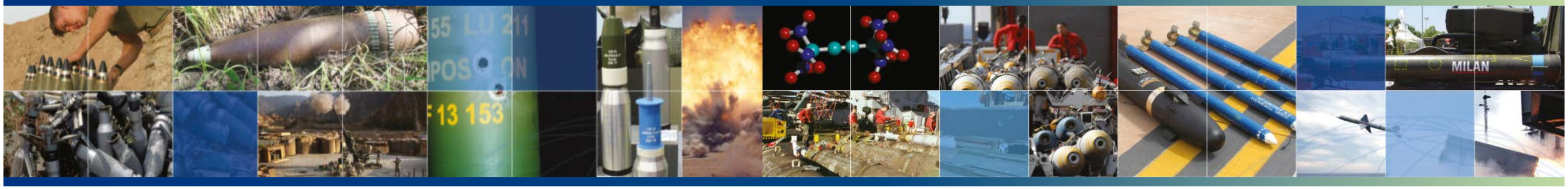
Munitions Safety Information Analysis Center
Supporting Member Nations in the Enhancement of their Munitions Life Cycle Safety



GUN LAUNCH SETBACK AND LABORATORY ACTIVATOR TESTS

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OVERVIEW

- Background
- Energetic Material Qualification
- Projectile Gun Firing Qualfication
- Laboratory Setback Actuators
- Actuator Ignition Physics
- Conclusions and Recommendations

BACKGROUND

- **Objective:**
  - Assess setback activator technology (2016) and gun launch ignition (2017). Inform on the need to develop a NATO standardized approach to proving the suitability of energetic materials for gun launch.
- **Issue**:
  - Need to assess new energetic materials for which there is little knowledge base and experience
  - Provide supplementary data for complex artillery
    - Allowing reduced the reliance on costly all-up-round level tests while maintaining confidence

Gap Analysis – Current Qualification of Artillery

- EM Qualification: STANAG 4170 – Principles and Methodology for the Qualification of Explosive Materials for Military Use
  - Chemical, Physical and Mechanical Properties
  - Sensitivity/Sensitiveness/Explosiveness
  - Performance Assessment

Relevance for Assessing against Gun Launch Forces?

- Intrinsic hazard properties with respect to impact and friction
  - Some use for ranking
- Shock
  - Time scale is much shorter than gun launch
- Confined Burning
  - Not representative of dynamic confinement of gun launch

    (note: under 15,000G the fuze has 15,000 times equivalent mass)
- Mechanical properties not measured at appropriate strain rates (10^3-$10^4 s^{-1}$) or pressures (up to 160 Mpa)

GAPS

- Testing of mechanical properties at appropriate strain rates.
- Methodology needed to develop an understanding of behaviour of energetic material under gun launch conditions, which would facilitate answering the following questions:
    - How the energetic material respond to gun launch set-back and centripetal forces (for riffled ammunition)?
    - Does apparently pristine energetic material (with defects less than approximately 100μm) react under gun launch conditions (what is the probability and is it acceptable)?
    - What are the characteristics of critical defects and what is the probability of one being formed under gun launch conditions?
    - What is the probability of a critical defect being present in the energetic material destined for artillery?
    - How do we set rejection criteria?

Qualification of Artillery (Final or Type Qualification)

- STANAG 4224 Large Calibre Artillery and Naval Gun Ammunition Greater than 40mm
- With respect to Energetic Material exposure to setback:
- Projectile Safety (Annex C)
  - Preliminary evidence to assess whether a projectile is prone to premature detonation; 120 or 60 split between firing at UFT or LFT
- Sequential Environmental Test: To determine the safety and suitability for service of ammunition subjected to environmental conditions representative of service use
  - – 120 rounds fired after sequential environmental exposure
- In reality rounds fired in qualification may be as little as around 240 compared to 100,000s during artillery program lifecycle. It is statistically insignificant.

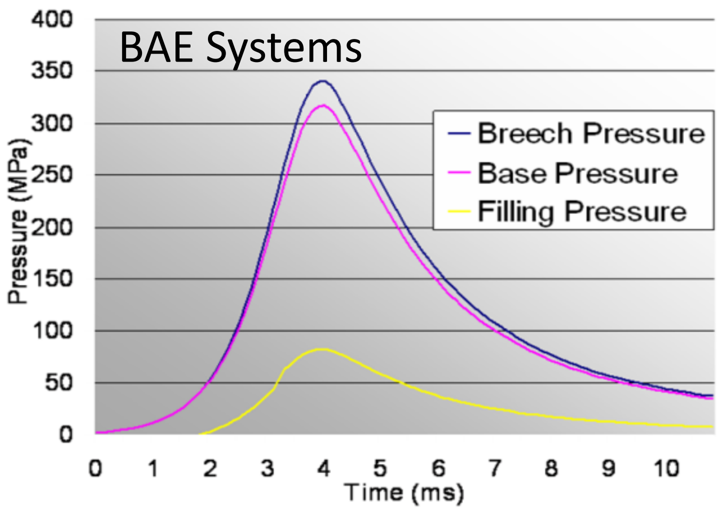
FAILURE CRITERIA WITH RESPECT TO EM

- Obviously, if there is an in-bore premature!
- "There shall be no significant voids, cracks, HE dust, bonding failures or other unacceptable features in the condition of the projectile, and, where appropriate, the sub-munition filling. Where there is evidence of voids, cracks, bonding failure, or other unacceptable features, the significance of these shall be explained by the developing nation."
- No guidance on how to set rejection criteria for defects
  - Role for the developing nation and the design authority

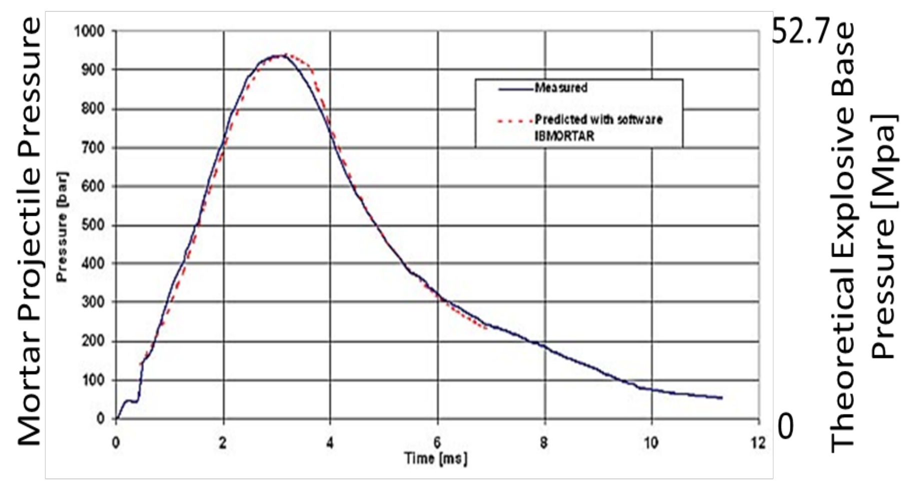
Theoretical Compressive Load

- The pressure that an explosive fill or component is exposed to is determined by the acceleration of the shell and increases linearly in an energetic component from the top of the charge (nose of the projectile) towards the base.
- The theoretical pressure in the explosive charge can be calculated at any point from the shell acceleration:

  Pressure = Density x Depth in fill x Acceleration



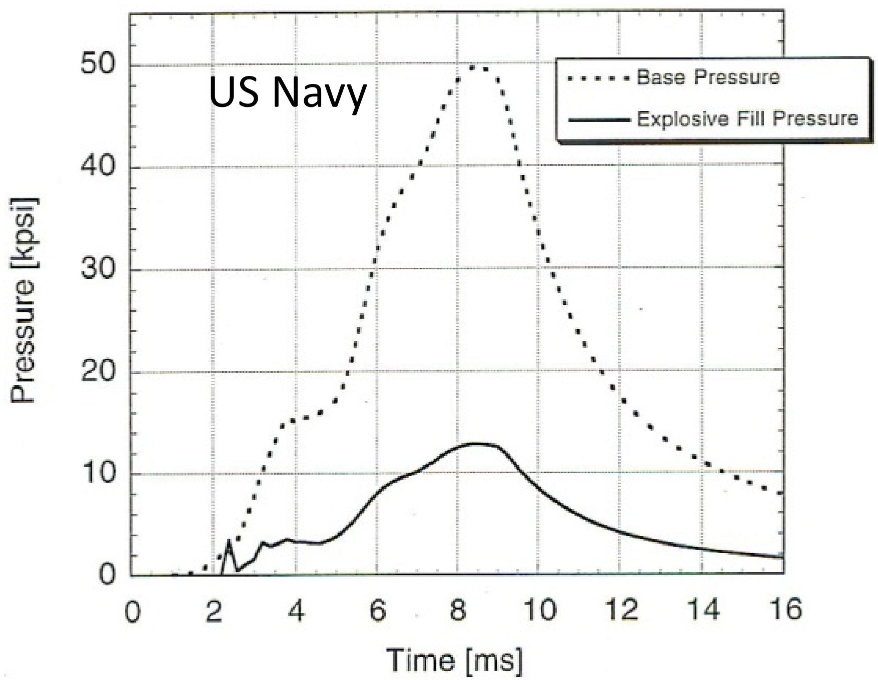
105mm artillery
calculated filling pressure



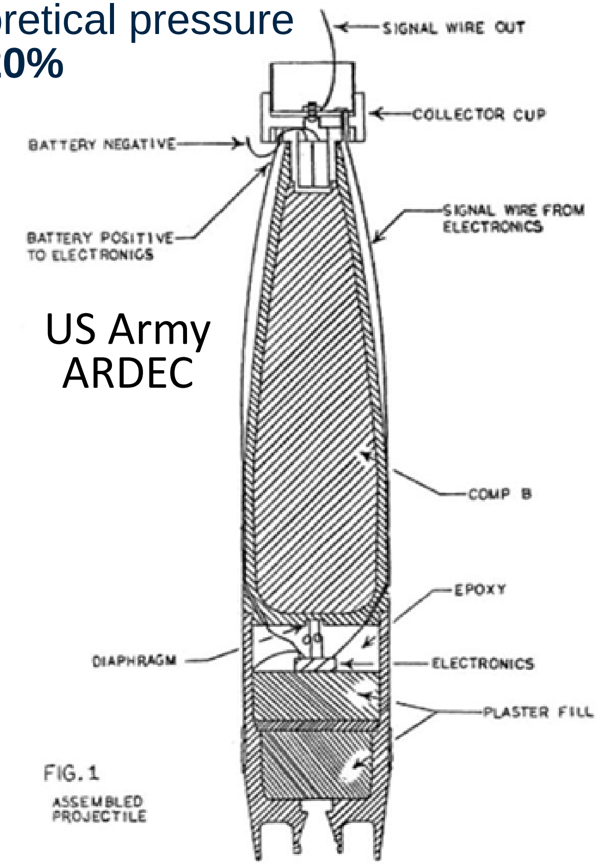
120mm mortar
calculated filling pressure

ACTUAL COMPRESSIVE LOAD

- From available data, actual explosive filling compressive loads are significantly less than theoretical explosive filling compressive loads
- Limited gun launch filling pressure measurements by ARDEC
  - Good fill castings between **7% and 16%** of the theoretical pressure
  - Lubricated case good castings between **10% and 20%**
  - Bad fill castings between **24% and 66%**



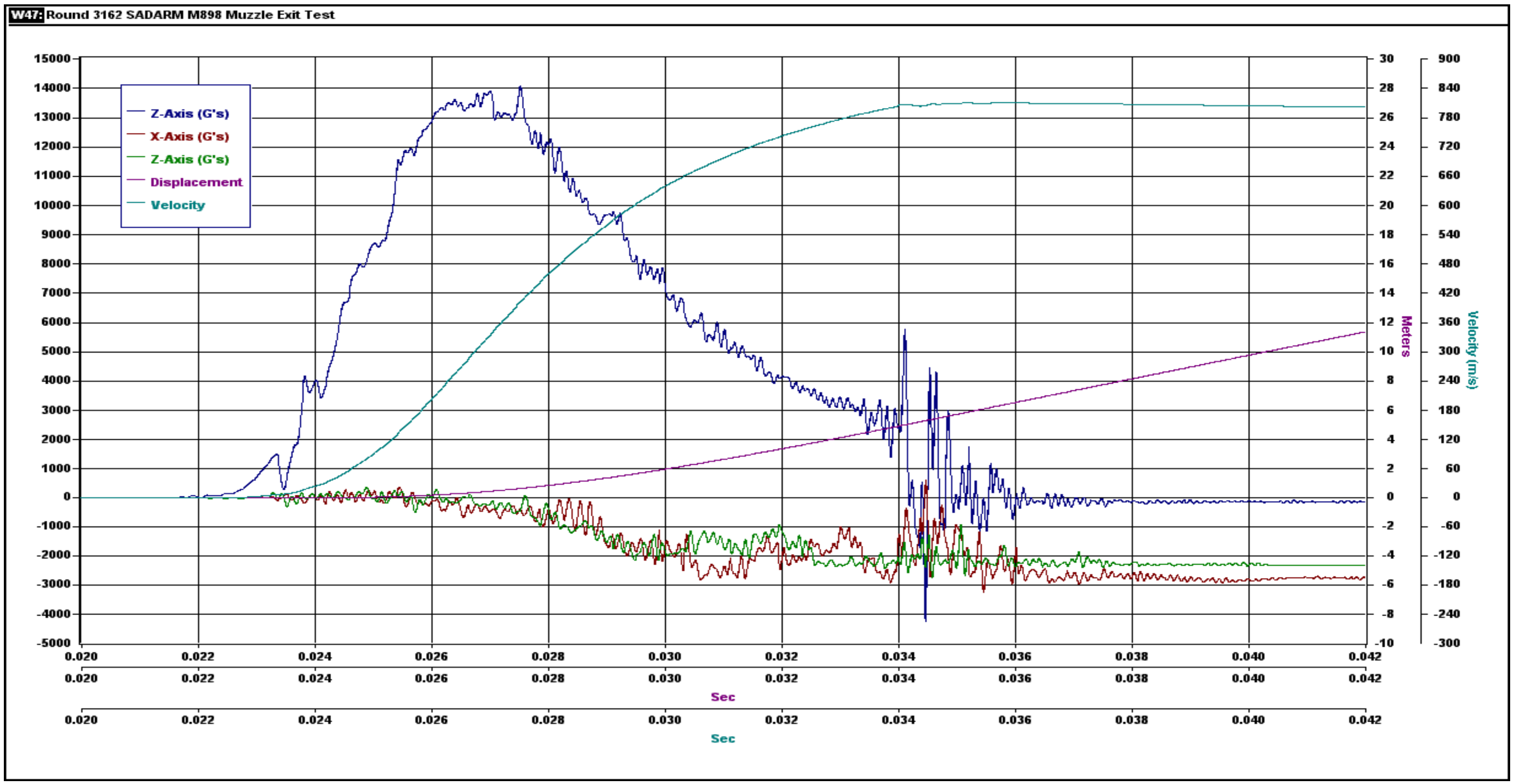
123mm Artillery
calculated filling pressure



155mm explosive filling
pressure measurement

Acceleration Perturbations

- Projectile balloting: commonly radial accelerations up to 5% of axial
- Axial acceleration perturbations: commonly up to 10%
- How much larger and how often do these perturbations occur?

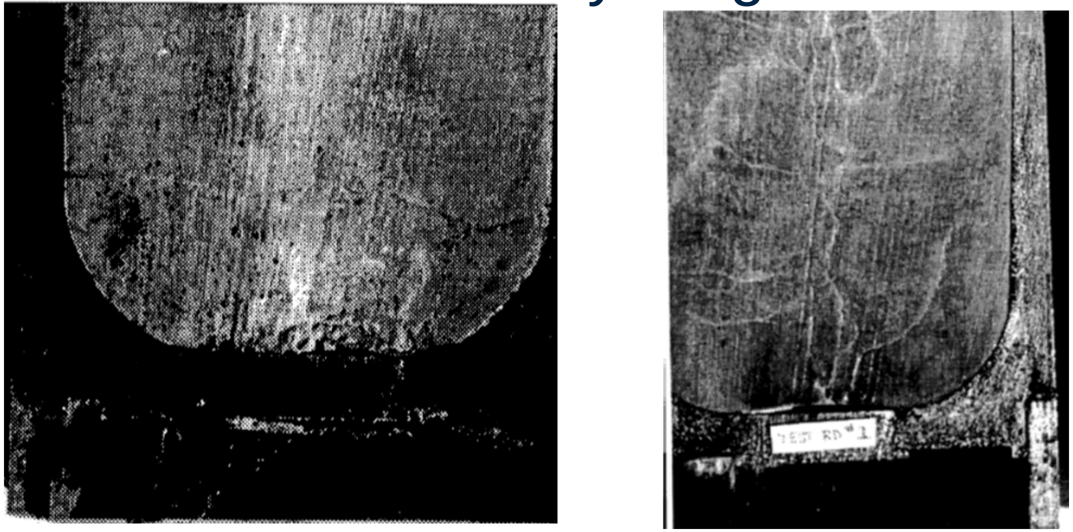


155mm projectile acceleration, velocity and distance measurements during launch

Cordes, J.A. et al., "Dynamics of a Simplified 155-mm Projectile", Proceedings of the 21st International Symposium on Ballistics, vol. 2, pp. 1164–1170, Adelaide, Australia, 2004.

Role of Defects

- Defects are important because they act as sites for stress strain concentrations which can lead to localised heating, hot spot formation, and ignition.
  - friction; adiabatic shear; viscoplastic work and if voids are present, adiabatic gas heating during cavity collapse and jetting.
- Defects can be EM Bulk or Interfacial, examples include:
  - Voids, Cavities, Cracks, Porosity, Foreign Material
  - Base Gaps, Shell Body roughness



155mm Comp-B cast projectiles with porosity (left) and cracks (right)

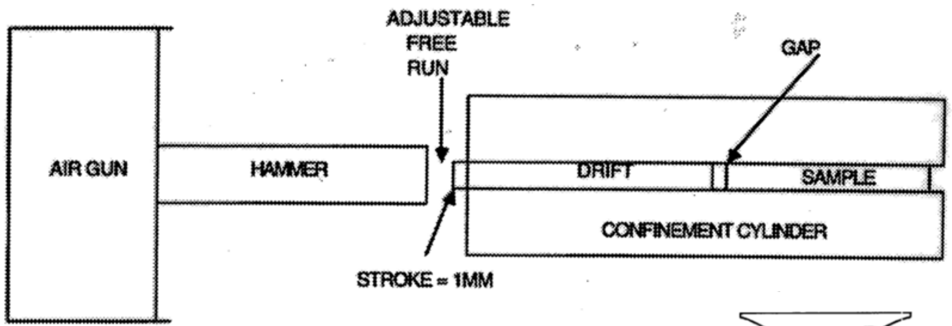
SETBACK ACTIVATOR CAPABILITIES

- A setback actuator test is a small scale test that involves exposing energetic material to setback forces similar to those experienced in an artillery round on gun launch.
- Techniques described in the 2016 paper generally apply a compressive load to a pellet of explosive via a piston and the response is observed as a go or no go reaction.
- The compressive load can be varied to try and mimic different gun systems and artillery types and calibres.
  - Pmax
  - dP/dt
  - Duration

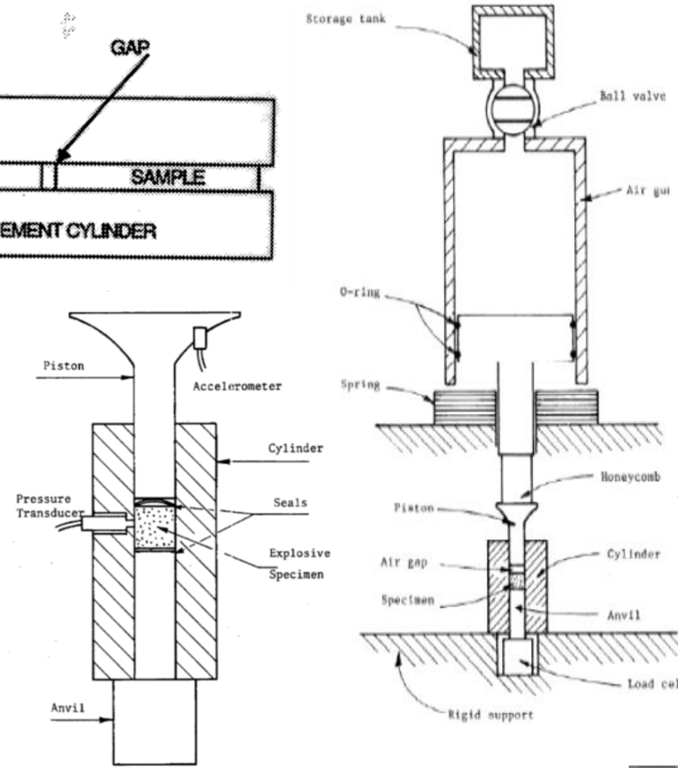
Means to Develop Compressive Load

- 3 methods described for developing the initial pressure:
  - drop weight
  - gas gun
  - via gun propellant combustion
- Some advantages and disadvantages of each technique
  - Explosive extrusion and pinching is a common issue
  - Control and vary dP/dt, Pmax and duration
- This can be complex.
  - For drop weight and gas gun driven pistons, the pressure pulse is tailored using intermediate conditioning materials.
  - For propellant driven systems, pressure release is required to taylor the pressure pulse
  - Requirement to measure driving pressure and sample pressures
  - An area for collaboration?

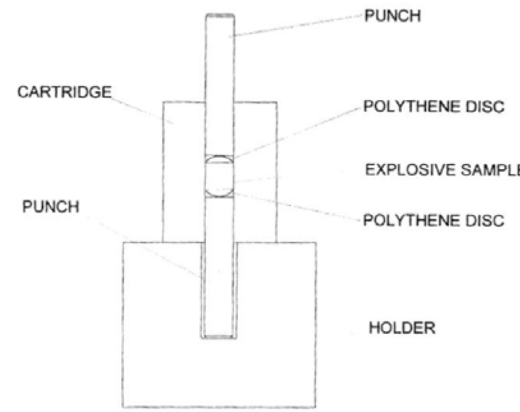
Setback Activator Capabilities – Gas/Weight Driven Piston



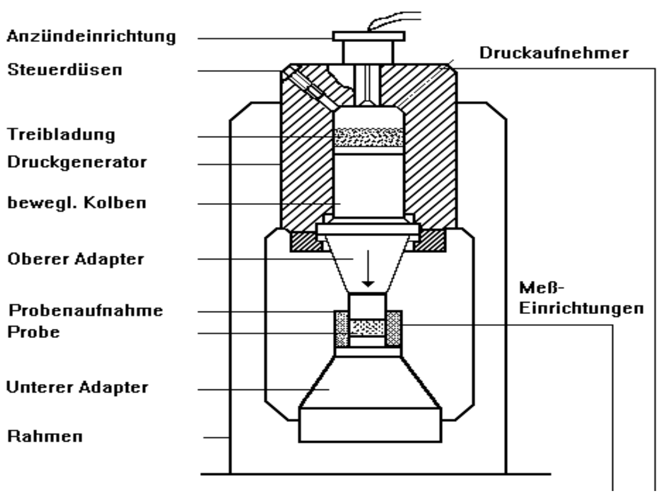
ARDEC
Setback Tester



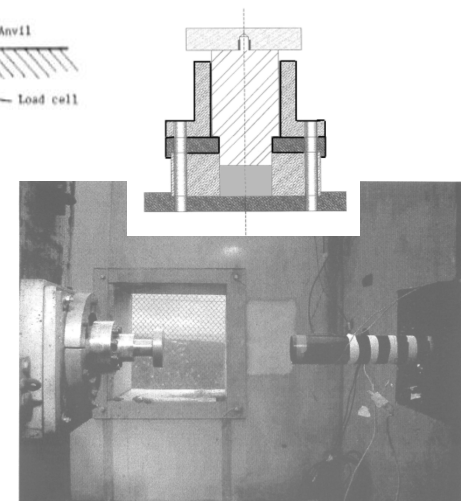
DREV Setback Simulator



DSTL/QinetiQ
Vertical Activator



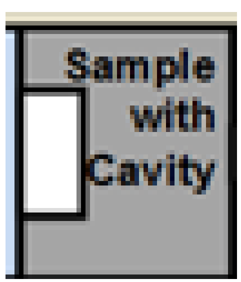
WTD 91

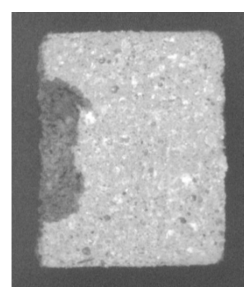


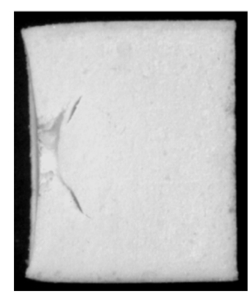
Cranfield University
COTEC Setback Simulator

IDEALIZED EXPERIMENT

- Manufacture and characterize pellets (2-4cm diameter) that include cavities
- Match the pressure history to in-service condition and then vary peak pressure.
- Increase pressure to achieve go reactions
  - Optimize the generation of data based on the results obtained (e.g. Bruceton Test, Langlie Test, Neyer D-Optimal)
  - Characterize variability.
    - mean and standard deviation and probability distribution.

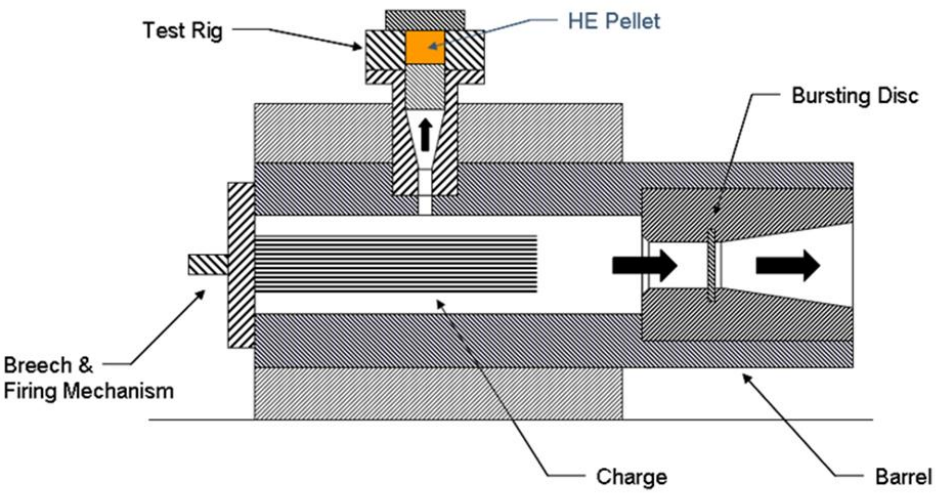




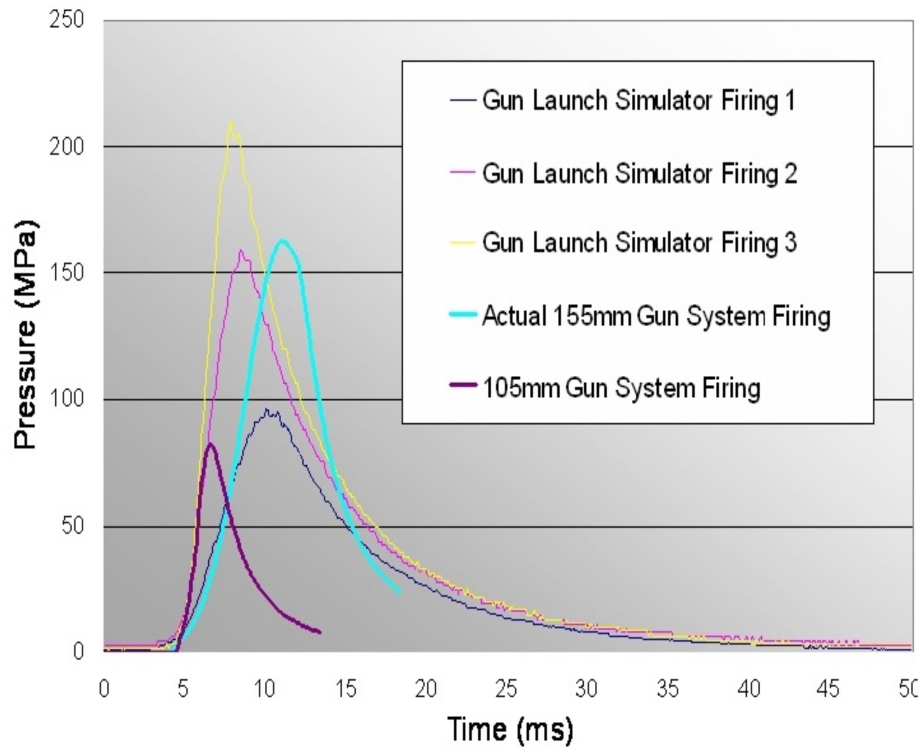


BAE Actual Experiment

- The pressure history with the closest peak pressure to the 105mm has about 1/4 of it's rate and about 3 times it's duration.
- The pressure history with the closest peak pressure to the 155mm has about twice it's rate and about 1.5 times it's duration.



BAE-GCS
Gun Launch Simulator



NSWC-IH Actual Experiment

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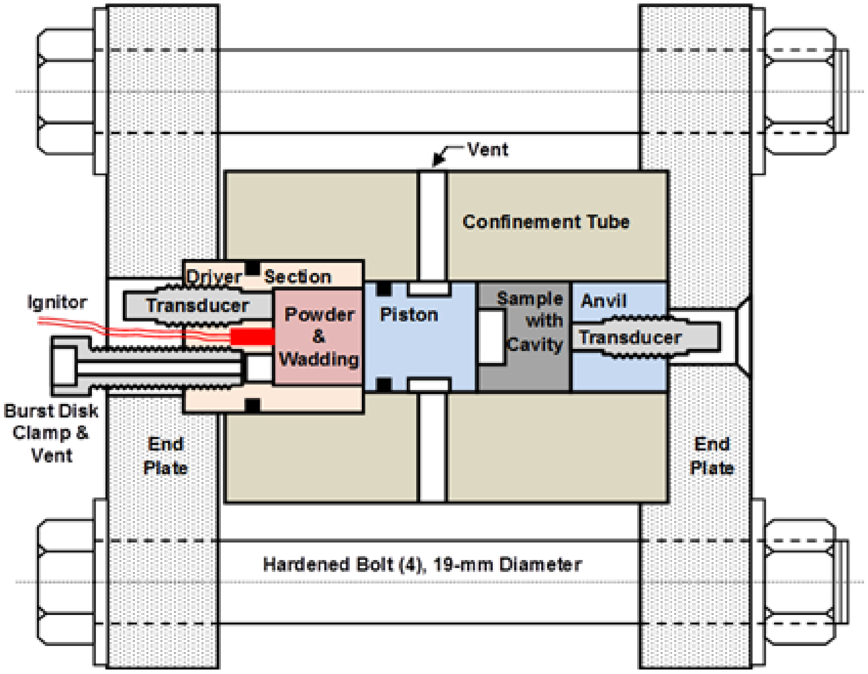
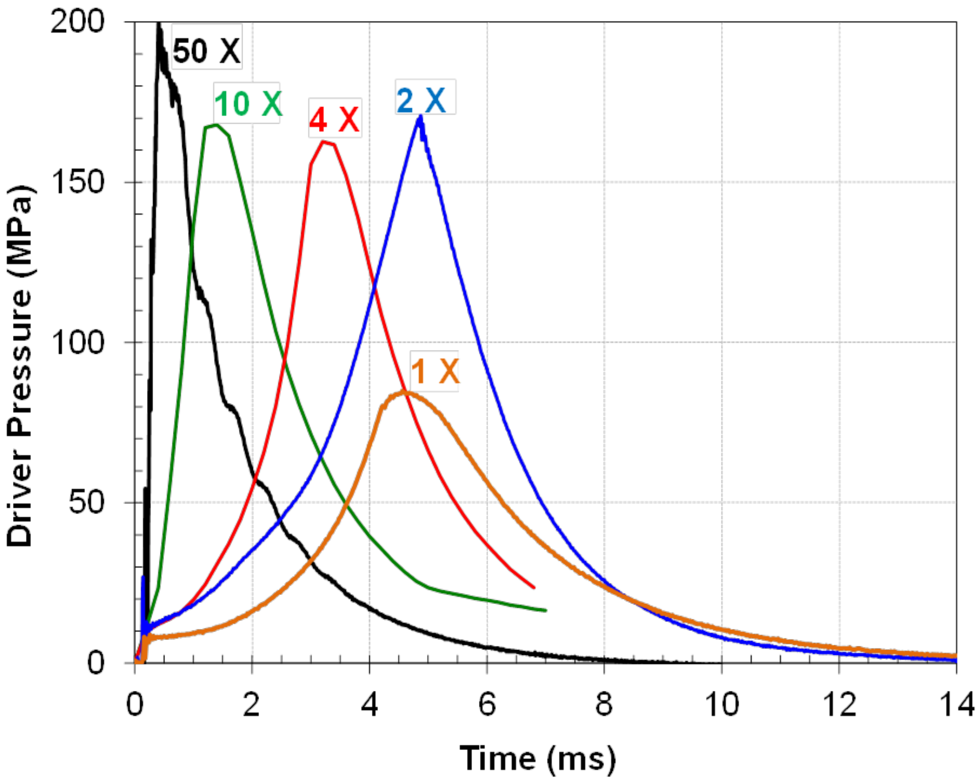
- Of the reviewed laboratory activator data produced pressure histories, only the NSWC-IH test appeared to match the theoretical in-service condition.
- Typical "go" reactions occur at 2X or 4X conditions





Activator Ignition Physics

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- For Setback Activator testing three ignition sources appear to dominate
  - Explosive extrusion and pinching: common unintentional ignition associated with sample holding geometry and materials (various approaches to eliminate or minimize the occurrence)
  - Adiabatic air heating: requires small (less then 50um) energetic particles to be present. Appears dominant for cast cure explosives, where small energetic particles are ejected into the sample cavity as a result of the initial impact.
  - Shear: mechanical deformation and the associated material damage. For melt pour (strong) explosives, this mechanism appears to be coupled with adiabatic heating to cause ignition.
- How do these mechanisms compare to real gun launch ignition?
  - Inspection to eliminate gaps, voids and cracks in the lower zones
  - Projectile acceleration perturbations
    - balloting, erratic burning and associated pressure waves
    - how large and how often?
- There is little data providing evidence that setback activator ignitions correlate to real gun launch ignitions

SETBACK ACTIVATOR OPPORTUNITIES FOR COLLABORATION & STANDARDISATION

Reviewing the tests indicates some common issues or areas for potential collaboration or standardization:

- Means to develop compressive load which can be varied and simulates the gun launch environment.
- Sampling; relationship to production and sample population size (linked to analysis)
- Defect analysis; energetic material and interface defect analysis.
- Many past activators have had issues with ignition due to explosive flow and pinching rather than the g-loading

Results analysis

- Statistical analysis and treatment of results
- Inference of reaction violence.
- Techniques appear to be used Ad Hoc Nationally.
- Can we agree an assessment methodology!

MSIAC report on setback actuators: L-212 “Use of Laboratory Setback Activator Tests to Assess Suitability for Gun Launch”, Dec 2016

MSIAC

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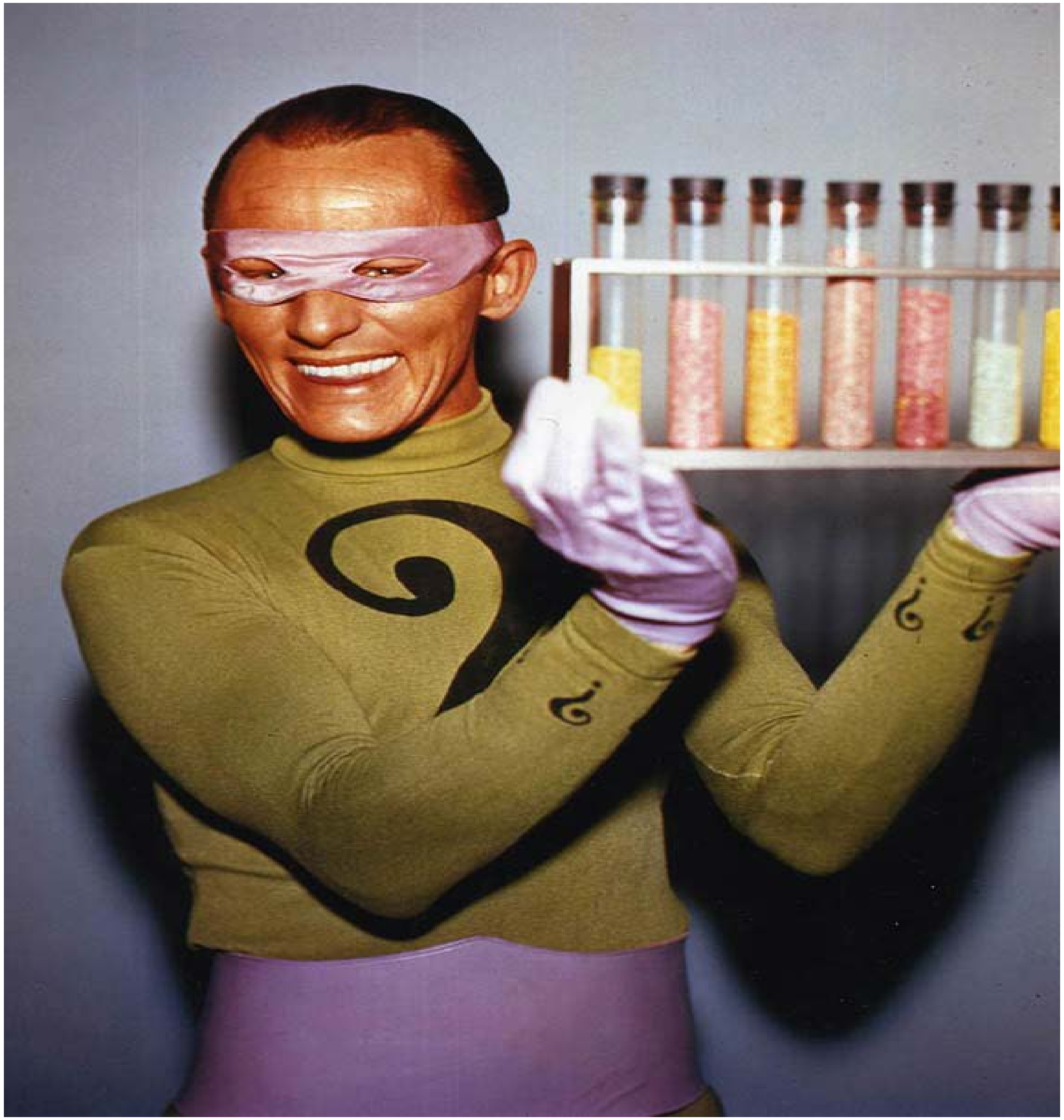
Questions?



Distribution Unlimited

BACKUP

PROBABILITY

- 50,000 rounds are fired a year in training and limited operations over a 20 year munition life the probability of an event per firing must be:

Per firing	*Events per Year*	*Events per Programme (20 years)*
1.00E-06	0.05	1
1.00E-07	0.005	0.1
1.00E-08	0.0005	0.01
1.00E-09	0.00005	0.001
1.00E-10	0.000005	0.0001

- Safety target of 1 event every 50 years equates to probability of 4×10^{-7} per firing.