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AD 25030

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 1200

LIQUID PROPELLANTS FOR GUNS

1st Partial Report

LIQUID PROPELLANT GUNS

1st Partial
Report

Task NPG-Re2d-12-1-53
Assignment NPG-Re5a-39-1-53

Copy No. 33

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Liquid Propellant Program
-----PART ASYNOPSIS

1. The liquid propellant research program at the Naval Proving Ground is presently concerned with the development of prepackaged rounds for standard Navy guns and the study of the erosion characteristics of liquid propellants. The objective of the tests reported here was to develop a prepackaged round for the 40mm gun with ballistic properties comparable to the standard solid propellant round. The propellant used in the test was a mixture of hydrazine, hydrazine nitrate, and water.
2. The data from 143 rounds includes a tabulation of charge weight and composition, mass ratio, type of primer stock and extension tube, case assembly and free volume of case, muzzle velocity, maximum case pressures and pressures at ejection, ignition delay, and ejection time. The pressure-time oscillograms at two positions in the chamber are included for more than 90 rounds. Relations between ignition delay and free volume, peak pressures and free volume, velocity and free volume, and velocity and mass ratio are presented graphically.
3. The following conclusions are made from the results obtained on these tests:
 - a. The service velocity of the 40mm gun can be exceeded by as much as 150 f/s by the use of the monopropellant hydrazine without exceeding the chamber pressure of the solid propellant service charge.
 - b. The performance of such a liquid propellant round is of sufficient uniformity to be used in studies of gun erosion.
 - c. Only two modifications to standard 40mm ammunition components are required for the round developed in these tests. The case volume must be reduced and a special type of primer extension tube used.
 - d. The wax used in these tests to reduce the case volume is not a completely satisfactory filler. A material which adheres more firmly to the case wall will be required for automatic loading of the round. Erosion studies under rapid fire conditions are dependent on a satisfactory solution to this problem.

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e. The prospects of obtaining a uniformity of performance for the monopropellant hydrazine comparable to that obtained with solid propellants are encouraging.

f. Based on the charge determined for the 40mm gun on these tests and the available data from other sources, the chamber volumes of most Navy guns appear to be 25 to 35% larger than required for liquid propellant ammunition.

g. Ignition of the propellant is affected by primer configuration and charge, propellant composition and free volume in the case.

h. Increasing the free volume in the case results in delayed ignition, increased burning rate and higher peak pressure.

i. An increase in the hydrazine nitrate content of the propellant is accompanied by an increase in burning rate, chamber pressure and muzzle velocity, and the production of secondary pressure peaks.

j. An increase in water content of the propellant is accompanied by an increase in ignition time, decrease in burning rate and velocity, and a smoothing of the pressure curve.

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PART B

INTRODUCTION

1. AUTHORITY:

The tests reported here were authorized by references (a) and (b) and conducted under Task Assignments NPG-Re2d-12-1-53 and NPG-Re5a-39-1-53.

2. REFERENCES:

- a. BUORD ltr NP9-Re5a-FBW:fl of 15 July 1952
- b. BUORD Conf ltr NP9-Re2d-WES:aph Ser 49271 of 17 Dec 1952
- c. U. S. Naval Ammunition and Net Depot Progress Report Nos. 1 through 6 on Task Assignment NAND-13-Re2d-514-1
- d. Report No. 17-1, Jet Propulsion Laboratory, California Institute of Technology
- e. NAVORD No. 2255
- f. NAVORD No. 2563

3. BACKGROUND:

Reference (a) established Task Assignment NPG-Re5a-39-1-53 to study erosion characteristics of liquid propellants in guns, and authorized the use of funds under this task in the development of a prepackaged liquid propellant round. Task Assignment NPG-Re2d-12-1-53 was established by reference (b). The objective of this task was to develop a prepackaged monopropellant hydrazine round for the 40mm gun and to test its performance in automatic fire. Combining the objectives of the two tasks, the liquid propellant program at the Naval Proving Ground is directed toward the development of a prepackaged round which can be used under rapid fired conditions to study the erosion characteristics of a liquid propellant.

In addition to being adaptable to automatic loading the following requirements have been laid down for this round:

- a. The velocity and pressure reproducibility, storage life, and temperature range should be equal to solid propellant ammunition.

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b. A velocity equal to or surpassing the standard solid propellant round should be obtained without developing excessive pressures at any point along the gun barrel.

c. The erosion rate should be less than that for a comparable solid propellant round.

d. The above results should be obtained with a minimum of modifications to existing ammunition components.

A standard 40mm barrel was chosen as the test weapon, because a gun of this size is relatively convenient to handle and instrument, and because it provides a convenient weapon for testing rounds under rapid fire.

4. OBJECT OF TEST:

The object of the tests was to develop a prepackaged monopropellant hydrazine round for the 40mm gun with ballistic properties comparable to the standard solid propellant round.

5. PERIOD OF TEST:

This report covers firings conducted between 30 July 1952 and 31 January 1953.

PART C

DETAILS OF TEST

6. DESCRIPTIONS OF ITEM UNDER TEST:

The liquid propellant used in these tests was a mixture of hydrazine, hydrazine nitrate and water. Hydrazine nitrate constituted 12.0% to 22.6% and water 4.3% to 10% of the propellant. The composition of each round is given in Table I of Appendix (B).

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7. DESCRIPTION OF TEST EQUIPMENT:

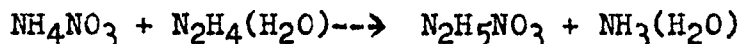
The firings were conducted in a 40mm Mk A Mod 1 barrel mounted in a 6 pdr mount Mk VII, Mod 1. The barrel and mount were modified to receive dynamic pressure gages in the chamber at 3"O and 10"O from the breech face (See Figure 1 Appendix (A)). The Mk 1 case was used on all rounds employing the Mk 21 primer stock and the Mk 2 with the Mk 14 and 41 stocks. The projectiles were either the T1E1 or Mk 2 with their weights adjusted to 902 grams.

The pressure gages were of the expanding tube type with a 500 Ω strain gage as the pressure sensing element. This type of pressure gage has been used extensively at the Naval Proving Ground in similar applications. Gage signals were amplified by D.C. amplifiers having a flat frequency response from 0 - 50,000 cps $\pm$ 0.5 decibel with a gain of 25,000. Pressure traces were recorded from four-beam cathode-ray oscilloscopes by drum cameras having continuously adjustable speeds from 5 - 1800 rpm.

Projectile velocities were determined from measurements by chronograph counters of the time interval required for the magnitized projectile to pass between two solenoid coils. Two sets of coils were used; one set at 60 and 120 feet from the gun muzzle and the second set at 63 and 123 feet. The velocities recorded in Table I, Appendix (B) are average coil velocities corrected to muzzle velocity.

8. PROCEDURE:

The propellant was prepared as follows: Hydrazine nitrate was made by adding the stoichiometric quantity of 95% hydrazine solution to dry C.P. ammonium nitrate. The reaction is



The ammonia and water were removed from the hydrazine nitrate at room temperature by a water injector operated 24 hours followed by evacuating for 24 hours by an oil seal type vacuum pump. The dry hydrazine nitrate was then dissolved in a sufficient quantity of 95% hydrazine to give a mixture of the following composition:

Hydrazine (N_2H_4)	57.0%
Hydrazine Nitrate ($\text{N}_2\text{H}_5\text{NO}_3$)	40.0%
Water (H_2O)	3.0%

Individual charges were prepared from this standard mixture by the addition of 95% hydrazine and water to give the desired hydrazine nitrate and water content.

Liquid Propellant Program

In general, a round was assembled as follows:

The projectile was crimped in the case; the case volume adjusted by the addition of wax; the projectile magnetized; the propellant added; and the primer inserted. The propellant and primer were assembled at the gun just prior to loading the round in the gun.

The general plan of the tests was to determine the effects of the various parameters, as case assembly, ignition, free volume, and propellant composition and weight on the operation of the liquid propellant system and to manipulate these parameters toward a performance comparable to that obtained with a solid propellant round. In the absence of a knowledge of the specific effects of any of the parameters over a wide range of conditions, it was expedient to investigate each in turn over comparatively narrow limits. Specifically, five variations of case assembly and three experimental primer tube designs, two standard tubes and three standard primer stocks were tested. Free volumes from 69% to 1% were investigated at different charge weights and compositions. Charge weights from 150 to 325 grams, with mass ratios from 0.167 to 0.360 respectively, were utilized with the hydrazine nitrate content varying from 11.7% to 22.6% and water content from 4.5% to 10%.

9. RESULTS AND DISCUSSIONS:

The following information and data are included in the appendices:

Figures 1, 2 and 3 of Appendix (A) are respectively sketches of pressure gage locations in the gun, case assemblies and types of primer extension tubes. Table I of Appendix (B) is a tabulation of data on the firings. This table contains, for each round, weight and composition of propellant, type and performance of primer, case assembly, free volume percentage, muzzle velocity, and pressures at maximum and at ejection. Reproductions of pressure-time oscillograms for more than 90 rounds are included as Figures 4 through 24 of Appendix (C). These are in numerical order by round number. Figures 25 through 30 and Tables II and III of Appendix (D) are summaries of data in tabular and graphical forms. In the discussion which follows, reference to rounds by numbers will in general involve data presented in Table I of Appendix (B) and/or the oscillograms of Figures 4 - 24 of Appendix (C).

Liquid Propellant Program

a. Case Assembly

Four different case assemblies have been used in these tests. The chamber geometry produced by each of these assemblies is shown in Figure 2 Appendix (A). The first assembly, C-1, consisted of a standard brass case divided into two sections by means of a thin brass diaphragm. This was similar to assemblies described in references (c) and (d). The liquid propellant was charged into either the forward or rear compartment. Extremely high pressures were obtained on rounds with case assemblies C-1-a and C-1-b. On round 2 with case assembly C-1-a, the pressure was estimated in excess of 100,000 psi; and on rounds 3 and 4 with assembly C-1-b, pressures estimated at 90,000, and 80,000 psi respectively were obtained. The propellant weight and composition and primer type for these rounds are given in Table I Appendix (B). While the propellant occupied 90% of the volume of the forward or rear section of the case in these rounds, only about 53% of the total case volume was occupied in round 2 and only about 41% in rounds 3 and 4.

It was assumed that the high pressures obtained with the C-1 case assemblies were largely the result of the high free volumes of these assemblies. To test this assumption, assembly C-2 was prepared. In this assembly, Figure 2 Appendix (A), the chamber volume was reduced by the cork so that the propellant occupied 90% of the remaining volume. Using this assembly on round 5, a maximum pressure of less than 50,000 psi was obtained with the same charge that produced a pressure in excess of 80,000 psi on round 4 with a C-1 case assembly.

While the cork used in assembly C-2 effectively reduced case free volume, the expulsion of the cork with the projectile was objectionable. To correct this objection, case assembly C-3 was developed. The excess case volume in this assembly was occupied by a 50-50 mixture of paraffin and beeswax distributed in the case as shown in Figure 2 of Appendix (A). On rounds 13, 14, 16 and 17 utilizing this assembly, velocities of approximately 2000 f/s were obtained. On similar rounds using the C-2 assembly (rounds 9, 11 and 12) the velocities were around 1800 f/s. In addition to reducing the filler material ejected with the projectile, the C-3 assembly was more adaptable to manipulations of case volume and charge weights without disturbing other parameters.

Liquid Propellant Program

The C-3 assembly was satisfactory for charge weights below 275 grams and free volumes of 10% and greater. This assembly was used in rounds 13 through 96 of these tests. As the charge weight exceeded 275 grams and at free volumes less than 10%, excessive amounts of wax were lost from the cases on firing. This suggested the desirability of placing as much as possible of the filler in the bottom of the case and resulted in case assembly C-4 shown in Figure 2 Appendix (A). The amount of wax which could be located in the base of the case was limited by the length of the extension tube of the primer. This relocation of the filler reduced the wax losses at the higher charges and lower free volumes.

While the C-4 assembly was, in general, satisfactory for test firings of single hand-loaded rounds, the wax would probably be loosened from the case wall in automatic loading of rounds. For rapid fire tests with automatic loading, a material having greater adherence to the case wall seems desirable.

b. Free Volume

Results reported by reference (d), in which 95% hydrazine was used as the propellant in a 60 caliber gun, indicated an unusual effect obtained with this propellant as compared to solid propellant ammunition. The peak chamber pressure increased as both the charge weight and loading density were decreased. Similar results obtained here are shown by rounds 16 through 23. In the series of rounds, 16 through 23, the peak pressure increased by about 4 times as the space in the case unoccupied by propellant was increased from 10% to near 50% of the total case volume available to the propellant. This case volume, available to but unoccupied by the propellant, is here designated the "free volume", and the ratio, expressed as a per cent, of this unoccupied chamber volume to the total case volume available to the propellant is the "per cent free volume". The free volume ratio is thus comparable to the reciprocal of the loading density as applied in solid propellant ballistics. Low loading densities correspond to high free volume. The use of the free volume concept instead of loading density in liquid propellant work seems preferable since loading densities greater than one are possible because the apparent and real densities of liquid propellants are the same. The dependence of maximum pressure on free volume as obtained on these tests is shown graphically in Figure 25 Appendix (D).

Liquid Propellant Program

At the lower free volume ratios on these tests, the ballistic system was characterized by relatively low maximum chamber pressure and low rates of pressure rise. This is illustrated by the pressure curves of rounds 12, 13, 14, 34 and 36. The propellant burning apparently extends throughout the projectile travel time in the gun with a large fraction of the propellant decomposing only a short time before ejection of the projectile in many cases. The secondary peaks in the pressure cycle on rounds such as 36, 114, 119, 120 and 125 indicate this latter.

The secondary peaks tended to become more pronounced and to reach a value nearer first maximum as the hydrazine nitrate composition and total charge weight was increased. This is shown by rounds 112 through 125. Secondary peaks were not observed at free volume ratios above 30%. On rounds such as 23, 30 and 32 it would seem that all the propellant is burned during the very short time of the initial pressure rise and that the pressure curve after peak pressure is that of the adiabatic expansion of the gases. Here the system is operating at high ballistic efficiency.

It was also observed that as the free volume increased, the amplitude of the high frequency oscillations on the pressure curves increased.

As the free volume was increased, ignition time (from close of firing key to initial pressure rise) increased. Ignition times vs per cent free volume are shown for representative rounds in Figure 28, Appendix (D). The long ignition times and frequent misfires occurring at high free volume values are probably the result of the primer venting partially or almost completely into the free volume above the propellant. All rounds on these tests were fired at elevations slightly above 0°.

No correlation was observed between free volume and velocity, as will be seen in the free volume-velocity plots of Figures 26 and 27 of Appendix (D).

c. Ignition:

The types of primer stocks and extension tubes, and the charge of the tube are tabulated for each round in Table I, Appendix (B). The design of the extension tubes are shown in Figure 3, Appendix (A). Table I, Appendix (A), and Figure 28 and Table III, Appendix (D) contain ignition delay data. The Mk 21 primer stock is a standard 40mm stock and the Mk 14 and Mk 41 are 3"/50 stocks. Results obtained with the Mk 21 stock were equal to that with the Mk 41 stock. Since this stock required no modification to the standard case, it was used throughout most of the tests.

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The first primer tube used, the ET-1, was modeled after the type described in reference (d) and was used with the Mk 21 and Mk 41 stocks. Satisfactory ignition was obtained with this tube when charged with 20 grains of black powder (FFG) and 0.20 grams of ammonium perchlorate.

On rounds 2 and 3, the Mk 14 stock and tube were used. While the excessive pressures obtained on these rounds were attributed primarily to the large free volume, it was thought that the comparatively high energy release of this primer probably contributed to the result by initiating a rapid burning rate or by igniting a large burning surface in the propellant.

The use of the Mk 21 stock and tube on 10 rounds (37 and 40-48) resulted in seven misfires and long ignition delays on two of the three rounds which were ignited. The use of the Mk 41 primer stock without its extension tube also resulted in a misfire (Round 6).

The cost and time involved in fabricating the ET-1 extension tube and the fact that the tube vented irregularly through one to four of the longitudinal grooves dictated the development of a cheaper and more uniformly performing tube. The ET-1 tube was first modified to vent through the end of the tube instead of through the longitudinal grooves. Satisfactory ignition was obtained on three rounds fired with the modified tube, designated ET-2 in Figure 3, Appendix (A). The design was then further simplified to the ET-3 type shown in Figure 3, Appendix (A). This extension tube with three different blowout disc thickness performed satisfactorily on four rounds (58 through 61). From these rounds, an optimum disc thickness of 0.022 was determined. This tube performed satisfactorily on approximately 80 rounds. The diaphragm thickness is the only critical dimension of the tube; rupture of the disc at too low pressure results in very long ignition delays or misfires. There is apparently a critical pressure below which ignition does not occur. The cost of fabricating this type of tube is a small fraction of that of the ET-1 type.

The relation between free volume and ignition is discussed under the section on "Free Volume".

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d. Charge Weight and Propellant Composition:

The relations between muzzle velocity and charge weight (or mass ratio) for different propellant compositions are shown in Figures 29 and 30 of Appendix (D). While, in general, velocity increases with increase in charge weight, there is some evidence from these plots that a charge weight is reached above which no increase in velocity is obtained and that a velocity drop will result if the charge is increased further. The charge weight at which this occurs would seem to be a function of hydrazine nitrate and water content and free volume ratio.

The results of increasing the hydrazine nitrate composition of the propellant were to increase maximum chamber pressure, muzzle velocity and the burning rate of the propellant. As the hydrazine nitrate was increased, it is also to be noted that the tendency increased for secondary peak pressures to occur and for the relative amplitude of these to approach that of the first pressure peak. At hydrazine nitrate concentrations of around 12%, round 36, with a charge weight of 350 grams, was the only one which produced a secondary peak. As the percentage was increased to 15, 18 and 22.6%, secondary peaks appeared more frequently and more closely approximated the amplitudes of the first pressure peaks.

The water content of the propellant used in these tests varied from 4.3% to 10% with the majority of rounds at approximately 6.0% and 10%. Increasing the water content increased the ignition time, decreased the burning rate and velocity and produced smoother pressure curves. The benefits of this latter effect was, however, more than offset by the adverse effect on the ignition time and rate of burning.

e. The 40mm Round

A muzzle velocity of the order of 3000 f/s was obtained with 310 - 325 grams of 22.6% hydrazine nitrate, 72.9% hydrazine and 4.3% water at 1% free volume. This exceeds by 150 f/s the velocity obtained with the standard solid propellant round in this barrel. The mean velocity on 10 rounds (125 - 134) with a charge of 325 grams was 3008 f/s with a standard deviation of 61 f/s or 2%. For 9 rounds (135 - 143) with a charge of 310 grams the mean velocity was 2968 f/s with a standard deviation of 71.5 f/s or 2.4%. The combined unbiased standard deviation for the 19 rounds was 70.1 f/s or 2.3%.

The maximum case pressures for these rounds was of the order of 18.8 tsi copper and comparable to that obtained with the standard solid propellant round for the gun.

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On the basis of these tests, service velocity of the 40mm gun can be exceeded by 150 f/s with no increase in chamber pressure by the use of monopropellant hydrazine. This was accomplished with only two modifications to existing ammunition components: (1) reduction of the case volume by the addition of a filler, and (2) the use of a special primer stock of simple design. The velocity uniformity obtained on these tests was well below solid propellant performance, but is considered good for the present state of development of liquid propellants in guns.

f. Liquid Propellant Charges for Other Navy Guns:

The approximate hydrazine service charges were calculated for several Navy guns and are presented in Table II of Appendix (D). The basis of these calculations were the results from the 20mm gun presented in reference (d) and from the 40mm obtained at the Naval Proving Ground. Assuming a propellant composition having a density near 1.1, the free volume for the charge and the charge for 10% free volume were calculated. Only in the 20mm gun would the charge produce a free volume near 10%; for all other guns for which calculations were made the free volume would be of the order of 35 to 40%. If a 10% free volume is concluded to be the maximum required or desired, it appears that the chamber volumes of most Navy guns in use today are 25 - 30% larger than required, or desired, for liquid propellant ammunition.

PART D

CONCLUSIONS

10. The following conclusions are made from the results obtained on these tests:

a. The service velocity of the 40mm gun can be exceeded by as much as 150 f/s by the use of the monopropellant hydrazine without exceeding the chamber pressure of the solid propellant service charge.

b. The performance of such a liquid propellant round is of sufficient uniformity to be used in studies of gun erosion.

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c. Only two modifications to standard 40mm ammunition components are required for the round developed in these tests. The case volume must be reduced and a special type of primer extension tube used.

d. The wax used in these tests to reduce the case volume is not a completely satisfactory filler. A material which adheres more firmly to the case wall will be required for automatic loading of the round. Erosion studies under rapid fire conditions are dependent on a satisfactory solution to this problem.

e. The prospects of obtaining a uniformity of performance for the monopropellant hydrazine comparable to that obtained with solid propellants are encouraging.

f. Based on the charge determined for the 40mm gun on these tests and the available data from other sources, the chamber volumes of most Navy guns appear to be 25 to 35% larger than required for liquid propellant ammunition.

g. Ignition of the propellant is affected by primer configuration and charge, propellant composition and free volume in the case.

h. Increasing the free volume in the case results in delayed ignition, increased burning rate and higher peak pressure.

i. An increase in the hydrazine nitrate content of the propellant is accompanied by an increase in burning rate, chamber pressure and muzzle velocity, and the production of secondary pressure peaks.

j. An increase in water content of the propellant is accompanied by an increase in ignition time, decrease in burning rate and velocity, and a smoothing of the pressure curve.

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Liquid Propellant Program

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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

First Partial Report
on
Liquid Propellants For Guns

First Partial Report
on
Liquid Propellant Guns

Project No.: NPG-Re2d-12-1-53
NPG-Re5a-39-1-53

Date:

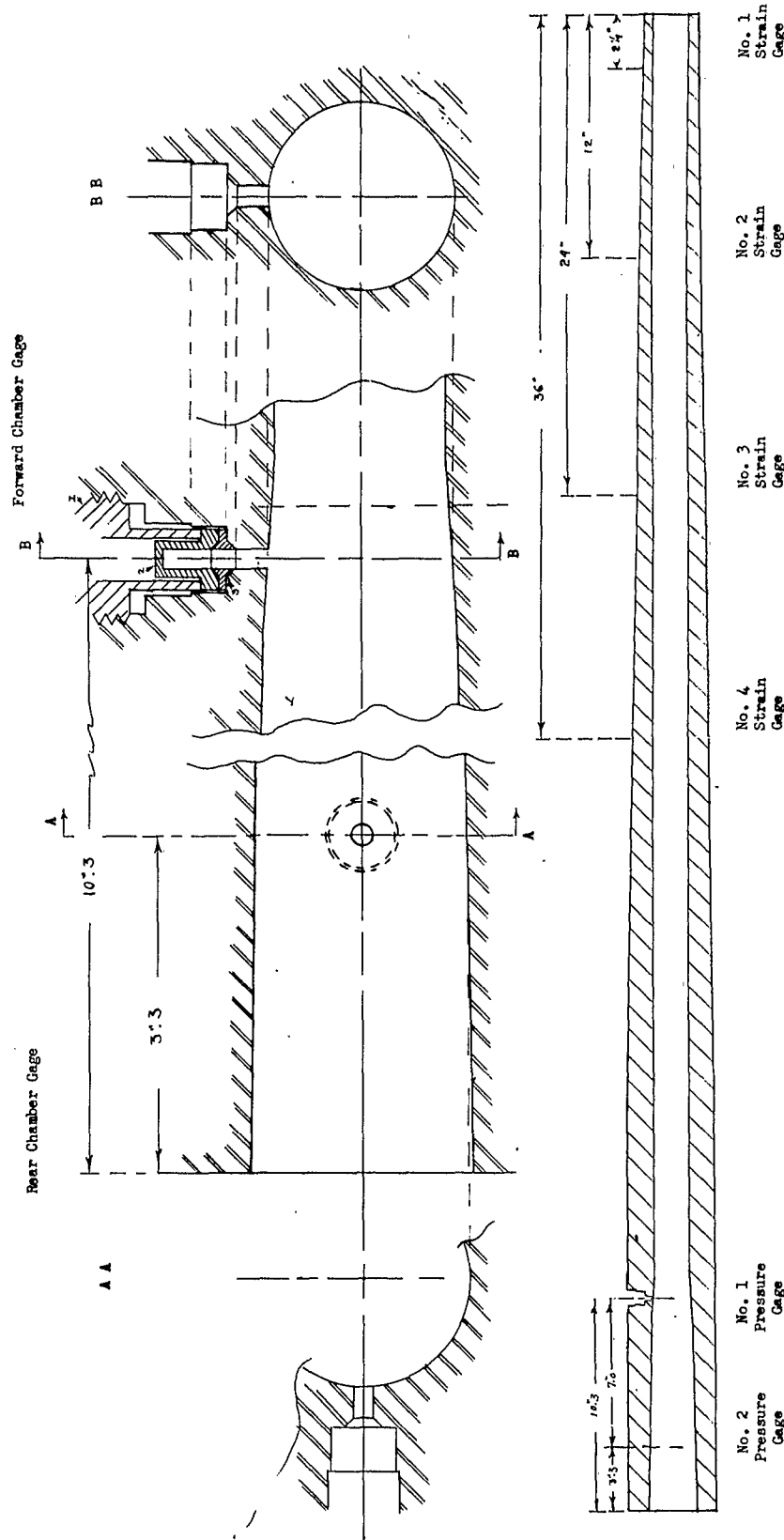
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U.S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
LIQUID PROPELLANT SECTION

GAGE LOCATIONS ON GUN SYSTEM



APP. A

Pressure Gages: Expanding tube type
1: Gage Hold Down Plug
2: Pressure Gage
3: Seal

Strain Gages: Patch Type
Cemented on
outside wall
of barrel

NP9-62828

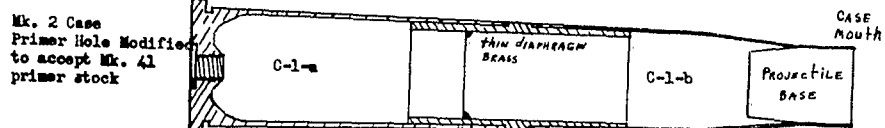
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Liquid Propellants Section

SKETCH OF 40 MM CASE ASSEMBLIES

C-1

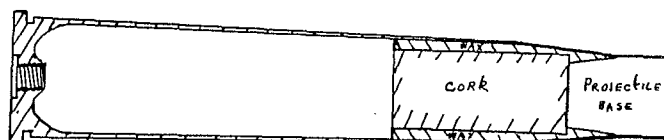


C-1-a: Propellant held
in rear portion
of case

C-1-b: Propellant held
in forward portion
of case

C-2

Mk. 1 Case
Mk. 21 primer
stock



C-3

Mk. 1 Case
Mk. 21 primer
stock



C-4

Mk. 1 Case
Mk. 21 primer
stock

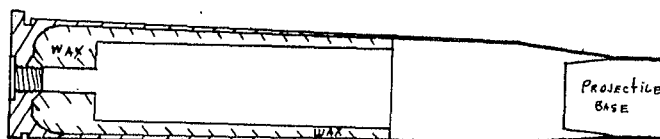


Figure 2

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

SKETCH OF EXTENSION TUBES

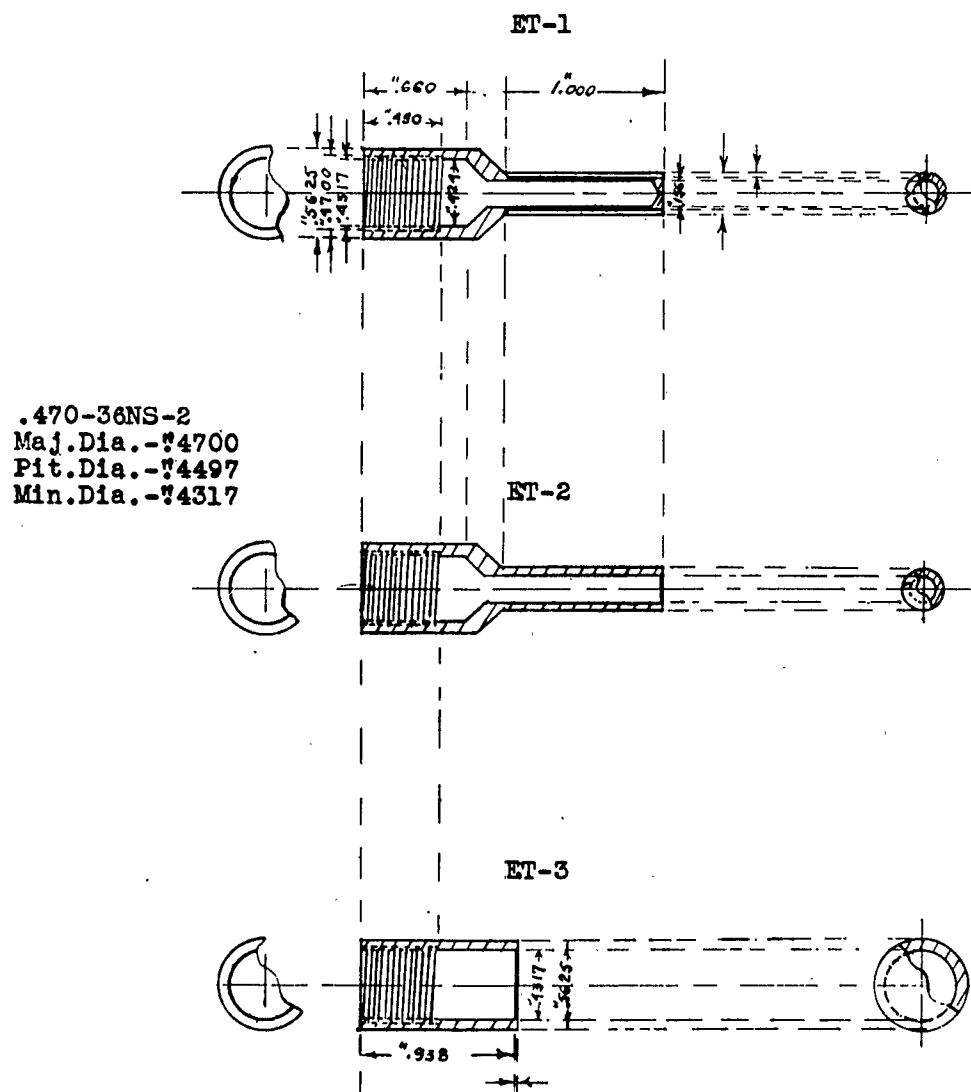


Figure 3

TABLE I

TABLE I

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TABLE I (Continued)

[illegible]

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NPG REPORT NO. 1200

Liquid Propellant Program

PRESSURE-TIME OSCILLOGRAMS

Gun: 40mm, Mk 1, Barrel No. 14934

Case: Modified Mk 1 and Mk 2

Primer: Special Designs

Propellant: Hydrazine, hydrazine nitrate, water solutions

Trace #1: Forward chamber pressure gage

Trace #2: Rear chamber pressure gage

Trace #3: Projectile ejection time

Trace #4: Time of close of firing key

Trace #5: Reference

CFK: Close of firing key

E: Ejection time

Timing: One millisecond marker

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SECURITY INFORMATION

APPENDIX C

NP9-62833

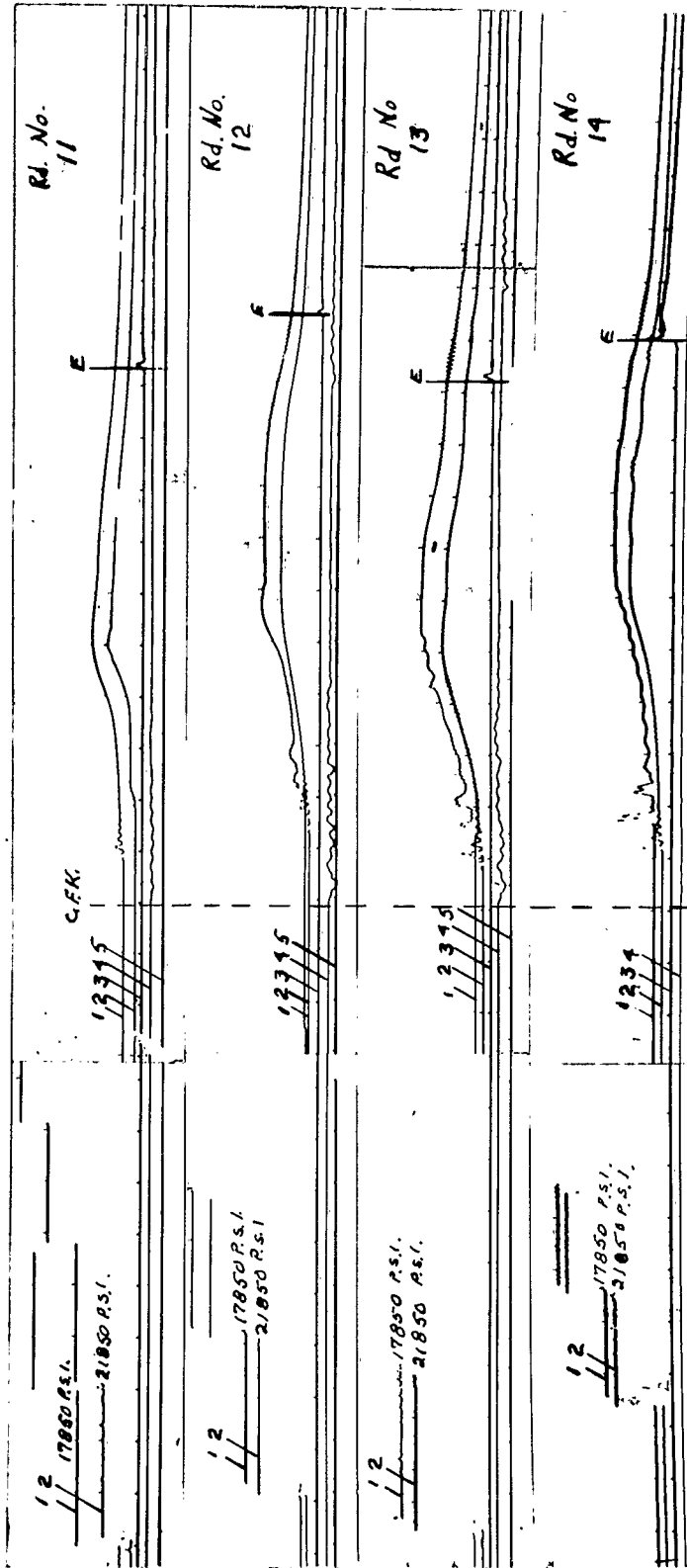
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/8/52	11	200 Grams	10.0%	12.0	78.0	10.0
8/11/52	12	"	"	"	"	"
8/12/52	13	"	"	"	"	"
8/14/52	14	"	"	"	"	"



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FIGURE 4

NP9-62834

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INTERIOR BALLISTICS DIVISION
Liquid Propellants Section
PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/15/52	16	200 Grams	10.0%	11.9	78.1	10.0
"	17	"	"	"	"	"
"	18	"	16.5%	"	"	"
"	19	"	25.1%	"	"	"

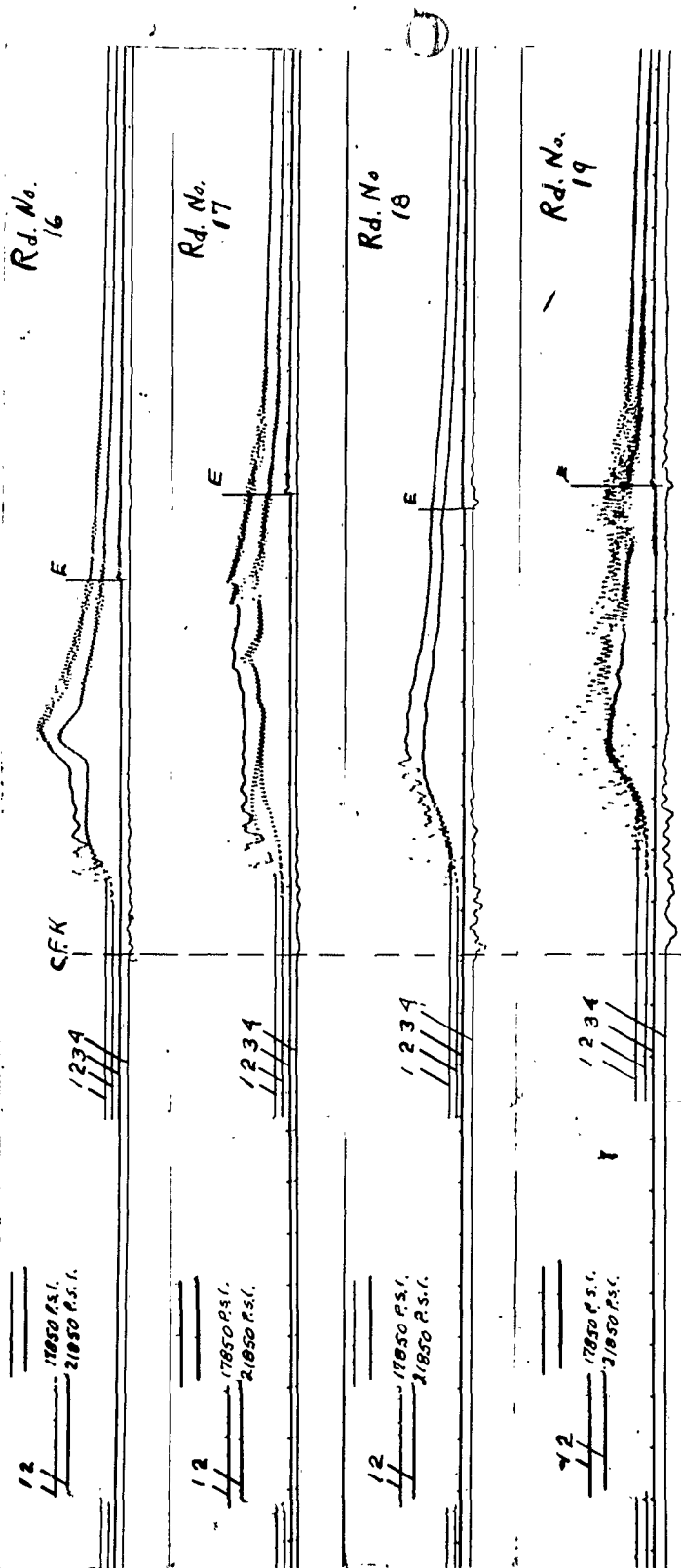


Figure 5

NP9-62835

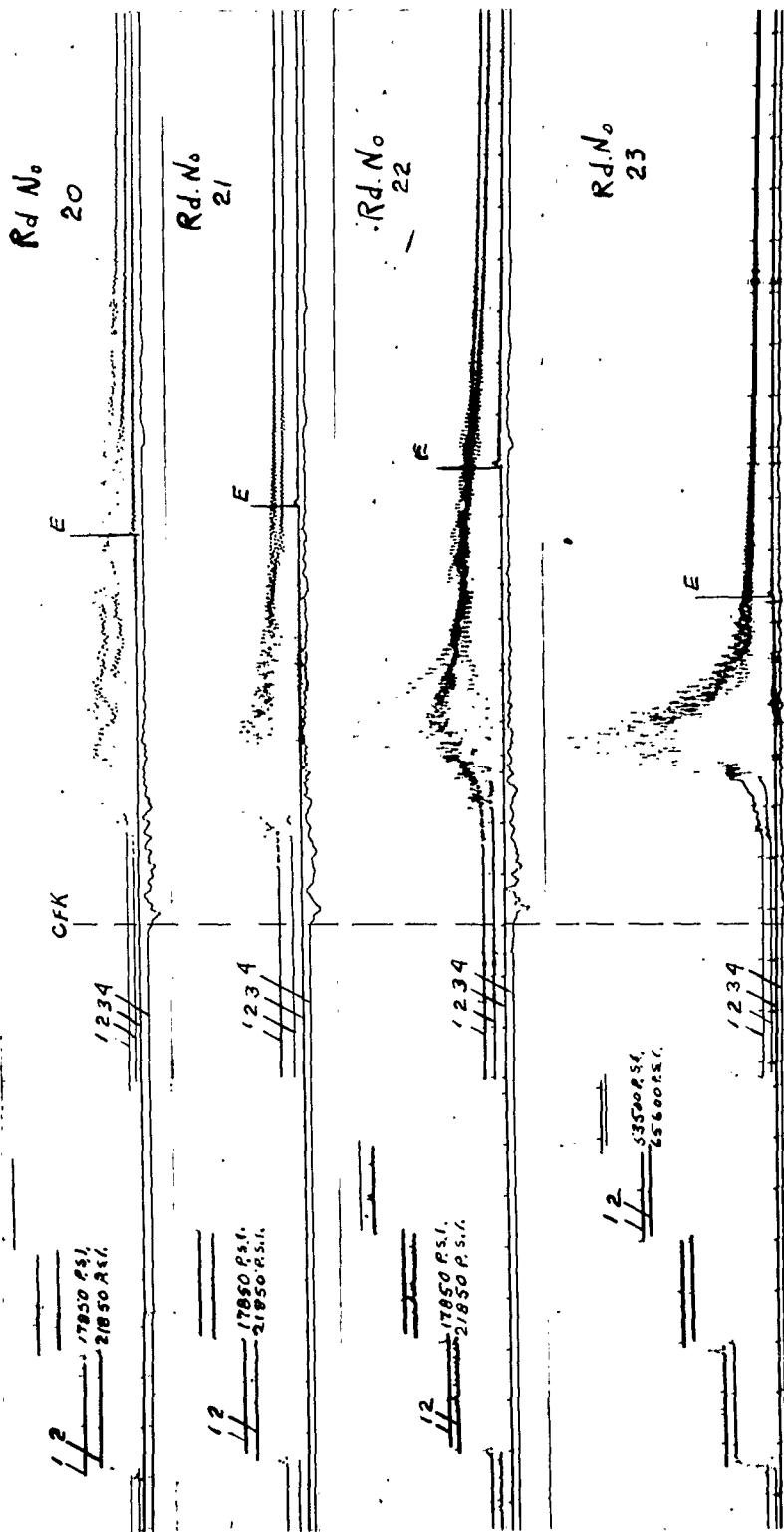
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/15/52	20	200 Grams	30.9%	11.9	78.1	10.0
"	21	"	35.2%	"	"	"
"	22	"	45.2%	"	"	"
"	23	"	49.4%	"	"	"



NP9-62836

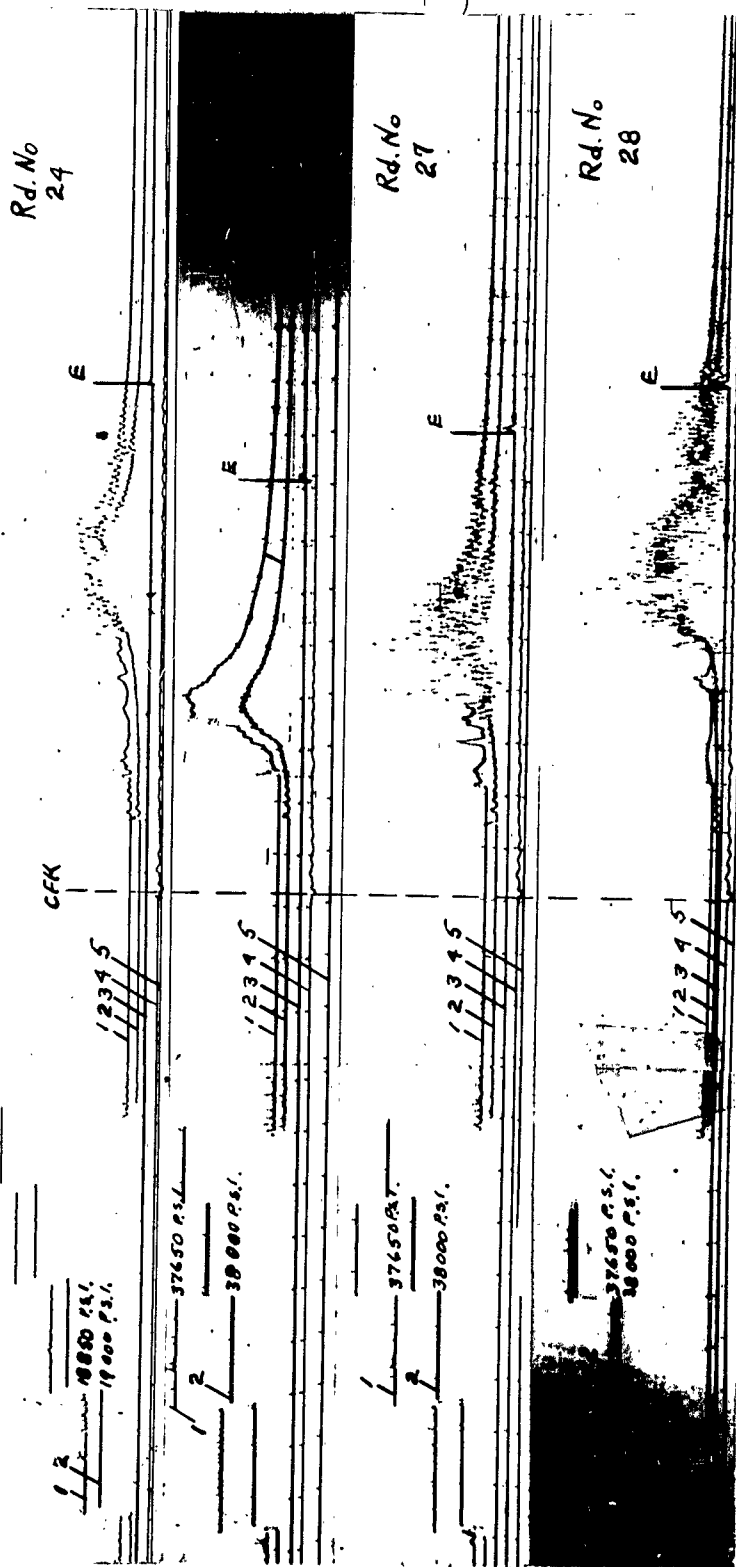
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/20/52	24	200 Grams	45.1%	11.9	78.1	10.0
"	26	150 "	50.0%	"	"	"
8/22/52	27	"	45.0%	"	"	"
"	28	"	50.0%	"	"	"



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SECURITY INFORMATION

FIGURE 7

NP9-62837

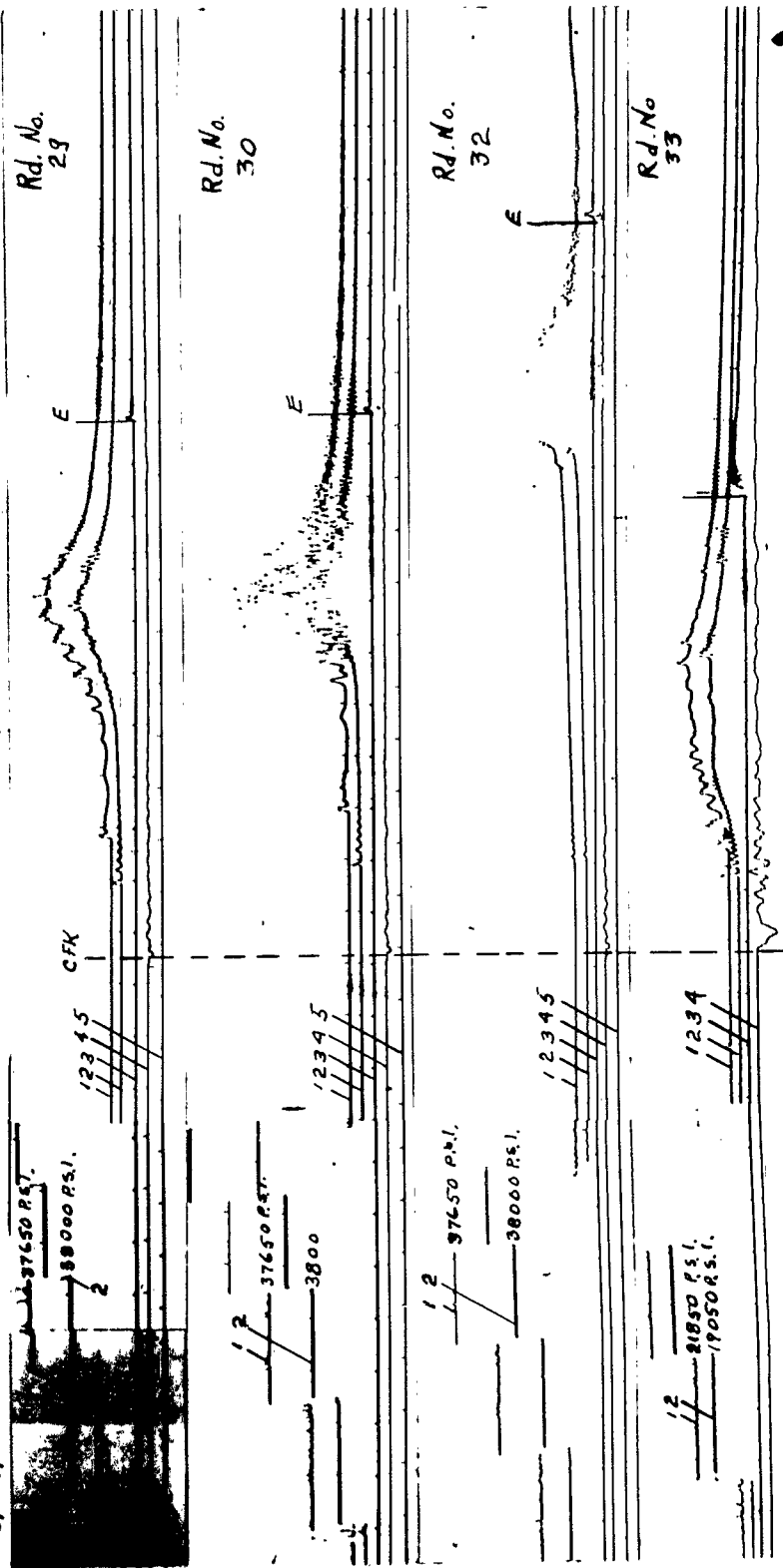
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/22/52	29	150 Grams	55.0%	11.9	78.1	10.0
"	30	"	60.0%	"	"	"
"	32	"	69.0%	"	"	"
8/26/52	33	"	35.0%	"	"	"



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SECURITY INFORMATION

FIGURE 8

NP9-62838

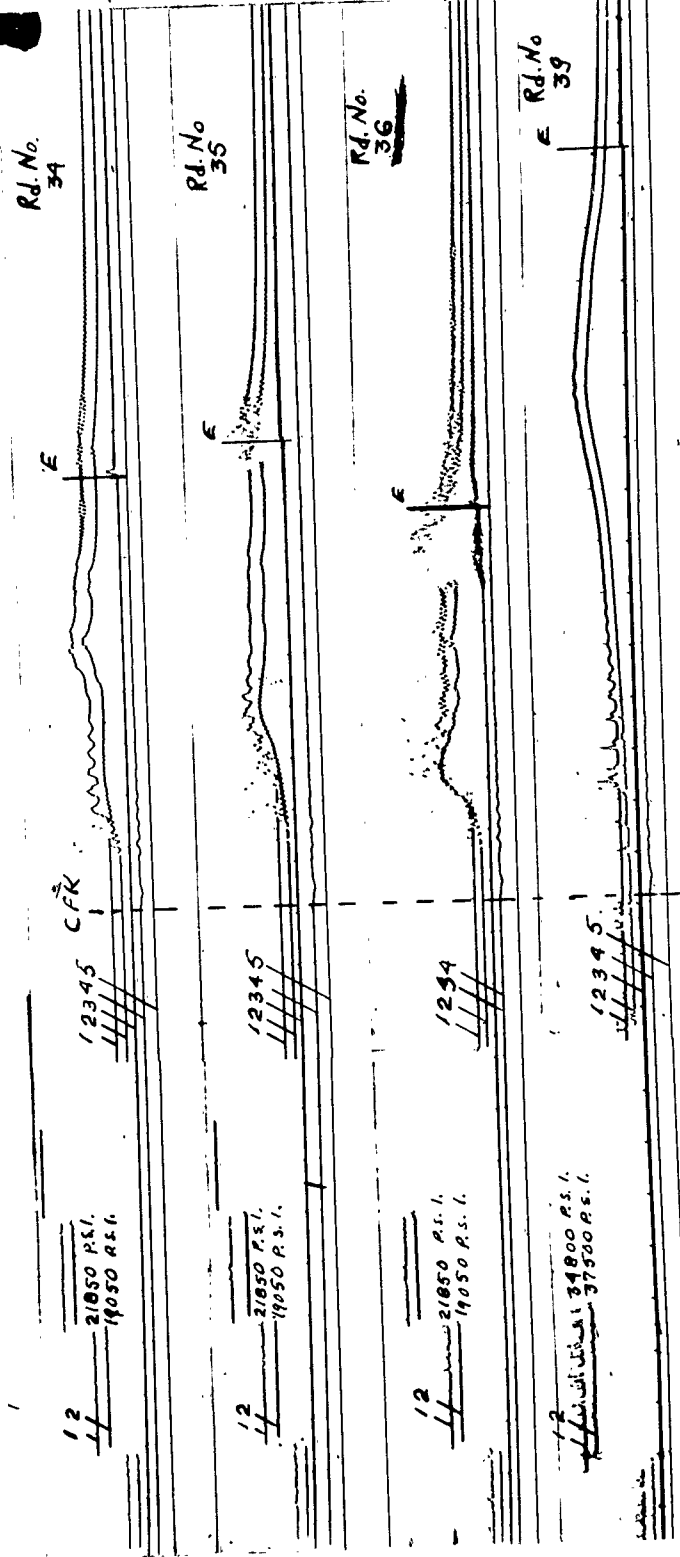
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/27/52	34	250 Grams	10.0%	11.9	78.1	10.0
"	35	300 "	"	"	"	"
"	36	350 "	"	"	"	"
9/10/52	39	200 "	"	"	"	"



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FIGURE 9

NP9-62839

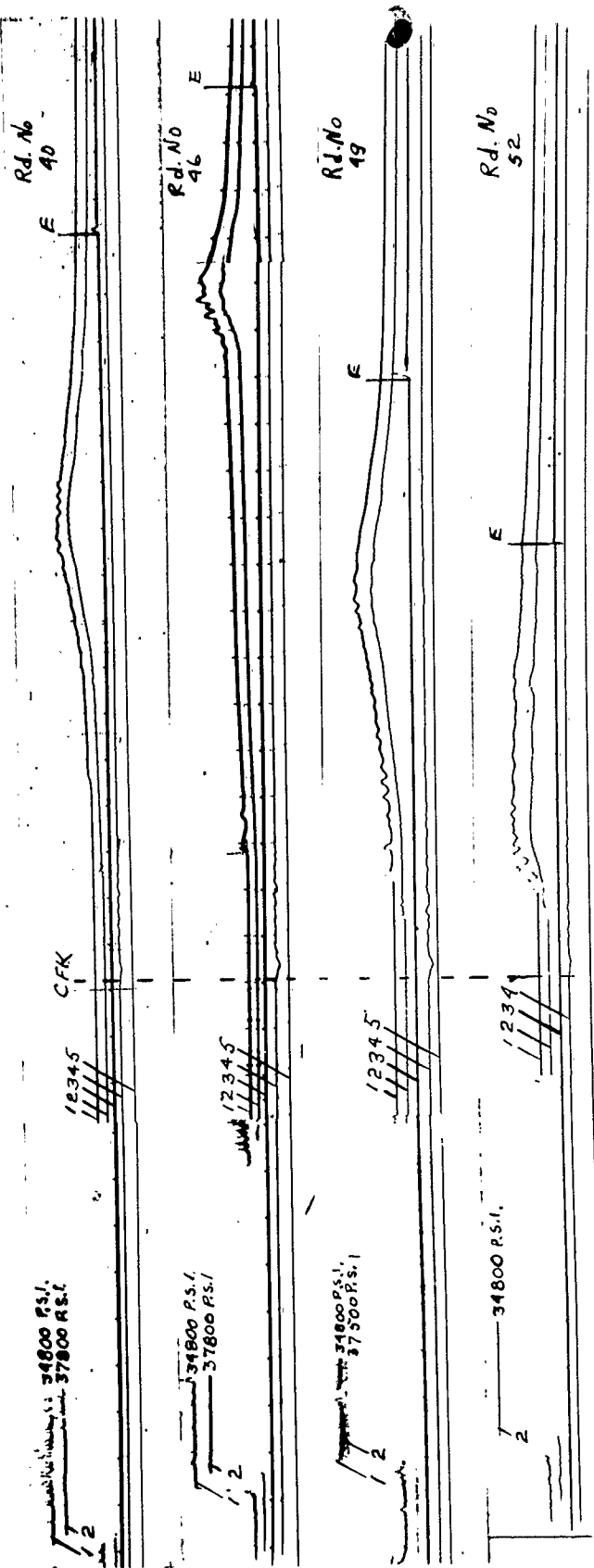
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
9/10/52	40	150 Grams	25.0%	11.9	78.1	10.0
"	46	"	20.0%	"	"	"
"	49	"	35.0%	"	"	"
"	52	"	10.0%	"	"	"



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NP9-62840

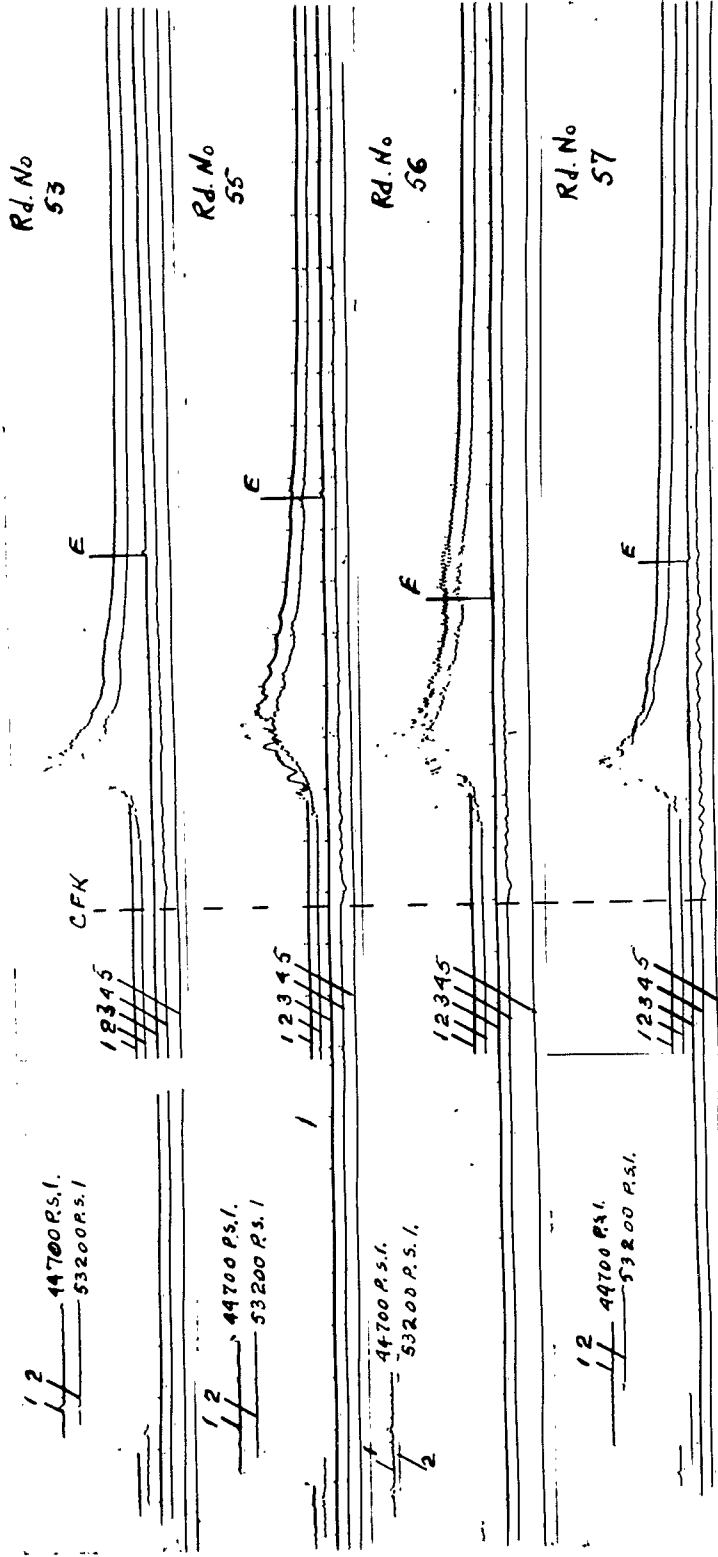
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% N ₂ H ₄ NO ₃	% N ₂ H ₄	% H ₂ O
9/16/52	53	150 Grams	17.0%	12.6	81.4	6.0
9/18/52	55	"	20.0%	"	"	"
"	56	"	"	"	"	"
"	57	"	"	"	"	"



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NP9-62841

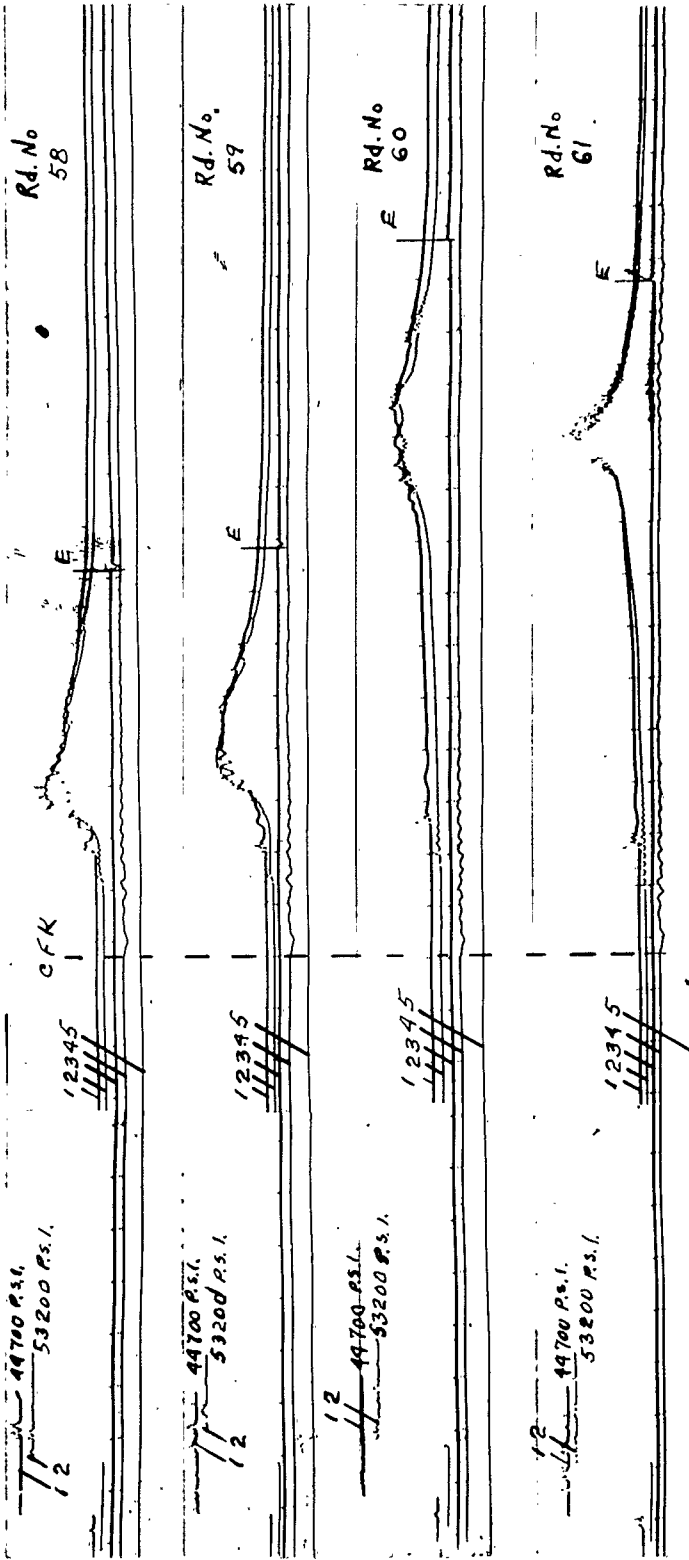
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/18/52	58	150 Grams	20.0%	12.6	81.4	6.0
"	59	"	"	"	"	"
"	60	"	"	"	"	"
"	61	"	"	"	"	"



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NP9-62842

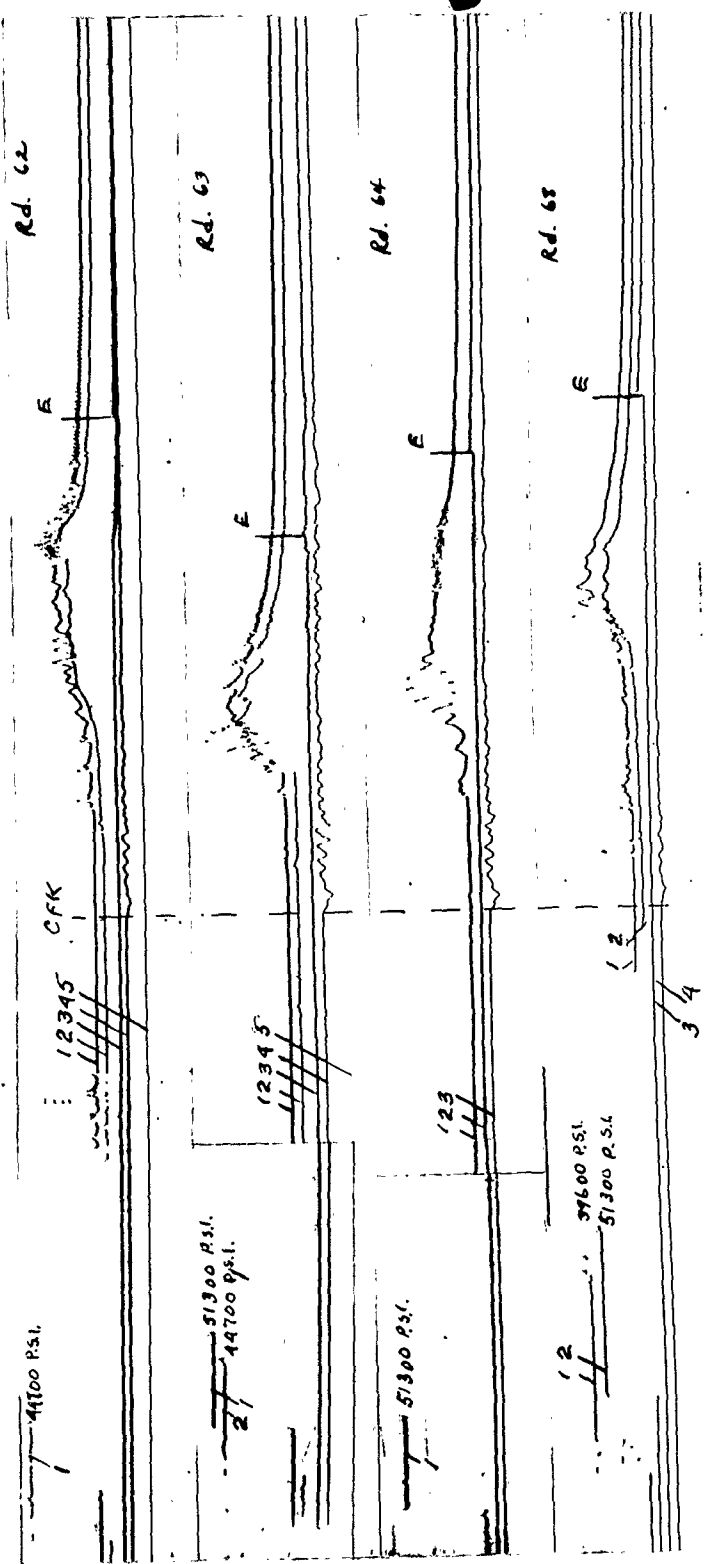
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_5	% H_2O
9/26/52	62	150 Grams	10.0%	12.6	81.4	6.0
"	63	"	20.0%	"	"	"
"	64	"	30.0%	"	"	"
9/29/52	68	"	40.0%	"	"	"



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NP9-62843

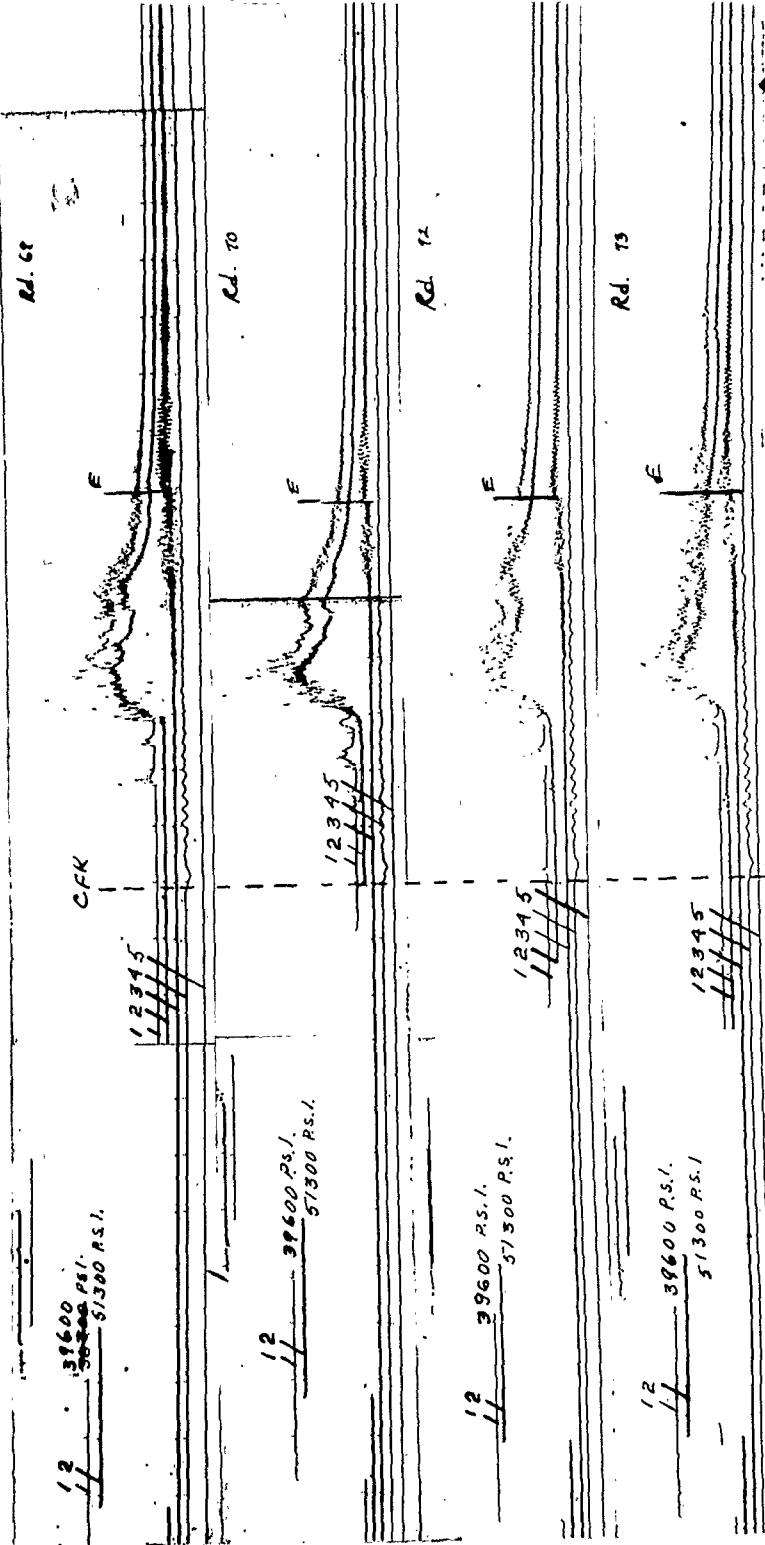
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_4NO_3$	% N_2H_4	% H_2O
10/1/52	69	200 Grams	30.0%	12.6	81.4	6.0
"	70	225 "	"	"	"	"
"	72	275 "	"	"	"	"
"	73	300 "	"	"	"	"



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FIGURE 14

NP9-62844

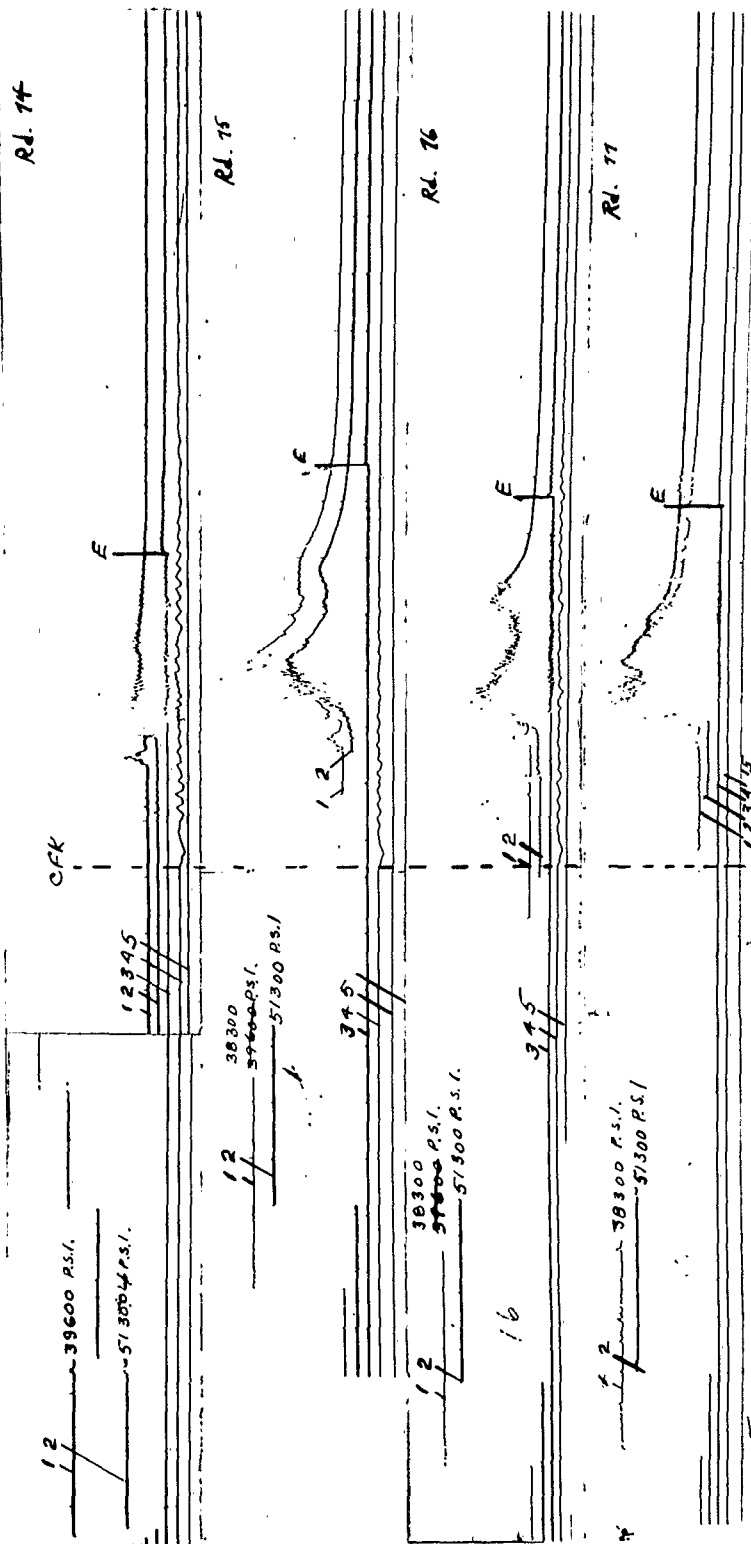
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	$N_2H_4NO_3$	% N_2H_4	% H_2O
10/2/52	74	150 Grams	30.0%	15.0	78.9	6.1
"	75	"	"	18.0	76.2	5.8
"	76	"	"	22.6	71.9	5.5
10/3/52	77	"	"	15.0	78.9	6.1



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FIGURE 15

NP9-62845

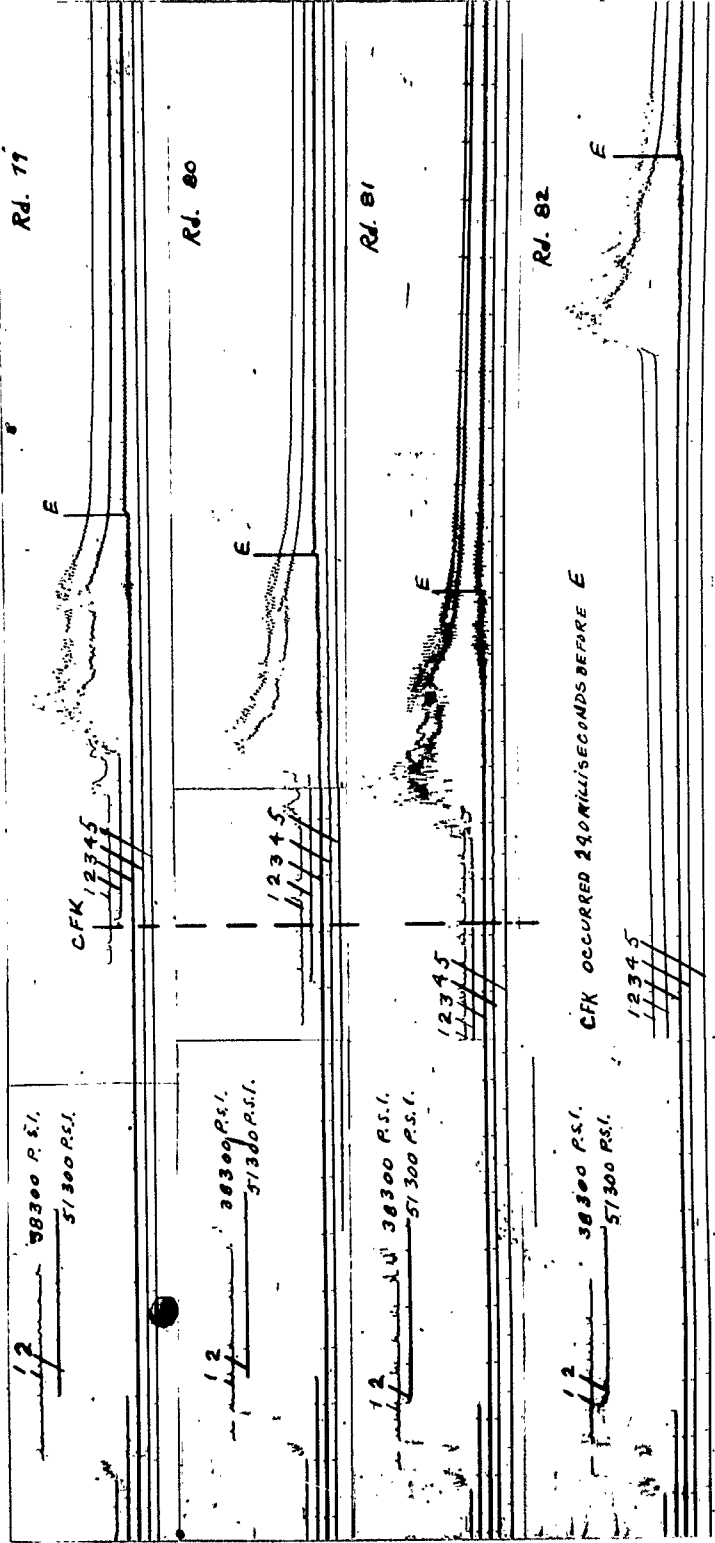
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/3/52	79	175 Grams	30.0%	18.0	76.2	5.8
"	80	200 "	"	"	"	"
"	81	225 "	"	"	"	"
"	82	250 "	"	"	"	"



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FIGURE 16

NP9-62846

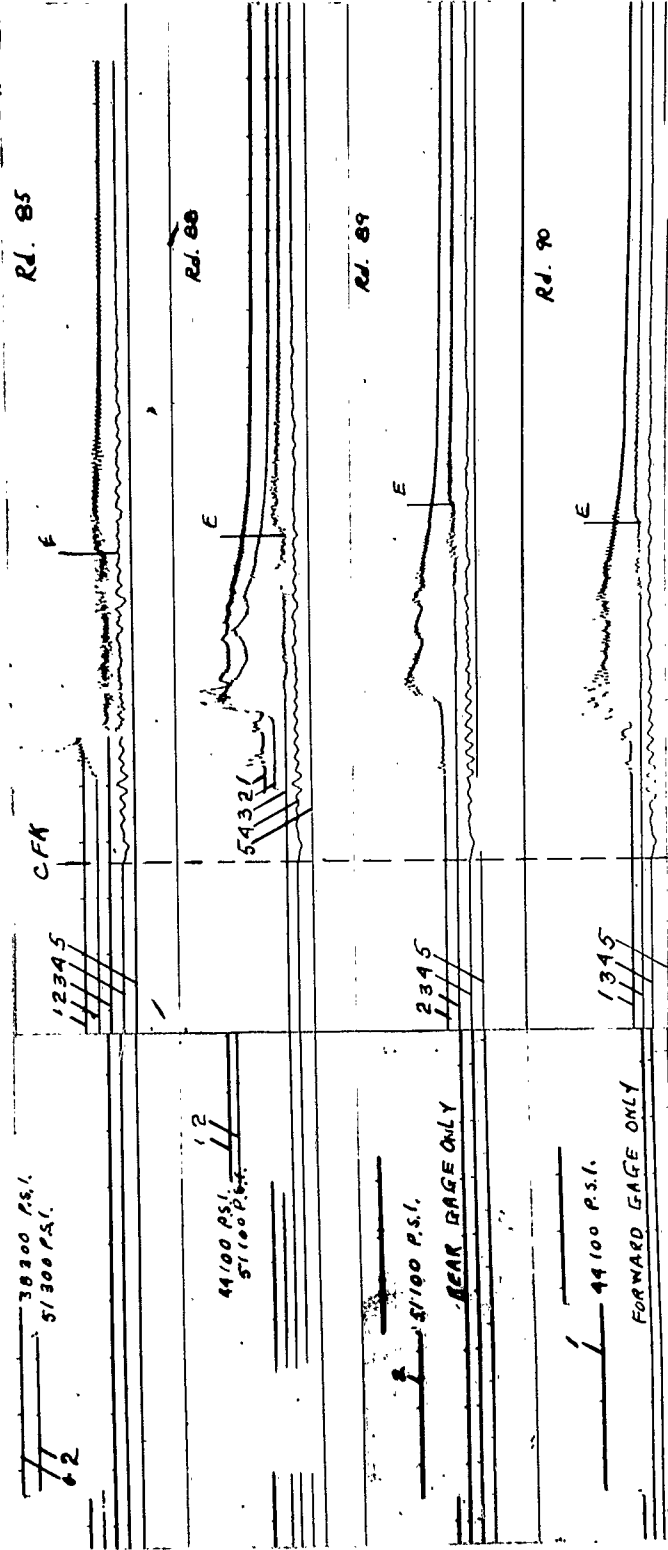
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/8/52	85	275 Grams	30.0%	18.0	76.2	5.8
10/14/52	88	"	10.0%	"	"	"
10/15/52	89	"	"	"	"	"
"	90	"	"	"	"	"



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FIGURE 17

NP9-62847

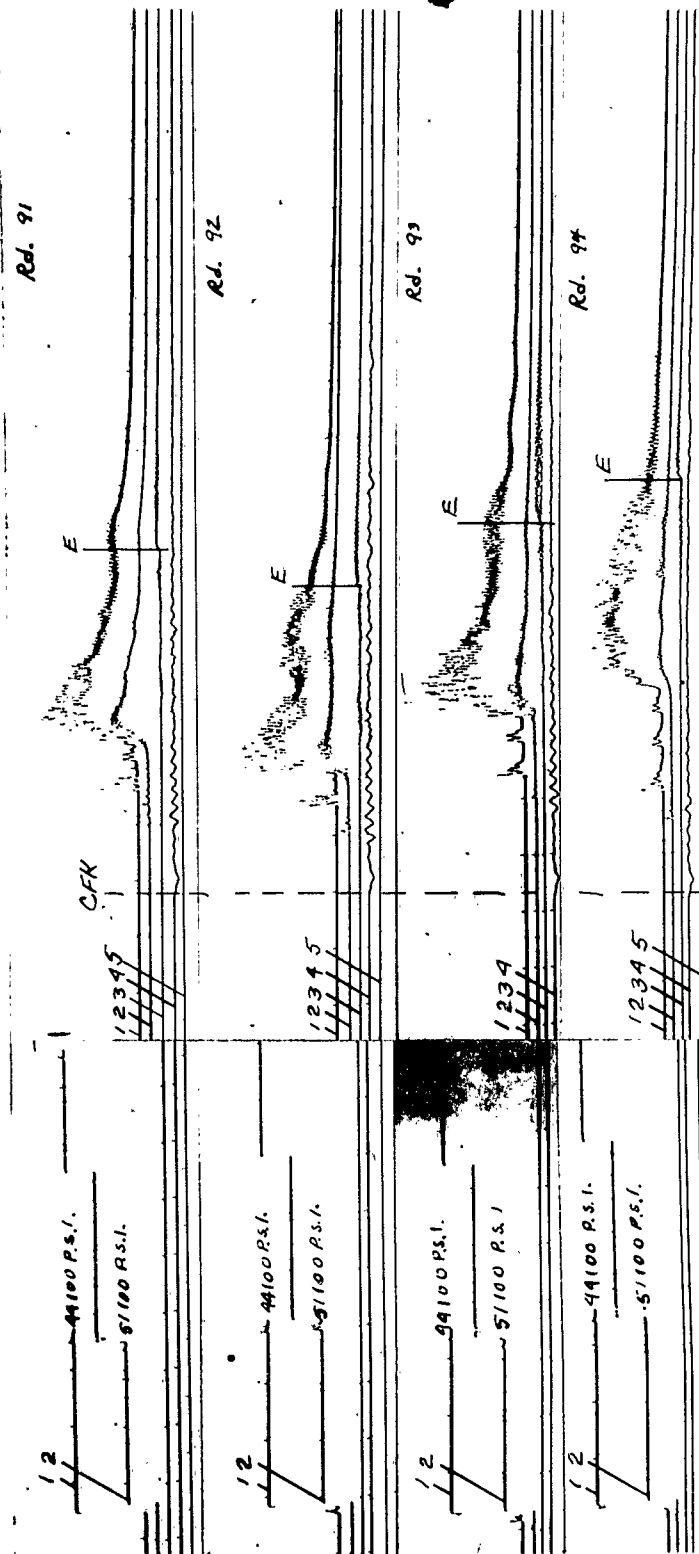
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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/16/52	91	290 Grams	10.0%	18.0	76.2	5.8
"	92	300 "	10.0%	"	"	"
"	93	275 "	30.0%	"	"	"
"	94	250 "	10.0%	15.0	78.9	6.1



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INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/16/52	95	250 Grams	20.0%	15.0	78.9	6.1
	96	"	30.0%	"	"	"
10/22/52	99	275 "	25.0%	18.0	76.2	5.8
	101	"	"	"	"	"

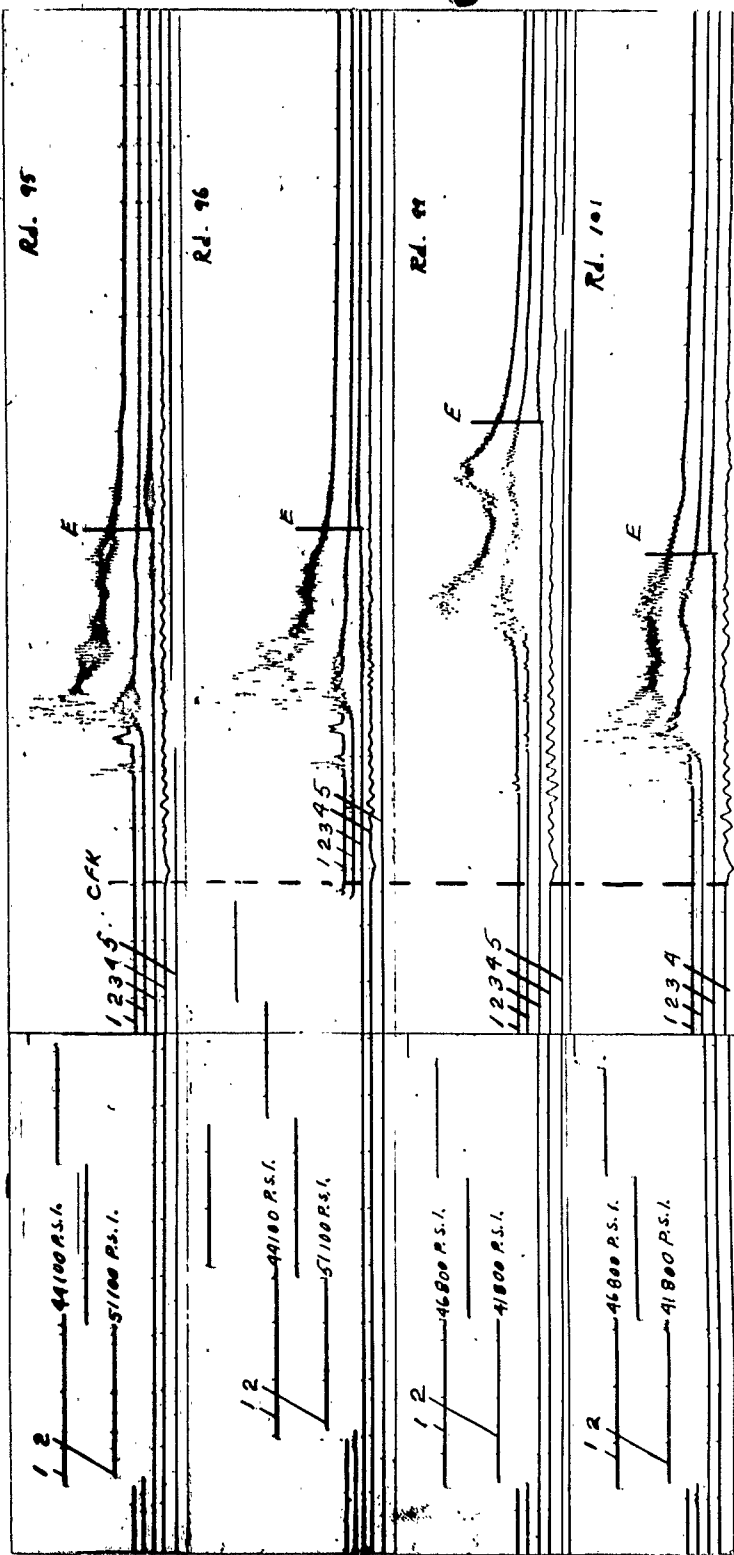


FIGURE 19

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NP9-62849

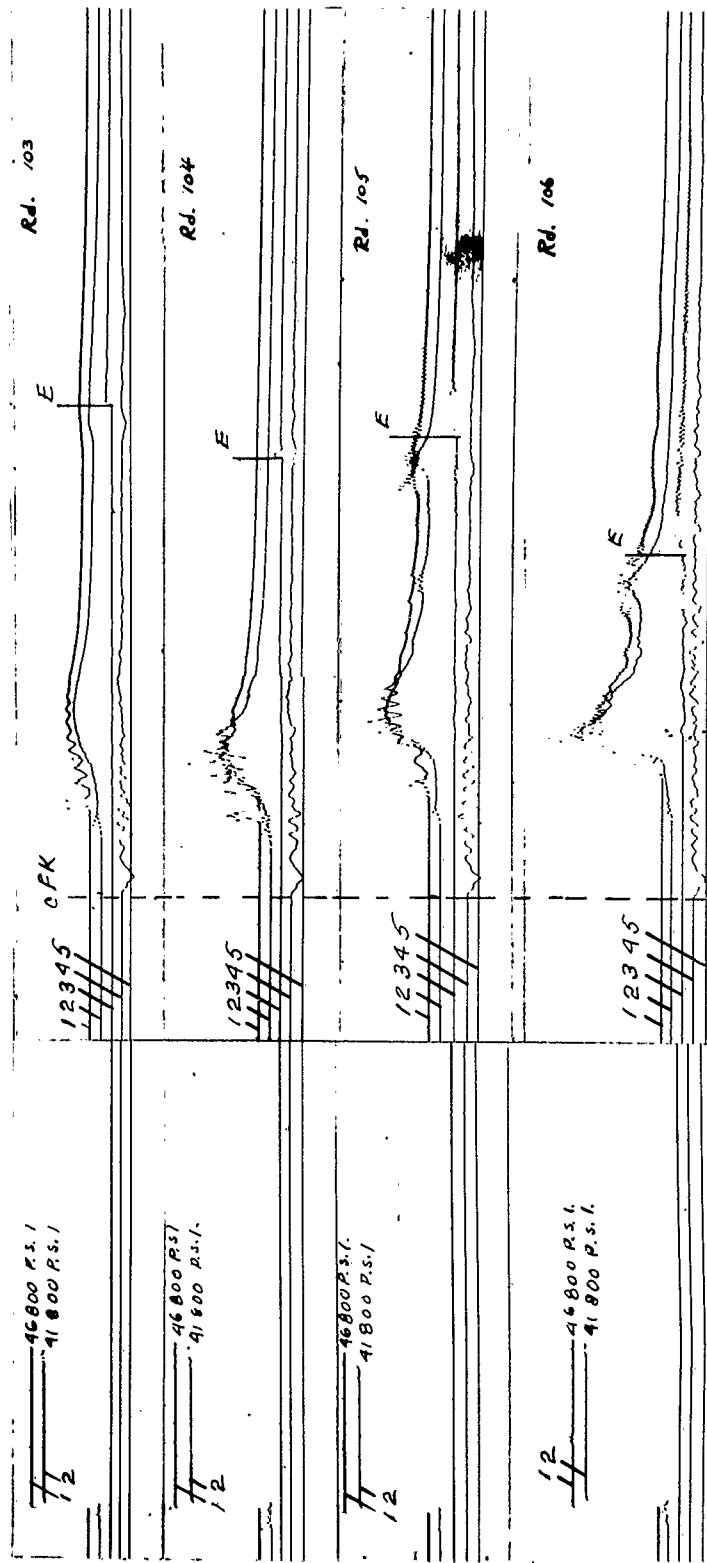
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	N ₂ H ₄ NO ₂ %	N ₂ H ₄ %	H ₂ O %
10/24/52	103	200 Grams	10.0%	12.0	78.0	10.0
"	104	150 "	20.0%	12.6	81.4	6.0
"	105	150 "	"	"	"	"
"	106	217.7 "	"	18.0	76.2	5.8



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FIGURE 20

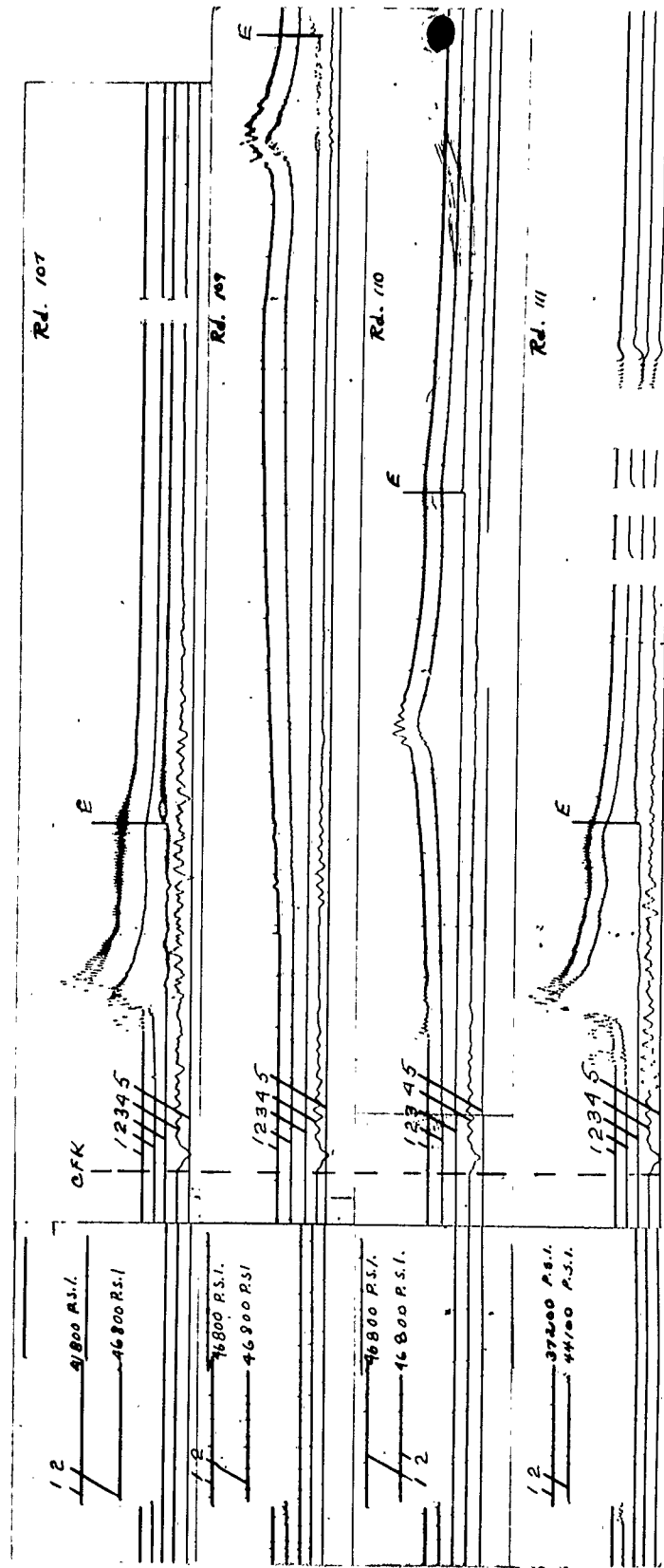
NP9-62850

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section
PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_5	% H_2O
10/27/52	107	217.7 Grams	20.0%	18.0	76.2	5.8
10/29/52	109	222.9 "	16.5%	17.6	74.4	8.0
"	110	227.9 "	15.2%	17.2	72.8	10.0
11/6/52	111	250 "	10.0%	15.0	80.5	4.5



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FIGURE 22

NP9-62851

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/6/52	112	250 Grams	5.0%	15.0	80.5	4.5
11/7/52	113	" "	1.0%	"	"	"
11/13/52	114	" "	"	18.0	76.2	5.8
"	115	" "	"	15.0	80.5	4.5

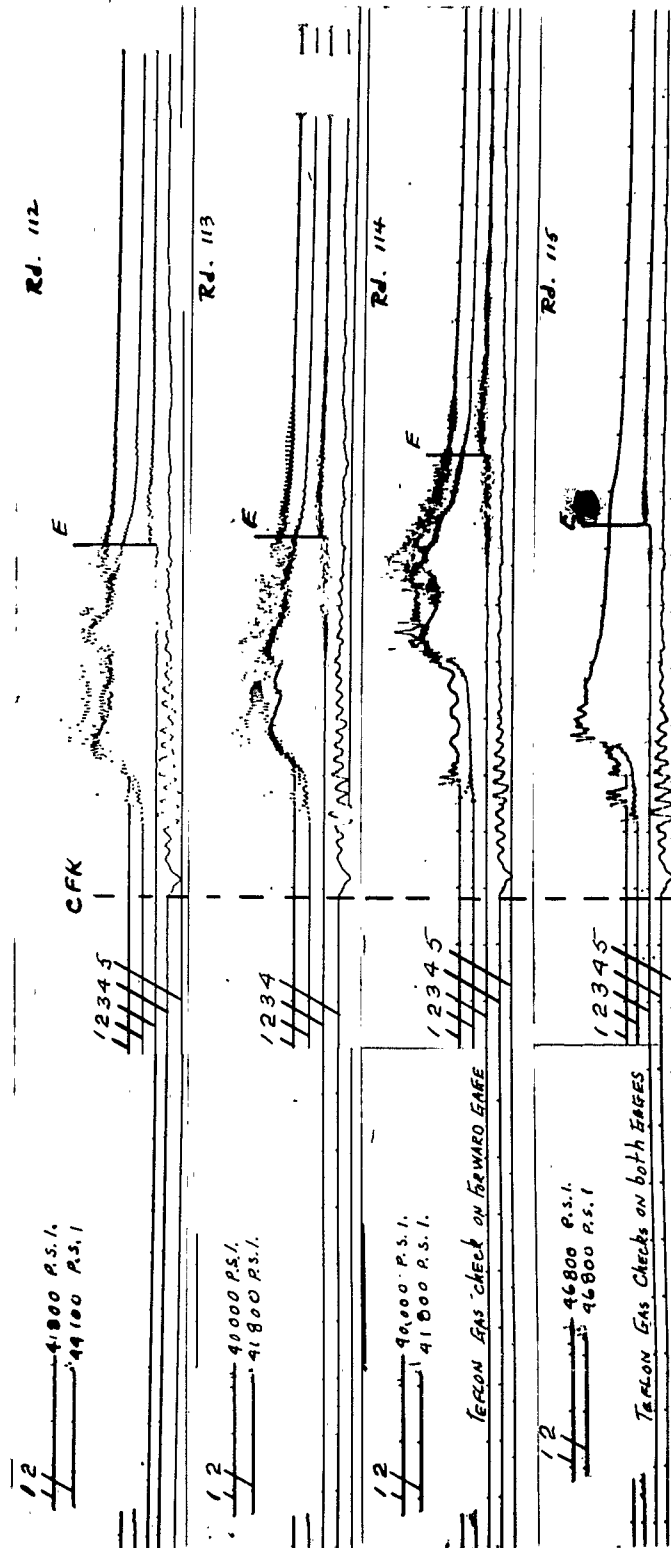
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FIGURE 22

NP9-62852

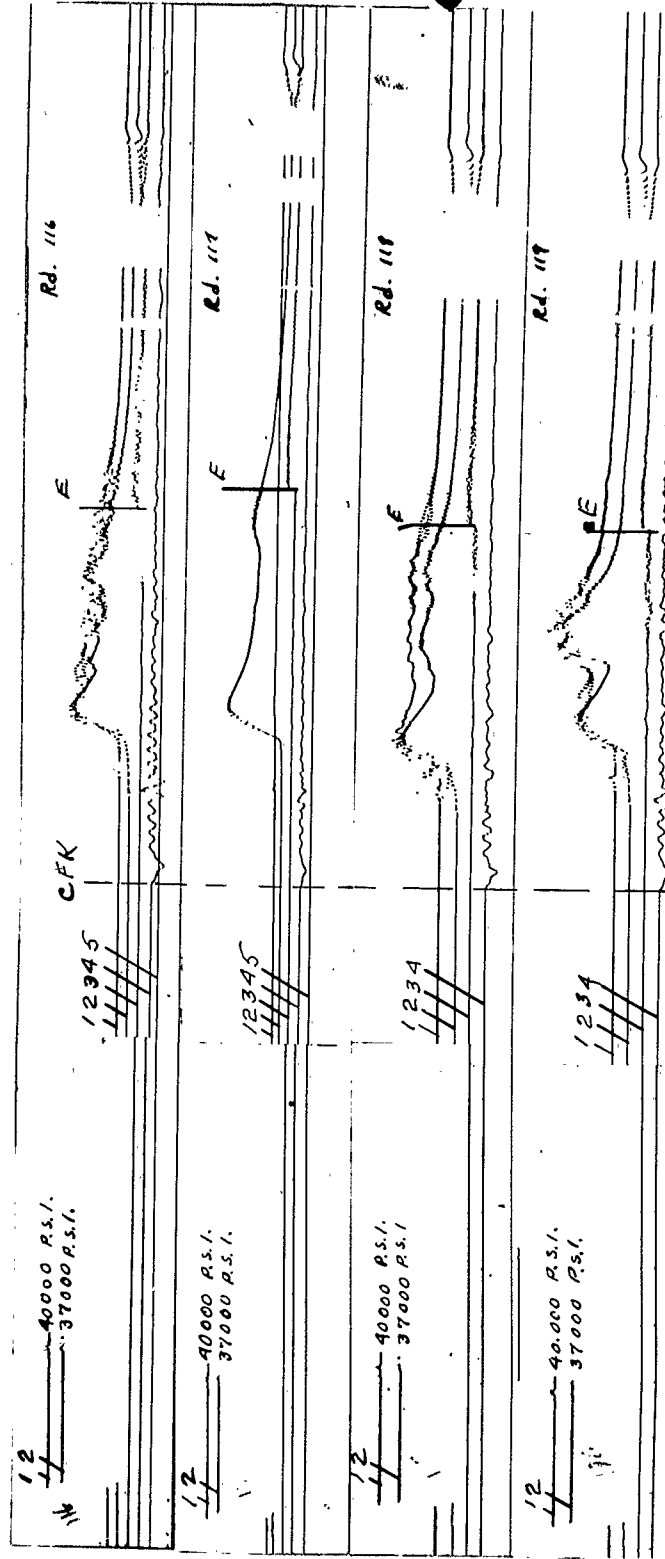
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/18/52	116	275 Grams	1.0%	15.0	80.5	4.5
"	117	300 "	1.0%	"	"	"
"	118	250 "	.8%	18.0	76.2	5.8
"	119	275 "	2.6%	"	"	"



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FIGURE 23

NP9-62853

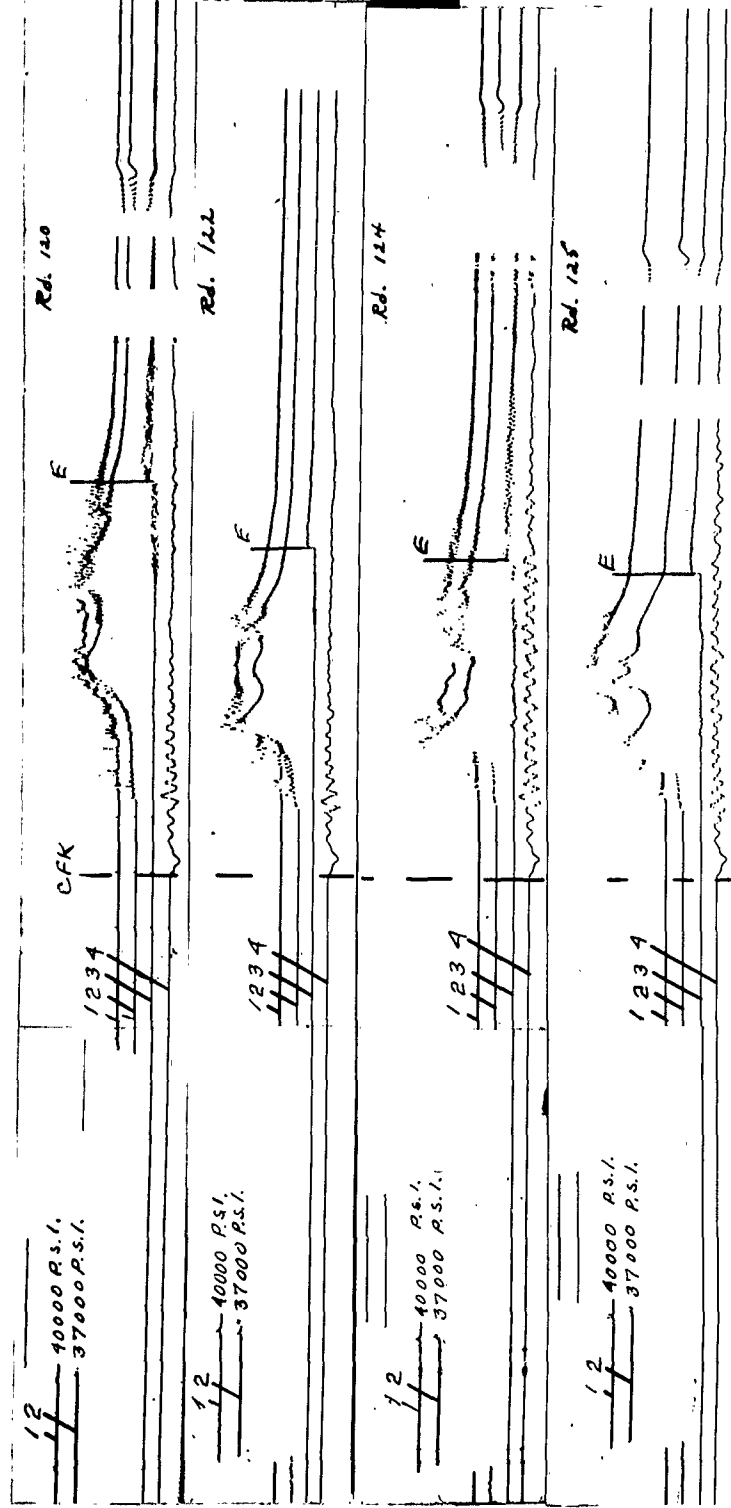
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/18/52	120	300 Grams	2.20%	18.0	76.2	5.6
11/19/52	122	250 "	.8%	22.6	72.9	9.3
"	124	300 "	2.2%	"	"	"
"	125	325 "	.8%	"	"	"



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FIGURE 24

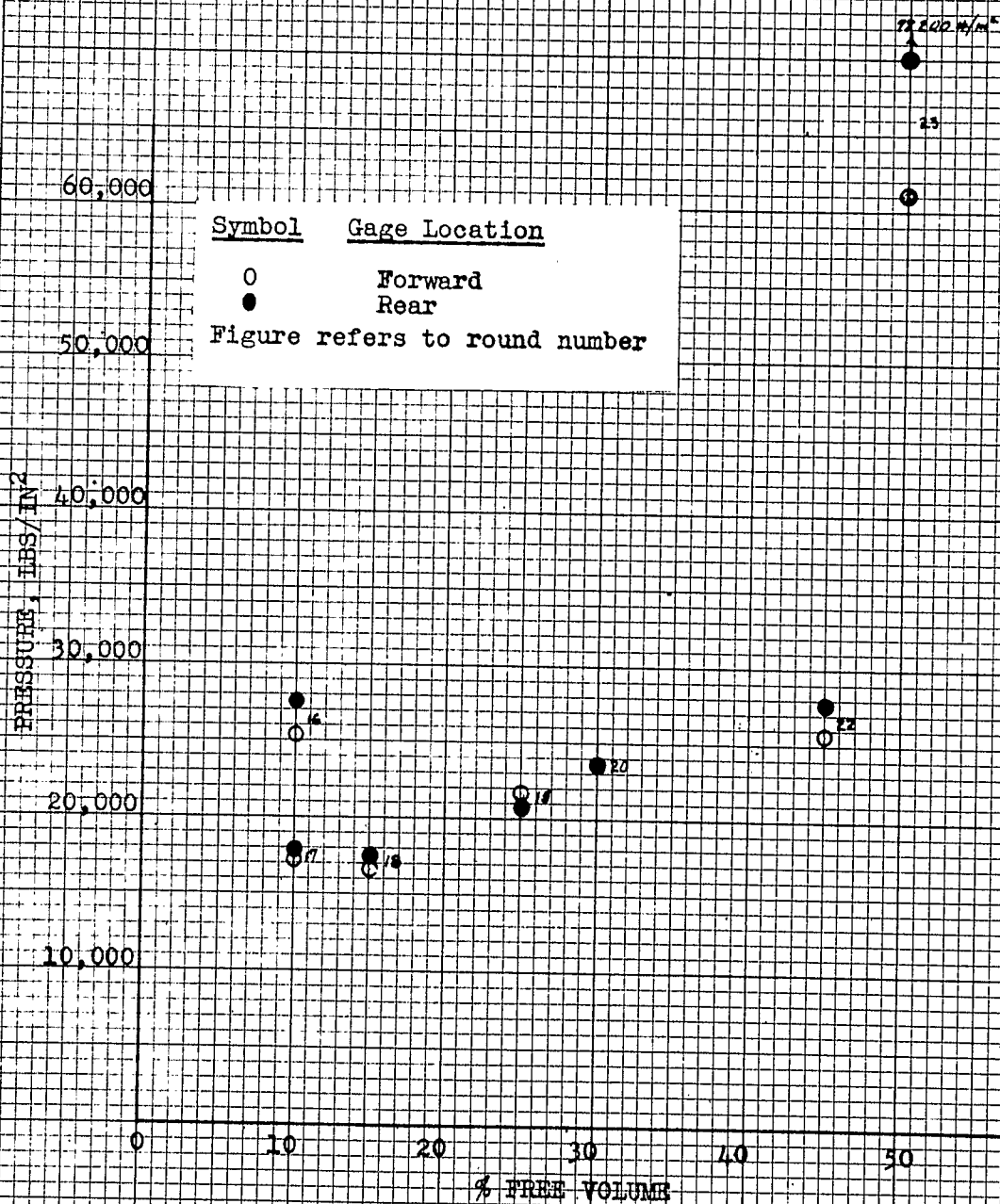
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PEAK PRESSURE VS % FREE VOLUME



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Figure 25

NP9-62862

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

VELOCITY VS % FREE VOLUME

Symbol	% $N_2H_5NO_3$	% H_2O	Charge Weight
○	11.9	10.0	150 Gms.
⊗	11.9	10.0	200 Gms.

Figure refers to round number

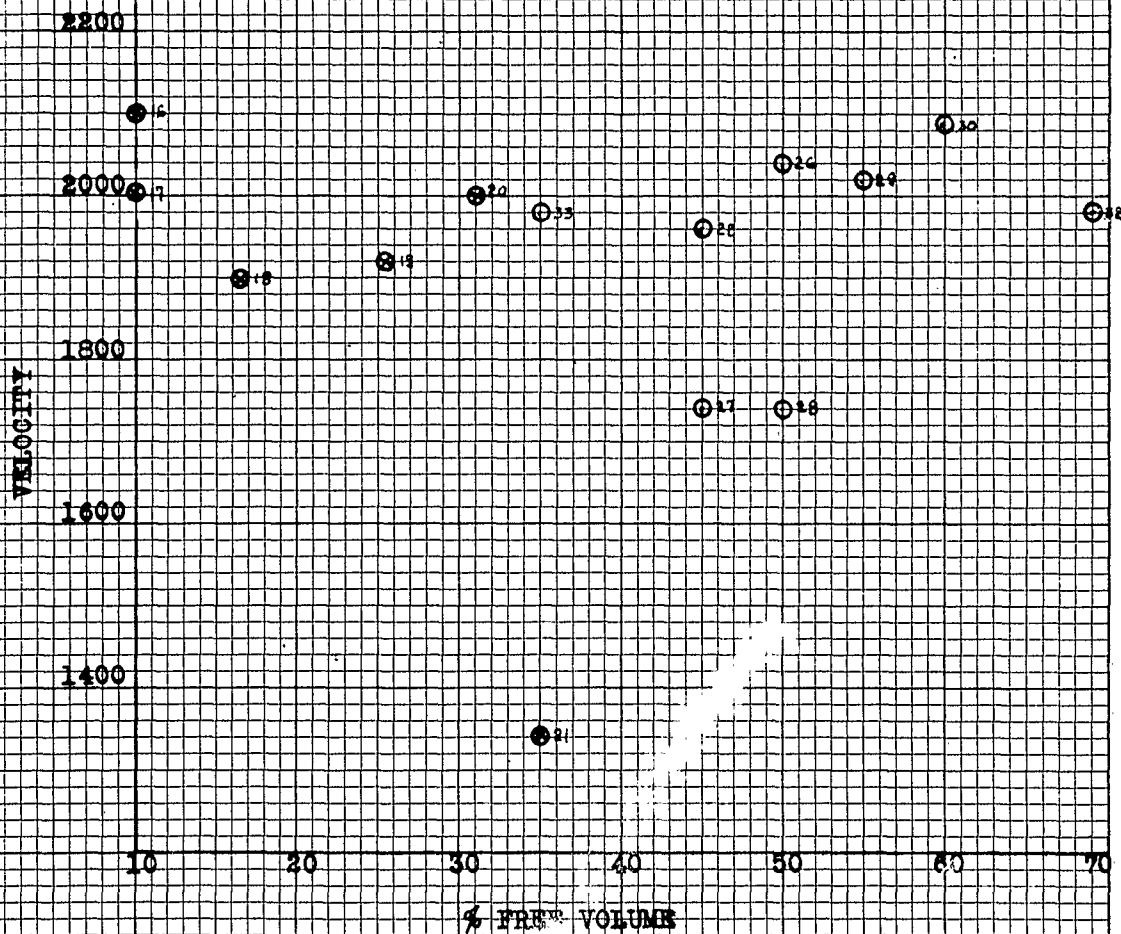
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Figure 26

REF-62061

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
Liquid Propellants Section

VELOCITY VS. % FREE VOLUME

2800

VELOCITY, FEET/SEC

2600

2400

2200

2000

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% FREE VOLUME

20

10

0

89

84

86

87

88

85

83

82

81

80

79

78

77

76

75

74

73

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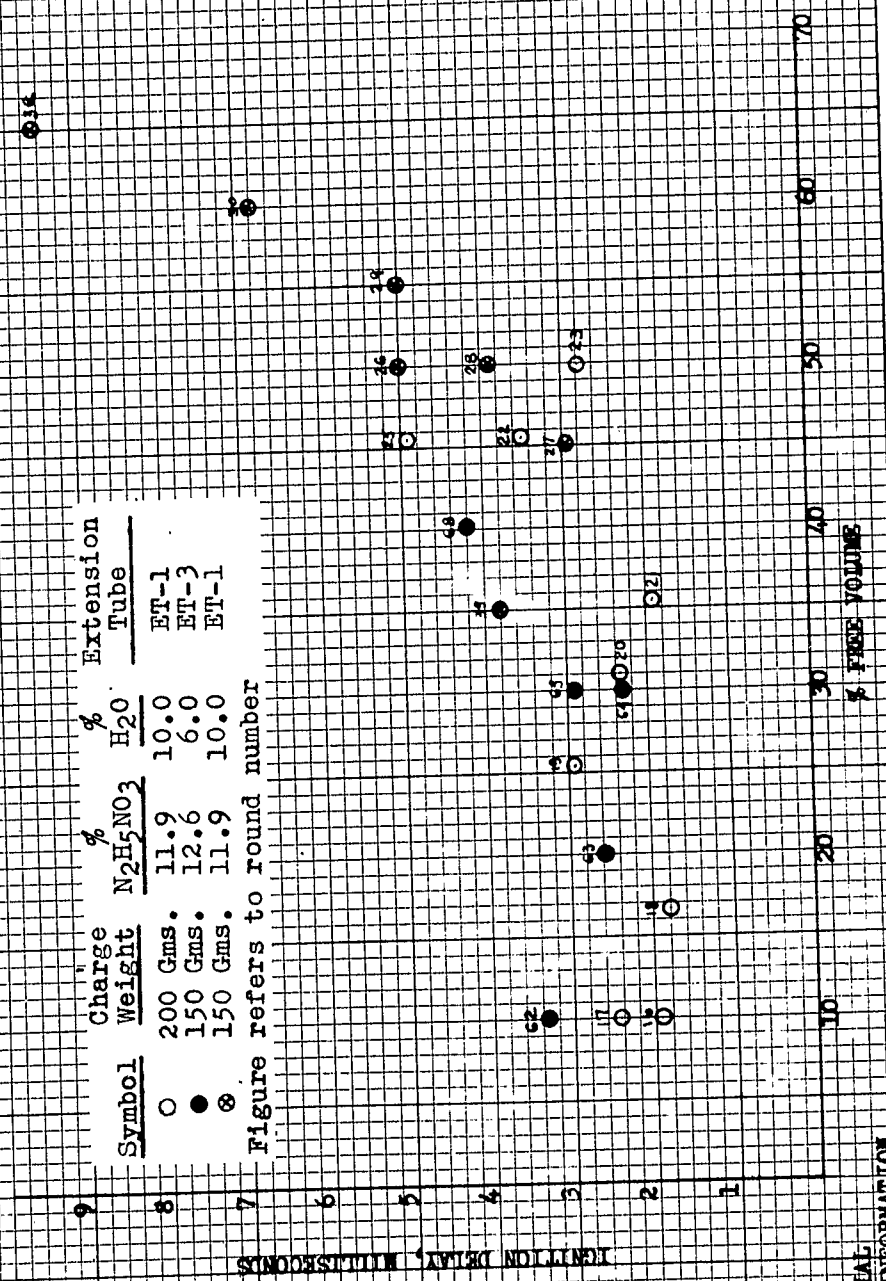
U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellant Section

IGNITION DELAY VS % FREE VOLUME

Symbol	Charge Weight	% $N_2H_5NO_3$	% H_2O	Extension Tube
O	200 Gms.	11.9	10.0	ET-1
●	150 Gms.	12.6	6.0	ET-3
⊗	150 Gms.	11.9	10.0	ET-1

Figure refers to round number



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Figure 28

NP9-62864

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

VELOCITY VS MASS RATIO

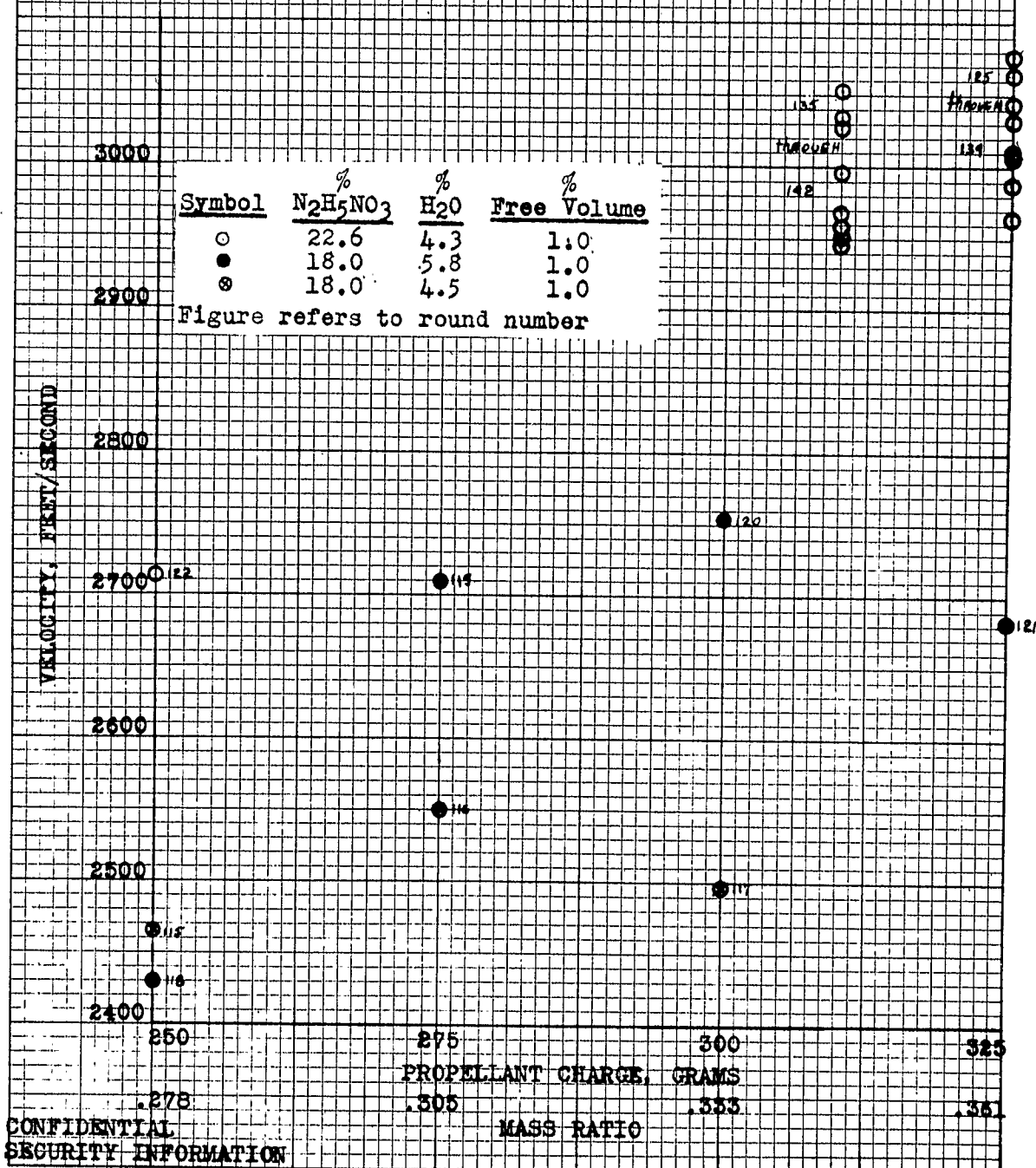


Figure 2-9

NP9-62663

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U. S. NAVAL POSTGRADUATE SCHOOL
HYDROGRAPHIC ENGINEERING DIVISION

Liquid Propellant's Section

VELOCITY VS MASS RATIO

Symbol	$\text{N}_2\text{H}_4\text{NO}_2$	H_2O	Free Volume
○	12.6	6.0	30.0
●	18.0	5.8	30.0
●	11.9	10.0	10.0

Figure refers to round number

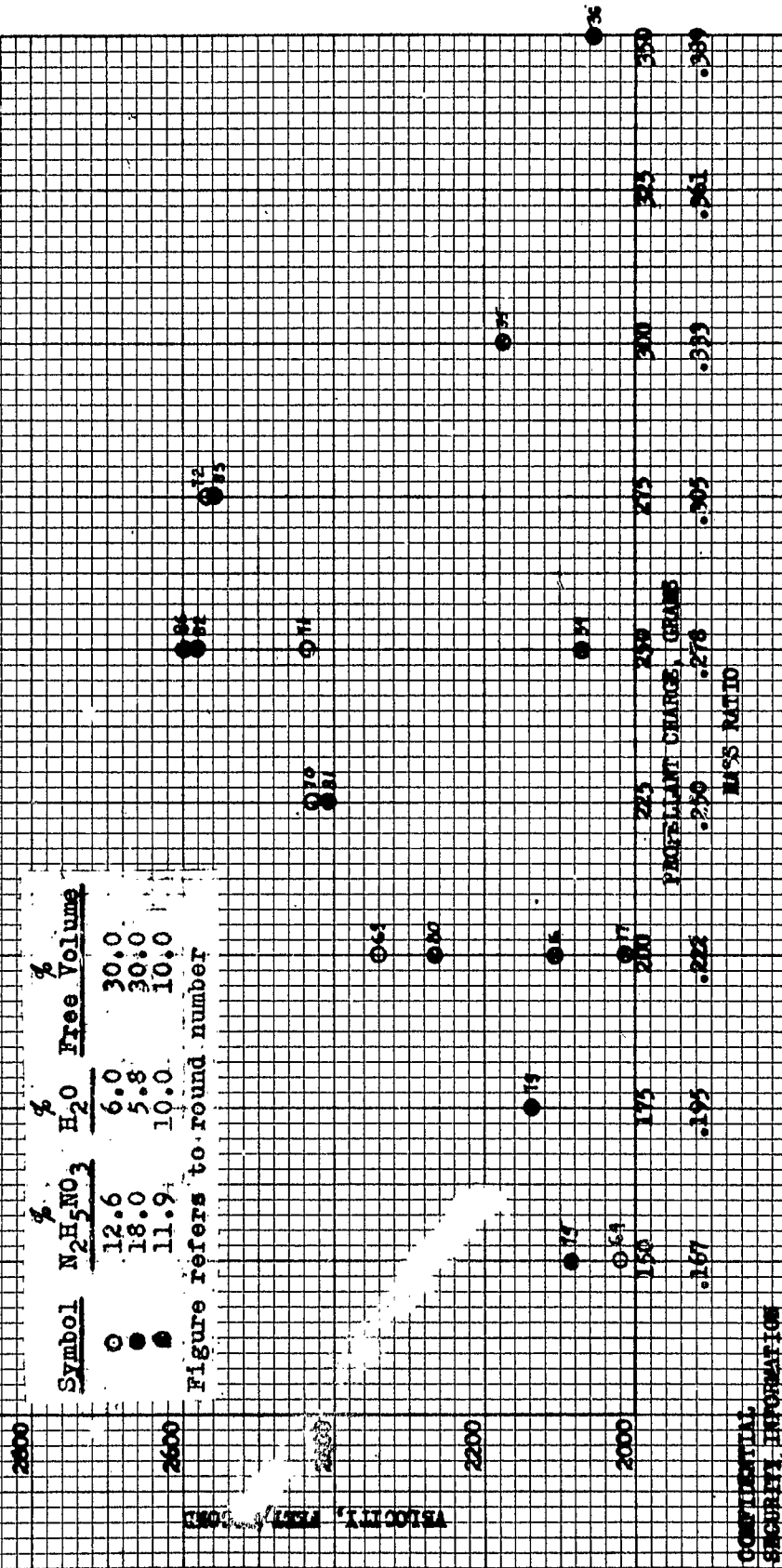


Figure 30

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TABLE II

Primer Design Effect on Ignition Delay

Round No.	Free Volume	Charge Weight	$\% \text{N}_2\text{H}_5\text{NO}_3$	$\% \text{N}_2\text{H}_4$	$\% \text{H}_2\text{O}$	Extension Tube	Diaphragm Thickness	Ignition Delay
15	10%	200 Grs.	12.0	78.0	10.0	ET-2	.003	misfire
53	17%	150 "	12.6	81.4	6.0	"	.006	2.0
57	20%	"	"	"	"	"	.004	1.6
54	"	"	"	"	"	"	.003*	misfire
58	"	"	"	"	"	ET-3	.025	1.4
59	"	"	"	"	"	"	.020	2.6
60	"	"	"	"	"	"	.015	7.6
61	10%	"	"	"	"	"	"	6.0
38	"	"	11.9	78	10	"	.008	misfire

* .003" thick with a small pinhole plugged with wax

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TABLE III

Approximate Free Volume for Various Caliber Guns

Gun Type	Approximate Chamber Volume	Approximate Solid Propellant Charge	Approximate Liquid Propellant Charge	Free Volume	Liquid Propellant Charge for 10% Free Volume
20mm	2.9 in ³	0.095 lbs.	0.095 lbs.	10	0.095 lbs.
40mm	28 in ³	0.66 "	0.66 "	35	0.92 "
3"/50	222 in ³	4.5 "	4.5 "	44	7.4 "
5"/38	650 in ³	15.5 "	15.5 "	34	21.5 "
5"/54	800 in ³	18.5 "	18.5 "	36	26.4 "
6"/47	1470 in ³	32.0 "	32.0 "	40	48.5 "
8"/55	3370 in ³	75.0 "	75.0 "	38.5	111.0 "

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