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Fragment Impact Modeling and Experimental Results for a 120mm Warhead

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2019 Insensitive Munitions & Energetic Materials Technology Symposium, Seville, Spain

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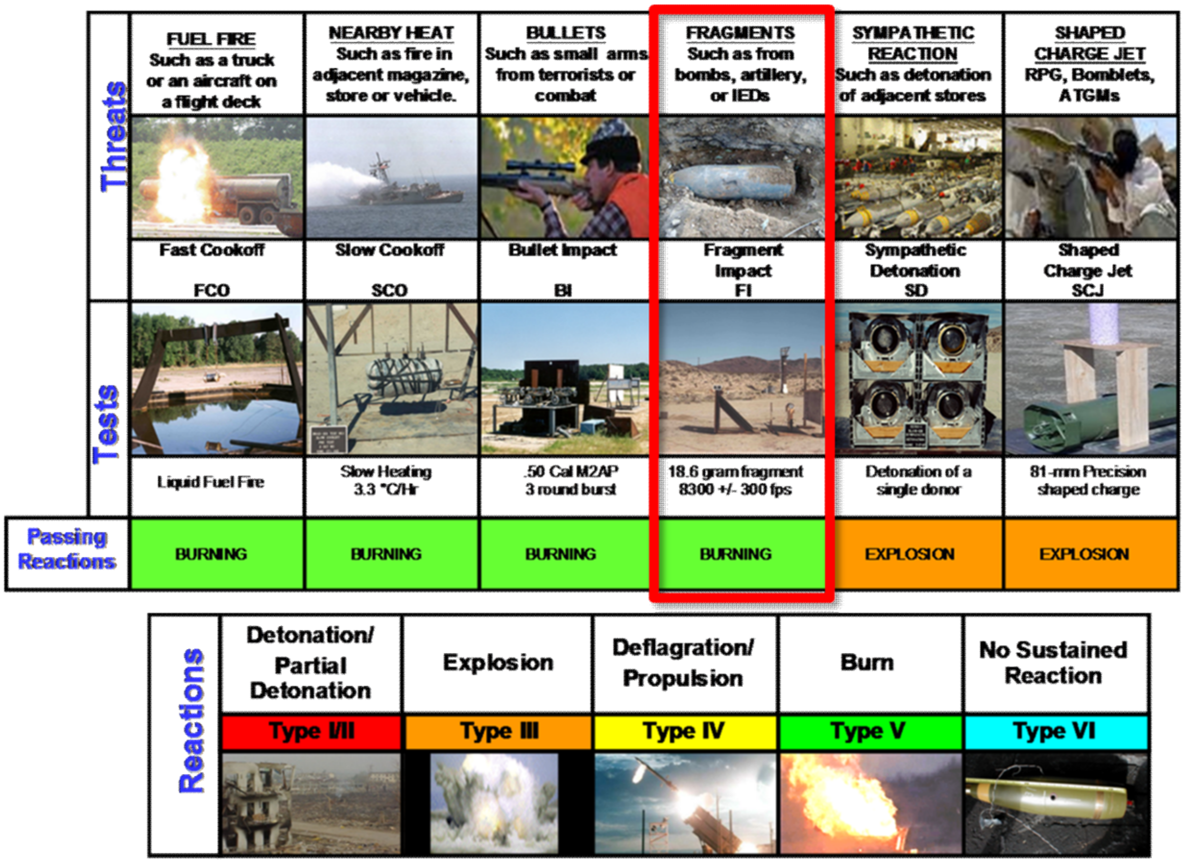
OVERVIEW

- Insensitive Munitions (IM) requirements
- NATO IM Fragment Impact (FI) testing
- 120mm warhead and packaging description
- General phenomenology and previous work
- FI mitigation design strategies and concepts of interest
- High rate continuum modeling methodology and predictions
- Experimental results
- Summary and conclusions

INSENSITIVE MUNITIONS REQUIREMENTS

Insensitive Munitions Testing



Fragment Impact (FI) Mitigation design of interest in this work

IM Tests

- Slow cookoff (SCO)
- Fast cookoff (FCO)
- Bullet impact (BI)
- Fragment impact (FI)
- Sympathetic Reaction (SR)
- Shaped charge jet (SCJ)

Response type determination

- Photographic evidence
- Blast overpressure
- Debris thrown/recovered
- Witness plate gouging

NATO IM FRAGMENT IMPACT TESTING

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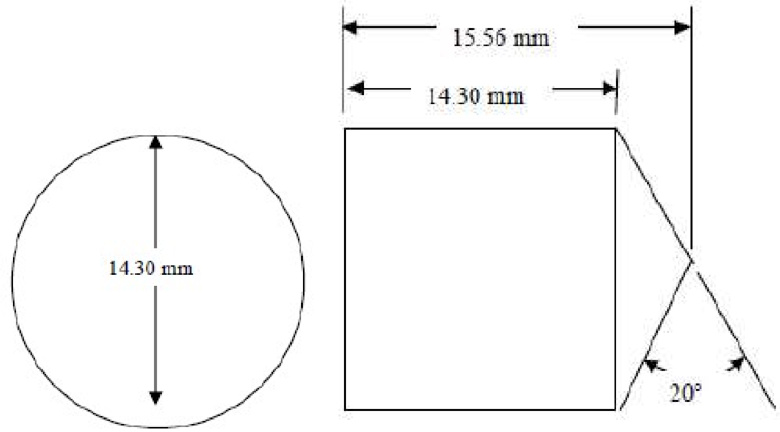
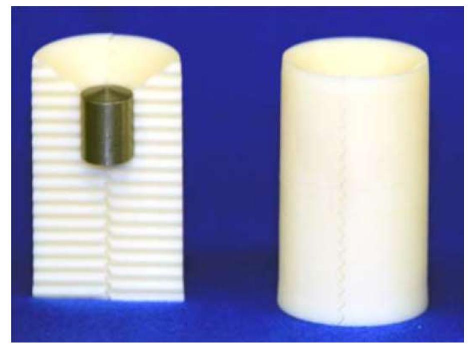
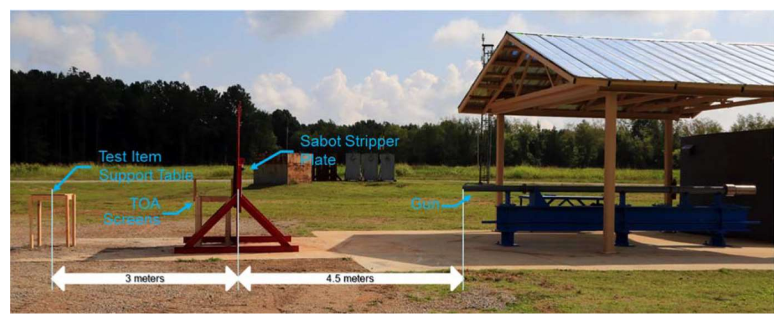
- NATO standard FI test (STANAG 4496) [1]
  - 14.3mm diameter, 18.6g, L/D~1, 160° conical nosed fragment
  - Mild steel, Brinell hardness <270
  - 2530±90 m/s impact velocity
  - Aimpoints: center of largest presented area of HE or most shock sensitive location
- Smooth bore 40mm powder gun often used in the U.S. [2]
  - Commercially available, used by various test facilities
  - Powder charge adjusted to obtain correct velocity
  - Replaceable wear section
  - Plastic sabot machined to fit
- Variability issues [2]





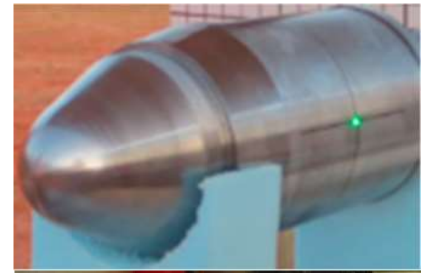


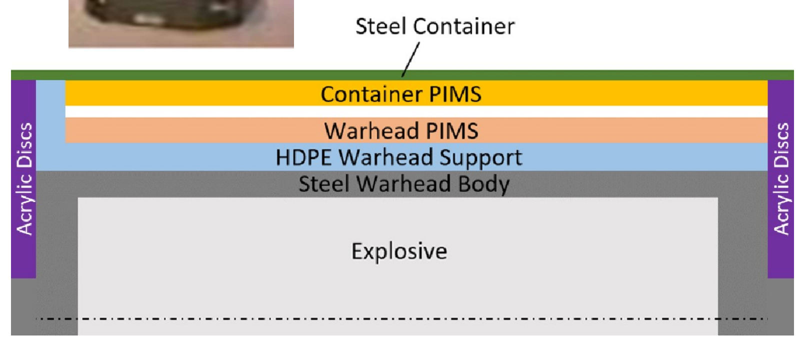
FRAGMENT IMPACT MITIGATION STRATEGY

- Objective in IM is to get a “Type V” response (nonviolent burn)
- Responses to design against
  - Shock initiation
  - Shear ignition – shear banding in HE, pressure dependent
  - Deflagration, DDT, XDT
- Step 1: Remove the initial impact shock
  - 1D 2530 m/s steel on steel: 650 kbar → ~240 kbar in HE
  - Thin plastic shock buffers have worked in past applications [3]
- Step 2: Reduce overall mechanical insult
  - Provide sufficient fragment velocity reduction, breakup and dispersion
- Particle Impact Mitigation Sleeves (PIMS) are what we typically call packaging barriers / warhead liners to accomplish this

ITEM AND CONFIGURATION DESCRIPTION

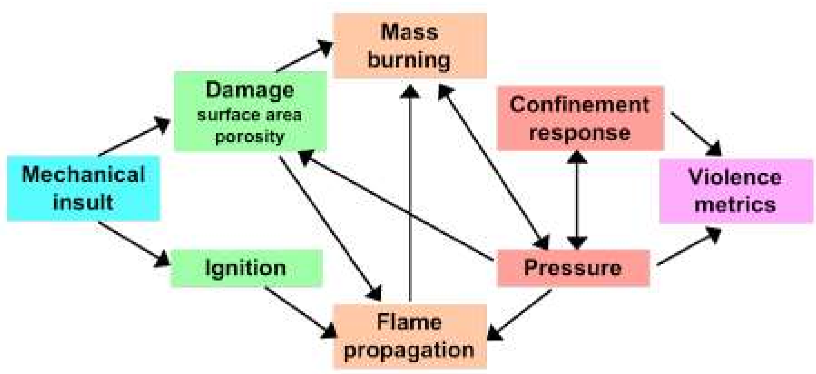
- 120mm IM warhead
  - 0.4in thick steel body
  - 2kg Picatinny Arsenal enhanced blast explosive (65% HMX, 20% Aluminum, 15% Binder)
  - Nose and aft simulants
- Logistical configuration
  - Packaged in ~1mm thick ammunition container
  - Warhead housed in 0.35” thick HDPE warhead support
  - Approx. 5/8” of space between OD of warhead support and ID of container
  - Can incorporate Particle Impact Mitigation Sleeves (PIMS)
    - Warhead, container or both
- Aimpoint – Middle of Warhead Body
- Warhead, plastic support and PIMS mounted in container with acrylic discs





SUB-DETONATIVE RESPONSE PHENOMENOLOGY

- Sub-detonative response: Long timescales (several ms), some HE unconsumed, large fragments projected long distances, relatively low pressures
- Rapid combustion coupled with damage and fracture of HE, conductive/convective heat transfer, mechanical confinement
- Modeling challenges: damage/porosity, ignition criteria, reaction rates, flame propagation in damaged reactant, strength/EOS for mixtures of solid reactant and gaseous products, interaction with confinement, possible transition to detonation
- Consistent theoretical framework, robust numerical implementation
- Models are CDAR-K [5], HERMES [6], but nothing for this particular HE
- Testing ultimately still relied upon for IM design

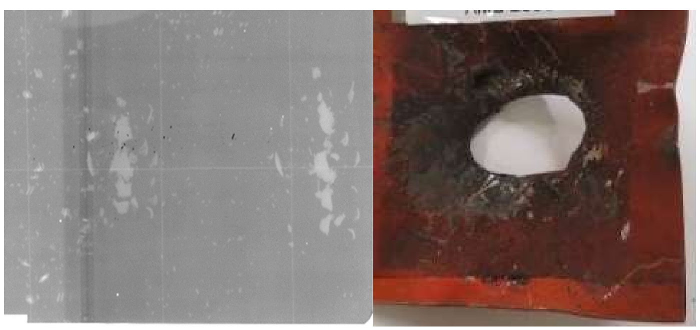


Sub-detonative response phenomenology (from [4], [5])

PREVIOUS WORK

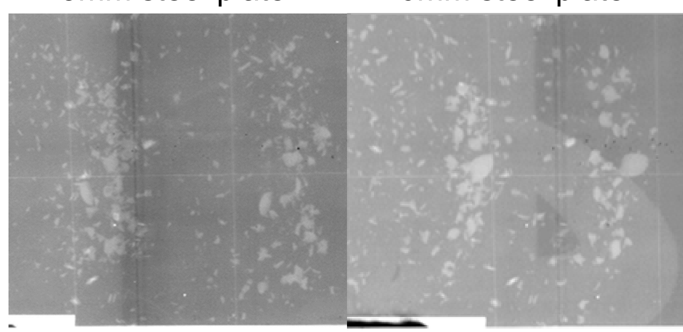
- Much work performed in the past to fully mitigate 8300 fps FI
  - Several mm thick steel and/or aluminum PIMS usually necessary (obviously depends on the item)
  - Example IM programs: TOW2B missile [7,8], M72 LAW [9]
  - Inert plate testing: CCDC-AC experimental program [10,11], TOW2B program [12]
- Successful designs provide velocity reductions of 1000-2000 fps and result in significant fragment breakup, which is clearly an essential feature of the problem

~1mm steel sheet



500fps velocity reduction

3mm steel plate | 6mm steel plate

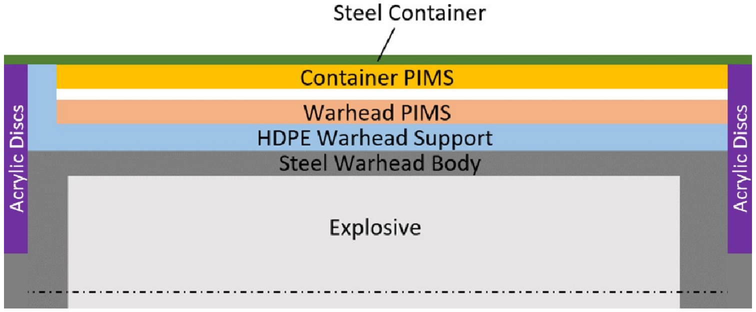


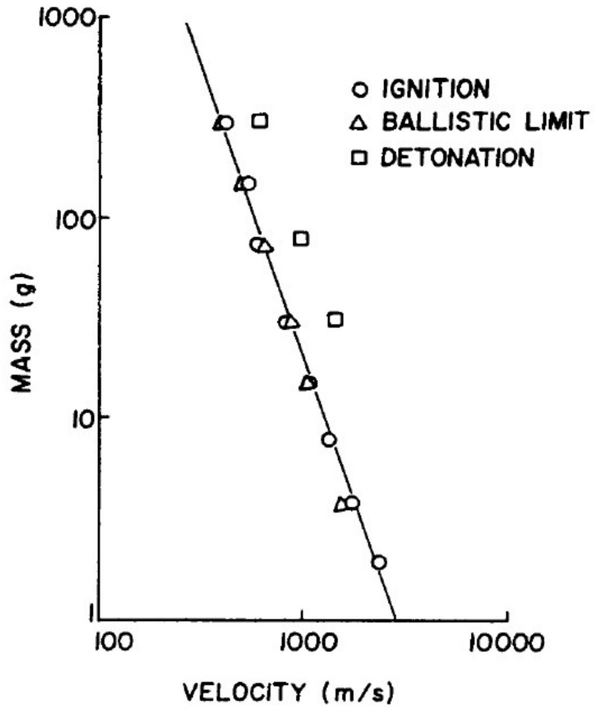
950-1200 fps velocity reduction | 1975 fps velocity reduction

6mm steel plate

HIGH RATE CONTINUUM MODELING

- Ballistic limit of warhead body suggested as an approximate threshold for violent sub-detonative munition response in heavily confined charges [15]
    - Also identifies plugging as case failure mechanism
- For several common explosives, transition from no reaction to violent explosion occurs over a narrow range of impact velocities, e.g., < ~650 fps [16]
- Plan is to computationally identify designs which result in minor deformation of the warhead body
    - Upper bound on required protection
    - Hone in on lightest successful configuration experimentally

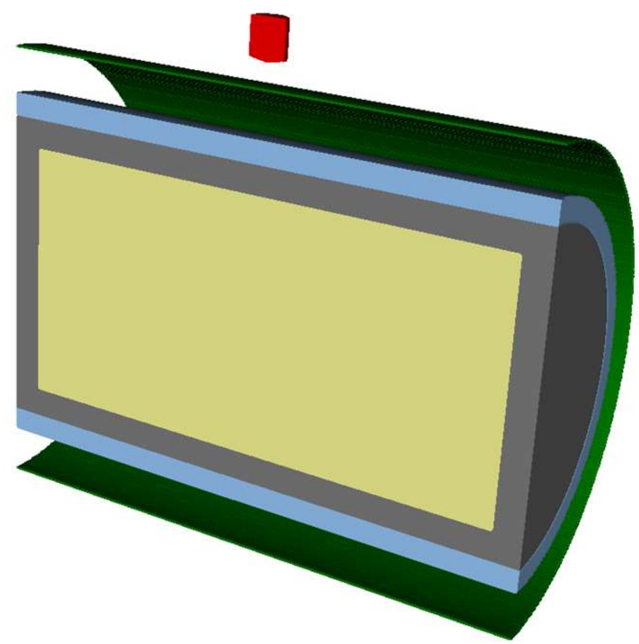




Threshold values for ignition of confined Comp B by steel fragments. Wall thickness 1cm (from [15])

HIGH RATE CONTINUUM MODELING

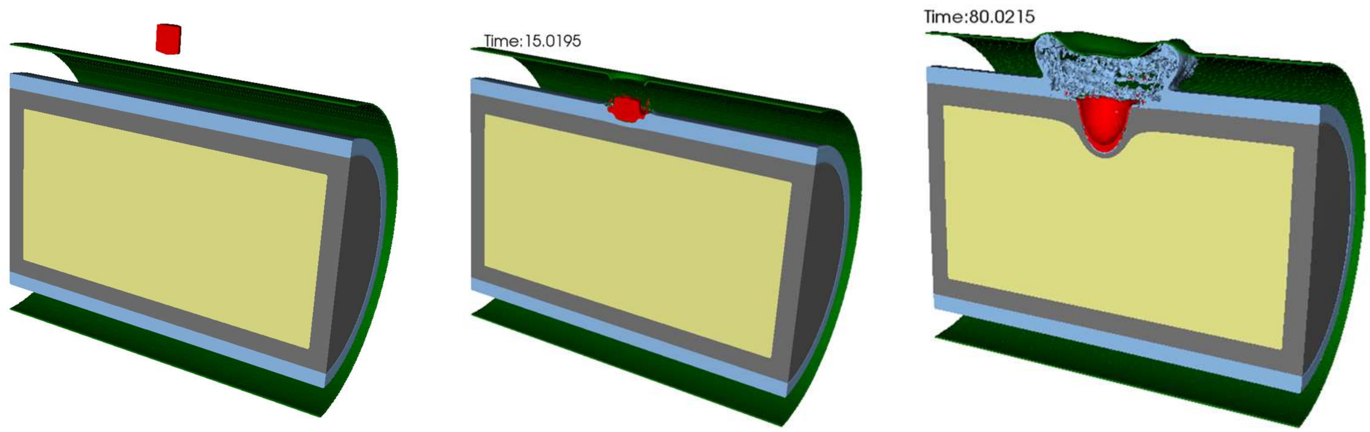
- Livermore ALE3D code was utilized
  - Lagrangian step followed by remap/advection step(s)
  - Equipotential mesh relaxation scheme to move zones to regions of interest
  - Second order monotonic advection algorithm
  - Standard artificial viscosity used to spread shock fronts over several zones
- Material Models
  - Mie-Gruneisen EOS for all solids
  - Steinberg-Guinan strength with von Mises yield surface
  - Spall failure approximated using maximum tensile hydrostatic stress
  - HE assumed elastic perfectly plastic with small amount of strength



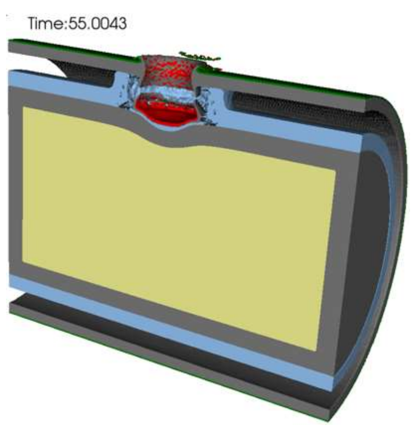
HIGH RATE CONTINUUM MODELING

- Steel and aluminum PIMS investigated, warhead and container configurations
- Baseline configuration: HDPE removes the impact shock, but fragment clearly perforates warhead body
- PIMS thicknesses identified to achieve mild deformation of warhead body

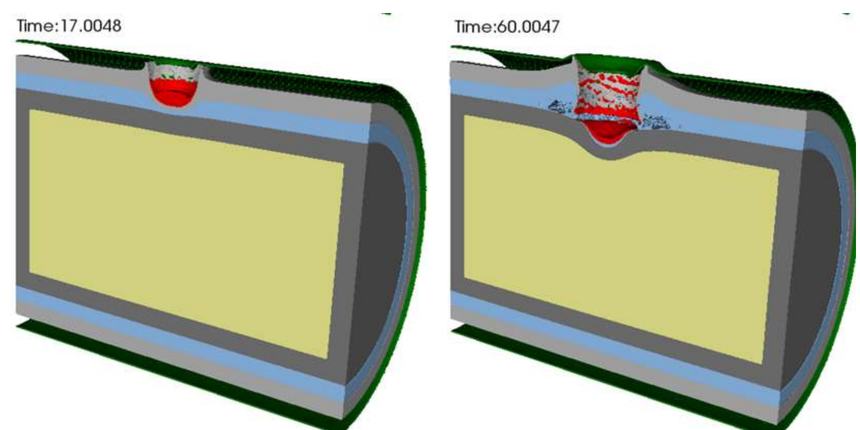
Baseline



0.25" Steel Container PIMS



0.375" Al Warhead PIMS

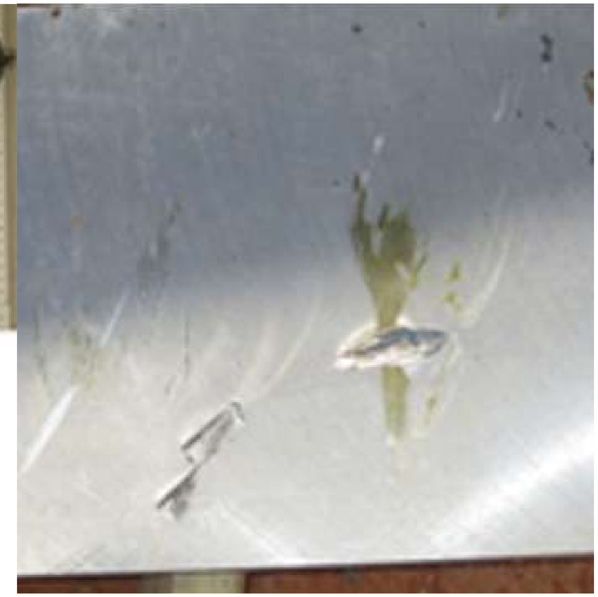


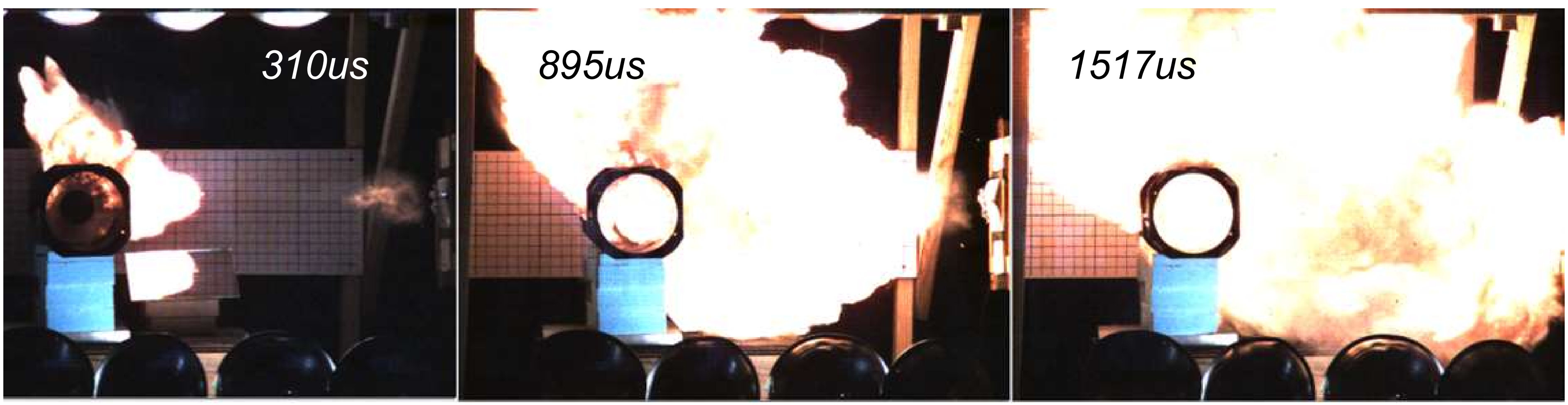
EXPERIMENTAL METHODOLOGY

- FI testing performed at GD-OTS Rock Hill test facility
- Nine warheads available
- 360 degree tube PIMS (conservative compared to arcs)
- Assembly mounted on acrylic discs and inserted into container
- Several thicknesses of 4140 steel and 6061-T6 aluminum PIMS fabricated
  - Limited quantity of 7075-T6 and hardened 4140 steel PIMS as well – evaluate strength effects
  - Modeling shows 1/8” increments reasonable
- Very good aimpoint accuracy and impact conditions achieved
- Blast pressures comparable to those produced by the gun

EXPERIMENTAL RESULTS – TEST 592 (BASELINE)

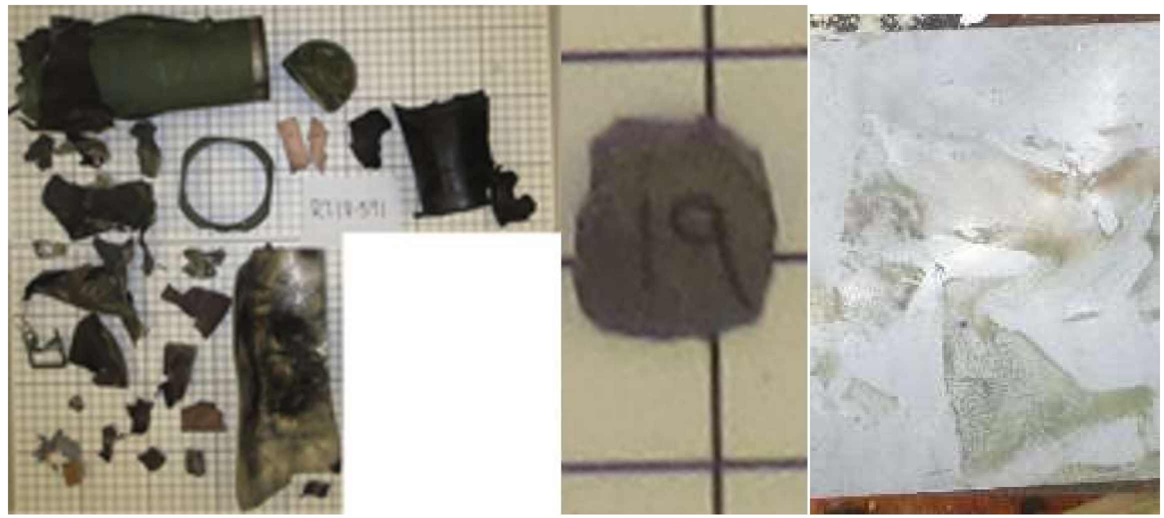
- Violent reaction observed (**Type III**)
- Launched large pieces of case, unreacted explosive, and nose/aft simulants outside the test facility
- Gouging on witness plate (occurred for all deflagrations)

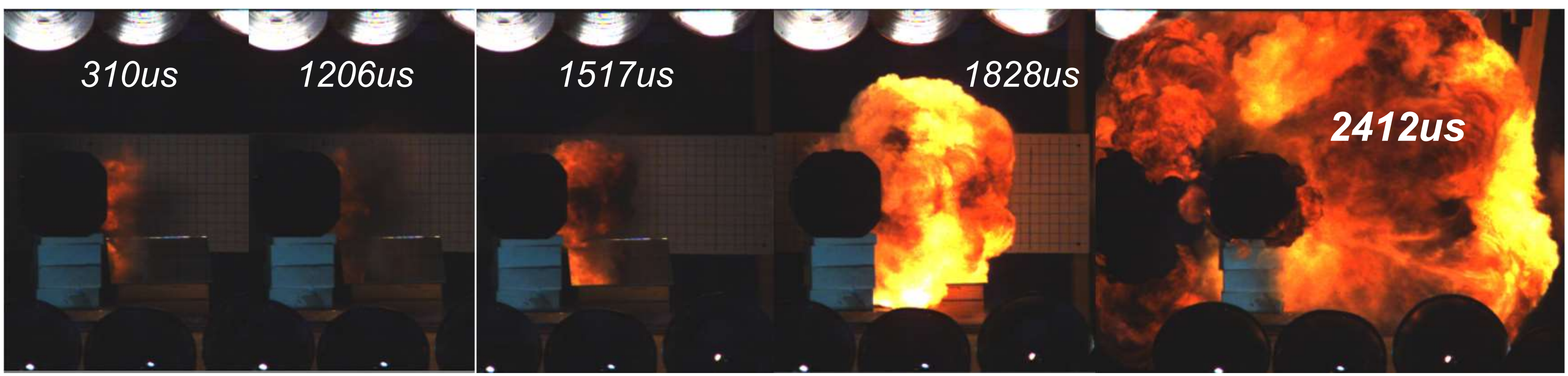




EXPERIMENTAL RESULTS – TEST 591

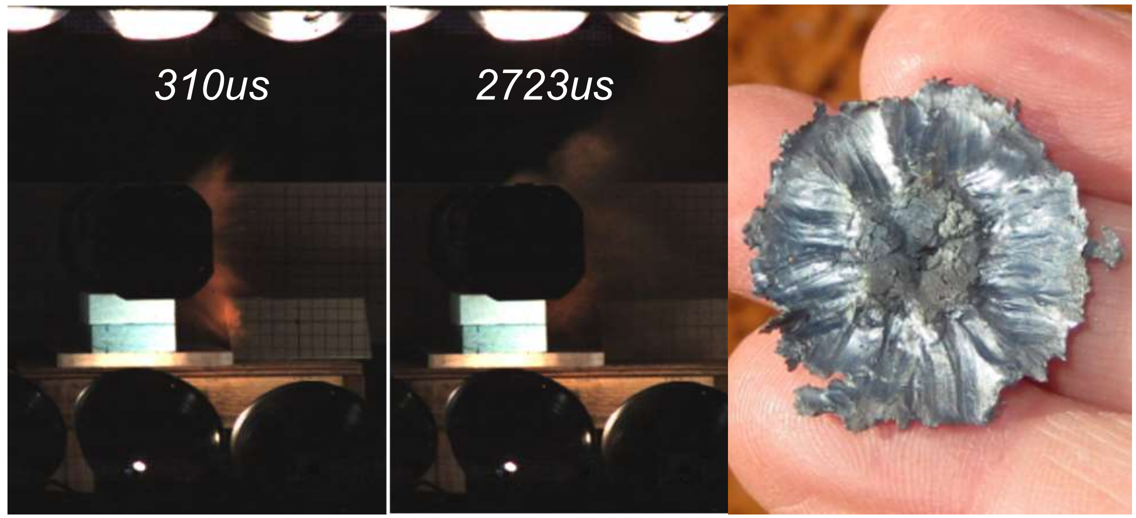
- 0.125” steel container PIMS (0.73 lb/in)
- Violent reaction observed (**Type III**)
- Delayed reaction until 1.5ms, plug of warhead body recovered
- PIMS fractured longitudinally through the impact point, blown through container in one piece, thrown 20 yards





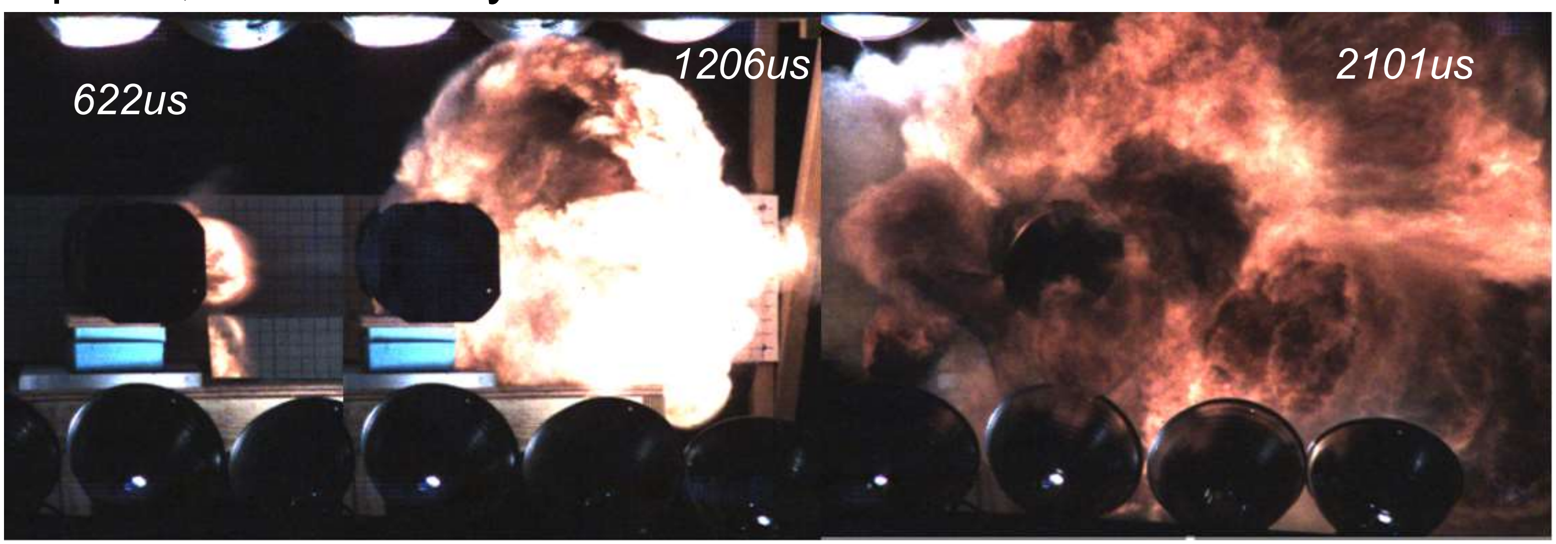
EXPERIMENTAL RESULTS – TEST 593

- 0.1875” steel container PIMS (1.07 lb/in)
- No reaction observed (**Type V**)
- Mitigation solution found; following tests attempt to further reduce weight per length of the PIMS on the fly with remaining hardware



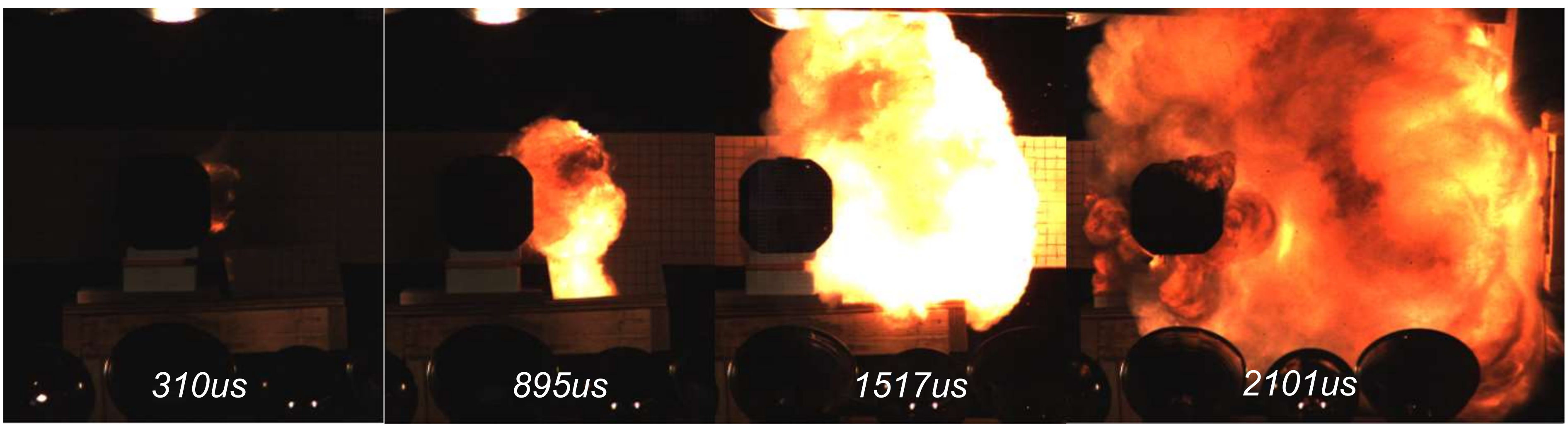
EXPERIMENTAL RESULTS – TEST 594

- 0.1875” steel warhead PIMS (0.96 lb/in)
- Violent reaction observed (**Type IV**)
- Warhead body split into several pieces, all recovered
- PIMS fractured longitudinally through the impact point, blown through container in one piece, thrown 100 yards



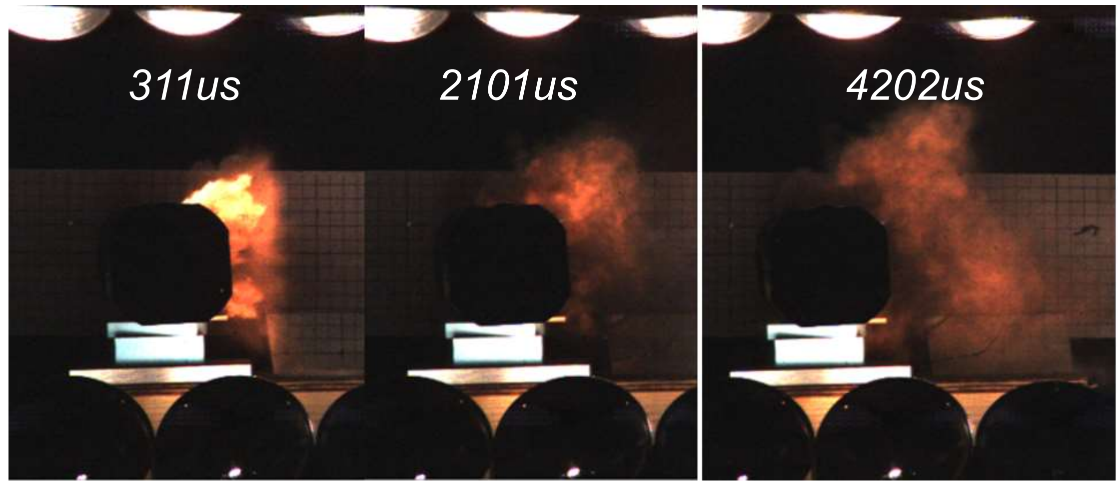
EXPERIMENTAL RESULTS – TEST 595

- 0.25” 6061 container PIMS (0.49 lb/in)
- Violent reaction observed (**Type IV**)
- Warhead body split into two halves, thrown 50 yards
- PIMS fractured longitudinally through the impact point, blown through container in one piece, thrown 30 yards



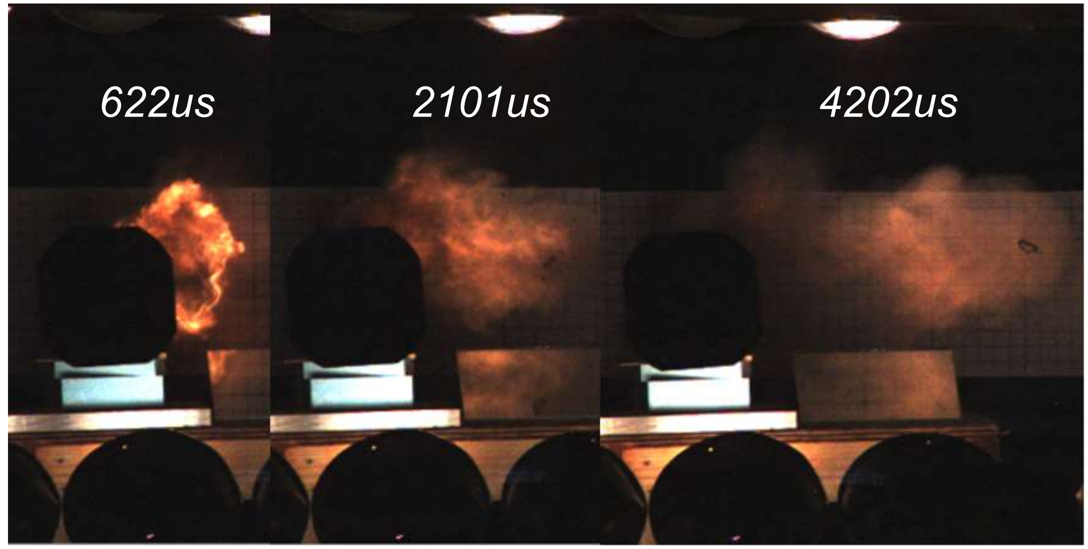
EXPERIMENTAL RESULTS – TEST 597

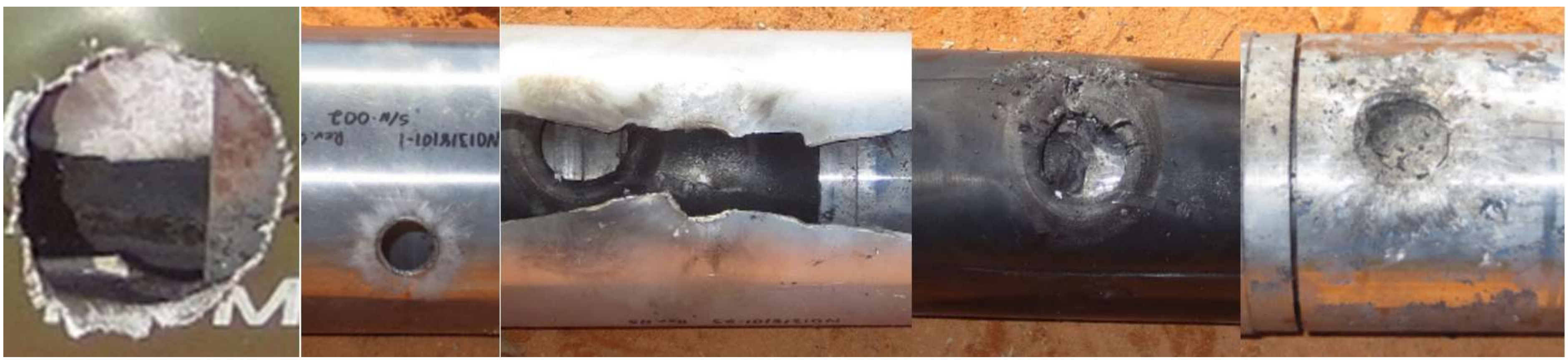
- 0.1875" hardened steel container PIMS (investigate whether choice of steel matters) (1.07 lb/in)
- No reaction observed (**Type V**)
- Warhead pulled from packaging intact with large dent containing residual fragment



EXPERIMENTAL RESULTS – TEST 598

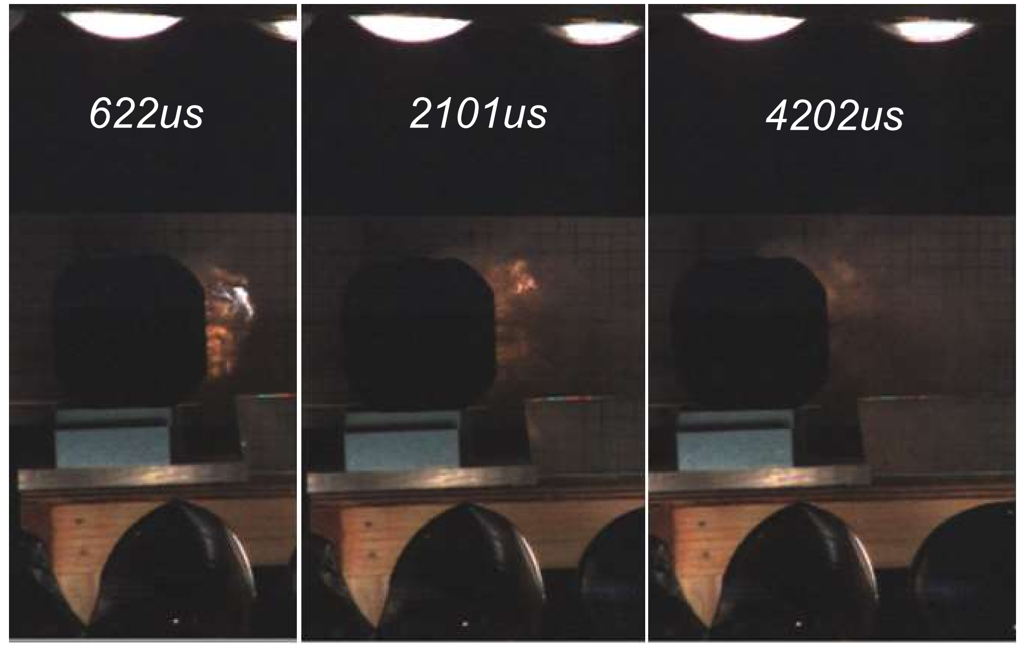
- 0.125” steel container PIMS with 0.125” 7075 aluminum warhead PIMS (0.96 lb/in)
- No reaction observed (**Type V**)
- Warhead pulled from packaging intact with large dent containing residual fragment

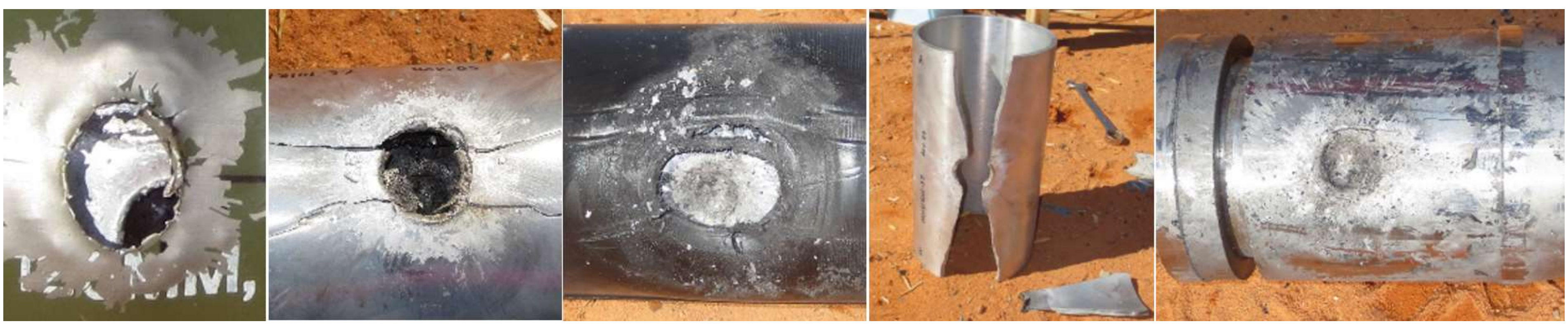




EXPERIMENTAL RESULTS – TEST 599

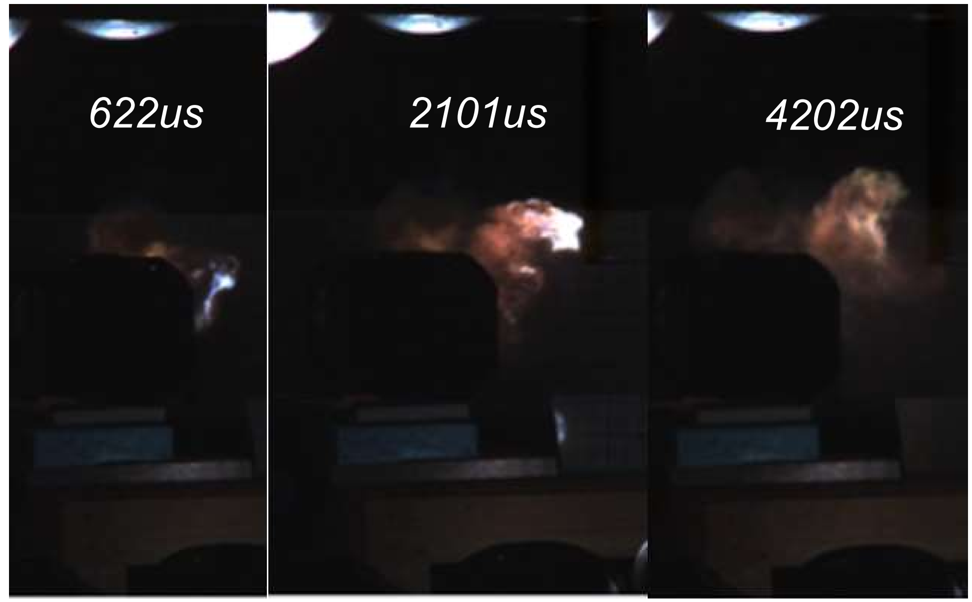
- 0.125” 6061 aluminum container PIMS with 0.25” 7075 aluminum warhead PIMS (0.72 lb/in)
- No reaction observed (**Type V**)
- Warhead pulled from packaging intact with large dent containing residual fragment

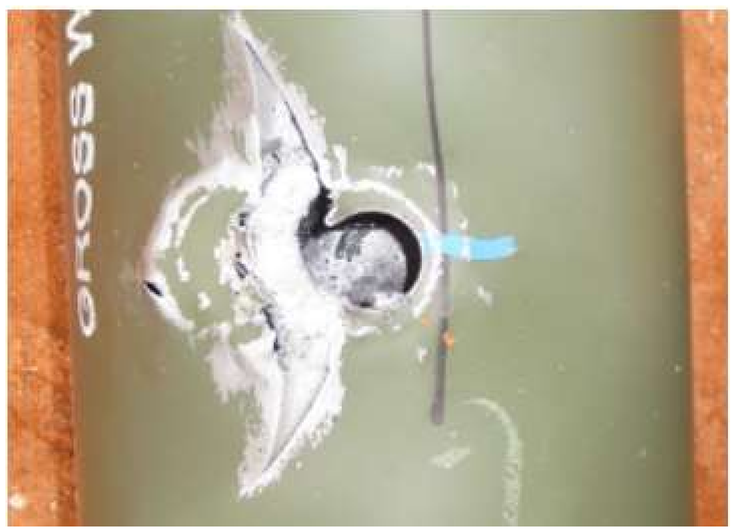




EXPERIMENTAL RESULTS – TEST 620

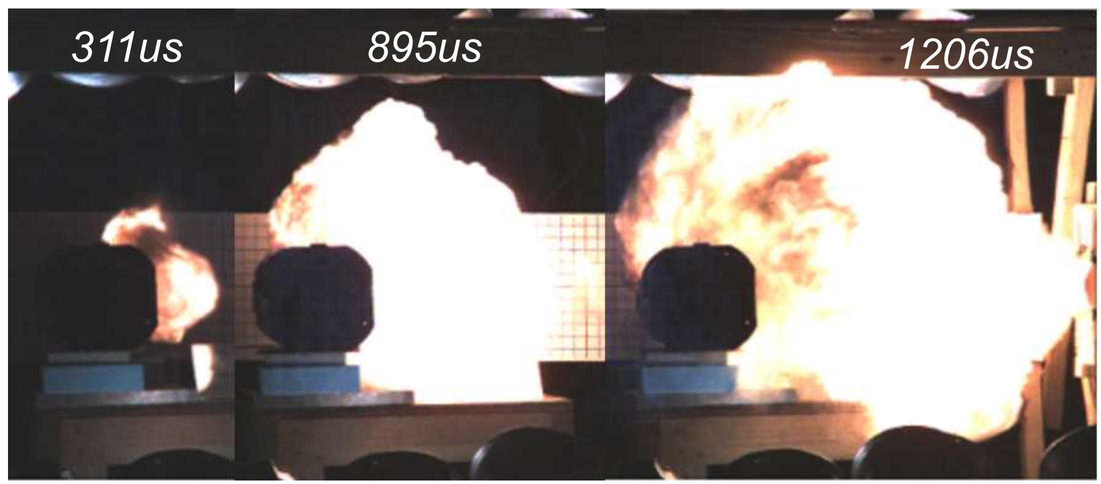
- 0.125” steel container PIMS with 0.125” 7075 aluminum warhead PIMS (0.70 lb/in)
- No reaction observed (**Type V**)
- Warhead could not be safely pulled from packaging





EXPERIMENTAL RESULTS – TEST 621

- 0.125” hardened steel warhead PIMS (0.63 lb/in)
  - Confines warhead less, only remaining design which would provide further weight improvement
- Violent reaction observed (**Type IV**)
- Warhead body split into two halves, thrown 100 yards
- PIMS fractured longitudinally through the impact point, blown through container in one piece, thrown 100 yards
- This concluded the test series



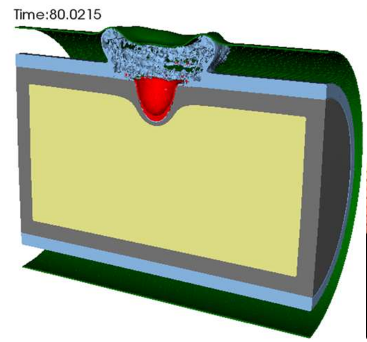
SUMMARY OF RESULTS

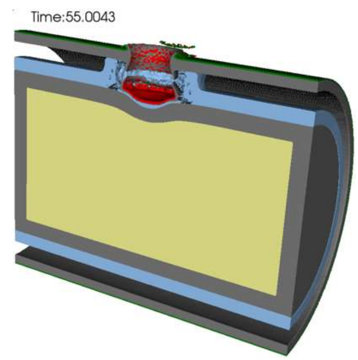
Serial No.	Container PIMS Material	Container PIMS Thickness (in)	Warhead PIMS Material	Warhead PIMS Thickness (in)	PIMS Weight per Length (lb/in)	Velocity (fps)	BOP at 10ft Peak 1 (psi)	BOP at 10 ft Peak 2 (psi)	Witness Gouge	Type
RT18591	Steel	0.125	---	---	0.729	8391	3.9	3	Y	III
RT18592	---	---	---	---	---	8253	---	1.9 at 20ft	Y	III
RT18593	Steel	0.1875	---	---	1.072	8345	1.75	---	N	V
RT18594	---	---	Steel	0.1875	0.959	8219	2.3	1.35	Y	IV
RT18595	6061 Al	0.25	---	---	0.490	8273	2.8	1.75	Y	IV
RT18597	Hardened Steel	0.1875	---	---	1.074	8287	2.2	---	N	V
RT18598	Steel	0.125	7075 Aluminum	0.125	0.956	8275	1.75	---	N	V
RT18599	6061 Aluminum	0.125	7075 Aluminum	0.25	0.716	8416	2.25	---	N	V
RT18620	6061 Aluminum	0.125	6061 Aluminum	0.25	0.700	8511	1.5	---	N	V
RT18621	---	---	Hardened Steel	0.125	0.628	8463	2.9	2	Y	IV

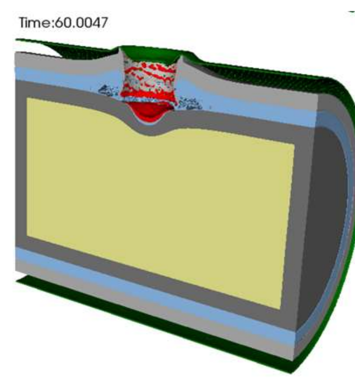
0.375” 6061 aluminum PIMS identified as lightest successful design!

CONCLUSIONS

- Several FI mitigation schemes for a 120mm warhead were modeled and tested
- Steel and aluminum PIMS
- Modeling used to qualitatively identify designs which produced minimal damage to warhead body
- Ballistic limit of warhead body has been suggested as an approximate threshold for violent sub-detonative response
- Aluminum spaced plate design was identified to fully mitigate FI with the least weight per unit length
  - 35% improvement over lightest steel PIMS found to work
- Steel hardness or aluminum grade did not appear to have an appreciable effect on test outcomes
- Future work – further optimization, more exotic materials



QUESTIONS

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