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MATERIALS EXAMINATION OF THE PALMARIA 155-MM GUN TUBE - FOREIGN SCIENCE AND TECHNOLOGY PROJECT 60044

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Advanced Engineering Branch, Benet Laboratories, conducted a comprehensive materials examination on two Palmaria 155-mm self-propelled howitzer gun tubes produced at Palmaria, Italy. Both tube forgings were manufactured by Breda Fucine Co., Milan, Italy. The purpose of this examination was to establish the dimensional and metallurgical characteristics of the subject gun tubes. Based on the results of our examination, we conclude that the Italians

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20. ABSTRACT (CONT'D)

(Breda Fucine Co.) have the capability of producing 155-mm gun tubes that meet both dimensional and mechanical property requirements of 155-mm gun tubes manufactured in the U.S. (Watervliet Arsenal).

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INTRODUCTION

The Advanced Engineering Branch, Benet Laboratories, conducted a comprehensive materials examination on two Palmaria 155-mm self-propelled howitzer finish-machined gun tubes (ID #3141-221-OTO-291 and #4082-128-OTO-286). Figure 1 shows the Palmaria gun system as installed in the 155/41 self-propelled howitzer. The purpose of this examination was to establish the dimensional and metallurgical characteristics of the subject gun tubes. Both tubes were manufactured by Breda Fucine Co., Milan, Italy, and procured through the U.S. Army Foreign Science and Technology Center as part of D650 Project No. 60044, " Exploitation of the Palmaria 155-mm Gun Tube (Italy)."

EXAMINATION PROCEDURE

The following examinations and analyses were performed:

1. Macrophotography and visual inspection (both tubes)
   * Bore evacuation system
   * Breech end keyway
   * Rifle configuration
2. Dimensional inspection (both tubes)
3. Metallurgical evaluation (tube #3141-221-OTO-291)
   * Chemical analysis (breech and muzzle ends)
   * Mechanical property analysis along the length of tube #3141-221-OTO-291 and sample fracture toughness
   * Metallographic examination and grain size determination
4. Residual stress determination (tube #3141-221-OTO-291)

RESULTS/DISCUSSION

Macrophotography and Visual Inspection

Both tubes were photographed in detail. This included overall views and close-up photographs of any unique external or internal features observed during our visual inspection.

Figure 2 is an overall view of the subject gun tube as-received. Figures 3 and 4 are overall views of each gun tube, showing breech end detail and poster ID. Close-up photographs revealing the ID No. stamped on the muzzle end of each tube are shown in Figures 5 and 6.

The visual inspection also revealed the following information about the subject gun tube:

* Bore Evacuation System. - An overall view of the Palmaria 155-mm evacuator zone is shown in Figure 7. This system utilizes four drilled, threaded, and staked plugs which allow propellant gases to exit the bore area. Each plug contains three holes as shown in Figure 8. In addition, the ball check valve which is free-floating and located inside the jet hole is contained through the use of this type plug.

The bore evacuation system for the U.S. 155-mm M185 gun tube is shown in Figure 9. This system consists of ten jet holes and ball check valves which are contained through the use of a valve ring.

* Breech End Keyway - A close-up view of the breech end detail, which includes the breech keyway of the Palmaria 155-mm gun tube, is shown in Figure 10. Based on the dimensions and location of this keyway, it would appear that the Italians rely on one locking key to locate the breech ring and control torque during firing. However, the U.S. 155-mm cannons utilize a secondary long keyway in addition to the keyway on the breech end, for locking purposes. In fact, the 155-mm M284 employs two secondary, long keys to control torquing as shown in Figure 10a.

* Rifle Configuration. - During the bore inspection portion of our visual inspection, it was observed that the Palmaria tube exhibited a rifling configuration consisting of 64 lands and grooves. This feature is shown in Figure 11; a comparison photograph of a U.S. 155-mm M185 rifled bore consisting of 48 lands and grooves is shown in Figure 12. The reason for the finer rifling exhibited by the Palmaria tube is unknown.

No other major geometric observations were made during the visual inspection of the Palmaria 155-mm gun tubes.

Dimensional Inspection

A dimensional inspection was performed on both Palmaria 155-mm gun tubes in order to obtain the inside diameter (I.D.) and outside diameter (O.D.) and lengths of various segments (tapered sections). Wall variations and O.D. straightness (Total Indicator Runout (TIR)) measurements were taken every foot over the length of each tube. Bore straightness measurements were taken every two feet over the rifled portion of each tube.

The inspection data and results are given in Figures 13 and 14 and Tables I through IV.

Figures 13 and 14 are tube drawings consisting of length and diameter measurements taken on both gun tubes. Examination of the drawings reveals that no major dimensional (length and diameter measurements) differences exist between the Palmaria 155-mm gun tubes and the U.S.-made 155-mm gun tube.

The results of the bore straightness measurements taken on each Palmaria gun tube and the required bore straightness for U.S. 155-mm gun tubes are given in Tables I and II. The results indicate that the bore straightness for both Palmaria tubes is comparable to U.S. 155-mm gun tubes.

The results of the TIR and wall variation measurements taken on each Palmaria 155-mm gun tube along with the required wall variation for U.S. 155-mm gun tubes are listed in Tables III and IV. Examination of these data indicates that both Palmaria gun tubes meet U.S. 155-mm requirements for wall variations. There is no U.S. requirement for O.D. straightness (TIR). These measurements were taken for informational purposes only.

Metallurgical Evaluation

* Chemical Analysis. - The results of the chemical analysis performed on specimens taken from the breech and muzzle ends of tube #3141-221-OTO-291 and the required chemical composition for a U.S. 155-mm follow:

Weight %

	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Al
Breech End	0.30	0.36	0.007	0.005	0.30	0.066	3.3	1.4	0.13	0.48	0.008
Muzzle End	0.30	0.37	0.007	0.006	0.30	0.069	3.4	1.4	0.14	0.49	0.008

Required chemical composition for the U.S. 155-mm M185 gun steel (as per Dwg. #11579755):

C	Mn	Mo	Si	Ti	Al	Cr	Ni	V	Pmax	Smax
0.32/0.36	0.55/0.65	0.45/0.55	0.25*	0.015*	0.01*	0.9/1.1	2.10/2.25	0.09/0.12	0.010	0.008

* Maximum value

Examination of these data indicates that the Palmaria gun tube material is not a standard grade steel, i.e., SAE 4335 or SAE 4340, but a modified steel containing lesser carbon and higher nickel and chromium content than U.S.

* Mechanical Property Analysis. - Our mechanical property analysis consisted of sectioning seven, 1-inch thick discs along the length of tube #3141-221-OTO-291. The exact location of each disc taken is shown in Figure 15. Tensile and Charpy test coupons were then cut from each disc, as shown in Figure 16. The number of test specimens per disc was dependent on the wall thickness and taper of the tube. The coupons were subsequently machined into standard size tensile (0.357 inch diameter) and Charpy V-notch specimens as per ASTM Standards E-8 and A-370, respectively. The specimens were then tested (tensile specimens at room temperature and Charpy V-notch specimens at -40 degrees F) by Benet Laboratories in order to determine the yield strength, ultimate tensile strength, percent reduction in area, and impact strength of this material. The results of these tests are given in Table V. Examination of the test data indicates that the material exhibits relatively high impact toughness, which is an important requirement in the mechanical property design and specification of gun tubes. Although some of the specimens tested did not meet the minimum yield strength requirement for U.S. 155-mm gun tubes, the material clearly shows this capability. Employing an adjusted heat-treat procedure (i.e., using a lower tempering temperature after quenching from the austenitizing temperature) would very likely increase the yield strength sufficiently to meet the U.S. requirement while maintaining acceptable levels of toughness and ductility. Further examinations of the average value obtained for all specimens tested indicate that except for a 1 Ksi (average) deficiency in yield strength, the Palmaria 155-mm gun tube meets all U.S. mechanical property requirements for 155-mm gun tubes manufactured in the U.S.

* Fracture Toughness. - Three 1.5-inch thick discs were sectioned from tube #3141-221-OTO-291 as shown in Figure 15. After residual stress tests were completed, two arc (C)-shaped fracture toughness specimens were machined as per ASTM Standard E-399-83 from discs #1 and #2. The results of the fracture toughness tests performed on all four specimens are given in Table VI.

Although these measurements are not valid plane-strain fracture toughness (K_{Ic}) values in strict accordance with ASTM Standard E-399, the standard for fracture toughness testing, our experience with modern gun tube materials allows us to conclude that the material tested is, from a fracture mechanics viewpoint, comparable in fracture toughness to modern U.S. made gun steels.

* Metallographic Examination and Grain Size Determination. - Metallographic examination of selected as-polished samples revealed the presence of discontinuous stringer-type oxide inclusions (Figure 17) in this material. Overall, the inclusion content (size, composition, and distribution) appeared comparable to that of U.S.-made 155-mm gun steel. The microstructure found throughout the entire length of the gun tube was a uniformly tempered martensite, as shown in

Figures 13 and 19. This microstructure is desirable over other types of microstructures due to its combination of strength and toughness.

Grain size measurements ranged from 4.1 in the breech end to 4.4 in the muzzle end of the Palmaria tube. The typical grain size for a U.S. 155-mm determined as per ASTM Standard E-112, ranges from 8.1 (breech) to 8.5 (muzzle). As ASTM grain size number decreases, the actual diameter of grains increases. Therefore, the Palmaria gun tube material actually has a larger grain size or grain diameter. This grain size is illustrated in Figure 20. Although larger grain size is frequently associated with low toughness, this material did not exhibit any deficiency in Charpy impact energy. For a given chemical composition, grain size is a function of austenitization temperature and time at temperature. Therefore, we may conclude that the Italians used either a higher austenitizing temperature, a longer time at temperature, or a combination of the two to attain this relatively large grain size.

Residual Stress Determination

Three 1.5-inch thick discs were sectioned from tube ID #3141-221-OTO-291 as shown in Figure 15. These discs were analyzed to determine the extent of autofrettage residual stresses contained in the gun tube. Two types of tests were utilized in measuring the amount of residual stress present. First, the splitting method was used on discs #1 through #3, followed by the hole drilling method conducted on discs #2 and #3. (See Appendix A for test procedures and graphic results.) The results of the tests are as follows:

Splitting Method

Disc #	% overstrain
1 (Breech end)	50%
2 (Midpoint)	35%
3 (Muzzle end)	0%

Hole Drilling Method

Disc #	% overstrain
2 (Midpoint)	35%
3 (Muzzle end)	NA

Gun tubes manufactured in the U.S. are typically autofrettaged on the order of 100 percent overstrain. However, the amount of overstrain measured in the Palmaria tube is considered sufficient for this application and is typical of gun tubes manufactured in Europe.

CONCLUSION

Based on the results of this examination, we may conclude that the dimensional and metallurgical qualities of the Palmaria tubes are comparable to 155-mm gun tubes manufactured in the U.S. Although the rifling configuration, bore evacuation system, and the breech keyway design vary, the tubes are physically comparable to U.S. designed gun tubes.

Examination of the inspection data reveals that the Palmaria tubes exhibit excellent bore straightness and minimal wall variation. Our metallurgical examination revealed that the chemical composition of the Palmaria gun material was likely selected due to its high impact toughness capability. While this composition is very close to the U.S. 155-mm gun material, the elemental differences (increased nickel, increased chromium, and decreased carbon contents) in the Palmaria gun tube material give it a higher impact toughness capability than the U.S. material, assuming all other metallurgical factors are equal. The relatively large grain size present in the Palmaria material indicates that it was heat treated using either (1) a very high austenitizing temperature, (2) a very long austenitizing time at temperature, or (3) a combination of the first two possibilities. The fact that this large-grained material (ASTM grain size numbers 4.1 and 4.2) still essentially meets U.S. 155-mm mechanical property requirements, supports our conclusion that this material has both high hardenability and high impact toughness capability at the 160 Ksi yield strength level. The toughness could be increased even further if the material were heat treated to a smaller grain size range, for example, 8.1 to 8.5. The inclusion morphology and content of the Palmaria material was comparable to that of high quality gun steel type alloys. The microstructure (tempered martensite) of this material is also typically found in properly heat-treated low alloy steel. The low weight and percentage of sulphur present in the Palmaria material suggests that this material was subjected to a secondary melting operation. The metallurgical results indicate that the chemical composition of the Palmaria gun tube material is a modified steel containing lesser carbon and higher nickel and chromium content than U.S. gun steel. Mechanical testing (tensile, Charpy impact, fracture toughness) demonstrated that the Palmaria gun tube material exhibited high impact toughness, sufficient strength, and fracture toughness characteristics comparable to gun steel produced in the U.S.

The grain size in the breech and muzzle ends of the Palmaria gun tube was nearly 50 percent larger than that of U.S. 155-mm gun tubes. The reason for such a large variance is most likely due to differences in both chemical composition and material processing methods.

Any comparisons made during this examination were used to show differences in geometry or design only. Without a larger sample size, statistical comparisons are not possible.

RECOMMENDATION

In order to metallurgically exploit the Palmaria 155-mm self-propelled howitzer gun tube material to the maximum extent possible, it is recommended that laboratory fatigue testing be conducted on the remaining Palmaria gun tube material. The data generated from this type test would enable us to predict the expected fatigue life for Palmaria 155-mm self-propelled howitzer gun tube.

TABLE I. BORE STRAIGHTNESS
TUBE #3141-221-OTO-291

FEET FROM ORIGIN OF RIFLING	TRUE BEND	SET UP ON TRUE VERTICAL	SET UP 90° FROM TRUE VERTICAL
		POSITION 3	POSITION 9
2	0.016^{1}	0.006	0.015
4	0.014^{8}	0.009	0.029
6	0.013^{6}	0.013	0.042
8	0.011^{4}	0.016	0.053
10	0.003^{6}	0.013	0.051
12	0.014^{8}	0.010	0.037
14	0.015^{5}	0.006	0.007
16	0.016^{1}		
ME	0.007		

BORE STRAIGHTNESS RESULTS:

Maximum Amount Measured in Any 24-Inch Length - 0.016
Total Cumulative Measured - 0.055

BORE STRAIGHTNESS REQUIREMENTS FOR U.S. 155-MM GUN TUBE PER DWG. #11578388:

The bend (excluding droop) in the tube/rifled portion shall not exceed 0.020 inch in any 24 inches nor accumulate to more than 0.060 inch.

ID No. 3141-221/291
Inspector's Initials RGM
Date: 9/17/88

TABLE II. BORE STRAIGHTNESS
TUBE #4082-128-OTO-286

FEET FROM ORIGIN OF RIFLING	TRUE BEND	SET UP ON TRUE VERTICAL	SET UP 90° FROM TRUE VERTICAL	
		POSITION 9	POSITION 3	POSITION 9
2	0.004	0.004	0.002	
4	0.004	0.008	0.002	
6	0.003	0.011	0.002	
8	0.005	0.015		
10	0.004[2]	0.018		0.003
12	0.005	0.014		
14	0.004	0.010	0.001	
16	0.007	0.003	0.001	
ME	0.003			

BORE STRAIGHTNESS RESULTS:

Maximum Amount Measured in Any 24-Inch Length - 0.005
Total Cumulative Measured - 0.018

BORE STRAIGHTNESS REQUIREMENTS FOR U.S. 155-MM GUN TUBE PER DWG. #11578388:

The bend (excluding droop) in the tube/rifled portion shall not exceed 0.020 inch in any 24-inches nor accumulate to more than 0.060 inch.

ID No. 4082-128/286
Inspector's Initials TEC
Date: 9/17/88

TABLE III. O.D. TIR AND WALL VARIATION MEASUREMENTS TUBE #3141-221-OTO-291

FEET	TIR	WALL VARIATION	12	3	6	9
1	0 ROLLER	0.009	2.691	0.682	0.688	0.689
2	0.006	0.015	2.733	0.723	0.721	0.736
3	0.019	0.015	2.750	0.742	0.749	0.757
4	0.025	0.014	2.848	0.842	0.842	0.856
5	0.038	0.022	2.843	0.833	0.852	0.855
6	0.046	0.017	2.845	0.834	0.851	0.850
7	0.055	0.025	2.844	0.834	0.852	0.859
8	0.068	0.020	2.330	0.324	0.349	0.354
9	0.070	0.023	2.335	0.329	0.346	0.352
10	0.075	0.022	2.338	0.329	0.350	0.351
11	0.080	0.022	2.337	0.322	0.339	0.354
12	0.090	0.025	2.047	0.038	0.057	0.063
13	0.080	0.014	2.044	0.044	0.053	0.058
14	0.090	0.008	2.045	0.048	0.052	0.053
15	0.075	0.005	1.729	0.728	0.728	0.724
16	0.060	0.011	1.727	0.733	0.730	0.722
17	0.040	0.008	1.747	0.748	0.742	0.740
18	0.025	0.013	1.462	0.470	0.467	0.457
19	0 ROLLER	0.009	1.358	0.363	0.363	0.354
20	0.030	0.006	1.253	0.256	0.253	0.250
21	0.080 ME	0.008	0.756	0.752	0.759	0.760

WALL VARIATION REQUIREMENTS FOR U.S. 155-MM GUN TUBE PER DWG. #11578388:

From the breech end to 6.10 inches shall not exceed 0.010 inch and from 6.10 inches to the muzzle end shall not exceed 0.060 inch.

TABLE IV. O.D. TIR AND WALL VARIATION MEASUREMENTS
TUBE #4082-128-OTO-286

FEET	TIR	WALL VARIATION	12	3	6	9
1	0 ROLLER	0.004	2.670	0.669	0.673	0.673
2	0.002	0.007	2.730	0.737	0.737	0.731
3	0.004	0.005	2.744	0.749	0.748	0.748
4	0.007	0.004	2.848	0.251	0.849	0.847
5	0.008	0.011	2.845	0.847	0.849	0.838
6	0.010	0.013	2.835	0.848	0.841	0.843
7	0.013	0.006	2.843	0.846	0.849	0.845
8	0.011	0.016	2.331	0.334	0.347	0.345
9	0.014	0.006	2.337	0.337	0.341	0.343
10	0.015	0.003	2.337	0.338	0.340	0.337
11	0.018	0.005	2.343	0.338	0.343	0.338
12	0.017	0.007	2.051	0.045	0.046	0.052
13	0.018	0.006	2.050	0.048	0.048	0.054
14	0.014	0.012	2.058	0.046	0.052	0.053
15	0.018	0.007	1.731	0.732	0.725	0.730
16	0.015	0.003	1.735	0.734	0.737	0.736
17	0.012	0.005	1.748	0.743	0.745	0.747
18	0.008	0.010	1.453	0.452	0.457	0.462
19	0 ROLLER	0.009	1.347	0.351	0.354	0.345
20	0 ROLLER	0.001	1.249	0.248	0.248	0.248
21	0.005 ME	0.002	0.754	0.752	0.754	0.754

WALL VARIATION REQUIREMENTS FOR U.S. 155-MM GUN TUBE PER DWG. #11578388:

From the breech end to 6.10 inches shall not exceed 0.010 inch and from 6.10 inches to the muzzle end shall not exceed 0.060 inch.

TABLE V. TENSILE AND CHARPY TESTS

ID#	Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	% Reduction in Area	Charpy V-Notch (ft-lb)
A1A	162	176	41.0	24.0
A1B	162	176	33.1	20.0
A2A	161	176	37.6	28.5
A2B	161	176	46.4	29.0
B1A	154*	176	52.1	28.5
B1B	163	177	47.0	30.5
B1C	158*	177	47.3	35.0
B2A	151*	175	50.1	30.0
B2B	159*	176	52.5	31.5
B2C	156*	176	50.6	35.0
C1A	160	177	52.9	32.0
C1B	162	177	54.4	35.5
C2A	162	176	54.4	35.0
C2B	178	192	38.5	36.0
D1A	157*	175	51.3	39.5
D1B	154*	175	53.6	38.5
D2A	157*	175	54.6	36.5
D2B	158*	176	51.3	38.0
E1	153*	173	48.6	41.0/37.5
E2	153*	164	54.0	37.5/38.0
F1	158*	175	55.4	33.5
F2	155*	174	52.5	35.0
G1	153*	175	52.5	30.5
G2	156*	175	52.7	35.0
Average Value	159	176	49.4	33.5

*Specimens which did not meet U.S. mechanical property requirement.

U.S. 155-MM MECHANICAL PROPERTY REQUIREMENTS AS PER DWG. #11579504 and MIL-S-46119:

Yield Strength	% Reduction in Area	Charpy V-Notch
160-180 Ksi	25 min.	15 ft-lb/min.

TABLE VI. FRACTURE TOUGHNESS TESTS

SPECIMEN ID #	K_Q (KSI $\sqrt{in.}$)
1A	157.3
1B	153.5
2A	154.2
2B	148.6

NOTE: The values listed are not valid plain-strain properties.

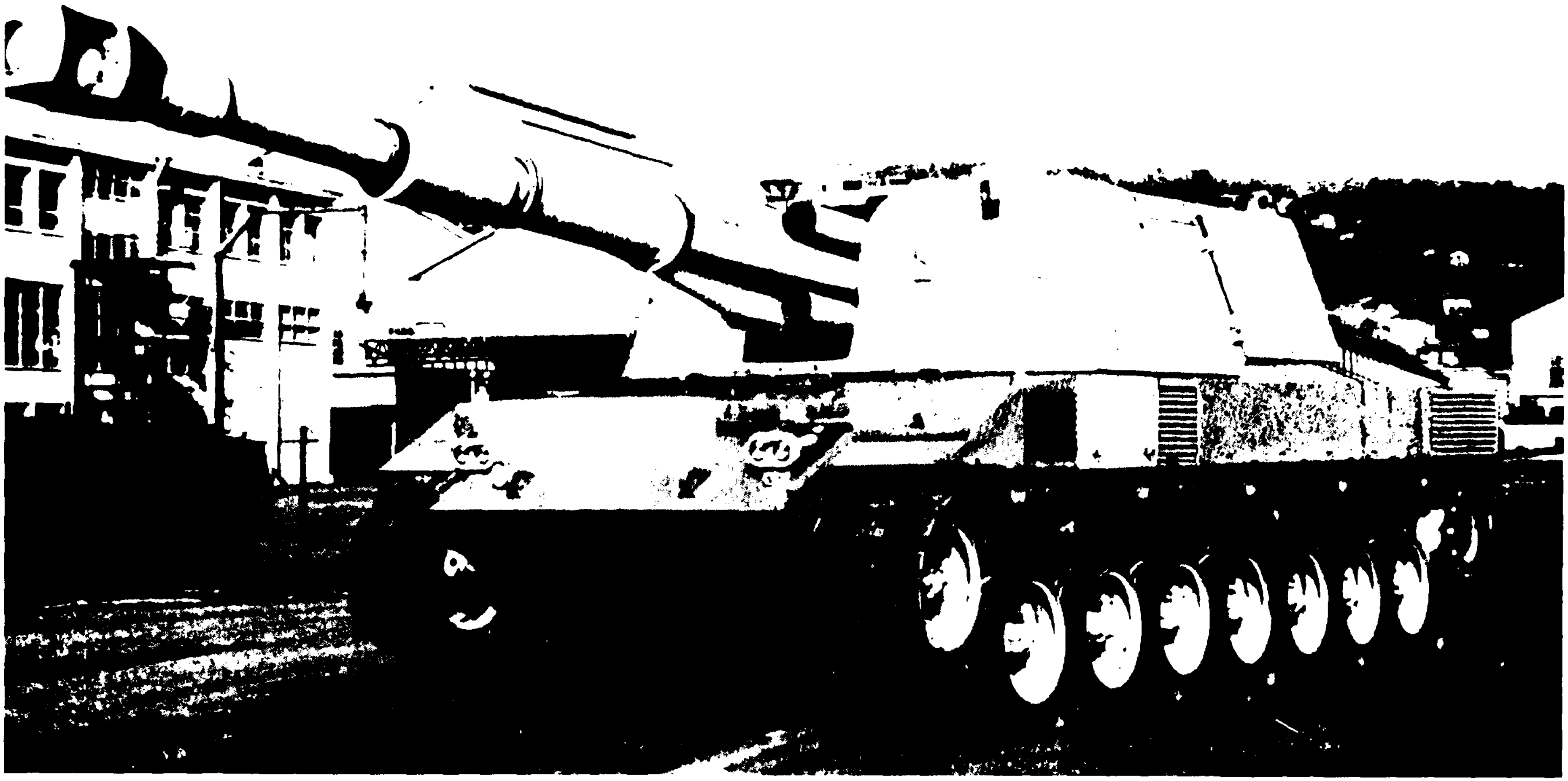


Figure 1. Palmaria 155/41 self-propelled howitzer.

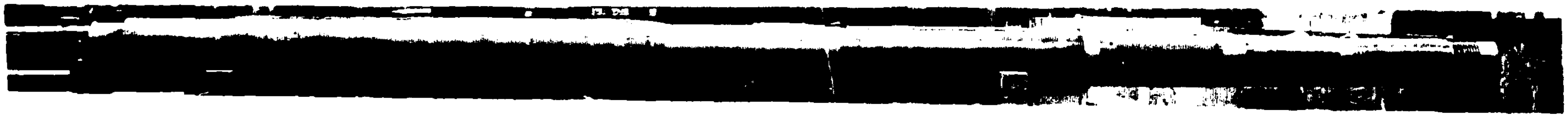


Figure 2. Palmaria 155-mm self-propelled howitzer gun tube as-received.

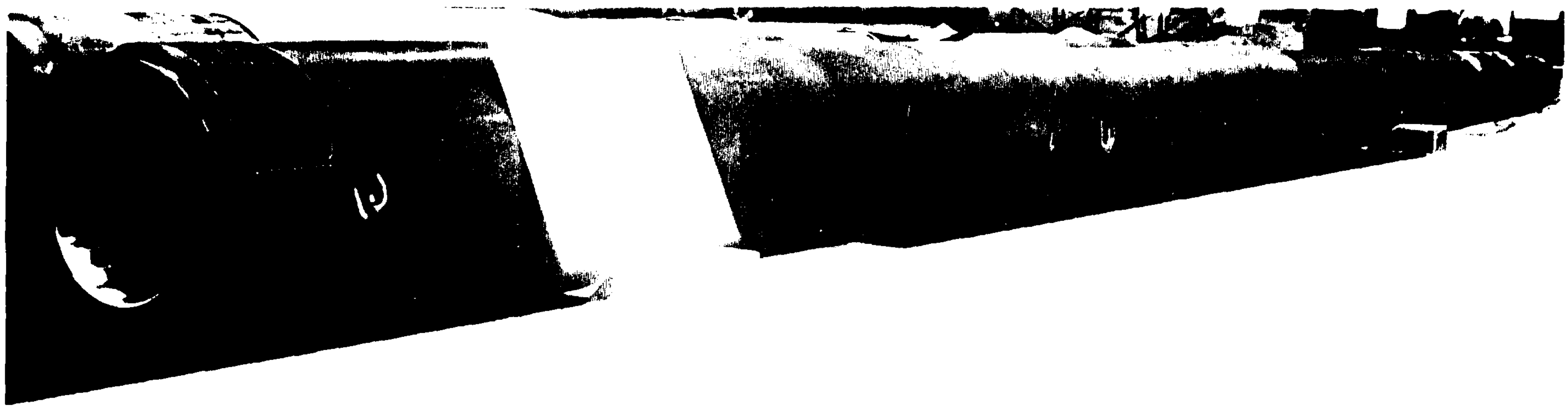


Figure 3. Tube #3141-221-OTO-291 showing breech end detail and poster ID.

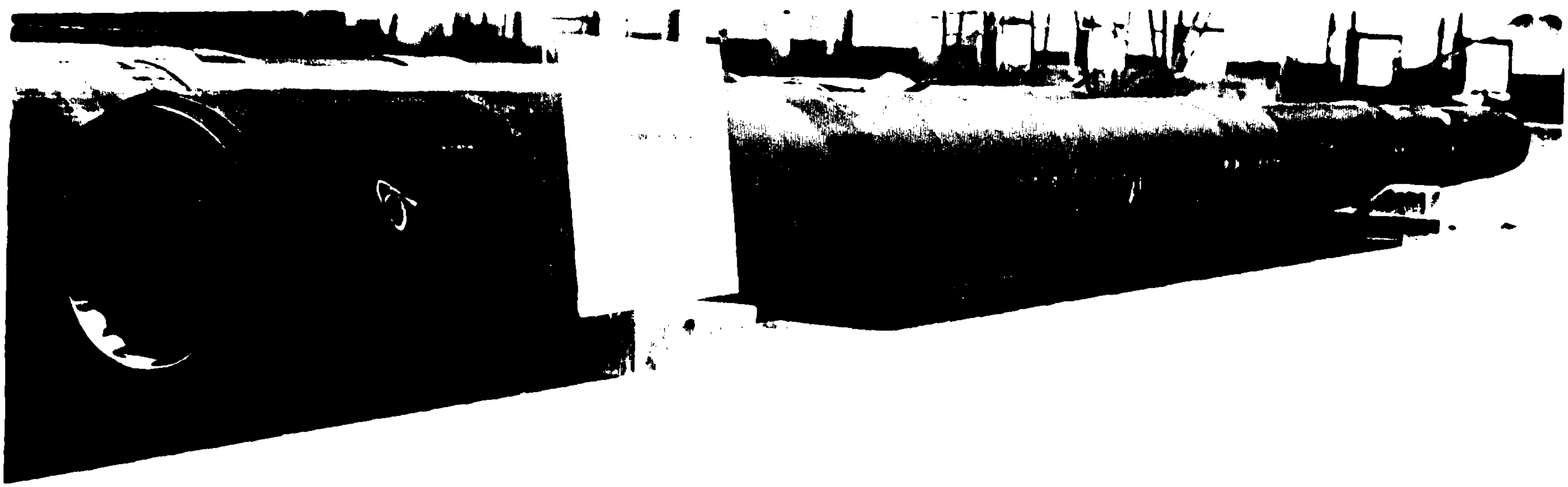


Figure 4. Tube #4082-128-OTO-286 showing breech end detail and poster ID.

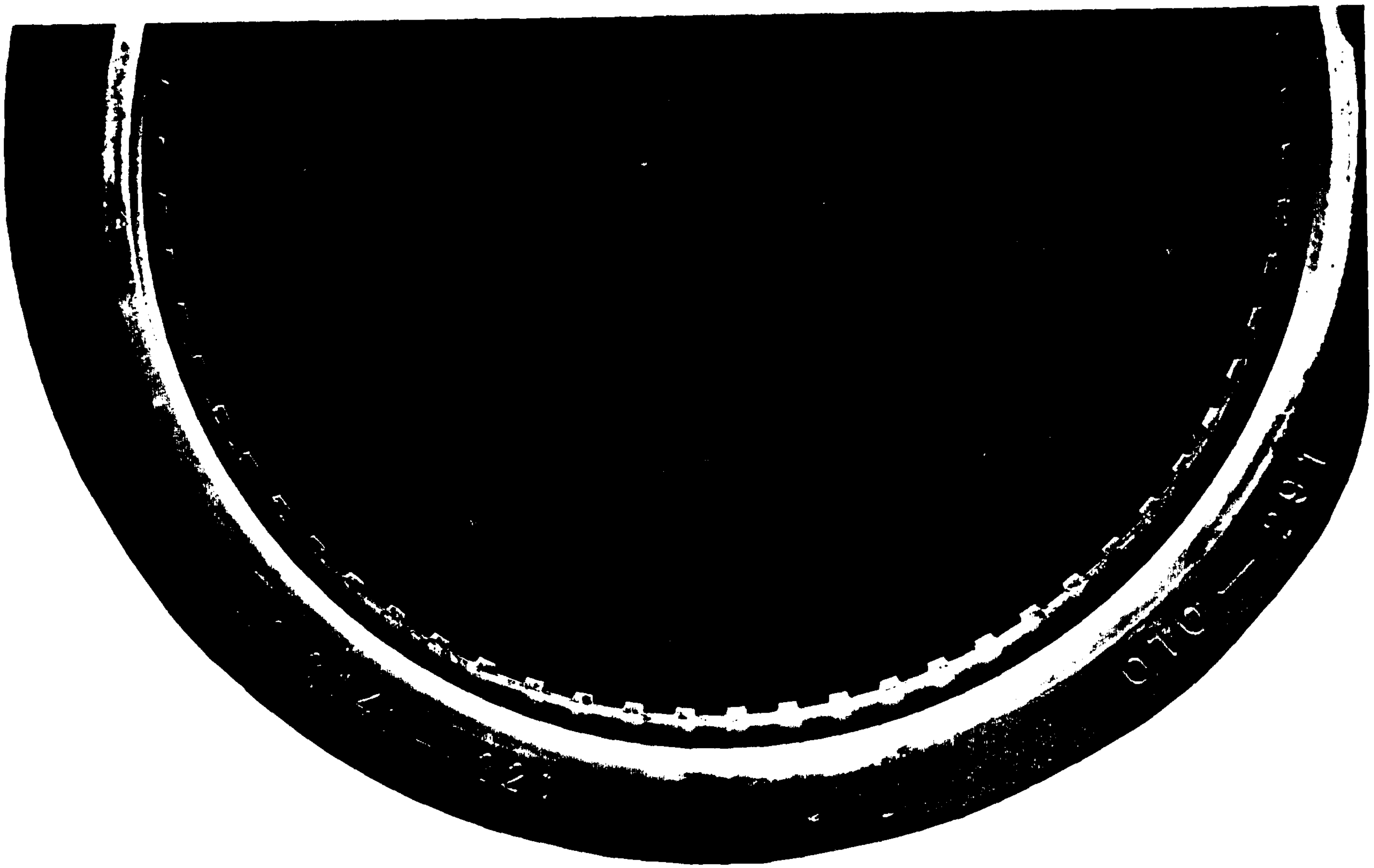


Figure 5. Close-up photograph revealing the ID number stamped on the muzzle end.

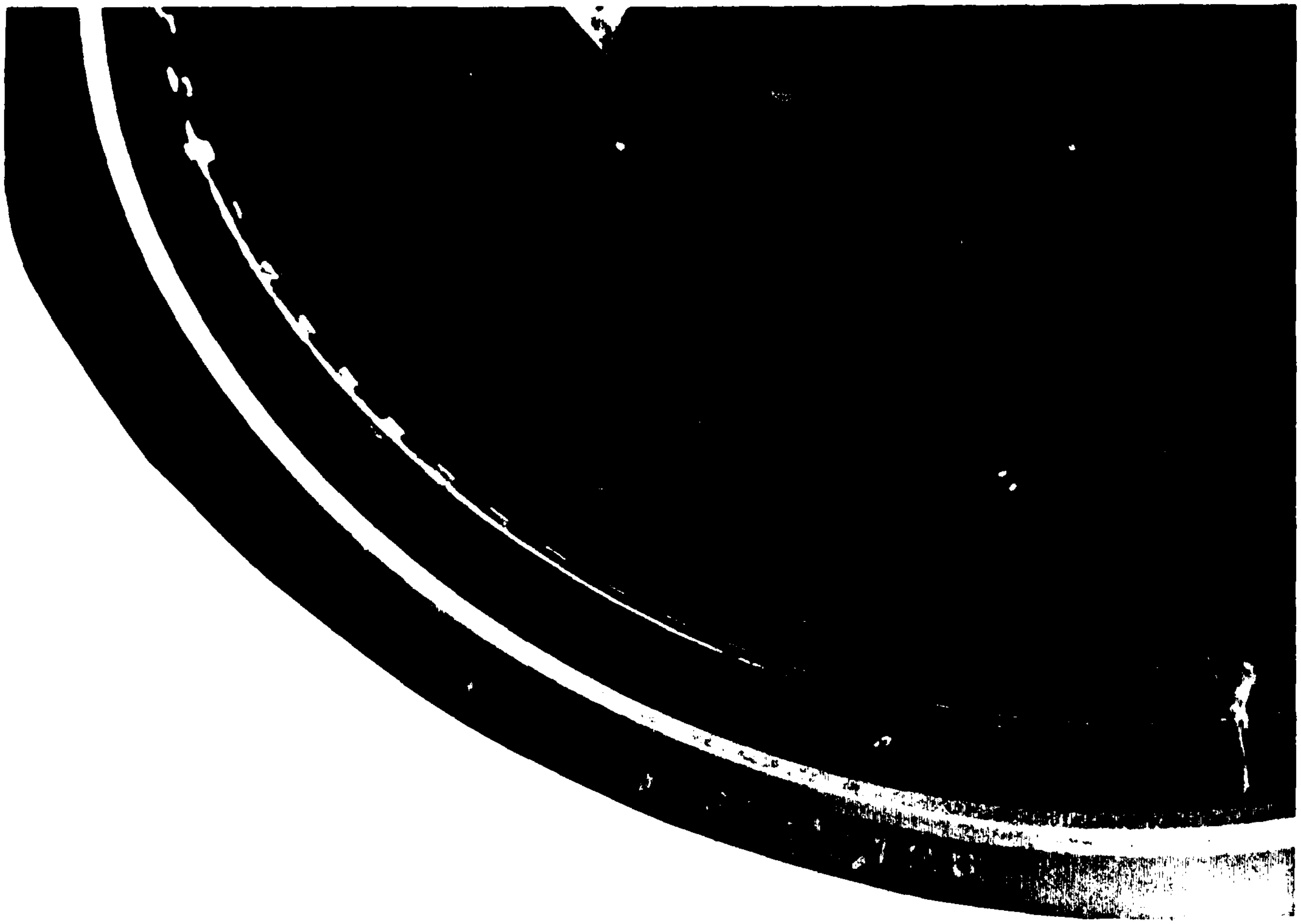


Figure 6. Close-up photograph revealing the ID number stamped on the muzzle end.

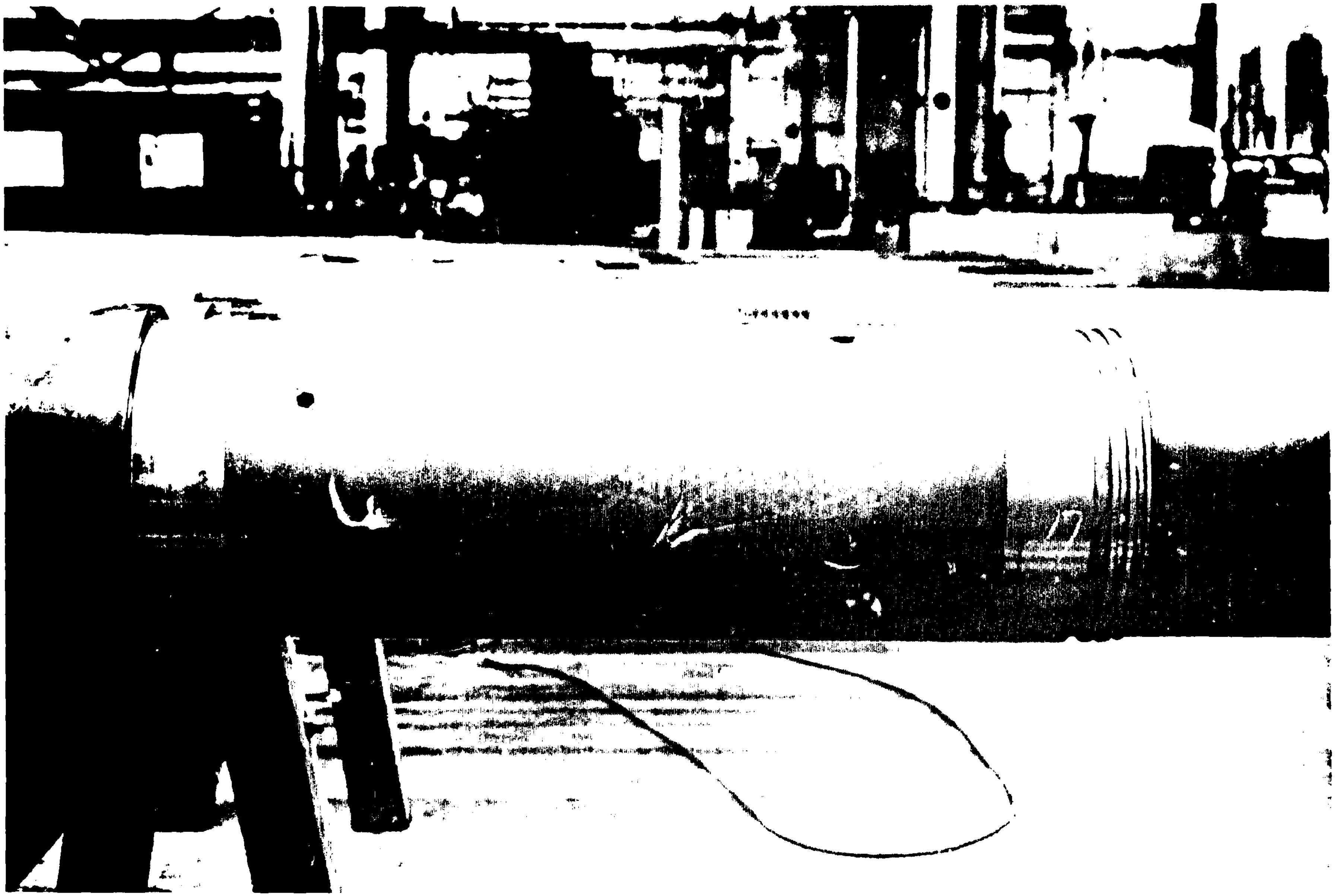


Figure 7. Overall view of the Palmaria 155-mm evacuator zone.

Figure 8. Close-up view of the plug used to evacuate propellant gases and retain the ball check valve in the Palmaria tube.

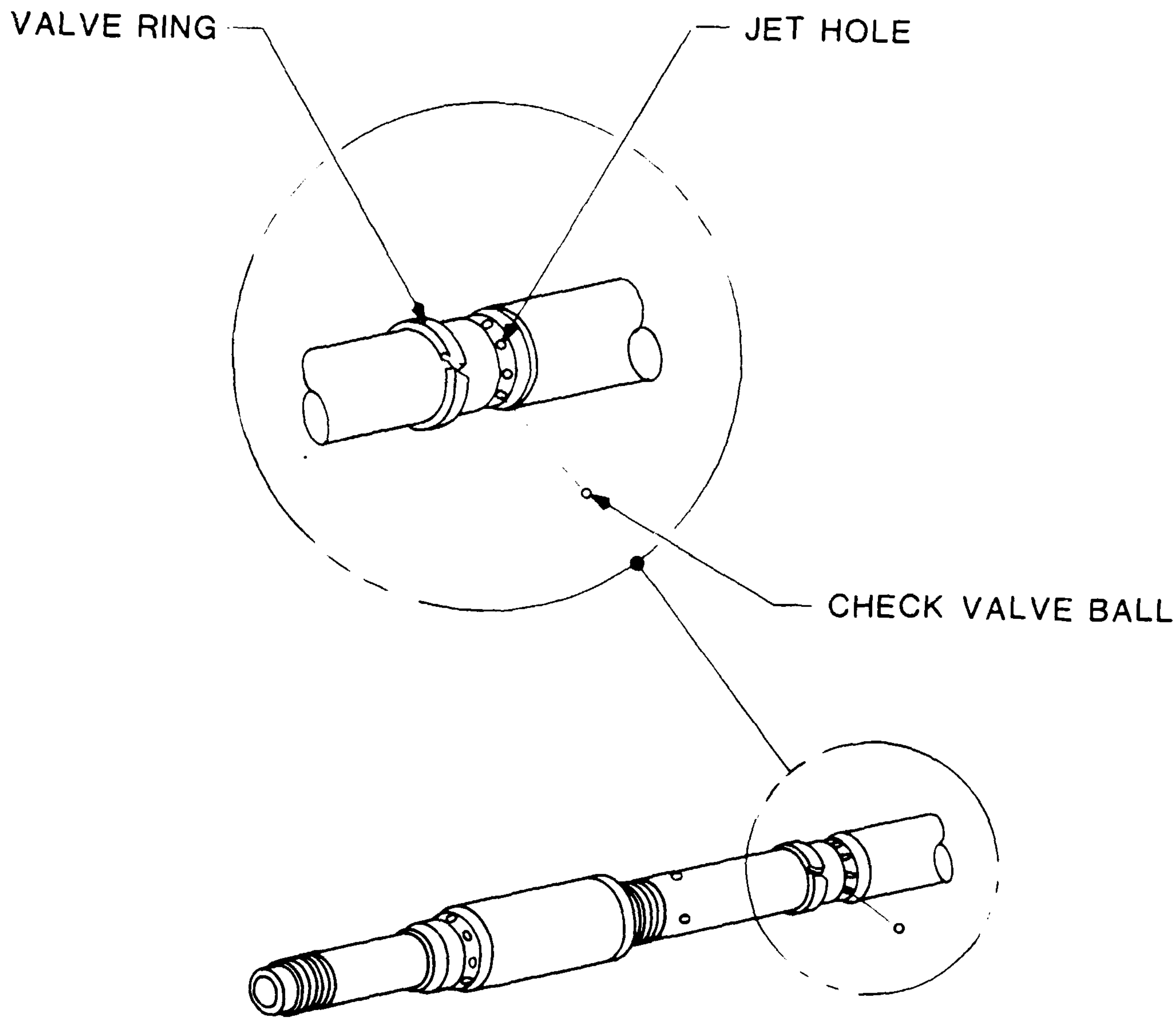


Figure 9. U.S. 155-mm M185 bore evacuation system.

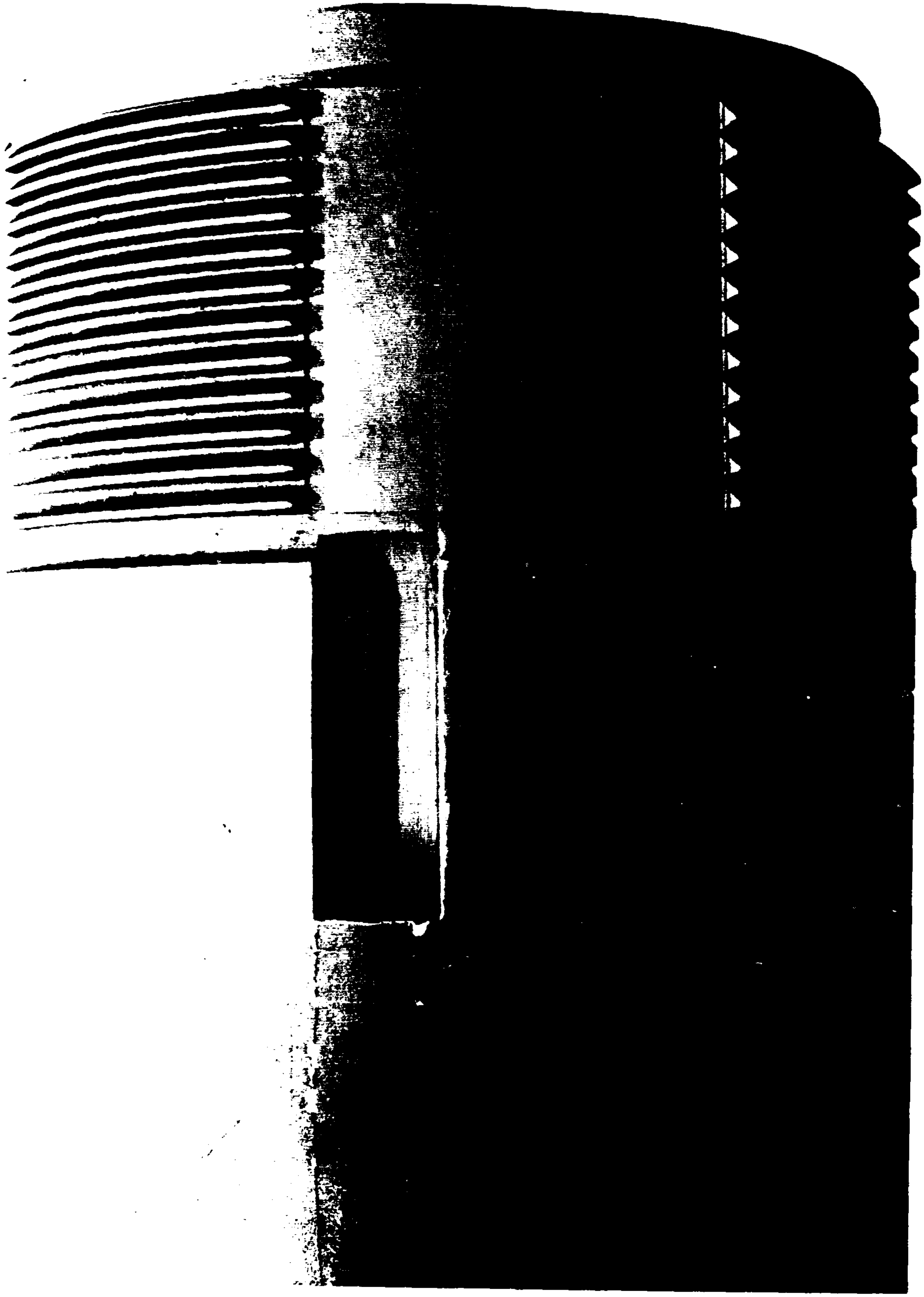


Figure 10. Close-up view of the breech end and keyway of Palmaria 155-mm gun tube.

Figure 10a. Secondary keyways on the U.S. 155-mm XM284.

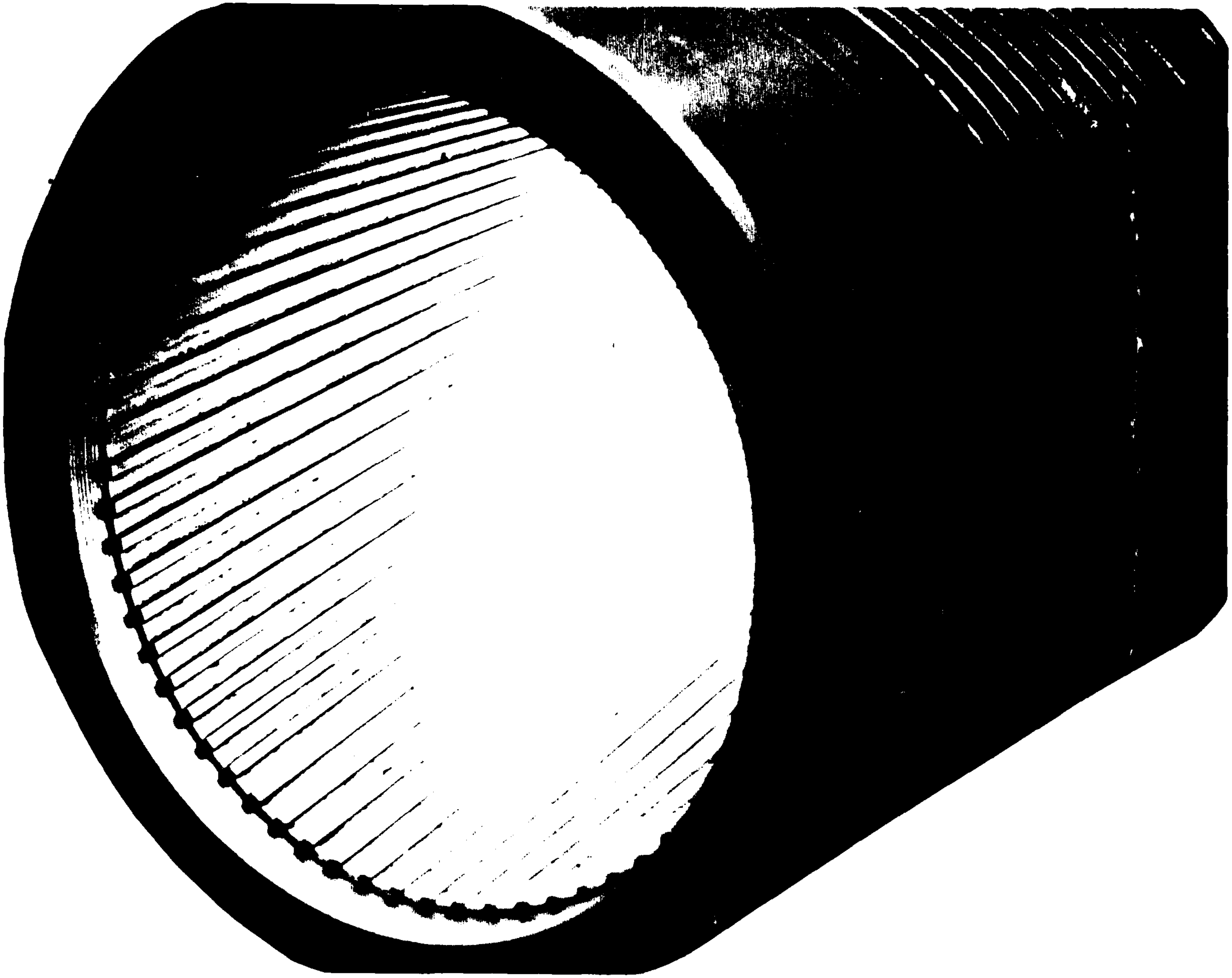


Figure 11. Rifling configuration of the Palmaria tube which is finer than the U.S.155-mm M185.

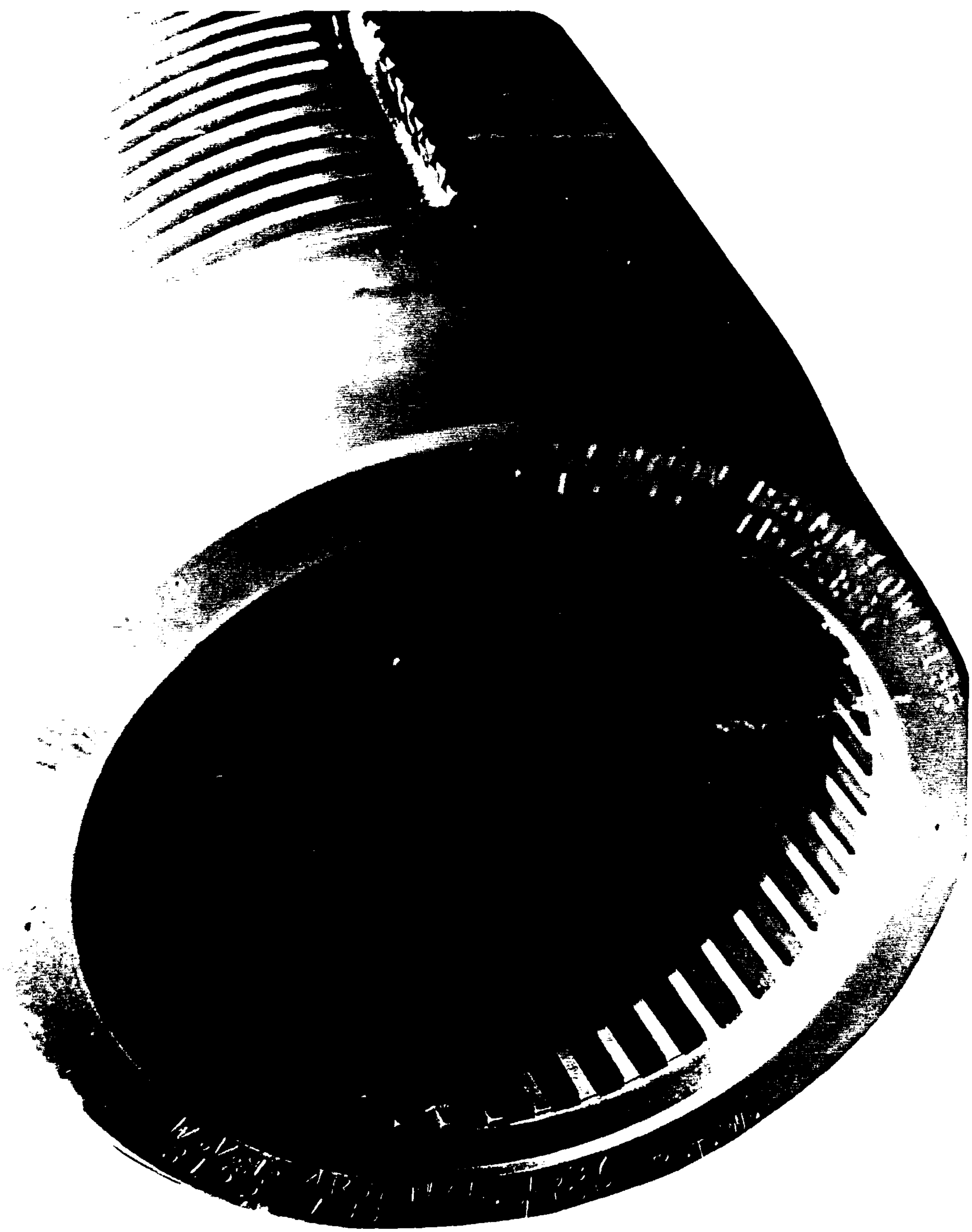


Figure 12. Rifling configuration of a U.S. 155-mm M185.

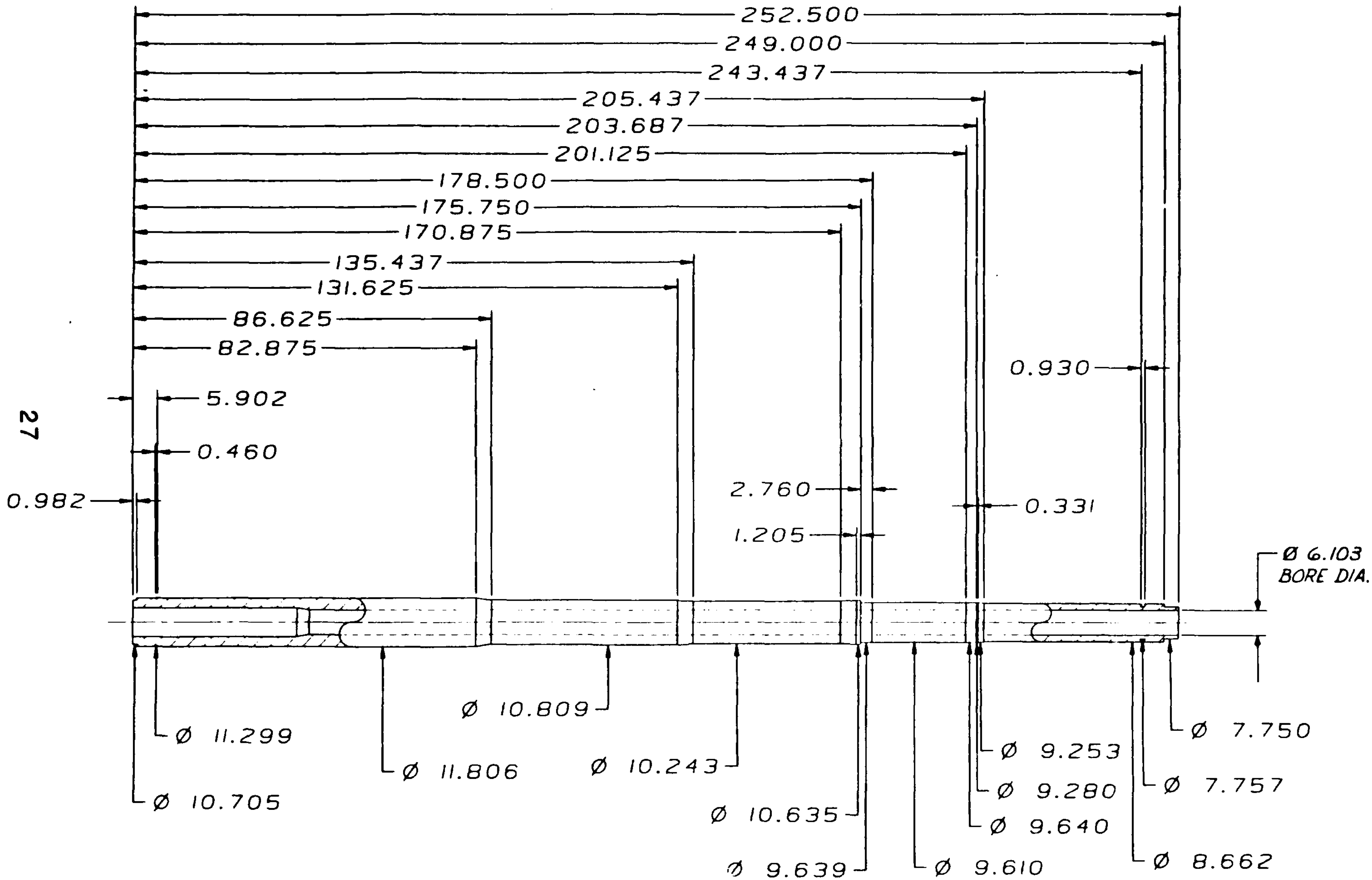


Figure 13. Length and diameter measurements taken on tube #3141-221-OTO-291.

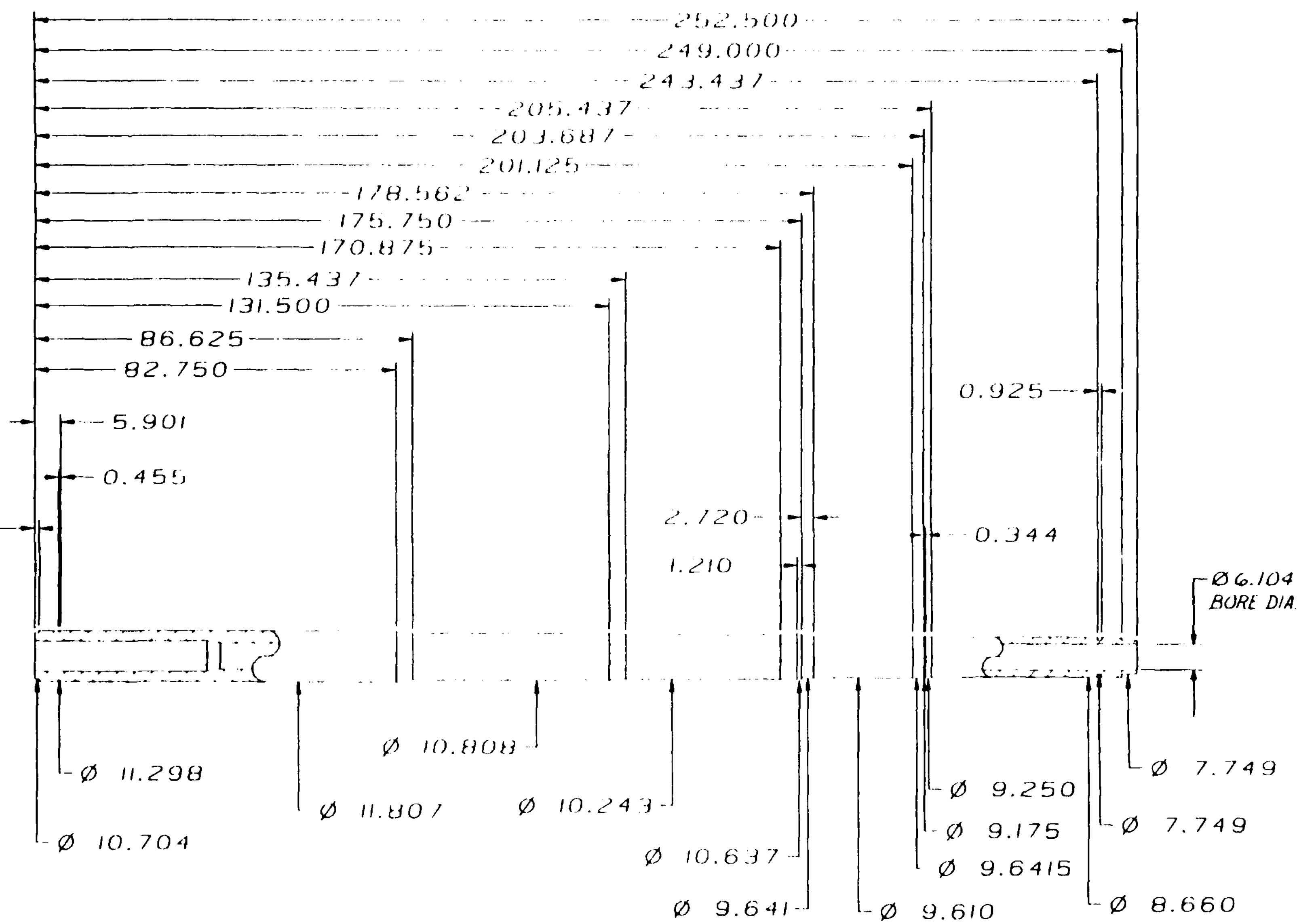
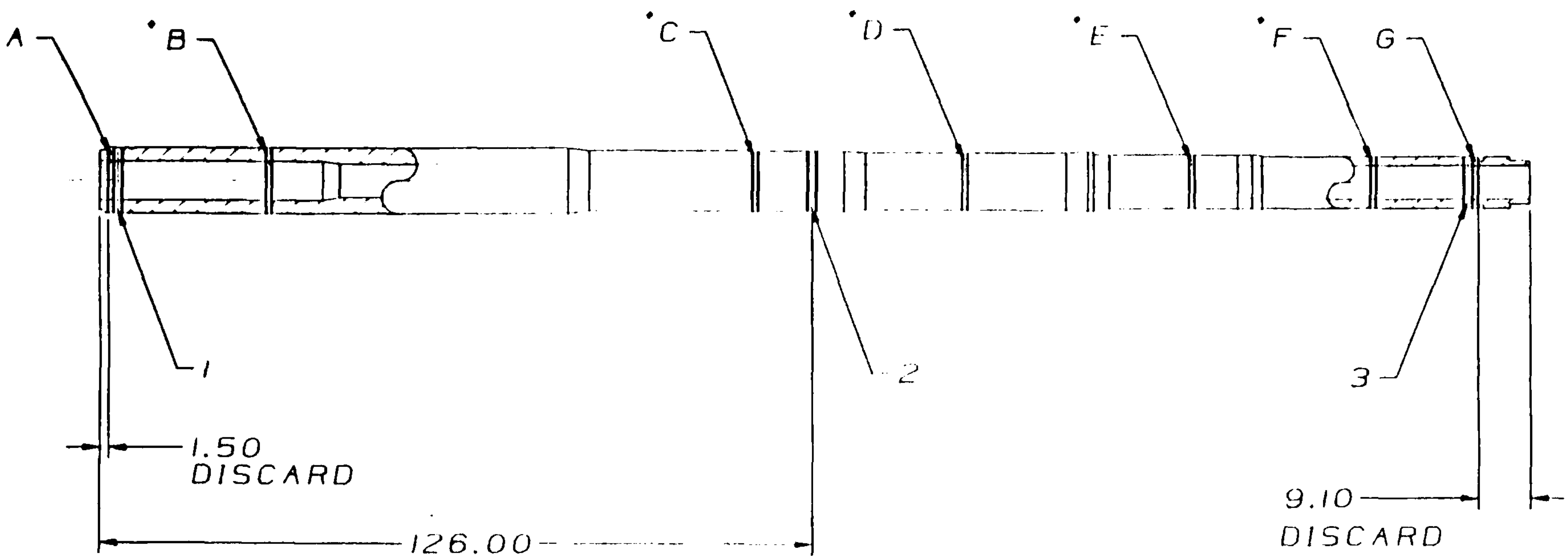


Figure 14. Length and diameter measurements taken on tube #4082-128-OTO-286.



REMOVE DISCS INDICATED • FROM APPROXIMATE MIDDLE OF ZONE IN WHICH LOCATED

CUT TEN DISCS

SEVEN 1" THICK DISCS (TENSILE & CHARPY SPECIMENS) IDENTIFY A THRU G AS SHOWN

THREE 1.5" THICK DISCS (RESIDUAL STRESS & FRACTURE TOUGHNESS SPECIMENS) IDENTIFY 1 - 3 AS SHOWN

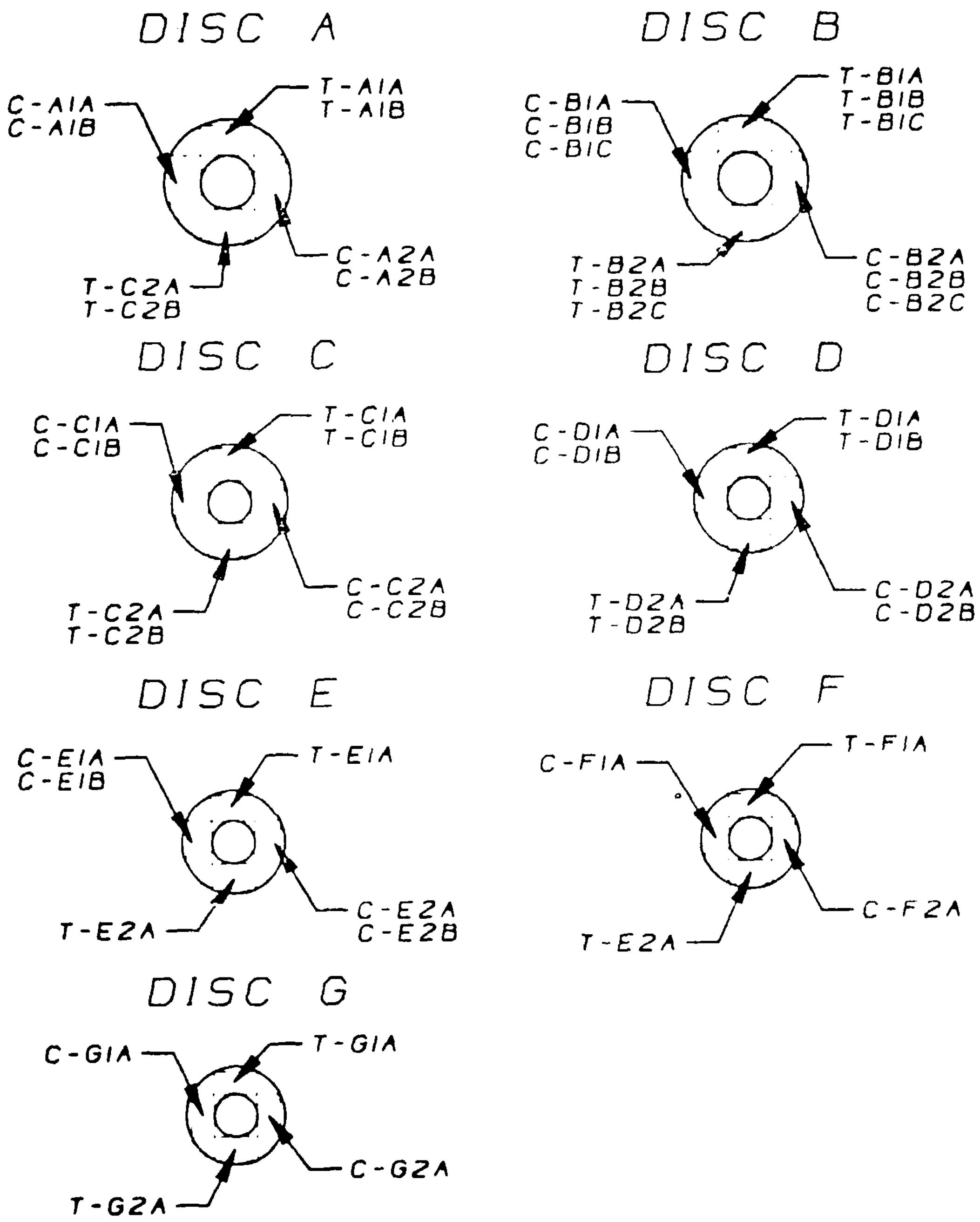
TOLERANCE ON DISC THICKNESS: +.25

TOLERANCE ON DISCARD LENGTH: +.25

TOLERANCE ON 126 LENGTH: +/-.25

SAVE ALL EXCESS

Figure 15. Location of test discs taken from tube #3141-221-OTO-291 for mechanical property evaluation.



NOTE: THE CUTTING ARRANGEMENT OF TENSILE AND CHARPY COUPONS WAS ADJUSTED IN ORDER TO ACCOMODATE THE VARIATION IN WALL THICKNESS OVER THE LENGTH OF THE TUBE.

CODE: EXAMPLE T-TENSILE SPECIMEN, C-CHARPY, A-DISC 1 OR 2-CLOCK POSITION, A-SPECIMEN LOCATION IN RELATIONSHIP TO THE BORE. (A-O.D., B-I.D.)

Figure 16. Cutting arrangement of tensile and Charpy test coupons as taken from each disc.

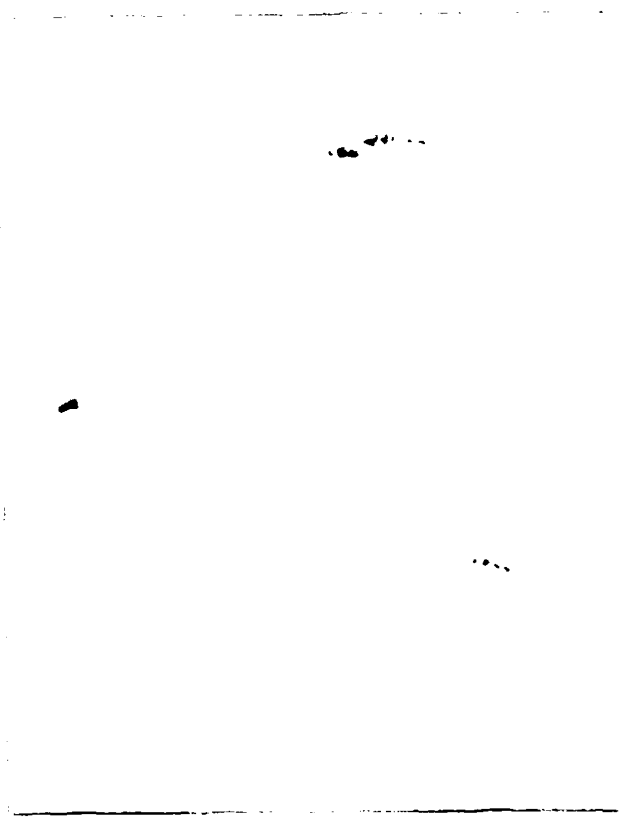


Figure 17. Photomicrograph of an as-polished sample showing stringer-type oxide inclusions present in the Palmaria gun tube material (100X).

Figure 18. Photomicrograph of an etched breech end sample revealing the tempered martensitic microstructure found throughout the Palmaria tube (1000X).

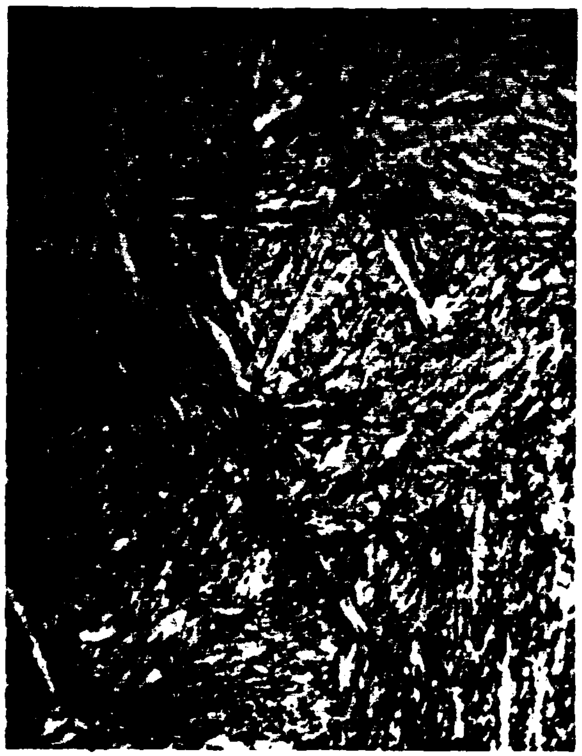


Figure 19. Photomicrograph of an etched muzzle end sample revealing a tempered martensitic microstructure (1000X).

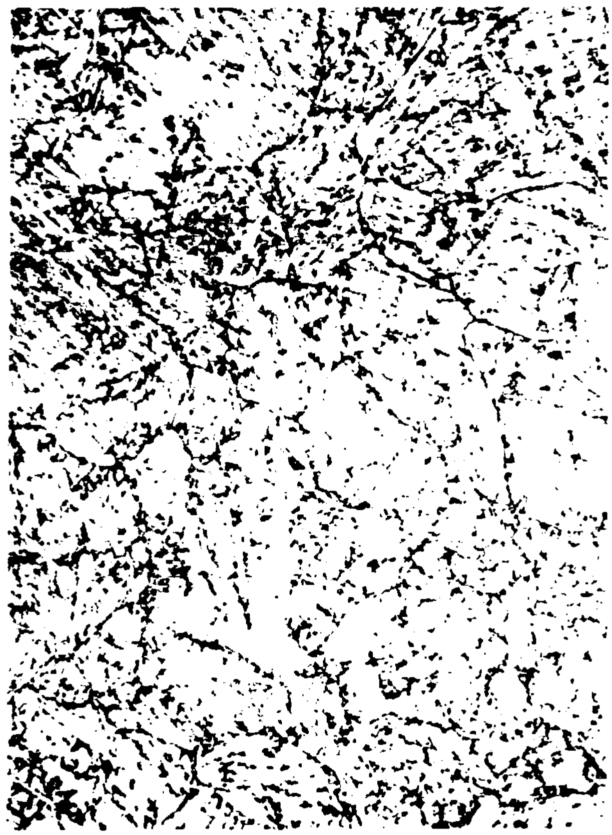


Figure 20. Photomicrograph illustrating the large grain size obtained in the breech end of the Palmaria 155-mm gun tube.

APPENDIX A

REPORT ON THE MEASURED RESIDUAL STRESS DISTRIBUTIONS IN THREE DISKS FROM A 155-MM ITALIAN MANUFACTURED HOWITZER

J.A.KAPP
21 Dec 1988

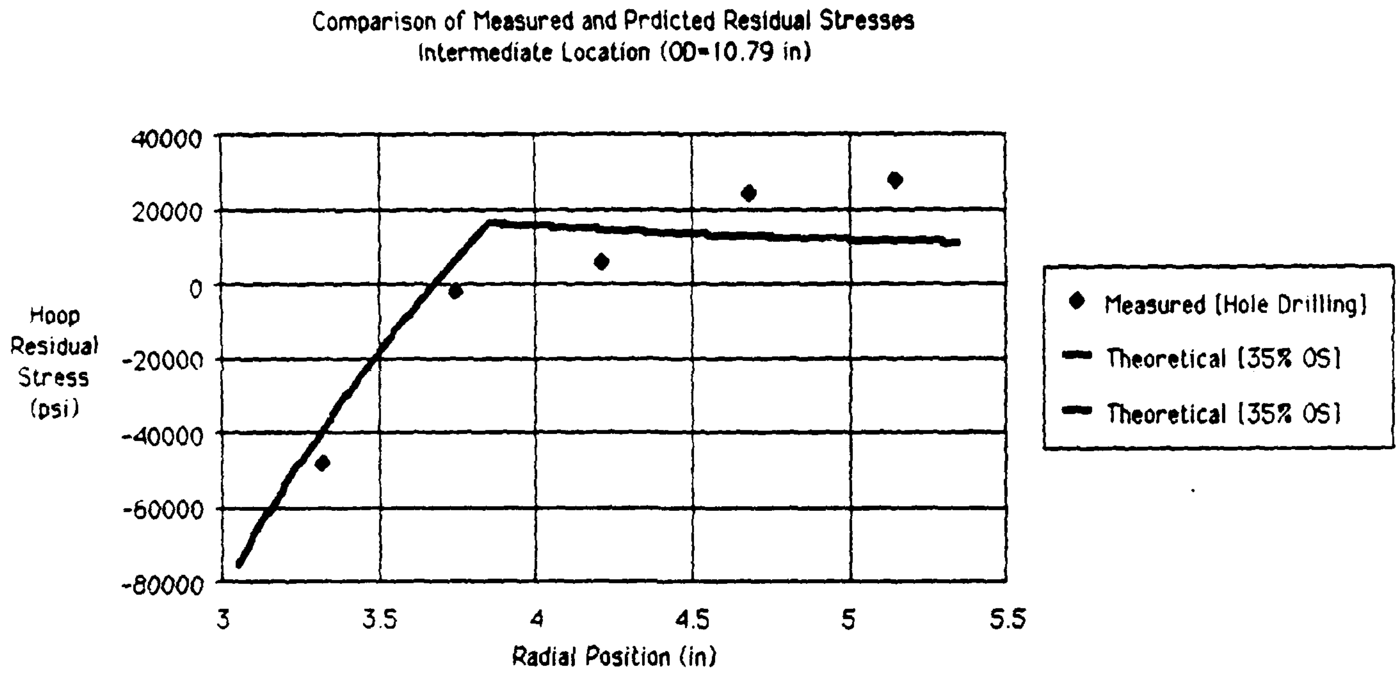
Three disks from a 155-mm Italian manufactured howitzer were analyzed to determine the extent of autofrettage residual stresses contained in the tube. The three disks were from different locations in the tube. The first section was from the chamber region. This disk was 2 inches thick, had an O.D. of 11.79 inches and an I.D. of 6.54 inches, and had an O.D. keyway notch. The second disk was from a section of the tube where the I.D. was 6.1 inches (155-mm) and had an O.D. of 10.79 inches. The final section was from the muzzle section of the tube. The I.D. of this disk was 6.1 inches (155-mm) and the O.D. was 8.64 inches. Neither the muzzle section nor the intermediate section had a keyway notch on the O.D.

Residual stresses were measured in two ways. First, the splitting method of B. Brown (ARLCB-TR-83042, December 1983) was used, and on two of the disks, the hole drilling method was used. In the splitting method, the disk is cut radially from the O.D. towards the I.D. If autofrettage residual stresses are present, when the cut is through to the I.D., the now split disk will spring open. The angle of opening is directly related to the amount of autofrettage residual stress (presented as percent overstrain). The hole drilling residual stress measurement method is outlined in ASTM E-837-85, "Standard Test Method for Determining Residual Stresses by the Hole Drilling Strain Gage Method." To measure the residual stresses, a three-gage strain gage rosette is bonded to the structure that contains the residual stresses. The rosette is oriented such that the center of each strain gage grid lies on a circle of known radius. A small diameter hole is drilled concentric to the strain gage position circle. The drilled hole is small enough that it does not damage the strain gage grids. When the hole is drilled, the area around the hole now acts as if it were a plate with a hole in it. Since a hole in space cannot support residual stresses, by drilling the hole the residual stresses are also relieved and will result in some strain to be observed by the strain gage rosette. The magnitude of the strain recorded on the strain gages can be related to the residual stresses at the location of the hole.

The results of the testing are as follows: For the breech end disk (containing the O.D. notch), the splitting method predicts a residual stress of 50 percent overstrain. For the intermediate disk, the splitting method predicts autofrettage residual stresses of 35 percent overstrain, and for the muzzle end section, the amount of autofrettage residual stress is predicted to be zero percent overstrain. It should be mentioned, however, that the splitting method was developed assuming that there were no discontinuities in the disk being tested. The angle of opening is a function of the stiffness of the disk. It has been shown that by introducing discontinuities such as O.D. notches, the stiffness of the disk is reduced and the magnitude of the residual stresses is affected (see Transactions of the ASME, Journal of Pressure Vessel Technology, Vol. 103, February 1981, pp. 76-84, Kapp and Pflegl). The effect of the notch is that the magnitude of the residual stresses is reduced over what would be predicted. Since 50 percent overstrain was measured, the level of autofrettage residual stresses may be somewhat more than 50 percent overstrain. But it is conservative to state that the amount of autofrettage residual stress in the breech end disk is 50 percent overstrain.

The hole drilling method was applied to two of the three sections, the intermediate section and the muzzle end section. Since the hole drilling must from necessity be performed prior to the splitting method, we gained no information at all on the muzzle end section. The hole drilling results for this section were inconclusive. The results from the intermediate section, however, did yield results that confirm the splitting method results. The accompanying figure demonstrates this. Plotted here are the hole drilling measured hoop residual stresses as functions of radial position; these measurements appear as the solid diamonds. Also plotted in the figure are the theoretical residual stresses based on the Von Mises' yield criterion and assuming a yield strength of

160,000 psi, 35 percent overstrain, and the dimensions of the disk. It is clear from this plot that the agreement is quite good. The residual stresses close to the outside diameter are somewhat higher than would be expected theoretically, but I believe that the differences are not critical. Therefore, it is safe to assume that at the location of the intermediate disk, the amount of autofrettage residual stress present is 35 percent overstrain.



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