Insensitive Munitions
Advanced Development
Ordnance Technology

NAVSEA
WARFARE CENTERS
DAHLGREN

Sheet-metal Ammunition Packing Tray for Mitigation of Secondary Cook-off of Medium-caliber Ammunition

2018 International Insensitive Munitions and Energetic Materials Symposium
Portland, OR
April 23 - 26, 2018

Greg Little, JP Shebalin, Jim Fetsko, Joe Silber
Naval Surface Warfare Center, Dahlgren Division, Dahlgren, VA

Jeb Brough
Matsys, Inc., Sterling, VA

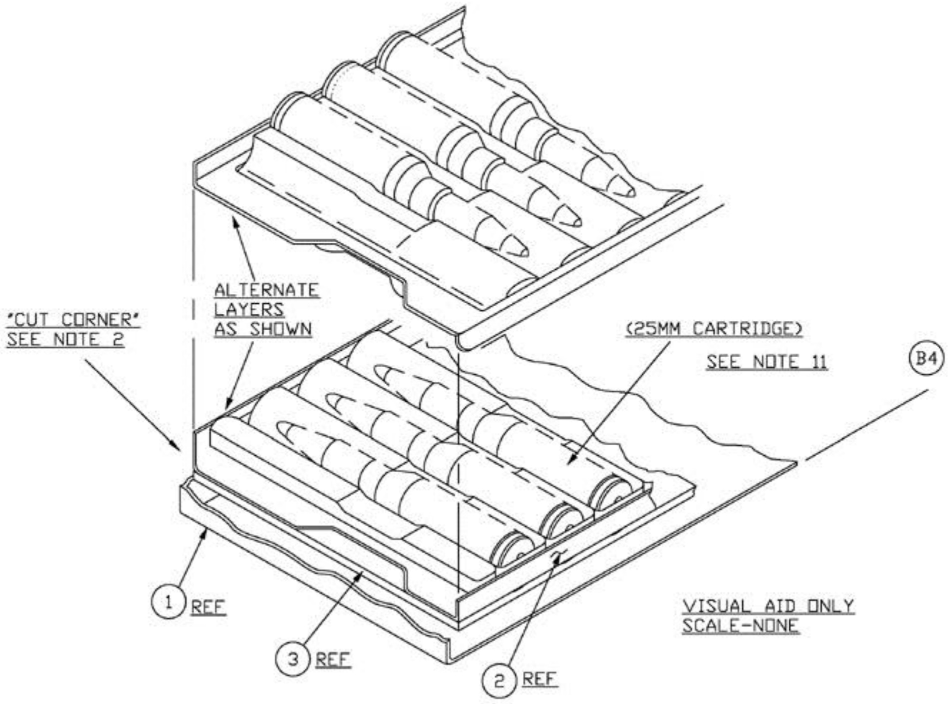
Email: greg.little@navy.mil
Phone: 540-653-0187

Background

- Insensitive Munitions (IM) testing of the 25mm PGU-47/U Armor Piercing High-Explosive Incendiary-Traced (“APEX”) Cartridge was performed by Nammo, the developer of the APEX, in 2014.
- In both Bullet Impact (BI) and Fragment Impact (FI) tests, delayed cook-off reactions of the ammunition remaining in the can were observed. These reactions occurred up to 42 minutes after the initial impact.
- This delayed cook-off is caused by the high-density polyethylene (HDPE) packing trays used to cushion rows of unlinked rounds.
- **This phenomenon was likely to impact other variants of ammunition stored in similar trays. A non-flammable replacement tray which still meets all packaging requirements will mitigate the subsequent cook-off reactions in impact scenarios.**

System Hardware – HDPE Trays

- **Each CNU-405/E container contains 100 25mm rounds stacked in 13 alternating layers of 7 or 8 rounds, with a 14th layer of 2 rounds to round out the total to 100.**
- **Layers are separated by the molded HDPE trays.**



7 rounds

8 rounds

A full set of HDPE trays (14 trays at 4.4 lbs total weight) contains the thermal energy equivalent of almost 0.75 gallons of gasoline.

PGU-47/U BI and FI Testing Results

- BI Test 1 (propellant aim point) resulted in minimal burning in the trays. Two post-impact reactions occur, at 4s and 21s after impact.
- BI Test 2 (projectile aim point) resulted in 24 delayed cook-off reactions over 11 minutes.
- FI Test 1 (propellant aim point) resulted in 2 reactions at approximately 3 and 8 minutes after impact.
- FI Test 2 (projectile aim point) resulted in 4 reactions at approximately 4, 12, 21, and 42 minutes after impact.

Delayed Cook-off Reaction due to burning HDPE trays

Approach

- **Design replacement tray that mitigates hazard while fulfilling all packaging requirements**
  - **Cost**
  - **Weight**
  - **Basic Safety Series testing**
  - **Manufacturability**

- **Characterize extent of hazard across ammunition types**
  - **Focus on widely used ammo first**
  - **Limited by funding and test cost**

Designing a working prototype tray easy to produce in testing quantities allows these tasks to operate largely independent of one another.

System Hardware – Aluminum Tray

Aluminum tray mass will be no greater than HDPE tray mass

- **Made of 5052 Aluminum. Folded edges improve stiffness compared with HDPE trays, which bow significantly when fully loaded.**
- **Alternating cutouts save weight while allowing rounds to nest in similar orientation to HDPE trays.**
- **Cutouts allow pressure to flow more easily between layers, reducing likelihood of ejecting the lid.**

System Hardware – PGU-32 SAPHEI-T

- **Initial mitigation testing focused on the PGU-32/U Semi-Armor Piercing High Explosive Incendiary, Tracer round (SAPHEI-T)**
  - **This round currently sees wide use across services**
  - **Contains propellant similar to that of the PGU-47/U, already proven vulnerable to delayed cook-off**

Test Methodology

- A limited first-year budget drove test scoping decisions.
  - Attempted to replicate, then mitigate, the phenomenon with the PGU-32/U.
  - Planned to repeat each test because the delayed burning reaction did not always occur in PGU-47/U testing.
- The cartridge case and similar propellant served as the aim point for BI testing.
  - A single 0.50 cal AP bullet was chosen to minimize the chance of a large scale reaction of projectiles that would destroy the confinement of the CNU-405/E.
    - Difficult to control the impact point of the second and third bullet without excessive confinement of the ammo can.
    - Only one bullet was required in the second BI test against PGU-47/U. Both other rounds missed due to the can jumping off the stand.

Navy

FY16 Test Review

Test Description	Target	Tray Type	Result
Single Bullet Impact	PGU-32 Propellant	HDPE	Does observed hazard occur in PGU-32/U?
Single Bullet Impact	PGU-32 Propellant	HDPE	Repeat of Test 1
Single Bullet Impact	PGU-32 Propellant	Aluminum	Demonstrate that aluminum trays mitigate delayed cook-off.
Single Bullet Impact	PGU-32 Propellant	Aluminum	Repeat of Test 2

HDPE PGU-32 Test Results – BI Tests 1 & 2

- **BI Test 1**
  - **Violent initial reaction ejected lid and roughly half the trays and rounds**
    - **Bullet likely hit a projectile (one reacted projectile found)**
  - **HDPE trays burned, resulting in a secondary reaction at 4 min 18 sec after impact.**
  - **All cartridges were recovered within 50 ft., but several components of the lid exceeded 50 ft.**

BI Test 1

- **BI Test 2**
  - **Can lid was blown clear, but the initial reaction was significantly less violent than in Test 1.**
  - **Trays did not ignite. No secondary reactions were observed.**
  - **Demonstrates the transient nature of the phenomenon – the hazard is present but does not always manifest.**

BI Test 2

HDPE PGU-32 Tests Tray Comparison

Dunnage from Test 1

Dunnage from Test 2

- **Thermal degradation of the trays in Test 1 is more pronounced than in Test 2, corresponding with the delayed reaction caused by tray burning witnessed in Test 1.**

Aluminum PGU-32 Test Results – BI Tests 3 & 4

- **BI Test 3**
  - **Some melting and charring in the impact vicinity, but the aluminum trays did not burn.**
  - **The ammo can lid stayed attached due to the tray's slotted design.**
  - **One secondary reaction occurred 1 minute after impact, ejecting a cartridge beyond 50 ft. All other debris remained inside can.**

BI Test 3

- **BI Test 4**
  - **Aside from localized melting/charring, no degradation was visible on the trays.**
  - **The lid remained attached to the container.**
  - **During the 25 second period after impact, two small audible reactions caused the container to jump.**
  - **No additional reactions occurred. All rounds were recovered in the can.**

BI Test 4

NAVSEA WARFARE CENTERS DAHLGREN

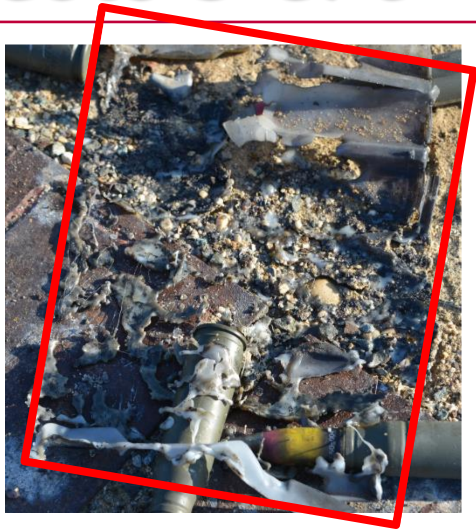
Test Matrix – FY17

Test Description	Target	Tray Type	Purpose
Triple Bullet Impact	PGU-32 Projectile	HDPE	Full BI Test of PGU-32 projectile for delayed cook-off vulnerability
Triple Bullet Impact	PGU-32 Propellant	HDPE	Full BI Test of PGU-32 propellant
Fragment Impact	PGU-32 Propellant	HDPE	Test PGU-32 Propellant for delayed cook-off vulnerability to FI
Fragment Impact	PGU-32 Propellant	Aluminum	Determine if Al trays worsen reaction violence

HDPE PGU-32 Test Results – BI Tests 5 & 6

- **BI Test 5**
  - **Much more violent than BI aimed at cartridge case**
  - **Entire can ripped apart, leaving no confinement to begin cook-off response.**
  - **Despite the lack of delayed cook-off, there was evidence of trays having burned outside the can.**

BI Test 5



- **BI Test 6**
  - **The initial impact blew the lid off along with numerous trays and rounds. The container otherwise remained intact.**
  - **Two delayed reactions occurred at 1 min 57 sec and at 4 min 13 sec. These ejected most of the can's remaining contents.**
  - **One piece of tray debris was found partially burned and melted to the cartridge case.**

BI Test 6

PGU-32 Test Results – FI Tests 1 & 2

- **FI Test 1 (HDPE Trays)**
  - **The fragment combined with the initial reaction to completely blow open the can's structure, removing any confinement.**
  - **No secondary cook-off occurred.**
  - **Furthest fragment distance was 216 ft. 24 pieces of debris exceeded the 50 ft threshold (22 exceeded 20 J).**

FI Test 1

- **FI Test 2 (Aluminum Trays)**
  - **The fragment impact completely blew open the can's structure, removing any confinement.**
  - **No secondary cook-off occurred.**
  - **Furthest fragment distance was 136 ft. 15 pieces of debris exceeded 50 ft (8 exceeded 20 J).**
  - **Aluminum trays may have mitigated violence compared to HDPE trays.**

FI Test 2

Tray Design Refinement

- Design optimization with a focus on logistical factors and manufacturability is underway in parallel with the testing effort.
    - Current waterjet-cutting method is appropriate for test quantities, but not mass-production.
    - Prototype small-scale production hardware has been fabricated to test out improved design process.
    - Once scaled up, improved design will address both logistical and safety issues.
    - After the improved design has been verified by environmental and impact testing, manufacturers will be approached to discuss costs associated with mass-production.

The Navy filed patent application 104525 in May, 2017 for "SHEET-METAL AMMUNITION PACKING TRAY."

Conclusions

- **Hazard**
  - Testing of the PGU-32 demonstrates that the delayed cook-off phenomenon is not limited to a single medium-caliber ammo type.
  - Delayed cook-off is a transient phenomenon, not occurring in every impact incident.
  - Even without direct cook-off of rounds in the can, slow-burning plastic is a long-duration hazard that could transition fire to adjacent spaces or munitions.

- **Solution**
  - BI and FI testing demonstrate that, in addition to addressing the specific hazard, the aluminum trays did nothing to worsen initial total item response and helped mitigate it in both cases.
  - Total elimination of post-impact reaction may not be possible. Residual heat of both impact and the initial reaction can prompt a violent response in the immediate aftermath.
  - HDPE trays are flimsy when fully loaded, frequently crack, and are typically discarded after a single use. Sheet-metal trays are stiffer and more durable, with greater potential for reuse.
  - **Replacement of HDPE trays with non-flammable, sheet-metal trays can address both hazard-mitigation and logistical concerns.**

Path Forward

- **Hazard Characterization**
  - Bullet Impact of PGU-23 and PGU-25 rounds to conclude hazard characterization.
- **Tray Design**
  - Tray design will be finalized for production readiness.
  - Environmental testing with intermediate/final tray design.
  - Impact testing will be conducted with the final design
- **Transition**
  - PMA-242 has been engaged throughout the process and has expressed interest in transition provided weight, cost, and packaging requirements are met with final design.

NAVSEA WARFARE CENTERS DAHLGREN

Acknowledgments

- **NOSSA**
  - **Ken Tomasello, IMAD Program Manager**
  - **Heather Hayden**
- **NSWCDD**
  - **Noel Colon-Diaz**
  - **Jim McConkie**
  - **Jacqui Williamson**
  - **Perry Fridley**
  - **Rachel Kramer**
  - **Donna Crabtree, Test Engineer**
  - **Daniel Ross, Test Engineer**
  - **Gerhard Thielman, NSWCDD Legal**
- **PMA-242**
  - **Pete Sweazy**
- **IHEODTD PHS&T**
  - **Elizabeth Lee**
  - **Earl Humphries**