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


Presented by

Greg Little, J.P. Shebalin, Jim Fetsko, Joe Silber
Naval Surface Warfare Center Dahlgren Division, Dahlgren, Virginia
Email: greg.little@navy.mil
Phone: 540-653-0187

And

Jeb Brough
Matsys, Inc., Sterling, VA


## Abstract


Bullet Impact (BI) and Fragment Impact (FI) Insensitive Munitions (IM) tests against unlinked, medium-caliber ammunition packaged in ammunition cans with high-density polyethylene (HDPE) packing trays have demonstrated a secondary hazard distinct from the rounds' initial reaction to impact. Specifically, the HDPE trays display a tendency to catch fire as a result of the impact and initial reaction of the ammunition. This fire begins a sustained series of secondary cook-offs of projectiles and cartridge cases that lasts until either the fire burns out or the contents of the ammunition can have reacted or been ejected due to secondary reactions.

This hazard has been witnessed in two types of 25mm ammunition, with two more due for demonstration testing in 2018. Any munitions packaged in similar trays may be vulnerable to this phenomenon due to the high energy density of the HDPE and its flammability properties. Secondary reactions often continue long after the initial impact with no obvious visual indication that combustion is taking place until a reaction occurs.

Replacement of these trays with a nonflammable alternative would mitigate this safety hazard. Preliminary testing of prototype sheet-metal ammunition packing trays has demonstrated favorable results in this regard without degrading the initial IM response. Currently, design refinements are underway to improve manufacturability of these trays. Once these refinements are complete, the trays are expected to meet all necessary packaging requirements (cost, weight, performance) while mitigating the secondary cook-off hazard.


## Background

Prior BI and FI testing conducted on containerized, unlinked PGU-47/U Armor-piercing High-explosive (APEX) 25mm ammunition (developed and tested by Nammo) revealed an unexpected hazard—the ignition and slow burn of the HDPE packaging trays, resulting in a series of cook-off reactions, often occurring after a significant delay and continuing for many minutes afterward (the reaction furthest in time occurred 42 minutes after initial impact). Given the ubiquity of the HDPE trays in packaging unlinked, medium-caliber ammunition, the similarity of energetics across ammo types, and the long service life of commonly used medium caliber ammo types, it was reasonable to expect that testing of common ammunition types under modern IM standards would reveal this hazard to be widespread. The Navy Insensitive Munitions Advanced Development (IMAD) Program funded a task to determine the extent of the delayed cook-off response and to develop and test possible replacement trays that would mitigate the hazard.

Unlinked 25mm rounds are packaged in the CNU-405/E, an ammunition can that holds one-hundred (100) rounds in fourteen stacked HDPE trays, thirteen alternating between seven and eight rounds per tray, with the top tray containing just two rounds to make the loadout an even one-hundred. Images of how alternating rounds nest together can be seen in Figure 1.

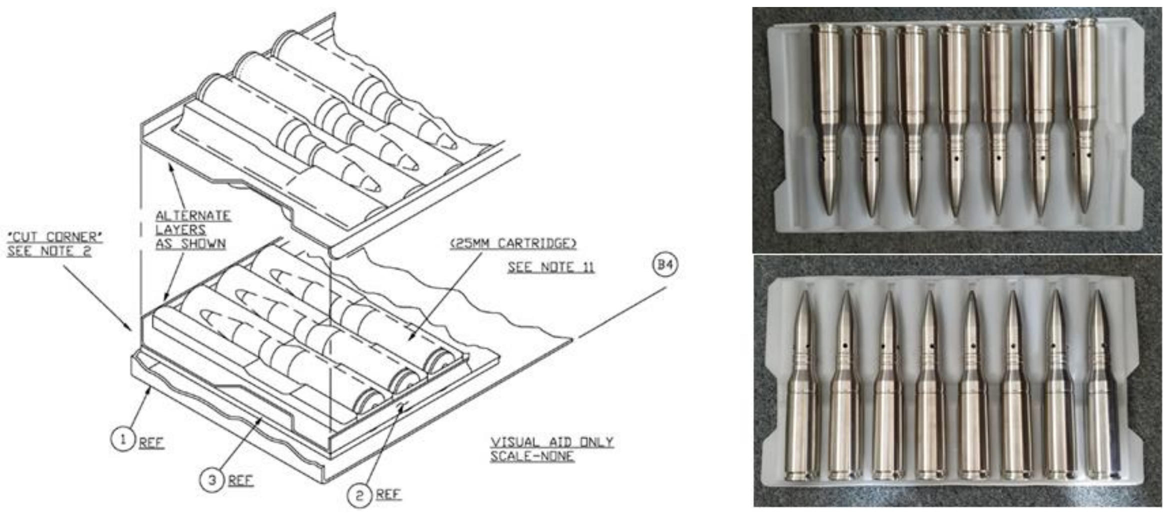


**Figure 1:** HDPE packing tray nesting (left) and 25mm round alternating tray layout (right)

## 2016 Progress

Due to availability issues with the PGU-47/U and a desire to characterize the extent of the hazard across different ammunition types, initial mitigation testing focused on the PGU-32/U Semi-Armor Piercing High-Explosive Tracered (SAPHEI-T) round, an all-purpose round in widespread use by the U.S. Navy and Marine Corps. The purpose of this testing was to determine whether the phenomenon occurs across different 25mm ammunition types and, if so, whether or not a nonflammable packing tray would mitigate the hazard.

The initial tested prototype was cut from 0.050” 5052 sheet aluminum. In addition to bending the edges to improve stiffness, a waterjet was used to cut slots for the nesting of the 25mm rounds, contrasting with the full cradles in the current HDPE trays. This offers two advantages. The first is a substantial weight savings over a solid tray, necessary as the new trays cannot weigh any more than the current HDPE trays. The second advantage is less obvious. The slots in each tray act as a path for gas pressure relief. When an impact occurs in the current packing arrangement, the sudden pressure rise forces every tray and round above the point of impact upward like a piston, ejecting the ammo can lid and much of the can’s contents at high velocity. With the aluminum packing trays, the same impact pressure rise flows through the slots between layers, attenuating throughout the can's entire volume. As will be seen in the test results section, this attenuation results in the ammo can lid remaining in place, containing most or all of the debris within the ammo can. The aluminum tray design can be seen in Figure 2.

**Figure 2:** Prototype aluminum tray (left); Three trays stacked with dummy 25mm rounds (right)

Initial testing against the PGU-32/U focused on testing with a single 0.50" armor-piercing (AP) bullet. Using a single bullet instead of three was deemed necessary during these early characterization tests due to the difficulty of controlling the impact point of the second and third rounds without restraint of the ammo can, which would be undesirable. Additionally, the aim point for all of these tests was the propellant center of mass. PGU-47/U and PGU-32/U rounds have dissimilar explosive fills but similar propellants, so targeting the propellant was deemed less likely to cause a reaction so violent that the can would lose all confinement. This would enable testing to focus on recreating the hazard seen in the initial PGU-47/U IM testing. Table 1 depicts the 2016 test matrix.

**Table 1:** 2016 Test Matrix

| Test Description | Aim Point | Tray Type | Purpose |
|---|---|---|---|
| Single Bullet Impact (BI Test 1) | PGU-32 Propellant | HDPE | Test PGU-32 round for delayed cook-off vulnerability |
| Single Bullet Impact (BI Test 2) | PGU-32 Propellant | HDPE | Repeat of Test 1 to demonstrate repeatability |
| Single Bullet Impact (BI Test 3) | PGU-32 Propellant | Aluminum | Demonstrate that tray swap mitigates delayed cook-off hazard |
| Single Bullet Impact (BI Test 4) | PGU-32 Propellant | Aluminum | Repeat of Test 3 to demonstrate repeatability |

BI Tests 1 and 2 demonstrated the transient nature of the delayed cook-off phenomenon. Test 1's impact ejected the ammo can's lid and resulted in clear signs of burning trays and a secondary cook-off reaction at 4 min 18 sec after impact. Conversely, despite an identical test setup, aimpoint and lid ejection, Test 2 trays did not sustain a burn and no secondary reactions were observed. Comparative pictures of the plastic trays from each test can be seen in Figure 3.

**Figure 3:** Comparison of plastic tray thermal degradation from Test 1 (left) and Test 2 (right)

BI Tests 3 and 4 repeated the test setup from 1 and 2, with the HDPE trays replaced by the prototype aluminum trays seen earlier in Figure 2. The difference in reactions was obvious. First, whereas the HDPE tests resulted in the ejection of the lid along with every tray and round above the point of impact, in the aluminum tests, the lid bowed upward but remained attached, keeping the trays and rounds inside which significantly limited the scattering of debris. This can be seen in Figure 4.

**Figure 4:** Comparison of post-test debris in BI Test 1 (left) and BI Test 3 (right).

Test 3 had a single round react and eject from the side of the ammo can one minute after initial impact, leaving a hole to the right visible in Figure 4. However, as there was no sign of tray burning in the post-test debris, this is most likely due to the initial heating caused by the impact and the immediate reaction of the propellant and/or explosive to that impact. There were no further reactions in Test 3 despite having roughly twice the energetic material remain inside the ammo can compared to Test 1 or 2. In Test 4 a pair of small, audible reactions that caused the ammo can to jump were observed in the first 25 seconds after impact, but nothing left the can. Aside from some char residue from the burning energetic material and localized melting near the point of impact, the aluminum trays showed no signs of degradation (Figure 5).

**Figure 5:** BI Test 4 rounds and trays.

The 2016 testing demonstrated that both the understanding of the hazard’s root cause and the proof-of-concept solution devised were valid. In addition, the prototype aluminum tray design (shown in Figure 1) allows attenuation of internal pressure rises, limiting the scattering of debris seen consistently in HDPE testing.

## 2017 Progress

Continuing work to characterize the scope of the threat was undertaken in 2017. Full BI and FI tests of the PGU-32 were performed, with varying aim points and tray types. Table 2 depicts the 2017 test matrix.

**Table 2:** 2017 Test Matrix

| Test Description | Aim Point | Tray Type | Purpose |
|---|---|---|---|
| Triple Bullet Impact (BI Test 5) | PGU-32 Projectile | HDPE | Test PGU-32 projectile for delayed cook-off vulnerability |
| Triple Bullet Impact (BI Test 6) | PGU-32 Propellant | HDPE | Determine vulnerability to IM test standard as compared to single bullet. |
| Fragment Impact (FI Test 1) | PGU-32 Propellant | HDPE | Test PGU-32 propellant for delayed cool-off vulnerability to FI |
| Fragment Impact (FI Test 2) | PGU-32 Propellant | Aluminum | Determine how aluminum trays affect overall FI response |

BI Test 5 represented the first attempt to perform a full triple-bullet impact test against PGU-32/U rounds for the explicit purpose of observing packing tray burning and subsequent delayed cook-off reactions. Prior-year testing was performed entirely with single-bullet impact tests into the propellant, deemed the less likely energetic material to induce a violent reaction. In increasing to the full triple-0.50” AP bullet configuration as specified in STANAG 4241 and setting the aim point at the more sensitive projectile, BI Test 5 can be considered a bounding, worst-case BI test for this ammunition type.

The results of the test validated the 2016 decision to target the propellant. The violence of BI Test 5 was sufficient to blow apart the ammo can and scatter the ammo and trays, providing no confined space in which a delayed cook-off event could take place. While these results did not provide useful data in categorizing the phenomenon in question, there was evidence of a tray that burned up almost entirely outside the ammo can, further illustrating the flammability of the HDPE under impact conditions. Evidence of these responses are shown in Figure 6.

**Figure 6:** Post-test debris of BI Test 5 showing catastrophic damage to the ammo can (left) and a burned HDPE packing tray (right)

The aluminum trays had already been proven not to burn under BI using this ammunition. Moreover, demonstrating the HDPE hazard under full triple 0.50” AP bullet threat was desirable. To avoid a repeat of the violence observed in BI Test 5 (and resulting lack of relevant data), BI Test 6 used three rounds to impact the original 2016 aim point of the propellant in the cartridge case. This test would conclude the BI characterization of the PGU-32/U delayed cook-off response.

BI Test 6 resulted in another clear indication of delayed cook-off responses. Two delayed responses occurred, one at 1:57 min. after impact and the other at 4:13 min. after impact. As can be seen in Figure 4, the can remained largely intact minus the typical ejection of the lid and upper layers of trays and ammunition. Figure 7 shows a burned and melted tray fused to an empty cartridge case.

**Figure 7:** Remains of cooked-off rounds and burned trays (left); A partially burned tray fused to empty cartridge case (right)

Initial testing focused exclusively on BI threats. However, because this delayed cook-off response was also seen in the PGU-47/U FI testing that inspired this work, characterizing both the likelihood of delayed cook-off response in the PGU-32 and the overall FI response in the presence of aluminum trays was deemed necessary.

For FI Test 1, a propellant cartridge aim point was chosen to lessen the possibility of catastrophic damage to the can such as that seen in BI Test 5. Despite this decision, the response was very similar to that of BI Test 5, with the can opening fully (Figure 8) and exposing the rounds and trays, leaving no confined conditions for the cook-off to take place. Rather than repeat a test where relevant data was unlikely to be acquired, focus turned to testing aluminum prototype trays under the same conditions. One important consideration for replacement packaging is that it should not worsen current IM reaction levels. FI Test 2 was therefore conducted to demonstrate that the reaction was no worse than FI Test 1.

**Figure 8:** Ammo can post-test, completely blown open

The test item response was very similar to that of FI Test 1, with a slight improvement in that max fragment distance decreased (from 216 ft. to 136 ft.) and fewer fragments exceeded the 20 J threshold (22 in FI Test 1 vs. 8 in FI Test 2). No worsening of the baseline reaction was evident, and it is possible that the slots in the aluminum trays allowed for pressure relief that would account for the response's mild improvement. These results are shown in Figure 9. Additionally, two other ammo types, the PGU-23 and PGU-25, were procured for 2018 testing to further demonstrate improved response to the threat.

**Figure 9:** Test stand post-test, showing scattered aluminum trays and rounds (left); Post-test debris that traveled farther than 50 ft (right).

### Aluminum Tray Design Refinement

In parallel with the hazard characterization work, design improvements to the prototype tray are underway. The original design used waterjet-cut aluminum sheets, well-suited to quick, cost-effective production of test articles. However, the waterjet is not an efficient method of mass-producing trays.

Prototype manufacturing hardware has been fabricated to test a mass-production process in small-scale before the effort proceeds to large-scale fabrication. Once the procedure has been perfected and the improved design has been verified by testing to address both safety and logistical concerns, manufacturers will be approached to begin discussing mass-production options and expected costs going forward.

### Conclusions

The slow burn-rate of the HDPE trays can provide the fuel for sustained fires. Secondary reactions have been observed as long as 42 minutes after impact when these trays are present. Replacement of the HDPE trays with nonflammable trays will result in a significant safety improvement in medium-caliber ammo cans. While secondary reactions can still occur due to the initial impact spilling propellant/explosive within the ammo can interior, the high burn rate of these energetic materials ensures such reactions will be confined to the immediate vicinity of the inciting event.

Additionally, showing that the aluminum trays do not worsen the immediate reaction in either Bullet or Fragment Impact events proves that one safety improvement isn’t coming at the expense of another safety issue. Provided the logistical and basic safety packaging requirements can be met, the sheet-metal ammunition packing tray offers a solution to the safety hazard of delayed cook-off.

## Path Forward

Testing of PGU-23 and PGU-25 rounds will occur in 2018 to characterize the phenomenon as completely as possible. Four BI tests are currently planned, one for each ammo/tray type combination. The test matrix is detailed in Table 3.

Further work will involve finalizing the tray design for manufacturability and weight constraints and subjecting it to final impact and environmental testing, as well as investigating potential sources of production as this initiative moves toward transition. Once a finalized design has been developed, a limited number of sets will be fabricated for environmental and BI testing, which should conclude the work no later than 2019.

**Table 3:** 2018 BI Test Matrix

| Test Description | Aim Point | Tray Type | Purpose |
|---|---|---|---|
| Triple Bullet Impact (BI Test 7) | PGU-23 Propellant | HDPE | Test PGU-23 projectile for delayed cook-off vulnerability |
| Triple Bullet Impact (BI Test 8) | PGU-23 Propellant | Aluminum | Demonstrate that tray swap mitigates delayed cook-off hazard |
| Triple Bullet Impact (BI Test 9) | PGU-25 Propellant | HDPE | Test PGU-25 projectile for delayed cook-off vulnerability |
| Triple Bullet Impact (BI Test 10) | PGU-25 Propellant | Aluminum | Demonstrate that tray swap mitigates delayed cook-off hazard |

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