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U.S. ARMY TEST AND EVALUATION COMMAND  
TEST OPERATIONS PROCEDURE

\*Test Operations Procedure 03-2-052  
DTIC AD No.

10 May 2019

MORTAR CANNON SAFETY TESTS

		<u>Page</u>
Paragraph	1. SCOPE.....	2
	2. FACILITIES AND INSTRUMENTATION.....	2
	2.1 Facilities .....	2
	2.2 Instrumentation.....	3
	3. REQUIRED TEST CONDITIONS.....	3
	3.1 Introduction .....	3
	3.2 Inspection and Measurement.....	5
	3.3 Servicing and Safety.....	6
	3.4 Ammunition.....	6
	3.5 Pressure Definitions .....	6
	4. TEST PROCEDURES .....	7
	4.1 Mortar Tube Wear Test .....	7
	4.2 Fatigue Testing .....	11
	5. DATA REQUIRED.....	13
	6. PRESENTATION OF DATA .....	13
	6.1 Data .....	13
	6.2 Safety Criteria.....	14
APPENDIX	A. STATISTICAL DETERMINATION OF FATIGUE LIFE..	A-1
	B. ABBREVIATIONS.....	B-1
	C. REFERENCES.....	C-1
	D. APPROVAL AUTHORITY.....	D-1

1. SCOPE.

This Test Operations Procedure (TOP) provides test procedures for determining the wear life and safe fatigue life for mortar cannons. This TOP augments TOP 03-2-050<sup>1\*</sup> Testing of Mortar Systems, which describes procedures for determining the operational capabilities of muzzle loaded mortar systems.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Firing Range	Selected to suit test requirements and to provide adequate protection for personnel and equipment; firing points must be sufficiently protected and remotely located to safely contain a premature ammunition detonation, ricochet, or catastrophic weapon or weapon component failure as well as contain discarding parts from projectiles. Local siting requirements apply.
Temperature Chamber	To be able to condition the test items to the required temperature and relative humidity from 5 to 95 percent. It is recommended that temperature chambers be able to condition ammunition from -51 to 71 °Celsius (°C) (-60 to 160 °Fahrenheit (°F)).
Laboratory Fatigue Cycling Facility	Hydraulic pressure simulation of propelling-charge pressure.
Electrical-Discharge Machining (EDM) Facility	To introduce flaws in mortar cannons that are representative of the maximum allowable cannon production flaw.
Inspection Facility	Inspection and measurements of cannons are usually made in a suitable shop area at the time of nondestructive inspections. Since measured values are influenced by temperature, ensure that the test items are in a conditioned area for sufficient time prior to the measurements being taken.

\* Superscript numbers correspond to Appendix C, References.

## 2.2 Instrumentation.

<u>Devices for Measuring</u>	<u>Permissible Measurement Uncertainty</u> <sup>(see NOTE 1)</sup>
Cannon chamber pressure (guidance in International Test Operations Procedure (ITOP) 03- 2-810(1)A <sup>2</sup> )	2 percent of reading.
Projectile velocity (guidance in ITOP 04-2-805 <sup>3</sup> )	0.1 percent of reading or 0.5 meters per second (m/s) (whichever is higher).
Weapon elevation	0.2 mil.
Record of test events (e.g., high- speed camera, video, still photography)	As required.
Cannon dimensions, flaw dimensions and locations, to assess cannon integrity (guidance in ITOP 03-2-802A <sup>4</sup> )	As required.
Meteorological conditions (guidance in TOP 03-1-003 <sup>5</sup> )	As required.

NOTE 1. The stated uncertainty ( $2\sigma$ ) is greater than the error in 95 percent of the measurements, assuming a normal distribution.

## 3. REQUIRED TEST CONDITIONS.

### 3.1 Introduction.

#### 3.1.1 Mortar Weapon System.

The mortar weapon system includes the mortar and those components required for its operation, comprising the aggregate of the mortar, the associated platform (e.g., tracked or wheeled vehicle), and the ancillary equipment necessary to test, aim, launch, and guide the ammunition, as applicable (e.g., bipod, recoil unit, and fire control components). The vehicle-mounted (Figure 1) and ground-mounted (Figure 2) are the two broad categories of weapon systems.

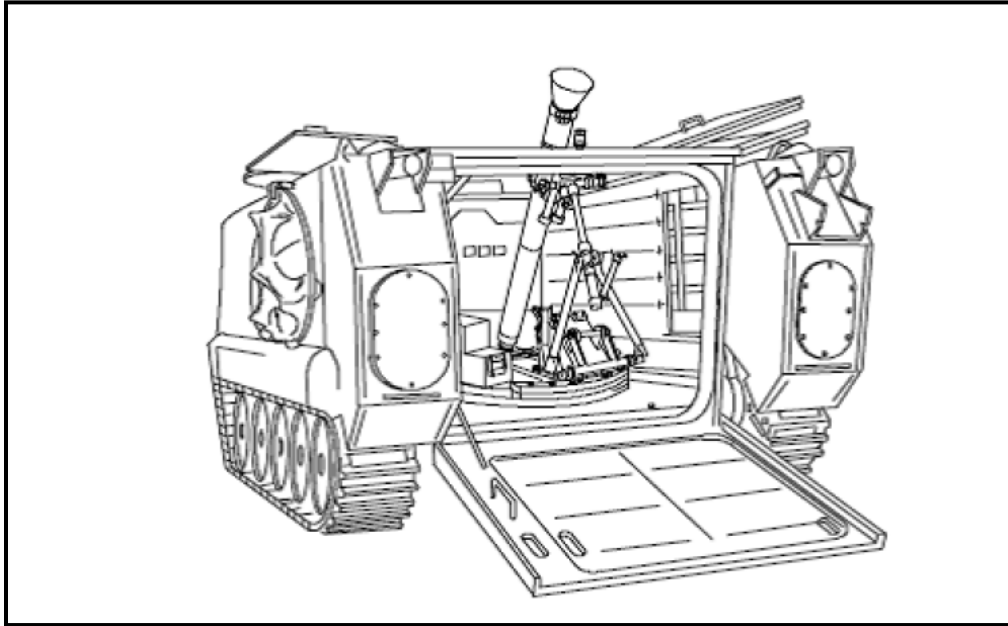


Figure 1. Vehicle mounted mortar.

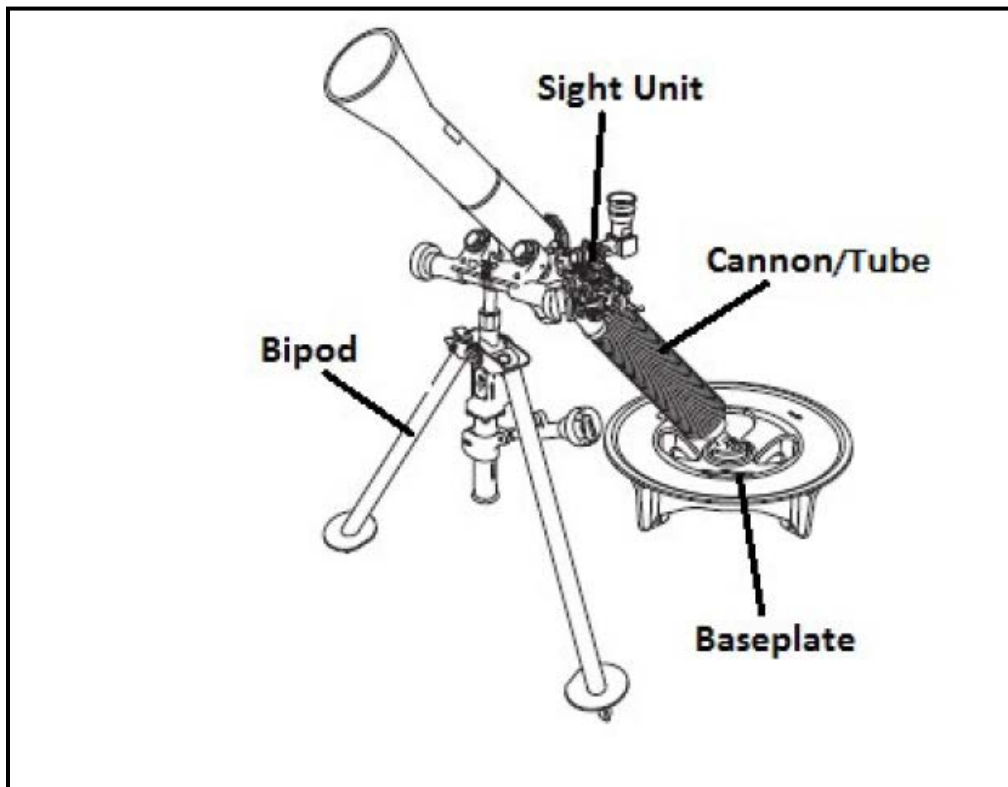


Figure 2. Ground mounted mortar.

- a. Mortar. A weapon system with a short barrel in proportion to its bore, rifled or smooth, for firing shells (cartridges/bombs) at high angles.
- b. Cannon. The cannon is comprised of the breech, tube, and firing assembly.
- c. Tube. The tube is the long cylinder that is part of the cannon.
- d. Breech (or base cap). A piece of metal or device that seals the base of the tube to allow for the accumulation of pressure generated by the propelling charge, which is released as the projectile moves toward and eventually exits the muzzle end of the tube.

### 3.1.2 Service Life.

The service life of a tube can be limited by fatigue or firing damage to the inner surface of the tube, particularly erosion of the metal of the bore surface. Service life for the tube in both cases can be expressed in terms of the number of rounds that can be fired before excessive firing damage or an unsafe condition could develop. Technical Manual (TM) 9-1000-202-14<sup>6</sup>, Evaluation of Cannon Tubes, provides information to aid in determining if a cannon tube can continue to be used or should be condemned, and in estimating the remaining life. The TM contains information on tube life, erosion (wear), damage, and inspection procedures which will be helpful in determining service life.

- a. The heat and pressure generated by firing a round of ammunition and the rapid movement of the projectile through the tube can cause damage to the bore surface of the tube, such as erosion of the base metal and loss or damage to any protective plating. Irregular damage or uniform wear that erodes the inner bore beyond a specified tolerance may cause dangerous firing conditions, or conditions that cause the projectile to perform outside of standard or accepted parameters.
- b. If firing damage to the tube is minimized, metal fatigue, which ultimately leads to an unsafe condition, can be the limiting factor relative to the service life of a mortar tube. Each firing of the weapon contributes to metal fatigue of the tube, and could eventually cause the tube to fail in a catastrophic manner. It is, therefore, essential that a margin of safety is established to ensure that firing be halted before a failure is experienced.

### 3.2 Inspection and Measurement.

- a. The tube is gauged and borescoped before the test firing is started and repeated at prescribed intervals throughout the progress of firing. The bore is photographed or videotaped and molding-compound impressions are made in the areas of maximum damage.
- b. Various nondestructive methods of inspection are used for determining the presence and extent of defects in tubes, breech caps, baseplates, bipods, and other components. The method used will depend on the item's material composition and what type of defect is being examined. The most commonly used methods are magnetic particle, eddy current, ultrasonic, and liquid penetrant inspection. It is advisable to use other methods (ultraviolet, radiographic,

magnetic recording borescope, etc.) to supplement these initial inspections. These inspections are performed as required before firing and at prescribed intervals throughout the firing.

c. Mortar cannon tubes will be notched by EDM (in accordance with the DTP) to simulate fatigue initiation. Initial EDM notch size verification and progression of the resulting crack shall be accomplished through ultrasonic inspection.

### 3.3 Servicing and Safety.

a. Ensure that all required system maintenance is performed in accordance with applicable TMs, lubrication orders, or other guidance documents. The assembled mortar cannon is visually examined for completeness of assembly; for verification of markings, including serial numbers; for model designation; and for freedom from chips, dirt and foreign matter. Breech cap and firing mechanism are checked for proper functioning, fit, and finish.

b. Safety procedures pertinent to the test area and weapon should be adhered to at all times. Inspect the system and test setup for safety hazards before testing and continually monitor the system and test setup for hazards during testing. When test objectives can be met, baseline, control, and test rounds should be inert. If inert is not available, training and live load ammunition can be used if local procedures allow.

c. Use experienced operators who have received training on the test system and ensure adequate protective clothing and equipment are worn, e.g., head, eye, ear, hand, and foot protection. Ensure operators are adequately protected when firing at chamber pressures or charges that may exceed the extreme service condition pressure or when the tube is being tested to prove material integrity (which is the general objective of tests covered under the TOP).

### 3.4 Ammunition.

In most cases, ammunition which produces the most severe erosion also produces the highest chamber pressure. A single ammunition type with propelling charges can usually be used to conduct the test regardless if firing damage or fatigue is the condemning factor.

### 3.5 Pressure Definitions.

During the design and test of a cannon it is necessary to specify quantitatively a value for the pressure in the cannon. North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4110<sup>7</sup>, Definition of Pressure Terms and Their Interrelationship for Use in the Design and Proof of Cannons or Mortars and Ammunition, sets out essential definitions and their interrelationship. While the STANAG defines pressure terms, the actual values will be set by cannon and ammunition designers with input from other stakeholders. The fatigue design pressure (FDP) and the extreme service condition pressure (ESCP) will be defined in the Detailed Test Plan (DTP).

#### 4. TEST PROCEDURES.

##### 4.1 Mortar Tube Wear Test.

a. Purpose. Mortar tube wear raises three issues. The three tests are conducted separately, and may be conducted in conjunction with other testing when it does not affect ability to gather data required.

(1) Range and Accuracy. A worn cannon may contribute to inconsistent flight, erratic and unsafe flight, and possibly short rounds. Does the worn cannon safely launch the round to the required range, accuracy and precision? A cannon at its wear limit should meet the range and accuracy limits spelled out in requirements documents.

(2) Structural Soundness. Is the cannon structurally safe at the wear limit? Can a cannon at (and beyond) the limits of allowed wear contain the maximum pressures expected to be launched? Is the remaining wall thickness sufficient to contain pressure?

(3) Durability. Does the cannon wear life satisfy the durability life requirement? The cannon should be able to fire the required number of mixed charge of rounds before the cannon diameter is worn in excess of its determined limit.

b. For each mortar system the target limit of wear is agreed to by the weapon and ammunition designers. Current mortar cannons wear very slowly, so once the limit has been established, test cannons for range and accuracy, and structural soundness will be machined to simulate wear. Cannons are normally machined over the length of the bore, but may be machined in specific regions if appropriate. Wear durability should be conducted during reliability, availability, and maintainability (RAM) firings if possible, tracking a single cannon's wear when firing a large number of rounds. This may be measured over approximately one-third of the required durability, and extrapolated to target life. There must be a high degree of confidence that this wear extrapolation is accurate.

##### 4.1.1 Range and Accuracy.

###### a. Test Methods.

(1) The Ballistic Similitude/Ballistic Match DTP, for assessing range and accuracy against requirements will be developed and managed by the agency responsible for preparing the firing tables (Combat Capabilities Development Command Armaments Center (CCDC Armaments Center) Firing Tables and Ballistics Division (FTaB)). Testing will follow ITOP 03-2-601<sup>8</sup>, Firing Tables and Ballistic Match Tests, modified if necessary to account for the wear allowance and evaluation.

(2) The normal test will use one test cannon machined to wear limit, tolerance -0.000/+0.003 inches (artificial wear), for the length of the bore, and a second control cannon identical to test cannons except bore will be near new (wear < 10 percent of allowance). Both cannons should be set up on one firing position where they can be fired in alternating sequence

as required by the specific test. Ammunition quantity and temperature conditioning is defined within the DTP.

b. Data Required.

- (1) As detailed in ITOP 03-2-601<sup>8</sup>.
- (2) Additional test data requirements defined by CCDC Armaments Center FTaB.
- (3) Video should capture the round leaving the cannon to check for pitch/yaw.

c. Data Analysis. The range and accuracy of the worn cannon compared to the control cannon and the system requirements will be assessed by FTaB. The requirement is that the worn cannon be ballistically similar to a new production tube corrected for the lost muzzle velocity attributable to wear.

4.1.2 Structural Soundness.

a. Test Methods.

(1) The cannon structural test is intended to show that a cannon, even at wear limit, will contain pressure. This will provide a safety margin for the case where a regular inspection misses an oversize condition.

(2) Using two artificial wear cannons (see paragraph 4.1.1.a(2)), one from the range/accuracy test and one new), inspect (dimensional, magnetic particle inspection/ultrasonic testing (MPI/UT), video borescope) the cannons, and hydraulic cycle the cannons in the fatigue critical location(s) at the fatigue design pressure. Cycling should be conducted for 5,000 cycles (or other appropriate number determined by the material developer based on planned number of lifetime cycles plus the required number of cycles for an appropriate safety margin). Perform periodic dimensional and MPI/UT inspections during cycling in accordance with the DTP. Repeat all inspections after test. After cycling and inspection, a burst test (test to failure) may be conducted if these data will enhance system safety, or is deemed important to system development.

b. Data Required.

- (1) Number of cycles and results of test (failure or no failure).
- (2) Results of inspections.
- (3) If a failure occurs during cycling, report cycles at first detection. Report size and location of final failure. Conduct materials analysis as near the failure as possible. Photograph the failure and the surrounding areas.

(4) If a cannon is burst, report the pressures at initiation of failure and burst pressure. Photograph the failure and the analysis pieces.

c. Data Analysis. The cannon should demonstrate adequate strength to be safe to fire repeatedly, even when worn to or past its limit. The intent is to provide a margin of safety to allow for a worn cannon not removed from service to fire enough ammunition to take it at least through its next scheduled bore inspection, normally 180 days, or a specified number of rounds. The number of hydraulic cycles, and the need for a burst test will be as agreed to by the system developer.

#### 4.1.3 Durability.

##### a. Test Methods.

(1) Cannon wear rate under firing conditions can vary widely based on particular pattern of use. Because wear in mortars is slow, a forecast of cannon durability can be used to evaluate the cannon's ability to remain serviceable over its required life. The data for this evaluation may be collected during RAM testing. RAM is evaluated using data from multiple cannons, but ideally one new cannon should fire more than the target mean rounds between failure (MRBF) (mission abort). Before RAM, the cannon should be inspected (bore dimension). At the start of the RAM firings on the new cannon, fire a set of 10 control rounds recording round weight, firing pressure, muzzle velocity, range, and accuracy. During RAM, repeat the bore dimension inspection at an interval of every 250 rounds. Repeat the control rounds every 500 rounds, or when wear is measured in excess of 10 percent of allowed wear.

(2) A full evaluation of the cannon's serviceability should be conducted at the end of the test.

(3) Because of the slow wear expected, the dimensional inspections need to be conducted with care. The temperature of the cannon at inspection must be consistent (same temperature), locations of measurement on the bore must be the same, and measurements should be taken to the highest accuracy possible.

(4) Control rounds must be taken from the same lot of ammunition, and conditioned the same (temperature and time).

##### b. Data Required.

(1) For each control round:

(a) Ammunition/component type, model, lot number, and temperature.

(b) Tube round number.

(c) Muzzle velocity, m/s.

- (d) Chamber pressure, megapascal (MPa).
- (e) Projectile weight.
- (f) Ammunition weight.
- (g) Impact location, range, and deflection.
- (h) For each recovered round, extent of any damage to the round.
- (i) Evidence of improper launch.
- (j) Any evidence of projectile malfunction, erratic flight, etc.
- (2) For expenditure rounds record:
  - (a) Tube round number.
  - (b) Ammunition/component type, model, lot numbers and temperature.
  - (c) Muzzle velocity (m/s) and chamber pressure (MPa) for first and last 10 rounds fired on each day.
    - (d) Tube temperatures, if required.
    - (e) Rate of fire.
    - (f) Any evidence of projectile malfunction, erratic flight, etc.
  - (3) Cannon:
    - (a) Record results of inspections for each cycle, to include quantification of damage to the interior bore, when applicable.
    - (b) Report and photograph any failed cannon component.
    - (c) Bore measurement and borescope results, as applicable.
    - (4) Metrological data for control rounds fired.
- c. Data Analysis. Wear data and accuracy collected during RAM testing will be assessed by the system designers. The forecasted life developed during system design, must exceed the durability requirements for the item. Wear extrapolation or other methods may be used in agreement with the system developer. The cannon should show no signs of violating any condemnation criteria over the test interval, and at test end the cannon should be found serviceable in order to meet the durability requirement.

## 4.2 Fatigue Testing.

### 4.2.1 Method.

- a. The current design activity shall identify, through finite element analysis or other engineering modeling, the most critical section(s) or feature(s) of the mortar tube. That is, the section(s) or feature(s) of the tube least tolerant, from a fatigue perspective, of a material soundness flaw.
- b. Unlike large caliber thick-walled tubes, mortars do not always develop heat checking from firing standard ammunition. Therefore, the fatigue limiting flaw will be the maximum allowable flaw from the manufacturing process. The approach for fatigue testing mortar tubes when heat checking does not develop during firing is to use tube specimens with the maximum allowable production defect located in the least defect tolerant region of the tube.
- c. Time constraints make it impractical to wait for the manufacturing process to generate the maximum allowable flaw. The flaw will be simulated through the use of EDM. This is a practice widely used in several major industries. A semi-circular EDM notch, the length and depth of the maximum allowable flaw, will be introduced longitudinally in the critical region or feature of the tube.
- d. Simulate firing by cycling the critical sections of the mortar tube to failure on a laboratory fatigue cycling test fixture. Laboratory fatigue cycling can be conducted in accordance with Appendix B of ITOP 03-2-829<sup>9</sup>, Cannon Safety Test. Simulated firing should be at, or above, the FDP curve value for the critical location. If actual firing is conducted to accumulate fatigue life round count, firing should be at ESCP, other rounds can be fired that are below the ESCP but they are not to be counted toward the fatigue life calculation.
- e. During cycling, inspect the tube at frequent intervals (in accordance with the DTP) to observe the transition of the EDM notch into a crack. Inspection method should be UT or other method capable of detecting crack depth. It is recognized that an EDM notch will not respond to pressure cycles in the same way a natural crack would, therefore, the cycles applied to transition the notch to a crack must be discounted from the cycle count to failure.
- f. After a crack has initiated, the cannon should be inspected (UT) at intervals to check progress of crack growth. It may be helpful to heat tint sample to calculate crack growth rate at the conclusion of the test.
- g. Breech (end) caps that are integrated into the cannon will be fatigue tested along with the cannon. Fatigue testing of breech mechanisms on breech loaded or moving breech block mortars are to be tested in accordance with ITOP 03-2-829.
- h. Mechanical properties of the material taken from the failed-fatigue-life sample should be measured as close as practical to the point of failure. This should include yield strength, tensile strength, Charpy impact energy, and fracture-toughness measurements.

i. If, over the life-cycle of the mortar system, it is determined or suspected that damage from operational use, within the field condemnation criteria, may reduce the safe fatigue life of the barrel a comparative fatigue test shall be executed using specimens representative of the new field condition.

#### 4.2.2 Data Required.

a. For laboratory cycling, the data shall include representative pressure-time traces and maximum pressure, and number of cycles.

b. Tube inspection.

(1) Quantification of damage to the interior bore, when applicable.

(2) Report and photograph any failed cannon component.

(3) Bore measurement and borescope results, as applicable.

c. Failed section data should include yield strength, tensile strength, Charpy impact energy, and fracture-toughness measurements.

d. Crack growth rate if available from heat tint data.

#### 4.2.3 Data Analysis.

a. Interim Safe Fatigue Life.

(1) An interim safe fatigue life is used for manned firing testing purposes until a final safe fatigue life can be generated. To establish an interim safe fatigue life, two mortar cannons (tube and breech) must be cycled to failure. If manned firing before final safe fatigue life is anticipated, the test planning should include a number of ESCP rounds from one cannon sufficient to cover the required firing test, see paragraph 4.2.3(a)(2) for calculation. If there is no requirement for manned firing during testing, interim life can be omitted. Final safe fatigue life will still require six cannons tested.

(2) For the two tubes and breech mechanisms tested, determine which produces a failure with the fewest number of firings (including laboratory cycles). Count only those cycles and firings with chamber pressures at 97 percent of the FDP or above. The data should be examined to make sure the average of all firings and simulations should be above the FDP and the simulated firings should be controlled to make the data as evenly distributed about the FDP as possible. Also, examine the data from all firing tests to determine the largest number of rounds actually fired on any one item of the design tested. The interim safe fatigue life is to be the smaller of the following:

(a) One-third of the smaller of the two failure cycle counts from the interim-fatigue-life test.

(b) The largest number of rounds actually fired on any one item of the design tested (not necessarily one of the items used in the interim-fatigue-life test).

(c) The safety criteria as specified in paragraph 6.2 must be considered as a limiting factor when assigning the interim safe fatigue life.

b. Final Safe Fatigue Life.

(1) The final safe fatigue life is used to establish a service life of the mortar system. The final safe fatigue life is the maximum number of rounds that can be fired with a suitably low risk of having an actual failure. A cannon may reach the final safe fatigue life and pass all inspections, even so the cannon is considered non-serviceable for field use. The service life of a mortar tube will be the minimum of its wear life as determined in paragraph 4.1 or its final safe fatigue life. To establish a final safe fatigue life, six mortar cannons (tube and breech) must be cycled to failure. The two cannons cycled to failure in establishing the interim safe fatigue life may be counted to reduce the subsequent sample size to four cannons.

(2) The final safe fatigue life for either the designated tube or breech mechanism will be determined by a statistical analysis of the cycles-to-failure data taken from a six-tube and a six-breech mechanism test sample. The six data points from the six test items should be examined to establish the parametric form of the probability distribution function. Using methods appropriate for the particular family of distribution chosen, a 90-percent lower confidence bound on the 0.1 percentile of the distribution is calculated. This value is the final safe fatigue life of the tested item (see Appendix A).

5. DATA REQUIRED.

The data required are specified in the individual test procedures of paragraph 4.

6. PRESENTATION OF DATA.

6.1 Data.

a. For each group of control and expenditure rounds fired, calculate means of pressures and velocities and applicable measurements of performance such as target impact dispersion, center of impact, and impact probable error. If more than one lot of control round is being used, calculate these measures separately for each lot.

b. Examine the result of each projectile-charge combination for outliers and trends that are related to tube bore condition. Do this for each tube, and pool the results if appropriate.

c. Prepare charts and graphs to show muzzle velocity, pressure, crack growth (if applicable), and any applicable measurements of bore condition, such as erosion depth and

chrome plating loss, versus rounds fired. Prepare charts and graphs to show muzzle velocity, pressure, crack growth (if applicable), and applicable measurements of performance such as target impact dispersion and probable error, as a function of the applicable measurements of bore condition.

- d. Determine the fatigue life per Appendix A.

## 6.2 Safety Criteria.

a. Assemble and tabulate all results and safety information generated during the safety tests in accordance with this TOP. Assign a hazard level and probability to each hazard in accordance with Tables 1 and 2. Report the conditions of use under which each hazard was observed, and describe any features that require further investigation. Describe fully all hazards identified and recommended actions required to eliminate or avoid each potential hazard.

TABLE 1. HAZARD SEVERITY

DESCRIPTION	CATEGORY	MISHAP DEFINITION
CATASTROPHIC	I	Death or system loss
CRITICAL	II	Severe injury, severe occupational illness, or major system damage
MARGINAL	III	Minor injury, minor occupation illness, or minor system damage
NEGLIGIBLE	IV	Less than minor injury, occupational illness, or system damage

TABLE 2. HAZARD PROBABILITY

DESCRIPTION	LEVEL	SPECIFIC INDIVIDUAL ITEM	INVENTORY
FREQUENT	A	Likely to occur frequently	Continuously experienced
PROBABLE	B	Will occur several times in life of an item	Will occur frequently
OCCASIONAL	C	Likely to occur sometime in life of an item	Will occur several times
REMOTE	D	Unlikely but possible to occur in life of an item	Unlikely but can reasonably be expected to occur
IMPROBABLE	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

b. Determine the safety of components from the considerations of hazard severity and probability. Hazard-severity categories are defined to provide a qualitative measure of the worst potential consequences resulting from personnel error, environmental conditions, design inadequacies, procedural deficiencies, system, subsystem, or component failure or malfunction. Hazard severity categories are shown in Table 1. These hazard severity categories provide guidance to a wide variety of programs; however, adaptation to a particular program may be required. This adaptation may include definite transition between categories and further definition of the degree of injury and damage.

c. The probability that a hazard will occur during the planned life expectancy of the system can be described in potential occurrences per unit of time, events, population, items, or activity. Assigning a quantitative hazard probability to a potential design or procedural hazard is generally not possible early in the design process. A qualitative hazard probability may be derived from research, analysis, and evaluation of historical safety data from similar systems. Supporting rationale for assigning a hazard possibility shall be documented in hazard-analysis reports. An example of a qualitative hazard probability ranking is shown in Table 2.

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APPENDIX A. STATISTICAL DETERMINATION OF FATIGUE LIFE.

A.1 INTRODUCTION.

Because of the small sample sizes usually associated with fatigue test, statistical methods must be used. Ideally, the family of statistical distributions of fatigue life should be determined by examination of the fatigue data. In this Appendix, two types of statistical distributions which have been used for fatigue life determination are presented: the (three-parameter) Weibull and the (two-parameter) lognormal. It is the intent of this Appendix to show that there are several candidates for fatigue life distributions. No inference or preference is made or suggested that a particular method be used.

A.2 THE WEIBULL DISTRIBUTION.

a. The (three-parameter) Weibull distribution has three unknown parameters, a scale parameter  $\theta$ , a shape parameter  $\alpha$ , and a threshold parameter  $\eta$ . Both  $\theta$  and  $\alpha$  must be positive, while  $\eta$  may be positive or zero. The cumulative distribution function (CDF) of the distribution is given by:

$$F(x; \theta, \alpha, \eta) = \begin{cases} 0, & x \leq \eta \\ 1 - \exp\left[-\left(\frac{x - \eta}{\theta}\right)^\alpha\right], & x > \eta \end{cases} \quad (\text{Equation A1})$$

The average of the distribution is  $\eta + \theta\Gamma\left(1 + \frac{1}{\alpha}\right)$  and its variance is  $\theta^2\left[\Gamma\left(1 + \frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right)\right]$ , where  $\Gamma$  denotes the gamma function:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \quad (\text{Equation A2})$$

If  $0 < p < 1$ , then  $100p^{\text{th}}$  percentile of the distribution is  $\eta + \theta[-\ln(1 - p)]^{1/\alpha}$ .

b. The three-parameter Weibull distribution is mathematically difficult to manipulate. Since classical statistical procedures for confidencing population percentiles do not exist, a Bayesian scheme has been used. The Bayesian scheme assumes improper uniform prior distributions for the parameters. The result is that if we have fatigue failure times  $x_1, \dots, x_n$ , and are given  $0 < c < 1$  and  $0 < p < 1$ , then a lower confidence bound on the  $100p^{\text{th}}$  percentile of the distribution with confidence level  $c$  is the number  $V$  determined by the equation:

APPENDIX A. STATISTICAL DETERMINATION OF FATIGUE LIFE.

$$\begin{aligned}
 & c \cdot \int_0^\infty \int_0^\infty \int_{-\infty}^y \frac{\alpha^n}{\theta^{n\alpha}} \left[ \prod_{i=1}^n (x_i - \eta) \right]^{\alpha-1} \exp \left[ -\theta^{-\alpha} \sum_{i=1}^n (x_i - \eta)^\alpha \right] d\eta d\theta d\alpha \\
 & = \int_0^\infty \int_0^\infty \int_{V-q}^y \frac{\alpha^n}{\theta^{n\alpha}} \left[ \prod_{i=1}^n (x_i - \eta) \right]^{\alpha-1} \exp \left[ -\theta^{-\alpha} \sum_{i=1}^n (x_i - \eta)^\alpha \right] d\eta d\theta d\alpha
 \end{aligned} \tag{Equation A3}$$

where  $y = \min(x_1, \dots, x_n)$  and  $q = -\ln(1-p)$ . Determining the number  $V$  is very laborious and requires an iterative method for solution.

A.3 THE LOGNORMAL DISTRIBUTION.

a. The (two-parameter) lognormal distribution is the distribution of a positive random variable whose natural logarithm has a normal (Gaussian) distribution. The lognormal distribution has two parameters, denoted by  $\mu$  and  $\sigma$ .  $\sigma$  must be positive and  $\mu$  may be positive, negative or zero. The CDF of the distribution is given by:

$$F(x; \mu, \sigma) = \begin{cases} 0, & x \leq 0 \\ \Phi\left(\frac{\ln(x) - \mu}{\sigma}\right), & x > 0 \end{cases} \tag{Equation A4}$$

where  $\Phi$  denotes the CDF of the standard normal distribution:

$$\Phi(x) = \int_{-\infty}^x \frac{e^{-y^2/2}}{\sqrt{2\pi}} dy \tag{Equation A5}$$

The average of the distribution is  $e^{\mu + \frac{\sigma^2}{2}}$  and its variance is  $(e^{\sigma^2} - 1)e^{2\mu + \sigma^2}$ . If  $0 < p < 1$ , then the 100<sup>th</sup> percentile of the distribution is  $e^{\mu + \sigma\phi_p}$ , where  $\phi_p$  is the solution of the equation  $\Phi(\phi_p) = p$ .

b. Statistical procedures for the lognormal distribution are derived from procedures for the normal distribution. In particular, if we have fatigue failure times  $x_1, \dots, x_n$ , then compute the mean  $m$  and the standard deviation  $s$  of the logarithms:

APPENDIX A. STATISTICAL DETERMINATION OF FATIGUE LIFE.

$$y_i = \ln x_i \text{ for all } i = 1, \dots, n \quad (\text{Equation A6})$$

$$m = \frac{1}{n}(y_1 + \dots + y_n) \quad (\text{Equation A7})$$

$$s = \sqrt{\frac{1}{n-1}[(y_1 - m)^2 + \dots + (y_n - m)^2]} \quad (\text{Equation A8})$$

$m$  is an estimate of  $\mu$  and  $s$  is an estimate of  $\sigma$ . If  $0 < c < 1$  and  $0 < p < 1$ , then a lower confidence bound on the  $100p^{\text{th}}$  percentile of the distribution with confidence level  $c$  is of the form  $e^{m - K_{p,c,n}s}$ , where  $K_{p,c,n}$  is a tolerance factor that depends only on  $p$ ,  $c$  and  $n$ . In calculating fatigue life, use  $p = 0.001$  and  $c = 0.9$ . Values of  $K_{0.001,0.9,n}$  are given in Table A.1 for various values of  $n$ .

TABLE A.1. EXAMPLE OF TOLERANCE FACTORS  
FOR THE LOGNORMAL DISTRIBUTION

( $p = 0.001, c = 0.9$ )

Sample Size, ( $n$ )	Tolerance Factor $K_{0.001,0.9,n}$
2	24.582
3	9.651
4	7.129
5	6.111
6	5.556
7	5.202
8	4.955
9	4.771
10	4.629

c. As an example of the above techniques, consider the following results of a fatigue test of some 155-mm artillery breeches. Six breeches were tested, yielding the following cycles to failure: 8,669, 8,633, 10,018, 9,580, 9,671 and 11,475. None of the breeches had been fired prior to being fatigue-tested. The data and the calculations may be conveniently organized as in Table A.2. Such a table is easily created using readily available spreadsheet programs.

APPENDIX A. STATISTICAL DETERMINATION OF FATIGUE LIFE.

TABLE A.2. EXAMPLE OF FATIGUE TEST CALCULATIONS

Original Data		Natural Logarithms	
$x_1$	8,669	$y_1$	9.0675
$x_2$	8,633	$y_2$	9.0633
$x_3$	10,018	$y_3$	9.2121
$x_4$	9,580	$y_4$	9.1674
$x_5$	9,671	$y_5$	9.1769
$x_6$	11,475	$y_6$	9.3479
Average		m	9.1725
Standard Deviation		s	0.1052

d. From Table A-1, we see that  $K_{0.001,0.9,6} = 5.556$ . Then the fatigue life is equal to  $e^{m-K_{0.001,0.9,6}s} = e^{9.1725-5.556 \times 0.1052} = 5,367$ . In practice, the fatigue life is usually rounded down to some round number for easier use in the field. In this case, a 5,300 round fatigue life is used.

APPENDIX B. ABBREVIATIONS.

°C	degrees Celsius
CCDC Armaments Center	Combat Capabilities Development Command Armaments Center (formerly the U.S. Army Armaments Research, Development and Engineering Center (ARDEC))
CDF	cumulative distribution function
DTP	Detailed Test Plan
EDM	electrical-discharge machining
ESCP	extreme service charge pressure
°F	degrees Fahrenheit
FDP	fatigue design pressure
FTaB	Firing Tables and Ballistics Division (part of CCDC Armaments Center)
ITOP	International Test Operations Procedure
m/s	meters per second
MPa	megapascal
MPI	magnetic particle inspection
MRBR	mean rounds between failure
NATO	North Atlantic Treaty Organization
RAM	reliability, availability, and maintainability
STANAG	Standardization Agreement
TM	Technical Manual
TOP	Test Operations Procedure
UT	ultrasonic testing

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APPENDIX C. REFERENCES.

1. TOP 03-2-050, Testing of Mortar Systems, 11 March 2010.
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7. STANAG 4110, Definition of Pressure Terms and Their Interrelationship for Use in the Design and Proof of Cannons or Mortars and Ammunition, (Edition 4), 30 November 2005.
8. ITOP 03-2-601, Firing Tables and Ballistic Match Tests, 16 October 1995.
9. ITOP 03-2-829, Cannon Safety Test, 22 May 2003.

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- a. Memorandum for Record, Subject: Testing Methodology for Mortar Tubes, CCDC Armaments Center (formerly RDECOM-ARDEC) and U.S. Army Test and Evaluation Command, 14 February 2018.
- b. ITOP 04-2-504(1), Safety Testing of Field Artillery Ammunition, 22 September 2005.

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM

10 May 2019

MEMORANDUM FOR

Commanders, All Test Centers  
Technical Directors, All Test Centers  
Directors, U.S. Army Evaluation Center  
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure 03-2-052 Mortar Cannon Safety Tests,  
Approved for Publication

1. Test Operations Procedure (TOP) 03-2-052 Mortar Cannon Safety Tests, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

a. This TOP provides test procedures for determining the wear life and safe fatigue life for mortar cannons. The procedures in this document augments TOP 03-2-050 Testing of Mortar Systems, which describes procedures for determining the operational capabilities of muzzle loaded mortar systems.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at <https://vdls.atc.army.mil/>.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to [usarmy.apg.atec.mbx.atec-standards@mail.mil](mailto:usarmy.apg.atec.mbx.atec-standards@mail.mil).

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Firepower Directorate (TEAT-FPM), U.S. Army Aberdeen Test Center, 400 Collieran Road, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: <https://www.atec.army.mil/publications/documents.html>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.