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Director, Operational Test and Evaluation


# M109 Family of Vehicles, Paladin Integrated Management (PIM)

Operational Assessment of the Initial Operational Test and  
Evaluation

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January 2017

  
J. Michael Gilmore  
Director

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# Executive Summary

This report provides my assessment of the operational effectiveness, operational suitability, test adequacy, and survivability of the M109 Family of Vehicles (FoV), known as Paladin Integrated Management (PIM) Self-Propelled Howitzer (SPH) and Carrier, Ammunition, Tracked (CAT) resupply vehicle. PIM is survivable against ballistic threats including small arms, fragmented Improvised Explosive Devices (IEDs), blast mines, and indirect fires. There are cybersecurity vulnerabilities and Live Fire test recommendations that the program should address prior to full-rate production. This operational assessment is based on data from the October 2016 Initial Operational Test and Evaluation (IOT&E), which was suspended for safety concerns for toxic fumes after completion of one of three planned record vignettes. IOT&E was not completed. The test was adequate to conclude the M109A7 SPH is not operationally effective and not operationally suitable. Cannon artillery units equipped with PIM SPH cannot execute delivery of cannon field artillery munitions using M232A1 Modular Artillery Charge System (MACS 5H) charge increment. The test was not adequate to conclude that the CAT is operationally effective and suitable. The Army Test and Evaluation Command (ATEC) conducted the first of three planned vignettes of the IOT&E in accordance with a test plan approved by the Director, Operational Test and Evaluation (DOT&E).

## System Overview

The PIM program refurbishes the fielded M109A6 SPH by replacing the chassis and turret components (e.g., changing the hydraulic system to a 600-volt electric drive system). The M109A7 SPH uses many existing M109A6 components, such as the breech and cannon mount.

## Training and Test Execution

During the initial pilot test prior to the IOT&E, the M109A7 SPH crews did not demonstrate a level of training proficiency that could meet the demands of the operational mode summary/mission profile (OMS/MP). Following a 5-day retraining period to improve section proficiency with crew drills and Fire Direction Center digital fire mission processing, ATEC conducted a second pilot test. During the second pilot test, the unit approached the operational tempo expected to be demonstrated in the Record Test (Vignettes 1, 2, 3). In pilot test 2, the unit improved their fire mission execution rate, but the rounds fired and missions completed still did not meet the intended OMS/MP. Because the second pilot test showed improvement over the first pilot test, the Army proceeded with the IOT&E Record Test. During the first record vignette, as mission execution rates began to increase to meet the OMS/MP, the M109A7 SPH suffered additional breech-related failures that inhibited the firing battery's ability to meet the required operational tempo. Following the end of the first record vignette, the IOT&E was suspended to address symptoms of toxic fume exposure by M109A7 SPH crew members. All 28 M109A7 SPH crew members showed symptoms of toxic fume exposure, and 14 of those soldiers required further assessment to address low peak flow respiratory readings. One soldier may have developed occupational asthma.

## **Operational Effectiveness**

The CAT performed well. The test was not adequate to conclude that the CAT is operationally effective and suitable. The M109A7 SPH is not operationally effective. The IOT&E was suspended after the first record test vignette because the soldiers were affected by toxic fumes released into the M109A7 SPH cab. The Army is investigating the safety issues relating to toxic fumes. Initial feedback from initial root cause assessments conducted by the Army indicates that the fumes may be related to breech problems when soldiers fire with the maximum charge (which is needed to reach beyond 17 kilometers of range) and improper M109A7 training provided to the crews. The majority of the reliability problems seen in the IOT&E were associated with the legacy breech. Many of the effectiveness issues can be attributed to reliability and training problems. The Program Office is planning an extended low-rate initial production period and will conduct a second IOT&E. The Army plans to address deficiencies, but has not decided on a schedule. At this time, the Army is not planning to change the breech before the second IOT&E. With an unchanged breech, many of the problems seen in this suspended IOT&E will recur in the second IOT&E.

Contradictory statements in the technical manuals confused the M109A7 SPH crews and left them unsure how to operate and maintain the SPH. It was discovered during a root cause analysis that developmental test crews from Yuma Proving Ground used different maintenance procedures and different crew drills compared to those taught in unit during pre-IOT&E training. The Army will clarify conflicting language in the technical manuals and adjust programs of instruction for both the Field Maintenance New Equipment Training (FMNET) and Operator New Equipment Training (OPNET) to clarify safety procedures and preventive maintenance actions.

A field artillery unit equipped with the M109A7 SPH conducted movement and maneuver that can keep pace with an Armored Brigade Combat Team (ABCT), but individual howitzers were not able to participate in the moves because of reliability problems, decreasing overall mileage accumulation. A unit equipped with M109A7 SPH did not demonstrate the required OMS/MP needed to maintain fire support capability to an ABCT. Because of the suspension of the IOT&E, there is not sufficient data to conclude whether the M109A7 SPH can execute adequate survivability movement to avoid enemy counterfire.

During the IOT&E, a field artillery unit equipped with M109A7 SPH was not able to provide the volume of fire needed to support an ABCT. A unit equipped with the M109A7 SPH executed 73 percent (119/162) of the fire missions and fired 45 percent of the rounds (1557/3441) planned for two vignettes evaluated, one of which was a pilot test. An M109A7 SPH-equipped unit did not meet the rate-of-fire requirement for missions fired with point-detonating fuzes, but was able to meet the requirement for missions fired with time fuzes. The M109A7 SPH-equipped unit was slower in delivering fires than units equipped with the current Paladin M109A6 SPH. M109A7 SPH-equipped sections achieved fire mission time standards 30 percent of the time for conventional fire missions during the IOT&E compared to 74 percent for the legacy M109A6 SPH during its 1992 Follow-on Operational Test and Evaluation (FOT&E). When the unit did fire, they were able to provide fires that met accuracy requirements.

The test unit equipped with the M109A7 SPH executed all missions fired using digital communications during two vignettes. The M1068/A3 Fire Direction Center Standard Integrated Command Post System tracked vehicle reliability and communication challenges forced a unit equipped with the M109A7 SPH and CAT to adopt a non-standard approach to command and control by moving a Fire Direction Center ahead of the rest of the main body to allow extra time to establish communications. The M1068/A3 Fire Direction Center tracked vehicle could not execute a mix of missions a self-propelled field artillery could execute. The M1068/A3 Fire Direction Center tracked vehicle is not a solution for the PIM FoV due to its inability to keep pace with the PIM FoV, lack of mobility, and poor reliability.

### **Operational Suitability**

The CAT resupply vehicle operated well. The test was not adequate to conclude that the CAT is operationally suitable. The M109A7 SPH is not operationally suitable. The M109A7 SPH did not meet reliability, availability, and maintainability requirements, while the CAT did meet its requirements. The primary M109A7 SPH failure modes are associated with the breech and its sub-components.

The IOT&E was suspended after the first record test vignette because the soldiers were affected by toxic fumes released into the M109A7 SPH cab. The Army is investigating the safety issues relating to toxic fumes. Feedback from initial root cause assessments conducted by the Army indicates that the fumes may be related to breech problems and improper M109A7 training provided to the crews.

The Army plans to field the M109A7 SPH with the legacy breech. The breech failures were most common when the unit fired high charge missions using the maximum number of MACS 5H increments. The MACS 5H is necessary in order for the M109A7 SPH to achieve range beyond 17 kilometers. Long ranges are needed because most threat countries have artillery ranges longer than 17 kilometers, and thus the extended range is required by the Army to avoid enemy counterfire. The IOT&E planned rate of MACS 5H firings was based upon the Army's estimate of the ranges required to support an ABCT in a major combat operation. The frequent breech-related failures contributed to the test unit's inability to achieve the required volume of fire. The Army has an ongoing breech reliability improvement program, but does not anticipate any material change to the breech until 2019.

During the IOT&E, the test unit generated very high demands for repair parts associated with the breech, in order to correct the frequent failures. The demand for breech parts during the IOT&E exceeded the supply inventory available at the test unit, and its associated Brigade, Division, Installation, and Army level. The failure frequency and protracted time to receive repair parts impacted the M109A7 SPH operational availability (Ao) and Mean Time To Repair (MTTR).

All PIM vehicles were equipped with the T2 add-on armor kit and one M109A7 SPH and one CAT had both the T2 and underbelly armor kits. T2 add-on armor kits add 4,000 pounds to the overall weight of each of the PIM vehicles, increasing wear that might lead to more

reliability issues. Increased weight may pose special challenges for suspension design and maneuverability, which will require continued attention during future testing.

Based upon the limited data from the suspended IOT&E, there is no evidence that vehicles with the underbelly armor kits were inhibited in their movement nor that they experienced any greater consumption of suspension components (road wheels and track pads) than their counterpart T2-weighted vehicles. The road wheel consumption data indicate that the objective-weight howitzer consumed three road wheels during the one record vignette compared to a range of three to eight for the other howitzers during the same period. The data is limited to what was observed during the one record vignette for the M109A7 SPH with both kits, since it did not participate in the pilot test due to a hydraulic system failure not attributable to the extra weight. Additional assessment of the objective weight vehicles will occur as part of the second IOT&E.

### **Survivability**

The M109A7 SPH and CAT are survivable on the battlefield. Cybersecurity assessments identified vulnerabilities such that PIM may be susceptible to insider and nearsider cybersecurity threats with physical access. Cybersecurity testing and results are reported in a classified annex to this report.

The M109A7 SPH and CAT are survivable against ballistic threats. Increased crew protection and vehicle survivability is a primary requirement for the PIM program. These critical capabilities were assessed by ballistic testing of armor resistance to penetration, testing of the vulnerability of mission critical components, and system-level testing against required and operationally expected direct fire, indirect fire, underbody blast, and fragmentary IED threats. ATEC tested the vehicles in both the T1 (without add-on armor) and T2 (with add-on armor, but no underbelly kit) armor configurations. ATEC conducted two objective-level underbody blast tests with an underbelly kit installed. The Army will deploy the systems in the T2 configuration.

Live Fire testing uncovered several areas the Army should address to improve survivability. The results of the Live Fire testing will be available in a separate classified report to support the full-rate production decision following completion of the second IOT&E.


### **Recommendations**

The Army should consider the following recommendations as the M109A7 PIM FoV program proceeds toward its second IOT&E and full-rate production.

- Conduct a second IOT&E.
- Address the breech failures that affect the ability of a unit to fire cannon artillery munitions specifically M232A1 MACS 5H charge increment.
- Assess feasibility of implementing an interim breech fix prior to a second IOT&E, and weigh it against delaying the second IOT&E until Extended Range Cannon Artillery (ERCA) is available with a new breech. Conducting a second IOT&E with the same breech will result in the same reliability as the first IOT&E.

- Assess the cause for toxic fumes in the vehicle and identify mitigation actions to ensure crew safety.
- Complete validation and update of technical manuals to address toxic fumes safety issues and clarify crew drills and maintenance requirements for the breech based upon lessons learned from the first IOT&E.
- Ensure the M109A7 SPH fire mission crew drill procedures and maintenance of the breech and cannon tube conducted during developmental testing is the same as outlined in technical manuals and approved field artillery crew drill procedures outlined by TCM-Fires, in the second IOT&E.
- Ensure the test unit during the second IOT&E has adequate time for collective training and is given adequate feedback in order to ensure it can execute the users requirement identified in the OMS/MP.
- Reassess the FMNET and OPNET points of interest to ensure a trained and ready test unit capable of performing fire support tasks according to the OMS/MP.
- Consider replacing the M1068/A3 Fire Direction Center tracked vehicle with an alternative vehicle until Armored Multi-Purpose Protection Vehicle is fielded.
- Examine suspension component wear associated with road wheels and track pads, and determine whether there is an inconsistency with the Bradley in comparable weight configuration.
- Determine a plan for installing T2 add-on armor kits and provide it to DOT&E.
- Address the ballistic survivability issues uncovered in Live Fire testing. These include: enabling reset of the high voltage (HV) system without engine shutdown to permit rapid rebooting of the HV system and restoration of power to the gun drives and rammer; fielding the underbody protection kit as part of the T2 configuration to provide underbody blast protection against realistic threats; redesigning the automatic fire extinguisher system to provide coverage of the M109A7 SPH crew compartment and better fire sensing in the engine compartment of both vehicles; redesigning the ammunition storage racks to allow venting of burning propellant; redesigning retention systems to prevent floor mats and ammunition from becoming secondary projectiles that could injure crew members during underbody blast events; and improving the protection of the armor features that failed armor testing.
- Resolve the identified cybersecurity vulnerabilities; refine tactics, techniques, and procedures relating to the identification of cybersecurity threat activity and responses;

then conduct a comprehensive Cooperative Vulnerability and Penetration Assessment and Adversarial Assessment to demonstrate the fixes and mitigations, as well as the mission impact of any remaining vulnerabilities.

A handwritten signature in black ink, appearing to read "J. M. Gilmore", with a long horizontal flourish extending to the right.

J. Michael Gilmore  
Director



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## Section One

# Test Adequacy

The Army Test and Evaluation Command (ATEC) conducted the Initial Operational Test and Evaluation (IOT&E) at Fort Hood, Texas, with a six-howitzer firing battery and support personnel during the period of September 25 through November 8, 2016. The test was suspended after the first record test vignette (of three planned vignettes) because toxic fumes from the firing were leaking into the howitzer cabs and making the soldiers sick. The IOT&E was not adequate and was not completed in accordance to the test plan approved by DOT&E. During the first vignette, 28 crew members of the 6 cannon crews exhibited symptoms consistent with toxic fume ingestion. Medical personnel determined that 14 of the 28 crew members required further respiratory evaluation and that one soldier may have been affected by occupational asthma. The Army halted the test to begin root cause analysis for the toxic fumes.

This operational assessment is based upon data gathered from two 72-hour vignettes—a pilot test vignette (conducted from October 12 – 15) and the first record test vignette (conducted from October 20 – 23). The test unit included a firing battery with two firing platoons of three howitzer sections, two platoon headquarters, a battery headquarters, the battalion Fire Direction Center, and the battalion-level operations and intelligence sections. A Fire Support team to observe fires and associated ammunition and maintenance support platoon personnel supported the firing battery.<sup>1</sup> Each of the two firing platoons was equipped with three Paladin Integrated Management (PIM) Self-Propelled Howitzer (SPH), three Paladin PIM Carrier, Ammunition, Tracked (CAT), and two legacy M1068 Command Post Carriers.

During the IOT&E, the test unit conducted fire missions, tactical road marches, and survivability moves, but was not able to maintain an operational tempo to satisfy the test plan or maintain consistency with either the Armored Brigade Combat Team (ABCT) operational mode summary/mission profile (OMS/MP) or standard Paladin howitzer tactics, techniques, and procedures.<sup>2,3</sup> The IOT&E operational tempo required by the OMS/MP called for each howitzer to fire 14 fire missions (totaling 104 rounds) and move 59 miles during a 24-hour period. Fire missions executed during the IOT&E included high-explosive, illumination, and smoke projectiles with M232A1 Modular Artillery Charge System (MACS 5H) propellant. Methods of control for fire missions included fire-when-ready missions and at-my-command procedures. The scenario included enemy counterfire threat and Improvised Explosive Device (IED) portrayal to provide operational realism and to prompt appropriate survivability movements and evasive tactics while conducting operations.

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<sup>1</sup> One additional Self-Propelled Howitzer (SPH) and a Carrier, Ammunition, Tracked (CAT) resupply vehicle served as spare vehicles to use when the test vehicles became inoperable for an extended period.

<sup>2</sup> In a tactical road march, the entire platoon moves to a new firing position. Survivability moves are short displacements (about 1,000 meters) made by individual howitzers after firing to avoid counterfire.

<sup>3</sup> U.S. Army Training and Doctrine Command, Army Capabilities Integration Center, Heavy Brigade Combat Team (HBCT) Operational Mode Summary and Mission Profile, December 18, 2009. Operational Mode Summary and Mission Profile for the M109 Family of Vehicles, July 22, 2015.

ATEC conducted cybersecurity testing, consisting of a Cooperative Vulnerability and Penetration Assessment and an Adversarial Assessment. Test conduct is discussed in detail in the cybersecurity annex. Due to known test limitations, the collected data are not sufficient to support a complete cybersecurity evaluation. ATEC will conduct additional cybersecurity testing as part of the second IOT&E.

The Live Fire Test and Evaluation (LFT&E) strategy consisted of building block tests from the armor protection against penetrating threats, vulnerability of components, effectiveness of the automatic fire extinguishing system (AFES), to full-up system-level survivability. The combination of these test events was adequate to support LFT&E. The details of the tests and LFT&E will be available in a separate classified report to support the full-rate production decision following completion of the second IOT&E.

### **Fire Mission Allocation**

ATEC employed Design of Experiments (DOE) techniques for the fire mission test matrix for the IOT&E. The fire mission matrix included missions in sufficient numbers and types to meet the user defined OMS/MP, i.e., the total number of rounds and missions for the platoons per day. The timeliness of the delivery of fires and the accuracy of the round impacts were the key operational effectiveness measures for the M109A7 SPH. The factors that varied in the test to span the operational envelope included: mission type (adjust fire or fire-for-effect), time of day (day or night), range to the target, traverse angle (from the direction of the lay of the howitzer), quadrant elevation (the angle of elevation), fuze type (point-detonating or timed fuzes), movement status, and mission-oriented protective posture (MOPP). Range and quadrant elevation are correlated.

The experimental design for the entire IOT&E consisted of a minimum of 120 platoon missions to satisfy sample size requirements for the analysis, and an additional 132 platoon missions to meet the OMS/MP operational tempo requirements. To maintain operational realism, the testers distributed the mission types of the additional 132 missions between adjust fire missions, missions using non-lethal munitions, emergency missions, missions with soldiers in MOPP Level 4 clothing, 12-round missions to test maximum rates of fire, missions requiring crews to pivot the vehicle chassis to a new azimuth of fire, and extra long-range missions using MACS 5H needed to match the OMS/MP.<sup>4</sup> Due to the suspended IOT&E, a majority of the experimental design was not executed.

### **Test Limitations**

Several test conditions during the IOT&E affected the evaluation of the Paladin PIM:

- The unit lacked proficiency in training. During the initial pilot test prior to the IOT&E, the howitzer crews did not demonstrate a level of training proficiency that could meet the demands of the OMS/MP. Following a 5-day retraining period to

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<sup>4</sup> MOPP Level 4 is the highest level of individual protective chemical, biological, radiological, and nuclear protection. When in MOPP Level 4, soldiers wear the MOPP suit jacket and trouser, boots, gloves, and protective mask with hood.

improve section proficiency with crew drills and Fire Direction Center digital fire mission processing, ATEC conducted a second pilot test. During the second pilot test, the unit improved the operational tempo expected to be demonstrated in the Record Test (Vignettes 1, 2, 3). In pilot test 2, the unit improved their fire mission execution rate, but the rounds fired and missions completed still did not meet the intended OMS/MP. Because the second pilot test showed improvement over the first pilot test, the Army proceeded with the IOT&E Record Test.

- The unit was not able to maintain the required operational tempo because of equipment failures. During the first record vignette, as mission execution rates began to increase to meet the OMS/MP, M109A7 SPH suffered additional breech-related failures that inhibited the firing battery’s ability to meet the required operational tempo. Following the end of the first record vignette, the IOT&E was suspended to address symptoms of toxic fume exposure by M109A7 SPH crew members. All 28 howitzer crew members showed symptoms of toxic fume exposure, and 14 of those soldiers required further assessment to address low peak flow respiratory readings. One soldier may have developed occupational asthma.
- The IOT&E was suspended after the first record vignette. This resulted in a significant loss of 2/3 the planned data (see Table 1-1).

**Table 1-1. Test Operational Tempo during Execution, Compared to the OMS/MP Required**

Vignette / Metric	Pilot 2	Record 1	Record 2	Record 3
Fire Missions Completed	55 of 72 (76%)	64 of 90 (71%)	0	0
Rounds Fired	630 of 1500 (42%)	927 of 1941 (48%)	0	0
SPH Miles Driven	750.7 of 902.7 (83.2%)	999.6 of 1062 (94.1%)	0	0
CAT Miles Driven	929.4 of 983.5 (92.8%)	1092.3 of 1157 (98.3%)	0	0

- M1068/A3 Fire Direction Center Standard Integrated Command Post System tracked vehicle poor reliability and poor communication challenges forced the firing battery to adopt a non-standard approach to command and control.
- Test instrumentation during the suspended IOT&E could not locate 36 percent of the high-explosive rounds fired, including some entire missions. This failure of the instrumentation has a bearing on the calculations of howitzer firing accuracy. Various causes contributed to the failure to locate rounds, such as incorrect orientation of the instrumentation and dust thrown up by the explosions of other rounds in the missions.
- Missions expected to be fired with the Excalibur round were not fired as planned. Just prior to test execution, the Army identified structural imperfections in the Excalibur round, and limited the firing of Excalibur to combat use, prohibiting firing

in training and operational testing environments. Compatibility of the M109A7 SPH and Excalibur rounds will be examined at a later operational test event.

## Section Two

# Operational Effectiveness

The Carrier, Ammunition, Tracked (CAT) resupply vehicle performed well. The test was not adequate to conclude that the CAT is operationally effective. The M109A7 Paladin Integrated Management (PIM) Self-Propelled Howitzer (SPH) was not operationally effective. Reliability issues were a major cause for the M109A7 SPH inability to meet required movement rates and rates of fire.

A field artillery unit equipped with M109A7 SPH was not able to maintain the howitzer movement rates needed to support an Armored Brigade Combat Team (ABCT). The platoons conducted the planned tactical moves, but individual howitzers were not able to participate in the moves because of reliability problems, decreasing the amount of overall mileage accumulation and failing to demonstrate the required operational mode summary/mission profile (OMS/MP) level of performance outlined by the Army.

The firing battery equipped with M109A7 SPH was able to deliver accurate fires, but not able to deliver the volume of fire needed in a timely fashion. The unit was not able to provide the volume of fire needed to support an ABCT. The PIM-equipped unit executed 73 percent (119/162) of the fire missions and fired 45 percent of the rounds (1557/3441) planned for the two vignettes evaluated. The firing battery did not meet the rate-of-fire requirement for missions fired with point-detonating fuzes, but was able to meet the requirement for missions fired with time fuzes. The M109A7 SPH-equipped unit was slower in delivering fires than units equipped with the current Paladin M109A6. The M109A7 SPH-equipped sections achieved fire mission time standards 30 percent of the time for conventional fire missions during the IOT&E compared to 74 percent for the legacy M109A6 SPH during its 1992 Follow-on Operational Test and Evaluation (FOT&E). When the firing battery did fire, they were able to provide fires that met the M109A7 SPH accuracy requirements. The unit met Field Artillery gunnery accuracy standards 78 percent of all fire missions.<sup>5</sup> By way of comparison, the legacy Paladin M109A6 met gunnery accuracy standards 62 percent of the missions in the 1992 M109A6 SPH FOT&E.

The unit struggled to execute tactical communication (voice and digital) throughout the test event. The M109A7 SPH-equipped sections executed all fire missions using digital communications. The M1068/A3 Fire Direction Center Standard Integrated Command Post System tracked vehicle reliability and communication challenges forced the firing battery to adopt a non-standard approach to command and control by moving a Fire Direction Center ahead of the rest of the main body to allow extra time to establish communications. The M1068/A3 Fire Direction Center tracked vehicle could not execute the OMS/MP required to maintain pace with the PIM Family of Vehicles (FoV). The M1068/A3 Fire Direction Center tracked vehicle could not execute a mix of missions a self-propelled field artillery unit would execute in support of an ABCT. The M1068/A3 is not a solution for the PIM FoV due to its inability to keep pace with the PIM FoV, lack of mobility, and poor reliability.

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<sup>5</sup> U.S. Army Training Circular (TC) 3-09.8, *Field Artillery Gunnery*, with change 1 dated 8 September 2016.

## Delivery of Fires

The M109A7 SPH-equipped unit was able to provide accurate, but not timely, fires to accomplish mission objectives.

### *Accuracy*

Providing lethal, responsive fires in support of maneuver units is dependent on M109A7 SPH-equipped units achieving accurate effects on threat targets. The PIM Capability Production Document (CPD) accuracy requirements are shown in Table 2-1. Circular error probable (CEP) is defined as the radius of a circle, around the aim point, into which 50 percent of the projectiles fired are expected to impact.<sup>6</sup>

**Table 2-1. PIM Accuracy Requirement in Low-Angle Fire Missions**

Range (kilometers)	CEP (meters)
0 – 9	105
9 – 15	131
Greater than 15	145

### **CPD Accuracy Analysis**

In the IOT&E, the M109A7 SPH battery met the CPD accuracy requirement for all conditions, except for missions fired at long ranges, using point-detonating fuzes, fired at night. The radial miss distance from the aim point to the impact for each projectile detonation was used to estimate the CEP. Table 2-2 summarizes the test unit's demonstrated PIM CEP accuracy for the low-angle fire missions at CPD ranges. Rounds fired during daylight met standards within the CPD requirement range bands for projectiles using both point-detonating fuzes and fuzes with a time setting that generates an airburst. The CEPs for M795 projectiles fired at night with a time fuze met CPD requirements, as did short-range missions using a point-detonating fuze. The CEP for projectiles armed with a point-detonating fuze during night missions at ranges greater than 15 kilometers did not meet the CPD requirement. Five of the six rounds with miss distances greater than 600 meters were fired at night in different fire missions. These outliers might be a result of human error by tired howitzer crews.

The increase in accuracy of missions using time fuzes as range increases is not expected. The anomaly might be a result of lack of data across the complete operational envelope and firing 1 of 3 vignettes. Table 2-2 shows how failure to complete the test design left gaps in data for missions with time fuzes and night missions. Because all detonations supporting the estimate in the short-range, day and time cell estimate came from a single fire mission, the accuracy increase might be a result of an unknown anomaly in that fire mission.

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<sup>6</sup> FM101-61-5-3, JMEM Indirect Fire Accuracy, Vol III, May 1980



**Table 2-2. Demonstrated CEP (meters) by Range for Light Conditions and Fuze Mode for IOT&E Low-Angle Fire-for-Effect Missions**

Light Condition	Fuze Mode	Range (80% confidence) <sup>c</sup>		
		≤ 9 km	9 – 15 km	> 15 km
M795 HE CPD Requirement		105 meters	131 meters	145 meters
Day	Point Detonation	95.5 m (89.2 – 104)	78.1 m (74.2 – 102)	109 m (103 – 118)
	Time	97.1 m (88.5 – 111)	Not Executed	71.6 m (56.5 – 83.6)
Night	Point Detonation	43.0 m (33.7 – 50.5)	Not Executed	173.4 m (162 – 180)
	Time	Not Executed	102 m (63.0 – 125)	60.8 m (52.4 – 76.0)

<sup>a</sup> HE – High Explosive; CPD – Capability Production Document; km – Kilometers; m – meters  
<sup>b</sup> Green = met requirement; Red = did not meet requirement; amber = met requirement, but not with confidence  
<sup>c</sup> Confidence intervals were calculated using the Bootstrap Method

The miss distance for all but 1 of the 11 projectiles armed with the Precision Guidance Kit (PGK) fuze was 96 meters, which is less than the short-range CEP requirement. All PGK missions were fired at ranges greater than 14 kilometers.

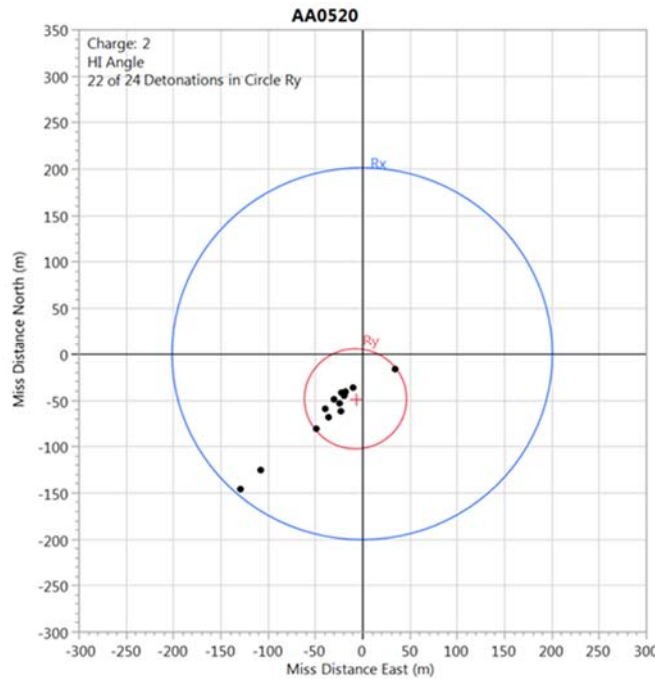
**Accuracy Analysis Using Field Artillery Training Standards**

The Army Training Circular (TC) 3-09.8, Field Artillery Gunnery, provides a graphical method used to measure unit fire mission accuracy. Field Artillery units use this graphical method to assess the proficiency and accuracy of PIM-equipped units in training. This mission-level technique is based on statistical analysis of firing data from ballistics laboratory testing and provides a comparison between M109A7 SPH and the M109A6 SPH. This graphical method was used to measure fire mission accuracy during the 1992 M109A6 SPH FOT&E.

The scoring process begins by drawing one circle, labeled RX, centered on the intended aim point. A second circle, labeled RY, is drawn inside circle RX such that RY captures the maximum number of projectile impact points. The Army TC specifies the radii of the two circles in look-up tables for various combinations of propellant charge and mission angle of fire. Per the training standard, if circle RY covers at least 75 percent of the rounds fired in a given mission, the mission is scored as a success.

Figure 2-1 is an illustrated example of the mission-level scoring results for one IOT&E fire mission (labeled Fire Mission AA0520). Twenty-four projectiles were fired using charge 2 at high angle in this mission. From Table D-27 in TC 3-09.8, the radius of RX is 201 meters and the radius of RY is 54 meters. For the example IOT&E fire mission AA0520, 22 of 24 projectile impact points were inside circle RY and the mission was accurate and scored as a success.

Seventy-eight percent (62 of 80; 80 percent confidence interval from 70 percent to 83 percent) of M109A7 SPH fire missions in the IOT&E met this mission-level accuracy standard.<sup>7</sup> By way of comparison with the legacy howitzers, the M109A6 SPH FOT&E test unit met mission-level accuracy standards in 62 percent (191 of 310; 80 percent confidence interval of 58 percent to 65 percent) of their fire missions. The M109A7 SPH-equipped unit demonstrated greater accuracy using the training standards metric than the M109A6 SPH-equipped FOT&E unit (p-value = 0.012).



**Figure 2-1. Example Graphical Accuracy Assessment for Mission AA0520**

### ***Timeliness***

As tested in the IOT&E, the M109A7 SPH-equipped sections did not meet either the emergency fire mission or conventional fire mission timeliness requirements, or the howitzer rate-of-fire requirement. Emergency fire missions are those received while the howitzer platoon is moving, while conventional fire missions are those received while the howitzer platoon is stationary in a firing position.

#### **Emergency Mission Timeliness**

The emergency mission requirement states that howitzer crews must stop and fire a round within 60 seconds when they receive a mission while moving. The M109A7 SPH unit did not meet this standard for any of the 19 individual howitzer response times attempted in emergency missions during the IOT&E. The median emergency mission time was 158 seconds (with an 80 percent confidence interval of 102 to 394 seconds) for 6 missions that required no fuze setting, and 177 seconds (with an 80 percent confidence interval of 121 to 231 seconds) for 13 missions

<sup>7</sup> Confidence bounds were calculated using the Clopper-Pearson method for binomial proportions.

that did require a fuze setting. All IOT&E emergency missions executed in the PIM IOT&E were low-angle fires.

### Timeliness of Conventional Fire Missions

M109A7 SPH conventional fire missions executed in the IOT&E were not timely. Between one and three howitzers participated in each platoon fire mission. Thirty percent (51 of 167 howitzer missions; 80 percent confidence interval of 26 percent to 36 percent) of individual howitzer response times for conventional fire missions met the time standards, compared to 74 percent (810 of 1099 missions; 80 percent confidence interval of 72 percent to 75 percent) in the M109A6 SPH FOT&E.<sup>8</sup> Table 2-3 shows howitzer response times for fire-for-effect fire missions. It does not include missions with soldiers in mission-oriented protective posture (MOPP) clothing, or missions that required the crew to pivot the M109A7 SPH chassis to a new azimuth of fire. Although traverse angle and fuze mode influenced howitzer response times, response times were slow across the operational envelope. Fire mission times for the individual M109A7 SPH sections under test showed significant differences between individual howitzers. The best-performing individual howitzer sections met the timeliness standard less than half the time.

**Table 2-3. Conventional Fire Mission Times**

Angle of Fire	Fuze Mode <sup>a</sup>	Traverse Angle	Time Standard (seconds) <sup>b</sup>	Fraction of Missions Meeting Time Standards	Median Response Time (seconds) <sup>c</sup>	80% confidence interval <sup>e</sup>
Low	PD	< 30°	30	17% (8 of 46)	71.5	(61 – 106)
		> 30°	60	46% (18 of 39)	79	(55 – 91)
	Time	< 30°	45	39% (15 of 38)	104	(106 – 138)
		> 30°	75	50% (1 of 2)	174.5	(85 – 264) <sup>d</sup>
High	PD	< 30°	45	18% (6 of 33)	84	(70 – 123)
		> 30°	75	33% (3 of 9)	92	(35 – 313) <sup>d</sup>

- <sup>a</sup> PD = Point-Detonating (no fuze setting); Time = Variable Time or Time Fuze (requires fuze setting)
- <sup>b</sup> Training standards allow an additional 15 seconds each for high-angle missions and fuze setting. PIM requirements allow an additional 30 seconds if the traverse angle is greater than 30 degrees, which requires the section to move the howitzer turret from the vehicle centerline onto the azimuth of fire.
- <sup>c</sup> Red = did not meet requirement
- <sup>d</sup> Range of response times provided due to small sample size.
- <sup>e</sup> Confidence intervals were calculated using the Bootstrap Method.

### Rate-of-Fire

During the IOT&E, the M109A7 SPH-equipped unit did not meet the rate-of-fire requirements for missions using point-detonating fuzes. Table 2-4 shows the M109A7 SPH rate-of-fire requirements, the median rates-of-fire achieved, and the 80 percent confidence bounds for large samples. The best rate-of-fire achieved in all IOT&E M109A7 SPH fire missions with four or more volleys was 3.1 rounds per minute. Neither of the factors by which requirements vary

<sup>8</sup> Confidence intervals were calculated using the Clopper-Pearson method for binomial proportions.

affected rates of fire during the IOT&E. Interruptions from stuck and ruptured primers contributed to delays in mission completion.

**Table 2-4. PIM IOT&E Rates-of-Fire**

Angle of Fire	Fuze Mode	Requirement (rds/min)	Sample Size	Median (rds/min) (80% CI)
Low	PD	4	105	1.15 (1.08 - 1.29)
	Time <sup>a</sup>	1	57	1.07 (0.83 - 1.18)
High <sup>b</sup>	PD	2	53	1.21 (1.08 - 1.30)
	Time	0.5	2	1.25 (1.0, 1.5)

<sup>a</sup> PD = Point-Detonating (i.e., no fuze setting is required); Time = Inductively Set or Time Fuze (requires fuze setting); CI = confidence interval

<sup>b</sup> Quadrant elevation greater than 45 degrees

<sup>c</sup> Green = met requirement, Red = did not meet requirement, Amber = not met with confidence

## Movement

Reliability problems during the IOT&E prevented the M109A7 SPH from achieving the full movement rates specified to support an ABCT. The CAT did achieve the required movement rates. The M109A7 SPH and the CAT-equipped test unit performed their assigned missions in a realistic field environment, requiring movement over improved roads, tank-trails, and cross-country through high plains and rolling terrain. The IOT&E scenario based on the supported unit OMS/MP called for the M109 FoV to travel 177 miles for each SPH and 192 miles for each CAT over the course of a 72-hour maneuver brigade tactical mission vignette. The IOT&E scenario was for the M109A7 SPH to travel 59 miles and the CAT to travel 64 miles per day in a combination of tactical road marches, resupply operations, and survivability moves in order to achieve that operational tempo. The test unit did execute the planned three tactical moves per day. During the IOT&E, the M109A7 SPH traveled a total of 1750.3 miles for a 52.6-mile per day rate, achieving 89 percent of the required OMS/MP mileage for one pilot test vignette and one record vignette. The CAT traveled 60.7 miles per day, achieving 94.4 percent of the OMS/MP for one pilot test vignette and one record vignette. Maintenance failures among the M109A7 SPH and CAT reduced the total number of vehicles available to accrue mileage during one pilot test and one record vignette. Table 2-5 shows the movement distances for both the M109A7 SPH and CAT during the IOT&E. When operational, the M109A7 SPH and CAT moved well and were able to negotiate the different types of terrain and maintain movement speeds to support the tactical scenario.

**Table 2-5. PIM IOT&E Vehicle Movement**

<b>Vehicle</b>	<b>Total Miles Driven (Required)</b>	<b>Daily Miles Driven (Required)</b>	<b>Percentage of OMS/MP Achieved</b>
SPH	1750.3 (1965)	52.6 (59)	89%
CAT	2021.7 (2141)	60.7 (64.3)	94.4%

**Communication**

The communications system in the M109A7 SPH is the same as in the current Paladin M109A6 vehicles. During the IOT&E, M109A7 SPH crews maintained voice and digital communications with their platoon leader, the platoon Fire Direction Center, and test control personnel using Single Channel Ground and Airborne Radio System (SINCGARS) radios. The onboard Paladin Digital Fire Control System (PDFCS) in each howitzer exchanged digital fire mission data and status reports with platoon Fire Direction Centers through the Advanced Field Artillery Tactical Data System (AFATDS). All of the 119 platoon fire missions fired during the IOT&E were conducted according to Army doctrine using the AFATDS to PDFCS digital interface. The AFATDS and PDFCS are legacy communications devices and were not part of the Paladin PIM upgrade program. Situational awareness data were brought into each M109A7 SPH and CAT through the Blue Force Tracker system.

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## **Section Three**

### **Operational Suitability**

The Carrier, Ammunition, Tracked (CAT) resupply vehicle met its reliability, availability, and maintainability requirements during the first record test vignette. The test was not adequate to conclude that the CAT is operationally suitable. The M109A7 Self-Propelled Howitzer (SPH) is not operationally suitable. Safety issues associated with the toxic fumes that caused suspension of the IOT&E are being investigated by the Army and the Health Services Command in order to identify a root cause. Poor breech reliability, improper training provided to the unit by the Army, and technical manual errors are believed to be contributing factors. The M109A7 SPH did not meet reliability, availability, and maintainability requirements. The primary M109A7 SPH failure modes are associated with the breech and its sub-components. The breech was not changed as part of the M109A7 Paladin Integrated Management (PIM) program. As of this assessment, the Army does not plan to change breech components as part of the M109A7 SPH program prior to the second Initial Operational Test and Evaluation (IOT&E).

During the portion of the IOT&E that was executed, the M109A7 SPH demonstrated a Mean Time Between System Abort (MTBSA) of 45.4 hours, with the 80 percent confidence interval ranging from 32.3 hours to 65.2 hours. The M109A7 SPH failed to meet its point estimate requirement of 62 hours MTBSA, but not with statistical confidence. The CAT demonstrated a MTBSA of 248 hours, with an 80 percent confidence interval of 112 to 676 hours. The CAT met its 103-hour reliability requirement with statistical confidence.

#### **PIM SPH Reliability**

During the IOT&E, the M109A7 SPH experienced 16 system aborts. The system aborts included howitzer armament and automotive failures. Eleven of the 16 failures were related to the breech components requiring parts replacement (firing mechanism, plunger pins, firing pin retainers, split rings, obturator pads, etc.) and/or field level repair. The breech is a legacy component from the fielded M109A6 SPH and was not changed as part of the M109A7 PIM program. Four failures were associated with hydraulic leaks traced to failed quick disconnects (fittings used to connect hydraulic lines to engine and transmission components), gaskets, and seals. One failure was associated with the Paladin Electric Servo Amplifier. This failure required multiple resets and prevented one SPH from completing a fire mission. In a separate incident, an engine fire occurred during a towing procedure during a recovery operation for a howitzer with a severe hydraulic system leak.

At this time, the Army plans to field the M109A7 SPH with the legacy breech. The breech failures were most common when the unit conducted high-charge missions using the M232A1 Modular Artillery Charge System (MACS 5H) increments. The MACS 5H is necessary in order for the M109A7 SPH to achieve ranges beyond 17 kilometers. Long ranges are needed because most threat countries have artillery ranges longer than 17 kilometers, and the extended range is required by the Army to avoid enemy counterfire. While some MACS 5H firing occurred in developmental testing, the frequency and volume in the IOT&E was much greater. The IOT&E planned rate of MACS 5H firings was based upon the Army's estimate of

the ranges required to support an ABCT in a major combat operation. The frequent breech-related failures contributed to the test unit's failure to achieve the required volume of fire. The Army has an ongoing breech reliability improvement program, but does not anticipate any material change to the breech until 2019. A parallel science and technology program known as the Extended Range Cannon Artillery (ERCA) includes a new breech and cannon, but that program is not expected to produce a material solution until 2024. The breech component failures seen during the IOT&E will continue in both M109A7 SPH-equipped units and legacy M109A6 SPH-equipped units when MACS 5H is fired at the rate experienced in the IOT&E. This is not an acceptable solution. The same breech components and cannon are on the M777 howitzer, a towed 155mm artillery piece in both the U.S. Army and U.S. Marine Corps.

Table 3-1 shows the reliability results with point estimates and the corresponding 80 percent confidence intervals for both the M109A7 SPH and CAT. The table shows the reliability for the M109A7 SPH with and without breech-related failures. The breech failures were the major source of system aborts for the M109A7 SPH in the IOT&E.

The Army intends for M109A7 SPH-equipped units to provide available cannon fires during an 18-hour per day mission. The M109A7 SPH 62-hour MTBSA requirement equates to a 75 percent probability that M109A7 SPH will complete an 18-hour combat mission without a system abort. The IOT&E results demonstrated a 67 percent probability of completing an 18-hour combat mission without a system abort, with an 80 percent confidence interval ranging from 57 to 76 percent. The results from the suspended IOT&E indicate that M109A7 SPH-equipped units failed their reliability requirement.

In the IOT&E, the test unit generated very high demands for repair parts associated with the breech in order to correct the frequent failures. The demand for breech parts during the IOT&E exceeded the supply inventory available at the test unit level and its associated Brigade, Division, Installation, and Army level. In order to satisfy the demand for parts generated by the frequent failures, the product manager had to draw spare parts from planned fielding stocks. The failure frequency and protracted time to receive repair parts impacted the M109A7 SPH operational availability (Ao) and Mean Time To Repair (MTTR). Table 3-2 shows the availability and maintainability results from the IOT&E.



**Table 3-1. PIM Reliability in IOT&E**

Measure/System	MTBSA Requirement	Demonstrated MTBSA (80% Confidence)	Mission Reliability Requirement	Demonstrated Mission Reliability (80% Confidence)
SPH	62	45.4 (32.3 – 65.2)	0.75	0.67 (0.57 – 0.76)
CAT	103	248 (112 - 676)	0.84	0.93 (0.85 – 0.97)
<b>Reliability Results Without Legacy Breach Failures for the M109A7 SPH</b>				
SPH	62	145.2 (78.3 – 298.5)	0.75	0.88 (0.79 – 0.94)

**Table 3-2. PIM Operational Availability (Ao) and Maintainability**

Availability			
System	Ao Requirement	Demonstrated Ao	80% Confidence Interval
SPH	78%	75.3%	64.4 – 86.4%
CAT	85%	90.5%	79.5 – 100%
Maintainability			
System	MTTR Requirement (hours)	Demonstrated MTTR (hours)	80% Confidence (hours)
SPH	2	5.1	3.5 – 6.7
CAT	1.7	7.3	1.4 – 13.2

**Comparison with M109A6 SPH Reliability**

The M109A6 SPH was very close to meeting its 62-hour MTBSA requirement during the 1992 FOT&E, where it demonstrated an MTBSA point estimate of 87 hours with an 80 percent lower confidence bound value of 61 hours.<sup>9</sup> The M109A7 SPH point estimate, as tested in the IOT&E, was 45.4 hours with an 80 percent lower confidence bound of 35.7 hours. In the M109A6 SPH FOT&E, the breach was newer and the MACS 5H propellant system did not exist, so the higher MACS 5H charge was not fired during the FOT&E.

<sup>9</sup> The primary reliability measure used in the M109A6 SPH FOT&E report was Mean Time Between Operational Mission Failure (MTBOMF), while the PIM uses MTBSA. The reliability threshold requirement is the same for both measures, and both measures were calculated in the same manner. *Test and Evaluation Report for the M109A6 Paladin Follow-on Operational Test and Evaluation (FOTE)*, 17 March 1993.

## **CAT Resupply Vehicle Reliability**

During the suspended IOT&E, the CAT had three system aborts and demonstrated an MTBSA point estimate of 248 hours with an 80 percent confidence interval of 112 to 676 hours. The CAT met its 103-hour requirement with statistical confidence (see Table 3-1).

## **M109A7 SPH and CAT Ao and Maintainability**

During the suspended IOT&E, the M109A7 SPH failed to meet its Ao, but not with statistical confidence, and failed to meet its MTTR with confidence. These results are a function of the frequent breech failures. The CAT met both its Ao and MTTR requirements, but not with statistical confidence. Table 3-2 shows the Ao and maintainability results from the portion of the IOT&E that was executed.

## **Impact of Additional Armor**

To protect against the enemy Improvised Explosive Devices (IEDs) and other ballistic weapons in combat, the M109A7 SPH and CAT have T2 add-on armor (an up-armoring kit that includes production line items for under-body armor plating and additional items that are part of theater-provided equipment). The kit adds 4,000 pounds to the weight of each of the PIM vehicles, increasing wear that might lead to more reliability issues. Increased weight may pose special challenges for suspension design and maneuverability that will require continued attention during future testing. During the IOT&E, all M109A7 SPH and CAT were equipped with the T2 add-on armor kit, and one M109A7 SPH and one CAT had an underbelly armor kits in addition to the T2 kit.

Based upon the limited data from the suspended IOT&E, there is no evidence that vehicles with the underbelly armor kits were inhibited in their movement, nor that they experienced any greater consumption of suspension components (road wheels and track pads) than the T2-weighted vehicles. The objective-weight M109A7 SPH consumed three road wheels during the IOT&E one record vignette, compared to a range of three to eight for the other howitzers during the same period. These data are limited to what was observed during the one record vignette for the M109A7 SPH with both kits, since it did not participate in the pilot test because of a hydraulic system failure not attributable to the extra weight. Additional assessment of the objective-weight vehicles will occur as part of the second IOT&E.

## **Logistics**

In the IOT&E, the CAT supported test unit operations. Ammunition resupply operations did not conform to the OMS/MP because of the suspended IOT&E timeline. The CAT operated from supply points in support of tactical operations, provided resupply operations in howitzer firing position areas, and conducted upload tasks at ammunition transfer points. Further logistical analysis will occur as part of a second IOT&E. Resupply operations for repair parts and petroleum products reflected a higher-than-anticipated use of hydraulic fluid that was traced to the hydraulic leaks from failed quick disconnects—a known developmental test failure mode

going into the IOT&E. The second IOT&E will include a full assessment of logistics and sustainability based upon unit operating procedures and Army doctrine.

During pre-IOT&E training and developmental testing, the combat developer discovered that when projectiles were fired using the MACS 5H propellant, the M82 primer expanded within the primer port and, in some cases, mushroomed in a fashion that prevented extraction of the spent primer after the round was fired.<sup>10</sup> There is also a condition known as stuck primer in which the primer expands without rupture, but does not eject after firing. These issues are not particular to the M109A7 SPH. The Program Executive Officer, Ground Combat Systems and Program Executive Officer, Ammunition established a special research team to identify a solution that included options involving modification or redesign of the primer and/or redesign of the breech and firing mechanisms.<sup>11</sup> For the IOT&E, the Program Office implemented a redesigned primer. The breech and firing mechanism redesign initiatives were not mature enough and so were not used in the IOT&E. The M109A7 SPH sections received two new tools to address primer extraction during the IOT&E. During the IOT&E, the howitzer sections experienced two or three mushroomed primer events consisting of a high frequency (often every round of an 8-round fire mission) of stuck primers when firing the MACS 5H charge. The stuck primer events coupled with breech component failures, contributed to the decrease in timeliness for multi-round missions.

### **Soldier Observations**

M109A7 SPH crew members complained that the M109A7 SPH has less room inside the turret than the M109A6 SPH because of the new electric rammer and wiring conduit for the 600-volt system. Soldiers found it difficult to operate the M109A7 SPH wearing the combat vehicle crewman helmet with their communication cables connected to the intercom system. The cables became intertwined and limited individual freedom of movement. Soldiers recommended that the Program Office examine the integration of a wireless capability. That proposed solution may have cybersecurity implications. Soldiers suggested reducing the size of the rammer to create more space inside the M109A7 SPH. Soldiers commented that the maneuverability and pivot capability of the new M109A7 SPH is a marked improvement over the M109A6 SPH. Soldiers commented that M109A7 SPH wheel and track pad wear was higher than on the lighter M109A6 SPH. Soldiers believe that the M109A7 SPH requires a more in-depth recurring preventive maintenance regimen when firing the OMS/MP volume of MACS 5H. This will have operational implications if more than 6 hours per day are necessary for crew rest and preventive maintenance.

### **Safety**

Contradictory statements in the technical manuals confused the M109A7 SPH crews and left them unsure how to operate and maintain it. During the effort to determine the root cause of the toxic fumes we observed that developmental test crews from Yuma Proving Ground used

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<sup>10</sup> If the system performs as designed, the primer ejects from the primer port during recoil.

<sup>11</sup> This particular discrepancy is prevalent with other artillery systems and is believed to be a function of the internal combustion pressures of the propellant and the inability of the primer to withstand the high pressures.

different maintenance procedures and different crew drill compared to that taught in unit during pre-IOT&E training. The product manager plans to conduct additional testing to ensure that the technical manual procedures describe crew actions during firings, and to identify additional measures for mitigating toxic fume exposure in cases where equipment malfunctions occur that require hatches to be opened. The Army will clarify conflicting language in the technical manuals and adjust programs of instruction for both the Field Maintenance New Equipment Training (FMNET) and Operator New Equipment Training (OPNET) to clarify safety procedures and preventive maintenance actions.

## **Section Four Survivability**

The M109A7 Self-Propelled Howitzer (SPH) and Carrier, Ammunition, Tracked (CAT) are survivable against ballistic threats as evaluated through Live Fire Test and Evaluation (LFT&E). The M109A7 SPH has cybersecurity vulnerabilities that can be exploited to degrade system capability and prevent the M109A7 SPH-equipped unit from completing its mission. The Paladin Integrated Management (PIM) Initial Operational Test and Evaluation (IOT&E) addressed non-ballistic survivability measures related to avoiding enemy counterfire and Improvised Explosive Devices (IEDs). Because of the suspension of the IOT&E, there is not sufficient data to conclude whether the M109A7 SPH can execute adequate survivability movement to avoid counterfire. The survivability movement frequency in the IOT&E was a function of adherence to the unit operating procedures and/or prescribed doctrine, not a function of the ability of the M109A7 SPH to displace in a rapid manner. Because of the suspended IOT&E, the firing battery encountered one of six planned simulated IED events. The firing battery was successful in avoiding IED effects by using the onboard Counter-Remote Electronic Warfare system. Additional assessment of both counterfire and IED survivability will occur during the second IOT&E.

### **Cyber Warfare**

The Army Test and Evaluation Command (ATEC) conducted a Cooperative Vulnerability and Penetration Assessment of the M109A7 SPH and CAT, then an Adversarial Assessment during emulated fire missions. These tests revealed cybersecurity vulnerabilities that can be exploited to degrade system capability and can prevent the M109A7 SPH-equipped unit from completing its mission. The M109A7 SPH and CAT will be reexamined in the second IOT&E. Test conduct and the specific vulnerabilities are discussed in the classified cybersecurity annex.

### **Live Fire Test and Evaluation (LFT&E)**

The M109A7 SPH and CAT are survivable against ballistic threats. Increased crew protection and vehicle survivability are primary requirements for the program. These critical capabilities were assessed by ballistic testing of armor resistance to penetration, testing of the vulnerability of mission-critical components, and system-level testing against required and expected direct fire, indirect fire, underbody blast, and IED threats. The vehicles were tested in both the T1 (without add-on armor) and T2 (with add-on armor, but no under-belly kit) armor configurations. ATEC conducted two objective underbody blast tests with an underbelly kit installed. The Army will deploy the systems in the T2 configuration.

The vehicles protect against most required threats but fail against common (but not required) overmatching shaped charge jet and explosive formed penetrator threats. Several armor features did not stop required bullet and fragment threats. System-level testing demonstrated that the vehicles protect their crews and retain mobility when attacked by small

arms, fragmented IEDs, blast mines, and indirect fires. The M109A7 SPH and CAT are more survivable than the fielded M109A6 SPH.

LFT&E uncovered several areas the Army should address to improve survivability. These include: enabling reset of the high voltage (HV) system without engine shutdown to permit rapid rebooting of the HV system and restoration of power to the gun drives and rammer; fielding of the underbody protection kit as part of the T2 configuration to provide underbody blast protection against realistic threats; redesigning the automatic fire extinguisher system to provide coverage of the M109A7 SPH crew compartment and better fire sensing in the engine compartment of both vehicles; redesigning the ammunition storage racks to allow venting of burning propellant; redesigning retention systems to prevent floor mats and ammunition from becoming secondary projectiles that could injure crew members during underbody blast events; and improving the protection of the armor features that failed armor testing.

The results of the LFT&E will be available in a separate classified report to support the full-rate production decision following completion of the second IOT&E.

## **Section Five Recommendations**

The Army should consider the following recommendations as the M109A7 Paladin Integrated Management (PIM) Family of Vehicles (FoV) program proceeds toward its second Initial Operational Test and Evaluation (IOT&E) and full-rate production.

- Conduct a second IOT&E.
- Address the breech failures that affect the ability of a unit to fire cannon artillery munitions specifically M232A1 Modular Artillery Charge System (MACS 5H) charge increment.
- Assess feasibility of implementing an interim breech fix prior to a second IOT&E, and weigh it against delaying the second IOT&E until Extended Range Cannon Artillery (ERCA) is available with a new breech. Conducting a second IOT&E with the same breech could result in the same reliability as the first IOT&E.
- Assess the cause for toxic fumes in the vehicle and identify mitigation actions to ensure crew safety.
- Complete validation and update of technical manuals to address toxic fumes safety issues and clarify crew drills and maintenance requirements for the breech based upon lessons learned from the first IOT&E.
- Ensure the M109A7 SPH fire mission crew drill procedures and maintenance of the breech and cannon tube conducted during developmental testing is the same as outlined in technical manuals and approved field artillery crew drill procedures outlined by TCM-Fires, in the second IOT&E.
- Ensure the test unit during the second IOT&E has adequate time for collective training and is given adequate feedback in order to ensure it can execute the users requirement identified in the operational mode summary/mission profile (OMS/MP).
- Reassess the Field Maintenance New Equipment Training (FMNET) and Operator New Equipment Training (OPNET) points of interest to ensure a trained and ready test unit capable of performing fire support tasks according to the OMS/MP.
- Consider replacing the M1068/A3 Fire Direction Center tracked vehicle with an alternative vehicle until Armored Multi-Purpose Protection Vehicle is fielded.
- Examine suspension component wear associated with road wheels and track pads, and determine whether there is an inconsistency with the Bradley in comparable weight configuration.
- Determine a plan for installing T2 add-on armor kits and provide it to DOT&E.
- Address the ballistic survivability issues uncovered in Live Fire testing. These include: enabling reset of the high voltage (HV) system without engine shutdown to permit rapid rebooting of the HV system and restoration of power to the gun drives

- and rammer; fielding the underbody protection kit as part of the T2 configuration to provide underbody blast protection against realistic threats; redesigning the automatic fire extinguisher system to provide coverage of the M109A7 SPH crew compartment and better fire sensing in the engine compartment of both vehicles; redesigning the ammunition storage racks to allow venting of burning propellant; redesigning retention systems to prevent floor mats and ammunition from becoming secondary projectiles that could injure crew members during underbody blast events; and improving the protection of the armor features that failed armor testing.
- Resolve the identified cybersecurity vulnerabilities; refine tactics, techniques, and procedures relating to the identification of cybersecurity threat activity and responses; then conduct a comprehensive Cooperative Vulnerability and Penetration Assessment and Adversarial Assessment to demonstrate the fixes and mitigations, as well as the mission impact of any remaining vulnerabilities.