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Cost and Performance Report

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Metastable Intermolecular Composites (MIC) Primers for Small Caliber Cartridges and Cartridge Actuated Devices

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TABLE OF CONTENTS

		Page
1.0	EXECUTIVE SUMMARY	1
2.0	TECHNOLOGY DESCRIPTION	3
2.1	TECHNOLOGY DEVELOPMENT AND APPLICATION	3
2.2	PROCESS DESCRIPTION	4
2.3	PREVIOUS TESTING OF THE TECHNOLOGY	6
2.4	ADVANTAGES AND LIMITATION OF THE TECHNOLOGY	6
3.0	DEMONSTRATION DESIGN	9
3.1	PERFORMANCE OBJECTIVES	9
3.2	SELECTION OF TEST PLATFORMS/FACILITIES	10
3.3	TEST FACILITY HISTORY/CHARACTERISTICS	11
3.4	PHYSICAL SET-UP AND OPERATION	12
3.5	MONITORING PROCEDURES	13
3.6	ANALYTICAL PROCEDURES	14
4.0	PERFORMANCE ASSESSMENT	15
4.1	PERFORMANCE DATA	15
4.2	PERFORMANCE CRITERIA	20
4.3	DATA EVALUATION	20
4.4	TECHNOLOGY COMPARISON	21
5.0	COST ASSESSMENT	23
5.1	COST REPORTING	23
5.2	COST ANALYSIS	23
5.3	COST COMPARISON	24
6.0	IMPLEMENTATION ISSUES	25
6.1	COST OBSERVATIONS	25
6.2	PERFORMANCE OBSERVATIONS	25
6.3	SCALE-UP	26
6.4	OTHER SIGNIFICANT OBSERVATIONS	26
6.5	LESSONS LEARNED	26
6.6	END-USER/ORIGINAL EQUIPMENT MANUFACTURER ISSUES	27
6.7	APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE	27
7.0	REFERENCES	29
APPENDIX A	POINTS OF CONTACT	A-1

LIST OF FIGURES

Page

Figure 1. MIC primer manufacturing process. 4
Figure 2. M855 cartridge. 11

LIST OF TABLES

Page

Table 1. 5.56 mm MIC percussion primer performance objectives. 9
Table 2. PVU-1/A MIC percussion primer performance objectives. 10
Table 3. CAD/PAD test platforms. 11
Table 4. 5.56 mm M855 cartridge performance and testing requirements. 15
Table 5. Expected and actual performance for Navy MIC primers. 16
Table 6. Expected and actual performance for CCU-51/A impulse cartridges. 16
Table 7. Expected and actual performance for CCU-61/A impulse cartridges. 17
Table 8. Expected and actual performance for M90 delay cartridges. 17
Table 9. Expected and actual performance for M93 delay cartridges. 17
Table 10. Expected and actual performance for the JAU8/A25 initiator. 18
Table 11. Primary and secondary performance criteria. 20
Table 12. Comparison of MIC and #41 primer performance in M855 cartridges. 21
Table 13. Actual and projected costs to produce a single batch of 500 MIC primers. 23
Table 14. Direct process annual cost for lead styphnate. 24

ACRONYMS AND ABBREVIATIONS

ATF	Armaments Technology Facility
ATK	Alliant Techsystems, Inc.
ARDEC	Armament Research, Development & Engineering Center
BHA	Black Hills Ammunition, Inc.
Bi_2O_3	bismuth trioxide
CAD	cartridge actuated device
DoD	Department of Defense
EPA	Environmental Protection Agency
ESD	electrostatic discharge
FA	Frankford Arsenal
FLIR	forward-looking infrared
IMP	Innovative Materials and Processes, LLC
in-oz	inch-ounces
JPO	Joint Program Office
LANL	Los Alamos National Laboratory
LAT	Lot Acceptance Test
LCAAP	Lake City Army Ammunition Plant
MIC	metastable intermolecular composites
MoO_3	molybdenum trioxide
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NEPA	National Environmental Policy Act
NSWC/IHDIV	Naval Surface Warfare Center/Indian Head Division
OSHA	Occupational Safety and Health Administration
PAD	propellant actuated device
PETN	pentaerythritol tetranitrate
PM-MAS	Program Manager for Maneuver Armament Systems
SD	standard deviation
SERDP	Strategic Environmental Research and Development Program
SOP	standard operating procedure

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ACKNOWLEDGEMENTS

This program was a joint U.S. Army and U.S. Navy effort to eliminate lead-based primer compositions from small arms and CAD/PAD percussion primers. Funding for this effort was shared by ESTCP and the U.S. Navy CAD/PAD Joint Program Office. A number of people at Armament Research, Development & Engineering Center (ARDEC) and Naval Surface Warfare Center/Indian Head Division (NSWC/IHDIV), including both on-site and off-site contractors, were directly responsible for successful completion of this program. At ARDEC, Tom Doris and Chris Csernica provided valuable skill and expertise in developing and testing MIC primer formulations, and generously allowed Navy researchers access to their facilities when needed. Additionally, Dr. Rao Yalamanchilli of ARDEC coordinated the Armaments Technology Facility (ATF) firings there, and was instrumental in producing the primers and loading the cartridges needed for the supplemental testing at Black Hills Ammunition, Inc. (BHA).

At NSWC/IHDIV Todd Allen was responsible for the formidable tasks of assembling all primer and cartridge hardware needed for CAD testing, coordinating NSWC and Innovative Materials and Processes, LLC (IMP) loading operations, and arranging for the tests at NSWC/IHDIV. Dr. Peter Ostrowski of Energetic Materials Technology archived and analyzed the data obtained in those tests.

Finally, Dr. Jan Puszynski and Dr. Jacek Swiatkiewicz of IMP are recognized for their efforts in developing the basic Al/Bi_2O_3 MIC formulation used in this test program and the water-based mixing and loading technique eventually adopted at both ARDEC and NSWC. They also conducted sensitivity tests of finished MIC primers, loaded the primers into all cartridges tested at NSWC/IHDIV, and directed the ballistic tests at BHA.

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1.0 EXECUTIVE SUMMARY

Current percussion primers in small caliber ammunition (i.e., 5.56 mm, 7.62 mm cal .50 and 20 mm) use a lead styphnate-based primer formulation that poses a long-term hazard to the environment and the operator of the weapon since airborne vaporized lead results from each successfully fired cartridge. Lead styphnate-based primer compositions are currently specified in all of the U.S. Army's combat small caliber ammunition and in many cartridge actuated devices (CAD) and propellant actuated devices (PAD) used in U.S. Navy aircraft ejection systems, countermeasure applications, and stores release systems. The CAD/PAD devices are used by all Department of Defense (DoD) components and foreign militaries that utilize U.S. manufactured aircraft. Lead is a known toxic material, which pollutes test ranges and exposes the manufacturers and users of these devices to serious health hazard liabilities. Lead is regulated by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA). Current EPA and OSHA regulations are directly impacting range and testing operations. Stricter regulations in the future will seriously impact or force closing of production, testing, and range operations. With the current production rate for all small caliber ammunition (less than 20 mm), the quantity of lead to be consumed for percussion primer production alone is well over 23,686 pounds or nearly 12 tons annually.

The purpose of this demonstration was to evaluate the performance of metastable intermolecular composite (MIC) primers with compositions formulated from commercially available lead-free nanoscale powders. For these tests, the MIC composition was substituted for the lead styphnate-based primer composition currently used in conventional small caliber percussion primers. Small caliber percussion primers are used by the Army in small caliber ammunition and by the Navy in several CAD/PAD applications. The major objective of the program was to demonstrate that the performance of the MIC primers was equivalent to that of the lead styphnate primers in several Army and Navy applications. These performance objectives were met in that all MIC primers tested were found to meet all applicable military specifications. For Army small arms applications, the MIC primer was slightly slower than its lead styphnate counterpart but still within specifications.

The following regulations and directives are applicable to this program:

- Executive Order 12856, Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements 1994
- NEPA – National Environmental Policy Act, 1969
- OPNAVINST 4110.2, Hazardous Material Control and Management
- Army 3.3b Reduce Hazardous Components in Ordnance and Alternative Treatment for Hazardous Waste from Ordnance Processing
- Navy 3.1.6.C, Energetic Production Pollution Prevention
- Air Force 974, Reduction of Lead Exposure at Firing Ranges.

The demonstration tests conclusively showed that both small arms ammunition and several CAD/PAD devices employing a lead-free MIC primer composition met all performance specifications. Thus, use of the MIC composition will allow both the Army and Navy to eliminate a major source of lead contamination in manufacturing, logistical, and training operations with these devices.

The MIC primers utilized in these tests were produced in small batches (500 or fewer) at both Innovative Materials and Processes LLC (IMP) and Armament Research, Development & Engineering Center (ARDEC). Actual costs to produce these primers over several days at IMP were $6.13 per primer, not including about $10,000 in capital equipment. This unit cost is somewhat lower than that for producing PVU-1/A primers at Naval Surface Warfare Center/Indian Head Division (NSWC/IHDIV) ($7.14 in 2005) in batches of 10,000. The estimated cost to produce a batch of 500 MIC primers at NSWC/IHDIV would be $5.54 per primer. This cost would be considerably lower if a continuous operation is used. Since the same process was used, ARDEC costs for small batches are similar to those at IMP. Current Army primer production is done in a semi-automated high volume process that produces millions of primers per day. Thus, the primer production costs incurred during the demonstration program have no relevance to the costs of the large-scale production that would be eventually used by the Army. The magnitude of the costs to implement MIC primer production of this magnitude will therefore have to be determined as an issue outside the demonstration program.

The successful demonstration of the Army MIC primer can now be used by the Program Manager for Maneuver Armament Systems (PM-MAS) to proceed with the authorization for an ammunition-based qualification test program that will lead to an engineering change proposal for qualifying the MIC primers. Once approval has been granted, a Mantech program sponsored by the PM-MAS would be required to proceed with the equipment prototyping and process alteration required to adopt the new MIC primer at Lake City Army Ammunition Plant (LCAAP).

Qualification of airborne CAD/PAD devices used by the Army, Navy, and Air Force is the responsibility of Naval Air Systems Command (NAVAIR) Program Office PMA 201 (Patuxent River Naval Air Station [NAS]) and the CAD/PAD Joint Program Office (JPO) (POC: Mr. David Williams, NSWC/IHDIV). For the CAD/PAD applications, the JPO is the authority for accepting the results of the demonstration plan for the Army and Air Force CADs and PADS deployed on board U.S. Army and U.S. Air Force aircraft. NAVAIR PMA201 is the authority for accepting the new primers into the Navy inventory and for foreign military sales.

In adopting the MIC primer technology for service use, a number of factors need to be addressed by the above Army and Navy qualification organizations. These are:

- Performance
- Toxicity
- Cost and availability of raw material
- Safety during manufacturing and loading processes, handling, and storage
- Interface with existing and future loading processes.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

MIC material has the potential to replace the current conventional energetic composition in the initiation subcomponents of ammunition and CADs known as the percussion primer. The novel properties associated with nanostructure materials have resulted in the development of thermite-like formulations of energetic materials by Los Alamos National Laboratory (LANL). These materials being of nano-sized particles offer the possibility of tunable energy release and high temperatures without appreciable gas generation and attendant high pressures. There are various examples of MIC applications that attracted a great deal of interest recently for weapon enhancement. One unique feature of MIC materials is their ability to produce particles hot enough to ignite a bed of propellant. Additionally, the MIC materials are impact sensitive, which makes them a good percussion primer mix candidate. MIC can be utilized as an initiation composition for replacing the existing Frankford Arsenal (FA)-956 and 5086 primer formulations, which contain lead styphnate, barium nitrate, and antimony sulfide. The MIC mixture is an environmentally friendly, lead-free composition, so that replacement of the FA-956 and 5086 primer compositions with MIC compositions will result in elimination of lead and other heavy metals from Army and Navy manufacturing, testing, storage, and training facilities for devices currently using #41 (FA-956) and PVU-1/A (5086) percussion primers.

In general terms, the MIC material is an engineered energetic composition consisting of a metal fuel (most often nanoscale aluminum) and metallic oxidizer that are exothermically reactive with each other. By utilizing nano-sized particles, the near atomic scale proximity of the reactants minimizes distances over which the fuel and oxidizer molecules must diffuse in order to reach each other, resulting in a dramatically increased reaction rate relative to that of conventionally sized pyrotechnic mixtures. Two of the most commonly used MIC compositions utilize molybdenum trioxide (MoO_3) or bismuth trioxide (Bi_2O_3) oxidizers, and have the following chemical reactions:

$$2Al + MoO_3 \rightarrow Mo + Al_2O_3$$
$$2Al + Bi_2O_3 \rightarrow 2Bi + Al_2O_3$$

For Army small caliber ammunition applications, the MIC primer must meet #41 primer all-fire and no-fire energy requirements and also ignite the propelling charge rapidly enough to meet the action time requirement for each individual cartridge application. The specific requirements are presented in more detail in Section 3.1.

For CAD/PAD applications, the MIC primer must meet the PVU-1/A primer all-fire and no-fire energy specifications and also must function such that the performance requirements for each individual application are met. Because the applications chosen for the demonstration represent a cross-section of the CAD/PAD spectrum, the performance requirements vary considerably from one application to another. The specific requirements for each of the CAD/PAD demonstration applications are also presented in Section 3.1.

2.2 PROCESS DESCRIPTION

Replacement of the FA-956 and 8056 primer compositions with MIC compositions will be largely transparent to the users of #41 and PVU-1/A primers, as the MIC primers will be designed to be drop-in replacements providing the same form, fit, and function of the lead-containing originals. The only difference will be in the manufacture of the MIC mixture and loading of the primers. The Al/Bi_2O_3 MIC mixture was selected for the demonstration because a wet mixing and loading process has been developed for it at IMP. This process is a significant improvement to the dry process used at NSWC/IHDIV for mixing and loading the 5086 composition into PVU-1/A primers. While a wet mixing and loading process is currently employed in the manufacture of #41 primers, the MIC process is considerably simpler and just as safe. This process was developed for batch sizes of 500 primers but is expected to be able to be scaled up for larger batches. A schematic diagram of the process is presented in Figure 1.

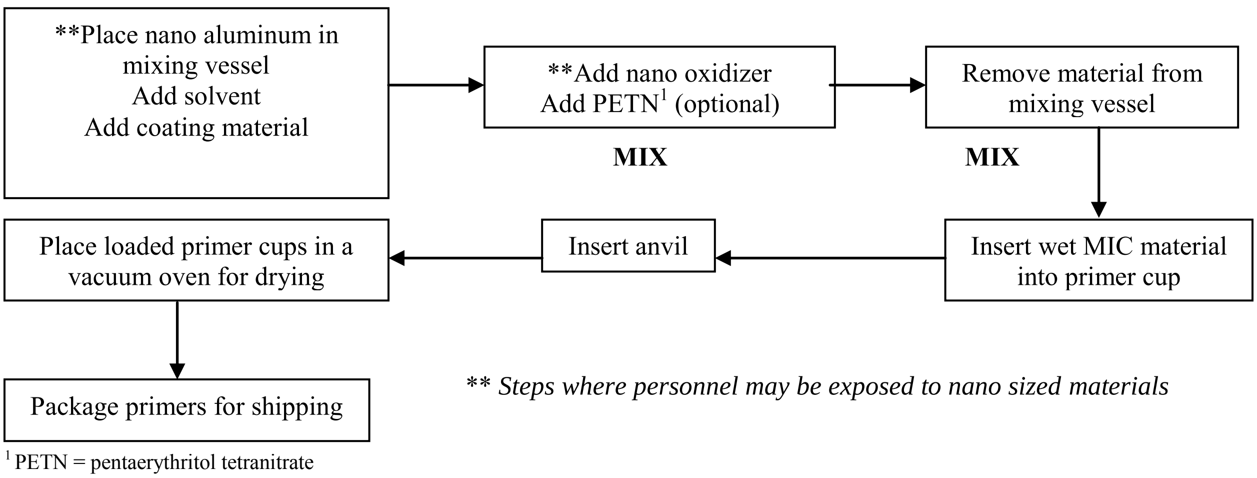

Figure 1. MIC primer manufacturing process.

Mobilization, installation and operational requirements for starting up the wet mixing and loading process at IMP included purchasing capital equipment (analytical balance, mixers, pipettor for loading primer cups, presses for mix consolidation and inserting anvils, and a low temperature drying system). Additional effort was expended for familiarizing manufacturing personnel with proper procedures for operating this equipment and ensuring that the primers are loaded and dried within 4 to 6 hours. In transferring these operations to ARDEC, some of the equipment was already in place and operational, therefore requiring minimal start-up operations. The same will be true when MIC manufacturing technology is eventually implemented at NSWC/IHDIV.

The MIC wet mixing and loading process employs basic procedures that are familiar to primer manufacturing personnel at both ARDEC and NSWC/IHDIV and does not require extensive re-training of these personnel. Grounding of equipment and operators is essential avoiding electrostatic discharge (ESD) incidents, procedures that are commonplace at both organizations. The use of masks and filters is required to avoid inhaling the nano-sized materials during mixing operations, and the usual precautions must be taken to avoid human contact with the solvent used and the coating material for the nano-aluminum. Similar procedures are already in place in laboratories and manufacturing facilities at ARDEC and NSWC/IHDIV and will require minimal adaptation for the specific materials involved in the MIC mixing and loading process.

There are a number of factors that influence MIC primer performance. These factors include the following:

- *Particle size of aluminum and oxidizer*. The particle size of the aluminum fuel can have a large impact on primer performance. Because the MIC composition must have intimate contact between fuel and oxidizer and a large surface area is also desired, sub-micron particle-sized fuel and oxidizer are required. Through testing, a size range of about 80 nanometers has been found to be optimum for this application.
- *Particle size distribution*. The sensitivity and burning rate of MIC compositions is strongly dependent on the particle size distributions of both fuel and oxidizer. Maintaining a uniform particle size distribution is essential to consistent primer performance.
- *Mixing process*. As with all chemical compounds, ensuring a uniform mixing of the ingredients is critical to achieving consistent, reliable performance. Proper weighing, solvating and ensuring the mixing/agitation cycles sufficient to create a homogeneous product are essential.
- *Protecting the aluminum from oxidation*. The extreme reactivity of nano-aluminum powder is one of the most significant properties of the MIC material. To maintain this reactivity, the aluminum powder must be passivated to protect it from oxidizing in the presence of air or water in the surrounding environment. This is an especially difficult problem in naval operations. An additional layer of an organic acid has been found to significantly increase the resistance to oxidation of the powder, even when in direct contact with water. Protecting the aluminum from oxidation for an extended period of time to prevent the MIC compound from losing sensitivity and thermal output will maintain performance and achieve the required shelf life for the end items.
- *Solvent removal*. As with all primers, removal of the desensitizing compound (solvent) is required to restore sensitivity and output performance. Any remaining solvent could cause a misfire or worse, a hangfire where the round ignition is delayed until the cartridge is outside the weapon system or the CAD/PAD device doesn't fire in sufficient time to activate the end system device.

To ensure that all MIC mixtures manufactured with the wet mixing process are well mixed and properly dried, a number of primers are selected at random from the batch and subjected to ball drop sensitivity testing. For #41 primer hardware, the ball drop apparatus at ARDEC includes a closed bomb containing a small charge of double base ball powder that must be ignited by the primer. Thus, the apparatus is used to ensure that the primers meet the minimum initiation energy and action time requirements specified in MIL-C-63989C. For MIC primers produced at IMP in PVU-1/A hardware, ball drop sensitivity must meet the requirements of MIL-P-46610E. There are no action time requirements for PVU-1/A primers. Primer batches that successfully pass the ball drop testing are then cleared for loading into the cartridges selected for the demonstration tests.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Nano powder-based thermite mixtures have been routinely investigated in the various laboratories at both government and commercial facilities. Under the Joint Munitions Technology Development Program at LANL, the use of nano aluminum powders was shown to be feasible. In the Toxic Elimination from Small Caliber Ammunition Program funded by Strategic Environmental Research and Development Program (SERDP), a solution for eliminating toxic components in the primer composition by using the nano powdered aluminum was developed. A final report, SERDP Project Number PP-1057, ―Elimination of Toxic Material from Small Caliber Ammunition," has been issued by ARDEC. This report can be accessed via the SERDP website at http://www.serdp.org/content/search?cqp=Standard&SearchText=PP-1057&x=32&y=9.

Development efforts at NSWC/IHDIV concentrated on the use of commercially available aluminum, CAD/PAD applications, mixing and loading technology, and evaluation of various oxidizers. A list of reports, technical papers, and presentations generated in these endeavors is listed in Section 7.3 of both the demonstration plan (Reference 1) and the final report (Reference 2).

2.4 ADVANTAGES AND LIMITATION OF THE TECHNOLOGY

The advantage of this technology is that it utilizes common, non-polluting materials processed in unique ways that result in an initiation compound possessing sufficient energy and sensitivity to function in ammunition and CADs. The main components of the material are aluminum, bismuth and oxygen, all materials routinely found in everyday items. The small amount of pentaerythritol tetranitrate (PETN) that makes up the remainder of the ARDEC primer compound is not common commercially but is a material produced in reasonably large quantities for a number of military applications, including the existing primer compound. Additionally, commercial and other government agencies are spending a relatively large amount of resources to start large scale production facilities for nano-particle sized metals.

The limitations of this technology are in the area of the processing of the materials to get to the end product state. Two areas are of particular concern and significant progress has been made in obtaining solutions. First, bare aluminum metal is extremely reactive and will react to oxidize instantly when exposed to oxygen. Early in the development of the nano-aluminum processing procedures, it was realized that a thin passivation layer needed to be added to the nano-particles to prevent this oxidation and maintain the reactivity of the metal. However, this passivation layer will readily break down when the nano-particle is exposed to water, either liquid or vapor, again causing oxidation of the aluminum material, which renders the material inert. Recent work by Dr. Jan Puszynski at the South Dakota School of Mines and Technology has shown that an additional thin layer of an organic acid can block the breakdown of the passivation layer without interfering with the ultimate reactivity of the aluminum. Dr. Puszynski has also shown that protection by the organic acid lasts for several hours—ample time for mixing and primer loading operations. After loading, the primer can be dried and hermetically sealed into any desired cartridge. While the present procedure has been successful with small batches of primers, scale-up to large batches must still be investigated, as well as more firmly establishing the procedures by which the primers can be either stored for future use or immediately installed into cartridge cases.

The second area of concern is that the present state-of-the-art of the water-based mixing and loading process has not addressed scale-up to either large batches or continuous processing. More work in this area will be required to make the MIC material fully compatible with the high volume production equipment presently utilized in ammunition and CAD/PAD device manufacturing, as well as that envisioned for the future.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The demonstration tests consisted of performance testing of MIC primers on the following types of platforms:

- U.S. Army M855 small arms ammunition normally employing a #41 lead-styphnate primer
- Several U.S. Navy CADs normally employing a PVU-1/A lead-styphnate primer.

Tables 1 and 2 summarize the performance objectives for each type of platform. All of these objectives were met in the tests.

Table 1. 5.56 mm MIC percussion primer performance objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	1. Maintain specifications for original M855 ammunition:		Yes
	Action time	All values < 3.0 msec & x bar plus 3 sigma < 3.0 msec	1.346 msec
	Chamber pressure	48,335 – 48,449 psi	48,913 psi
	Port pressure	16,701 – 17,317 psi	17,290 psi
	Velocity	2968 – 2976 ft/sec	2,971 ft/sec
	Function & casualty	No metal parts breakup & no ammunition induced stoppages. Cyclic rate of 800 shots per minute	No breakup or stoppage 762 – 798 rounds/minute
	2. Eliminate hazardous materials from the primer	Zero percent lead, barium and antimony in primer	Yes
Qualitative	1. No degradation in system performance	Same operation and weapon function as with lead core ammunition	Yes

Table 2. PVU-1/A MIC percussion primer performance objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	1. Maintain specifications for original PVU-1/A	Meet individual cartridge LAT performance specifications	Yes
	2. Eliminate lead from the primer	Zero percent lead Material certification from vendors	Yes
Qualitative	1. No degradation in system performance	Same operation and system function as with lead-based primer	Yes

3.2 SELECTION OF TEST PLATFORMS/FACILITIES

Test Facilities: The demonstration tests were conducted at the ARDEC Armament Test Facility for the small caliber ammunition tests and at the CADTEST facility at NSWC/IHDIV for the CAD/PAD applications tests. Both facilities are equipped for and regularly perform similar testing. Testing conforms to standard test procedures as outlined in the SCATP 5.56 ammunition and the Lot Acceptance Test (LAT) procedures found in the weapon specifications for the specific CAD/PAD devices. These are listed in Section 7.2 of the demonstration test plan (Reference 1). Testing at both facilities must also be in accordance with ammunition specifications requirements and operational standard operating procedures (SOPs). The SOPs used in the CADTEST facilities are restricted to use in those facilities only and cannot be copied or otherwise publicly disseminated. Accordingly, they are included here by reference only.

Test Platforms (5.56 mm): All weapon platforms are currently fielded and in extensive use. The selected Army test weapon configuration is the M16A2 rifle. A single shot test barrel was used for collecting individual round performance data and an automatic weapon was used for full rate firing to test the ammunition interfaces with the weapon. The M16A2 weapon is representative of the 5.56 mm family of weapons, which are the M16A2, M249 Squad Automatic Weapon, and M4 carbine for the U.S. military forces. All three weapons are extensively used and represent a significant portion of the Army's small caliber firepower. Figure 2 shows the M855 cartridge, which was used in the demonstration tests. The PM-MAS has cognizance over introduction of the MIC primer into these weapons.

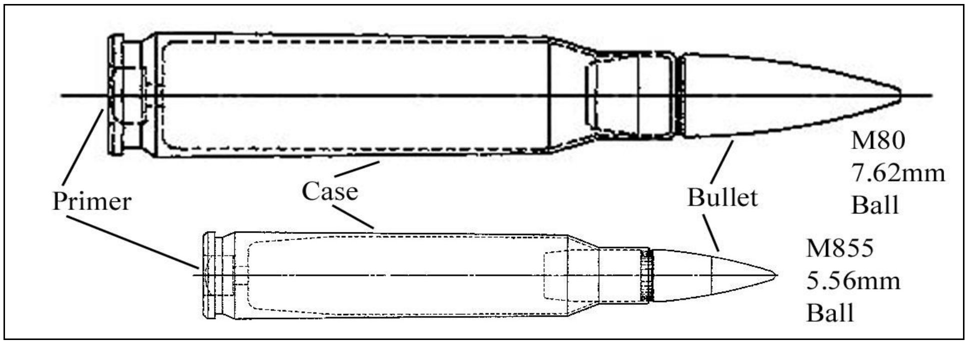

Figure 2. M855 cartridge.

<u>CAD/PAD Test Platforms</u>: The PVU-1A percussion primer is used in the 85 different cartridges. These cartridges are used by the Army, Navy, and Air Force, and all use the Navy PVU-1/A primer to initiate the pyrotechnic train in each. It would be cost prohibitive to demonstrate the PVU-1/A primer performance in all 85 applications. Thus, the cartridges listed in Table 3 were selected as a representative sample of the cartridge group. They also include some worst case conditions regarding ignitability of the main (propellant) charge.

Table 3. CAD/PAD test platforms.

Cartridge	Performance Requirements (SOP)
Mark 4 Mod 2 Delay Cartridge	F84164 CH 2
CCU-51/A Impulse Cartridge	F84214 CH 2
CCU-61/A Impulse Cartridge	F84127
M-90 Delay Cartridge	F84066 CH 2
M-93 Delay Cartridge	F84170 CH 2
JAU-8/A25 Initiator	F84249 CH2

3.3 TEST FACILITY HISTORY/CHARACTERISTICS

The Armament Technology Facility is a full-service armament design and development laboratory for small and cannon caliber (through 40mm) weapon systems. It includes computer modeling and simulation capabilities, engineering workstations tied into rapid three-dimensional plastic prototyping (stereo lithography), electronic ties to robotically driven metal parts fabrication machinery, a model shop, in-house armament designers, plus a weapon assembly and repair facility. It also has four weapon validation bays with an environmental chamber capable of weather conditions between -65°F to +165°F; two indoor ranges—the first 100 m in length and the second 300 m. The latter can accept a Bradley Fighting Vehicle System firing its primary armament, or an Abrams-series tank firing secondary armament. The 300 m range also has a -65°F to +165°F environmental chamber for conditioning weapon systems through 40 mm. Data acquisition and analysis capabilities include high-speed video (up to 150,000 frames per second). Available still photography with a billionth of a second shutter speed and forward-looking infrared (FLIR) systems are examples of the on-hand, state of the art instrumentation.

The NSWC/IHDIV CAD Test facility conducts approximately 90% of the qualification, LAT, and surveillance testing of the Navy's CAD devices, and 5% of the Air Force CAD item testing. This translates into roughly 24,000 individual live ballistic tests per year with Navy and Air Force CAD items. The substantial breadth of the CAD testing performed at NSWC enables quick turnaround of LAT, Quality Evaluations, Engineering Investigations, and special tests required for both stock and issue items, as well as critical failure and crash investigations.

Reduction of lead pollution at the above test facilities will provide a less hazardous operating environment for Army and Navy test personnel. More importantly, however, elimination of lead-based primer compositions from weapons systems employing percussion primers will significantly reduce lead pollution throughout their entire logistic footprint of production, storage and handling, testing, and training operations.

3.4 PHYSICAL SETUP AND OPERATION

The demonstration started with synthesis of the MIC primer compositions for #41 primers at ARDEC and PVU-1/A primers at IMP. Although one of the objectives of the MIC primer development program was to develop a single MIC composition that would meet the required performance for both primers, this objective has not yet been met. Thus, the demonstration tests were conducted with two similar but different MIC compositions, the major difference being the addition of a small percentage of PETN to the composition used in the #41 primer. Because of the sensitive nature of the information, the exact compositions used and some of the details of the mixing and loading operations have been omitted from the final report issued in February 2008 (Reference 2) as well as in this report.

Early development work with MIC primer compositions used a solvent-based mixing process. Later on, a water-based mixing process was developed at IMP for mixing and loading of an Al/Bi_2O_3 composition. Both mixing processes were used for the primers tested at ARDEC, while the water-based process was used exclusively for those tested at NSWC/IHDIV in PVU-1/A hardware. The demonstration began with production of MIC primers at ARDEC in March 2005 and finished when testing was completed at NSWC/IHDIV in November 2007. A detailed timeline is presented in Reference 2.

The mixing and loading operations, subsequent ball drop testing of loaded primers, and installation of the primers into M855 cartridges performed at ARDEC used existing operational equipment and required no mobilization or demobilization. Similar operations conducted at IMP required capital expenditures to obtain and mobilize the necessary equipment (see Section 2.2). An operational ball drop tester previously purchased by IMP for earlier research efforts required no mobilization and remains in service at IMP. Loading tools for installing PVU-1/A (MIC) primers into cartridges were loaned to IMP by NSWC/IHDIV.

All tests utilized MIC formulations that were loaded into either standard #41 or PVU-1/A hardware. The MIC primers were then installed into the appropriate test platform at either ARDEC or IMP, after which they were tested alongside stock cartridges employing the standard #41 or PVU-1/A lead styphnate primer composition. The tests consisted of the standard LAT tests for the particular platform. These are routinely conducted at each organization and require no mobilization of personnel or resources there. Some of the details of the test facilities and equipment used can be found in Section 3.6 of Reference 2.

3.5 MONITORING PROCEDURES

All primer and cartridge testing in the demonstration was performed in accordance with established LAT procedures for each platform. A complete listing of these can be found in Section 7.2 of the demonstration test plan (Reference 1). Two test platforms were used in the ARDEC Armaments Technology Facility (ATF) – a single shot MANN barrel and an M16A2 rifle firing in both single shot and burst mode. The MANN barrel was instrumented to monitor action time, bullet velocity, chamber pressure and port pressure. These performance parameters and the methods used to measure them are explained more fully in Section 3.1 of Reference 1. For the Function & Casualty (M16A2) tests, the rifle was fired through witness panels that would record the impact of debris should in-flight break-up occur with any of the fired projectiles. The original test plan (see Section 3.6.6, Reference 1) called for 140 shots in the ATF using primers from a single lot. A second lot of primers (also 140 shots) was added to the program to allow performance comparison of primers produced with the water-based and solvent-based mixing and loading processes. In addition, supplemental testing was conducted at Black Hills Ammunition, Inc. (BHA) to evaluate some modifications to the MIC composition and the propelling charge, and to fire PVU-1/A hardware in 5.56 mm ammunition. Only bullet velocity and action time were measured in these tests in a test fixture similar to that used in the ARDEC ATF.

MIC primer testing at NSWC/IHDIV consisted of both primer tests and cartridge tests with MIC primers installed. The complete test matrix is given in Table 4, Section 3.6.6, of Reference 1. In all cases, the performance was compared to that with standard lead-styphnate PVU-1/A primers. The primer tests consisted of 13-inch dud tests, ball-drop sensitivity, and sensitivity to off-center hits, all conducted in the CADTEST ball drop sensitivity apparatus. The dud and sensitivity tests were repeated in empty MK4 Mod 2 cartridge cases to evaluate cartridge installation procedures. Flame tests were also conducted by firing primers in empty MK 4 Mod 2 cartridge cases in front of a background grid and monitoring the spatial and temporal extent of the flame with a high-speed framing camera.

The ball-drop sensitivity test apparatus is permanently installed in CAD Test Bay 4 and requires no mobilization. Set-up procedures consist of mounting a sacrificial primer in the device and ensuring that the specified ball hits the firing pin squarely and on center. Ball height measurement is also recalibrated at this time. Prior to the start of testing, the firing pin is inspected for wear and replaced if necessary. All testing is done at room temperature with no temperature conditioning of the primers, which are transported to Bay 4 on the day of testing. Primer dud testing requires all primers in the dud lot to fire when the ball is dropped from the specified height. Sensitivity testing entails finding the 50% all-fire energy and standard deviation (SD) for the lot. The 50% all-fire energy is that at which the primers fire only 50% of the time, and requires testing the primers to failure. The referenced weapons specifications and SOPs call for the Bruceton method to be used to establish energy levels (ball drop heights) for the tests. As is discussed in Section 3.6.6 of Reference 1, a more modern and more efficient technique, the Neyer Sensitivity Test, is currently being used at NSWC/IHDIV in place of the Bruceton, and was therefore also used for all sensitivity testing conducted in the demonstration.

For cartridge testing, the LAT test fixture is retrieved from storage and set up in the selected test bay the day before testing is to begin, while all electronic diagnostic equipment is assembled on the morning of testing. For all cartridge tests except the MK4 Mod2, the test fixture was a closed bomb instrumented with a pressure transducer. The volume of the bomb and specific pressure measurement (time to first indication of pressure, peak pressure, time to peak pressure, etc.) varied according to the individual SOP for each cartridge tested. All equipment was checked for calibration and appropriate serial numbers were recorded as per the SOP, which all operators were required to review prior to the start of testing. Cartridges were temperature-conditioned and readied for test according to each SOP. Initial testing for each cartridge began with the PVU-1/A baseline units to ensure that the cartridge lot met the appropriate Weapon Specification LAT requirements. Baseline testing of the CCU-51/A and CCU-61/A impulse cartridges revealed that peak pressure was out of specification for both PVU-1/A lots—slightly low for the CCU-51/A and slightly high for the CCU-61/A. At the time, a decision was made to continue testing, as it was expected that the MIC lots which had been produced at the same time would also be slightly out of specification, but the performance comparison would be valid. This turned out to be exactly the case (see Tables 6 and 7 in Section 4.1).

3.6 ANALYTICAL PROCEDURES

For the ARDEC ATF tests, mean values and SDs were computed for all data taken at a given test condition. These were then presented in both tabulated and bar chart format in the final report to allow for direct comparison of the performance of the two lots tested (water-based and solvent-based mixing and loading) versus standard #41 primer. No other treatment of the data was performed. For the BHA tests, mean values and SDs were computed for the data collected at each test condition. Due to the relatively small number of shots in these tests, the data was presented in tabular format only, with no further treatment of the data.

The primer sensitivity data obtained at both IMP and NSWC/IHDIV was presented as the usual parameters (50% all-fire drop height, SD, computed all-fire, and no-fire energies) in tabular format for easy comparison. Mean values and SDs of cartridge data were also computed for MIC and standard PVU-1/A lots, but for informational use only. Cartridge LAT performance requirements are based on individual cartridge performance, not the average for the lot. Thus, failure of one cartridge to meet performance is sufficient to reject an entire production lot. For this reason, the test summaries presented individual cartridge data in tabular format as the primary means of assessing cartridge performance. The mean values and SDs were plotted in bar chart format, however, to also provide an additional comparison of the MIC and PVU-1/A lots as a whole, although this information is not required for LAT purposes.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

A complete listing of the primer and cartridge data obtained in the demonstration can be found in Section 4.0 of the final report (Reference 2). This data is briefly summarized and compared to pre-demonstration performance metrics in Tables 4-10, which in some cases are abbreviated versions of those presented in the final report.

Table 4. 5.56 mm M855 cartridge performance and testing requirements.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in SCATP-5.56 and MIL-C-63989, summarized below	Physical test in accordance with SCATP-5.56	
Extreme temperature function	See Section 4.2 of Final Report (Ref 2)	Physical test in accordance with SCATP-5.56 & MIL-C-63989	Performance similar to standard M855 rounds
Action time match	1. Ballistic match with the M855 is to be no more than 3 milliseconds.	EPVAT & MIL-C-63989	1.39 msec solvent 1.22 msec water
System accuracy	1. Both average vertical standard deviation and the average horizontal standard deviation shall be no greater than 6.8 inches at 600 yards, or alternatively, no greater than 1.8 inches at 200 yards.	Physical test in accordance with SCATP-5.56 & MIL-C-63989	Not tested: Hand assembly is not representative of the current high speed assembly process
Barrel erosion	1. The average life of the barrel shall not be less than 10,000 rounds.	Physical test in accordance with SCATP-5.56	To be completed as part of final cartridge qualification testing
Waterproof	1. Each cartridge shall not emit more than one air bubble when subjected to an internal pressure of 7.5 psi for a minimum of 30 seconds.	LCAAP test requirements	Not tested: Assembly was by hand, not automated machine
Hazardous materials	1. No lead in the projectile	Certification of material	All materials were free of lead

Table 5. Expected and actual performance for Navy MIC primers.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in WS21535B and summarized below.	Physical test in accordance with SOP F84164 CH 4	
Primer performance Flash test	1. All-fire energy must be less than or equal to 25.49 inch-ounces (in-oz) 2. No-fire energy must be greater than or equal to 3.84 inch-ounces 3. No misfires in 13-inch dud test 4. All-fire and no-fire energy with off-center hits 5. Measure flash length and time duration	Neyer sensitivity test Neyer sensitivity test 13-inch dud test Neyer sensitivity test High-speed camera	16.47 in-oz 7.24 in-oz No misfires Slightly higher all-fire with MIC at zero to moderate off-sets* Longer, brighter flame with MIC, duration similar to PVU-1/A*
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All primer mixes were lead-free

* - see Final Report, Section 4.3

Table 6. Expected and actual performance for CCU-51/A impulse cartridges.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in WS20502 and summarized below	Physical test in accordance with SOP F84214 CH 2	
	1. Peak pressure must be 950 to 1350 psi 2. Maximum time to peak pressure is 50 msec	Closed bomb	892 – 1088 psi 8.4 – 36.1 msec
Leakage	$<1.0\times10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 7. Expected and actual performance for CCU-61/A impulse cartridges.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in WS20508 and summarized below	Physical test in accordance with SOP F84127	
	1. Peak pressure must be 450 to 950 psi	Closed bomb	816 – 1034 psi
Leakage	$<1.0x10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 8. Expected and actual performance for M90 delay cartridges.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in MIL-C-60553 and summarized below	Physical test in accordance with SOP F84066 CH 2	
	1. Ignition delay must be 0.150 to 0.450 seconds 2. Peak pressure must be 2000 to 2700 psi 3. Maximum time to peak pressure is 12 msec	Closed bomb	0.288 – 0.342 sec 2,415 – 2,565 psi 8.4 – 12.0 msec
Leakage	$<1.0x10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 9. Expected and actual performance for M93 delay cartridges.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in MIL-C-46228 and summarized below	Physical test in accordance with SOP F84170 CH 2	
	1. Ignition delay must be 0.85 to 1.30 seconds 2. Peak pressure must be 2300 to 3400 psi 3. Maximum time to peak pressure is 50 msec	Closed bomb	1.02 – 1.18 sec 2865 – 3105 psi 32.6 – 42.0 msec
Leakage	$<1.0x10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 10. Expected and actual performance for the JAU8/A25 initiator.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product testing	Must pass individual product tests specified in WS18778 and summarized below	Physical test in accordance with SOP F84249 CH 2	
	1. Peak pressure must be greater than 300 psi 2. Maximum time to peak pressure is 40 msec	Closed bomb	414 – 531 psi 15.0 – 32.5 msec
Leakage	<1.0x10^{-5} cc/sec	SOP F84234	All passed
Hazardous materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

The results of the ATF tests showed that the cartridges with MIC primers met all M855 performance requirements, with the water-based mixing and loading lot achieving slightly better performance than the solvent-based lot. With regard to bullet velocity and also case mouth and port pressures, the MIC lots were nearly identical to the reference lot. Both MIC lots exhibited longer action times than the reference lot, however, but still easily met the 3.0 msec requirement. Action time for the water-based lot was 26% longer than the reference lot, while the solvent based lot was about 45% longer. As would be expected, the longer action times resulted in somewhat lower rates of fire with the MIC primers.

The BHA test results indicate that action times can be reduced by doubling the PETN load in the primer mix, but more testing is required to confirm these results. Also, little difference was found between the use of PVU-1/A and #41 hardware.

Two primer no-fire events occurred during the ATF tests—both with the water-based MIC primers. The first occurred during the EPVAP tests at –65°F, while the other occurred during the burst mode M16A2 shots at ambient temperature. No positive identification of the cause for either has been identified, however. Inspection of the firing pin indents in each primer revealed what appeared to be normal indents for each. Hence, either low primer load or handling-induced fracture of the primer charge leading to reduced charge weight are thought to be the most likely causes of the no-fires.

The ball drop sensitivity testing conducted at NSWC/IHDIV showed that the (water-based) MIC primer lot used for cartridge tests had slightly less sensitivity compared to a PVU-1/A reference lot and also exhibited slightly more sensitivity degradation due to moderate off-center hits.

In general, the results of the NSWC/IHDIV cartridge testing showed increased primer performance (shorter ignition delays, faster times to peak pressure, and less temperature sensitivity) for the MIC-primed cartridges as compared to standard PVU-1/A primers. In all cases, maximum pressures were very nearly the same for both MIC and PVU-1/A primers. This result is not surprising, as peak pressure is controlled more by output load than primer performance. In fact, for LAT closed bomb testing, cartridge output loads are generally adjusted to center the peak pressure in the specification band. With both impulse cartridges tested

(CCU-51/A and CCU-61/A), the lots were slightly out of specification with regard to maximum pressure, being slightly high with the CCU-61/A (Table 7) and slightly low with the CCU-51/A (Table 6). This was true for both sets of primers, however, so that the performance comparison is valid. The PVU-1/A primers appeared to be considerably more erratic in the CCU-61/A cartridges, however.

A total of 4 MIC primer misfires were experienced during the cartridge testing, all with delay cartridges, two with the M-90, and two with the M-93. These occurred across the temperature range of the tests, and appear to be random. To date no specific cause has been identified.

Several primer misfires were experienced with both MIC and PVU-1/A primers in the flame tests with empty MK4 Mod2 cartridge cases. The cause appears to be firing pin spring wear in the test fixture, as no misfires occurred with either primer after the spring was replaced. The flame tests showed about a 4.0 msec flame duration for both, but about three times greater spatial extent for the MIC.

The demonstration test results show conclusively that with one exception, the MIC primer has ignition performance that is either better than or equal to that for existing lead styphnate-based primer compositions. The one exception is slightly longer action time in M855 cartridge tests, which results in slightly lower rates of fire in burst mode. The MIC primer easily meets the M855 3-sigma requirement, however. Thus, the MIC primer as it now exists meets the objective of a drop-in, lead-free replacement for the primers currently found in DoD small arms ammunition and CADs. The demonstration, therefore, has been entirely successful. This does not mean that the MIC primer is ready for qualification, as two major issues with it must still be resolved.

The most difficult issue is whether a common primer formulation can be found for both Army and Navy applications, which have quite different performance specifications. The supplemental small arms testing reported here indicates that addition of moderate amounts of PETN to the MIC composition does not reduce action time. Additional testing (presumably in the ATF) must be done to confirm this result, as elimination of PETN in the M855 primers would result in a common MIC formulation for both Army and Navy applications. If action times comparable to the #41 primer are desired, a reduction of about 20% would be needed, as more work on the formulation would be required.

The second issue is misfires. While none are desired, the small number experienced in this extensive test program is not particularly worrisome. The majority of the misfires appear to be a Mk4 Mod2 test fixture problem, and an investigation into this possibility is in progress. All misfire cartridges, including the M90 and M93 delay cartridges, have been retained and will be thoroughly examined as part of this investigation. The major operational objective of the test program has been to demonstrate that the MIC primers work at least as well as those they are intended to replace, and without question, this has been accomplished. The MIC primer composition used to date has not yet been fully optimized, and it is expected that further effort in this direction will result in elimination of misfires and even better performance. Procedures for primer installation into cartridges also need to be re-examined, as they could be a contributing factor to primer misfires.

4.2 PERFORMANCE CRITERIA

Detailed primary and secondary performance criteria for the MIC primer demonstration are presented in Tables 5-7 in the demonstration plan (Reference 1), and again in Tables 7-9 in the Final Report (Reference 2). A concise summary of the primary and secondary performance criteria for each of the test platforms appears in Table 11.

Table 11. Primary and secondary performance criteria.

Test Platform	M855 Cartridge	PVU-1/A Primer	Navy Cartridges
Product testing	Primary	Primary	Primary
Hazardous materials	Primary	Primary	Primary
Factors affecting technology performance	Secondary	Primary	Primary
Process waste	Secondary	Secondary	Secondary
Reliability	Primary	Primary	Secondary
Ease of use	Secondary	Secondary	Secondary
Versatility	Secondary	Secondary	Secondary
Maintenance	Secondary	Secondary	Secondary
Scale-up constraints	Secondary	Secondary	Secondary

A listing of the performance assessment methods for each platform tested in the demonstration are provided in Tables 4-10 in Section 4.1. Details of these methods are too complex to be expounded upon here but can be obtained by consulting the SOPs and MILSPECs listed in the table for each platform. There were no significant deviations from the demonstration plan other than the addition of the BHA tests, for which the test procedures were similar to those used in the ARDEC ATF. These additional tests were conducted primarily as a first look at some primer modifications, and therefore only a limited amount of data was collected. Tables 4-10 also contain a summary of actual performance data for each test platform.

4.3 DATA EVALUATION

MIC primer performance in M855 cartridges was found to be similar to that of the #41 lead styphnate-based primer with regard to bullet velocity and both case mouth and port pressures (Reference 1). As is shown in Table 12, however, single shot action time was found to be longer with both MIC primers tested. This result may be attributed to the low gas output of the MIC primers. Accordingly, rates of fire with both MIC primers were somewhat lower than that of the reference round. It is not immediately obvious why the water-based MIC composition, which has the lower single shot action time, has a lower rate of fire than the solvent-based MIC composition. Both MIC lots meet the 3.0 msec requirement, however. While the ATF tests demonstrate that action times for the MIC primers can be reduced with the addition of PETN to the primer composition, the amount required to match the #41 primer may be prohibitive, especially if a common composition is desired for both Army and Navy applications. Additional research will be required to determine if this goal can be reached.

Table 12. Comparison of MIC and #41 primer performance in M855 cartridges.

Test Lot	Action Time* (Std Dev) [μsec]	Rate of Fire (Std Dev) [rounds/sec]
Reference (#41)	856 (30)	821 (5)
MIC solvent	1229 (39)	787 (12)
MIC sater	1072 (50)	769 (7)

The performance of the water-based MIC primer composition used in PVU-1/A hardware was found to either exceed or equal that of the standard lead styphnate-based PVU-1/A. This was true with regard to ignition delay and pressure rise time in LAT closed bomb tests. Although the peak pressure data in Tables 6 and 7 seems to suggest that the MIC primer performance was out of specification, the pressures with the standard PVU-1/A were also either high (CCU-61/A) or low (CCU-51/A), indicating that the output charge weight had not been properly adjusted to meet LAT specifications when the cartridges were loaded.

Minimal personnel training was required to mix and load the MIC primer compositions used in the demonstration tests. Furthermore, by design, the conduct of the actual test program was totally transparent to the test personnel. Thus, the goal of producing a lead-free drop-in replacement primer for the #41 and PVU-1/A has been met, and no personnel were exposed to lead contamination in any phase of the demonstration where the MIC primers were used. At present, the only limitations on the use of MIC primers is that a common primer composition has not yet been found that meets both Army and Navy requirements, and scale-up of primer production to very large lots (required for the Army only) has not been investigated.

4.4 TECHNOLOGY COMPARISON

The only known existing alternative to the Al/Bi_2O_3 primer compositions used in the demonstration tests is the Al/MoO_3 composition used in early phases of the MIC primer development program. Because the advantages of the water-based mixing and loading processes with the Al/Bi_2O_3 composition are so great, it is doubtful that the Al/MoO_3 would be considered for use in the future.

Finally, there are Navy research efforts currently in progress to find a lead-free replacement for lead styphnate. Reference 3 provides an overview of the program. If successful, such efforts may produce a new primary explosive which could replace the lead styphnate in the existing #41 and PVU-1/A primer compositions. Should this occur, direct comparison of this technology with the MIC primer technology should be undertaken to examine the pros and cons of replacing only the lead-containing component in the existing primer mixes versus complete replacement of the mixes with MIC compositions. Replacement of the lead styphnate only would have the disadvantage of retaining the antimony sulfide and barium nitrate pollutants in the primer composition, however.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

Because MIC primer manufacturing at IMP is primarily a series of hand operations, the operational costs for manufacturing Bi_2O_3 MIC primers there are dominated by labor costs. The same is true for current PVU-1/A production at NSWC/IHDIV, which is normally done in small batches. Table 13 lists the cost of producing a lot of 500 MIC primers at IMP. Case A represents the actual costs of producing the primers used in the demonstration and includes storage costs (one hour of labor) but not capital equipment costs, which were about $10,000. Case B shows projected costs with a reduced labor rate corresponding to a continuously running mixing and loading operation. Case C shows projected costs to produce a 500 primer lot at NSWC/IHDIV, where the hourly labor rate is considerably higher than those used in Cases A and B. The actual costs to produce the primers used in the ATF tests at ARDEC and the supplemental tests at BHA are assumed to be about the same as the NSWC/IHDIV projections. This is because the same batch manufacturing process was used at both organizations, and labor rates are essentially the same.

Table 13. Actual and projected costs to produce a single batch of 500 MIC primers.

TASK	CASE A (actual)	CASE B (projected)	CASE C (projected)
Initial preparation (labor)	3hrs@90= $270	3hrs@40= $120	3hrs@130= $390
Slurry preparation	2hrs@90=$180	2hrs@40=$80	2hrs@130=$260
Wet loading	1hr@90=$180	1hr@40=$40	1hr@130=$130
Drying and testing	3hrs@90=$270	3hrs@40= $120	3hrs@130= $390
Pressing, pepressing, and anvil insertion	9hrs@90=$810	9hrs@40= $360	9hrs@130= $1170
Final inspection	3hrs@90=$270	3hrs@40= $120	3hrs@130= $390
Overhead (60%)	$1188	$504	N/A
Materials 3 g Al (nano 80 nm) 17 g Bi_2O_3	 $30 $10	 $30 $10	 $30 $10
Total cost per 500 primers	$3064	$1384	$2770
Total cost per one primer	$6.13	$2.77	$5.54

5.2 COST ANALYSIS

Despite the fact that hourly labor rates at NSWC/IHDIV are considerably higher than at IMP, the projected cost to build a batch of 500 primers at NSWC/IHDIV is cheaper than at IMP. This is because there is no overhead cost directly applied to labor at NSWC/IHDIV (or ARDEC). Thus, the cost figures in Case C represent estimated full production rates at NSWC/IHDIV. They do not, however, represent full production rates for the Army. The reason for this is that the Army production rates are so high (typically millions per day), that a large-scale automated process must be used. The per primer cost for semi-automated mixing and loading, which is obviously non-labor intensive, is expected to drop considerably, perhaps to just a few cents, but has not been calculated. Such an undertaking would involve development of production equipment that does not presently exist and would be extremely capital equipment-intensive. The estimated costs of scaling up MIC primer production to typical Army production rates must therefore be determined separately from the demonstration costs.

Once capital equipment is in place, however, the cost to produce an MIC primer in a fully automated production line should be about the same as the present cost of a #41 primer at LCAAP, which is currently around $0.02 per primer.

5.3 COST COMPARISON

Cost savings associated with elimination of lead styphnate in primer production at LCAAP have been discussed in the Demonstration Plan (Reference 1). These savings result primarily from the reduction of hazardous material handling costs and wastewater treatment costs associated with lead styphnate. These are summarized below in Table 14. Actual production costs associated with the MIC primer are expected to be about the same as those for the #41 primer once the capital equipment needed for large-scale has been purchased and installed.

Table 14. Direct process annual cost for lead styphnate.

Lead Styphnate (Annual Cost)

Resource	Annual Quantities Used And Cost Factors		Annual Cost
Lead	29,686 lbs/year	$.75/lb	$22,264
Labor	2080 hrs	$60/hr	124,800
Waste water	100 gal	$18.94/Kgal	1894
Waste drums	2 drums	$65/drum	130
Utilities	1000 sq ft	$0.50/sq ft	500
Air handling systems	Maintenance	$5000 per year	5000
Filters for scrubbers	10	$1000 ea	10,000
Clothing	260 (laundered)	$10 per day	2600
Total	….	….	$167,188

Replacement of lead styphnate primer compositions with MIC primer compositions eliminates production worker exposure not only to lead but also to barium and antimony, which are also contained in the lead styphnate primer composition. The Al/Bi_2O_3 MIC composition contains no materials that are considered hazardous to human health.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The key factors that affected project costs were for labor expended in producing the MIC primers, loading the primers into the cartridges used as test platforms, and executing the test program. All of these costs were well known at the time the demonstration plan was written, and no significant deviation from planned costs occurred during the demonstration. There were some delays in the program due to safety issues at both ARDEC and NSWC/IHDIV, but these had little effect on program costs other than a $17,000 cost extension at ARDEC. As is discussed in Section 5.1, costs of producing small batches of MIC primers are expected to decline if a continuous process is developed. This would apply to primer production at NSWC/IHDIV only. MIC primer production for Army small arms applications will require a significant scale-up in production rates as compared to those in the demonstration. The costs to pursue this endeavor cannot be estimated from the demonstration costs, as they apply to small batch production only. If production rates are significantly increased, however, some savings in procurement costs for raw materials would be expected.

6.2 PERFORMANCE OBSERVATIONS

The demonstration successfully showed that an MIC primer meets performance specifications for primers in selected small arms and CADs. Thus, the goal of creating a drop-in replacement for lead styphnate primers has been met. There are two areas where improvements in MIC primer performance can be beneficial, however—reduction in action time in small arms ammunition and elimination of misfires.

At the present time, neither somewhat slower rates of fire in small arms nor an occasional misfire is considered to be a serious impediment to the introduction of MIC primers into Army and Navy munitions. The slower action time results from the relatively lower output pressure of the MIC primer as compared to a lead styphnate primer. The burning rate of the double base propelling charge in M855 ammunition is sensitive to pressure, so that lower pressure makes it more difficult to ignite and slower to burn. This is partially compensated by the higher temperature of the MIC primer combustion products but not enough to overcome the initially slower burning of the propelling charge. The demonstration tests have shown that the addition of PETN to the MIC composition reduces action time, but the quantities investigated in the demonstration have not been sufficient to increase rates of fire to the level of that with lead styphnate primers. Whether the 6% reduction in rate of fire experienced with the water-based MIC composition is acceptable still must be determined. Also, additional testing needs to be completed to verify the demonstration rate of fire results, which were obtained with very few rounds.

Primer misfires, while undesirable, do not appear to be a serious problem, considering that only six were experienced in roughly 1000 shots. The difficulties experienced with the MK4 Mod2 cartridges appear to be the result of a test fixture problem, and these have not been counted as primer misfires. When they fired, the MIC primers performed very well. Thus, the misfires do not appear to be a design flaw but most likely are the result of inconsistencies somewhere in mixing, loading, and installation operations. Primers are notoriously susceptible to small variations in these types of operations, and at this point in the MIC primer development cycle, it would not be unusual to require in the future a more complete understanding of acceptable production tolerances.

6.3 SCALE-UP

Scale-up of MIC primer production from demonstration rates is primarily an issue for Army primers, which are normally produced at rates that are several orders of magnitude higher than was the case for the demonstration. Demonstration rates of primer production are adequate for Navy applications.

The #41 primer, which the MIC primer would replace, is currently made on a semi-automated assembly line operation. The basics (safety and performance) of the operation are based on handling a desensitized, pliable, doughy material. This material is rolled into dies to form primer pellets that are ultimately consolidated into primer cups. To interface with the existing loading process, the desensitized MIC materials would have to be of a similar physical texture and consistency, that is, the primer mix would have to be thickened prior to loading into primer cups. Doing so, however, would eliminate the major advantage of the present water-based process, namely rapid loading through pipettes with a thinner mixture. It is also possible that the time limitations on the MIC loading process may become untenable with a thicker mix.

Full automation of the #41 primer assembly is being investigated at this time. To fully automate the process, the primer material will have to be more of a slurry type mixture to facilitate the basic operations of handling, metering, and direct insertion of the mix into the primer cup. The water-based MIC mixing and loading process used in the demonstration meets this requirement perfectly, hence represents a unique opportunity for developing a fully automated primer production process. At the present time, the equipment needed for a high rate of production of MIC primers does not exist and would have to be developed. The costs associated with that effort would depend heavily on requirements mandated by Alliant Techsystems, Inc. (ATK), Minneapolis, MN, the present operator of LCAAP, and cannot be estimated at the present time.

6.4 OTHER SIGNIFICANT OBSERVATIONS

The performance results obtained in the demonstration indicate that MIC primer technology provides an excellent lead-free replacement for lead styphnate percussion primers. Aside from the somewhat lower rate of fire in small arms ammunition (6%) and occasional misfires noted in Section 6.2, no other problems have been identified that would prevent implementation of this technology by either the U.S. Army or U.S. Navy. As was stated in Section 6.2, these two problems are not considered to be serious or insurmountable.

6.5 LESSONS LEARNED

For the most part, the demonstration tests went very smoothly. One reason for this is that the tests were carried out in ARDEC and NSWC/IHDIV facilities by personnel who perform these and similar tests on a daily basis. Despite the expertise of the test personnel involved, difficulties were experienced in the flame tests in MK4 Mod2 cartridge cases. These appear to have been the result of attempting an unusually large number of tests in a test fixture that was designed and used for much fewer, resulting in wear-out of the firing pin spring part way through the test matrix. Thus, the extension of LAT tests and procedures beyond normal operations to gain additional information without appropriate analysis of the test fixture has been shown to be risky, and in hindsight, should not have been attempted.

Also, loading of primers into cartridge cases is generally recognized by those who do it on a regular basis as being an arcane process. Difficulties experienced in loading MIC primers into MK4 Mod2 cartridge cases required the primers to be remanufactured, and thus, the flame tests were carried out with a different batch of primers than all the other cartridge tests. This situation could have been avoided by manufacturing a larger number of spares in the original batch to cover unforeseen loading problems.

6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER ISSUES

The implementation of the MIC primer should be unnoticeable to the end users. Primed cartridges used in U.S. Army small arms ammunition would look identical to those presently used and would require the same shipping, storage, and handling procedures. Assuming that the rate of fire with MIC primers can eventually be adjusted to reach those of the #41 primer, there would be no observable difference in performance. For U.S. Navy CAD applications, the use of MIC primers would be totally transparent to the end users.

MIC primer production could be implemented at LCAAP to replace the current primer assembly facilities under a modernization effort, or alternatively could be contracted out to civilian firms who meet the quality controls and ship the assembled primers to LCAAP. ATK has been reluctant to implement an automated primer assembly program due to the incompatibility of the current lead styphnate-based formulation with automated equipment. The current material has a —dughy” texture and has not interfaced well with automatic dispensing equipment that works with less viscous materials. The work completed as part of the ESTCP demonstration has developed a promising process where the MIC material is solvated in water. The texture of the material is currently a slurry, which would be more conducive to automated handling equipment. Scale-up of the present batch mode mixing and loading process needs to be completed before serious investigation of an automated process can begin, however.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The regulations and directives listed below are applicable to this program. Implementation of the MIC primer technology into percussion primer production at LCAAP and NSWC/IHDIV will result in reduced exposure of production personnel to heavy metal pollution, primarily lead. In addition, lead pollution will also be reduced at all Army, Navy, and Air Force firing ranges and at all storage and handling facilities associated with cartridges currently using #41 and PVU-1/A primers. Since the MIC primers contain only Al, Bi_2O_3, and potentially PETN, no new approvals, licenses, or permits will be required to adopt the technology.

- Executive Order 12856, Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements 1994
- NEPA – National Environmental Policy Act, 1969
- OPNAVINST 4110.2, Hazardous Material Control and Management

- Army 3.3b Reduce hazardous Components in Ordnance and Alternative Treatment for Hazardous Waste from Ordnance Processing
- Navy 3.1.6.C, Energetic Production Pollution Prevention
- Air Force 974, Reduction of Lead Exposure at Firing Ranges
- Zero Discharge Study for LCAAP, Aug 1997.

7.0 REFERENCES

1. Fronabarger, John, William Sanborn and Magdy Bichay. 2001. *An Investigation of Some Alternatives to Lead Based Primary Explosives.* AIAA-2001-3633. 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Salt Lake City, UT. July 11, 2001.

2. Hirlinger, John and Bichay, Magdy. 2005. *Demonstration Plan, Metastable Intermolecular Composites (MIC) Primers for Small Caliber Cartridges and Cartridge Activated Devices.* ESTCP Project WP-0205. February 2005.

3. Hirlinger, John and Bichay, Magdy. 2008. *Final Report, Metastable Intermolecular Composites (MIC) Primers for Small Caliber Cartridges and Cartridge Activated Devices.* ESTCP Project WP-0205. February 2008.

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Appendix A

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