Common Low-cost IM Explosive Program

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Department of the Army
Office of the Project Manager for Combat Ammunition Systems
Attn: Mr. Charlie Patel
Tel 973-724-8507 Fax 973-724-2048
charlie.patel@us.army.mil
Picatinny Arsenal, New Jersey 07806-5000

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14. ABSTRACT

One of the tenets of the Project Manager for Combat Ammunition Systems Mission is to perform life-cycle management of tube-launched indirect fire munitions. Contained within this area are high explosive (HE) projectiles and cartridges for artillery and mortar applications. There are a total of fifteen HE projectiles: four for 105mm artillery, three for 155mm artillery three for 60mm, three for 81mm and two for 120mm mortar. All of these HE cartridges use either TNT or Comp-B fill. The PM decided to take a holistic review of pursuing IM and elected to execute the Common Low-cost Insensitive Munitons Explosive program. The CLIMEx Program Goals are as follows: Primary Goal ? Selection of one single common explosive fill for all artillery and mortar products; Secondary Goal ? Selection of two explosive fills, one that is common for replacement of TNT and another that is common for replacement of Comp B. During Phase 1 and Phase 2 of the CLIMEx program, a world-wide search of candidates was completed. During Phase 1, twenty three candidates were subjected to a battery of IM tests as per the specified protocol. The test protocol was established to account for screening candidates in a fair manner and at a affordable cost and schedule impact. Based on the results of the tests 3 candidates were identified as suitable to replace TNT and one candidate was identified as a candidate to replace Comp B. The three TNT candidates were further evaluated in Phase 2. IMX-101 was chosen as the TNT replacement candidate and IMX-104 was selected as Comp B replacement candidate. This paper will present an overview (background, protocol and results) of the U.S. Army?s program to qualify a low cost, common IM explosive to replace TNT and Comp B along with the environment, safety and occupational health aspects of the new formulations.

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KEYNOTE ADDRESS
DEVELOPMENT OF NEXT GENERATION INSENSITIVE MUNITIONS: A SUCCESS STORY

MR. CHARLIE PATEL
U.S. Army, PEO-AMMO, PM-CAS
B172
Picatinny Arsenal, NJ 07806-5000
(973) 724-8507
charlie.patel@us.army.mil

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Insensitive Munitions (IM) Roadmap: Transition Toward Full Compliance

Legacy Ammo

17 Major Munitions-related Incidents since 1926
(600+ Casualties / 1,600+ Injuries / $4B+ Losses)

Port Chicago (1944)

USS Forrestal (1967)

Camp Doha (1991)

Afghanistan (Sep 2009)
MRAP carrying sixteen 60mm M768 Mortars hit by IED
IM design resulted in the fuze separating from the shell body preventing high order detonations thus saving the lives of the Soldiers.

Lake Denmark (1926)

IM Improvements

60mm M720A1/M768 Mortar (PAX-21 Explosive)
155mm MACS Propelling Charge
PM-CAS Common IM Explosive (CLIMEx)

Camden, AR (Nov 2007)
MACS LAP-facility Fire
3.3 tons of Energetics – Burned only
No Injuries, Building remained

81mm Slow cook-off results
With IMX-104
Type V – Burning Reactions

Unit's SPC Alan Ng with his father Peter Ng, PM CAS-ARDEC Engineer IM programs.

Fully-IM Fielded

105mm M1 IM (IMX-101 Explosive)
155mm M795 & M1122 (IMX-101 Explosive)
60/81/120mm Mortar (IMX-104 Explosive)

Common Low-cost IM Explosives

Joint program with Army (PM-CAS) & USMC (PM-AMMO)

Artillery HE Projectiles

105mm HE (M1, M760) | 105mm HE-RA (M927, M913) | 155mm HE (M107) | 155mm HE (M795) | 155mm HE-RA (M549A1)

Baseline Explosive = TNT

TNT filled Projectiles FAIL all IM Tests

Mortar HE Cartridges

60mm HE (M720, M768, M888) | 81mm HE (M821, M889) | 120mm HE (M933, M934)

Baseline Explosive = Comp-B

Comp-B filled Cartridges FAIL all IM Tests

(except 60mm passes 1 of 6, BI)

➢ISSUE:

- ✓ TNT & Comp-B explosives have poor IM results
- ✓ Mortar and Artillery HE items require IM Waiver
- ✓ IM explosives identified under prior efforts
  - – Specific to individual program requirements
  - – Lacked commonality
  - – Some IM improvements – still need waiver
  - – NTIB Cost Impacts

➢CORRECTIVE ACTION:

- ✓ Investigate new IM Explosives with intention to insert into production in near-term

Primary Objective is to provide a Common IM Fill
-- or --
one common TNT replacement (Artillery)...
...and one common Comp-B replacement (Mortars)

Goals of the Common Low-cost Insensitive Munitions Explosive Program

- **Effective**
  - ✓ Maintain Lethality with minimal or no degradation
- **Less Sensitive**
  - ✓ If not fully compliant, must show improvement over Baseline explosive
- **Affordable**
  - ✓ Artillery Cost Drivers = Steel Body Material & Explosive Fill
  - ✓ Mortar Cost Drivers = Steel Body Material, Fuze & Propelling Charges
- **Producible within the National Technology and Industrial Base**
  - ✓ Infrastructure
  - ✓ Raw Ingredients
  - ✓ Explosive formulation
  - ✓ Projectile Load, Assemble & Pack (LAP)
- **Other Considerations**
  - ✓ Demilitarization
  - ✓ Environmental
  - ✓ Intellectual Property Rights

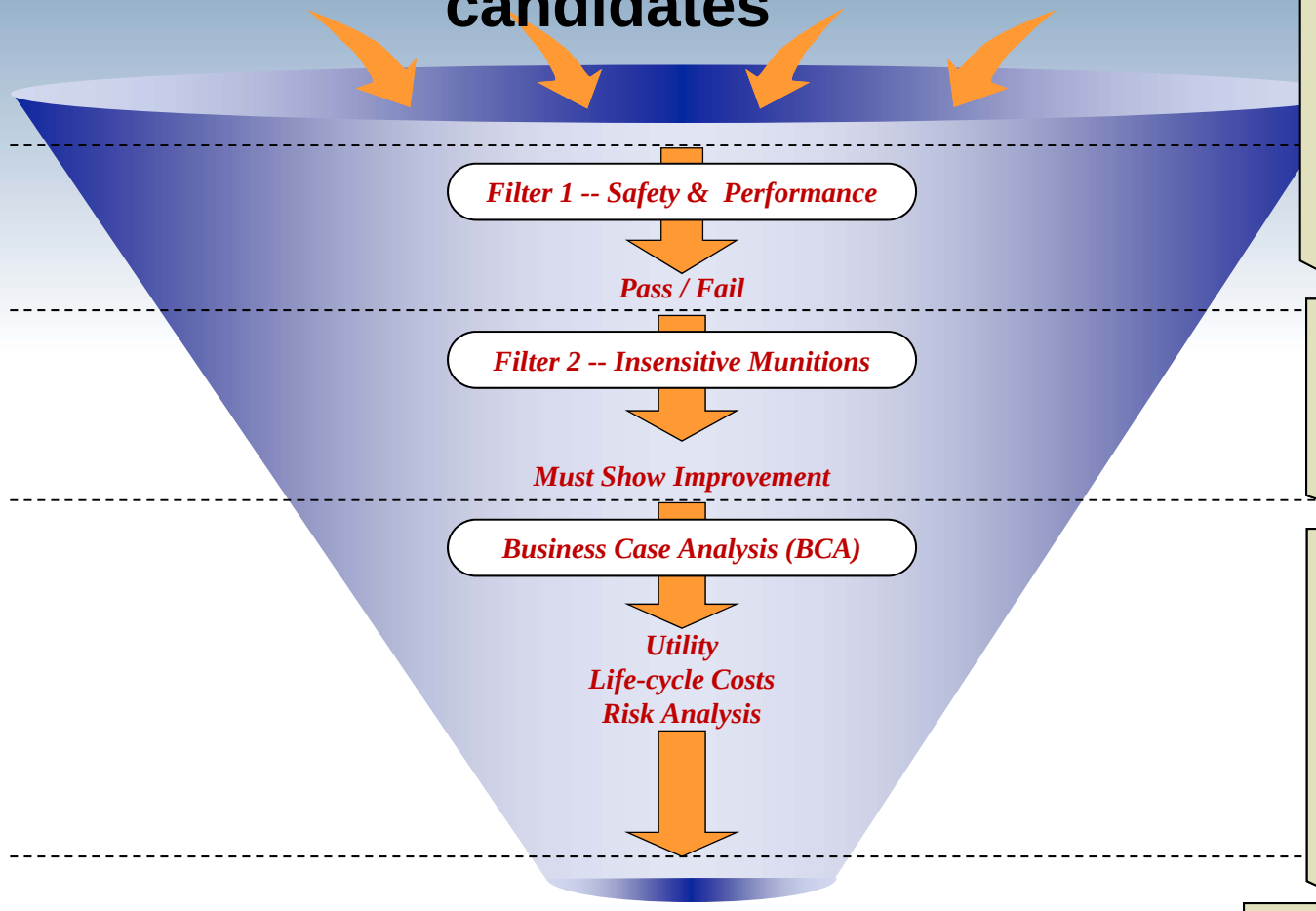
Common Low-cost IM Explosive Program

Value to the Warfighter

- ✓ Drastically increase Safety from unplanned stimuli
  - ✓ Increases Soldier Survivability
  - ✓ Increases Equipment Survivability
- ✓ Maintains Lethality
- ✓ Significantly improve their ability to store and move ammunition
- ✓ Safer transport on combat loaded vehicles, air cargo and Navy ammo ships

Common Low-cost IM Explosive Program

"Funnel" framework to progressively screen candidates



Filter 1 Criteria

- Cheetah Calculations
- Standard Safety Tests
- Electrostatic
- Friction Impact Sensitivity
- Vacuum Thermal Stability
- Differential scanning
- Critical Diameter

Filter 2 Criteria

- Tier 1 IM Tests (BI, FI, SCO, SD)
- Tier 2 IM Tests (FCO, SCJI)

BCA Criteria

- IM Tests, Lethality, Logistics, Safety, Platform
- Performance of the alternatives against weighted factors
- Risk analysis
- Comparable cost analysis
- Sensitivity Analysis

IM Explosive Fill for TNT & Comp B Replacement

Arena Test & Qualification

Replacement Candidates

23 IM explosive candidates

- 12 for TNT replacement, 11 for Comp B replacement

- **Melt-pour**
  - ✓ Traditional Ingredients
    - RDX
    - HMX
  - ✓ Less Sensitive Explosive Filler
    - NTO
    - NQ
  - ✓ Less Sensitive Energetic binder
    - DNAN
    - Nitrate Salts
  - ✓ Reduced Nitramines (Aluminized)

- **Cast-cure**
  - ✓ Inert binder
    - RDX
    - IRDX
    - Rounded RDX

- **Press-fill**
  - ✓ Inert binder with RDX
    - (Redesign of metal parts – Not Evaluated)

- **155mm HE selected for screening TNT replacement candidates**
  - 9 candidates tested => IMX-101
- **120mm HE selected for screening Comp B replacement candidates**
  - 9 candidates tested => IMX-104

M795 IM Projectile Design

155mm, 78 lb hi-frag steel body loaded with 24 lbs of HE

- M795 IM Design
  - oIMX-101 Main Fill (24 lbs)
  - oPBXN-9 Supplementary Charge (0.3 lbs)
  - o Warhead Venting
    - oMeltable Liner
    - oMeltable Fuze Plug
    - oModified Pallet Design

IM Tests & Passing Requirements

FUEL FIRE Such as a truck or an aircraft on a flight deck

NEARBY HEAT Such as fire in adjacent magazine, store or vehicle.

BULLETS Such as small arms from terrorists or combat

FRAGMENTS Such as from bombs, artillery, or IEDs

Passing Criteria

FCO **Burn**

SCO **Burn**

BI **Burn**

FI **Burn**

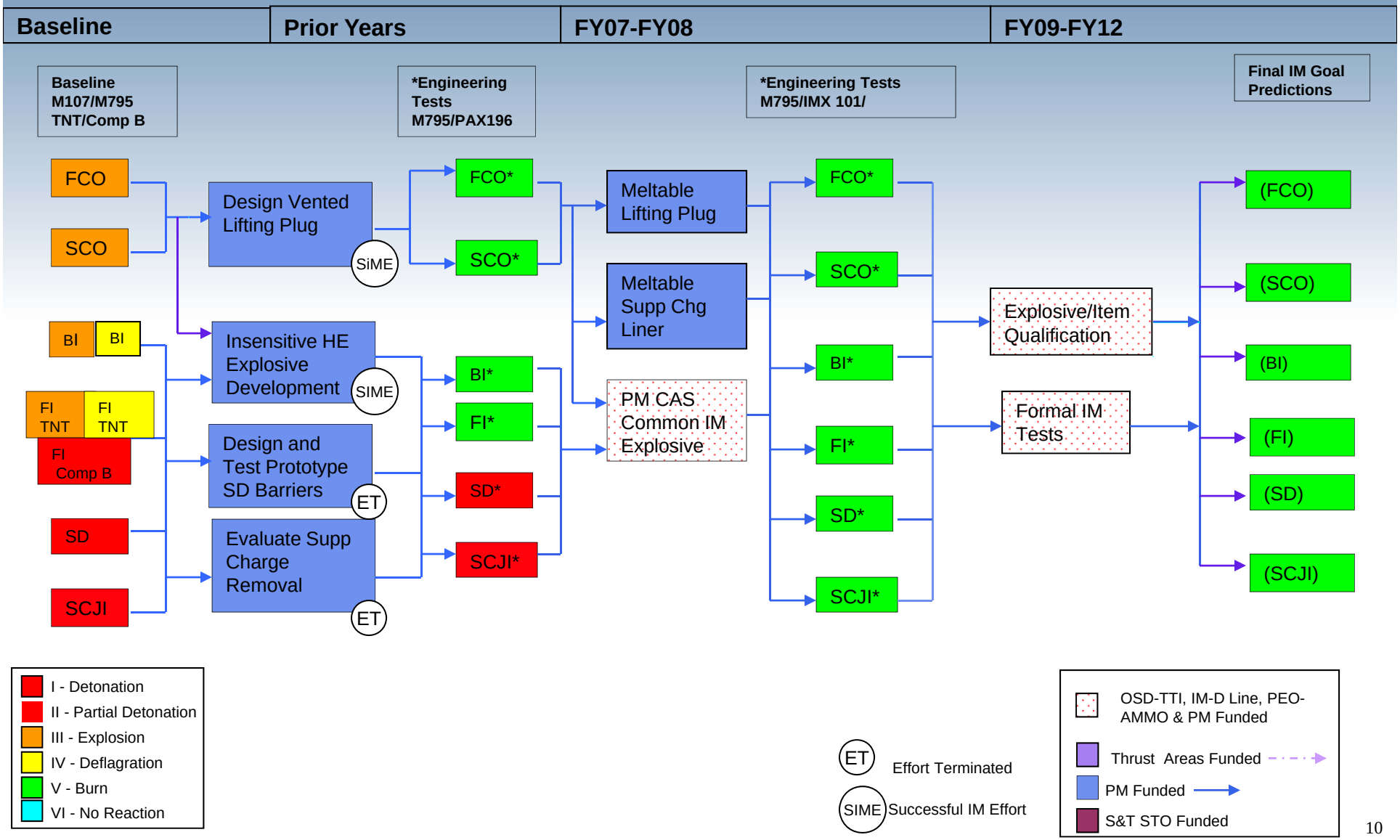
SYMPATHETIC REACTION Such as detonation of adjacent stores

SR **Low pressure burst**

SHAPED CHARGE JET RPG, Bomblets, ATGMs: Combat or terrorists

SCJI **Low pressure burst**

155mm M107/M795 IM Compliant Roadmap



Implementation Approach

- Explosive Producibility - Assure explosives can be robustly manufactured in production scale and ingredient supplies are available
  - 180K lbs of IMX-101 produced at Holston Army Ammunition Plant

- Load, Assemble & Pack - Assure projectiles can be loaded without defects.
  - Loading process developed at ARDEC – Picatinny Arsenal
  - Technology transitioned for high volume loading trials at Iowa Army Ammunition Plant

Implementation Approach (cont'd)

- Venting - IM venting technology implemented in systems design to pass thermal tests

Standard
Lifting Plug
Will *Not* Pass (Type III)

Partial Venting
(Type IV)

SCO

FCO

- Energetic Material Qualification - Ensure explosives are safe to process, handle, store, and transport.
  - IMX-101 explosive formulation fully qualified by U. S. Army

12 Litre Cook-Off Test

Implementation Approach (cont.)

- Initiation Reliability - Reconfigure initiation system to reliably initiate the IM explosives
  - Initiation trials performed to confirm performance and reliability

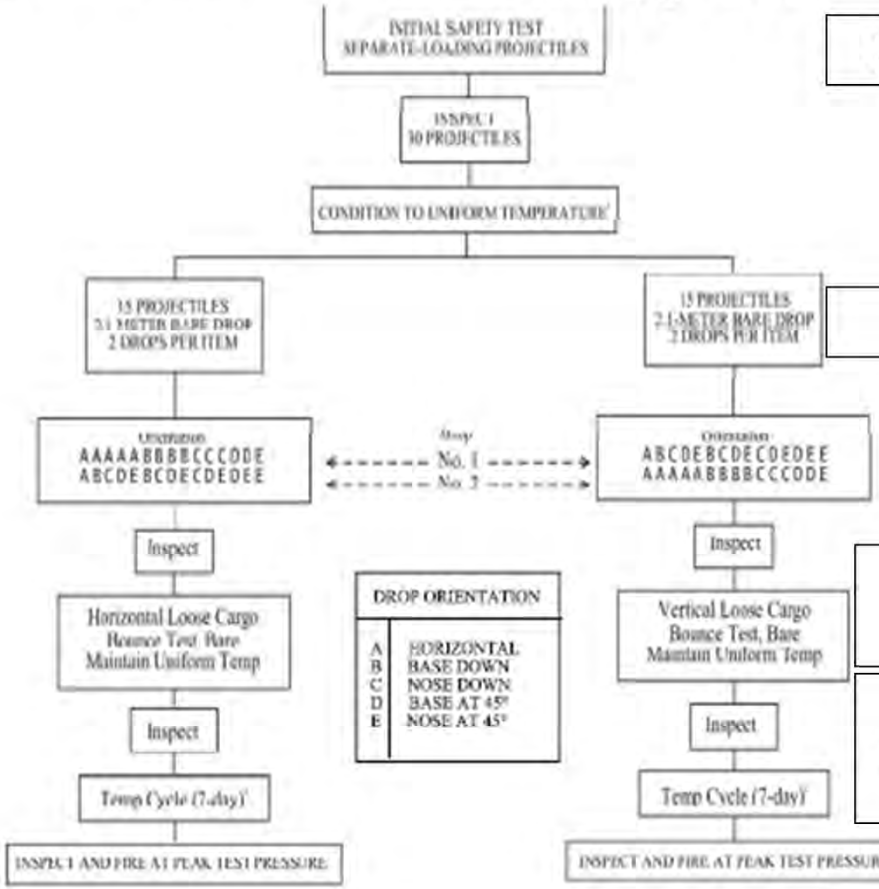
- Qualification of End Item Munitions - Assess
  - Safety
  - Performance
  - Reliability

M795 IM Qualification Plan

Initial Safety Test

ITOP 4-2-504(1)
22 September 2005

Safety Test – Phase 1



30 projectiles each at for hot and cold phase

Two 2.1m drops on each projectile

Loose cargo vibration test to simulate transport by using Unit

7-Day Environmental Cycle
Hot Cycle: 33 C at 80% RH to +71 C at 14% RH
Cold Cycle: -51 C

Gun firings at maximum service conditions pressures at hot and cold temperatures

* The entire test is conducted with two independent, identical samples - one conditioned to 65° and one conditioned to -51°C; thus 60 projectiles are required.

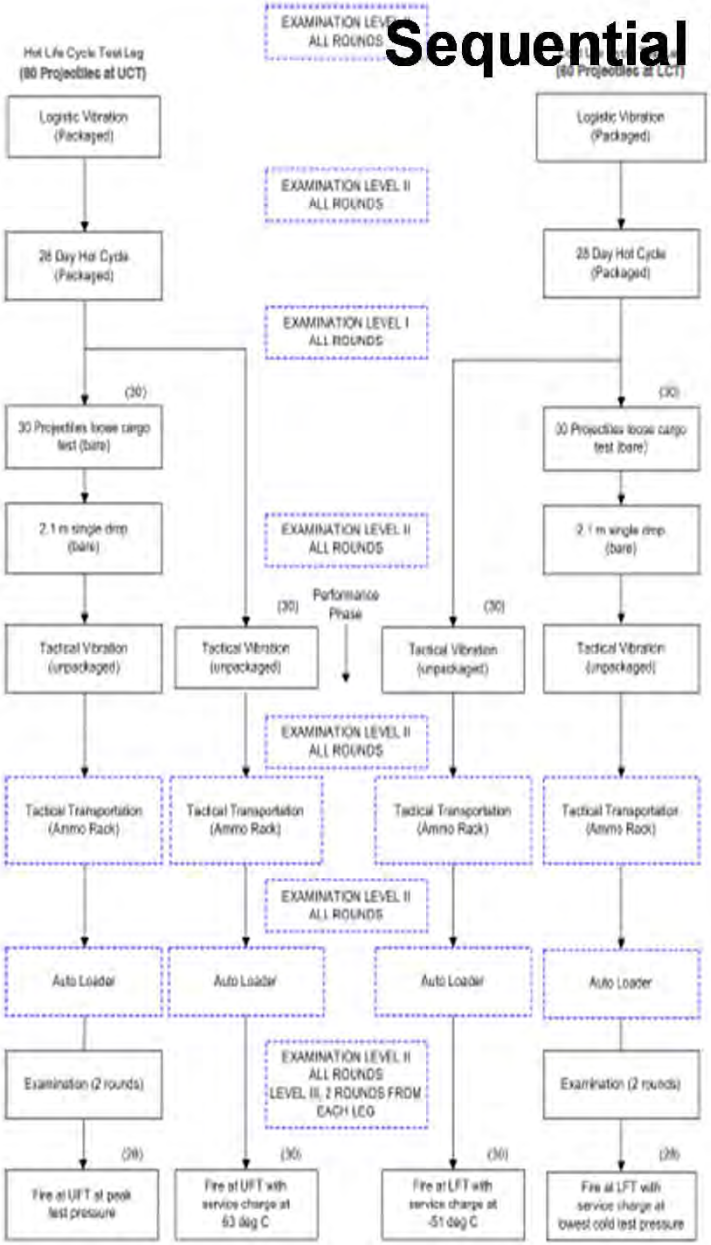
* The temperature cycle for the 63°C and the -51°C samples is B3.

Pass

Figure 1. Initial Safety Test for Separate-Loading Projectiles.

Performance & Safety Tests

Sequential Environmental Test



60 projectiles each at for hot and cold phase

Logistic Vibration

Transportation (land, air, and sea) from the factory to overseas storage depot and to the Ammunition Supply Point

Environmental Cycle

28 Day Hot Cycle: 33 C at 80% RH to +71 C at 14% RH
14 Day Cold Cycle: -51 C

Loose Cargo Vibration Test

Transport by using Unit

One 2.1m drops on each projectile

Accidentaly drop during unloading by using Unit

Gun firings

Subject the items to severe interior and exterior balllistic environments by firings at maximum service conditions pressures at hot and cold temperatures

Pass

Adverse Environment & LogisticsTests

Supplementary Environmental Tests

High-humidity and Fungus Humidity: 10 cycles at 30 C to 60 C at 95% RH Fungus: 28 days at 30 C at 95% RH 16 rounds Gun firings at top service charge	Pass
Solar Radiation Cycle represents peak conditions of 1120 W/m2 solar radiation and 43 C (110 F) 8 rounds Gun firings at top service charge	Pass
Thermal Stability 48 hours at 75C	Pass
12 Meter Drop Test 10 rounds each at hot and cold temperatures	Pass

Summary of M795 IM Test Results for IMX-101 JSIMTP/AIMB Scores

Test	Official Tests Scores	Notes on test results
Fast Cook-off	V	Single round and pallet configuration
Slow Cook-off	V	Heating rate is 3.3°C/hr
Bullet Impact into HE	IV	Type V if scored to criteria that existed at program start
Fragment Impact into HE	V	2,532 m/s
Sympathetic Reaction	Pass	Confined and unconfined
Shaped Charge Jet Impact	Pass	LX-14 conditioned jet

M795 IM Fast Cook-off Results

- **Single Round**

- No blast overpressure
- No hazardous fragments beyond 15m.

Type V

- **Palletized**

M795 IM Slow Cook-off Results

Type V

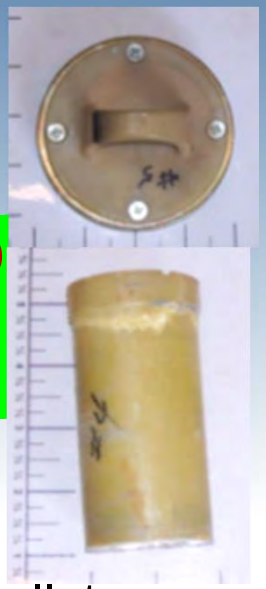
MFP Inside oven

Bullet Impact Results

- **Three 0.50 caliber AP bullets into HE**

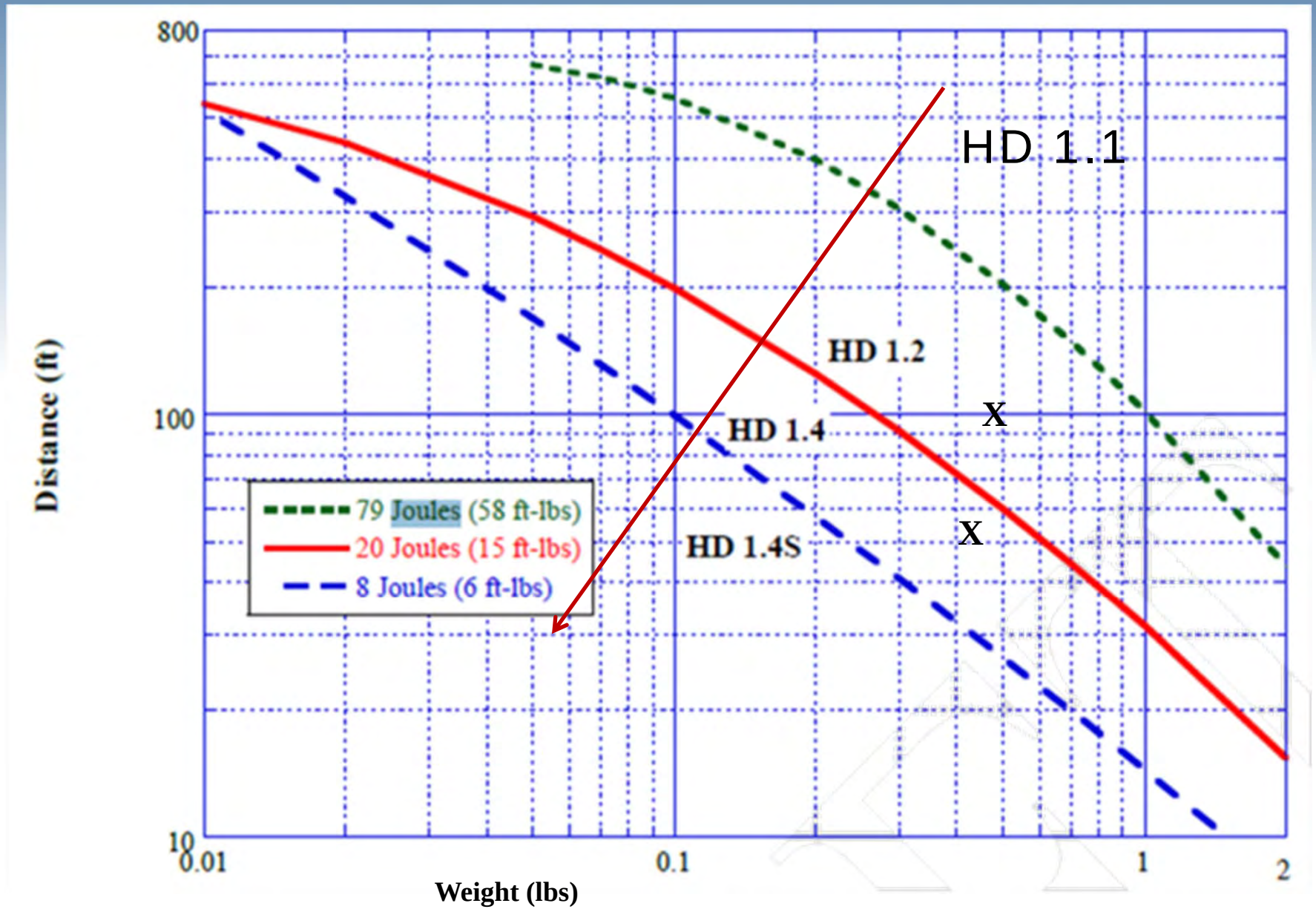
Type V to AOP-39 Ed 2 Feb 09

Type IV to new criteria



- Smoke on impact from first bullet
- Fireball on impact of second bullet, round broke in 3 large pieces
- Lifting plug (263.6g) and s/c (211.8g) thrown at 31m and 18m respectively
- Large amount of unreacted explosive collected

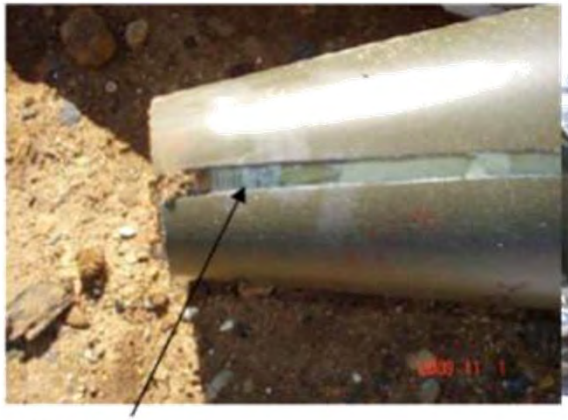
Hazardous Fragment Analysis from TB700-2 (Aug 2008)



Fragment Impact

18.6 gram fragment fired 2,471 m/s into HE
Round intact, no fragments past 15m

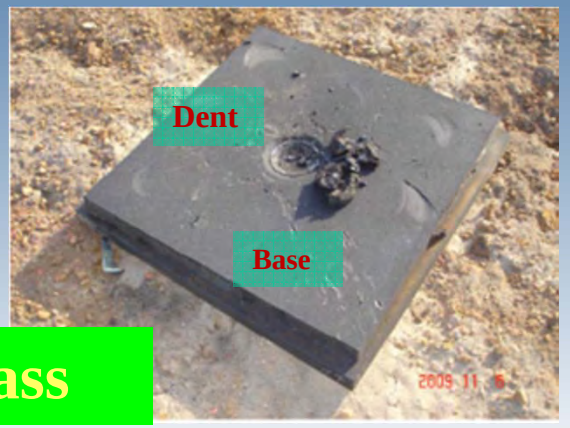
Type V



Supp Chg

M795 Unconfined SR Results

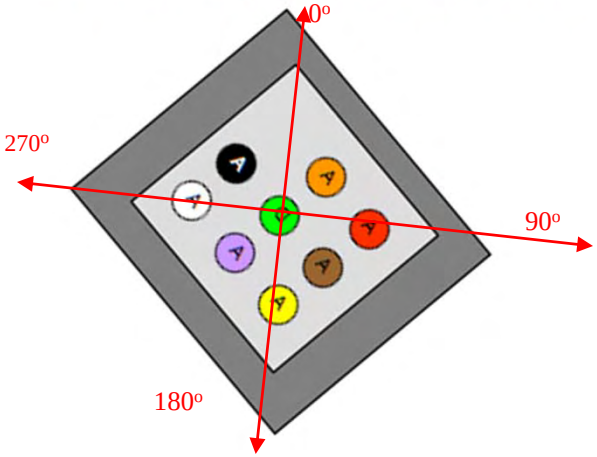
Post Test Acceptors



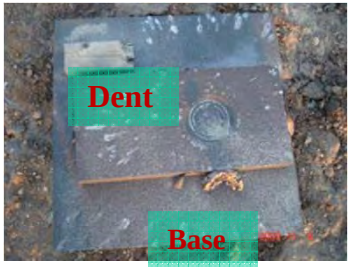
Pass

Single dent from donor

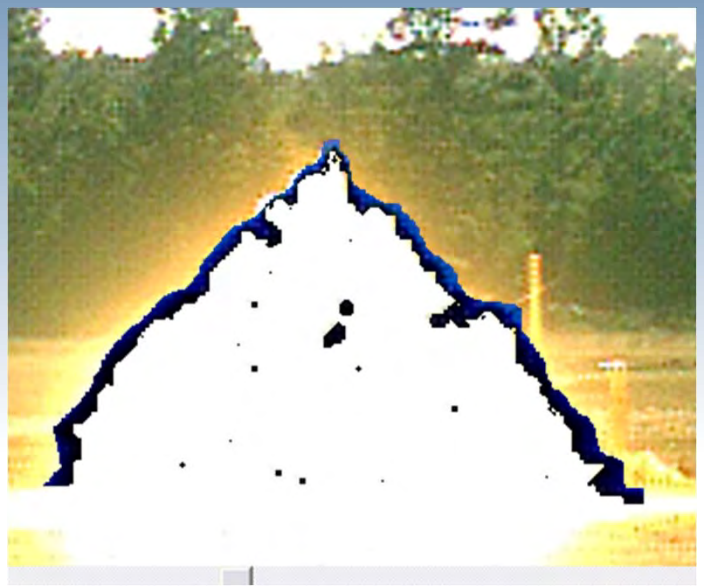
Test Setup
Un-Confined Sympathetic Detonation Test



Single round calibration



M795 Unconfined SR Results



Unconfined SR 1ms after trigger

Detonation Calibration 1ms after trigger

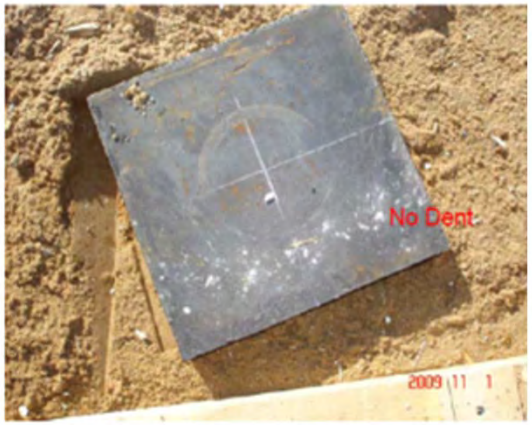
Acceptor Rounds do not contribute to dynamic reaction!!

M795 SCJI Results

- 81mm Shaped Charge Jet Impact
- Round broke into large pieces some beyond 15m
- No dents on witness plate
- No increase in SC blast overpressure
- Unconsumed Explosive

1st shot

2nd shot



Pass

Summary of Tests

IM Test:

M795 IM Scores*

FCO	SCO	BI	FI	SD	SCJI
V	V	IV	V	Pass	Pass

* Reaction from IMX-101

Test	Status
Initial firing tests	√
12m Drop	√
Initial Safety Test	√
Sequential Environmental Safety & Performance	√
Shock Attenuating Lifting Plug	√
Worn Tube	√
Explosive Ordnance Disposal	√
High Humidity & Temp /Fungus	√
Solar Radiation	√
Initiation Reliability	√
Final Firing Table Confirmation	√
Arena Testing	√
IM Testing	√

- ✓ **Effective**
  - ✓ **Confirmed Ballistic Match**
  - ✓ **Met M795 Lethality rqmts**
- ✓ **Suitable**
  - ✓ **IM**
  - ✓ **Reliable**
  - ✓ **Human Factors**
- ✓ **Supportable**
  - ✓ **Maintained same palletization**

✓Received Safety Confirmation from Development Test Command

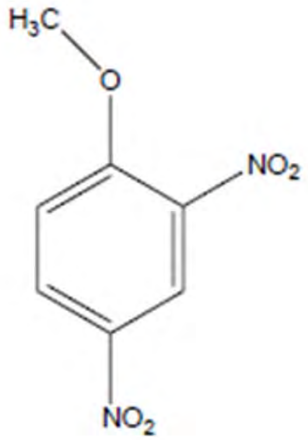
✓Tech Data Package signed 06/2010

✓Achieved HC 1.2.1

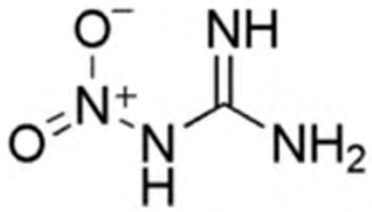
IMX-101

- ***IMX-101 Formulation***

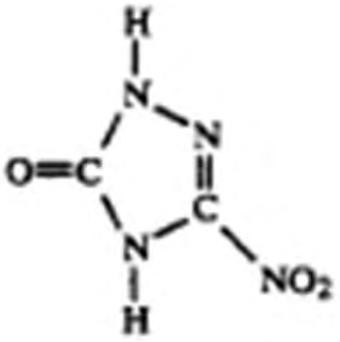
	IMX-101	TNT	Comp B
2,4-Dinitroanisole (DNAN)	43.5 (±2)	--	--
Nitroguanidine (NQ)	36.8 (±2)	--	--
3-Nitro-1,2,4-triazol-5-one (NTO)	19.7 (±2)	--	--
Trinitrotoluene (TNT)	--	100	40
RDX	--	--	60



DNAN



NQ



NTO

DNAN and NTO ESOH Data: What is Known?

-1-. NQ – Legacy energetic, DNAN – first used in PAX-21, NTO – newest energetic in the formulation

IMX-101: Focus on NTO and IMX-101

Nitroguanidine: LD50 is 10,200 mg/kg

DNAN: LD50 is 199 mg/kg

NTO: . LD50 >2000 mg/kg

Ref: TNT of 795 - 1010 mg/kg, RDX is 68 – 100 mg/kg

-2-. DNAN: OEL established as 0.09 mg/m3 (TNT: 0.1 mg/m3)

-3-. NTO: Revised OEL of 1.6 mg/m3

Aquatic C. Daphnia toxicity data for NTO of 830 mg/L (24 hours), and 460 mg/L (48 hours): NTO considered aquatically practically Non-Toxic.

ESOH workshops held in June 2010 and Dec 2010 to review existing data and determine pathways to fill in data gaps

ESOH Pathforward

TOXICOLOGY STUDY NO. 87-XE-03N3-05: ASSESSING THE POTENTIAL ENVIRONMENTAL CONSEQUENCES OF A NEW ENERGETIC MATERIAL: A PHASED APPROACH SEPTEMBER 2005
Published: December 2007

Conclusion: "Initially, cost for obtaining relevant toxicological and environmental criteria necessary in evaluating the fate and transport of proposed new compounds is low, yet uncertainty is high. As the compounds and subsequent systems are refined, a greater degree of rigor in these data is proposed."

The ingredients of IMX-101 are currently undergoing rigorous evaluation to determine the ESOH impacts.

* Updated MSDS published for DNAN, NTO, IMX-101 in October 2011, future updates will be prepared as studies are completed

Summary of M795 Munition

- U. S. Army's CLIMEx competition for the IM M795 155mm Artillery Munition selected IMX-101 as the IM explosive fill from >20 global candidates.
- The legacy TNT filled M795 failed all Army IM safety criteria.
- IMX-101 demonstrated significant IM technology advancements.

IM Test:	Fast Heating	Slow Heating	Bullet Impact	Fragment Impact	Sympathetic Detonation	Shaped Charge Jet Impact
Passing Criteria	Type V	Type V	Type V	Type V	Type III	Type III
M795 Baseline (TNT)	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
M795 with IMX-101	PASS	PASS	FAIL*	PASS**	PASS	PASS

Note (*): The M795 passed the original IM Bullet Impact criteria (one 50-cal bullet through the system subcharge) but failed the Army's new BI criteria (three 50-cal bullets through the system subcharge). The lift plug was thrown 50'

(**): The Fragment Impact data represents the IM response from IMX-101.

Conclusions

- CLIMEx program was successful in identifying and qualifying IMX-101 Explosive as a common insensitive replacement for TNT.
- CLIMEx program was successful in identifying IMX-104 Explosive as a common insensitive replacement for Comp B.
- IM Explosives have demonstrated far superior IM properties.

Quote from US Army Public Health Command (formerly USACHPPM) presented at the Force Health Protection Conference

The decreased toxicity, coupled with the reduced sensitivity to environmental stimuli and equal performance during testing, make the formulations tested desirable replacements for currently fielded munitions