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Characterization of Two 120-mm Primers – the M129 and M125

by Stephen L. Howard and Anthony W. Williams

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Stephen L. Howard and Anthony W. Williams
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT
Increased precision/lethality of large-caliber weapons has been a goal of many for a number of years. Different (more energetic propellant compositions and configurations have provided much of the increases in performance. However, ever-increasing loading densities and the goal of more insensitive propellants translate to the need for ignition systems that are optimized for the propelling charge. Without such optimization, pressure waves can increase, thus endangering the gun and crew, or the ignition stimulus can be inappropriate, with resulting ignition delays and/or weakened ignition. The thrust of this investigation was to obtain interior pressure measurements and venting temperatures of the M129 and M125 primers (standard 120-mm primers). These data, coupled with the venting patterns revealed by high-speed video, provide baseline data for computer model formulation and validation so that the optimization process with the possibility of increase precision/lethality can be realized.

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primer, large-caliber ammunition, M129 primer, M125 primer, igniter studies

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1. Introduction

Many large-caliber ammunition cartridges contain a primer that extends a substantial distance into the propellant bed. The primer should be designed so that the round can be fired safely and in such a manner as to fulfill mission requirements. Many factors can lead to undesirable, and potentially destructive, pressure-wave generation during the ballistic cycle (*1*). Proper design of the primer, within spatial constraints of the round, can reduce and/or eliminate these factors.

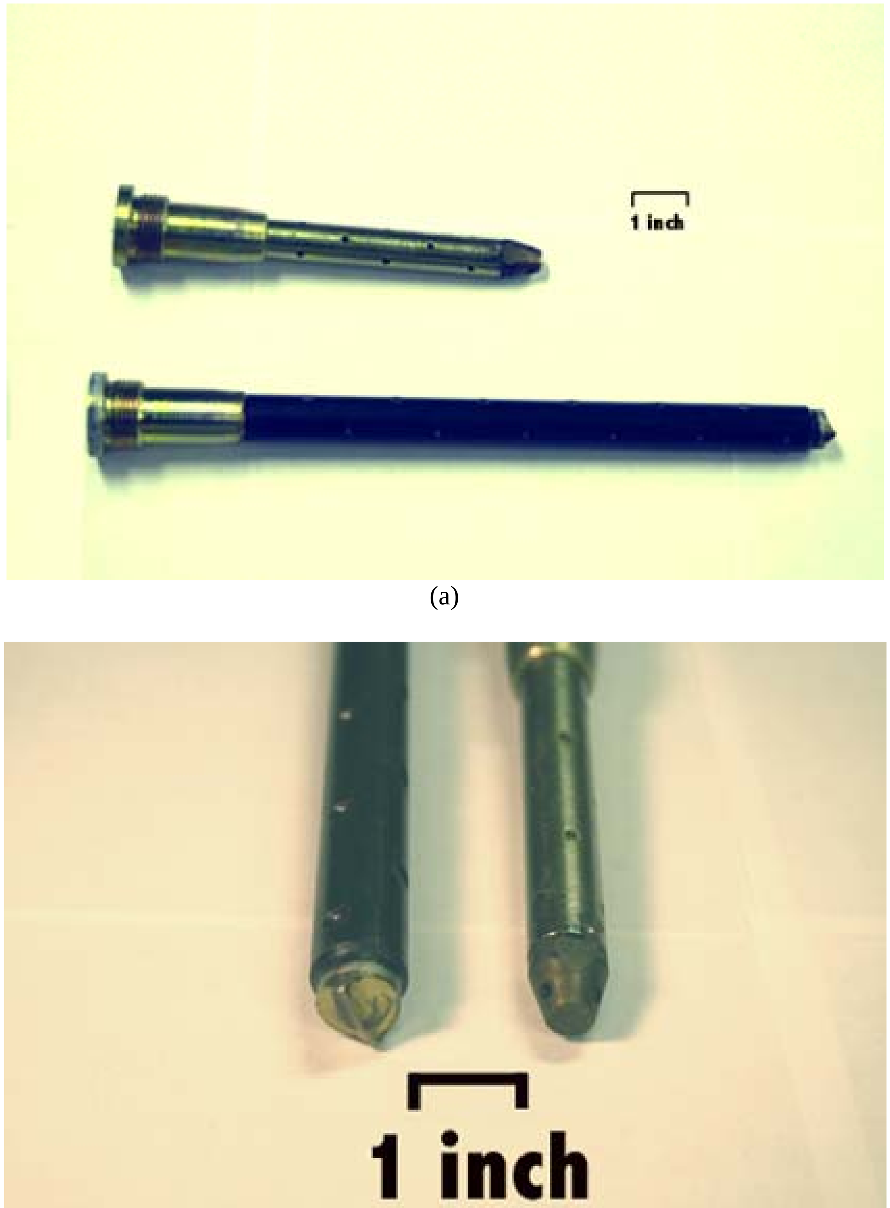
Since the primer interacts intimately with the propellant bed, much of the primer-development work to date has used heuristics and trial-and-error testing with gun simulators or actual gun firings (*2*–*5*). Some work has been due to the results of accidents or manufacturing defect detection (*2*–*5*).

Continual improvement is the name of the game in outpacing the projected enemy. The aim of this study is to characterize two primers that work well in current ammunition. With this characterization, optimization of primer qualities for newer, improved, and harder to ignite rounds can progress. It is also possible for safer, less corrosive, and more potent materials to be used in the primer—if only we knew what the primer currently provides as a comparison.

Pressure characterization of the interior of a long metal tube primer and characterization of the temperature of its venting gases do not seem to be areas of interest that have had much attention (*6*–*8*). With the ever-enduring search to improve weaponry, even the ignition system can be improved to fit mission requirements. Two primers that were chosen for this study were the M125 and M129 primers (see figure 1). These primers have been used in many systems (especially 105- and 120-mm tank rounds), have been generally accepted, and are viable candidates for improvement if enhancements are desired. Some enhancement items may be improved performance, reduction of erosion producing components, use of "greener" materials, replacement of benite as the main energetic material contained in the tube, etc. It is with these goals in mind that we performed the characterizations in this study.

2. Experimental

The primers were initiated by a 24-V power supply with both the voltage and current utilized by the primer monitored on a Nicolet Integra 20 digital storage oscilloscope (current measured through use of a Pierson coil). Compression clamps were fashioned to fit over two of each primer's vent holes (one near the base and one near the tip). The clamps were fashioned to seal a Kistler 211B1 pressure transducer against the primer body and to allow any other vent hole that



(a)

(b)

Figure 1. Photographs of (a) M129 (taper tip) and (b) M125 (black rubber coated) primers.

would normally be covered by the clamp to freely vent. Fine-wire S-type thermocouples were placed in the vicinity of an additional vent hole for temperature measurements of the venting gases. High-speed video of both end and axial views were obtained with a Phantom V digital camera.

3. Results and Discussion

Since the measurement of an object can change its properties, pains were taken to reduce the impact of the act of measuring the temperatures and pressures of the gases that these primers produced. For example, the clamps for holding the pressure transducers in place were designed to only cover and seal one vent hole (see figures 2 and 3). The other venting holes in the clamp were designed so as to minimize pressure perturbations in the venting jet. With pressure measurement desired at the base of the primer and at the tip, this measurement necessitated two vent holes to be covered (for the M125 primer, this number was 2 out of 24, and for the M129, 2 out of 18). Other studies may have had designs for the clamps that possibly covered other vent holes (or impaired the venting) at the same axial position (*8–10*). It should be remembered that properties of a gas or a particle-laden gas through a vent can be strongly influenced by the backing pressure into which it is vented. Such properties include velocity, expansion radius, residual pressure, and temperature. Therefore, the vent in the clamp must take such variables into account in its design.

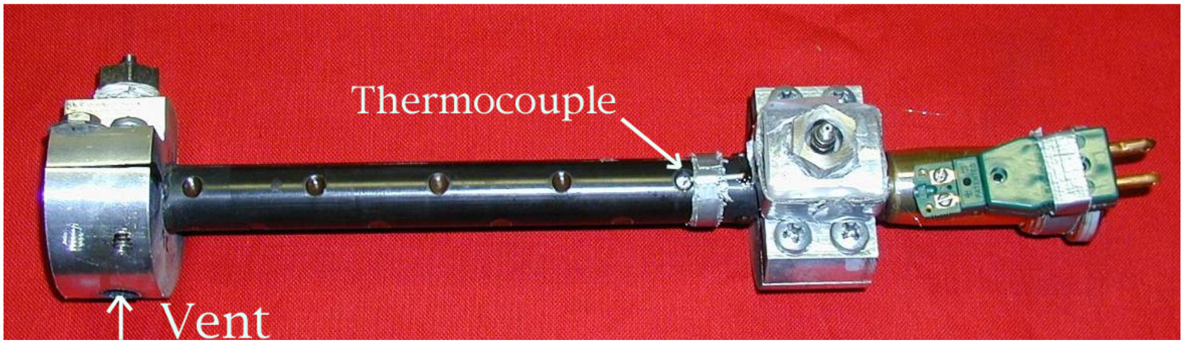


Figure 2. Photograph of M125 primer with pressure clamps (note vent hole on bottom of left clamp) and thermocouple in place.

A couple of placement methods for the thermocouple were tried (see figures 4 and 5). Previous work with planar ignition waves in solid propellant beds used a holder (figure 4) that contained the thermocouple for protection and to maintain laminar flow past the thermocouple (*11*). This holder was placed next to the primer tube over the top of an opened vent hole (with paper liner punctured to allow early gases to be detected) at a distance of ~6 or 14 mm from the primer. The larger distance was chosen in an attempt to protect the thermocouple (early tests at 6 mm resulted in severed thermocouple wires), but it worked about as well as the 6-mm distance in this holder. It was later found upon examining the high-speed video that large chunks of material were ejected from the vent hole and so a fine-wire thermocouple stretched across the vent hole would

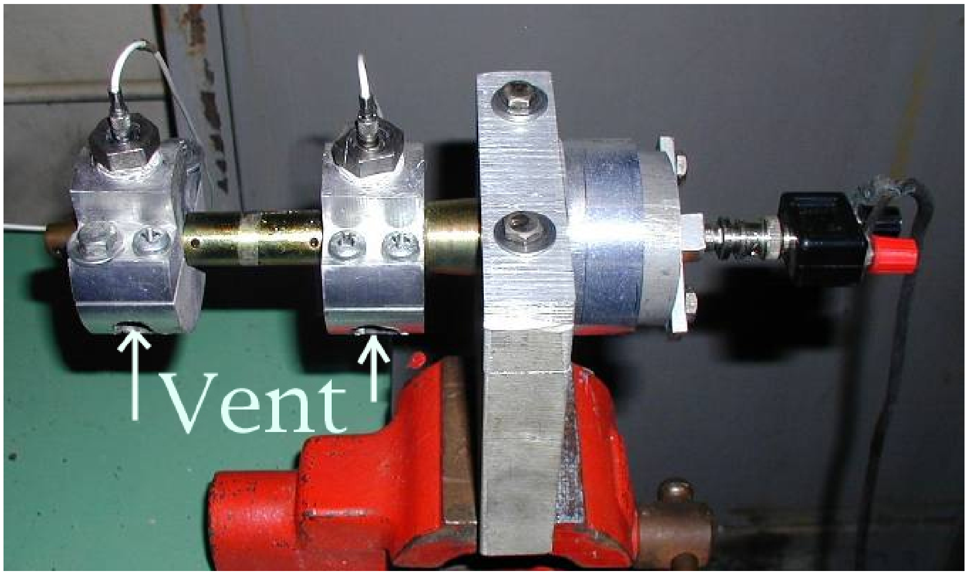


Figure 3. Photograph of M129 primer held in fixture with pressure clamps in place (note one of two vents on bottom of each clamp).

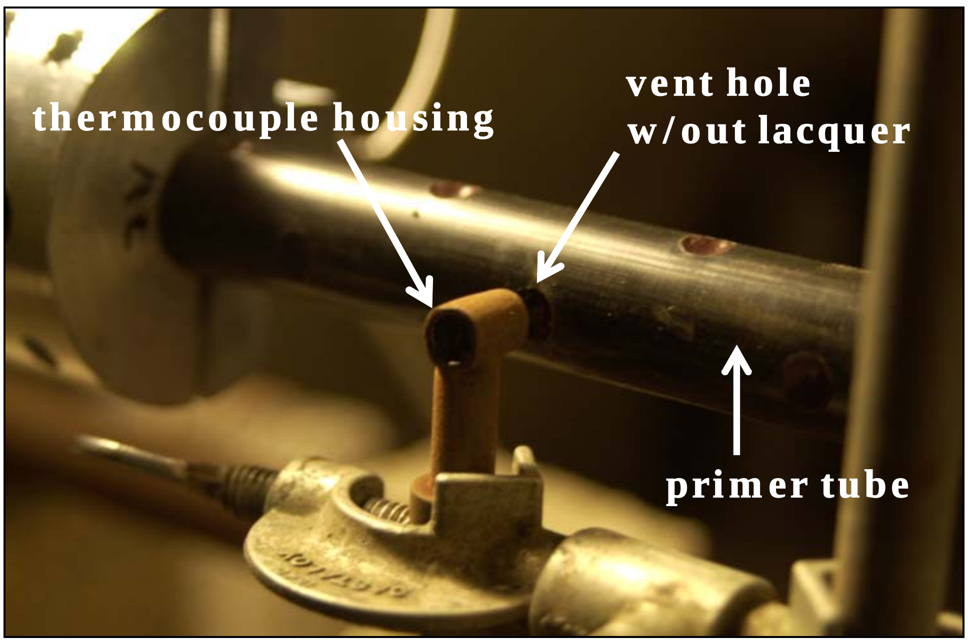


Figure 4. Photograph of a 3-mil thermocouple inside a planar wave thermocouple holder near vent hole of an M125 primer.

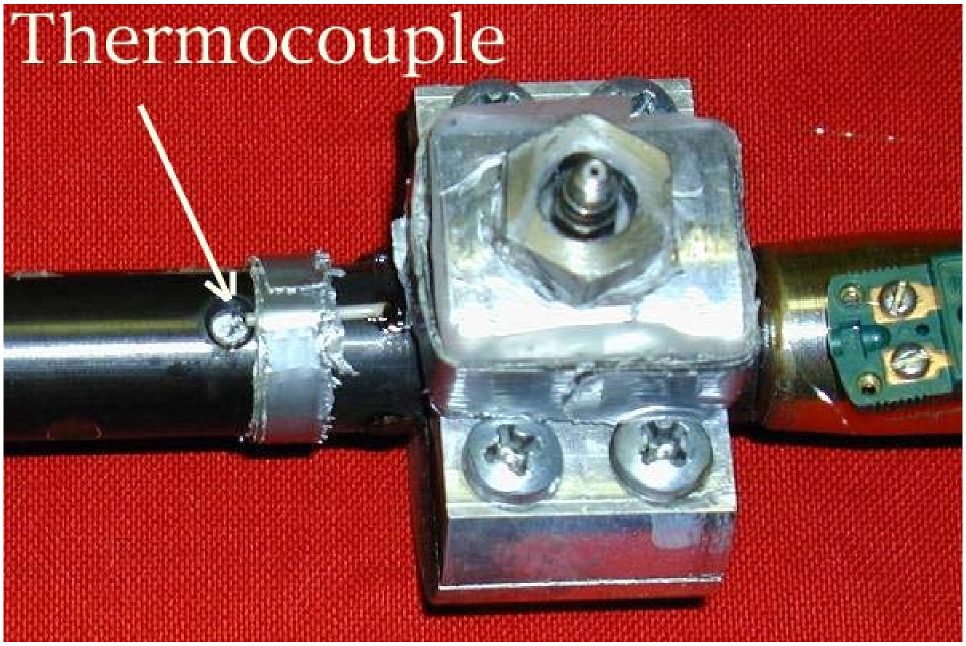


Figure 5. Photograph of a 2-mil thermocouple in a ceramic tube support taped next to a vent hole on an M125 primer.

not likely survive. The thermocouple wire diameters used included 1 mil (25 µm), 2 mil (51 µm), and 3 mil (76 µm). The lag times for thermocouples were estimated from previous work to be less than 0.3, 1, and 2 ms, respectively (*11*). Since the thermocouples did not survive well, a second placement method was developed.

In the second method, the two wires of the thermocouple were threaded through a small section of a two-holed ceramic tube leaving the thermocouple junction a small distance from the tube end. The tube was taped securely to the primer tube with the thermocouple junction (which was slightly separated from the end of the ceramic tube) slightly protruding into the region of the vent hole where the venting jet would be located (figure 5). The ceramic tube was held in place by several laps of a fiber-reinforced tape with sufficient strength to hold the ceramic tube securely in position during the entire venting process.

As can be seen in figures 6 and 7, it is possible that the junction of even the 1-mil and the 2-mil thermocouple wires can survive the venting event when mounted with the two-holed ceramic tube. The voltages from the thermocouple were processed through a miniature ice point and recorded on the digital oscilloscope. Correction was made for radiation cooling (*11–13*) and results for the M129 primers are plotted in figure 8. The similar temperature results for the M125 primer are plotted in figure 9.

Figure 6. Photograph of 1-mil thermocouple junction mounted with ceramic tube after venting event.

Figure 7. Photograph of 2-mil thermocouple junction mounted with ceramic tube after venting event.

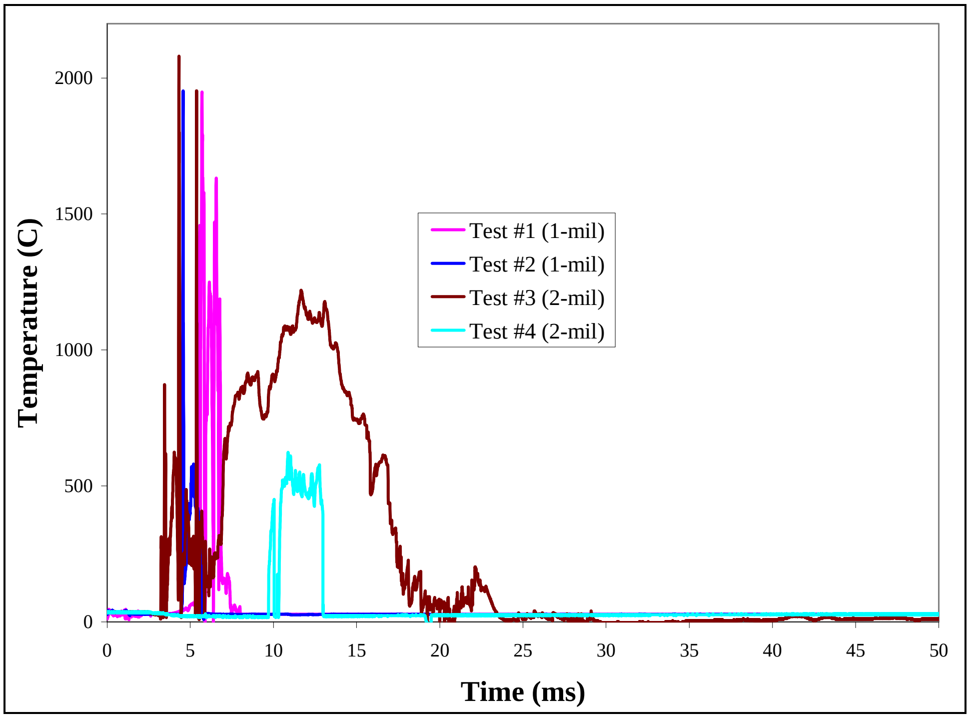


Figure 8. Temperature-time histories recorded for M129 primer.

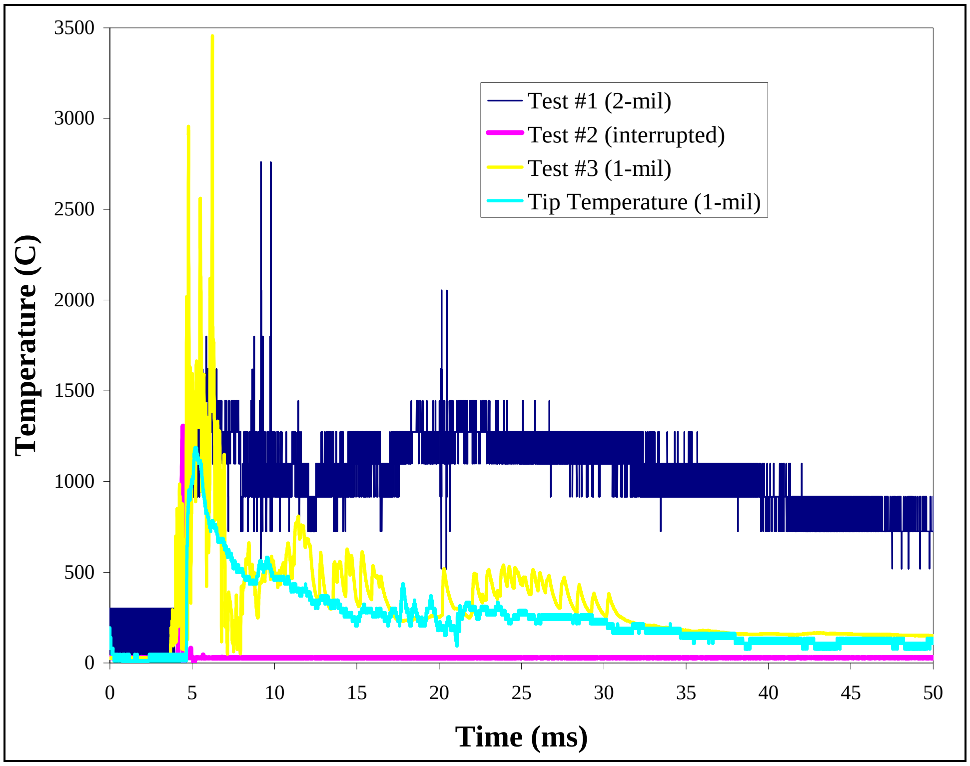


Figure 9. Temperature-time histories recorded for M125 primer.

As shown in figure 8, the similarity from shot-to-shot with regards to temperature was not too good (it will be shown later in the high-speed video that the opening and venting of the pattern of vent holes was not as uniform as desired). However, there were some similarities from shot to shot. The temperatures increased after the pressure began building in the primer and the temperatures decreased at lower pressures. The rapid fluctuations at the beginning of the temperature increase appeared to be real and to correlate somewhat with the timing of shock structures (regions of intense light emissions) in the expanding jet that was evidenced in the high-speed video.

These same fluctuations also were noted for the M125 primer (see figure 9). However, the hole size in the M125 (nominal 4 mm in diameter) was bigger than the hole size in the M129 (nominal 3 mm in diameter). Therefore, the supersonic flow from the M125 vent hole would exhibit a lower Mach number and a potentially shorter and weaker shock structure than for the M129 (this trend was evidenced in the high-speed video).

The rubber coated M125 gave no pressure sealing problems when the clamps were tightened properly. Originally, a sheet of rubber was used as a gasket on the M129 primer, but leakage would often occur (the pressure in the primer was great enough to extrude the rubber sheet if it was not properly engaged). However, when the gasket material was changed to the fiber type used in internal combustion engines, the leakage stopped. The change of gasket material also had other fortuitous advantages.

Early pressure measurements of the M129 primer with only a rubber gasket around the sealed vent hole resembled the typical pressure-time history as shown in figure 10. The early pressure peak was assumed to be from the headstock initiating since it occurred at the appropriate time and the strength of the headstock initiation was previously unknown. However, in later measurements (in this study) the dynamic electrical parameters of the bridgewire in the headstock also were measured (figure 11). Upon comparison of the firing current and the early pressure peak, the two traces were very similar in shape and timing. It was therefore assumed that a voltage leakage or ground loop problem existed between the bridgewire (firing supply) power supply and the pressure gauge (with associated electronics). The fiber-type gasket material was then placed completely around the entire circumference of the M129 primer tube (with proper placement for the two remaining vent holes at that particular axial position). Once the fiber was in place, electrical contact between the primer tube and the clamp holding the pressure gauge was broken. At this point, the alleged pressure peak disappeared.

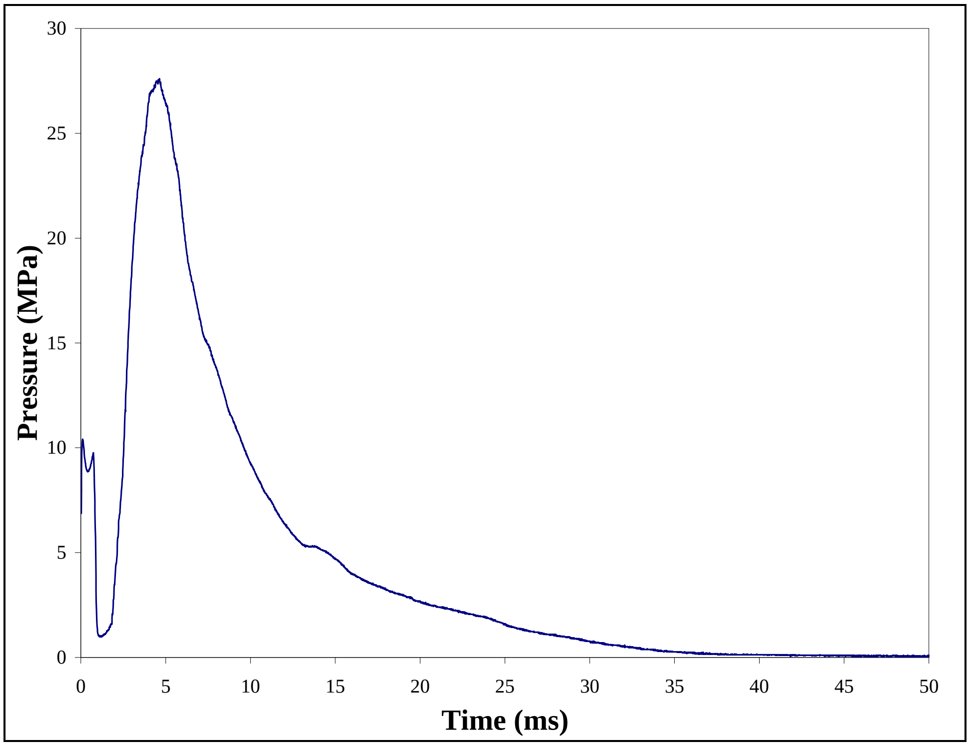


Figure 10. Early pressure-time history obtained for the M129 primer.

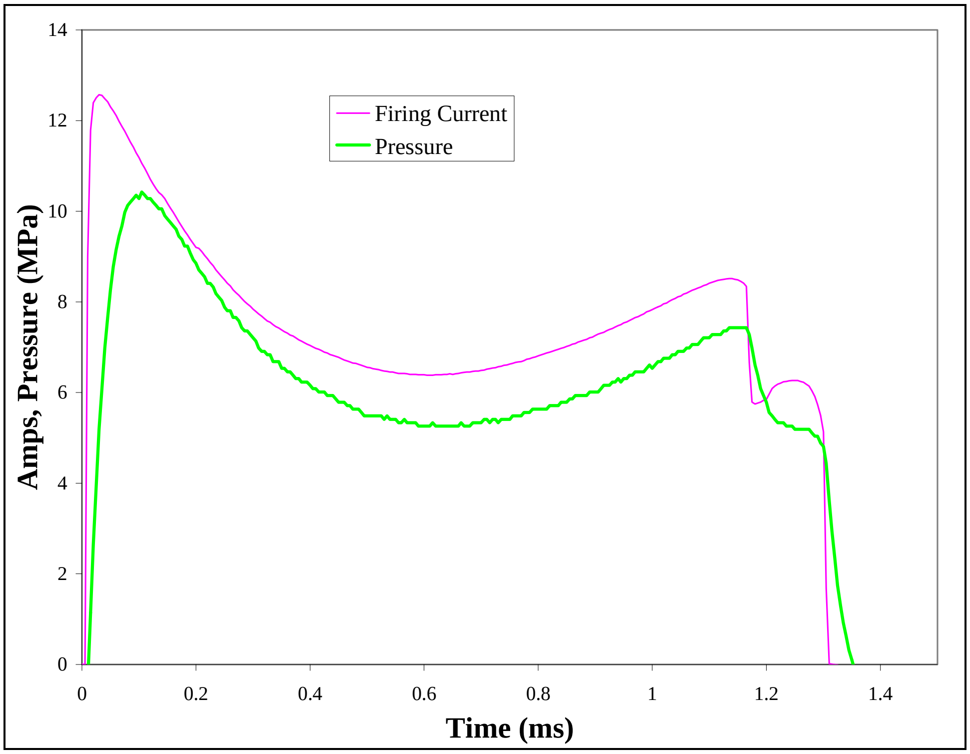


Figure 11. Comparison of firing current trace and early peak in pressure-time history of an M129 primer from figure 10.

Figures 12 and 13 show the average pressure-time histories (averaged over three primer tests) for each primer (the M129 and M125, respectively). The first difference noted was the lack of pressure oscillations in the histories for the M129 and their presence for the M125. The M125 is considerably longer than the M129 and pressure differences (active pressure waves) between the base and the tip could be more easily created (*1*).

The maximum pressure of the M129 primer occurred slightly earlier than that of the M125 (4.35 vs. 4.5 ms) and the base and tip pressures more closely tracked one another. The maximum pressure produced in the M129 was 24.3 MPa and was 25.2 MPa in the M125. It was originally assumed that since the M129 had fewer holes than the M125, and that since the holes had a smaller diameter, that the pressure would be higher. It would appear that the complicated arrangement of a higher loading density in the M129 as related to that of the M125 (1.6 vs. 1.3 g/cm) and increased number of holes per unit length (1.5 vs. 0.9 holes per cm) allowed the pressures to vent as they did. The high-pressure venting of the M129 was slower than that of the M125. The high-pressure full-width-half-maximum of the of the pressure-time histories was 3.4 vs. 2.5 ms. It has been noted in plasma-ignited gun simulators (*14*) that a longer venting time for the primer gases could lead to increased ignitability (propellant bed dependant). This effect could be useful for harder-to-ignite ammunition.

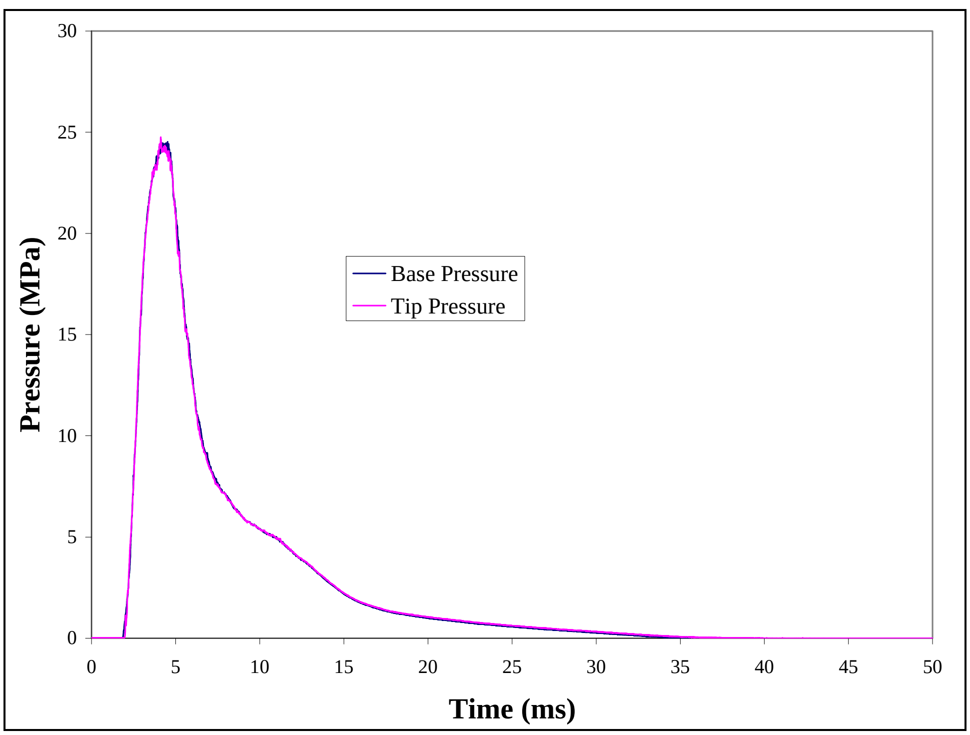


Figure 12. Average pressure-time history produced in the M129 primer (three tests).

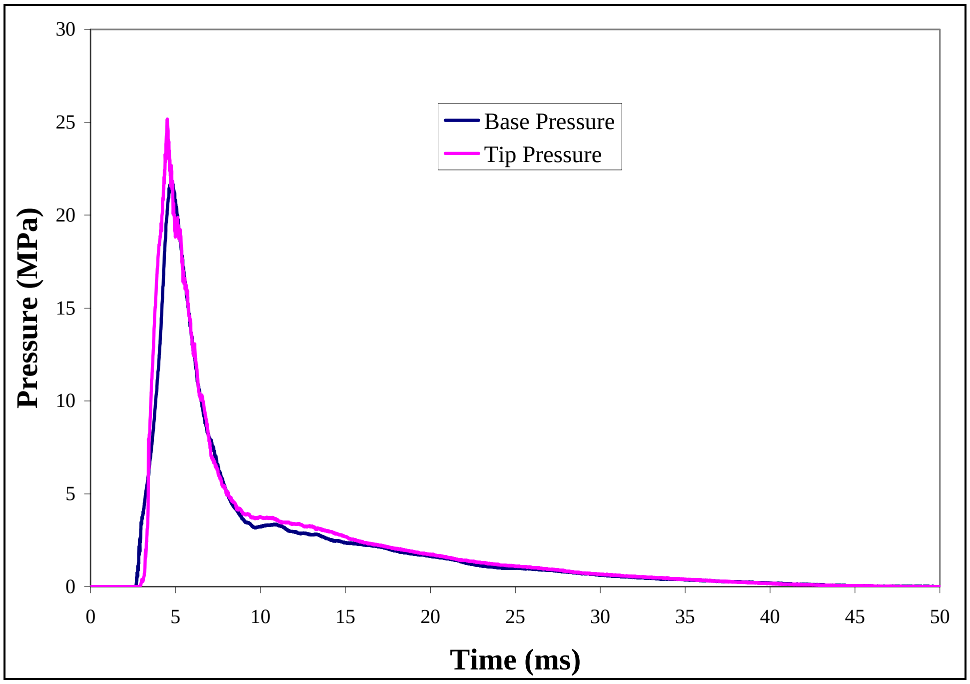


Figure 13. Average pressure-time history produced in the M125 primer (three tests).

The use of the ceramic support allowed the use of 1- and 2-mil thermocouples that would usually survive the entire venting. As shown in figures 14 and 15, the smaller thermocouples follow the pressurization/depressurization more closely than the larger thermocouple and show that the fluctuations in the early venting were very narrow in time and approach the temperatures that could be expected in the supersonic expansion shock structure (*15*). Equilibrium (longer duration) measurements were somewhat lower than the theoretical benite flame temperature (2518 C, obtained from an adiabatic flame temperature calculation). These lowered temperatures were also reflective of various heat loss mechanisms as the gases vented (such as heat loss to the metal primer tube, radiative heat losses, and temperature drop due to high-pressure/high-velocity expansion of venting gases). Initial delay in the temperature rise from the onset of pressurization should also have included the delay that escaping ambient temperature gases from the primer tube in advance of the flame-heated gases would have created.

Temperature measurements by spectral means could potentially give better estimates of the gas temperatures central to the venting jet depending upon the usual items to be taken in account for spectral measurements of dirty environments. Such items such as spectral density, whether the venting stream is optically thin or thick, the particle density in the venting gas stream, other optical properties such as emissivity coefficients, etc. all affect the data reduction and reliability of spectral measurements.

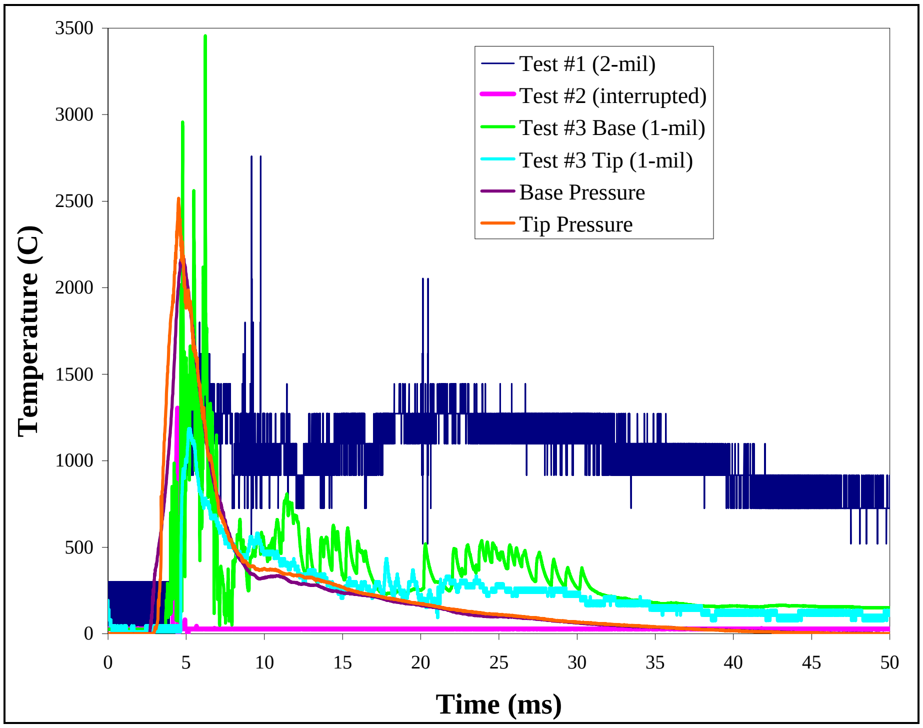


Figure 14. Pressure-time histories produced by the M125 primer in figure 13 compared to temperature-time histories in figure 9.

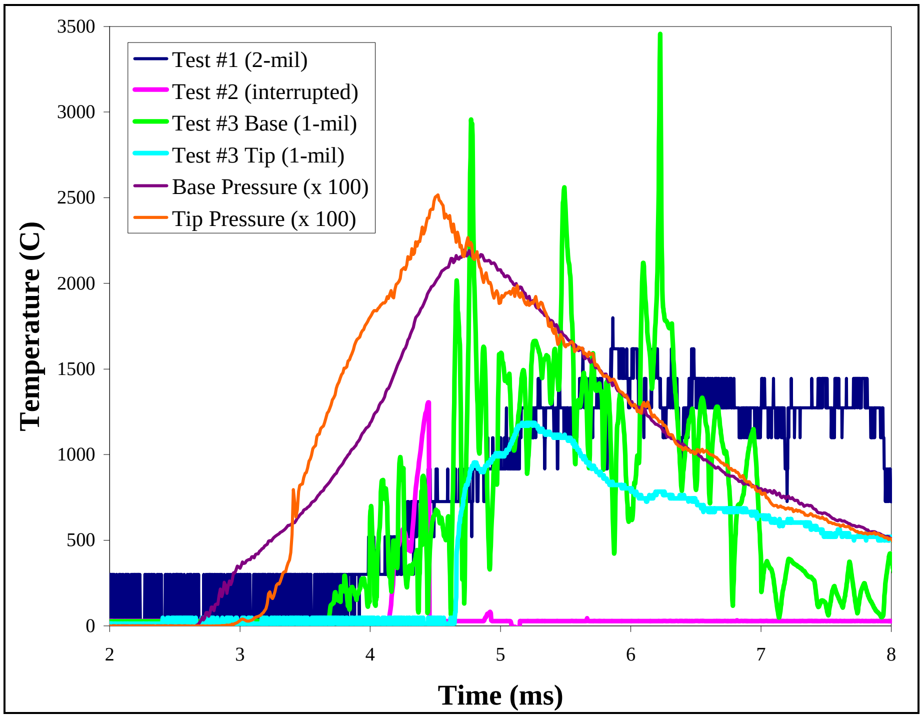


Figure 15. Close-up of pressure-time history and temperature-time history produced by the M125 primer in figure 14 showing delays in temperature rise relative to onset of pressurization.

It was noted that a much longer low-pressure venting occurred after the high-pressure venting in both primers. It was assumed that this effect was, in part, due to firing the primer in open air and not within a ballistic simulator where the venting gases would be trapped and the pressure surrounding the primer would increase, especially when the propellant bed ignited. It was noted in the high-speed video that during this low-pressure venting that the light emissions from the venting gases diminished. The diminished light emissions generally correlated with decreased temperature of the venting gases as reported by the thermocouple. Another important item noticeable during this time was, due to the diminished light emissions, the view of many glowing (possibly burning) particles (for example, the M125 primer in figure 16). Most likely, these particles were present during much of the venting period but visual reporting of their glow was not possible due to the large visible emissions from the hot gases that would mask their presence.

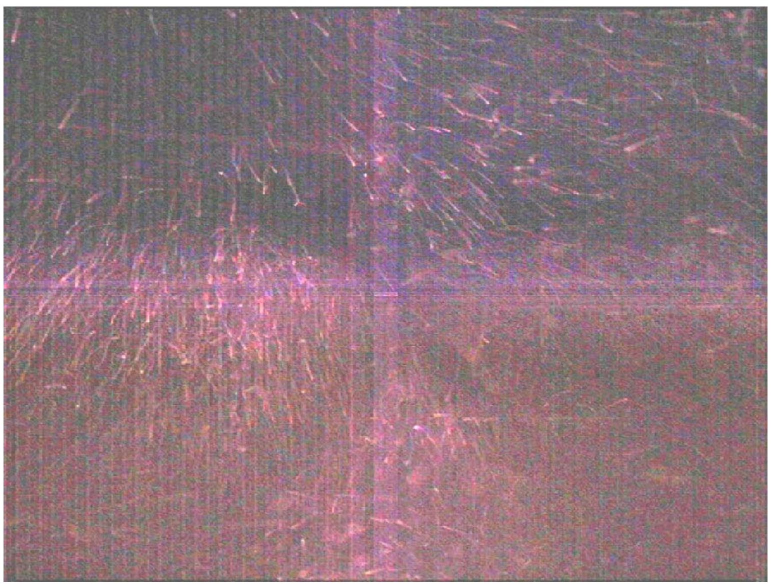


Figure 16. Photograph of end view of M125 firing during low-pressure venting showing glowing particles.

High-speed video was taken of each primer looking along the long axis and also looking down that axis from the tip end. Figures 17 and 18 show still photographs prior to firing of the M129 and M125, respectively. The axial view of the M129 firing in figure 19 shows that not all of the vent holes operated at the same time. The first light showed greatest intensity near the bridgewire and then was somewhat evenly distributed over the rest of the primer. The hole-to-hole venting pattern then quickly changed. Venting started near the bridgewire and at the end of the primer with little in between. The tip vents, in particular, showed high pressure venting with detached shocks at a distance from the vent hole. After ~2 ms, the hole-to-hole venting pattern became more erratic with different vent holes showing varying amounts of light and jet structure. At long time (after ~9 ms), and at much lower pressure than maximum (~1/5th of maximum), the

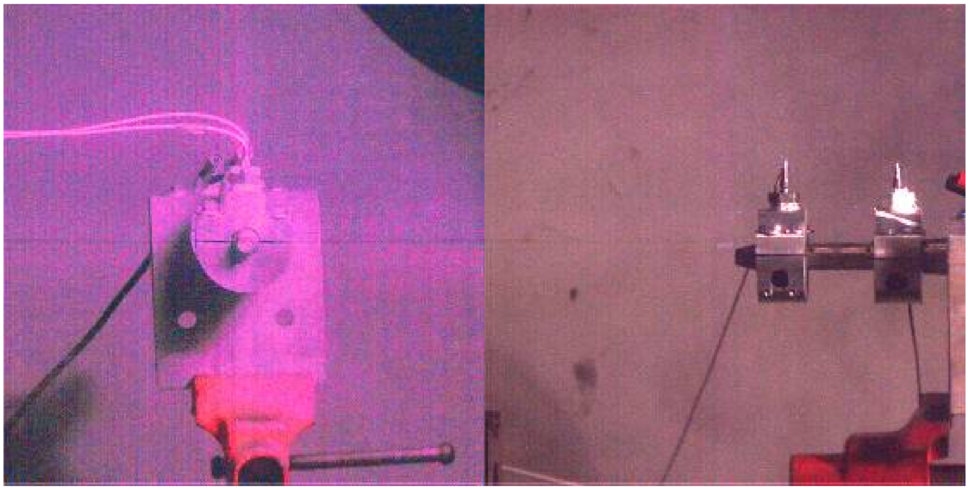


Figure 17. Photographs of M129 primer in firing fixture from tip end (left) and axial (right) views.

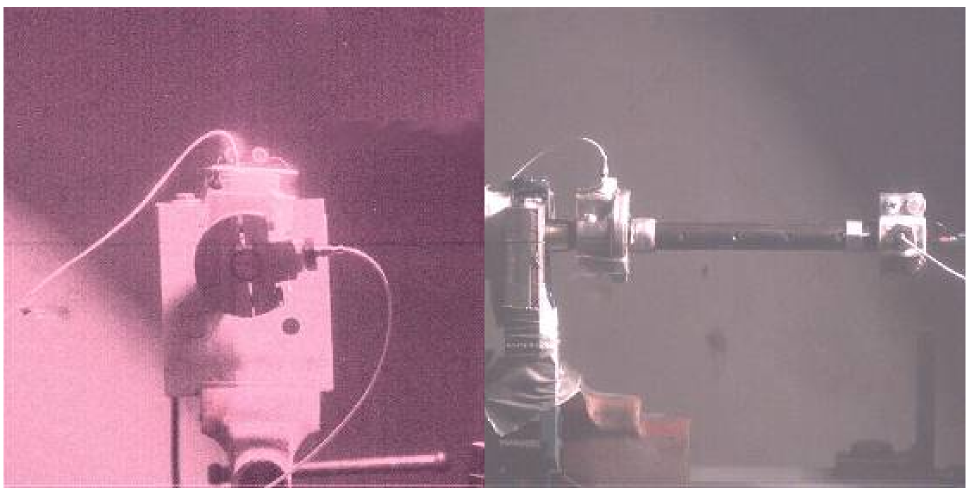


Figure 18. Photographs of M125 primer in firing fixture from tip end (left) and axial (right) views.

hole-to-hole venting pattern once again became mostly even. The end view (figure 20) also showed the shock structure from the tip vents (until the jets from the other vent holes had expanded past the radius of the pressure clamp as shown in figure 17, they were not visible). The end view showed that the venting pattern was erratic during the entire venting process with the most active vents changing from frame to frame. Even at low pressure, the erratic hole-to-hole venting (not so obvious in the final frames of the axial view in figure 19) continued.

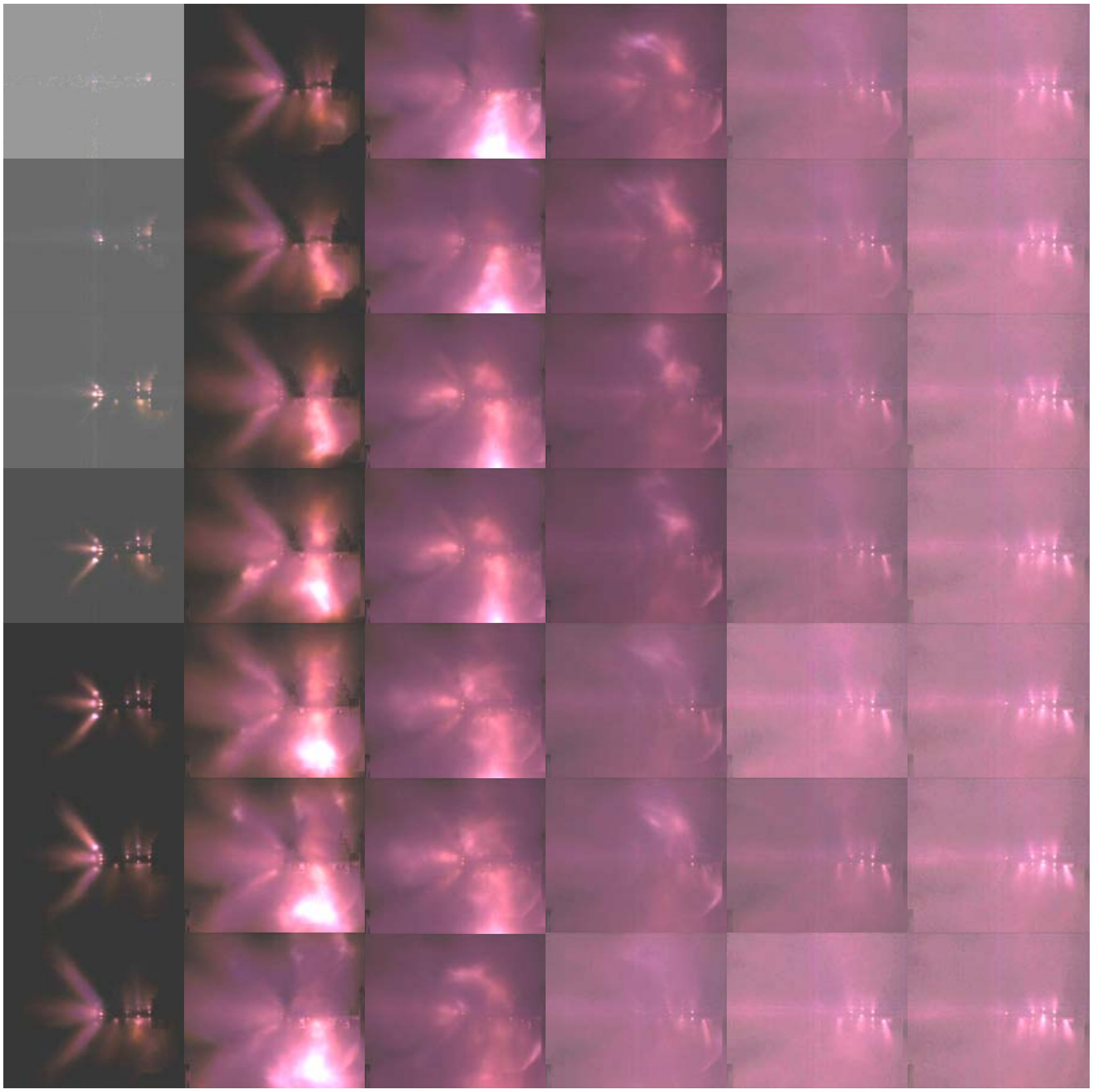


Figure 19. High-speed frames (from top to bottom) of axial view of M129 primer; frame time was 263 µs.

The view of the tip vents of the M129 primer in figure 20 and the axial view of the M125 primer in figure 21 clearly showed that the benite was not totally consumed within the confines of the primer body. Dark chunks that looked like pieces of benite were seen in the jet flows during the approximate interval of 1–5 ms. If they continued to escape the primer body after this interval, the background illumination from the expanding jets was not sufficient to allow detection. After firing, small pieces of benite were found on the table under the primer as well as across the room (see figure 22). It is unknown from which primer each piece of benite originated since the pieces were not found until experimental series had finished. However, the long piece in the photograph was ~2 cm in length. It was assumed that the only manner by which it could have escaped the primer tube was through the vents on the tip of the M129 primer since the tip vents were aligned axially as was the original benite rods.

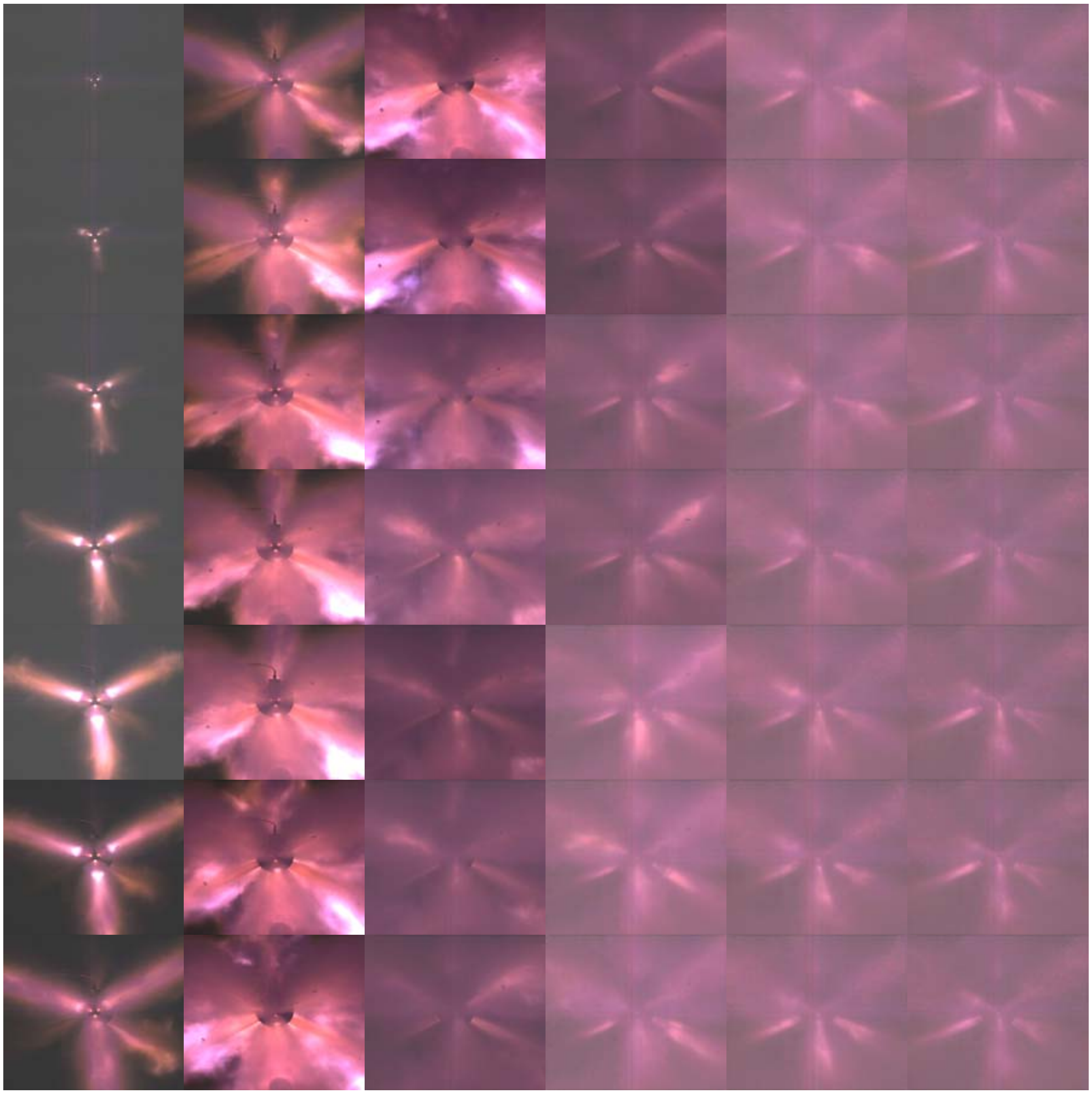


Figure 20. High-speed frames (from top to bottom) of end view of M129 primer; frame time was 263 µs.

The findings on the high-speed video for the M125 are shown in figures 21 and 23. Both the unevenness in hole-to-hole venting and the relatively large solid objects in the venting jets show quite readily. For particular integrated ammunitions, these attributes must be taken into account in order to design the optimal performance or remove safety concerns.

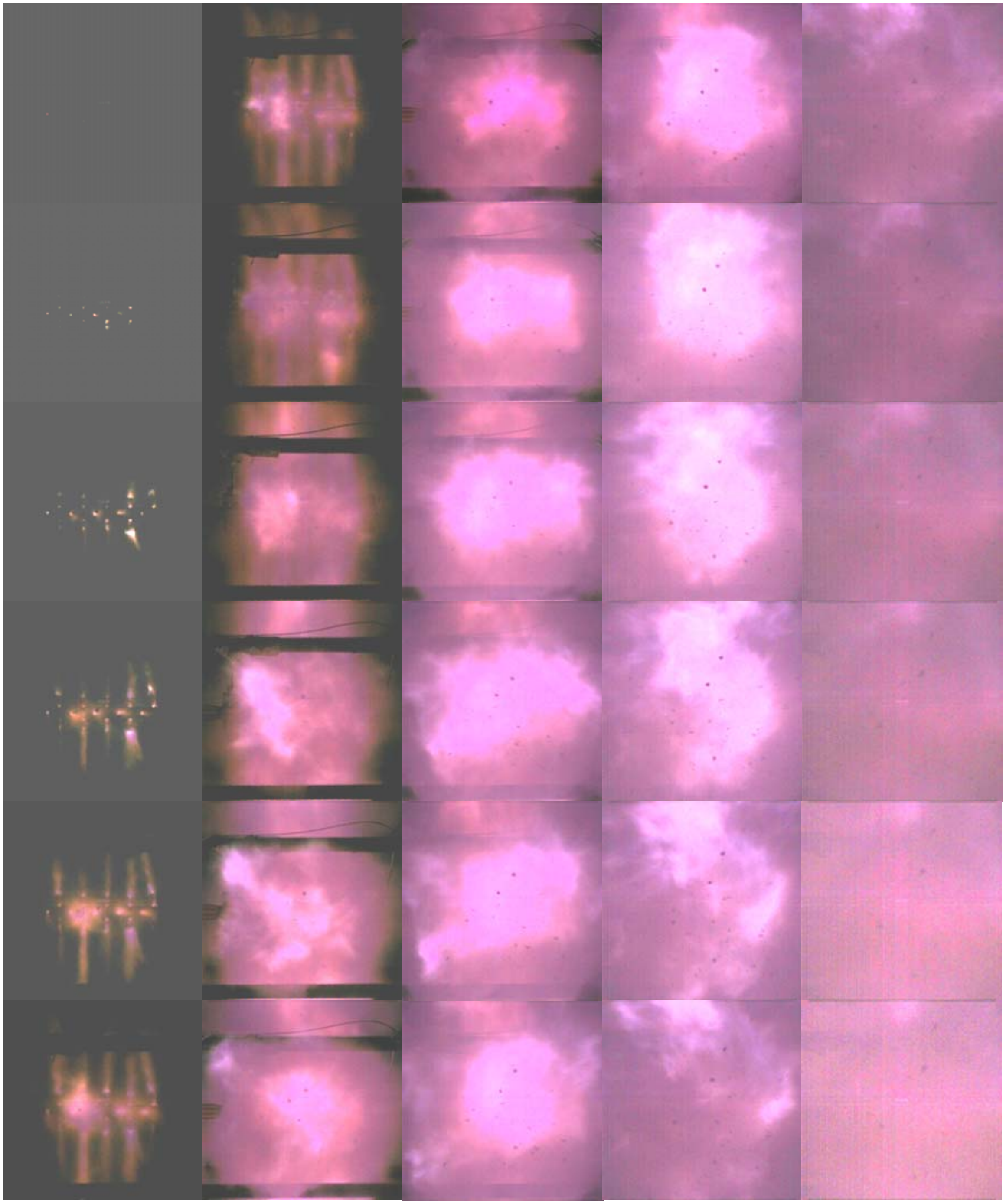


Figure 21. High-speed frames (from top to bottom) of axial view of M125 primer; frame time was 263 μs.

Figure 22. Photograph of pieces of benite found on floor after experiments (origin from M129 or M125 unknown, long piece probably from M129 due to length).

4. Summary

M125 and M129 primers have been used in many models of ammunition. This report attempted to characterize the current ignition stimulus output from each primer. Temperature measurements by thermocouple needed to take into account the expansion and shock structures of the gases expanding from each vent hole. Also evident were relatively large pieces of benite that left unburnt through the vent holes. Pressure measurements at each end of the primer were easier to do that the thermocouple measurements. The pressure curves showed a maximum pressure of ~25 MPa for both primers with somewhat different venting patterns. High-speed video showed much variability in hole-to-hole venting. The burning/non-burning characteristics of benite probably influenced this variability to a large extent. For some proposed high-density propellant loading schemes this variability could pose future problems. During part of the venting cycle, a myriad of fine, hot (and possibly burning) particles was noted in the jet areas around the vent holes. These particles may have been present during the entire ignition cycle but their luminosity was masked by the more visible venting gases. It is likely that these particles would aid in the ignition process. The data obtained in this study should be helpful in providing necessary characteristics for computer simulation and experimental verification of enhanced materials and designs for next-generation primers.

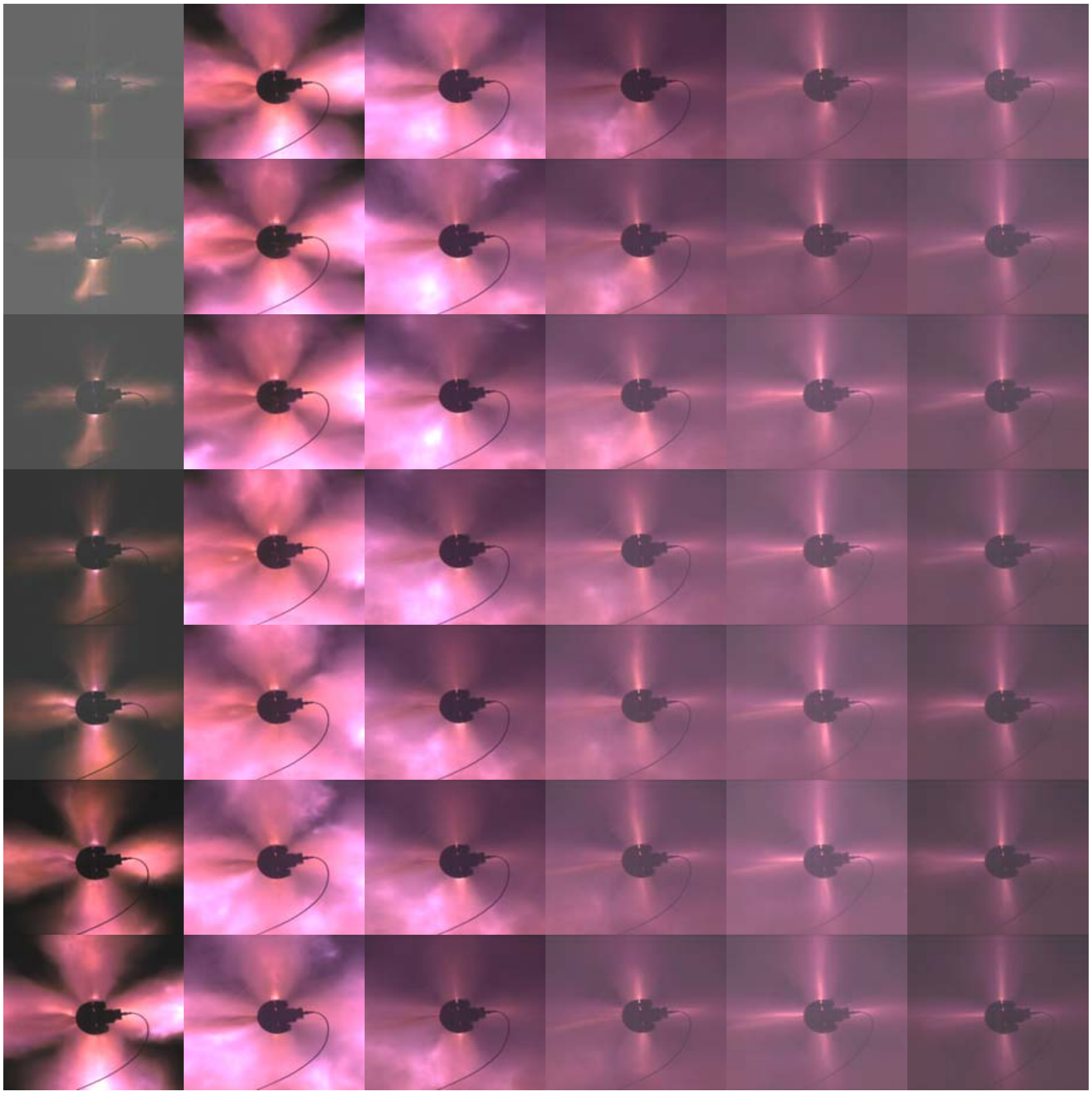


Figure 23. High-speed frames (from top to bottom) of end view of M125 primer; frame time was 263 µs.

5. References

1. May, I. W.; Horst, A. W. *Charge Design Considerations and Effects on Pressure Waves in Guns*; ARBRL-TR-0227; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, December 1978.

2. Ruth, C. R.; Chang, L.-M.; Colburn, J. W.; Hewitt, J. R.; Williams, A. W. *Defective M129 Primers in the M829A1 Cartridge: Charge Safety and Performance Implications*; ARL-MR-130; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, March 1994.

3. Ruth, C. R.; Chang, L.-M.; Bowen, J. E.; Hewitt, J. R.; Tuerk, J. F.; Raley, B. F. *Safety Implications of Firing an M829A1 Cartridge with a Defective M129 Primer*; ARL-MR-84; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, July 1993.

4. Ruth, C. R.; Hewitt, J. R.; Tuerk, J. F.; Koszoru, A. A. *Safety Implications of Firing an M829A1 Cartridge With an M129 Primer Partially Unscrewed From Its Base Headstock*; ARL-MR-204; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, February 1995.

5. Chang, L.-M.; Ruth, C. R.; Howard; S. L. *Simulator Tests of M125 Primers: Thick Wall Tube vs. Standard (Rubber Coated) Tube*; ARL-MR-343: U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, April 1997.

6. FMC. *Laboratory Electrothermal Gun*; contract DAA21-88-C-0271; Electrical Enhancement Follow-on Program, July 1992.

7. Powell, J. D. *Analysis of Piccolo-Type Injectors for Electrothermal-Chemical Launch*; ARL-TR-952; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, January 1996.

8. Chang, L.-M.; Rocchio, J. J. *Simulator Diagnostics of the Early Phase Ignition Phenomena in a 105-mm Tank Gun Chamber*; BRL-TR-2890; U.S. Army Ballistics Research Laboratory: Aberdeen Proving Ground, MD, March 1988.

9. Resnik, K. P. Ignition Development for Advanced 105-mm Penetrator. *Proceedings of the 1985 JANNAF Combustion Meeting*, 1985, CPIA Publication, *432* (II), 471.

10. Chang, L. M.; Deas, R.; Grosh, J. *Ignition Studies with Two-Piece Cartridges for an Advanced Tank Cannon System (ATACS)*; BRL-TR-3249; U.S. Army Ballistic Research Laboratory: Aberdeen Proving Ground, MD, 1991.

11. Howard, S. L.; Chang, L.-M.; Kooker, D. E. *Thermocouples for Interior Ballistic Temperature Measurements*; ARL-MR-146; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 1994.

12. Hayhurst, A. N.; Kittleson, D. B. *Heat and Mass Transfer Considerations in the Use of Electrically Heated Thermocouples of Iridium versus an Iridium/Rhodium Alloy in Atmospheric Pressure Flames*; NASA SP-273; NASA Lewis Research Center: Cleveland, OH, March 1976.

13. Peterson, R. C. Kinetics of Hydrogen-Oxygen-Argon and Hydrogen-Oxygen-Argon-Pyridine Combustion Using a Flat Flame Burner. Ph.D. Thesis, Perdue University, West Lafayette, IN, 1981.

14. Chang, L.-M.; Howard, S. L. Electro-Thermal Chemical (ETC) Plasma Ignition of Gun Propelling Charges: The Role of Pulse Length. *Proceedings of the JANNAF 39th Combustion Meeting*, Colorado Springs, CO, JSC CD-24, 1–5 December 2003.

15. DeSpirito, J. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD. Private communication, September 2006.

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