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IM and Ballistic Assessment of 105-mm Cartridges with Foamed Celluloid Combustible Case

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Objectives

- Improve cook-off and fragment impact responses to Type IV or better
  - Develop foamed celluloid combustible cartridge case (FCCCC) as an effective IM venting technology by reducing internal pressure/ temperature and eliminating steel debris cloud
- Transition technology to multiple 105-mm Stryker munitions
  - M900, M724A2, M393A3, M467A1, M1040
- Potential transition to other munitions using felted fiber cases
  - 155-mm artillery propulsion system (e.g. MACS)
  - 120-mm tank munitions (e.g., M829A4, M830A1, M865, M1002, M1028, XM1147)
  - Pyrotechnic systems/components (e.g., flash tube, training simulators)

Background (1)

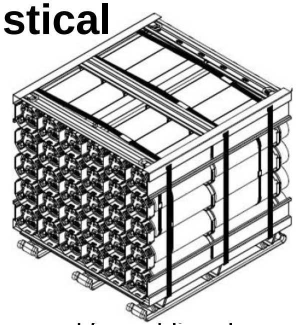
- 105-mm M724A2 failed IM due to a large amount of propellant confined inside a fixed steel cartridge case
  - 120-mm M1002 with felted fiber combustible cartridge case and vented PA171 steel container passed IM

	MATG V Goals Year 2023	105-mm M724A2 with Steel Case	120-mm M1002 with Combustible Case
Fragment Impact	Type IV	Type III	Type IV
Bullet Impact		Type IV	Type V
Slow Cook-Off	Type IV	Type III	Type V
Fast Cook-Off	Type IV	Type III	Type V

  - Logistical configuration consists of bare M724A2 packaged in unvented PA117 steel container; tactical configuration consists of bare round stored inside the Stryker vehicle

M724A2

Logistical



Tactical

Background (2)

- Various venting technologies investigated but none could provide a total solution; improving IM reactions, maintaining current item ballistic and rough handling performance, reducing post-fire residue and reducing cost.
  - 105-mm felted fiber case passed initial autoloader rough handling but failed ballistic performance due to incomplete burning

Tradeoff Study of Venting Technologies (red=worst, green=best)

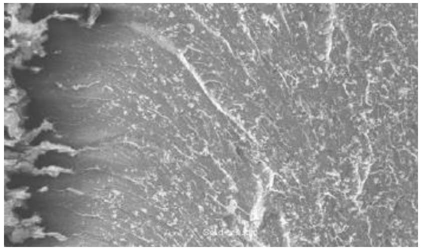
Cartridge Case Venting Technology	System	*Applicable to 105mm Tank Cartridge?*					
		Thermal Venting	Performance	Post-Fire Residue	Autoloader	Rough Handling	Cost
Metal cartridge with eutectic Vents	105mm artillery						
Felted fiber	105mm tank						
Foamed celluloid in sheet form	120mm mortar						
Foamed celluloid in bead form	(105mm tank)[1]						

Note 1: Item has not been tested. Analogy is based on 120mm mortar increments made of sheet celluloid and 105mm tank felted fiber case.

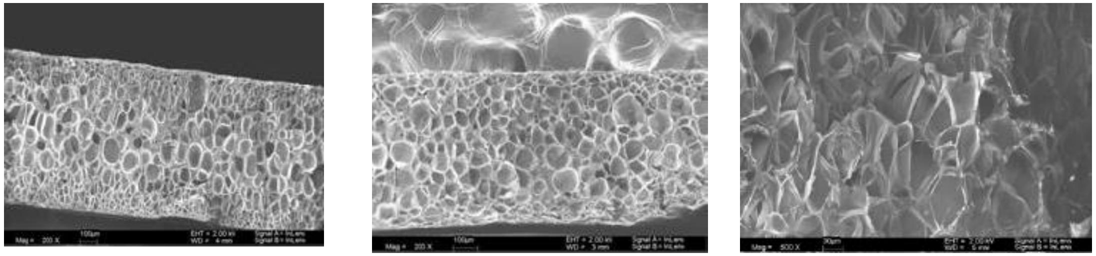
Background (3)

- **Foamed celluloid**
  - Foaming celluloid produces a porous structure, increases surface area and reduces density, resulting in increased burn rate, reduced residue and enhanced mechanical properties
  - Commercial celluloid classified as 4.1 flammable solid

Unfoamed



Foamed (50%, 75%, 90% reduction in density)



- **Beaded celluloid to be developed for tank munitions**
  - Pro: Can be formulated, molded and machined into various densities, thicknesses, and complex geometries; more robust; other benefits similar to sheet celluloid
  - Con: Technology requires development in celluloid bead formulations, bead-making processing, and bead foaming & fusing (molding & demolding) process to optimize mechanical properties and reduce post-fire residue

Technical Approach

Overview

Flow Chart for Foamed Celluloid Combustible Cartridge Case Development

10 Establish Requirements →

20 Develop Celluloid Bead Formulations & Bead-Making Processes →

30 Design & Fabricate Specimen molds →

40 Develop Foaming & Fusing (Molding & Demolding) Process for Specimens →

50 Characterize Beads & Specimens →

60 Design Case Adaptor, Case Body, Case Bottom, Stub Base, Projectile Slug →

70 Develop Autoloader & Drop Test Modeling & Simulation →

If Fail, Go To 60/20

80 Down Select →

90 Design & Fabricate Case Molds →

100 Develop Foaming & Fusing (Molding & Demolding) Process for Cases →

If Fail, Go To 90/20

110 Determine Linear Burn Rates (Closed Bomb Test) →

120 Develop Interior Ballistics Modeling & Simulation →

130 Design & Fabricate Prototypes →

140 Loading & Assembly →

150 Developmental Testing (IM, Autoloader, Drop, Ballistic Firing)

Technical Results
Fragment Impact Test Setup

- **Test item in packaged configuration: M724A2 projectile slug, FCCCC, M14 propellant, propellant bag, electric primer, stub base, vented PA117 container**
- **Aim point: middle of the primer**
- **Fragment & impact velocity: 18.6 g mild-carbon steel fragment at velocity ≥ 8,300 feet/second**
- **Instrumentation: blast pressure gauges, high speed & standard video camera to measure fragment velocity and record reaction severity**

Technical Results

Fragment Impact Summary of Results (1)

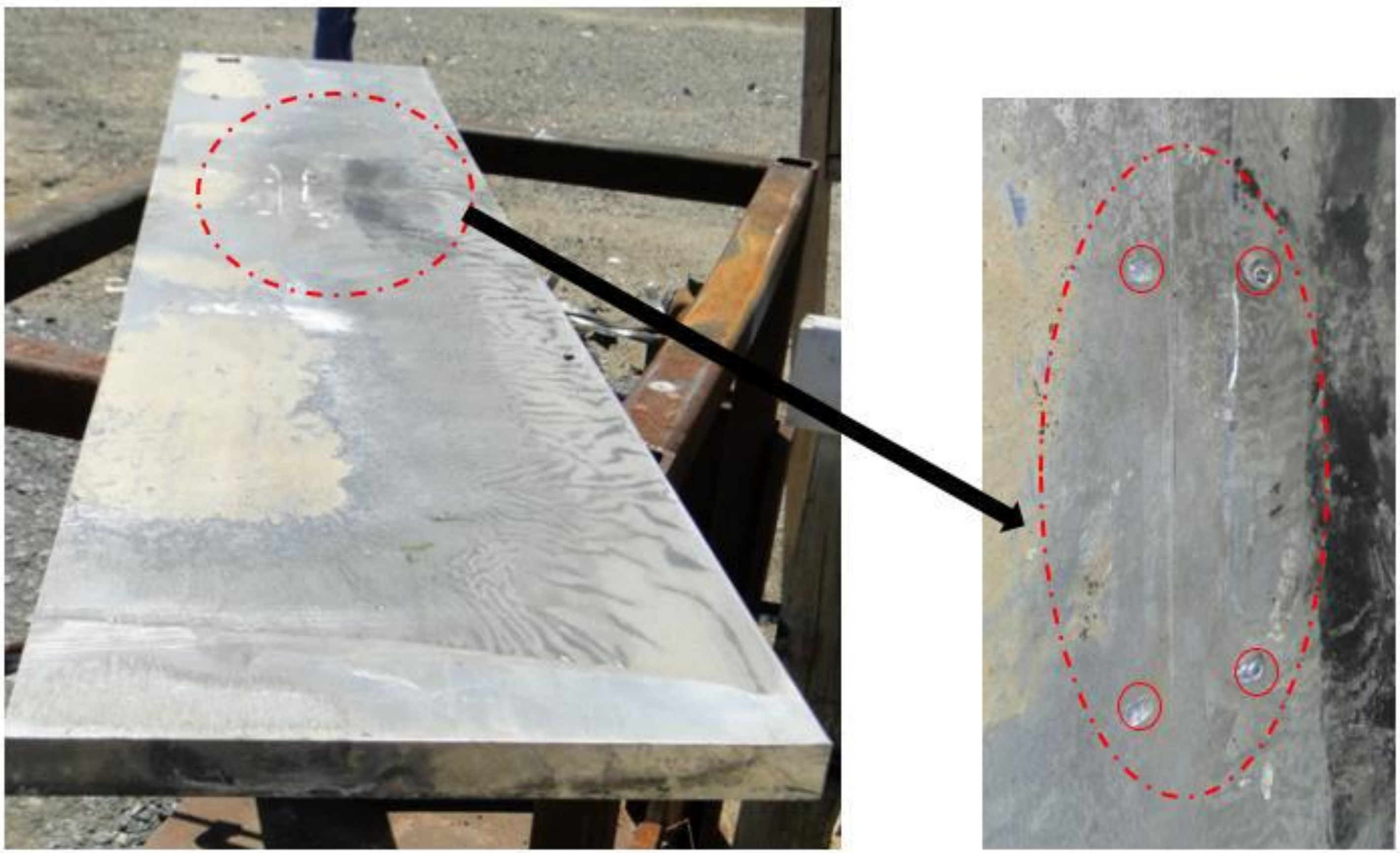
- **Fragment velocity: 8206 ft/s**
- **Fragment impacted the test item at the intended aim point (middle of primer)**
- **Fire and smoke visible when fragment impacted item**
- **Witness plate recovered on test stand; some minor denting noted on witness plate (imprints of rivets from the shipping container)**
- **Five pieces of shipping container, two pieces of ionomer window vent and the primer tube (severed in two pieces) were recovered at a range greater than 50 feet from the test stand**
- **Shipping container with foam packaging material and inert projectile recovered four feet from the test setup**
- **Stub base recovered five feet from the test stand**
- **Approximately 95% of unreacted propellant scattered out to a range of 100 feet from test stand**
- **Blast overpressures were low but measurable**

Technical Results

Fragment Impact Summary of Results (2)

- **IM score: Fragment Impact improved from Type III (steel case as baseline) to low Type IV**
  - Fewer fragments (~1/3 of steel case during Qualification Test, see backup slides), shorter distance
  - Lower Blast Overpressure (~1/2 of steel case)
  - Extremely little propellant burned

- **Post-test condition of witness plate: minor denting were found (imprints of rivets from the shipping container)**



- **Test item remains recovered within 50 feet of the test stand**

Technical Results

Fragment Impact

➢ **Test item remains recovered outside 50 feet of the test stand**

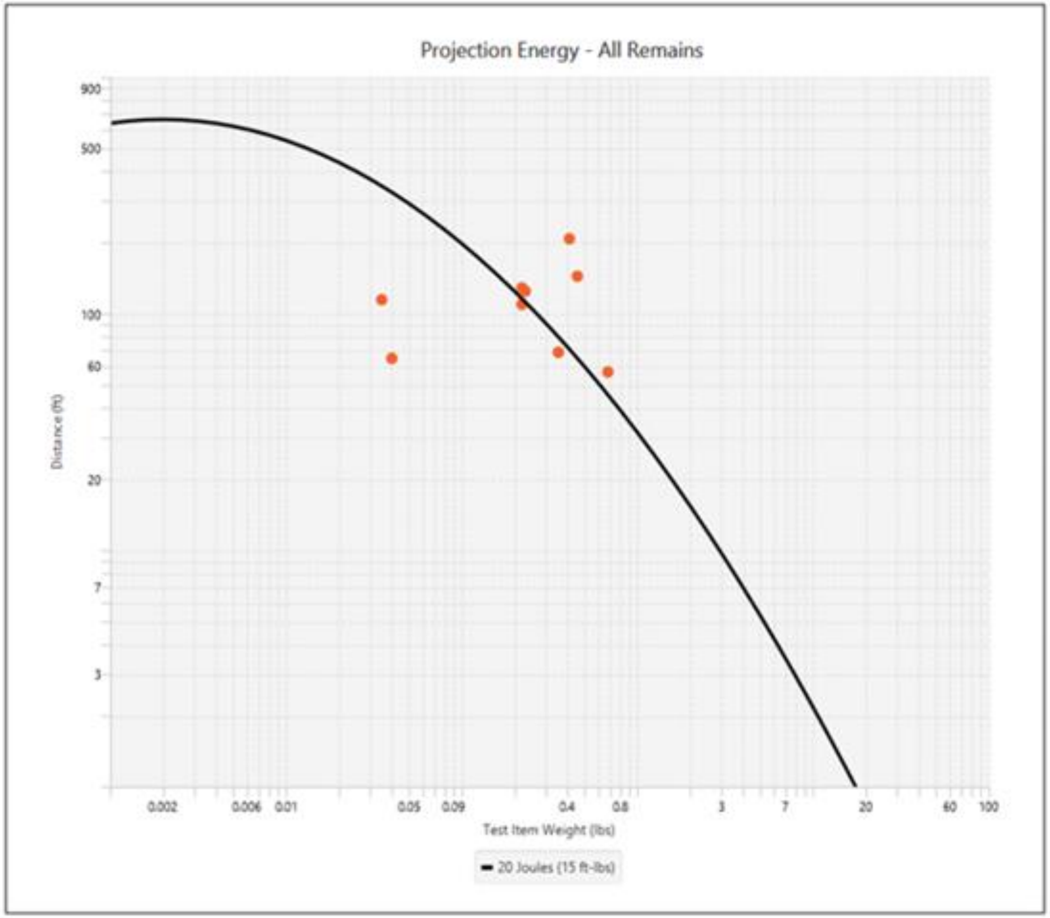
➢ **Range, angle and weight of test item remains**

Item Number	Item Description	Range (feet)	Angle (°)	Weight (lb.)
1	Priming tube piece	57	120	0.68
2	Container piece	110	145	0.22
3	Container piece	125	130	0.23
4	Container piece	69	190	0.36
5	Ionomer window piece	115	135	0.04
6	Container piece	65	115	0.04
7	Container piece	129	45	0.22
8	Window flange	208	135	0.41
9	Priming tube piece	144 ½	150	0.46

Technical Results

Fragment Impact

- Five pieces of test item remains exceeded or slightly exceeded the 20-joule projection energy criterion of AOP-39 Edition 3.



Technical Results

Fragment Impact

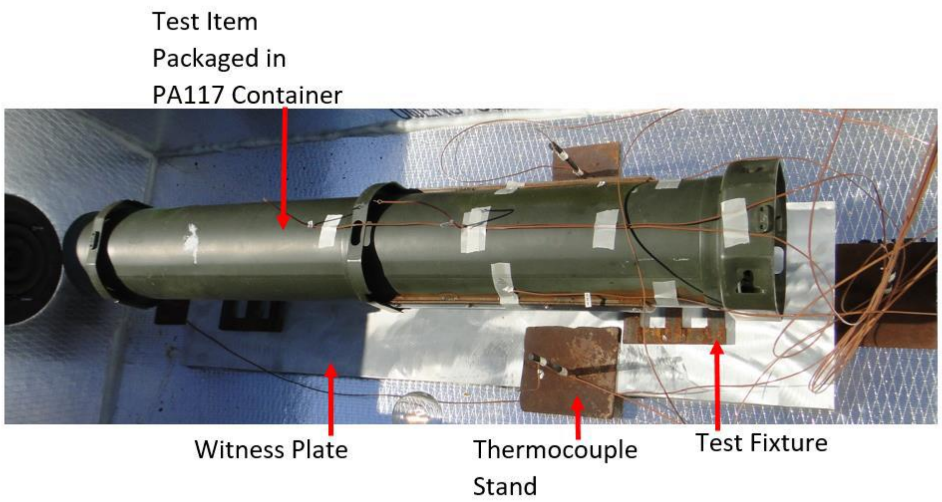
- **Blast overpressures of FCCCC with vented PA117 were approximately half of steel case with unvented PA117**

Blast Overpressure Measurements		
Gage Number	Distance from Test Item (ft)	Pressure Measurement (psi)
1	10	1.5
2	13	1.1
3	16	0.8
4	10	1.7
5	13	1.1
6	16	0.8

Technical Results

Slow Cook-Off Test Setup (1)

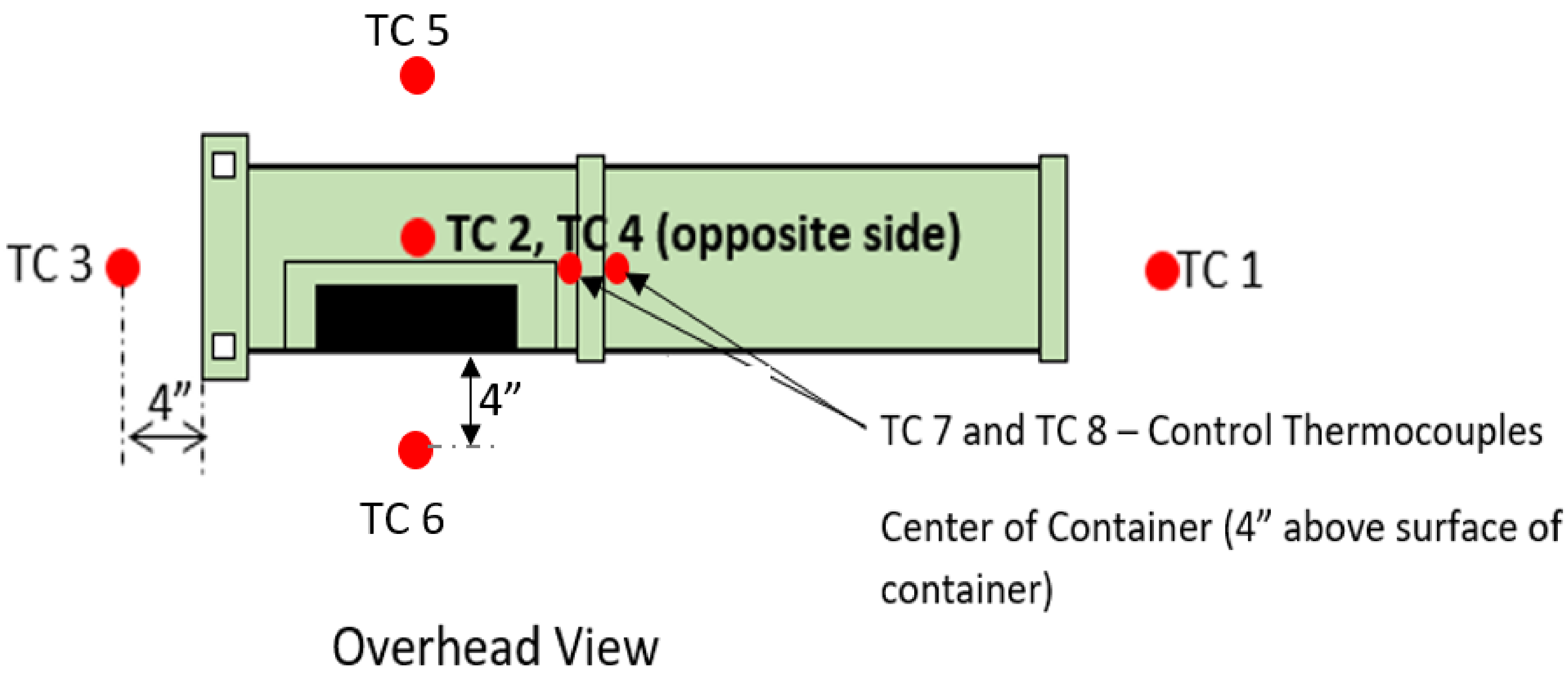
- Test item in packaged configuration: M724A2 projectile slug, FCCCC, M14 propellant, propellant bag, electric primer, stub base, vented PA117 container
- Test item was supported on a steel test fixture and centered in the oven in a horizontal orientation
- Oven temperature ramp rate: 27 °F per hour
- Instrumentation: blast pressure gauges, thermocouples, high speed & standard video camera to measure temperatures and record reaction severity



Technical Results

Slow Cook-Off Test Setup (2)

➢ **Thermocouple locations**



Technical Results

Slow Cook-Off Summary of Results

- **Average oven air temperature at time of reaction 320 °F**
- **Average surface temperature of test item container at time of reaction: 304.6 °F**
- **Shipping container remained on test stand**
- **All post-test remains recovered inside of shipping container**
- **All energetic material consumed**
- **Fire burned for approximately eleven minutes after reaction**
- **Smoke dying down approximately seventeen minutes after reaction**
- **No damage to the witness plate or support fixture**
- **No blast overpressures recorded**
- **IM score: Slow Cook-off had improved from Type III (steel case) to Type V (FCCCC)**
  - Oven intact (eventually burned)
  - No Blast Overpressure (gauges fully functional)
  - Container on test stand with cartridge metal components inside

Technical Results
Slow Cook-Off Post-Test Photo

Post-test condition of test oven

Post-test condition of Shipping Container

Shipping container on test stand

Both ends of shipping container remained closed

Test item remains removed from shipping container

Priming tube and steel case base

Witness plate with burn marks

Technical Results

- Ballistic Firing: Test Plan

- Test items: Twelve each of M724A2 projectile slug, FCCCC, M14 propellant, existing propellant bag for the 120-mm cartridge, electric primer, stub base with rubber seal.
- M724A2 cartridges (empty) were preassembled at Picatinny
- Pressure ports, energetics LAP, x-ray, and ballistic firing were conducted at APG
- A M68 cannon tube was ported to provide pressure-time data and negative differential pressures; equipped with a thermal shroud and inoperable bore evacuator to evaluate any post-fire residue.
- Charge Establishment (CE) Test consisted of 3 rounds to determine propellant charge weight required to meet a target velocity of 1570 mps required for M724A2 at +21°C
- Charge Verification (CV) Test consisted of 9 rounds to evaluate both performance and safety at -46°C, -32°C, +21°C, +52°C, +63°C
- Muzzle velocities, breech and shoulder pressures, negative differential pressures (NDP) and T4 time were measured
- Post-fire residues were collected and weighed

Technical Results

- Ballistic Firing: Summary of Results

- **LAP was successful with sufficient propellant load volume**
  - Propellant load study indicated a maximum of 4.6 kg (with bag) or 5.365 kg (without bag) propellant could be loaded into each FCCCC without any vibration device. The team decided to remove the oversized 120-mm heavy rayon bag until a bag or an integrated case/bag is designed for the 105-mm.
  - Final charge weight was determined to be 4.955 kg. X-ray shows 7.6% ullage (free space).
- **Ballistic firing had mixed results**
  - **Velocities:** FCCCC and steel case are comparable at ambient & hot. At cold FCCCC was significantly higher than steel case.
  - **Pressures:** FCCCC are higher than steel case but still well below gun’s safety limit.
  - **NDP: Most NDP were below 345 bar. Two rounds at cold** had higher NDP but pressure-time traces look normal.
  - **Post-fire residues**: Residue was a mixture of ash and expoxy adhesive. Most residues had an ash content of less than 0.5 gram.

Technical Results

- Ballistic Firing: Summary of Results

- **Ignited grass:** The first two CE rounds with higher charge weights ignited the grass upon impact.
- **Flareback/burning ember:** Most rounds (with 4.6 and 4.955 kg propellant) had flareback and burning ember issues, except the first two CE rounds with higher propellant charge weights (4.908 and 5.365 kg propellant).
- **Ejected case bases**: Most case bases were covered with soot, indicating a poor seal.

105-mm M68 Cannon Test Stand

M724A2 with FCCCC

Technical Results

- Ballistic Firing

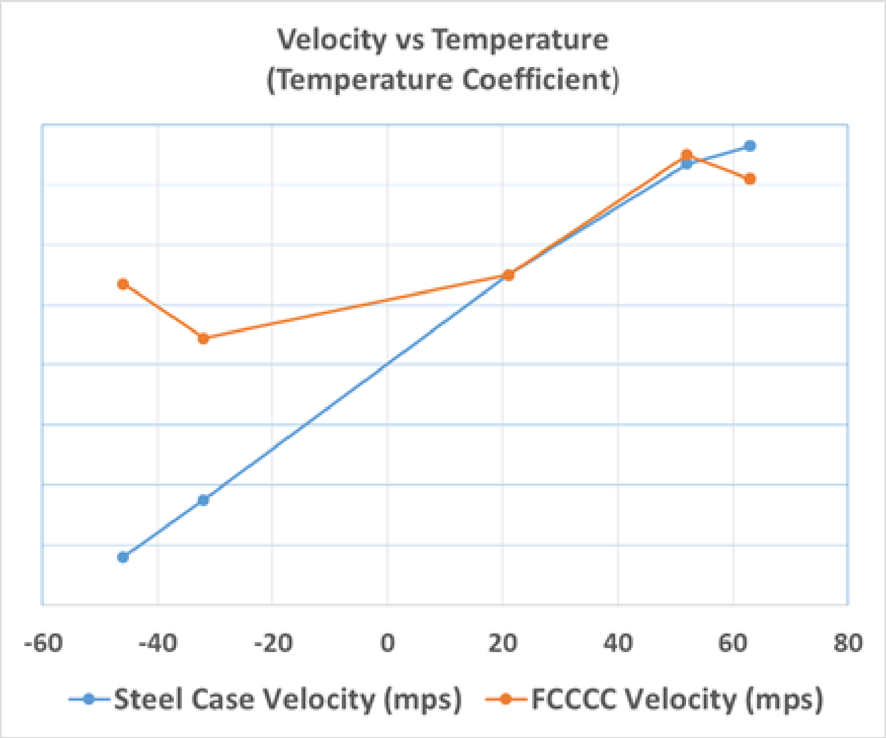
- **Charge Verification Test Matrix**

Test Round #	Temp (°C)	Charge Weight (kg)
TRN 4, 5	-46	4.955
TRN 6	-32	4.955
TRN 7, 8	21	4.955
TRN 9, 10	52	4.955
TRN 11, 12	63	4.955

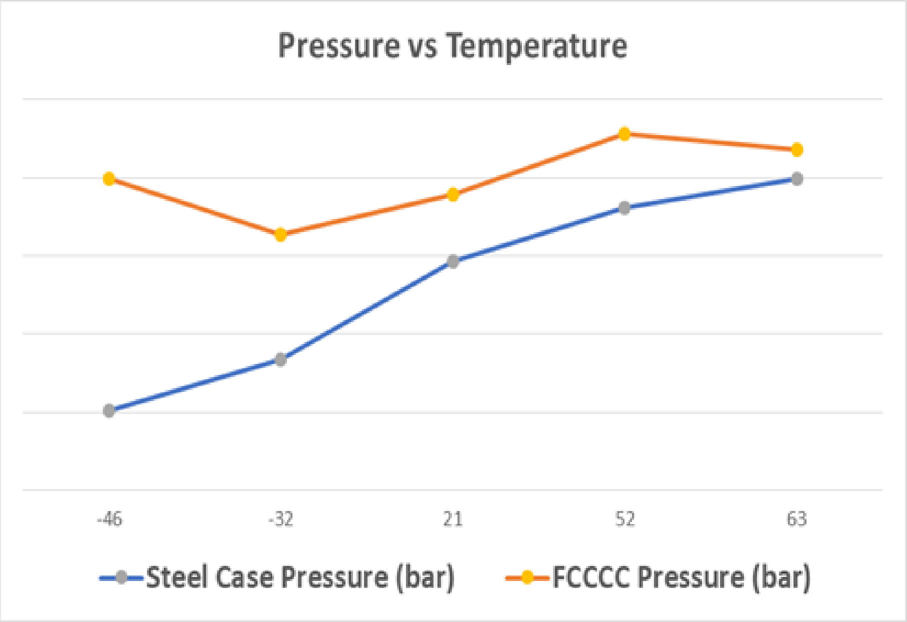
- **Charge Establishment Test Matrix**

Test Round #	Temp (°C)	Charge Weight (kg)
TRN 1	21	4.980
TRN 2	21	5.365
TRN 3	21	4.600

- Velocity vs Temperature (FCCCC vs Steel Case)



- Pressure vs Temperature (FCCCC vs Steel Case)



Technical Results

- Ballistic Firing

- Flareback and burning ember (TRN #12 @ +63°C)

Technical Results

- Ballistic Firing

- **Stub base with epoxy**

- **Post-fire residues**

Test Round Number	Total Residues (gram)	Epoxy (Estimated)	Ash (Estimated)
TRN 1, 2, 3	0.398	0.282	0.116
TRN 4	1.125	0.380	0.745
TRN 6	0.595	0.314	0.281
TRN 7	0.898	0.143	0.755
TRN 8	1.002	0.700	0.302
TRN 9	0.102	0.097	0.005
TRN 10	1.159	0.745	0.414
TRN 11	0.255	0.000	0.255
TRN 12	0.785	0.769	0.016

Conclusion & Recommendations

- **FCCCC combined with vented PA117 had been proven to be an effective IM venting technology**
  - FI had been improved from Type III to Type IV
  - SCO had been improved from Type III to Type V (passing)

- **Ballistic firing results have shown that**
  - FCCCC had matched the steel case in performance at ambient and probably at hot. Although FCCCC had a flatter temperature coefficient than steel case at cold, it may be considered an improvement in performance.
  - The Ultem adaptor might have ignited the grass. Ultem is fire resistant under normal situations, but will burn well if pulverized and superheated.
  - The flareback, burning embers and residue might have come from the double-walled thick lap joint. Increasing propellant and reducing foamed celluloid and epoxy could also help to eliminate these issues.

Conclusion & Recommendations

- **Improve designs of FCCCC and stub base/rubber seal**
  - Replace the case adaptor and Ultem with a one-piece design
  - Eliminate the double-walled thick LAP joint and epoxy with a one-piece design
  - Redesign stub base and rubber gas seal
  - Reduce wall thickness from 4-mm to 3-mm. Reinforced case with fiber reinforcement technology if necessary.

- **Transition FCCCC to Stryker and any future 105-mm vehicles**
  - Technology insertion during upgrade of Stryker autoloader and firing tables. A slight improvement on roller bearing units (e.g., springs, roller width) could significantly improve survivability of any combustible case.