TM 9-1000-202-35

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

OPERATING RROCEDURES

EVALUATION OF CANNON TUBES

HEADQUARTERS, DEPARTMENT OF THE ARMY
MAY 1959

TECHNICAL MANUAL No. 9-1000-202-35

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WASHINGTON 25, D. C., *4 May 1959*

OPERATING PROCEDURES: EVALUATION OF CANNON TUBES

*** This manual supersedes TB 9-1860-3, 28 April 1948, and together with TM 9-3140-34, 15 August 1957, supersedes TB ORD 555, 12 March 1954.**

CHAPTER 1

INTRODUCTION

1. Scope

a. The scope of this series of manuals, as listed in *b* below, is to cover the latest information and instructions for judging cannon tubes for the guidance of ordnance personnel concerned with cannon tube inspection and calibration. The subjects covered are: Evaluation of cannon tubes; the operation and maintenance of bore inspection devices; and operation and maintenance of velocity measuring equipment.

b. This manual is one of the series relating to cannon tube inspection. The complete series is listed in (1) through (3) below.

(1) TM 9–1000–202–35—Operating Procedures: Evaluation of Canon Tubes.

(2) TM 9–4933–200–35—Operation and Field and Depot Maintenance: Pullover Gages, Borescopes M1 and M2, and Pressure Gage M3.

(3) TM 9–1860–7 —Operation and Organizational Maintenance: Field Sky Screen and Counter Chronograph.

c. This manual differs from TB 9–1860–2, 29 November 1945, as follows:

(1) Adds information on:
Tables showing correlation between bore measurement, and remaining life or muzzle-velocity loss, wear characteristics, and ballistic data for additional weapons.
Equivalent full charge values for all ammunition.

(2) Revises information on:
Estimated service life of weapons.
Measuring points used in taking bore measurements with a pullover gage.
Wear characteristics of weapons (chrome plated bores).

(3) Deletes reference to:
37-mm gun cannons M3 and M5.
3-inch gun cannons M5 and M7.
6-inch gun cannon M1 (T2).

2. General

a. Inspection procedures for cannon tubes are established for the determination of conditions within cannon tubes that may affect the tube ballistically or defects which may endanger the lives of the using personnel. These conditions are determined by visual inspection, gage inspection, and velocity measurement.

b. Visual inspection is used to discover and evaluate damage in cannon tubes. This damage can be due to external sources such as hostile fire, malfunction of ammunition, etc., or it can be due to structional defects within the metal as evidenced by cracks.

c. Gage inspection is used to determine the amount of normal erosion to which a cannon tube has been subject. As this erosion is a direct result of firing, and as the amount of erosion can be predicted with some accuracy, the bore measurement taken with the pullover gage can be used to estimate the remaining service life of a cannon tube.

d. Velocity measurement can be used to calibrate cannon tubes because wear and damage in a cannon tube results in a loss of velocity in the projectile.

CHAPTER 2

TYPES OF EROSION AND DAMAGE

Section I. EROSION

3. General

Erosion is the phenomena of removal of metal from the interface of cannon by movement of high-temperature gases and residues generated from the burning of propellant, as well as by the movement of the projectile through the bore. Erosion is often divided into three phases: "gas wear", from the washing action of the gases, appearing as a smooth enlargement of the rifling; "scoring" or localized "gas

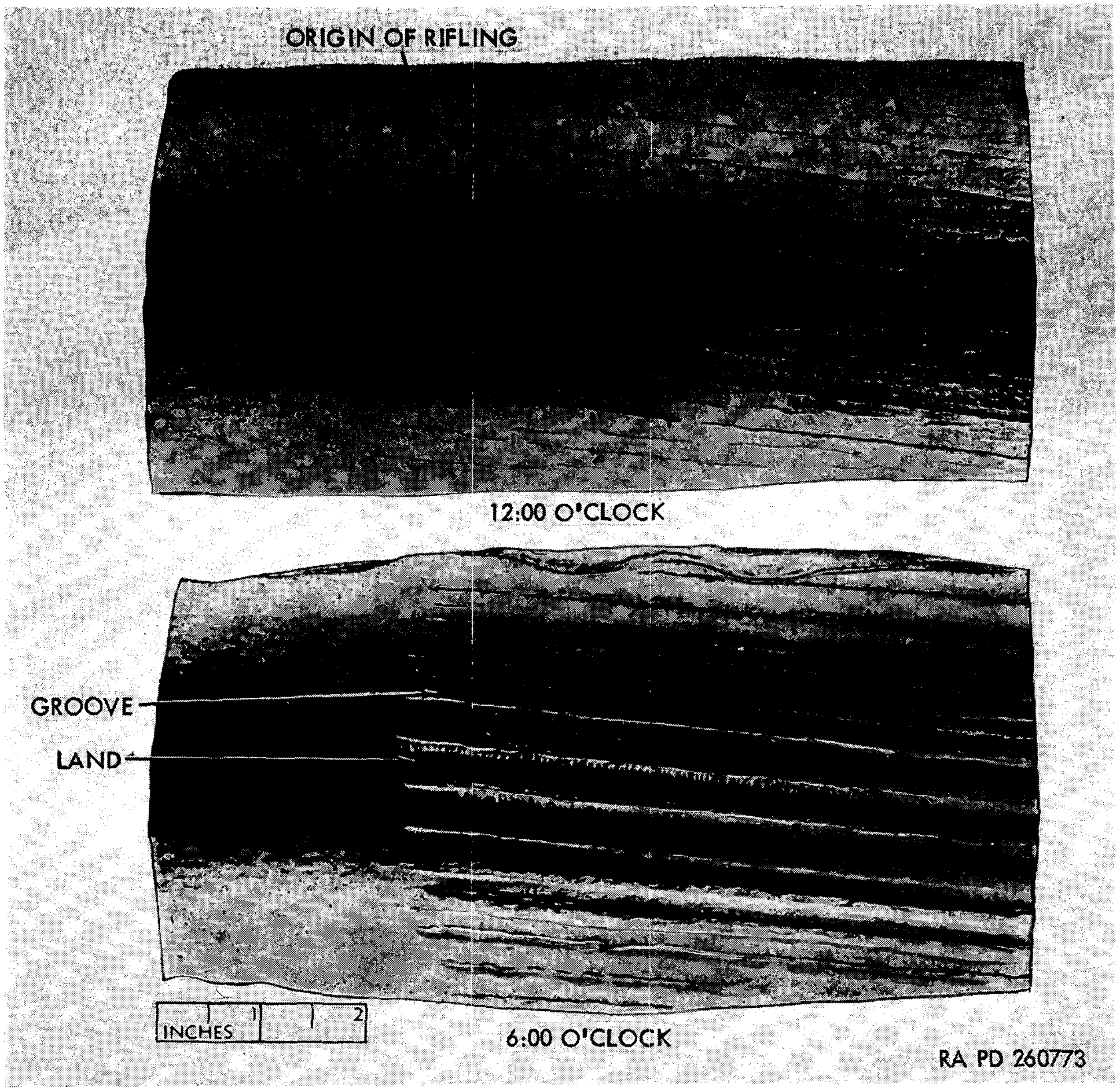

Figure 1. Origin of rifling of 155-mm gun showing lands obliterated at 12 o'clock (top) and advanced gas erosion at 6 o'clock (bottom).

wear", appearing as guttering at an increasing rate; and "abrasion", or "mechanical wear", caused by the projectile rubbing against the bore interface. These three phases are described in detail below. Combinations of the three effects will appear to a varying degree in different gun models, depending primarily on the projectile type fired, the velocity level, and whether or not the bore is chrome plated.

a. Gas Erosion. The smooth wearing away of the metal by the action of the hot gases is termed "gas erosion". This removal of metal is caused by a combination of the movement of the gases, the heating of the steel, and a chemical action. Both lands and grooves are affected, but the action is usually greater on the lands at the commencement of rifling. The greatest gas erosion per round fired generally occurs initially and then decreases with subsequent firing. In the early stages of gas erosion, the lands become rounded at the edges. As the wearing-away continues, the lands might become obliterated at the 12 o'clock position and well worn at the 6 o'clock position (fig. 1). Gas erosion at the mouth of the chamber or front end of the cartridge case for guns firing fixed or semifixed ammunition appears as "annular erosion" (fig. 2).

b. Scoring. Scoring is attributed to a nozzle or vent action of the gas escaping past the rotating band. Scoring may appear as a longitudinal streak fanning out toward the muzzle (fig. 3) or sometimes as a trough (fig. 4). Tool marks or land damage usually start the scoring because of incomplete obturation or sealing by the rotating band at that point. Once started, scoring unlike gas erosion, increases with each round although it does not become evident until after a number of rounds have been fired. Usually the grooves are more affected than the lands except in plated bores. The longitudinal streaks then develop into irregular gutters and indentations, extending gradually over the grooves and into the nondriving side of the land. When severe gas erosion accompanies the localized scoring, the effect of the scoring is somewhat less (fig. 1), and the pattern is usually irregular. Scoring frequently begins on the upper part of the bore around the 12 o'clock region, due to the weight of the projectile causing the greater clearance at the top when seated. This is usually more evident in guns firing separate-loading ammunition. Firing at rapid rates after scoring has once started produces severe scoring (fig. 5). Deep scoring reduces the strength of the cannon tube, but most cannon tubes will fail ballistically before scoring becomes dangerous.

c. Abrasion.

(1) Abrasion is a slow mechanical wearing away of the lands. The greatest wear usually occurs at the 6 o'clock position

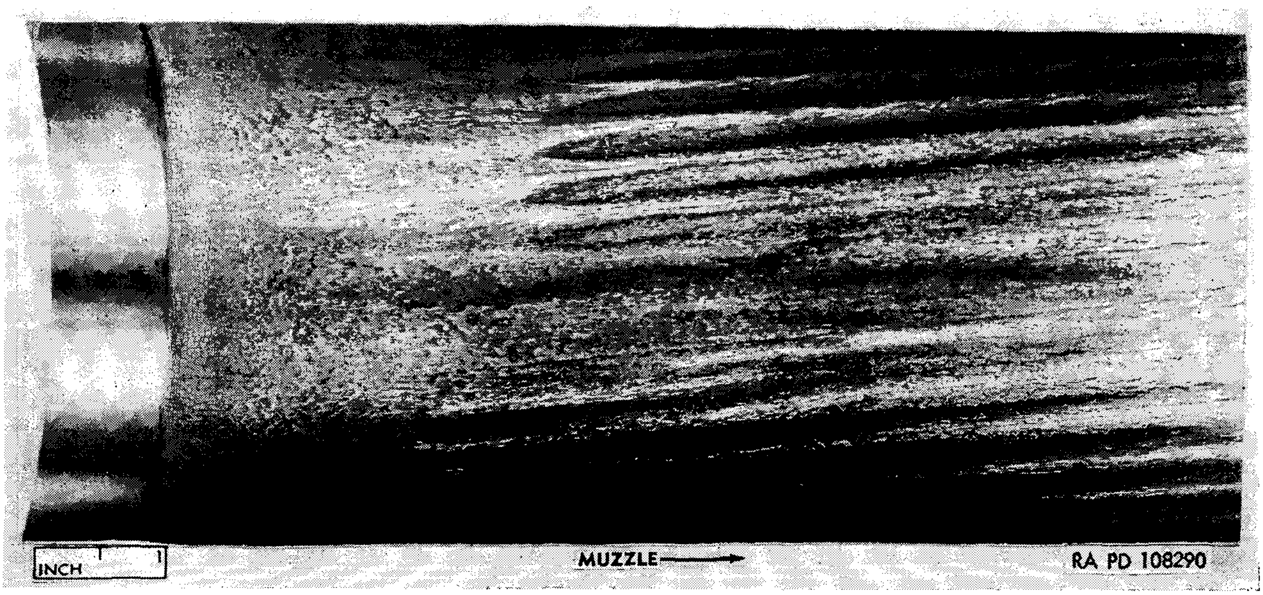

Figure 2. Gas erosion at mouth of chamber ("annular erosion") in 90-mm gun.

at the origin of rifling, because of the greater friction between the projectile and the bore at the bottom. This wear permits the rotating band to drop, allowing a larger clearance between the top of the rotating band and the tube, which accelerates gas erosion and then scoring (fig. 6).

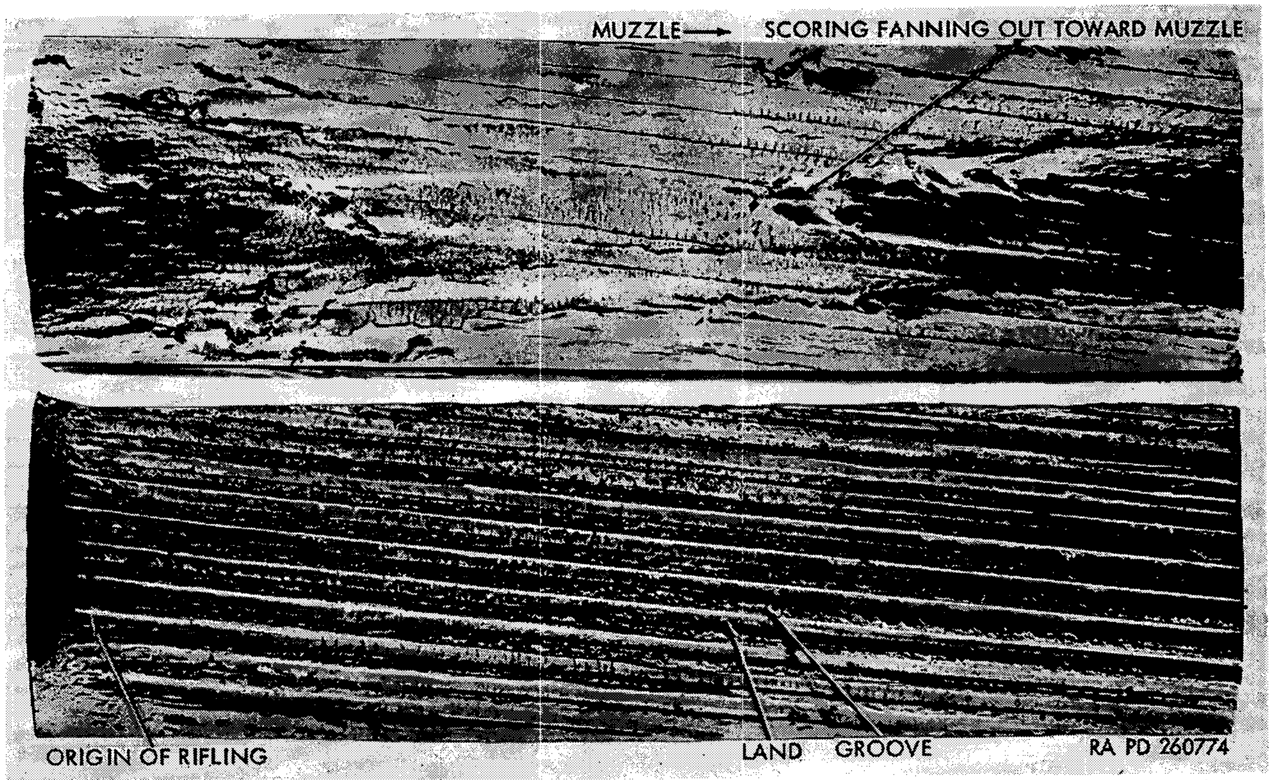

Figure 3. Scoring at 12 o'clock and gas erosion at 6 o'clock (with light scoring in the grooves) of 155-mm gun.

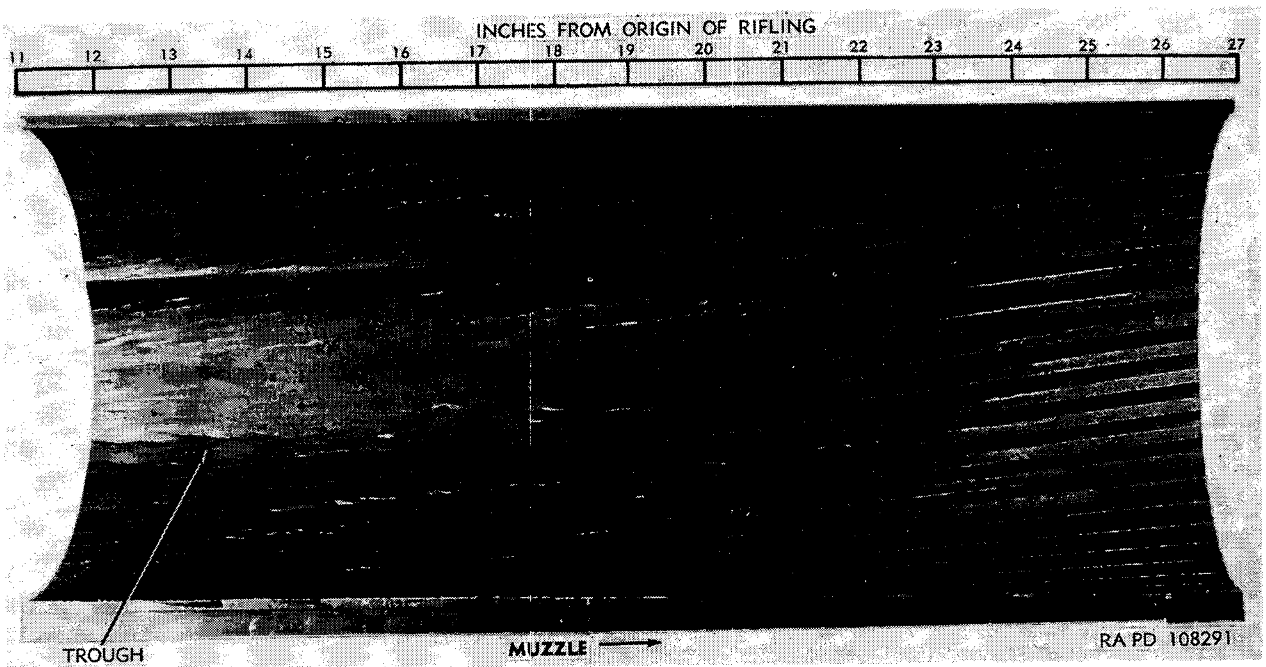

Figure 4. View of a section from a test model, 155-mm gun showing a long shallow trough at 12 o'clock created by scoring effect.

(2) Eccentric rotation of a projectile from poor ramming or other causes results in spiral wear or erosion of the same group of lands down the bore following the rifling (fig. 7).

(3) Abrasion at the muzzle end generally takes the form of reduced land height, beginning somewhere about midlength in the bore and increasing toward the muzzle along the same lands.

4. Erosion in Plated and Nonplated Bores

a. The mechanics of erosion between chromed and nonchromed bores are distinctly different. Erosion in unplated bores is usually of a smooth, even nature, extending a considerable distance down bore, with heavy scoring occurring in the latter stages of tube life. Erosion in these tubes is measurable almost from the initial firing. In plated bores, however, erosion is not usually measurable until a number of rounds have been fired.

b. A limited amount of chrome plate is sometimes removed from the bore during the first proof rounds. This is due to irregularities in the plate such as nodules or treeing of the deposit during the plating process. This removal may be in the nature of spalling, wherein the base metal is not affected, or of chipping, wherein some portion of the base metal is removed with the plate. The limit to which this may occur and be acceptable is outlined in the detail specification for the individual weapon. This phenomena in 75-mm or 90-mm is normally scattered lightly throughout the bore but in 120-mm and larger bores, it occurs to a more severe degree at the muzzle end. As this condition stablizes early in firing, it is not believed to be a factor in life evaluation.

c. As firng continues, erosion begins on the sides of the lands at, and just forward of the commencement or rifling (fig. 8). Erosion progresses across the lands, removing the base metal, and undermining the chrome plating, causing it to break away (fig. 8). Continued erosion of the base metal advances the wear down the bore, but not to as great an extent as in unplated bores. After the plating has been removed, normal erosion, primarily scoring occurs to the base metal. Since the lands are affected first, it is not uncommon to find them scored below groove depth in the area of the commencement of rifling, before the plating has been removed from the grooves. In most cannon, erosion is usually greater in the vertical axis.

5. Effects of Erosion

a. Combinations of the three phases of erosion will very often appear in varying degrees in different weapon models or in different weapons of the same model used differently. Erosion in bores will reduce the muzzle velocity.

b. Erosion in most weapons is usually greatest at the origin of rifling (fig. 9), thus enabling propellant gas to escape past the rotating band. In the same gun, where two different weights of projectiles are used, the muzzle-

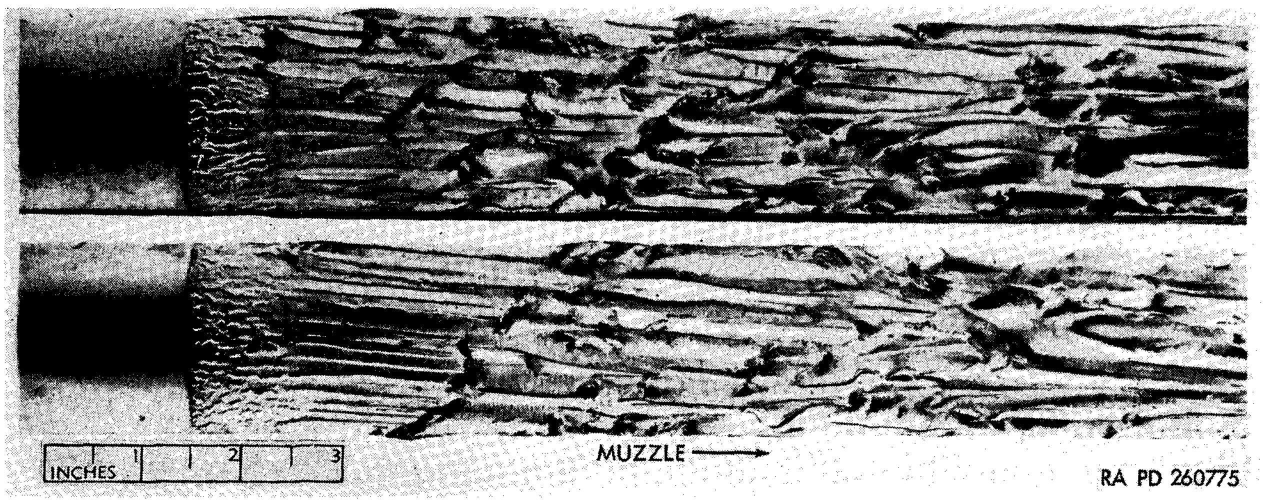

Figure 5. Severe scoring caused by rapid and prolonged firing of a 76-mm gun at origin of rifling (condemned): (top) 12 o'clock (bottom) 6 o'clock.

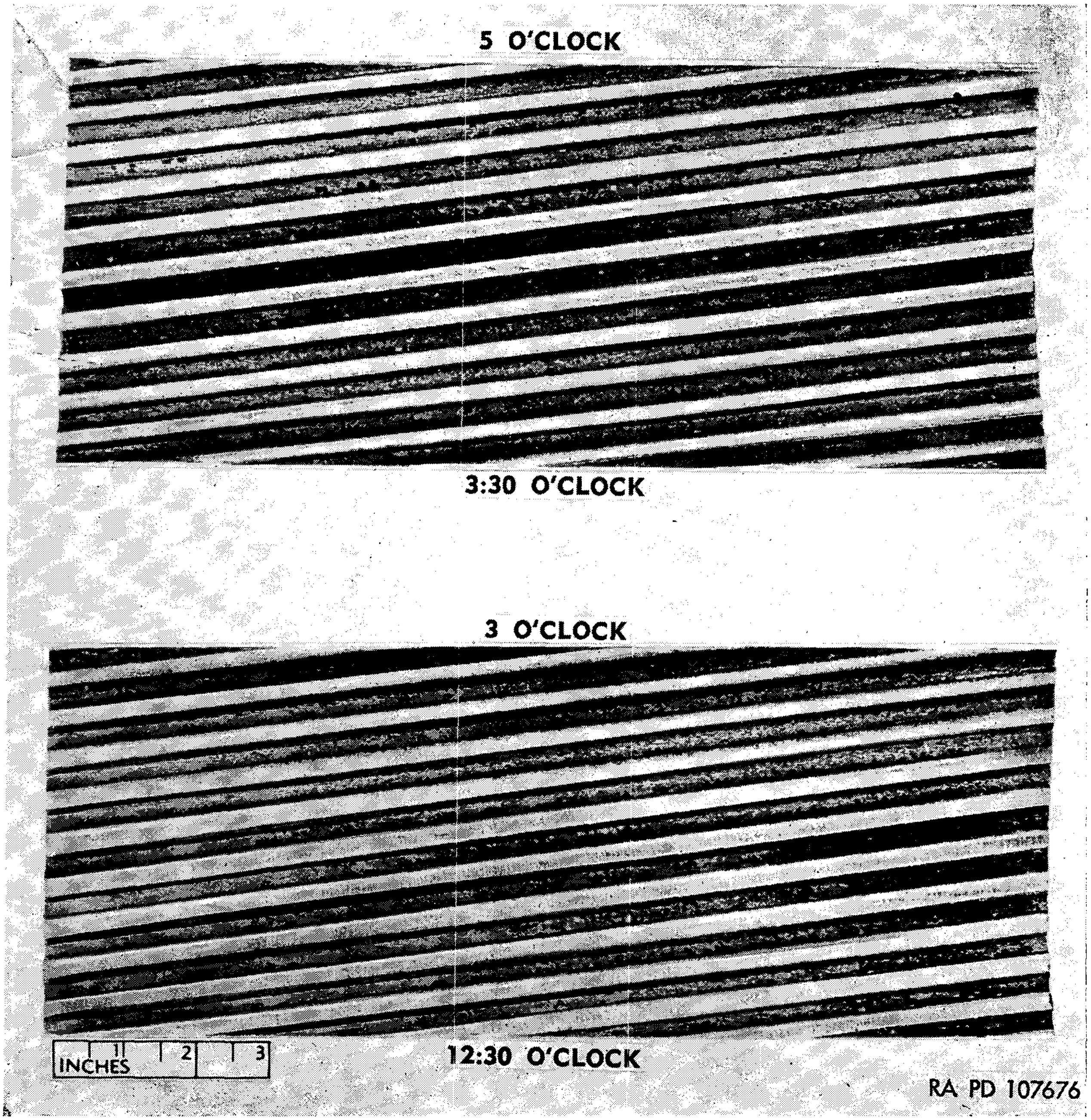

Figure 6. Abrasion at 5 o'clock accompanied by a greater gas wear at 12 o'clock in 155-mm gun.

velocity loss for a given bore measurement is greater for the heavier projectile. Where two propellants for the same velocity level but different granulations are used, the muzzle-velocity loss for a given bore measurement is greater for the slower-burning propellant.

c. Since one of the primary effects of erosion is a loss of muzzle velocity, there must be a corresponding decrease in maximum range. Up to a certain point, such variations in muzzle velocity can be compensated for by changes in elevation, but eventually the tube will reach a stage of wear which permits projectile to achieve some measure of velocity before fully engaging the full form of the rifling. This wear will eventually cause stripping or shearing of the rotating band. By this is meant the shearing of the engraved portion of the band so that the band surface is smooth, or the stripping of the band from the projectile. This condition prohibits further use of the tube from a ballistic standpoint.

d. Within the condemnation limits prescribed for most weapons there is no significant change in the probable error. Loss of precision in direction will not occur to any considerable degree except when the projectile fails to attain proper rotation. The loss in range under these circumstances may be as much as 40 percent of the range predicted for the muzzle velocity and the elevation. The primary cause of failure to attain proper rotation is strippng or shearing of the rotating band.

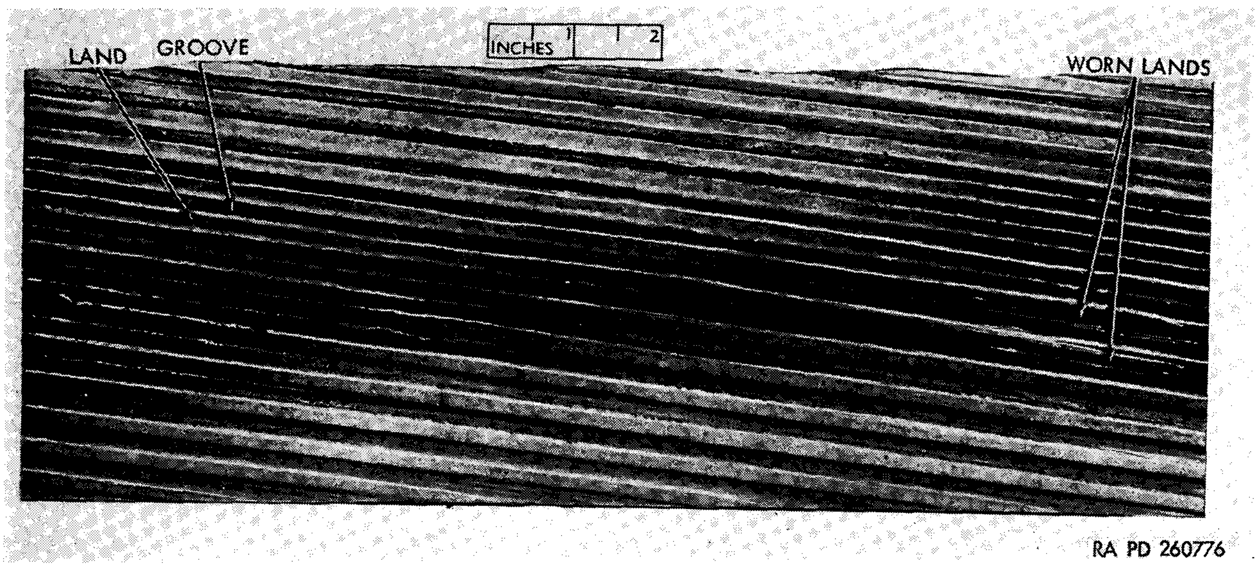

Figure 7. Wear following a group of lands in 8-inch gun tube at 6 o'clock, 41 to 59 inches from muzzle face.

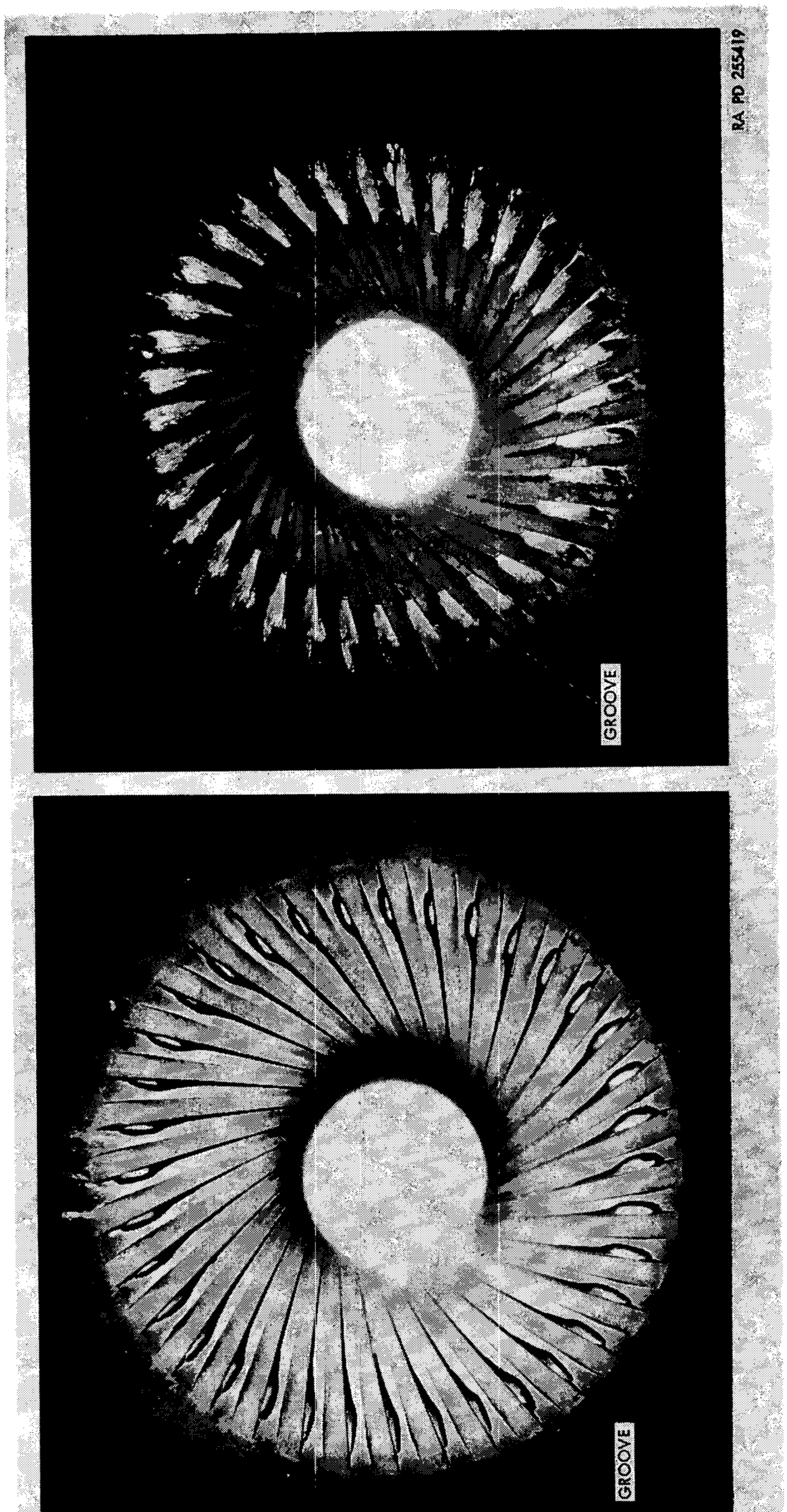

Figure 8. Erosion in chrome-plated tubes.

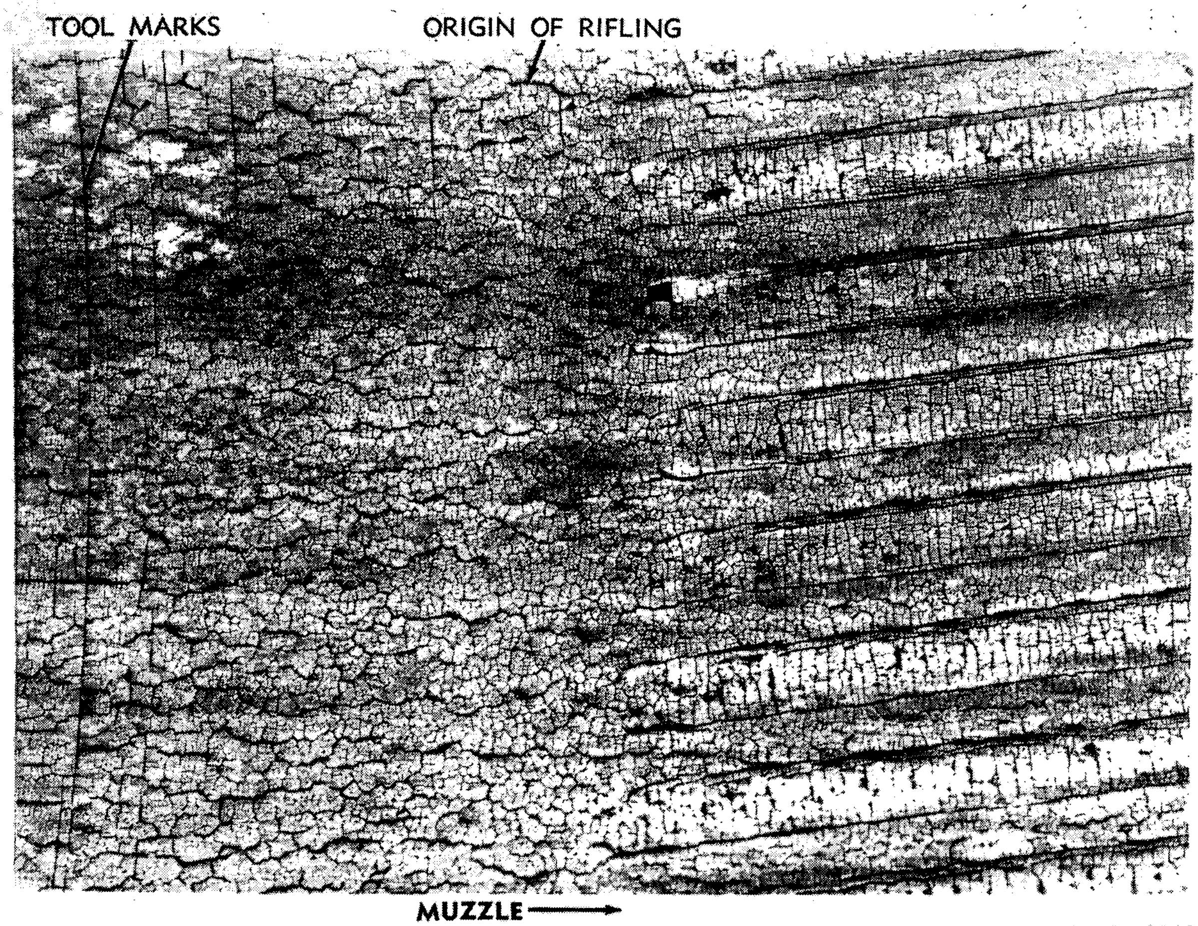

Figure 9. Advanced gas erosion at origin of rifling near 6 o'clock region of 155-mm gun.

Section II. DAMAGE

6. Manufacturing Defects

Every cannon is subject to minor flaws of raw materials, finish imperfections, and variations of dimensions within tolerances in manufacture. Superficial surface scratches and checks are often accepted, since these are considered negligible in effect. Small gouges in rifling are included in this category. Radial tool marks (fig. 10) affect the pattern of heatchecking.

7. Coppering

In new cannon tubes, copper from the rotating band of projectiles is deposited in the tube as the rounds are fired and the tube becomes hot. This temporarily affects the muzzle velocity, due to the copper buildup and resulting bore constriction, until succeeding rounds are fired, after which the condition becomes stabilized. When changing from a high-zone charge to low-zone charge, the first few rounds are considered "conditioning" rounds and are disregarded insofar as range correction is concerned. Except for the conditioning rounds, there is no serious ballistic effect, either in velocity or dispersion, due to coppering.

Note. This condition has been minimized by the addition of decoppering agents in some ammunition.

8. Expansions

Small expansions of tubes have the same effect as any other enlargement, namely, a velocity loss. Large expansions indicate a structual deformation of the tube wall, which is considered unsafe.

9. Rust

The small pits caused by the removal of rust tend to increase the coppering effect. Since rusting causes a removal of metal resulting in an increase of the diameter of the bore, some muzzle-velocity loss may be expected.

10. Constrictions

A constriction of the bore is a deformation which may be caused by a raised land or external blow, which decreases the diameter of the bore.

11. Deformation of Lands

The condition of the lands affects the performance of the projectile as it travels through the bore and eventually toward the target. This is especially true in high-velocity cannon where it can result in the stripping or shearing of the rotating band. The characteristics of deformation of the lands in cannon tubes are covered in *a* through *d* below.

a. In some tubes, the lands become hammered or battered allowing propellant gas to leak past the projectile, thus adversely affecting interior ballistics. The cause is thought to be imperfect centering or severe ramming of the projectile.

b. When the edges of a flattened land chip or spall (fig. 11), the corner is said to be chipped. This condition is the breaking away of the driving or nondriving edges of the land caused by a combination of land flattening and side thrusts on the lands.

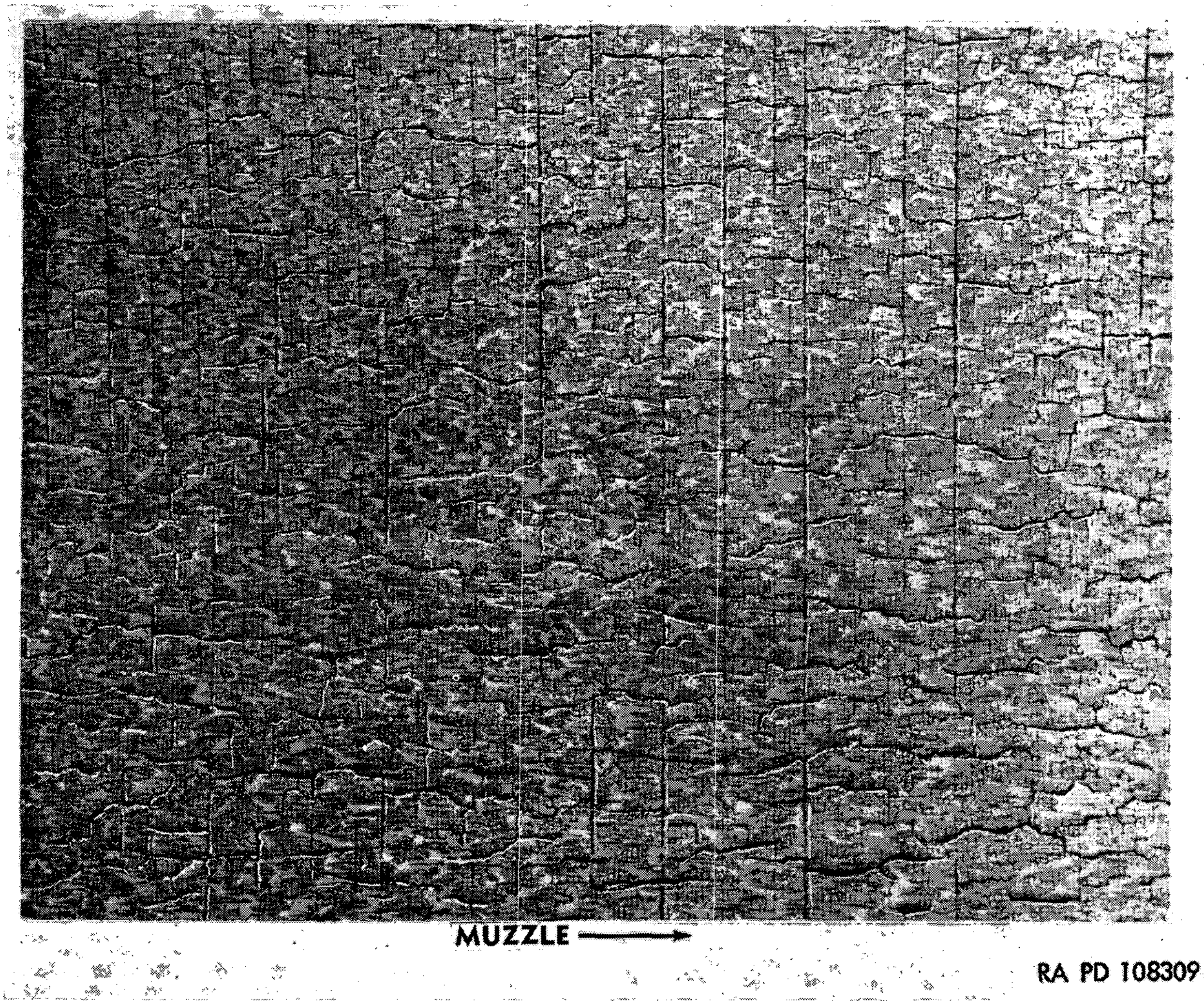

Figure 10. View of 1 o'clock region near breech end of chamber front slope, 46 inches from breech face of 155-mm gun tube, showing check progression and influence of tool marks.

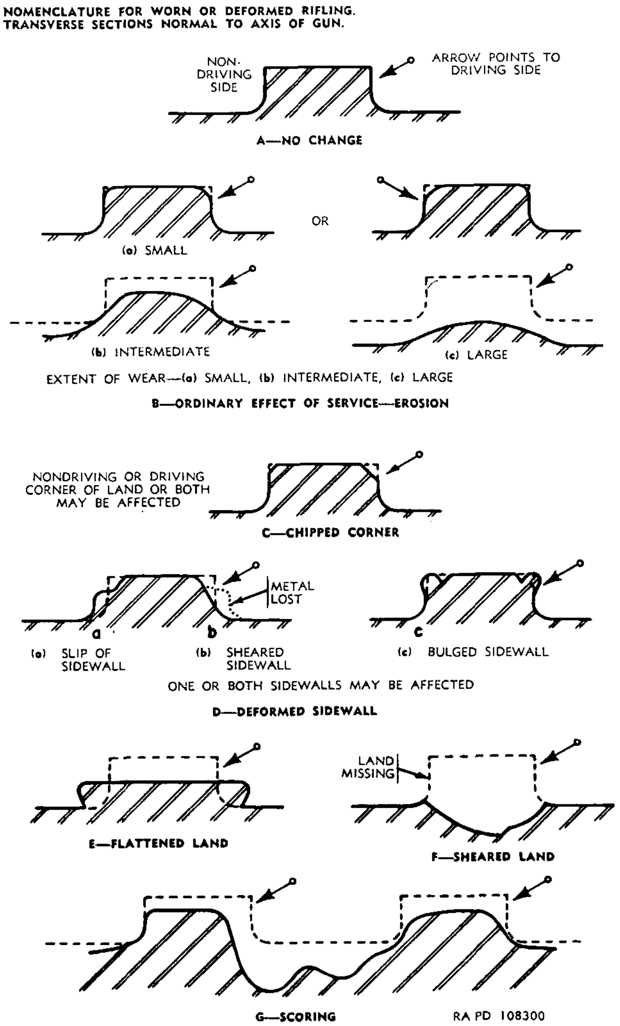

Figure 11. Sketch of transverse section normal to axis of gun tube, showing nomenclature for worn or deformed rifling.

c. The stress concentration at the root of the land induces a slippage of the metal and cracking at the corner. When the crack spreads upward, a part of the land is sheared (fig. 11 and 12).

d. When a crack spreads fully across or underneath the land (fig. 12), the land is said to be sheared (fig. 13). When the ends of the sheared land remain attached to the bore interface, the land is raised (fig. 14). If the raised portion is near the origin of rifling, it often prevents the loading or seating of a projectile. When the ends break off and the land is missing, the land is said to be stripped (fig. 15). The lands in recoilless rifles may be deformed due to orientation of the round in the chamber.

12. Pastilles

When an indentation appears in the bore interface which resembles a gas pocket in the casting, the indentation is known as a pastille (figs. 16 and 17). Pastilles do not usually have a serious ballistic effect.

13. Ammunition Malfunctioning

a. Prematures in the bore of a gun tube, resulting from fuze malfunctioning, weakness of the projectile, or other causes, generally damage the tube seriously. The damage may vary from a small bulge caused by low-order functioning of the explosive charge to a fragmented tube caused by high-order functioning of the explosive charge.

b. When fuze safety wires are inadvertently left on the projectile, light indentations can be made in the bore by the round fired (figs. 18 and 19).

c. Cartridge case splits may cause longitudinal or circumferential scoring of the chamber. This scoring does not seriously impair the strength of the chamber but may cause case extraction difficulties if any degree of depth is evident.

14. Material Left in Bore

Particles of dirt, stones, sticks, debris, or any other foreign material in the bore when the gun is fired may cause varying degrees of damage.

15. Damage by Hostile Fire

Small arms projectiles or fragments from high-explosive projectiles can damage tubes (figs. 20–22).

16. Progressive Stress Damage

In certain types of cannon tubes, minute defects started by fatigue, heat checking, or tool marks deepen with repeated firing. This continued or progressive defect enlargement, known as progressive stress damage will lead ultimately to failure of the cannon tube. Failure of this type will usually occur by fragmentation or fissuring. Limits on the number of rounds to be fired should give ample safety margin.

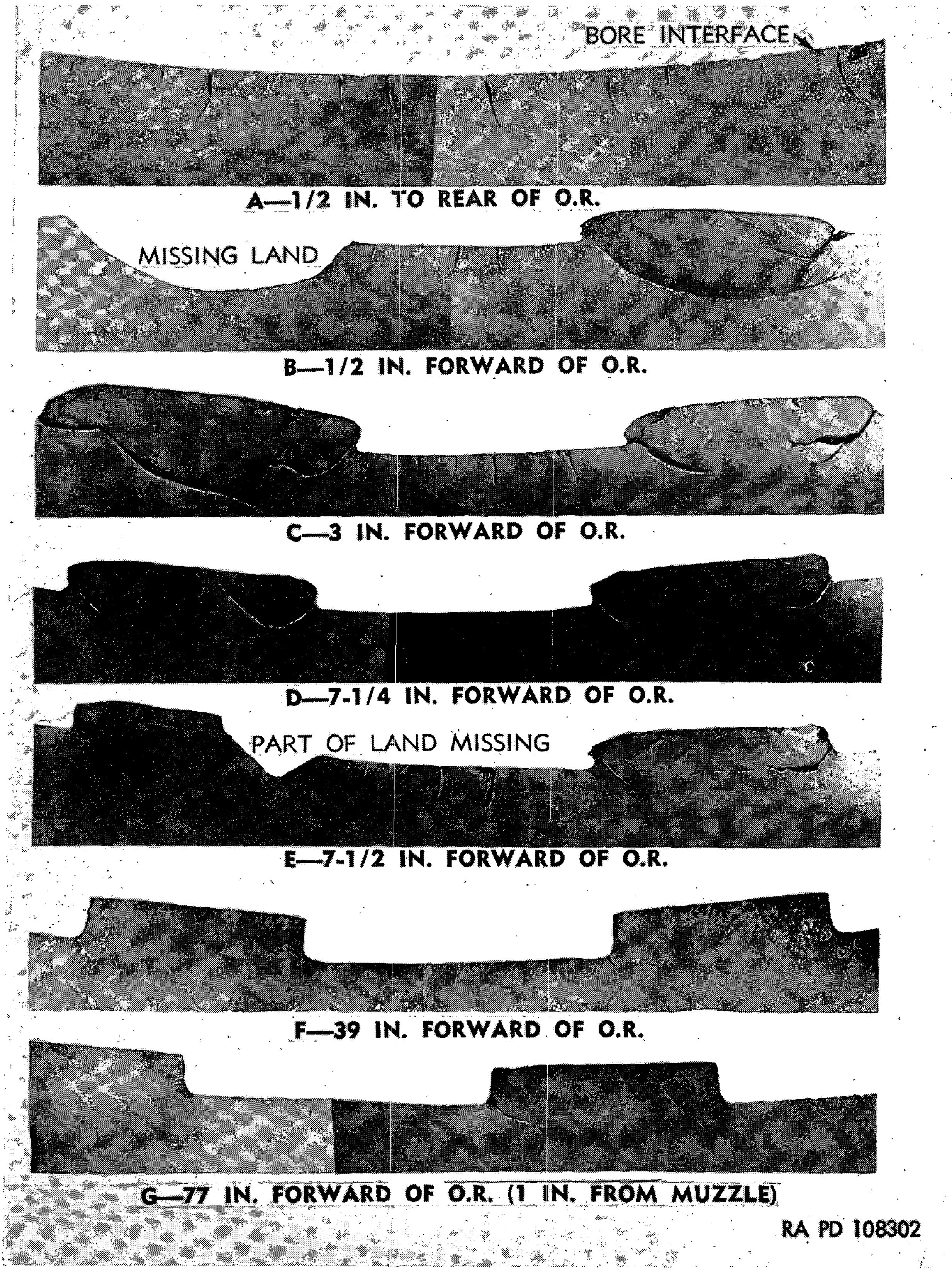

Figure 12. Transverse section of 105-mm howitzer tube showing shearing, stripping, and deformation of lands (driving side of land is on the right).

Figure 13. Origin of rifling in 105-mm howitzer tube showing sheared lands (arrow indicates land at 6 o'clock).

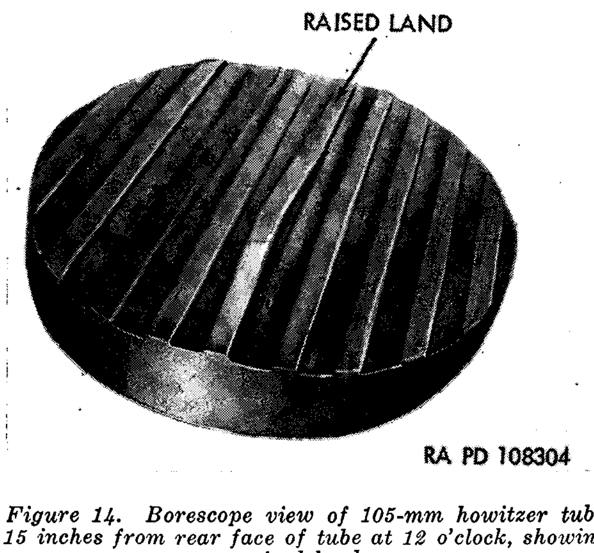

Figure 14. Borescope view of 105-mm howitzer tube, 15 inches from rear face of tube at 12 o'clock, showing raised lands.

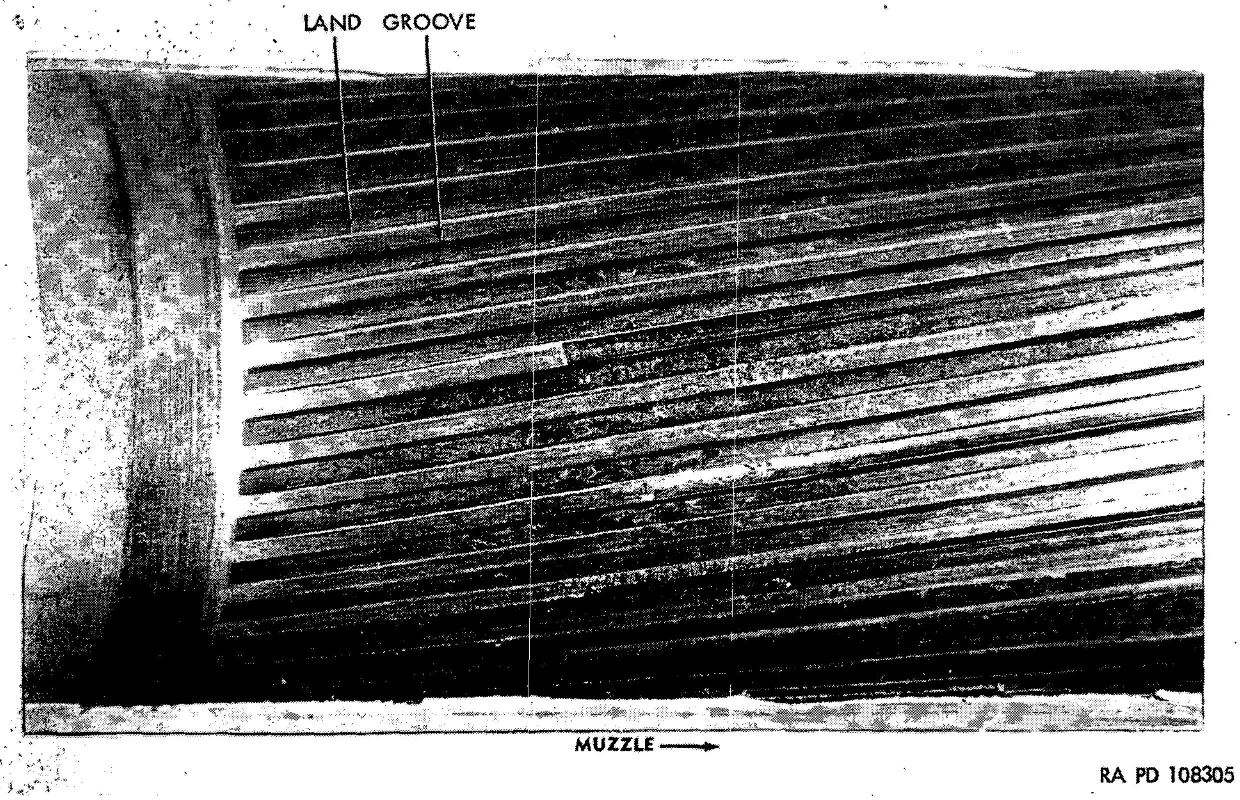

Figure 15. View of vicinity of origin of rifling in 105-mm howitzer tube, showing lands missing, known as "stripping".

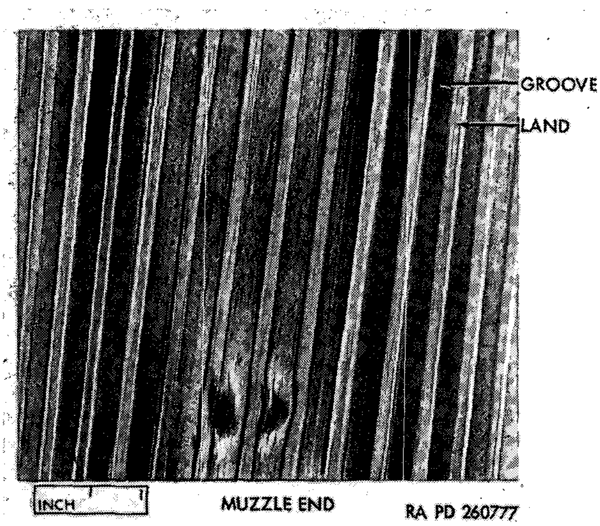

Figure 16. A pastille 30 inches from the muzzle at 6 o'clock in a 155-mm howitzer.

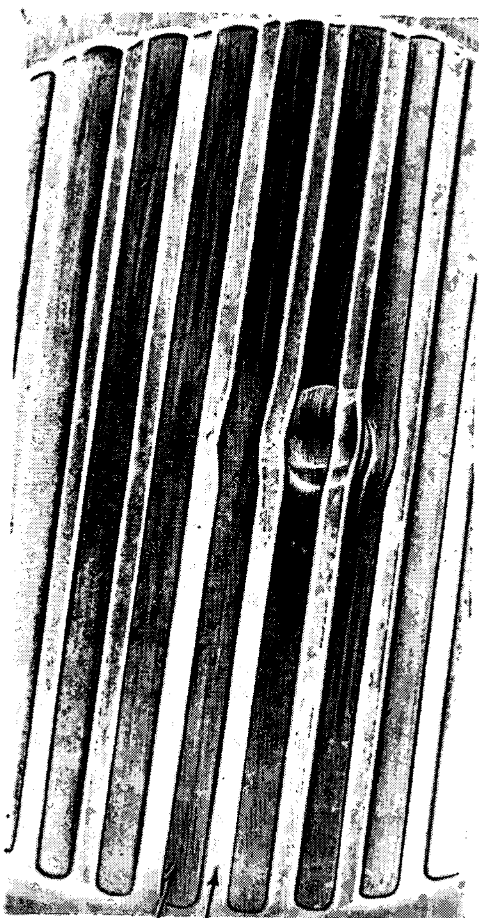

Figure 17. A pastille 23 inches from the muzzle at 5:30 o'clock in a 155-mm howitzer.

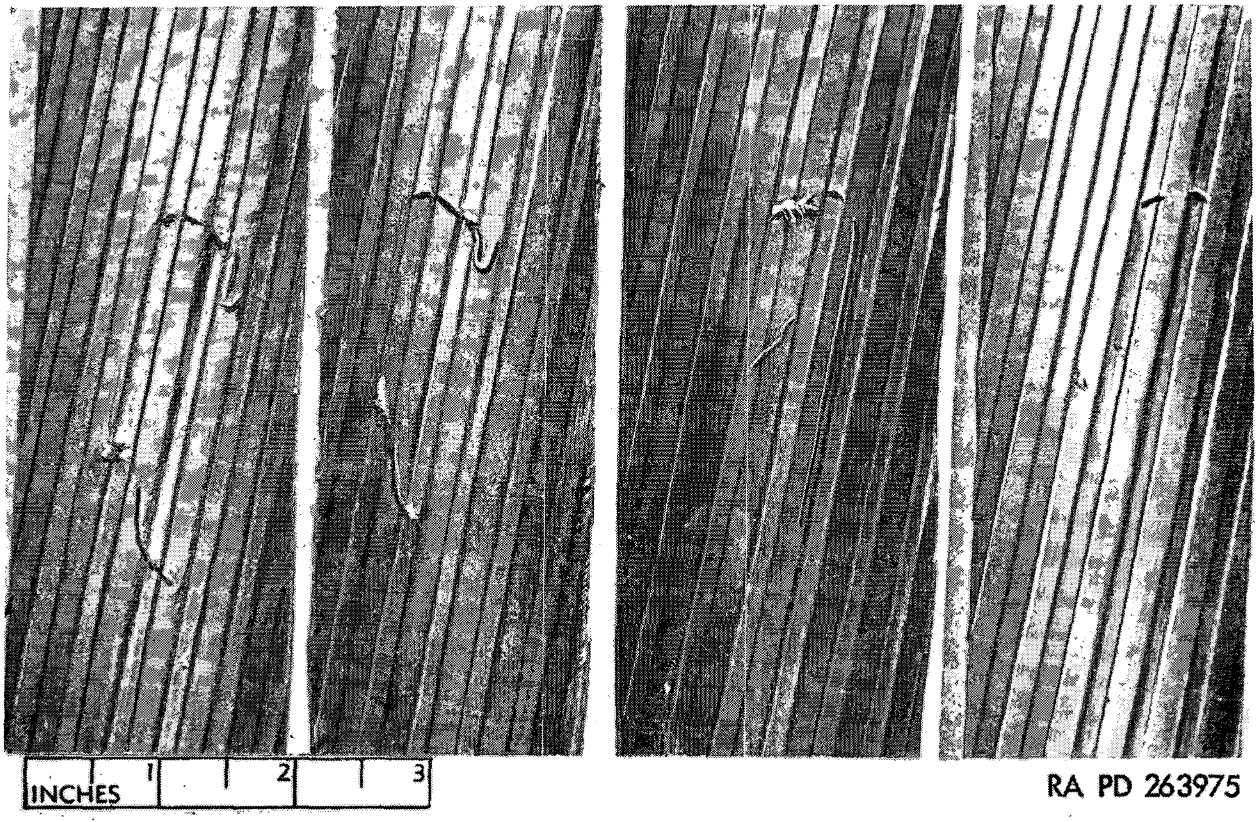

Figure 18. Damage to 105-mm howitzer tube, caused by leaving safety pull wire in fuze.

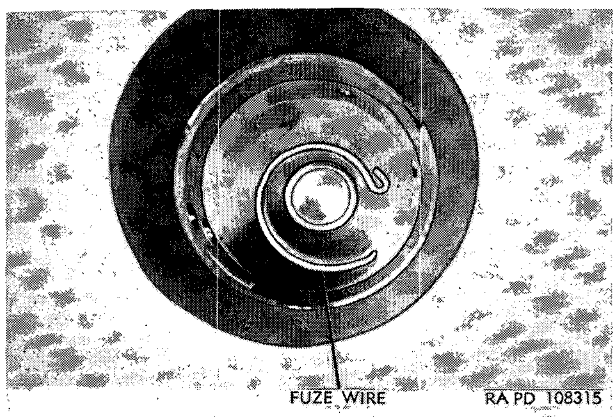

Figure 19. View of 105-mm point-detonating fuze M54, showing fuze wire which causes damages shown in figure 18.

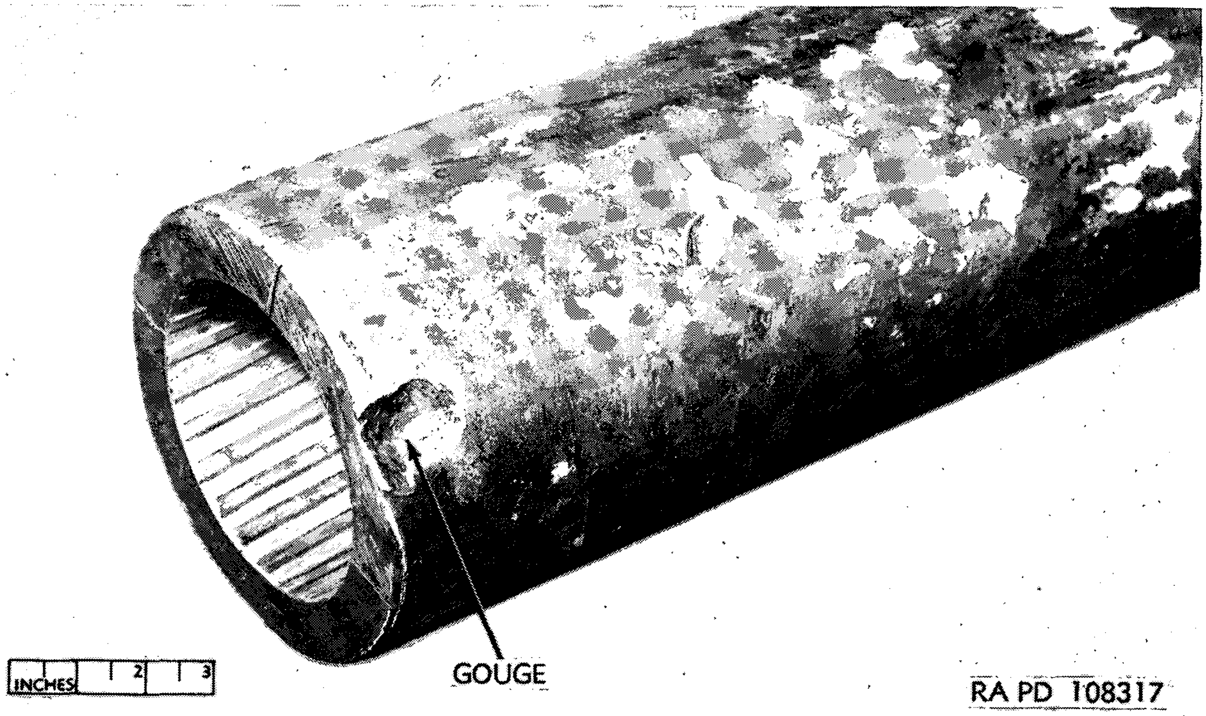

Figure 20. Gouge at muzzle of 75-mm cannon tube by hostile fire which caused a constriction within the tube.

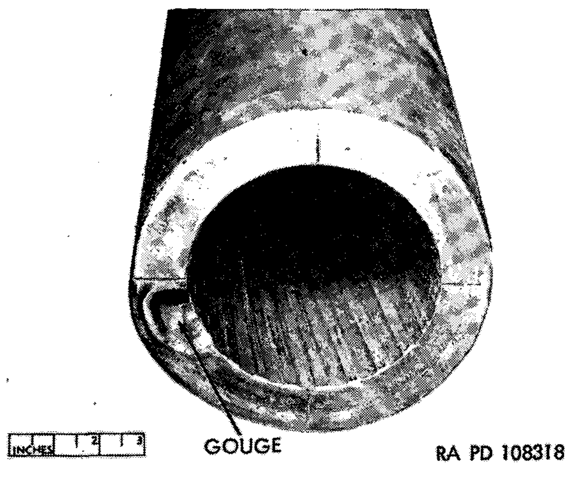

Figure 21. Gouge at muzzle of 75-mm cannon tube by hostile fire.

17. Heat Checks

Heat checks are due, it is believed, to thermal shock and can be observed after early firing. The checks increase in depth and size with firing. Heat checking is associated with gas erosion but it is not considered erosion in itself, since, it does not entail removal of metal. The characteristic pattern of heat checking (figs. 23–25) may be observed in any used tube.

Figure 22. Exterior of 75-mm cannon tube damaged by hostile fire.

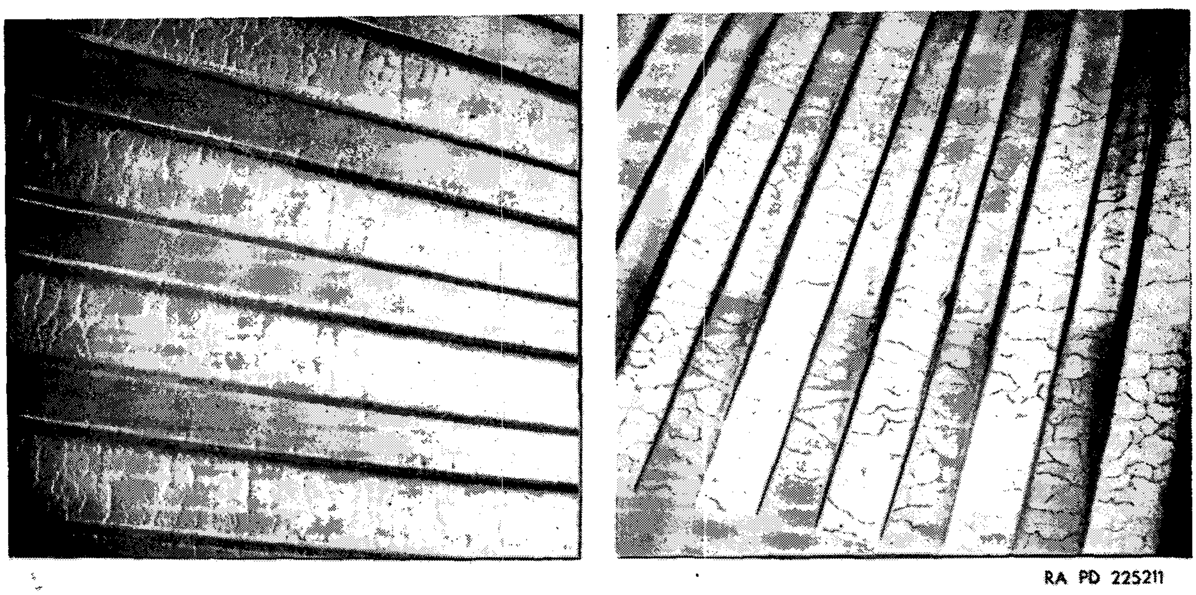

Figure 23. Early stages of heat checking—acceptable.

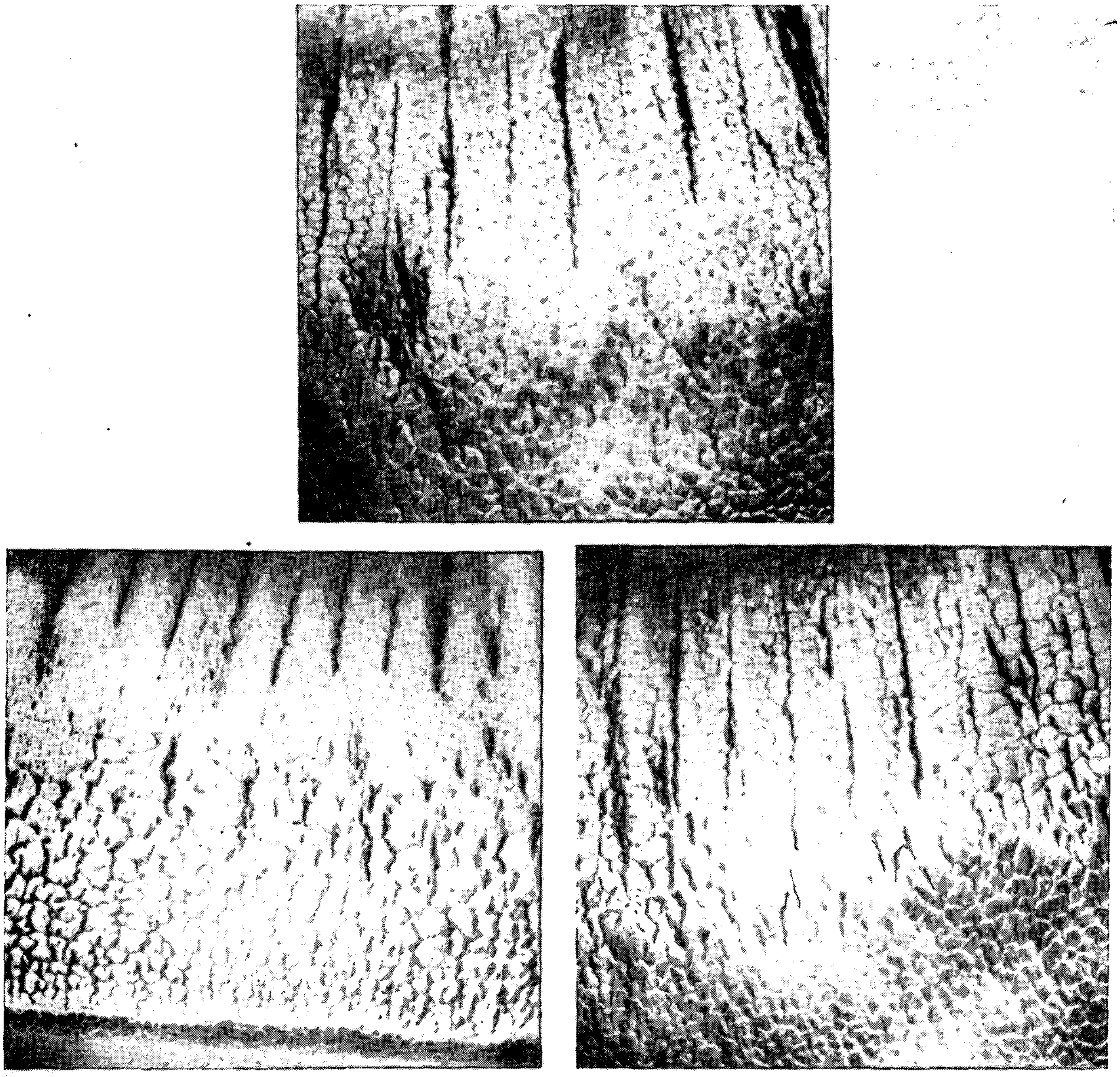

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Figure 24. Advance stages of heat checking—acceptable.

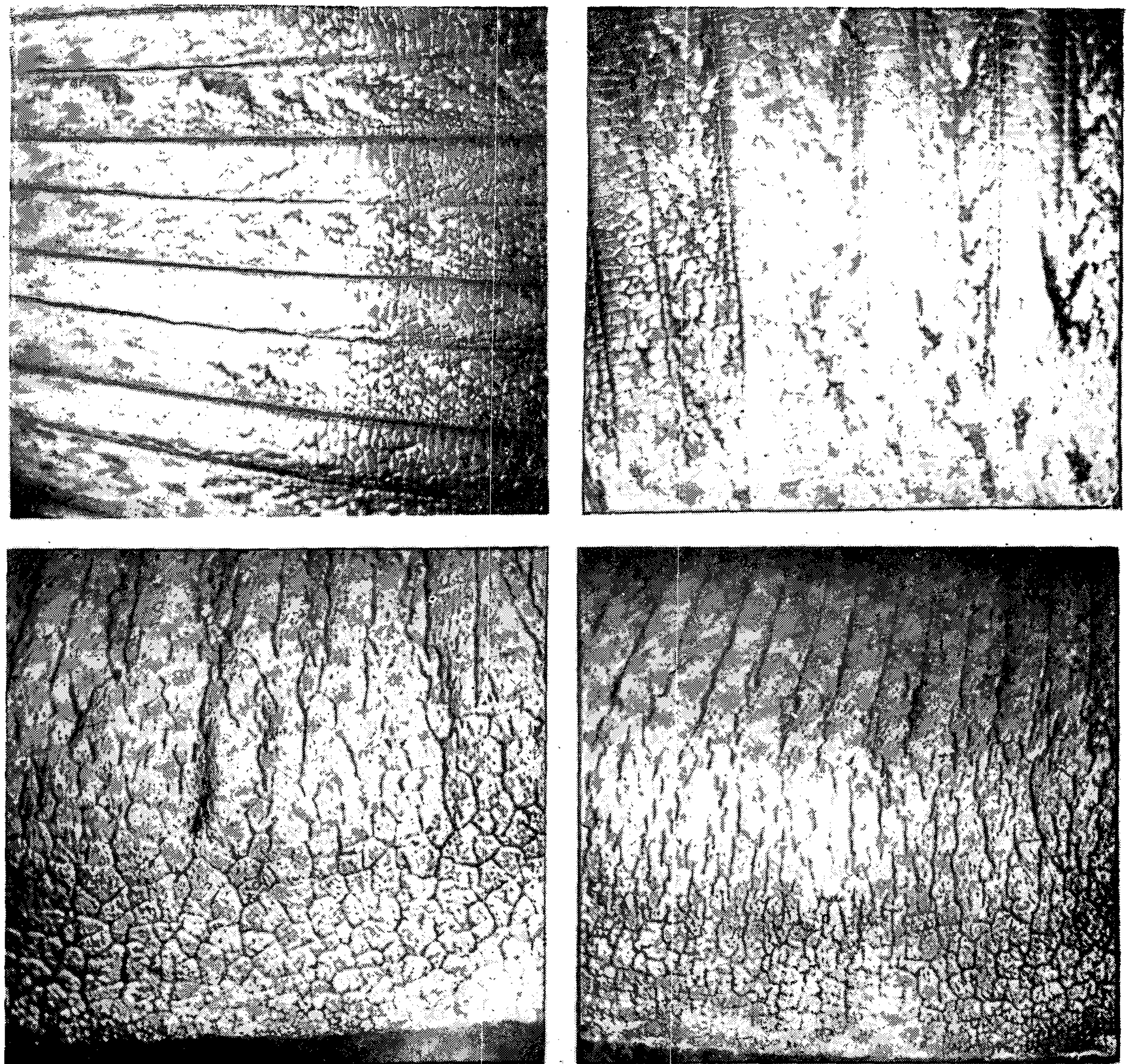

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Figure 25. Advance stages of heat checking—acceptable.

CHAPTER 3

INSPECTION

Section I. GENERAL

18. Visual Inspection

The primary purpose of visual inspection is to expose defects, or to observe progressive affects of defects, in the cannon bore which will detract from the normal structural strength. Defects, other than cracks, unless they are serious enough to indicate a structural deformation of the tube, or to affect the rotation of the projectile, will not materially affect the service life of the tube.

19. Gage Inspection

The greatest concern in the field is generally the evaluation of normal erosion. This evaluation is usually based on bore measurements taken with a pullover gage.

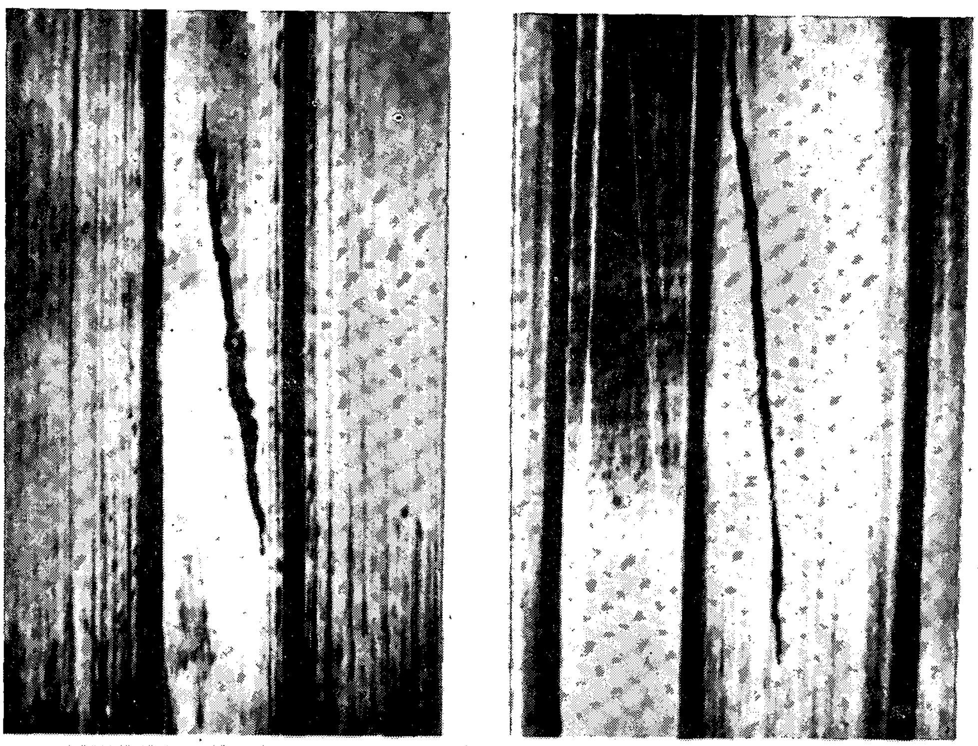
Section II. VISUAL INSPECTION

20. General

Experience has shown that erosion and other damages or defects to the bore of the cannon tube may be overestimated by visual inspection. Careful visual inspection, however, is very necessary and useful and should in nearly all cases supplement other means for evaluating erosion. Visual inspection must accompany a bore measurement, whenever the tube is not condemnable for wear alone.

21. Cracks in Cannons

Cracks may develop in any portion of the tubes and at any age of the cannon. Not all de-



LONGITUDINAL CRACK ON LAND LONGITUDINAL CRACK ON GROOVE

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Figure 26. Cracks in cannon bores—unacceptable.

fects that appear to be cracks are true cracks; therefore, it is necessary to evaluate each defect prior to condemnation of the weapon. Cracks must be differentiated from other defects such as scratches, heat checks, stripped lands, and superficial metallic flaws. Typical characteristics of a crack may include feathered edges, running in an irregular line, varying width, and in extreme cases depth may be determined. Tool marks, scratches, etc., will commonly be characterized by running in a straight line, smooth edges, uniform width, and shallow depth. Cracks may be found in any portion of the bore and the development of the crack has no relation to the age of the cannon. Cracks may be found running parallel to, or at an angle across the lands and grooves (figs. 26–29). Cracks may also be found in the chamber portion of the cannon (fig. 30).

22. Frequency of Inspection

As a minimum, cannon tubes in the hands of using troops must be visually inspected by technically trained personnel for the presence of any causes for condemnation, particularly cracks, as specified below:

a. Cannon tube will be inspected within 90 days prior to the initial firing and within each 90-day interval when utilized for continuous or recurring firing.

b. Cannon tubes will be inspected within 90 days prior to the initial firing when utilized for firing at semiannual, annual, or at other irregular periods.

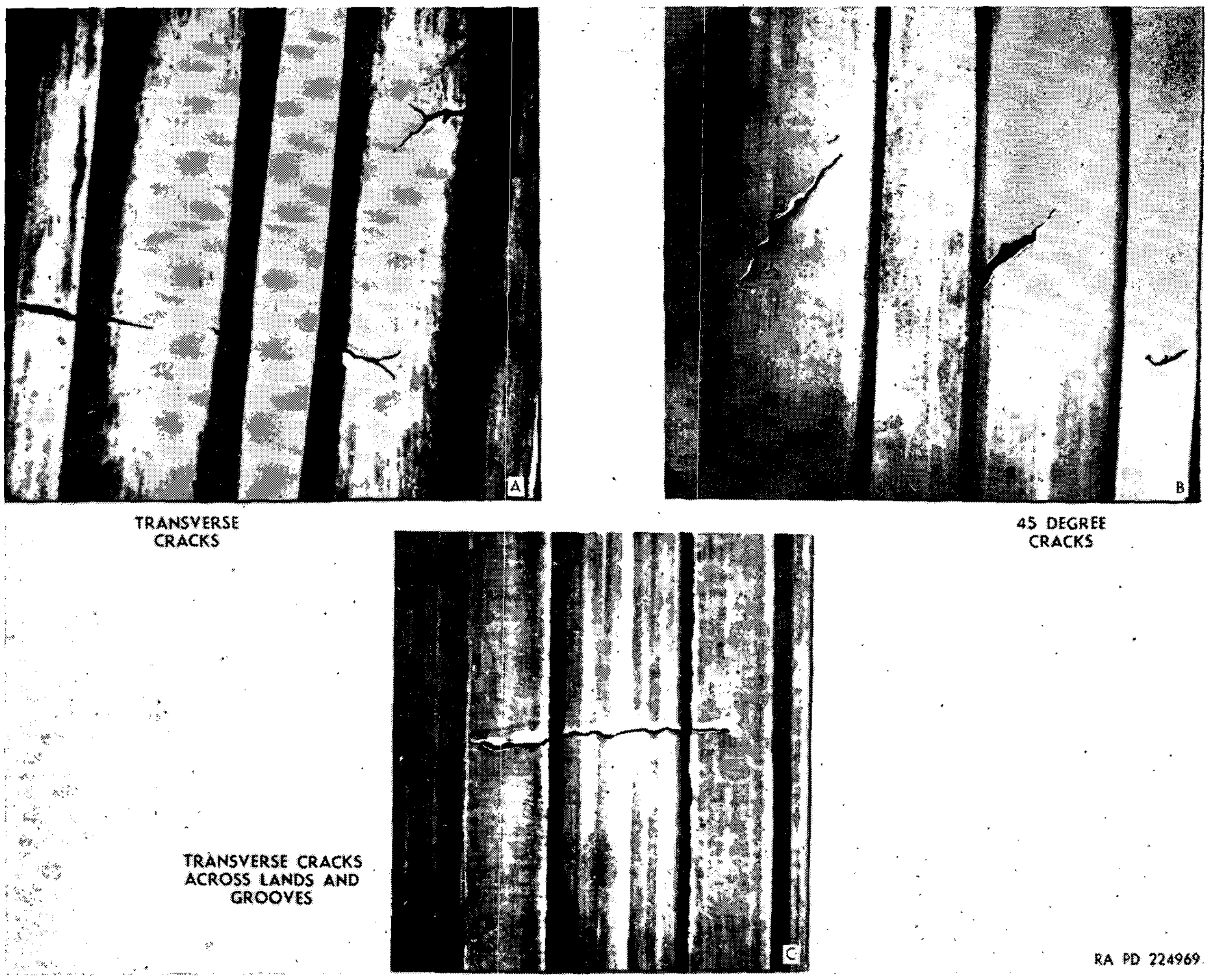

Figure 27. Cracks in cannon bores—unacceptable.

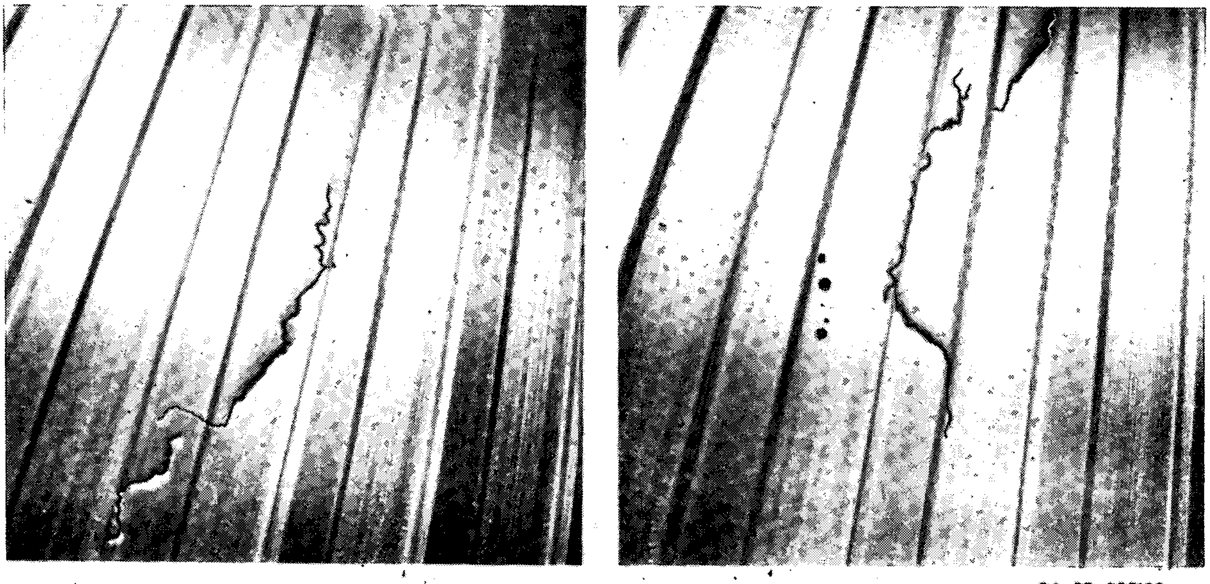

Figure 28. Cracks in cannon bores—unacceptable.

23. Preparation for Inspection

a. Cleaning. It is essential that the bore and chamber of the cannon to be inspected be thoroughly cleaned and dried prior to inspection. *Do not atempt to obtain a bright finish beyond absolute cleanliness.* A properly cleaned bore is, normally, uniformly light gray in color.

b. Decoppering. Decoppering will generally not be required, but if coppering interferes with visual inspection it will be removed by foil additive to the propellant charge. The amount of foil needed is approximately one percent of the weight of propellant in the charge. Ordinarily, no less than one ounce of foil is used. It is not necessary to break down the quantity used to less than one ounce increments. Pure lead foil, a lead-tin alloy foil, or pure tinfoil have all been found satisfactory for the purpose. Lead foil will generally be cheaper and more readily available. It is common, however, to refer to all of the compositions by the generic term "tinfoil". Foil will be added to the various types of ammunition as follows:

(1) *Separate-loading ammunition.* Foil is attached to the end of the increment which is closest to the muzzle.

(2) *Separated ammunition.* Foil is attached to the plug before ramming the cased charge into the weapon.

(3) *Semifixed ammunition.* The projectile is removed from the case, foil is placed inside atop the propellant surface, and the projectile is replaced before firing.

(4) *Fixed ammunition.* No instructions are provided for adding foil to fixed ammunition in the field.

24. Borescopes

A borescope is basically a straight-tube telescope, using a mirror set at an angle to present a view of the bore being inspected. A source of light is provided as an integral feature of the instrument. These instruments present a closeup view of the bore of a weapon, thus affording the inspecting personnel an opportunity to make a detailed inspection of any part of the bore. The borescope is available in two models. Borescope M1 (figs. 31 and 32) is for use in weapons in the 20-mm through 40-mm range. Borescope M2 (fig. 33 and 34) is for use in weapons in the 57-mm through 280-mm range. Each borescope comes complete with storage case, illuminating devices, tube supports to center it in the various weapons in which it is to be used, and the tools with which to perform organizational maintenance. Operation and maintenance of borescopes are covered in TM 9–4933–200–35.

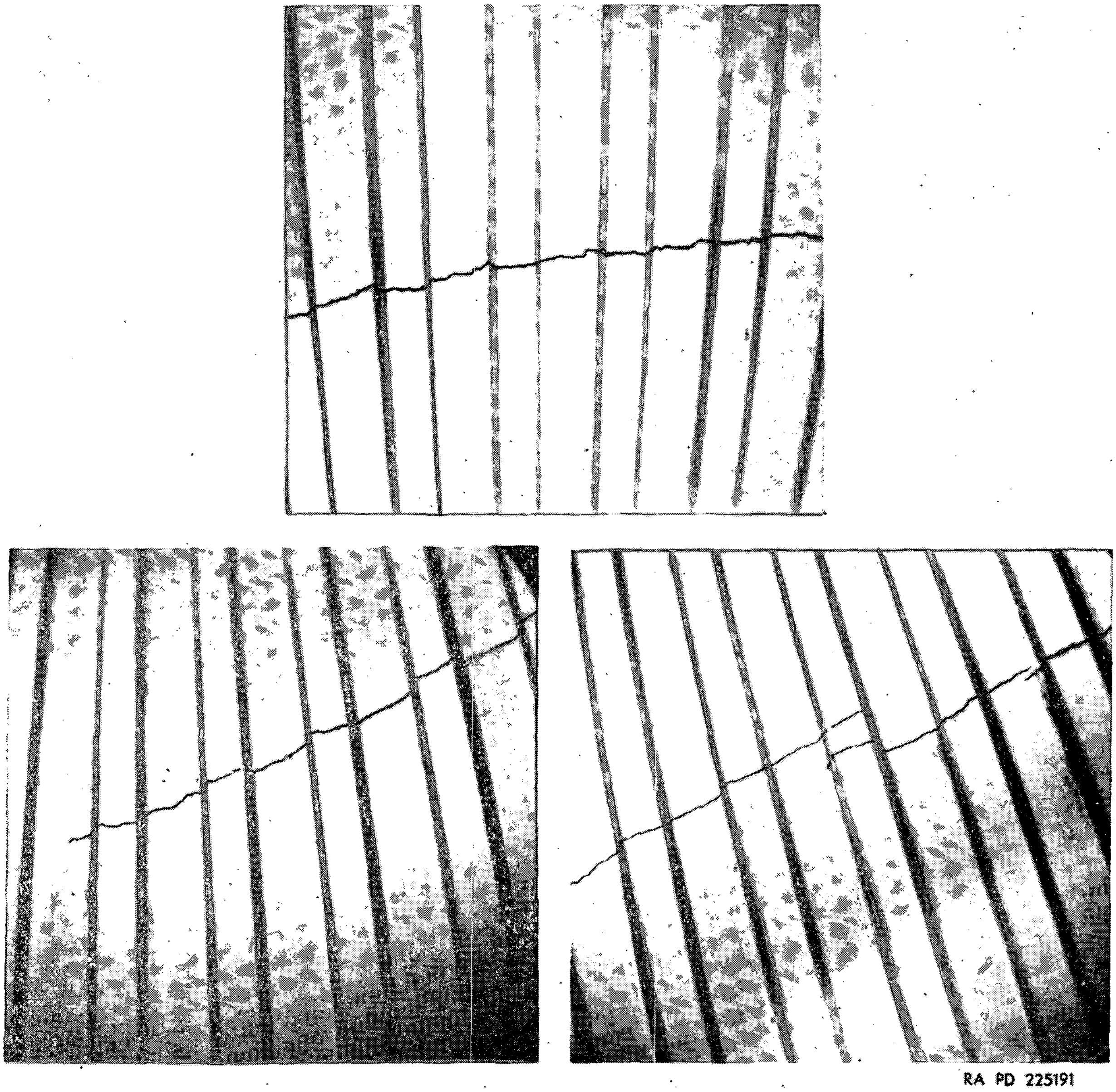

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Figure 29. Circumferential cracks in cannon bores—unacceptable.

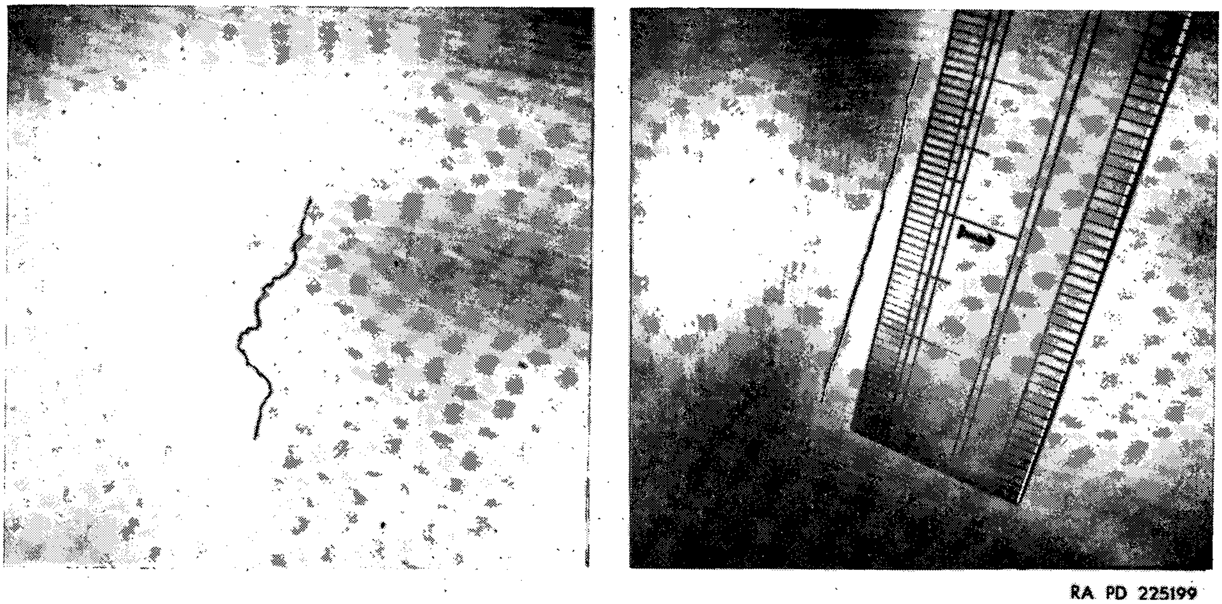

Figure 30. Cracks in chamber of cannon bores—unacceptable.

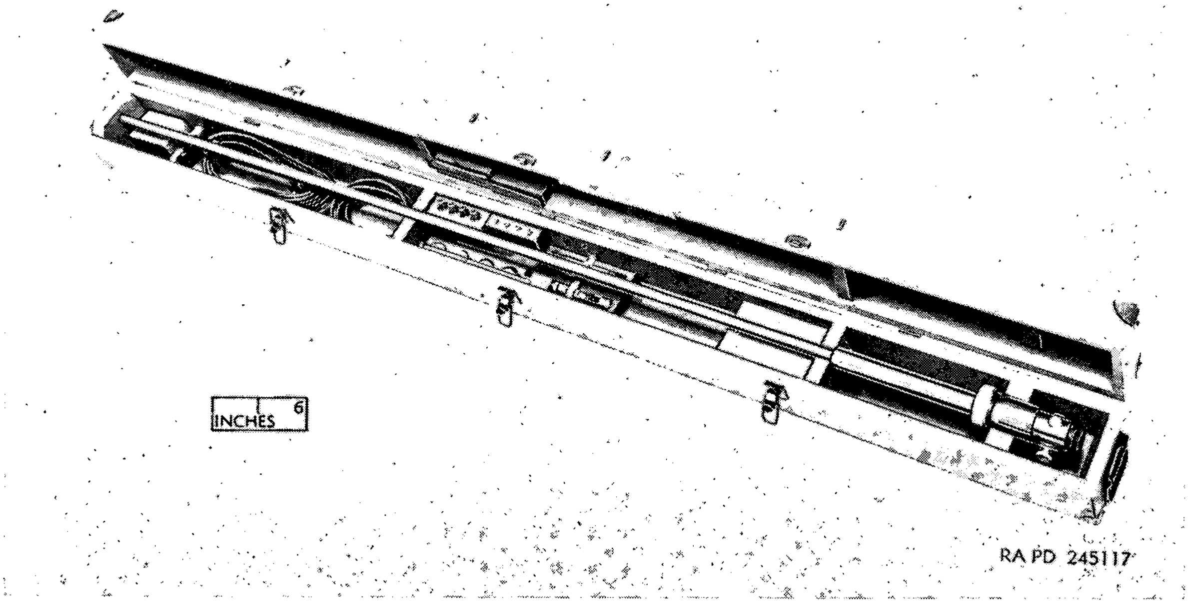

Figure 31. M1 borescope in case.

25. Comparison Gage

The comparison gage (fig. 35) is used with the borescope to assist the operator in evaluating the cannon bore as seen through the borescope. This device is intended for evaluation of the chamber section of the separate loading weapons.

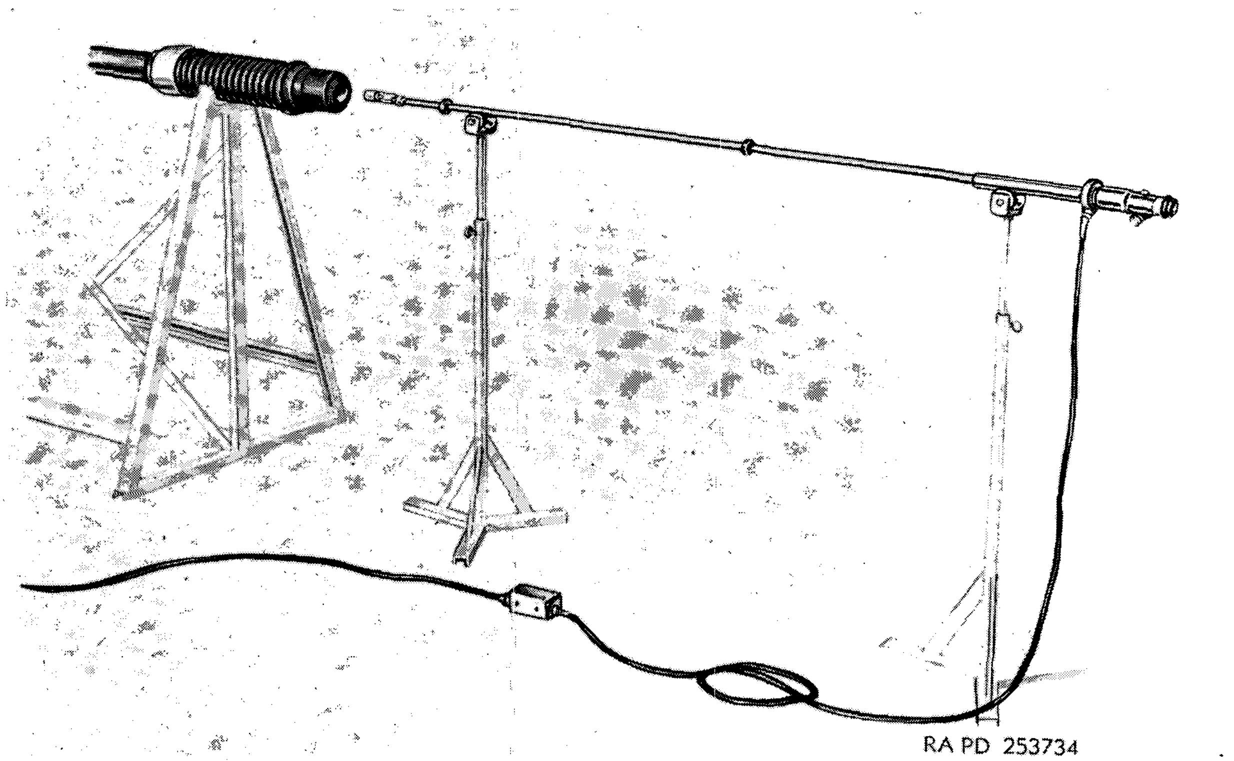

Figure 32. M1 borescope ready for inspection of cannon bore.

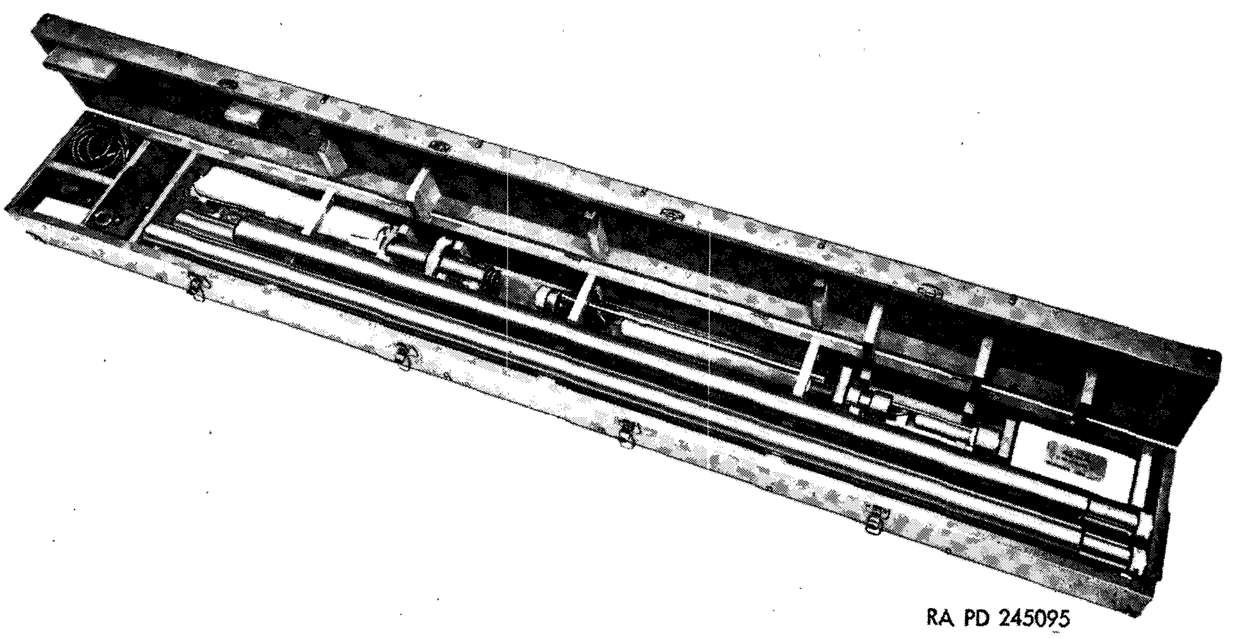

Figure 33. M2 borescope in case.

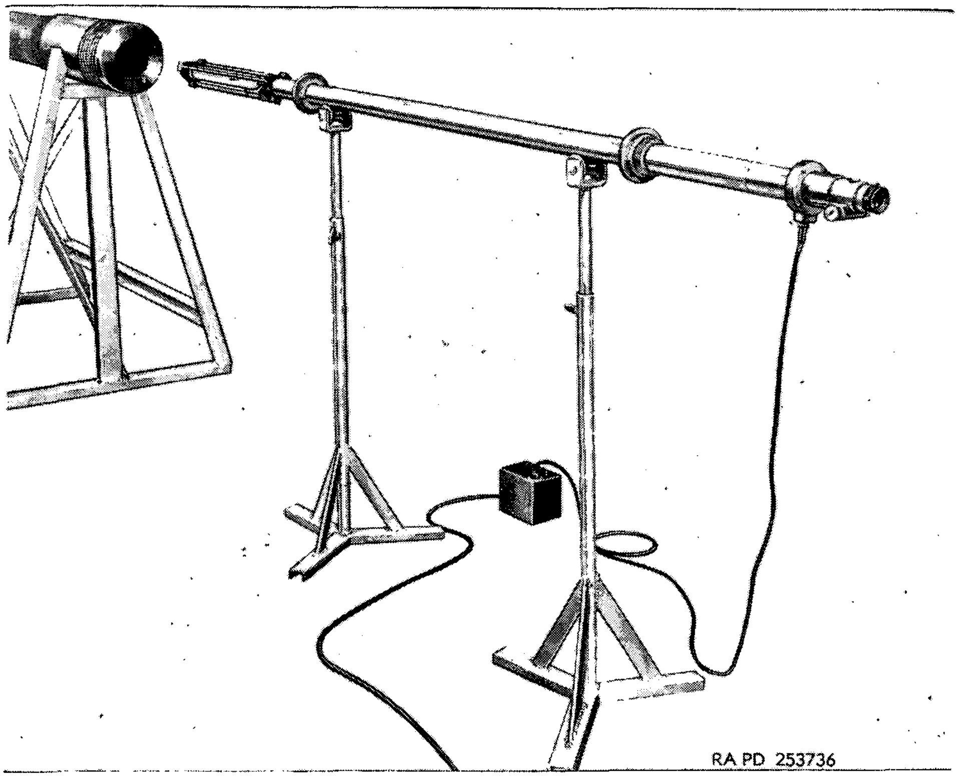

Figure 34. M2 borescope ready for inspection of cannon bore.

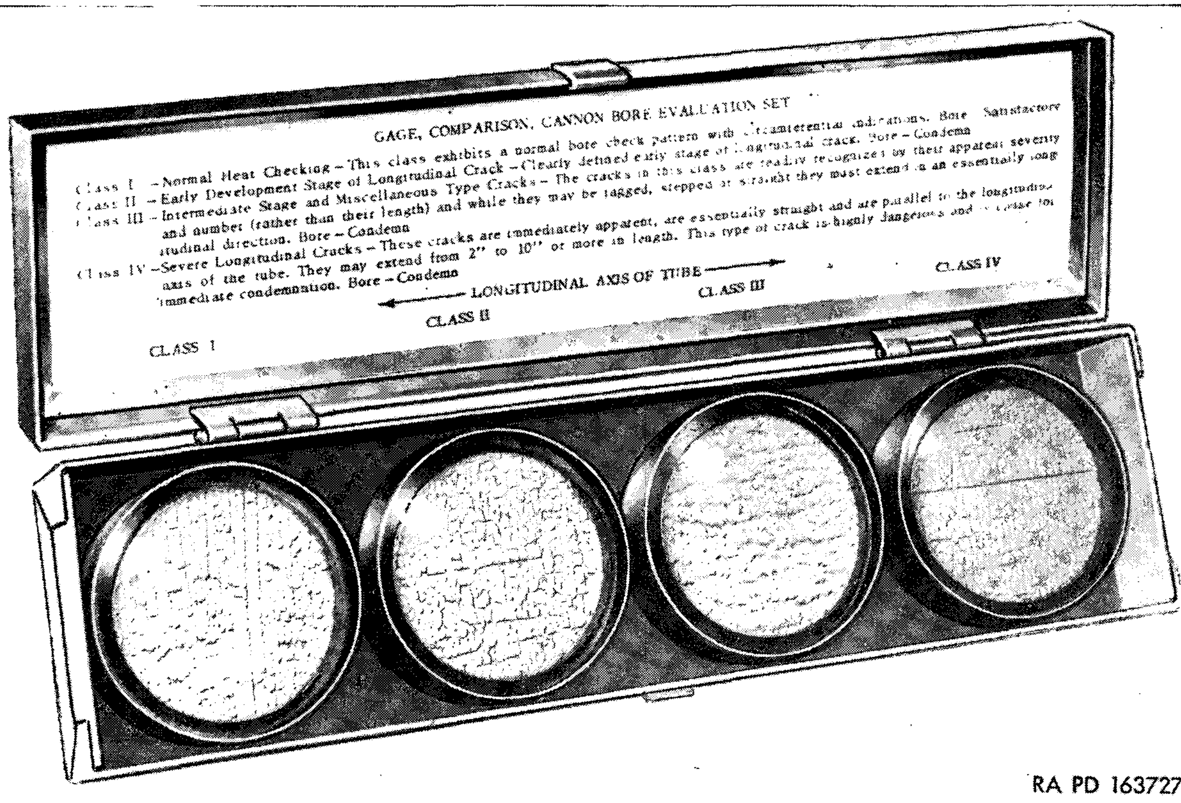

Figure 35. Comparison gage for evaluating the condition of the chamber of separate-loading weapons.

Section III. GAGE INSPECTION

26. Measuring Method

The measurement of some dimension in the bore has proven to be the most practicable method of evaluating serviceability. Since erosion is generally more sensitive in the vicinity of the commencement of rifling, a measurement of a point within this area has proven to be most useful.

27. Pullover Gage

The pullover gage is used to measure wear in the vertical axis in the vicinity of the commencement of rifling (fig. 36). The operation and maintenance of the pullover gage is covered in TM 9-4933-200-35. The points at which the measurement will be taken in the various weapons are listed in table XXIII.

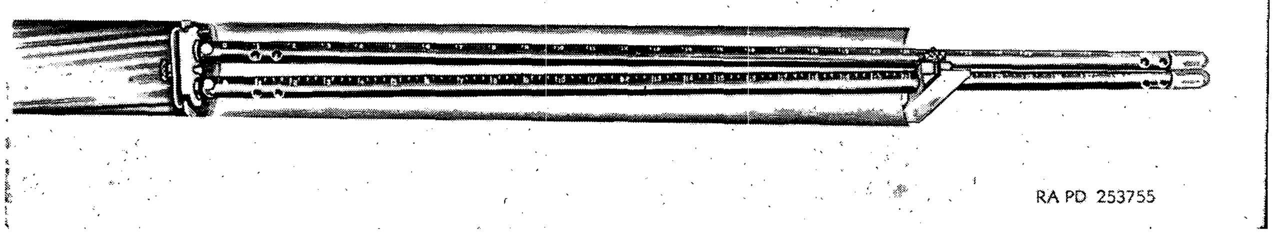

Figure 36. Pullover gage in gaging position measuring bore of a 76-mm gun.

CHAPTER 4

EVALUATION OF CANNON TUBES

Section I. EVALUATION

28. Estimation of Remaining Life

a. General. The early method of estimating the serviceability of a gun tube by the number of rounds fired was entirely unsatisfactory when variables such as zone charges, varying weights and types of projectiles, varying rates of fire, varying number of rounds fired in a group, etc., were introduced. The actual life of an individual gun tube in rounds might vary from 10 percent to 300 percent of the average life figure.

b. Equivalent Full Charges (EFC). As an approximate rough guide for estimating the differences in round life, the term "equivalent full charge" (EFC) was adopted. One round of the primary ammunition for the pertinent cannon has been designated as one EFC round with a factor of 1.00. Other ammunition used is designated specific EFC rounds to the estimated remaining life in rounds of that particular ammunition. These factors are provided primarily to assist personnel engaged in planning tube requirements.

Note. Tube condemnation will always be based on actual bore measurement and visual inspection; under no condition will a tube be condemned on the basis of actual or EFC rounds fired.

29. Condemnation Criteria

Cracks, defects, and other damage normally bear little relation to the age of the cannon or to the number of rounds fired, although, they may grow progressively worse through continued firing. For this reason a cannon may be condemnable even though the condemnation limit for wear has not been reached; however, care must be taken not to overestimate a defect (par. 20).

30. Condemnation Limits

Since erosion causes damage to or removal of metal, resulting in a change of dimension of the bore, the most practical method of evaluating serviceability is by measuring the diameter at a point in the tube and correlating this dimension with wear limits established by providing ground tests.

Section II. ESTIMATION OF REMAINING LIFE

31. General

An estimated life in EFC rounds (par. 28) has been established for each tube for estimating remaining life only. Tables have been prepared to show the estimated remaining life in percentage and in EFC rounds for a given pullover gage reading. The remaining life in rounds of a particular type of ammunition can be computed using the applicable EFC factor given in the pertinent table (tables I–XXII). For example, if the pullover gage reading of a tube in a 120-mm gun cannon M58 is 4.880 inches, a reading of the table for this weapon will show an estimated remaining life of 150 in EFC rounds. If it is desired to show this life in rounds using the HE–T projectile M356 (T15E3) the figure 150 will be divided by the EFC factor 0.094 giving an estimated quantity of 1596 rounds. ($\frac{150}{0.094} = 1596$).

Note. Estimates of remaining life based on the weapon record book records of rounds fired are not valid, although some approximation can be made for a small number of rounds after a bore measurement is known.

32. Estimation of Remaining Life of Specific Weapons

a. 37-mm Cannon M6.

(1) The tubes characteristically exhibit deep scoring (gas wash) during the latter stages of life in addition to gas

erosion and abrasion. Progressive wear in one tube is illustrated in figure 37. When double-base propellant (standard for this weapon) is used, heavy heat checks develop early with severe annular erosion ahead of the cartridge case mouth. Balloting and flattening of lands occur frequently (fig. 38).

(2) The estimated remaining life in EFC rounds at any given bore measurement, regardless of previous rounds fired, is shown in table I. The EFC round is one round using the armor-piercing-capped cartridge M51B2.

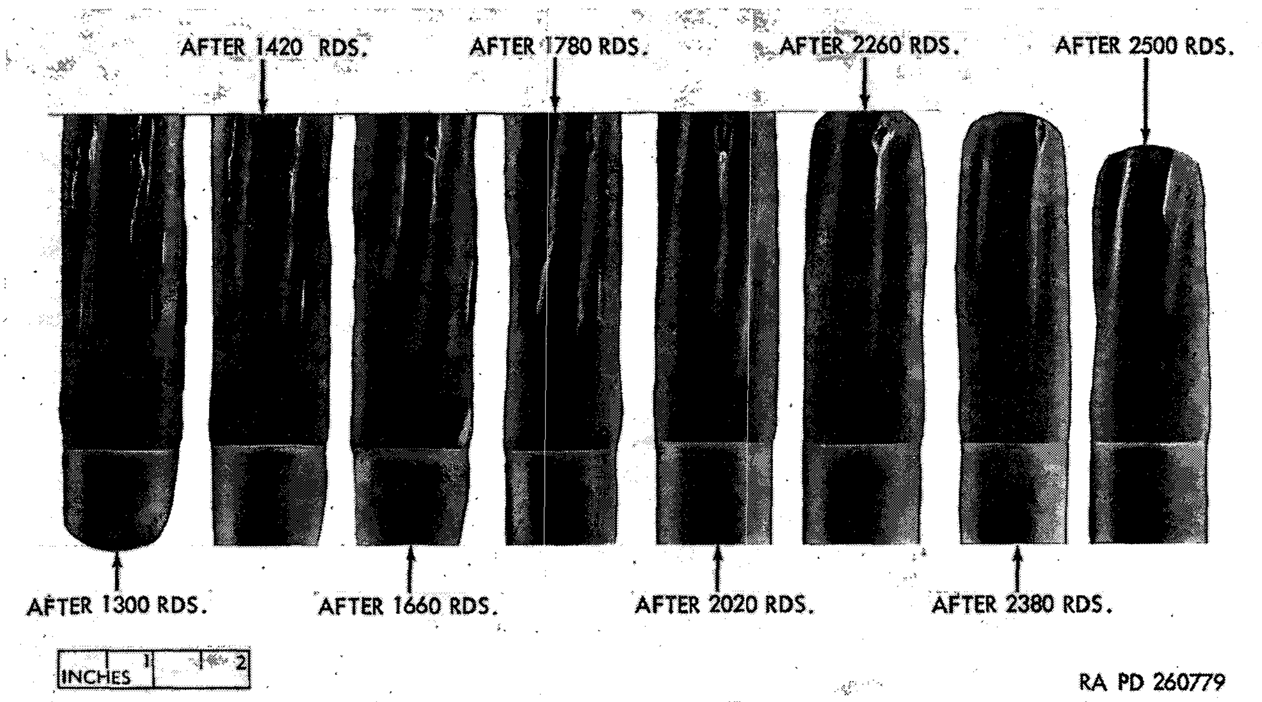

Figure 37. Origin of rifling of a 37-mm gun tube in the 6 o'clock region, showing progressive wear between 1,300 and 2,500 rounds.

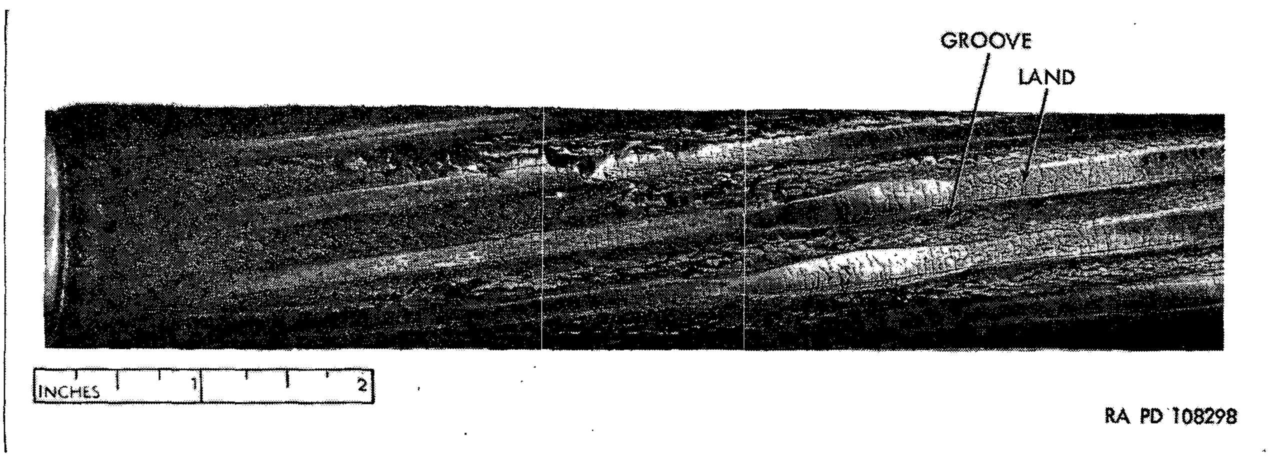

Figure 38. 37-mm cannon tube showing balloting of lands 4 inches forward of origin of rifling at 6 o'clock.

Table I. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 37-mm Gun Cannon M6

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 9.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	1.457	100	700
0.003	1.460	95	665
0.007	1.464	90	630
0.011	1.468	85	595
0.015	1.472	80	560
0.018	1.475	75	525
0.022	1.479	70	490
0.026	1.483	65	455
0.029	1.486	60	420
0.033	1.490	55	385
0.037	1.494	50	350
0.040	1.497	45	315
0.044	1.501	40	280
0.047	1.504	35	245
0.051	1.508	30	210
0.054	1.511	25	175
0.058	1.515	20	140
0.062	1.519	15	105
0.065	1.522	10	70
0.068	1.525	5	35
0.071*	1.528 *	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Cartridge model	Estimated round life	EFC factor
APC-T, M51B2	700	1.00
TP-T, M51A2	700	1.00
HE, M63	1,600	0.45

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

b. 40-mm AA Gun Cannon M1 and M2 Series.

(1) The characteristic wear of the tube used in this gun is a combination of the three types normally found in all weapons; namely, gas erosion, scoring, and abrasion. Although heat checks are quite prevalent, especially during the latter stages of tube life, there is no indication of chipped, raised, or stripped lands. Figures 39 through 41 illustrate the types of erosion which may be expected in the 40-mm tube. An explanation of the illustrations is as follows:

(*a*) Figure 39 shows a tube through which approximately 4,500 EFC rounds have been fired which equals about 38 percent of its life. Heat checks are prominent at the commencement of rifling, and scoring is evident for approximately the first two inches forward of the commencement of rifling.

(*b*) Figure 40 illustrates the type and extent of erosion which may be expected in a tube which has reached the condemnation limit. It can be seen that scoring and severe heat checks are prevalent throughout the first six inches forward of the origin of rifling. It can also be seen that the lands have worn to such an extent that the exact location of the origin of rifling is no longer distinguishable.

(*c*) Figure 41 illustrates the condition of a tube which has been kept in use far beyond its service life. At this stage, severe scoring is evident as well as deformation of the lands caused by balloting of the projectiles as they passed through the bore.

(2) Table II shows the remaining EFC rounds and percentage of remaining life compared to the vertical measurement of land diameter regardless of rounds previously fired.

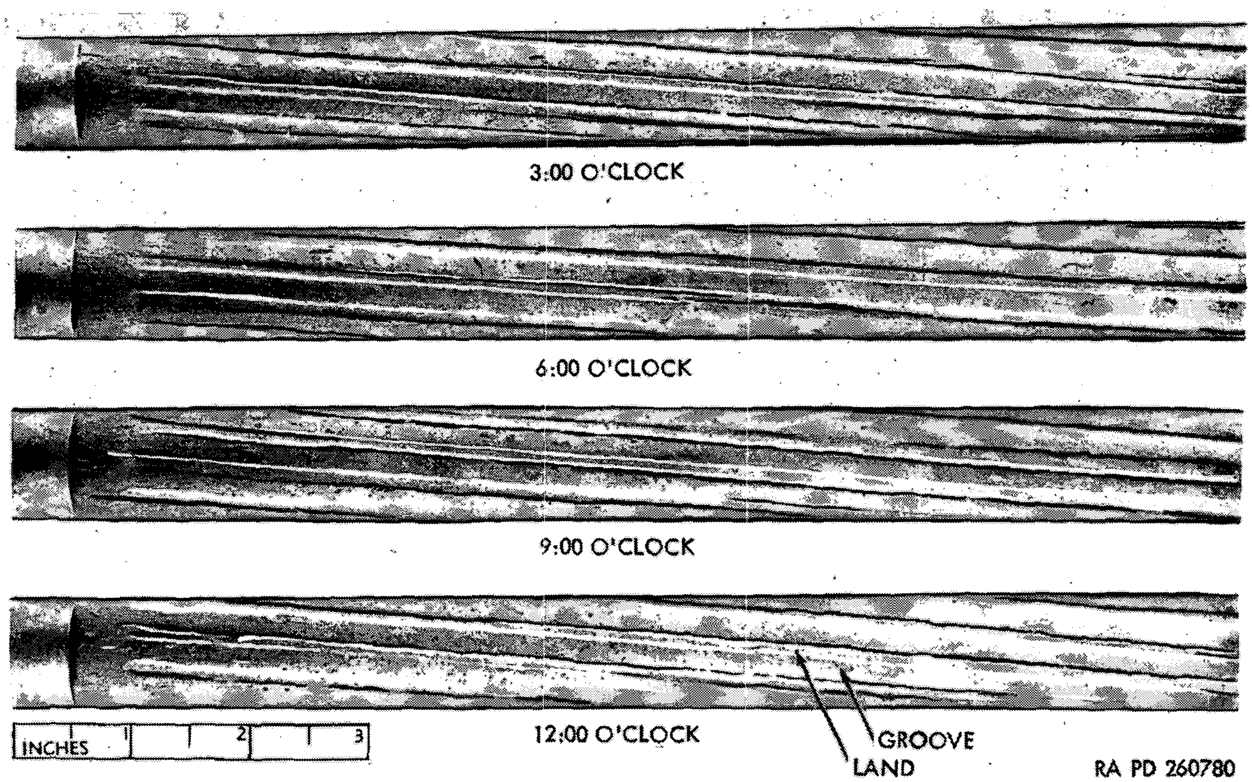

Figure 39. The origin of rifling of a 40-mm cannon tube which has fired approximately 4,530 rounds.

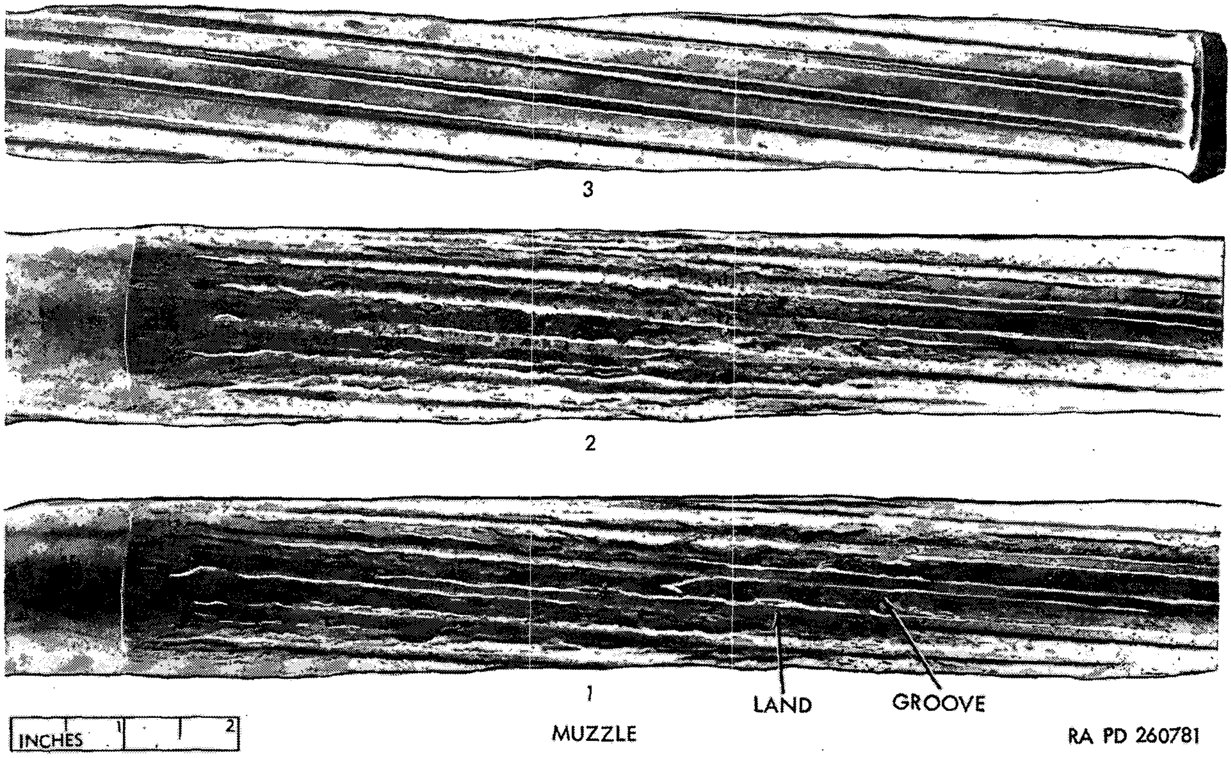

Figure 40. Bore of a 40-mm gun tube which has reached the condemnation limit: (1) vicinity of origin of rifling at 12 o'clock: (2) vicinity of origin of rifling at 6 o'clock: (3) muzzle end of rifling at 6 o'clock.

Table II. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 40-mm AA Gun Cannon M1 and M2 Series

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 13.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	1.573	100	12,000
0.002	1.575	95	11,400
0.003	1.576	90	10,800
0.004	1.577	85	10,200
0.006	1.579	80	9,600
0.008	1.581	75	9,000
0.010	1.583	70	8,400
0.013	1.586	65	7,800
0.015	1.588	60	7,200
0.018	1.591	55	6,600
0.021	1.594	50	6,000
0.024	1.597	45	5,400
0.027	1.600	40	4,800
0.030	1.603	35	4,200
0.033	1.606	30	3,600
0.036	1.609	25	3,000
0.039	1.612	20	2,400
0.042	1.615	15	1,800
0.045	1.618	10	1,200
0.049	1.622	5	600
0.052*	1.625*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Cartridge model	Estimated round life	EFC factor
HE, T227	12,000	1.00
CHEM, T228	12,000	1.00
CSTR, T229E7	12,000	1.00
AP-T, M81A1	12,000	1.00
TP-T, M81	12,000	1.00
HE-T, Mk II	12,000	1.00
TP-T, Mk II	12,000	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

c. 75-mm Howitzer Cannon M1A1, M2, and M3.

(1) The characteristic wear of tubes for 5-mm howitzers is a combination of the three types of wear: gas erosion, scoring, and abrasion (with abrasion predominating). Heat checks are obtained to a moderate degree, especially in the grooves, for several inches forward of the origin of rifling (fig. 42). The lands sometimes show sheared sidewalls especially in the top and bottom at the origin of the rifling (fig. 43). Appearance of the tube may be very misleading because of the negligible effect on serviceability produced by conditions such as sheared lands or minor indentations caused by wedging of fuze safety wires, etc. The condemnation criterion shall be the bore measurement as given in the condemnation table (table XXIII).

(2) The estimated remaining life in EFC rounds at any given bore measurement, regardless of previous rounds fired, is shown in table III. One charge four is taken as equal to one EFC round.

Table III. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 75-mm Howitzer Cannon M1A1, M2, and M3

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 11.50 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	2.950	100	7,000
0.007	2.957	95	6,550
0.013	2.963	90	6,200
0.016	2.966	85	5,950
0.020	2.970	80	5,600
0.023	2.973	75	5,250
0.026	2.976	70	4,900
0.028	2.978	65	4,550
0.030	2.980	60	4,200
0.032	2.982	55	3,850
0.034	2.984	50	3,500
0.036	2.986	45	3,150
0.038	2.988	40	2,800
0.040	2.990	35	2,450
0.042	2.992	30	2,100
0.043	2.993	25	1,750
0.045	2.995	20	1,400
0.046	2.996	15	1,050
0.047	2.997	10	700
0.049	2.999	5	350
0.050*	3.000*	0	0

*See footnote at end of table.

Table III. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 75-mm Howitzer Cannon M1A1, M2, and M3—Continued

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Cartridge model	Charge	Estimated round life	EFC factor
HE, M48, WP, M64	4	7,000	1.00
HEAT-T, M66		35,000	0.20
CSTR, T30E2		7,000	1.00
HEP-T, T150E11		3,300	2.11

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

d. 75-mm Gun Cannon M3, M6 and M17.

(1) The characteristic wear of tubes used in these cannons is a combination of the three types, in the order of principle effect: abrasion, gas erosion, and scoring during the latter stages of life. Heat checks and chipped lands may be evident to a moderate degree near the origin of rifling. Light heat checks and several chipped lands within four inches forward of the origin of rifling are shown in figure 44. These chipped lands and heat checks will not affect the serviceability of the tube.

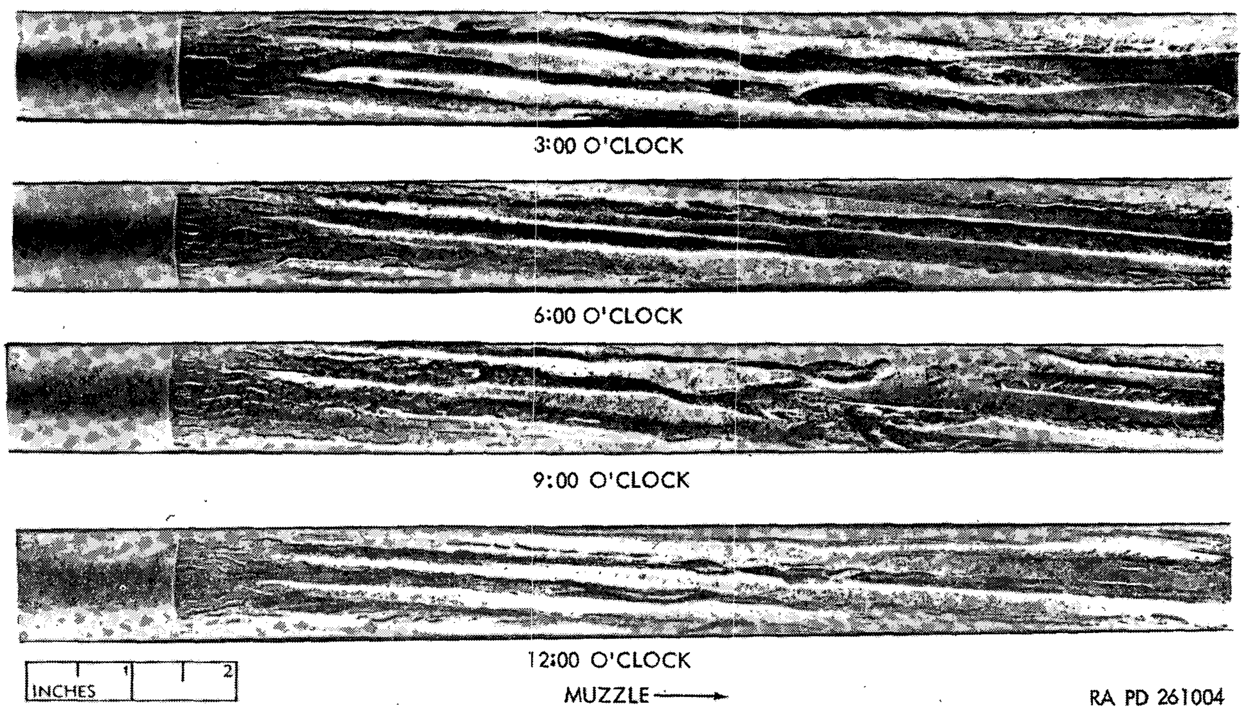

Figure 41. Bore of a 40-mm gun tube which has been fired beyond its accuracy life.

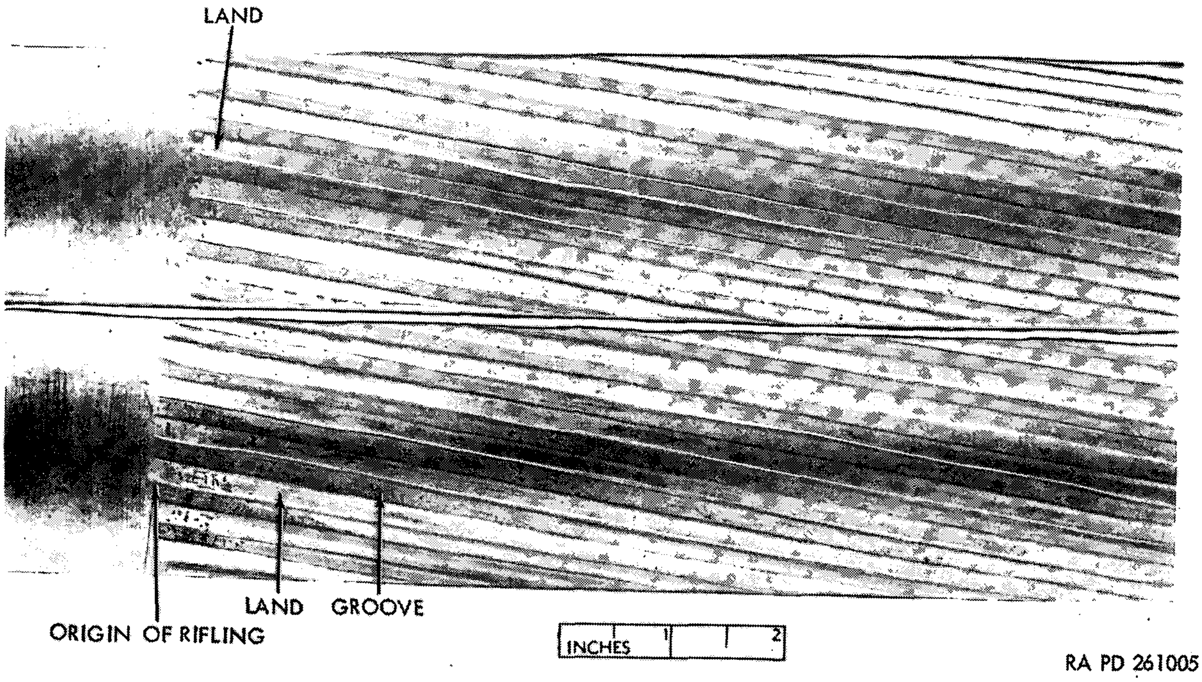

Figure 42. Moderate heat checks starting at the origin or rifling in a 75-mm howitzer tube: (top) 12 o'clock: (bottom) 6 o'clock.

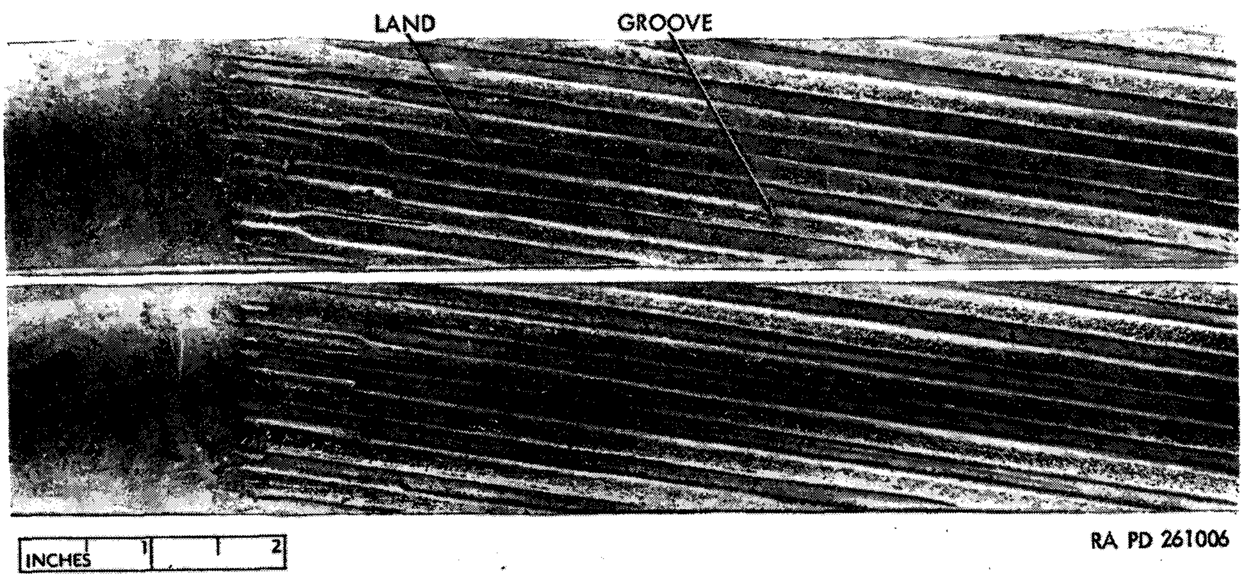

Figure 43. The origin of rifling in a 75-mm howitzer tube showing lands having sheared sidewalls in the 12 o'clock (top) and 6 o'clock (bottom) regions.

(2) Tables IV and V show the remaining EFC rounds and percent of remaining life compared to the vertical measurement of land diameter regardless of rounds previously fired. One armor-piercing-capped cartridge M61A1 is taken as equal to one EFC round.

Table IV. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 75-mm Gun Cannon M3, M17, M6, w/Tube 7230679

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 14.50 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	2.950	100	4,700
0.001	2.951	95	4,465
0.003	2.953	90	4,230
0.004	2.954	85	3,995
0.006	2.956	80	3,760
0.007	2.957	75	3,525
0.008	2.958	70	3,290
0.009	2.959	65	3,055
0.011	2.961	60	2,850
0.012	2.962	55	2,585
0.013	2.963	50	2,350
0.014	2.964	45	2,115
0.015	2.965	40	1,880
0.016	2.966	35	1,645
0.016	2.966	30	1,410
0.017	2.967	25	1,175
0.018	2.968	20	940
0.018	2.968	15	705
0.019	2.969	10	470
0.020	2.970	5	235
0.020*	2.970*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Cartridge model	Charge	Estimated round life	EFC factor
HE, M48, WP, M64	Normal	26,000	0.18
	Super	6,000	0.78
APC-T, M61A1		4,700	1.00
AP-T, M338A1		2,500	1.88
HEP-T, T165E11		4,800	0.99

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

Table V. Estimated Remaining Life of Cannon Tube 75-mm Gun Cannon M6 w/Tube 7230179

Tube life is limited to 1000 rounds due to fuze malfunctioning.

Estimated remaining life	
Percentage	Rounds
100	1,000
95	950
90	900
85	850
80	800
75	750
70	700
65	650
60	600
55	550
50	500
45	450
40	400
35	350
30	300
25	250
20	200
15	150
10	100
5	50
0	0

e. 75-mm AA Gun Cannon M35 (T83E7).

(1) The characteristic wear of the tube used in this gun is similar to that found in other plated tubes. As erosion commences, the chrome is removed from the driving edges of the lands, beginning first in the area of the forcing cone, and gradually advancing into the main bore. Erosion progresses across the lands by attacking the exposed base metal, thereby undermining additional chrome, causing it to break away. In this weapon, about 650 rounds of firing are required before the chrome will have been completely removed in the origin area. Wear, as measured by a pullover gage, will be negligible at this time. Once the chrome has been completely removed, however, abrasion, gas erosion, and scoring proceed at a very rapid rate, and in the same general manner as in unplated tubes.

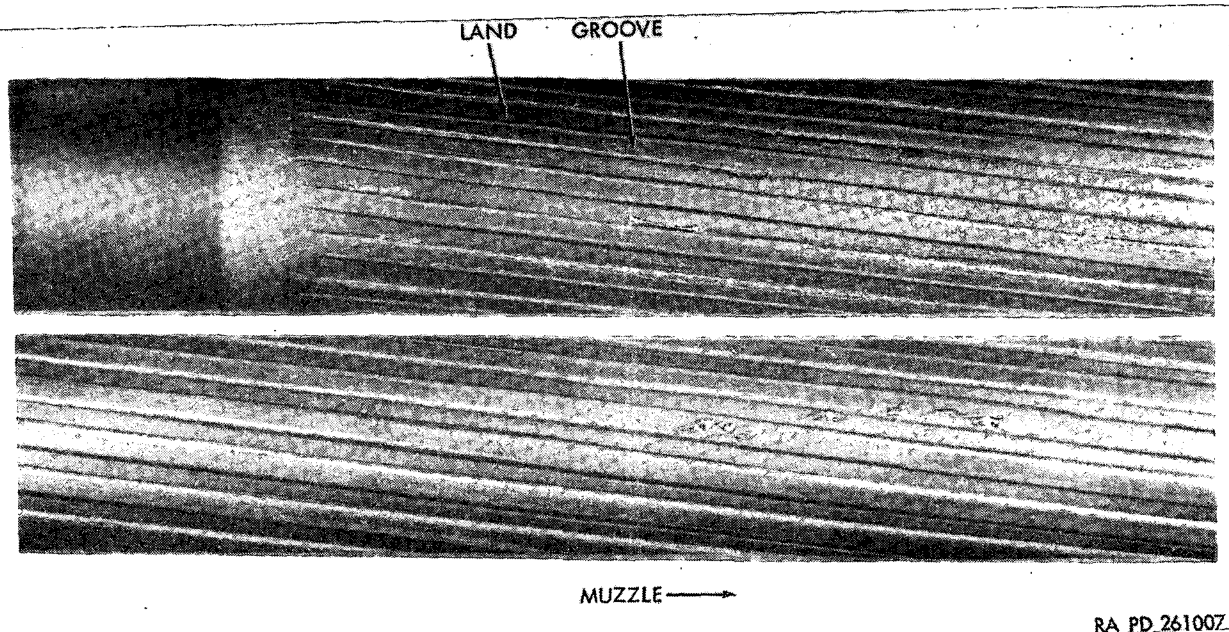

Figure 44. Light heat checks and chipped lands in the 12 o'clock region at the origin of rifling (top) and slight bore defects 37 inches from breech face of tube in 12 o'clock region (bottom) in a 75-mm cannon tube.

(2) Table VI can be used to estimate the remaining life of this weapon in terms of rounds or percent. Because wear is negligible for approximately 650 rounds, initial estimates of remaining life must be based on the actual total number of rounds fired. After the first 650 rounds, however, the vertical land diameter is expected to equal or exceed 2.955 inches, and all subsequent estimates of remaining life should be based on a measurement of vertical land diameter. One cartridge M334 (T50E2) is taken as equal to one EFC round. Tubes subjected to either prolonged fire or to extremely slow fire may be worn to condemnation with 20 percent less or more rounds, respectively, than is indicated in the table.

Table VI. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 75-mm AA Gun Cannon M35 (T83E7)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 22.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
Estimated remaining life in this area cannot be based on pullover gage reading. It must be based on Weapon Record Book Records of Rounds fired.	------------	100	1,300
	------------	95	1,235
	------------	90	1,170
	------------	85	1,105
	------------	80	1,040
	------------	75	975
	------------	70	910
	------------	65	845
	------------	60	780
	------------	55	715
0.005	2.955	50	650
0.007	2.957	45	585
0.009	2.959	40	520
0.011	2.961	35	455
0.016	2.966	30	390
0.027	2.977	25	325
0.037	2.987	20	260
0.045	2.995	15	195
0.050	3.000	10	130
0.053	3.003	5	65
0.055*	3.005*	0	0

*See footnote at end of table.

Table VI. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 75-mm AA Gun Cannon M35 (T83E7)—Continued

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Cartridge model	Estimated round life	EFC factor
HE, M334 (T50E2)	1,300	1.00
TP, T50E2	1,300	1.00
AP-T, T149E1	400	3.25
CHEM, T252	1,300	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

f. 76-mm Gun Cannon M1 Series.

(1) The characteristic wear of the tubes used in this weapon is a combination of the three types: gas erosion, scoring, and abrasion. Heat checks and lands having sheared sidewalls may be evident to a moderate degree near the origin of rifling. Figure 45 illustrates a condition of wear in a tube which has been fired less than half its service life. It can be seen that the lands have worn to such an extent that the exact location of the origin of rifling can no longer be accurately distinguished. Flattened lands can also be seen about five inches forward of the origin of rifling. Figure 46 illustrates lands having sheared sidewalls approximately one inch forward of the origin of rifling. This condition is not serious enough to warrant condemnation.

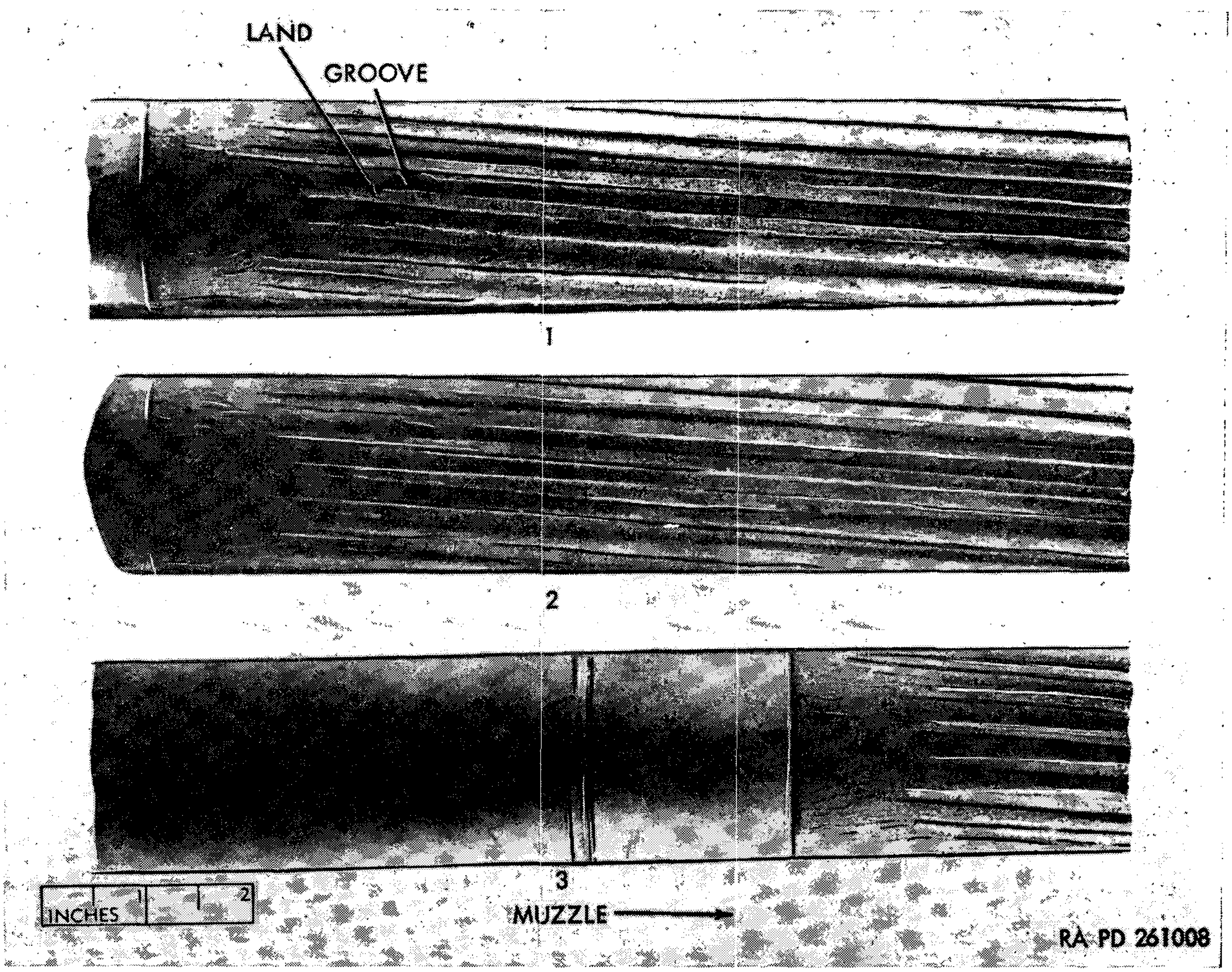

Figure 45. Gas erosion at the origin of rifling with worn and flattened lands: (1) 12 o'clock: (2) 6 o'clock: and (3) forward slope of chamber and origin of rifling at 6 o'clock.

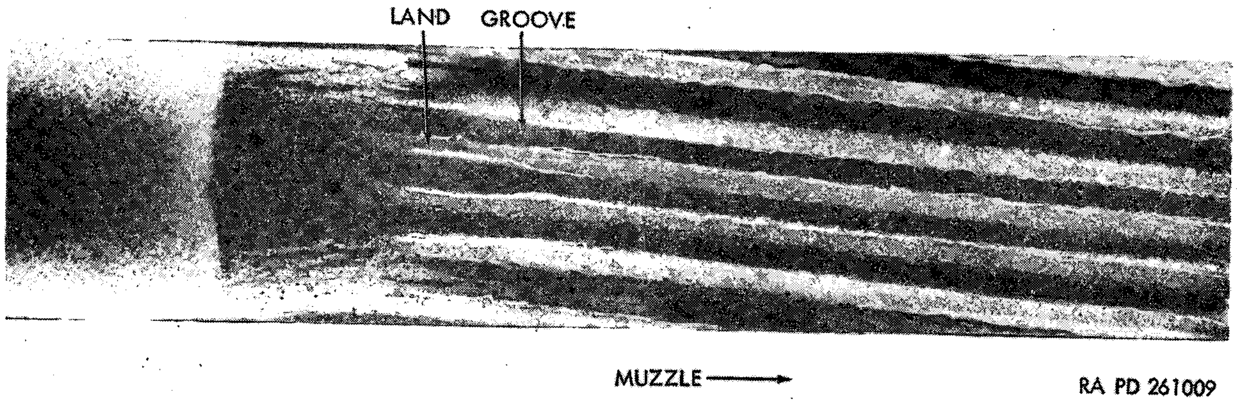

Figure 46. The origin of rifling in the 12 o'clock region, showing lands having sheared sidewalls.

(2) Table VII shows the remaining EFC rounds and the percentage of remaining life compared to the vertical measurement of the land diameter regardless of rounds previously fired.

Table VII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 76-mm Gun Cannon M1 Series

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 22.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	3.000	100	3,000
0.013	3.013	95	2,850
0.023	3.023	90	2,700
0.030	3.030	85	2,550
0.037	3.037	80	2,400
0.043	3.043	75	2,250
0.049	3.049	70	2,100
0.051	3.051	65	1,950
0.057	3.057	60	1,800
0.061	3.031	55	1,650
0.064	3.064	50	1,500
0.068	3.068	45	1,350
0.071	3.071	40	1,200
0.073	3.073	35	1,050
0.076	3.076	30	900
0.079	3.079	25	750
0.081	3.081	20	600
0.083	3.083	15	450
0.086	3.086	10	300
0.088	3.088	5	150
0.090*	3.090*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition

Cartridge model	Estimated round life	EFC factor
HE, M42A1	3,900	0.77
APC-T, M62A1	3,000	1.00
HVAP-T, M93A1	1,600	1.91
WP, M312	3,900	0.77
HVTP-T, M315A1	1,600	1.91
AP-T, T166E3	2,800	1.06
HEP-T, T169E1	7,300	0.41
HE-T, T286	3,900	0.77
HEAT, T319	3,600	0.83

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

g. 76-mm Gun Cannon M32 (T91E3), and M48.

(1) The characteristic wear of the tube used in this gun is similar to that found in other unplated tubes. In early life, heat checking is evident in the area of the origin of rifling. Wear is of a smooth, even nature, extending a considerable distance down bore, depending upon the number and type of rounds fired. In the latter stages of tube life, severe gas erosion, deep scoring, and uneven tube wear occur, so that a measurement of bore diameter taken vertically will usually be slightly greater than one taken horizontally.

(2) Table VIII can be used to estimate the remaining life of this weapon in terms of EFC rounds or percent, regardless of the number and type of rounds previously fired. One AP-T cartridge M339 (T128E6) is designated one EFC round.

Table VIII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 76-mm Gun Cannon M32 (T91E3) and M48

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 24.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EMC round
0.000	3.000	100	350.0
0.009	3.009	95	332.5
0.017	3.017	90	315.0
0.024	3.024	85	297.5
0.031	3.031	80	280.0
0.036	3.036	75	262.5
0.042	3.042	70	245.0
0.047	3.047	65	227.5
0.053	3.053	60	210.0
0.057	3.057	55	192.5
0.062	3.062	50	175.0
0.067	3.067	45	157.5
0.071	3.071	40	140.0
0.075	3.075	35	122.5
0.079	3.079	30	105.0
0.083	3.083	25	87.5
0.087	3.087	20	70.0
0.090	3.090	15	52.5
0.094	3.094	10	35.0
0.097	3.097	5	17.5
0.100*	3.100*	0	0.0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Cartridge model	Estimated round life	EFC factor
HVAPDS, M331A2	250	1.35
AP–T, M339 (T128E6)	350	1.00
TP–T, M340 (T212)	350	1.00
HE–T, M352 (T64)	1,700	0.20
CHEM, M361 (T140E2)	1,600	0.22
CSTR, M363 (T3E7)	550	0.63
HVTP–T, T74E1	350	0.99
HVAPDS, T89E5	350	0.99
CHEM–T, M361A1 (T140E4)	1,600	0.22
HEAT, T180	500	0.69
HVTP–T, M315A1 (T290)	350	0.99

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

h. 90-mm Gun Cannon M1, M2, M3, and M26 Series.

(1) Erosion of tubes used in these guns is usually a smooth even wear of the lands with scoring during latter stages. Figure 47 illustrates normal erosion at about half life; note heat checks in grooves and region ahead of cartridge case. Abnormal wear conditions such as flattened, chipped, or stripped lands are sometimes associated with these tubes but not to a marked degree. Examples of abnormal wear are as follows:

(*a*) Flattened lands, appearing as a series of waves, is caused by balloting of the projectile (fig. 48). A condition as serious as shown in figure 48 is sufficient cause for tube condemnation regardless of bore measurement.

(*b*) Stripped lands alone will not be used as a basis of condemnation unless ammunition malfunctions occur (fig. 49).

(*c*) Light scoring, heat checks in the grooves at the origin of rifling, and severe gas wear alone will not be used as a basis of condemnation; the bore measurement limit will govern.

(2) While the tubes for these guns are essentially the same physically, the utilization of the guns themselves is entirely different. The M1 and M2 are antiaircraft weapons, while the M3 and M26 are used primarily for antitank purposes. For this reason, it is considered advisable to state the life of each in terms of the primary round of ammunition fired. The average life of the tube for the M1 and M2 guns is approximately 2800 EFC rounds, where one round of HE cartridge M71 is designated one EFC. For the M3 and M26 weapons, tube life is about 2000 EFC rounds, where the EFC in this case is one round of AP–T cartridge M31. Tables IX and X can be used to estimate the remaining life of a tube for the respective weapons in terms of EFC rounds or percent, regardless of the number of rounds previously fired.

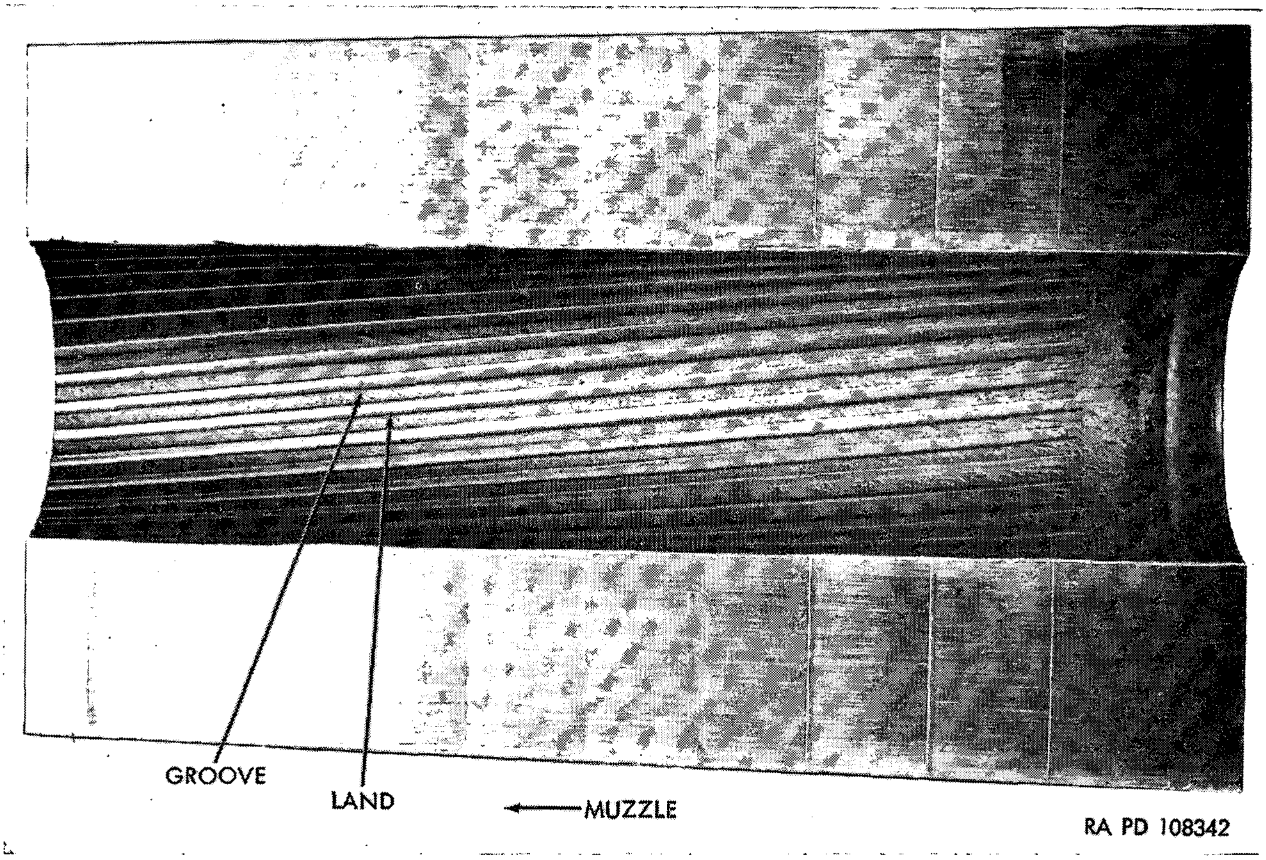

Figure 47. Origin of rifling of a 90-mm gun tube, showing gas erosion, heat checks, and light scoring at about half life.

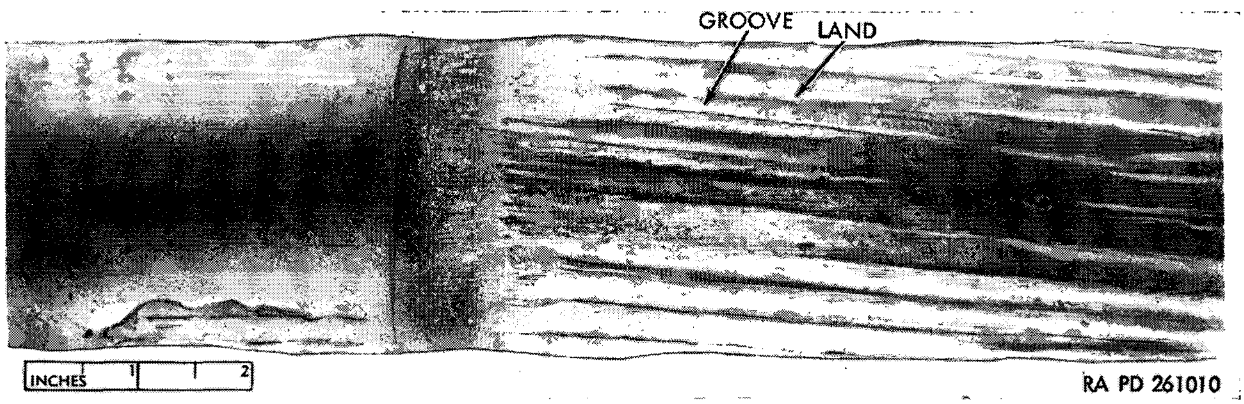

Figure 48. 90-mm gun tube, 6 inches forward of origin of rifling, showing flattened lands at 6 o'clock.

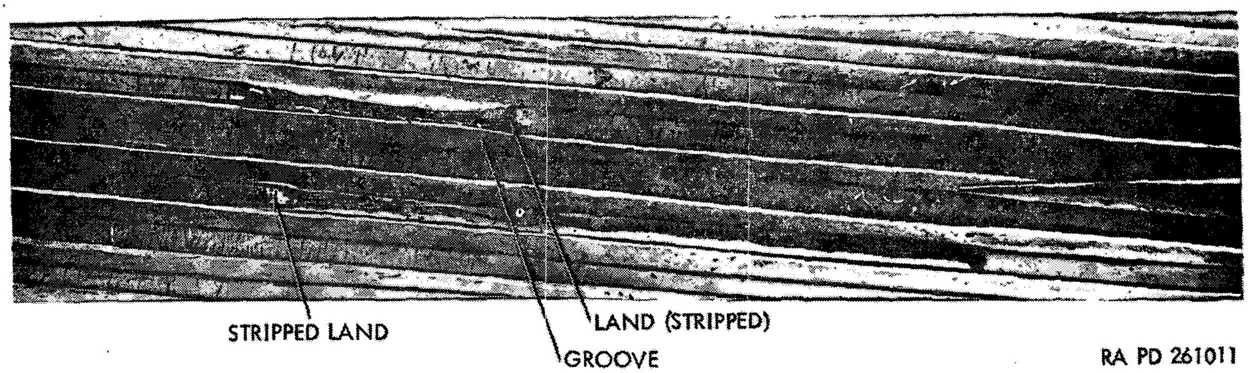

Figure 49. Stripped lands in the 1 o'clock region, 36 inches from the breech face of a 90-mm gun tube.

Table IX. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 90-mm AA Gun Cannon M1 and M2 Series

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 25.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	3.543	100	2,800
0.027	3.570	95	2,660
0.045	3.588	90	2,520
0.054	3.597	85	2,380
0.063	3.606	80	2,240
0.071	3.614	75	2,100
0.078	3.621	70	1,960
0.085	3.628	65	1,820
0.091	3.634	60	1,680
0.097	3.640	55	1,540
0.102	3.645	50	1,400
0.107	3.650	45	1,260
0.112	3.655	40	1,120
0.117	3.660	35	980
0.122	3.665	30	840
0.127	3.670	25	700
0.131	3.674	20	560
0.135	3.678	15	420
0.141	3.684	10	280
0.145	3.688	5	140
0.149*	3.692*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition

Cartridge model	Estimated round life	EFC factor
HE, M71	2,800	1.00
TP, M71	2,800	1.00
WP, M313	2,800	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

Table X. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 90-mm Gun Cannon M3, M26

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 25.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	3.543	100	2,000
0.031	3.574	95	1,900
0.045	3.588	90	1,800
0.055	3.598	85	1,700
0.063	3.606	80	1,600
0.070	3.613	75	1,500
0.077	3.620	70	1,400
0.084	3.627	65	1,300
0.090	3.633	60	1,200
0.096	3.639	55	1,100
0.102	3.645	50	1,000
0.107	3.650	45	900
0.112	3.655	40	800
0.117	3.660	35	700
0.122	3.665	30	600
0.127	3.670	25	500
0.132	3.675	20	400
0.137	3.680	15	300
0.142	3.685	10	200
0.146	3.689	5	100
0.150*	3.693*	0	0

*See footnote at end of table.

Table X. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 90-mm Gun Cannon M3, M26 —Continued

Cartridge model	Estimated round life	EFC factor
Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
HE, M71	2,800	0.72
TP, M71	2,800	0.72
APC–T, M82	2,000	1.00
HVAP–T, M304	1,600	1.23
WP, M313	2,800	0.72
HVTP–T, M317A2	1,600	1.23
AP–T, M318 (T33)	2,000	1.00
HVAP–T, M332A1	1,400	1.40
HVTP–T, M333A1	1,400	1.40
CSTR, M336	1,900	1.07
HEAT, M348 (T108E46)	5,500	0.36
HEP–T, T142E5	6,900	0.29

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

i. 90-mm Gun Cannon M36, M41, and M54.

(1) The characteristic wear of the tubes used in these guns is similar to that found in all plated tubes. Erosion is not usually measurable until several rounds have been fired. The first noticeable change is a heat checking of the chrome in the area of the forcing cone. As additional rounds are fired, the chrome chips from the driving edges of the lands, and advances into the main bore (fig. 23). Once the chrome is removed, erosion of the base metal begins. Erosion progresses across the lands, continually breaking away additional chrome. In very worn tubes it is not uncommon to see lands scored below groove depth. This occurs because the lands are affected before the chrome has been removed from the grooves. Once the chrome is completely removed, abrasion, gas erosion, and scoring progress the same as in unplated tubes.

(2) Table XI can be used to estimate the remaining life of this weapon regardless of the number and types of rounds previously fired. One AP–T cartridge M318A1 (T33E7) (TP, T225) is designated one EFC round.

Table XI. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 90-mm Gun Cannon M36, M41, and M54

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 25.25 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	3.543	100	700
0.001	3.544	95	665
0.003	3.549	90	630
0.015	3.558	85	595
0.031	3.574	80	560
0.055	3.598	75	525
0.072	3.615	70	490
0.083	3.629	65	455
0.100	3.643	60	420
0.110	3.653	55	385
0.120	3.663	50	350
0.129	3.672	45	315
0.137	3.680	40	280
0.145	3.688	35	245
0.153	3.695	30	210
0.161	3.704	25	175
0.169	3.712	20	140
0.176	3.719	15	105
0.183	3.725	10	70
0.190	3.733	5	35
0.197*	3.740*	0	0

*See footnote at end of table.

Cartridge model	Estimated round life	EFC factor
Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
HE, M71	1,700	0.42
TP, M71	1,700	0.42
APC–T, M82	1,100	0.61
HVAP–T, M304	900	0.76
WP, M313	1,700	0.42
HVTP–T, M317A2	900	0.76
AP–T, M318A1 (T33E7)	700	1.00
HVAP–T, M332A1	700	0.94
HVTP–T, M333A1	700	0.94
CSTR, M336	1,000	0.78
HEAT, M348 (T108E46)	3,100	0.21
HE–T, T91	5,000	0.13
CHEM–T, T92	5,000	0.13
HVAPDS, T137	500	1.37
HEP–T, T142E3	3,100	0.16
HEAT, T300	550	1.28
AP–T, M318 (T33)	1,100	0.61
TP–T, M353 (T225)	700	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

j. 105-mm Howitzer Cannon M2A1, M2A2, M4, M4A1, and M49 (T96E1).

(1) Tubes for 105-mm howitzers wear primarily by abrasion of lands, caused by the projectile passing through the bore, and by slight scoring and gas erosion. However, other conditions which may manifest themselves are as follows:

(*a*) The degree of land stripping which is serious enough to cause condemnation of the tube is not known. Tests conducted on a tube having 28 lands stripped for a distance of two to six inches forward of the commencement of rifling, and partial stripping continued forward for a much greater distance, proved the tube to be serviceable.

(*b*) It is desirable to remove a raised land where possible by severing each end with a chisel and then smoothing the rough portion, using a file and emery cloth. This is especially important if the raised land is near the origin of rifling, as it may prevent seating of the projectile. If allowed to remain in this condition, the raised land may become further detached due to progressive cracking, and will eventually strip. Should the land strip, the tube may become damaged by the projectile wedging the land against the bore interface.

(*c*) A condition which often occurs in the 105-mm howitzer tube is a flattening of the lands which eventually causes chipping. This condition in itself is not sufficient reason for condemnation of tubes, although the bore diameter at point of flattening of the lands is increased. The effect may be considered similar to that of increasing the bore diameter by frictional wear.

(*d*) Chipped lands are often prevalent in 105-mm howitzer tubes. It is not believed that this condition will reach a point where serviceability of the tube will be affected (fig. 50). Progressive chipping of lands may be checked somewhat by smoothing the land at the point of chipping, if possible, using a file and emery cloth.

(*e*) Occasionally a tube will develop a condition that is believed to be the result of the fuze safety wire being inadvertently left on the fuze within the bore, and subsequently wedging between the projectile and the bore interface (fig. 51). Although serviceability of the tube is not affected materially by this condition in itself, it may accelerate condemnation for other causes.

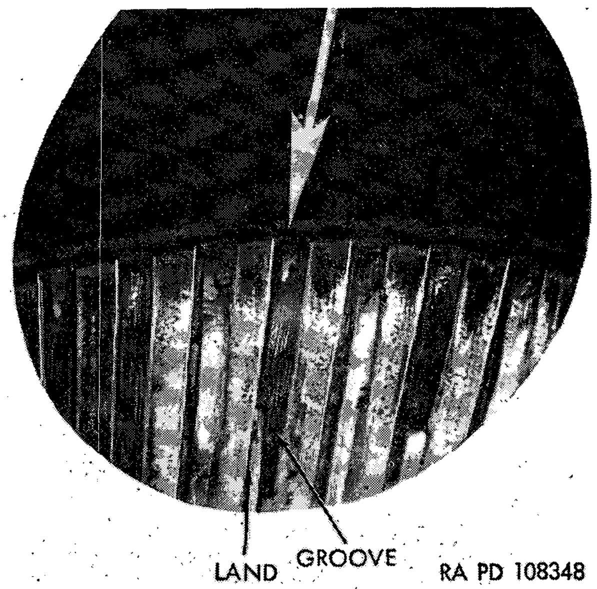

Figure 50. Borescope views of the origin of rifling in the 6 o'clock region of a 105-mm howitzer tube, showing chipped and sheared lands.

(2) Table XII shows the remaining EFC rounds and percent of remaining life compared to the vertical measurement of land diameter regardless of rounds previously fired. One charge seven is taken as equal to one EFC round.

Table XII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 105-mm Howitzer Cannon M2A1, M2A2, M4, M4A1, M49 (T96E1)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 16.00 inches forward of breech face (15.50 inches forward of breech face for M4, and M2A1)		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	4.134	100	20,000
0.009	4.143	95	19,000
0.016	4.150	90	18,000
0.022	4.156	85	17,000
0.027	4.161	80	16,000
0.031	4.165	75	15,000
0.035	4.169	70	14,000
0.038	4.172	65	13,000
0.041	4.175	60	12,000
0.044	4.178	55	11,000
0.047	4.181	50	10,000
0.050	4.184	45	9,000
0.052	4.186	40	8,000
0.054	4.188	35	7,000
0.057	4.191	30	6,000
0.059	4.193	25	5,000
0.061	4.195	20	4,000
0.063	4.197	15	3,000
0.065	4.199	10	2,000
0.068	4.202	5	1,000
0.070*	4.204*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Cartridge model	Charge	Estimated round life	EFC factor
HE, M1; COL MKR, M1 CHEM, M60; BE, M84B1; ILLUM, M314A1; BE, T107E2; CHEM, M360 (T173E1).	7 6 5 4	20,000 62,000 167,000 488,000	1.00 0.32 0.12 0.041
HEAT-T, M67	----------	91,000	0.22
CSTR, T18E	----------	5,300	3.76
HEP-T, M327 (T81E28)	----------	6,800	2.96
HEAT, T131E31	----------	11,000	1.87
CSTR, T310E	----------	8,300	2.41

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

k. 120-mm AA Gun Cannon M1, M1A1, M1A2, and M1A3.

(1) The characteristic wear of the tube used in 120-mm AA gun cannon M1, M1A1, M1A2, and M1A3 w/tube D36361 comprises severe gas erosion with deep scoring during the latter stage of tube life. Figure 52 illustrates a state of wear corresponding to the condemnation limit established for this tube. It can also be seen that heat checks are present at the origin of rifling. This tube wears unevenly at the origin of rifling, so that a vertical measurement of land diameter will be greater than one taken horizontally.

(2) The characteristic wear of the tube used in 120-mm AA gun cannon M1A3 w/tube 7307112 is similar to that found in other chrome plated tubes, except that the initial loss of plate during proof is greater at the muzzle end than in smaller bore weapons. With additional firing, progressive chrome breakdown first occurs along the driving edge of the lands in the area of the forcing cone. Chrome chipping and spalling then advances across the lands and into the bore a considerable distance until all the chrome is removed from lands in this area. As the chrome is removed severe gas erosion and deep scoring occurs in the base metal of these localized areas causing very irregular and uneven wear characteristics. It is not uncommon for the lands to become scored below groove depth in the origin area before the chrome has been removed from the grooves.

(3) Tables XIII and XIV show the remaining EFC rounds and the percentage of remaining life compared to the vertical measurement of the land diameter regardless of rounds previously fired.

Table XIII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 120-mm AA Gun Cannon M1, M1A2, and M1A3 w/Tube D36361

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 41.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	4.700	100	500
0.020	4.720	95	475
0.050	4.750	90	450
0.068	4.768	85	425
0.087	4.787	80	400
0.104	4.804	75	375
0.120	4.820	70	350
0.134	4.834	65	325
0.147	4.847	60	300
0.158	4.858	55	275
0.167	4.867	50	250
0.176	4.876	45	225
0.183	4.883	40	200
0.191	4.891	35	175
0.198	4.898	30	150
0.205	4.905	25	125
0.213	4.913	20	100
0.220	4.920	15	75
0.227	4.927	10	50
0.233	4.933	5	25
0.240*	4.940*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Projectile model	Estimated round life	EFC factor
HE,M73------	500 (M1, M1A1, M1A2 and M1A3 w/tube D36361).	1.00

*Condemnation limit (condemnation will be based on tube wear an not on rounds fired).

Table XIV. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 120-mm Gun Cannon M1A3 w/Tube 7307112

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 41.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	4.700	100	1,100
0.011	4.711	95	1,045
0.046	4.746	90	990
0.090	4.790	85	935
0.130	4.830	80	880
0.160	4.860	75	825
0.188	4.888	70	770
0.210	4.910	65	715
0.223	4.923	60	660
0.239	4.939	55	605
0.253	4.953	50	550
0.265	4.965	45	495
0.278	4.978	40	440
0.288	4.988	35	385
0.300	5.000	30	330
0.312	5.012	25	275
0.322	5.022	20	220
0.332	5.032	15	165
0.342	5.042	10	110
0.352	5.052	5	55
0.360*	5.060*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Cartridge model	Estimated round life	EFC factor
HE, M73------------	1100 (M1A3 w/ tube 7307112)	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

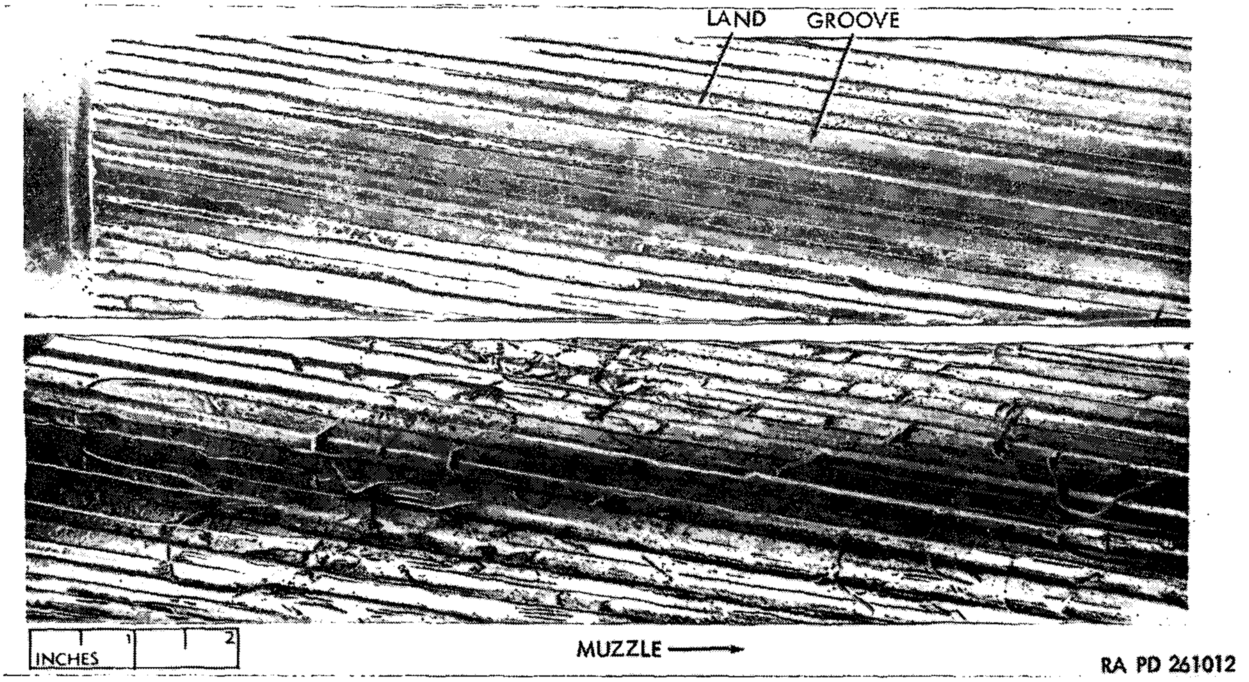

Figure 51. A 105-mm howitzer tube at the origin of rifling in the 12 o'clock region (top), showing chipped lands, and 36 to 48 inches from the breech face of the tube in the 12 o'clock region (bottom), showing damage caused by the fuze safety wire being left in the fuze.

l. 120-mm Gun Cannon M58 (T123E1).

(1) The characteristic wear of the tube used in this gun is similar to that found in other chrome-plated tubes, except that chrome breakdown occurs more rapidly than in smaller bore weapons. The chrome chips first from the driving edges of the lands in the area of the forcing cone, and gradually this condition advances into the main bore. Erosion of the exposed base metal progresses across the lands, causing additional chrome to break away. Once the chrome plating is completely removed in a given area, severe gas erosion and deep scoring occur, resulting in very irregular and uneven wear. In the vicinity of the origin of rifling, it is not uncommon for the lands to become scored below groove depth before the chrome has been entirely removed from the grooves.

(2) Table XV can be used to estimate the remaining life of this weapon in terms of EFC rounds or percent regardless of the number and type of rounds previously fired. One round with AP–T projectile M358 (T116E7) is designated one EFC round.

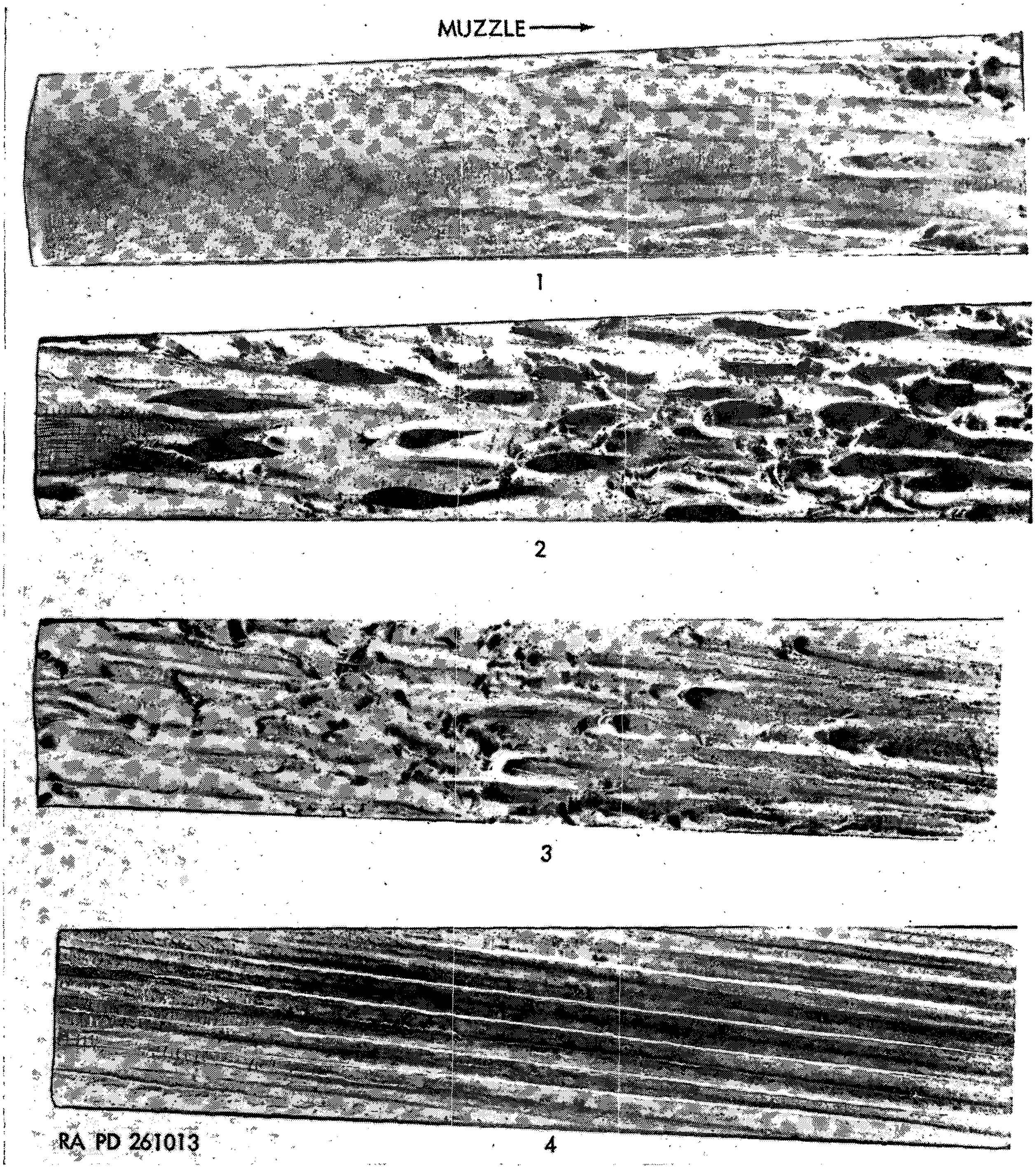

Figure 52. The bore of a 120-mm gun tube at: (1) 6 o'clock position at the origin of rifling: (2) 6 o'clock position at 32 inches to 44 inches from breech face of tube: (3) 6 o'clock position at 42 inches to 54 inches from breech face of tube: and (4) 6 o'clock position at 52 inches to 64 inches from breech face of tube which show severe gas erosion and deep scoring.

Table XV. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 120-mm Gun Cannon M58 (T123E1)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated reamining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 38.25 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	4.700	100	250
0.002	4.702	95	237.5
0.010	4.710	90	225
0.062	4.762	85	212.5
0.090	4.790	80	200
0.109	4.809	75	187.5
0.124	4.824	70	175
0.138	4.838	65	162.5
0.149	4.849	60	150
0.160	4.860	55	137.5
0.170	4.870	50	125
0.179	4.879	45	112.5
0.188	4.888	40	100
0.197	4.897	35	87.5
0.205	4.905	30	75
0.213	4.913	25	62.5
0.221	4.921	20	50
0.228	4.928	15	37.5
0.236	4.936	10	25
0.243	4.943	5	12.5
0.250*	4.950*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition		
Projectile model	Estimated remaining life	EFC factor
AP-T, M358 (T116E7)	250	1.00
TP-T, T147E4	250	1.00
HVAPDS, T102	200	1.13
HE-T, M356 (T15E3)	2,700	0.094
CHEM-T, M357 (T16E3)	2,700	0.094
HEP-T, T143E4	3,500	0.071
HEAT, T153E13	350	0.75

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

m. 155-mm Howitzer Cannon M1, M1A1, and M45 (T186E1).

(1) The rate of wear of the tubes for this howitzer is very low and a large number of rounds may be fired through the tube before the wear increases to a state which will affect its serviceability. Conditions such as chipped lands, heat checks, etc., make the bore appear to be unserviceable; however, appearance of the bore can be very deceiving and conditions of flattened, chipped, raised, or stripped lands are not in themselves sufficient cause for condemnation. Illustrations of the appearance of the bore during early stages of wear are explained below.

(*a*) Figure 53 illustrates damage to the bore which does not affect the serviceability of the tube. The damage shown in this illustration was caused by fuze safety wires becoming detached from the projectile while in the bore and wedged between the projectile and the bore. Extreme conditions of this nature do not materially affect serviceability of the tube.

(*b*) Figure 54 illustrates the beginning of a series of heat checks at the origin of rifling. Slight land chipping is also in evidence.

(*c*) After 10,000 EFC rounds have been fired, the lands show a more advanced state of chipping, as shown in figure 55. The heat checks are much more in evidence and are deeper than in earlier stages. The tube at this state of wear is still serviceable and should remain so for approximately an additional 5,000 EFC rounds. The chrome plating in the M1A1, and the M45 (T186E1) is confined to the chambers and will not materially affect the wear characteristics of the bore.

(2) The bore diameter taken with a pullover gage determines the percentage of remaining life which then may be converted into remaining EFC rounds by use of tables XVI and XVII.

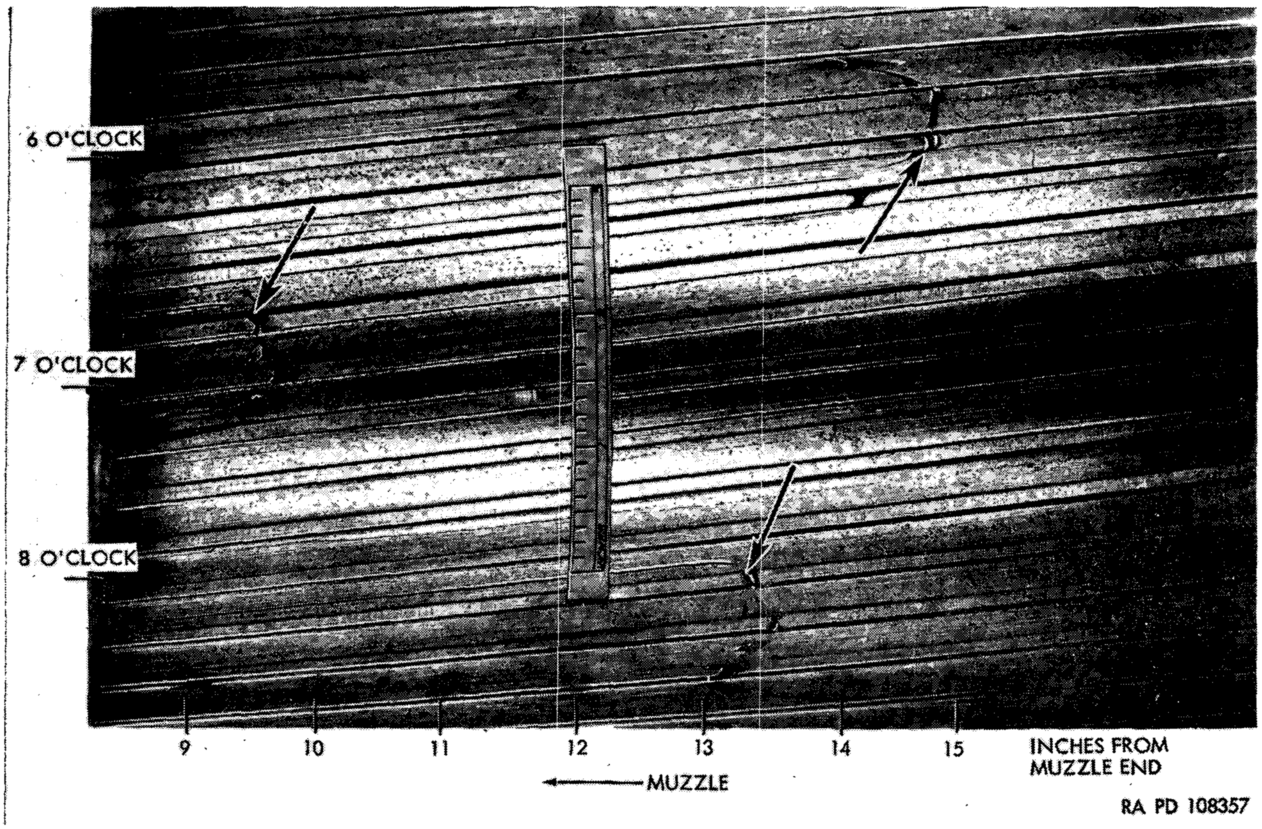

Figure 53. Section of 155-mm howitzer tube, 8 to 16 inches from muzzle end in the 7 o'clock region, showing slight damage to lands caused by the fuze safety wire becoming wedged between the projectile and the bore interface.

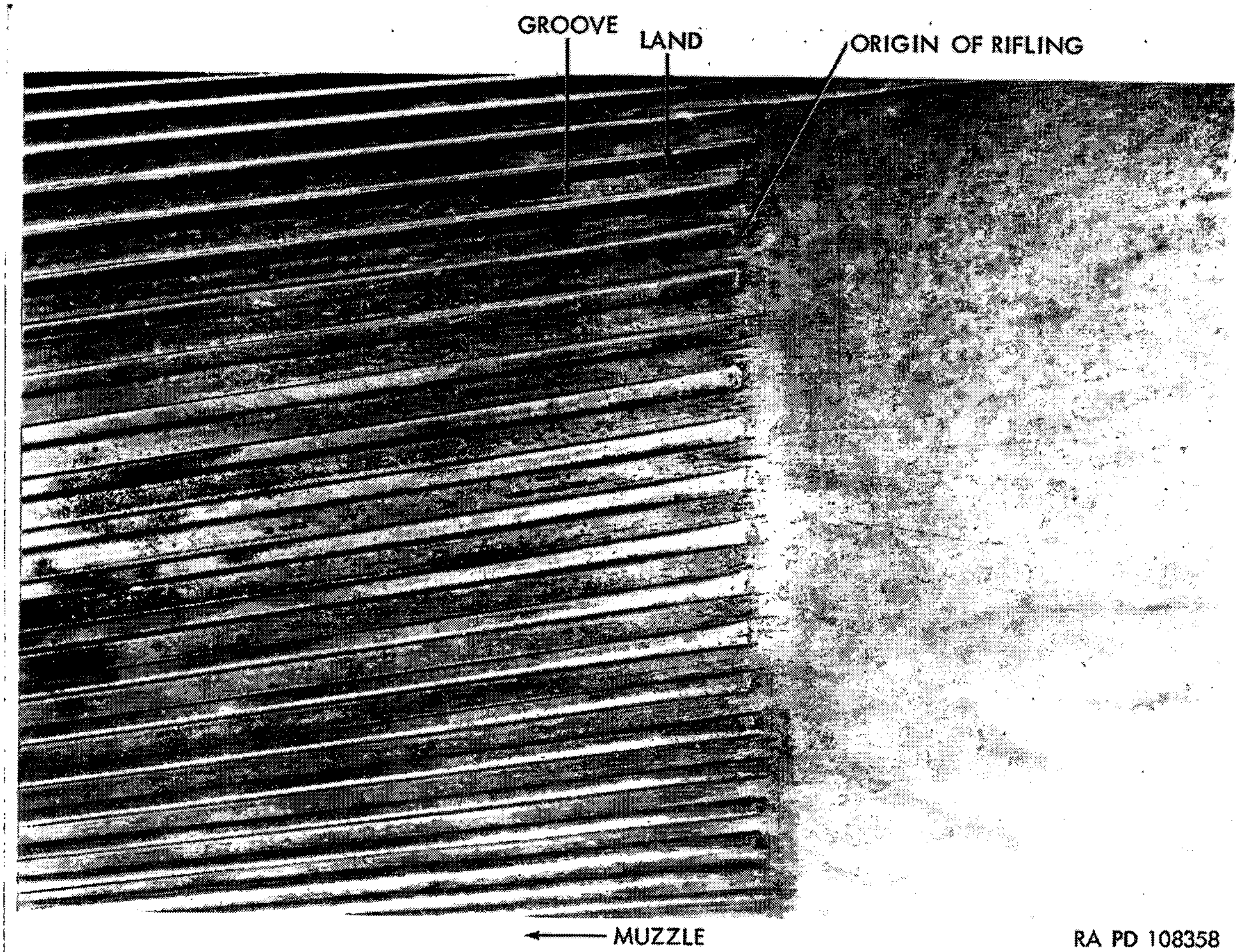

Figure 54. Origin of rifling of a 155-mm howitzer tube, showing heat checks and land chipping.

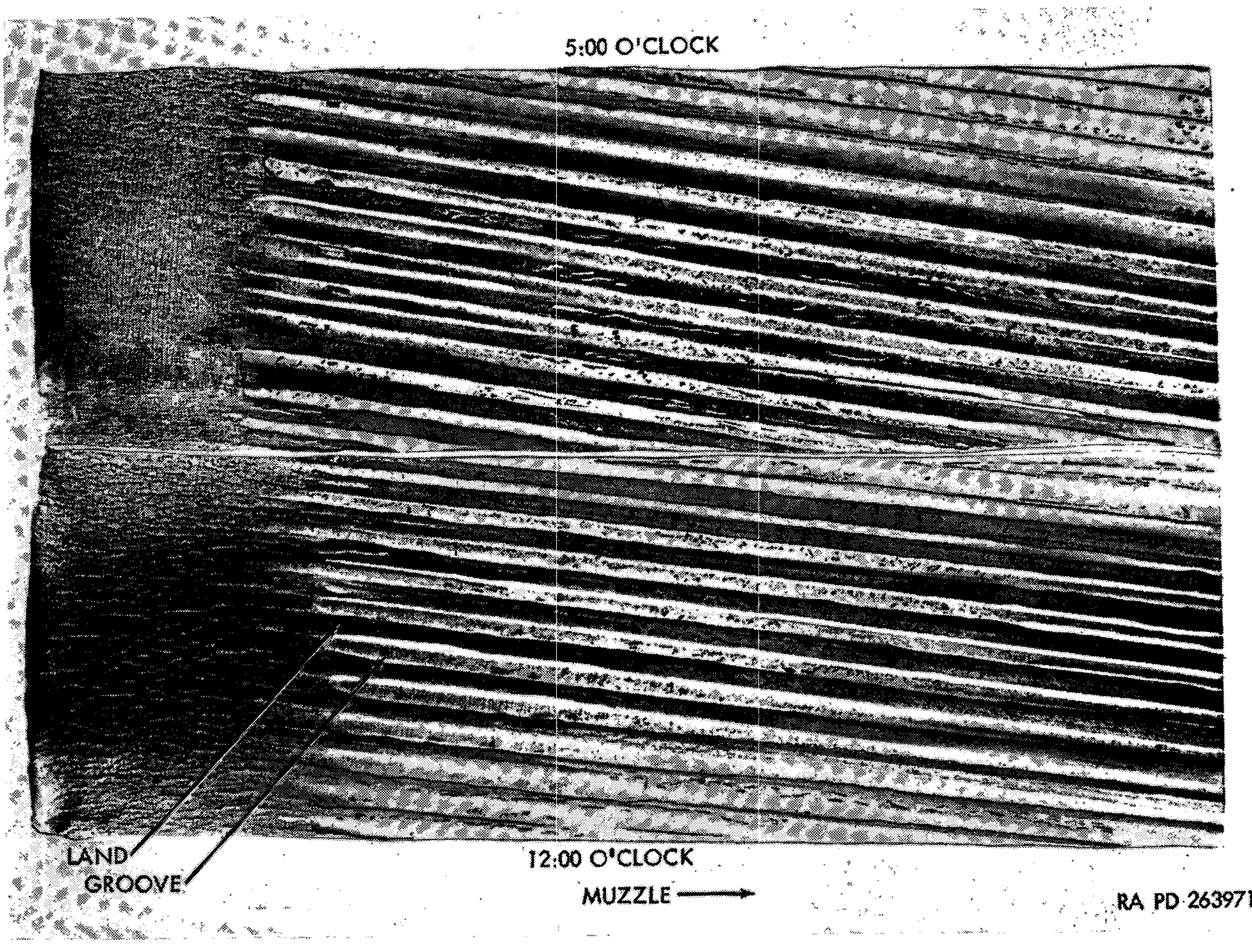

Figure 55. The origin of rifling in the 5 o'clock and 12 o'clock regions, which show advanced heat checks, some gas erosion, and light land chipping in a 155-mm howitzer tube.

Table XVI. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 155-mm Howitzer Cannon M1

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 30.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	6.100	100	3,000
0.008	6.108	95	2,850
0.013	6.113	90	2,700
0.017	6.117	85	2,550
0.021	6.121	80	2,400
0.025	6.125	75	2,250
0.029	6.129	70	2,100
0.032	6.132	65	1,950
0.035	6.135	60	1,800
0.038	6.138	55	1,650
0.041	6.141	50	1,500
0.044	6.144	45	1,350
0.047	6.147	40	1,200
0.050	6.150	35	1,050
0.052	6.152	30	900
0.054	6.154	25	750
0.056	6.156	20	600
0.057	6.157	15	450
0.058	6.158	10	300
0.059	6.159	5	150
0.060*	6.160*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition

Projectile model	Charge	Estimated remaining life	EFC factor
WP, M105; HE, M107; CHEM, M110; BE, M116; ILLUM, M118A1; BE, T72E1.	M4A1, 7	3,000	1.00
	M4A1, 6	8,200	0.37
	M4A1, 5	25,000	0.12
	M4A1, 4	60,000	0.050
	M3, 5	35,000	0.086
	M3, 4	89,000	0.034

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

Table XVII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 155-mm Howitzer Cannon M1A1, M45 (T186E1)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 30.00 inches forward of breech face (31.25 inches forward of breech face for M45 (T186E1) if tube 7307637 is used)		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	6.100	100	15,000
0.025	6.125	95	14,250
0.041	6.141	90	13,500
0.052	6.152	85	12,750
0.060	6.160	80	12,000
0.068	6.168	75	11,250
0.073	6.173	70	10,500
0.078	6.178	65	9,750
0.083	6.183	60	9,000
0.087	6.187	55	8,250
0.091	6.191	50	7,500
0.095	6.195	45	6,750
0.099	6.199	40	6,000
0.102	6.202	35	5,250
0.105	6.205	30	4,500
0.108	6.208	25	3,750
0.111	6.211	20	3,000
0.114	6.214	15	2,250
0.116	6.216	10	1,500
0.118	6.218	5	750
0.120*	6.220*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition

Projectile model	Charge	Estimated round life	EFC factor
WP, M105; HE, M107; CHEM, M110: BE, M116; ILLUM, M118A1; BE T72E1.	M4A1, 7	15,000	1.00
	M4A1, 6	40,000	0.37
	M4A1, 5	125,000	0.12
	M4A1, 4	300,000	0.050
	M3, 5	174,000	0.086
	M3, 4	440,000	0.034

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

n. 155-mm Gun Cannon M2, M2A1, and M46 (T80).

(1) A study of the wear characteristics of tubes used in these weapons indicates that they may wear in several different patterns. The various types of wear, such as smooth even wear on the lands; scoring in the grooves; heat checks; flattened, chipped, raised, and stripped lands all appear in these tubes but not necessarily in the same way in every tube. It is known that the bore wears oval at the origin of rifling so that a measurement between lands in a vertical plane will be greater than a measurement between the lands in a horizontal plane. As the wear increases there is a tendency for the wear to be more severe at 12 o'clock than at 6 o'clock. Deep scoring is often evident at the 12 o'clock position with occasional stripped lands a few inches forward of the origin of rifling. The chrome plating in the M2A1, and M46 (T80) is confined to the chambers and will not materially affect the wear characteristics of the bore.

(2) One round with HE projectile M101 fired at full charge is to be taken as equal to one EFC round. The land diameter measured vertically determines the percentage of remaining life which then may be converted into remaining EFC rounds by using table XVIII. Previous rounds fired must not be used to estimate remaining life, because of the variations of rate of wear from tube to tube.

Table XVIII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 155-mm Gun Cannon M2, M2A1, and M46 (T80)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 47.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	6.100	100	700
0.007	6.107	95	665
0.014	6.114	90	630
0.021	6.121	85	595
0.028	6.128	80	560
0.035	6.135	75	525
0.042	6.142	70	490
0.049	6.149	65	455
0.056	6.156	60	420
0.062	6.162	55	385
0.068	6.168	50	350
0.074	6.174	45	315
0.079	6.179	40	280
0.084	6.184	35	245
0.089	6.189	30	210
0.093	6.193	25	175
0.097	6.197	20	140
0.100	6.200	15	105
0.103	6.203	10	70
0.107	6.207	5	35
0.110*	6.210*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Projectile model	Charge	Estimated round life	EFC factor
HE, M101; WP, M104; ILLUM, M118A1; BE, T265.	Full Reduced	700 2,900	1.00 0.24

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

o. 8-inch Howitzer Cannon M1, M2, M2A1, and M47 (T89).

(1) The tube follows the general wear pattern of howitzers in that the primary type of erosion is gas wear with a considerable degree of abrasion also taking place. Scoring is usually not evident. It is also a common occur-

rence for lands to become flattened as the tube wears, with chipping, sheared sidewalls, and stripping also taking place, especially near the commencement of rifling. In some instances long sections of lands have been known to strip at a considerable distance forward of the commencement of rifling without apparently affecting the accuracy or serviceability of the tube.

(2) One HE projectile M106 with M2 charge seven is to be taken as equal to one EFC round. Table XIX compares physical measurement with remaining life in rounds and percent, and this measurement should always be used when evaluating the extent of tube wear.

Table XIX. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 8-inch Howitzer Cannon M1, M2, M2A1, and M47 (T89)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 38.00 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	8.000	100	6,000
0.016	8.016	95	5,700
0.032	8.032	90	5,400
0.046	8.046	85	5,100
0.059	8.059	80	4,800
0.070	8.070	75	4,500
0.080	8.080	70	4,200
0.089	8.089	65	3,900
0.097	8.097	60	3,600
0.104	8.104	55	3,300
0.110	8.110	50	3,000
0.116	8.116	45	2,700
0.121	8.121	40	2,400
0.126	8.126	35	2,100
0.130	8.130	30	1,800
0.134	8.134	25	1,500
0.138	8.138	20	1,200
0.141	8.141	15	900
0.144	8.144	10	600
0.147	8.147	5	300
0.150*	8.150*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Projectile model	Charge	Estimated round life	EFC factor
HE, M106; CHEM, T19E1; CHEM, T147E.	M2, 7	6,000	1.00
	M2, 6	14,000	0.42
	M2, 5	35,000	0.17
	M1, 5	40,000	0.15
	M1, 4	113,000	0.053

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

p. 8-inch Gun Cannon M1.

(1) The characteristic wear of tubes for this weapon is peculiar in that the wear is predominantly one of smooth, even, gas erosion and abrasion with little or no scoring evident through its service life. The appearance of a tube for the 8-inch gun M1 at the condemnation point is shown in figure 56. It can be seen that the pattern of heat checks follows the original rifling even though the lands are completely obliterated. An oval wear condition, known as spiral wear, appears in this tube at the origin of rifling and follows the rifling through the bore rather than remaining at the same clock position relative to the bore.

(2) One round with HE projectile M103 with M10 full charge is to be taken as equal to one EFC round. The estimated remaining life in EFC rounds at any given bore measurement, regardless of previous rounds fired, is shown in table XX.

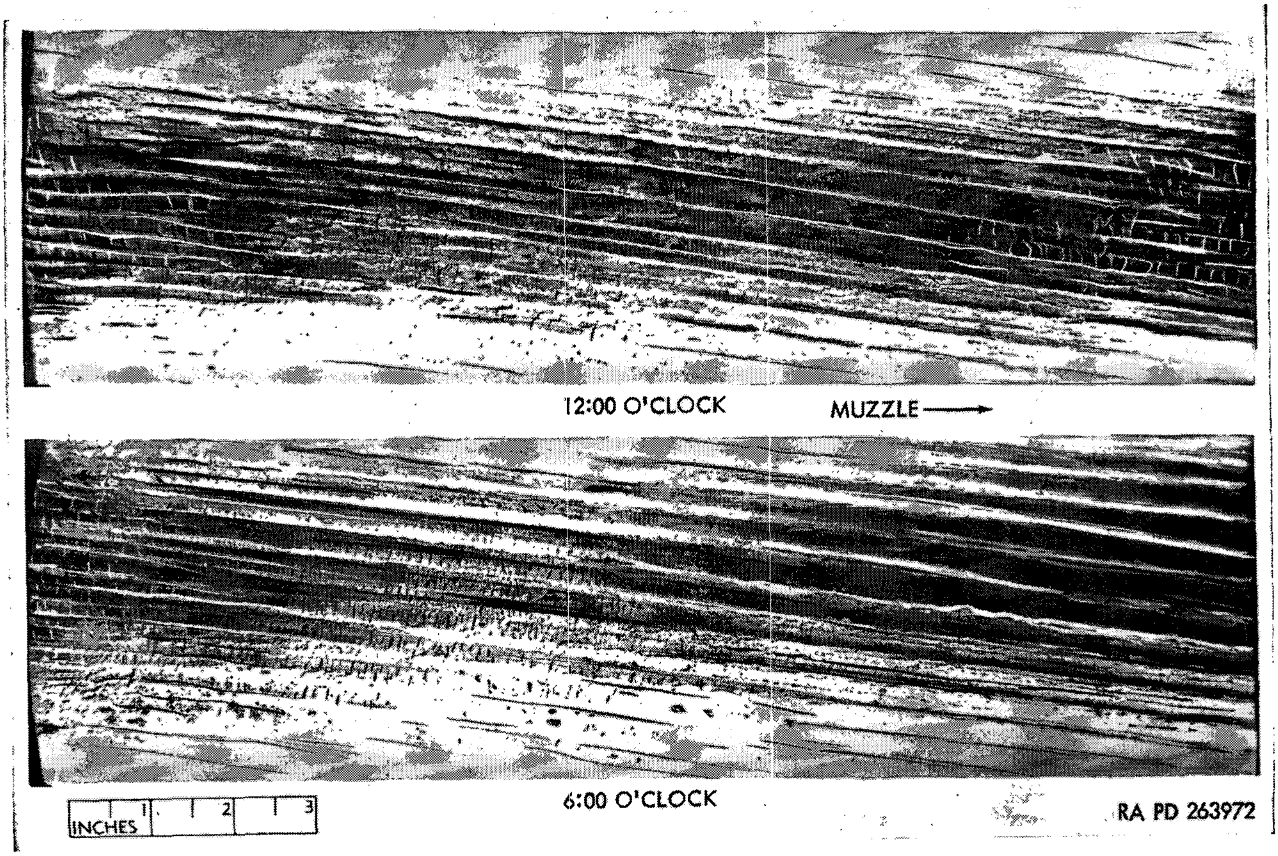

Figure 56. The origin of rifling in an 8-inch gun at the 12 o'clock region (top) and 6 o'clock region (bottom) which show advanced gas erosion of condemnation limit.

Table XX. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 8-inch Gun Cannon M1

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 72.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	8.000	100	700
0.046	8.046	95	665
0.092	8.092	90	630
0.132	8.132	85	595
0.164	8.164	80	560
0.192	8.192	75	525
0.212	8.212	70	490
0.232	8.232	65	455
0.246	8.246	60	420
0.260	8.260	55	385
0.272	8.272	50	350
0.284	8.284	45	315
0.295	8.295	40	280
0.305	8.305	35	245
0.315	8.315	30	210
0.324	8.324	25	175
0.332	8.332	20	140
0.339	8.339	15	105
0.346	8.346	10	70
0.353	8.353	5	35
0.360*	8.360*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Projectile model	Charge	Estimated round life	EFC factor]
HE, M103	M10, Full	700	1.00
	M10, Reduced	1,100	0.64
	M9, Full	1,200	0.57
	M9, Reduced	4,100	0.17

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

q. 240-mm Howitzer Cannon M1.

(1) The tube for 240-mm howitzer cannon M1 wears primarily by abrasion of lands, caused by the projectile passing through the bore and by smooth, even, gas wear. However, scoring exists to a limited extent at the origin of rifling when projectiles are fired through hot tubes or ramming is not vigorous. The tube at the origin of rifling has a tendency to wear unevenly, so that a vertical measurement of land diameter will be greater than the horizontal measurement. As this condition progresses, lands will wear smooth at the 12 o'clock position, whereas at the 6 o'clock position considerable rifling will remain (fig. 57). There is also a tendency for the driving edges of the lands to wear rapidly, thus giving the land a rounded appearance. Severe heat checks are usually in evidence at the origin of rifling and in the chamber (fig. 58–60). Flattened, chipped, raised, or stripped lands are occasionally in evidence, but this condition is not serious and wll not be used as a basis for condemnation.

(2) One HE projectile M114 with charge four is to be taken as equal to one EFC round. Table XXI is an estimated table, which shows the remaining life compared to bore measurement.

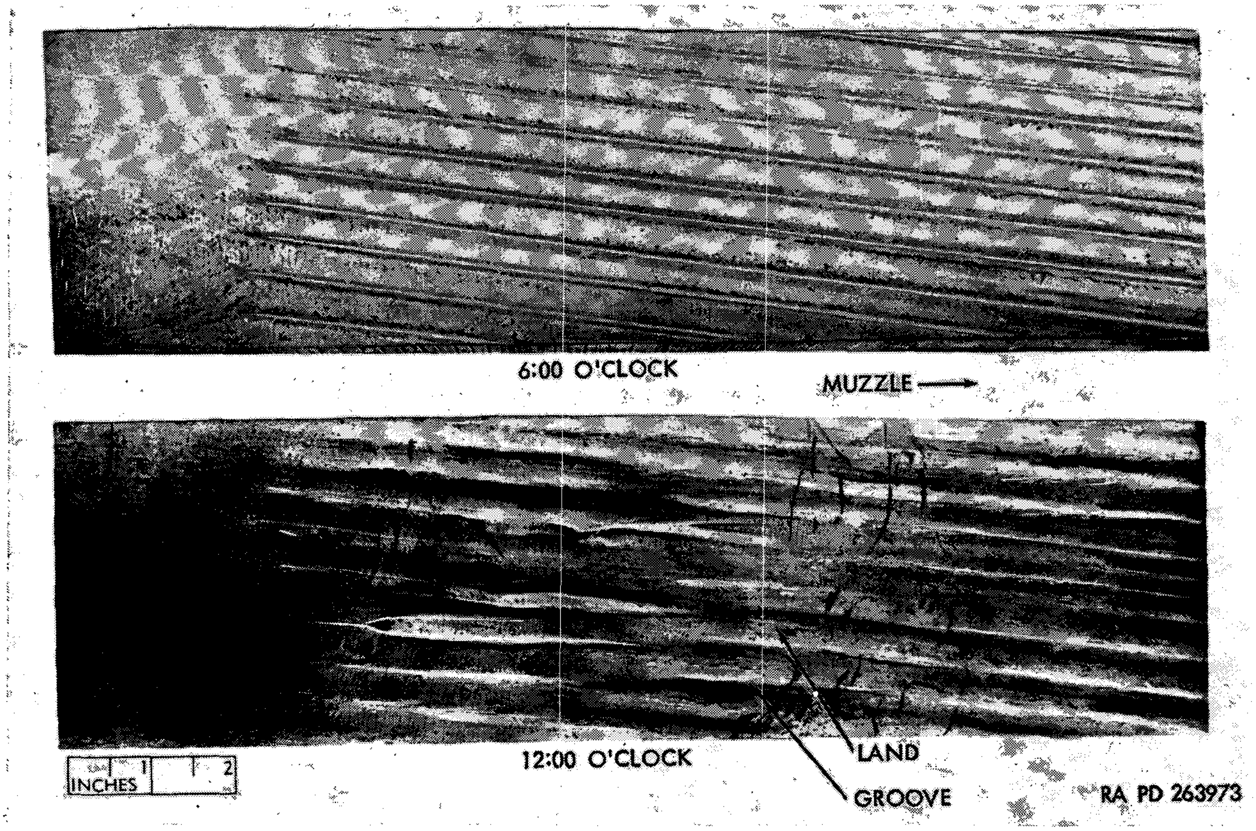

Figure 57. The origin of rifling in a 240-mm howitzer tube, showing the beginning of scoring at 12 o'clock (bottom) while the rifling is still well defined at 6 o'clock (top).

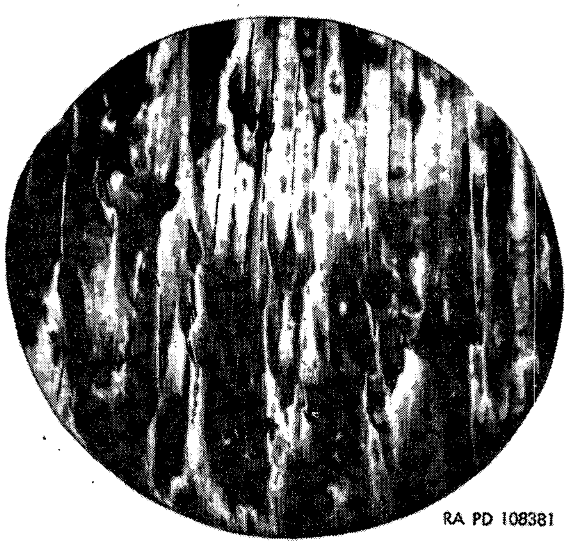

Figure 58. Borescope view of the origin of rifling in a 240-mm howitzer tube, showing advanced scoring at 12 o'clock at the condemning limit.

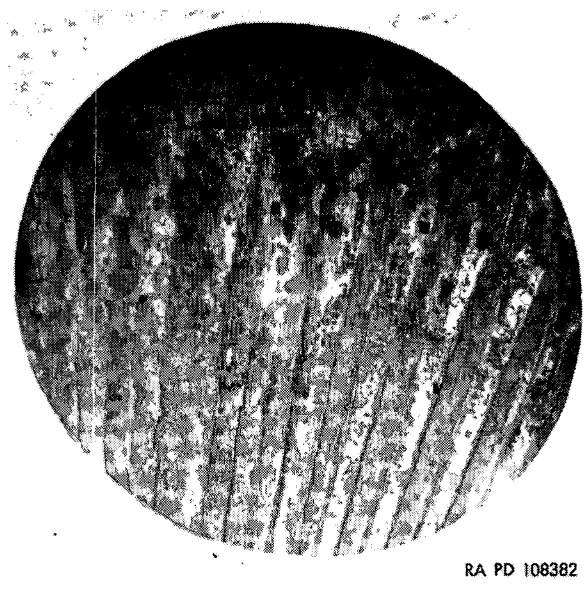

Figure 59. Borescope view of the origin of rifling of the 240-mm howitzer illustrated in figure 58, showing advanced wear of lands, heat checks, and coppering at 6 o'clock.

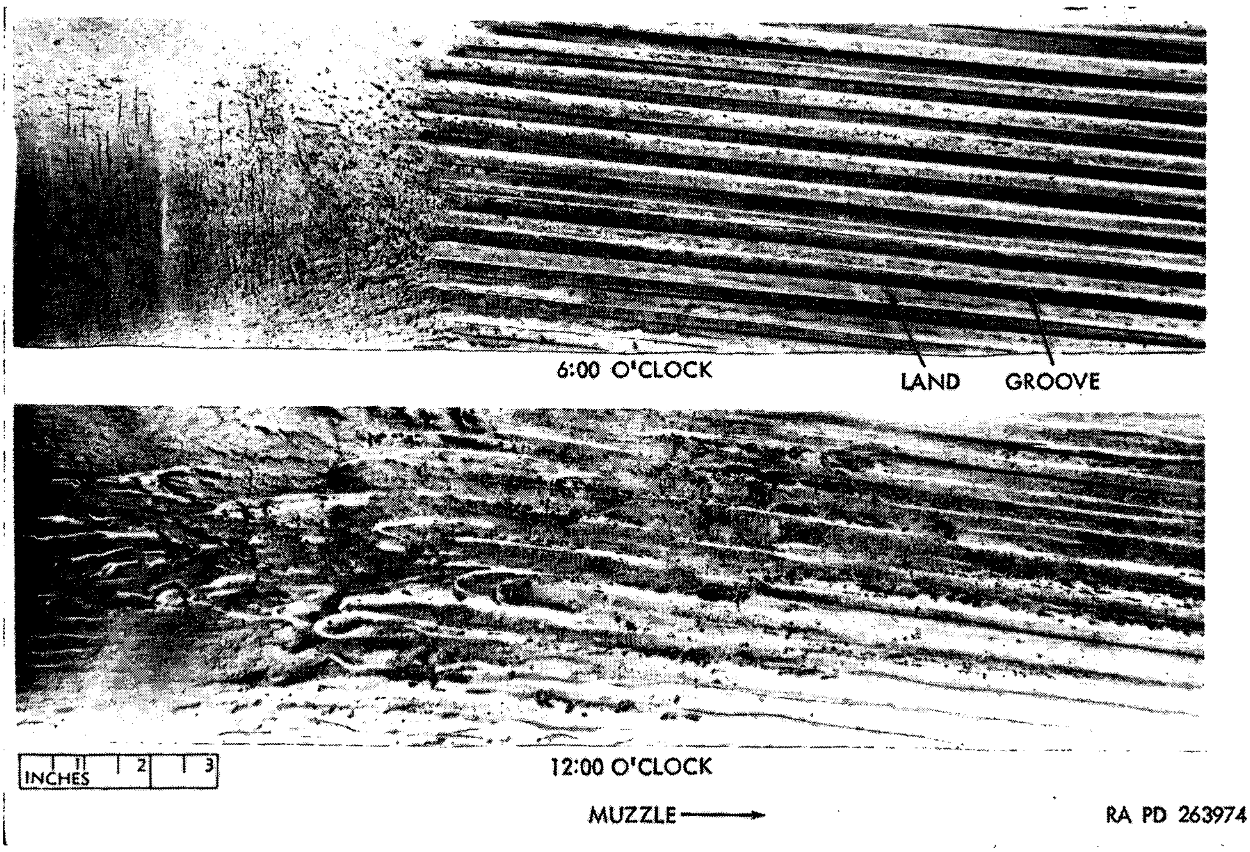

Figure 60. The origin of rifling in a 240-mm howitzer, showing scoring at 12 o'clock (bottom) and wear of lands at 6 o'clock (top) at condemning limit.

Table XXI. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 240-mm Howitzer Cannon M1

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 64.50 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	9.440	100	2,000
0.026	9.466	95	1,900
0.050	9.490	90	1,800
0.068	9.508	85	1,700
0.083	9.523	80	1,600
0.095	9.535	75	1,500
0.106	9.546	70	1,400
0.115	9.555	65	1,300
0.123	9.563	60	1,200
0.131	9.571	55	1,100
0.138	9.578	50	1,000
0.145	9.585	45	900
0.151	9.591	40	800
0.157	9.597	35	700
0.163	9.603	30	600
0.168	9.608	25	500
0.173	9.613	20	400
0.178	9.618	15	300
0.183	9.623	10	200
0.188	9.628	5	100
0.192*	9.632*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Projectile model	Charge	Estimated round life	EFC factor
HE, M114	4	2,000	1.00

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

r. 280-mm Gun Cannon M66 (T131).

(1) The tube for the 280-mm gun cannon M66 (T131) wears primarily by abrasion of the lands, caused by the projectile passing through the bore, and by smooth, even, gas wear. Moderate stress damage and heavy heat checking become more evident as additional rounds are fired. This condition is usually found in the forward area of the chamber, and extending into the main bore. The lands become rounded on both the driving and nondriving edges from the origin of rifling to a considerable distance down the bore, depending upon the number of rounds fired. The vertical measurement of land diameter is usually larger than the horizontal measurement.

(2) Table XXII can be used to estimate the remaining life of this weapon regardless of the number and type of rounds previously fired. One round of HE projectile M124 (T122) at charge four is designated one EFC round.

Table XXII. Estimated Remaining Life of Cannon Tube Based on Bore Measurement 280-mm Gun Cannon M66 (T131)

EFC rounds shown in table are based on primary ammunition, EFC factor 1. For computing estimated remaining life of cannon tube in rounds of other ammunition, use appropriate EFC factor as outlined in instructions in paragraphs 28 through 32.

Bore measurement 92.75 inches forward of breech face		Estimated remaining life	
Wear (gage reading)	Actual diameter	Percentage	EFC round
0.000	11.025	100	300
0.017	11.042	95	285
0.032	11.057	90	270
0.044	11.069	85	255
0.056	11.081	80	240
0.067	11.092	75	225
0.077	11.102	70	210
0.087	11.112	65	195
0.097	11.122	60	180
0.106	11.131	55	165
0.114	11.139	50	150
0.122	11.147	45	135
0.130	11.155	40	120
0.138	11.163	35	105
0.145	11.170	30	90
0.152	11.177	25	75
0.159	11.184	20	60
0.165	11.190	15	45
0.170	11.195	10	30
0.175	11.200	5	15
0.179*	11.204*	0	0

*See footnote at end of table.

Estimated round life of cannon tube and EFC factor based on use with specific ammunition			
Projectile model	Charge	Estimated round life	EFC factor
HE, M124 (T122); TEST, T160.	4	300	1.00
	3	750	0.40
	2	1,800	0.17
	1	8,100	0.037
HE-S, M350 (T123); TEST, T159.	Full	500	0.063
	Reduced	1,200	0.25
HEDS, T121; TEST, T161.	----------	300	1.05

*Condemnation limit (condemnation will be based on tube wear and not on rounds fired).

Section III. CONDEMNATION CRITERIA

33. Cracks

All cracks except cracks through the lands associated with stripping of the lands (fig. 61), are sufficient cause for condemnation.

34. Rifling Damages

Where lands are destroyed by balloting appearing as a series of waves, by bulges caused by low-order functioning of a premature burst, or by gouges one caliber in length, provisional condemnation is justified. Light gouges, nicks, short pastilles, or similar defects do not warrant condemnation. A bulge which enlarges the diameter across the groove 0.01 inch or more for a distance of one and one-half calibers or more, is cause for condemnation. Bulges as large as this tend to disturb the functioning of the fuze. Any rifling damage which may result in a shearing or stripping of rotating bands, or any evidence that such shearing or stripping has occurred (shearing or stripping will be evidenced by sudden extremely short ranges during firing) is a cause for condemnation. Mushroomed overhang on the lands often chips off in strips (fig. 62). This is a serious condition and may result in condemnation.

35. Scoring

When an erosion trough appears abnormally early in the tube life, the tube will be condemned when this condition extends from the origin of rifling forward one and one-half calibers. Deep scoring extending forward three calibers or more is cause for condemnation.

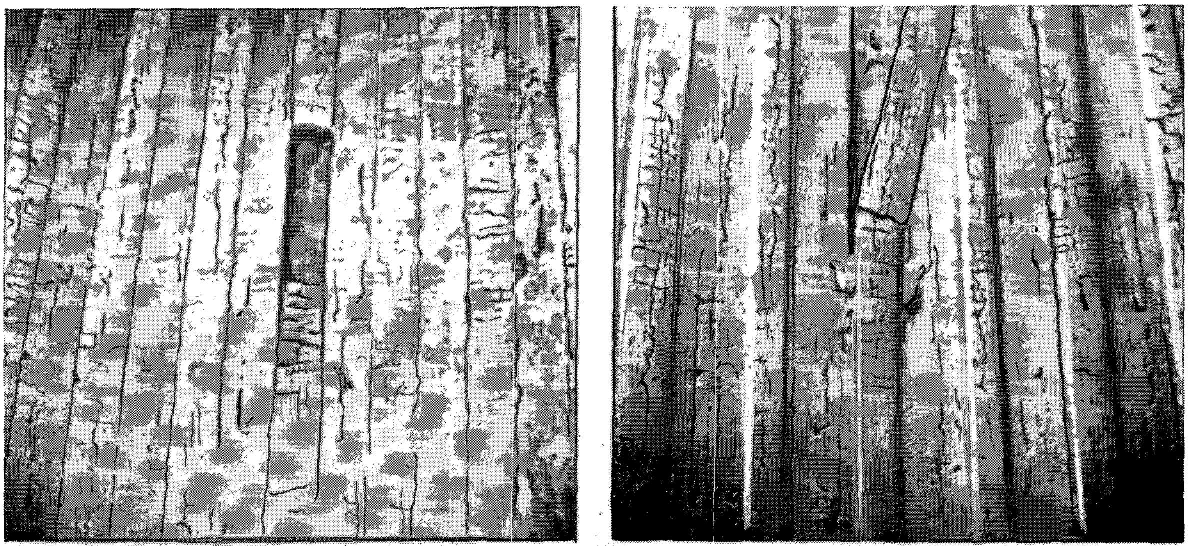

Figure 61. Stripped lands—acceptable.

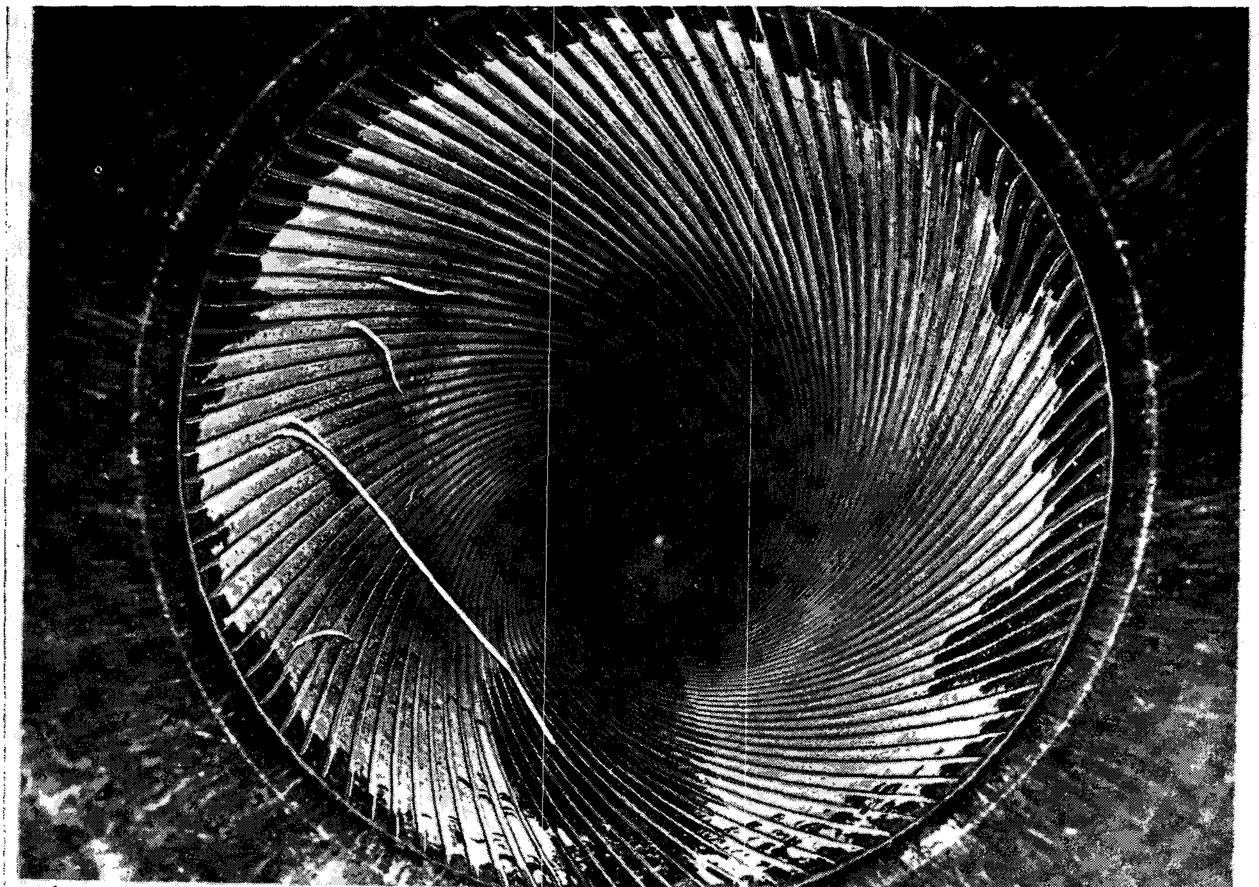

Figure 62. Flattened lands at origin of rifling showing mushroomed overhang spalled off in strips.

36. Exterior Gouges

Gouges caused by hostile ammunition which penetrate more than one-fourth the wall thickness of any tube or which extend more than one-half caliber in length are cause for condemnation.

37. Constrictions

a. Constriction of the bore due to impact of projectile or other reasons may cause prematures or breakup of projectiles if greater than 0.01 inch. A constriction up to 0.005 inch times the caliber in inches may be removed when possible by honing, stoning, or filing. Constrictions greater than this are sufficient cause for condemnation.

b. Constriction caused by copper is not cause for condemnation. If copper choke is sufficient to interfere with loading, the removal of the copper will be accomplished with a tinfoil addition to a special charge as outlined in paragraph 23*b*. Decoppering by means of wire brush, scraping, or similar means is prohibited.

38. Condemnation Criteria for Recoilless Rifle Tubes

Weapons will be declared unserviceable, irreparable, and disposed of in accordance with existing regulations, if a test projectile fails to pass through the bore or if exterior gouges penetrate tube more than one-fourth the wall thickness or extend one and one-half inches in length. Before disposal of weapon, serviceable parts will be removed for use on other weapons or returned to stock.

39. Condemnation Criteria for Mortar Cannon Tubes

a. Bulges. Visible bulges on the tube or bulges that enlarge the bore to a diameter greater than the condemning limit diameter specified in table XXV will be condemned.

b. Dents. Tubes with dents, that will not permit either a dummy round or an improvised basic bore diameter plug gage to pass freely through the bore, will be condemned.

c. Pits. Tubes which contain pits larger than 0.375 inch in width or length, and 0.010 inch in depth will be condemned. Pits smaller than the above dimensions are allowable, but it is desirable to hone these bores to remove as much of the pits as practical and still maintain acceptable bore diameters.

d. Land Damage. Rifled tubes will be visually inspected as outlined in paragraph 24. Stripped or missing lands, excessive spot wear, peening, cracks or other defects that would cause improper obturation will be cause for condemnation.

Section IV. CONDEMNATION LIMITS

40. Bore Measurement

The absolute limit for a tube can only be determined by actual firing, but this is usually impractical or impossible. The condemnation limits for wear have been set at a safe margin for all weapons; therefore, the pullover gage reading will normally be accepted as the basis for determing serviceability of the tube in gun and howitzer cannon.

41. Table for Specific Cannon

The wear limits for the individual gun and howitzer cannon models as established by proving ground tests, are listed in table XXIII. The condemning limits for recoilless rifles are listed in table XXIV.

42. Recoilless Rifle Tubes

a. 57-mm Rifles. The rifle is to be condemned when the weapon can no longer be stabilized with a +10 throat ring. There are five sets of throat rings manufactured with each weapon. The —4 ring is installed at the time of manufacture and is used by the proof facility to achieve initial stabilization. If the weapon cannot be stabilized with the —4 ring the +4 ring may be used.

b. 75-mm and 105-mm Rifles. The estimated service life of the 75-mm and 105-mm recoilless rifles is 2,000 rounds. The stabilization of this weapon during firing depends on the extent of erosion of the vent bushing, which has an estimated life of approximately 500 rounds. The estimated service life of the weapons is

Table XXIII. Condemning Limits for Cannon Tubes

Caliber	Model No.	Basic bore diameters		Condemning limit diameter	Distance from breech end of tube	Stop length	Wear (gage reading)
		Bore	Grooves				
	Gun Cannons						
37-mm	M6	1.457	1.497	1.528	9.75	2	0.071
40-mm	M1 and M2 series	1.573	1.618	1.625	13.75	3½	0.052
75-mm	M3, M17	2.950	2.990	2.970	14.50	4	0.020
	M6 w/tube 7230179	2.950	2.990	Limited to	1,000 rounds		
	M6 w/tube 7230679	2.950	2.990	2.970	14.50	4	0.020
	M35 (T83E7)	2.950	3.010	3.005	22.75	4	0.055
76-mm	M1	3.000	3.080	3.090	22.75	4	0.090
	M32 (T91E3) and M48	3.000	3.090	3.100	24.75	4	0.100
90-mm	M1 and M2 series	3.543	3.623	3.692	25.00	6	0.149
	M3 and M26	3.543	3.623	3.692	25.00	6	0.149
	M36, M41 and M54	3.543	3.638	3.740	25.25	6	0.197
120-mm	M1, M1A1, M1A2 and M1A3 w/tube D36361	4.700	4.790	4.940	41.00	9	0.240
	M1A3 w/tube 7307112	4.700	4.800	5.060	41.00	9	0.360
	M58 (T123E1)	4.700	4.800	4.950	38.25	9	0.250
115-mm	M2, M2A1, M46 (T80)	6.100	6.200	6.210	47.75	9	0.110
8-in.	M1	8.000	8.140	8.360	72.75	15	0.360
280-mm	M66 (T131)	11.025	11.205	11.205	92.75	15	0.180
	Howitzer Cannons						
75-mm	M1A1 and M3	2.950	3.010	3.000	11.50	4	0.050
105-mm	M2A1 and M4	4.134	4.194	4.204	15.50	6	0.070
	M2A2, M4A1, M49 (T96E1)	4.134	4.212	4.204	16.00	6	0.070
155-mm	M1	6.100	6.200	6.160	30.00	9	0.060
	M1A1, M45 (T186E1)	6.100	6.200	6.220	30.00	9	0.120
	M45 (T186E1) w/tube 7307637	6.100	6.200	6.220	31.25	9	0.120
8-in.	M1, M2, M2A1 and M47 (T89)	8.000	8.140	8.150	38.00	15	0.150
240-mm	M1	9.449	9.609	9.632	64.50	15	0.183

Table XXIV. Condemning Limits for Rifle Tubes

Caliber	Model No.	Basic bore diameters		Estimated round life	Condemnation criteria
		Bore	Grooves		
	Recoilless Rifles				
57-mm	T15E16, M18, M18A1			2500	Limited by the inability to stabilize the weapon with a +10 throat ring.
75-mm	M20, T21E12			2000	Limited to the utilization of four vent bushings to achieve stabilization.
105-mm	M27, M27A1			2000	Limited to the utilization of four vent bushings to achieve stabilization.
106-mm	M40A1, M40A1C			2500	Limited to the utilization of two vent assemblies to achieve stabilization.

based on the utilizaton of four vent assemblies. The actual service life of the weapons is unknown but a limit has been established to condemn the rifle after four vent assemblies have been utilized in order to maintain a high safety factor. Wear on the lands is negligible and is not convertible to rounds expended or expected remaining life.

c. 106-mm Rifle. The estimated service life of the 106-mm recoilless rifle is 2,500 rounds. The stabilization of the rifle during firing depends on the adjustment of the recoil compensating ring. When the rifle cannot be stabilized by adjustment of the recoil compensating ring (normally after approximately 1,250 rounds have been fired) it will be returned to Ordnance for a critical inspection. If the tube is found serviceable, a new vent assembly with recoil compensating ring will be installed and stamped number "2". The weapon will then be returned to the user. The actual service life of the rifle is unknown, but a tenative limit has been established to condemn the rifle after it can no longer be stabilized by adjustment of the second recoil compensating ring in order to maintain a high safety factor. Wear on the lands is negligible, and is not convertible to rounds expended or expected remaining life.

43. Mortar Cannon Tubes

a. The increase in bore diameter resulting from wear or other removal of metal, such as removing pits, will be measured by pullover gage as outlined in TM 9–4933–200–35 with the exceptions listed below:

(1) The pullover gage listed in table XXV will be used, as gages with the exact basic diameters of mortar cannon are not available.

(2) Multiple readings at unspecified locations throughout the length of the tube will be taken. A reading at any location in excess of the condemning limit diameter listed in table XXV will be cause for condemnation.

(3) Readings will be taken in actual bore diameters rather than the amount of wear taken from the vernier of the pullover gage. It is recommended that the reading be taken with the vernier caliper, that is normally used to calibrate the gage.

b. Condemning limit diameters for mortar cannon are listed in table XXV.

Table XXV. Condemning Limits for Mortar Cannon Tubes

Caliber	Model No.	Basic bore diameter	Pullover gage used	Condemning limit diameter
60-mm	M2, M19	2.392	57-mm	2.411
81-mm	M1, M29	3.205	76-mm	3.227
4.2 inch	M30 (T104)	4.200*	105-mm	4.221

* Land diameter.

CHAPTER 5

CALIBRATION OF CANNON TUBES

Section I. CALIBRATION

44. Calibration Methods

a. Regardless of the many ballistic variables, the effectiveness of our armament is impressive. This is the combined result of vigorous regulation and constant inspection in the manufactured process, which limits the finished product to very slight tolerances, plus measurement of pressures and velocities in the weapons under all conditions. The statistics determined by such calibrations are tabulated and provide a convenient means of anticipating the effect of any conditioning circumstances of the accuracy of the weapon. For example, it has been found that an increase in the bore diameter of 0.060 inch in a 155-mm gun M2 will bring about a reduction of 16 fps in muzzle velocity. With this knowledge it is possible to compensate for the loss in range, due to erosion, by increasing the elevation. Similarly, if it is known that propellant temperature is too low, the proper correction can be included in the initial laying of the piece.

b. Advances in fundamental knowledge of interior ballistics depend on accurate observation and measurement of all the phenomena that take place within the gun. These include measurements of pressure distribution, temperature distribution, bore friction, motion of the solid powder, and many other things inside the gun. For most practical purposes, however, the only tests in use are measurements of muzzle velocities and of peak pressures. Such tests are commonly made both at proving grounds and by ballistic teams in theaters of operation. Proving ground measurements of muzzle velocity and powder pressure may be made for several quite different purposes: for research and development concerned with new weapons or ammunition, for acceptance tests, and for surveillance tests. The measurement of muzzle velocity is commonly carried out by means of a solenoid chronograph. The measurement of pressure may be done with a crusher type pressure gage. Pressure gages measure peak pressure. Powder in an acceptance test is checked for uniformity. Peak pressures are often measured in these tests to make sure that safety limits are not being too closely approached; these measurements, however, give additional information about uniformity. At this time powder charges are established to give required muzzle volocities. Surveillance tests, on the other hand, are made to test propellant or ammunition which has been in storage for some time. They are concerned mainly with drop in muzzle velocity produced by deterioration of propellant or by erosion of tubes. With a knowledge of the actual muzzle velocity and the dispersion pattern that is obtained, proper action may be taken. The action may be condemnation if the dispersion is too great, or it may consist simply of varying the angle of elevation to bring the range back to its desired value. Tests made by ballistic teams in the field are essentially surveillance tests.

45. Velocity Calibration

a. Muzzle velocity is not measured by the same method as chamber pressure. Normally, muzzle velocity is thought of as being the speed of a projectile at the instant it leaves the bore, while the actual measurement is taken approximately 70 feet forward of the muzzle. This is necessary to protect the instruments from damage due to muzzle blast. And, since the projectile continues to accelerate for a short time after it leaves the muzzle (because of the velocity and pressure of the propelling gases behind it), the greatest velocity is reached outside the bore of the tube. Velocity, as such, is not measured directly. Instead, an instrument known as a chronograph is used to record the time required for a projectile to travel a short, known base distance. The rate (velocity) at the mid-point of the base distance is determined by dividing the distance by the time; then, through certain exterior ballistic calculations, the velocity of the projectile at the muzzle can be derived (TM 9–1860–7).

b. The velocity of projectile can be measured using the chronograph and sky screens. The chronograph is essentially a stop watch and the sky screen is an "electric eye" that provides the push to start and stop the chronograph. In normal operation two sky screens are used to set up two sensitized areas a given distance apart across the line of sight of a weapon (fig. 63). When the projectile passes the first sensitized area the chronograph starts to measure time and when the projectile passes through the second sensitized area it stops measuring time. The velocity of the projectile can then be computed from this time of flight through a given distance. In normal operation two chronographs are used so that one can be checked against the other. Operation and maintenance of sky screen and chronograph are covered in TM 9–1860–7.

46. Pressure Calibration

The crusher type pressure gage operates on the principle that a certain pressure will cause a corresponding amount of permanent compression in a copper cylinder. (These cylinders are machined to exact dimensions from stock of uniform physical characteristics. Samples from each lot are then subjected to various known pressures in a testing machine, and the resulting distortion is tabulated.) A pressure gage containing one of these cylinders can be placed in the chamber of artillery pieces. When the weapon is fired, the resulting pressure acts on a movable piston within the gage. This, in turn, transmits a corresponding pressure to the copper cylinder, causing a permanent distortion in the metal. The amount of this distortion, when compared to the table of distortion previously mentioned, gives an indication of the peak pressure within the chamber of the weapon. Because the pressure in a gun is applied only momentarily the reading obtained tends to be somewhat low. By multiplying crusher values for peak pressure by a suitable factor, usually about 1.2, correction is made for this error. Operation and maintenance of the pressure gage M3 are covered in TM 9–4933–200–35.

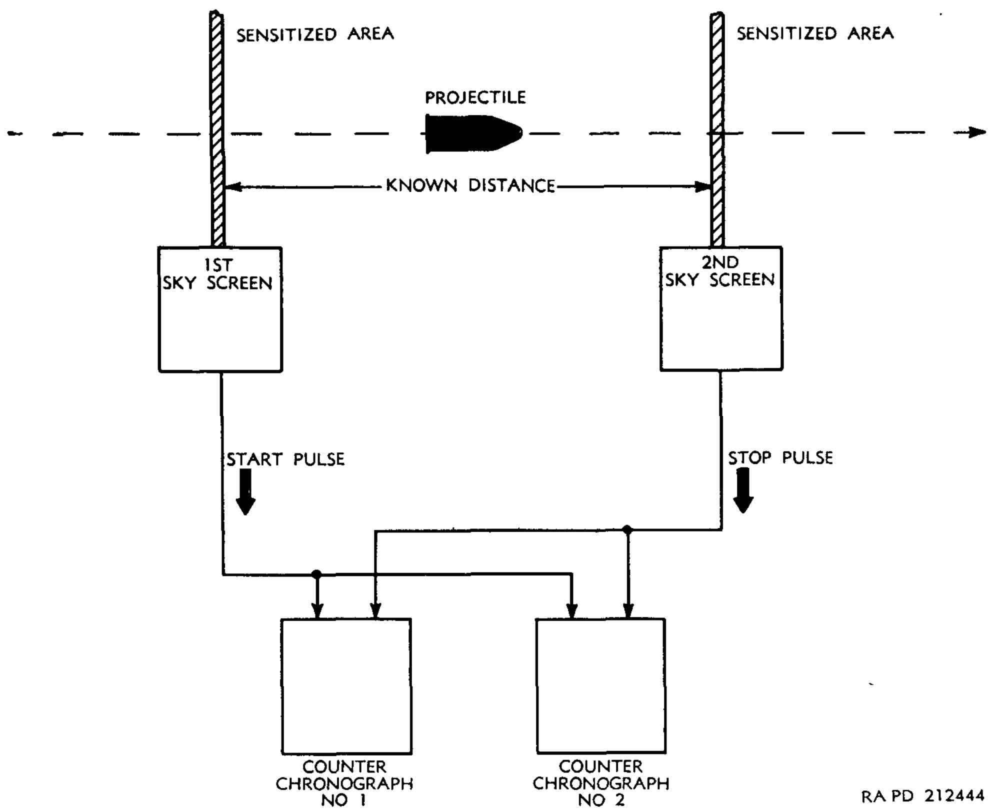

Figure 63. Operation of field sky screen and counter chronograph.

Section II. EVALUATION

47. General

The only absolute method of determining serviceability of a cannon tube is by actual firing. Given standard ammunition, stable and known atmospheric conditions, and instruments for measuring velocity and fall of projectile, the relative serviceability of tubes can readily be determined. This is impractical under field conditions, since each of the conditions stated is variable. The closest approach is the use of calibration teams to calibrate the velocity levels of the guns in the battery. Knowing the bore measurement and the velocity calibration, it is possible to predict a velocity-loss table for average conditions. The deviation of the individual tube from the average as represented by the table should be fairly constant. However, it is essential that the velocity calibration be correlated with the bore measurement.

48. Estimation of Muzzle-Velocity Loss of Specific Weapons

a. 37-mm Gun Cannon M6.

(1) The approximate muzzle-velocity loss which may be expected at any given bore measurement is indicated in table XXVI.

(2) With kinetic-energy projectiles, such as the type APC–T, the thickness of armor which can be penetrated decreases as the muzzle velocity decreases. To obtain the same penetration with a worn tube, that can be obtained with a new tube, the target must be engaged at closer range. For example, consider firing the APC–T cartridge M51B2 to an armor target at 30° obliquity and 2000 yards range, using a tube worn to the condemning limit. The muzzle velocity of the worn tube will have dropped from 2900 fps to 2684 fps, and as a result, about 0.1 inch less armor will be penetrated. In terms of range, a tube at the condemning limit must engage the target at 1700 yards range, in order to match new tube performance at 2000 yards range. The armor-defeating capability of a tube at the condemning limit is considered satisfactory under current U. S. development policy for armor-defeating ammunition.

Table XXVI. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 37-mm Gun Cannon M6
(Based on specific ammunition)

Bore measurement 9.75 inches forward of breech face		Muzzle velocity loss (fps)
		Cartridge model
Wear (gage reading)	Actual diameter	APC–T, M51B2
0.000	1.457	0
0.003	1.460	12
0.006	1.463	20
0.009	1.466	29
0.012	1.469	38
0.015	1.472	47
0.018	1.475	56
0.021	1.478	65
0.024	1.481	74
0.027	1.484	83
0.030	1.487	92
0.033	1.490	101
0.036	1.493	108
0.039	1.496	118
0.042	1.499	126
0.045	1.502	137
0.048	1.505	148
0.051	1.508	156
0.054	1.511	164
0.057	1.514	174
0.060	1.517	182
0.063	1.520	192
0.066	1.523	202
0.069	1.526	212
0.071	1.528	216

(3) The accuracy of the tube remains fairly constant throughout its life. No projectile malfunctions, attributable to erosion, are expected to occur within the condemnation limits (table XXIII).

b. 40-mm AA Gun Cannon M1 and M2 Series.

(1) Velocity may be expected to drop approximately 168 fps at the end of accuracy life with no perceptible increase in velocity dispersion. However, beyond this point the velocity dispersion increases very rapidly and soon the error in lead caused by velocity dispersion becomes greater than the minimum error of 0.20 mils expected from the director. During the life of

the tube, the error in lead caused by velocity dispersion is less than one and one-half mils in elevation and less than five mils in azimuth. The difference in probable error between a new tube and one which has reached the condemning point will result in a lead error of less than 11 feet in azimuth and four feet in elevation for 50 percent of the rounds fired at a range of 1,500 yards. The effect of a probable error in velocity of 30 fps (obtained at the point of condemnation) on the vertical dispersion of impacts corresponds to a probable error of one-half mil in elevation at a range of 2,500 yards. This is considered very small in view of the fact that it is equivalent to an error of only one percent in time of flight. Table XXVII plots muzzle-velocity loss compared to bore measurement so that the velocity level may be estimated for any condition of wear.

(2) The accuracy of the tube during its life, not considering variations due to the mount, etc., is such that the vertical and horizontal probable error of impact may be expected to be within two-thirds of a mil. The accuracy of the tube can be expected to remain practically constant until the projectile rotating bands shear. This will not occur until the wear has increased beyond that established as the condemnation limit. Resultant projectile instability causes the dispersion pattern to rise sharply.

c. 75-mm Howitzer Cannon M1A1, M2, and M3. The velocity loss and corresponding range loss for these tubes is very small throughout their service life. A loss of 35 fps in muzzle velocity (zone four) may be expected from a tube having 13,000 EFC rounds fired through it. Periodic velocity calibration is not considered necessary for these tubes in view of the small loss obtained. Dispersion in range does not appreciably increase up to this stage in the life of the tube, and is not expected to increase materially until the wear reaches a stage at which the projectile rotating bands shear. Projectiles exhibiting this condition generally have insufficient rotational velocity to be stable in flight and, therefore, fall short of the range table figure by as much as 40 percent. At this stage of wear the tube is no longer serviceable and should be condemned.

Table XXVII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 40-mm AA Gun Cannon M1 and M2 Series

(Based on specific ammunition)

Bore measurement 13.75 inches forward of breech face		Muzzle velocity loss (fps)
		Cartridge model
Wear (gage reading)	Actual diameter	HE–T, Mk II
0.000	1.573	0
0.002	1.575	11
0.004	1.577	18
0.006	1.579	23
0.008	1.581	27
0.010	1.583	30
0.012	1.585	33
0.014	1.587	35
0.016	1.589	37
0.018	1.591	39
0.020	1.593	41
0.022	1.595	43
0.024	1.597	46
0.026	1.599	50
0.028	1.601	54
0.030	1.603	60
0.032	1.605	66
0.034	1.607	73
0.036	1.609	82
0.038	1.611	93
0.040	1.613	101
0.042	1.615	112
0.044	1.617	123
0.046	1.619	134
0.048	1.621	141
0.050	1.623	156
0.052	1.625	168

d. 75-mm Gun Cannon M3, M6, and M17.

(1) The drop in velocity which occurs during the life of this tube is considered negligible and does not warrant calibration. Variations in velocity with resultant variations in range may be caused by differences within an ammunition lot or, even more pronounced, differences existing from lot to lot.

(2) For kinetic-energy, armor-piercing projectiles, such as the types APC–T and AP–T, the thickness of armor which can be penetrated decreases as

the muzzle velocity of the weapon decreases. Because the muzzle-velocity loss due to tube erosion is negligible with these weapons, a worn tube will continue to match new tube performance against armor targets at all ranges. This capability well exceeds the requirements outlined in current U. S. development policy for armor-defeating ammunition.

(3) Throughout tube life, accuracy remains fairly constant. No ammunition malfunctions affecting accuracy are expected to occur within the condemnation limit (table XXIII).

Table XXVIII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 75-mm AA Gun Cannon M35 (T83E7)

(Based on specific ammunition)

Bore measurement 22.75 inches forward of breech face		Muzzle velocity loss (fps)
		Cartridge model
Wear (gage reading)	Actual diameter	HE, M334 (T50E2)
0.000	2.950	0
0.002	2.952	9.5
0.004	2.954	15.0
0.006	2.956	20.0
0.008	2.958	23.5
0.010	2.960	26.5
0.012	2.962	29.0
00.14	2.964	31.0
00.16	2.966	32.5
0.018	2.968	33.5
0.020	2.970	34.5
0.022	2.972	35.0
0.024	2.974	36.0
0.026	2.976	37.0
0.028	2.978	37.5
0.030	2.980	38.5
0.032	2.982	39.5
0.034	2.984	40.5
0.036	2.986	41.5
0.038	2.988	42.5
0.040	2.990	44.0
0.042	2.992	45.5
0.044	2.994	47.0
0.046	2.996	49.0
0.048	2.998	51.5
0.050	3.000	55.0
0.052	3.002	58.5
0.054	3.004	64.5
0.055	3.005	70.0

e. 75-mm AA Gun Cannon M35 (T83E7).

(1) The muzzle-velocity loss which may be expected at any stage of tube wear is shown in table XXVIII.

(2) There is no indication at this time that accuracy is adversely affected by erosion within the prescribed condemnation limit (table XXIII).

f. 76-mm Gun Cannon M1 Series.

(1) The estimated muzzle-velocity loss which may be expected at any stage of wear in the tubes used in these weapons is shown in table XXIX.

Table XXIX. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 76-mm Gun Cannon M1 Series

(Based on specific ammunition)

Bore measurement 22.75 inches forward of breech face		Muzzle velocity loss (fps)			
		Cartridge model			
Wear (gage reading)	Actual diameter	HEP–T, T169E1; HEAT, T319	HE, M42A1; WP, M312	APC–T, M62A1	AP–T, T166E3; HVAP–T, M93A1; HVTP–T, M315A1
0.000	3.000	0	0	0	0
0.005	3.005	0.5	2	2	3
0.010	3.010	1	3.5	5.5	6
0.015	3.015	2	6	8	9
0.020	3.020	3	9	11.5	13.5
0.025	3.025	4	12	16	19
0.030	3.030	6	16	20	25
0.035	3.035	8	21	26	33
0.040	3.040	11	26	33	43
0.045	3.045	14	32	40	53
0.050	3.050	17	39	48	64
0.055	3.055	20	48	59	80
0.060	3.060	23	55	67	93
0.065	3.065	27	63	77	108
0.070	3.070	31	73	90	124
0.075	3.075	36	83	103	142
0.080	3.080	40	94	118	160
0.085	3.085	45	105	133	180
0.090	3.090	50	120	150	200

(2) With kinetic-energy, armor-piercing projectiles, such as the types APC, AP–T, and HVAP–T, armor targets must be engaged at closer range when using a worn tube, than when using a new tube, to obtain equivalent results. For example, consider firing the APC–T cartridge M62A1 to an armor target at 2000 yards range, using a

tube worn to the condemning limit. Since the muzzle velocity will have dropped from 2600 fps to 2450 fps, the worn tube will penetrate about 0.3 inch less armor at 30° obliquity, or about 0.2 inch less at 60° obliquity, than would a new tube. In terms of range, a tube at the condemning limit must engage the target at 1500 yards range, in order to match new tube performance at 2000 yards range. For chemical-energy, armor-defeating projectiles, such as the types HEAT and HEP–T, terminal ballistic performance is relatively unaffected by muzzle-velocity loss due to tube erosion. Therefore, a tube at the condemning limit and a new tube will have equal capability against armor targets at all ranges. According to current U. S. development policy for armor-defeating ammunition, a tube at the condemning limit meets the minimum requirements for penetrating armor, using any of the standard cartridges provided for that purpose.

(3) There is no indication that accuracy is materially affected by normal erosion within the condemnation limit (table XXIII).

g. 76-mm Gun Cannon M32 (T91E3), and M48.

(1) The muzzle-velocity loss which may be expected at any stage of tube wear for some of the ammunition types used in these weapons is shown in table XXX.

(2) When firing kinetic-energy projectiles, such as the types AP–T, HVAP–T, and HVAPDS–T, from a worn tube, an armor target must be engaged at closer range to achieve results comparable to a new tube. For example, consider firing the AP–T cartridge M339 to an armor target at 2000 yards range, using a tube worn to the condemning limit. With the worn tube, the muzzle velocity will have dropped from 3200 fps to 2040 fps, resulting in about 0.3 inch less armor penetration at 30° obliquity, or 0.2 inch less at 60° obliquity, than when using a new tube. A tube at the condemning limit must therefore engage armor targets at 1600 yards range in order to match new tube performance at 2000 yards range. For chemical-energy, armor-defeating projectiles, such as the type HEAT, penetration is relatively unaffected by muzzle-velocity loss due to tube erosion. Such ammunition is therefore equally effective in new and worn tubes, regardless of target range. According to current U. S. development policy for armor-defeating ammuni-

Table XXX. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 76-mm Gun Cannon M32 (T91E3), and M48

(Based on specific ammunition)

Bore measurement 24.75 inches forward of breech face		Muzzle velocity loss (fps)		
		Cartridge model		
Wear (gage reading)	Actual diameter	HE–T, M352 (T64); CHEM–T, M361A1 (T140E4)	HVAPDS, M331A2 and TP–T, M340 (T212); HVTP–T, T74E1; HVTP–T, M315A1 (T290)	AP–T, M339 (T128E6); TP–T, M340A1 (T212E1)
0.000	3.000	0	0	0
0.004	3.004	0.5	1.5	1.5
0.008	3.008	1.0	2.5	3.0
0.012	3.012	2.0	4.0	5.0
0.016	3.016	3.0	5.5	7.0
0.020	3.020	4.5	7.0	9.5
0.024	3.024	6.0	9.0	12.0
0.028	3.028	8.0	11.0	15.0
0.032	3.032	10.5	14.0	18.5
0.036	3.036	13.0	17.0	22.0
0.040	3.040	15.5	20.0	26.0
0.044	3.044	18.5	23.0	30.0
0.048	3.048	21.5	26.5	34.5
0.052	3.052	24.5	30.5	39.5
0.056	3.056	28.0	34.5	44.5
0.060	3.060	32.0	39.0	50.5
0.064	3.064	36.0	44.0	57.0
0.068	3.068	40.0	49.5	63.5
0.072	3.072	44.0	55.0	70.5
0.076	3.076	48.5	61.5	79.0
0.080	3.080	53.0	68.0	88.0
0.084	3.084	58.0	75.0	99.0
0.088	3.088	63.0	83.0	111.5
0.092	3.092	68.0	91.5	126.5
0.096	3.096	74.0	100.5	143.0
0.100	3.100	80.0	110.0	160.0

tion, a tube at the condemning limit has a satisfactory capability for penetrating armor, using any of the standard cartridges provided for that purpose.

(3) There is no indication at this time that accuracy is adversely affected by erosion within the prescribed condemnation limit (table XXIII).

h. 90-mm Gun Cannon M1, M2, M3, and M26 Series.

(1) The drop in velocity which may be expected at any given degree of wear is shown in table XXXI for some of the ammunition used in these weapons.

Table XXXI. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 90-mm Gun Cannon M1, M2, M3, and M26 Series

(Based on specific ammunition)

Bore measurement 25.00 inches forward of breech face		Muzzle velocity loss (fps)			
		Cartridge model			
Wear (gage reading)	Actual diameter	HEAT, M348 (T108E46); HEP-T, T142E5	HE, M71; WP M313	APC-T, M82; AP-T, M318 (T33)	HVAP-T, M332A1; HVTP-T, M333A1
0.000	3.543	0	0	0	0
0.008	3.551	2	8	10	15
0.016	3.559	4	15	19	30
0.024	3.567	6	22	28	45
0.032	3.575	8	30	39	60
0.040	3.583	10	38	48	75
0.048	3.591	13	45	59	90
0.056	3.599	16	54	69	107
0.064	3.607	19	61	79	123
0.072	3.615	22	69	90	138
0.080	3.623	25	78	100	156
0.088	3.631	28	85	111	172
0.096	3.639	31	94	123	192
0.104	3.647	34	103	135	211
0.112	3.655	37	112	148	229
0.120	3.663	40	121	160	249
0.128	3.671	44	131	172	270
0.136	3.679	48	141	185	290
0.144	3.687	53	151	198	315
0.149	3.692	55	157	205	320

(2) When firing kinetic-energy, armor-piercing projectiles, such as the types AP–T, APC–T, and HVAP–T, the thickness of armor which can be penetrated decreases as the muzzle velocity of the weapon decreases. It is therefore necessary to engage targets at closer range when using a worn tube, than when using a new tube, in order to obtain equal results. For example, consider firing the AP–T cartridge M318 (T33) to an armor target at 2000 yards range, using a tube worn to the condemning limit. The muzzle velocity will have dropped from 2800 fps to approximately 2595 fps, resulting in about 0.5 inch less armor penetration at 30° obliquity, or about 0.25 inch less at 60° obliquity, than with a new tube. In terms of range, the tube at the condemning limit must engage the target at 1300 yards range. If, in the above example, the HVAP–T cartridge M332A1 has been used, the worn tube would have penetrated only 0.4 inch less armor at 30° obliquity, or 0.2 inch less at 60° obliquity, than a new tube. The worn tube could then engage the target at 1500 yards range, and equal new tube performance at 2000 yards. Although the degeneration in performance from a new to a worn tube is less with the HVAP–T cartridge M332A1, the AP–T cartridge M318 has the greater capability for penetrating high obliquity armor targets, regardless of tube wear. For example, a tube at the condemning limit, firing the AP–T cartridge M318 to a target at 2000 yards range, will defeat approximately 0.25 inch more armor at 60° obliquity, than will the HVAP–T cartridge M332A1. In fact, a condemned tube, firing the AP–T cartridge M318, will still defeat about 0.1 inch more 60° armor at 2000 yards than will the HVAP–T cartridge M332A1, fired from a new tube at the same range. For low obliquity targets, however, the situation is reversed. At 2000 yards range, the cartridge M332A1 is superior against 30° obliquity armor by 0.5 inch and 1.0 inch,

respectively, for a new and a worn tube. With chemical-energy, armor-defeating ammunition, such as the types HEAT and HEP–T, a tube at the condemning limit is equally effective against armor targets as a new tube, regardless of range, since the penetrating capability is governed primarily by the quantity of explosive, rather than the muzzle velocity.

(3) Under current U. S. development policy for armor-defeating ammunition, a tube at the condemning limit has slightly less than the armor penetrating capability desired when firing the AP–T cartridge M318, and just meets minimum requirements when using the HVAP–T cartridge M332A1. To increase the effectiveness of the worn tube from 1300 yards to 1500 yards range, with the AP–T cartridge M318 the tube should be condemned at a vertical land diameter of about 3.650 inches. However, this limit would amount to a 40 percent reduction in present tube life, a high price indeed for only 200 yards range improvement. This is particularly true under training conditions, where a small decrease in armor penetration due to tube erosion is of little consequence. If, in certain combat situations, a higher degree of worn tube effectiveness with the AP–T cartridge M318 is deemed warranted, and adequate logistical support is available, local revision of the condemnation criteria to a lower limit will be within the jurisdiction of the Army Ordnance officer.

(4) There is no indication that accuracy is adversely affected by normal erosion within the condemnation limit (table XXIII).

i. 90-mm Gun Cannon M36, M41, and M54.

(1) The muzzle-velocity loss which may be expected at any given stage of tube wear for the various ammunition types used in these weapons is shown in table XXXII.

Table XXXII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 90-mm Gun Cannon M36, M41, and M54

(Based on specific ammunition)

Bore measurement 25.25 inches forward of breech face		Muzzle velocity loss (fps)				
		Cartridge model				
Wear (gage reading)	Actual diameter	HEAT, M348 (T108E46); HE–T, T91; CHEM–T, T92, HEP–T, T142E3	HE or TP, M71, and WP, M313	APC–T, M82	HVAP–T M332A1, HVTP–T, M333A1; HVAPDS, T137	AP–T, M318A1 (T33E7); and TP–T, M353 (T225)
0.000	3.543	0	0	0	0	0
0.007	3.550	4	8	10	21	31
0.014	3.557	8	15	19	36	52
0.021	3.564	11	22	28	49	67
0.028	3.571	15	29	36	60	83
0.035	3.578	18	36	44	71	95
0.042	3.585	20	42	54	84	108
0.049	3.592	23	47	59	91	119
0.056	3.599	25	55	66	100	129
0.063	3.606	27	61	73	109	139
0.070	3.613	29	67	80	117	148
0.077	3.620	31	74	87	125	157
0.084	3.627	33	80	94	133	167
0.091	3.634	35	86	101	142	176
0.098	3.641	37	93	108	150	185
0.105	3.648	39	99	115	158	194
0.112	3.655	42	106	122	166	203
0.119	3.662	44	112	129	174	212
0.126	3.669	46	119	136	182	220
0.133	3.676	49	126	144	190	230
0.140	3.683	51	133	151	196	239
0.147	3.690	54	140	159	205	248
0.154	3.697	56	148	166	210	257
0.161	3.704	59	155	175	220	266
0.168	3.711	62	163	183	229	276
0.175	3.718	65	171	191	238	286
0.182	3.725	69	179	200	247	298
0.189	3.732	73	187	209	256	307
0.197	3.740	78	198	220	268	320

(2) With kinetic-energy projectiles, such as the types AP–T, APC–T, HVAP–T, and HVAPDS–T, the thickness of armor which can be penetrated decreases as the muzzle velocity decreases. When firing a worn tube, the target must therefore be engaged at closer range, than when using a new tube, to obtain equal performance. For example, consider firing the AP–T cartridge M318A1 (T33E7) to an ar-

mor target at 2000 yards range, using a tube worn to the condemning limit. Since the muzzle velocity of the worn weapon will have dropped from 3000 fps to approximately 2680 fps, about 0.75 inch less armor at 30° obliquity, or about 0.4 inch less at 60° obliquity, will be penetrated than with a new tube. In terms of range, a tube at the condemning limit must engage the target at 800 yards range to match new tube performance at 2000 yards range. If, in the above example, the HVAP–T cartridge M332A1 had been used, the worn tube would have penetrated only about 0.3 inch less armor at 30° obliquity, or about 0.1 inch less at 60° obliquity, than a new tube. The worn tube could then engage the target at 1600 yards range, and equal new tube performance at 2000 yards. Although the degeneration in performance from a new to a worn tube is much less with the HVAP–T cartridge M332A1, the AP–T cartridge M318A1 has a greater capability for penetrating high obliquity armor targets, regardless of tube wear. For example, a tube at the condemning limit, firing the AP–T cartridge M318A1 to a target at 2000 yards range, will defeat about 0.2 inch more armor at 60° obliquity, than will a new tube firing the HVAP–T cartridge M332A1. Against low obliquity targets, however, the situation reverses. The cartridge M332A1 is superior to the M318A1 by about 0.4 inch, when engaging 30° obliquity armor at 2000 yards range with a tube worn to the condemning limit. With chemical-energy, armor-defeating ammunition, such as the types HEAT and HEP–T, a tube at the condemning limit is as effective as a new tube against armor targets, regardless of range, since the penetrating capability is governed primarily by the quantity of explosive, rather than the muzzle velocity.

(3) Under current U. S. development policy for armor-defeating ammunition a tube at the condemning limit has considerably less than the desired armor penetrating capability with the AP–T cartridge M318A1, but is satisfactory using the HVAP–T cartridge M332A1. In order to increase the worn tube capability, using the cartridge M318A1, from 800 yards range to 1500 yards range, the tube should be condemned at a vertical land diameter of approximately 3.608 inches. However, this limit would reduce present tube life by about 70 percent, which would indeed be a great logistical sacrifice, even for 700 yards range improvement. This would be particularly true under training conditions, where the decrease in armor penetration due to tube erosion is of little concern. However, if in certain combat situations, a higher degree of worn tube effectiveness with the cartridge M318A1 is considered essential, and adequate logistical support is available, the Army Ordnance officer is authorized to lower the condemning limit diameter on a provisional basis.

(4) There is no indication at this time that accuracy of the weapon is adversely affected by erosion within the condemnation limit (table XXIII).

j. 105-mm Howitzer Cannon M2A1, M2A2, M4, M4A1, and M49 (T96E1). The approximate muzzle-velocity loss which may be expected at any stage of wear is shown in tables XXXIII and XXXIV. Extremely short ranges might suddenly be encountered when the rotatng bands become fully sheared. Velocity loss is not considered critical and will only affect the weapon by lowering the maximum range. A decoppering agent has been added to the dual-granulation charge used in most 105-mm rounds. This decoppering agent minimizes the velocity changes due to the coppering and decoppering effects of the various zone charges. Other variations in range and velocity are caused by either incorrectly assessed powder charges or interior and exterior ballistic differences between projectiles.

Table XXXIII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 105-mm Howitzer Cannon M2A2, M4A1, and M49 (T96E1)

(Based on specific ammunition)

Bore measurement 16.00 inches forward of breech face		Muzzle velocity loss (fps) Cartridge model
Wear (gage reading)	Actual diameter	HE, M1 w/dualgran charge
0.000	4.134	25.0*
0.005	4.139	29.5
0.010	4.144	33.5
0.015	4.149	37.0
0.020	4.154	40.0
0.025	4.159	43.0
0.030	4.164	45.5
0.035	4.169	48.0
0.040	4.174	50.5
0.045	4.179	53.0
0.050	4.184	55.5
0.055	4.189	57.5
0.060	4.194	59.5
0.065	4.199	61.5
0.070	4.204	63.5

* Initial muzzle velocity loss of 25 fps is due to design of forcing cone.

Table XXXIV. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 105-mm Howitzer Cannon M2A1 and M4

(Based on specific ammunition)

Bore measurement 15.50 inches forward of breech face		Muzzle velocity loss (fps) Cartridge model
Wear (gage reading)	Actual diameter	HE, M1 w/dualgran charge
0.000	4.134	0.0
0.005	4.139	4.5
0.010	4.144	8.5
0.015	4.149	12.0
0.020	4.154	15.0
0.025	4.159	18.0
0.030	4.164	20.5
0.035	4.169	23.0
0.040	4.174	25.5
0.045	4.179	28.0
0.050	4.184	30.5
0.055	4.189	32.5
0.060	4.194	34.5
0.065	4.199	36.5
0.070	4.204	38.5

k. 120-mm AA Gun Cannon M1, M1A1, M1A2, and M1A3.

(1) The approximate muzzle-velocity loss, which may be expected at any stage of wear is shown in table XXXV for 120-mm AA gun cannon M1, M1A1, M1A2, and M1A3 w/tube D36361, and in table XXXVI for 120-mm AA gun cannon M1A3 w/tube 7307112. The limit of permissible velocity loss is 275 fps. During the life of the tube the velocity dispersion is quite uniform.

Table XXXV. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 120-mm AA Gun Cannon M1, M1A1, M1A2, and M1A3 w/Tube D36361

Based on specific ammunition)

Bore measurement 41.00 inches forward of breech face		Muzzle velocity loss (fps) Projectile model
Wear (gage reading)	Actual diameter	HE, M73
0.000	4.700	0.0
0.012	4.712	7.5
0.024	4.724	15.0
0.036	4.736	22.5
0.048	4.748	32.5
0.060	4.760	40.0
0.072	4.772	50.0
0.084	4.784	60.0
0.096	4.796	70.0
0.108	4.808	78.5
0.120	4.820	88.5
0.132	4.832	100.0
0.144	4.844	112.0
0.156	4.856	125.0
0.168	4.868	140.0
0.180	4.880	156.0
0.192	4.892	173.5
0.204	4.904	193.5
0.216	4.916	236.0
0.228	4.928	241.0
0.240	4.940	275.0

Table XXXVI. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 120-mm AA Gun Cannon M1A3 w/Tube 7307112

Based on specific ammunition)

Bore measurement 41.00 inches forward of breech face		Muzzle velocity loss (fps)
		Projectile model
Wear (gage reading)	Actual diameter	HE, M73
0.000	4.700	0
0.020	4.720	12
0.040	4.740	17
0.060	4.760	20
0.080	4.780	22
0.100	4.800	26
0.120	4.820	29
0.140	4.840	33
0.160	4.860	37
0.180	4.880	43
0.200	4.900	49
0.220	4.920	57
0.240	4.940	66
0.260	4.960	78
0.280	4.980	93
0.300	5.000	112
0.320	5.020	140
0.340	5.040	182
0.360	5.060	275

(2) The accuracy of fire shows no appreciable loss throughout the life of the tube. Projectile rotating bands have not been known to shear, nor have fuze malfunctions occurred as the result of tube wear within the prescribed condemnation limit (table XXIII).

l. 120-mm Gun Cannon M58 (T123E1).

(1) The muzzle-velocity loss which may be expected at any stage of tube wear for some of the ammunition types usde in this weapon is shown in table XXXVII.

(2) The thickness of armor which can be penetrated by kinetic-energy projectiles, such as the types AP–T and HVAPDS–T, decreases as the muzzle velocity of the weapon decreases. Therefore, when firing a worn tube, an armor target must be engaged at closer range, than when firing the AP–T projectile M358 (T116E7) to an armor target at 2000 yards range, using a tube worn to the condemnation limit. Because the muzzle velocity will have dropped from 3500 fps to approximately 3100 fps, the worn tube will penetrate about 1.0 inch less armor at 30° obliquity, or about 0.7 inch less at 60° obliquity, than if a new tube were used. In terms of range, the target must be engaged at 400 yards with the worn weapon, to match new weapon performance at 2000 yards. The performance of chemical-energy, armor-defeating ammunition, such as the types HEAT and HEP–T, is gov-

Table XXXVII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 120-mm Gun Cannon M58 (T123E1)

(Based on specific ammunition)

Bore measurement 38.25 inches forward of breech face		Muzzle velocity loss (fps)	
		Projectile model	
Wear (gage reading)	Actual diameter	HE–T, M356 (T15E3)	AP–T, M58 (T116E7)
0.000	4.700	0.0	0
0.010	4.710	4.0	23
0.020	4.720	7.0	39
0.030	4.730	8.0	52
0.040	4.740	8.5	63
0.050	4.750	9.0	72
0.060	4.760	9.5	83
0.070	4.770	10.0	93
0.080	4.780	10.5	104
0.090	4.790	11.0	115
0.100	4.800	12.0	122
0.110	4.810	14.0	135
0.120	4.820	16.0	150
0.130	4.830	18.0	163
0.140	4.840	20.0	176
0.150	4.850	23.0	190
0.160	4.860	26.0	204
0.170	4.870	31.0	222
0.180	4.880	34.0	240
0.190	4.890	38.0	258
0.200	4.900	44.0	278
0.210	4.910	50.0	299
0.220	4.920	56.0	322
0.230	4.930	62.0	342
0.240	4.940	68.0	372
0.250	4.950	76.0	400

erned primarily by the quantity of explosive in the projectile, and is relatively independent of weapon muzzle velocity. In this case, a worn tube and a new tube will have equal capability against armor targets at all ranges.

(3) A tube at the condemning limit, firing the AP–T projectile M358, has far less than the desired armor penetrating capability, as outlined in current U. S. development policy for armor-defeating ammunition. To increase the range from 400 yards to 1500 yards, that a worn tube must engage a target to match a new tube at 2000 yards, the condemning limit diameter should be approximately 4.795 inches. However, such a low limit would reduce present tube life by about 80 percent, making sustained logistical support extremely difficult, if not impossible. Under training conditions particularly, such restrictions are entirely unnecessary, since the decrease in armor penetration due to tube erosion is of little consequence. If, in certain combat situations, a higher degree of worn tube effectiveness is considered essential, and adequate logistical support for the operation is available, it is within the jurisdiction of the Army Ordnance officer to lower the condemning limit on a provisional basis.

(4) There is no indication at the present time that accuracy will be adversely affected by erosion within the prescribed condemnation limit (table XXIII).

m. 155-mm Howitzer Cannon M1, M1A1, and M45 (T186E1).

(1) The velocity drop is very slight. As an example, 10,000 EFC rounds fired through a tube resulted in a velocity drop of approximately 20 fps when firing the zone VII charge (1,850 fps). It is expected, however, that the velocity drop will be greater when firing the lower-zone charges, although sufficient information to plot a calibration table is not available at the present time. The need for calibration of these tubes is not as imperative as it is for higher-velocity, faster-wearing tubes.

(2) Range accuracy is expected to remain fairly constant throughout the life of the tube until rounds begin to fall short of calculated range by as much as 40 percent, due to the shearing of the rotating band. When this condition occurs, the tube has exceeded its useful life.

n. 155-mm Gun Cannon M2, M2A1, and M46 (T80). Velocity dispersion does not materially increase during the life of this tube. This dispersion may be as high as a probable error of seven fps but it is usually not more than a probable error of five fps. This is true for both the normal charge and supercharge. Range accuracy also remains fairly constant through the life of the tube and varies only as it may be affected by variations in muzzle velocity and exterior ballistic effects. When the projectile rotating band shears, and rounds fall short of expected range, the tubes are worn beyond the condemning point. Unless projectiles fall short of the target, as described above, the tube is still serviceable from a standpoint of range accuracy. Table XXXVIII compares the bore measurement against the loss of muzzle velocity for both the normal charge and supercharge, making possible an estimate of velocity obtainable at any given stage of wear.

o. 8-inch Howitzer Cannon M1, M2, M2A1, and M47 (T89). The amount of velocity loss encountered in 8-inch howitzer tubes during their life is not known; however, the rate of velocity loss is low, and the total amount of velocity loss encountered is small. The accuracy of the weapon is believed to remain fairly constant throughout its life so that a sizable increase in probable error should not be expected.

p. 8-inch Gun Cannon M1.

(1) During the life of the tube, the muzzle

velocity may be expected to drop to 2,670 fps when firing the charge M13 or the charge M10 of 0.85 inch web size. During the life of the tube, the probable error of velocity rises from five fps to nine fps, which change is relatively insignificant. The approximate muzzle velocity which may be expected at any given bore measurement is indicated by table XXXIX.

Table XXXVIII. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 155-mm Gun Cannon M2, M2A1, and M46 (T80)

(Based on specific ammunition)

Bore measurement 47.75 inches forward of breech face		Muzzle velocity loss (fps) — Projectile model
Wear (gage reading)	Actual diameter	HE, M104 w/full charge
0.000	6.100	0.0
0.005	6.105	1.0
0.010	6.110	1.5
0.015	6.115	2.5
0.020	6.120	3.5
0.025	6.125	4.5
0.030	6.130	6.0
0.035	6.135	7.5
0.040	6.140	9.0
0.045	6.145	10.5
0.050	6.150	12.0
0.055	6.155	14.0
0.060	6.160	16.0
0.065	6.165	18.0
0.070	6.170	20.5
0.075	6.175	22.5
0.080	6.180	25.0
0.085	6.185	27.0
0.090	6.190	29.5
0.095	6.195	32.0
0.100	6.200	34.5
0.105	6.205	37.5
0.110	6.210	40.0

(2) The range accuracy is not materially affected by erosion during the life of the tube; however, if the tube is continued in service beyond the bore measurement established as the condemnation point, projectile rotating bands may be expected to shear.

Table XXXIX. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 8-Inch Gun Cannon M1

Based on specific ammunition)

Bore measurement 72.75 inches forward of breech face		Muzzle velocity loss (fps) — Projectile model
Wear (gage reading)	Actual diameter	HE, M103 w/full M10 charge
0.000	8.000	0
0.012	8.012	5
0.024	8.024	10
0.036	8.036	16
0.048	8.048	22
0.060	8.060	28
0.072	8.072	34
0.084	8.084	40
0.096	8.096	46
0.108	8.108	52
0.120	8.120	60
0.132	8.132	68
0.144	8.144	75
0.156	8.156	82
0.168	8.168	89
0.180	8.180	98
0.192	8.192	106
0.204	8.204	114
0.216	8.216	124
0.228	8.228	132
0.240	8.240	141
0.252	8.252	149
0.264	8.264	160
0.276	8.276	168
0.288	8.288	178
0.300	8.300	188
0.312	8.312	198
0.324	8.324	208
0.336	8.336	220
0.348	8.348	232
0.360	8.360	244

q. 240-mm Howitzer Cannon M1.

(1) The accuracy of this tube in range and deflection is not expected to decrease during its life. At an advanced stage of wear it is expected that the rotating bands of the high-explosive projectile M114 will shear, causing rounds to fall short of calculated range. An estimated muzzle-velocity loss which may be expected at any stage of wear is shown in table XXXX. Normally, velocity dispersion will be obtained within one lot of ammuniton, yet in all zones this dispersion is such that the probable error will be approximately

three fps. From various lots of ammunition the dispersion may be as high as six fps. Dispersion in range equivalent to this dispersion in velocity is normal.

Table XL. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 240-mm Howitzer Cannon M1

(Based on specific ammunition)

Bore measurement 64.50 inches forward of breech face		Muzzle velocity loss (fps)
		Projectile model
Wear (gage reading)	Actual diameter	HE, M114
0.000	9.449	0.0
0.008	9.457	1.5
0.016	9.465	3.5
0.024	9.473	5.5
0.032	9.481	7.5
0.040	9.489	9.5
0.048	9.497	11.5
0.056	9.505	13.5
0.064	9.513	15.5
0.072	9.521	17.5
0.080	9.529	20.0
0.088	9.537	22.5
0.096	9.545	25.0
0.104	9.553	27.5
0.112	9.561	30.0
0.120	9.569	32.5
0.128	9.577	34.5
0.136	9.585	37.5
0.144	9.593	40.5
0.152	9.601	43.5
0.160	9.609	46.5
0.168	9.617	49.5
0.176	9.625	52.5
0.183	9.632	55.0

(2) Tubes used in this weapon have a tendency to produce considerable blast when ammunition is fired during the latter stages of tube life. This condition may become so aggravated that the gun crew can no longer operate successfully. It is believed that excessive blast will not occur prior to reaching the limit of wear for the tube; however, if it should occur, the tube may be condemned.

r. 280-mm Gun Cannon M66 (T131). The muzzle-velocity loss which may be expected at any stage of tube wear for the HE projectile M124 (T122) is shown in table XXXXI. Present information is not sufficient to establish a similar relationship for the HE–S projectile M350 (T123), but based on theoretical considerations, the velocity loss should be equal to or only slightly greater than that for the HE projectile M124 (T122).

Table XLI. Muzzle Velocity Loss of Cannon Tube Based on Bore Measurement 280-mm Gun M66 (T131)

(Based on specific ammunition)

Bore measurement 92.75 inches forward of breech face		Muzzle velocity loss (fps)
		Projectile model
Wear (gage reading)	Actual diameter	HE, M124 (T122) w/all charges
0.000	11.025	0.0
0.006	11.031	2.0
0.012	11.037	4.0
0.018	11.043	7.0
0.024	11.049	9.0
0.030	11.055	11.5
0.036	11.061	14.0
0.042	11.067	17.0
0.048	11.073	20.0
0.054	11.079	22.5
0.060	11.085	25.5
0.066	11.091	28.0
0.072	11.097	31.0
0.078	11.103	34.0
0.084	11.109	37.0
0.090	11.115	40.0
0.096	11.121	43.0
0.102	11.127	46.0
0.108	11.133	49.0
0.114	11.139	52.0
0.120	11.145	55.5
0.126	11.151	59.0
0.132	11.157	62.0
0.138	11.163	65.5
0.144	11.169	69.0
0.150	11.175	72.5
0.156	11.181	76.0
0.162	11.187	79.5
0.168	11.193	83.0
0.174	11.199	86.5
0.180	11.205	90.0

APPENDIX

REFERENCES

1. Publication Indexes

DA pamphlets of the 310 series and DA Pam 108–1 should be consulted frequently for latest changes or revisions of references given in this appendix and for new publications relating to materiel covered in this technical manual.

2. Supply Manuals

The following supply manuals of the Department of the Army supply catalog pertain to this materiel:

Index of Supply Manuals—Ordnance Corps.	DA Pam 310–29
Introduction	ORD 1
Tool Set, Field, Special Ordnance Ballistic and Technical Service Team and Cannon Bore Inspection Equipment.	ORD 6, J33

3. Other Publications

Accident Reporting and Records (reports control symbols CSGPA–147 (R–I), 115 (R–2), 459).	AR 385–40
Artillery Materiel and Associated Equipment.	TM 9–2300
Authorized Abbreviations	AR 320–50
Defense Against C B R Attack.	FM 21–40
Dictionary of United States Army Terms.	AR 320–5
Field Sky Screen and Counter Chronograph.	TM 9–1860–7
Fundamentals of Artillery Weapons.	TM 9–2305
Index of Army Motion Pictures, Film Strips, Slides, and Phono-Recordings.	DA Pam 108–1
Index of Technical Manuals, Technical Bulletins, Supply Bulletins, Lubrication Orders, and Modification Work Orders.	DA Pam 310–4
Military Symbols	FM 21–30
Military Training	FM 21–5
Operation and Field and Depot Maintenance: Pullover Gages, Borescopes M1 and M2, and Pressure Gage M3.	TM 9–4933–200–35
Techniques of Military Instructions.	FM 21–6

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[AG 472.81 (7 Apr 59)]

By Order of *Wilber M. Brucker*, Secretary of the Army:

MAXWELL D. TAYLOR,
General, United States Army,
Chief of Staff.

Official:

R. V. LEE,
Major General, United States Army,
The Adjutant General.

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  Benicia Arsenal (10)
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MAAG (1)
Mil Msn (1)
JBUSMC (2)
JUSMAG (Greece) (2)
Fld Comd, AFSWP (1)
Units org under fol TOE:
  9–510 BA (2)

NG: State AG (3); units—same as Active Army except allowance is one copy to each unit.

USAR: None.

For explanation of abbreviations used, see AR 320–50.

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