FOX-7, an IM Ingredient Candidate – Where Are We Today?

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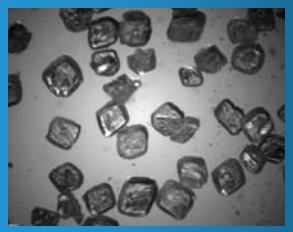
Outline

- Why new Energetic Molecules
- FOX-7 Basics
- FOX-7 Crystals
- FOX-7 Formulations and Applications
- Conclusions

Ways to Insensitive Munitions..

Modify the energetic material



Modify the composition

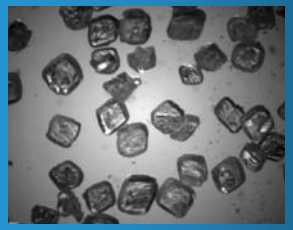
Modify the munition

Modify the packaging

Modify the ammunition depot or storage

Ways to Insensitive Munitions..

Modify the energetic material



Modify the composition

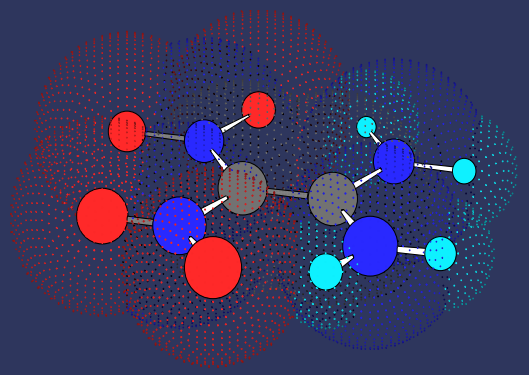
Modify the munition

FOI activities

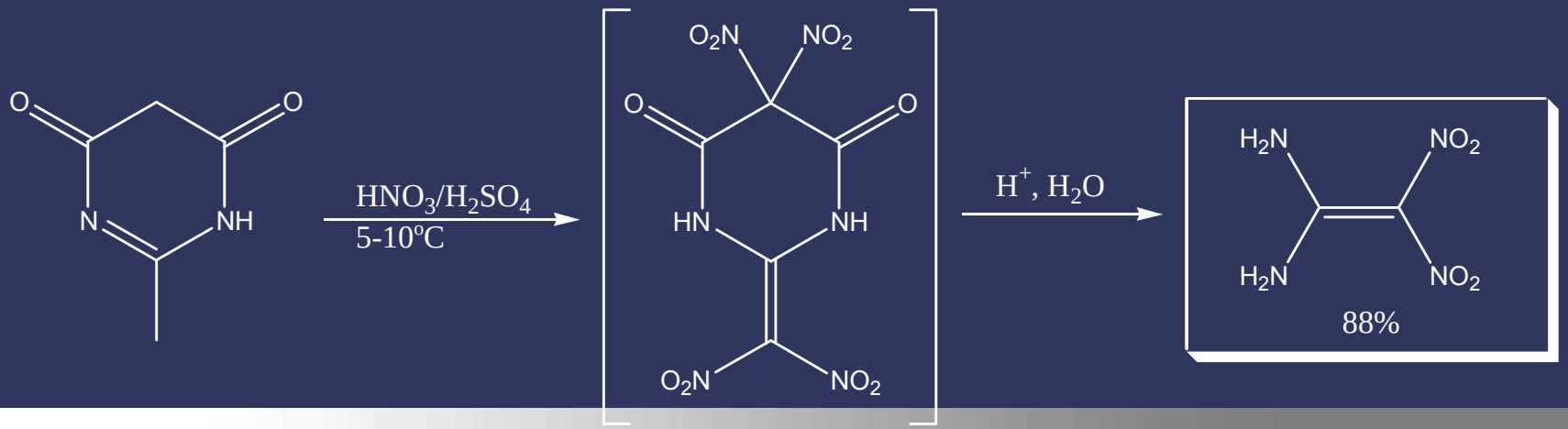
Modify the ammunition depot or storage

Modify the packaging

FOX-7



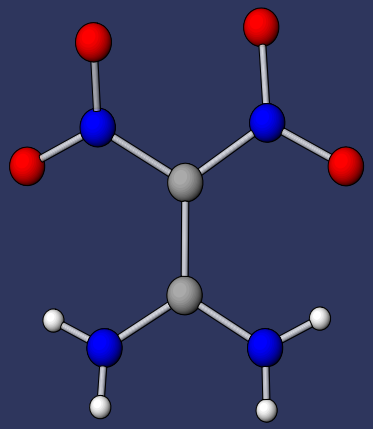
- 1,1-Diamino-2,2-dinitroethylene
- Developed at FOI in 1997--
- WO Patent No. 9903818
- Produced by EURENCO Bofors AB under licence by Swedish Government

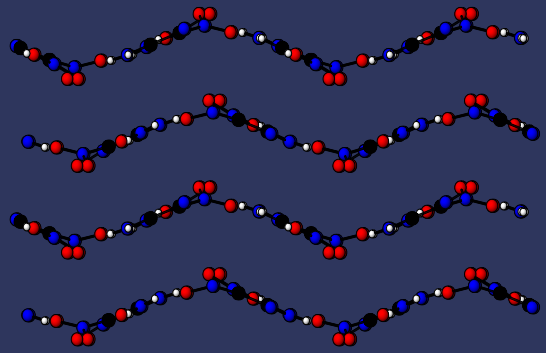


FOX-7 **Basics**

Low sensitivity explosives

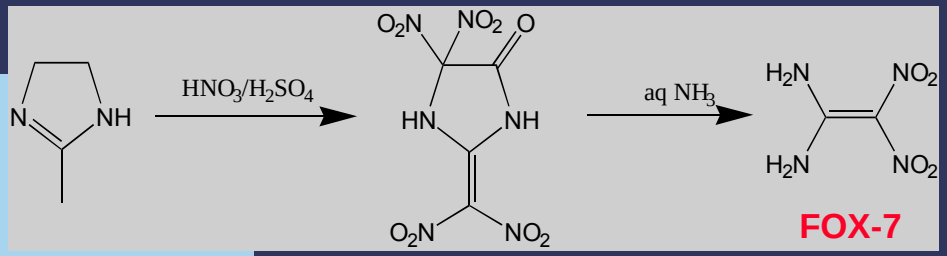
Simple synthesis





Crystal Structure

Density (crist): 1.885 g/cm^3
Heat of Formation: -32 kcal/mole
Sensitivity: drop weight 70 cm *(RDX 38 cm)*
friction > 350 N *(RDX 120 N)*
Explosion Temperature: 215 ^oC *(RDX 220 ^oC)*
Detonation Pressure (calc): 33.96 GPa *(RDX 34.63 GPa)*
Detonation Velocity (meas.): 8870 *m/s* *(RDX 8930 m/s)*



Synthesis

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Impact and Friction Sensitivity of FOX-7

Sample	Drop height (cm)	Friction (N)
FOX-7 (recryst., 250–355 µm)	79	
FOX-7 (recryst., < 70 µm)	63	>340
RDX	38	126

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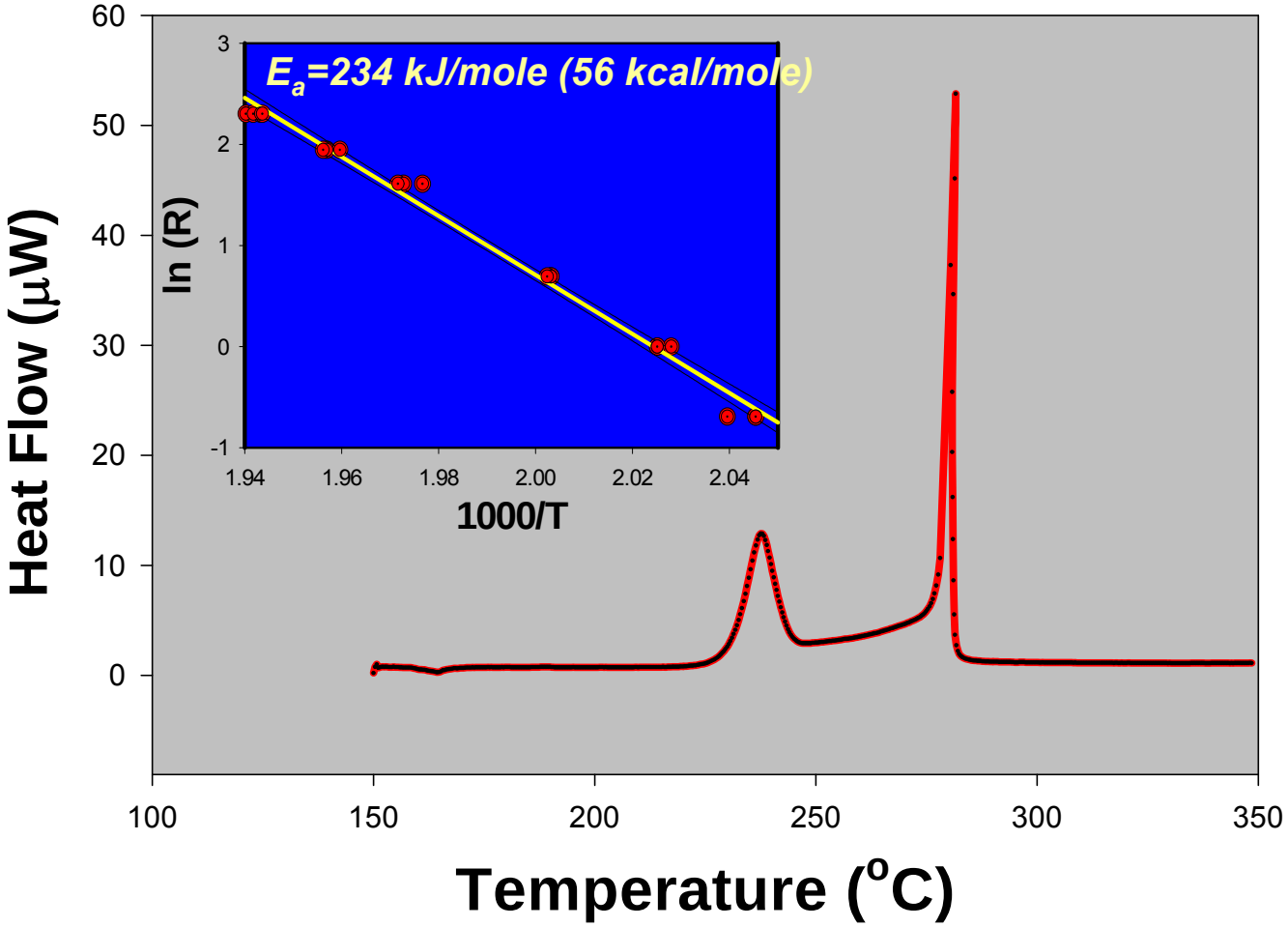
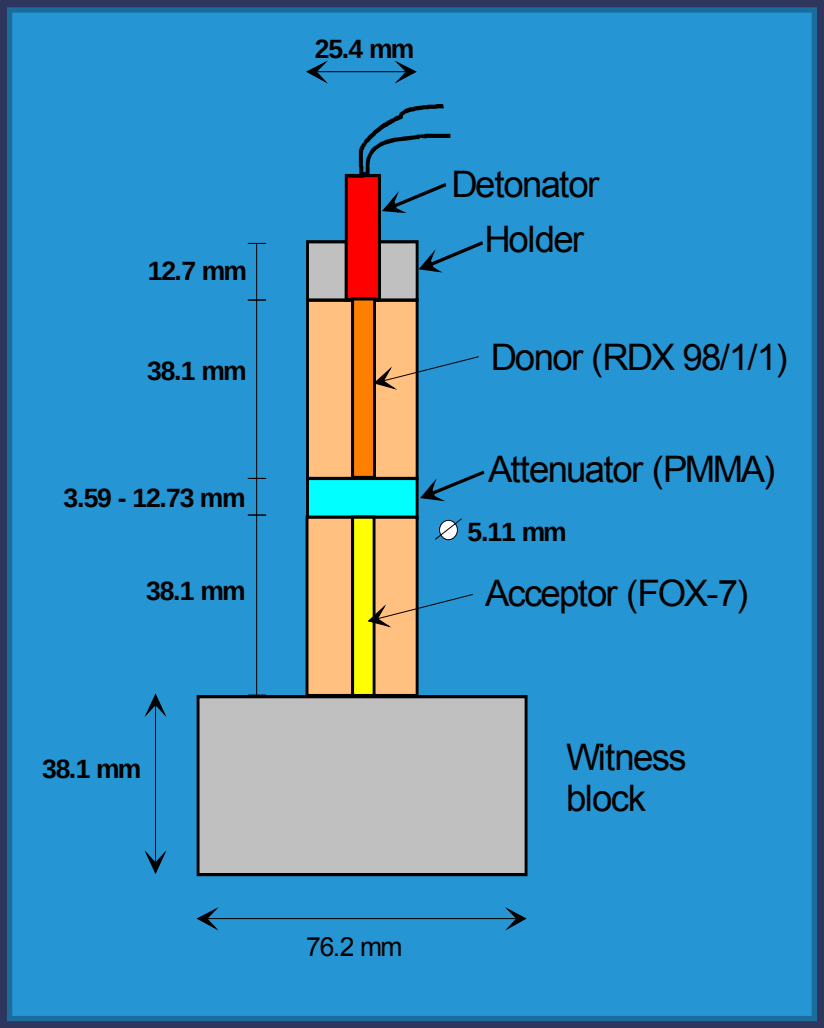
FOX-7: DSC


E_a=234 kJ/mole (56 kcal/mole)
ln (R)
1000/T
Heat Flow (μW)
Temperature (°C)

FOX-7: SSGT



EXPLOSIVE	DENSITY (g/cc)	Attenuator Thickness (mm)
Tetryl	1.65	8.36
HNS II	1.635	7.19
TNT	0.92*TMD	6.4
HMX	0.92*TMD	10.3
RDX	0.92*TMD	9.33
FOX-7	1.634	6.22

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FOX-7

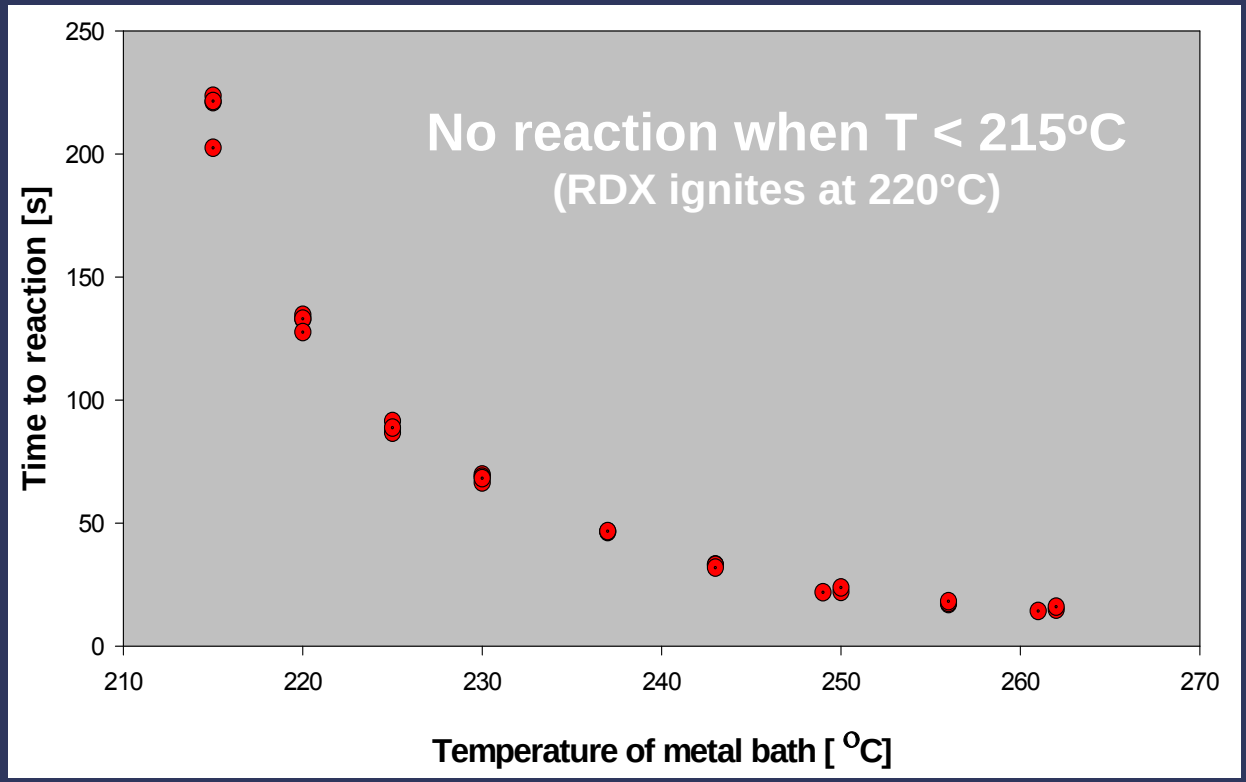
Small-scale gap test

Name	Density	Distance (50% probability point)
FOX-7	1.63 g/cm^3 (86% of TMD)	6.2 mm
TNT	1.53 g/cm^3 (92% of TMD)	6.4 mm
RDX	1.66 g/cm^3 (92% of TMD)	9.3 mm

Air gap test

Name	Density	Distance (50% probability point)
TNT	1.51 g/cm^3 (91% of TMD)	34 – 35 mm
FOX-7	1.72 g/cm^3 (91% of TMD)	35 – 37.5 mm
Composition B	1.59 g/cm^3 (91% of TMD)	60 – 62.5 mm

FOX-7: Ignition Temperature
(Wood's metal bath)



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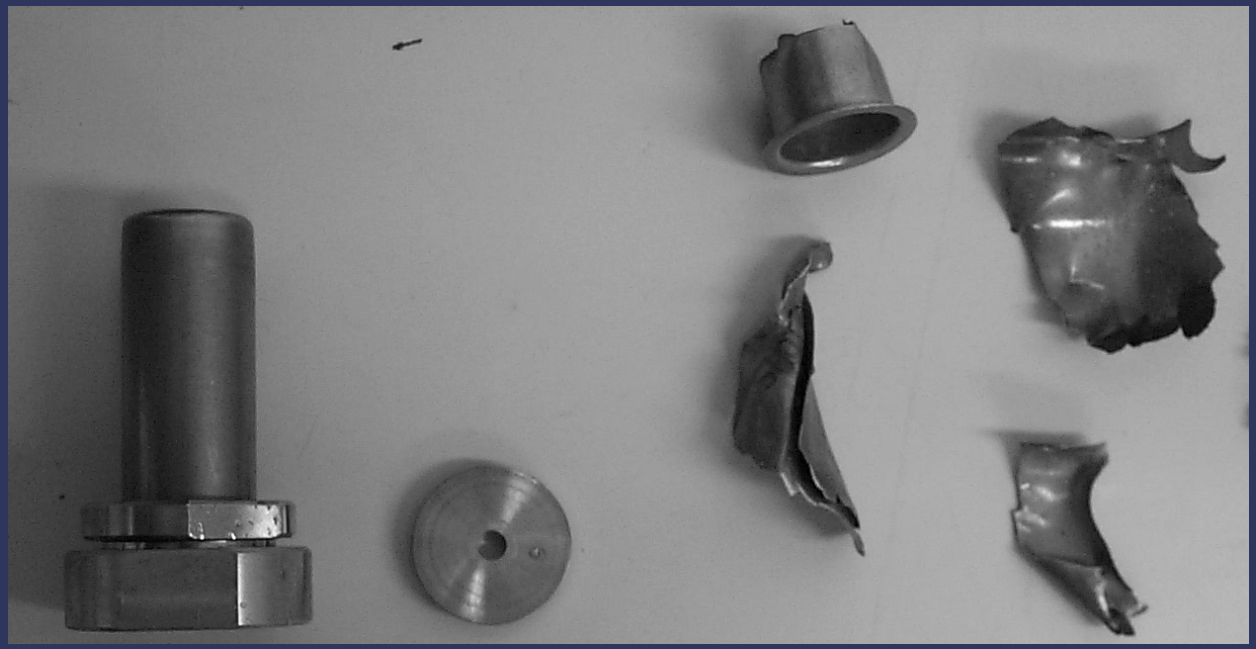
FOX-7: KOENEN TEST
(Steel sleeve test)



Type “F” reaction at nozzle plate diameter 6 mm
RDX explodes at nozzle plate diameter 8 mm

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FOX-7: Compatibility by HFC

$$C_{ab} = E_{ab} - \frac{E_a - E_b}{2}$$

Incompatible:

C>20 J/g/week

Slightly Incompatible:

10 J/g/week

<C<20J/g/week

Compatible:

C<10 J/g/week

Polymer	E_a (J/g/week)	C_{ab} (J/g/week)
CAB (BF900)	0.38	-0.38
Estane	0.27	-0.26
GAP (SNPE)	2.57	-0.44
HTPB (R-45 HT)	1.89	3.89
HTPB (Krasol LBH)	0.24	0.13
Viton	0.10	0.03
Isocyanate		
H_{12}MDI	0.70	0.41
Plasticizer		
Butyl-NENA	1.07	0.16
K-10	0.41	0.44

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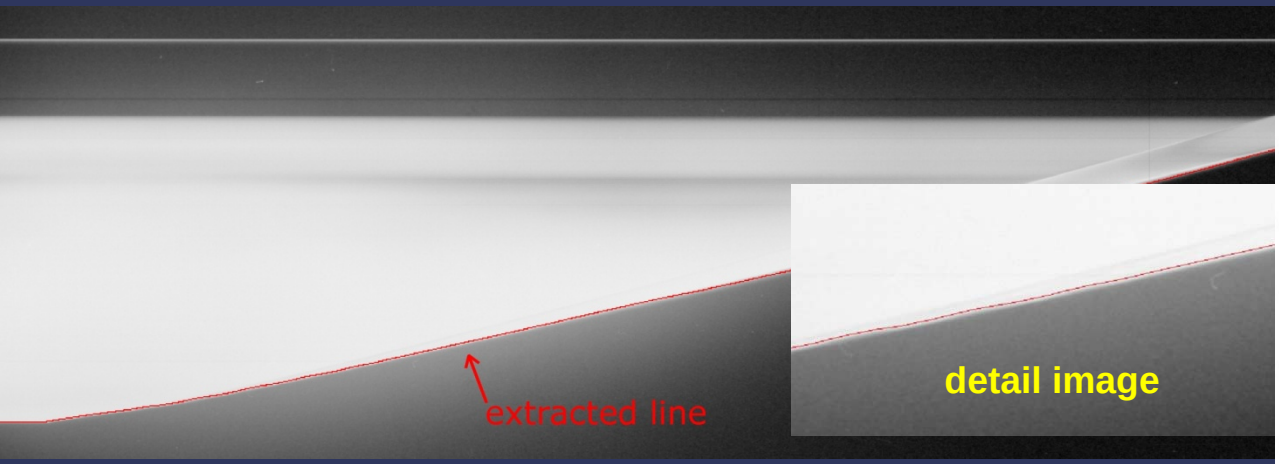
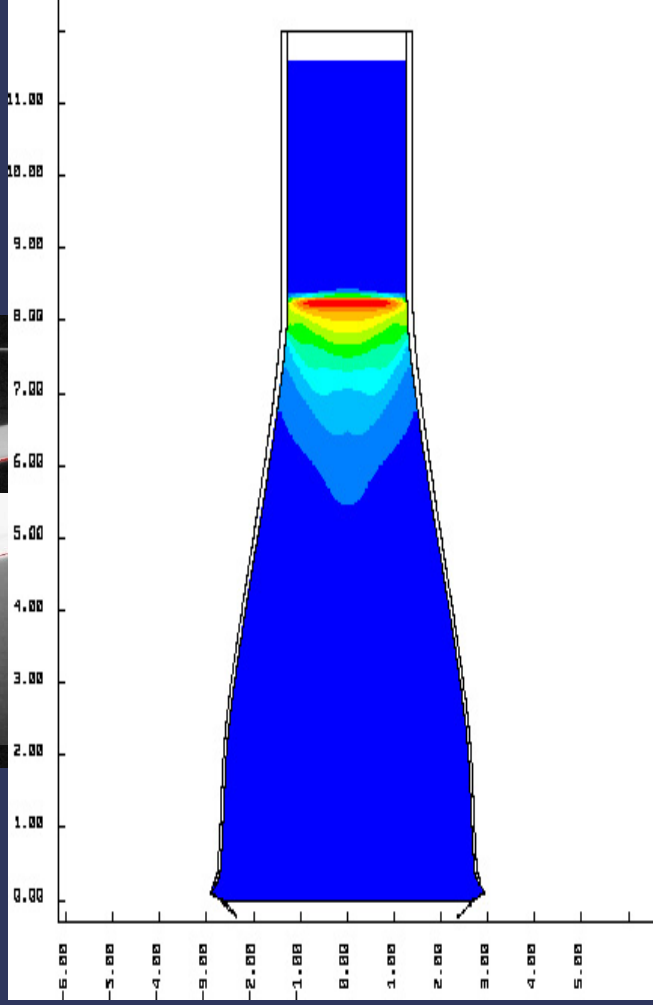
FOX-7 Cylinder tests



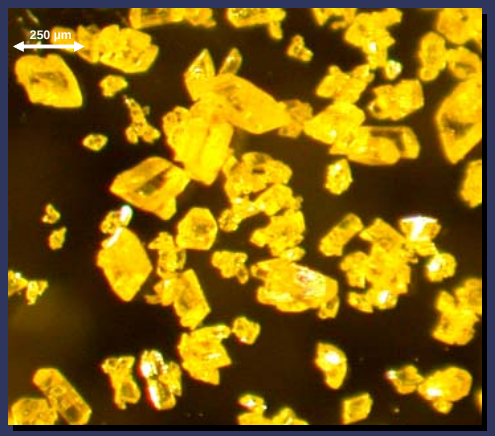


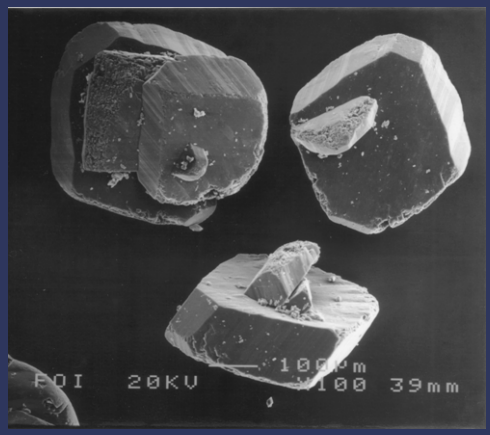
Pcj (Gpa)	E0 (kJ/cc)	A (Gpa)	B (Gpa)	R1	R2	w
27.9	8.663	998.6	8.78	4.93	1.12	0.40

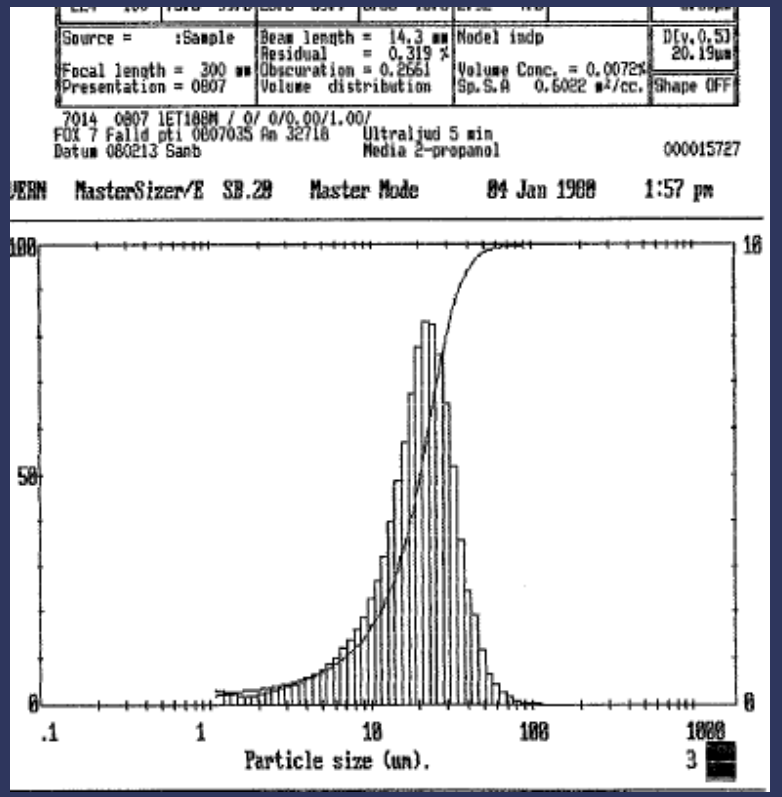
Data for FOX-7 + 1.5 w% wax, *δ = 1.756 g/cc* The detonation velocity was estimated to 8.335 ± 0.025 mm/*μs;* A Cheetah calculation, BKWC, gave a velocity of 8.266 mm/*μs, which is in good agreement* with the experimental value.

FOX-7

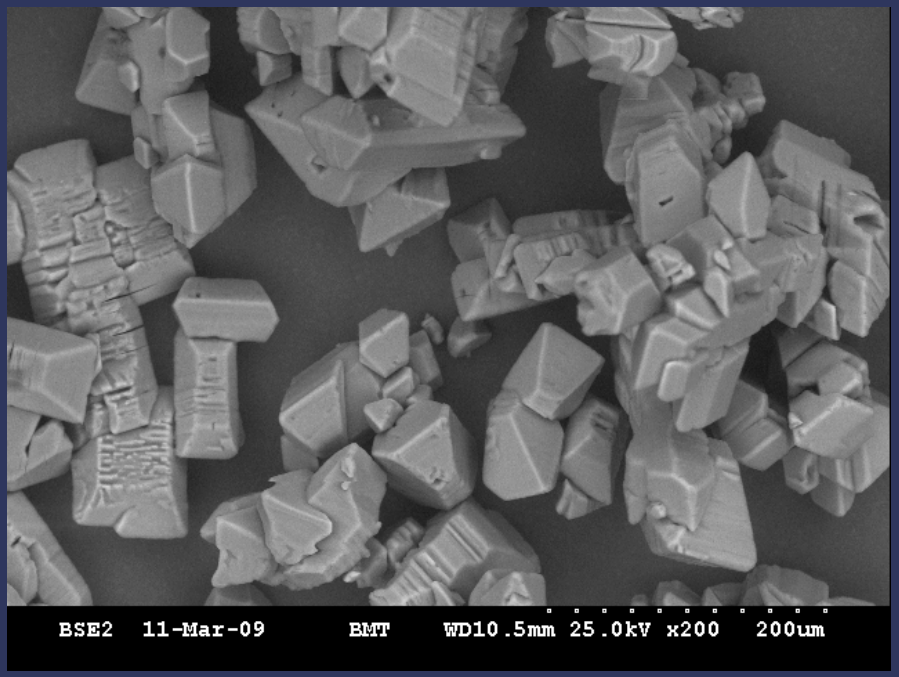
- Candidate for ingridients in
  - Boosters
  - Shape Charge warheads
  - High performance warheads
  - Rocket and gun propellants
- Particle size and particle quallity is very important for sensitivity and processing properties

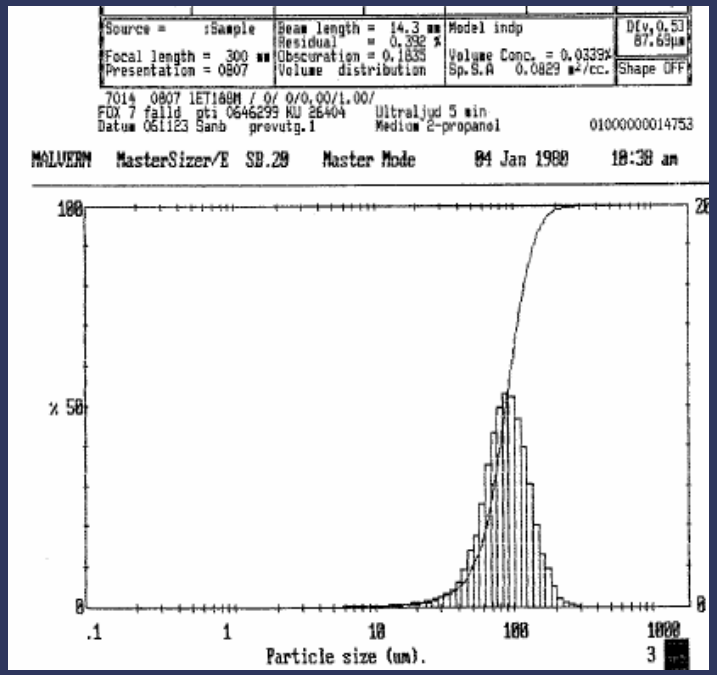




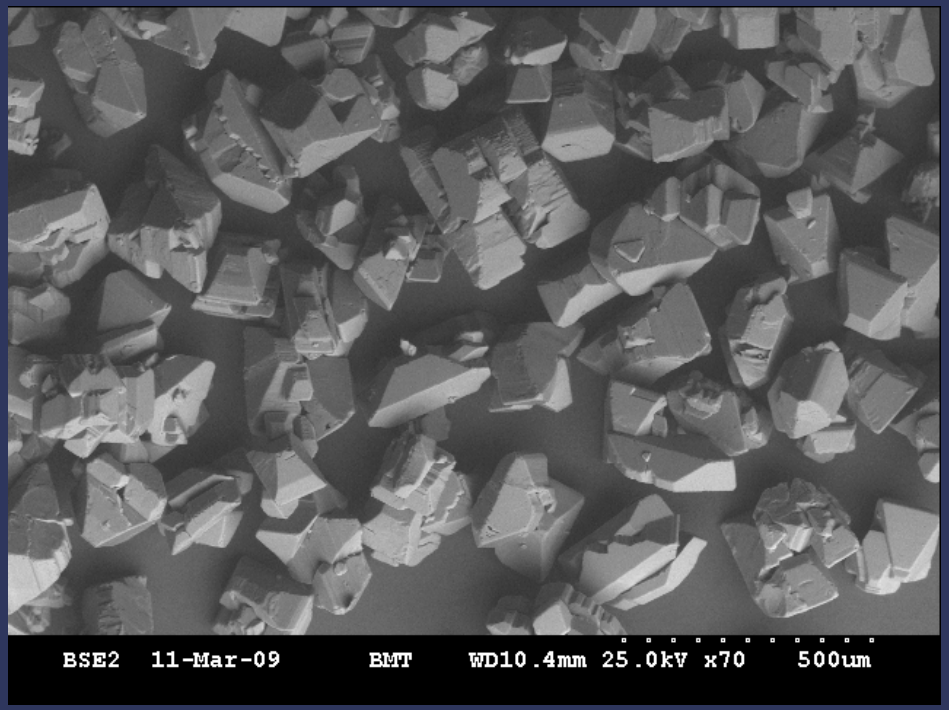


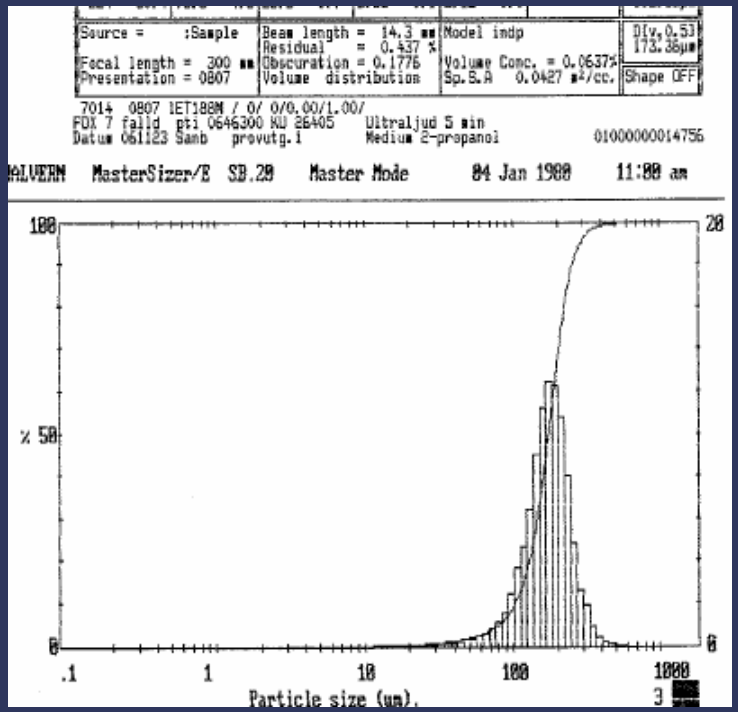
NSF 110 (20 – 40 µm) is the smallest particle size available which also gives a relatively low bulk density, < 0.6 g/cm^3 according to Hall measurements. Below, a SEM-photo with a1000 times magnification is shown together with a particle size distribution measured by Malvern is shown.





NSF 120 (50 – 100 µm) gives a bulk density of approximately 0.7 g/cm^3 according to Hall. The picture shows a 200 times magnification of the particles and a particle size distribution measured by Malvern.





NSF 130 (100 – 200 µm) gives a bulk density of approximately 0.85 g/cm^3. The SEM photo is a 70 times magnification and the particle size distribution is a Malvern measurement.

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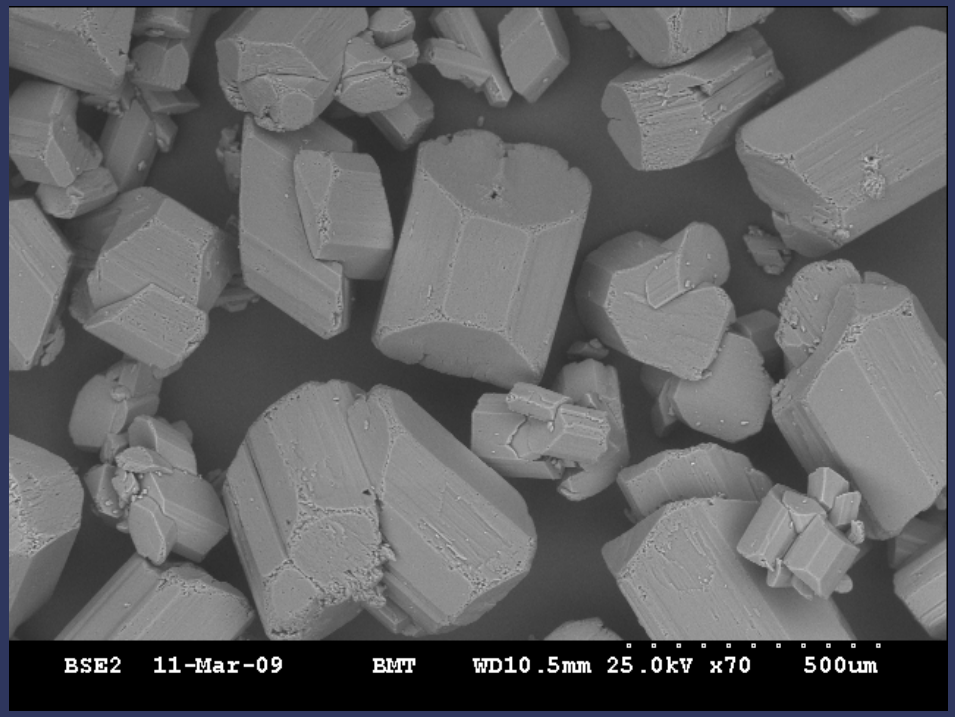
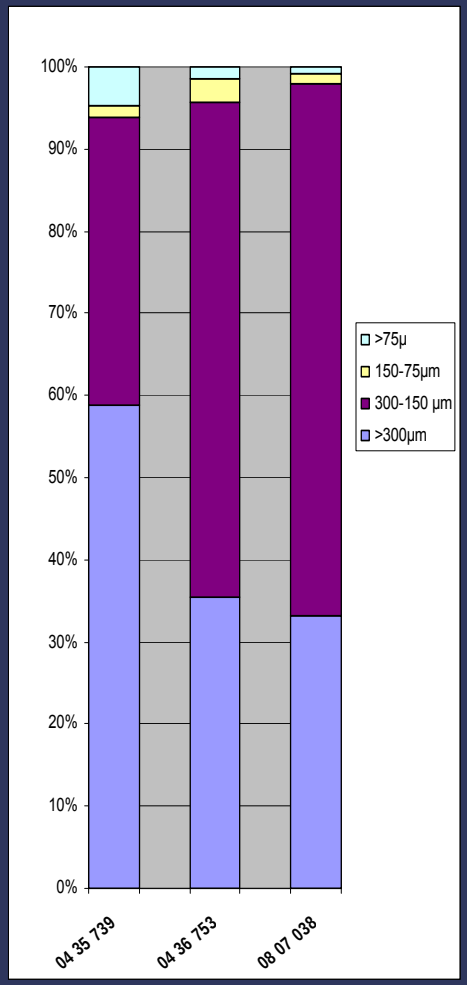
GROUPE SNPE





NSF 140 (250 – 350 µm) is the largest particle size available at present. This quality has a bulk density of approximately 0.95 according to Hall. The SEM photograph is 70 times magnification and sieving results for a couple of batches are shown a long side.

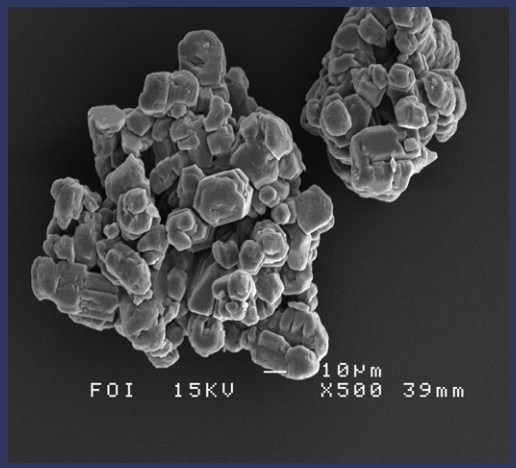
Scaling up of FOX-7

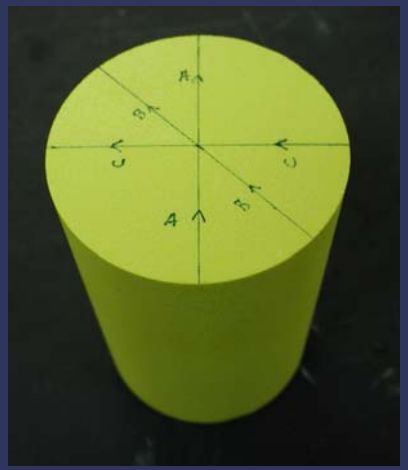
- Eurenco Bofors AB has produced nerly 1000 kg (7 kg batches, 1 to 3per day) of FOX-7 in its own pilot plant
- Molar yield 80 % for nitration step
- Very small particle size has caused problems to wash the filter cake. A separate washing step has been introduced to obtain pure product
- HPLC-purity is more than 99 % for washed product

Insensitive Formulations and Applications

Pressed Explosives

- Pressed FOX-7/wax (97.8/2.2 wt%)
- Investigated as an explosive for use in shape charge applications





FOI

A. Helte et al. *23rd Int Symp on Ballistics, Spain* (2006)
A. Helte et al. *FOI-R-1780-SE* (2005)

Pressed Explosives

- ✓ Jet straightness
- ✓ Jet velocity
- ✓ Fragmentation time
- FOX-7 > Comp B

- ✓ Penetration (ARMOX 300S)
- FOX-7 230 mm (2.9 cal)
- Comp B 265 mm (3.3 cal)

FOI

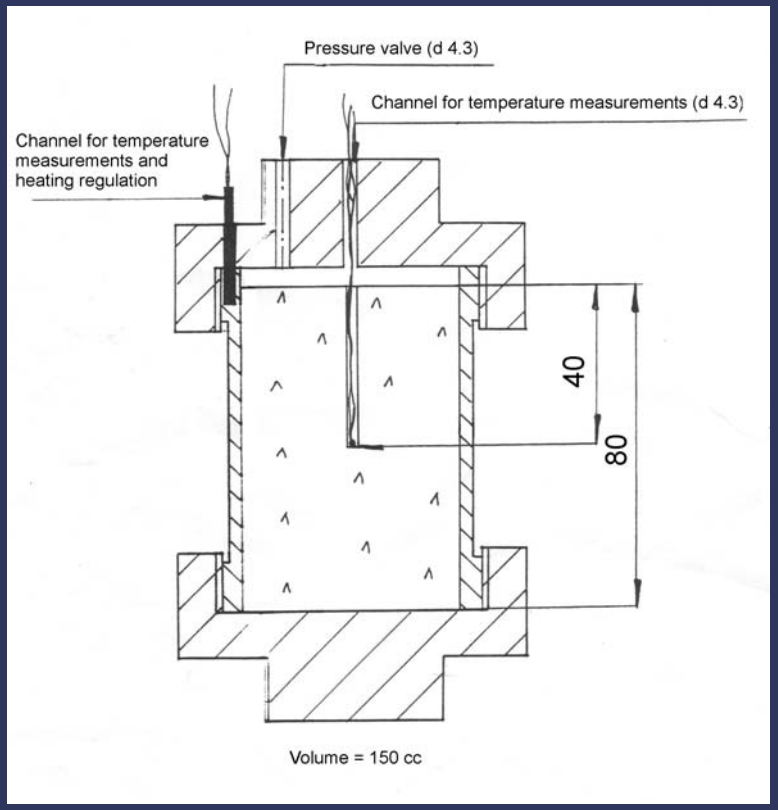
A. Helte et al. *23rd Int Symp on Ballistics, Spain* (2006)
A. Helte et al. FOI-R-1780-SE (2005)

FOF-2

FOX7 (255-350mm)	50 wt%
FOX7 (< 70mm)	20 wt%
PolyGlyN	21wt%
Butyl-NENA	5 wt%
H12MDI (Desmodur-W)	4 wt%
DBTDL	0.03 wt%

- Tg = -35°C
- Thermally stable at 65°C (14 days)

Small-scale slow cook-off



100-400°C
Heating rate: 3.3°C/hour

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Small-scale slow cook-off - Results

RDX/TNT 60/40

$T_{cook-off}$ 207°C (Type I reaction)

FOF-2

$T_{cook-off}$ 220°C (Type V reaction)

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A New Explosives Formulation - FOF-5

FOX-7 (238µm)	38.1 %
FOX-7 (32µm)	25.4 %
HMX (22 µm)	16.5 %
Energetic binder	20%
PolyGlyN	7.2 %
GAP	7.2 %
Butyl-NENA	3.6 %
H_{12}MDI (Desmodur-W)	2.0 %
DBTDL	

Slow Heating (Slow Cook-Off)

First test (inert fuze) ⇨ Type V response (fire)

Second test (HNS II-based fuze) ⇨ Type IV response (deflagration)

Composition B *⇨ Type I response (detonation)*

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Fast Heating/Fuel Fire (Fast Cook-Off)

Blast pressure (max 160 Pa) and no significant heat radiation

⇨ Type IV response (fire)

Debris (fuze) recovered at > 24 meters from test stand

⇨ Type IV response (deflagration)

Composition B ⇨ Type I response (detonation)

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Bullet Impact

Debris (fuze) recovered less than 15 meters from test stand

⇨ Type V response (fire)

Composition B ⇨ Type I response (detonation)

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A Potential IM Explosive?

- FOF-5 is a cast-cured explosive based on FOX-7 and HMX with the same performance (calc.) as Composition B (RDX/TNT 60/40).
- Initial IM testing of ammunition containing FOF-5 - results:

	Slow Cook-Off	Fast Cook-Off	Bullet Impact
FOF-5 (Batch No. 1)	Fire (1st test) Fire/Defl (2nd test)	Deflagration	Fire
Composition B	Detonation	Detonation	Detonation

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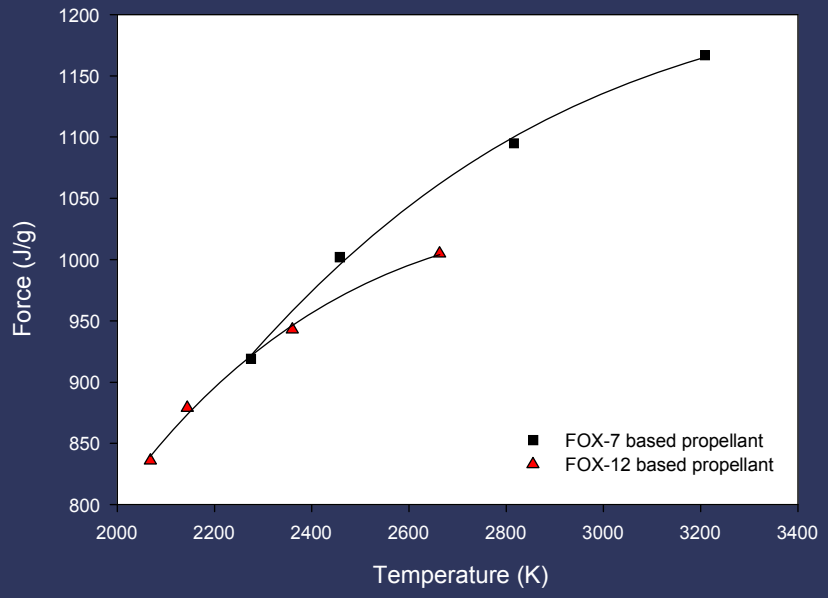
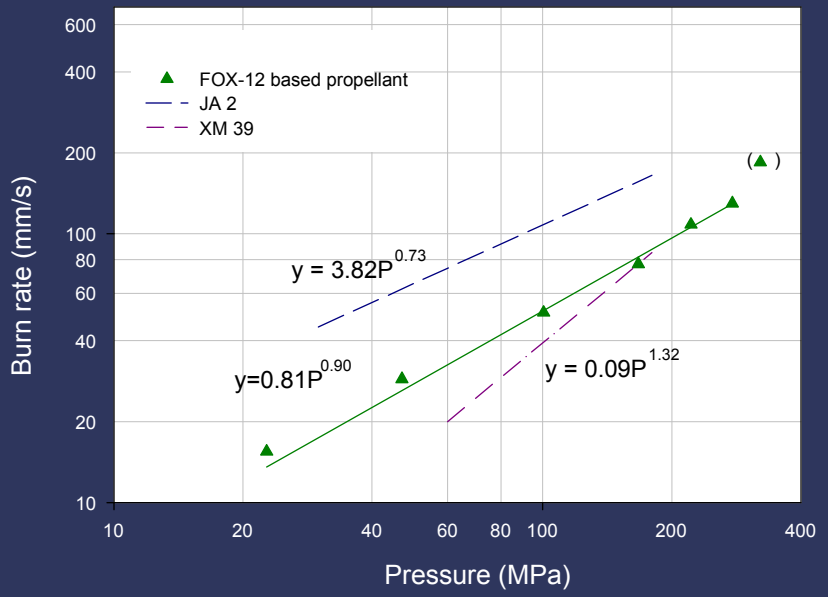
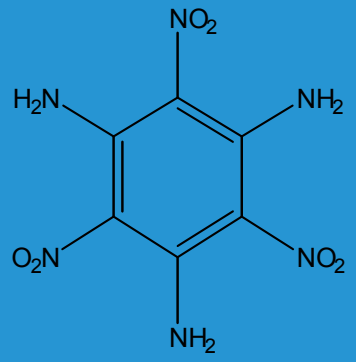
Composite propellants

- FOX-12/RDX and FOX-7/HMX based compositions
- Energetic binder

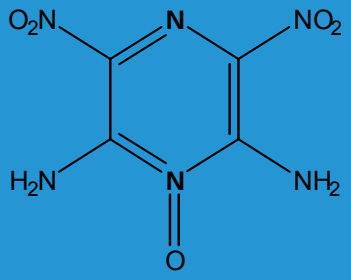




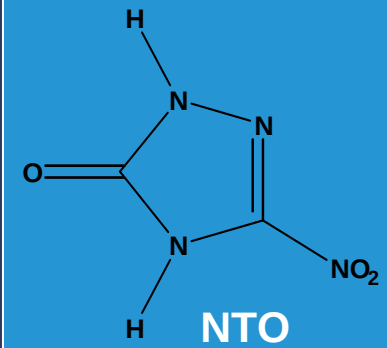
Low Sensitivity Explosives HE



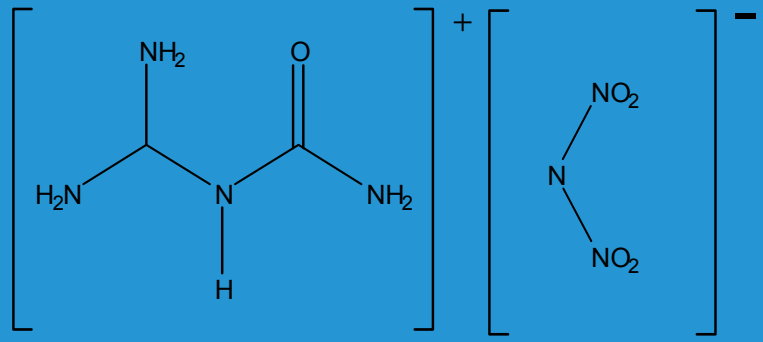
TATB



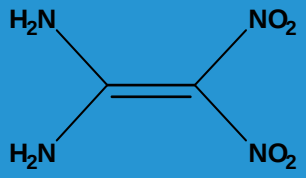
LLM-105



NTO



FOX-12



FOX-7

Conclusions

- FOX-7 is very insensitive.
- FOX-7 makes it possible to produces low sensitivity charges with high performance, as exemplified by the shaped charge and 40mm small caliber examples.
- The availability of more and better characterized particle sizes will enable an easier development of new low sensitivity, high performance applications.
- FOX-7 is available in large quantities