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TEAE-AF

8 January 2015

MEMORANDUM FOR U.S. Army Product Manager Self Propelled Howitzer Systems (PdM-SPHS) (SFAE-GCS-HBCT/LTC Michael Zahurancic), 6501 E. 11 Mile Road, Bldg 229, Warren, MI 48397-5000

SUBJECT: Safety Confirmation for the 155mm M284 Cannon Tube Bore Evacuator Hole Repair Process Provided for Fielding

1. References:

- a. MIL-STD-882E, Department of Defense (DOD), Standard Practice, System Safety, 11 May 2012.
- b. DOD Interim Instruction 5000.02, Operation of the Defense Acquisition System, 25 November 2013.
- c. U.S. Army Test and Evaluation Command (ATEC) PAM 73-1, (Volume 1 System Test and Evaluation Procedures), 9 July 2013.
- d. AR 700-142, Type Classification, Materiel Release, Fielding, and Transfer, Headquarters Department of the Army, 17 January 2013.
- e. Safety Assessment Report (SAR), Safety Assessment Report for the 155mm M284A1 Tube Reclamation Project for the Howitzer, Medium, Self-Propelled: 155MM M109A6 (Paladin), Amendment 1, Quality Engineering and System Assurance Directorate, 22 December 2014.
- f. FRAGO, FRAGO 1 to HQDA EXORD 055-15, subject: M109A6 Self-Propelled Howitzer – M284 Cannon Safety and Readiness, 8 December 2014.
- g. Report, U.S. Army Armaments Research, Development and Engineering Center (ARDEC), Weapons and Software Engineering Center, Benét Labs, subject: Fatigue Testing of the 155MM M284 Cannon Tubes for Safe Service Life Determination, January 2012.

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- h. Test Plan, Engineering Evaluation Test Plan for the M284 Durability Testing, ARDEC, ATEC Project Number 2014-DT-YPG-PAPIM-F8117, December 2013.
- i. Email, Yuma Test Center (YTC), TEAE-YPY-G-MW, Mr. Steve Flores, December 2014, subject: M284 testing EXSUM.
- j. Email, Yuma Test Center (YTC), TEAE-YPY-G-MW, Mr. Steve Flores, December 2014, subject: Bushing depth measurements.
- k. Memorandum, ARDEC Benét Labs, RDAR-WSB-PC, 10 December 2014, subject: Minutes of Meeting: M284 Cannon Tube Bushing Repair Safety Confirmation Path.
- l. Memorandum, ARDEC-Benét Labs, RDAR-WSB-CC, 11 December 2014, subject: Analysis of Bushing Movement in Repaired M284 Bore Evacuator Intake (90-degree) Holes.
- m. Maintenance Advisory Message (MAM), Draft, subject: MAM, TACOM Life Cycle Management Command, (LCMC) Control No. MA 15-XXX, Proper cleaning and inspection of M284 Cannon Tube, M109A6 Howitzer, Medium Self-Propelled.
- n. TM 9-2350-314-10 Series, Operator's Manual for 155MM M109A6 Medium Self-Propelled Howitzer, May 2014.
- o. Technical Report, Paladin 155mm M284 Cannon Tube Modification/Reclamation Gun Tube Bore Evacuator Section Fatigue Technical Report, ARDEC-Benet Labs, 22 September 2014.
- p. TM 9-1000-202-14, Evaluation of Cannon Tubes, February 1999.
- q. Memorandum, Fatigue Technology , 4 October 2013, subject: ForceMate Bushing Removal from Cannon Tube Section.
- r. Memorandum, ARDEC-Benét Labs, RDAR-WSB, 5 January 2015, subject: Supplemental Data Supporting M284 Tube Repair ATEC Safety Confirmation.
- s. Report, Finite Element Analysis Report (FEA) for ForceMate Application 1602 and 1603 for Benét Laboratory, Fatigue Technology, Mr. Brian Aher, FTI Report # 633228, 27 March 2013.
- t. Report, YTC, subject: Engineering Durability Evaluation 155-MM M284 Cannon with the Lightweight Bore Evacuator, YPG No. 14-EDT-0272-L5, Draft.

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2. Purpose. This Safety Confirmation for the 155mm M284 Cannon Tube Bore Evacuator Hole Repair process, herein referred as M284 Cannon with bushings, is provided for Fielding. A safety assessment in accordance with (IAW) MIL-STD-882E (reference 1a) has been conducted. The overall risk for the use (operation) of the M284 Cannon with bushings is considered MEDIUM provided the warnings, cautions, and procedures addressed in references are implemented.

3. System Description.

a. The 155mm M284 Cannon is the primary weapon on the M109A6 Paladin Self Propelled Howitzer. Recent evaluations of M284 gun tubes have indicated severe corrosion in the bore evacuator section of the tube. Evidence points to a lack of maintenance under the bore evacuator, likely due to the difficulty the Soldiers have when attempting to disassemble the bore evacuator from the tube.

b. Recent surveys of M284 cannon tube have indicated a significant number of tubes displaying severe corrosion and pitting in the bore evacuator region. This corrosion and pitting is attributed to lack of proper maintenance and storage practices. Per TM 9-1000-202-14 (reference 1p), pitting in the bore evacuator holes of the M284 cannon is a cause for tube condemnation. Surveys conducted between 2012 and 2014 of unit and depot gun tubes identified that a high percentage of M284 Cannons fall within the condemnation criteria for pitting in the bore evacuator region. Due to the large number of tubes which meet this condemned condition, Benét Laboratories began an investigation into the possibility of repairing these corroded tubes to bring them back to a serviceable condition to eliminate the cost of fabricating new tubes. The M284 Cannon tube bore evacuator hole repair process is comprised of the following steps:

(1) Remove Corrosion from the bore evacuator holes. Destructive analysis of corroded bore evacuator holes indicated environmental cracking and corrosion could be found to a depth of 0.03 inches. To insure the corrosion on the vast majority of repaired gun tubes would be eliminated, the 0.03 inch value was doubled to 0.06 inches. Therefore each bore evacuator hole, would be opened up to 0.120 inches larger than their original size to ensure that the corrosion in the bore evacuator holes is removed.

(2) Restore Bore Evacuator Hole Size. To insure the bore evacuator performance was not degraded, the bore evacuator holes had to be brought back to their original diameters. This was done by inserting a bushing into the hole (Figure 1). The bushings were inserted using an overstraining process, similar to the autofrettage process used to increase the strength and fatigue life of gun tubes. The process permanently sets the bushings in place and also imparts favorable compressive residual stresses into the bushing and gun tube. The compressive stresses prevent environmental stress cracks from forming in addition to increase the fatigue life.

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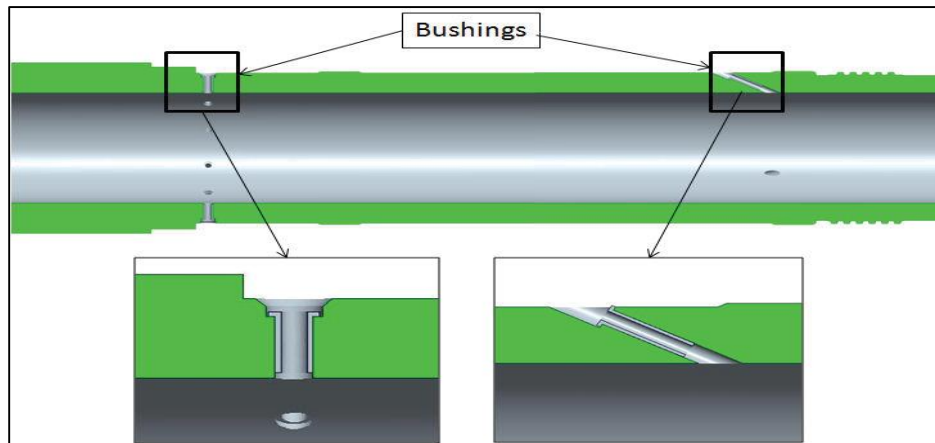


Figure 1. M284 Cannon bore evacuator holes with bushings.

(3) Prevent further Corrosion. The bushings used in the bore evacuator holes are made from PH 17-4 stainless steel (Figure 2) which has a far higher corrosion resistance than standard gun steel and are expected to prevent future corrosion in the bore evacuator holes.



Figure 2. M284 Cannon bore evacuator holes and bushings.

4. Evaluation Limiting Factors. This Safety Confirmation is not an evaluation of system performance and does not address system effectiveness, suitability, or survivability.

5. Evaluation Results.

a. This Safety Confirmation is derived through Test Manager analysis of the results of testing by YTC, ARDEC-Benét Labs, U.S. Army Aberdeen Test Center, and Fatigue Technology, and a review of referenced documentation. The definitions from MIL-STD-882E were used to assign hazard severity, probability of occurrence, and a Risk

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Assessment Code (RAC) of identified hazards. The M284 Cannon with bushing does not contain safety significant software as defined by reference 1c. Identified safety hazards are summarized below.

b. Extensive safety testing was conducted at YTC (references 1f, 1i, 1j, and 1t) to address the tube repair process on three cannon tubes with bushings. Table 1 shows a history of the three M284 Cannon tubes.

Table 1. M284 Cannon Tubes Test History

M284 Cannon S/N	Test Dates	EFCs	Maximum Measured Bushing Movement
101CT	May – Dec. '14	2,650	0.084 inches
1540T	Dec. '14	1,500	0.047 inches
823T	Dec. '14	1,501	0.082 inches

c. The M284 Cannon SAR (reference 1e) identify potential hazards associated with the repaired process of removing corrosion on the bore evacuator holes and the insertion of the bushings into the bore evacuator holes. Identified SAR safety hazards are summarized below:

(1) There is a potential of personal injury or equipment damage if bore evacuator hole bushings are improperly installed. The potential for equipment damage or personal injury may be controlled by ensuring the proper installation of the bushing at the manufacturing facility and providing the Soldiers proper maintenance and inspection procedures. ARDEC-Benet Labs is supporting a U.S. Army Tank and Automotive Command issued Maintenance Work Order and/or MAM with technical content that will define cleaning, maintenance, and inspection procedures (to include an inspection tool). The MAM is currently been developed and the expectations is that the MAM will accompany the repaired M284 Cannon fielding. This is assessed as a Marginal-Remote hazard (RAC 3-D, MEDIUM Risk). In addition, test results (references 1k, 1l, 1q) show that proper installation of the bushings mitigates this hazards.

(2) There is a potential of personal injury due to loss of bore evacuator function due to clogging of bore evacuator bushings resulting in Toxic Fumes accumulating in the cab. The potential for personal injury may be controlled by ensuring Soldiers follow proper TMs and MAM procedures (references 1m, 1n and 1p) and providing the Soldiers proper maintenance and inspection tools. Personal injury due to loss of bore evacuator function is assessed as Catastrophic-Improbable hazard (RAC 1-E, MEDIUM Risk). Properly training Soldiers to operate and maintain systems will mitigate risks to an acceptable level.

(3) There is a potential of personal injury or equipment damage due to crack on bore evacuator holes which reduce the fatigue life of the cannon tube. The potential for

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equipment damage or personal injury may be controlled by ensuring the Soldiers following proper TM procedures (reference 1n) and providing the Soldiers proper maintenance and inspection procedures. Additional mitigation for this hazard is the test results from firing 823T, 101CT and 1540T cannon tubes. This testing indicates that once pitting is removed from bore evacuator holes and bushings are inserted, repaired tubes can be fired with little chance of crack formation and propagation. Personal injury or equipment damage due to fatigue crack in bore evacuator holes is assessed as Catastrophic-Improbable hazard (RAC 1-E, MEDIUM Risk).

d. ARDEC-Benet Labs conducted an analysis of the bushing movements during live-fire testing of two repaired tubes at YTC (references 1k and 1l). Measurements of bushing outward movements were taken on all ten bushings locations at different intervals and specified equivalent full charge (EFC). The analysis showed that bushing outward movement is independent of the bushing location. The two repaired tubes were live-fired up to 2,650 EFCs and 1,500 EFCs, with a maximum observed bushing movement of 0.084 inches and 0.047 inches, respectively. There is a potential of equipment damage or personal injury due to possibility of bushings migrating outward and reinitiating of pitting or corrosion. Corrosion can result in the same fatigue conditions that the repair is intended to correct. This is assessed as Catastrophic-Improbable hazard (RAC 1-E, MEDIUM Risk) hazard. ARDEC-Benét Labs recommends that the M284 Cannon with bushings be restricted to a maximum of 0.10 inches of bushing movement outward or to a maximum of 24 months of use in the field to minimize this risk. In addition, the fatigue life for the M284 Cannon with bushings remains at 2,650 EFCs, which is the current fielded M284 cannon EFC per references 1n, 1o, 1p, and 1r.

e. The Fatigue Technology conducted testing to determine the force required to remove the bushings from a repaired cannon tubes (reference 1q). The anticipated bushing removal force was expected to be 1,000 lbs. The test was conducted on two bushings. Data show that the force required for the bushing to start moving outward was approximately 16,000 lbs, which far exceeds the expected value. No safety hazards were observed during the test.

f. The Fatigue Technology conducted an FEA on the ForceMate bushing installation process in the radial and angled bore evacuator area holes (reference 1s) to ensure structure integrity for all the regions of the cannon tube area holes. The FEA results were accepted by Benét Labs and indicated the structural integrity was maintained in all the regions in contact with the bushings. No safety hazards were observed.

g. The ARDEC- Benét Labs conducted laboratory fatigue testing on two repaired cannon tubes to determine if the repair process results in a fatigue life loss due to corrosion in the bore evacuator holes (reference 1o). Two cannon tubes bore evacuator areas were fatigue tested per reference 1t. The results were compared against previously tested breech-end sections (reference 1o). The data indicates that the bore

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evacuator on the repaired tube sections exceeded the unrepaired breech-end sections by a statistically significant margin. No safety hazards were observed during testing.

h. There is a potential of personal injury due to sharp edges and/or rough surfaces. Soldiers shall be trained to visually inspect the M109A6 for any obvious irregularities prior to operations. Soldiers shall wear approved personal protective equipment IAW all Training; Tactics, Techniques, and Procedures; and associated TMs (references 1p).

6. Conclusions and Recommendations. This Safety Confirmation for the M284 Cannon with bushings is provided for Fielding. A safety assessment has been conducted to support program risk acceptance. The M284 Cannon with bushings has a combined total of 4 identified MEDIUM hazards. The overall risk for the operation of the M284 Cannon with bushings is considered MEDIUM, which is the highest individual risk identified for the system, provided the warnings, cautions, procedures, and mitigations identified in this document and references are implemented.

a. The hazards identified in paragraph 5 should be eliminated or controlled to an acceptable level. If the hazards are not eliminated, the residual hazards must be accepted by the appropriate decision authority IAW Interim DODI 5000.02 (reference 1b). The technical or operational limitations or precautions identified herein, needed to prevent injury and property damage during operation, are the responsibility of the PM SPHS.

b. If the PM SPHS elects to alter the hardware or software of this system from the configuration defined herein, this Safety Confirmation will no longer be applicable; a new Safety Confirmation will be required. The PM SPHS for the system shall coordinate a plan with the ATEC System Team Chair to verify and validate the new configuration through testing and/or analysis.

c. This Safety Confirmation does not negate the need for other safety activities or documents required for materiel release in AR 700-142.

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7. The AEC point of contact is Edwin Rivera, TEAE-AF-F, 443-861-9554, DSN 848-9554, Edwin.c.rivera.civ@mail.mil.

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