MANUFACTURING & CHARACTERIZATION OF INSENSITIVE HIGH-ENERGY EXPLOSIVE CONTAINING FLUID ENERGY MILLED NITRAMINE (ABSTRACT #22238)

IMEMTS 2019 (Session 2B Energetic Materials)

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October 22, 2019

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Briefing Outline

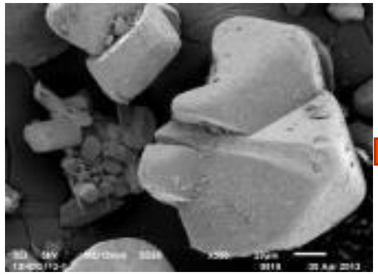
- Program Overview
- Review of Test Result to Date
- New Formulation Effort
- Conclusion
- Acknowledgements

Fluid Energy Mill Technology

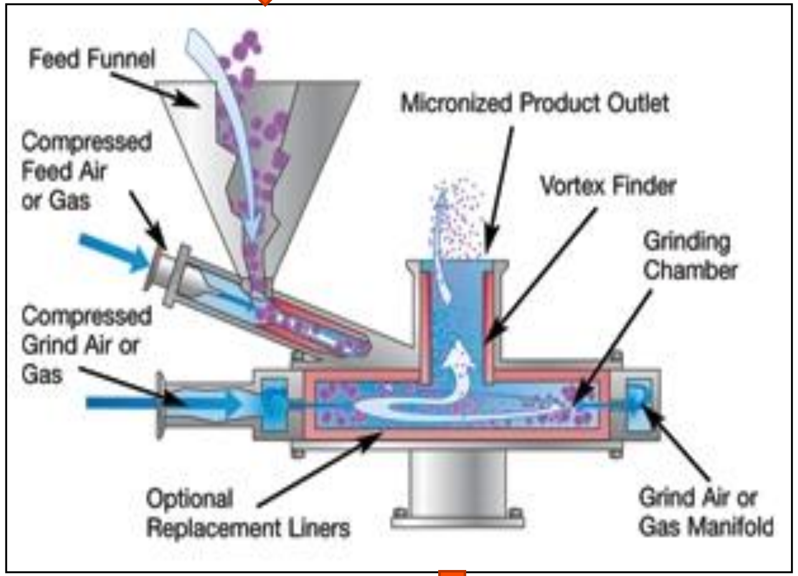
- Traditional mechanical particle size reduction technology
  - Particles mechanically milled
  - Rough, irregular shapes of product crystals

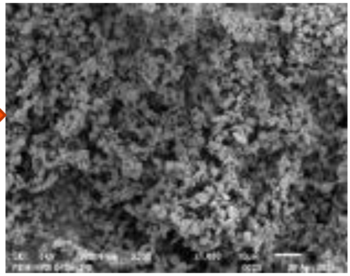
- Innovation of the technology resides in its simplicity:
  - Compress air employed to move explosive particles in mill chamber
  - Particle-to-particle impacts reduce size of explosive
    - Capable of reaching ~ 1 μm

- Advantages of FEM Technology
  - No moving parts with regards to Energetic Processing
  - No "in-process" sensitization of explosives
  - No "pinch points" – risk reduction
  - FEM explosive product exhibited improved sensitivity
    - Crystal defects (cracks/voids) eliminated by milling
    - Reduced particle size a key factor



Explosive Feedstock
(>150 μm)

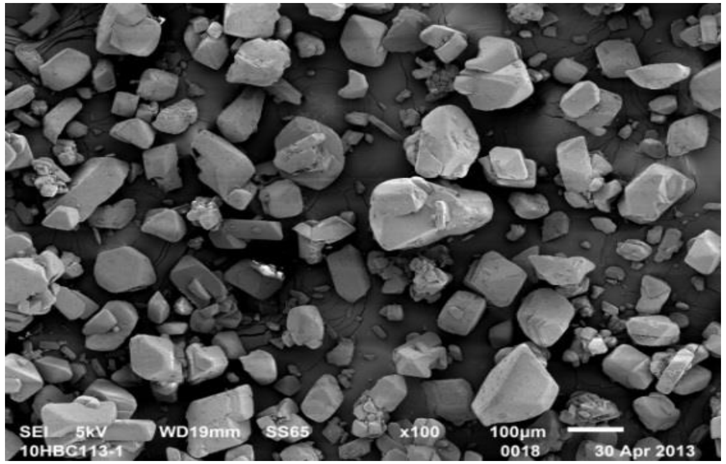




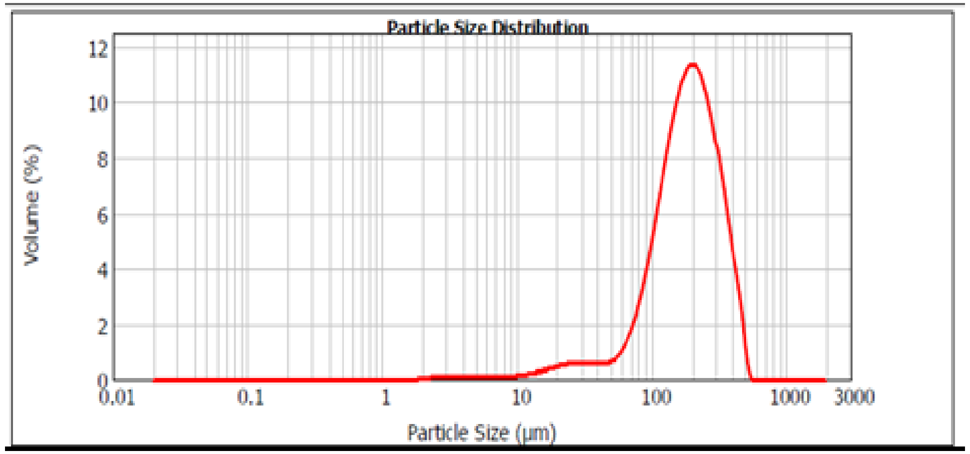
FEM Products
(< 10 μm)

Particle Size Reduction through FEM

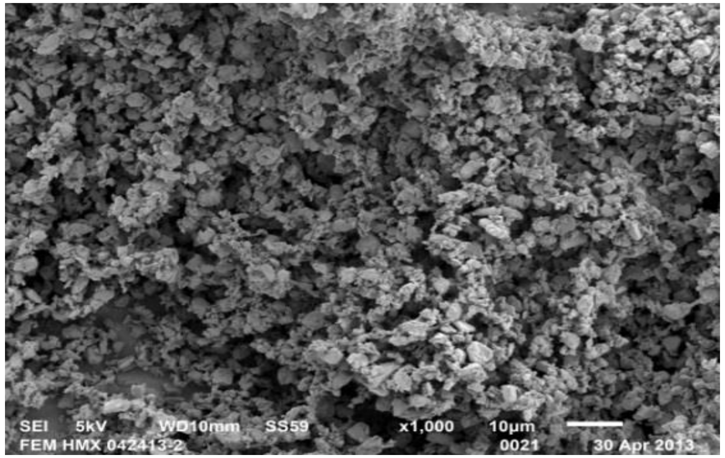
- HMX Class 1 Precursor
  - d_{50} ~ 200 µm



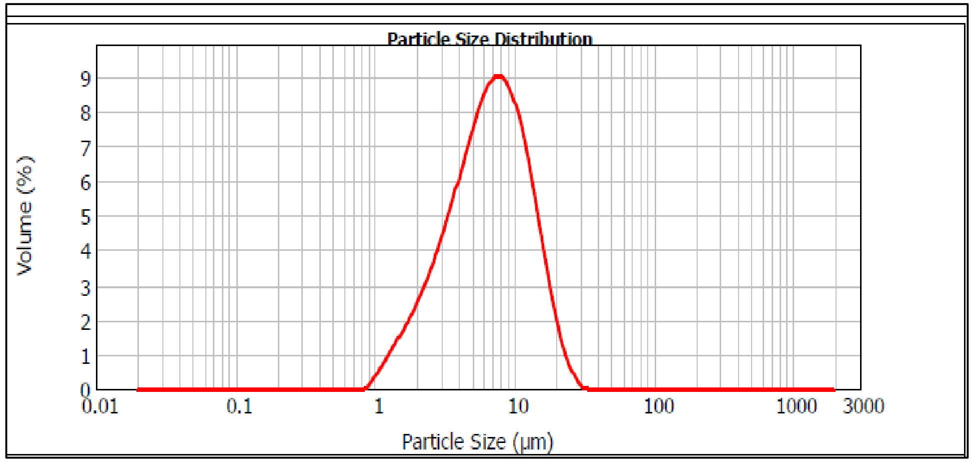
HMX Class 1 (X100)



- Fluid Energy Milled HMX
  - d_{50} ~ 5 µm



FEM HMX (X 1,000)



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Fluid Energy Mills at BAE Systems HSAAP

- **R&D Pilot Scale**
  - 4” Diameter Fluid Energy Mill
  - Use for product and process development
  - Successfully demonstrated milling of coated RDX precursor, retaining the plasticizer post milling (ACE FEM Program, IMEMTS 2015)

- **Production Scale**
  - 15” and 24” Diameter Fluid Energy Mill
  - Production “Work-Horse” to produce Fluid Energy Milled RDX, HMX and NTO

FEM Products	Main Use
FEM RDX	CXM-AF-5, CXM-AF-7; IMX-104
FEM HMX	CXM-AF-8, Various New Formulations featured in this briefing
FEM NTO	IMX-101, IMX-104

  - Future plan to install additional Fluid Energy Mills due to high demands

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FEM Formulation Methodology

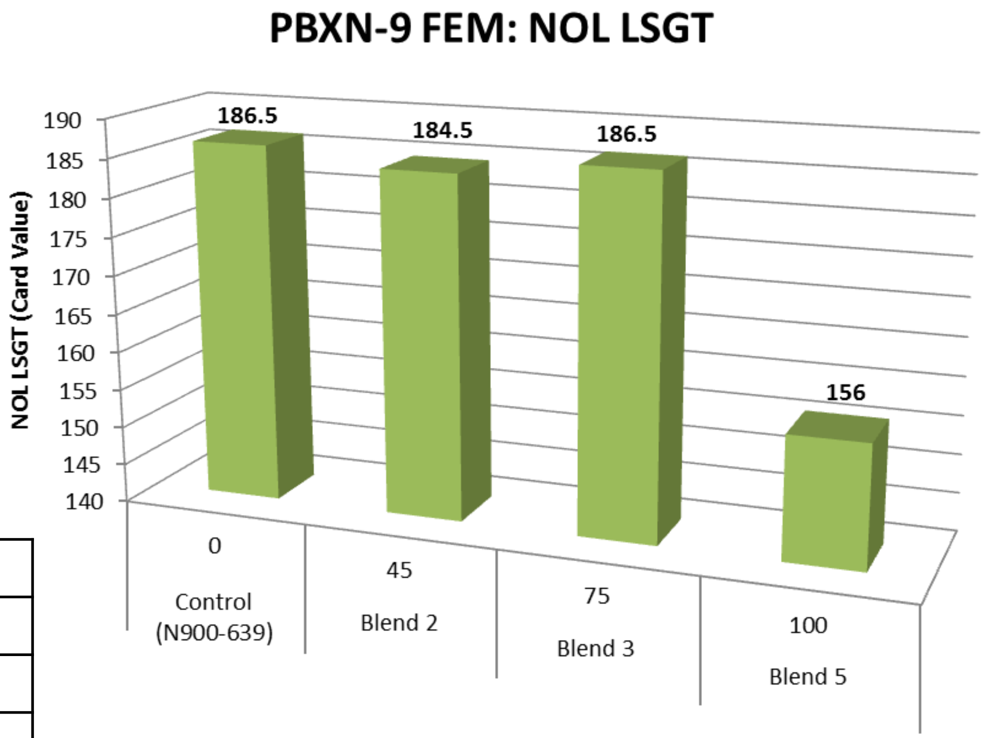
- **Why?**
  - FEM explosives demonstrated improved IM properties when used in formulations
    - Crystal internal defects eliminated with milling
    - No more rough edges
  - No deterioration in explosive performances
    - FEM HMX = Regular HMX
    - Overcome one of the most important deficiencies in terms of IM Technology Insertion
- **How?**
  - In high performance HMX & RDX based explosive products, substitute legacy nitramines with FEM equivalent nitramines
    - LX-14 (HMX / Estane Binder)
    - PBXN-9 (HMX / Hytemp / Diocytl Adipate)
    - Composition A-5 (RDX / Stearic Acid)
  - Conducted lab scale experiment initially, followed by pilot scale production
- **Goals**
  - Reduce sensitivity of the high energy explosives without compromises in explosive performances

PBXN-9 with FEM HMX – Laboratory Trial Highlights

Experiment Summary

- Standard PBXN-9 Slurry Coating Processing
- Adjusted HMX to FEM HMX Ratio
- Selected candidates tested for Shock Sensitivity (NOL LSGT)

- Blend 5 (100% FEM HMX substitution) showed the most significant improvement in shock sensitivity
    - Baseline: 186.5 cards (24.7 kbar)
    - Blend 5: 156.0 cards (36.3 kbar)



Sample ID	FEM/Legacy HMX Ratio	% HMX (91-93% w/w)	% Binder (7-9% w/w)	NOL Large Scale Gap Test	
				50% Card Gap	Pressure (kbar)
Baseline	0/100	91.90	6.30	186.5	24.7
Blend 2	45/55	91.82	6.24	184.5	25.3
Blend 3	75/25	91.91	6.08	186.5	24.7
Blend 5	100/0	91.89	6.13	156.0	36.3

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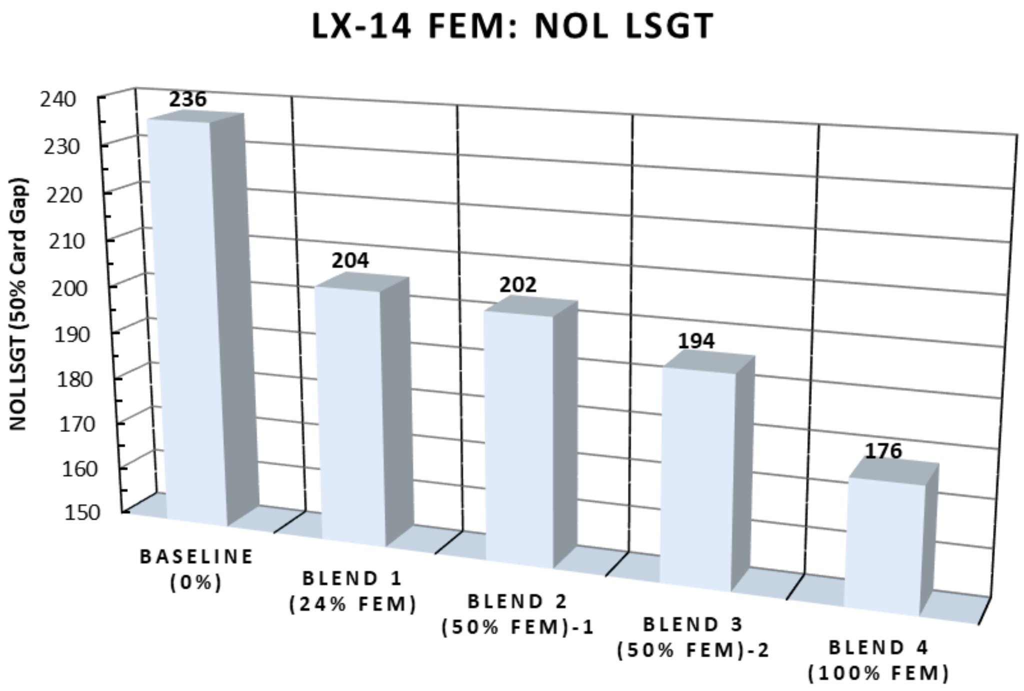
LX-14 with FEM HMX – Laboratory Trial Highlights (1)

Experiment Summary

- Standard LX-14 Slurry Coating Processing
- Multiple classes of HMX featured in original composition
- Adjusted HMX to FEM HMX Ratio
- Selected candidates tested for Shock Sensitivity (NOL LSGT)

- Blend 4 (100% FEM HMX substitution) showed the most significant improvement in shock sensitivity
    - Baseline: 236.0 cards (14.7 kbar)
    - Blend 4: 176.0 cards (28.0 kbar)

Sample ID	FEM/Legacy HMX Ratio	NOL Large Scale Gap Test	
		50% Card Gap	Pressure (kbar)
Baseline	0/100	236.0	14.7
Blend 1	24/76	204.0	20.1
Blend 2	50/50	202.0	20.5
Blend 3	50/50	194.0	22.5
Blend 4	100/0	176.0	28.0



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LX-14 with FEM HMX – Laboratory Trial Highlights (2)

Experiment Summary

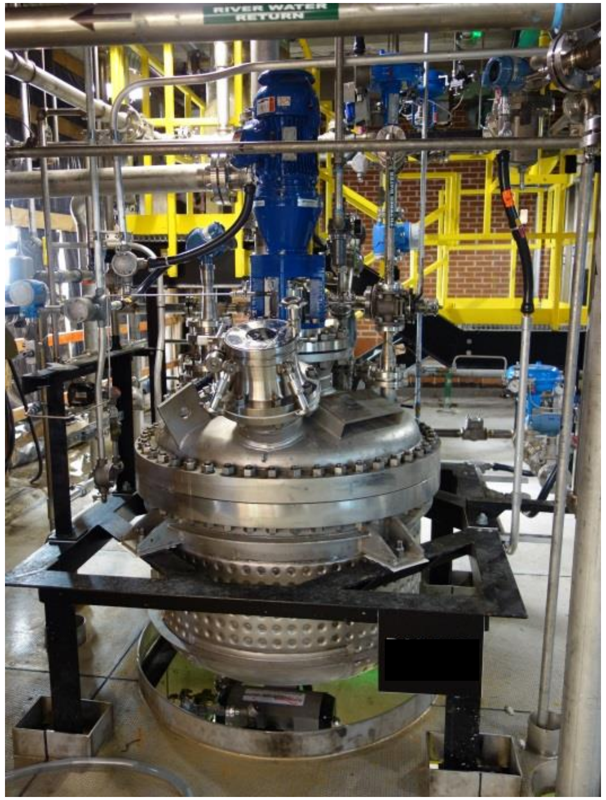
- 2 blends tested by US ARMY CCDC AC
  - FEM to regular HMX 80/20
  - 100% FEM
- Pressed density ~ 1.81 g/cc
  - 3 pellets per tube
- Lower shock sensitivity at 100% FEM than BAE's result
  - BAE Result: 176 cards
  - CCDC AC Result: 161.5 cards

Sample ID	FEM/Legacy HMX Ratio	NOL Large Scale Gap Test	
		50% Card Gap	Pressure (kbar)
Baseline *	0/100	236.0	14.7
Blend 1	80/20	166.5	31.6
Blend 2	100/0	161.5	33.8

Pilot Scale Manufacturing Effort

Scale-Up Effort @ Holston R&D Pilot Plant

- After successful lab campaign, both formulations were scaled at Pilot Plant in anticipation of larger scale manufacturing
- 2 Pilot Scale Formulation Coating Vessels
    - Smaller Vessel: up to 250 lbs.
    - Larger Vessel: up to 800 lbs.
- Target Batch Size for PBXN-9 and LX-14 with FEM HMX
    - 100-300 lbs.
- Quantities manufactured to date
    - PBXN-9 with FEM HMX (590 lbs.)
    - LX-14 with FEM HMX (536 lbs.)
- Process parameters similar to those for the legacy products
    - Smooth transition to Full Scale Production (~500 lbs. batch size) with optimization effort



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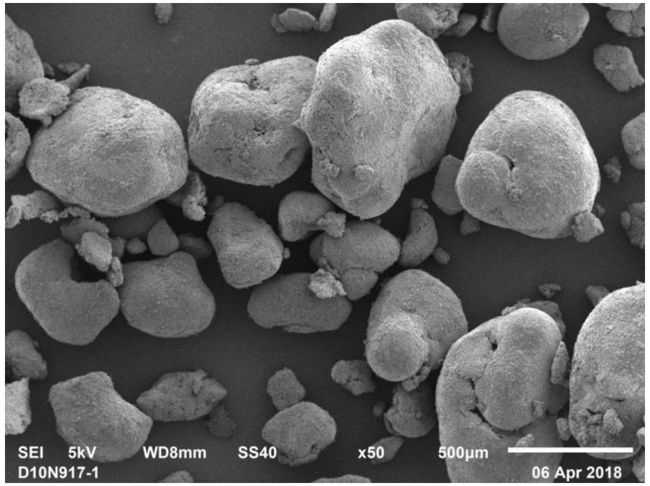
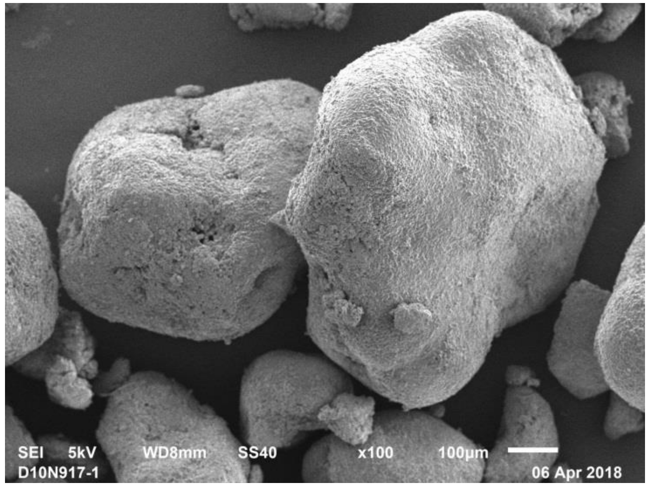
Pilot Plant: PBXN-9 with FEM HMX

PBXN-9 with FEM HMX - Analytical Result Summary

Batch/ Notebook #	Lab/Pilot	Batch Size (lbs.)	% FEM HMX	Composition			Bulk	Pressed	Flowdex	Friction	Granulation			Naval Impact		VTS
				HMX %	DOA %	Hytemp %	Density	Density		Co-eff	Pass #6	Pass #8	Pass #40	N-9	RDX Std	
				91.0-93.0	5.0-7.0	1.5-3.0	>0.80 g/cc	>1.73 g/cc		<220	99-100	95-100	0-5	>RDX Std		<0.5
D10N917-1	Pilot	145	90	92.02	5.77	2.21	0.71	1.69	12	208.74	99.8	98.1	45.2	84.14	12.12	0.0304
D10N917-2	Pilot	145	100	91.66	5.83	2.50	0.71	1.677	7	121.77	99.9	99.3	5.1	89.13	12.12	0
D10N917-3	Pilot	300	90	91.78	5.88	2.34	0.67	1.692	9	147.74	99.6	98	9.2	39.81	13.14	0.0247

- NOL LSGT 50% Gap = **167.5 cards (27.5 kbar)** @ 1.72 g/cc charge density
  - Legacy PBXN-9 typical value = 200 – 220 cards (significant improvement)





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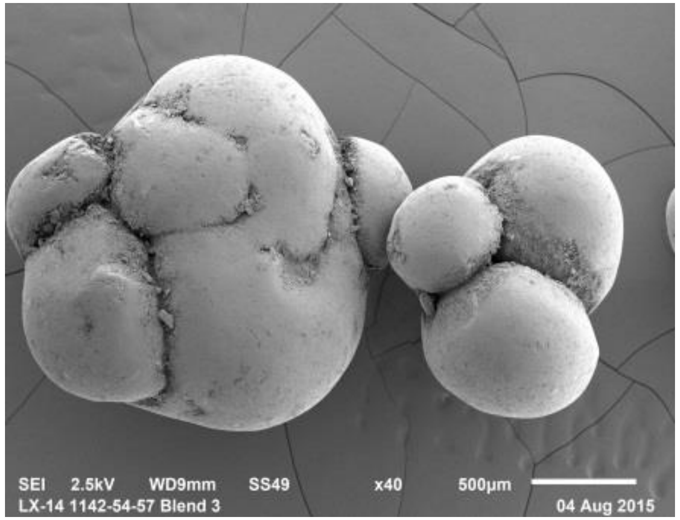
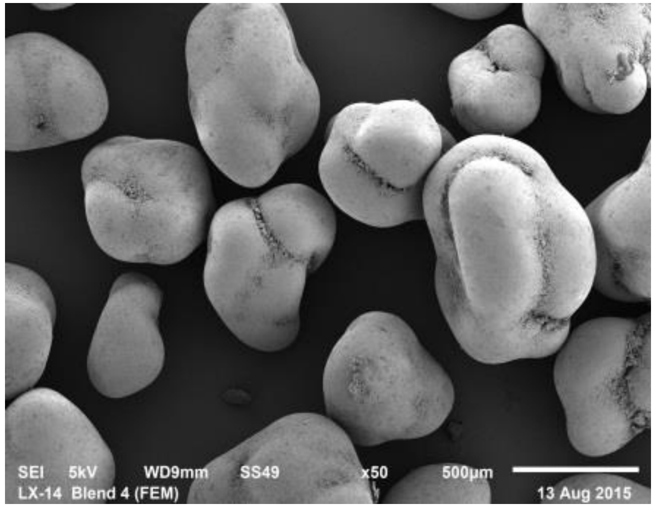
Pilot Plant: LX-14 with FEM HMX

LX-14 with FEM HMX - Analytical Result Summary															
Batch/ Notebook #	Lab/Pilot	Batch Size	% FEM HMX	Composition		Bulk Density	Volatiles	Granulation				Insolubles		Color
				HMX %	Estane %	(g/cc)		Retain 5/16"	Retain #4	Retain #50	Retain #80	USSS #40	USSS #60	
				94.9 - 96.1	*3.9 - 5.1*	*> 0.85 g/cc*	*0.10% Max*	*None*	*1 max*	*95 min*	*98 min*	*0 max.*	*5 max.*	
D10LX14FEM17-1	Pilot	118 lb.	80	96.1	3.90	0.878	0.071	0	0	84.4	13.2	0	0	White
D10LX14FEM17-2	Pilot	300 lb.	80	95.36	4.64	0.85	0.06	0	0	91.8	72	0	0	White
D10LX14FEM17-3	Pilot	118 lb.	80	95.33	4.67	0.877	0	0	0	94	6	0	0	White

- NOL LSGT: 50% Gap = **178.5 Cards (27.20 kbar)** @ 1.81 g/cc charge density
  - Legacy LX-14 typical value = 200 – 240 cards (significant improvement)





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New Effort – Composition A-5 with FEM RDX (1)

Objectives

- Can we achieve the same IM Response Improvement in Composition A-5 with FEM RDX?
- Composition A-5 (98.75% RDX Class 1 and 1.25% Stearic Acid)
- Used in multiple shaped charge/warhead application including the 40mm M430A1

Experimental

- Replace portion of the RDX Class 1 with FEM RDX
- Evaluate how % FEM RDX in Comp A-5 affects the physical properties of the final product
- Down-select candidate for performance and IM properties assessment
- Exclusively laboratory study

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New Effort – Composition A-5 with FEM RDX (2)

Experimental (continue)

- Factors evaluated
  - Type of Solvent
  - FEM RDX to RDX Class 1 Ratios
  - Slurry concentration (Solids Loading)
  - Agitation Rate

- General Trend Observed (so far)
  - Increase in FEM RDX reduces particle size and bulk density
  - Flow properties also different to legacy product
  - No significant difference observed in impact sensitivity
    - All candidates less impact sensitive than standard RDX Class 5
  - Shock Sensitivity and Friction Sensitivity to be evaluated
    - 75% FEM RDX vs. 0% FEM RDX

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Conclusion

- The use of Fluid Energy Milled Nitramine in Legacy PBX formulation demonstrated significant improvement in Shock Sensitivity
  - PBXN-9 with FEM HMX (90-100%)
  - LX-14 with FEM HMX (80%)
- No degradation in Explosive Performance
- Both products successfully scaled up in Pilot Equipment – shall transition to Full Production Scale without complication
  - LX-14 and PBXN-9 with FEM HMX ready for production; and for larger weapon system IM evaluation
- Composition A-5 evaluation on-going; interested to see whether this technology can apply to FEM RDX
  - Shock sensitivity comparison to take place
- Benefits of this technology
  - Relatively low cost to implement (simple solution / short development cycle / limited re-qualification)
  - Cost effective IM Solution
  - No compromise in Explosive Performance

Acknowledgements

DEVCOM ARMAMENTS CENTER	• Phil Samuels
BAE SYSTEMS	• R&D Analytical Group • Neil Tucker, Brian Alexander, Jacob Morris, Denise Painter, Chris Long, Todd Dye, Tracy Kelly

Thank you