National Institute of Justice 2007-DE-BX-K002

Standoff Defeat Technology for Domestic VBIED Threats

NIJ Briefing 14 May 2008

Develop Conops for “Ryder truck threat”

Develop Reactive Projectiles to neutralize threat

Demonstrate effectiveness against ANFO

System must be compatible with

12-gauge disruptor

Robotic platform

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VBIED: Program Goals & Team

- Program Goal
  - Neutralization of typical explosives (e.g. ANFO) in VBIED domestic scenarios
    - Solution must not detonate the ANFO
    - Solution must eliminate or significantly reduce collateral damage
    - Solution must be compatible with the bomb squad operational tactics & tools
- Neutralization Method
  - Projectile carrying a specialized reactive material (RM) fired into explosive to cause a vented deflagration
    - Ballistic impact initiates RM, which subsequently produces a controlled self-propagating reaction, e.g. deflagration of the ANFO
    - Must work for “lightly” confined 55 gal drum
- Platform
  - Develop a RM projectile compatible with common bomb squad equipment, specifically a 12-gauge disruptor
    - Subscale testing with 0.50 cal reveals new tool for SWAT

VBIED Program Risks & Status

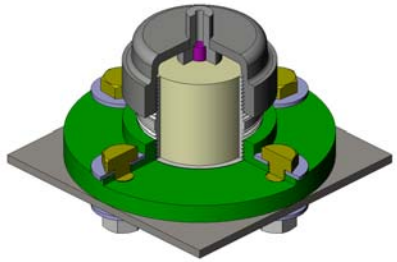
- Risks/Challenges
  - RM must be able to take setback loads from gun launch, but
    - RM must react from shock loading created by the ballistic impact to a 55 gal drum containing ANFO
  - RM must burn a sufficient mass of ANFO to produce sufficient overpressure to rupture 55 gal drum
  - ANFO must not detonate
- Status
  - Critical elements of the technology have been demonstrated
    - Developed RM projectile that ignites upon impact w/ 1/16-in steel plate
    - RM repeatedly causes deflagration of ANFO in static tests
      - RM shown to have unique characteristics
      - 19 static test experiments performed
    - Successful render safe solution in small-scale dynamic test
      - 0.50 cal RM bullet into ½ gal bucket w/ 1500 g (3.3lb) of ANFO
      - 28 dynamic test experiments performed
    - Intermediate-scale tests (~ 40 lb of ANFO in 5 gal bucket) on 5/31/08 were successful – produced render safe soltion

VBIED Test Protocol

NIJ Test Program is similar to EMPI's DTRA and JIEDDO C-IED Program for 155mm artillery shells and mirrors the work by NSWC/Indian Head

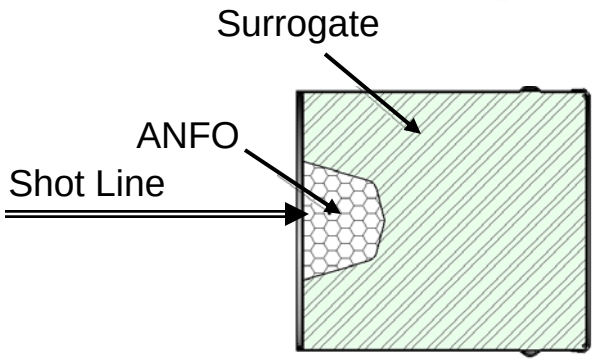
Three Basic Test Articles:

- Heavy Confinement Pipe Bomb
  - ANFO mass: 330 g (3/4 lb)
  - ANFO Mass: 660 g (1 ½ lb)
- Light Confinement Buckets
  - 0.5 gal bucket (ANFO mass: 1.5 kg (3.3 lb)
  - 5.0 gal bucket (ANFO mass: 2.0 kg (4.4 lb) remainder surrogate
  - 5.0 gal bucket (ANFO mass: 18 kg (40 lb)
- 1/16" plate to test RM initiation threshold



Two Test Configurations:

- Static Tests: RM initiated by detonator
  - Isolates effect of RM from bullet impact
- Dynamic Tests: RM initiated by ballistic impact
  - Bullet (kinetic) + RM (chemical) energy



VBIED Test Plan Summary

Nine Month Feasibility Study

- Test Plan Summary
  - **Static Tests:** Conduct a series of "static tests" to demonstrate ability of RM to produce a vented deflagration against ANFO
    - RM is initiated by a detonator to simulate ballistic impact
    - Small-scale (up to 4.4 lb of ANFO) laboratory tests with diagnostics
  - **Dynamic Tests:** Conduct a series of "dynamic tests" using optimal RM from static tests against ANFO
    - Small-scale (up to 4.4 lb of ANFO) laboratory tests with diagnostics
    - Initial dynamic tests will use a sub-scale (.50 caliber) projectile
    - Final dynamic tests will use RM projectile fired from a 12 gauge disruptor
  - **Develop CONOPS:** The technology shall be compatible with existing operational issues and tools used by domestic bomb squads

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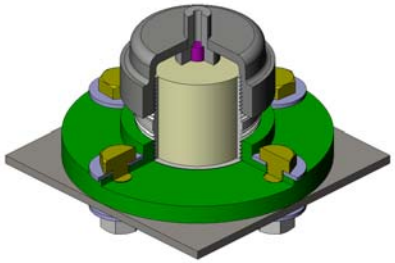
VBIED Task Summary

Six Basic Test Sequences: Three static and three dynamic tests

- **Task 1: CONOPS**
  - Additional requirement to show integrated solution
- **Task 2: 1st Static Test:** (Test RM on ANFO)
  - Similar geometry & confinement of NSWC/IH test rig
  - Quickly demonstrated "qualified" render safe solution w/ APEX* RM
- **Task 3: 2nd Static Test:** (Determine Pressure Field)
  - Obtain useful "scientific" data using carbon gages
- **Task 4: 3rd Static Test:** (Test RM on ANFO)
  - 5 gal bucket w/ 4.4 lb of ANFO plus surrogate
  - Demonstrated "qualified" render safe solution w/ APEX RM
- **Task 5: 1st Dynamic Test:** (RM Projectile Function)
  - Demonstrated projectile function: reaction at ~ 850 m/s but no reaction at ~700 m/s against 1/16" plate
- **Task 6: 2nd Dynamic Test:** (Test RM Projectile on ANFO)
  - 1/2 gal bucket (3.3 lb of ANFO) 50 cal reactive bullet
  - Demonstrated render safe solution w/ APEX RM
- **Task 7: 3rd Dynamic Test:** (Test RM projectile on ANFO)
  - 5 gal bucket w/ 4.4 lb of ANFO plus surrogate – Lab Tests
  - 5 gal bucket w/ 40 lb of ANFO – Field Tests 30 May 2008
  - Demonstrated render safe solution w/ APEX RM



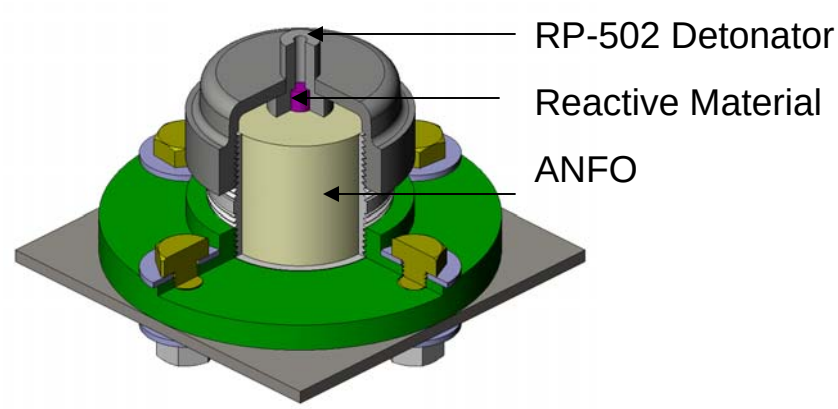
Heavy Confinement Test Article

Light Confinement Test Article

Task 2: Static Test of RM on ANFO

First Static Tests w/ Pipe Bomb Geometry

- **Objective:** Demonstrate deflagration of ANFO using different RMs
- **Test Plan:** Deflagrate 330 g (3/4 lb) and 660 g (1 ½ lb) of ANFO with RM initiated with an RP-502 detonator
- **Schedule:** Tests began on 14 Nov 2007 and ended on 24 Nov 2007
- **Deliverables:** Post-test analysis of pipe bomb to show successful "render safe" solution in laboratory scale test.
- **Status:** Completed - "render safe" proof-of-concept successful



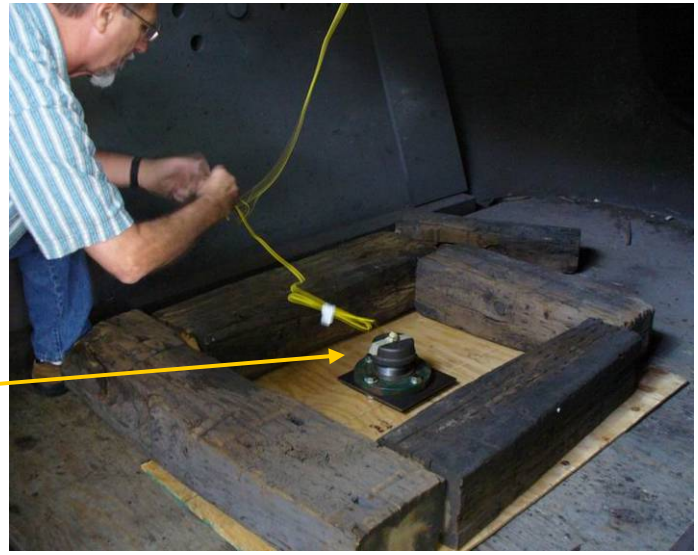
Schematic of Test Article

Post Test Photograph

Task 2: Sample of Test Results

2nd Static Test
14 Nov 2007

Test article loaded into explosion tank



Top view of post test “pipe bomb” with minimal ANFO residue on bottom plate

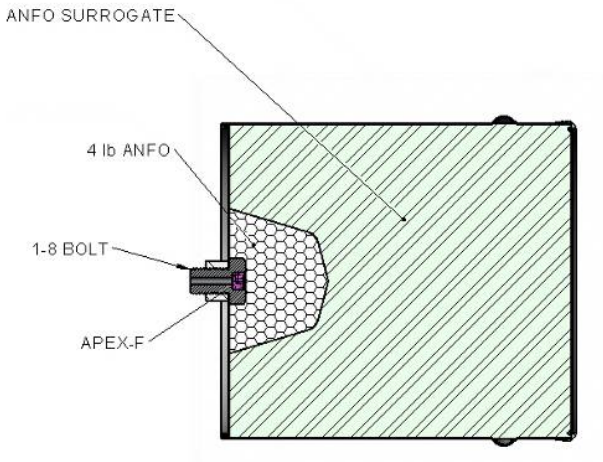
Side view showing ¼ - in base plate deformation from pressure buildup but no detonation

Task 4: Static Test of RM on ANFO

Third Static Tests w/ 5 Gallon Bucket Geometry

- **Objective:** Demonstrate deflagration of ANFO w/ realistic "inertial" confinement and obtain engineering data
- **Test Plan:** Test using a 5 gallon metal bucket filled with 4 pounds of ANFO and the remaining volume w/ an appropriate surrogate material
- **Schedule:** Bucket tests begin on 3/07/2008
- **Deliverables:** Post-test analysis to show successful "render safe" solution in laboratory scale test and pressure data from carbon gauge
- **Status:** Qualified render safe solution

3-D View of Test Article



Cross section of Test Article

Task 4: Static Test of RM on ANFO

Static Test 17: 5 Gallon Bucket 1/4” Base Plate, Bottom Charge Geometry, APEX RM mass ~ 13 g

2000 g of ANFO

Bucket base blew open, lower bucket bulged

Qualified Render Safe Solution

Task 4: Static Test of RM on Inert

Static Test 18: 5 Gallon Bucket, 1/4” Base Plate,
Bottom Charge Geometry, APEX RM mass ~ 13 g

Surrogate (Inert) Fill

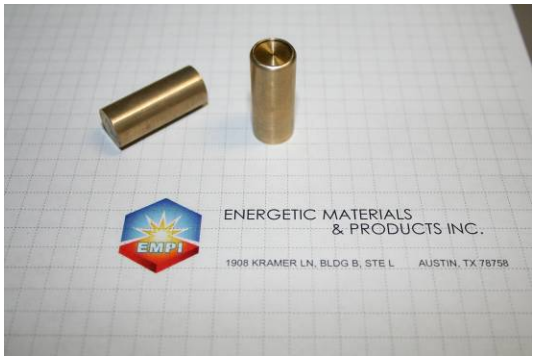
Comparison of Inert vs. ANFO

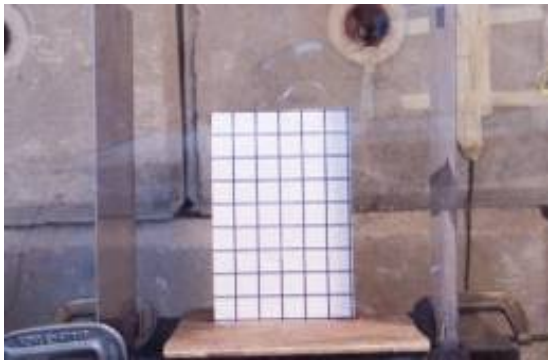
Conclusion: RM/ANFO reaction produces desired overpressure

Task 5: RM Projectile Function

First Dynamic (50 cal) Tests w/ Plate Geometry

- **Objective:** Demonstrate initiation of RM with .50 cal projectile on impact with the thin skin of the target. This step will help refine the final bullet design and determine the initiation threshold of the RM.
- **Test Plan:** Design and test sub-scale 0.50 caliber at 650-900 m/s. High-speed and open shutter images of the impact process will be taken. AUTODYN simulation conducted to support design of candidate projectiles.
- **Schedule:** Loading curve shots on 2/22/2008. RM shots against 1/16-inch plate began on 2/6/2008 and end by 4/15/2008
- **Deliverables:** Post-test analysis and high speed images
- **Status: Initial** RM Projectile design was successful

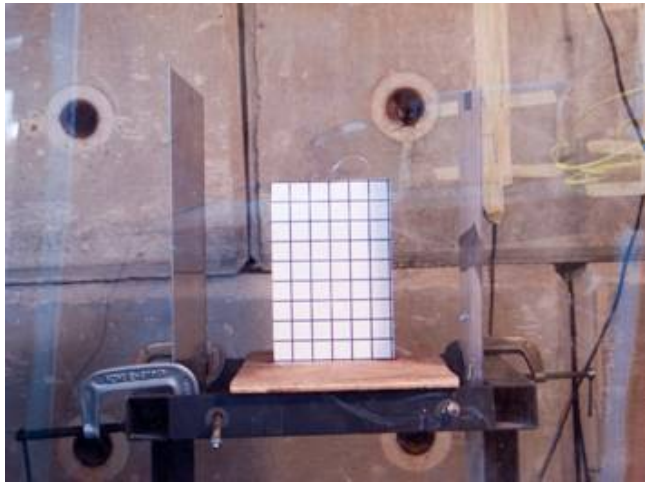




Task 5: 0.50 Cal Round

Spin Stabilized 0.50 cal bullet, m = 18.59 g
APEX 17/17 RM, m = 5 g
Target = 1/16” Steel Plate
Velocity= 862 m/s

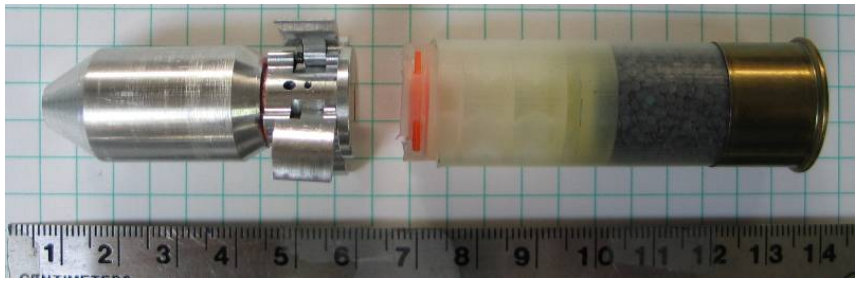
RM Formulation is Critical for Bullet/RM Function

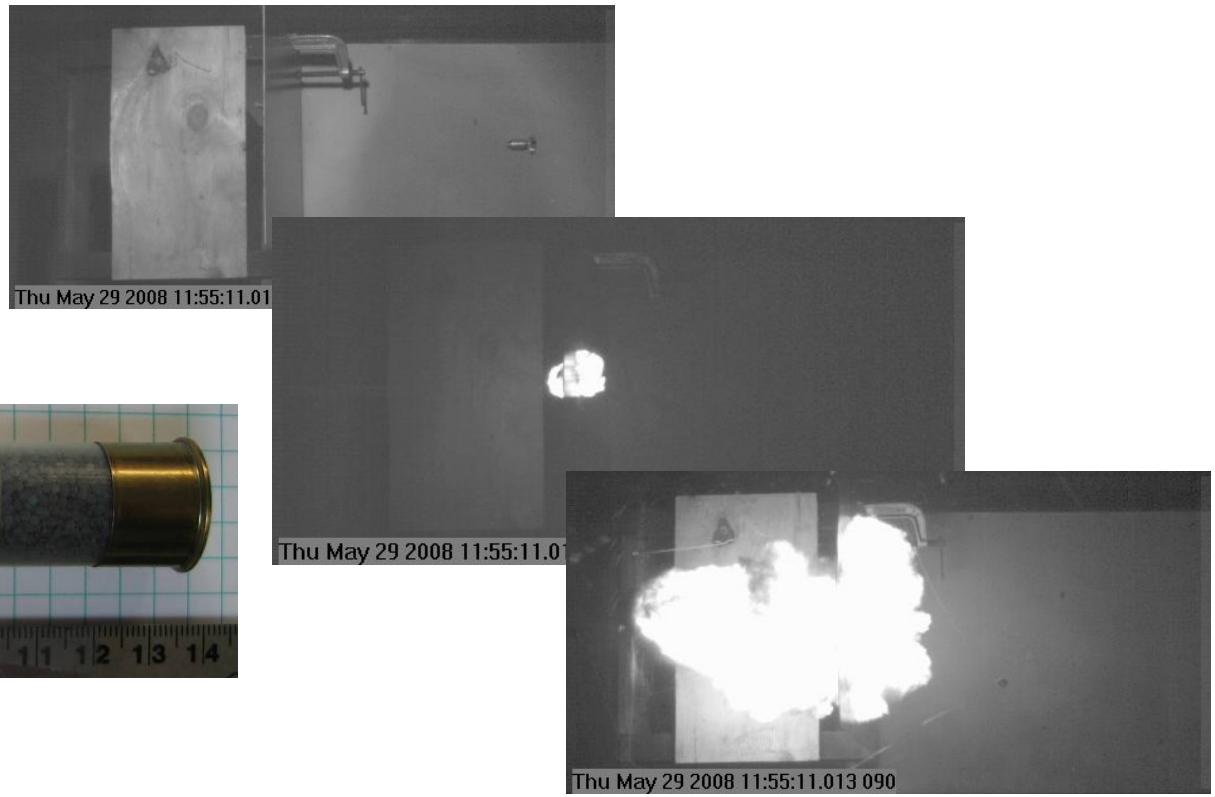


Open Shutter Image

Task 5: 12 G Disruptor Round

- *Fin Stabilized Bullet Test*
- Ballistics: *360 m/s*, 7.0 grams Blue Dot Powder, plastic wad, 2.75” plastic hull
- Target: 1/16” steel sheet
- Result: projectile stable and RM initiates upon impact w/ plate

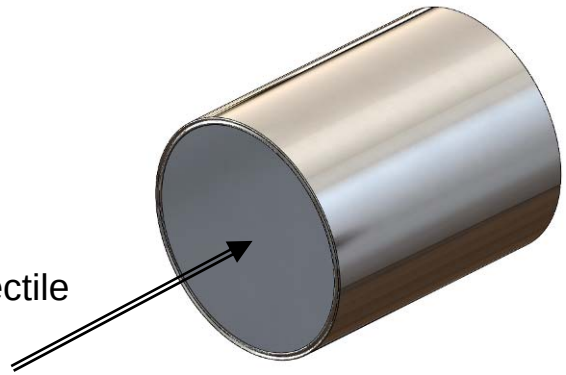




Task 6: RM Projectile into ANFO

Second Dynamic (50 cal) Tests w/ 0.5 Gallon Bucket Geometry
Lab Scale Testing

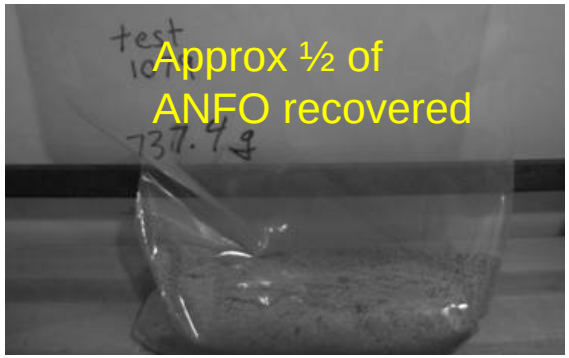
- **Objective:** Demonstrate deflagration of ANFO w/ realistic “inertial” confinement. This test will confirm that our render safe approach works by showing that the RM causes a deflagration of the ANFO.
- **Test Plan:** RM projectile fired into bucket with 4 lb of ANFO with the remaining volume filled with surrogate material.
- **Schedule:** Tests begin on 04/1/08 and end by 05/1/08
- **Deliverables:** Post-test analysis of metal bucket showing successful “render safe” solution in laboratory scale test
- **Status:** Demonstrated render safe solution



Task 6: RM Projectile into ANFO

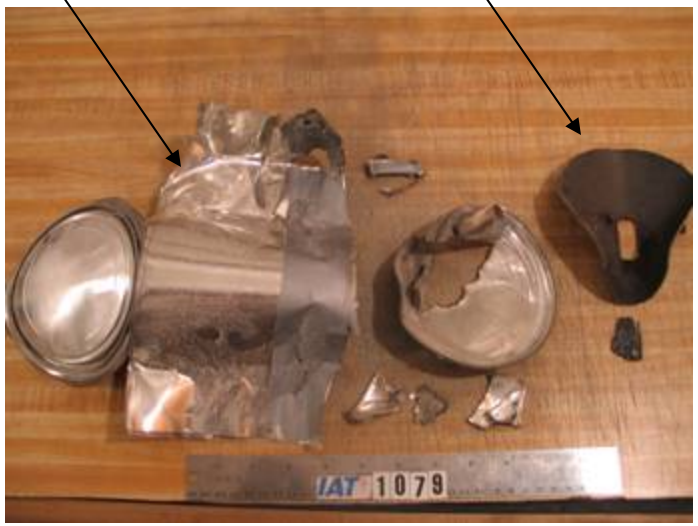
First successful render safe shot on 25 April 2008

Bullet 0.50 cal: m = 18.5 g,
APEX 17/17 m = 5.0 g
Target: 1/2 gal bucket w/
1/16” cover, 1500 g ANFO
Velocity = 821 m/s



can split no exit hole

yawed impact



Task 6: RM Projectile into ANFO

Bullet 0.50 cal: m = 18.81 g,
APEX 17/17 m = 5.06 g
Target = 1/2 gal bucket w/ 1/16" cover plate, 1540 g ANFO,
Velocity = 748 m/s

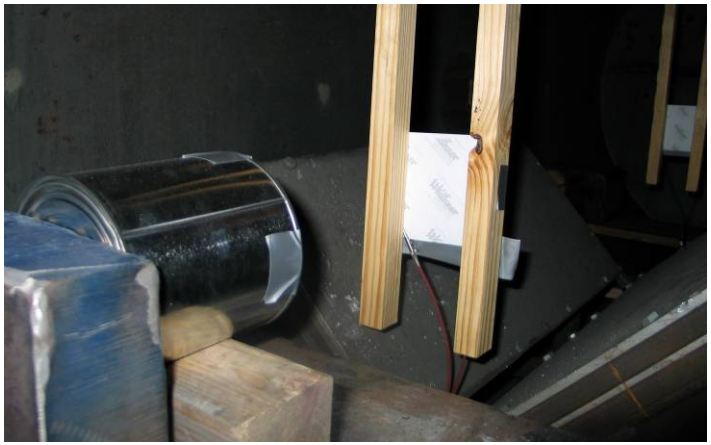
Presumed Deflagration, ~ 10% of ANFO consumed, wood block stand survived

ANFO splattered on wall

Task 6: RM Projectile Into ANFO

Presumed Detonation, ANFO all consumed, wood block stand consumed

Bullet 0.50 cal: m = 18.6 g,
APEX 17/17 m = 5.15 g
Target = 1/2 gal bucket w/ 1/16”
cover plate, 1500 g ANFO
Velocity = 987 m/s

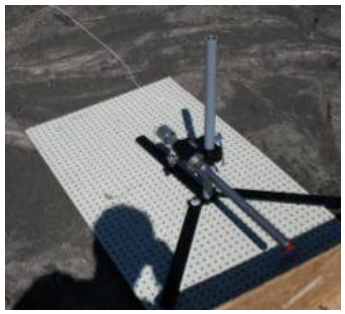


RM Projectile velocity appears to be critical!

Task 7: RM Projectile into ANFO

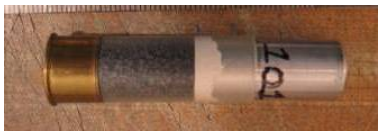
Third Dynamic (PAN Disruptor) Tests w/ 5 Gallon Bucket Geometry

- **Objective:** This test will confirm that our technology works by showing that the ANFO burns from a 12-gauge bullet impact and the subsequent RM/ANFO reaction opens the bucket and disperses the ANFO.
- **Test Plan:** Redesign projectile for 12-gauge barrel. Target 5 gal bucket w/ 4.4 lb ANFO and remaining surrogate.
- **Schedule:** Tests begin on 05/05/2008
- **Deliverables:** Post-test analysis
- **Status:** Testing complete

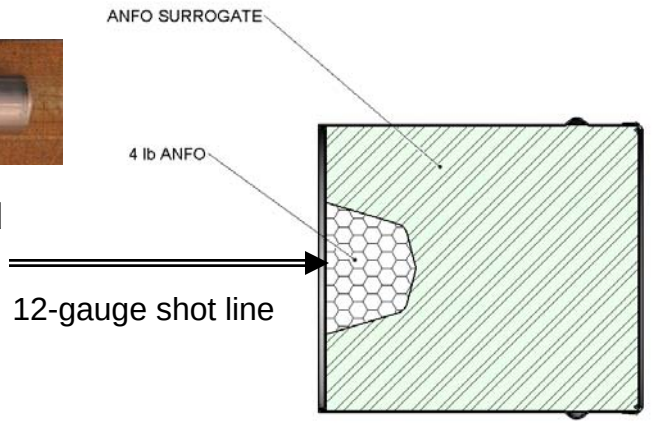


Disruptor Cannon

Final Spin-Stabilized
RM Disruptor Round



RM Test Round



Task 7: RM Projectile into ANFO

Bullet 12 gauge: m = 26.57 g,
APEX 17/17 m = 15.93 g
Target = 5 gal bucket w/ 1/16” cover plate
Velocity = 765 m/s

2000 g of ANFO

Small-scale Lab Tests

No apparent reaction
Suspected cause: The impact velocity for the 12 gage round may be too low. Surrogate may have an influence on overpressure

Test conducted 5/7/09

Task 7: RM Projectile into ANFO

Bullet 12 gauge: m = 26.02 g,
APEX 17/17 m= 16.10 g
Target = 0.5 gallon Bucket w/ 1/16" cover plate
Velocity = 800 m/s

Small-scale Lab Tests

1540 g of ANFO

Cover Plate

Deflagration w/ ~10 % ANFO consumed. The increase in velocity may have been a factor in causing apparent RM reaction. Additional testing will be conducted w/ 5 gal bucket to explore the effect of velocity.

Note: Test conducted 5/12/08

Bucket

Task 7: RM Projectile into ANFO

Intermediate-scale Field Tests

- Ballistics: 125 grains Blue Dot Powder, bullet taped into hull
- Target: Bottom of 5 gal steel bucket with 40 lb ANFO – reinforced with 1/16” steel sheet, 6 ft SOD
- **Result: Successful Render Safe of 5 gal ANFO target, successful initiation of RM and deflagration of ANFO**

Task 7: RM Projectile into ANFO

Intermediate-scale Field Tests

600 fps video

Task 7: RM Projectile into ANFO

Intermediate-scale Field Tests

- Ballistics: 125 grains Blue Dot Powder, bullet taped into hull
- Target: Side of 5 gal steel bucket with 40 lb ANFO, 6 ft SOD
- **Result: Successful Render Safe of 5 gal ANFO target, successful initiation of RM, deflagration of ANFO and adequate destruction of ANFO container**

Task 7: RM Projectile into ANFO

Intermediate-scale Field Tests

600 fps viedo

Field Tests: Fin Stabilized Bullet

Intermediate-scale Field Tests

- Ballistics: 125 grains Blue Dot Powder, bullet taped into hull
- Target: Bottom of 5 gal steel bucket with 40 lb ANFO – reinforced with 1/16” steel sheet, 25 ft SOD
- **Result: Partial initiation of RM, minor pressurization, unsuccessful ANFO dispersion**

Velocity ~ 570 m/s
(1875 ft/s - 8 frames @ 600 fps, 25 ft)

NIJ VBIED Summary

- Static tests using APEX RM were successful
  - The ANFO was “rendered safe”
    - Determined RM mass threshold limit of ~ 5 g
- Dynamic tests demonstrated that the APEX RM can be successfully initiated by a 1/16” sheet that simulates the skin of a 55 gal drum.
  - The APEX RM was characterized by NSWC/IH and has an IHC
- Dynamic tests with sub-scale 0.50 cal were successful
  - RM produced render safe solution
- Dynamic testing with 12 gage disruptor round underway
  - Preliminary results w/ 40 lb of ANFO are extremely encouraging
- Feasibility study has taken concept to TRL 4

VBIED NIJ Program

- Back Up Slides

EMPI's Disruptive Energetics

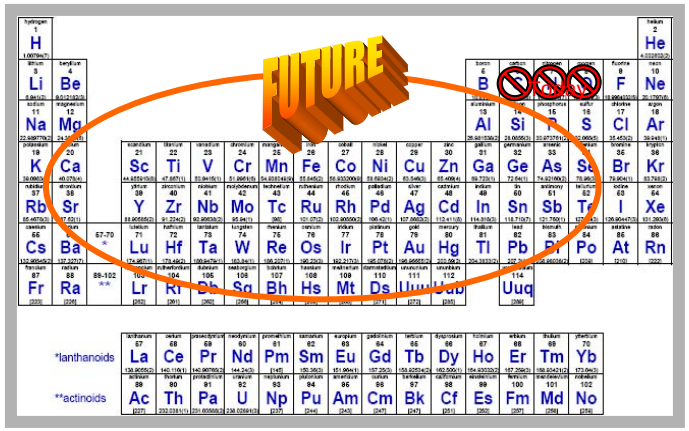
Precursor Materials → **Formulations** → **Technology** → **Multiple Applications**

Metals & Metal Oxides
Polymers
Fluorocarbons
Hydrocarbons

Modified-MIC

LAX-134 Derivatives

APEX*



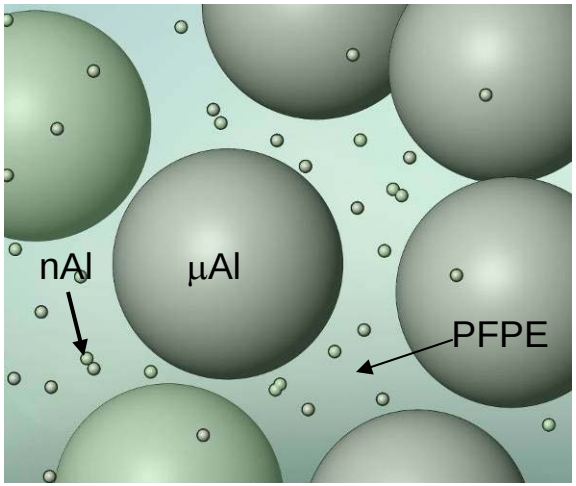
- **Green Energetics**
  - Primers
  - Electric igniters
  - Green primaries
- **Advanced Reactive Materials**
  - KE Penetrators
  - Wall Breaching
  - C-IED C-VBIED C-RAM
  - Structural Energetics
- **Advanced (Modified) Explosives**
  - Enhanced Blast
  - Dial-a-Yield
  - Agent Defeat
  - Low Impulse Launch

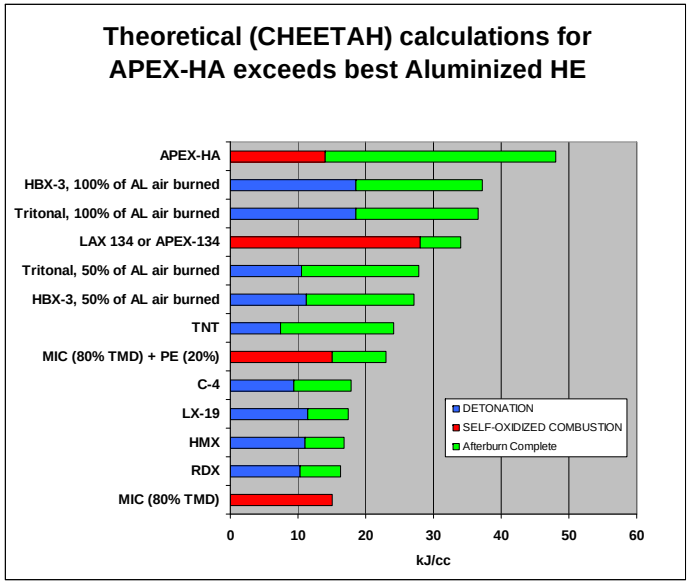
Leveraging DoD funded MOUT programs for GWOT applications

***APEX= Aluminum PFPE Explosive**

Disruptive Energetics: APEX

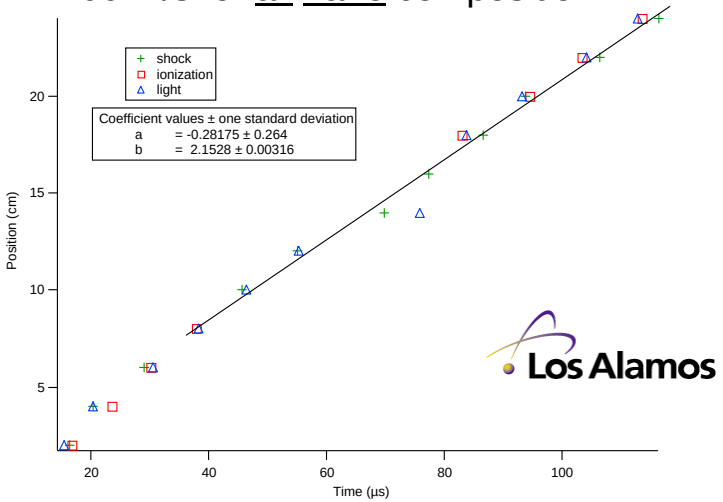
Physical Characteristics



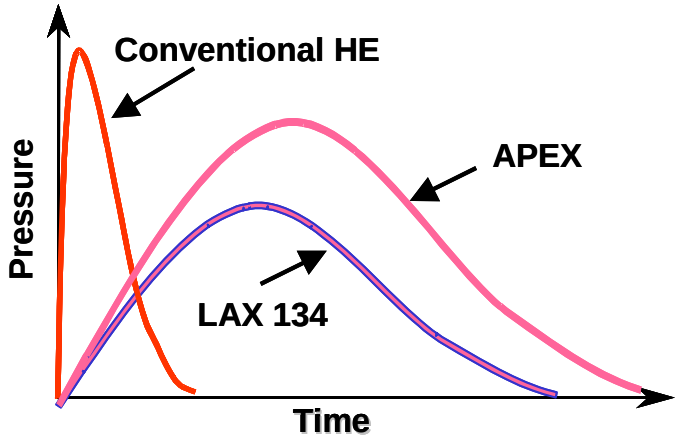


Psuedo (or Quasi) Detonation

Self-oxidized combustion speed for LAX-134 is ~ 2100 m/s for <u>all</u> <u>nano</u> composition



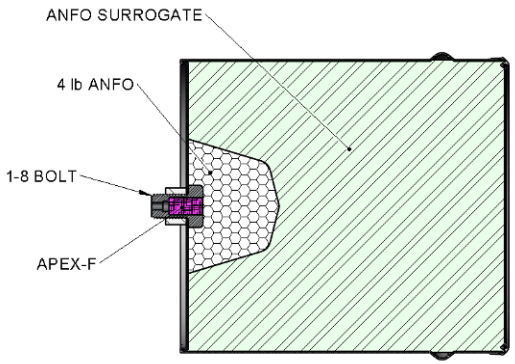
Unique Tunable Pressure Output



EMPI Proprietary

Static Test Rationale

- Static tests isolate effect of RM from bullet impact and are useful in quickly screening potential RM material.
- Tests designed to duplicate relevant parameters
  - RM Initiation
    - Energy flux
    - Power flux
  - Explosive Target
    - Total ANFO mass
    - Confinement



Static Test w/ RP-502 Detonator

Ballistic Impact Initiation

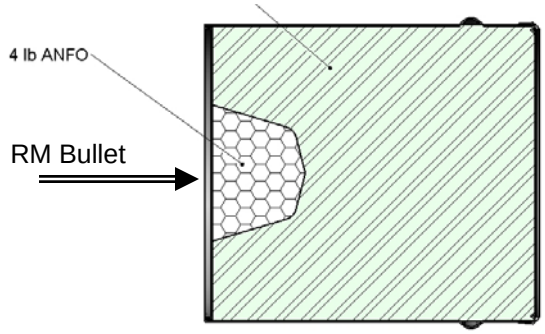
Power flux: P/A ~ 3 GW/cm^2

Energy flux: E/A ~ 3 KJ/cm^2

Explosive (Detonator) Initiation

Power flux: P/A ~ 2 GW/cm^2

Energy flux: E/A ~ 2 KJ/cm^2



Dynamic Test showing RM bullet impact

Ballistic vs. Explosive Ignition of RM

Ballistic Impact Initiation

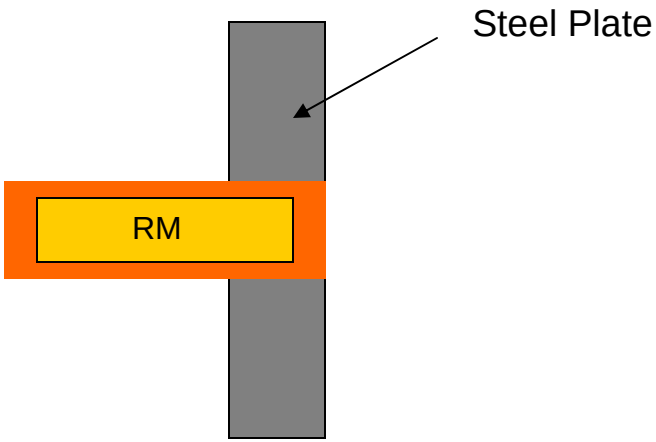
Power flux: P/A ~ 3 GW/cm^2

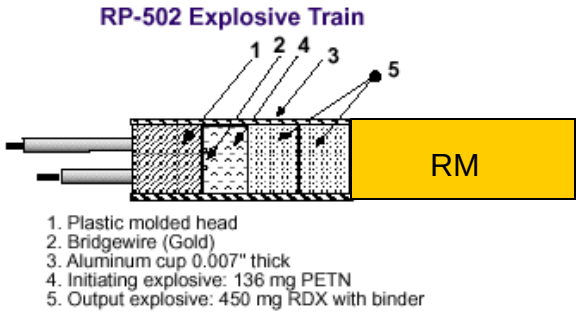
Energy flux: E/A ~ 3 KJ/cm^2

Explosive (Detonator) Initiation

Power flux: P/A ~ 2 GW/cm^2

Energy flux: E/A ~ 2 KJ/cm^2





Conclusion: RP-502 simulates the power flux and energy flux the ballistic impact (shock) initiation.

See Backup slides for details of calculations

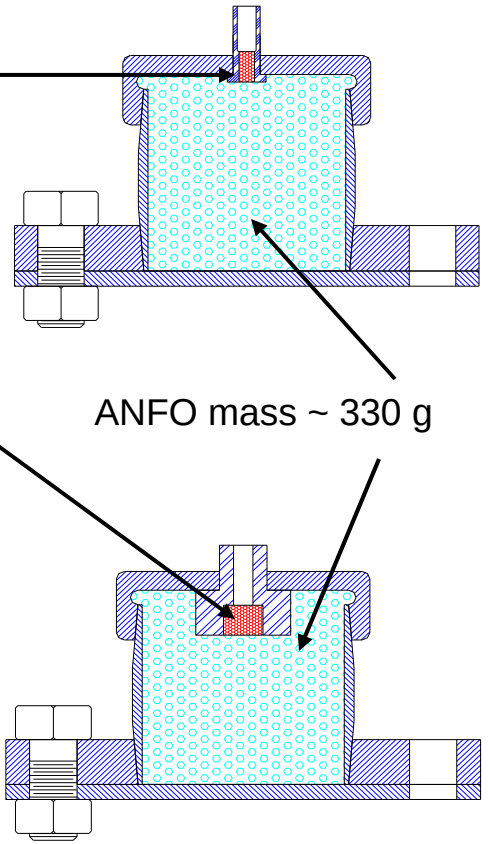
Task 1: CONOPS

- An additional (CONOPS) requirement was placed upon the team at the October 10, 2007 NIJ Kickoff Meeting. The CONOPS report included the following information
  - Tactics: Historical Background
  - Physical Characteristics of the VBIED Threat
  - Policy and Operational Issues
  - Current Technology and Industry Providers
  - Our Concept of Operations (CONOPS)
    - The first component of our solution is the standoff defeat neutralization tool that contains a RM inside a round that can be fired from a conventional 12-gauge disruptor. This tool is designed to cause a predictable and safe vented deflagration.
    - The second component of our solution involves an “exposure tool” that is designed to expose the contents inside a truck or van so the ANFO or other HE is accessible. This component is not part of the current NIJ program but is one, which we believe could be quickly developed, based upon our success in aligned programs**.**
  - **Status:** Report sent into NIJ

Task 2: First Static Tests

Static test conducted to quickly screen RMs

- Test Article design was selected to be similar to NSWC Indian head RM test article
  - Initial test used an RM mass of ~ 2.3 g
    - Test was unsuccessful, e.g. no reaction of ANFO was observed
  - Larger RM mass of 5.6 g was tested
    - First test (11/9/07) was a success, e.g. approximately 75% of the ANFO deflagrated
    - Second test (11/14/07) was a success, e.g. approximately 95% of the ANFO deflagrated
    - Third test with 660 g of ANFO was a success, e.g 50% of the ANFO deflagrated and test article opened without detonation
    - Tests with a detonator only and inert material substituted for RM had no effect
    - A total of six tests were conducted and all resulted in a render safe solution



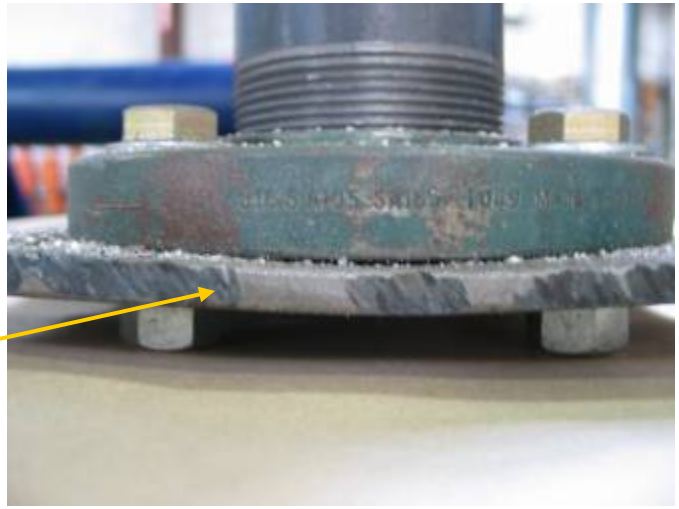
Task 2: Sample of Test Results

3rd Static Test
15 Nov 2007

Test article loaded into explosion tank

Top view of post test “pipe bomb” with minimal ANFO residue on bottom plate

Side view showing ¼ - in base plate deformation but no detonation

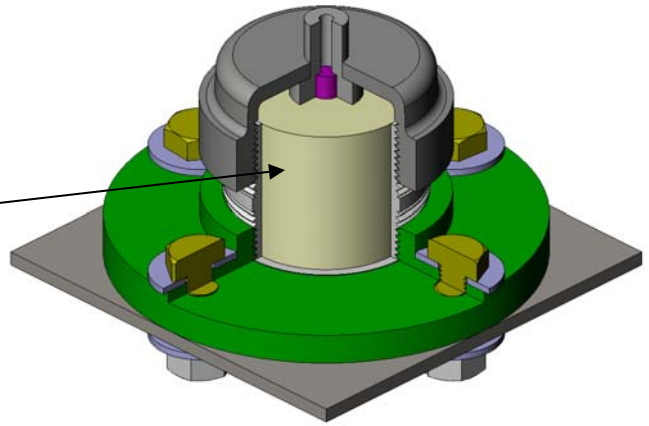


Task 3: Determine Pressure Field

Second Static Tests w/ Pipe Bomb Geometry & Carbon Gauges

- **Objective:** Obtain scientific and engineering data for deflagration and detonation of ANFO
- **Test Plan:** Use pipe bomb geometry w/ carbon gauges and deflagrate ANFO with RM initiated with an RP-502 detonator or with HE booster
- **Schedule:** Tests began on 2/19/2008
- **Deliverables:** Experimental techniques for characterization of ANFO reaction & baseline static data.
- **Status:** Completed tests: Data inconclusive

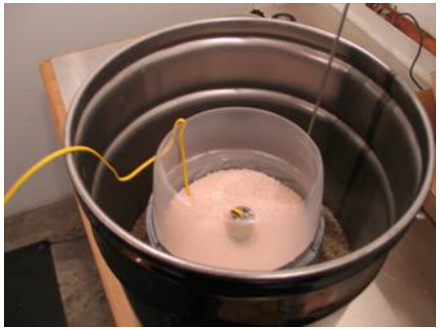
Carbon gauges



Task 4: Static Test of RM on ANFO

Static Test 19: 5 Gallon Bucket, 1/4” Base Plate, Center Charge Geometry, APEX RM mass ~13 g

2000 g of ANFO



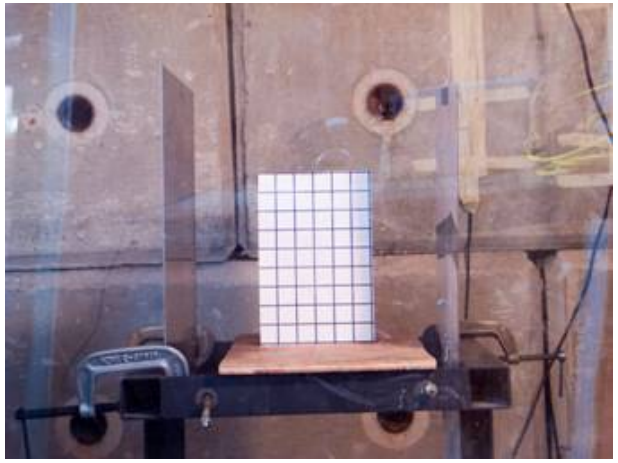
Comparison of Static Test 17, 18 and 19

Top View: Pre-test loading
Bottom View: Post-test deformation

Task 5: Sample of Tests Results

Bullet CB07: m = 18.34 g
APEX 34/0 RM m = 5 g
Target = 1/16” Steel Plate
Velocity= 877 m/s

RM Formulation is Critical for Bullet/RM Function



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Task 5: Sample of Tests Results

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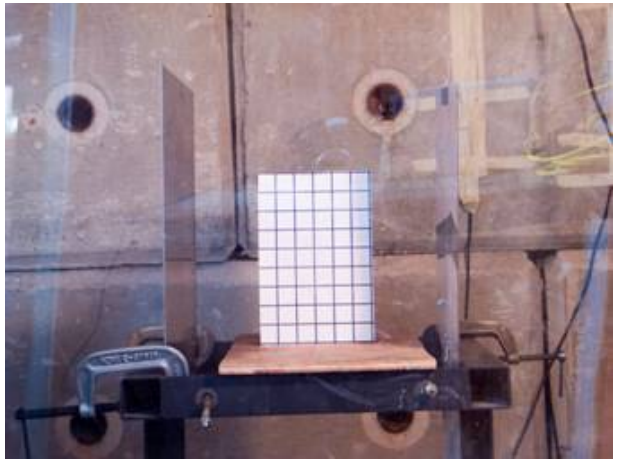

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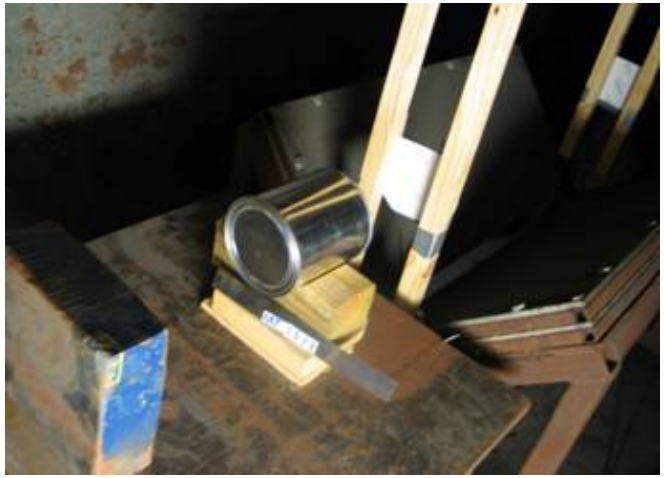
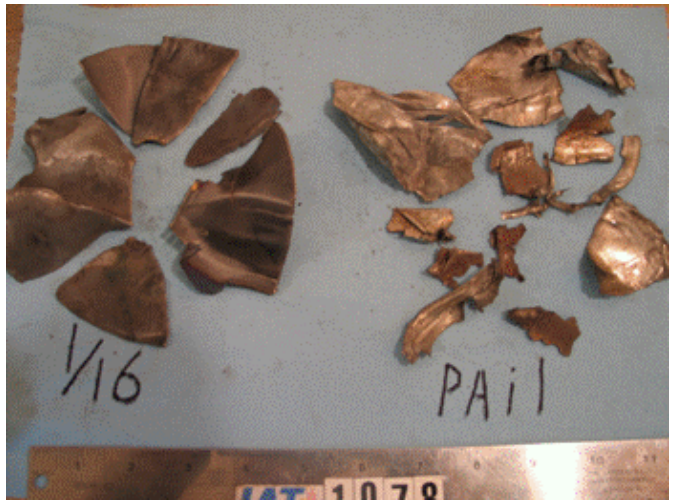
Task 6: RM Projectile into ANFO

Presumed Detonation, ANFO all consumed, wood block stand consumed

Bullet CB14: m = 18.8 g,
m = 5.15 g APEX 17/17
Target = 1/2 gal bucket w/ 1/16”
cover plate, 1500 g ANFO,
Velocity = 981 m/s



Repeat of previous test: RM Projectile velocity appears to be critical



Task 6: Inert Projectile Into ANFO

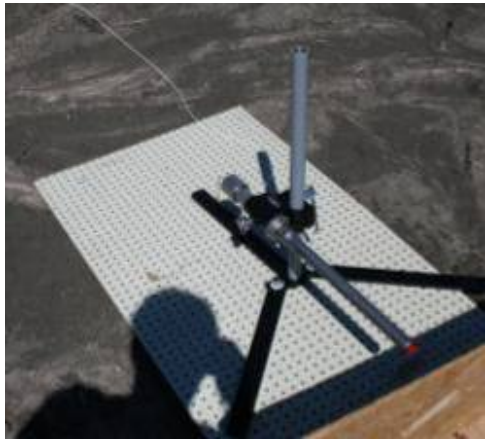
Bullet: 0.50 Caliber Ball, 42.0 g
Target: 1/2 gal bucket w/ 1/16” cover plate, 1540 g ANFO
Velocity = 789 m/s

No Reaction, Bucket simply perforated

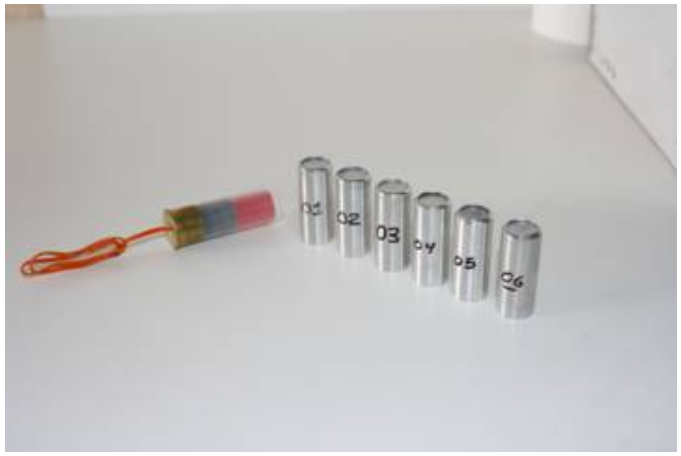
Task 7: Bullet Design & Loading

Task 7 in Progress

- Design 12 gage prototype rounds to survive in-bore acceleration
  - Disruptor cannon maximum breech pressure is 85 ksi
  - Fabricate 10 each of inert and APEX 17/17 RM rounds w/ target mass ~ 16 g
- Generate Loading Curves with Inert Bullet
  - SCR shots: 1093 - 1096



Commercial Disruptor



Disruptor round with inert slug for loading curves at top and rounds with APEX 17/17 RM at left