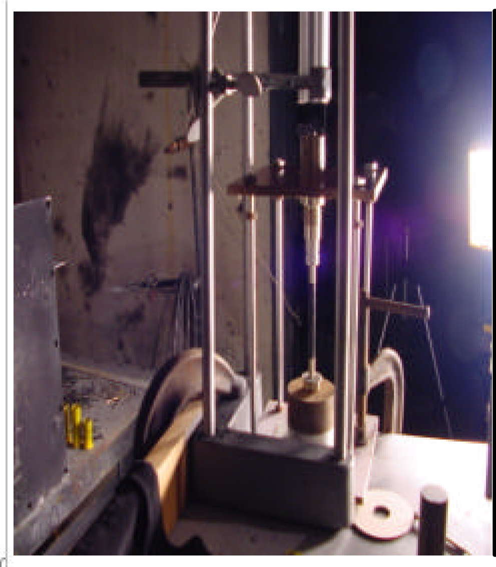

400-1100 nm light output:
- High density- weak, slow
- Medium density- intense, and quick; 50-70% higher in total light integral

Ignition flame:
- High density- consistent & full flame spread along the flash tube
- Medium density- initially partial flame spread along the flash tube; longer burning

High Density Pocal

Medium Density Hitech

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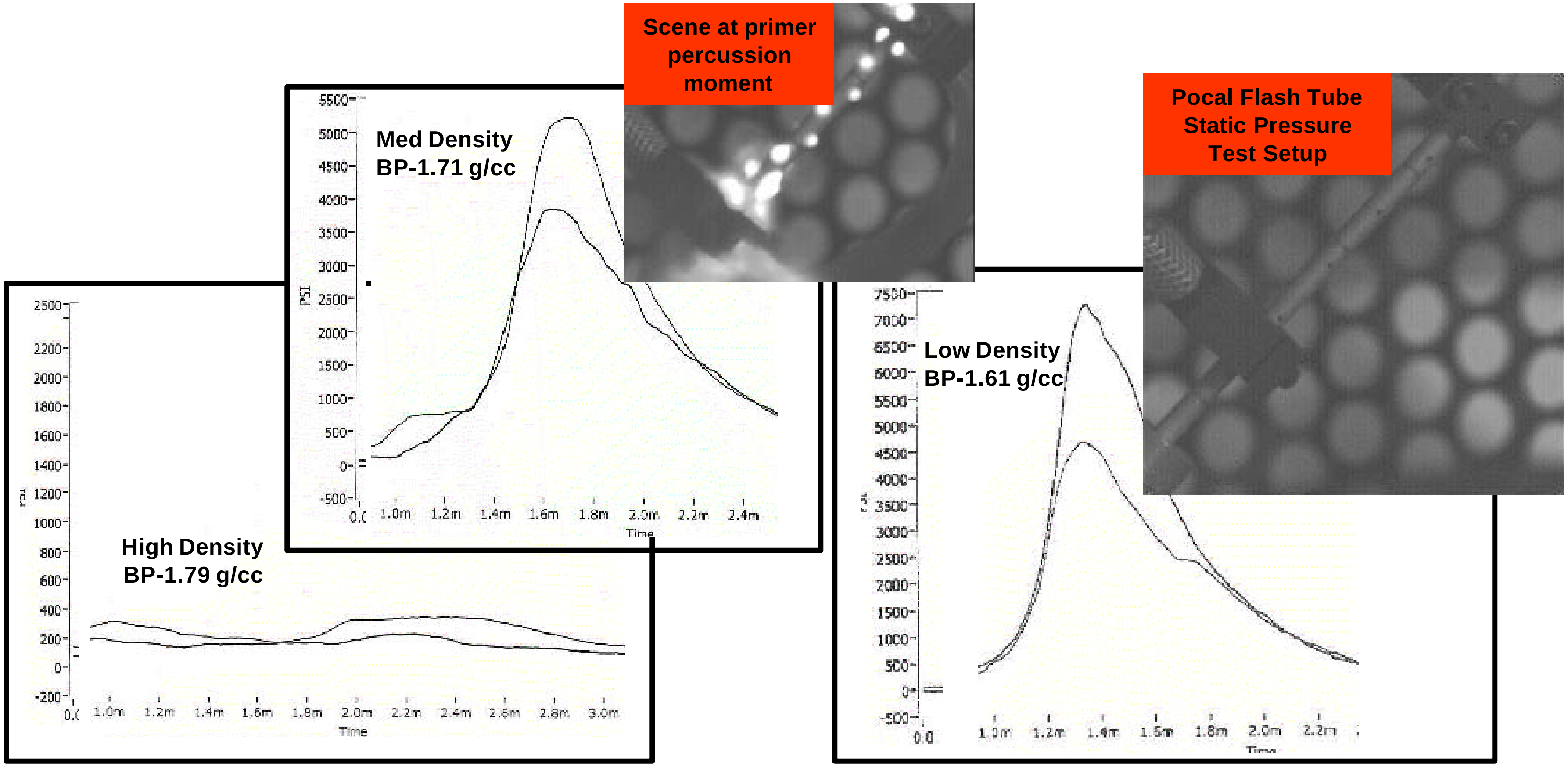
Pocal Static Pressure Test - M1020/B (w/o Propellant)
Representative Flash Tube Internal Pressures-Top & Bottom



Effect of MRBPS Pellet Density/Crush Strength on Ballistics-M1020 Primer Bomb (5 Pellets) (Before Paradigm Shift)

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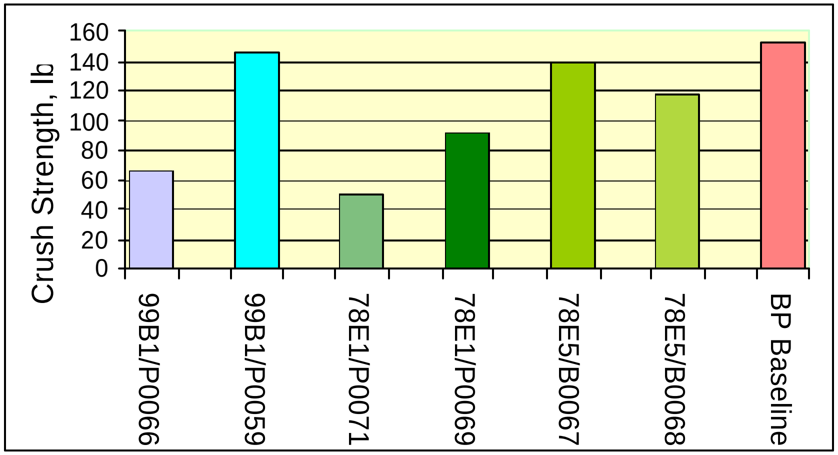

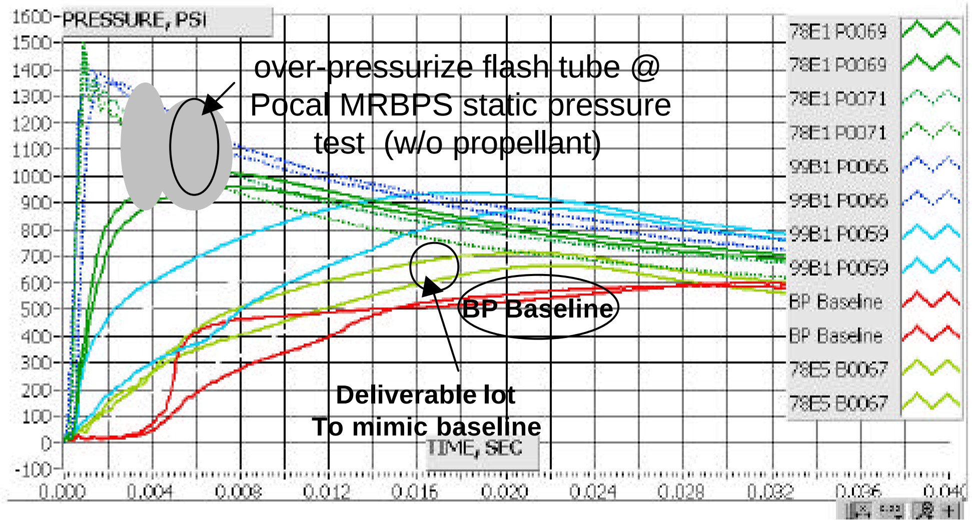

Lot No	99B1/P0066	99B1/P0059	78E1/P0071	78E1/P0069	78E5/B0067	78E5/B0068	Baseline BP
Instron 4204 Axial Crush, lb	66	146	50	92	140	117	152
Instron 4204 Trans-Axial Crush, lb	6.9	13.5	4.7	7.6	11.4	10.3	10.8
Pellet Weight, gm	0.1788	0.1895	0.1697	0.1774	0.1693	0.1695	0.1891
Pellet Height, in	0.2218	0.2233	0.2238	0.2225	0.2098	0.2098	0.2212
Pellet OD, in	0.2015	0.203	0.2018	0.2021	0.2	0.2	0.1993
Pellet ID, in	0.0442	0.0444	0.045	0.0446	0.0491	0.0491	0.0479
Pellet Density, g/cc	1.6134	1.6804	1.5226	1.5946	1.669	1.671	1.774
Stokes 539 Tester, Trans-Axial, lb	6.7	10.9	3.8	7.6	9.7	9.7	9.7

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MRBPS Pellet Optimization Primer Bomb (Single Pellet)

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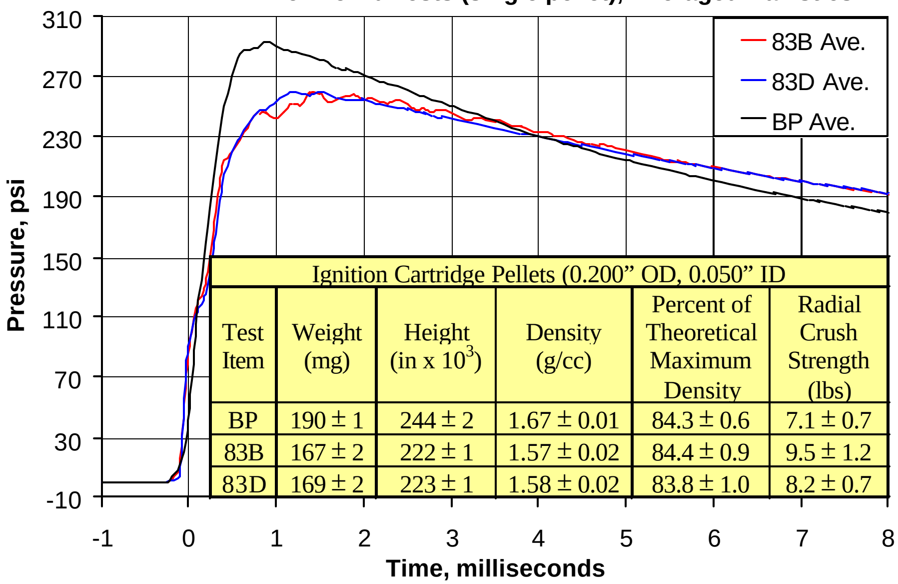
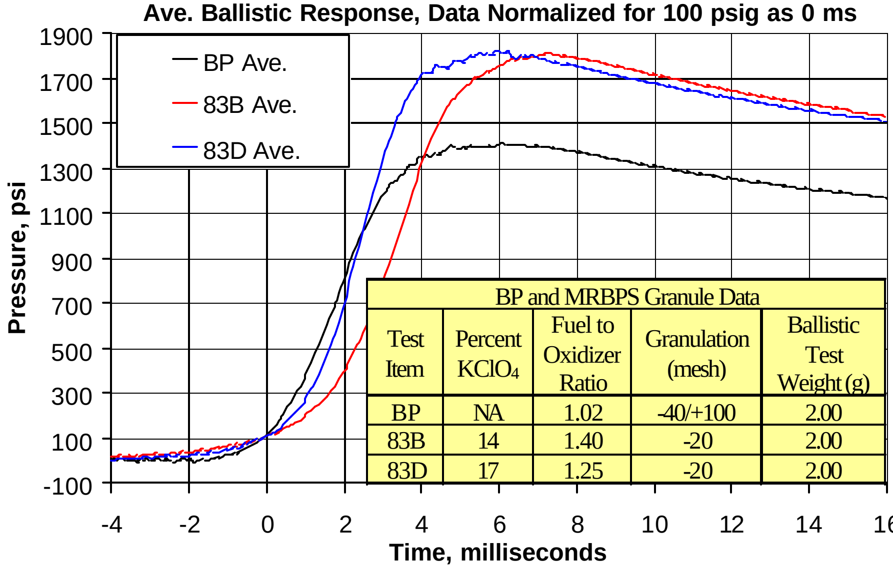
ATK Primer Bomb Tests (single pellet), Averaged Ballistics



Ignition Cartridge Pellets (0.200” OD, 0.050” ID

Test Item	Weight (mg)	Height (in x 10^3)	Density (g/cc)	Percent of Theoretical Maximum Density	Radial Crush Strength (lbs)
BP	190 ± 1	244 ± 2	1.67 ± 0.01	84.3 ± 0.6	7.1 ± 0.7
83B	167 ± 2	222 ± 1	1.57 ± 0.02	84.4 ± 0.9	9.5 ± 1.2
83D	169 ± 2	223 ± 1	1.58 ± 0.02	83.8 ± 1.0	8.2 ± 0.7

45-cc Closed Bomb Test, 2.00g of Pellet Feedstock
Ave. Ballistic Response, Data Normalized for 100 psig as 0 ms



BP and MRBPS Granule Data

Test Item	Percent $KClO_4$	Fuel to Oxidizer Ratio	Granulation (mesh)	Ballistic Test Weight (g)
BP	NA	1.02	-40/+100	2.00
83B	14	1.40	-20	2.00
83D	17	1.25	-20	2.00

- ❑ Static tests of MRBPS in M1020 Mortar Ignition Cartridges (120 mm, five pellets, w/o propellant) were conducted.
  - • Conducted on MRBPS with 20%KP and 1.20 F to O
  - • High density pellets (89% TMD) yielded low pressures- pellets are surface burning
  - • Low density pellets (<85% TMD) cause over-pressurization in flash tubes- pellets are pulverizing
  - ▪ Pellets at intermediate densities gave inconsistent performance- combination of surface burning and crushing
- ❑ MRBPS was optimized to lower its brisance (to yield lower Pmax) at low to intermediate density (to yield consistent Pmax).
  - • Two formulations yielded promising results
    - ✓ “83B” 14% KP, 1.40 Fuel to Oxidizer Ratio
    - ✓ “83D” 15.5% KP, 1.25 Fuel to Oxidizer Ratio
  - • Pellets were pressed to the same %TMD currently targeted for BP pellets (84% TMD, 1.66 g/cc)
    - ✓ MRBPS Pellet (167-169 mg) performance in the ATK primer bomb is slightly less than BP (190 mg); weight or density can be adjusted to match
  - ▪ Granule performance in 45 cc closed bomb
    - ✓ 14% higher Pmax than BP (equal volume basis); 25% higher Pmax than BP (equal mass basis)
    - ✓ 83D has comparable rise time to BP; 83B has slightly longer rise time
- ❑ Test on optimized pellets in full-up M1020 ignition cartridge is pending.

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MRBPS Pellet Optimization
M1020 Primer Bomb (5 Pellets)

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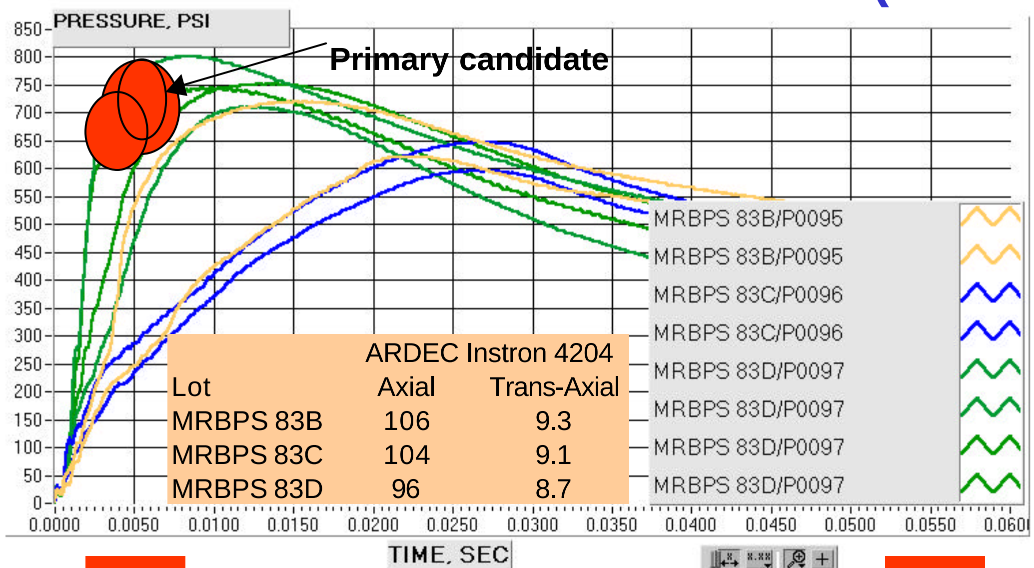
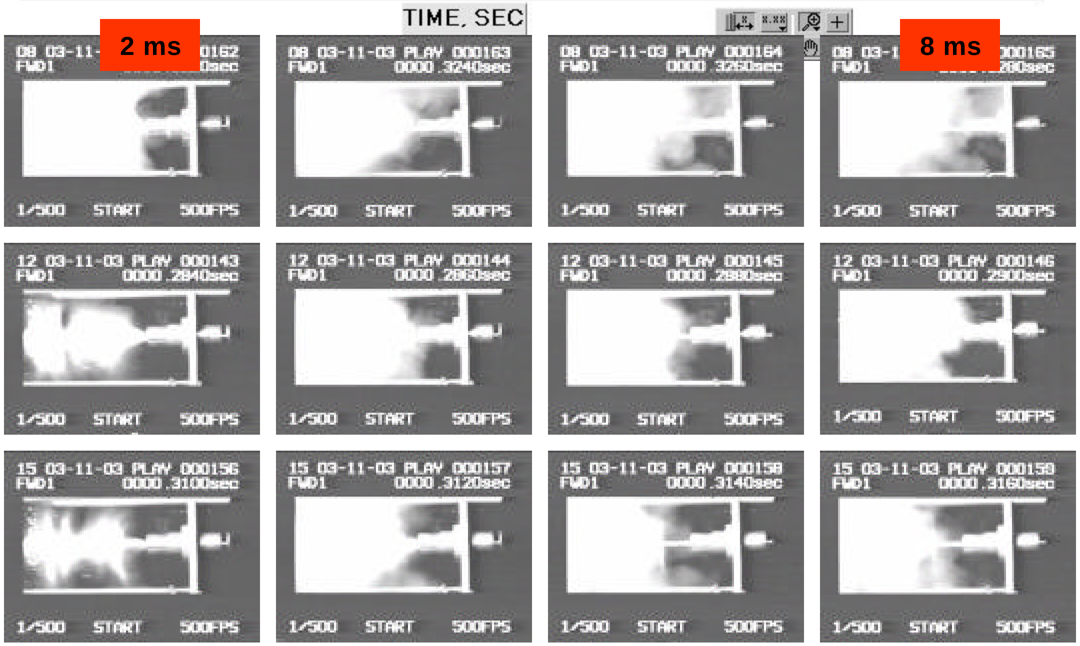


	ARDEC Instron 4204	
Lot	Axial	Trans-Axial
MRBPS 83B	106	9.3
MRBPS 83C	104	9.1
MRBPS 83D	96	8.7

83D

83C

83b



✓ **Three optimized lots ready for full- up M1020 ignition cartridge test**

83D: (primary candidate)
- **Full flame spread in 1st 2 ms**
- **8-10 ms rise time; 710-800 psi peak**
- **Consistent output**

83C: (backup candidate)
- **Partial flame spread in 1st 2 ms**
- **26 ms rise time; 500-650 psi peak**

83B: (backup candidate)
- **Partial flame spread in 1st 2 ms**
- **15-22 ms rise time; 620-720 psi peak**

✓ **No flash tubes bent, broken or bulged for lots 83 B, 83C, and 83D in open flame testing**

✓ **Formulations adjusted to reduce peak pressures and pellet densities**

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Summary

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- A viable substitute for black powder has been identified: MRBPS
  - It is significantly more resistant to moisture absorption than black powder.
  - The formulation performance can be tuned to meet the needs of specific applications.
- The mechanism for effective function of mortar ignition cartridge pellets has been identified.
  - Pellets pressed to low to medium densities (1.61-1.71 g/cc) yield acceptable performance.
    - ✓ Shock wave from the Federal 150 primer pulverizes the pellet.
    - ✓ High surface area of low to medium crushed pellet allows for its rapid & consistent combustion.
    - ✓ The resulting flames fill the complete length of the M1020 ignition cartridge flash tube.
- Low to medium density mortar ignition cartridge pellets combust similarly to granules but have the following advantages:
  - The pellet's packing density is 50% greater than granules.
    - ✓ More bang per unit volume
  - Safer and easier to load/assemble than granules.
  - Pellet weight and dimensions are controllable.
- MRBPS pellets with comparable function to that of low to medium density BP pellets have been identified.