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FATIGUE BEHAVIOR OF THICK-WALLED CYLINDERS
(7.62 MM RIFLED SPECIMENS)

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TECHNICAL REPORT

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QUALITY ASSURANCE DIRECTORATE

U.S. ARMY WEAPONS COMMAND

WATERVLIET ARSENAL

WATERVLIET-NEW YORK

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<p>This report deals with fatigue life testing employing 7.62MM rifled barrels in order to secure information on the relationship of specimen life achieved through cyclic hydraulic pressure stressing and that achieved by firing of service type ammunition. Materials used included standard M14 rifle barrel stock from several suppliers and 175MM M113E1 cannon tube forging material from three suppliers.</p> <p>The report also addresses the problem of "life" reliability prediction and demonstrates the potential usefulness of small barrel specimen testing in providing insight to "big gun" research, development, manufacturing, field support and quality engineering type problems.</p>			

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(7.62 MM RIFLED SPECIMENS)

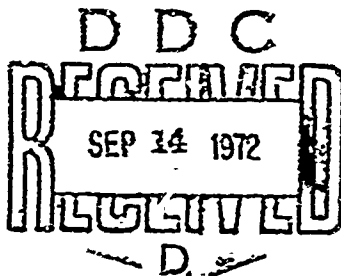
TECHNICAL REPORT

BY

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AND

PETER G. GOUTOS



JUNE 1972

QUALITY ASSURANCE DIRECTORATE

U.S. ARMY WEAPONS COMMAND

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FATIGUE BEHAVIOR OF THICK WALLED CYLINDERS
(7.62 MM RIFLED SPECIMENS)

ABSTRACT

This report deals with fatigue life testing employing 7.62mm rifled barrels in order to secure information on the relationship of specimen life achieved through cyclic hydraulic pressure stressing and that achieved by firing of service type ammunition. Materials used included standard M14 rifle barrel stock from several suppliers and 175mm M13A1 cannon tube forging material from three suppliers.

The report also addresses the problem of "life" reliability prediction and demonstrates the potential usefulness of small barrel specimen testing in providing insight to "big gun" research, development, manufacturing, field support and quality engineering type problems.

CROSS REFERENCE DATA

Fatigue Failure
Pressure Cycling
Fired Life
Firing Damage
Cannon Tube Material
7.62mm Barrel Material
Reliability Prediction/
Verification
Correlation Hydraulic
Simulation/Firing

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1. INTRODUCTION

Establishment of safe cannon life by the firing of ammunition is expensive, particularly when determining risk levels associated with metal fatigue of a critical component such as a cannon tube. Firing a single 155MM howitzer tube to its fatigue life for a price of one million dollars is considered a bargain. Destruction of a sufficient number of tubes by firing to achieve a statistically valid reliability quickly becomes prohibitive even with full consideration to moral issues and professional ethics. Duplication of firing phenomenon with attendant extremes in temperatures, pressure, and energy being developed in minimal time is difficult if not impossible. Therefore in order to gain a better understanding of life testing, small size specimen experimentation appeared as a logical approach for generation of data by which to look into the theoretical, statistical and experimental methods now being explored by many investigators.

2. OBJECTIVES

The immediate goals of this study are:

- a. To correlate ammunition firing pressure fatigue effects to hydraulic pressure cycling fatigue effects using thick walled gun barrels.
- b. To determine fatigue life performance of cannon tube material furnished by different contractors, produced to a common specification but by proprietary processes.

The long range goal of this study and similar future studies is to develop a more sensitive material test that would permit categorization of tube forgings by life expectancy.

3. APPROACH

Phase I - "Establishment of Test Techniques" -

The 7.62MM Rifle M14 was selected as a test vehicle because of low cost and availability of ammunition and rifle barrels. Since the fatigue life of a standard M14 rifle barrel was estimated high in comparison with that of a typical cannon, it was decided to neck down the barrel just over the origin of rifling to about four to six inches down barrel in order to precipitate earlier failure. Initial tests were run with barrels necked to a 1.4 wall ratio (ratio of outside diameter to inside rifling groove diameter). A rate of fire of six (6) rounds per minute was selected as being reasonable. Even at this low rate, barrel heating seriously degraded life (barrels turned blue) and a decision was made to water cool the remaining 1.4, 1.6, and 1.8 wall ratio specimens during firing. (See Appendix A for information and data pertaining to this phase of work).

Phase II - "Correlation of Hydraulic Pressure Cycled Life to Fired Life" -

The following decisions were made based on Phase I results:

- a. Use a standard proof fired M14 barrel modified to a 1.8 wall ratio in the vicinity of the origin of rifling.
- b. Fire at 6 rounds per minute.

c. Water cool the critical barrel area to minimize temperature effects on barrel material.

d. Use standard M1 rifle ammunition. See AIA 12711.

e. Hydraulic cycle at 40,000 PSI at 7 cycles per minute.

A sketch of the M1 rifle barrel and function, photographs of the firing stand and hydraulic pressure cycling equipment are shown in Appendix B. In order to demonstrate the relationship between firing and hydraulic pressure cycling, three levels of testing were selected and three replicates at each level. The levels were set by amounts of firing (beyond critical point) to be performed on each specimen i.e., 0, 1000, 2,000, 3,000, and 4,000 rounds. All specimens were subsequently hydraulically pressure cycled to destruction. In order to confirm fatigue life predicted by the above mentioned testing, three additional barrels were fired to destruction.

Phase III - "Comparison of 175M Tube Forging Material

Produced by Three Contractors F, Y, & Z"

Five 175M tube forging breach end sections (three from each of three suppliers) were prepared to secure longitudinal 1.5" diameter bars for manufacture of 7.62M size fatigue specimens.

This test series consisted of 9 specimens to be destroyed by pure hydraulic pressure cycling (no firing); 9 specimens fired to destruction (no hydraulic cycling), and 15 specimens fired to specified levels followed by hydraulic cycling to destruction.

Additional specimens were also planned to cover unexpected events.

Microbiology, rate of flow, rate of hydraulic cycling, specimen geometry, accumulation type etc., were the same or very similar to those used in Phase III. See Appendix I for details of specimen selection, and the Phase III test plan.

4. RESULTS AND DISCUSSION

Phase I - "Correlation of Test Techniques"

The information shown in Appendix A shows the feasibility of using the "24" style and accumulation system for test of solid, metal welded barrel Scrupus Helium.

The test check crack formation, the crack growth, and final rupture is considered similar to those normally experienced in common barrels.

Phase II - "Correlation of Hydraulic Pressure Cycled Rate to Fixed Rate"

Plots of the data generated from tests at the following test levels

<u>TEST LEVEL</u>	<u>HYDRAULIC PRESSURE</u>	<u>CYCLES</u>	<u>APPROXIMATE TEST TIME</u>
1	1	10,000	12,000
	1	15,000	
	1	20,000	
2	1,000	8,000	9,400
	1,000	9,000	
	1,000	11,000	

<u>TEST LEVEL</u>	<u>ROUNDS FIRED</u>	<u>HYDRAULIC CYCLES</u>	<u>AVG FTD CYCLES PER TEST LEVEL</u>
3	2,000	10,462	7,808
	2,000	7,416	
	2,000	5,545	
4	3,000	2,973	6,373
	3,000	7,046	
	3,000	9,101	
5	4,000	2,939	2,666
	4,000	2,474	
	4,000	2,587	
6	5,653	0	6,144
	6,263	0	
	6,457	0	

are shown in Appendix C and yields a relationship between hydraulic pressure cycled specimen life to fired specimen life of

$$Y(\text{cycles}) = -2.21 X(\text{rounds}) + 12,122$$

or 2.21 hydraulic cycles are equal to one fired round.

It should be noted that although large differences are evident among individual specimen lives at any one level, the average life at each level closely adheres to the straight line relationship.

The fired to destruction barrels (test level 6) confirm the validity of the resultant equations over in predicting mean fatigue or catastrophic failure.

An analysis of variance was performed on the six (6) levels, three (3) replicates per level and there appears to be no significant difference among the mean equivalent lives at each

level. See Appendix D for details.

A reliability life determination is shown in Appendix E along with photographs of failed M14 rifle specimens.

An application of the life prediction technique, used with the M14, to standard cannon is shown in Appendix F. The concept of retiring 1000 or more safe still usable tubes to prevent a single accident as a result of metal fatigue has in recent years become an acceptable practice. Additional safeguards are also provided as a result of other reasons for condemnation such as bore wear (origin or muzzle), rifling damage, rust or pitting, transportation hazards, enemy action etc.

Phase III - "Comparison of 175MM Tube Forging Material Produced by Three Contractors X, Y, Z."

Data generated from this experiment and a graphical portrayal of this data is shown in Appendix H.

Comparing M14 rifle material plot to 175MM gun material plot shows more variation in M14 rifle material life. This may be attributed to the fact that all 175MM specimens were manufactured by one machinist on common machinery while the M14 rifle barrels were drawn from stock and involve a variety of manufactures.

In both the M14 test and the 175MM material test, hydraulic pressure cycling was performed at about 3000 PSI less than the average firing pressure. This might account for the M14 2:1 hydraulic cycles per firing cycle but then it does not account for the 1:1 relationship shown with 175MM material with specimen fired beyond the 500

round level. See Appendix N for ammunition calibration information.

The 175MM material appears to be very seriously affected by firing damage as demonstrated on the graph with the pure (unfired) hydraulically pressure cycled specimens versus those fired to destruction. Also the combination fired/cycled 5 rd., 50 rd., and 100 rd. specimens show a sizable drop in life as compared with the unfired specimens. The M14 material did not exhibit this effect although proof of one round may promote sufficient firing damage to account for this condition.

In order to perform a comparison of life data within a forging, among forgings from a particular supplier, and among forgings from different suppliers, data was transformed to a common base as shown in Appendix I. The difference among forging life data are considered normal and acceptable fatigue behavior irrespective of forging supplier. Material properties and quality are considered to be effectively the same. Appendix J contains life/reliability information. Appendix K shows life and material properties data and plots while Appendix L contains photos of specimens fired to destruction.

Appendix M shows information on a field failure and specimen test results. While the results cover a wide range, from 1676 rounds through 7810 rounds, the three out of four low life values indicate cause for concern about material behavior.

5. CONCLUSION

The multi-level testing technique and 7.62MM bore fatigue specimens, as demonstrated by these studies, are each considered useful tools and reasonable (cost/effective) methods for problem exploration.

Typical problems for possible application being:

Swage tube vs hydraulic autofrettage tube life

Rate of fire effects

Effects of pressure levels

Changes in chemistry

Changes in heat treat

Changes in forging practices

Chrome or other type plating effects

Refractory liners

Cooling effects

Aging and rest between firing effects

Hydrogen embrittlement

Long term storage chemical effects

Straightening

Thermal treatment effects

Dirt size and count

6. RECOMMENDATION

Continued funding of projects using specimens of the type employed in this study in order to promote knowledge for production of superior cannon tubes and safely exploiting maximum life from these tubes.

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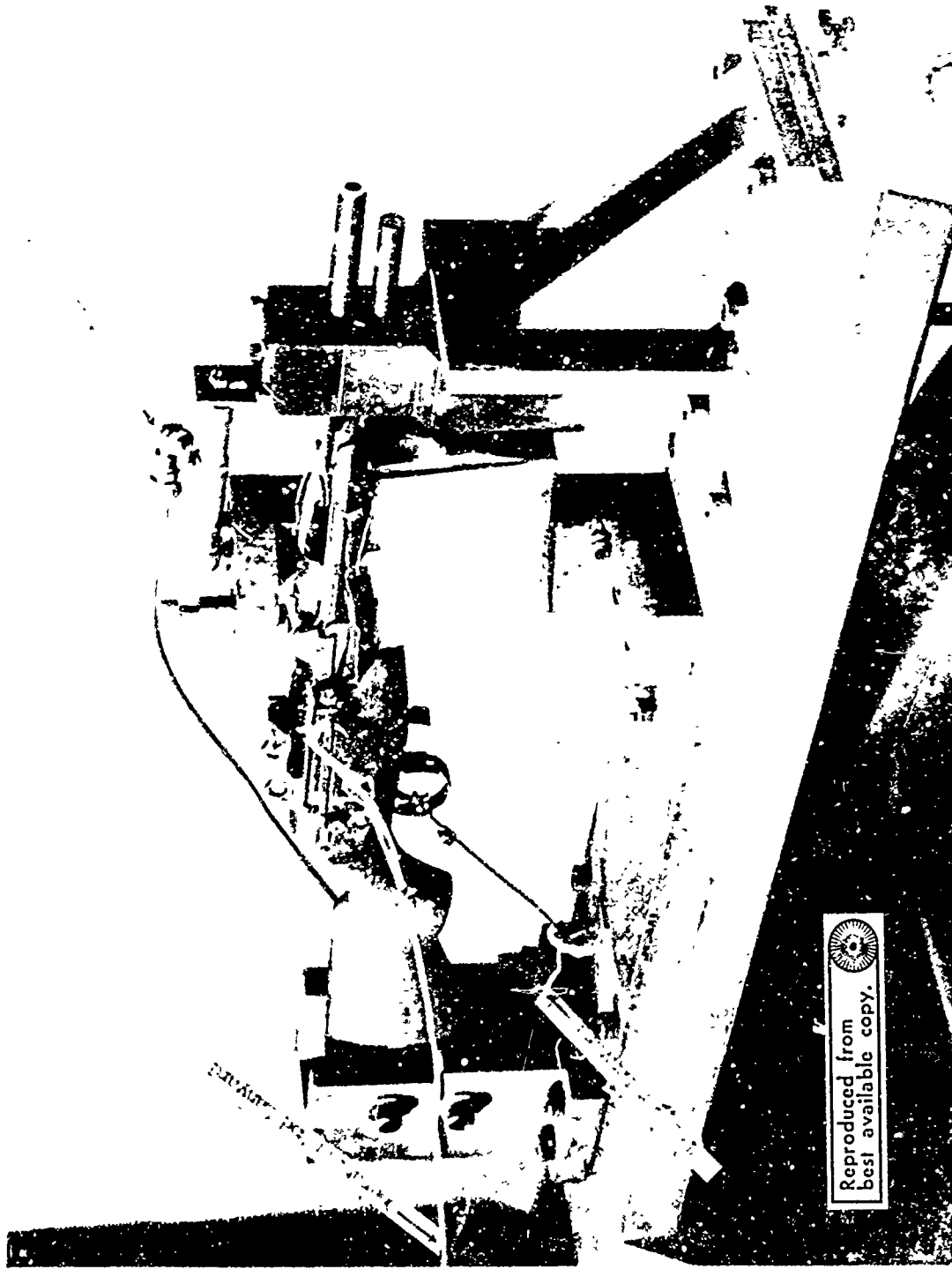
APPENDIX A

(PHASE I)

ESTABLISHMENT OF TEST TECHNIQUES

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A



Firing Fixture (7.62M) w/Water Cooled System & Firing Tray (1)

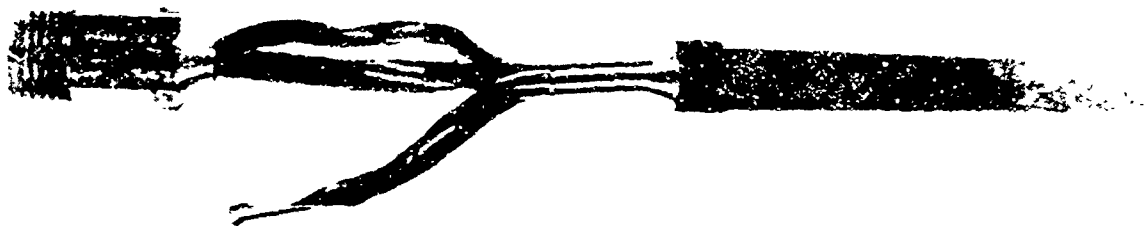
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A

7.62MM Modified M14 Rifle Barrels
1.4 Wall Ratio Fatigue Specimens
Air Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 10 $\frac{1}{2}$ " , Ammunition Lot LC 13023
Project No. 4332-1, Negative No. 197-4-69



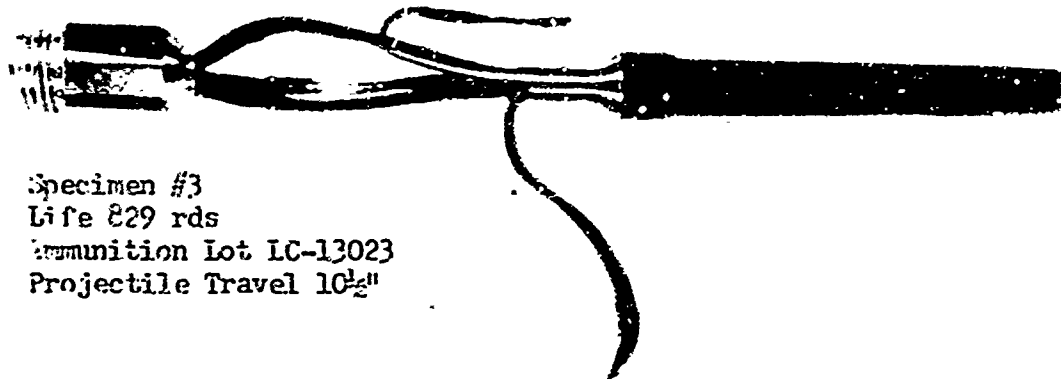
Specimen #1
Life 387 rds



Specimen #2
Life 69 rds

A

7.62MM Modified M14 Rifle Barrels
1.4 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Project No. 4332-1, Negative No. 197-2-69



Specimen #3
Life 829 rds
Ammunition Lot IC-13023
Projectile Travel 10 $\frac{1}{2}$ "



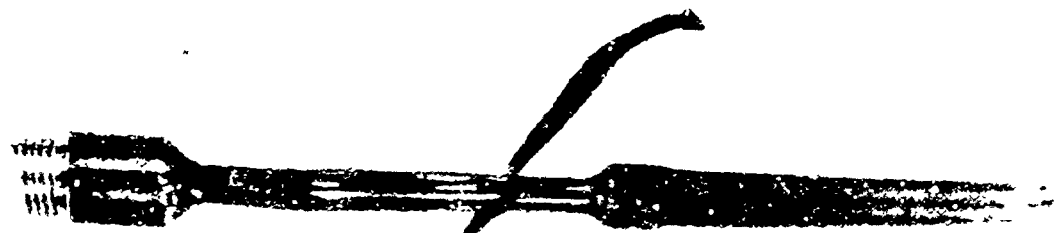
Specimen #10
Life 1193 rds
Ammunition Lot WRA-22713
Projectile Travel 19 $\frac{1}{4}$ "



Specimen #11
Life 1011 rds
Ammunition Lot WRA-22713
Projectile Travel 19 $\frac{1}{4}$ "

A

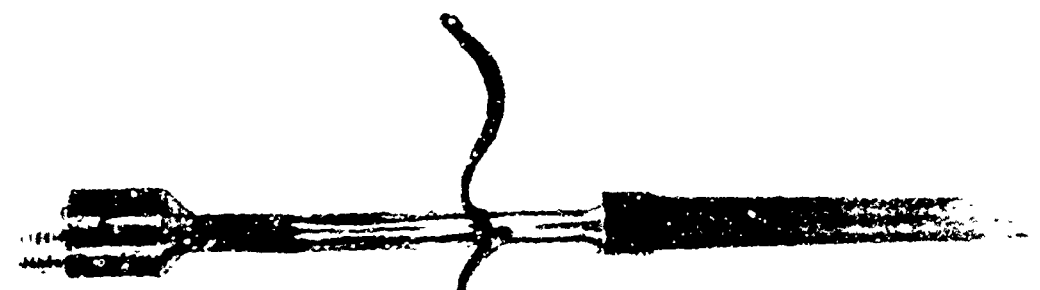
7.62MM Modified MD1 Rifle Barrels
1.6 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 10¹/₂" , Ammunition Lot LC 13023
Project No. 4332-1, Negative No. 197-1-69



Specimen #4
Life 2756 rds



Specimen #5
Life 2336 rds



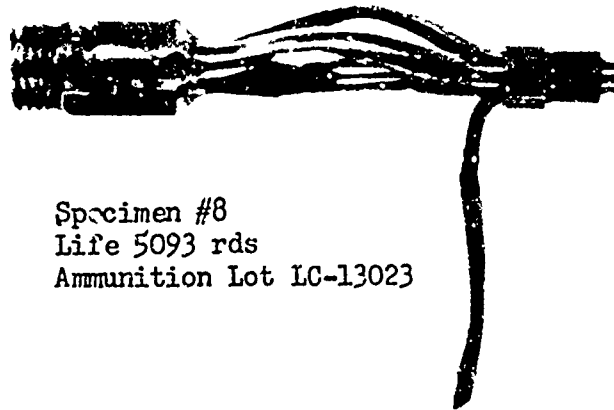
Specimen #6
Life 2284 rds

A

7.62mm Modified M14 Rifle Barrels
1.8 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 19 $\frac{1}{4}$ ", Project No. 4332-1
Negative No. 197-3-69



Specimen #7
Life 5474 rds
Ammunition Lot LC-13023



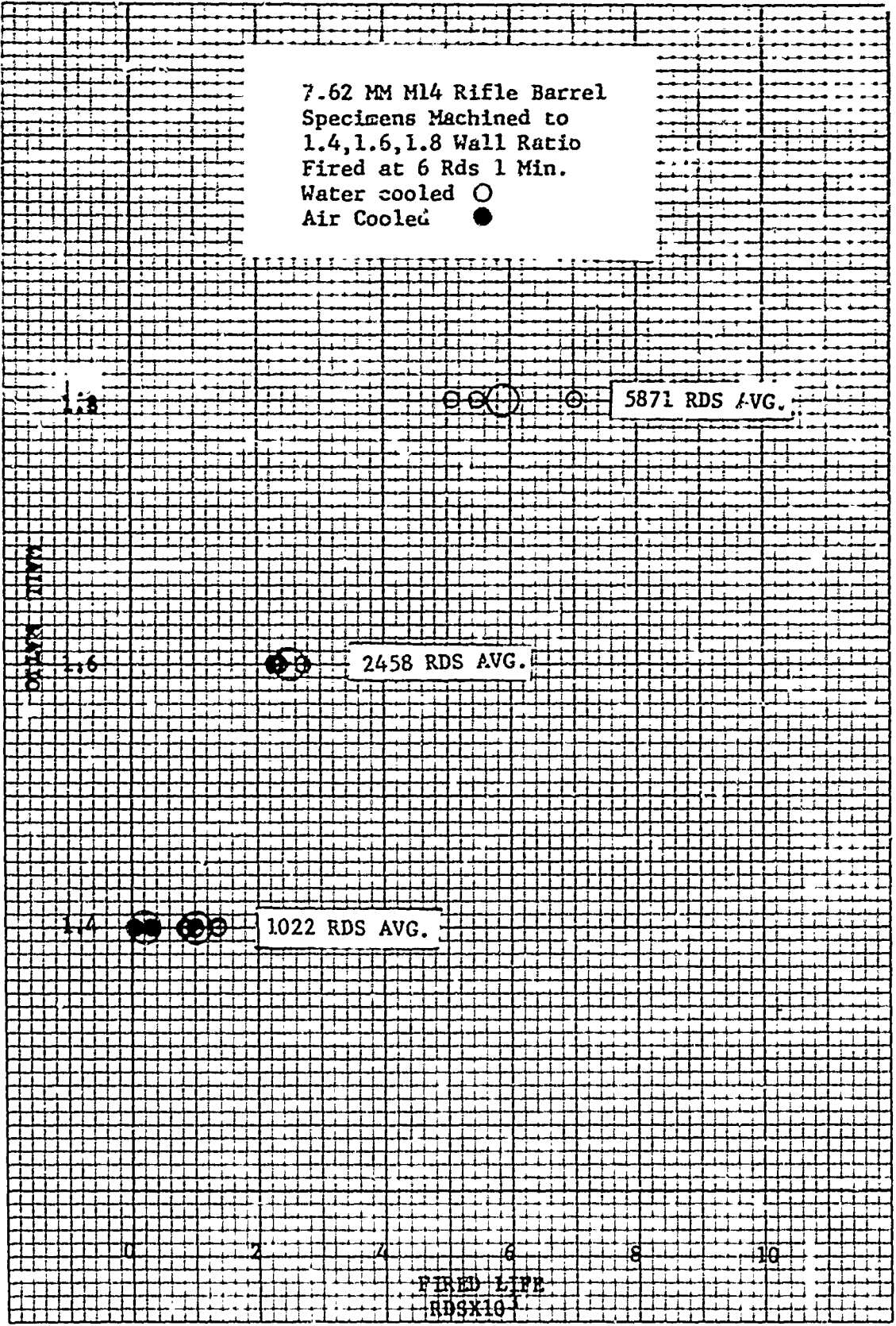
Specimen #8
Life 5093 rds
Ammunition Lot LC-13023



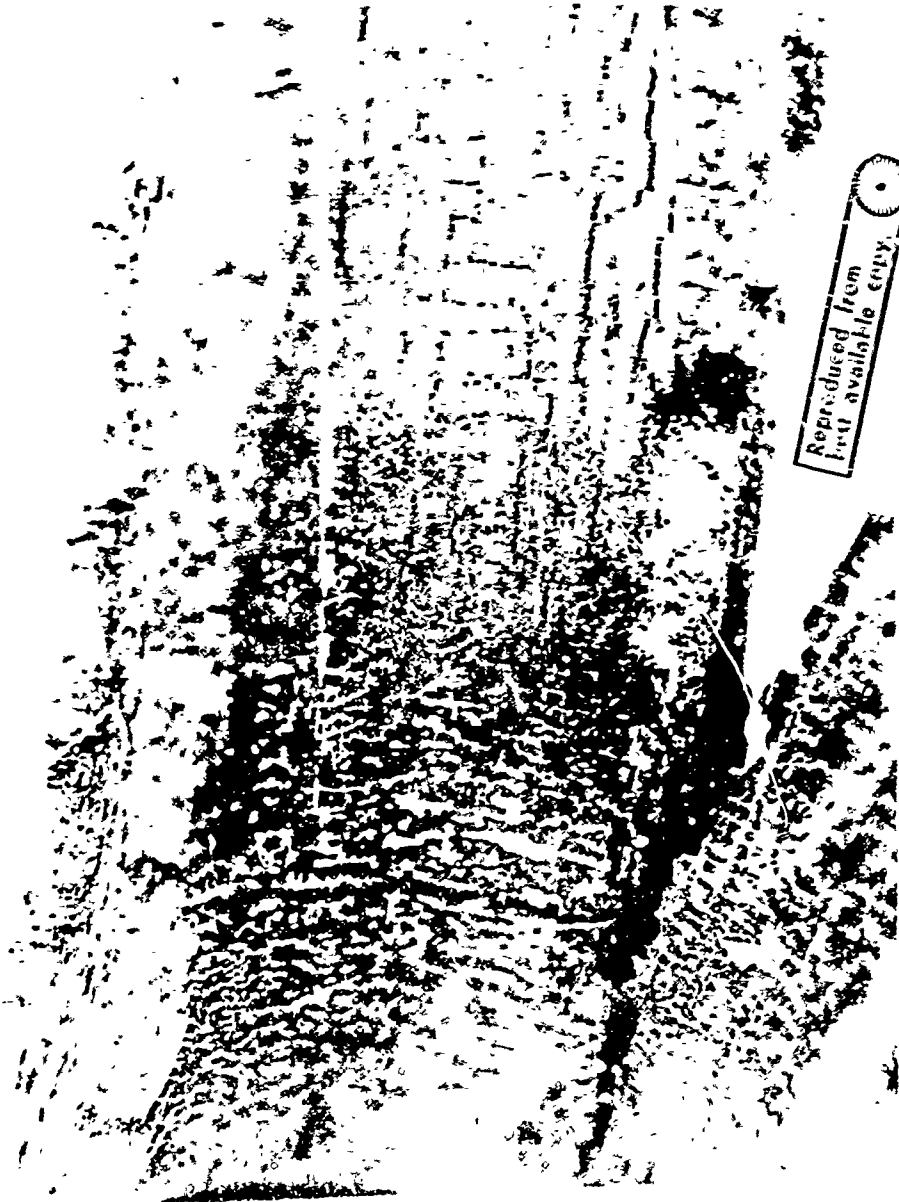
Specimen #9
Life 7047 rds
Ammunition Lot WRA-22713

A

7.62 MM M14 Rifle Barrel
Specimens Machined to
1.4, 1.6, 1.8 Wall Ratio
Fired at 6 Rds 1 Min.
Water cooled ○
Air Cooled ●



A



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Specimen #9 Heat Check Pattern
10/25/1940

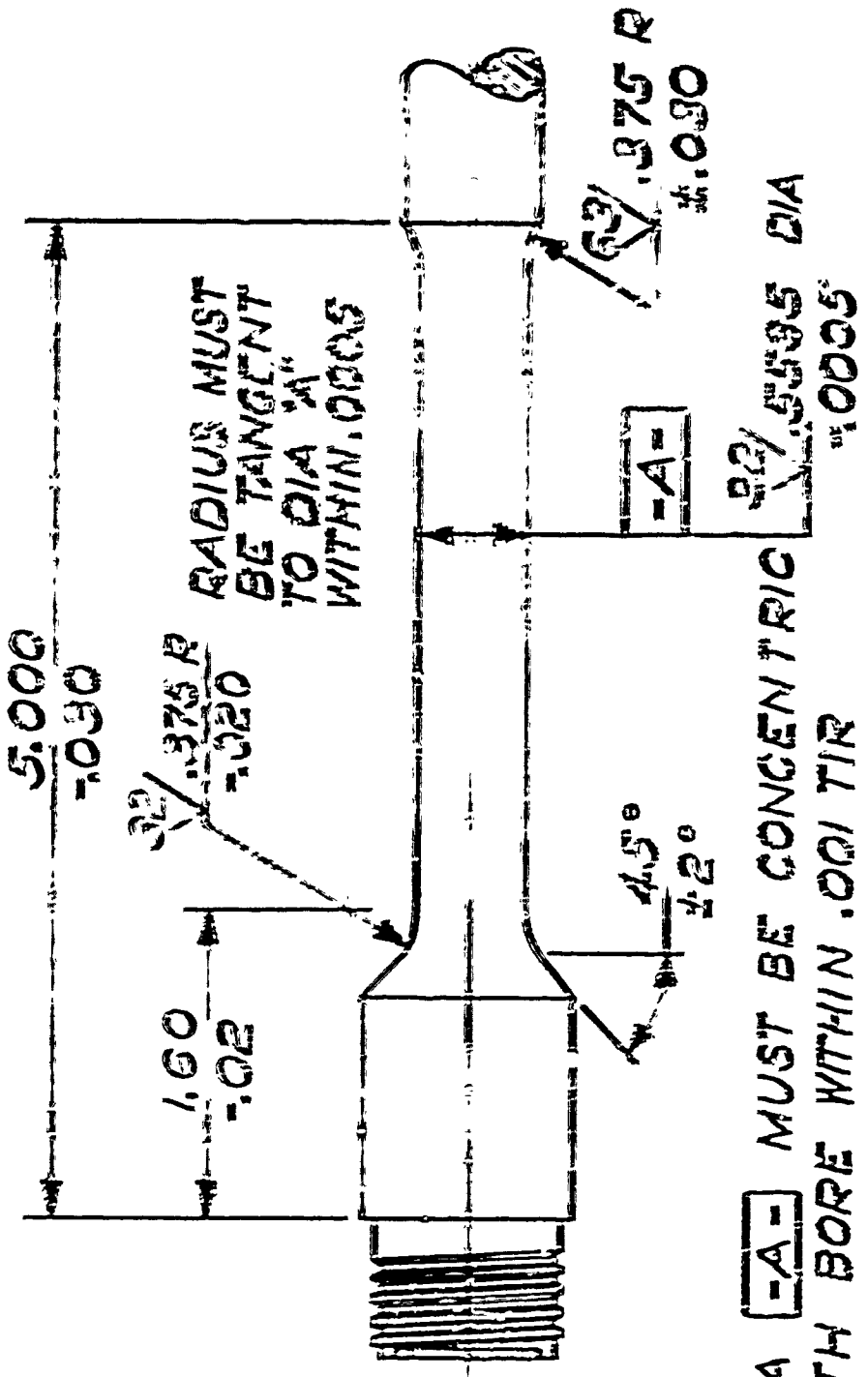
APPENDIX B

(PAGE 11)

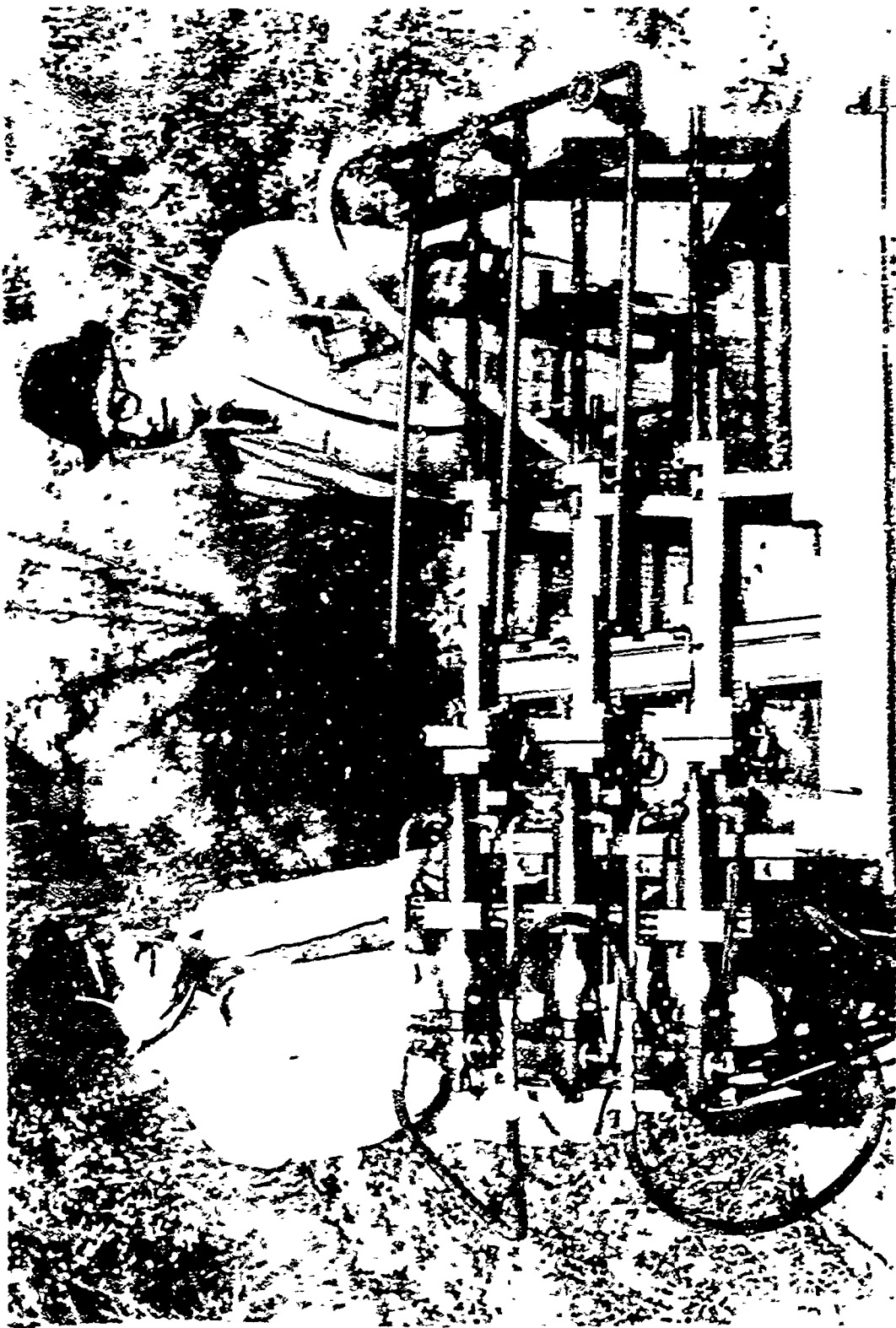
DESCRIPTION OF REVISIONS PROCEDURE BEING MADE TO FILE 11-3

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2.	Triple Gun Firing Test Stand	19
3.	Hydraulic Pressure Test Stand	20

MODIFICATION OF BARREL, RIFLE; 7.62_{MM}, M14_{GP}
 FSN 1005-628-9052 DWG 7790190



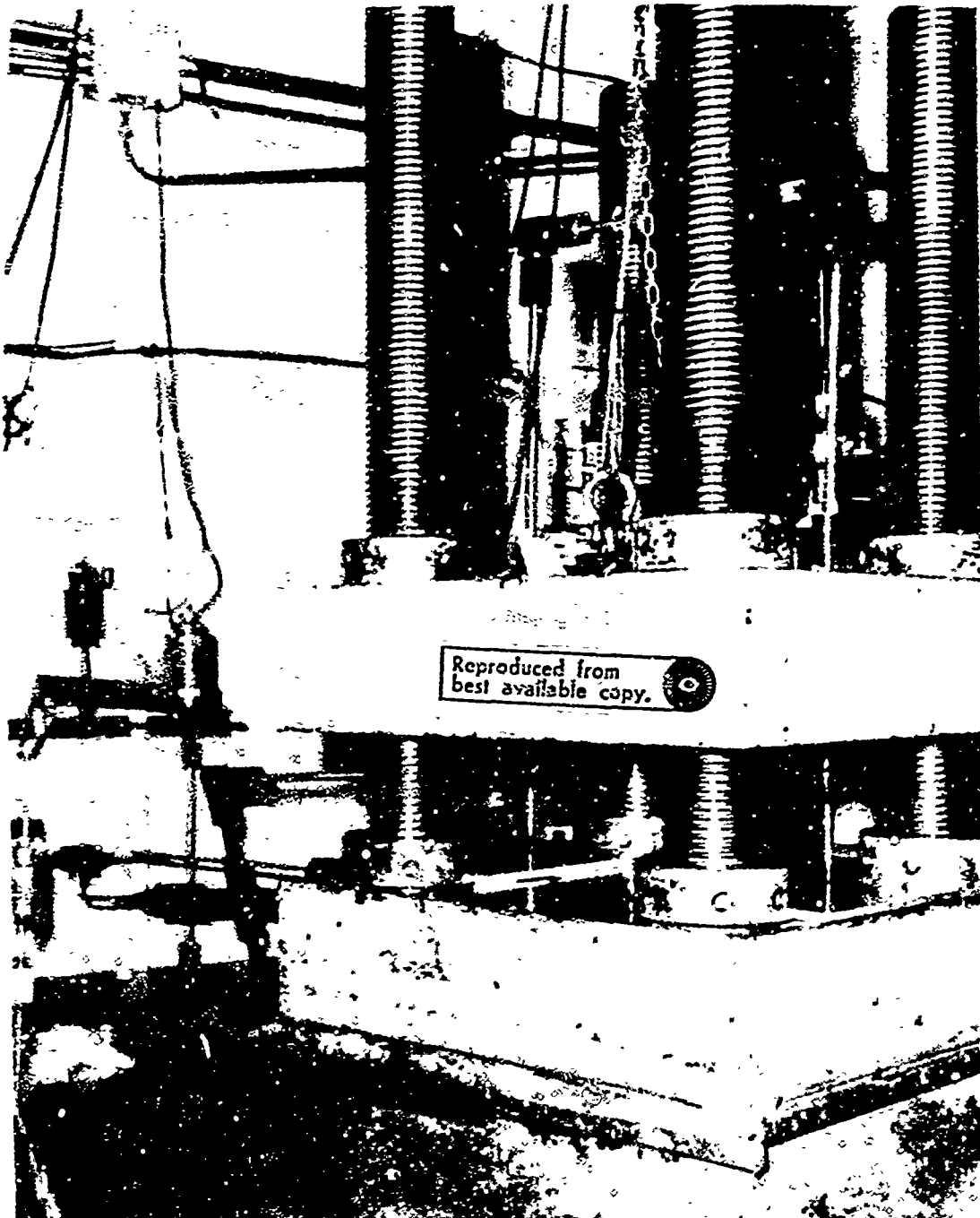
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B

Triple Gun Firing Test Stand

B



Hydraulic Pressure Test Stand

APPENDIX C

(PHASE II)

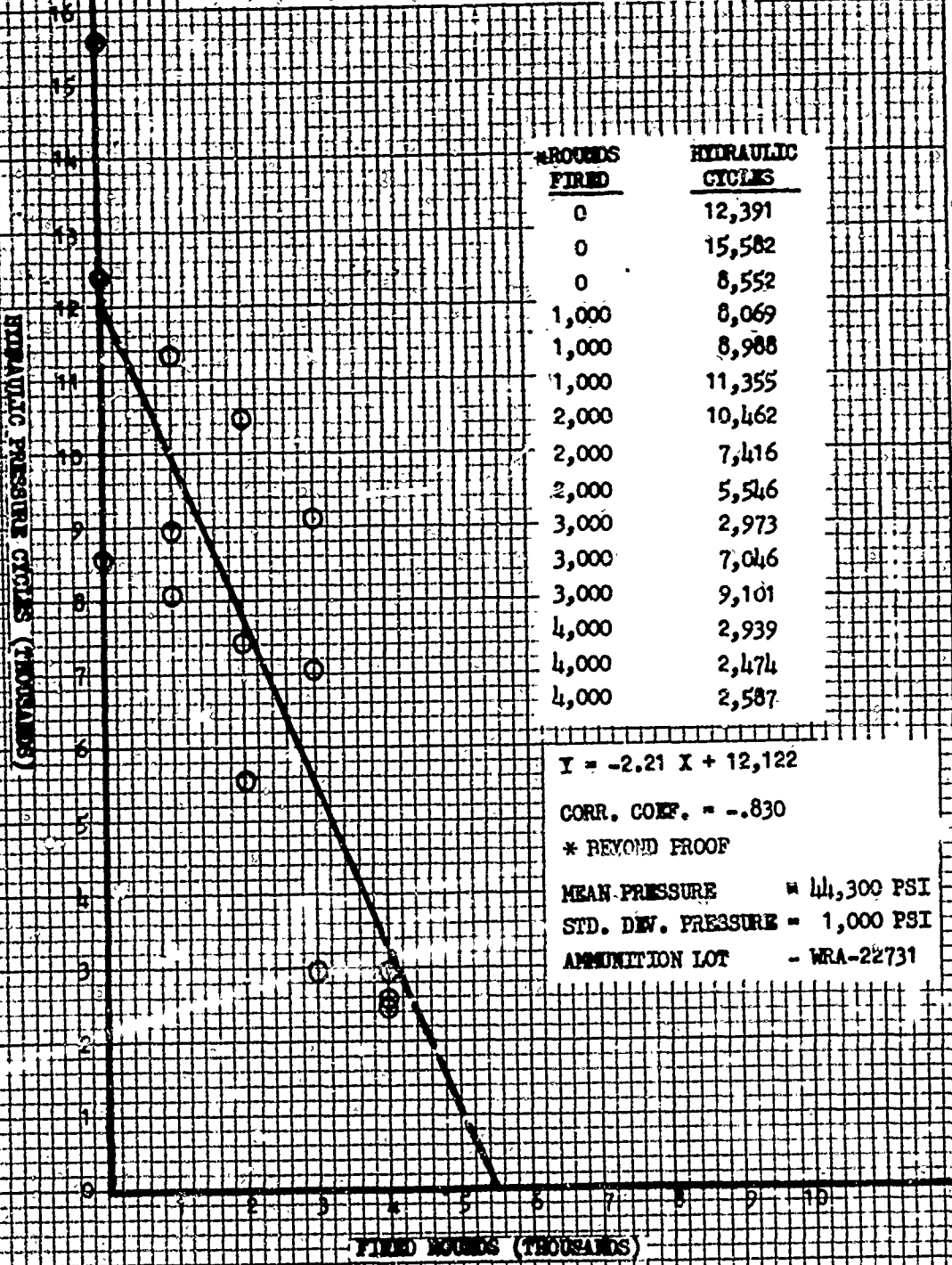
CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

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1.	Graph - Hydraulic Cycles vs Rounds Fired	22
2.	Graph - Avg Hydraulic Cycles vs Rounds Fired	23

C

**CORRELATION OF HYDRAULIC CYCLES VERSUS ROUNDS FIRED ON
7.62MM, 1.8 WALL RATIO, M14 RIFLE BARREL TEST SPECIMENS**

**SPECIMENS FIRED AT 6 ROUNDS/MIN (WATER COOLED)
AND/OR HYDRAULICALLY CYCLED AT 7 CYCLES/MIN**

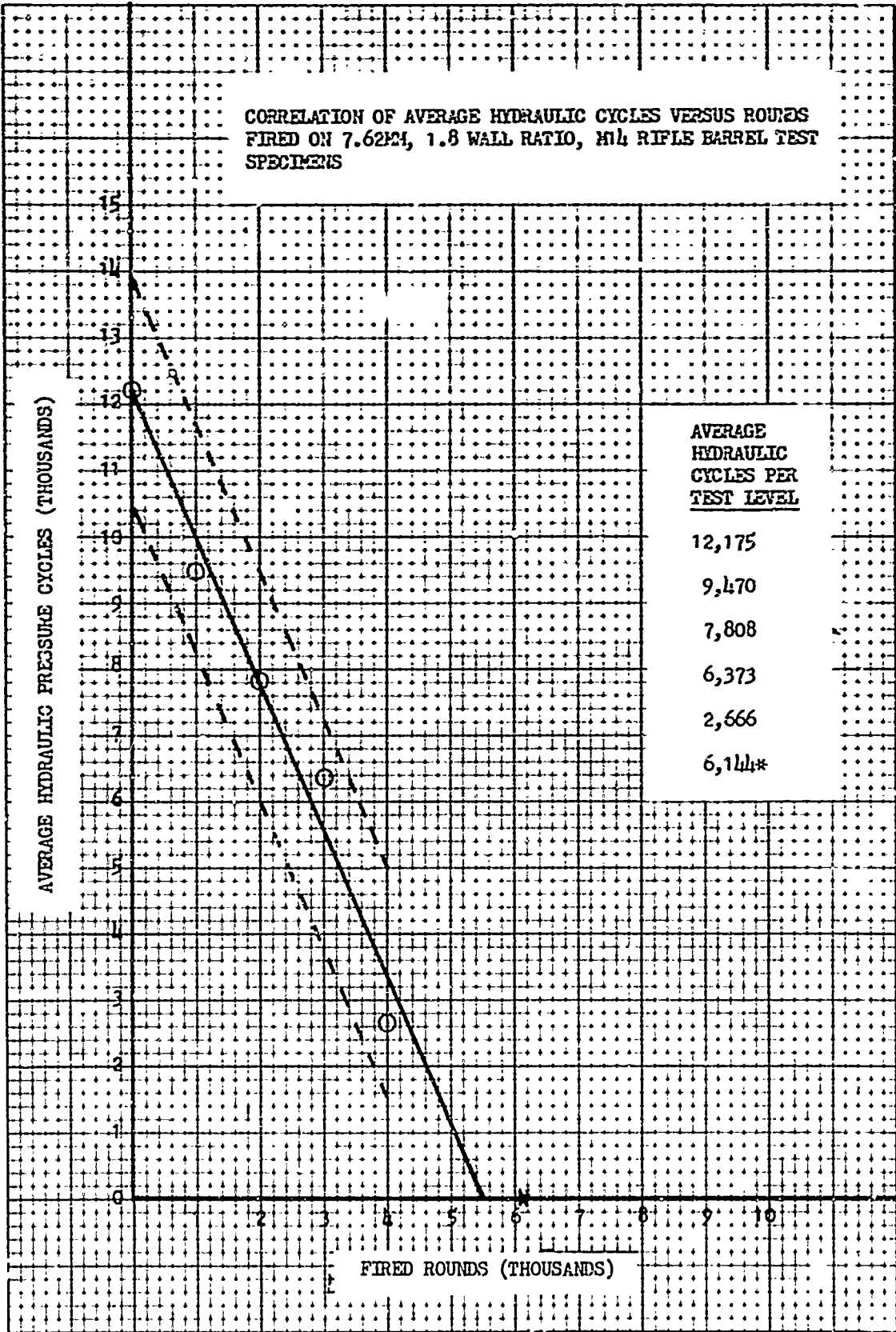


APPENDIX C

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

<u>NO.</u>		<u>PAGE</u>
1.	Graph - Hydraulic Cycles vs Rounds Fired	22
2.	Graph - Avg Hydraulic Cycles vs Rounds Fired	23



D

APPENDIX D

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE vs FIRED LIFE

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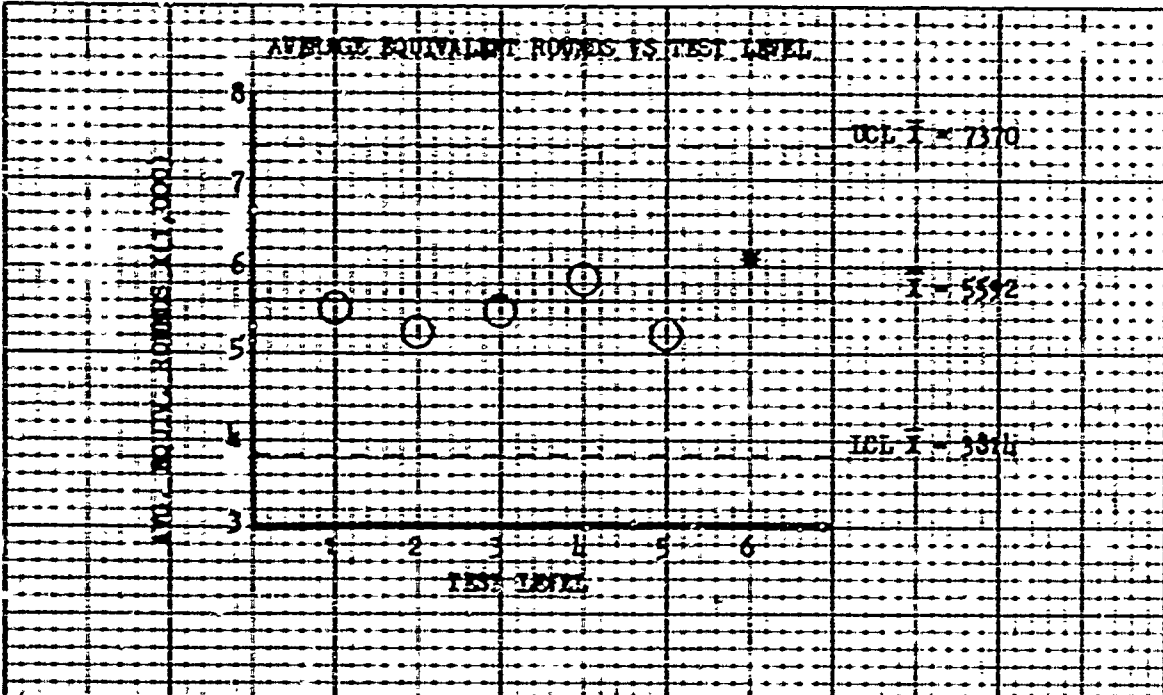
D

CONVERSION TO EQUIVALENT ROUNDS

$$I(\text{Rounds}) = \frac{I(\text{Cycles})}{2.211}$$

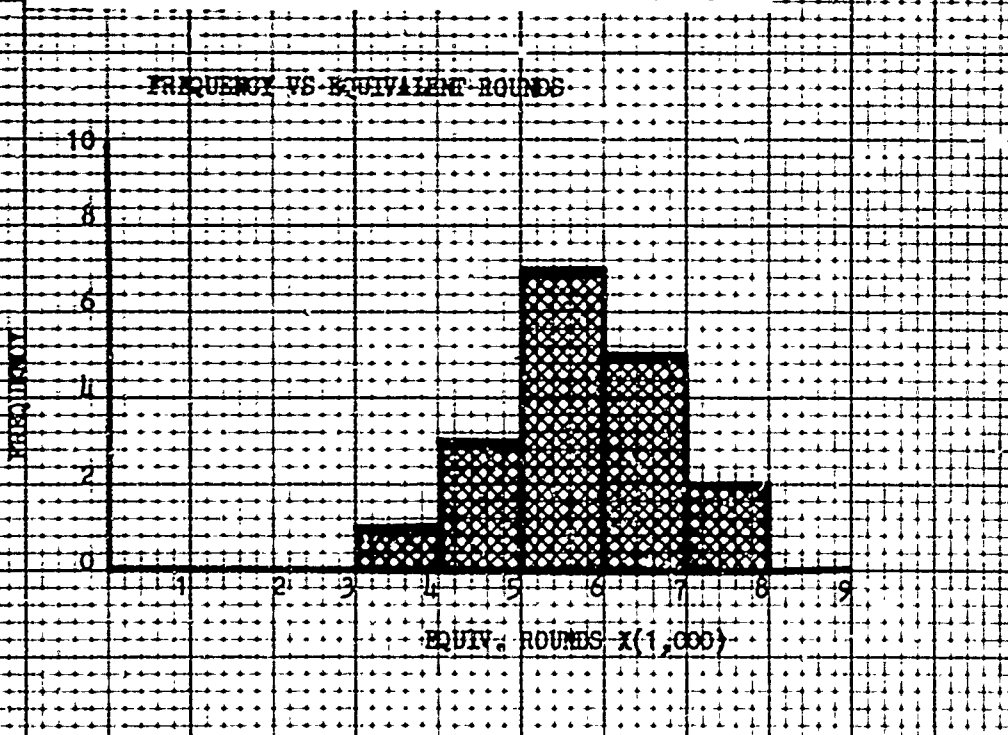
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
<u>TEST LEVEL</u>	<u>FIELD CYCLES</u>	<u>HYDRAULIC CYCLES</u>	<u>AVG MID CYCLES PER TEST LEVEL</u>	<u>RDS/ EQUIV RDS TO FAILURE</u>	<u>AVG RDS/ AVG EQUIV RDS TO FAILURE</u>
1	0 0 0	12,391 15,582 6,552	12,175	5,603 7,016 3,867	5,506
2	1,000 1,000 1,000	3,069 8,988 11,355	9,470	4,619 5,064 6,135	5,283
3	2,000 2,000 2,000	10,462 7,416 5,516	7,808	6,731 5,354 4,508	5,531
4	3,000 3,000 3,000	2,973 7,046 9,101	6,373	4,344 6,186 7,115	5,882
5	4,000 4,000 4,000	2,939 2,474 2,587	2,666	5,329 5,119 5,170	5,206
6	5,683 6,263 6,487	0 0 0	6,144	5,683 6,263 6,487	6,144

D



TEST LEVEL	1	2	3	4	5	6*
EQUIV RDS	5,603	4,649	6,731	4,344	5,329	5,683
TO	7,046	5,064	5,354	6,186	5,119	6,263
FAILURE	3,867	6,135	4,508	7,115	5,170	6,487
AVERAGE	5,506	5,283	5,531	5,882	5,206	6,144

*ALL FIRED



ANALYSIS OF VARIANCE (ANOVA)

In general, there are three ANOVA classifications:

(i) FIXED EFFECTS - Where particular levels of a factor are studied and the result is a comparison of mean effects of THOSE particular levels.

(ii) RANDOM EFFECTS - Where levels of each factor are randomly chosen from a large finite or infinite population of levels and the resulting analysis estimates the component of variance contributed by each factor to the total variance rather than the main effects and interactions at particular levels of each factor.

(iii) MIXED

The combination of (i) and (ii) resulting in a more complicated analyses.

The analysis of variance technique enables us to partition the variance of the measured variable into portions caused by the factors, singly or in combination, and an experimental error component.

ONE FACTOR ANALYSIS

PURPOSE ...

To compare "L" different levels of a single factor having "M" replicates (repeat experiments) per level.

ASSUMPTIONS ...

(1) The "M" replications for any level represent a sample drawn at random from a normal population.

D

(ii) (a) FIXED EFFECTS

The "L" levels are systematically chosen as the important (or only) levels of the factor.

(b) RANDOM EFFECTS

The "L" levels are randomly chosen from a normal population of levels of the factor.

ANALYSIS ...

- Let
- $\alpha \equiv$ Level of Significance
 - $L \equiv$ Number of Levels
 - $M \equiv$ Number of Replicates
 - $N = (L)(M) \equiv$ Sample Size
 - $X_{it} \equiv$ Replication t of Level i

Then, the partitioning of the total sum of squares (S.S.) of deviations from the mean into its components is as follows:

Source of Variation:

Among Levels

$$\text{S.S. (AMONG)} = \frac{L \sum_{i=1}^L \left(\sum_{t=1}^M X_{it} \right)^2 - \left(\sum_{i,t} X_{it} \right)^2}{N}$$

... associated degrees of freedom = (L-1)

Within Levels

$$\text{S.S. (WITHIN)} = \text{S.S. (TOTAL)} - \text{S.S. (AMONG)}$$

... associated degrees of freedom = (N-L)

Total Sum of Squares:

$$\text{S.S. (TOTAL)} = \frac{N \sum_{i,t} X_{it}^2 - \left(\sum_{i,t} X_{it} \right)^2}{N}$$

... associated degrees of freedom = (N-1)

The Mean Squares (variance estimates) are formed by dividing the Sum of Squares by their associated degrees of freedom.

If the null hypothesis (H_0) of no difference among levels (equal means) is true, then the mean squares (M.S.), among and within, are independent estimates of the same quantity and should be approximately equal (except for sampling error) with a ratio (among M.S. to within M.S.) near unity. A ratio greater than or equal to the tabled value for (L-1, N-L) degrees of freedom would occur in random sampling with probability α if H_0 were true. Therefore, we would reject the null hypothesis and say there is a difference among levels (i.e., averages).

If an F - ratio less than unity is calculated, consideration should be given to its reciprocal being statistically significant rather than accepting H_0 immediately. If the reciprocal is significant, possibly the postulated model is inadequate (Reference 2).

ANOVA, FIXED EFFECTS, LEVELS 6, REPLICATES 3

LEVEL	1	2	3	4	5	6
EQUIVALENT	5603	4649	6731	4344	5329	5683
ROUND	7046	5064	5354	6186	5119	6263
REPLICATES	3867	6135	4508	7115	5170	6487
SOURCE OF VARIATION	SUM OF SQUARES		DEGREES OF FREEDOM		MEAN SQUARE	
Among	1,934,449		5		386,890	
Within	13,106,290		12		1,092,190	
Total	15,040,740		17			

D

Resulting F ratio is .354 which is less than the table value 3.11 and therefore there is no significant difference among the mean lives of the six (6) levels considered.

Similarly the reciprocal of the F ratio, $1/F$ is 2.82, which is less than the table value of 4.68, and the model can be considered adequate. (Reference 3, tables).

References:

1. STATISTICS MANUAL by E. Crow, F. Davis, M. Maxfield, Dover Publications
2. STATISTICS IN RESEARCH by B. Ostle, Iowa State University Press
3. ENGINEERING STATISTICS by A. H. Bowker and G. J. Lieberman

E

APPENDIX E

(PHASE II)

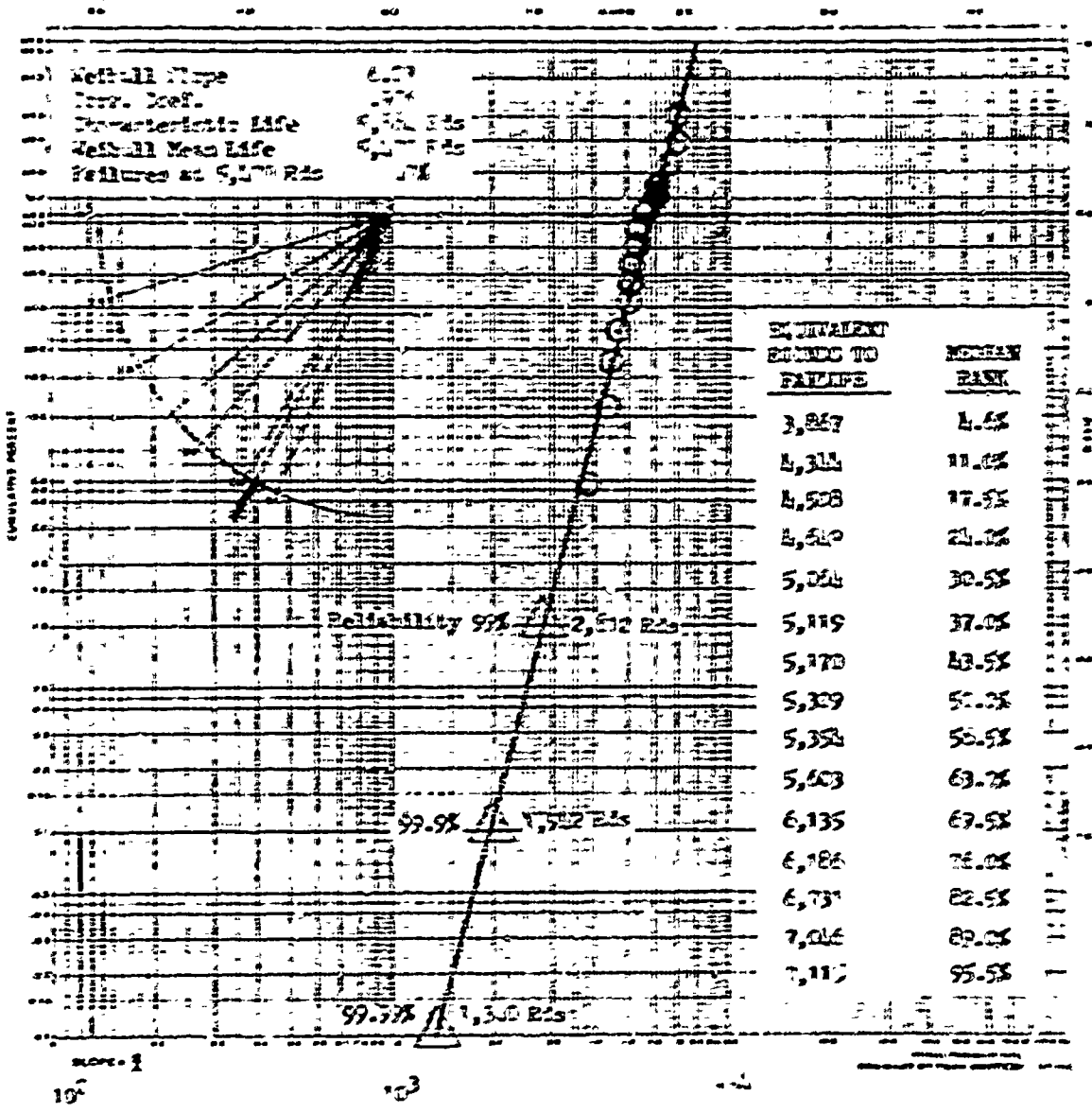
CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

<u>NO.</u>		<u>PAGE</u>
1.	Graph - Reliability vs Equivalent Rounds to Failure	32
2.	Photos of Failed M14 Rifle Specimens	33-36

7.62MM 1.8 MALL BATED

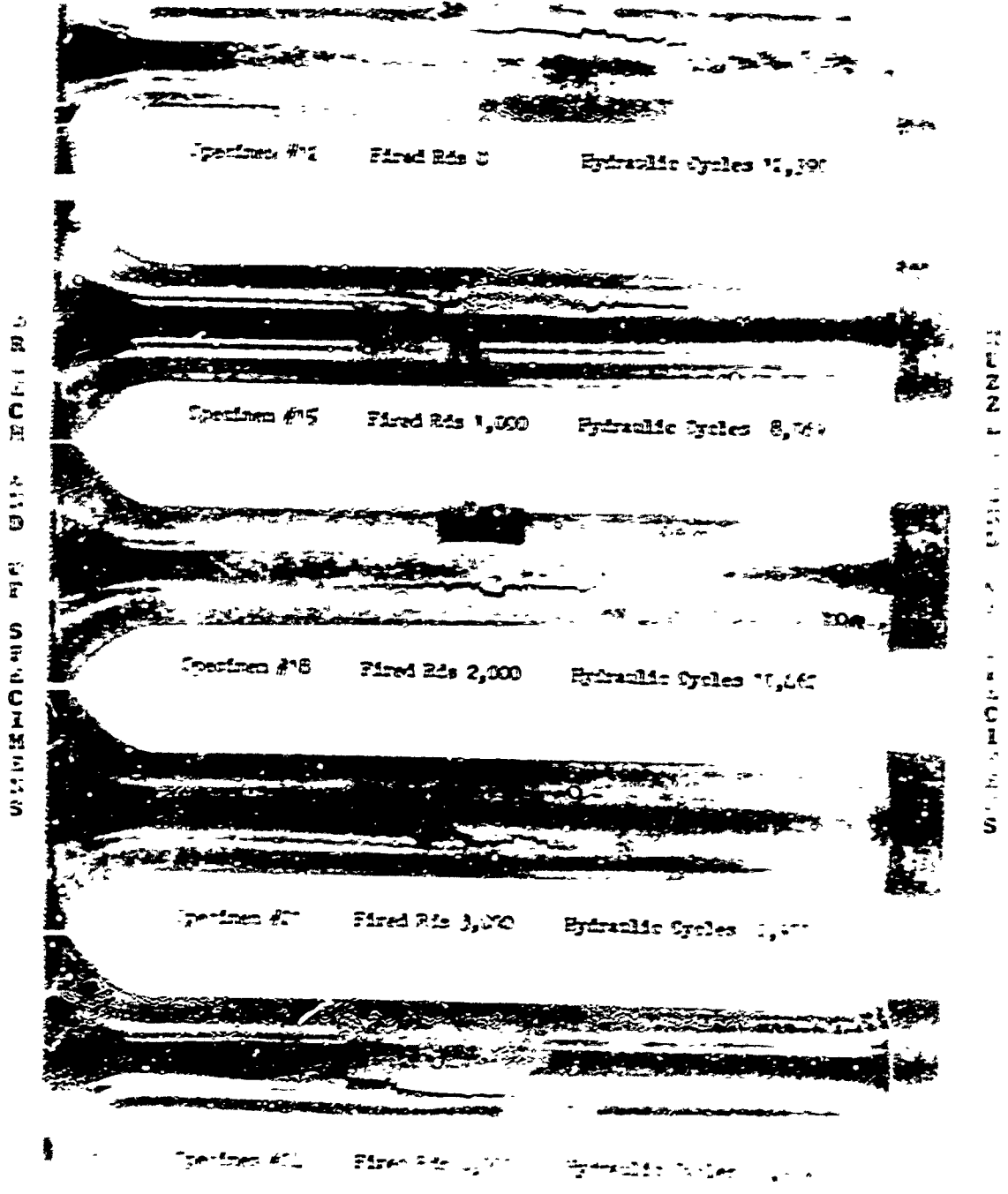
15 - 100 RIFLE BARREL TEST SPEEDS

ALL FIRED TO VARYING DEGREES AND THEN CYCLED TO FAILURE



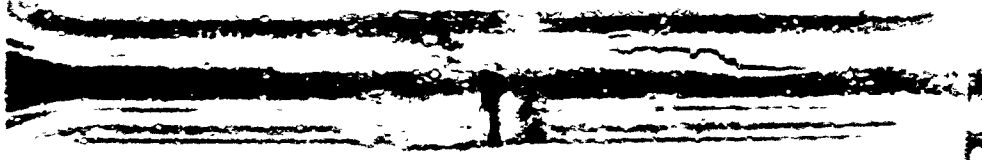
EQUIVALENT ROUNDS TO FAILURE

COMPARISON OF CRACK GEOMETRY AND LOCATION

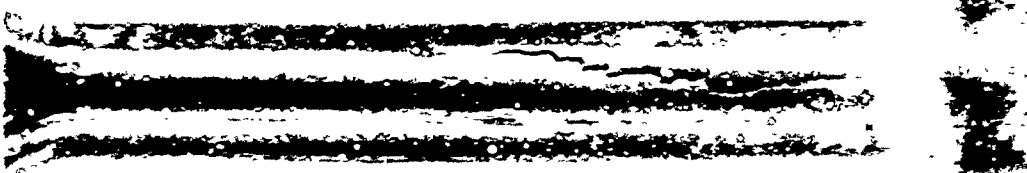


E

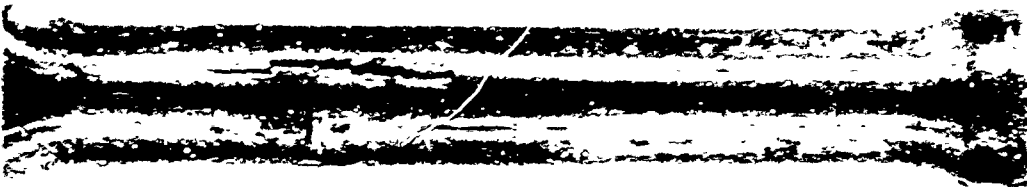
DISCONTINUITY OF FIBER BUNDLE BY FIBER LOCATION



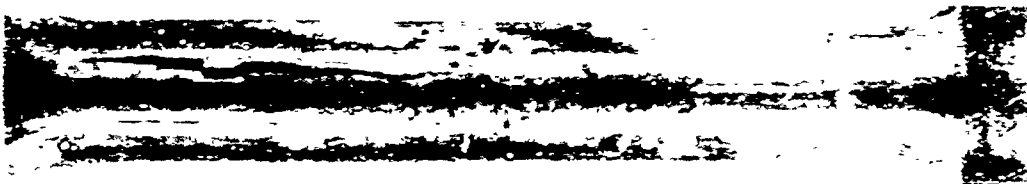
Specimen #3 Fired Rds 0 Hydraulic Cycles 15,552



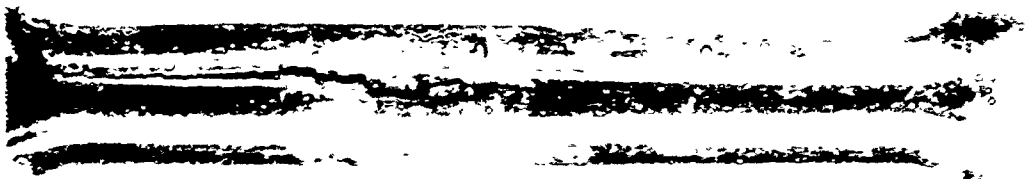
Specimen #4 Fired Rds 1,000 Hydraulic Cycles 8,588



Specimen #5 Fired Rds 2,000 Hydraulic Cycles 7,416



Specimen #6 Fired Rds 3,000 Hydraulic Cycles 7,000



Specimen #7 Fired Rds 4,000 Hydraulic Cycles 6,500

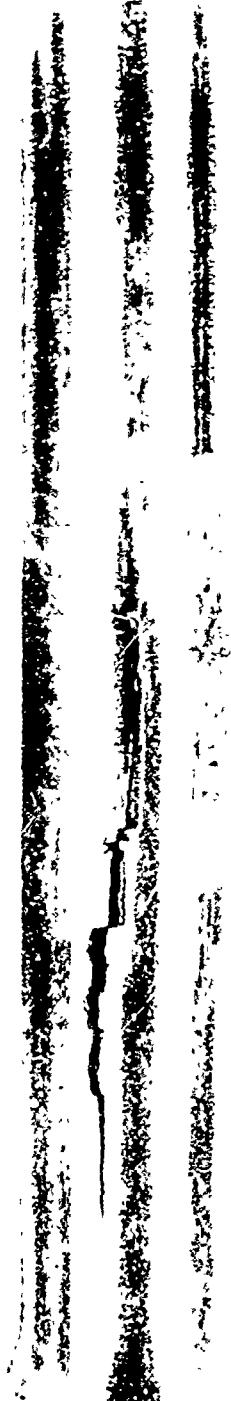
COMPARISON OF FAILURE BETWEEN A FIRED TO DESTRUCTION SPECIMEN AND A SPECIMEN
HAVING A COMBINATION OF FIRING AND HYDRAULIC CYCLING TO DESTRUCTION

F



Specimen #31 Fired Rds 9,869 Hydraulic Cycles 0

Reproduced from
best available copy.



Specimen #24 Fired Rds 4,000 Hydraulic Cycles 2,739

B R E E C H E N D O F S P E C I M E N :

M U Z Z L E E N D O F S P E C I M E N :

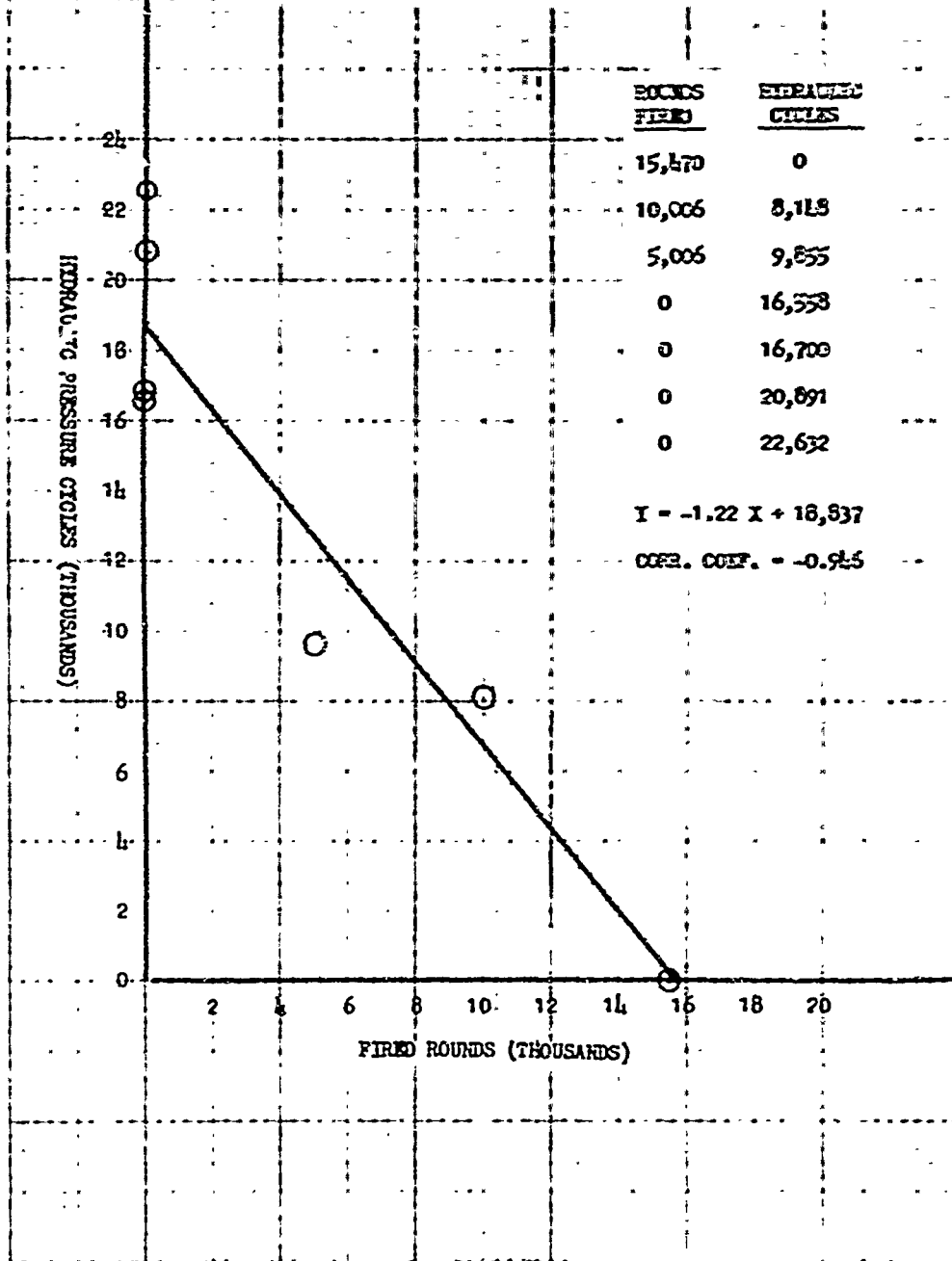
APPENDIX F

APPLICATION OF MULTI-LEVEL TESTING TO STANDARD CANNON

<u>NO.</u>		<u>PAGE</u>
1.	Cannon 155MM Howitzer M1A1 Graph - Hydraulic Cycles vs Rounds Fired	38
2.	Cannon 155MM Howitzer M1A1 Graph - Reliability Predictions	39
3.	Cannon 175MM Guns M113 & M113A1 Graph - Hydraulic Cycles vs Rounds Fired	40
4.	Cannon 175MM Guns M113 & M113A1 Graph - Reliability Predictions	41

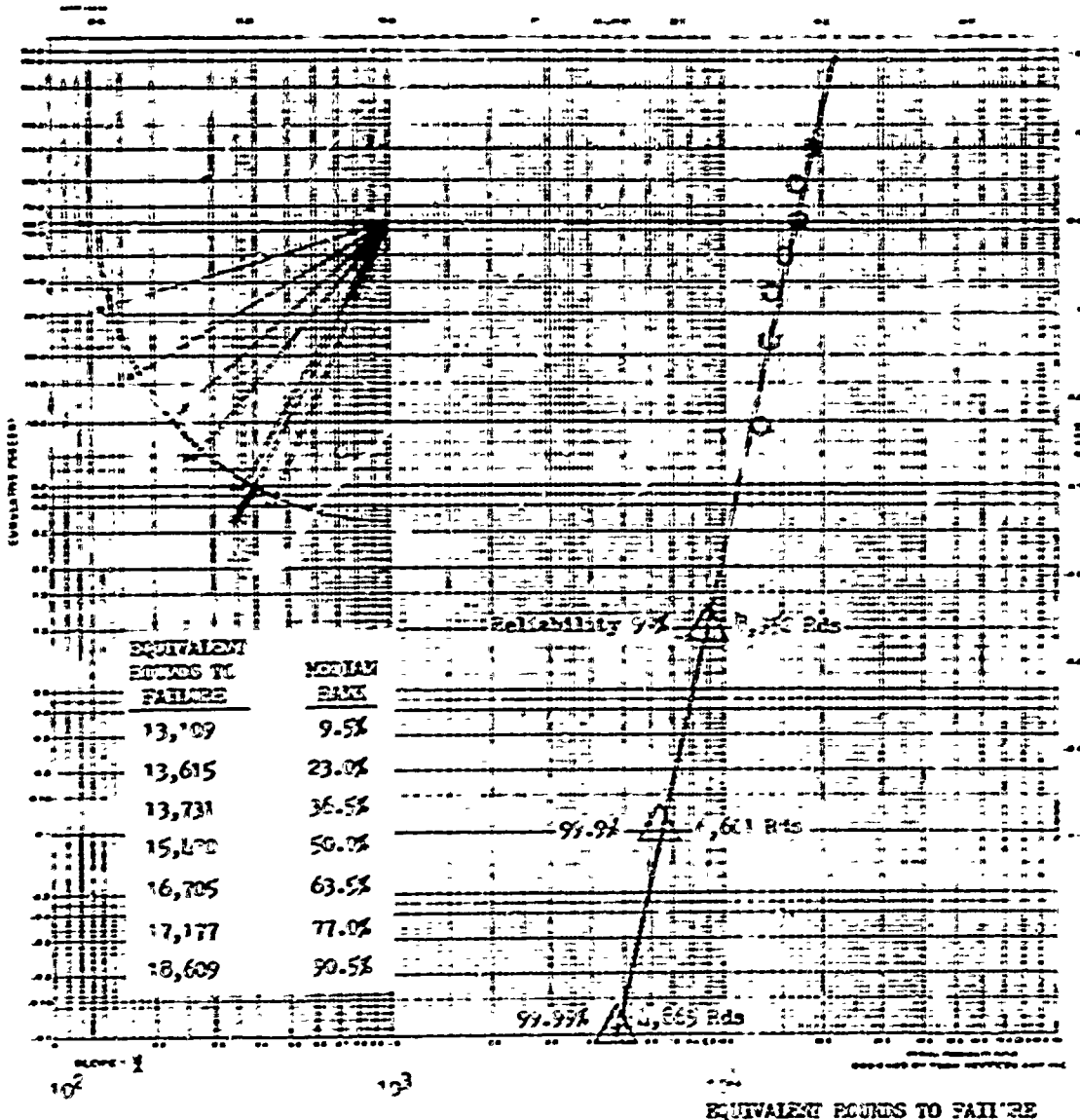
F

CASHE, 155MM HOWITZER M1A1
 ORIGIN OF RIFLING SPECIMENS
 HYDRAULIC PRESSURE CYCLES VERSUS ROUNDS FIRED AT 33,000 PSI



F

MINI, 155MM SHORTER MAP
 DESIGN OF REFLING SPECIMENS
 7 TESTED AT 32,000 PSI

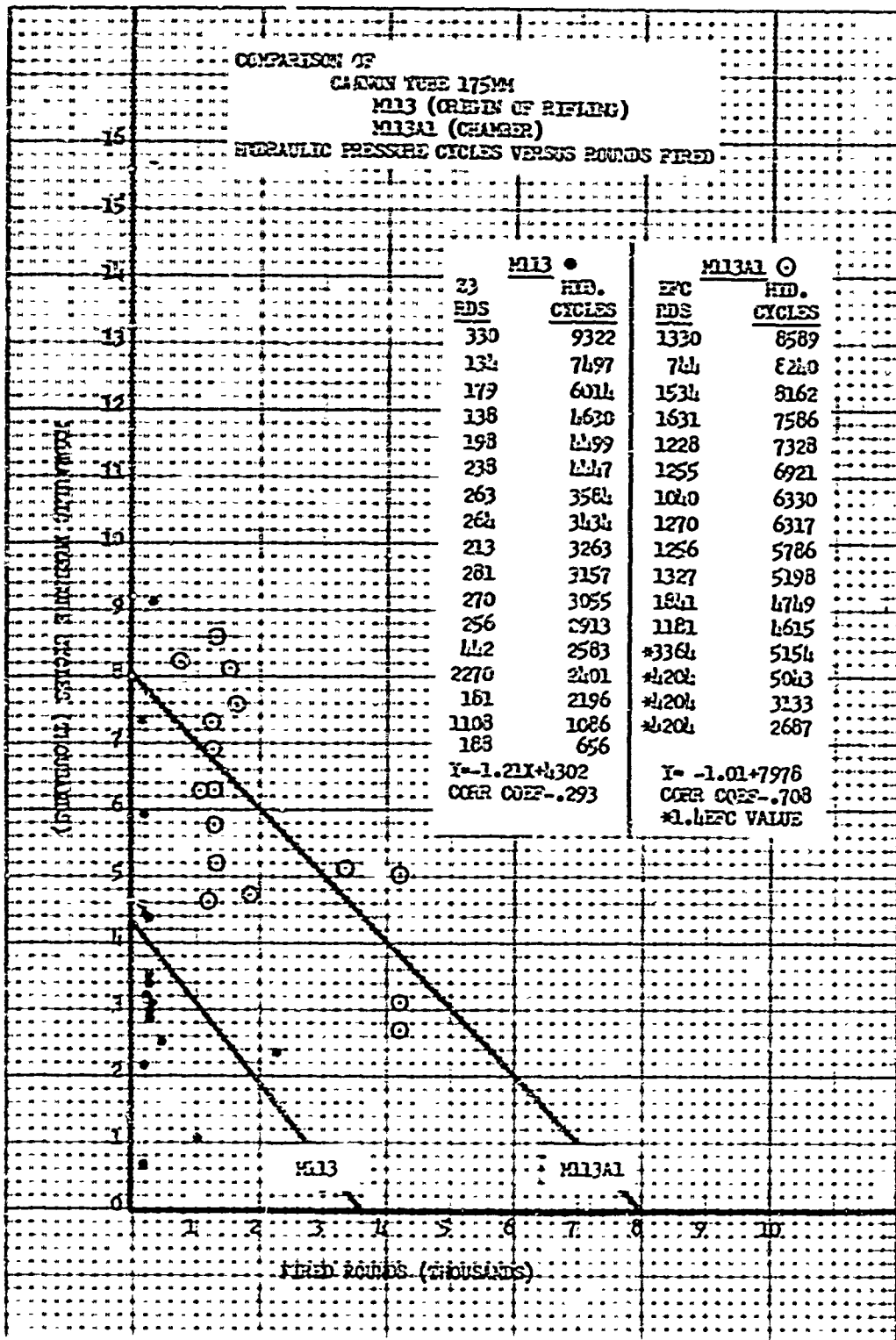


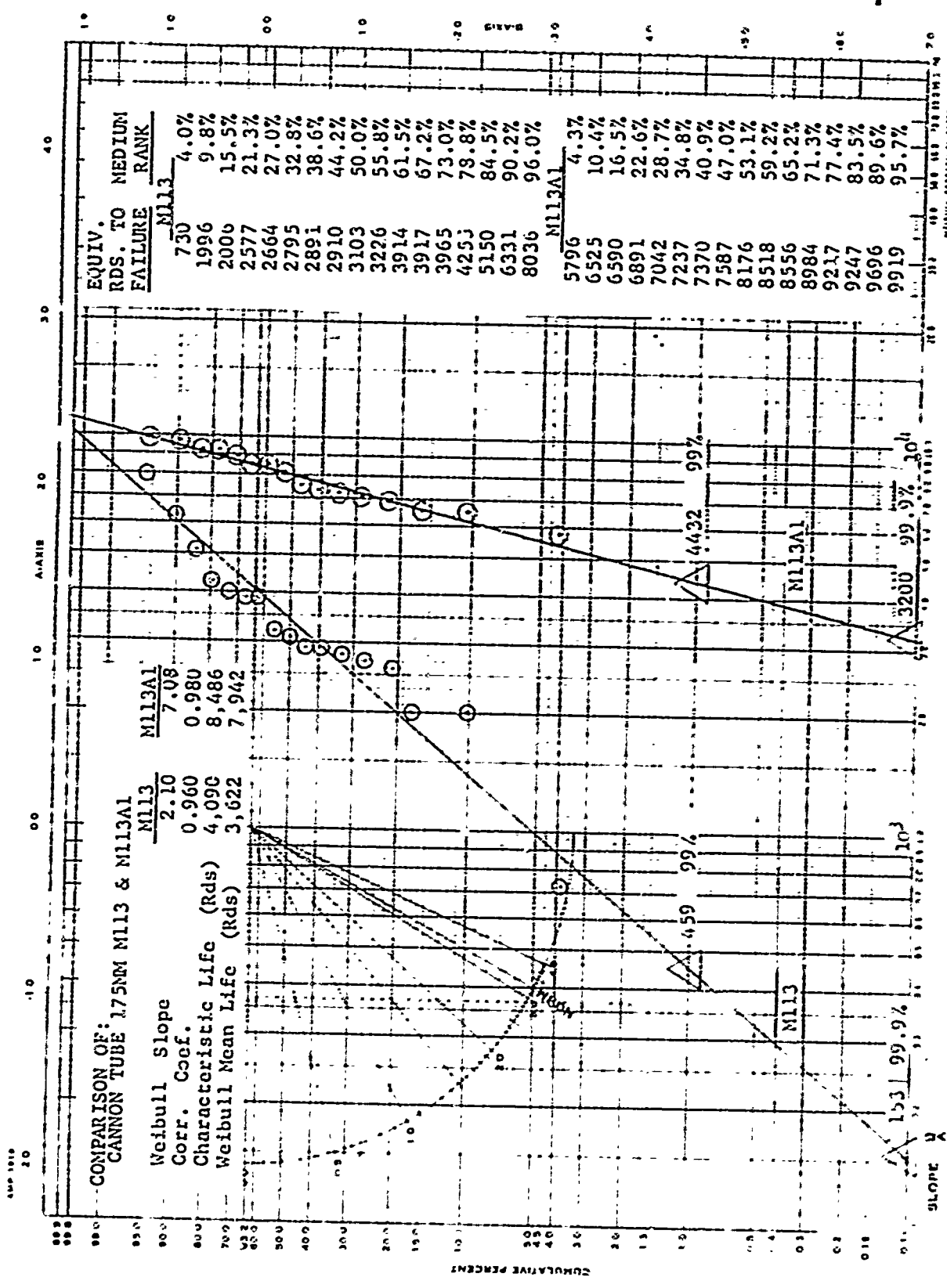
10²

10³

EQUIVALENT ROUNDS TO FAILURE

F





DESIGNED BY TECH SERVICES AMP INC

G

APPENDIX G

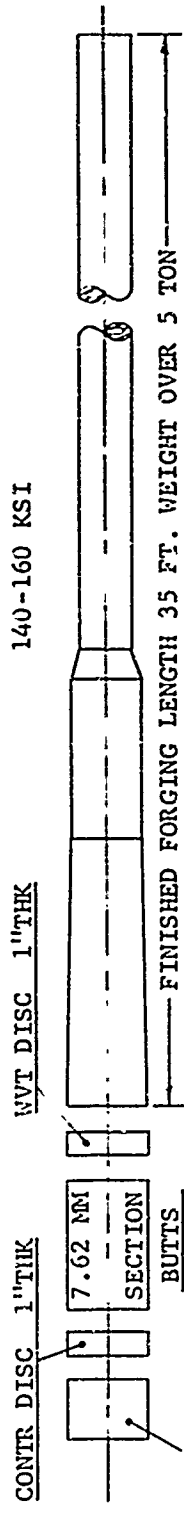
(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

<u>NO.</u>		<u>PAGE</u>
1.	Specimen Selection 175MM M113A1 Forging Material	43
2.	Phase III Test Plan	44

7.62mm LIFE TEST
 USING 175mm M13A1 CANNON TUBE FORGING STEEL FROM THREE SUPPLIERS X, Y, Z,
 WITH THREE FORGINGS FROM EACH SUPPLIER AND THREE TO FIVE 7.62mm SPECIMENS
 FROM EACH FORGING.



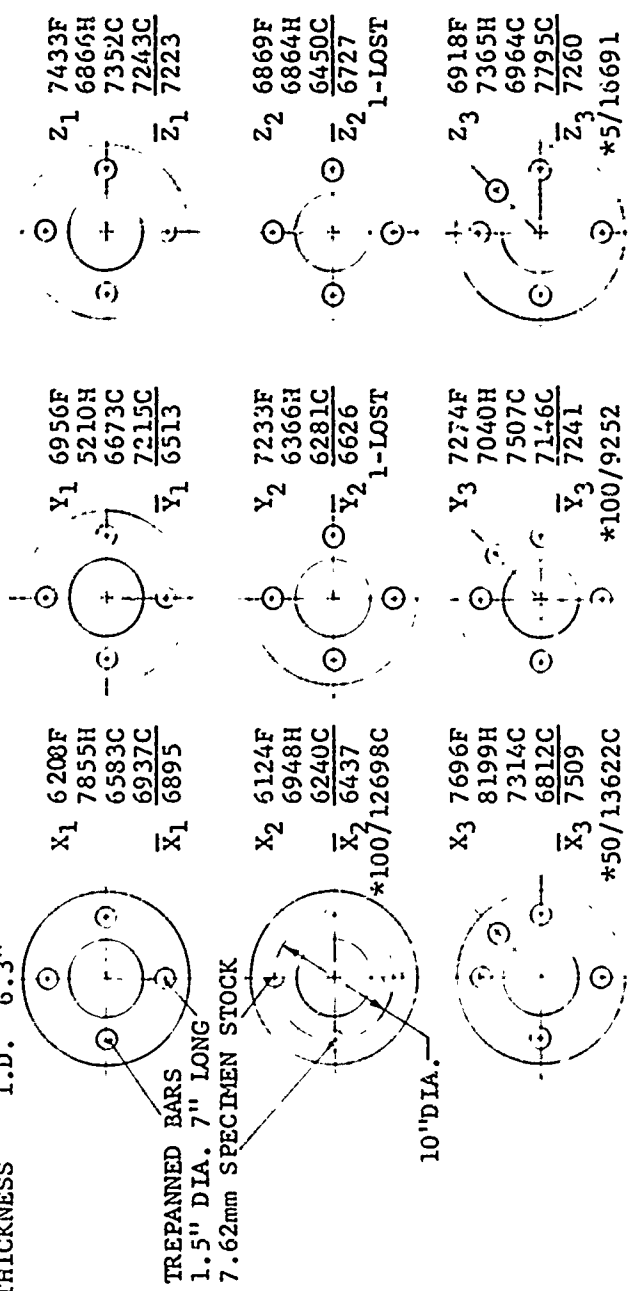
DISCARD
 ONE WALL
 THICKNESS

7.62 MM
 SECTION

BUTTS
 Length 15"
 O.D. 18"
 I.D. 6.3"

CONTR DISC 1"THK WVT DISC 1"THK 140-160 KSI

FINISHED FORGING LENGTH 35 FT. WEIGHT OVER 5 TON



X₁ 6200F
 7855H
 6583C
 6937C
 6895
 \bar{X}_1

Y₁ 6956F
 5210H
 6673C
 7215C
 6513
 \bar{Y}_1

Z₁ 7433F
 6866H
 7352C
 7243C
 7223
 \bar{Z}_1

X₂ 6124F
 6948H
 6240C
 6437
 *100/12698C
 \bar{X}_2

Y₂ 7233F
 6366H
 6281C
 6626
 1-LOST
 \bar{Y}_2

Z₂ 6869F
 6864H
 6450C
 6727
 1-LOST
 \bar{Z}_2

X₃ 7696F
 8199H
 7314C
 6812C
 7509
 *50/13622C
 \bar{X}_3

Y₃ 7274F
 7040H
 7507C
 7146C
 7241
 *100/9252
 \bar{Y}_3

Z₃ 6918F
 7365H
 6964C
 7795C
 7260
 *5/16691
 \bar{Z}_3

\bar{X} 6947

\bar{Y} 6793

\bar{Z} 7070

*UNADJUSTED RAW
 DATA NOT INCLUD-
 ED IN AVG.

G

PHASE III

TEST PLAN

FOR 7.62MM SPECIMENS, 175MM TUBE MATERIAL

<u>CATEGORY</u>	<u>QTY</u>	<u>TYPE TEST</u>
PURE	9	HYDRAULIC PRESSURE CYCLED
SPECIAL	1	5 RDS/CYCLED
4 COMBINATION	1	50 RDS/CYCLED
	2	100 RDS/CYCLED
	3	500 RDS/CYCLED
	3	2000 RDS/CYCLED
15 COMBINATION	3	3000 RDS/CYCLED
	3	4000 RDS/CYCLED
	3	5000 RDS/CYCLED
REAL	9	FIRE
TOTAL	<u>37</u>	

H

APPENDIX H

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

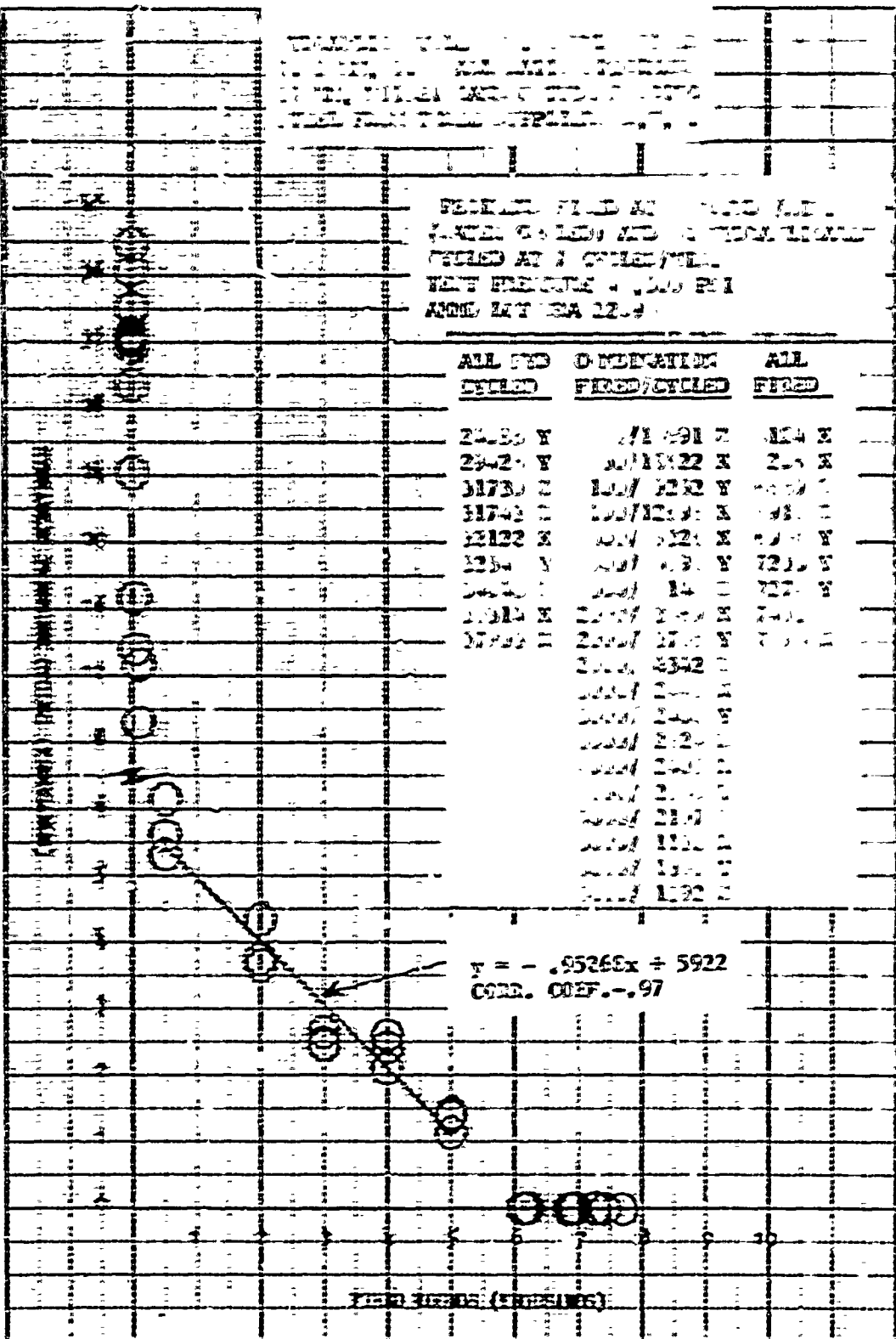
<u>NO.</u>		<u>PAGE</u>
1.	Original Data - 175MM M113E1 Cannon Tube Material	46
2.	Graph - Hydraulic Cycles vs Rounds Fired 175MM M113E1 Cannon Tube Material	47

ORIGINAL DATA
 7.62MM, 1.0 VALL RATIO SPECIMENS
 175MM, M13E1 O/MON TUBE FORGING
 STEEL FROM TIRE; SUPPLIERS X, Y, Z

FORGING SUPPLIER	X			Y			Z		
	SPECIMEN NUMBER	FORGING IDENTIFY	QUANTITY	SPECIMEN NUMBER	FORGING IDENTIFY	QUANTITY	SPECIMEN NUMBER	FORGING IDENTIFY	QUANTITY
ALL FIRED	1	LX 1	6300	13	LY 1	6954	25	LZ 1	6190
	5	LX 2	6124	17	LY 2	7233	30	LZ 2	6474
	6	LX 3	7696	21	LY 3	7274	33	LZ 3	6474
ALL CYCLED	2	LX 1	36314	14	LY 1	24089	26	LZ 1	4474
	9	LX 2	32122	19	LY 2	33763	16	LZ 2	4474
	10	LX 3	37903	22	LY 3	36346	18	LZ 3	4474
COMBINATION FIRED AND HYDRAULIC CYCLED	3	LX 1	5000/1600	15	LY 1	5000/1774	28	LZ 1	5000/1362
	7	LX 2	5000/1138	16	LY 2	5000/1108	28	LZ 2	5000/1362
	7	LX 3	3000/2445	20	LY 3	3000/2445	32	LZ 3	3000/1362
	8	LX 4	4100/1362	10	LY 4	4100/1362	32	LZ 4	4100/1362
	11	LX 5	5000/2445	23	LY 5	5000/2445	42	LZ 5	5000/1362
	12	LX 6	5000/3228	24	LY 6	5000/3228	42	LZ 6	5000/1362
	34	LX 7	# 50/1362	30	LY 7	# 50/1362	42	LZ 7	# 50/1362
	35	LX 8	# 50/1362	30	LY 8	# 50/1362	42	LZ 8	# 50/1362
	36	LX 9	# 50/1362	30	LY 9	# 50/1362	42	LZ 9	# 50/1362
	37	LX 10	# 50/1362	30	LY 10	# 50/1362	42	LZ 10	# 50/1362

* Special Tests to show effect of firing damage on life reduction (See Graph)

** Only combination fired and hydraulic cycled data was used to generate the straight line relationship $y = -.05200x + 5922$ (excluding the 4 special test data points)



APPENDIX I

(PLATE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL FURNISHED

BY THREE CONTRACTORS X, Y, Z.

No.

PAGE

1. Transformation of Data to an All Fired Base
2. Adjusted Life Data

49

50

TRANSFORMATION OF DATA TO AN ALL FIRED BASE

A	B	C	D	E	F
ALL FIRED CYCLED	ALL HYD CYCLED	ALL HYD CYCLED ADJUSTED	COMBINATION FIRED/CYCLED	COMBINATION EQUIV. FIRED	COMBINATION EQUIV. FIRED ADJUSTED
6124	24088	5210	3000/2445	5566	6240
6208	29428	6366	3000/2480	5603	6281
6869	31730	6864	3000/2624	5734	6450
6918	31743	6866	2000/3689	5872	6583
6956	32122	6948	2000/3765	5952	6673
7233	32546	7040	500/5326	6091	6828
7274	34048	7365	5000/1132	6188	6937
7433	36314	7855	4000/2107	6212	6964
7696	37903	8199	500/5596	6374	7146
6968	32214	6968	5000/1368	6436	7213
			5000/1392	6461	7243
			4000/2405	6524	7314
			2000/4342	6558	7352
			4000/2568	6696	7507
			500/6148	6953	7795
				\bar{E} 6216	\bar{F} 6969

$$C = (\bar{A}/\bar{B}) B \quad (y) \text{ CYCLED}/(\times) \text{ FIRED RELATIONSHIP}$$

$$E = D \text{ fired} + (D \text{ cycled} / .95268) \quad y = -.95268x + 5922$$

$$F = (\bar{A}/\bar{E}) E$$

7.62MM, 1.8 WALL RATIO SPECIMEN FATIGUE FAILURE DATA
 175MM, M13E1 CANNON TUBE FORGING STEEL FROM THREE SUPPLIERS X, Y, Z

ADJUSTED LIFE DATA

FORGING SUPPLIER	X			Y			Z		
	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA
ALL FIRED	1	X ₁	6208	13	Y ₁	6956	25	Z ₁	7433
	5	X ₂	6124	17	Y ₂	7233	30	Z ₂	6869
	9	X ₃	7696	21	Y ₃	7274	33	Z ₃	6918
ADJUSTED ALL CYCLED	2	X ₁	7855	14	Y ₁	5210	26	Z ₁	6866
	6	X ₂	6948	19	Y ₂	6366	31	Z ₂	6864
	10	X ₃	8199	22	Y ₃	7040	34	Z ₃	7365
ADJUSTED COMBINATION FIRED AND CYCLED	3	X ₁	6583	15	Y ₁	6673	27	Z ₁	7352
	4	X ₁	6937	16	Y ₁	7215	28	Z ₁	7243
	7	X ₂	6240	20	Y ₂	6281	32	Z ₂	6450
	11	X ₂	7314	23	Y ₃	7507	35	Z ₃	6964
	12	X ₃	6828	24	Y ₃	7146	36	Z ₃	7795

ANALYSIS OF VARIANCE

		F-RATIO
ALL ADJUSTED	X	2.11
ALL ADJUSTED	Y	1.81
ALL ADJUSTED	Z	.009
ALL FIRED	XYZ	.65
ALL ADJ CYCLED	XYZ	3.56
ALL ADJ COMBO	XYZ	.84
TABLE VALUE		5.14

In order to simplify, adjusted combination fired and cycled X₁'s, X₂'s, Y₁'s, Y₂'s etc. were averaged to provide three replicates per cell.

APPENDIX J

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

<u>NO.</u>		<u>PAGE</u>
1.	Life Characteristic Comparison by Material Supplier (Using Adjusted Data)	52
2.	Life Characteristics Comparison by Test Method (Using Adjusted Lives)	53
3.	Graph - Rel'ability Prediction (Using All Adjusted Data)	54

COMPARISON BY FORGING MATERIAL SUPPLIERS X, Y, Z.

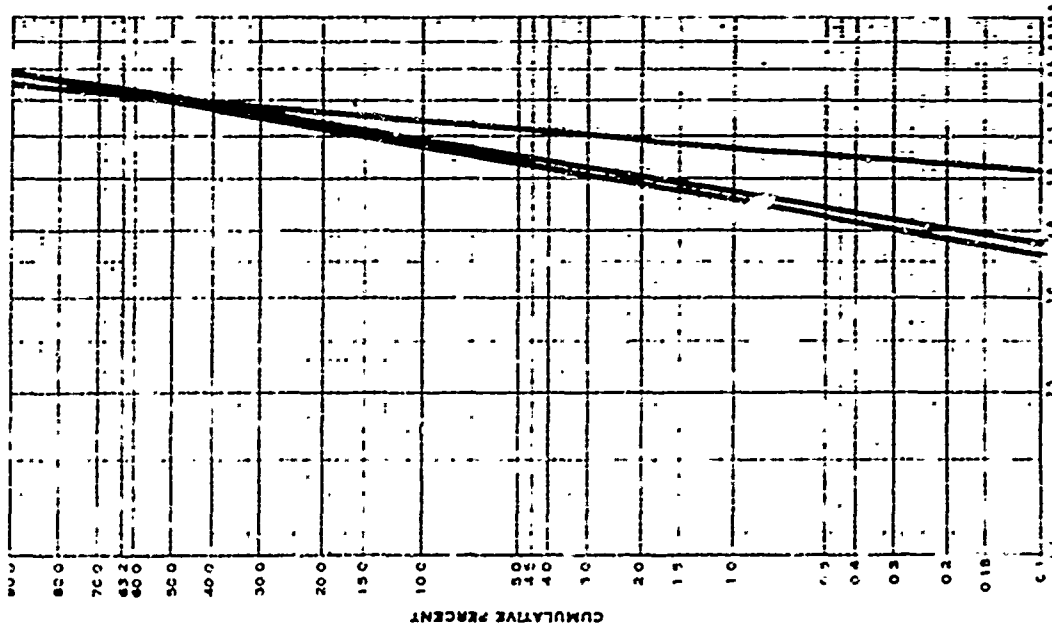
7.62 MM, 1.8 WALL RATIO LIFE TEST DATA

175 MM, M13E1 CANNON TUBE FORGING MATERIAL

FORGING MANUFACTURER	X	Y	Z
CORR. COEF	.948	.947	.946
WEIBULL SLOPE	10.7	10.2	20.2
% FAILED AT WEIBULL MEAN LIFE	45	45	44
WEIBULL MEAN LIFE	6976	6793	7088
CHARACTERISTIC LIFE	7313	7134	7280

RELIABILITY	99 %	99.9 %	93.9 %	85.1 %	76.3 %	67.5 %	58.8 %	50.0 %	41.2 %	32.5 %	23.7 %	14.9 %	6.1 %																										
MEDIAN RANK	4758	4554	5797	3835	3635	5171	8199H	7507C	7795C	7855H	7274F	7433F	7696F	7233F	7365H	7314C	7215C	7352C	6948H	7146C	7243C	6937C	7040H	6964C	6828C	6956F	6918F	6583C	6673C	6869F	6240C	6366H	6866H	6208F	6281C	6864H	6124F	5210H	6450C

F FIRED
 C COMBINATION FIRED/HYDRAULIC CYCLED
 H HYDRAULIC CYCLED
 NOTE: DATA TRANSFORMED TO AN ALL FIRED BASE

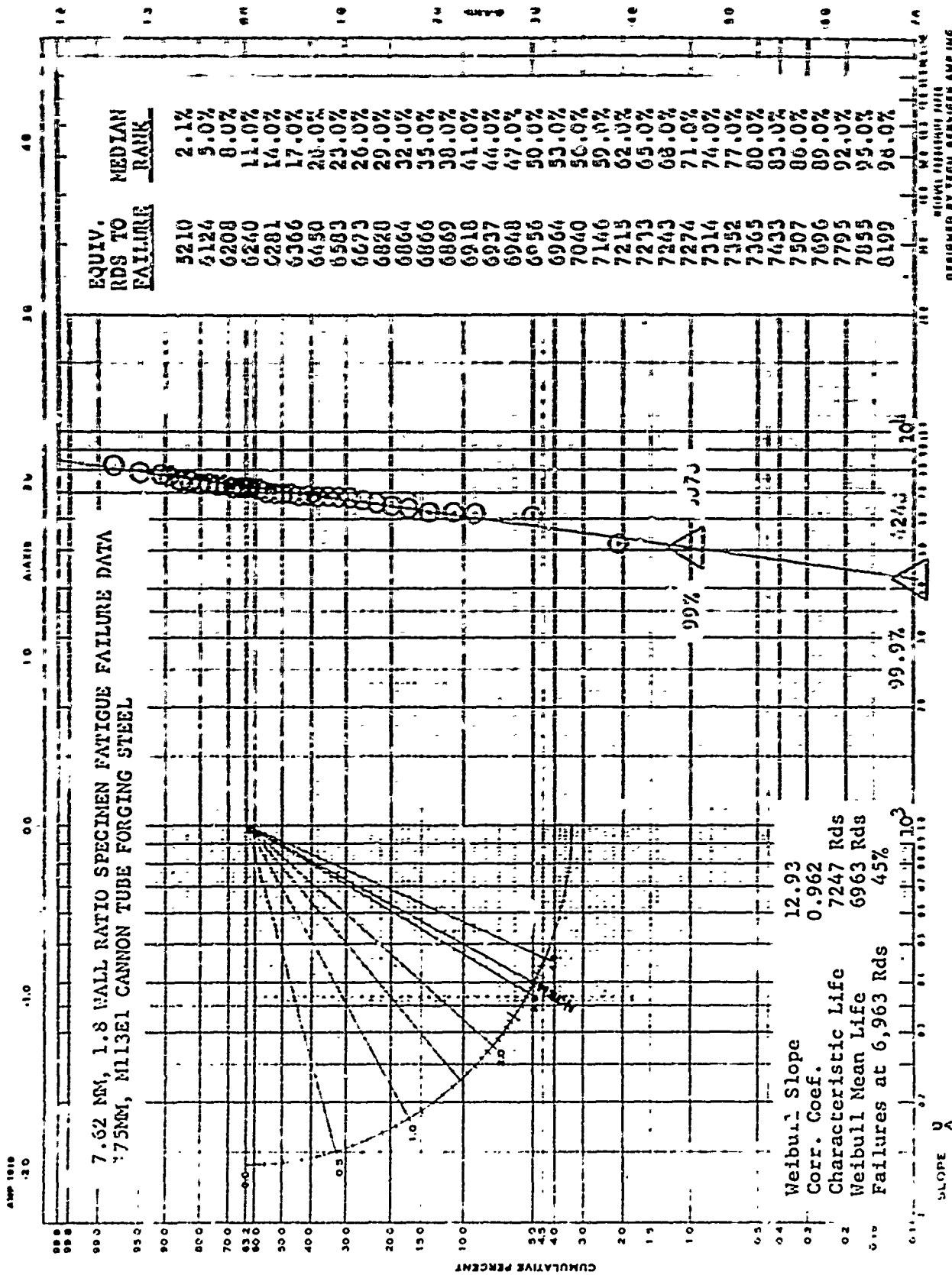


ADJ. LIFE (RMS X 10³)

7.62MM, 1.8 WALL RATIO LIFE TEST COMPARISONS
 175MM, M13E1 CANNON TUBE FORGING MATERIAL

FORGING SUPPLIER	COMBINATION FIRED/CYCLED (ADJ)				ALL FIRED	ALL DATA
	X ₅ *	Y ₅	Z ₅	XY ₂ ₁₅	XYZ ₉	XYZ ₃₃
HYDRAULIC TO FIRED SLOPE	-.888	-.891	-1.079	-.953		
CORR. COEF	-.979	-.969	-.982	-.970		
WEIBULL SLOPE	17.12	14.27	14.44	16.96	13.99	12.93
CORR. COEF	.985	.980	.904	.977	.974	.962
% FAILED AT WEIBULL MEAN LIFE	44	45	45	44	45	45
WEIBULL MEAN LIFE	6754	6934	7130	6956	6948	6963
RELIABILITY 99.9%	4655	4434	4582	4777	4402	4240

*X₅ - CONTRACTOR X, FIVE SPECIMENS



DESIGNED BY TECH SERVICES AMP INC

APPENDIX K

(PHASE III)

COMPARISON OF 175CM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

<u>NO.</u>		<u>PAGE</u>
1.	Material Properties	56
2.	Life vs Mechanical Properties	57
3.	Adjusted Life vs Material Supplier	58

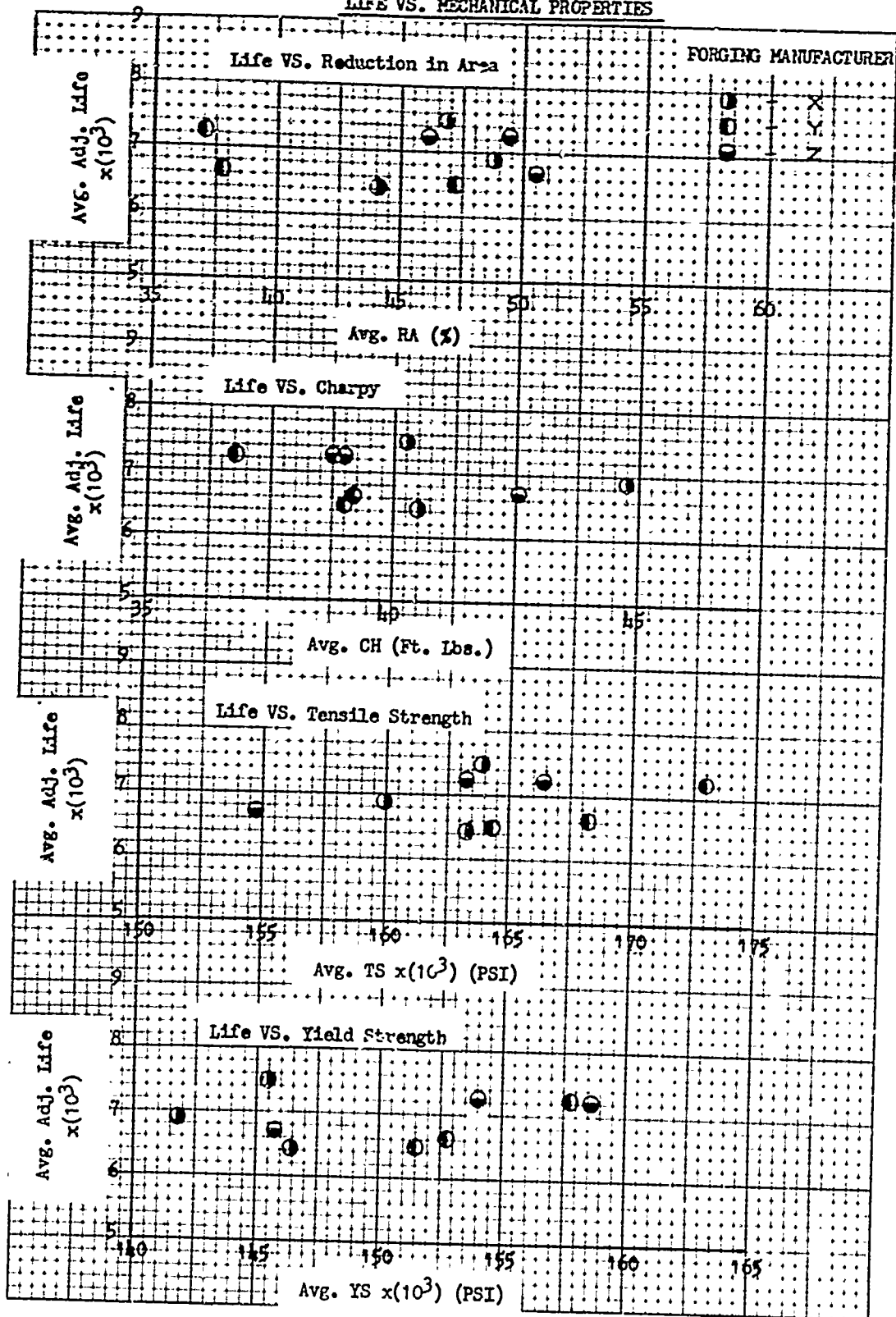
K

NATURAL PROPERTIES

TUBE FORGING CODE	MECHANICAL PROPERTIES			*AVERAGE			CHEMICAL COMPOSITION										SPECIMEN NO.	TEST FINDER	DATA	U.S. LIFE	ADJ. AVE. LIFE
	YSX10	RAX	GH-10	TSX10	FLX	ELX	C	Mn	P	S	Si	II	Cr	Mo	V	U.S. LIFE					
X ₁	112.0	46.9	16.0	160.0	15.5		.36	.12	.007	.009	.06	3.30	0.12	.66	.09	1	34	0	6208	6208	
	111.0	50.8	13.0	159.0	17.0											2	35	0	7045	7045	
	112.0	47.7	15.0	160.5	14.5											3	36	3000	3600	6203	
	112.0	49.5	15.0	160.0	16.0											4	35	5000	1712	6237	
X ₂	117.0	46.6	11.0	164.0	16.0		.37	.10	.008	.014	.01	3.25	0.82	.66	.68	5	32	0	6121	6121	
	115.0	41.6	10.0	162.5	15.0											6	35	0	6908	6908	
	117.5	43.1	11.0	164.0	15.0											7	34	3000	2145	6210	
	115.5	44.9	10.0	162.5	15.0											8	36	100	14760		
X ₃	116.30*	44.05*	10.50*	163.25*	15.25*		.37	.11	.008	.015	.03	3.08	0.84	.64	.12	9	36	7076	0	7026	
	116.5	46.6	10.0	164.5	15.5											10	36	0	7190	8199	
	114.5	48.0	11.0	163.5	15.0											11	36	4000	2105	7114	
	116.0	46.0	10.0	164.5	16.0											12	37	500	6736	6830	
Y ₁	114.5	46.9	10.0	163.0	16.5		.33	.58	.015	.004	.37	3.01	0.74	.54	.60	13	34	50	13103	0	
	115.30*	46.87*	10.25*	163.88*	15.75*											14	36	0	0	0	
	151.0	48.7	38.5	161.5	14.9											15	35	0	24700	5210	
	151.0	45.5	39.5	165.0	14.1											16	35	0	3765	6873	
Y ₂	153.0	47.5	10.0	167.0	13.5		.33	.62	.013	.004	.36	3.01	0.78	.54	.60	17	36	3000	2180	6366	
	151.50*	47.20*	39.00*	164.30*	13.97*											18	36	0	2180	6366	
	154.0	33.8	38.0	168.0	12.1											19	36	0	0	0	
	153.0	38.2	42.5	174.0	11.5											20	36	3000	2180	6366	
Y ₃	154.0	47.5	11.1	169.0	10.1		.33	.53	.013	.003	.34	3.05	0.75	.55	.60	21	37	7274	0	7274	
	152.75*	37.82*	39.13*	168.25*	11.27*											22	37	0	32516	7043	
	150.0	40.9	36.0	176.0	13.1											23	37	4000	21560	7507	
	157.0	37.8	38.0	173.0	12.3											24	36	500	51596	7106	
Z ₁	157.0	34.8	35.5	173.0	11.5		.31	.42	.008	.007	.08	3.12	1.14	.54	.12	25	35	100	0	0	
	157.75*	37.17*	36.88*	173.00*	12.32*											26	37	0	0	0	
	157.0	47.3	35.0	165.0	16.4											27	38	3000	41743	6866	
	159.0	49.7	41.0	168.0	16.4											28	38	5000	41743	7352	
Z ₂	158.63*	46.30*	39.00*	166.70*	16.05*		.27	.34	.010	.009	.02	3.10	1.11	.54	.11	29	37	5000	17392	7243	
	150.0	49.3	41.5	152.0	15.0											30	37	0	0	0	
	147.0	52.5	44.0	155.0	17.1											31	34	0	31730	6064	
	140.0	50.1	42.5	150.0	15.7											32	35	3000	21734	6158	
Z ₃	156.75*	50.60*	42.63*	154.75*	16.05*		.36	.34	.008	.009	.02	3.06	1.12	.54	.12	33	33	0	0	0	
	156.0	47.7	37.5	165.0	17.1											34	33	0	0	0	
	157.0	47.7	38.0	166.0	15.7											35	36	1000	34440	7345	
	151.0	52.9	39.5	160.0	16.4											36	36	500	2107	6964	
	154.00*	49.40*	38.75*	163.25*	16.57*											37	36	5	161691	7795	

K

LIFE VS. MECHANICAL PROPERTIES



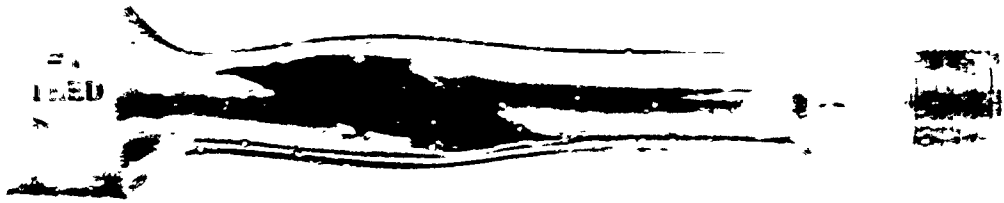
APPENDIX L

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED
BY THREE CONTRACTORS X, Y, Z.

<u>NO.</u>		<u>PAGE</u>
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2.	Photos of Specimens Fired to Destruction Material Supplier Y	61
3.	Photos of Specimens Fired to Destruction Material Supplier Z	62

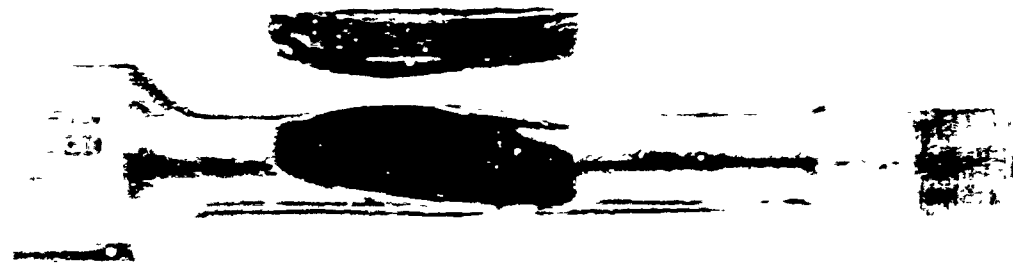
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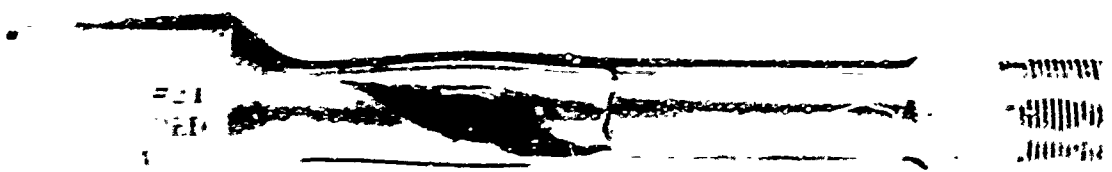


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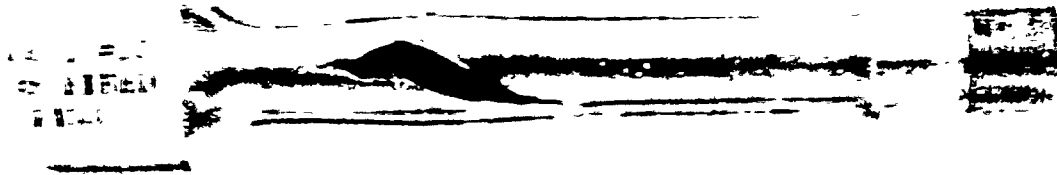
17
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APPENDIX M

APPLICATION OF 7.62MM BARREL SPECIMENS TO A FIELD FAILURE PROBLEM

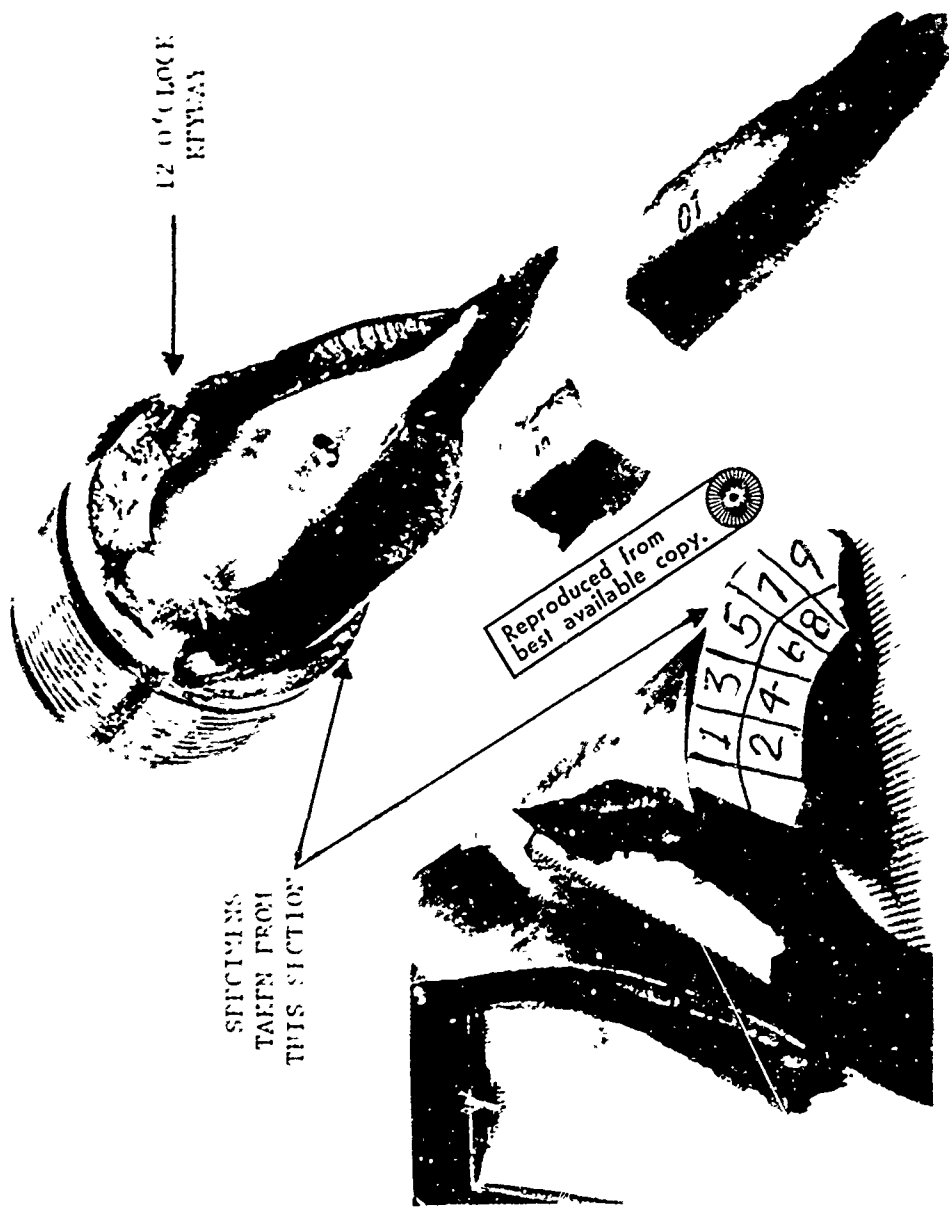
<u>NO.</u>	<u>PAGE</u>
1. Field Failure Photos	65
2. Tube Section and Specimen Location	66
3. Failed Specimens	67
4. Mechanical Properties of Forging	68

M

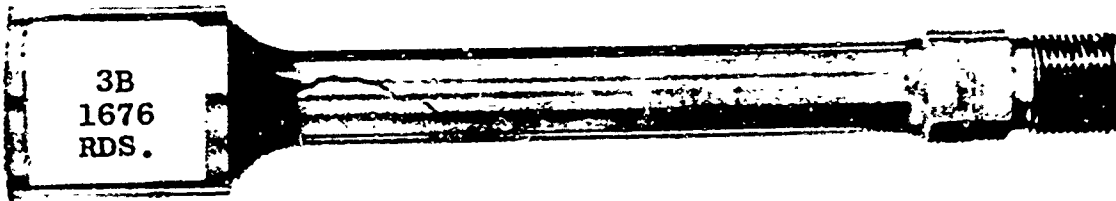


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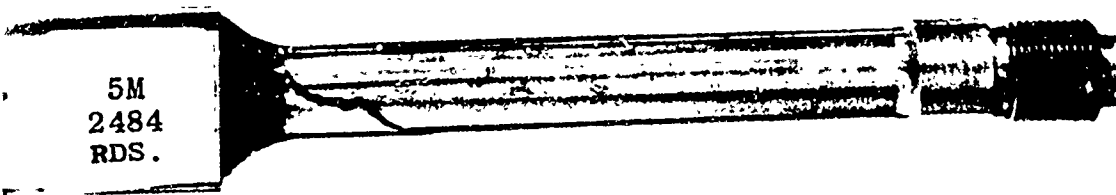
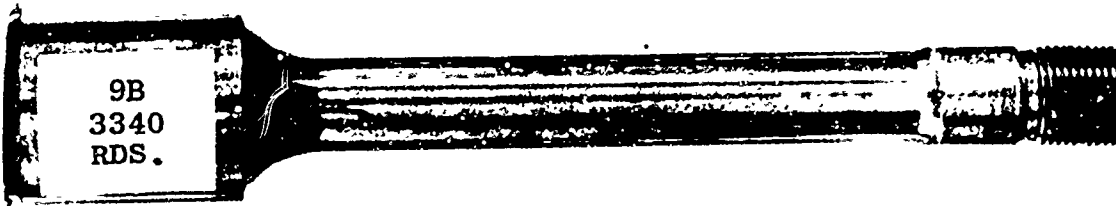




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MECHANICAL PROPERTIES OF FORGING

<u>TEST BAR</u>	<u>YIELD STRENGTH (PSI)</u>	<u>TENSILE STRENGTH (PSI)</u>	<u>ELONGATION (%)</u>	<u>REDUCTION IN AREA (%)</u>	<u>CHARPY (FT.LBS)</u>
B	188,000	202,500	9.6	21.3	12.5
B	189,000	203,500	8.4	11.5	---
M	179,000	198,000	9.8	21.3	13.5
N	185,000	200,500	8.0	14.8	---

M

N

APPENDIX M

7.62MM AMMUNITION CALIBRATION

NO.

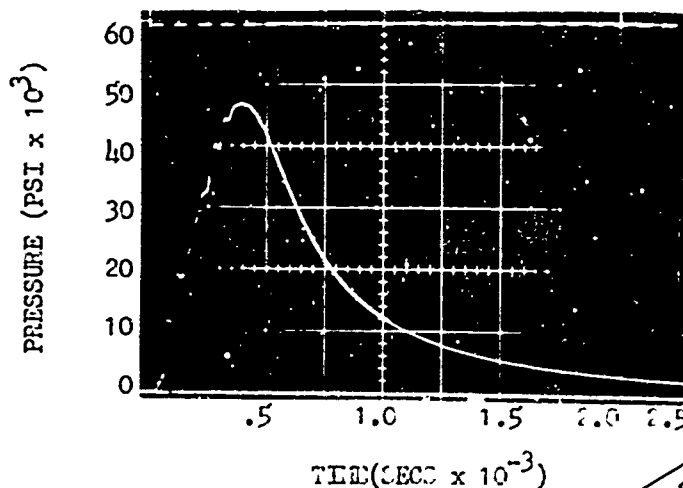
PAGE

1. Ammunition Calibration

69

N

AMMUNITION CALIBRATION



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TIME (SECC x 10⁻³)

TYPICAL P-T CURVE

7.62MM (M14 Rifle Mat'l) Test

Ammo Lot WRA-22731

Calibration	Date	Mean Pressure	Std Dev.	Mean Velocity	Std Dev.
Original	8/67	44,300	1000	Not Avail.	Not Avail.
1st Check	11/70	47,800	1300	2701	16
2nd Check	2/71	47,900	1100	2740	28

7.62MM (M13E1 Cannon Mat'l) Test

Ammo Lot WRA 22896

Calibration	Date	Mean Pressure	Std Dev.	Mean Velocity	Std Dev.
Original	10/68	45,300	1000	2751	19.7
1st Check	11/70	47,500	1600	2687	28
2nd Check	2/71	48,300	1200	2731	19

NOTE: Check tests were performed by Frankford Arsenal.
Hydraulic cycling pressure was established on original ammunition contractor calibrations.

0

APPENDIX O
MISCELLANEOUS REFERENCES

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MISCELLANEOUS REFERENCES

1. "Establishment of Cannon Life Criteria" -R. E. Weigle 1967
Watervliet Arsenal (Plus additional R&E laboratory test data).
2. "Fatigue Characteristics of Open-End Thick-Walled Cylinder
Under Cyclic Internal Pressure"; T. E. Davidson, R. Eisenstadt,
A. N. Reiner - 1962 Watervliet Arsenal WVT-R1-6216.
3. "175MM M113A1 Gun Tube Special Test for Service Life";
B. B. Brown, T. E. Davidson, D. G. Forkas, M. E. Kraut,
T. Moraczewski, A. N. Reiner, P.K. Rummel, R. Soanes Jr. -
1971 Watervliet Arsenal.