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MINISTRY OF SUPPLY

ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

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A.R.D.E. MEMORANDUM (P) 3/56

GROUP 1
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Guns using Liquid Propellants

Progress Report No. 3, for the Period
1st July to 31st December, 1955

A. M. Goodall

Fort Halstead,
Kent.

February
1956

[redacted]

A.R.D.E.
Publishing Section

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Ministry of Supply

ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

A.R.D.E. MEMORANDUM (P)3/56

Guns using Liquid Propellants

Progress Report No. 3, for the period
1st July to 31 December, 1955

A. M. Goodall (P.1)

Summary

Progress in all branches of the project during the period is reported.

Research into the various problems associated with the use of monopropellants is being activity pursued. The corresponding practical experiments in large guns are somewhat handicapped by lack of equipment. The delay in beginning these firings is, however, expected to be short, and the complete programme now planned is expected to be under way early in 1956.

Approved for issue:

D.H. Chaddock, Principal Superintendent "P" Division.

[redacted]

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PREFATORY NOTE

This report was prepared in December, 1955, for presentation to the Mutual Weapons Development Team of the United States Mission to N.A.T.O.

Acknowledgments are due to a number of collaborations in the project, too numerous to mention individually, for contributions on their own branches of their work.

1. INTRODUCTION.

Progress is reported for all parts of the project on which work was done during the period. Where no work has been done, the position is stated, if different from that last given. Whenever possible, references are made in each section to corresponding passages in Progress Report Nos. 1 and 2, or the "Statement of the Position at 1st July, 1954". The section number of these passages is preceded by (R1) or (R2), indicating the first or second Progress Report, or by (S) to denote the Statement of 1st July, 1954.

2. BI-PROPELLANT TANK GUN (Reference (R2) 2).

2.1 Experimental 20 pr. gun (Reference (R2) 2.2)

The modifications to this gun have been completed. Firings are planned for the immediate future using the bottom and right injectors, the other two being blanked off with plugs. The pistons are fitted with spray plates having a total orifice area of 1.75 sq.in. (Oxidant .826 sq.in., fuel .924 sq.in.).

2.2 Chromium plating of gun steels (Reference (R2) 2.2)

The contractor's report on the latest position of this investigation (5) shows that considerable difficulty is still being experienced. Although chromium is itself shown to be resistant to corrosion, no means has yet been found of preventing attack of the under layers through cracks in the chromium. Among the conclusions so far drawn from the experiments are the following :

1. Chromium deposits from conventional sulphate types of solution are probably too cracked to be satisfactory in service

2. Deposits from fluosilicate type solutions appear slightly better.

3. The addition of indium sulphate to a sulphate type of chromium solution does not appear to result in reproducible deposits.

4. The deposition of chromium-tungsten deposits has been found to be very difficult, and was in fact impossible in the present series of experiments.

5. The alloy deposits of tungsten with nickel, iron or cobalt are quite unsatisfactory.

6. The quality of surface finish of the base metal affects the rate of corrosion.

7. Raising the solution temperature to 180°F improves the corrosion resistance by decreasing the extent of cracks. This is true of fluosilicate types of solution, though not of sulphate solutions.

A number of other apparently promising lines of investigation are still being examined.

2.3 Static and dynamic seals (Reference (R2) 2.3)

2.3.1 The seal testing apparatus is now complete and trials of a specially designed sealing device are about to commence. A drawing of the apparatus is given at Fig.1.

As will be seen, the essential parts are a piston and a cylinder. The part of the piston on which the seal works is $3\frac{1}{2}$" diameter. The remainder of the piston is slightly larger in diameter, and the small difference in size enables a high pressure to be exerted on the enclosed liquid by the application of a moderate force to the end of the piston. The pressure is measured by means of a strain-gauge type pick-up whose output is fed to a cathode-ray oscillograph so that the pressure-time characteristic can be recorded.

When a seal is being tested the piston is forced forward by a press or some similar device and the pressure in the liquid is controlled by the needle valve. Any leakage during the test can be detected visually. The piston is returned by the pressure of the liquid in the storage tank.

The apparatus is suitable only for seals of $3\frac{1}{2}$" internal diameter, but a variety of types and cross-sections can, of course, be accommodated.

2.3.2 Arrangements are about to be put in hand for the development in Great Britain of seals using the Kel F elastomer produced by the M.W. Kellogg Company of Jersey City, N.J.

2.4 Contract with Experiment Incorporated (Reference (R2) 2.4)

2.4.1 After the decision taken in June to discontinue bi-propellant work on this contract the firm was visited on September 7th by a representative of A.R.D.E. to discuss the revised programme of investigation into monopropellants. The development of a technique for determining rate of burning under various pressure conditions with a tangential injection apparatus is now in hand. It is hoped that some results will shortly be available.

2.4.2 The A.R.D.E. has a secondary interest in a number of other developments in progress at this firm, such as, for example, the use of Stellite liners and bushes in propellant injectors in order to reduce wear and distortion; and the sealing of pistons by means of laminated stainless-steel rings pre-loaded with grease in the base of the ring groove and the annular space between the two piston rings. With this system there is no pressure intensification on the grease, which is fed by a normal grease gun. A further device, based on a suggestion by A.R.D.E, for ballistic control of monopropellant during injection is now being tried in a 60 mm gun.

3. MONO-PROPELLANT WORK IN LARGE GUNS (Reference (R2) 3)

3.1 Bulk loaded gun. 17 pr. (I.C.I. Ltd.) (Reference (R2) 3.2)

3.1.1 The previously reported damage to the breech of the gun, which led to the suspension of firings, has been attributed to impact of the cartridge case on the breech block in rounds which showed a very steep initial rise in pressure. Firings were resumed with a new gun and a total of 100 rounds has now been fired.

Two unsuccessful attempts were made to reproduce an earlier round which showed a more gradual pressure rise. These two rounds caused increases in cartridge head clearance of .003 and .002?in. respectively and rapid pressure rises were recorded.

All subsequent rounds have been fired with an interference packing between the base of the case and the block and there has been no further increase in head space although similar rapid pressure rises have been recorded.

3.1.2 A group of 24 rounds was fired with primers standardised at 6 grammes filling and 2.3 tons/sq.in. bursting pressure, but with the size and number of venting holes varied. The size of rubber sponge (Rubazote) pad was also varied. These rounds have indicated that venting holes of .125 in. dia. give successful ignition with rapid pressure rise. With holes of smaller diameter ignition did not always occur, but whenever it did a slow pressure rise was recorded. It appears that hole size is critical and that variation by as little as .005 in. can produce a marked change in behaviour.

3.1.3 Irregularity of ignition was considered to be in part due to variations in the initial movement of the shot, which has about $\frac{1}{2}$" of free travel in this gun. An attempt was made to eliminate this variant by separately loading the shot for a series of 3 rounds. Ignition was successful with a diffusion head which might have been expected to fail to ignite, but ballistic performance was irregular, probably because of the inclusion of air between the rubber pad at the front of the case and the base of the shot.

3.1.4 The shot was then redesigned by altering the position of the driving band to ensure that the band engaged the rifling on loading as a fixed round, and a series of 17 rounds was fired, varying igniter hole size and thickness of Rubazote pad. Conclusions drawn from this series were :

(a) Variation of hole size has little effect on initial pressure rise
(b) Ignition is successful with holes of .125" dia. but is not always successful with smaller holes - about 50% success is achieved with holes of .113 in. dia.
(c) Increasing the size of pad from 5 cu.in. to 10 cu.in. tends to produce a very rapid initial pressure rise, while removing the pad entirely introduces the chance of failure to ignite.

3.1.5 A further group of 3 rounds was fired in which charge weight was increased by steps from 1250 to about 1800 grammes. There was little difference between the first two of these and earlier rounds, but the last round gave a very rapid pressure rise, the reason for which is not yet clear.

The firings were continued using gradually increasing charges.

3.1.6 Work on primer development in connection with these firings has been mainly concerned with measuring venting time, defined as the time required for the pressure to fall from its maximum value at the time of burst of the bursting disc to $\frac{1}{3}$ of that value. The diffusion head was varied from 6 holes of 1/16" dia. to 12 holes of $\frac{1}{8}$" dia. and times of venting varied correspondingly from 14 to 3 milliseconds.

3.1.7 A number of experimental primers were fired in the A.R.D.E. transparent chamber. Most of the tests were vitiated by early bursting of the chamber, which appeared to be due to the boring action of the jets venting from the diffusion head. One round with a diffusion head of 12 holes at 1/16" dia. gave some indication of the manner in which the gases may be expected to vent into the liquid in the 17 pr. gun.

3.1.8 For ballistic analysis purposes five rounds have been analysed using a conventional energy-balance system and a force constant of about 45 tons/sq.in/gramme/c.c. has been deduced.

3.1.9 Work on spark ignition has been directed towards the determination of minimum energies and optimum conditions of ullage in the spark chambers. Results are not yet conclusive, but it appears that zero ullage is essential in the spark chamber and desirable in the second plenum chamber.

3.1.10 Some work has also been done to determine the most suitable electrode material. Nickel, copper, brass, mild steel, stainless steel, Nimonic and Monel have been used in both air and iso propyl nitrate and further experiments are contemplated to examine the effect on the ignition process of metal vapour produced by the spark.

3.1.11 A detailed report covering the work done during the first half of the period under review has been published by I.C.I. Ltd. (8).

3.2 Bulk loaded gun. 17 pr. (A.R.D.E.) (Reference (R2) 3.3)

3.2. It is hoped that the first of these guns, together with the necessary fittings and apparatus, will be delivered early in 1956.

3.3 Bulk loaded gun. 20 pr. (Reference (R2) 3.4).

Delivery of the slave gun and liquid supply mechanism is expected shortly and a programme of firings is being planned.

Trials on the hydraulic shot-ramming device have been continued with a redesigned valve, and using various kinds of sealing device on the base of the shot.

The sealing of the redesigned valve has been successfully tested in a cordite gun at pressures up to 35 tons/sq.in.

3.4 New A.R.D.E. Gun Emplacement

A new emplacement capable of taking these large monopropellant guns has been built at the A.R.D.E., Langhurst, Sussex, and will shortly be brought into use.

4. INTERNAL BALLISTIC RESEARCH (Reference (R2) 4).

4.1 Transparent-chamber firings.

4.1.1 Firings have been made using primers venting through a single axial hole to measure jet velocity and penetration and their dependance upon hole size and primer filling. The velocity of penetration appears to be roughly proportional to hole area and to the fourth root of the primer loading density, and is greater in nitromethane than in water. Further firings will be made to try to establish a definite relationship.

4.1.2 The apparatus is being modified to take $1\frac{1}{2}$" dia. tubes as well as $2\frac{1}{2}$" dia. so that the effects of variation of primer parameters may be compared visually in the transparent chamber and ballistically in the 2 pr. gun.

Various kinds of glass fibre tube have been tried, but none were found to be satisfactory as regards strength and translucency. The possibility of using crystal-clear P.V.C. is now being explored. This material has considerable elasticity and may provide stronger tubes in the smaller diameter.

4.2 Gun firings with iso propyl nitrate.

4.2.1 Firings in the 2 pr. were undertaken to obtain initial information on the behaviour of I.P.N. in a gun and to study the effect of variation of shot weight with all other parameters held constant. For all rounds the case was filled with IPN (390 c.c. ≡ .91 lb) and ignited by a No.12 Primer modified for electric firing. (Filling : 64 grains G.12 powder).

Results were as follows:-

Shot Weight	M.V. ft/s	Max.pressure	Pressure/time curve
¼ lb	ca 5500	Approx. 23 tons/sq.in.	Very sharp peak
[illegible] lb	ca 4000		Less sharp peak and beginning of second peak
¾ lb	ca 3100		3 peaks

Nominally identical rounds have very different pressure/time curves, indicating the need for many more firings.

4.2.2 In order to obtain information on full-scale firings a parallel investigation was begun, using a 17 pr. gun. For all rounds the case was filled with liquid (about 11 lb) and ignition was by a No. 9 Primer (16 drams G12).

Results were as follows:-

Rd.	Propellant	Shot Weight	M.V. ft/s	Max.pressure Approx.	Remarks
1	IPN	3¾ lb	5320	24 tons/sq.in.	Normal
2	IPN	3¾ lb	5152		
3	IPN	6 lb	4390	30 "	
4	Nitro-Methane	3¾ lb	6641	35 "	Gun badly damaged.

The records all showed early shot ejection. A change to a 77 mm gun was then proposed. The 77 mm has a chamber capacity of 152 cu.in., a shot travel of 11 ft and an expansion ratio of 7.4, compared with 4.5 in the 17 pr.

4.2.3 The only gun immediately available had been shortened by 4 feet, reducing the expansion ratio to 4.8.

Results in this gun were as follows:-

Charge : 2450 c.c. IPN ≡ 5.725 lb
Ullage : 2%
Ignition : No.11 Primer (6 drams G12).

Shot Weight	M.V. ft/s.	
3¾ lb	4505	Max. Pressure approx. 26 tons/sq.in.
	4496	P-t curve has 2 peaks
	4503	
	4522	
	4462	
Mean	4518	

Shot Weight	M.V. ft/s	
6 lb	3953	) Max. pressure approx. 26 tons/sq.in.
	3733	) P-t has 2 peaks, with 2nd peak much closer in
	3822	) height to 1st than formerly.
	3774	)
Mean	3820	

The series with the lightweight shot is sufficiently regular for a detailed internal ballistic study. A full length 77 mm has, however, now been procured, and firings have been carried out in it with the following results:

Shot Weight	M.V. ft/s	Shot weight	M.V. ft/s	Shot weight	M.V. ft/s
	4875		3967		3552
	4972		3999		3536
$3\frac{3}{4}$ lb	4771	$5\frac{3}{4}$ lb	4120	$7\frac{3}{4}$ lb	
	4829		4040		
	4844		4142		
Mean	4858	Mean	4054	Mean	3544

Charge : 2400 c.c.
Ignition : No.11 Primer

4.2.4 Pressures were measured in the chamber and at points in the bore, using standard A.R.D.E. tourmaline piezo-electric gauges. The chamber pressure-time curves show a double peak which now seems to be characteristic of bulk-loaded liquid propellant firings. The magnitude of the first peak appears to be reduced with increases in shot weight, while the second seems independent of this.

4.2.5 Analysis of the records shows that a fair amount, up to one half initially, of the liquid charge follows the shot down the bore and that consequently normal pressure-gradient considerations do not apply. The need for further work on this point is evident before a satisfactory internal ballistic system for liquid propellant guns can be evolved.

4.3 Ignition studies (Reference (R2) 4.6)

4.3.1 Following earlier trials to determine ignitibility of various mono-propellants, coupled with ease of supply and control over explosive sensitiveness, a series of firings using a No.42 primer was carried out in a one-inch smooth bore gun using a mixture of 90% ethyl nitrate/10% N. butanol. These tests indicated a high degree of overall efficiency, cool burning and absence of flash. Pressure/time curves had a reasonably flat top and, weight for weight, muzzle velocities were high when compared with conventional solid propellants.

Repeatability of performance was not good, e.g. ± 70 ft/s at 2,300 ft/s (1).

Analysis of pressure curves indicated variation of ignition conditions as the probable cause, - a problem already found by other workers - and a new set of tests was carried out using a modified No. 42 primer.

4.3.2 In these further firings, using the same propellant, the No.42 Primer was separated from the propellant charge by a blow-out disc bursting at 800 to 1000 lb/sq.in. In order to obtain results applicable to conventional guns, a 30 mm Aden gun barrel was used. 49 rounds were fired using a fixed propellant charge of 34.5 grammes, and good repeatability was obtained at an average muzzle velocity of 2085 ft/s.

It was found after firing that slight expansion of the barrel had occurred at the commencement of rifling. This may, however, have been due to an initial dimensional error. A new barrel and breech chamber have been manufactured and the trials will be resumed.

4.3.3 A programme covering the determination of ignition criteria for the following series of monopropellants has been formulated, and work on the programme is taking place.

(a) Nitromethane
(b) Hydrazine/hydrazine nitrate/water
(c) Nitroglycerine/triacetin
(d) Ethyl nitrate
(e) Ethyl nitrate/nitro mixture
(f) Propyl nitrate/nitromethane
(g) Ethyl nitrate/butanol
(h) Hydrogen peroxide/acetic acid/water
(j) Hydrogen peroxide/diethylene glycol/water
(k) Isopropyl nitrate

4.4 Liquid Propellant Igniter (Reference (R2) 4.6)

Firings with this device have continued, and Fig.4 shows a series of enlarged views from a film of the firing event taken with a high-speed camera. It is hoped eventually to obtain a reasonably systematic break-up of the liquid, producing a burning surface of some regularity which will take the place of the "shape" of a solid propellant in ballistic calculations.

4.5 Gas snatching device (Reference (R2) 4.4)

Trials of this device have been carried out on a vented bomb firing iso propyl nitrate. The samples of gas are still under analysis.

A further systematic gas analysis is in progress, using a bomb fitted with a valve which enables samples to be taken after combustion is complete.

5. PROPELLANT RESEARCH (Reference (R2) 5).

5.1 Machines for testing sensitiveness.

5.1.1 The Working Party's attention has been drawn to two machines for testing sensitiveness of liquid propellants. One, which is of Canadian origin, is of the ball mill type and has been developed by P.E.Braid and R.C. Langille. (3). The other, a drop weight tester, was designed by the Olin Mathieson Chemical Corporation. (4). It has not yet been subjected to really extensive trials.

A critical examination of the two designs was made by E.R.D.E. and led to the following general conclusions:

5.1.2 (i) Braid and Langille Machine.

This is an extremely ingenious device in which the results are automatically integrated, thus avoiding the tedious statistics normally associated with impact machine work. It has, however, two major defects:

(a) The comparison of the sensitiveness of the explosives depends in this test on the actual volumes of gas evolved. The true basis of comparison is the fraction of the maximum possible evolution and this is different for different explosives. As this quantity may not be easily determined either experimentally or theoretically the procedure is fundamentally unsound.

(b) The machine is unsuitable for any material with appreciable vapour pressure, since a vapour phase explosion could lead to the consumption of all the explosive at once, with the probable destruction of the apparatus.

In view of these defects further work along the lines suggested by this machine does not appear to be justified at present.

5.1.3 (ii) Olin Mathieson Drop Weight Tester.

The impact testing of liquids presents certain difficulties, most of which are associated with the fact that air or other gas occluded with the sample affects the probability of explosion. This instrument is probably the best example yet of design to overcome these difficulties. Points in its favour are the precise regulation of the volume of air entrapped, the use of an explosion indicator (a burster disc) which avoids subjective data, and the ability to initiate very insensitive materials.

Its defects are the precise construction needed and the probable short working life, together with the excessive length of time taken to reassemble for each shot. The time element is important because all impact testing is statistical in character and a large number of shots are always wanted.

The machine appears to be well suited for mono-propellant testing, but in view of the lack of practical experience with it some reserve as to its actual value is still necessary.

The whole question of testing sensitiveness has been referred to the Sub-Committee appointed for the purpose. (Reference (R2) 5). In the meantime an application has been made to B.J.S.M., Washington, to obtain working drawings of the Olin Mathieson apparatus.

6. AIR-TO-AIR GUN

6.1 Test Gun (Reference (S) 2.8)

6.1.1 Some 17 schemes for the proposed air-to-air gun were analysed and the results published in the form of an appreciation. (Reference (S) 4.2.4). Several of these schemes have since been further developed to the sketch-design stage, and two of the most promising are briefly described below and illustrated by the drawings at Figs. 2 and 3. Work on these designs has now been stopped, but a full report on this branch of the project is in preparation.

6.1.2 Fig.2 shows a gun having a regenerative propellant-chamber system. The essential mechanical movements for feeding the round and charging the chamber occur simultaneously during the same cycle. This arrangement has been shown to be essential to the achievement of very high rates of fire. The principle of rearward ramming has been adopted, since it offers a slight gain in time over forward ramming. The firing cycle has been calculated for a rate of fire of 1500 rounds/min.

The operation of the scheme is as follows: On firing gas is tapped from the barrel and exerts pressure on the gas piston, which in turn operates a spring-loaded sliding cam. The cam, which is of horseshoe form, actuates a loading shuttle containing two chambers and on the outward stroke moves it through half its travel. The cam returns under spring pressure and in doing so completes the movement of the shuttle, bringing the chamber which has just been fired into a position ready for re-loading. On the other side of the shuttle the second chamber, which has already been loaded in the previous firing cycle, is moved into the firing position. The liquid propellant is under constant pumping pressure and will enter and fill the regenerative chamber unless an opposing firing pressure prevents it. As the drawing shows, the cut-off is effected by a cylindrical flange valve adjacent to the inlet ports, which has feed holes out of line with these ports. Thus, when the chamber pressure is applied to the liquid propellant through the piston head, the flange valve closes and prevents further ingress of propellant during firing.

The regenerative piston head with its central valve is similar to those used in the injectors previously described. Since the shuttle is loaded alternately from the right and left hand sides of the gun the ramming gear is duplicated to suit. The cam on its return stroke operates the appropriate side of the ramming gear through a system of levers as the shuttle reaches the firing position. The projectile is rammed by an impulsive force applied to the nose, and enters the shuttle chamber base first under its own impetus.

No ignition device is shown on the drawing.

6.1.3 Fig.3 shows a 3-chamber revolver-type gun in which gas pressure tapped from the barrel provides the power for rotating the drum, and also for initial loading of the round. As before, the essential mechanical movements are completed during one firing cycle. The projectile is again loaded base first by an impulsive force applied at the nose. At the end of the loading movement a deformable skirt on the base of the projectile is driven on to a conical bush in the end of the chamber, thus spreading the skirt and creating a liquid-tight seal. The projectile is then rammed forward on to the shot seating by the pressure of the incoming liquid propellant acting on its base. In this way the ullage in the chamber on firing is reduced to a minimum.

The propellant is led to the three chambers of the drum from an inlet on an axial supply pipe. Entry of liquid to each chamber is controlled by an inlet valve fitted with pressure-intensifying seals. The three valves are actuated from a stationary circular cam in such a way that while two valves are kept closed the third is free to lift under the action of the liquid pressure and admit propellant to the chamber, into which a projectile has already been loaded. Before firing the valve is closed by the cam, assisted by spring pressure, and the additional pressure of firing is intensified to create a gas-tight seal.

The ignition system has been omitted from this drawing also.

7. HANDLING, STORAGE AND STOWAGE OF LIQUID PROPELLANTS (Reference (R1) 6.2)

7.1 General

Early experience in providing experimental guns with propellant indicated the importance of this subject and the necessity for a detailed study of the methods of supplying propellant from the factory to the gun chamber. A preliminary survey of the literature showed that much useful information was available from work on rocket research and development. This work was, however, not entirely applicable to liquid propellant guns; moreover, a number of gaps occur in the available knowledge which would have important effects on a system, manually operated in a fighting compartment, in which closely metered quantities of propellant have to be supplied under pressure. Further, it is necessary to consider the effect of enemy action on the installation. A programme of research and development has therefore been instituted to cover this subject. Full details have not yet been evolved, but the main headings may be said to be:

1. Logistics
2. Engineering of supply
3. Supply hazards (e.g. Toxicity)

While each item is in itself an important field of effort, assuming availability and effective performance of the various propellants, it appears that Items 1 and 2 will depend in detail on what can be said with regard to 3. For this reason primary consideration has been given to the study of supply hazards. The work already in hand on feed systems for experimental trials will, of course, continue. A contract for the investigation of the supply problem, covering research and engineering development, has been placed with Messrs. Electro-Hydraulics Ltd. of Warrington, Lancashire, a subsidiary of Rubery Owen Ltd. Exploratory work has now commenced.

7.2 Logistics

As a first exercise the problem of supplying guns fitted in Armoured Vehicles is being considered. Estimates are being formulated of the quantities of propellant required for each regiment, etc. General questions of the suitability of bulk containers or ready-use cans as the means of supply from the factory are being studied in relation to transport by road, rail, sea and air, base handling, and transfer into the supply tanks of Armoured Vehicles.

7.3 Engineering of Supply

7.3.1 The two propellant pumps developed by J. & E. Arnfield Ltd., and the A.R.D.E. (Reference (R1) 6.2) are under test. The Arnfield equipment is now under modification to overcome difficulties caused by "pick-up" on stainless steel parts, and trials will be resumed early in 1956. The tests of the A.R.D.E. pump have so far proceeded without incident.

7.3.2 The development of the 50-lb portable container by Portsmouth Aviation Ltd. is being continued. (Reference (R1) 6.2). Various methods of transfer from the container to the gun ready-use tank are now being studied. Some rough-usage trials have also been carried out. An analysis of cost has been made in preparation for a limited production of the container for development trials.

7.3.3 Corrosion tests have been carried out on stainless steel (EN58F) and aluminium (99.5%) both in electrical contact and electrically insulated, also with and without movement of the propellants under test, (Nitric acid 65%; Hydrazine/hydrazine nitrate/water; Ethyl nitrate/butanol). In 65% nitric acid, aluminium was less resistant than stainless steel and the corrosion rate of aluminium was increased by approximately 60% when in electrical contact with stainless steel. Stirring further increased the corrosion rate by 10%. In hydrazine/hydrazine nitrate, stainless steel was less resistant than aluminium and the corrosion rate was increased by approximately 10 to 20% by electrical contact. The effect of stirring was to increase the rate of corrosion of stainless steel, particularly when in electrical contact with aluminium. In ethyl nitrate/butanol corrosion was in all cases negligible. A further series was carried out in 95% nitric acid, iso propyl nitrate, and nitromethane. With 95% nitric acid, the rate of corrosion of the aluminium was increased by three times by contact with stainless steel, being about 10 thousandths of an inch per year. When the corroding medium was stirred this factor was reduced from 3 to 1.5. Further, the effect of stirring was to increase the corrosion rate of aluminium when not in contact with stainless steel to about 7 times. In nitro methane there was found to be a measurable rate of corrosion of aluminium when in contact with stainless steel, but not of the stainless steel itself. In iso propyl nitrate corrosion rates appear to be negligible.

7.3.4 Some exploratory tests have been carried out to indicate the possible use of self-sealing propellant tanks in the gun locality. A self-sealing composition to Air Ministry specification D.T.D.1094 was used. With alkyl nitrates the inner skin of vulcanised rubber swells more than the foamed latex, but not very rapidly. Rubber appears to promote the decomposition of hydrazine.

7.4 Supply hazards - Toxicity

7.4.1 An investigation into the toxic hazards associated with the use of liquid propellants has been put in hand at the Chemical Defence Experimental Establishment (C.D.E.E), Porton, Wiltshire. Samples of some six monopropellants have been supplied to Porton, and a preliminary examination of their acute toxicity has been carried out. (2). The six liquids were:-

(a) Ethyl nitrate
(b) Iso propyl nitrate
(c) Ethyl nitrate (60%)/iso propyl nitrate (40%)
(d) Ethyl nitrate (91%)/N. Butanol (9%)
(e) Hydrazine (76%) in water
(f) Hydrazine (54%)/hydrazine nitrate (36%)/water (10%)

Gasoline MT80 was used for comparison purposes. The experiments included vapour exposure, subcutaneous injection and percutaneous toxicity studies on mice, rats, rabbits, guinea pigs and a monkey, also a brief vapour exposure with human volunteers. No vapour exposure had been made with the hydrazine propellants (e) and (f) as a suitable vapour concentration could not be obtained owing to their low vapour pressures.

The alkyl nitrate propellants (a), (b) (c) and (d) were of the same order of toxicity as gasoline. The hydrazine propellants (e) and (f) were highly toxic by the subcutaneous and percutaneous routes. It has been agreed that the acute toxicities of nitromethane and nitroglycerine/triacetin should be investigated and that, if facilities allow, the following should be examined for chronic effects:-

(h) Ethyl nitrate
(j) Nitromethane
(k) N. Butanol
(l) Gasoline.

7.4.2 A contract has been arranged with Messrs. Nash and Thompson Ltd., of Tolworth, Surrey, to survey literature and develop a suitable toxicity alarm instrument for use in both experimental and service installations. The advantages and disadvantages of various methods of detection have been discussed (6) (7) and it has provisionally been decided to concentrate on infra-red absorption, with catalyst poisoning as a second choice. The methods discussed are:-

(a) Magnetic susceptibility
(b) Heat of combustion
(c) Absorption and Emission of radiation
  (i) Ultra-violet
  (ii) Visible
  (iii) Infra-red
  (iv) Short wave
(d) Mass spectrometry
(e) Poisoning of catalyst
(f) Velocity of sound
(g) Surface absorption
(h) Positive ion emission
(j) Thermal conductivity
(k) Density

7.4.3 An infra-red analyser for gases has been obtained for Messrs. Nash & Thompson and has been tested with various concentrations of ammonia in air, with a view to finding the optimum concentration for detector filling. Ammonia was chosen for ease of working and for its relatively non-toxic properties, also to throw light on its use as a detector filling for hydrazine. The conditions for producing and continuously analysing gas mixtures from 8 to 25000 parts per million of ammonia in air have been determined. The research is at much too early a stage to give any firm indication as to Service practicability. It is, however, obvious that instrument simplification is necessary and apparent that it can be done. An apparatus has been obtained for preparing mixtures of nitrous oxides and air of known concentration.

8. DISCUSSION AND ASSESSMENT.

8.1 Bi-propellant injector guns.

With the completion of the short trial on the experimental 20 pr. gun, (See 2.1 above), British work on bi-propellant guns will be brought to a close. It is hoped to publish later a full report on this branch of the investigation, including the related work on internal ballistics.

Work at Experiment Incorporated on the hydrocarbon fuels has already been concluded.

8.2 Monopropellant work in large guns.

The extensive programme of experimental work on bulk loading is not yet in full operation because of delays in manufacturing the various guns required.

Delivery of this equipment is now imminent and an early start on the experimental programme is to be expected.

In the meantime experiments on a considerable scale have continued at I.C.I. Ltd., using a 17 pr. gun and loading the liquid propellant into cartridge cases. Primer development has formed a large part of these experiments. No conclusive results have yet emerged.

8.3 Internal ballistic research.

The study of the ignition process continues along two main lines of analysis:

(i) by high-speed photography of the firing of a charge in a transparent chamber;
(ii) by special firings in small guns, in an attempt to determine ignition criteria for various propellants.

Experiments by the first of these methods are somewhat hampered by the fragility of the available tube material, so that the part of the process which can be photographed is still only very short.

Spark ignition remains the subject of particular study. The ultimate aim of these trials is to establish optimum general conditions which could be used to guide the design of an ignition system for any given propellant.

Firings in the 77 mm gun using iso propyl nitrate loaded in cartridge cases have now reached a stage where a fair degree of regularity has been achieved. An anlysis of the results has been begun, but many more firings are still necessary to the evolution of a satisfactory ballistic theory.

8.4 Propellant research.

A long programme of experiments on sensitiveness is still being worked through.

The meetings of the special sub-committee to define an acceptable limit of sensitiveness for gun propellants have begun.

8.5 Air-to-air gun.

Work on the design of this weapon has now stopped because of the change in policy. The particulars given at Section 6 above provide some indication of the stage of mechanical design finally reached.

8.6 Handling, Storage and Stowage of Liquid Propellants.

Some work on this subject formed part of the earliest investigations into the potentialities of the liquid-propellant gun. (Reference (S) 2.6.3). The concentration of effort on the mono-propellant tank gun has enabled the investigation to be narrowed somewhat. The gap in the knowledge as regards toxic hazards has also become apparent. The programme of physiological experiments now launched at C.D.E.E., Porton, together with the contract for the development of a toxicity alarm, is intended to fill that gap, by eliminating obviously dangerous liquids, and so facilitate work on the engineering and logistic aspects of the problem.

8.7 General conclusion.

Research into the various probelms associated with the use of monopropellants, e.g. ignition, sensitiveness, toxicity and the development of a ballistic theory, is being actively pursued. The corresponding practical experiments in large guns are somewhat handicapped by lack of equipment. The delay in beginning these firings is, however, expected to be short, and the complete programme now planned will probably be under way early in 1956.

BIBLIOGRAPHY

1. A.R.D.E. Report (S) 16/55.
Ignition of Monopropellants in a Caseless One Inch Smooth Bore Gun.
J. E. Roberts and A. J. Taylor.

2. C.D.E.E. (Medical Division) Unpublished Report.
Preliminary Report on the Toxicity of Some Liquid Monopropellants.

3. Canadian Journal of Technology, 1955, 33, 228-235
A New Type of Impact Machine for Evaluating Sensitiveness of Explosives.
P. E. Braid, R. C. Langille.

4. Olin Mathieson Chemical Corporation Memorandum, January, 1955.
A Drop Weight Tester for Liquid Propellants.

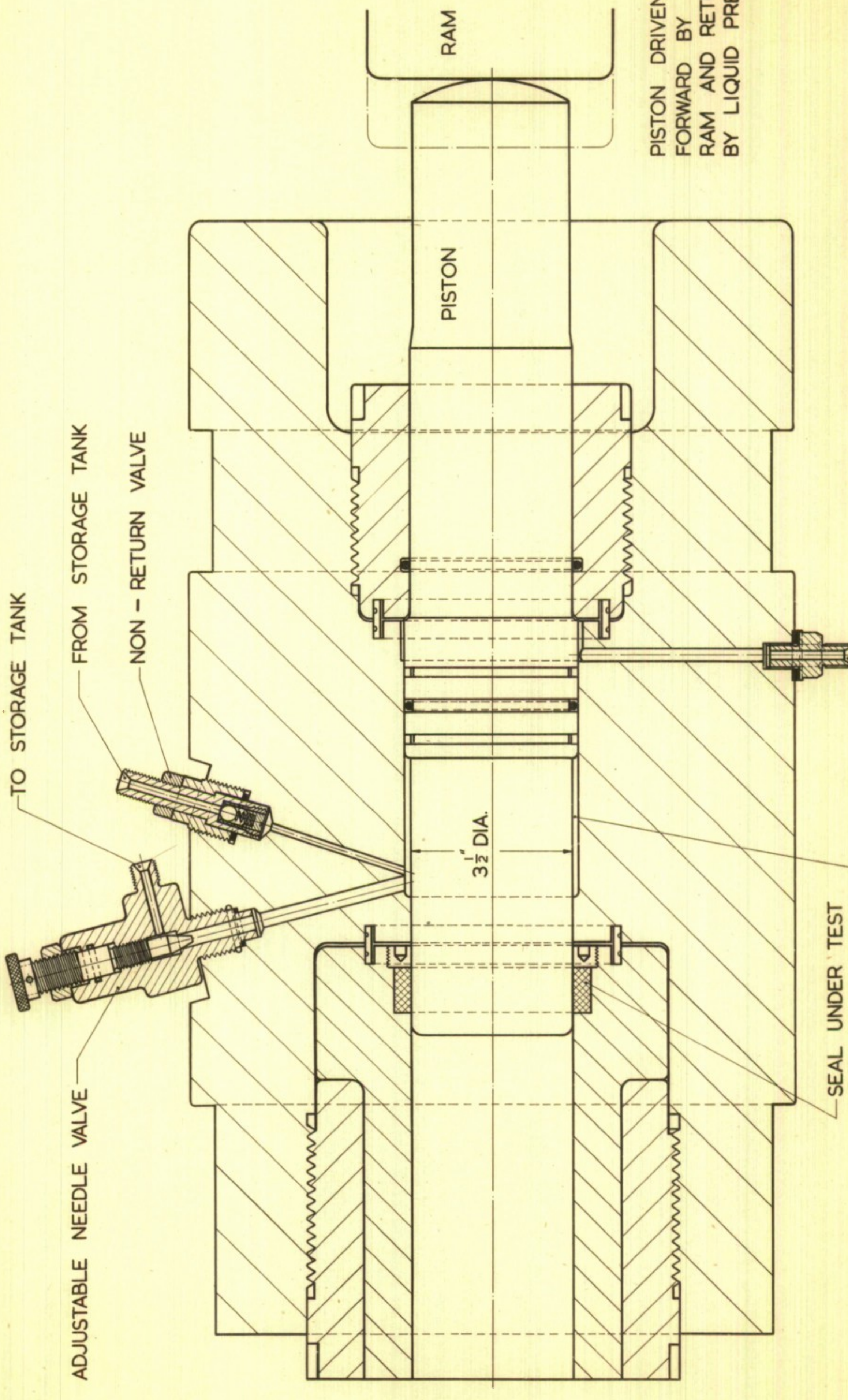
5. Ionic Plating Company Ltd.
Gun Development of Protective Metallic Coatings. Report No. 6
November, 1955.

6. Nash and Thompson Ltd.
Development of a Toxicity Alarm. Examination of the Problem and Recommendations for Practical Work. May 1955.

7. Nash and Thompson Ltd.
Development of Toxicity Alarm. November 1955.

8. Imperial Chemical Industries Ltd., Nobel Division,
Research Work on the Use of Liquid Monopropellants in Guns.
Progress Report for the Period 1st July to 30th September, 1955, with Supplement.

FIG. 1



SEAL TESTING APPARATUS

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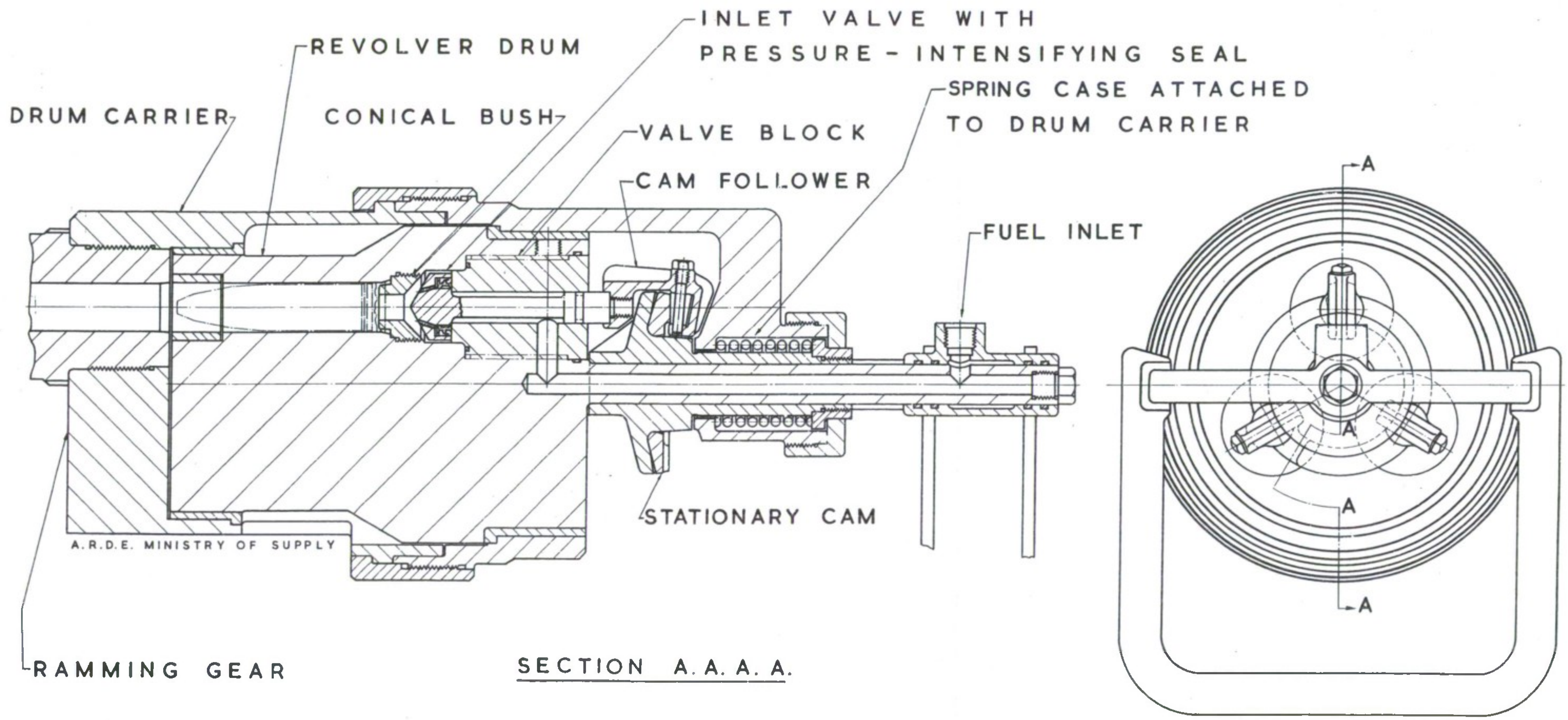
FIG. 3



LIQUID FEED SYSTEM FOR MONO - PROPELLANT
3 - CHAMBER REVOLVER - TYPE GUN

CONFIDENTIAL DISCREET

Fig. 2

REGENERATIVE PROPELLANT - CHAMBER GUN SYSTEM

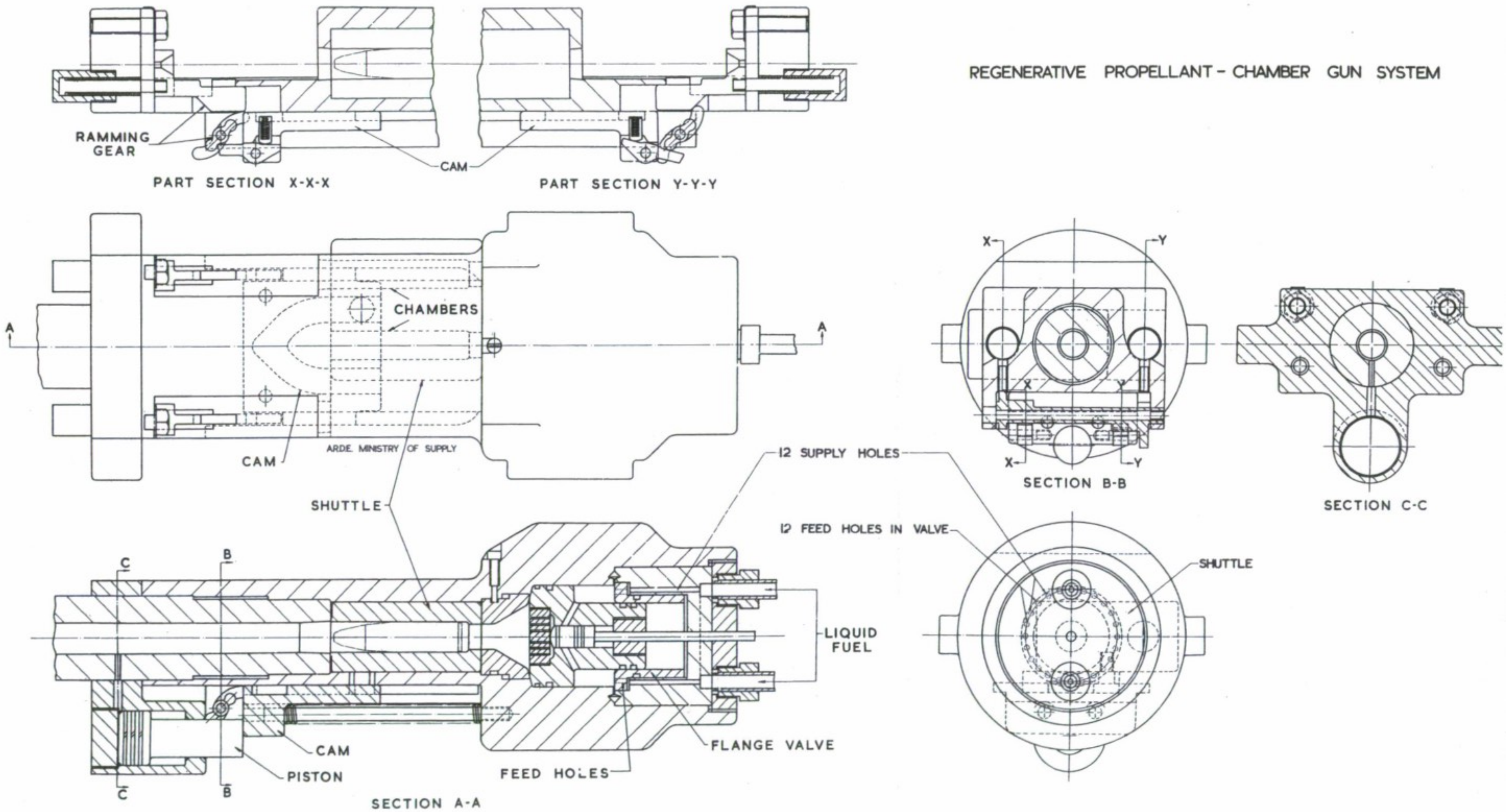


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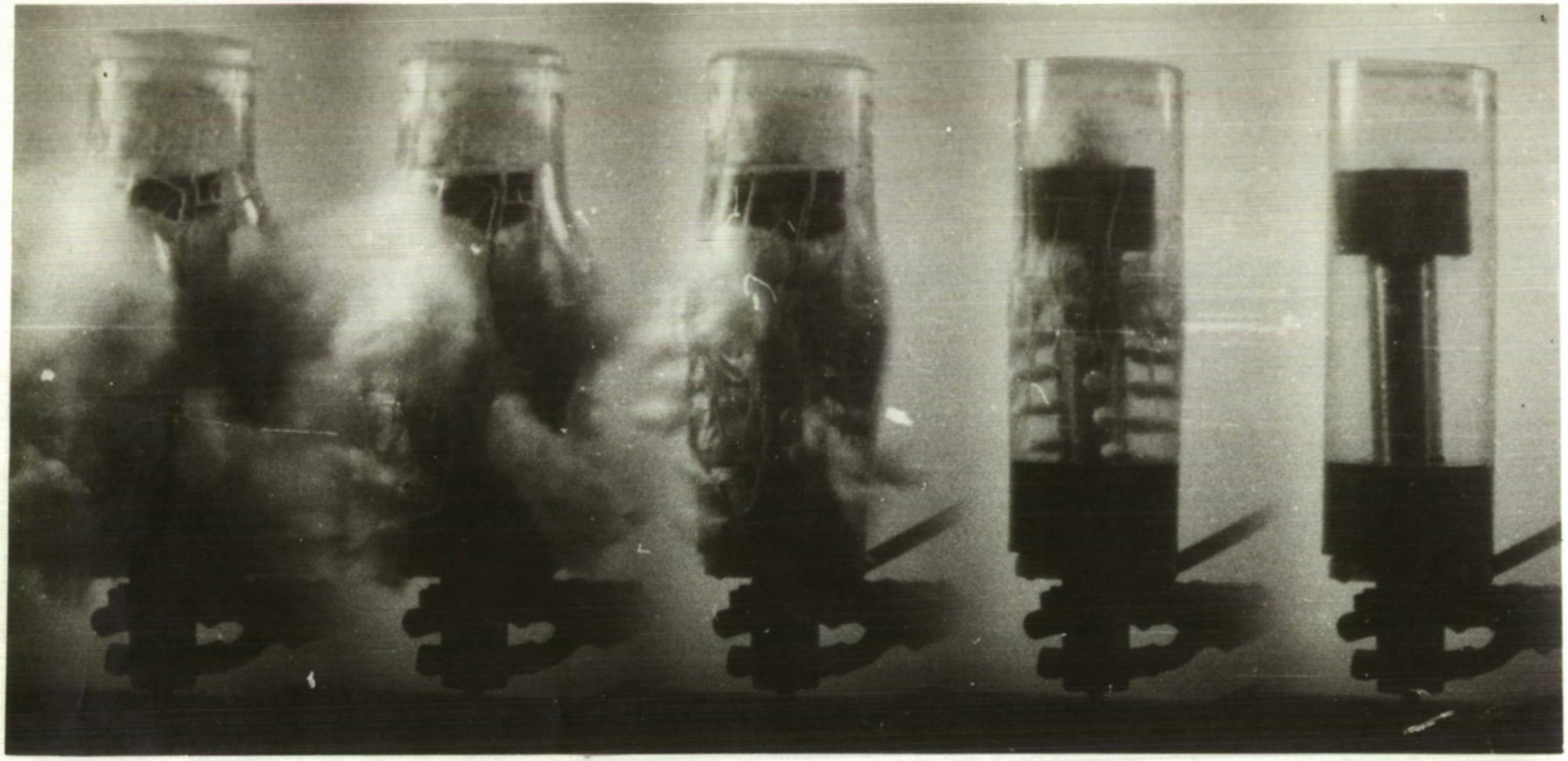
FIG. 4



← LIQUID LEVEL.

IGNITION BEGINNING. ← TIME VENTING FROM BODY BEGINNING.

ENLARGED PRINTS FROM FILM TAKEN WITH FASTAX CAMERA OF ELECTRIC IGNITER IN VERTICAL OPEN-ENDED PERSPEX TUBE CONTAINING NITROMETHANE.

SPARK ENERGY ABOUT 100 JOULES AT 5 K V.

FILM:- HP3 AT 12,000 FRAMES PER SECOND. ILLUMINATION:- 2 P.F. 100 PHOTO-FLASH BULBS.

CAMERA:- 2 IN. LENS AT F/2 APERTURE.

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