AVT-340 Research Workshop on Preparation and Characterization of Energetic Materials

Small-scale tests applied to the characterization of explosives

Multi-Channel Optical Analyzer MCOA-UC

R. Mendes, J. Góis and J. Baranda
University of Coimbra, ADAI
PORTUGAL

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Experimental tests instrumented with the MCOA-UC

- **DRZ Performance Test**
  - Spatially-resolved simultaneous measurements of reaction localizations in detonation front, local speed of detonation front, detonation front curvature and 3D-shock field at interface with optical monitor.

- **Shock sensitivity tests**
  - Failure Cone Test
  - Wedge Test
  - Kinetic Rate/Reaction Radiance
  - Single Crystal Shock Reactivity Tests (Crystal-in-binder)

- **Other tests**
  - Corner turning test
  - Collision of detonation wave Test

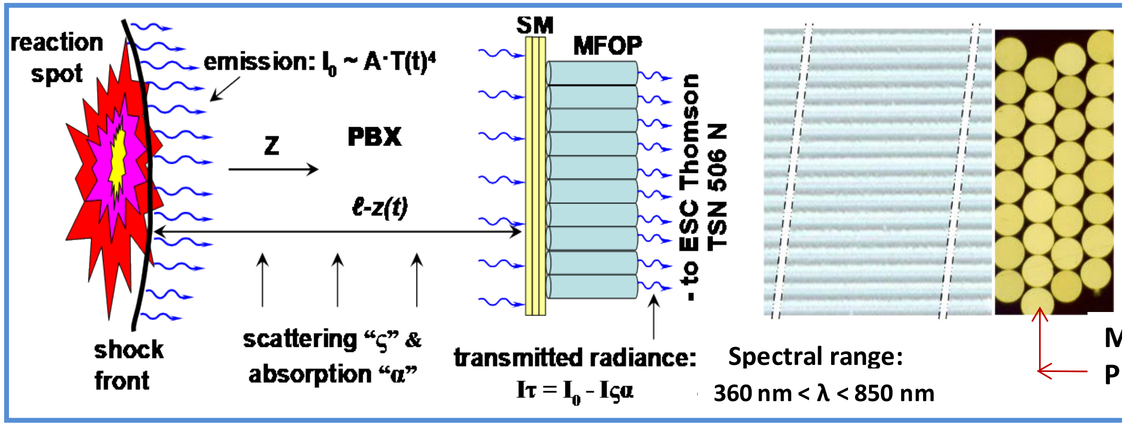
Experimental tests instrumented with the MCOA-UC

- Very small amount of test material is required for tailoring PBXs on shock sensitivity and DRZ performance, less than 10g;

- Experimental results obtained with MCOA-UC allows to charcaterize the shock and detonation wave mechanisms at meso-scale level;

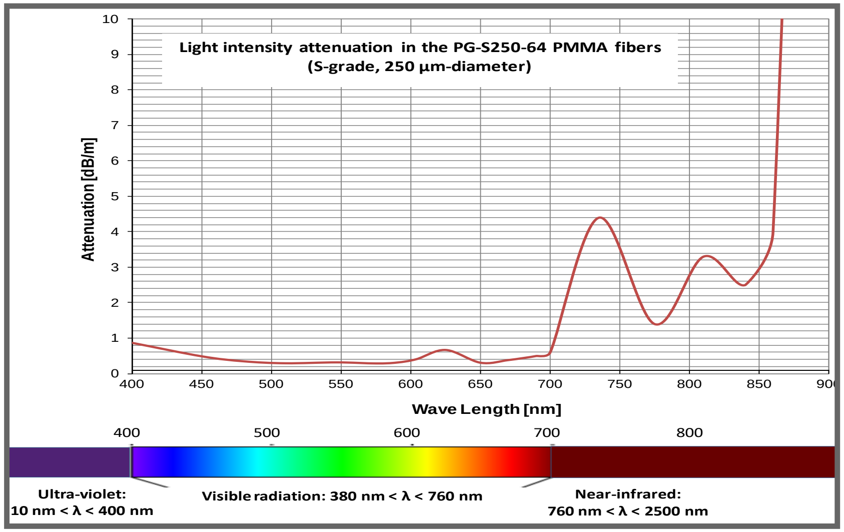
- These techniques have particular interest in the study of crystalline explosives: due to the characteristic small-scale heterogeneity and anisotropy of polymer bonded explosives (PBXs), the reaction dynamics exhibit inhomogeneities and local detonation intensity perturbations;

MCOA - UC

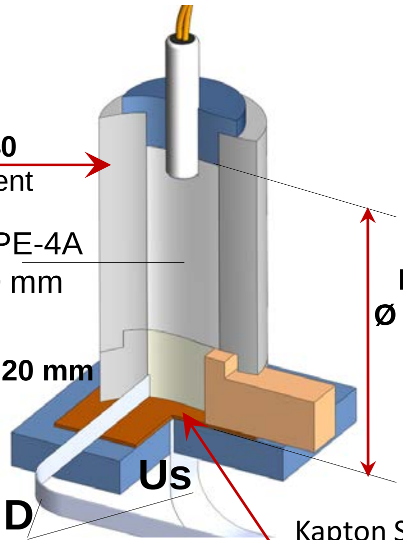


Multi-mode optical fiber array

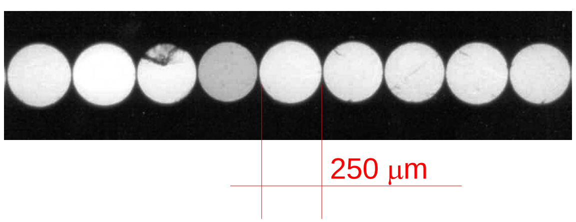
- ***Multi-Fiber Optical Probe* (MFOP-96)**
  - Multi-Mode PMMA Fiber Optic Array
  - Spatial Resolution: 250µm
- **High-Speed Electronic Streak Camera**
  - Model: *Thomson TSN 506 N*
  - Temporal Resolution: ~1ns



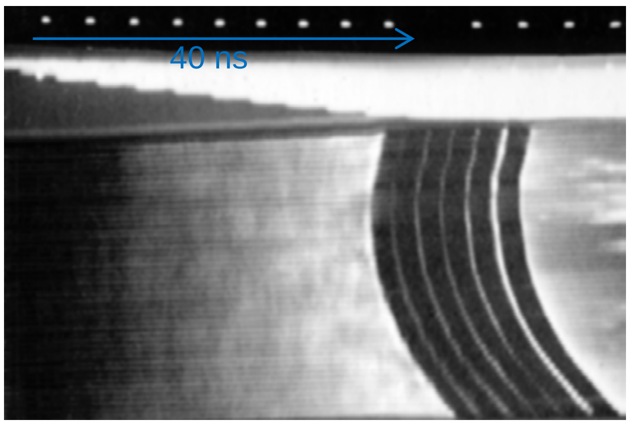
Long charge test - I



Multi-Fiber Optical Probes
→ to ESC Thomson TSN 506 N



RDX 93.0 / 7.0 wt. HTPB

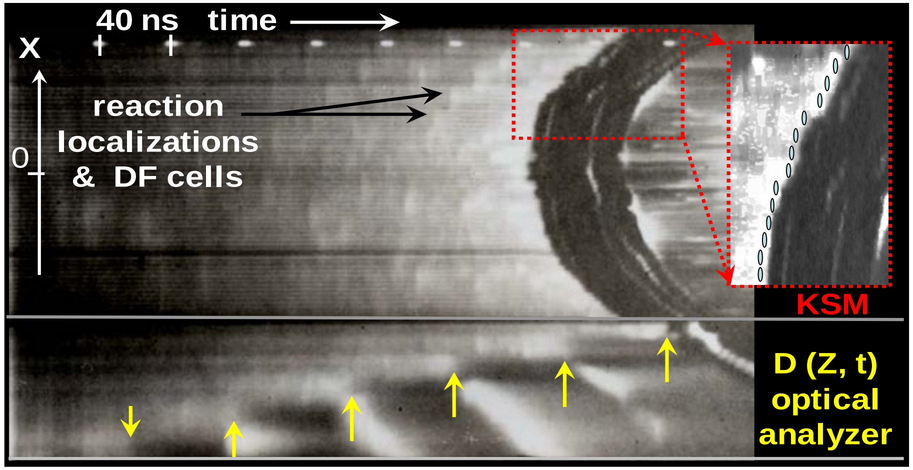


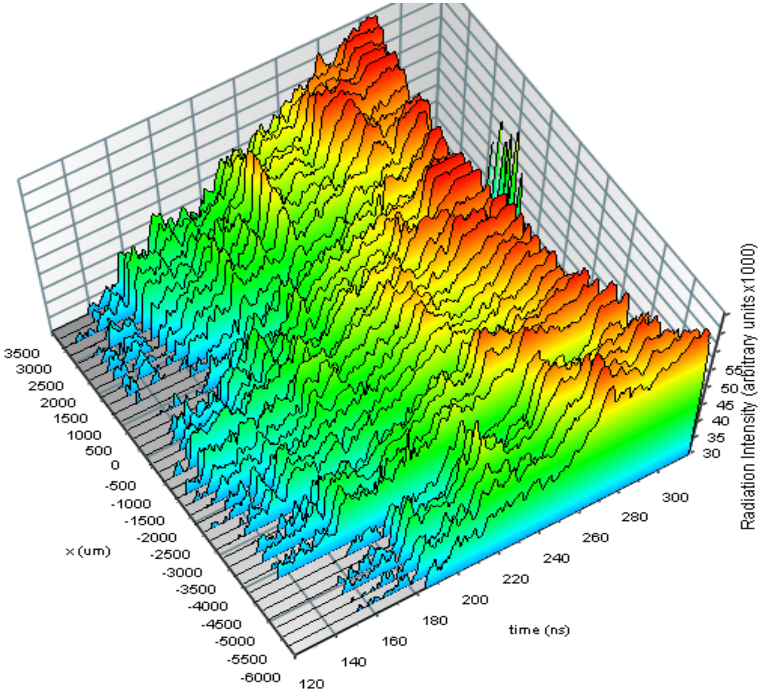
Kapton Stacked Monitor

Shock Hugoniot of Kapton:

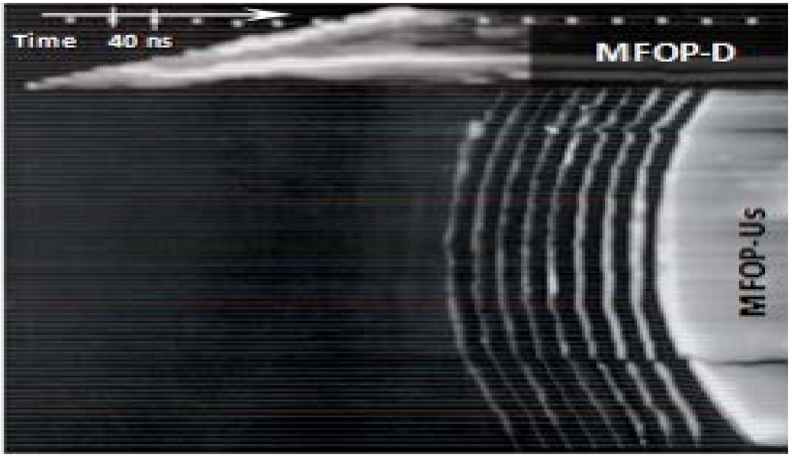
$P(Us)_{Kapton} \cong 3.7 \times (\tanh(4 \times (Us\ 6.24)+1)+0.5 \times (\tanh(50 \times Us-125)+1) \times (1.009 \times Us^2-3.118 \times Us+1.547)$

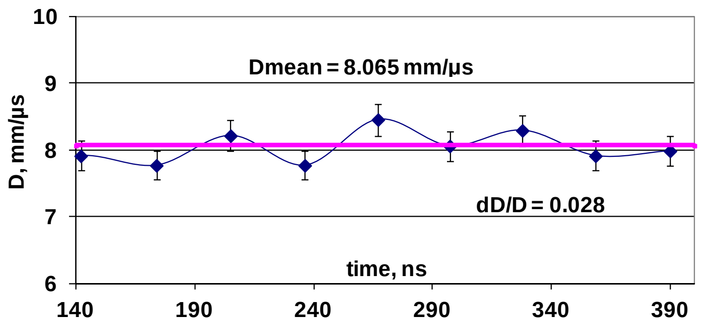
Long charge test - I

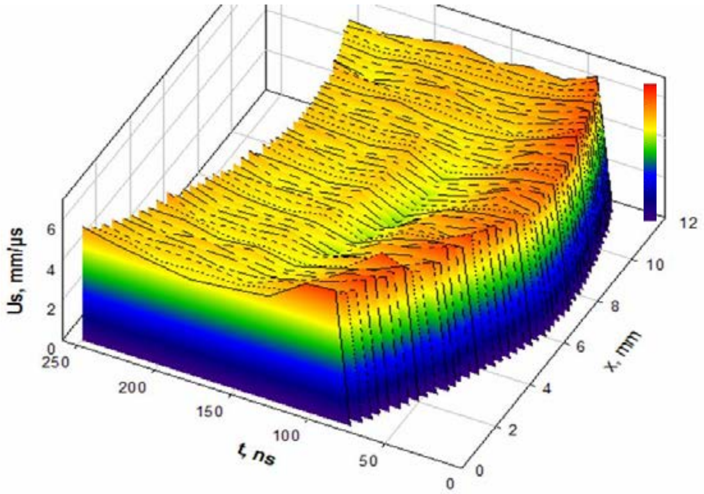


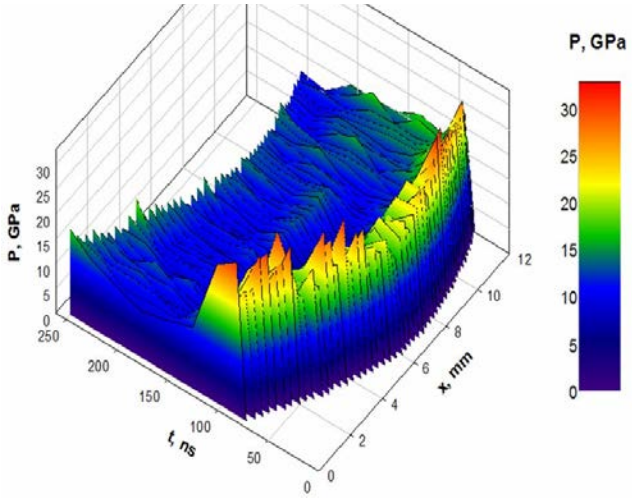


Long charge test - I





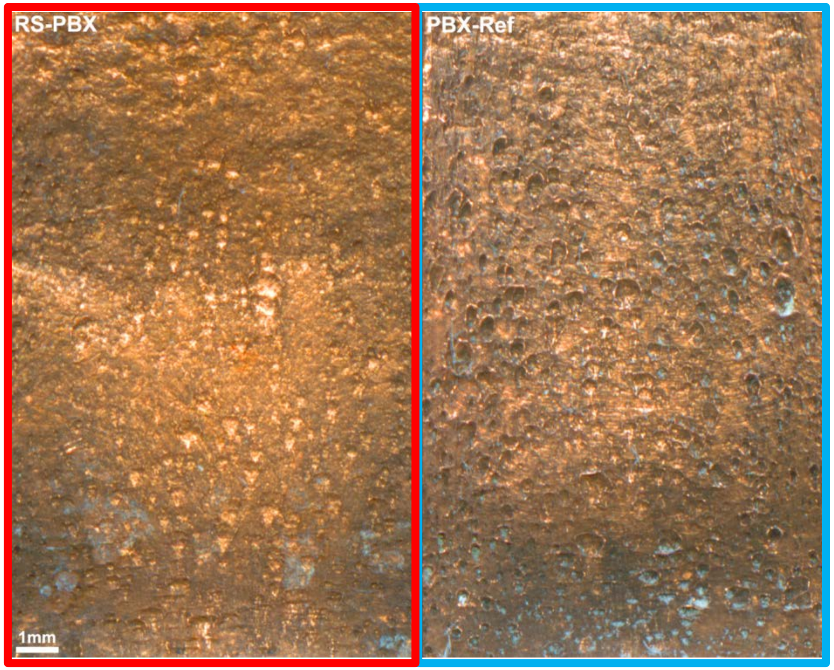




Long charge test - I

RS-PBX:
RC-HMX/UF HMX/HTPB
68/17/15 wt. %

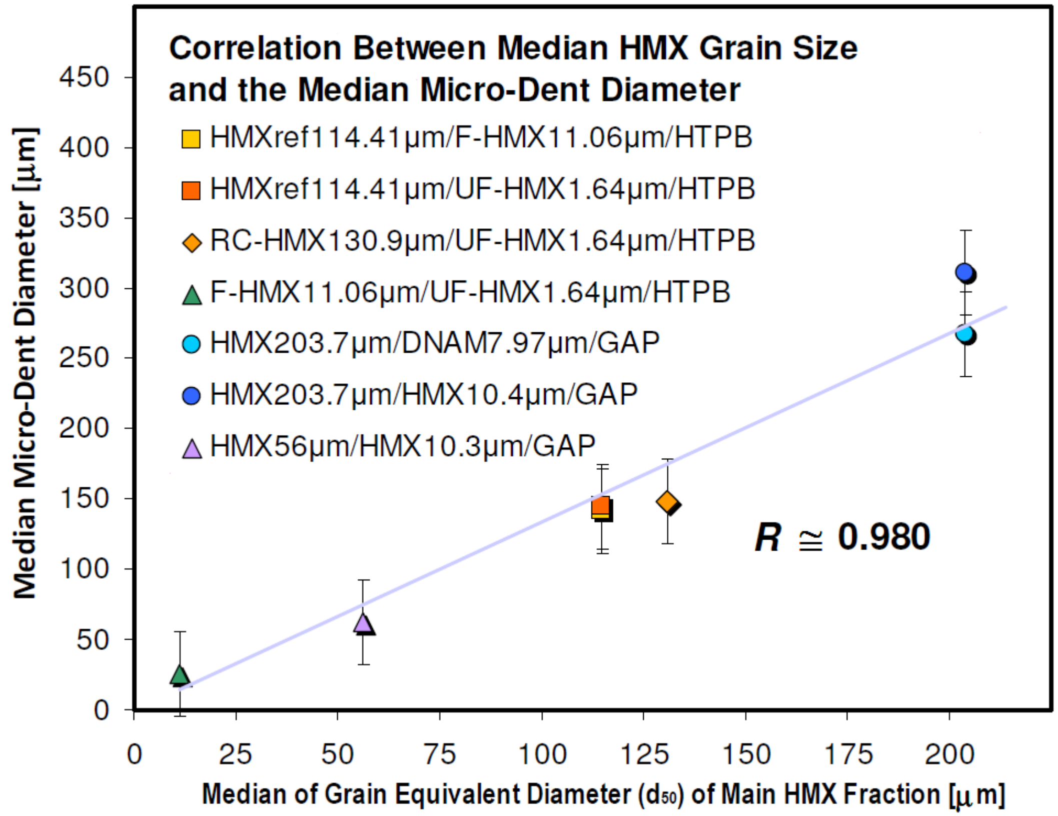
Reference PBX:
HMX $_{Ref}$/ HMX $_{Fine}$ /HTPB
68/17/15 wt. %



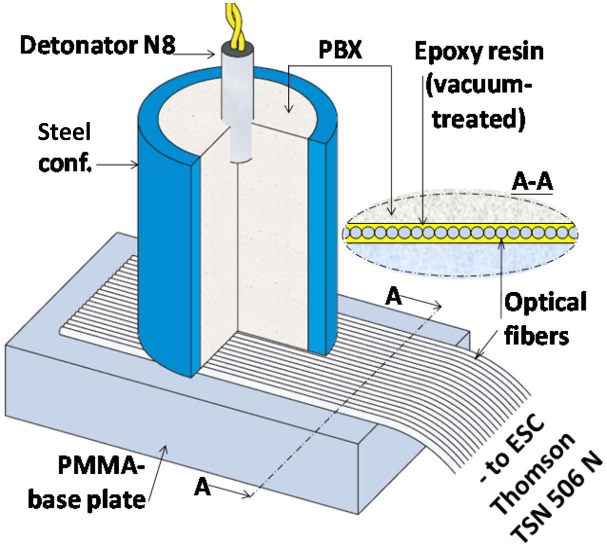
- Micro-craters are much more easily identifiable on the PBX-Ref plate than on the RS-PBX.
- On PBX-Ref, craters are clearly "deeper“: lighting conditions are identical in both micro-photos and present an elevated "rim".
- In case of the PBX-Ref, the number of craters is also greater and they occupy a larger portion of the sample surface than in the RS-PBX.
- The DRZ-induced perturbations are smaller in case of RS-PBX than in PBX Ref

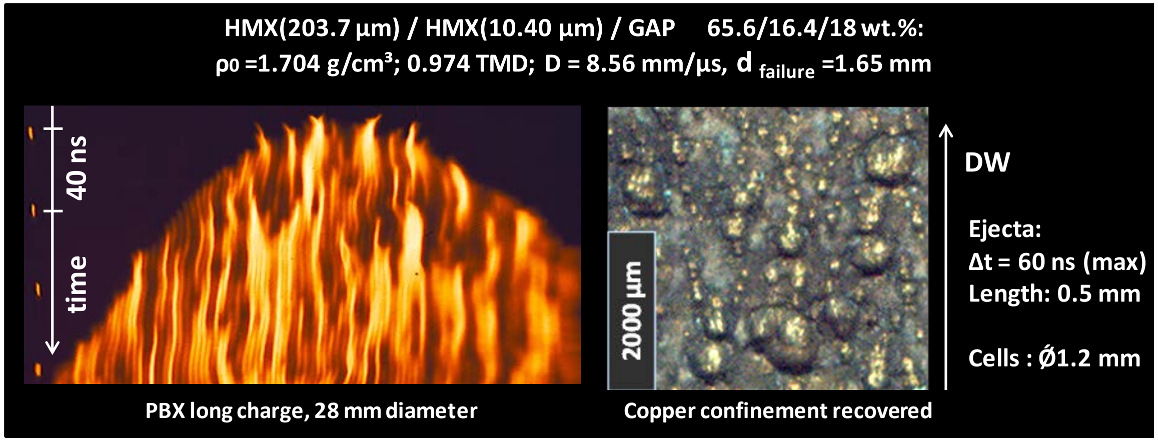
Long charge test

- **Witness Plate (Copper Insert) Surface Analysis**



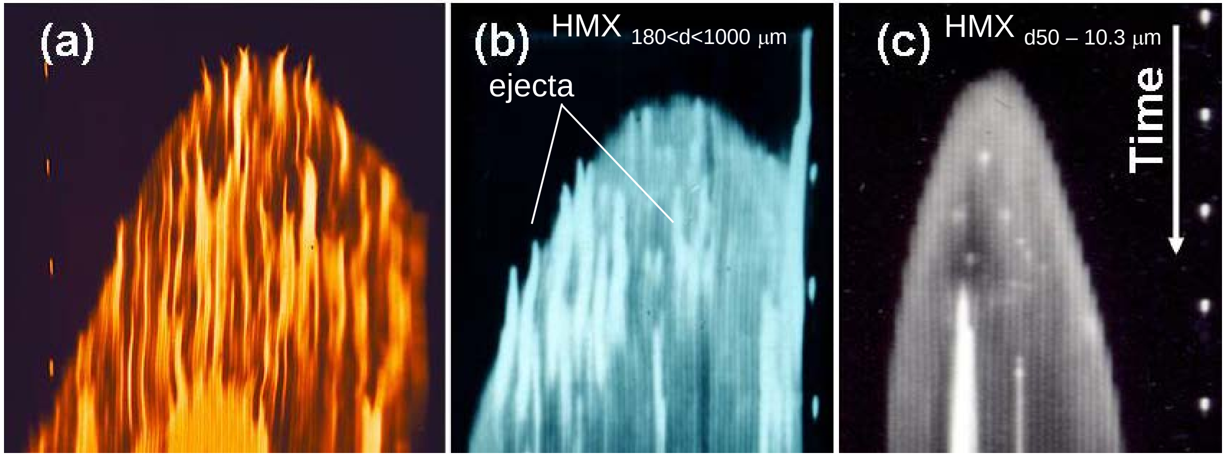
Long charge test -II





- Spatially-resolved registration of the DRZ-localizations was performed with application of 96-channel optical analyzer MCOA-UC.
- Bright spots are corresponding to high-Temperature localizations;
- Reaction localizations produce significant perturbations in the boundary layer of copper-confinement & PBX-driven liner (recovered copper-confinement is shown in the right image)

Long charge test - II



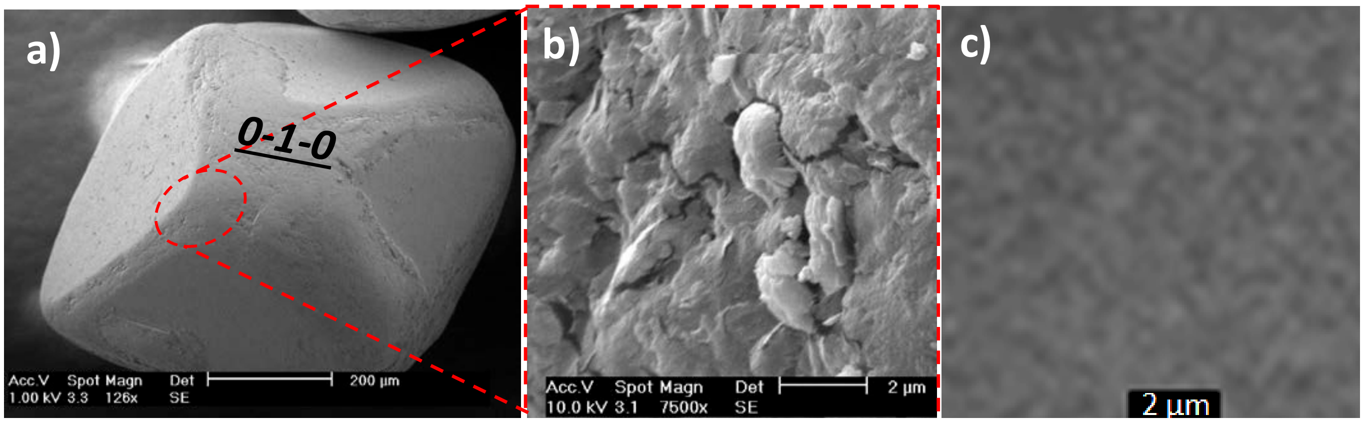
PBX_{st} (a) HMX_C/Water (b) HMX_F/Water (c). 40ns

- In case of porous PBXs, when ρ0 ≥ 0.96 TMD, the gaseous micro-voids (porosity) contribute to the reaction localizations in the DRZ via the radiation of shock-compressed gas, whereas Jetting from micro-voids plays a minor role in general ejecta pattern.

- In case of polycrystalline explosive materials and PBXs, reaction localizations in the DRZ and ejecta are caused by the kinetic non-equilibrium between the coarse particles and “dirty binder”.

Single crystal reaction test

- **Defect structure of surface layer in β-HMX crystals from fractions 595 µm < d < 707 µm.**

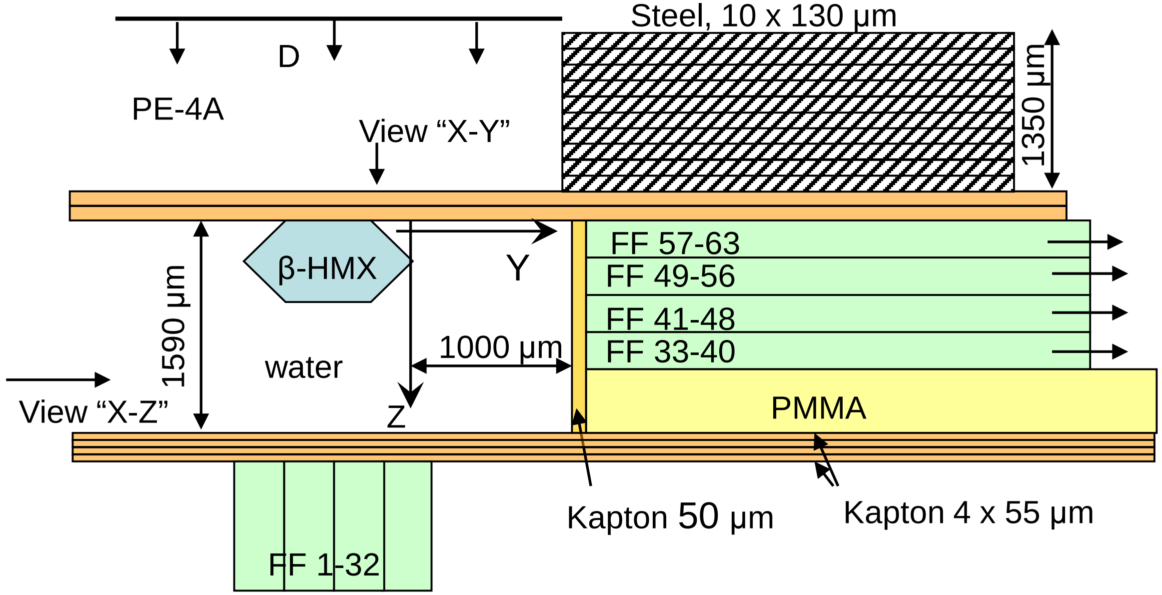


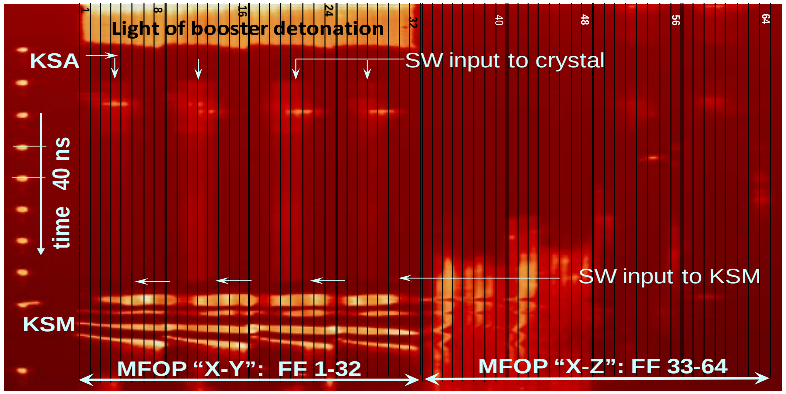
a) β-HMX crystal from fraction 595 µm < d < 707 µm: d_{mean} = 652 µm; $\rho_0 = 1.896 \pm 0.019$ g/cm^3; $\upsilon = 2{,}8$ [vol. %]

b) Surface structure in vertex zone: defects, incrustations, fissures,…

c) Central core: highly homogeneous structure; $\upsilon \approx 0$

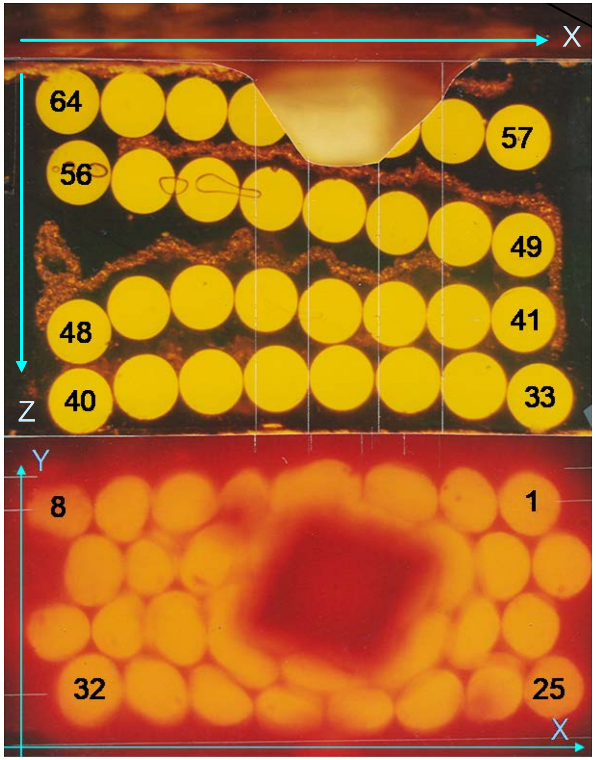
Single crystal reaction test



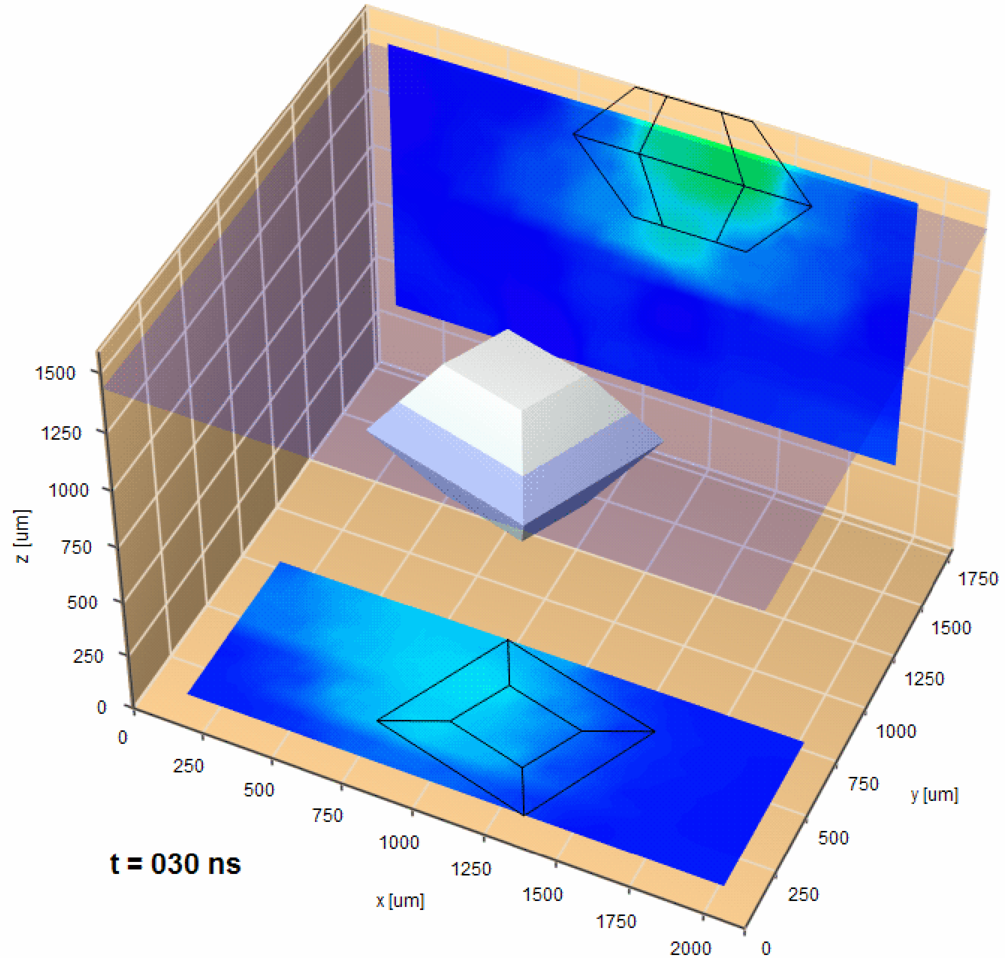


Coarse HMX particle

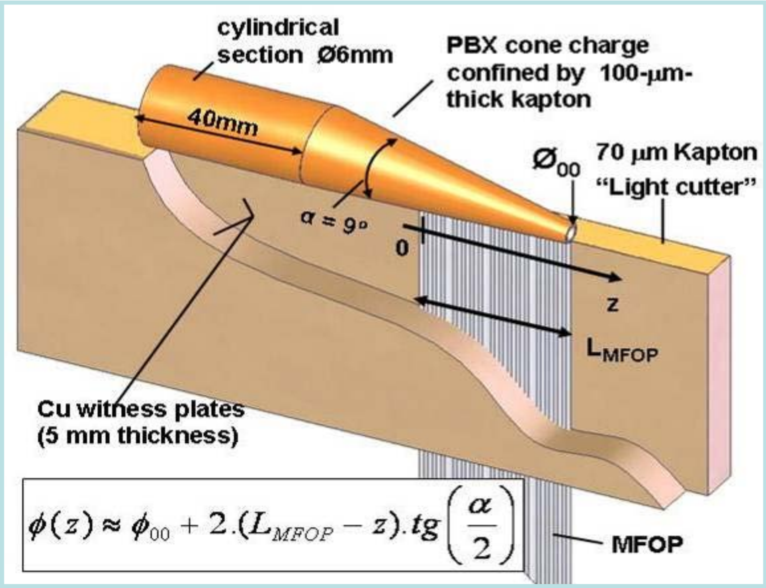
Two-Plane Observation



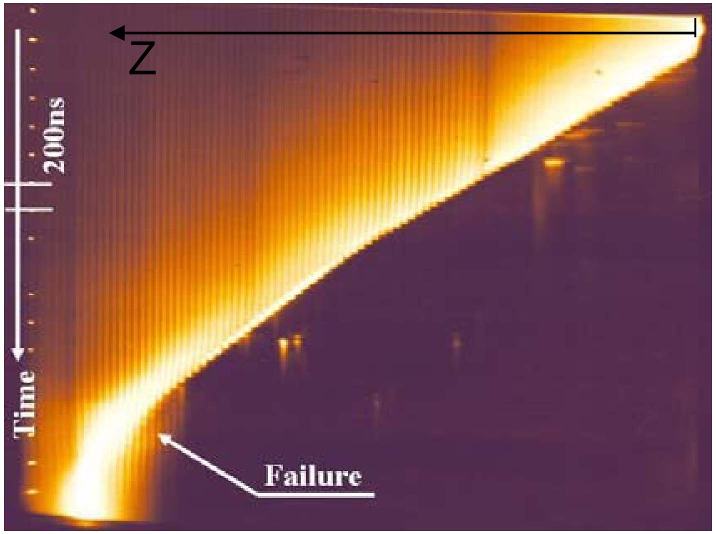
Single crystal reaction test



Failure Cone Test



Detonation Failure Diameter is a measure of detonability of crystalline HE [Dremin, 1997]

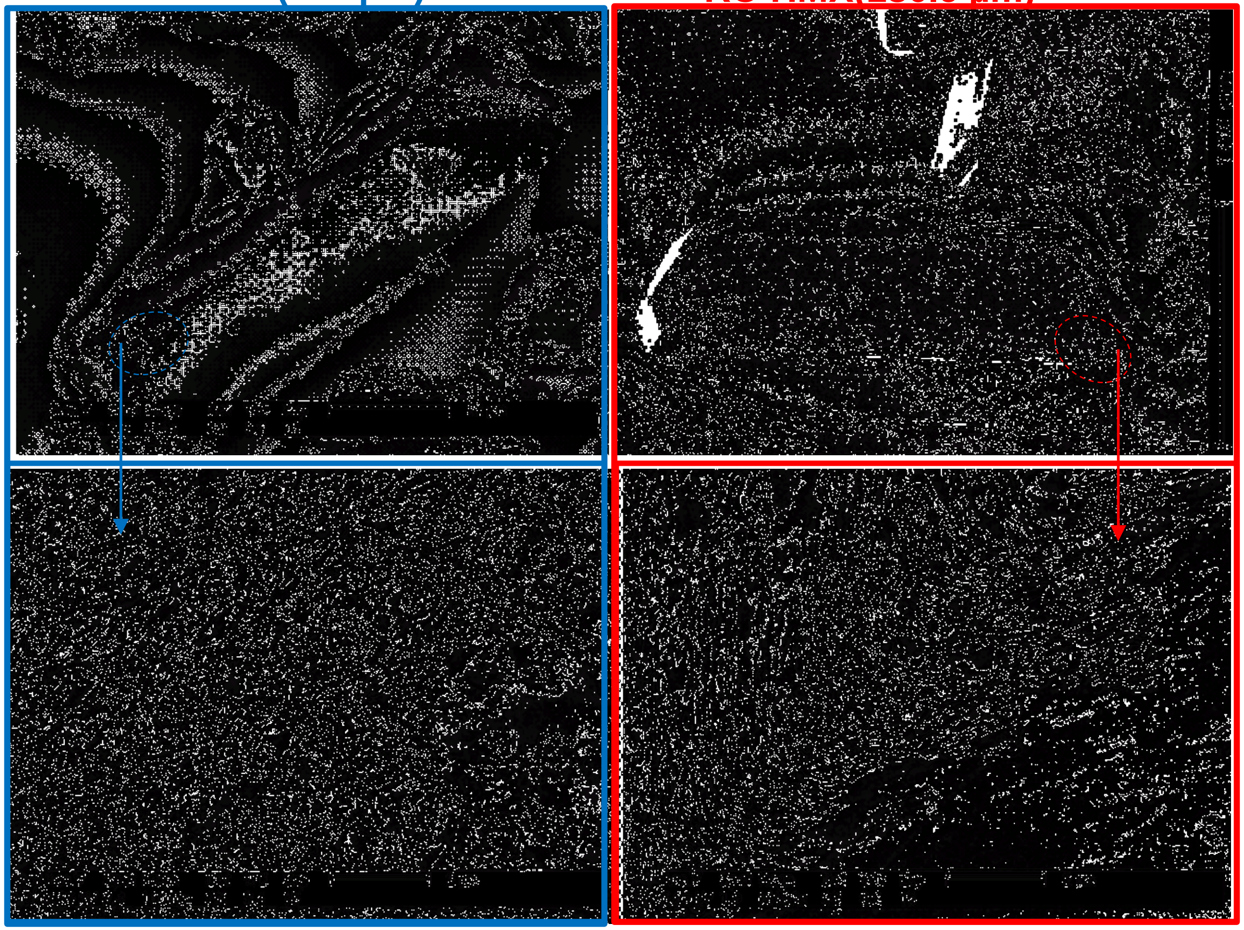


HMX particles

"Ref. HMX(114μm)"
Ref. HMX Class-1 military grade (Dyno Nobel)
Mono-modal (PSD):
d_{50} =114,408 μm
ρ_0 = 1.881±0.006 g/cm³

"RC-HMX(130.9μm)"
Fraunhofer ICT
re-crystallization
Mono-modal PSD:
d_{50} =130,925 μm
ρ_0 = 1.892±0.006 g/cm³

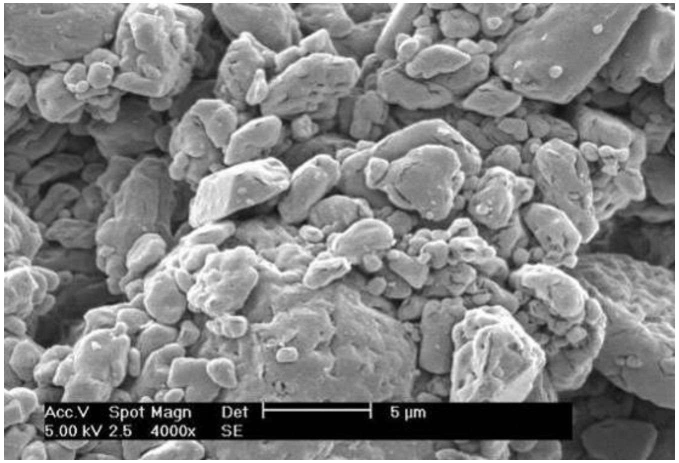
"Ref. HMX(114 μm)" "RC-HMX(130.9 μm)"



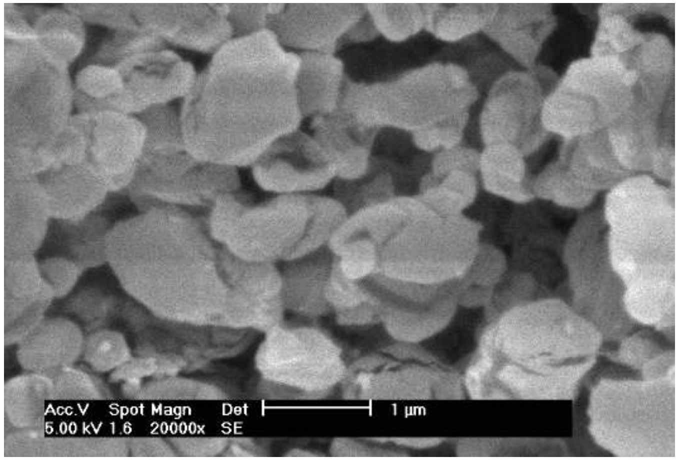
Plaksin et. al, Insensitive munitions and energetic materials Tech. Symp., 2012

HMX particles

<u>Particles P04:</u> ”F-HMX (11.1 µm)”
obtained at Fraunhofer ICT -Rotor-Stator Milling technology [1], particles P01 used as a row material
Mono-modal PSD: d_{50} = 11.06 µm
ρ0 = 1.874±0.008 g.cm^{-3}



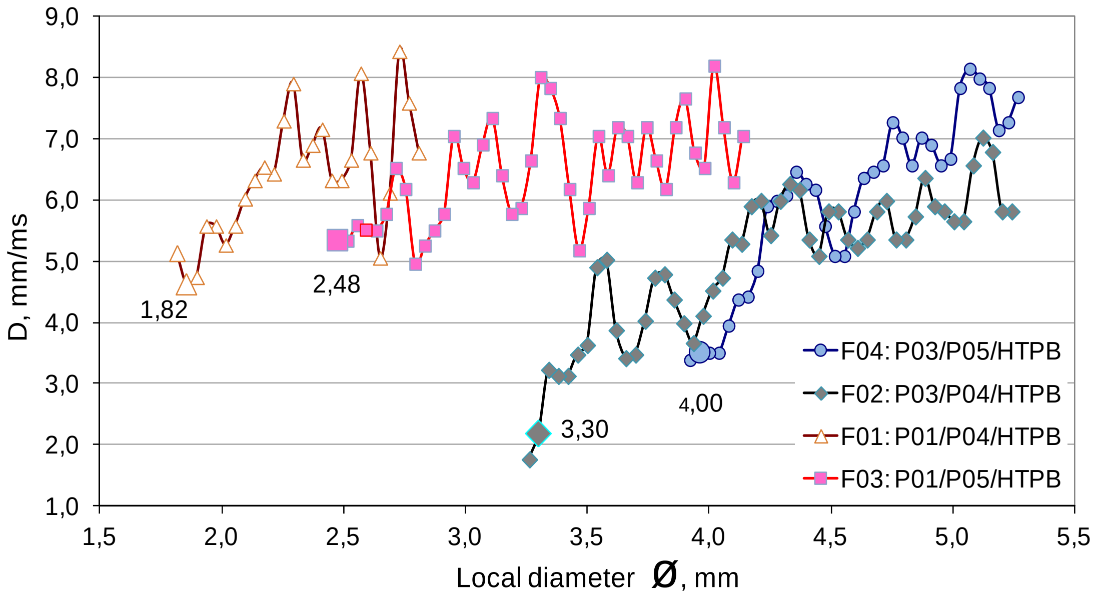
<u>UF-particles P05</u>: “UF-HMX (1.6)”
comminuting the water slurry of P04-grains on “Annular Gap Ball-Mill” technology (Fraunhofer ICT [1])
Mono-modal PSD: d_{50} =1.64 µm
ρ0 = 1.933±0.005 g/cm^{-3}



P05-particles are almost free of substructures and seems clusters separated from the crystal body at milling.

[1] Energetic Materials: Particle Processing and Characterization (Ulrich Teipel, Ed.), Wiley-VCH Verlag, GmbH & Co. KGaA, ISBN: 3-527-302240-9, 2005, 43-46.
[2] Plaksin et. al, Insensitive munitions and energetic materials Tech. Symp., 2012

Failure Cone Test

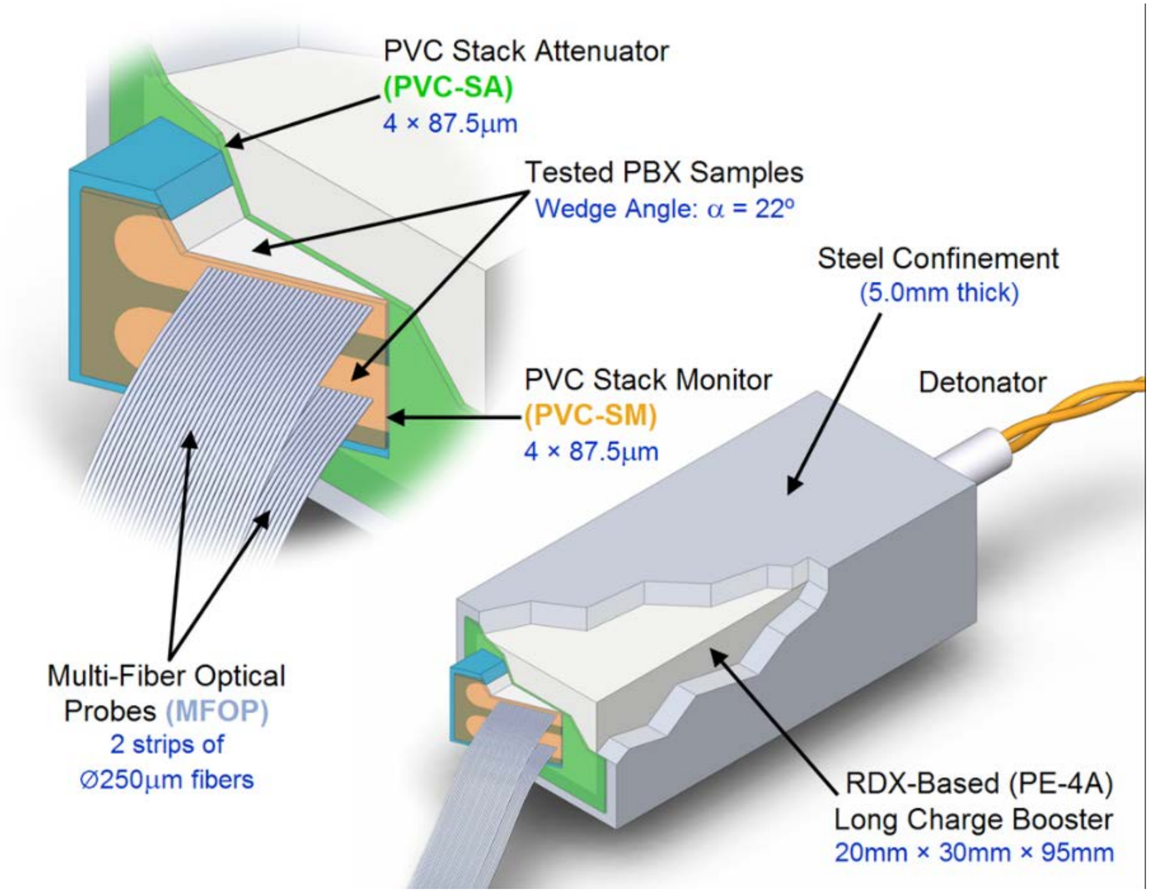


	75.6 / 16.4 / 18 wt%
F01	**Ref-HMX + F-HMX** + HTPB
F02	RC-HMX + **F-HMX** + HTPB
F03	**Ref-HMX** + UF-HMX + HTPB
F04	RC-HMX + UF-HMX + HTPB

Plaksin et. al, Insensitive munitions and energetic materials Tech. Symp., 2012

The RS-PBX "**F04 = P03/P05/HTPB 65.6/16.4/18 wt.%**" is possessing the Detonation Failure diameter on the level of the purified TATB (4 mm, 1.860 g.cm^{-3}) explosive material of 0.97 TMD.

Wedge test


PVC Stack Attenuator
(PVC-SA)
4 × 87.5μm
Tested PBX Samples
Wedge Angle: α = 22º
Steel Confinement
(5.0mm thick)
PVC Stack Monitor
(PVC-SM)
4 × 87.5μm
Detonator
Multi-Fiber Optical
Probes (MFOP)
2 strips of
Ø250μm fibers
RDX-Based (PE-4A)
Long Charge Booster
20mm × 30mm × 95mm

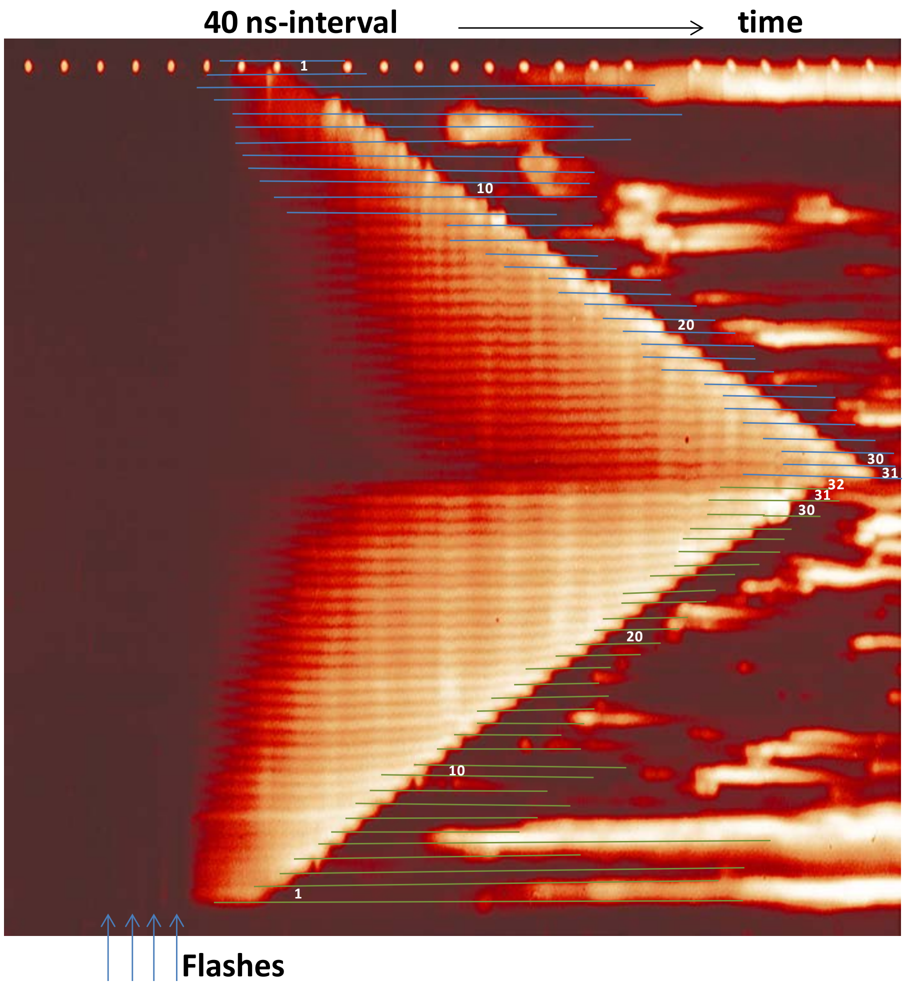
Wedge test

#7: HMX (203.7 µm)/DNAM(7.98µm)/GAP 65.6/16.4/18 wt. %“

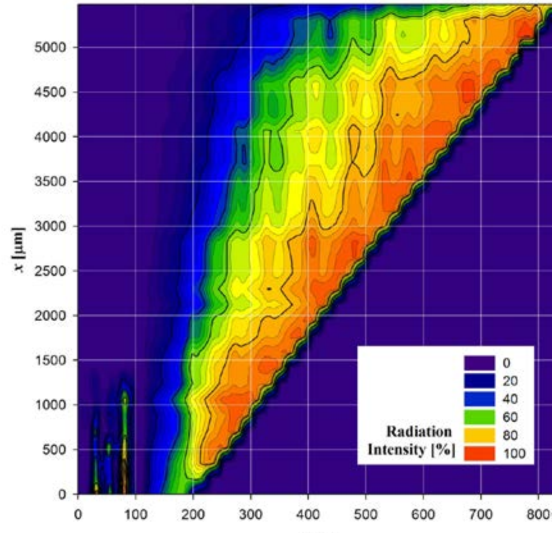
31 FF, ΔZ = 180.227 µm

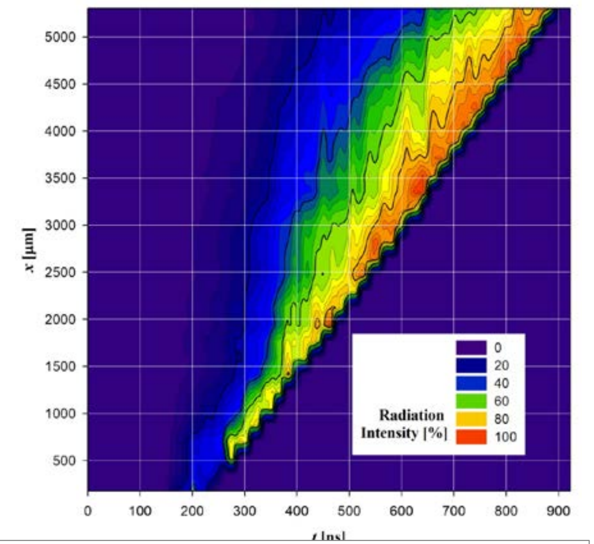
#6: HMX (203.7 µm)/HMX (10.4 & 56 µm)/ GAP = 65.6/16.4/18 wt. %“

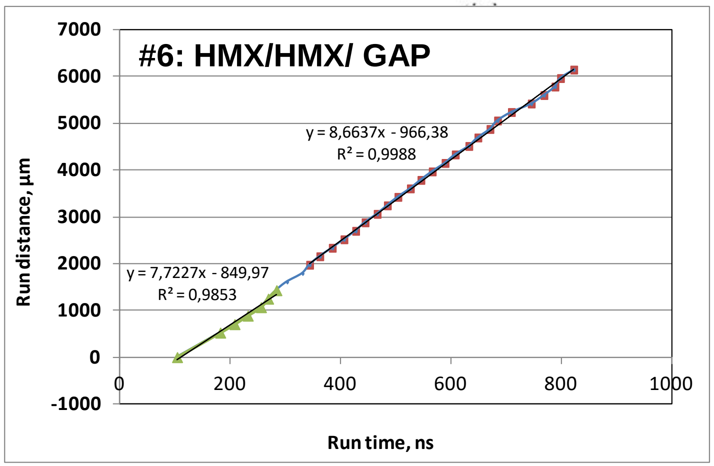
32 FF, ΔZ = 176.192 µm

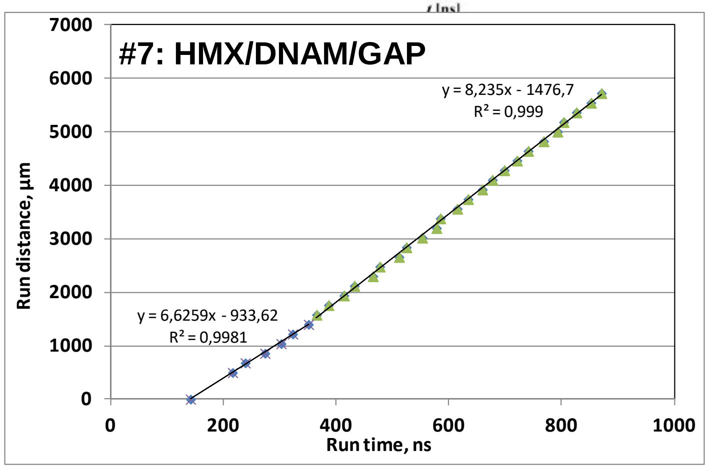


Wedge test

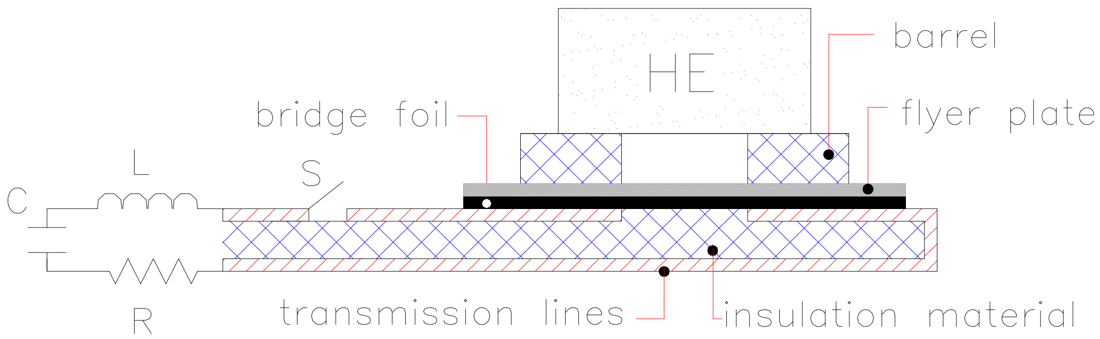

x [μm]
Radiation Intensity [%]
0
20
40
60
80
100

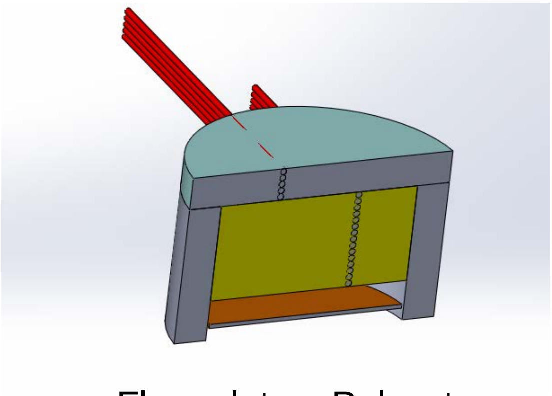

x [μm]
Radiation Intensity [%]
0
20
40
60
80
100


#6: HMX/HMX/ GAP
y = 8,6637x - 966,38
R² = 0,9988
y = 7,7227x - 849,97
R² = 0,9853
Run distance, μm
Run time, ns

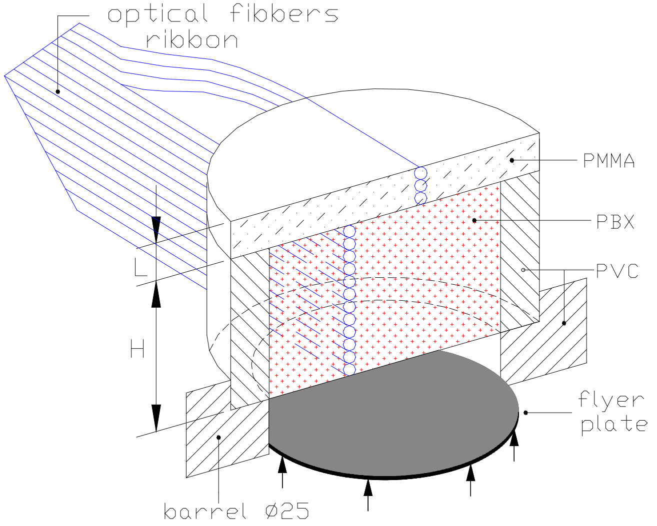

#7: HMX/DNAM/GAP
y = 8,235x - 1476,7
R² = 0,999
y = 6,6259x - 933,62
R² = 0,9981
Run distance, μm
Run time, ns

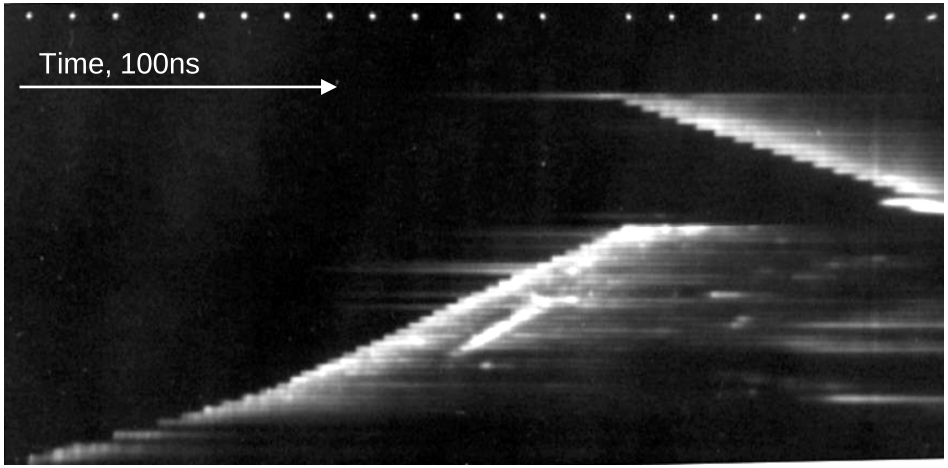
Flyer plate impact - SDT



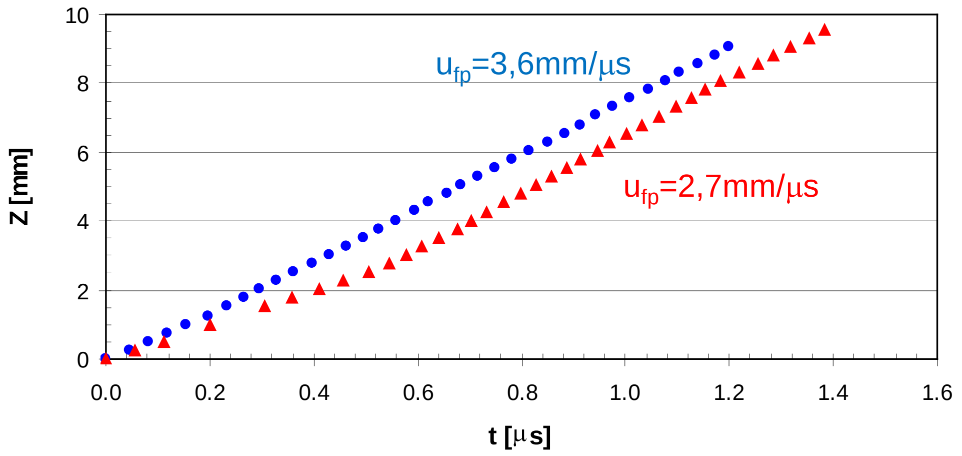


Flyer plate – Polyester,
Thickness - 350 μm
U_{fp} – 2.7 mm/μs
PBX: 85% RDX - 15% HTPB





Flyer plate impact - SDT



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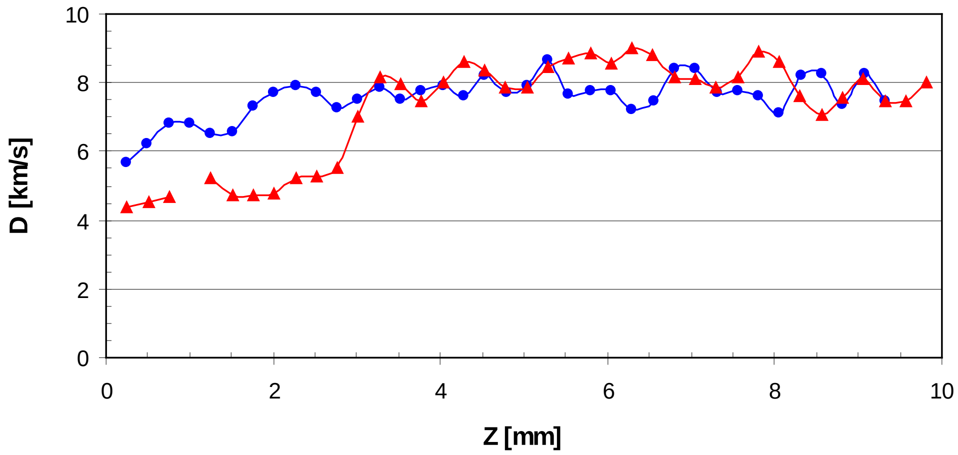

Conclusions

- DRZ Performance Test; Single Crystal Shock Reactivity Tests; Wedge Test; Detonation Failure Cone Test and Flyer plate impact test both instrumented with *Multi-Channel Optical Analyzer MCOA-UC* produce quantitative data on DRZ and sensitivity of crystalline PBX-samples.

- Small-scale tests allow to identify non-Steady State Detonation Propagation (local reaction domains/cells and “hotspots”); evidence of significcant perturbations in reaction intensity and induced pressure fields; ejecta phenomena on detonation front roughness.

Thank you for your attention!

ricardo.mendes@dem.uc.pt

Igor Plaksin will be remembered forever by his colleagues as an outstanding scientist and a great friend.

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