Verifying Performance of Thermobaric Materials for Small to Medium Caliber Rocket Warheads

by

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Agenda

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2. What is a Thermobaric Material
3. Thermobaric Material Performance
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5. Limitations on Thermobaric Materials
6. Optimization of Thermobaric Materials
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The Detonation Event

Detonation of Composite Explosives

- Detonation can be Viewed as Three Discrete Events Merged Together
  - 1. The Initial Anaerobic Detonation Reaction
    - Microseconds in Duration
    - Primarily Redox Reaction of Molecular Species
  - 2. Post Detonation Anaerobic Combustion Reaction
    - Hundreds of Microseconds in Duration
    - Primarily Combustion of Fuel Particles too Large for Combustion in Initial Detonation Wave
  - 3. Post Detonation Aerobic Combustion Reaction
    - Milliseconds in Duration
    - Combustion of Fuel Rich Species as Shock Wave Mixes with Surrounding Air

Note: Aerobic combustion as used here means combustion with air.

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What is a Thermobaric Material

First Thermobaric Weapons

- Russians Fielded first Thermobaric Materials 20 Years Ago
  - RPO-A or “Schmel” Fielded in 1984 was First Thermobaric Weapon
    - RPO-A is a Shoulder Launched Recoiless Inflantry Flame Thrower with a Thermobaric Warhead
    - Replaced LPO-50 Backpack Flame Thrower
- Russians have Developed and Deployed Several Other Thermobaric Weapons, although the RPO-A is the Most Readily Available World Wide
  - Examples of Russian Thermobaric Weapons Include:
    - TBG-7 Grenade Launched Round
    - RShG-1 Rocket Propelled Grenade

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What is a Thermobaric Material

Thermobaric Compositions

- Thermobaric Compositions are Fuel Rich High Explosives that are Enhanced through Aerobic Combustion in the Third Detonation Event
  - Performance Enhancement Primarily Achieved by Addition of Excess Metals to Explosive Composition
    - Aluminum and Magnesium are Primary Metals of Choice
  - Third Event Enhanced by Aerobic Combustion of Fuel Rich Species in Shock Front, ie:
    - $4Al + 3O_2 \Rightarrow 2Al_2O_3$
    - $2Mg + O_2 \Rightarrow 2MgO$
    - $2H_2 + O_2 \Rightarrow 2H_2O$
    - $2CO + O_2 \Rightarrow 2CO_2$

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What is a Thermobaric Material

Thermobaric Compositions

- Thermobaric Compositions are a Hybrid Explosive Composition having the Characteristics of both a High Explosive and a Fuel/Air Explosive
  - Compositions are Generally Detonable
    - Talley is Currently Working on a High Heat Output Formulation that may result in a non-detonable "Thermobaric" Composition
  - Compositions may be Liquid or Solid
    - Original Russian Formulations were Liquid
    - More Recent US Formulations are Solid
  - Compositions are Generally Less Sensitive than Classical High Explosives
- Highly Metallized Standard High Explosives meet the Definition of a Thermobaric Composition

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Thermobaric Material Performance

Thermobaric Compositions

- All Three Explosive Events can be Tailored to Meet System Performance Needs
  - Initial Detonation Reaction Defines System's High Pressure Performance Characteristics: Armor Penetrating Ability
  - Post Detonation Anaerobic Reaction Define System's Intermediate Pressure Performance Characteristics: Wall/Bunker Breaching Capability
  - Post Detonation Aerobic Reaction Characteristics Define System's Personnel/Material Defeat Capability - Impulse and Thermal Delivery

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Talley Thermobaric History

PROGRAM	SPONSOR	COMPLETION DATE	BRIEF DESCRIPTION OF EFFORT
Flame Incendiary Technology (FIT)	Talley IRAD	1990	Develop and Test Various Thermobaric Compositions
Shoulder-Fired Encapsulated Flame Thrower (SEFT)	CRDEC	1992	Develop and Test Various Thermobaric Compositions
Shaped Charge Follow Through (SCFT)	CRDEC	1994	Develop and Demonstrate Tandem (predator sized) and Unitary (TOE sized) Thermobaric penetrating Warheads
Conceptual Warhead Technology Program	MICOM	1995	Develop and Demonstrate Tandem (predator sized) and Unitary (TOE sized) Thermobaric penetrating Warheads
Concept Demonstrator	Talley IRAD	1999	Develop and Demonstrate Unitary Thermobaric Warhead for Carl Gustaf sized, 84mm Shoulder Launched Weapon
Concept Demonstrator	Talley IRAD	1999	Develop and Demonstrate Thermobaric Warhead for 40mm Door Breech Shoulder Launched Weapon
High Impulse Thermal (HIT) Materials Demonstration	Talley US Army	2001	Demonstrate Single, Tandem, and Bunker Firings of HIT Materials
SMAW-HIT Demonstration	Talley US Marine Corp.	2001	Demonstrate HIT Containing Warheads against Cave and Bunker Targets
Golden Dragon/Bring Down the House Demonstrations	Fort Leonardwood	2001/2002	Thermobaric Materials Demonstrations - Destroy an Earth & Timber Bunker and a Block House
SMAW NE	Quantico SYSCOM	2002	Develop and Qualify Thermobaric Dual Purpose Warhead for Marine's SMAW System

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Current Talley Thermobaric Programs

PROGRAM	SPONSOR	COMPLETION DATE	BRIEF DESCRIPTION OF EFFORT
High Heat	Edgewood Arsenal	In Progress	Manufacture And Test Various Thermobaric Compositions Maximizing Thermal Output
Thermobaric Composition Development CRADA	AMRDEC	In Progress	Manufacture And Test Various Thermobaric Compositions
Concept Demonstrator	NSWC Indian Head	In Progress	Develop and Demonstrate Unitary thermobaric warhead for 66 mm M72 sized shoulder launched weapon
Concept Demonstrator	Talley IRAD ARDEC	In Progress	Develop and Demonstrate Unitary thermobaric warhead for SMAW-D

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Limitations on Thermobaric Materials

Aerobic Combustion

- Aerobic Combustion Requires Mixing with Sufficient Air to Combust Excess Fuels
  - Most Themobaric Materials Require 3 - 6 lb. Air per lb. Material for Complete Combustion
  - Requires Expansion to V/V_0 of about 4000 to 8000 before Displacing Sufficient Air for Complete Combustion
    - Shock Wave Pressures at these Expansion Ratios are Less than 10 Atmospheres
    - Cheetah Simulations Predict Closer to 1 Atmosphere Ignoring Additional Energy Available from Aerobic Combustion
    - Majority of Aerobic Combustion Energy is Available as Heat
    - Some Low Pressure Shock Wave Enhancement can also be Expected (Personnel Defeat)

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Optimizing Aerobically Enhanced Explosives

- Aerobically Enhanced Explosives are Primarily Intended for Personnel/Material Defeat
- Selection of HE Type and Quantity Primarily Defines Detonation Reaction Characteristics
- Selection of Fuel Materials, Quantity, and Form (Particle Size, Morphology, etc.) Defines Both Anaerobic and Aerobic Combustion Reaction Characteristics
- Careful Selection of HE and Fuel Additives can Provide Multiple Target Defeat Capability (Armor, Structure, Material and Personnel Defeat)
- Personnel/Material Defeat with Minimum Collateral Structure Damage Requires Maximum Aerobic Enhancement
  - Highest Energy Practical Fuel Additives: Boron, Aluminum, Silicon, Titanium, Magnesium, Zirconium, Carbon, Hydrocarbons

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Metal and High Energy Non-Metal Fuel Additives

- Boron, Aluminum, and Hydrocarbons Provide Highest Practical Fuel Energy Density Based on Mass and Volume

Fuel Additive	Hcomb (cal/g)	Hcomb (cal/cc)
Boron	13,970	33,100
Aluminum	7,560	20,410
Titanium	4,260	19,130
Zirconium	2,880	18,390
Silicon	7,320	17,720
Carbon*	7,840	13,820
Magnesium	6,020	10,530
Hydrocarbons*	10,000	9,000

* Assumes combustion to CO2.

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Measuring Thermobaric Material Performance

Instrumentation Requirements

- Primary Outputs of Thermobaric Materials are Impulse and Heat
  - Temperature and Heat Flux Provide Best Assessment of Thermal Output
    - Temperature Measurements Should use Finest Gauge Thermocouple Wire Practical (Talley has Successfully used 36 AWG, 40 AWG too Mechanically Weak)
    - Thermocouple Bead Must Stand off From T/C Lead Wire Support by at Least 10 Wire Diameters
    - Blast Shielding Should be at least 5 Shield Diameters Upstream of Instrumentation
    - Heat Flux Gauges should be Fast Response (<0.05 sec.) and Robust (High Heat Fluxes will Damage More Sensitive Gauges)

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Measuring Thermobaric Material Performance

Instrumentation Requirements

- Pressure Transducers Should be very Fast Response (piezo-capacitive or resistive w\ > 400 kHz response recommended)
- Pressure Transducers should be Protected from Temperature and Light
  - Extremely High Thermal output of Thermobaric Compositions will Result in False Readings and Transducer Damage if not Protected
    - >= 0.06” Opaque RTV or Permatex Recommended
    - Thick Protective Layer Requires Stiff Transducer Element to Minimize Effect on Response Time (piezo elements work best)
- Transducers Should be Unobstructed
  - Placing Transducer Face Perpendicular (side on) to Shock Wave Maximized Protection of Transducer Element from Shrapnel

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Measuring Thermobaric Material Performance

Instrumentation Maintenance

- Thermocouple Beads must be Inspected and Cleaned after each Shot
  - No foreign Residue Allowed on Bead or Bridging Lead Wires
- Heat Flux Gauges Must be Cleaned after Each Shot
  - No foreign Residue Allowed on Heat Flux Element
  - Complete Removal and Replacement of Black Paint off of Heat Flux Element Between Each Shot Highly Recommended
    - Black Stencil Ink Provides Very Good Black Body Response with Fast Response Time
      - Ink Thickness <0.0005”
      - Easily Dried with Heat Gun in <1 Minute
      - Carbon Black Loaded for Excellent Thermal Conductivity and Good Emissivity

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Measuring Thermobaric Material Performance

Instrumentation Maintenance & Setup

- Pressure Transducers should be Inspected after Each Shot
  - Clean Foreign Matter From Transducer Face
  - Replace Protective Coating as Required
- Make Sure Debri Shields are Oriented to Protect Gauges from Shrapnel Prior to Each Shot
  - Gauge Stands can get Bumped causing Improper Alignment
- Where Possible Set up Gauges and Charge to Minimize Reflections
- Other than Shrapnel Shields, Provide Direct Line of Sight to Charge

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Thermobaric Material Performance Comparison

Enclosure Test Comparison

- Enclosure Test Performed in 12' x 8' x 10' Reinforced Concrete Enclosure
- Constant Volume Charge
- Baseline Charge: 1 lb. C4
- Themobaric Charge: 1.6 lbs. Talley Mix 5672-10

32% wt Aluminum
40% wt Zirconium
26.75% wt Isopropyl Nitrate
1.25% wt Gellant

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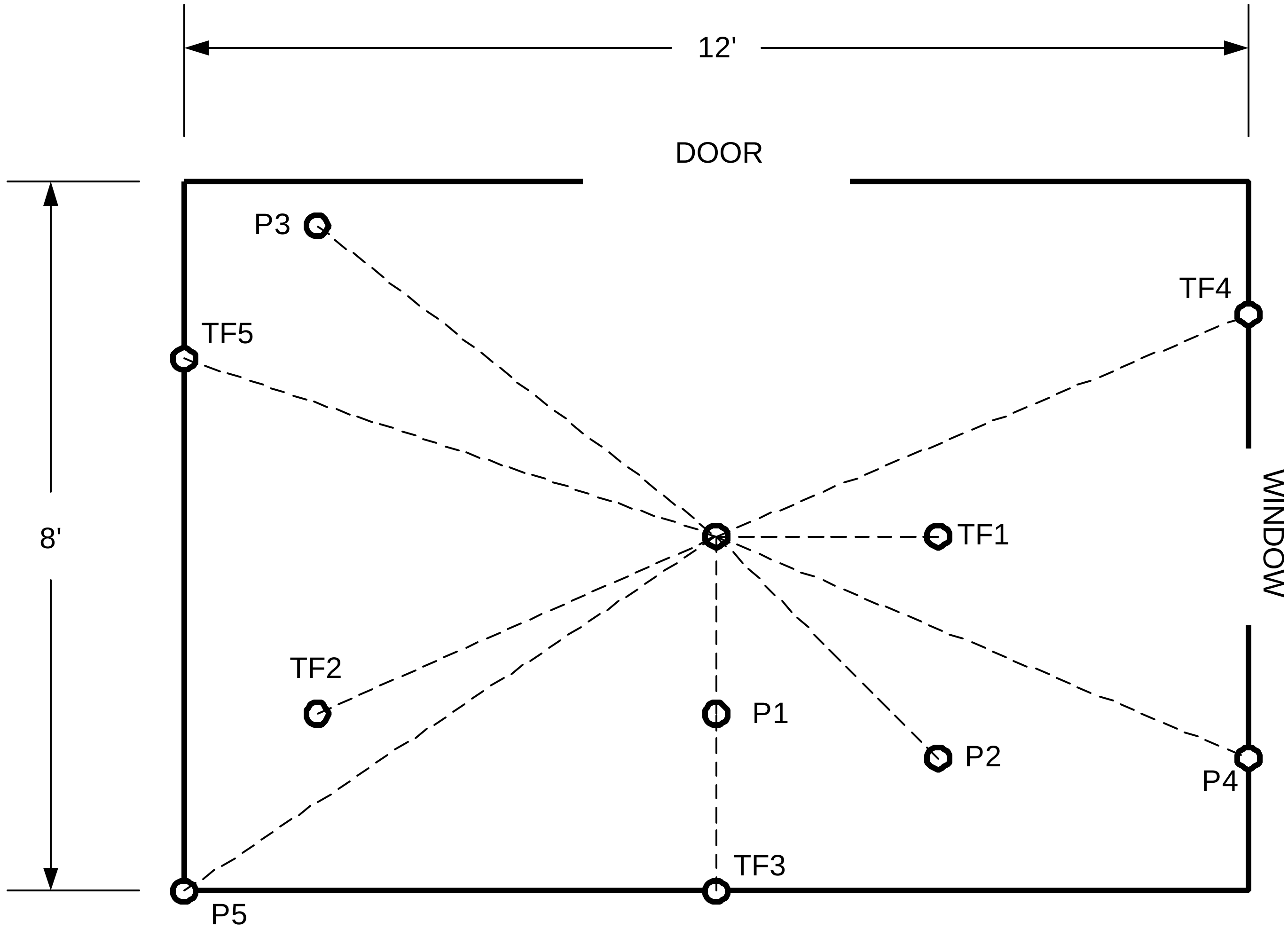
Thermobaric Material Performance Comparison

Instrumentation Locations for Enclosure Test



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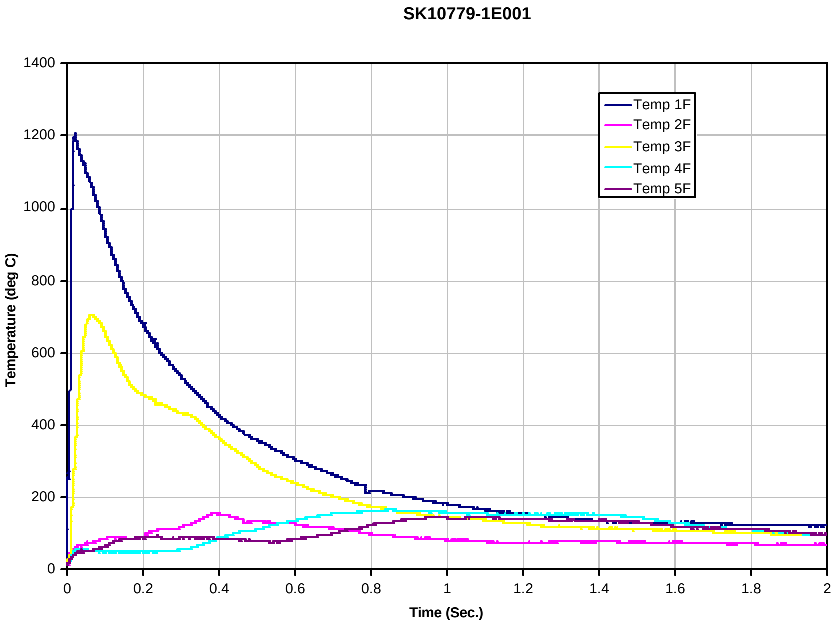
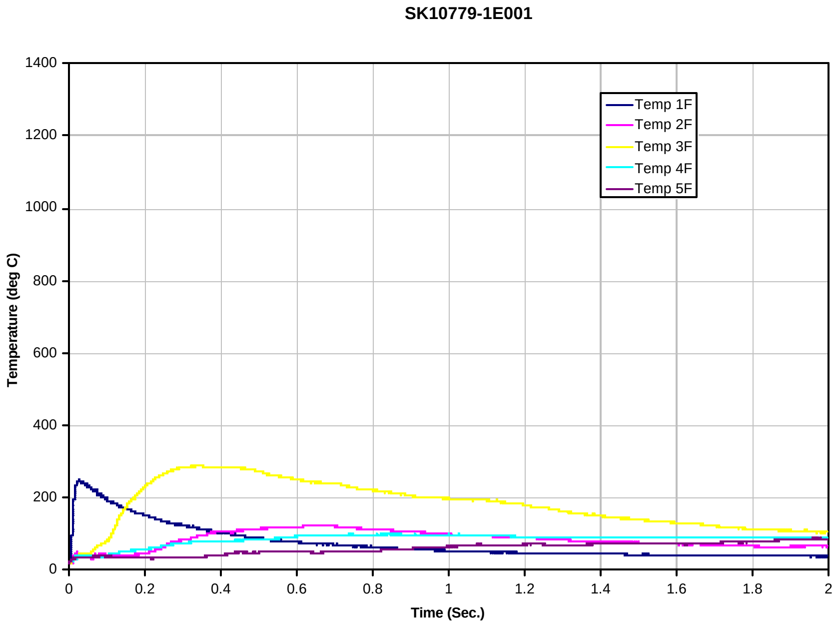
Thermobaric Material Performance Comparison

Enclosure Test: Temp -Time History

Thermobaric Mix 5672-10 vs. C-4 Baseline





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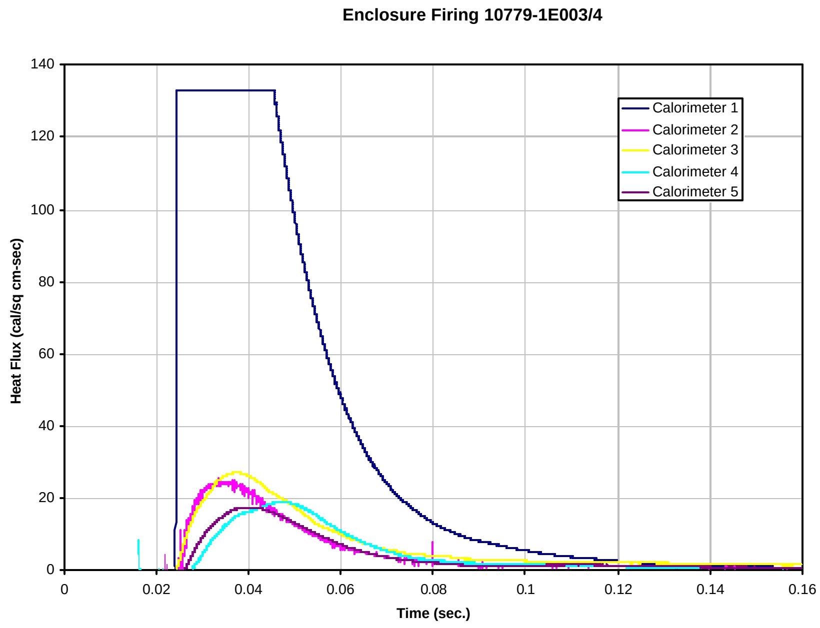
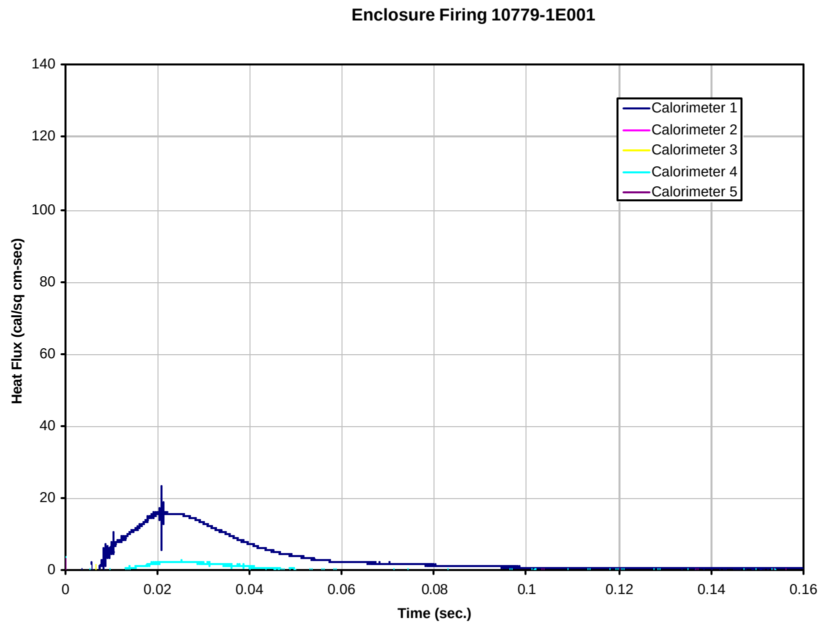
Thermobaric Material Performance Comparison

Enclosure Test: Heat Flux -Time History

Thermobaric Mix 5672-10 vs. C-4 Baseline





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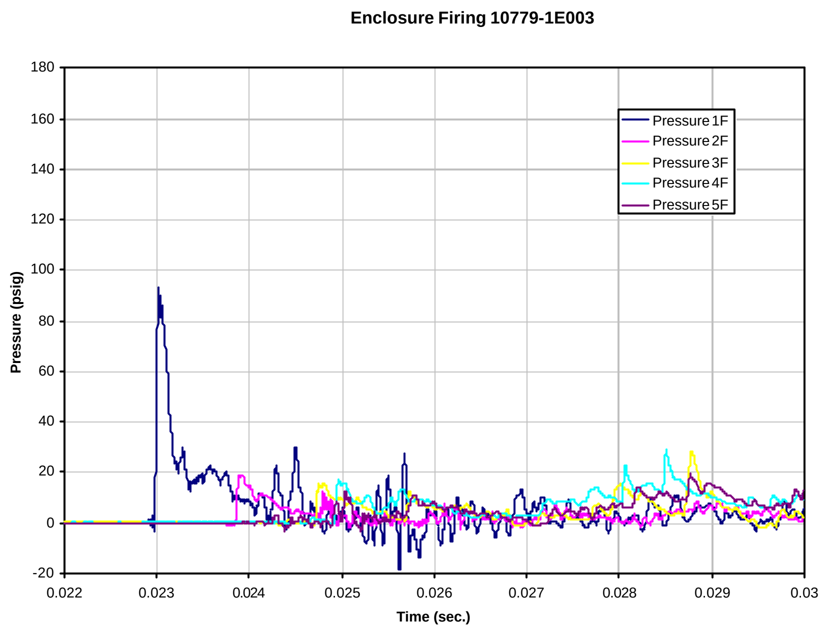
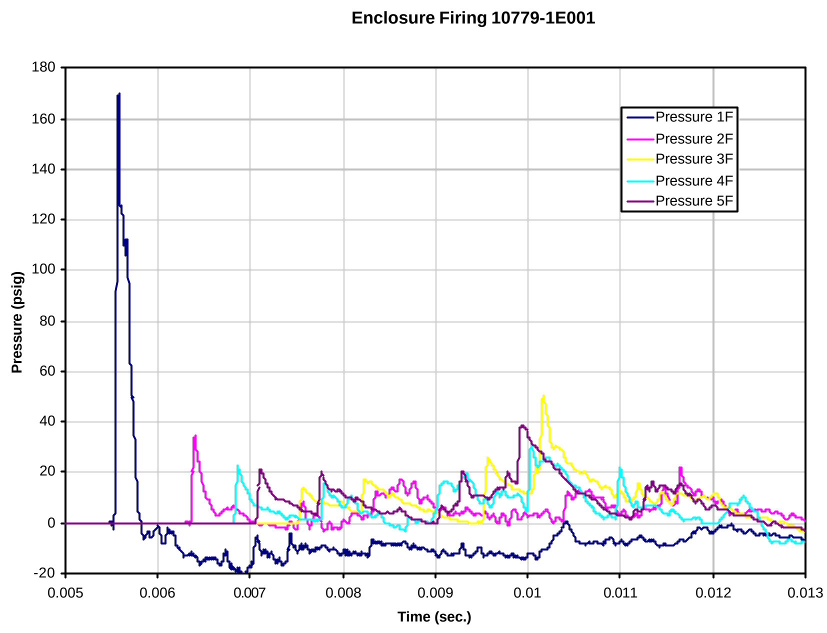
Thermobaric Material Performance Comparison

Enclosure Test: Pressure -Time History

Thermobaric Mix 5672-10 vs. C-4 Baseline





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Conclusions

Advantages of Thermobaric Materials

- Thermobaric Materials are Low Sensitivity Materials Ideal for Use in Insensitive Munitions
- Thermobaric Material Performance can be Tailored to the Target Set of Interest
  - Output can be Tailored from High Blast to High Thermal Output
- Thermobaric Materials are Best Suited to Personnel/Material Defeat
- Thermobaric Materials can Provide Significantly Higher Total Energy Output than Conventional High Explosives
  - Majority of Additional Energy Available as Low Pressure Impulse and Heat

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