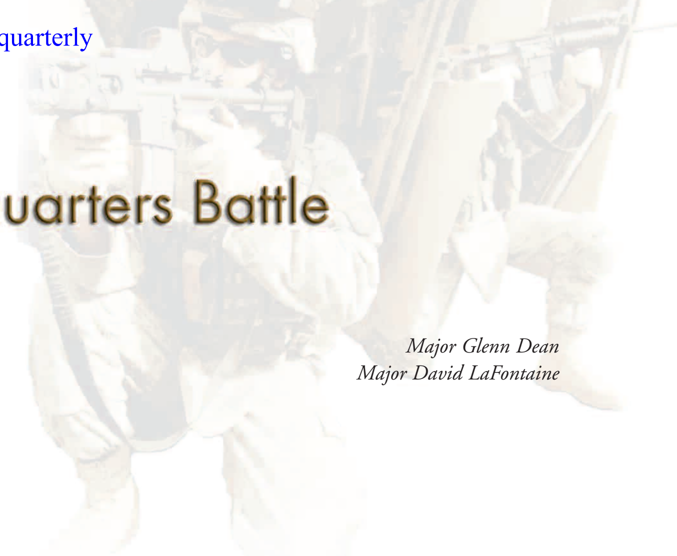

Small Caliber Lethality:
5.56mm Performance in Close Quarters Battle

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Not long after the US Army's entry into Afghanistan, reports from the field began to surface that in close quarters engagements, some Soldiers were experiencing multiple "through-and-through" hits on an enemy combatant where the target continued to fight. Similar reports arose following the invasion of Iraq in 2003. Those reports were not always consistent – some units would report a "through-and-through" problem, while others expressed nothing but confidence in the performance of their M4 carbines or M16 rifles. The M249 Squad Automatic Weapon, which fires identical bullets as the M4 and M16, did not receive the same criticism. Often, mixed reports of performance would come from the same unit. While many of the reports could be dismissed due to inexperience or hazy recollections under the stress of combat, there were enough of them from experienced warfighters that the US Army Infantry Center asked the Army's engineering community to examine the issue. Specifically, the Infantry Center asked it to examine the reports of "through-and-through" wounds, determine if there was an explanation, and assess commercially available ammunition to determine if there was a "drop in" replacement for the standard issue 5.56mm M855 Ball rounds that might provide improved performance in close quarters battle (CQB).

What resulted grew into a lengthy, highly technical, and highly detailed study of rifle and ammunition performance at close quarters ranges that involved technical agencies from within the Army, Navy, and Department of Homeland Security; medical doctors, wound ballisticians, physicists, engineers from both the government and private sector; and user representatives from the Army, US Marines Corps, and US Special Operations Command.

After having made some significant contributions to the science of wounds ballistics effects and ammunition performance assessment, this Joint Services Wound Ballistics (JSWB) Integrated Product Team (IPT) was eventually able to conclude that: (1) there were no commercially available 5.56mm solutions that provided a measurable increase in CQB performance over fielded military ammunition, (2) the reports from the field could be explained and supported with sound scientific evidence, and (3) there are steps that can be taken to immediately impact performance of small arms at close quarters ranges.

BACKGROUND

Development of small caliber ammunition is an area which in recent years has largely been left to the manufacturers of the civilian firearms industry. Although there have been efforts by the military services to assess the performance of its small arms, the levels of effort and resources involved have been extremely low compared to those spent on other weapons systems: bursting artillery rounds, anti-tank munitions, etc. The general assumption within the services, despite evidence to the contrary from the larger wound ballistics community, has been that small arms performance was a relatively simple, well-defined subject. What has developed in the interim in the ammunition industry is a number of assessment techniques and measurements that are at best unreliable and in the end are able to provide only rough correlation to actual battlefield performance.

The major problem occurs at the very beginning: What is effectiveness? As it turns out, that simple question requires a very complex answer. For the Soldier in combat, effectiveness equals death: the desire to have every round fired result in the death of the opposing combatant, the so-called "one-shot drop." However, death – or lethality – is not always necessary to achieve a military objective; an enemy combatant who is no longer willing or able to perform a meaningful military task may be as good as dead under most circumstances. Some equate effectiveness with "stopping power," a nebulous term that can mean anything from physically knocking the target down to causing the target to immediately stop any threatening action. Others may measure effectiveness as foot-pounds of energy delivered to the target – by calculating the mass and impact velocity of the round – without considering what amount of energy is expended in the target or what specific damage occurs to the target. In the end, "foot-pounds of energy" is misleading, "stopping power" is a myth, and the "oneshot drop" is a rare possibility dependent more on the statistics of hit placement than weapon and ammunition selection. Effectiveness ultimately equates to the potential of the weapons system to eliminate its target as a militarily relevant threat.

The human body is a very complex target, one that has a number of built-in mechanisms that allow it to absorb damage and continue to function. Compared to a tank, it is far more difficult to predict a human target's composition and what bullet design will be most advantageous. The combinations of muscle, bone, organs, skin, fat, and clothing create a staggering number of target types which often require different lethal mechanisms. Physical conditioning, psychological state, size, weight, and body form all play a factor in the body's ability to resist damage, and all add to the complexity of the problem. The same bullet fired

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against a large, thick, well-conditioned person has a very different reaction than that fired against a thin, malnourished opponent.

The physical mechanisms for incapacitation – causing the body to no longer be able to perform a task – ultimately boil down to only two: destruction of central nervous system tissue so that the body can no longer control function, or reduction in ability to function over time through blood loss. The closest things the human body has to an "off switch" are the brain, brain stem, and upper spinal cord, which are small and well-protected targets. Even a heart shot allows a person to function for a period of time before finally succumbing to blood loss. What the wound ballistics community at large has long known is that the effectiveness of a round of ammunition is directly related to the location, volume, and severity of tissue damage. In other words, a well-placed .22 caliber round can be far more lethal than a poorly placed .50 caliber machine gun round. Setting shot placement aside for the moment, though, the challenge becomes assessing the potential of a given round of ammunition to cause the needed volume and severity of tissue damage, and then relating this back to performance against a human target.

TERMINAL BALLISTIC TESTING

A common way of measuring this "damage potential," or "terminal ballistic effectiveness," is through what are known as "static" testing methods. Typically, these involve firing a weapon at a tissue simulant which is dissected after the shot to allow assessment of the damage caused by the bullet. Tissue simulants can be anything from beef roasts to blocks of clay to wet phone books, but the typical stimulant is ballistic gelatin. Gelatin has the advantage of being uniform in property, relatively cheap to make, and simple to process, which means that this form of static testing can be done almost anywhere without the need for special facilities. Unlike other simulants, gelatin is transparent. Therefore, assessment can take the form of video footage of a given shot, measurement of the cavity formed in the gelatin ("gel") block, and recovery of the bullet or its fragments for analysis. Static methods measure real damage in gel, but have difficulty translating that damage to results in human tissue.

When the Infantry Center initially asked its questions about 5.56mm performance, two agencies moved quickly to provide an answer through static testing, firing a small number of shots against gel blocks to compare several bullet types. Unfortunately, tests at the Naval Surface Warfare Center at Crane, IN, (NSWC-Crane) and the Army's Armaments Research, Development, and Engineering Center (ARDEC) at Picatinny Arsenal, NJ, produced significantly different results. Further analysis revealed that the two agencies had different test protocols that made the results virtually impossible to compare – and as it turns out, these test methods were not standardized across the entire ballistics community. The JSWB IPT began work to standardize test protocols among the participating agencies to allow results to be compared. Unfortunately, after that work had been completed and static firings of a wide range of calibers and configurations of ammunition were under way (see Figure 1), the IPT discovered that results were still not consistent. Despite using the same gel formulation, procedures, the same lots of ammunition, and in some cases the same weapons, the static testing results still had differences that could not initially be explained.

The IPT was ultimately able to determine a reason for the differences. The Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD, has long used a type of testing know as "dynamic" methods to evaluate ammunition performance, which estimate probable levels of incapacitation in human targets. Dynamic methods are resource intensive – the ARL measures the performance of the projectile in flight prior to impacting the target as well as performance of the projectile in the target. ARL was able to identify inconsistencies in bullet flight that explained the differences in the static testing results. Ultimately, the best features of both static and dynamic testing methods were combined into a new "Static/Dynamic" method that is able to much better assess weapon and ammunition performance. This method takes into account a range of parameters from the time the bullet leaves the muzzle, to its impact on the gel block target, its actions once in the target, and then uses a dynamic analysis tool to correlate the gel block damage to damage in a virtual human target. It provides a complete "shooter-to-target" solution that combines both live fire and

Figure 1. **Original Study Ammunition Configurations (Source: ARL)**

Ammunition Given Full Static/Dynamic CQB Analysis	Weapons Tested to Answer the Problem Statement:
◆ M855 "Green Tip" (62-gr.)	◆ M16A1
◆ M995 AP (52-gr.)	◆ M4
◆ M193 (55-gr.)	◆ M16A2/A4
◆ Mk 262 (77-gr.)	◆ Mk 18 CQBR (10" M4)
◆ COTS (62-gr.)	◆ M14
◆ COTS (69-gr.)	
◆ COTS (86-gr.)	
◆ COTS (100-gr.)	
◆ M80 7.62 (150-gr.)	

Figure 2. **Final Analysis Systems (Source: PM-Maneuver Ammunition Systems)**

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simulated testing, but is very time and resource-intensive to perform. As a result, the study effort narrowed, focusing on providing complete analysis of the most promising 5.56mm systems, and one reference 7.62mm system, needed to answer the original question (see Figure 2).

TERMINAL MECHANICS

Before providing an explanation of the JSWB IPT's results, a brief discussion of small caliber, high velocity terminal ballistics is in order. The small caliber, high velocity bullets fired by military assault rifles and machine guns have distinct lethality mechanisms; conclusions provided here do not necessarily apply to low velocity pistol rounds, for example, which have different damage mechanisms. The performance of the bullet once it strikes the target is also very much dependent upon the bullet's material and construction as well as the target: a bullet passing through thick clothing or body armor will perform differently than a bullet striking exposed flesh. This study focused on frontal exposed targets.

Take an average M855 round, the standard round of "green-tip" rifle ammunition used by US forces in both the M4 and M16 series weapons and in the M249 SAW. The 62-grain projectile has an exterior copper jacket, a lead core, and a center steel penetrator designed to punch through steel or body armor. An M16 launches the M855 at roughly 3,050 feet per second, and the M855 follows a ballistic trajectory to its target, rotating about its axis the entire way, and gradually slowing down. Eventually, the bullet slows enough that it becomes unstable and wanders from its flight path, though this does not typically happen within the primary ranges of rifle engagements (0-600m). (For more detailed ballistic discussion, see FM 3-22.9).

Upon impacting the target, the bullet penetrates tissue and begins to slow. Some distance into the target, the tissue acting on the bullet also causes the bullet to rotate erratically or yaw; the location and amount of yaw depend upon speed of the bullet at impact, angle of impact, and density of the tissue. If the bullet is moving fast enough, it may also begin to break up, with pieces spreading away from the main path of the bullet to damage other tissue. If the target is thick enough, all of these fragments may come to rest in the target, or they may exit the target. Meanwhile, the impacted tissue rebounds away from the path of the bullet, creating what is known as a "temporary cavity." Some of the tissue is smashed or torn by the bullet itself, or its fragments; some expands too far and tears. The temporary cavity eventually rebounds, leaving behind the torn tissue in the wound track – the "permanent cavity." It is this permanent cavity that is most significant, as it represents the damaged tissue that can impair and eventually kill the target, provided, of course, that the damaged tissue is actually some place on the body that is critical.

This is where the balance of factors in bullet design becomes important. Volume of tissue damage is important – which might suggest high velocities to enable the bullet to tumble and fragment sooner, materials that cause the bullet to break up sooner, etc. – but it must also occur in critical tissue. If the bullet immediately breaks up, it may not penetrate through outer garments to reach tissue, or it may break up in muscle without reaching vital organs underneath. The projectile must have enough penetration to be able to reach vital organs to cause them damage. At the same time, it must not have so much penetrating capability that it passes completely through the target without significant damage – resulting in a so-called "through-and-through." Energy expended outside the target is useless (incidentally, this is why "impact energy" is a poor measure of bullet comparison, as it does not separate energy expended in damaging the target from energy lost beyond the target). The ideal bullet would have enough energy to penetrate through any intervening barrier to reach vital organs without significantly slowing, then dump all of its energy into damaging vital organs without exiting the body. Unfortunately, design of such a bullet is nearly impossible in a military round, even if all human bodies were uniform enough to allow for such a thing. A round that reaches the vital organs of a 5-foot 6-inch 140-pound target without over-penetration is likely to react differently against a 6-foot 2-inch 220-pounder, even without considering target posture. To complicate matters, when hitting a prone firing target the bullet might have to pass through a forearm, exit, enter the shoulder, then proceed down the trunk before striking heart or spinal cord. A flanking hit would engage the same target through or between the ribs to strike the same vital regions. All these possibilities are encountered with the same ammunition. Ultimately, bullet design is a series of tradeoffs complicated by the need to survive launch, arrive at the target accurately, possibly penetrate armor, glass, or other barriers, and be producible in large quantities (1+ billion per year) at costs the military can afford.

FINDINGS

The significant findings of the JSWB IPT's efforts include:

1. *No commercially available alternatives perform measurably better than existing ammunition at close quarters battle ranges for exposed frontal targets.* Based on current analysis through the static/dynamic framework, all of the rounds assessed performed

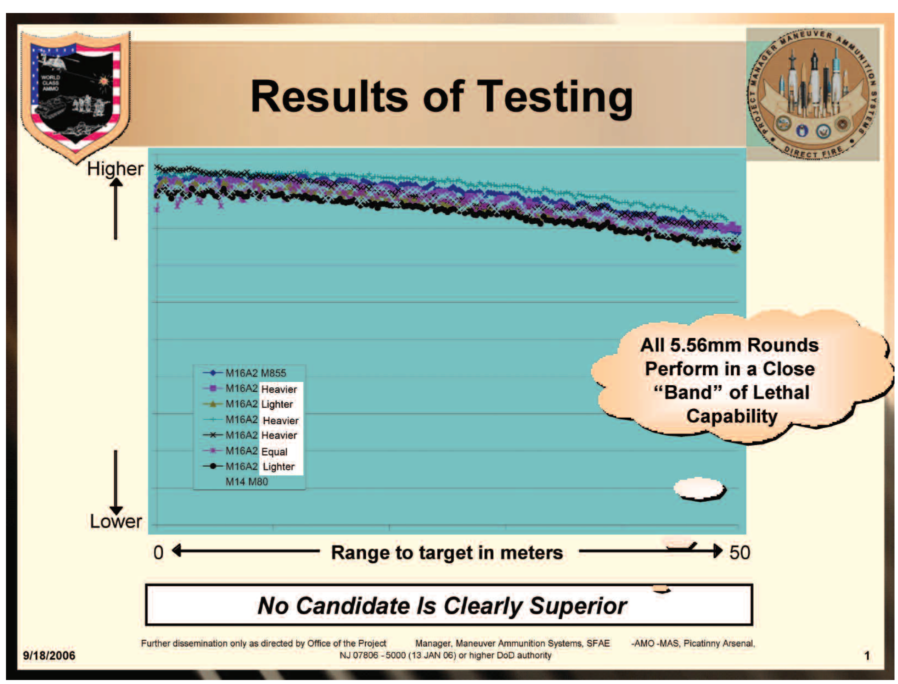

Figure 3. System Effectiveness for Studied Rounds (Source: PM MAS)

similarly at the ranges of 0-50 meters. Though there might be differences for a single given shot, the tradeoffs of delivery accuracy, penetration, fragmentation and wound damage behavior, and speed and efficiency of energy deposit all serve to render differences between rounds minimal. The following chart (Figure 3) shows the rounds of interest plotted together. The specific values of the chart are not meaningful; what is meaningful is the fact that all of the rounds act in the same band of performance. Interestingly, the one 7.62mm round that received the full evaluation, the M80 fired from the M14 rifle, performed in the same band of performance, which would indicate that for M80 ammunition at least there appears to be no benefit to the larger caliber at close quarters range.

2. *Shot placement trumps all other variables; expectation management is key.* Though this should produce a "well, duh!" response from the experienced warfighter, it cannot be emphasized enough. We try hard to inculcate a "one-shot, one-kill" mentality into Soldiers.

When they go to the qualification range, if they hit the target anywhere on the E-type silhouette, the target drops. The reality is that all hits are not created equal – there is a very narrow area where the human body is vulnerable to a single shot if immediate incapacitation is expected. Hits to the center mass of the torso may eventually cause incapacitation as the target bleeds out, but this process takes time, during which a motivated target will continue to fight. While projectile design can make a good hit more effective, a hit to a critical area is still required; this fact is borne out by the Medal of Honor citations of numerous American Soldiers who continued to fight despite being hit by German 7.92mm, Japanese 6.5mm and 7.7mm, or Chinese or Vietnamese 7.62mm rounds. A more realistic mantra might be "One well-placed shot, one-kill."

3. *Field reports are accurate and can be explained by the phenomenon of bullet yaw.* Shot placement aside, why is it that some Soldiers report "through-and-through" hits while others report no such problems, despite using the same weapons and ammunition? The phenomenon of bullet yaw can explain such differences in performance.

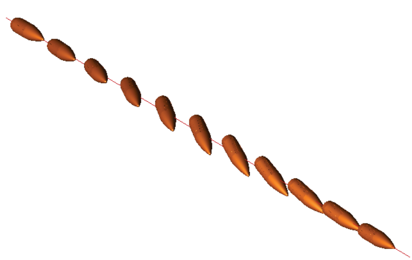

Figure 4. **Bullet Yaw vs. Path of Flight.**

Yaw is the angle the centerline of the bullet makes to its flight path as the projectile travels down range (Figure 4). Although the bullet spins on its axis as a result of the barrel's rifling, that axis is also wobbling slightly about the bullet's flight path.

Yaw is not instability; it occurs naturally in all spin-stabilized projectiles. However, bullet yaw is not constant and rifle bullets display three regions of significantly different yaw (see Figure 5). Close to the muzzle, the bullet's yaw cycles rapidly, with large changes of angle in very short distances (several degrees within 1-2 meters range). Eventually, the yaw dampens out and the bullet travels at a more-or-less constant yaw angle for the majority of its effective range. Then, as the bullet slows, it begins to yaw at greater and greater angles, until it ultimately destabilizes. A spinning top which wobbles slightly when started, then stabilizes

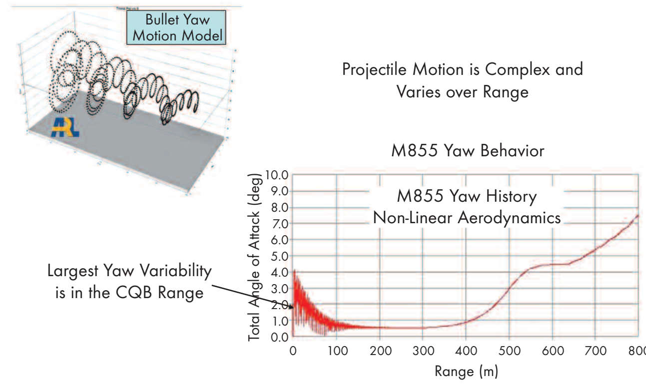

Figure 5. **Overview of Bullet Yaw (Source: ARL)**

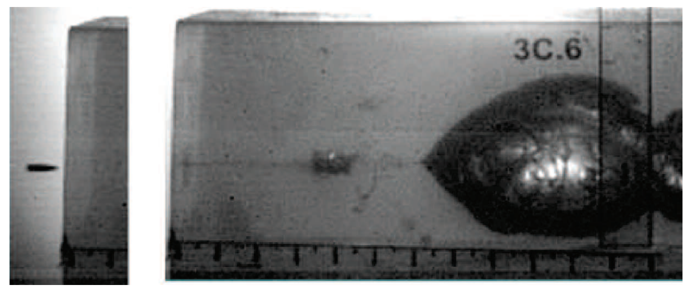

Figure 6. **Low Yaw Impact (Source: ARDEC)**

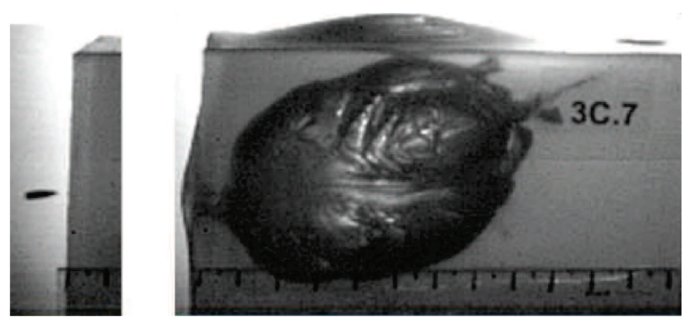

Figure 7. **High Yaw Impact (Source: ARDEC)**

for a time, then ultimately wobbles wide and falls over demonstrates the same phenomenon.

Unfortunately, projectiles impacting at different yaw angles can have significantly different performance, particularly as the projectile slows down. Consider the two photos on this page. In the first (Figure 6), the bullet impacted at almost zero yaw. It penetrated deeply into the gel block before becoming unstable. In a human target, it is very likely that this round would go straight through without disruption – just as our troops have witnessed in the field. In the second photo (Figure 7), the bullet impacted the gel block at a relatively high yaw angle. It almost immediately destabilized and began to break, resulting in large temporary and permanent wound cavities. Our troops have witnessed this in action too; they are more likely to report that their weapons were effective.

So all we have to do is fire high-yaw ammunition, right? Unfortunately, it's not that easy. High yaw may be good against soft tissue but low yaw is needed for penetration – through clothing, body armor, car doors, etc. – and we need ammunition that works against it all. Further, we currently cannot control yaw within a single type of ammunition, and all ammunition displays this tendency to some degree. Both of the shots were two

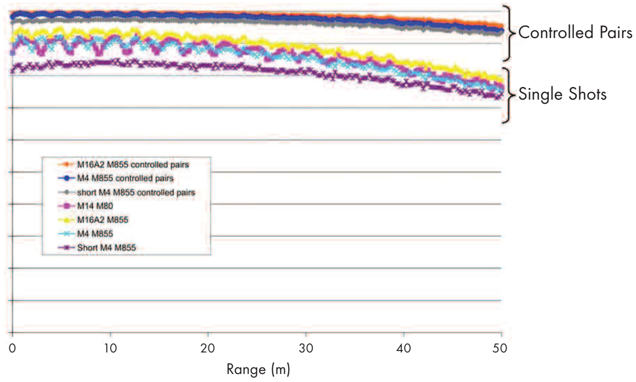

Figure 8. **Improvement in Performance Due to Controlled Pairs (Source: ARL)**

back-to-back rounds fired from the same rifle, the same lot of ammunition, at the same range, under the same conditions. Yaw requires more study, but the Army solved a similar problem years ago in tank ammunition.

4. There are doctrinal and training techniques that can increase Soldier effectiveness. The analysis tools used in this study were used to evaluate some alternative engagement techniques. The technique of engaging CQB targets with controlled pairs – two aimed, rapid shots as described in Chapter 7 of FM 3-22.9 – was shown to be significantly better than single aimed shots (see Figure 8). While that should certainly not be surprising to those who have been using this technique for some time, we now know why. Not only are two hits better than one, but controlled pairs help to average out striking yaw; on average, the Soldier is more likely to see a hit where the bullet's yaw behavior works in his favor.

CAVEATS

This study was an extremely detailed, indepth analysis of a specific engagement (5.56mm at CQB range); we must be careful not to apply the lessons learned out of context. The study did not look at the effectiveness of ammunition at longer ranges, where differences in projectile mass, velocity, and composition may have greater effect. The target set for this analysis was an unarmored, frontal standing target; against targets in body armor, or crouching/prone targets, the results may be different. Of course, most targets on the modern battlefield can be expected to be engaged in some form of complex posture (moving, crouching, or behind cover) and future analysis will have to look at such targets, too. The study evaluated readily available commercial ammunition; this does not rule out the possibility that ammunition could be designed to perform significantly better in a CQB environment. Human damage models need further refinement to move beyond gelatin and more closely replicate the complex human anatomy. While these caveats should not detract from the importance of the study's findings, they should be considered as a starting point for continued analysis.

CONCLUSION

Soldiers and leaders everywhere should take heart from the fact that despite all the myth and superstition surrounding their rifles and ammunition, they are still being provided the best performing weapons and ammunition available while the armaments community works to develop something even better.

More work remains to be done in this area, and the work is continuing with the participation of the major organizations from the original study. That effort is planned to look at longer ranges, intermediate barriers, and different target postures, and will further refine the tools and methods developed in the original study. The lessons learned are being put to immediate use as part of an ongoing program to develop a lead-free replacement for the M855 cartridge; the information obtained from this study will be used to develop a round that is expected to be more precise and consistent in its performance while still being affordable.

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