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A Tracer Analysis for the M1002 Training Projectile

by James Garner, Xaiogang Huang, Jason Mishock, and John Kostka

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14. ABSTRACT
Testing to qualify the M1002 round was conducted in FY08. The M1002 round has met its accuracy requirements as a training round to replace the M831A1. The present configuration achieves acceptable performance but could be improved. This report provides an understanding of some of the tracer’s launch conditions, which are important in determining what might be done to further improve tracer performance.

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1. Introduction

The M1002 is the high-explosive antitank training round planned to replace the M831A1. The round has achieved type classification and substantially meets its requirements as a training round. A nagging shortcoming of tracer burnout at cold conditions was observed in a number of tests and merited examination as to its source. The purpose of the tracer is to allow the projectile trajectory to be immediately visualized so that a judgment can be made as to where the round impacted and if the flight was as expected. This information is essential in training scenarios as gunner accuracy is the skill being developed and requires instant round-to-round accuracy assessment by the trainee. Tracer failure for the M1002 round is defined as nonvisibility at the 3000-m range. This normally manifests itself in premature tracer burnout (the tracer was seen to ignite near the muzzle but was not visible at the 3000-m location).

The U.S. Army Research Laboratory was asked to perform finite-element analyses and materials characterization studies to better understand the phenomena observed in testing. Initial stress analyses presumed mechanical properties and were coupled with appropriate boundary conditions to yield results for comparison with in-flight testing and recovered test article data. Mechanical properties of the tracer material remain to be accomplished to establish a broader database on their stress-strain behavior. These data can be reinserted in analysis codes to better understand the range of possible effects.

2. Projectile Tracer Configuration and Propellant Properties

The configuration of the tracer well, the tracer material, and the interior ballistic conditions in the ballistic cycle are all critical to understanding the course of events and end results observed. Figures 1 and 2 show a projectile assembly, flare cone, and tracer cup (shown in yellow with a gray cap) cross sections with tracer fill material (shown in red). The gray cap and filled tracer cup is threaded into the projectile flare cone to form the completed projectile assembly.

The tracer fill/burn material in the cup comprises three pellets pressed together and glued in place at the pellet-cup interface with an igniter layer (shown in gray) covering the third pellet. Ideally during the launch cycle, a protective brass diaphragm enclosing the tracer mix is broken, and the igniter and pellets burn in sequence forward throughout the projectile flight. Once the diaphragm breaks, the fill material is exposed to the base pressure and hot gasses. The effect of this pressure was thought to be minimal as the fill material is contained. For an incompressible solid, this is a believable condition, but the extent to which the fill material is incompressible is uncharacterized, leaving questions as to its actual behavior during the interior ballistic launch cycle. Detailed stress analyses were conducted using varying boundary conditions and pellet configurations to attempt to model the launch conditions and ultimately match observed test results.

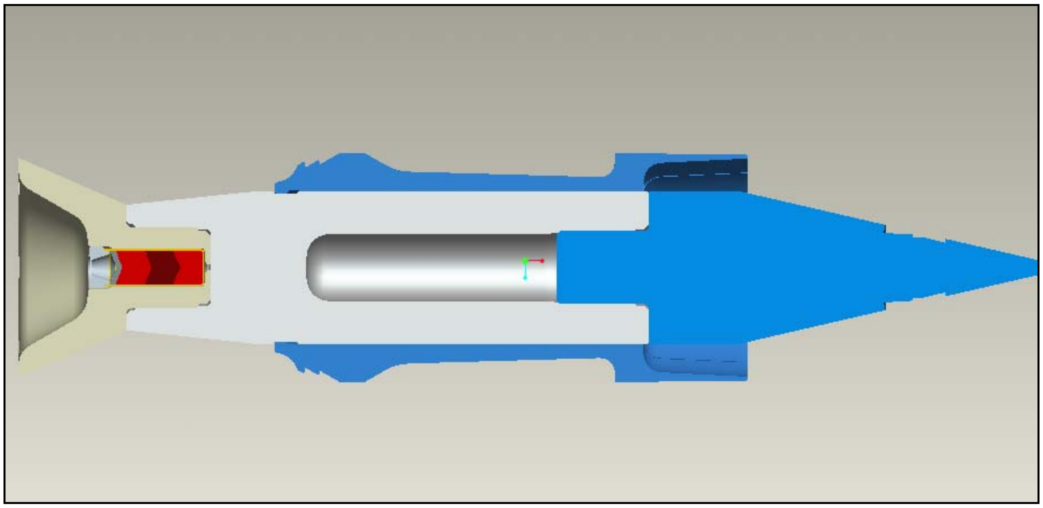

Figure 1. M1002 projectile assembly cross section.

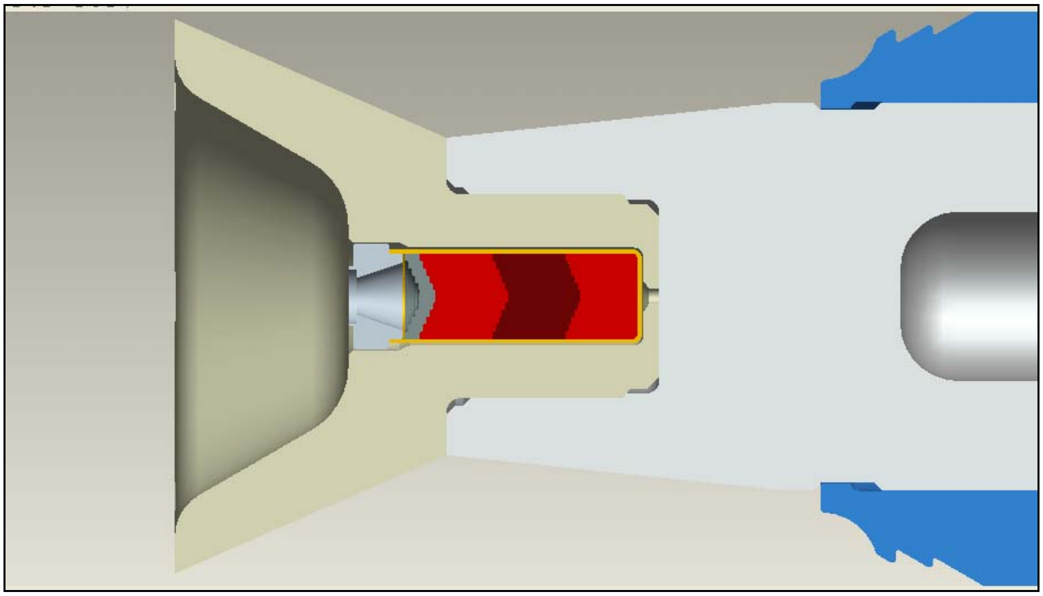

Figure 2. M1002 flare cone cross section with three-pellet tracer configuration.

Premature tracer burnout raises several questions. Does the burn react to the interface between the pellets? Does the launch acceleration fracture the pellets? Is there benefit in a double or single pellet design to replace the present three-pellet design? Do cold conditions affect the tracer fill mechanical properties. Table 1 illustrates the change in properties under varying temperature conditions with the associated moduli.*

Table 1. Tracer material properties variation with temperature.

Temperature (°C)	**Modulus E (psi)**	**Shear Modulus G (psi)**	**Ultimate Stress Compressive (psi)**
52	19,000	6333	700
21	49,000	16,333	1700
–32	118,000	39,333	5400

A stress analysis is useful in understanding a possible sequence of events and relating those events to those observed. The properties in table 1 were supplied for modeling purposes. While ARL has facilities to determine propellant mechanical properties, this testing remains to be completed. An independent verification of the properties would improve the credibility of the data and thereby improve model credulity. The failure mechanism that determines ultimate strength was unspecified in table 1. The burning that results from a brittle catastrophic failure (lots of smaller particles and an increased propellant surface area) is much different than a buckling failure that might be more of a bend with a single fracture in the propellant grain. The surface area and burning properties for the latter might remain closer to its original condition.

3. Finite-Element Modeling and Results

A model of the tracer cup was constructed, and boundary conditions were applied using ABAQUS.[1,2] A tracer cup model section sketch is shown in figure 3. A three-dimensional model of the tracer cup assembly was used to assure fidelity of the solution and contain material under the projectile base pressure load. The pressure seen across the nozzle of the tracer (after the diaphragm breaks) is greatly reduced relative to the base pressure. A scaled pressure loading factor of 0.2× the base pressure was selected to account for pressure reductions due to choked flow across the tracer nozzle and volume changes, as the projectile translates downbore, and

*Shear modulus calculated: $G = E/2(1+\upsilon)$, where $\upsilon = 0.499$ (measured for propellant at 21 °C).

[1]ABAQUS, Inc. *ABAQUS Theory Manual*, version 6.6; Providence, RI, 2006.

[2]ABAQUS, Inc. *ABAQUS/Standard User's Manual*, version 6.6; Providence, RI, 2006.

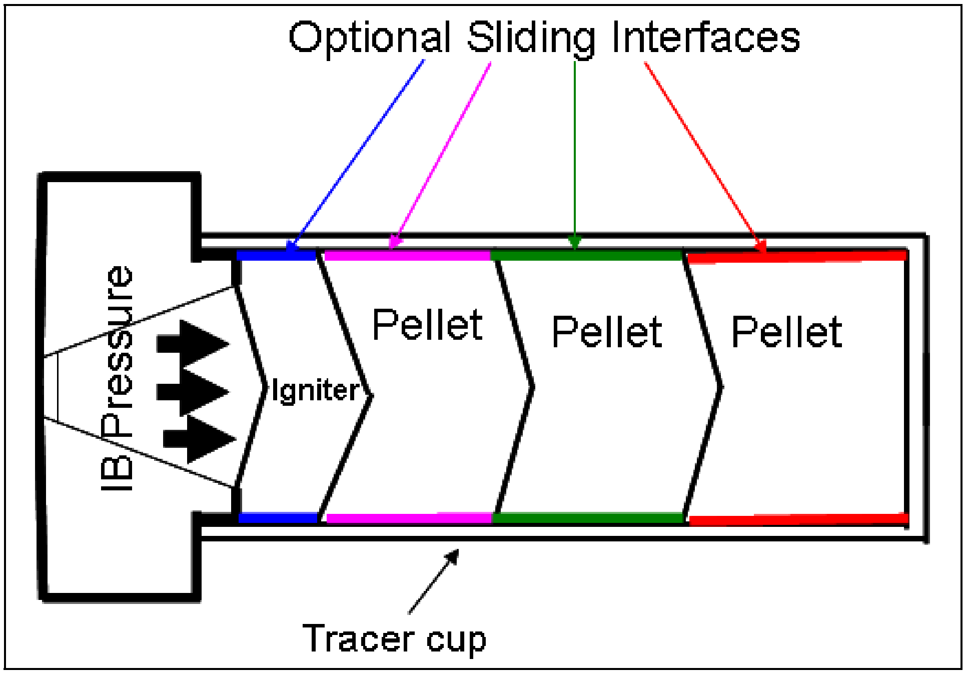

Figure 3. A schematic section of the tracer cup.

averaged loading conditions on the tracer mix. The exact pressure exerted on the fill is unknown. The ABAQUS analysis code allows for sliding elements. The sliding elements modeled the scenario of the pellet (wall bond shearing and allowing an individual pellet to slide). The Von Mises stress is plotted using a scaled base pressure with perfect bonding (no sliding) of the pellets at the cup wall (see figure 4). Areas that are deep blue and light blue most likely do not fail, while other colors indicate stress levels that probably do fail.

The realistic modeling of the sequence of events during launch is always a challenge. The model assumes the tracer pellet(s) and the cup wall are glued together and, in theory, they are rigid up to a yield stress level. Above that stress level, the material may fracture. Test data clearly indicate that the tracer material fractures as pieces of material are sometimes expelled. Absent is the effect of temperature. In the cold condition, the tracer material may be more brittle and therefore more inclined to fracture and propagate stress and fracture under a rapid loading. The following analyses use the presumption that when the stress level exceeds the shear strength of the pellet material, it fractures at the cup-pellet interface and becomes a sliding mass with a sliding surface at the pellet-cup interface. Then the next pellet (moving from top to bottom) is tasked with supporting the weight of the free pellet as well as its own weight under pressure. Figure 5 shows the case of the first pellet sliding, and figure 6 shows the shearing for a fully sliding tracer fill. The last pellet is unable to slide downward as its base is supported by the metal tracer cup. The metal tracer cup, though thin, is supported by the aluminum flare material and is essentially rigid.

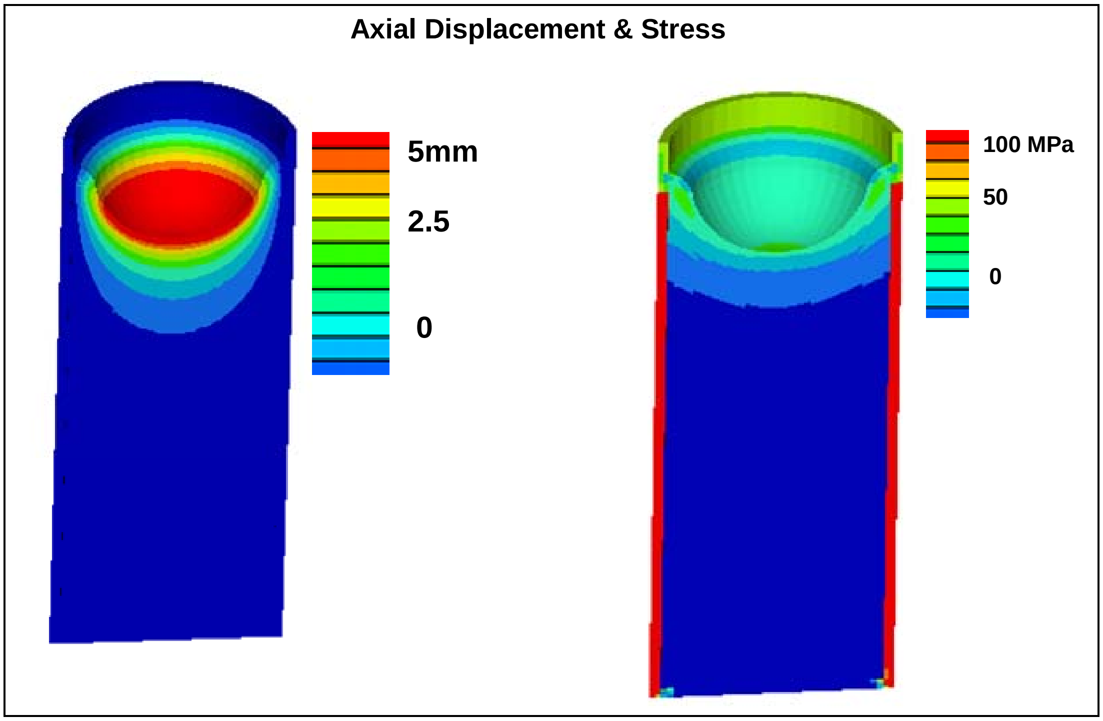

Figure 4. Complete bonding of pellets to cup wall.

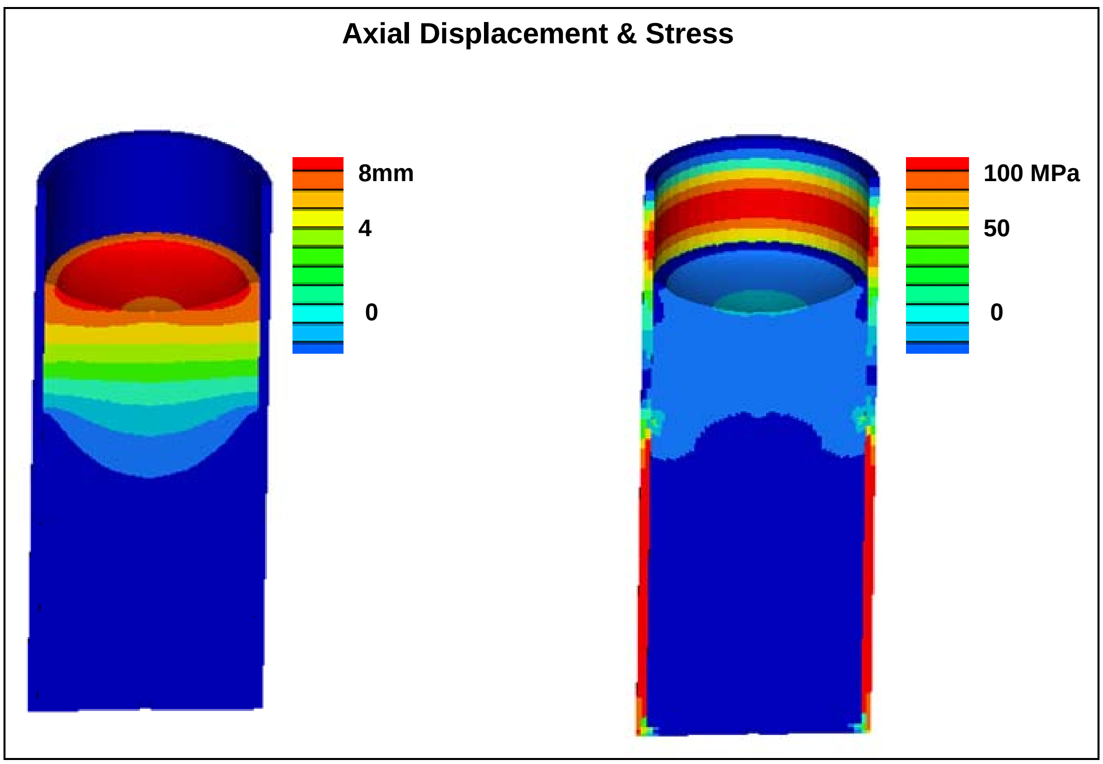

Figure 5. Stress contours allowing first pellet sliding boundary condition.

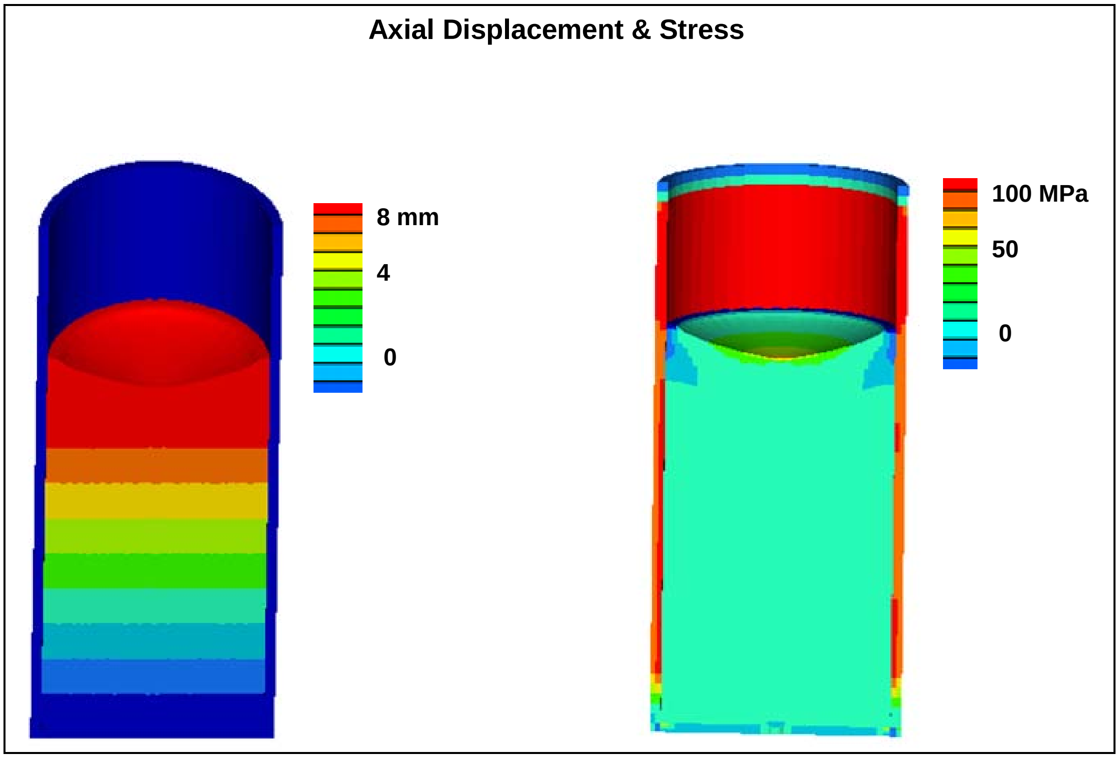

Figure 6. Displacement and stress contours with pellets 1 and 2 sliding at the boundary.

With the all-sliding boundary condition, the final result is that the tracer material becomes highly compressed against the base of the cup. Once the pressure is substantially released (on muzzle exit), the tracer material is free to slide backward (unloading) within the cup. During the subsequent projectile free flight, the tracer material may even be expelled unburned through the nozzle.

A number of caveats are worth mentioning when comparing modeling results to results from live-fire testing. The tracer material properties used in the analysis are obtained at room temperature. The ductility of the material likely varies with temperature changes. Changes in ductility could and probably do result in different fracture behaviors for the tracer material, and this condition in turn can result in burning anomalies. Most of the anomalies in tracer performance have surfaced under “cold condition” firings. The tracer fracture situation is somewhat random as to where the fracture occurs during ignition. Whether the fracture occurs at the cup-pellet interface or somewhere within the pellet is unknown. Whatever the resultant tracer material geometry is after fracture will change the surface area for burning, and this greatly affects the burn progression. If the fracture, created by the launch pressure, results in a substantial gap (say between two pellets) within the tracer fill, it is possible the burn progression does not bridge that gap, and the tracer burns out prematurely leaving unburned pellets. Recovered projectiles have shown evidence of unburned material. The burn rate of a highly compressed tracer material is another question that logically arises. The mechanical compressive stress wave from the pressure load exceeds the burn progression rate so that mechanical effects will occur initially. If the tracer material remains compressed after being subjected to the launch loads (a plastic deformation), the burning rate of a compressed material is unknown as well. How the tracer fill material ages is yet another variable. If the fill material somehow absorbs water, or if any outgassing of the material has taken place, the material burn properties may again be affected.

A simple scenario may be most applicable. Pellet gaps that are pre-existing (coming from an assembly process) could also explain the premature burnout. These could be created by the inert particles or glue residue at the pellet (pellet interfaces as shown in figure 7).

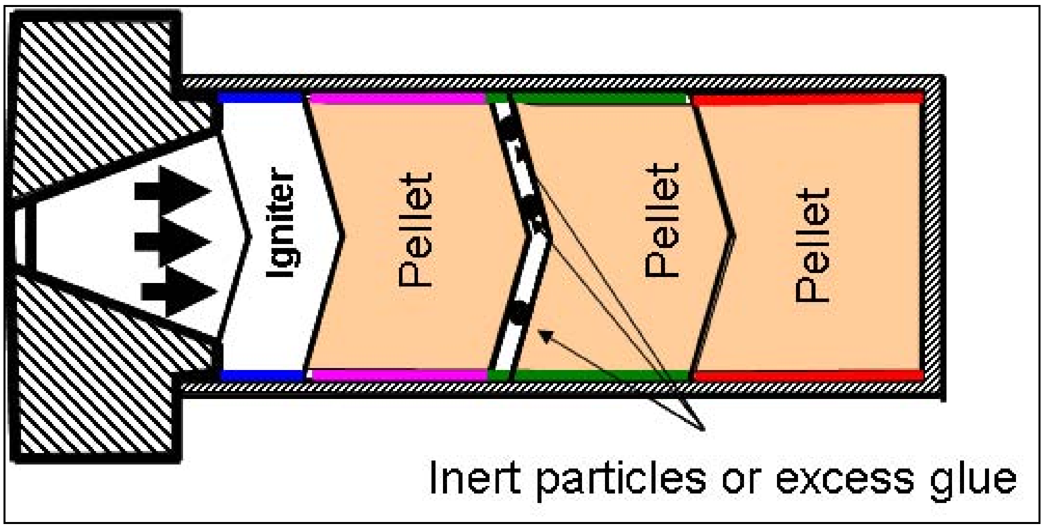

Figure 7. Pellet-to-pellet interface gaps.

It is presumed that care is taken to eliminate such gaps. But if assembly gaps are the problem, at least two solutions could be considered. The first is a single pellet design that eliminates the interfaces entirely. The production problems that would be introduced by this suggestion are uncertain. A question of homogeneity for a larger volume pellet might also be at issue. The second solution is to maintain the three-pellet geometry but have a center perforation in each pellet such that the combusting high-pressure gas could reach all of the pellets more or less simultaneously and better assure complete combustion of the fill material. This is shown in figure 8. The burning rate of this configuration would have to be examined to verify its functioning for ranges >3 km. The center hole (perforation) diameter could be adjusted to produce the burn time (flight time) required yet still promote complete tracer function/combustion. While this solution is classed as a solution, it may create processing or fabrication challenges. These would have to be evaluated in light of the anticipated improvement in tracer function.

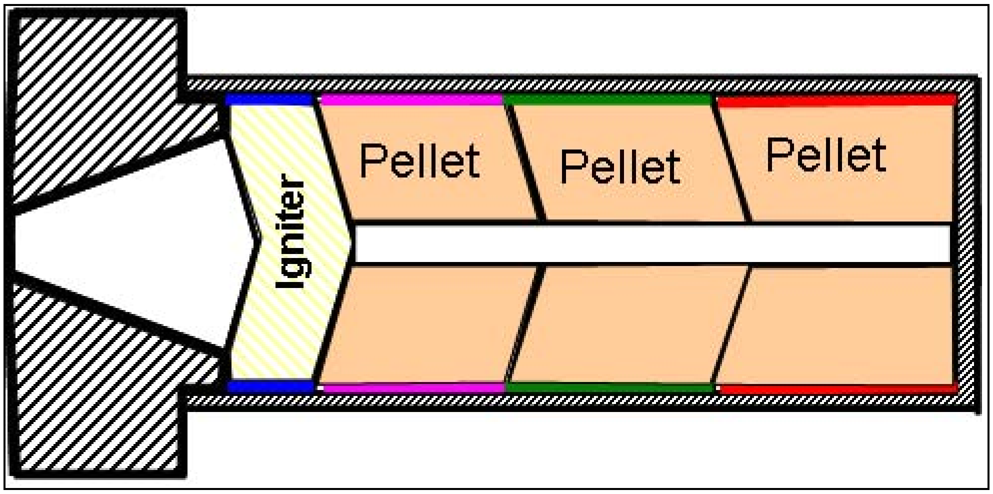

Figure 8. Enhanced burning configuration for tracer pellets.

4. Recent Test Results

Fortunately, the most recent M1002 testing has demonstrated that the tracer material is performing as expected even at the cold temperatures. The manufacturing processes have not changed nor have the material constituents changed for the tracer; the performance improvement, while welcome, is not completely understood.

5. Conclusions

An M1002 tracer modeling capability exists to examine the response of the tracer material configurations under loading. This capability offers significant insight into possible in-bore mechanical behaviors of the tracer design and can be used in assessing future configurations of double or single pellet fills. These analyses are only as reliable as the tracer material properties that are used. These analyses highlight the need for material properties that reflect the state of the tracer material during launch.

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