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ARMAMENT RESEARCH ESTABLISHMENT

PERMANENT RECORD OF RESEARCH AND DEVELOPMENT

No. 4.000(c)

Flashless Propellants

J. N. Pring

M.248/48.

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Key to symbols and abbreviations

ann.	annulus.
A.R.D.	Armament Research Department.
B.L.	breech loading.
cal. val.	calorimetric value.
carb.) carbamite) centralite)	diethyl-diphenyl-urea (symmetrical).
C.D.E.S.	Chemical Defence Experimental Station.
cry.) cryolite)	Na_3AlF_6
C.S.A.R.	Chief Superintendent Armament Research.
c. secs.	candle seconds.
C.V.	closed vessel.
D.B.P.	di-butyl phthalate.
d.c.d.a.	dicyandiamide.
D.E.R.	Director of Explosives Research
d.g.n.	diethylene-glycol-dinitrate.
diam.	diameter.
D.N.O.	Director of Naval Ordnance.
D.N.T.	dinitrotoluene.
D.P.A.	diphenylamine.
E.C. Mins.	Explosives Committee Minutes. (Oct. 1900 - April 1906).
E.F.C.	Effective full charge (the equivalent of the number of full rounds of standard charge previously fired).
F.A.	fixed ammunition.
f.s.	foot seconds.
G.C.	guncotton.
G.P.) R.F.G.) G.7, G.12.)	gunpowder.
H.V.S.S.	high velocity star shell.
K. cry.	$K_3Al F_6$
L.S.	Land Service.
m.d.	mean deviation.
M.J.	mineral jelly.

m.s.	milli-seconds.
M.T. / M.T. 7	multitubular (7 hole).
M.V.	muzzle velocity.
N.	nitrogen.
N.C.	nitrocellulose.
N.G.	nitroglycerine.
N.S.	Naval Service.
O.B.	Ordnance Board.
O.B. Mins.	Ordnance Board Mins. (Jan. 1908 - Dec. 1915).
O.B. Procs.	Ordnance Board Proceedings (Jan. 1939 -).
O.C.	Ordnance Committee.
O.C. Memos. B. (O.C.B.)	(July 1917 - April 1938).
O.C. Memos.	(April 1938 - Dec. 1938).
O.C. Mins.	(Dec. 1915 - Dec. 1926).
O.R.B.	Ordnance Research Board Mins. (May 1906 - Oct. 1907).
Petrolite / Picrite	nitroguanidine.
Q.F.	quick firing.
Q.L.	calorimetric value (water-liquid) Ardeer method.
R.D.	Research Department (later known as Armament Research Department or A.R.D.).
R.F.G.	See G.P.
R.G.P.F.	Royal Gunpowder Factory, Waltham Abbey.
R.N.C.F.	Royal Naval Cordite Factory, Holton Heath.
R.N.P.F.	Royal Naval Propellant Factory, Caerwent.
R.O.F.	Royal Ordnance Factory.
S.C.	solventless cordite or solventless carbamite.
S.L.	separate loading.
S.R.N.P.F.	Superintendent Royal Naval Propellant Factory.
S.S.	star shell.
S.S.C.	scroll solventless cordite.
S.T.	slotted tube.
S.V.	silvered vessel.
T.	tubular.

T.A.R.	Tank Armament Research.
T.N.T.	Trinitrotoluene.
V. of A.	velocity of adjustment, namely the velocity, with proof shot at 80°F., to which charges are adjusted. The "adjusted charge weight" of a lot of propellant is the weight of that lot required to give a specified velocity, known as the velocity of adjustment, in a new gun at a charge temperature of 80°F. with proof shot and crusher gauges.
V.M.	volatile matter.
W.G.	water gaseous.) in calorimetric determinations.
W.L.	water liquid.) in calorimetric determinations.

System of Nomenclature

The nomenclature employed for the propellants recorded in this monograph has been changed at different periods. For the purpose of uniformity the following designations have been adopted.

The chemical compositions denoted by the titles are tabulated in Appendix G. (p.100).

Except in the case of the cord form that part of the title denoting composition is normally followed by an oblique stroke denoting geometrical form, e.g.

/S , /M , /R , /T

N.F.Q./S and N/P/M

S denoting slotted tube

M " multi-tube

R " ribbon

and T " tubular

The letter P following an oblique stroke denotes the inclusion of 1 per cent of potassium sulphate and K denotes potassium cryolite. Larger percentages of these salts are denoted by figures e.g. /2P, /5P.

(a) Nomenclature employed		(b) Some earlier titles
Cordite	Mark I	R.D.N./A.Q. = N/A.Q.
"	M.D.	R.D.N./F.Q. = N.F.Q.
"	C.D.	
"	M.C.	R.D.N./A
"	R.D.B.	/B etc.
"	W	R.D.H./A
"	W.M.	R.D.H./A.Q. = R.D.Q.
"	S.C.	N/A
"	H.S.C. (In the case of this propellant the tubular form is denoted by H.S.C.T.)	
"	H.S.C./K (In the case of this propellant, the tubular form is denoted by H.S.C.T./K)	
"	L	
"	N	
"	N/P	
"	N.F.Q.	
"	S.N.F.Q. (now M.N.F.Q.)	
"	NQ	
"	N.Q.F./P	

Nomenclature employed (contd.)

Cordite N.Q.F.

" H.N.

" H.N./P

" H.P.

" H.P./P

" AN

" A.S.N.

" A

N.C.T. propellant

NH

FNH

FNH/P

In this Monograph, Roman numerals are used for denoting the Mark numbers of both Naval and Land Service Guns.

Abstract

A survey is made of the work conducted at Woolwich and elsewhere on the development of flashless propellants from the earliest date at which records on this subject have been available. The items included are, for the most part, quoted from the Minutes of the Ordnance Committee and Ordnance Board, from departmental reports and, in the case of work abroad, from publications in scientific journals. The main theories put forward to account for the factors which have been found to control the occurrence or suppression of muzzle flash are reviewed and a detailed resume is given of the steps by which flashlessness has been achieved in ordnance of pressively increasing size. The application of modified ignition systems has been involved and the advances have also been concerned with improvements in ballistic regularity, chemical stability, reduced gun erosion and the minimising of the amount of smoke accompanying the firing. A description is given of the method of manufacture and some of the properties of the new ingredient, nitroguanidine, which has been adopted for the first time as the main constituent of gun propellants.

Note: Since this Record was compiled in 1946 changes have been made in the titles of various establishments in the Ministry of Supply: the Armament Research Department, for example, has been renamed the Armament Research Establishment.

I. Historical survey of period prior to 1921

A. Service work

It is apparent from available records that the first systematic investigations directed by Service departments to the production of a so-called flameless propellant began at the time of the reconstitution of the Explosives Committee in May, 1900, with Lord Rayleigh as President.

The object of this Committee was for the co-ordination of work on the general improvement of ordnance, and for the conducting of investigations directed to this purpose there was founded, at Woolwich, the Experimental Establishment which was separate from the earlier Manufacturing Department at Waltham Abbey and the Inspection Department at Woolwich. This new Establishment, which later became known as the Research Department, was sited in the neighbourhood of the Proof and Experimental Establishment.

The position with propellants at this time was that, apart from a number of compositions consisting mainly of nitrocellulose, and known as "smokeless powders", which had been developed by industrial firms for use in rifles, shot guns and small weapons, a nitrocellulose-nitroglycerine composition known as Mark I cordite had been adopted by the Services for use in rifles and in larger ordnance. This propellant contained 58 per cent of nitroglycerine and, on account of its high calorimetric value (1225 cal./grm. (W.L.)), had an objectionably high erosive action on the barrels of guns.

As the outcome of investigations which were conducted at the E.C.
R.G.P.F. Waltham Abbey and by the Nobel Company at Ardeer to reduce Min.
the erosive effect, a composition was developed in which the N.G. 20
content was lowered to 30 per cent. The cal. val. of this compo- 320
sition, which was designated M.D., is about 1025 (W.L.) and the 451
propellant was approved for general adoption by both Land and Naval 560
Services in 1902. 594
612

With a view primarily to reducing erosion the earliest investigations of the reconstituted Explosives Committee were directed mainly to trials with a nitrocellulose composition known as the Rottweil powder. This consisted, apart from a high V.M. content, of 87.7 per cent soluble nitrocellulose and 11.9% insoluble N.C., the mean nitrogen content being 12.3 per cent. The composition was gelatinised with ether-alcohol. Though it was shown in firing trials to be less erosive than M.D. for a given velocity, the
ballistic regularity was found to be unsatisfactory which was 494
apparently due to the high and variable content of volatile matter. 619

Efforts were then devoted to the possibility of employing temperature-reducing agents in conjunction with the M.D. type of cordite. Consideration was first given to the addition of materials external to the propellant and later to the possibility of their incorporation in the compositions.

The addition of "wads" of water to propellant charges had been considered in 1893 and firing trials in the B.L. 6-inch Mk. VII gun were conducted in 1895 with additions of water and of ammonium
oxalate. In measurements made by Sir A. Noble with vented vessels, 307
a considerable reduction of erosion was found to result when wads of 317
water, ammonium nitrate or ammonium oxalate were added to the cordite charge in amounts up to 40 per cent of the cordite. These measurements were followed by gunfiring trials in 4-inch and 8-inch guns.

With a view to the production of a flameless propellant it was suggested by Sir W. Crookes that an addition be made to cordite of a double compound of potassium and ammonium nitrate which was

E.C. Mins.

alleged to be non-hygroscopic. Lord Rayleigh, in 1901, suggested — 430
that 4 or 5 per cent of lamp black or naphthalene be added to cor- — 443
dite. In firing trials with these compositions in the Q.F. 6 Pdr., — 1064
bright flashes and increased smoke were given by these compositions. — 39, 40
Other additions which had previously been suggested were castor oil and aniline.

A nitro-cellulose powder made at Waltham Abbey in 1902, consisting of 80 parts of guncotton and 20 parts of nitrocellulose
(12.43 per cent N_2) gelatinised with acetone-alcohol (3 : 1) was — 812
found to be flameless in the Q.F. 15-Pdr. and in the B.L. 6-inch How. — 967

Firing trials with propellants containing 2 per cent of barium nitrate, strontium nitrate or potassium antimony tartrate showed that the potassium salt reduced or eliminated flash in a nitro-cellulose
powder, but not in cordite M.D. — 1119

A propellant developed by Messrs. Vickers consisted of 71 N.C., — 1278
23 N.G., 5 M.J., 1 sodium bicarbonate, cal. val. 965 (W.L.) and was — 1317
found to be flameless in the Q.F. 12 Pdr. 12 cwt. and Q.F. 15 Pdr., — 1429
but gave flashes in the B.L. 6-inch Mk. XII. — O.R.B.187

Sir W. Crookes states that the addition of dicyandiamide to dynamite renders the explosive flameless. In a composition of
Mk. I cordite containing 10% d.c.d.a. the calorimetric value was — E.C. Min.
lowered from 1254 to 1054 and the total gases per gram increased — 1023
from 878 to 1026 c.c. A composition with 20 per cent d.c.d.a. of cal. val. 945 cal./grm. was prepared by Sir A. Noble and found in C.V. measurements to give a total gas volume of 1176 c.c. per grm. It was found that cordite with 5 per cent d.c.d.a. which had been on climatic trial for 4 months at 100°F. exploded violently during
a silvered vessel test after 4,000 hours, and the usual indication — O.B. Min.
of imminence of danger from instability was absent. No further — 376
trials were undertaken with this compound. — 689

Nitrodicyandiamide and nitrodicyandiamidine were suggested by the Superintendent of Chemical Research as alternatives to d.c.d.a.
The chemical stability of these compositions, particularly in — O.R.B.Min.
presence of water, was, however, not considered to be satisfactory. — 86
178

With a view of obtaining a propellant of greater power at a lower temperature the use of a composition containing guanidine picrate was suggested by A.A. da Silva. Manufacturing trials were conducted, and closed vessel measurements were made with compositions consisting of (a) 30 per cent guanidine picrate, 20 per cent
nitroglycerine and 50 per cent nitrocellulose, and (b) guanidine — E.C.Mins.
picrate 44.45, N.C. 11.1 and N.G. 44.45 (cal. val. 1068 cal./grm.). — 1193
The efficiency of the powders was found to be practically the same — 1450
as that of M.D. No gun firing trials were conducted as the powder was not considered to offer any advantage over M.D.

In 1904 Sir G. Beilby proposed the use of compositions con- — 1246
taining nitroguanidine with a view to reducing erosion. The manu- — 1345
facture of these compositions was investigated at Woolwich and at Waltham Abbey. Closed vessel measurements with these propellants
showed that the heat and power produced were practically identical — 1381
with M.D. The Explosives Committee concluded as follows:- "a nitroguanidine powder on the lines proposed does not offer any advantages to counterbalance its increased cost, and recommends that no further action is taken." The use of this type of composition to effect flash suppression was apparently not contemplated at that time, nor were firing trials conducted. It was further considered that "propellants embodying a large proportion of a crystalline body, particularly if a high explosive are not readily
brought to burn by layers from the surface. The property of — O.R.B.Min.
burning by layers is an indispensable quality of a propellant, — 93
being essential to safety. Trouble in this respect had been met — O.C.B.10832
with before 1914, and again came to notice on several occasions." — 24701

The use of flameless powders in large Naval guns was considered to be of importance in order to overcome back flash on opening the breech. E.C. Mins. 1365

In order to determine the extent to which the temperature of the muzzle gases should be reduced to give flamelessness, a series of compositions of the M.D. type with calorimetric values ranging
from 853 to 1087 was prepared. It was concluded by the 1405
Superintendent of Chemical Research in 1905 that the "precise condition necessary to produce flamelessness was that the pyrometric value of the powder was sufficiently low for the resulting temperature of the gases after mixing with the necessary quantity of air to be below the ignition point, which, in the case of gases from M.D. when fired in a closed vessel at 18 tons pressure, was estimated to be 605°C. In the various flameless powders which had 1424
been examined in the Chemical Research Department, this result had been achieved by cooling agents, and a judicious attention to pressure curves."

A number of firing trials were conducted with a composition proposed by H.H. Slade and consisting of 70 per cent nitrocellulose and 30 per cent nitroglycerine. Flashlessness was not, however, obtained. O.R.B. 58

Sir A. Noble conducted C.V. trials with the addition of 2 and 4 per cent sodium bicarbonate to Mk. I and M.D. cordites. A
slight decrease in the CO_2 and H_2 and increase of CO and H_2O in the 108
gaseous products was noted.

Other additions to propellant compositions which were investi-
gated at this time included D.N.T., T.N.T., cane sugar, starch and 113
nitronaphthalene. To determine the effect of calorimetric value on flashlessness, a series of compositions was prepared consisting
of Mk. I cordite with progressively increasing amounts of colophony 139
ranging from 3.3 to 8.3 per cent. In selecting the most suitable additions, consideration was given to the heats of formation in order to secure the maximum cooling effect. Firing trials in the Q.F. 12 Pdr. 12 cwt. gun were conducted with compositions containing
4.3 to 5.6 per cent carnauba wax, 7.3 per cent colophony, 8 per cent 187
nitronaphthalene, 10 per cent dinitrobenzene, 15 per cent D.N.T., 15 per cent T.N.T. Many of these were flameless when of a suitable size.

The suppression of muzzle flash in a Q.F. 15 Pdr. gun, by the application to a composition known as Chilworth powder (consisting of 75 parts G.C., 25 parts N.G. plus 5 per cent M.J.) of carbon dioxide amounting to 2.3 litres at N.T.P. and contained in a sparklet bulb was attempted without success, similarly with 1.5 litres
of CO_2, enclosed in the sealed Q.F. case. A considerable reduction O.B. Min.
of flash resulted however, by the incorporation in the propellant 671
of 1% sodium bicarbonate.

Firing trials were conducted in the Q.F. 15 Pdr. with this same propellant, in which was incorporated 1 per cent of platinum black, sodium carbonate, sodium oxalate, sodium chloride, sodium
hydroxide or silica. With the exception of the composition with 1200
silica, the rounds were flashless in this gun.

A composition (F.430/13) consisting of N.C. 30.8, N.G. 48.2,
T.N.T. 15, M.J.5, KNO_3 1, was found to be flashless in the Q.F. 2216
12 Pdr. 12 cwt.

Flashlessness was obtained in the Q.F. 12 Pdr. 12 cwt. with a composition consisting of 25.4 per cent N.G., 68.7 per cent N.C., 4.2 per cent diamylphthalate, 1.3 per cent V.M., 0.4 per cent ash,
but for L.S. guns the increase in smoke which resulted was con- 3251
sidered to be more objectionable than the flash of a service cordite.

The addition of acetyl urea to be distributed throughout the O.B. Min.
charge was proposed by Dr. Hodgkinson. Trials conducted in a 8787
Q.F. 12 Pdr. with this addition in a silk cloth bag failed to give 9357
flashlessness.

The position with flashlessness at this time (1914) was sum- 9564
marised as follows:-[1]

(a) "Flamelessness in a gun is simply the failure of the muzzle gases to ignite when they meet the air, and is the easier to obtain the smaller the gun and the lower the ballistics required.

(b) The largest gun in which flamelessness has been obtained is
the 12 Pdr. 12 cwt.; and it has been obtained in two ways, by 3251
addition to cordite M.D. of certain metals in chemical combination
specially chosen as the result of experiment, and also with powders 3375
of which the heat value was considerably lowered.

(c) By whatever means flamelessness is attained, smoke appears to be its concomitant and is due to the failure of carbon particles to undergo that combustion in air which takes place when the gases light up in a round giving flame. Objection has been taken to this smoke as interfering with laying and as disclosing position. Up to the outbreak of war (1914) no proposals for practical application of the principles came forward."

In 1918, Dr. Silberrad reported investigations aimed at the
production of a flashless propellant by the introduction of com-
pounds with a high oxygen content in association with carbon so as
to produce a maximum amount of CO_2 in the products of decomposition
and at the same time possessing a high heat of formation, so as to
give a maximum lowering of temperature on decomposition. These
requirements were considered to be most satisfactorily met by O.C.Memos
starch and a number of compositions were prepared which were based B.
on Mk. I and M.D. cordites with the inclusion of from 10 to 28 per 322, 430
cent of starch. Flashlessness was obtained in the Q.F. 18 Pdr. 517,1203,
and in the Q.F. 4-inch Mk. IV and B.L. 60 Pdr. results with these 4484
compositions were partially successful. No reduction of flash O.B. Min.
resulted, however, in the B.L. 6-inch Mk. VII. The results were 10126
concluded to be only moderately satisfactory in smaller natures of
guns, and to offer no promise of success in larger guns. On
account of additional disadvantages in respect of increase in
charge weight to give service ballistics, pronounced hangfires
which occurred and irregular ballistics, the propellants were in
1921 considered unsuitable.

Further consideration was then given to the possibility of
employing flash-reducing charges to be added separately to B.L.
charges for use at night. In trials of this method conducted in
a B.L. 15 Pdr. with a number of salts, the use of sodium oxalate 16444
was found to be the most successful and the salt was most
effective when placed at the front end rather than when spread at
the base or when mixed with the cordite sticks. The best results,
in which the flash was reduced to a red glow, were obtained with a
mixture of sodium oxalate amounting to 11 per cent by weight of
the charge and 5 per cent by weight of R.F.G. meal powder. Except O.C. Mins.
for the excessive smoke produced, equally satisfactory results were
obtained by this method in the Q.F. 4.5-inch How. when using 141
ballistite propellant. In the B.L. 4.7-inch, a reduction of
flash was only obtained by the addition of 20 per cent of R.F.G. 387
meal powder. In the B.L. 6-inch Mk. VII with M.D. cordite the
addition of 20 per cent of a mixture of sodium oxalate and G.P. 1417
gave no reduction of flash, similarly in the B.L. 60 Pdr., with a
charge of 9 lb. 12 oz. of M.D. cordite, the addition of 46.8 oz.
of a mixture of sodium oxalate and R.F.G. meal powder had no use- 1608
ful effect in reduction of flash. A trial was conducted in
4.7-inch guns with the addition of 1 lb. 6 oz. of ammonium fluoride

to a charge of M.D. without any noticeable reduction of flash. It was concluded from the results of a large number of trials that flame reduction depends on the presence of a volatile metal of highly positive character and that the nature of the acid radicle in O.C. Mins
combination with the metal has little influence. In the B.L. 2259
9.2-inch How. with a charge of 10 lb. 4 oz. cordite M.D. 20-10,
flash suppression was obtained by a mixture of 2 lb. sodium oxalate 2629
and 1 lb. R.F.G. powder contained in a batiste bag.

A requirement was put forward by the G.O.C. in C. France for
the supply of special cordite charges marked for night firing only,
so as to avoid their use by day, when smoke would disclose the 2754
position. A very large number of trials were conducted in dif-
ferent guns both at home and under Field conditions with a wide 2942
range of salt additions, including flash reducing charges (usually 3242
potassium chloride) in use by the Germans. It was found that with 8273,1059
the cooler N.C.T. and R.D.B. propellants, which were at this time 11282
brought into use, the addition of mixtures of sodium oxalate and 22302
R.F.G. powder suppressed flash in most howitzers including the 23616,239
B.L. 6-inch 20 cwt. and B.L. 8-inch but an urgent requirement for 24462,332
reduction of flash in the B.L. 6-inch Mk. VII could not be met.

The use of oxanilide to the amount of 5 per cent, either
incorporated in the propellant or distributed in the charge or
added in bags, had been found in America to give some success in 32739
flash suppression in 5-inch and 6-inch guns, but the difficulty of 33861
supply prevented its further use.

It was reported in American "Army Ordnance" (Dec. 1921) that
in flashless powder trials at Aberdeen U.S.A. progress had been 43047
made in reducing flash, but a flashless propellant had not been
produced for 5 and 6-inch guns.

Efforts were then directed to the design of muzzle attachments
to act as flash eliminators, following a design of Prof. Langevin,
which had been successfully applied to French 75 mm. and 155 mm. 15241
guns. The experiments made included the application of streams 19410
of water and of carbon dioxide to the muzzle gases. After unsuc- 19801
cessful results in the Q.F. 18 pdr., 60 pdr. and B.L. 6-inch Mk.VII, 21351
and on account of the prohibitive weight of these attachments,
further trials were at the time abandoned and the best remedy that
could then be suggested for obscuration of flash was the use of
smoke bombs in front of the battery.

In Nov. 1920, trials were again made with a Langevin funnel
on a B.L. 60 Pdr. gun with R.D.B. propellant. A slight reduction 40,957
of flash was obtained, the shape being changed from a spherical 41,347
form to an elongated tongue-shaped form. The amount of reduction 41,523
obtained was not considered sufficient to justify the complication
of its adoption, though it was still desired to investigate all
possible means of reducing flash.

B. <u>References in published literature on the proposed use of compounds of high nitrogen content as constituents of propellants</u>

Flemming(2), in 1898, recommended the use of nitroguanidine for neutralising the residual nitric acid in nitrocellulose during the stabilisation process. The advantages which were pointed out over the use of alkali carbonates were that no residue was left after combustion and no hydrolytic action was exerted by nitroguanidine on the nitrocellulose.

Vieille[3], in 1901, proposed the use of nitroguanidine as a cooling agent in propellant compositions.

Abelli referred to the results of trials made with the addition of 25 per cent of dicyandiamide to ballistite[4] and also proposed the use of dicyandiamidine nitrate, guanidine nitrate, nitroguanidine and nitrosoguanidine in amounts up to 25 per cent in propellants for the reduction of erosiveness by lowering the temperature of the explosion.[5]

Frank, in 1906[6], suggested the use of dicyandiamide in powders to suppress muzzle flash.

Bergmann[7] reported that the addition of dicyandiamide to the powder had resulted in depressing the explosion temperature and, in larger additions, in enriching the powder gases with the non-combustible nitrogen. Through these influences, but especially through the first, the tendency of the gases to ignite at the mouth of the gun was reduced. It was stated, however, that dicyandiamide in this respect did not behave more favourably than other already known substances which had been used for the same purpose.

Rusch[8] referred to the use in nitro powders of cooling additions such as alkali carbonates, soaps, urea and nitroguanidine, the latter of which gave off a large amount of free nitrogen on gasification, and so was useful in tending to prevent muzzle flash.

W. McNab and B.J. Flurscheim[9] in 1914 proposed the use of nitroguanidine in propellants composed of tetranitro bodies colloided with rubber.

G.C. Hale and F. Olsen[10] in 1925 described a propellant composition consisting of pentaerythritol tetranitrate, nitroguanidine, triphenyl phosphate and ammonium perchlorate.

C. Summary of work in the period prior to 1921

It is seen from the records referred to that in this period all attempts to obtain flashless propellants, which had been taken to the stage of firing trials in guns, were based on one of the following two principles:-

(1) The selection of compositions in which, with charges necessary to give the required ballistics, the calorimetric value and the volume of gases evolved were such that, after shot ejection and admixture with air, the gases were below the temperature necessary for ignition and propagation of flame.

(2) The presence of elements such as alkali salts, which inhibited the ignition of the muzzle gases.

Though several proposals had been put forward both by service departments and outside workers to reduce the inflammability of muzzle gases by the inclusion of compounds which increased the nitrogen content, no method for effecting this had been suggested which had been considered sufficiently practical to justify gun-firing trials.

II. Development of inherently flashless propellants in the period 1921-1946

A. Introductory

In 1921 investigations on the production of improved propellants were more intensively resumed on the institution of a new and enlarged establishment in the Research Department. The requirements which were now called for were a combination of the following features in a self-contained composition. O.C.Memo B

(1) Flashlessness without excessive smoke. 9555

(2) Diminished erosive action on the gun. 13024

(3) A higher degree of chemical stability than was possessed by by existing propellants. 17337

(4) Ingredients to originate from materials of indigenous origin and to require the minimum quantity of food stuffs.

To obtain flashlessness the procedure on which efforts were concentrated was to develop a propellant in which the heat value was reduced without, at the same time, increasing the proportion of hydrogen and carbon monoxide such as normally results from a decrease in the degree of oxidation of the gaseous products of decomposition. The possible methods for effecting this were seen to be:-

(a) The use of a high proportion of an ingredient or ingredients containing a high nitrogen content so as to reduce the inflammability of the muzzle gases by dilution with nitrogen.

(b) The use of ingredients with a high heat of formation so that decomposition proceeded with minimum heat evolution and the use of compounds in which carbon and hydrogen were already combined with oxygen in the molecular structure so that H_2O and CO_2 were yielded without further evolution of heat.

(c) The use of compounds which gave the maximum volume of gas per unit weight so that a given force could be obtained with gases at a lower temperature.

(d) The use of any means whereby the formation of methane and possibly ammonia could be accelerated catalytically and the proportion of free hydrogen and the inflammability thereby substantially reduced.

To obtain an improvement of the chemical stability and keeping properties of compositions in which nitrocellulose and nitroglycerine were present it was seen to be essential to employ a compound with basic properties accompanied by very low affinity and aminolytic constants so as to enable combination with the acid products of decomposition to proceed without, at the same time, catalysing the breakdown of the nitric esters which was brought about by an active base. In order to resist exposure to moisture a low solubility and a low rate of hydrolysis in contact with water was also essential.

After a detailed survey was made of all available compounds of high nitrogen content, including measurements of physical properties (e.g. solubility, basicity, aminolytic constants and stability in contact with nitric esters)[11] nitroguanidine was finally selected as an ingredient to be introduced in propellants of a colloided nitrocellulose basis to be submitted to manufacturing and firing trials. Apart from the suitability for this purpose of this compound as indicated by these tests, an important factor in the decision for its employment was the advantage offered from supply considerations in that the compound is readily derived from calcium cyanamide, which is produced synthetically from lime, coke (or anthracite) and atmospheric nitrogen. The production of nitroguanidine by manufacture in this country, besides effecting an economy through its lower cost of production compared with nitrocellulose and nitroglycerine, would dispense with all imports from abroad, and would not encroach on the supply of any product derived from foodstuffs.

It is of interest to recall that the erection of a plant for the manufacture of calcium cyanamide in Essex had been recommended by the Nitrogen Products Committee of the Ministry of Munitions in 1919 as being one of the most economical methods for the production of ammonia.[12]

Compositions were first manufactured consisting of existing service cordites with or without nitroglycerine in which a proportion of 10 per cent of nitroguanidine was incorporated. Firing trials in a Q.F. 18 pdr. gun showed this proportion to be inadequate for flashlessness and the investigation then turned to ascertain the maximum amount of nitroguanidine that could be introduced in a composition sufficiently colloided to be ballistically stable. Nitroguanidine has no measurable solubility in the remaining ingredients employed in the cordites and for maximum homogeneity it was obviously desirable to prepare this compound in as finely divided a condition as possible. As the methods of pulverising were at the time limited to mechanical mills, it was not however practicable to reduce the cyrstal size below about 0.15 mm. diam. Compositions were prepared with a proportion of nitroguanidine as high as 70 per cent, the remainder consisting of nitrocellulose either alone or together with nitroglycerine.

In October 1924, in firing trials with the B.L. 6-inch Mk.XII star shell charges, F.500/11, F.500/12 and F.463/67 gave either considerable reduction or elimination of flash. (cf. p. 69) O.C.B. 8227

Firing trials in the Q.F. 18 pdr. in September and October 1925 with F.500/12 gave satisfactory ballistic regularity and flashlessness while the smoke was estimated to be about 25 per cent greater than with M.D. 9240 9417

In night firings with the Q.F. 18 Pdr. in October, 1925, with observation from an aeroplane at a height of 1500 feet above the gun, it was reported that in 10 rounds only one flash could be observed while the flash of the ordinary Service propellant could be seen clearly from a distance of three miles up to any height. 9468

Hangfires of $\frac{1}{2}$ sec. - 1 sec. were occasionally obtained, however, with the igniters used with these charges. 9546 9565

In the B.L. 60 pdr. Mk. II, flashlessness was given with F.500/12 size .054 and reduced flashes with size .059. 9741

In the Q.F. 3-inch 20 cwt. gun, F.500/12 was not completely flashless and trials were carried out with a cooler composition F.500/19, which was flashless in this gun, while the smoke was about 50 per cent greater than with M.D. 10,070

In a night-firing trial with the B.L. 6-inch Mk. XII star shell charge, F.500/19 size .0295 was flashless. 10165

In a trial in the Q.F. 3.7-inch How. to overcome back-flash the composition F.463/67 tubular (034 - 017) suppressed both muzzle and back flash. 10678

Closed vessel measurements with the compositions made at this time from mechanically milled nitroguanidine showed irregular burning indicating that this did not proceed in parallel layers. A high pressure had been obtained in the Q.F. 18 pdr. and again in the Q.F. 3-inch 20 cwt. when charges were employed to give more than 15 tons. Cavities or fissures could be detected in many of the cords and density measurements gave results which were variable and below the theoretical values. O.C.B. 10832

Hangfires in the Q.F. 18 pdr. with F.500/19 were overcome with igniters of 4 drs. of either R.F.G.2 or ballistite. 10857

Trials at sea were carried out on September 21, 1926 in H.M.S. "Revenge" and "Hood" with F.500/19 in the B.L. 6-inch Mk. XII and Q.F. 4-inch Mk. V as star shell charges. The flash was reported to be reduced to an inconspicuous dull-red glow. 11725

The ratio of N.C. to N.G. was found to have a determining effect on the physical characteristics of the cordite and on the departure of the densities from the theoretical values.* More satisfactory results were then obtained with the compositions F.500/43 which contained 50 per cent nitroguanidine and F.500/44 and F.500/57 which contained 60 per cent nitroguanidine.[13] (* cf. Appendix F)

After satisfactory closed vessel tests, these propellants were fired in the Q.F. 3-inch 20 cwt. and, in larger sizes, in the B.L. 4.7-inch Mk. I gun at pressures up to 24 tons with much improved results as regards ballistic regularity. Complete flashlessness was obtained in the Q.F. 3-inch 20 cwt. gun and in a Q.F. 4.5-inch How. and small flashes in the B.L. 4.7-inch Mk. I gun. O.C.B. 14694

B. Propellants of calorimetric value about 755 (W.L.) with picrite content of 55 per cent (R.D.N., R.D.N./A.Q., N, N.F.Q. etc.)

(1) Early trials

From the results of trials with the above compositions F.500/43, F.500/44 and F.500/57, which showed little difference in the degree of flashlessness it was decided to concentrate attention on an intermediate composition which was designated R.D.N. and 16489
contained 55 per cent nitroguanidine. After extensive trials to establish the chemical and ballistic stability of the cordite when exposed to severe climatic conditions which extended over a period 17457
of one year, it was arranged in 1928 for the manufacture to be conducted at R.G.P.F. Waltham Abbey of 10,000 lb. of R.D.N. for Field trials at the Practice Camps.

Satisfactory results were obtained at proof of these W.A. lots when fired in the Q.F. 18 Pdr., 3-inch 20 cwt. and B.L. 6-inch Mk. XII Star shell. 20927

From observations made during firing at night it was reported from the Practice Camps in 1929 that only a slight reddish glow was observable at the muzzle. Some inconvenience was found to result from the fumes mainly on account of the presence of 18791
ammonia in the muzzle gases. A noticeable increase of smoke and 1924
resulted during day firings. Consistent flashlessness was not obtained in the B.L. 60 pdr. and B.L. 6-inch Mk. VII.

For flashless star shell charges satisfactory trials in the B.L. 6-inch Mk. XII gun were conducted with R.D.N. .036, using 4 oz. R.F.G. igniters. O.C.B. 20439

An important advance was, at this time, made in the development in the Research Department at Woolwich of a plant, for the production of nitroguanidine in a more finely-divided condition, which consisted in the projection of an atomised spray of a heated nitroguanidine solution on to the cooled walls of a large rotating drum.* The product thus obtained had a predominating crystal size of 0.003 to 0.005 mm. diam. and was designated as "picrite". Propellant with this material was first prepared at Woolwich in March 1930 and, to distinguish from the earlier R.D.N. made from coarser nitroguanidine (known as "petrolite"), the designation R.D.N./A was applied to the cordite when made from N.C. of 12.2% N. of cotton origin. Apart from the improved density and better regularity of R.D.N./A compared with R.D.N. the rate of burning was found by closed vessel measurements and gun firings to be higher. In the Q.F. 18 pdr. for instance R.D.N./A. of size .042 was required to give the same ballistics as R.D.N. .036.

(* cf. p.42)

On the successful completion of the Spray Picrite plant at Woolwich larger units were with minor modifications constructed at Waltham Abbey, later with further modifications at R.N.C.F. Holton Heath and still later with other improvements at Messrs. I.C.I. at Ardeer, and employed in conjunction with the processes in operation at these factories for the manufacture of picrite from imported calcium cyanamide.

Satisfactory ballistic and flashless performance were given with R.D.N./A in the $1\frac{1}{2}$ pdr., 18 pdr., Q.F. 3-inch 20 cwt., B.L. 60 pdr., Q.F. 4-inch star shell, B.L. 6-inch Mk. XII S.S., B.L. 4.7-inch gun and B.L. 4.5-inch How.

In ballistic trials with cordite after subjecting to climatic trials, it was further found that R.D.N. gave occasional high pressures whereas R.D.N./A was free from this defect even after soaking in water for extended periods. (cf. 49) O.C.Memo B. 21041

Experimental production of R.D.N./A proceeded at R.G.P.F. amounting to 25 tons in 1931/1932 for the Q.F. 18 Pdr. (or Q.F. 3-inch 20 cwt.) while 18 tons were ordered to be made in 1932/1933. The bulk of this was size .042 inch for the Q.F. 18 pdr. gun. 22532
R.D.N./A was found to provide satisfactory flashless star shell charges for Naval guns of 3-inch, 4-inch, 5.25-inch and 6-inch calibres and the manufacture of charges for trials with the Fleet was undertaken at R.G.P.F. 23471

In a review of the position with flashless propellants in 1932 it was reported on 19th August, 1932 that "in the view of the Ordnance Committee propellants of the R.D.N./A type possess, in addition to the outstanding advantage of being flashless in guns of 60 pdr. and below and in Hows. 6 inch and below, great advantages over cordite M.D. in respect of:- 24701

Facility of supply in peace and war,
Chemical stability,
Ballistic regularity when new."

In March 1938, reports which had been called for were received from various ships in the Fleet on the results of the performance of flashless propellant. With the Q.F. 4-inch Mk. XVI and Q.F. 4-inch Mk. V star shell charges it was reported that no flashes were seen at ranges of 3000 to 5000 yards. 36229 and 36482

In September 1938 further reports of equally successful results were received from firings in the Q.F. 4.7-inch Mk. VIII and 4.7-inch Mk. XI, also 4-inch Mk. XVI. O.C. Memo 1125

In order to obtain a further improvement in flashlessness, trials were commenced at Woolwich in October 1936 with R.D.N./A compositions containing a small proportion of cryolite, the amount of which was limited to 0.3 per cent in order to avoid excessive smoke. This composition originally known as F.556/1 became designated R.D.N./A.Q. (and later N/A.Q.) or if made of nitrocellulose of 12.2% N. content from wood in place of cotton, as later became the practice at R.N.C.F. Holton Heath, R.D.N./F.Q. (or N.F.Q.).

After a considerable number of firings of N/A.Q. as star shell charges, a trial was, in April 1938, conducted in the B.L. 60 pdr. Mk. II gun. In a worn gun the propellant proved to be flashless provided a total of 3 oz. of gunpowder was employed for the ignition.

The further developments with cordites N and N.F.Q. may be more conveniently classified under the headings of different guns as follows:-

(2) Land Service and anti-aircraft guns:-

(a) Q.F. 3-inch 20 cwt.

In order to determine the most satisfactory shape of propellant a firing trial was conducted in the Q.F. 3-inch 20 cwt. worn gun with R.D.N./A.Q. in the forms of cord, .042 and .052, tube and slotted tube, ann. .035, and multi-tube of webs .025, .029 and .031, in comparison with M.D. "11" and W "8". The most satisfactory results were given with propellant in the form of slotted tube which gave the required velocity at an average of 2 tons lower pressure than cordite W 057. Multitubular propellant also gave satisfactory results. In this trial an appreciable reduction of the blast effect was noted to result from the use of flashless propellant and further evidence was afforded of the advantages it offered for A.A. guns. O.B. Procs. 2214

In a further trial in the Q.F. 3-inch 20 cwt. worn gun with N/A.Q. propellant in the forms of cord .052, S.T. ann. .035 and M.T. of web .029 and .031, the M.T. gave the highest degree of flashlessness and the service velocity at the lowest pressure which 2945
amounted to 3 tons/sq. in. below that given with cordite W.

(b) Q.F. 3.7-inch Mks. I-III

In an investigation to determine the effect on the wear of a Q.F. 3.7 Mks. I-III gun with N/A.Q. in the forms of multitube, tube, or slotted tube, compared with that of cordite W when fired in a separate liner, the rate of wear was found to be very much less with N/A.Q. than with cordite W. With regard to the incidence of flashes the M.T. gave an average of 19 per cent of flashes 135
of magnitude assessed at $2\frac{1}{2}$ - 10 per cent compared with 17 per cent of flashes for tube and 57 per cent for S.T. 2210

A further comparative trial with cordite W and N/A.Q., in M.T., T. and S.T. forms in the Q.F. 3.7-inch Mks. I-III in December 1939 showed satisfactory regularity and flashlessness in all cases with N/A.Q. while a big reduction of wear resulted from the flashless propellant and for a given degree of wear the drop 3815 and
of M.V. was less for the flashless than with cordite W. (cf. Fig.24) 6158

Use of guncotton in Land Service propellants

On account of the supplies of guncotton (13.1 - 13.2 per cent N.) being more readily available than N.C. of 12.2 per cent N. at O.B.Procs.
the L.S. factories it was required in November 1940 to consider 10343
the use of compositions modified so as to employ guncotton. The composition selected consisted of Picrite 55, G.C. 19, N.G. 18.5, carbamite 7.5, cryolite 0.3, (Cal. val. 755 (W.L.)) and in due course was adopted as the standard land service propellant with the designation cordite N. The composition was subsequently modified to picrite 55, G.C. 19, N.G. 18.7, Carb. 7.3, cryolite 0.3 (Cal. val. 765 (W.L.)). (cf. p.13)

In order to replace the major part of the carbamite by dibutyl phthalate, trials were conducted with a composition F.527/32. Satisfactory ballistic and flashless results were obtained in the Q.F. 3.7-inch with S.T. 160-050 and in the Q.F. 4.5-inch Mk. II
with S.T. 192-055. 11493

In order to overcome the occurrence of the sporadic flashes given by cordite N and also to dispense with the necessity of core igniters, a trial was conducted in which the following salts were incorporated in cordite N together with or without 0.3 per cent cryolite:- (a) 2 per cent potassium dinitrophenate, (b) 1 per cent potassium nitrate and (c) 0.8 per cent potassium sulphate. Trials in the Q.F. 3.7-inch Mk. I and III (as in the Naval guns Q.F. 4.5-inch and 4-inch Mk. XVI full charge) showed that these compositions, in the absence of any G.12 igniters, are at least as flashless as cordite N with the igniter. The firing intervals were generally short and regular, but an occasional hangfire occurred when the
igniter was omitted. 16376

In a comparison of the flashless performance of the British and American types of propellant in the Q.F. 3.7-inch A.A. gun, FNH/P web .049 in. containing 1.64 per cent K_2SO_4 was reported from Canada to have given 26 full and 179 partial flashes in 433 rounds.

It was reported from I.G. Canada on 23rd June, 1942 that N/S
164-048 made at Nobel had been fired in the Q.F. 3.7-inch with 18583
satisfactory results.

The method of manufacture employed consisted in dehydrating the guncotton with alcohol and subsequently adding acetone as sol-
vent for the incorporation, the N.G. being added in solution in 18631
acetone.

A statistical analysis of flashes during proof in the R.D. in 1942 showed that in the firing of N/S 164-048, in the Q.F. 3.7-inch Mks. I - III gun, the number of flashes recorded amounted to 22 in a total of 7759 rounds (corresponding to 0.27%). The
tendency for these to occur in groups is seen by the fact that 18444
16 of these occurred in 4 firings (cf. p. 79).

The adoption of N/A.Q. in multitubular form for the Q.F. 3.7-inch Mks. I - III gun became necessary in order to obtain the maximum velocity. With slotted tube the maximum charge which could be loaded gave a velocity of 2694 f.s. compared with 2850 f.s. for a loadable charge of M.T. The limitation to the
loadability of a stick form of propellant was due to the heavy 6765
necking of the cartridge case used for this gun. The maximum loadable charge of N/A.Q./S 0.058" was 8 lb. 8 oz. compared with 10 lb. 8 oz. of M.T.7.

The adoption of this propellant for this gun was concluded to lead to the following advantages:- O.B.Procs.

(1) An increase of about 400 per cent in accuracy life. (cf. Fig.2

(2) A reduction of rate of loss of muzzle velocity for equivalent
full charges to about $\frac{1}{4}$ of the present figures. 6158
and

(3) The almost complete elimination of flashes. 6788

Comparative firings were conducted with N, N/S, N/T, N/M and
FNH with No. 11 Mk. III primers in all cases. The width of slot
was found to have no effect. N/S cordite was found the most
satisfactory, but in order to assist the loading it was decided to
raise the calorimetric value from 755 to 765 by lowering the car- 15209
bamite content from 7.5 to 7.3 per cent and increasing the N.G. 18829
from 18.5 to 18.7 per cent.

Satisfactory ballistics were given with cord .086 with a charge weight amounting with one lot to 9 lb. 3 oz. which was near the top limit of loadability as a single bundle. The flashlessness was less satisfactory than with S.T.

With N/S 164-046 (ann. .059), chopped 0.5 in. long, fired at
the rear end with a No. 11 primer only, a pressure measured at
38 tons was obtained causing serious damage to the mechanism,
which precluded further trials with this form of propellant.
Further consideration of cord propellant was also abandoned in 15444
favour of slotted tube. 15831

(c) <u>Q.F. 3.7-inch Mk. VI</u>

The manufacture of N/M for this gun both at Ardeer and in 20949
Canada was achieved satisfactorily. The mean web thickness was 26975
.061 in. and the length of the grains 0.9-inch. The granular 27610
charge was readily loadable in the necked cartridge cases.

N/P/M (web .061) lot B.S. 12,443 with an adjusted charge
weight of 17 lb. 4 oz. 6 drm. was accepted as master standard to
give 3505 f.s. and 22.9 tons/in^2. With the omission of a supple- 31418
mentary igniter of 2 oz. g.p., which had been adopted to ensure
flashlessness and later abandoned because of its tendency to give
sporadic high pressures, the flashless performance of N/P/M became
somewhat unsatisfactory. An increase of K_2SO_4 to 2% gave an
appreciable improvement, and was found preferable to 2.36% KNO_3. 31527

In a firing trial in 1946 a picrite-oxamide composition (F.560/64) with 0.5 per cent K. cry. gave a flashless performance superior to that of N/P/M (1 per cent K_2SO_4) and in accordance with its higher cal. val. of 775 (W.L.) gave service ballistics with a lower charge weight.

In a later trial a comparison was made of the flashless performance of the following compositions when fired in the Q.F. 3.7-inch Mk. VI and in the Q.F. 17 Pdr.

Type	Salt	Cal. Val. (W.L.)	Approx. Flame Temp. °K.	Per cent of CO + H_2	Per cent of picrite
(1) N	0.3 Na. cry.	765	2520	53.8	55
(2) N	0.5 K. Cry.	765	2520	53.8	55
(3) F.527/127	"	730	2420	53.7	60
(4) F.487/40	"	730	2360	53.2	60
(5) F.560/64	"	775	2520	44.7	50

With both guns the relative flash performance was as given in the above order (1) giving some large flashes and (5) only small flashes in worn guns by night. The conclusion to be drawn from these trials is that a reduction of the percentage of inflammable gases from 53.8 to 44.7 has a greater effect on flash performance than reducing the flame temperature from 2520 to 2360. A.R.D. minute B.265/1

(d) Q.F. 4.5-inch Mk. II A.A. Gun

In this gun a difficulty was encountered in the loading of flashless propellant in the form of cord or tube unless the size was reduced so that the required velocity could only be obtained at unacceptably high pressures. It was found however, that by using the propellant in multitubular granular form the service velocity could be obtained with readily-loadable charges at pressures 2 tons/sq. in. below those given by cordite S.C. With tubular propellant the pressures were moreover irregular. O.B. Proc. 2212

A firing trial with N/A.Q./S 198-054 in comparison with N.F.Q. of a similar size in the Q.F. 4.5-inch Mk. III gun showed the regularity of both compositions to be similar to that with cordite S.C. or W.

N/S 198-054 made at Ardeer with Canadian (Welland) picrite gave similar ballistics to that from home picrite and involved no change in die size. 14112

A further comparative trial was conducted in the Q.F. 4.5-inch Mk. III with N/S and N/P/S. To obtain satisfactory ignition the use of a supplementary igniter of 3 oz. G.P. in conjunction with a No. 11 primer could not however be dispensed with. As all rounds were flashless no conclusions could be drawn from this trial. 18026

In order to overcome a loading difficulty which had occurred with N/S in the Q.F. 4.5-inch Mk. II a trial was conducted with N/A/M (multitubular) propellant, web .058 inch. In order to dispense with a supplementary igniter the composition included 0.8% K_2SO_4 and no cryolite. With a No.9 primer, the flashlessness and firing intervals were satisfactory throughout. 16377

A trial with cordite N, cord sizes .109 and .100, showed that service ballistics (2465 f.s. at 19.5-20.5 tons) were given with a 14 lb. 3 oz. 8 drm. charge of cord .109 and with 13 lb. 9 oz. 14 drm of cord .100, the latter being near the top limit of pressure while the former charge could not be loaded as a single bundle. The flashlessness was inferior to that given with S.T.

A batch of N/S 198-054 was prepared in Canada and fired satisfactorily in the Q.F. 4.5-inch gun. On account of a somewhat higher rate of burning which had apparently resulted from this Canadian method of manufacture a slight increase of size was indicated. 18873

To assist flashlessness further, the adoption of N/P/S 198-054 with 1 per cent K_2SO_4 was recommended. The S.T. form was adopted so as to permit the use of an axial supplementary igniter of 3 oz. of G.P. To facilitate loading the composition was modified by increasing the N.G. content from 18.5 to 18.7 and lowering the carbamite from 7.5 to 7.3 per cent. (cf. p.13). 18829

For data on the effect of wear of gun on flash see section XI p. 79.

(e) Q.F. 6 Pdr. 6 cwt.

N/P/M web .040-inch with a charge of 3 lb. 7 oz. (loading density 0.8) and No. 15 primer with 2 oz. bandolier igniter gave

small flashes (17.7 c. secs.) and a sporadic high pressure. In a O.B. Proc.
half-worn gun N/P/M web .035-inch gave small flashes (9 c. secs.) 21985
similar to those with FNH/P .038 compared with 112,000 c. secs. 22781
for NH. Similar results were obtained with N/P/M .032 and .035 24757
when employed with a No. 15 primer, and 1 oz. G.12 bandolier 25084
igniter.

(f) <u>Q.F. 12 Pdr. 12 cwt.</u>

A firing trial with N cord .052-inch and .059-inch compared
with N.F.Q. .059 showed these to give a satisfactory ballistic
(2265 f.s. at 14.4 tons) and flashless performance. .052 was
close to the top limit for pressure and N .059 was approved for
adoption. 18159

(g) <u>Q.F. 5.25-inch Mk. II Gun (L.S.)</u>

In this gun a lot of N/P/S 263-066, made at Ardeer, when fired 22720
in 6 different guns gave m.d.'s ranging from 4.0 to 7.6 f.s. The 22983
ignition used was primer No. 17 Mk. II together with an 8½ oz. 23979
G.12 core igniter. This lot was approved as master standard. 24849

The specification limit for m.d. of M.V. was fixed at 10 f.s.
In the proof firings of 76 lots which had so far been conducted, 25056
68 of these gave m.d.'s not exceeding this figure of 10 f.s. for
the service ballistics of 2842 f.s./21.6 tons. 25972

(h) <u>B.L. 6-inch Mk. VII* and XXIV</u>

In these guns, satisfactory ballistics and flashlessness or 4862
semi-flashlessness were given with N/A.Q. slotted tube, ann. .058- 7393
inch. The loadability in the cylinders without a cardboard 19867
liner, of a size which would pass through existing hoists from the 23091
magazine to the gun positions, was however found to leave little 26520
margin for lot variations.

(i) <u>B.L. 6-inch Mk. XII</u>

In the B.L. 6-inch Mk. XII satisfactory ballistic and flashless results were given with N/A.Q. cord .100; slotted tube 198-054 was rather less satisfactory.

(j) <u>B.L. 7.2-inch How.</u>

For the B.L. 7.2-inch How., cordite N .042 for charges I and
II and a composite charge of N .042 and N/S 198-054 for charge III 21375
were found to give satisfactory ballistics and flashlessness.
Cordite N .045 was found satisfactory for charges I, II and III 21647
together with N/S 198-054 for charge IV and was finally adopted. 21902
A trial with NQ cord .050 showed this also to give satisfactory
ballistics though with some doubt as to its flashlessness with a
6 oz. G.12 igniter. Further trials with NQ were not considered 22567
necessary.

(k) <u>B.L. 8-inch How.</u>

Satisfactory flashless results were obtained with N/A.Q.
(F.556/1) .033 inch for the 4 lower charges and a composite O.C.Memo
charge of .033 inch and .061 inch for the two top charges. 737

(l) <u>B.L. 9.2-inch How.</u>

In the B.L. 9.2-inch How. with 315 lb. shell, cordite N/S O.B.Proc.
116-036 gave satisfactory ballistics and flashlessness with an 16492
igniter of 6 oz. G.12 at each end of the charge.

For a supercharge to give 1600 f.s. at 12.3 tons, N/S 164-048 O.B.Proc.
was found satisfactory and was approved for adoption. 18299
21266

(3) Tank and anti-tank guns:-

(a) Q.F. 6 Pdr. 7 cwt.

NQ/S 142-042 (made with guncotton) with a No. 15 primer gave service ballistics of 2725 f.s., at 18.5 tons with freedom from large flashes. A loose filling would however have been required for a velocity of 2850 f.s. 16149

As the result of trials with FNH/P, it was decided that for tank and anti-tank guns the extra smoke given by this propellant would be more objectionable than the flash of W, NH, or FNH, and that flashless propellant would accordingly not be required for these guns. 16299

(b) Q.F. 17 Pdr.

N/P/M web .048 and N/P/M of "rosette" (6 leaf-clover) section, web .052, with No. 9 primer and 4 oz. bandolier igniter or with No. 16 primer and a 2 oz. primer of 12" length gave only small flashes and much less smoke than FNH/P. 23186

The use of a muzzle brake was found to increase the size of residual flashes with this gun. 21774

Investigations have been made at T.A.R. and C.D.E.S.[23] on the various factors affecting obscuration and the effect of flash, smoke, and dust in preventing observation of fire from tank guns.

In trials in a Q.F. 17 pdr. Mk. II with cordite N/M .049 and NH .055 with cine-photographic recording, although a quantitative assessment of the factors was impracticable and varied with wind and other conditions, it was apparent that the shimmer (due to the varying refraction of light through the heated turbulent mass of gas in the field of view) was at least of comparable importance with the smoke of a flashless charge. A further obscuring factor which would be increased by the blast from a flash and would vary with ground conditions was the dust raised. In night actions the elimination of flash becomes of still greater importance. (cf. p. 62)

(c) Q.F. 95 mm. Tank How.

Regular ballistics and good flashlessness were obtained with all the following cordites:- NQ/R .023 x .118, NQ .032, N/R .020 x .112, N .026 in all cases with No. 11 Mk. III primers for the ignition. O.B.Proc. 22960

By the use of a smokeless (C.9) type of primer (cf. p.59) in place of the No. 11 primer, with NQ/R propellant flashlessness was obtained in this gun without any noticeable increase of smoke beyond that given by a flashing propellant[14]. (cf. Fig.22). 25248 28996

(4) Naval Service guns:-

(a) 12 Pdr. 12 cwt.

For use with guns in submarines, it was found that, in a well worn gun, muzzle glow only could be observed with a full charge of N/A.Q. or N.F.Q. size .052. 6072 6667 (cf. p.19)

As a star shell charge, N.F.Q. .029 gave satisfactory results in a night firing trial on 27th December, 1940. O.B.Proc. 10689

N.F.Q. .059 was found satisfactory for the full charge and approved for adoption in view of the lower pressure compared with size .052. 16488

(b) Q.F. 3-inch 20 cwt.

N.F.Q. .052 with a No. 9 primer gave results which were satisfactory in avoiding blinding of personnel and the adoption of this charge to give a velocity of 2100 f.s. at 14 tons was recommended. 6667

(c) Q.F. 6 Pdr. 6 cwt. (N.S.)

N.F.Q. or N/A.Q. cord .029 with a No. 15 primer was found to give a charge of satisfactory ballistics and flashlessness to replace H.S.C.T. 134-055 for ballistics of 1400 f.s./19.8 tons. 13933 14329

(d) Q.F. 4-inch Mks. IV, V, XII, XIX, and XXII

In an extended trial on 28th February, 1938 in the Q.F. 4-inch Mk. V and Q.F. 4-inch Mk. XVI, S.S. charges, the results indicated that N/A.Q. (F.556/1) was less liable to give sporadic flashes than N/A and it was decided to adopt this modified composition for future supplies. O.C.Memo 187

In the Q.F. 4-inch Mk. V worn gun with full charge N/A.Q./S ann. .058 with No. 9 primer and 2 oz. G.12 igniter gave satisfactory flashlessness in a night trial reported on 19th November, 1940. O.B.Proc. 10679

In a further trial, equally satisfactory results were obtained with N.F.Q. cord .052 and N/A.Q./S 116-036 (ann. .040 in.). A No. 9 primer and 2 oz. G.12 core igniter were employed. A comparison of N.F.Q./S 119-039 with N/A.Q. cord .051 during a night firing gave muzzle glows only in both cases with some advantage in favour of the S.T. A further 1 oz. of G.P. in the igniter gave no further improvement. 11665

In the Q.F. 4-inch Mks. IV and XII with both fixed ammunition and separate loading, N.F.Q. .059 with No. 9 primer with full charges gave satisfactory ballistics and complete flashlessness except for a dull-red glow. N.F.Q. .070 was later approved for adoption. In the B.L. 4-inch Mk. VII, star shell charge, N.F.Q. .029 with an igniter of 1 oz. G.12 in rear of the charge gave flashlessness except for a small red glow. 11766

In the B.L. 4-inch Mk. IX and Mk. VII star shell, N.F.Q. .029 gave satisfactory results similar to those with N/A.Q. 11759 11761

In the Q.F. 4-inch Mk. XIX, N.F.Q. .042, .052 and .059 were all found to give a satisfactory performance for a star shell of 29 lb. 9 oz. with a velocity of 1600 f.s. at 7.75 tons. 16065

With a full charge and shell of 35 lb. these propellants with a No. 9 primer also gave the required performance of 1300 f.s. with the same pressure limit. The smaller size was found preferable for flashlessness and for maintenance of ballistics in a worn gun. 16064

In a firing trial conducted in a worn gun with N.F.Q. .042 and .052 with No. 11 and No. 9 primers, hangfires resulted with No. 11 primers while No. 9 was satisfactory at 30°F. Flashlessness was generally satisfactory throughout. Considerable unburnt cordite was found with the N.F.Q. .052 rounds. Similar results were obtained with N.F.Q. .042 in this gun with a star shell charge. 17261

In this gun with a star shell projectile of 29 lb. 9 oz. N.F.Q. .042 with No. 9 primer and no supplementary igniter gave satisfactory ballistics and flashlessness. O.B. Proc. 17453

In the Q.F. 4-inch Mk. V, star shell, cordite N .029 made in Canada gave satisfactory results similar to those with N/A.Q. 21492

In the Q.F. 4-inch Mks. IV and XII guns (S.L.) a comparison between N.F.Q./S 164-048 and N.F.Q. cord .070 in a worn gun gave in all cases only muzzle glows which with N.F.Q./S were about 0.3 candle secs. compared with 0.1 candle sec. for N.F.Q. which gave a higher pressure. 23184

In the Q.F. 4-inch Mk. XXII gun, a comparative trial was conducted with N.F.Q. .042, .052 and .059 with a view to improve the regularity. Size .042 exceeded the acceptable pressure for service velocity. Size .052 gave rather better regularity than .059 and was recommended for adoption. All rounds were flashless in a new gun. 31158

In the Q.F. 4-inch Mks. IV and V guns, an analysis of the results obtained at cordite proof showed that no flashes were obtained in a total of 410 rounds of N.F.Q. .059, N.F.Q. .070 and N .070 in a Q.F. 4-inch Mk. IV gun (separate loading). In the Q.F. 4-inch Mk. V, 1 large flash in a total of 694 rounds with N.F.Q./S 164-048, separate loading, and 2 large flashes in a total of 629 rounds with N.F.Q./S 116-036, fixed ammunition, were obtained. 33952

(e) Q.F. 4-inch Mk. XVI, Star Shell, and submarine guns

In trials to determine the optimum size of N/A.Q. for the high velocity star shell charge in the Q.F. 4-inch Mk. XVI, propellant of size .052 was superior in flashlessness to size .029. O.C. Memo 137 & 949

With charges giving a muzzle velocity of 2125 f.s. sporadic flashes occurred particularly with a worn gun. These could be prevented or minimised by filling the barrel with carbon dioxide or by ramming the shot well into the rifling. In some instances, as had previously been found in firings in worn Q.F. 3-inch 20 cwt. guns, the insertion of felt wads in the mouth of the cartridge cases was also found to suppress the residual flashes. The conclusion was accordingly reached that sporadic flashes are mostly caused by the escape of hot inflammable gases past the shot before the driving band seals the bore effectively. The temperature of these gases should be higher than normal through not having effected work and, due to the initial low pressure of burning, it is to be expected that they will contain some oxides of nitrogen which are known to lower markedly the ignition temperature of CO and H_2. (cf. p. 72) O.B. Proc. 596

In 1939 it was decided that flashless propellant should be supplied for the star shell charges of all guns and this was followed by a requirement for flashless or semi-flashless charges for the main armament guns of destroyers commencing with the Q.F. 4.7-inch Mks. IX and XII and Q.F. 4.7-inch Mk. XI. 1277 1404

The results in general of reports from the Fleet in 1939 in firings of Naval star shell charges in Q.F. 4-inch XVI, 4.5-inch, 4.7-inch and 5.25-inch guns with charges of N/A.Q. were that "the residual flashes would not have attracted the attention of anyone not looking directly at the firing ship". 1607

A trial was conducted in a worn Q.F. 4-inch Mk. XVI gun with a H.V.S.S. charge of cordite N/S containing 2 per cent KNO_3 compared with 1.75 per cent K_2SO_4 (of equal K. content) and N/S without salt but with igniter increased to give the same total amount of K. salt. Shots of reduced weight were employed to increase the liability to flash. No appreciable difference was found between the different charges but there was an indication that for a given total salt content the flashless results were better with the propellants containing incorporated salts. Satisfactory results were also given in this gun with a H.V.S.S. charge by a picrite-oxamide composition, F.560/13 (cf. p.28). | O.B. Proc. 21229 22545 20794

A firing trial was conducted to determine the comparative flashless performance of N/S with 0.3 per cent cryolite and N/P/S containing 1, 2, 3 and 5 per cent of K_2SO_4. The effect on cal. val. was to cause an increase from 760 for N/S to 770 for N/5P/S, while the gas volume (W.L.) fell from 891 (c.c./grm.) for the first to 815 for the last. The rate of burning did not vary appreciably.

Firings in a worn gun with a lightened shot gave a large proportion of large flashes in all cases while, in a new gun, no large flashes were given with the compositions containing K_2SO_4. The glowmeter readings indicated minimum flash with the 1 per cent K_2SO_4 composition and no improvement resulted from a further increase in the K. salt. 22921

A requirement was put forward for flashless full charges in guns mounted in submarines, the main object being to obviate the blinding of personnel by flash. The guns concerned were the Q.F. 4-inch Mk. XII, Q.F. 3-inch 20 cwt. and Q.F. 12 pdr. 12 cwt. and trials with N/A.Q. were arranged. 6072 (cf. p.16)

For a 4-inch Mk. XII submarine gun, N.F.Q. cord .059 with a No. 9 primer was found to give a satisfactory flashless charge, and was recommended for adoption. A summary giving a comparison between N/A.Q. and N.F.Q. when fired in the Q.F. 4-inch Mk. IV, 4.7-inch Mk. VIII, Q.F. 4.7-inch Mk. IX and Q.F. 5.25-inch Mk. I showed the difference between the two to be negligible as far as ballistics and flashlessness were concerned. 6385 7268

Q.F. 4-inch Mk. XVI. Full Charge

N.F.Q./S (ann. .058) was adopted for this charge. 5626

N/A.Q./M. web 0.047-inch was found to provide a satisfactory full charge when using a metal igniter 21 inches long with side venting and filled 4 oz. g.p. 6092 6817

N.F.Q./S 164-048 with a No. 14 primer and 3 oz. G.12 core igniter gave generally satisfactory flashlessness and ballistics though flashes occurred with rounds following those of the S.C. controls and partial flashes were given in a worn gun. 11806

N.F.Q./S 164-048 compared with N/S of this size using a core igniter of 3-4 oz. G. 12 gave generally satisfactory results. Irregularities with N.F.Q. were attributable to slight variations of size and composition, and to the use of picrite of a variable and larger crystal size. The use of less finely-divided material was found to result in a cordite of lower density indicating the presence of fissures. This fault was further agravated by the use of nitrocellulose of wood in place of cotton origin. 14396 17026 17398 17859

In a comparative trial in a nearly new gun with N.F.Q./S 164-064 (ann. .050) and 164-048 (ann. .058) no large flashes were obtained and no significant difference in either flash or smoke between the two sizes was apparent. 32784

(f) Q.F. 4.5-inch Mk. III O.C. Memo

In the Q.F. 4.5-inch star shell charges, satisfactory flash- 1576
lessness was obtained with N/A.Q. size .059 or .072 at M.V.'s of
2200 f.s.

A trial in the Q.F. 4.5-inch Mks. II and III gun, full charge, O.B. Proc.
was conducted with N/A.Q. and N.F.Q./S of annuli varying from .068
to .074. The regularity of both compositions was found to be 10364
similar to that of cordite S.C. or W. No flashes were obtained 11638
with N/A.Q. rounds when using a percussion primer of 6 dr. of g.p. and a
3 oz. core igniter of G.12 while a proportion of flashes was given
with N.F.Q. with a 1 oz. electric primer together with a 3 oz.
igniter. Subject to confirmation by further trials N/A.Q./S or
N.F.Q./S 198-054 was recommended for adoption.

In a Q.F. 4.5-inch Mk. III part worn gun (E.F.C. 276), and
4-inch Mk. XVI long range star shell charge, N.F.Q./S 198-054 gave
satisfactory ballistics with small residual flashes. In a worn 18042
gun (E.F.C. 725) large flashes were obtained which were unaccept-
able.

The temperature corrections for N and N.F.Q. in the Q.F. 4.5-
inch gun were estimated at 11.5 f.s./0.4 ton per 10°F. 18420

Trials to determine the relative rates of wear with full
charges of N and N.F.Q. cordites in comparison with S.C. in the 11664
Q.F. 4.5-inch Mks. I, III and V guns showed that the wear caused 33728
by the flashless was about 1/4 that resulting from S.C. The
regularity of different lots of propellant and the effect on
ballistics of a given amount of wear was found to be approximately
the same for all the propellants (cf. Fig. 24).

With a view to determine its suitability for use in Naval
guns on extensive trial with cordite N/S 198-054 made at different
L.S. factories was conducted in the Q.F. 4.5-inch and Q.F. 4.7-
inch guns and with N/S 164-048 in the Q.F. 4-inch Mk. XVI. Though
some differences in the performance of the products from the
different factories were apparent it was concluded that cordite N
from any factory should be suitable to replace N.F.Q. and that
picrite propellant was inherently hardly any more irregular (mean
dev. of M.V.) than S.C., W or W.M. 19889

With N.F.Q. full charges in the Q.F. 4.5-inch Mk. III, Q.F.
4-inch Mk. XVI and Q.F. 12 Pdr. 12 cwt. satisfactory flashlessness 22318
was reported from the Fleet to have been obtained. It was stated
that the propellant would be of particular value when attacking a
convoy and when engaging an enemy in low visibility.

In the Q.F. 4.5 H.V.S.S., comparative firings with N.F.Q./S,
N.F.Q./P/S and N.F./P/S (without cryolite), 3 oz. and 7 oz. core
igniters were employed for the N.F.Q./S and 3 oz. igniters for
the others. The N.F.Q./S with 3 oz. igniter gave a slightly
better result (14 candle secs.) than with a 7 oz. igniter (22
candle secs.). The N.F.Q./P/S (with cryolite) was better
(13 candle secs.) than N.F./P/S (30 candle secs.). The ordinary 21417
star shell charge by comparison gives about 1 candle sec. The
flashes were in all cases small but could be observed at 8000
yards, and were not considered satisfactory in meeting the require-
ment of not attracting attention at 4000 yards.

In a firing trial at Eastney on 25th May, 1943 with obser-
vation from the sea, N.F.Q./P/S 198-054 appeared superior to 23588
N.F.Q./S of the same size, but both gave small non-blinding
flashes visible at 8000 yards. In a repeat trial at H.M.S.
"Excellent", it was concluded that N.F.Q./S and N.F.Q./P/S ful- 25815

filled the requirement of not attracting the attention of the naked eye at a range of 14-16000 yards, but not at 8-10,000 yds. in a clear atmosphere. The charges moreover were "completely non-blinding and immensely better than S.C.". No consistent difference could be observed between the degree of flashlessness of the two propellants. The adoption of N.F.Q./S 198-054 was accordingly recommended as being the best available for this charge. O.B. Proc.

A trial with the addition of packages of potassium salts to reduce the small residual flashes was unsuccessful, and the additional smoke which resulted was found objectionable. More favourable results were obtained however with packages of washing soda, and this device gave similar beneficial results in trials in 27601
the Q.F. 4-inch Mk. XVI and B.L. 6-inch Mk. XXIII.

N.F.Q./S 168-048 was found to be acceptable for pressure. In a new gun, the propellant with a 2 oz. 12 drm. G.12 igniter gave a proportion of large flashes, and the adoption of this charge with a 4 oz. G.12 igniter was approved for both fixed and 31305
separate loading charges. 31879

In a night-firing trial with N.F.Q./S 198-054 and N.F.Q./S 168-048 with 4 and 7 oz. G.12 igniters with a part worn gun (291 E.F.C.) separate loading gave in all cases flashes less than 2 c, secs. The smaller size 168-048 gave a slight improvement in 32727
flashlessness. The shot weight was 49 lb. 14 oz.

The temperature correction was 9 f.s./0.3 ton per 10°F. and the top limit of mean pressure was specified at 20.8 tons.

In master standardisation in a new gun, N.F.Q./S 168-048 with 4 oz. G.12 igniter gave 5 large flashes in 36 rounds with fixed ammunition, but 1 small flash only in 35 rounds with separate 33211
loading. Master standardisation of the charge was approved. It was pointed out that the specification mean pressure of 20.3 tons would admit of size 164-058.
(For data on effect of wear on flashlessness with this gun see p. 79.)

Star Shell Charges - General

Details of star shell charges which were approved or under 31780
trial in August 1945 are given as follows:-

Gun	Weight of proof shot representing star shell			Nature and size of cordite	Top limit of mean pressure in Specification A. 231
	lb.	oz.	dr.		Tons
Q.F. 5.25-inch	71	10	0	N.F.Q. .080	17.5
"	71	10	0	N.F.Q./S 198-054	
Q.F. 4.7-inch Mark XI	55	11	11	N.F.Q. .059	17.5
"	55	11	11	N.F.Q./S 198-054	
Q.F. 4.7-inch Marks IX and XII	41	14	5	N.F.Q. .042	9.0
"	47	11	0	N.F.Q./S 168-048	
Q.F. 4.7-inch Mark VIII	41	13	4	N.F.Q. .052	9.0
Q.F. 4.5-inch	42	12	12	N.F.Q. .059	16.5
"	51	12	8	N.F.Q./S 198-054	
"	49	15	8	N.F.Q./S 198-054	
Q.F. 4-inch Mark XVI	29	10	3	N.F.Q. .052	14.5
Q.F. 4-inch Mark XIX	29	10	3	N.F.Q. .042	
Q.F. 4-inch Marks XII and XXII	28	0	8	N.F.Q. .042	9.0
"	29	10	3		
Q.F. 4-inch Mark V (F.A.)	28	0	8	N.F.Q. .042	9.0

Gun	Weight of proof shot representing star shell	Nature and size of cordite	Top limit of mean pressure in Specification A. 231
	lb. oz. dr.		Tons
Q.F. 4-inch Mark V (S.L.)	27 12 4	N.F.Q. .029	9.0
Q.F. 3-inch 20 cwt.	11 15 15	N.F.Q. .029	9.0
Q.F. 12 pdr. 12 cwt.	12 1 0	N.F.Q. .029	9.0
B.L. 4.7-inch Mark I	41 14 5	N.F.Q. .042	9.0
B.L. 4-inch Mark IX	27 12 4	N.F.Q. .029	9.0

In 1937, the supply of R.D.N./A.042 to the Home and Mediterranean Fleet for star-shell charges in the Q.F. 4.7-inch Mks. IX and XII guns was directed in Admiralty Confidential Fleet Orders No. 2772/37. O.C.Memo B 35822

(g) Q.F. 4.7 Mk. XI

Comparative firing trials with star shell charges were conducted in 1938 in part-worn guns (E.F.C. 200 to 242) with N/A.Q. (F.556/1) of cord sizes .045, .059 and .075 and No. 14 primers fitted with 1 and 2 oz. g.p. magazines. Flashlessness was obtained at the highest velocity (2587 f.s.) in individual instances with size .075, but consistent flashlessness at somewhat lower velocities was given best by size .059. 35936 O.C. Memo 67

To determine the effect of a change from nitrocellulose of cotton origin to that of wood, a comparative trial with N/A.Q. and N.F.Q. .070 showed no appreciable difference in ballistics or flashlessness. In a part-worn gun (E.F.C. 200) flashes were obtained with a 2 oz. primer but with a No. 13 primer and a brass axial igniter with 4 oz. g.p. the rounds were flashless. O.B. Proc. 3197

For a full charge, N.F.Q./S 198-054 gave satisfactory ballistics and flashlessness in a fairly new gun. 14719

The temperature correction was found to be 9.6 f.s. 0.34 tons per 10°F. In Q.F. 4-inch and Q.F. 4.5-inch guns, temperature corrections ranged from 9 to 12 f.s. and 0.2 to 0.4 tons pressure; in the Q.F. 3-inch 20 cwt., 7 f.s. and 0.3 ton; and in the 12 Pdr. 12 cwt., 17 f.s. and 0.25 ton per 10°F. 14785

With N.F.Q./S 198-054, an igniter of 6 oz. of g.p. gave rather better results than one of 4 oz. of g.p. 14989

A comparative trial with N.F.Q./S sizes 198-054 and 168-048 showed no noticeable difference in flashlessness. 32859

(h) Q.F. 4.7-inch Mks. IX and XII

In December 1939 the provision of flashless propellant for full charges of Q.F. 4.5-inch, Q.F. 4-inch Mk. XVI and Q.F. 5.25-inch was asked for mainly on account of the reduction of wear. It was found that in the Q.F. 4.7-inch Mks. IX and XII with a 55 lb. shot, flashlessness was obtained with N/A.Q. .101 when a supplementary igniter of 4 oz. of G.12 was used in addition to the primer. 3941 4254

A charge to give the required ballistics could not however be loaded if in cord form, but only as S.T. or M.T. Flashlessness was obtained with N.F.Q./S. (ann. .058) with a No. 24 primer and supplementary igniter of 4 oz. of G.12, and the adoption of this charge was recommended. Similarly with the Q.F. 4.5-inch the charge recommended was N.F.Q./S (ann. .072). (The symbol S being adopted to denote slotted tube.) 4858 4859

O.B. Proc.

A review which was given of the results of a number of
firings in different guns of N/A.Q. in different forms confirmed
the lower pressure at which a given velocity could be obtained
with slotted tube, than with other forms. Apart from the loading 5456
difficulty with cord the tendency of the S.T. form to flash was 5638
less.

It was reported by the 5th Destroyer Flotilla from a trial
carried out at night in February 1941 that, when firing full
charges of N.F.Q. in the Q.F. 4.7-inch Mks. IX and XII gun, no 10641
flash could be seen by the firing or target ships.

Satisfactory flashlessness was obtained in this gun, when
either new or slightly worn, with N/S 164-048 made at Ardeer or 14652
N.F.Q./S 179-054 made at R.N.C.F.

The proof results of 14 lots of N.F.Q./S 164-048 (ann. .058)
showed good regularity with pressures of 19.5 to 20.2 tons. To
reduce the pressure an annulus of .060 was recommended for immedi- 15242
ate production. A trial was conducted with N.F.Q./S 168-048 of
Caerwent manufacture in 6 new guns with a No. 14 primer. The 18230
regularity varied in the different guns. A night-firing trial in
a worn gun gave very small flashes.

Similar results were obtained with N.F.Q./S 172-052 of
R.N.C.F. manufacture. A glowmeter measurement of the small
flashes given when using a No. 9 primer gave these as 8 c. secs. 18666

(i) <u>Q.F. 4.7-inch Mk. VIII</u>

In this gun satisfactory ballistics (2452 f.s. at 19.2 tons)
were obtained with N.F.Q./S 164-048 (full charge). A nominal 16164
charge of 10 lb. 5 oz. was provisionally recommended with a No. 9 16776
primer and 4 oz. core igniter and was approved as master standard. 22708

(j) <u>Q.F. 5.25-inch Mk. I gun</u>

In a firing trial with a star shell charge for this gun in
November 1939 with N/A.Q. cord 0.080 inch with igniters containing
4 oz. and 6 oz. g.p., flashlessness was obtained in all rounds, 3689
but the extra powder tended to increase the muzzle glow. A 5892
minimum amount of 2 or 4 oz. powder was found necessary to suppress
the sporadic flashes. 7115

For a full charge, N.F.Q./S 224-058 proved to give satisfac-
tory ballistics and a proportion of small flashes. For the
ignition, trials were conducted with total amounts of g.p. ranging
from 5 to 11 oz. The best results were given with a No. 17 12713
primer and $8\frac{1}{2}$ oz. G.12 or with 4 oz. G.12 for the reduced charge.

In the Q.F. 5.25-inch high velocity star shell, a trial with
N.F.Q./S 224-058 (ann. .084) and 251-065 (ann. .093) showed that
the former was unlikely to give the required velocity of 2850 to
2900 f.s. at a mean pressure of 21.5 tons while both sizes gave 18120
glows visible in daylight. FNH/P fired in comparison gave full
flashes.

In this gun N/S 224-058 made in Canada, though of somewhat 21492
variable annulus, gave regular ballistics and the flashlessness
was similar to that given with N.F.Q./S of home manufacture.

N.F.Q./P/S (and the same propellant with cryolite omitted) in
sizes 224-058 and 251-065 gave better results, though not complete-
ly flashless, by the definition of not being visible at night at 21664
8000 yards.

FNH/P .061 containing 3 per cent potassium sulphate gave

large flashes in a worn gun and was unsatisfactory. O.B. Proc.
21819

In a trial with N.F.Q./S 198-054 and a 4 oz. G.12 core
igniter to determine the influence of shot weight on flashlessness,
it was apparent that with an 80 lb. proof shot as used with the
full charge, 21 lb. of the propellant gave only very small flashes
while with a 71 lb. H.V.S.S. shot larger flashes were obtained.
No improvement resulted by reducing the propellant size to 164-048
or by increasing the g.p. igniter to 8 oz., though N.F.Q./P/S 164- 22990
048 gave only small flashes (23 to 160 c. secs.) with the lighter
shot.

N.F.Q./S 198-054 was recommended for adoption for the full 23707
charge, while the high velocity star shell charge remained unsatis-
factory by the definition of visibility at 8000 yards, but was 23751
satisfactory from the non-blinding aspect. The use of a heavier
shell or shorter range was considered. 25307

In December 1944 it was decided to increase the supply of
N.F.Q./S 198-054 charges to 100 per cent of the outfit for this 29854
gun.

In new Mk. VII guns at proof N.F.Q./S 198-054 (full charge) 24883
with a 4 oz. igniter gave 4 large flashes in 60 rounds. In a 25486
trial with an 8 oz. G.12 igniter at propellant proof 1 large and 26617
3 small flashes only were given in 123 rounds.

In a comparative trial with shots of 71 lb. 10 oz. (H.V.S.S.)
and 80 lb. (full charge) in a new gun small flashes of 40 to 150 c.
secs. were given with the lighter shell and flashes of 20 to 80 c.
secs. with the heavier shell. In an old gun none of the flashes 26725
exceeded 1.5 c. secs.

Ardeer solventless propellant, A.S.N./T (ann. .081) with a 25331
2 oz. G.12 core igniter gave large flashes and was unacceptable. 25810

Cordite S.N.F.Q./S (later known as M.N.F.Q.) 198-054 made at
the R.N.P.F. by the "semi-solventless" process (cf. p. 85) gave a
satisfactory flashless performance in a part-worn gun with a
No. 17 primer and 8 oz. G.12 core igniter, and gave an indication
of a slight improvement of regularity of velocity (m.d.'s 1.5 and 33431
2.2 f.s. compared with 2.6, 3.7 and 1.8 for N.F.Q./S).

(k) <u>B.L. 6-inch Mk. VII, Mk. XII and Mk. XVII</u>

In the B.L. 6-inch Mk. VII (N.S.), N.F.Q./S 224-058 with an
igniter of 4 oz. G.12 at each end and a core of 6 oz. g.p. gave 12872
small flashes only.

In a further trial with 4 oz. G.12 igniters and a 10 oz. core
the propellant gave satisfactory ballistics and was flashless in a
new gun, but gave small non-blinding flashes in a worn gun.
Varying the igniters from a total of 16 oz. to 20 oz. g.p. made
little difference to the flashes. 14740

In the Mk. XVII gun N.F.Q./S 224-058 was found to give a
satisfactory flashless charge as in the Mk. VII gun, though the
charge of 34 lb. 4 oz. required for the ballistics in a new gun of
2880 f.s. at 17.75 tons could not be contained in the cases
employed with existing hoists. 15855

In the Mk. XII gun N.F.Q./S 198-054 was found to give
satisfactory ballistics and the V. of A. at about 18.5 tons. 16477

(l) B.L. 6-inch Mk. XXIII | O.B. Proc.

(For trials with NQ/P and H.P./P propellants see p. 34.)

Satisfactory results were obtained with N/A.Q. cord .137 and S.T. 251-064 with a 1-inch tube containing 1 oz. g.p. and an igniter of 6 oz. G.12 in the rear and 2 oz. G.12 in front of the charge. 11336

In a trial in a gun in its fourth quarter of life, small flashes only were given with igniters of 12 oz. and of 16 oz. of g.p. There was little to choose between cord and S.T. for flashlessness, but the cord was, if anything, slightly better. 14320

A firing of N.F.Q. cord .135 with 8 oz. G.12 core igniters at low temperatures (0°F.) gave unacceptable regularity. One round gave a 50 per cent flash, while the remainder were flashless. 14733

N.F.Q./S 224-058 (ann. .083) gave small flashes of 100-200 c. secs. compared with 600,000 c. secs. for S.C. cordite as measured by a glowmeter. This charge could only be loaded in Service containers as two half-charges. 17802

N.F.Q. .100 was found to be satisfactorily flashless and to give service ballistics at a pressure of 20.5 to 20.9 tons/sq. in. 28231
The charge would not however load into existing containers or in a proposed new design of container. 31448

A firing trial with S.N.F.Q. .100 (i.e. N.F.Q. made by a solventless process, cf. Appendix A), N.F.Q. .100 and N.Q.F./P .128 showed that the small flashes or muzzle glows with S.N.F.Q. and N.F.Q. were slightly less bright than those given by N.Q.F./P but that the required charges were on the limit of loadability in the containers and the charges slightly exceeded the acceptable pressure. 32918

(m) B.L. 8-inch Mk. VIII

A firing trial in a part-worn gun with N.F.Q./S 346-101 (ann. .122) and N/A.Q. cord .176 showed that no secondary flash resulted when using as igniters 7 oz. G.12 at the front and rear of the charge. It was found however that the dimensions of the charges required for service ballistics precluded their use in existing ships through the space limitation in existing designs of hoists and rammers. 12810 16814

The propellant NQ/P/S 348-095 which was subsequently tried was found to be neither flashless nor satisfactorily non-blinding. 20649

(n) B.L. 14-inch Mk. VII

The compositions which had until April 1946 been subjected to preliminary firing trials in this gun were as follows:-

N; N/2P; N/5P

F.560/64 (Picrite 50, oxamide 10.8, G.C. (13.2% N.)19, N.G. 18.7 carb. 1.5, K. Cry. 0.5) cal. val. 775 (W.L.)

F.527/127 (picrite 60.0, G.C. (13.1% N.) 16.6, N.G. 16.4, Carb.7)

F.527/127/2P (2% potassium sulphate) (cal. val. 757 (W.L.)

F.487/40/2P (picrite 60, G.C. (13.1% N.) 18.1, D.G.N. 18.1, Carb. 3.8, K_2SO_4 2) cal. val. 754 (W.L.)

Cordite N .270 in a B.L. 14-inch gun fired horizontally failed to give flashlessness. 26927 29886

On 16th January, 1945, two rounds of N .270 made with superfine picrite (sp. surface 40,000 sq. cm. per c.c.) fired in a part-worn elevated gun gave one flashless and one flashing round. The flashless round was a slightly reduced charge and the grey smoke produced was apparently less than that from a flashing S.C. round. O.B. Proc. 30106

In a trial in a new gun on 15th March, 1945, N/2P .263 in charges adjusted to give service ballistics gave no large flashes in two rounds while N/5P .264 in two rounds gave large flashes estimated to be about 1/5 of the service S.C. flash.

In a trial on 10th August, 1945 in an almost new gun N/2P .269 and .264 gave no large flash in 6 rounds.

F.560/64 cord .233 (with 0.5% pot. cry.) gave 3 large flashes in 3 rounds at service ballistics and F.527/127 cord .257 gave 1 large flash in 3 rounds.

Trials with N/2P, "cool N/2P" (F.527/127/2P), and "cool D.G.N./2P" (F.487/40/2P) were carried out at Shoeburyness by day in January 1946 in a slightly worn gun (54 E.F.C.) and at Woolwich by night in a worn gun (213 E.F.C.). 4 rounds of each composition were fired on both occasions. In the day trial one partial flash (1/5 to 1/4 service) resulted with one round of N/2P while no large flashes were observed with any of the remaining rounds, the best result being given with the D.G.N. composition (F.487/40/2P). In the night trial in the worn gun, medium or large flashes (exceeding 120,000 c. secs. though smaller than with S.C. cordite) were given with all the N/2P rounds, while only small flashes resulted with the remaining rounds except with one round of F.527/127/2P which gave a large flash. The best results were given with the cool D.G.N./2P composition (1200 to 1300 c. secs.). These picrite compositions gave an indication of a smaller effect of wear on ballistics compared with S.C. 33449 (cf. Fig.20 and Fig.21)

(o) B.L. 16-inch Mk. II

In a firing trial in a nearly new gun on 28th August, 1945, cordite S.N.F.Q./2P cord .272 gave no large flash in 3 rounds at service ballistics.

In the same nearly new gun on 12th and 13th June, 1945, no large flashes were given in three rounds with N/2P .269 or N/5P .269. The igniters used were $16\frac{1}{2}$ lb. G.12. The smoke with N/2P was estimated at 30%, and that with N/5P at 50%, greater than with S.C. (cf. Fig.22) O.B. Proc. Q.3753

C. Propellants of calorimetric values from 700 to 750 (W.L.)

With compositions of calorimetric value below about 750 cal./grm. (W.L.) the measurement of heat value by the calorimeter method gave an uncertain result due to the commencement of the separation of free carbon which occurred and led to an illusory higher calorimetric value than resulted when the combustion occurred without separation of carbon at the higher pressures obtaining in the gun. In this range of 700 to 750 cal./grm. the measured values could accordingly only be regarded as approximate while with compositions giving still lower values, a calculated rather than a measured value became necessary.[15]

With propellant cooler than cordite N, manufacturing and firing trials have, at different times, been conducted with compositions containing (a) 40, (b) 55 and (c) 65 per cent picrite. A.R.D. file

(a) The main 40% composition of this type which was investigated in 1933 was F.535/32 with a cal. val. of 730 (W.L.). This propellant when fired in a Q.F. 18 Pdr. with a S. of A. primer containing only 0.5 grm. of G.P.* was flashless, but gave a flash in 1 out of 2 rounds when fired with a primer filled with F.503/67 composition without G.P. C.3989/33 *(cf. p.58)

(b) Of a number of compositions with 55 per cent picrite and of cal. val. about 30 cals. below that of cordite N which were investigated in 1930 and again in 1937, firing trials were conducted with F.518/6 which had a cal. val. of 725 (W.L.) (measured). In trials with compositions without cryolite a comparison made in 1930 with cordite R.D.N. in the Q.F. 3-inch 20 cwt., Q.F. 4-inch Mk. XVI S.S., Q.F. 4.5-inch S.S. and Q.F. 4.7-inch Mk. XI S.S. failed to establish any advantage with this cooler composition. In 1937, firing trials were conducted with F.518/6 (with 0.3 per cent cryolite) in comparison with N/A.Q. in the Q.F. 4.5-inch with S.S. charge, Q.F. 4.7-inch Mk. XI and Q.F. 5.25-inch S.S. No superiority over N/A.Q. in reducing the residual flashes was shown by this cooler composition. O.C.Memos.B 34864 35018

(c) With compositions containing 65 per cent picrite and of lower cal. val. than cordite N, manufacturing trials were conducted in 1930 in order to determine the proportions of ingredients for optimum physical properties.

In trials conducted during 1945-6 to develop flashless charges for the B.L. 14-inch and B.L. 16-inch guns, the use of compositions containing 60 per cent picrite and of cal. val. about 730 (W.L.) (calculated) gave a definite improvement in flashlessness compared with cordite N. (cf. p.26)

D. Composition of calorimetric value from 750 to 820 (W.L.) with picrite contents of 40 and 65 per cent.

(a) 40 per cent picrite. A composition with 40 per cent picrite which was most extensively investigated was F.535/2 of cal. val. 815-820 (W.L.). This propellant was mainly flashless in the Q.F. 18 Pdr., Q.F. 3-inch 20 cwt., Q.F. 4-inch S.S. and Q.F. 3.7-inch How. In the Q.F. 3-inch 20 cwt. gun, flashes occurred, however, in about 20 % of the rounds with No. 11 Mk. I primers. Climatic trials of this propellant, which were extended over a period of 6 years, showed this to be of satisfactory chemical and ballistic stability. O.C.B. 36142 O.B. Proc. 11299 (cf. p.49)

(b) 65 per cent picrite. A composition F.507/5 (cal. val. 765 (W.L.)) was satisfactory in the Q.F. 3-inch 20 cwt. but gave flashes in the B.L. 6-inch Mk. VII. F.500/163 of cal. val. 810 (W.L.) was flashless in the Q.F. 3-inch 20 cwt., F.514/1 of cal. val. 775 (W.L.) was flashless in the Q.F. 4.7-inch Mk. VIII and an improvement on R.D.N., but gave a proportion of large flashes in the B.L. 6-inch Mk. VII. A.R.D. file C.2438/29 O.C.B. 21466 II

E. Compositions with alternative cooling agents O.B. Proc.

(1) Cellulose acetate. In order to obtain for a given cal. val. a reduction in the content of inflammable gases (CO and H_2), a number of compositions with various proportions of different types of cellulose acetate were investigated. F.536/38 of cal. val. 745 (W.L.) and containing 60 per cent picrite and 8.5 per cent cellulose acetate and F.536/39 of cal. val. 755 (W.L.) with 55 per cent picrite and 11 per cent cellulose acetate gave satisfactory results in the Q.F. 3.7-inch Mk. I.

(2) Oxamide. A composition F.560/13 of cal. val. 783 (W.L.) with 40 per cent picrite and 15 per cent oxamide gave satisfactory 20794
flashlessness when fired in the Q.F. 3-inch 20 cwt. and in the Q.F. 4-inch Mk. XVI H.V.S.S. F.560/50 of cal. val. 800 (W.L.) pressed solventless with 42 per cent picrite and 13 per cent oxamide gave satisfactory results in the Q.F. 4-inch Mk. XVI H.V.S.S., B.L. 6-inch Mk. XXIII, and B.L. 8-inch Mk. VIII with small flashes only in a part worn gun.

In a firing trial in the Q.F. 3.7 inch Mk. VI in 1946, A.R.D. file
composition F.560/64 of cal. val. 775 (W.L.) and containing 50 per B.265/1/1A
cent picrite and 10.8 per cent oxamide gave a flashless performance superior to that of N/P/M (1% K_2SO_4) though containing only 0.5 per cent K. cry. and of slightly higher cal. val. than cordite N. In the B.L. 14-inch gun, however, the flashlessness was inferior to that of N/2P (cf. page 26).

F. Composition of calorimetric value of about 880 (W.L.) (cordites H.P.; NQ)

Propellants of higher heat value were originally designed for use with Field guns in order to lower the concentration of CO (and of NH_3) in the muzzle gases and so diminish the toxicity. In order to help to counteract the greater tendency to flash with the hotter compositions the possibility of increasing the nitroguanidine content was investigated. The coarser crystal size of the compound originally used and known by the code name of "petrolite" was prepared by mechanical milling of large crystals and corresponded to a predominating size of about 0.15 mm. diam. It was found that compositions containing more than the proportion
in R.D.N. of 55 per cent of this material were not ballistically O.C.Memo B
regular on account of the presence of fissures in the cords while 19702
R.D.N. itself in large sizes made from this material was not satisfactory. It was ascertained that the more finely-divided product made by the spraying process, the crystals of which had a
predominating size of 0.003 to 0.005 mm. diam. and designated (cf. p. 43).
"picrite", enabled compositions to be prepared containing 65 per cent of the compound without detriment to the compactness and density of the cordite and to the ballistics.

To provide a hotter propellant, the composition finally decided on for extended trials after numerous preliminary physical tests had a calorimetric value of 880-890 (W.L.), was designated H.P. ("hot picrite") and contained 65 per cent picrite.

Satisfactory ballistic and flashless results were obtained with this in trials in the Q.F. $1\frac{1}{2}$ Pdr., Q.F. 6 Pdr., Hotchkiss,

Q.F. 18 Pdr. Mk. IV, Q.F. 3-inch 20 cwt. (reduced charge), O.C.Memo B
Q.F. 3.7-inch and Q.F. 4.5-inch How. and indicated that it would
be advantageous to replace this for R.D.N. in small land guns and 20272
howitzers.

Satisfactory results were given in the Q.F. 3-inch 20 cwt.
(full charge) with H.P. .045 with a 4 drm. igniter. 21485

Arrangements were made for conducting comprehensive stability trials with this propellant also with a modification in which the gun cotton was replaced by nitrocellulose of similar nitrogen content derived from wood cellulose.

Slight flashes were obtained with H.P. in the B.L. 6-inch
26 cwt. How. with cord .048 when fired with a 100 lb. shot and 20762
pressure of 13.2 tons.

A further composition (F.551/27), later designated R.D.H./A, containing 55 per cent picrite and of approximately the same cal. val. as H.P. which was designed and investigated consisted of:- Picrite 55; N.C. (12.2 per cent N) 21; N.G. 21; Carbamite 3. (cal. val. 885 (W.L.)). The addition of 0.3 per cent cryolite was later introduced and the number F.551/58 given.

This propellant (F.551/58), made with N.C. of cotton origin,
was designated R.D.H./A.Q. or R.D.Q. and satisfactory results were
obtained with cord size 0.046 when fired in the Q.F. 6 Pdr. 10 cwt. O.C.Memo
with a No. 15 Mk. I primer. 956

A report of trials by Service units in 1938 of cordite R.D.H/A
in Q.F. 18 Pdr. and B.L. 6-inch How. batteries concluded that
flashless propellant has "definite tactical advantages over the
existing service cordites and that the amount of smoke produced
was not such as to outweigh the great advantages of eliminating 1766
the flash."

An extensive trial was carried out at Larkhill on 15th July, 1938 with Q.F. 18 Pdr., Q.F. 4.5-inch How. and Q.F. 25 Pdr. guns sited in sheltered non-ventilated enclosures. The results of measurements of carbon monoxide concentrations and of blood tests on the gun teams are given on p.51.

Trials with R.D.H./A in the Q.F. 6 Pdr. 10 cwt. in comparison
with R.D.N./A showed that occasional full flashes resulted with
the former, but that its advantages over R.D.N./A as regards smoke O.B. Proc.
and fumes outweighed the disadvantages of an occasional flash. 1797

In order to utilise N.C. of 13.1 per cent N. content in place 2290
of 12.2 per cent for Land Service factories, firing trials were 2990
conducted in the Q.F. 2 Pdr., Q.F. 25 Pdr., Q.F. 6 Pdr. 10 cwt.
and Q.F. 40 mm. with the composition designated NQ and consisting 8263
of:- picrite 55; G.C. 21.5; N.G. 20.0; carbamite 3.5; 8858
cryolite 0.3 (cal. val. 880 (W.L.)). The flashlessness was, in 9029
all cases, satisfactory but the regularity of these early batches
was poor. 14381

In order to use the same G.C. - N.G. paste composition as that employed for cordite N, further minor modifications of composition were made and the proportions of ingredients finally specified for Land Service propellants were as follows:-

Cordite	Picrite	G.C.	N.G.	Carbamite	Cryolite
N	55	19	18.7	7.3	0.3
NQ	55	20.8	20.6	3.6	0.3

NQ/S propellant of annulus .031 to .034 was found to be satisfactory for the Q.F. 40 mm. | O.B. Proc. 16353

As progress was made with the manufacture of this propellant, firing trials were conducted in different guns with the results detailed below:-

(a) Q.F. 2 Pdr. Mks. IX and X

NQ cord .034, a size in common with that recommended for the Q.F. 6 Pdr. 10 cwt., was found satisfactory and its adoption awaited a decision on the policy for flashless propellants in anti- 16110
tank guns.

(b) Q.F. 2 Pdr. Mk. II gun

Cordites NQ/S and NQ/T 082-032 were found to be satisfactorily flashless for a V. of A. of 2040 f.s. at 14.5 - 15.2 tons with No. 27 primers and with or without igniters of 20 grains of G.20. The larger igniter was necessary, however, for an acceptable firing interval. 17308

(c) Q.F. 2 Pdr. Mk. VIII

The maximum charge of NQ/S 082-032 which could be loaded in conjunction with a No. 12 primer was 1800 grains which was insufficient to operate the automatic loading in a worn gun at -5°F. The compositions of higher cal. val. which it was necessary to develop for this gun are dealt with in Section G,(p.36.)

(d) Q.F. 6 Pdr. 6 cwt.

NQ/M and NQ/P/M (1 per cent potassium sulphate), cord .046, were not flashless in this gun, though with NQ/P/M the flashes 21273
were less bright than with NQ/M. N/M (web .040) with a No. 15
primer and 2 oz. bandolier igniter gave only small flashes (17 c. 21985
secs.) similar to those with FNH/P. N/P/M web .035 with a No. 15
primer and 1 oz. igniter gave flashes of 5 c. secs. in a 1/3 worn 22781
gun, and in a ½ worn gun the flashes were measured as 9 c. secs.
(compared with 112,000 for NH). 24757

In a further trial in a nearly new gun to determine a charge to give 3150 f.s. for a pressure less than 21.5 tons, N/P/M gave small flashes measured at 12-28 c. secs. With these charges using a No. 15 primer and 1 oz. G.12 bandolier igniter, occasional high and irregular pressures resulted and were attributed to the use of a base igniter. 25084

Measurements made with FNH/P showed that irregularities in the pressure-time curves were overcome by the use of American axial primers (M.22 A 3) containing 65 grains of G.P. while no 25517
sporadic high pressures occurred in gun firings.

Satisfactory trials were conducted with the American type of magazine adapted to fit the No. 15 primer base. 26035

Similar measurements in the Q.F. 6 Pdr. 10 cwt. with FNH showed that irregularities in the pressure-time curves were smoothed out by these primers. 26088

The smoothest pressure-time curves were eventually given with either FNH/P or N/P/M propellants by the use of primers with Q.3663
cordite-wall magazines (cf. p.60). 33340

(e) Q.F. 6 Pdr. 7 cwt.

NQ/S 142-042 made from guncotton and Welland picrite when

fired with a No. 15 Mk. III primer and 1 oz. G.12 core igniter O.B. Proc.
gave large flashes with most rounds, while a similar composition
with the finer Waltham picrite and NQ/S 132-042 from Waltham
picrite gave small or no flashes. 16149

A firing trial with NQ/S 126-042, NQ/P/S 126-042 and
NQ/S 144-040 showed that NQ/S with a No. 15 primer and 1 oz. G.12
core gave a proportion of big flashes and NQ/P/S muzzle glow only
(6 to 8 candle secs.) compared with 47,000 candle secs. for NH
propellant, but an increased amount of smoke. The NQ/S was found
to be equally flashless if the core igniter was increased to $1\frac{1}{2}$ oz.
so that the total amount of K salt present was the same as with
NQ/P/S. Charges to give service ballistics could not however be
loaded as a single bundle but only as a loose charge. It was
concluded that for the Q.F. 6 Pdr. and 17 Pdr., for which a high
density of loading was necessary, cordite in stick form was 19655
unlikely to be satisfactory for easy filling.

Apart from the elimination of flash, the use of flashless
propellants for the anti-tank and tank guns Q.F. 6 Pdr. 7 cwt. and
Q.F. 17 Pdr. was considered to be of particular advantage on
account of the reduction of blast which resulted from their use. 19677

In these two guns NQ/S was considered to be unsuitable on
account of the difficulty of loading. FNH/P, which it was 20211
decided to adopt as an alternative, was found, however, not to be
flashless in the Q.F. 17 Pdr. even when 2 per cent potassium salt 20557
was included. FNH/P with 3 per cent potassium sulphate gave in
the Q.F. 17 Pdr. smaller non-blinding flashes, but accompanied by
excessive smoke. 22372

A trial with the propellant in ribbon form (i.e. NQ/R .046 x
.243) gave only small flashes in a worn gun with a No. 15 primer
and 1 oz. G.12 igniter. The flashes measured with a glowmeter
were from 20 to 57 candle secs. when a muzzle brake was used com-
pared with values of about 12 candle secs. previously obtained
without muzzle brake. An increase of propellant size to .052
thickness which was indicated by these results was expected to
lead to difficulty of loading as a single bundle. 23060

For the Q.F. 6 Pdr. 7 cwt. Mks. IV and V (Air Service) NQ/S Q.1563
134-040 with a No. 15 primer and $1\frac{1}{2}$ oz. G.12 igniter was found Q.3145
satisfactory and a charge to give 2920 f.s. at 20.5 tons was
finally recommended.

(f) Q.F. 17 Pdr. Mk. I. (See also under Q.F. 6 Pdr. 7 cwt. and p.16).

NQ/P/S 193-052 (ann. .074) with a No. 9 primer gave satis-
factory ballistics and in absence of a muzzle brake gave a much 17982
reduced flash compared with NH .055 or FNH/P.

In a trial conducted with NQ/P/S (ann. .074) containing 1 and
2 per cent K_2SO_4 with a No. 9 primer and 1, 2, and 3 oz. G.12
igniter no difference could be detected between the flashlessness
of propellants with 1 or 2 per cent K_2SO_4. Increasing the
ignition from 2 to 3 ozs. also made little or no difference. Small
flashes apparent at night as a muzzle glow with a central white
flash up to 3 feet long were obtained in all cases. The charge of
NQ/P/S could not moreover be loaded as a single bundle. 20139

(g) Q.F. 6 Pdr. 10 cwt.

R.D.Q. cord .045 was found to provide a satisfactory charge 6436
for this gun. 7336

(h) Q.F. 40 mm. Bofors Mk. I. | O.B. Proc.

Trials with F.551/58 in M.T. and S.T. form in replacement of W/T 144-048 showed that the M.T. form of web size .032 with a No. 16 primer and 6-inch igniter containing 140 grains G.20 powder gave satisfactory and regular ballistics and was practically flashless and more easily loaded than the S.T. charge. 2377

NQ/S (ann. .031) made at Ardeer with guncotton was satisfactory except for poor regularity. 8858

NQ/S 101-041 (ann. .030) made at Ardeer from guncotton and Waltham picrite gave no flashes, but to reduce the pressure to the specification limit, an increase of annulus to about .034 would be required. 16353 The results of a firing of NQ/S 113-045 (ann. .034) were reported as very satisfactory though the required charge of 10 oz. 6 drms. would not load as a single straight bundle. A more easily loadable charge was provided by NQ/R .033 x .164. 20121 With a No. 18 primer this charge gave satisfactory flashless and ballistic results, but was on the borderline of loadability as a single bundle. 21749

NQ/S 096-032 (ann. .032) with a No. 12 primer and no igniter gave service ballistics of 2915 f.s. at 16.3 tons and flashlessness, but the charge was too near the loading limit to be practical.

Firing trials with N.F.Q./M web .021, N.Q.F./R thickness .031, N/M web. .0215 and H.P./M .026 gave satisfactory results with a No. 12 primer in all cases. 31601

N.F.Q./M gave smoke similar to FNH/P and N.Q.F./R only about one third of this amount. At the time of writing the monograph further trials were in hand with the use of primers with smokeless fillings and to ascertain if the ignitions used would be adequate at -30°F.

When using a multi-barrel equipment it was found that N.Q.F./R of thickness .031 was superior in flashless performance to NH and FNH/P but with this equipment the smoke produced by the three variants was substantially the same. 33315

In a night-firing trial with a worn gun (E.F.C. 1227) comparative firings with N.Q.F./R thickness .031, N.F.Q./M .021 and FNH/P .022 gave in all cases only muzzle glows or very small flashes ($<$1.5 c. secs.). The best results were given by N.F.Q./M .021 with a No. 12 primer with U.S. type magaine (64 grains G.7). 33649

(i) Q.F. 40 mm. class "S" gun

NQ/S 082-032 was found suitable and approved for use with H.E. shell. 20408 20481 20773

NQ/R of thickness .027-inch was flashless and gave an increase of about 50 f.s. compared with a loadable charge of NQ/S 082-032, but would still be about 75 f.s. below the M.V. given by the approved charge of H.S.C.T./K. 22704

(j) Q.F. 25 Pdr.

A trial in the Q.F. 25 Pdr. and B.L. 6-inch 26 cwt. How. with NQ/S 142-042 made with Welland picrite and NQ/S 132-042 made with the finer Waltham picrite showed that an annulus of approx. .052 should be suitable for both varieties. 16148 (cf. p.34)

For the Q.F. 25 Pdr. supercharge, NQ/S 144-040 (ann. .052) was found to be satisfactory for ballistics and flashlessness when made with either Welland or Ardeer picrite. The rate of burning appeared to be less susceptible to the type of picrite used and the method of mixing employed than in the case of cordite N. O.B. Proc.

For service ballistics and so as to be suitable also for use 18329
in the B.L. 6-inch 26 cwt. a reduction of propellant size to ann. 18777
.048 was recommended.

The size finally approved, in common with that for the B.L. 22528
9.2-inch How. Mk. II was 134-040 (ann. .047).

For a further increase of velocity which was required, i.e. from 1780 f.s. to 2055 f.s. when using A.P. shot weighing 20 lb. compared with the normal 25 lb. H.E. shell, an additional separate incremental charge was satisfactorily introduced and consisted of $5\frac{1}{2}$ oz. of NQ/S. 134-040 in addition to the main charge of 2 lb.
12 oz. of this propellant. 23020

For the ordinary charge the propellant recommended as a result
of further trials was NQ/S 047-027 for charge I and NQ cord .050 18465
for the incremental charges.

On account of the difficulty of manufacture of the small size of slotted tube, trials were made with a more easily made ribbon
form of propellant .014 x .048" and this was found to be equally 20070
satisfactory for charge I as regards ballistics and flashlessness. 22162

In a firing trial for master standardisation of NQ/R .014 x .048 and NQ .050 of Ardeer manufacture the regularity of the NQ lots
was better than that of the NH standard. 22929

NQ (cord .018) was found to be as satisfactory as NQ/R for 31150
charge I.

With NQ propellant and a "smokeless" C.9 type of primer (cf. p.59) the amount of smoke was found to be only slightly
greater than with a flashing propellant in the Q.F. 95 mm. Tank 25248
How. and Q.F. 25-Pdr. (Fig.22). When using a muzzle brake however, 28996
a proportion of flashes was obtained. 33117

(k) <u>B.L. 4.5-inch How.</u>

R.D.Q. cord .045 for charge I and S.T. (ann. .065) for charges II and III gave complete flashlessness with the full charge, but
flashes estimated a $\frac{1}{4}$ service were given with the lower charge II. 7892
Satisfactory flashlessness was obtained with all charges by
employing NQ .050 for charge I and N/S 164-048 for II and III. 19811

(l) <u>B.L. 5.5-inch Mk. III gun-howitzer</u>

With a shell of 100 lb. weight R.D.Q. cord .045 was found satisfactory for charges I and II in this gun and R.D.Q./S 158-048 (ann. .055) for charges III and IV, an igniter of 1 oz. G.12 being
employed at each end of charge III. 5003

As the result of later trials the charges adopted were NQ .050 for I and II and either NQ/S or N/S 164-048 for charges III and IV. The igniter used consisted of 1 oz. G.12 at each end of charge I. In a determining trial the ballistics and flashless-
ness were satisfactory except that with NQ/S one round in 21 with 22548
charge IV gave a flash in a new gun. The N/S 164-048 was satisfactory except for rather high m.d.'s of M.V. On account of the larger charge of N/S, the NQ/S charge was preferred.

For an 80 lb. shell however, N/S 164-048 was adopted as a 23256
single bundle with a 2 oz. g.p. igniter at each end. 24685

An analysis of sporadic full flashes with the NQ propellant used with the 100 lb. shell showed that in 7000 rounds with 2 oz. G.12 igniters at each end of charge III the number of full flashes amounted to 3.2 per cent with charge III and the same percentage with charge IV. The flashes nearly all occurred with guns which had previously fired between 4500 to 5700 rounds. As a supercharge for use with an 82 lb. shell a composite charge of NQ .050 for charges, I, II and III and NQ/S 164-048 for charge IV was found to give satisfactory ballistics and flashlessness in a nearly new gun. The igniter used was 2 oz. G.P. at each end of charge III.

O.B. Proc.
29337
32637

(m) B.L. 6-inch 26 cwt. How.

R.D.Q. cord .045 or alternatively S.T. (ann. .032) was found suitable for charges I - IV. NQ/S 142-042 or 132-042 made with either Welland or Waltham picrite was also found satisfactory in common with the charge of ann. .052 for the Q.F. 25-Pdr. 5019 16148

(n) B.L. 6-inch Mk. XXIII. (For trials with N.F.Q. in this gun see page 25).

In order to reduce the flash given in this gun by NQ, trials were conducted with NQ/P (1 per cent K_2SO_4). With a charge of 31 lb. 13 oz. of cord size .137-inch, service ballistics were obtained with non-blinding flashes of 200 to 400 c. secs. as measured by the glow meter. A 4 oz. core igniter was used together with a 2 oz. spread igniter at each end of the charge. 17082

In a comparative trial with different propellants, NQ/P cord gave non-blinding flashes in a new gun, but blinding flashes occurred with a well-worn gun. NQ/P/S gave non-blinding flashes in a new gun with occasional full flashes in a well-worn gun. N.F.Q./S gave completely non-blinding flashes in both new and worn guns. 17802 18180

Full charges of NQ/P/S and N.F.Q./S would not, however, fit into the existing cardboard containers, but could be loaded as two half charges.

The adoption of NQ/P cord was recommended together with the provision of some N.F.Q./S in special stowages for use with worn guns and for initial firings where a higher degree of flashlessness was required.

A firing trial in a worn gun at night with NQ/P .138 and NQ/P/S (ann. .101) showed, however, that in a worn gun the flashes, estimated at about 40 per cent of those of S.C. cordite, were objectionably bright. 18407

N.F.Q./S 224-058, which could be loaded only as two half charges, was otherwise satisfactory.

In a demonstration at Inchterf on the night of 10th June, 1942 which was attended by representatives of the C. in C. Home Fleet, NQ/P/S was almost completely non-blinding in a worn gun, while with NQ/P cord the blinding effect though slight was greater than with S.T. The cord charge was found just to fit in the present cardboard containers whereas NQ/P/S, as with N.F.Q./S which gave only very small flashes, would require to be loaded as two half charges. 19006

A trial was conducted with NQ/K (2 per cent K. cryolite) cord .138, made at Ardeer with Welland picrite, in comparison with NQ/P made at Woolwich. In both cases the flashes were considered to be on the limit of "non-blinding", the largest being of the order of 8000-10000 candle secs. compared with 500,000 candle secs. for S.C. To facilitate loading, a slight reduction of size with a small pressure increase was recommended and the replacement of the K. 20001 cryolite by KNO_3, in order to increase the rate of burning and give a lower charge weight. O.B. Proc.

Approval was given for an increase of top limit of mean pressure from 19.5 to 20.5 tons. 20331

Trials with NQ/P containing 2 per cent KNO_3 compared with 2 per cent K. cryolite showed no appreciable difference between the two salts. In a new gun small flashes of from 370 to 3700 candle
secs. were given and larger flashes up to 36000 candle secs. in a 21117
worn gun.

In a trial with N.Q.F./P cord .128, service ballistics at a pressure of 20 tons were obtained with a charge loadable in the cardboard container. With a 12 oz. G.P. igniter non-blinding
flashes of 1000 to 4300 c. secs. were given except with one round 22785
which gave a large flash in a new gun. This result was considered
satisfactory and bulk manufacture of this charge was approved sub- 23500
ject to satisfactory loading being obtained which was accomplished. 24325
On a later occasion, however, the results in a worn gun were less
satisfactory. 24558

In reports from the Fleet, H.M.S. "Ajax" and H.M.S. "Orion"
found the non-blinding quality of N.Q.F./P .128 to be satisfactory 28276
and H.M.S. "Aurora" reported the non-blinding effect to be most 28865
marked and satisfactory. 30669

In providing a reduced (2/3) charge, large flashes were given 25757
with N.Q.F./P .128 which was, however, found to be ballistically too large and this requirement of a flashless reduced charge was
met by a special cartridge of N.F.Q./S 164-048 with a 12 oz. g.p. 27824
igniter and this charge was approved for provisional adoption.

Measurements of temperature correction of N.F.Q./P .128 in this gun gave the following results:-

23°-82°F.	8.6 f.s./0.25 ton per 10°F.	31453
82°-118°F.	12.9 f.s./0.28 " " "	

The mean correction recommended over the range 20°-120°F. was
10 f.s./0.25 ton per 10°F. which compared with 15.0 f.s. for S.C. 32778
150.

H.P./P Cordite

H.P./P when made with normal Naval grade picrite was found to
give a flashless performance similar to that of NQ/P, but when made 31393
from superfine picrite (38.000 sq. in/c.c.) was markedly superior. (cf. p.44)
Additional advantages of H.P./P propellant compared with NQ/P were the higher density and reduced charge weight which would facilitate bulking.

(o) B.L. 8-inch Mk. VIII

As the flashless N.F.Q. charge which had been developed for this gun exceeded the limits of acceptable charge dimensions for
the containers, a trial was conducted with NQ/P/S (1 per cent O.B. Proc.
K_2SO_4) S.T. 348-095. This gave large flashes even with an igniter 20649
of 36 oz. G.12, though these were less blinding than the flashes given with S.C. cordite.

G. Cordites of higher calorimetric value (H.N.)

With the 2 Pdr. Mk. VIII a special difficulty resulted from O.B. Proc.
the small chamber of the gun which involved the use of propellants
of still higher calorimetric level and it was required for these
to be flashless or non-blinding. NQ/P/S gave practically no
flashes, being, in this respect, superior to H.S.C.T./P (2 per cent
K_2SO_4), though with a loadable charge the M.V. is reduced by 70 f.s.

H.S.C.T./K with 1 per cent K cryolite was found to provide a
non-blinding charge and a slight improvement resulted by increasing
the K. salt to 2 per cent. Alternative compositions containing
picrite were designed to be of higher cal. val. than that of NQ to
give a loadable charge for service ballistics. The compositions
tried were F. 563/5 (cal. val. 1115 (W.L.)) consisting of Picrite 17036
40, G.C. 25, N.G. 34, Carb. 1, K_2SO_4 1; and F.563/7 (1058 cal./gm.
(W.L.)) consisting of Picrite 50, G.C. 21.5, N.G. 28, Carb. 0.5,
K_2SO_4 1. The most promising results were given with F.563/5 in
slotted tube form of annulus .035.

In a worn gun these propellants gave small non-blinding
flashes which were seen from oscillograph records to commence from
2 to 3 milliseconds before the emergence of the shot and were thus
apparently due to the escape of gas past the driving band.

A modified composition F.563/9 in which the K_2SO_4 content was
increased to 2 per cent and which offered less difficulty in manu- 18482
facture gave a further slight reduction of flash but the charge
necessary for service ballistics appeared to be unlikely to load 19634
readily.

In order to facilitate manufacture of F.563/5 (now designated 20405
H.N./P) trials were conducted with a ribbon form of dimensions
.035 x .166 and known as H.N./P/R. A charge to give service
ballistics was readily loaded and the flashlessness with a No. 27
primer and 20 grain G.20 igniter was satisfactory. 21341

Very favourable results were reported by the 16th Destroyer
Flotilla with H.S.C.T./K in 2 Pdr. Mk. VIII and by H.M.S. "Garth" 21578
during a night action in February 1943. 22336

In a trial in a gun fitted with a service flash eliminator
H.S.C.T./K and H.N./P when fired during damp atmospheric conditions
gave equally flashless results. 21869

A comparative firing of H.N./P/R .041 x .210 and H.S.C.T./
K 134-055 showed little difference in the flashless performance.
A loadable charge of H.N./P/R gave however some 75 f.s. less than 23094
H.S.C.T./K and the latter was recommended for adoption.

In the Q.F. 2 Pdr. Mk. II gun H.N./P/S (ann. .030) was found
to give the required ballistics and the use of a 30 grain primer
was found desirable for optimum regularity. Complete flashless- 22461
ness except for muzzle glow resulted, and in this respect the 19806
propellant was superior to H.S.C.T./K which had previously been
adopted for this gun.

With a further batch of H.N./P/R .035 x .166 made at R.N.C.F.
however, velocities and flashlessness equivalent to those of
H.S.C.T./K were given though the pressure was higher. 23185

In the Q.F. 2 Pdr. Mk. VIII, H.N./Q/R .036 x .180 (which
consisted of H.N./P/R in which the potassium sulphate was replaced
by 0.3 per cent cryolite) was fired in comparison with H.S.C.T./K
and H.S.C.T. With H.N./Q/R, the smoke was found not to be
noticeably greater than with H.S.C.T. while the flashlessness was

equal to that with H.S.C.T./K. O.B. Proc. 31349

The further investigation of H.N./Q/R was later suspended as the production of further ammunition for this gun was not required. 31608

H. Review of position with flashless propellants in 1942-3

In a statement by D.N.O. on 14th November, 1941, reporting the increasing importance to the Naval Service of flashless propellant the advantages enumerated were (a) prevention of disclosure of the ship's position to the enemy (b) avoiding blinding of personnel (c) reduced wear of gun (d) reduced blast (e) lower liability to accidental ignition, while the disadvantages were (a) greater bulk (b) greater toxicity of gases (c) inferior regularity and (d) increased smoke. 15521

It was considered, however, that except for increased smoke the remaining disadvantages could be countered and observations of smoke were at this time inconclusive.

In a review of the development of British and American types of flashless propellant made by the President of the Ordnance Board in March 1942, it was pointed out that the R.D. picrite propellant was flashless in all Naval guns of Q.F. 5.25-inch and below and had given promising results in the B.L. 6-inch and 8-inch guns but that it was doubtful if the required charge (for the B.L. guns) could be accommodated in the hoists etc. 16703

FNH/P was flashless in the Q.F. 4.5-inch and 4-inch Mk. XVI guns, but there was some uncertainty about its freedom from giving erratic ballistics.

With regard to the toxicity of the gases from the breech, that with R.D. picrite propellants was the least toxic, in view of the lower CO content, while service propellants were intermediate and American N.C.T. propellant most toxic.

Flashless propellants gave more smoke but this dispersed more quickly than the smoke from S.C. cordite.

In addition to the lower erosion, the reduction of blast with flashless propellants was also considered to be of special value for tank and anti-tank guns. 19677

In July 1941 the production of flashless (picrite) propellant at R.N.C.F. was 8 tons per week rising to 15 tons per week by the end of 1941. Arrangements were made for a designed output at R.N.P.F. Caerwent of 75 tons per week in 1942 (for the Naval Service). (cf. p.103) O.B. Proc. 13155

In a review by the Ordnance Board in October 1942 of the ballistic results with flashless propellants, it was concluded that, except in the Q.F. 4-inch Mk. XVI, the regularity with N.F.Q. was of the same order as that with S.C. and that N and N.F.Q. could be adopted for 100 per cent of outfits for Q.F. guns of 4.7-inch and below without any appreciable loss of ballistic efficiency. 19891

The problem which still remained at this time was to reduce the muzzle glow or primary flash which occurred with all charges, the occasional brighter incipient flashes, and the sporadic large flashes which resulted with some charges. Better standardisation of manufacturing technique at the different factories remained to be effected in order to improve ballistic regularity. The comparative efficiencies of KNO_3 and K_2SO_4 as flash inhibitors remained to be determined. O.B. Proc. 20142

With regard to the location of the salt, a review of the results of a large number of trials showed there to be no evidence of any consistent difference according to whether the salt was incorporated in the propellant or added as igniter. 20851

Ballistic Regularity

The m.d.'s of M.V. for cordites S.C., N/S, N.F.Q. and W.M. as determined during proof in 1942 were summarised as follows:- 19889 22793

Gun	Mean of m.d.'s of M.V. in f.s.			
	S.C.	W.M.	N/S	N.F.Q./S
4-inch Mk. XVI	5.1		9.4	8.2
4.5-inch Mks. I and III	4.2		4.7	
4.7-inch Mks. IX and XII	4.0			4.2
Q.F. 3.7-inch A.A.		4.5	5.4	

Other data on the regularity of N/S in the Q.F. 4.5-inch and 5.25-inch are given on pps. 15, 20 and 23. 19889 22720

In the Q.F. 3.7-inch Mks. I and III, A.A. gun the ballistic regularity of N/S 164-048 was concluded to be sufficient to enable fixed charge weights to be employed for loading. Q.1261

In the B.L. 5.5-inch How., the firing of a lot of N/S 164-048 for master standardisation in 6 new B.L. guns in 1945 gave m.d.'s in the different guns ranging from 0.8 to 4.6 f.s. with an average of 3.3 f.s. In the B.L. 4.7-inch Mk. I gun, different lots of N.F.Q./S 164-048 of R.N.P.F. manufacture fired for determination of master standards gave m.d.'s ranging from 3.0 to 8.0 f.s. 31435

Temperature correction for N.F.Q. was found to range with different guns from 7 to 17 f.s. and pressures from 0.20 to 0.35 tons for 10°F. while there was no evidence of serious departure from linearity of correction between 100°F. and -5°F. 17423

With N.Q.F./P .128 in the B.L. 6-inch Mk. XXIII gun, a temperature correction for velocity of 10 f.s./10°F. was found to apply. 33000

I. Methods of manufacture O.B. Proc.

The methods of manufacture of picrite propellants which had been brought into use were of four types:-

(a) Dry-mix

(b) Displacement of water from the N.C. by alcohol followed by use of acetone-alcohol solvent.

(c) Wet-mix (of N.C. and N.G.).

(d) Solventless or semi-solvent technique during extrusion.

(a) The dry-mix technique was that originally devised in order to utilise the existing plant for solvent cordite manufacture which was available at the R.G.P.F. Waltham Abbey.

The weighed amounts of nitrocellulose and nitroguanidine were mixed by hand on a lead table, nitroglycerine was then added and the mixture put in an incorporator together with a suitable proportion of solvent, which normally consisted of 16 per cent of acetone-water 92:8. A weighed quantity of carbamite and small proportions of other ingredients such as chalk, cryolite or potassium salts were then added. After several hours incorporation the colloidal paste was removed, filled in the cylinder of a press and extruded through dies to give a product of the required form and size. The solvent was then removed by stoving.

A modification of this procedure which was brought into use and adopted at the R.O.F.'s and at Ardeer consisted in hand-mixing 14233
the G.C. and N.G. and then adding alternate charges of this dry
paste and picrite together with acetone. (cf. p.45)

(b) As an alternative to acetone-water it was found that equally favourable results were given with an acetone-alcohol solvent and this solvent was generally adopted in Canada for cordite N manufacture in order to use the alcohol displacement process for eliminating the water from the guncotton.

Comparative firings with normal N/S conducted in the Q.F. 3.7-inch Mk. VI and Q.F. 4.5-inch showed the acetone-alcohol product O.B. Proc.
to have a somewhat higher rate of burning so as to require for the 15139
same ballistics a change of web size from .058 to .062 for the 16935
Q.F. 3.7-inch Mk. VI.

It was found in further experimental trials at Woolwich that alcohol alone in conjunction with carbamite had equally good gelatinising properties if the temperature of the incorporator was raised to 50°-70°C.

(c) In the wet-mix process the procedure was that employed in S.C. manufacture. The N.C. and N.G. were mixed by mechanical agitation with excess of water, filtered to form a paste sheet which was then dried, either in sheet form or after crumbling, by the passage of hot air in truck dryers or in stoves.

The dried paste in small lumps was then added to the incorporator together with picrite and finally the carbamite and other ingredients (chalk, cryolite) were added as in the dry-mix process. This method of manufacture was approved for the Naval Service in November 1939. 3614

A trial was conducted in the Q.F. 4.5-inch Mk. II gun with N/S 198-054 made with Ardeer picrite with the following variations in manufacturing procedure (a) dry-mix, (b) wet-mix, carbamite added at incorporator stage, (c) wet-mix, carbamite added at wet-mix stage. In each series the ballistics were very regular but increased progressively in the order (a), (b) and (c), the pressures for service velocity being respectively 19.6, 20.4 and 20.7 tons. The use of Ardeer picrite with either wet-mix process was accordingly unacceptable with the sizes of cordite employed. The recommendation that when employing the wet-mix process the carbamite should be added to the incorporator was endorsed. 16845 17090

O.B. Proc.

(d) Prolonged trials with a "solventless" or "semi-solvent" technique were originally conducted at Woolwich in 1927, but the application of this procedure was abandoned until revived later by S.R.N.P.F. at Caerwent. By this method the charge was first incorporated with the usual solvent content, the dough was then formed into sheet by passing through cold rolls and, after removal of part or the whole of the solvent by stoving, the sheet was again passed several times through rolls heated to 65°C., cut into discs of the required size and extruded from a cylinder at 70°C. - 85°C. as with S.C. cordite. (cf. p. 87) Appendix A

The main compositions at first employed for production by this process were F.500/43 (consisting of Nitroguanidine 50, N.C. 15, N.G. 26, carbamite 9) and F.500/57 (consisting of Nitroguanidine 60, N.C. 12, N.G. 21, Carb. 6.5 per cent.).

The extrusion pressure at a temperature of 75°C. for the first composition when the solvent had been reduced to below 0.5 per cent amounted, with cord 0.077, to 8000 lb./sq. in. and that with the F.500/57 composition to 11800 lb./sq. in. under the same conditions. With the semi-solvent technique, the extrusion pressures were found to fall progressively with increase in solvent content.

With 1 per cent solvent the pressures fell to about one-half and with 2.5 per cent to about one quarter that with the fully dried material. (cf. Figs. 1-2)

Firing trials with compositions made by this process were conducted with satisfactory ballistic results in the Q.F. 18 Pdr., Q.F. 3-inch 20 cwt., B.L. 60 Pdr. and B.L. 4.7-inch. The cords made by this process were of inferior mechanical strength compared with those made by the normal solvent method. For the smaller sizes of cordite no advantage could be established by this procedure and its use for propellants for small and medium size guns was not further pursued at the time.

Variations in manufacture which affected ballistics and might necessitate a change of size were summarised as follows:-

(a) Crystal size of picrite.

(b) Stage at which carbamite was added during the mixing.

(c) Type of solvent (acetone-alcohol compared with acetone-water).

The following variants appeared to have no effect on ballistics:-

(a) All methods of mixing so far employed with the exception of the stage at which carbamite was added.

(b) Re-working up to twice.

It was concluded that an increase in the rate of burning resulting from a reduction of crystal size by reworking was counteracted by the N.C. loss which would lower the rate of burning. 17168

When using coarser picrite, the use of N.C. of wood origin proved, compared with that of cotton, to give inferior results. 17894

To investigate further the effect of the stage at which carbamite was added to the propellant, batches of cordite N/S 260-056 (ann. .102) were made by the two procedures. With carbamite added at the incorporator stage the density of the product was 1.641 and the rate of burning 0.33 in. per sec. per ton. With carbamite added at the wet-mix the density was 1.629 and rate of burning 0.41. On firing in the Q.F. 5.25-inch gun, the latter composition gave a sporadic high pressure with one round. | O.B. Proc. 18263

A laboratory investigation of this subject in the A.R.D. established that in all instances the carbamite formed a double compound with the nitroguanidine containing equal molecules of the two ingredients. The rate of burning of the propellant varied with the degree of sub-division of the particles of this complex and this was determined by the time at which the carbamite was added to the remaining ingredients. This complex was more finally-divided and more completely dispersed, resulting in a lower rate of burning, when the carbamite was added later. It was accordingly specified that carbamite should be added at a period between $\frac{1}{4}$ hr. and $\frac{1}{2}$ hr. after adding the remaining ingredients to the incorporator. | 22564 (cf. p.45)

Manufacture at Naval Factories

In the early manufacture of N.F.Q. at R.N.P.F. Caerwent, the product was found to be unsatisfactory on account of low density which was traced to the presence of fissures or cavities in the cords. With bigger sizes of cordite the faults became more pronounced. The defect was attributed to the combination of the use of nitrocellulose of wood origin and coarse Welland picrite. It was decided to supply the R.N.P.F. requirements with picrite produced by the Ardeer spray process. | O.B. Proc. 17026 17398

The use of guncotton (13.1 per cent N_2) in place of N.C. of wood origin was found to effect an improvement and consideration of the change to G.C. as employed in the Land Service cordite N was recommended. | 19842

Batches of N.F.Q./S 224-058 made at R.N.C.F. and R.N.P.F. using N.C. from wood of 12.2 per cent N. were fired in the B.L. 6-inch Mk. XXIII and Q.F. 5.25-inch. The R.N.C.P. products were of good density (1.634-1.641) and gave regular ballistics (m.d. of M.V. 2.6-6.6) while the R.N.P.F. products were of unsatisfactory density and ballistic regularity. | 20443

Without resorting to the use of guncotton the manufacture of N.F.Q. at R.N.P.F. was finally achieved satisfactorily by the adoption of a mechanical or lever-stemming device for compressing the charge of cordite paste in the press cylinders. | 22722

For the preparation of large sizes of cordite, a further improvement was initiated by S.R.N.P.F. by the introduction of the "solventless" and "semi-solvent" procedure during extrusion. (cf. Appendix A) | 30653

Form of propellant

In considering the ease of manufacture of different forms of propellant while, except for the smallest sizes, cord is the most readily produced, a comparison of slotted tube and multi-tube at all Land Service and Naval factories led eventually to the conclusion that given suitable cutting machines the ease of manufacture of the two forms was equal. | 11054 11947

Early troubles with S.T. cordites consisted in the slots not being at right angles to the hole or occasionally being closed or the holes not being central. With plain tubular cordites it was | 12085 found necessary to use air-fed dies in order to avoid collapsed holes. With multitubular cordite non air-fed dies were found satisfactory provided care was taken to prevent the holes at the ends of the tubes from being closed.

J. Production of finely-divided picrite

The process for the manufacture of nitroguanidine from imported calcium cyanamide which was originally developed in the R.D. Woolwich[16] consisted, in stage 1, in the treatment of the $CaCN_2$ with water and carbon dioxide or alternatively with hot water alone to form dicyandiamide in accordance with the reactions:-

(a) carbon dioxide process:-

I. $$CaCN_2 + CO_2 + H_2O \longrightarrow CaCO_3 + CNNH_2$$

II. $$2\ CNNH_2 \longrightarrow H_2NC(:NH)NHCN$$

or (b) hot water process:-

I. $$CaCN_2 + 2H_2O \longrightarrow Ca(OH)_2 + CNNH_2$$

II. $$2CNNH_2 \longrightarrow H_2N.C(:NH)NHCN$$

In stage 2 the dicyandiamide was caused to react with ammonium nitrate either by fusing together the dry materials or by heating an aqueous solution in an autoclave. Guanidine nitrate was thereby formed in accordance with the equation:-

$$H_2N.C(:NH)NHCN + 2NH_4NO_3 \longrightarrow 2H_2\ N.C(:NH)NH_2HNO_3$$

In stage 3 the guanidine nitrate was gradually dissolved in concentrated sulphuric acid with continued stirring. Interaction occurred to form nitroguanidine in accordance with the equation:-

$$H_2NC(:NH)NH_2HNO_3 + H_2\ SO_4 \longrightarrow H_2N.C(:NH)NHNO_2 + H_2SO_4H_2O$$

The contents of the nitration were then discharged into an excess of water and, after cooling, the precipitated crystals of nitroguanidine were separated by filtration in a centrifuge, washed and dried. The resulting crystals at this stage retained appreciable amounts of occluded strong acid which could not be removed by washing, but were eliminated by subsequent recrystallization which was also carried out for the purpose of obtaining a product in a fine state of subdivision.

In the process originally brought into operation at R.G.P.F. Waltham Abbey and at R.N.C.F. Holton Heath, the hot water extraction process was used for stage 1 and the fusion process for stage 2.

Recrystallization of the nitroguanidine was then brought about in a spray crystallizer by the following procedure:-

The moist cake of nitroguanidine from the centrifuge was dissolved in sufficient boiling water (and mother liquor from a previous crystallization) to give a 6 per cent solution which was passed through a heated filter to the feed tank of the spray crystallizer. This consisted of a group of atomising nozzles, operated by compressed air which projected the hot solution, in the form of a fine spray, through openings in the cover of a cylindrical vessel fitted with a brine cooling jacket and a high speed stirrer. When in operation the vessel contained a small amount of a sludge of crystallized nitroguanidine and its mother liquor which was spread, by the vigorous action of the stirrer, over the whole inside surface of the vessel up to the level of an overflow exit near the top. The minute particles of hot solution produced by the sprays impinged upon the surface of the sludge which had been cooled by the brine and the sudden cooling thus produced caused crystallization of the nitroguanidine in a very fine state of division. The apparatus worked continuously, the sludge of crystals and mother liquor overflowing as fast as it was produced. O.B. Proc.

The nitroguanidine crystals were filtered off on the centrifuge, washed with water and dried by hot air upon aluminium trays. The dried cake of crystals was ground by means of a high speed disintegrator of the Schutz O'Neill type, and was stored in rubber bags until required. The product obtained from this spray crystallization was in the form of needle-shaped crystals, the predominating size of which was normally from 0.003 mm. to 0.006 mm. diam. and the length 0.05 - 0.1 mm. These sizes corresponded to values of from about 9000 to 22,000 sq. cm. per c.c. for the specific surface as measured by the specification air-flow test which had been adopted (cf. Appendix C, p. 90). For the finer or "superfine" grade (up to 35,000 specific surface) superheated solutions were employed under pressure at temperatures in excess of 100°C. by a process which was developed by Messrs. I.C.I. at Ardeer. For still finer or so-called "ultra-fine" grades, protective agents were employed. Methods for the production of this type of finely-divided material and for the assessment of crystal size are described in Appendices B. and C.

Effect of crystal size of picrite on ballistics

The method originally adopted for specifying crystal size was that 50 per cent by weight should consist of crystals of mean diameter not exceeding 0.003 mm. At the commencement of manufacture of picrite cordites for the Land Service in June, 1941 a 17733
relaxation of predominating crystal size to 0.005 mm. was allowed 7311
for the product made at Welland in order to expedite output. Considerable difficulties had been experienced in the assessment of crystal size, and in arriving at a satisfactory definition of the term "predominating size" which had been specified. Discrepancies occurred in the estimates made by the Inspection staffs in Canada and in this country. The air-flow method which was developed in the A.R.D. was finally adopted for measuring the total specific surface of test samples of picrite. Ballistic irregularities which had occurred with cordite N in the Q.F. 3.7-inch and 4.5-inch guns and with early batches of N.F.Q. made at Caerwent were attributed partly to the use of lots of Welland picrite which exceeded a predominating crystal size of .005 mm. diam. It was accordingly arranged for R.N.P.F. to be supplied with Ardeer-
sprayed picrite. To investigate further the effect of crystal 17859
size on ballistics a trial was conducted with batches of N.F.Q. propellant made at R.N.C.F. using Welland picrite as imported and the finer R.N.C.F. sprayed picrite. Propellant batches were made with these different types of picrite under otherwise identi-
cal conditions for firing in the Q.F. 4-inch Mk. XVI, Q.F. 12 Pdr. 17894
12 cwt. and Q.F. 3-inch 20 cwt. Apart from the higher charge weights due to the known slower burning of the propellants when made from Welland picrite, a notable increase in regularity of ballistics as shown in the m.d.'s of M.V. was found to result from

the use of the finer picrite compared with the Welland product. A similar result was also obtained from propellants made at R.N.P.F. with different picrites when fired in the Q.F. 4-inch Mk. XVI.

Apart from earlier observations on the increase in the rate of burning of cordite N when made from picrite compared with that made from the coarser "petrolite", the following data have been obtained on the influence of crystal size of picrite on the rate of burning of the propellant as measured in Closed Vessels:- (cf. p.10)

Picrite Type	Specific surface	cal. val. of cordite batch	β (rate of burning in secs. per $ton/inch^2$)*
	$cm^2/c.c.$		
(1) Welland normal	9,200	763	0.28
(2) Welland fine, lot No. 8760	16,000	758	0.30
(3) Ardeer blended, lot No. 1493	20,900	756	0.315
(4) Ardeer in current use lot No. 1424	22,600	755	0.32
(5) Welland "Blue band" lot No. 8449	21,625	758	0.32

* rate of reduction of radius of cord.

A comparison which was made of propellant prepared from normal and superfine picrite (18,000 and 38,000 sp. surface respectively) showed that with N.F.Q./S 198-054 fired in the Q.F. 4.5-inch Mk. III, both types were equally flashless, but the m.d. of velocity was lower with the sample made from the superfine grade. O.B. Proc.

In the Q.F. 4-inch Mk. XVI, N.F.Q./S 164-048 from normal picrite gave one large flash in 9 rounds while with superfine picrite 9 rounds were all flashless.

In the B.L. 6-inch Mk. XXIII, H.P./P .128 made with superfine picrite gave a marked reduction in the intensity of flash compared with the batch made from normal picrite. No significant difference in regularity was shown. The rate of burning of the propellant with superfine picrite was greater by about 2 per cent and the cords from the finer picrite were more flexible. 31393

The grade of picrite required for the Naval Service (sp. surface not below 18,000 sq. cm. per c.c.) for use by S.R.N.P.F. (Caerwent) since May 1942 was produced at Ardeer from imported guanidine nitrate and later by recrystallising the coarser Welland picrite. At one period the importation was made from Welland of picrite which had been prepared to comply with the Naval specification (and known as "Fine Welland"). 31960

The adjusted charge weights of N.F.Q./S 198-045 in the Q.F. 4.5-inch (S.L.) with propellants made from the different picrites were found to be as follows:-

Lots	Description	Actual carbamite	Calorific Value	Adjusted charge		
		per cent		lb.	oz.	dr.
R.N.P. 1465	Fine Welland picrite, 7 per cent carbamite	6.98	767.6	13	7	15
Average of four previous	Fine Welland picrite 7.5 ± 0.5 per cent. carbamite	7.45	757.1	13	14	5
Average of five last lots	Ardeer picrite, 7.5 ± 0.5 per cent. carbamite	7.43	754.2	13	8	13
R.N.P. 1470	Ardeer special * picrite 7 per cent. carbamite.	7.02	766.2	13	3	9

(* Mixture of one third coarse Welland and two-thirds Ardeer re-crystallised at Ardeer.)

On account of a difficulty which had arisen in the loading of service charges of N.F.Q. propellant in Q.F. 4.5-inch cases, it was proposed to increase the cal. val. by lowering the carbamite content to 6.5%. A reduction to 7% was finally approved. In firings in the Q.F. 4.5-inch gun this propellant was found, however, to give a flashless performance inferior to that of N.F.Q. of normal composition.

O.B. Proc. 17894, 31356, 33590

Superfine picrite

The effect of using a still finer grade of picrite, viz. of specific surface of about 38,000 $cm.^2/cm.^3$, was investigated by comparative trials conducted with N.F.Q. in the Q.F. 4-inch Mk. XVI and Q.F 4.5-inch and with H.P./P in the B.L. 6-inch Mk. XXIII. The rate of burning of the cordite made with this superfine picrite was found to be about 2 per cent greater than that made with the normal Naval grade (18,000-20,000). No significant difference in regularity was found with the two grades but in the B.L. 6-inch Mk. XXIII, with H.P./P propellant the superfine picrite gave a marked reduction in intensity of flash compared with normal picrite. In the Q.F. 4-inch Mk. XVI, with N.F.Q. made from normal picrite, a large flash was obtained in 1 out of 8 rounds fired and no flashes in 8 rounds with N.F.Q. made from superfine picrite.

31393

(cf. p. 35)

K. Compound formation between picrite and carbamite and its effect on ballistics[17]

A further factor which determined the structural properties of the cordite and the rate of burning, apart from the initial size of the picrite crystals, was due to the fact that the picrite combined with the carbamite to form a complex or double compound and the state of subdivision and aggregation of this complex varied according to the stage of manufacture at which the carbamite was introduced.

The existence of this compound in cordite was originally established in an attempt to explain the abnormally high gun pressures recorded at firing proof of the first batches of cordite N/S ann. .058 and ann. .072 manufactured at Dalbeattie factory by the process of wet mixing the G.C., N.G. and carbamite. The procedure employed was compared with that in use at Ardeer where the methods employed were (a) dry mix process and (b) wet mix process[18]. One difference occurred in that the carbamite in the Ardeer dry-mix process was added to the incorporator in the form of disintegrated flakes, measuring up to approximately $\frac{1}{4}$ inch x $\frac{1}{4}$ inch x .015 to .020-inch whereas in the R.O.F.'s the carbamite was ground before addition, the state of division depending on the particular factory. In the wet-mix process employed at Ardeer the carbamite was added in flake form to the incorporator containing the dried G.C.-N.G. paste from wet-mixing. The Dalbeattie process, as originally designed to be practised, was the procedure used in S.C. manufacture and consisted in the initial preparation of a G.C.-N.G. suspension followed by the addition to the wet-mix vessel of the carbamite in the form of a wet-milled slurry, which was then separated on a filter table to form a paste sheet and dried. The addition of picrite, cryolite, chalk and solvent was then made in the incorporator. No perceptible difference could be detected in the batches of guncotton used at Dalbeattie in comparison with those at Ardeer. A microscopic examination in January 1942 of a sample of cordite N made at Dalbeattie indicated, however, a detectable difference between this sample and a normal dry-mix cordite N. It was observed that thin sections of the Dalbeattie cordite when mounted in the usual glycerol-water (1-1 by volume) medium and viewed under transmitted light revealed certain large, broad crystals, about .02 x .04 mm. in size which differed from any crystals that had previously been observed in cordites N, N/A, N.F.Q., or NQ. These crystals were subsequently identified as an equimolecular compound of picrite and carbamite which could be readily prepared by the interaction of picrite with a concentrated solution of carbamite in acetone. This preparation was most conveniently conducted by refluxing picrite in the thimble of a Soxhlet apparatus with acetone contained in a flask and having in solution 40 grm. carbamite in 150 c.c. acetone. Crystals of the compound of any desired size and quantity could thus be formed in the solution. (cf. Fig. 10) The formation of this compound was found to be accompanied by the evolution of a considerable amount of heat. The identity of the compound was further well-established by measurements of refractive index of the crystals* and by photographs of X-ray diffraction patterns made at Woolwich and by Messrs. I.C.I. at Ardeer.

(* cf. Appendix E)

The procedure devised for the identification and separation of the crystals of this compound is given in Appendix D. ("The Microscopic Examination of Flashless Cordite.")

L. Rate of burning experiments

Apart from the effect of size of picrite crystals on the rate of burning, the increased burning rate of early samples of Dalbeattie manufacture was found to be due to the coarse state of subdivision of the picrite carbamite complex, while cordite N of normal ballistics and rate of burning was shown to contain this complex in a fine state of subdivision.

Rates of burning measurements were made in a Closed Vessel of the following three types of cordite made as follows:-

1. Control. (a) N.F.Q. (R.N. 1905 S.). Complex very fine. (cf. Fig. 7)

   (b) N.F.Q. (R.N.P.). Complex very fine. Welland picrite.

2. F.527/44. Cordite N as made by the original Dalbeattie wet mix process. Complex fairly coarse, intermediate between 1 and 3. (cf. Fig. 8).

3. F.527/30 Lot 11. Cordite N, but carbamite dissolved in the solvent. Complex extremely coarse. (cf. Fig. 9).

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No.	Cordite type	Rate of Burning (ins./sec./ton/in.^{2})
1 (a)	N.F.Q. (R.N. 1905 S.)	0.336
1 (b)	N.F.Q. (R.N.P.)	0.321
2	F.527/44 wet-mix N.	0.390
3	F.527/30 Lot 11	0.441
4	Ardeer dry-mix N.	0.32 (from I.C.I. data)[18]
5	Dalbeattie wet-mix N.	0.39 (- ditto -)

16480

Provided the same solvent composition was used in the final colloiding operation, there was no indication that the past history of the N.C.-N.G. paste alone, i.e. whether made by wet or dry mix, affected the rate of burning. Cordites W.M. and N made with acetone-alcohol were, as previously mentioned*, about 5 per cent faster burning than the normal product made with acetone-water.

* (p. 14)

M. Stabiliser-coolants in replacement of carbamite

An examination was made of samples of cordite N in which the carbamite had been replaced by methyl centralite, (dimethyl-diphenyl urea) whose stabilising properties had been fully established and which was found not to form a chemical compound with the picrite. The solubility of methyl centralite in organic solvents is much lower than that of carbamite, however, and a cordite N containing 7½ per cent of the compound developed striking efflorescence within a few days after removal from the drying stoves. Measurements made with the N.C.-N.G. colloid alone in absence of picrite showed that a content of about 9 per cent methyl centralite on the colloid or about 3½ per cent on the cordite was the limiting quantity of this compound which could be retained without effloresence.

Experiments made with phenyl urethane (solid) and phenyl benzyl urethane (liquid) in place of carbamite showed that both these substances were retained by the colloid without showing any efflorescence or oxidation. An improvement in flexibility was shown by these compositions compared with cordite N.

With regard to other inert substitutes it was found, in a firing trial in the Q.F. 3-7-inch gun with a composition of cordite N type containing 6 per cent dibutylphthalate and 2 per cent carbamite, that this had a noticeably lower rate of burning than cordite N though of similar calorimetric value. (cf. p.12)

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N. Tests for chemical and ballistic stability of flashless propellants O.C.Memos B

On deciding to concentrate attention on the composition known
as R.D.N. a comprehensive series of climatic trials with this
propellant containing a number of different contaminants and under 16489
various conditions of storage was arranged. These included
trials to inflammation at 110°F., 120°F. and 130°F., also hot-wet 18340
alternating trials and with cordites partially immersed in sea
water for one month. These trials were commenced in May, 1929
with R.D.N. and R.D.N./A cordites and a similar series with H.P. 21258
was begun in February 1931. The ballistic trials included firing
in the Q.F. 3-inch 20 cwt. gun at pressures up to 19 tons and the
effect of subjecting the cordite to rough usage was included.
Compositions made from nitrocellulose of wood and of cotton
origin were employed.

It was further arranged to conduct routine climatic trials
of samples of every lot manufactured, the trials to continue for 21466 III
5 years and corroded samples to be put on trial to inflammation.

An extension was subsequently made to include the use of
nitrocellulose from home-grown wood, of picrite contaminated with
calcium chloride and certain organic compounds which were liable
to occur during the preparation of the picrite. 22956

At a firing after 6 months storage the R.D.N./A rounds were
satisfactory but the R.D.N. rounds gave occasional high pressures
which in one round amounted to 27.8 tons compared with the normal
20 tons. The chemical stability of R.D.N. and H.P. continued to 21041
be uniformly satisfactory while the ballistic results of R.D.N./A
and H.P. remained normal except in one trial in which R.D.N./A
after 13 months storage at 115°F., 75 per cent saturated, gave in
one instance a rise of pressure of $7\frac{1}{2}$ tons and several rises of 22266
$2\frac{1}{2}$ to 3 tons. During the exposure a considerable amount of water
had collected in the case. It was concluded that the conditions
of this trial had been unduly drastic while evidence was later
obtained indicating that the batch of picrite used had acquired
some contamination during milling.

A consideration was then called for of the worst conditions
that could arise during tropical storage. A programme in the
first place was arranged for the storage of Q.F. 3-inch 20 cwt.
rounds of R.D.N./A at Ferozepore in boxes placed, in one series,
under a tarpaulin and, in another, stored in limbers for periods
of 2 weeks and then returned to the magazine and at intervals
during 4 years a number of the rounds were returned to Woolwich
for firing trials. During exposure of half of the rounds the
joint between the shell and the cartridge case was broken. Fur- 22267
ther climatic trials were staged in this country and designed to
meet the conditions encountered during tropical storage. These
included, in one series, weekly alternating cycles of $5\frac{1}{2}$ days at
115°F. (75 per cent saturated) followed by cooling to atmospheric
temperature for $1\frac{1}{2}$ days and, in a second series, cycles of three 23470
weeks consisting of one week at 120°F. (60 per cent saturated),
one week at 100°F. (100 per cent saturated) and one week at 120°F.
dry.

In order to ascertain the suitability of N.C. derived from
straw a programme of limited trials was put in hand with R.D.N./A
cordite made from cotton, wood and straw and including batches
made with N.C. of 12.6 per cent and 12.9 per cent N. contents.
After 2 years climatic trial, the propellants were all found to 24006
be satisfactory ballistically. With R.D.N. and H.P. cordites, 28769
made from nitrocellulose of either cotton or wood origin, the
ballistics were well maintained after 6 years storage in the R.D. O.C.Memo
climatic huts. 322

To determine the effect of contact with water, climatic trials with R.D.N./A have included storage for 4 months at temperatures alternating between 80°F. and 120°F. when the propellant had 0.2% $CaCl_2$ included in its composition and when sealed in metal boxes containing water. In a further trial the cordite was inserted in 10 times its weight of cold water for 41 days with occasional changes of water. The loss of picrite amounted to 2.8 per cent and that of N.G. to 7.2 per cent. In another trial the propellant was immersed in water at 45°C. for 16 days. In all instances the propellant after drying was fired in the Q.F. 3-inch 20 cwt. gun and showed no irregularity of ballistics. O.C.B. 24732

With R.D.N./F climatic ballistic trials were conducted in the Q.F. 3-inch 20 cwt. with satisfactory results. O.B. Proc. 150

R.D.N./A in Q.F. 3-inch 20 cwt., after 3, 4 and 5 years storage at Rawalpindi, when fired at Woolwich in 1939 showed no abnormality. 2008

Climatic trials on various types of cordites, including R.D.N./A and H.P. made with N.C. derived from wood and straw cellulose, showed that after 5 years storage at 120°F. these were all of satisfactory stability. 28168

Cordite R.D.N./F .042 after storage for 6 years at 120°F. (which is equivalent to 16 years at 90°F.) in the form of both Q.F. and B.L. charges, including rounds subjected to rough usage, showed only a slight fall in ballistics (10 f.s.) in the Q.F. 3-inch 20 cwt. gun with Q.F. rounds, but an appreciable and progressive fall of ballistics, with charges stored as for B.L. rounds, amounting to 52 f.s. (compared with 57 f.s. for an M.D. control similarly exposed.) The chemical stability was satisfactory, the carbamite content having fallen with B.L. stored 31860
rounds from 7.37 to 6.77. Composition F.535/2 with 40 per cent O.C.B.
picrite, after 6 years climatic trial at 120°F. continuous and 36142
under alternating conditions ($5\frac{1}{2}$ days at 115°F. (75 per cent saturated) followed by cooling to atmospheric temperature for $1\frac{1}{2}$ days), O.B. Proc.
gave satisfactory ballistic results when fired in the Q.F. 3-inch 11299
20 cwt. A gradual drop of ballistics occurred which was approximately 20 f.s. greater than that of the M.D. controls. The fall of carbamite amounted to about 1 per cent corresponding to a time to half value of 150 years at 80°F. It was decided that this propellant composition could, if necessary, be accepted for service use. R.D.N./F .042 after 3 years climatic storage gave 11498
satisfactory ballistic results in the Q.F. 3-inch 20 cwt.

With cordite N/A.Q./M firings were conducted in a Q.F. 3.7-inch gun with propellant which had been stored at 120°F. for about 2 years. The results showed that little or no deterioration of the propellant had occurred. 13484

With NQ/M, web .032, a firing trial was conducted with propellant which had been stored at 140°F. (95 per cent saturation). Apart from a considerable fall in ballistics no irregularity occurred with the materials after these extreme conditions of storage. Compatibility tests did not reveal any deterioration 15120
of the physical properties of the propellant.

With N.F.Q. cord .042 after four years climatic storage as Q.F. rounds and as B.L. rounds in contact with G.P. igniters the hot stored Q.F. rounds showed no significant change in ballistics but the hot stored rounds in leaky B.L. cases showed a progressive fall in ballistics. The fall in carb. content was inappre- 16306
ciable.

N.F.Q. containing numerous contaminants was shown to possess a satisfactory stability after subjecting to 2 years climatic trial. O.B. Proc. 19574

In order to determine the change of ballistics of cordites W or W.M. and N/S after storage with Service Units, rounds from 74 propellant lots of W or W.M., 22 lots of N/S and 6 lots of NH were returned from batteries and fired in the Q.F. 3.7-inch Mks. I-III.

The muzzle velocities given, corrected for the wear of the gun, were with W or W.M. 21 f.s. lower than the new gun M.V.'s given in the wear table while with N/S the average corrected M.V. was only 1 f.s. below the wear table value. The average mean deviations in M.V. were 7.9 f.s. for W or W.M. lots, 7.2 f.s. for N/S lots and 7.7 for NH lots. 33224

O. Toxicity of propellant gases

It was previously well-known that the older propellants gave fumes which had a serious toxic action on gun crews if restricted ventilation caused them to collect in enclosures. It was thought that this effect might be aggravated with R.D.N. as, although the amount of CO in the products of decomposition was less than that given by the earlier cordites (M.D., W, S.C. etc.), the elimination of muzzle flash prevented the CO in the gases in front of the gun from burning to CO_2, though the CO remaining in the barrel would be less with the R.D.N. propellants than with M.D., W, or S.C. A preliminary investigation was conducted at Woolwich in April 1930 by placing an 18 Pdr. gun in a sheltered enclosure designed to simulate a gun pit and on a calm day firing 15 rounds of M.D. on one occasion and 15 of R.D.N. on another at a rate of fire of 12 rounds per minute. Samples of air taken from various positions showed the highest concentration of CO to be 0.05 per cent with R.D.N. and, in general, the concentrations of this gas were about 50 per cent greater than with cordite M.D. O.C. Min. 28168 O.C.Memo B 20471

In Field trials conducted with R.D.N. in an 18 Pdr. battery at Larkhill, it was reported that the fumes, on account of ammonia, were obnoxious to an extent which, in enclosed gun-pits, might become serious. In view of these results it was decided to conduct firing trials with compositions of lower picrite content and of higher calorimetric value than R.D.N. 24620

Measurements made at Porton on the concentrations of CO and NH_3 produced when R.D.N./A and M.D. were fired from guns in sheltered positions showed that the fumes produced from the flashless propellant were more toxic than those from M.D. and that the degree of harmfulness would depend on the length of exposure. 28100

The noxious effect of the fumes was considered to be aggravated by the gunpowder, apart from its detrimental effect in increasing the smoke. Consideration was accordingly given to the reduction of the G.P. as far as possible and assisting the ignition by the use of a suitable nitrocellulose composition.

In extended trials conducted at the Practice Camps with Q.F. 18 Pdr. batteries using R.D.N./A and primers to design R.D.4804, it was reported that, while flashlessness was generally obtained, flashes were observed with a small proportion (about 30053

10 per cent) of the rounds. A slight degree of discomfort from O.C.Memo B
fumes was generally observed. Further physiological tests and
analyses of gases were then conducted in a modified type of
shelter designed to allow a reasonable amount of ventilation.
After firing for a prolonged period the average concentrations of
CO which were recorded amounted to 1 in 3500 (0.028 per cent) for
R.D.N./A and 1 in 20,000 for M.D. cordite, 1 part in 20,000 (0.005
per cent) of NH_3 with R.D.N./A and a trace with M.D. It was
considered that the degree of toxicity would be rendered acceptable
by improving the ventilation. Trials were then conducted with 30054
the hotter composition (F.551/58 or R.D.H./A.Q. (cf. p.29))
designed to lower the CO concentration in the Q.F. 18 Pdr. and
Q.F. 4.5-inch How. With the Q.F. 18 Pdr., ignition was effected
with a No. 1 Mk. II primer containing 2 drms. of G.P. which was
used together with a supplementary igniter consisting of a bundle
of 6 drms. of tubular cordite (055-030) of high calorimetric
value (cf. p.59).

Trials conducted at Porton in 1937 with R.D.N./A in a Q.F.
18 Pdr. in an unventilated shelter gave undesirably high concen-
trations of CO. 33556

Further detailed trials were conducted at Porton in June 1939
with Q.F. 18 Pdr. guns placed in gun-pits arranged to offer a
reasonable amount of ventilation by providing openings between
the eaves of the roof and the walls of the pit. The firing was
done on a calm day which minimised ventilation. 2410

The propellant used was F.551/58 in comparison with cordite
W. Blood tests of the gun team showed that the gases from the
flashless propellant were somewhat more toxic than those from
cordite W and were objectionable with both types. Chemical tests
showed there to be no great difference in the concentration of CO
with the two propellants. It was decided that with adequate
precautions there was no further objection to the use of this
flashless propellant and its adoption by the Field Army was
accordingly approved. Other advantages given by this propellant 2922
which were apparent in this trial were that the concussion effect
on the detachment serving the guns was much less with flashless
than with flashing cordites and the blast of the flashless was
observed to raise less dust in front of the pit.

In trials in tank guns to determine the relative toxicity of
W/T and R.D.Q. it was found that the concentrations of CO in the
air and in the blood of the operators was no higher with R.D.Q.
than with W/T and the adoption of R.D.Q. was recommended owing to 6418
the advantages of the reduced flash, blast and gun erosion.

It was finally concluded from the results of all trials that
accidental variations of wind direction and speed, rate of venti-
lation, and the location of crew had been preponderating influ-
ences rather than the type of propellant used. 16277

In the Naval Service, measurements of CO concentrations
when R.D.N./A propellants were fired in comparison with S.C. in
star shell charges were made in 1936. The concentration of CO
in the casemates which arises mainly from the residual gases 32189
remaining in the cartridge cases amounted to a maximum of 0.008
per cent for R.D.N./A compared with 0.007 per cent for S.C.
cordite while the concentration of NH_3 was almost negligible and
traces only of nitrous fumes were found with either propellant.

P. Flashless propellants other than nitroguanidine type — O.B. Proc.

(a) Cordites AN; A.S.N.

On account of the necessity of increasing the supplies of flashless propellant and of limitations to the quantity of nitroguanidine which could be produced, the possibility of making S.C. and W.M. types of cordite flashless by modifications to their composition was called for, the only available alternative being FNH/P.

The following composition was in the first place proposed and
investigated by Messrs. I.C.I.:- G.C. 65, N.G. 24, M.J.6, Carb. 5, 18116
together with a small proportion of K_2SO_4. 20258

A solventless flashless composition which was proposed by Messrs. I.C.I. for use in the Q.F. 3.7-inch gun consisted approximately of:- N.C. 50, N.G. 34, D.B.P. 8, Carb. 5.5, K. salt 2.5.
A cooler composition of cal. val. 728 was also prepared. In 18567
preliminary trials flashlessness was obtained with this propellant.

A series of solventless compositions was then made in which the carbamite was partly replaced by D.B.P. and by D.N.T. and an adjustment of composition made to give cal. vals. ranging from 724 to 782 (W.L.). A firing trial in a Q.F. 3.7-inch Mk. III gun showed that in every case, though the results were good in a new gun, a high proportion of flashes was given in a worn gun and the
propellant was less satisfactory than cordite N. 19941

A solvent cordite composition which was devised consisted of G.C. 56.5, N.G. 25, D.N.T. 10, Carb. 5, M.J. 3.5, KNO_3 or K_2SO_4 1.0; cal. val. 800 (W.L.). Firing trials in the Q.F. 25 Pdr. B.L. 4.5-inch, and B.L. 5.5-inch gave a satisfactory flashless performance with some increase of smoke. Consideration was then given to the composition:- G.C. 57, N.G. 25, D.N.T. 10, Carb. 4.5, M.J. 3.5,
KNO_3 0.5, cal. val. 815 (W.L.). This was designated Propellant A. 19940
In the B.L. 4.5-inch this propellant was found to be reasonably flashless in a new gun provided an extra amount of G.P. was used
in the igniter. 20436

Investigations in the A.R.D. were also directed to the production of alternative compositions in which the picrite and carbamite were partly replaced by other ingredients while, at the same time, giving some improvement in the ultimate compositions which would further assist flashlessness. The most promising indications were obtained by the replacement of a portion of the
nitroguanidine and of the carbamite by oxamide or by nitrodicyandiamidine (N.D.C.D.)[18a]. 20023

In a firing trial in the Q.F. 3-inch 20 cwt. a satisfactory flashless performance was given with the composition:- N.D.C.D.55,
G.C. 23, N.G. 21, Carb. 1, cal. val. 776 (W.L.). As a result of 20145
climatic trials under wet storage conditions this composition was considered to be unsatisfactory and the use of N.D.C.D. was not further proceeded with.

In the Q.F. 3.7-inch gun with FNH/P .049, an increase of K_2SO_4 from 1 to 1.62 per cent improved flashlessness though results reported from Canada showed no apparent difference. Satis-
factory ballistic and flashless results were obtained with the 20317
Ardeer propellant (A) with 0.5 and 0.75 KNO_3 in the B.L. 4.5-inch
and B.L. 7.2-inch How. The optimum proportion of KNO_3 was 20457
apparently 0.75 per cent. In the Q.F. 17 Pdr. new gun a trial with FNH/P containing 1 per cent and 2 per cent K_2SO_4 gave large flashes with all rounds, though with the latter propellant the flashes were smaller and estimated at 20-60 per cent of the full flash. The propellant was accordingly considered unsuitable

for flashlessness in this gun. Samples containing 3 per cent O.B. Proc.
K_2SO_4 were ordered from America. In the Q.F. 3.7-inch and 20557
4-inch Mk. V guns a firing trial with an Ardeer solventless pro- 20778
pellant consisting of G.C. 54, N.C. 29, D.N.T. 9, Carb. 8,
K. cryolite 3 showed that this gave full flashes in partly worn
guns of both calibres. 20841

In the 6 Pdr. 6 cwt. A.A. gun, a trial with FNH/P .039 containing 1 and 2 per cent K_2SO_4 gave no secondary flash in either case but indicated a slight benefit with the 2 per cent compo-
sition, the mean candle secs. being 19 compared with 28 for the 21010
1 per cent composition.

The nomenclature of the Ardeer D.N.T. composition was fixed as cordite AN, and the composition was defined as:- G.C. 56.5, N.G. 25.5, D.N.T. 10.0, Carb. 4.5, M.J. 3.5, KNO_3 0.7 (cal. val.
825 (W.L.)). 20997

In the Q.F. 5.25-inch H.V.S.S., FNH/P .061 containing 3 per cent K_2SO_4 gave fairly good flashless results but in a worn gun
the results were definitely bad and unacceptable. 21819

ANS was adopted as the nomenclature of Ardeer solventless
propellant (but later changed to A.S.N.) and the final composition 21343
is given in Appendix G.

In the B.L. 6-inch Mk. VII gun, cordite AN .106 (containing
0.7 per cent KNO_3 and of cal. val. 822 (Q.L.)) gave full flashes 21642
in both new and old guns.

In the Q.F. 25 Pdr. a trial with cordite AN (cal. val. 821
(Q.L.)), ann. 0.043, showed that the bulking of a service charge 21719
would be too large to be practicable for factory filling.

In the Q.F. 4-inch Mk. XVI, cordite A.S.N. (ann. .059, cal. val. 726) gave only small flashes in both new and worn guns and
was satisfactory in this trial. 21811

Satisfactory results were obtained in a firing trial in the Q.F. 4-inch Mk. XVI with P.14593 consisting of:- 49.00 N.C., 34.18 N.G., 5.50 Carb., 8.18 D.B.P., 0.16 M.J. and 2.98 Pot. cry., cal. val. 771 (Q.L.). This gave in this particular trial a better flashless performance than a modification of this composition of lower cal. val. (about 726) and containing 3.5 per cent
Pot. cryolite. 22227

In a new B.L. 4.5-inch Mk. II How. and 5.5-inch Mk. III How.
flashlessness was obtained with AN when using a 4 oz. G.P. igniter,
the amount of smoke being about double that with N/S rounds. In 29845
a worn B.L. 4.5-inch Mk. II, the AN gave large flashes at charge
II, but was flashless at charge III.

On account of limitations in the supply of picrite it was
decided that developments with AN for the B.L. 5.5-inch should 29953
proceed. For this same reason cordite AN was provisionally
approved for the Q.F. 25 Pdr. 30372

Firing trials with A.S.N. propellant in a number of different guns led to the following conclusions:- In the Q.F. 4.7-inch Mks. IX and XII, A.S.N./T 190-054 was generally satisfactory, the flashless performance being slightly inferior to that of N.F.Q. In the Q.F. 4-inch Mk. XVI, A.S.N./T 190-054 gave a small proportion of large flashes, but the general flashless performance was similar to that of N.F.Q. In the Q.F. 4.5-inch Mk. III A.S.N./T 234-074 gave a high proportion of large flashes in a part-worn gun and was considered unacceptable.

The temperature corrections for 10°F. for the different propellants over the range 0° - 125°F. were given as follows:- O.B. Proc.

	A.S.N.		N.F.Q.		S.C.	
	M.V.	Press.	M.V.	Press.	M.V.	Press.
Q.F. 4-inch Mk. XVI	25	0.6	8.0	0.2	15.8	0.5
Q.F. 4.5-inch	20	0.77	12.0	0.4	13.6	0.5
Q.F. 4.7-inch Mks. IX and XII	15.4	0.4	9.0	0.3	15.2	0.5

30025

In the Q.F. 4-inch Mk. XVI, A.S.N. after 12 months climatic storage under standard alternating conditions showed a slight rise of ballistics. Chemical tests showed that only a small fall of carbamite content had occurred and it should be possible to counteract a development of acidity which had occurred by a suitable chalk addition. 30070 30384

In considering the adoption of propellants for production in Australia, the position was summarised as (a) little difference in the performance of AN and NQ in low pressure weapons, (b) in guns of medium performance NQ was superior to AN (c) in guns of high performance N or N/P with various proportions of K_2SO_4 were the best. The smoke with AN would, in all cases, be greater than with N or NQ and flashlessness with smokeless primers would be more readily obtained by the N and NQ propellant. The toxicity of the muzzle gases with AN was greater than with N and NQ due to an increase of carbon monoxide concentration of 58% compared with N, and 87% compared with NQ. The high temperature correction made AN unacceptable for certain high performance guns. From a manufacturing consideration, the processing advantages were with the picrite propellant. 30576

In a comparative trial of A.S.N. .062 and N.F.Q. .052 when fired with a No. 14 primer alone in a new Q.F. 4-inch Mk. XVI gun, star shell charges, the A.S.N. gave 1 flash in 10 rounds while N.F.Q. was flashless. In a worn gun both gave a proportion of flashes. 30916

In a new Q.F. 4-inch Mks. XII and XXII gun, Star Shell charge, A.S.N. .050 with a No. 9 primer gave muzzle glows only and A.S.N. .062 gave a proportion of flashes. N.F.Q. .045 and .052 were flashless and gave less smoke than A.S.N. 30989

In a night-firing trial in the Q.F. 4.5-inch Mk. III, long range star shell charge, with a part-worn gun (275 E.F.C.) with F.A. and S.L. rounds and 4 oz. G.P. igniters, the A.S.N. propellant gave large flashes with all F.A. rounds and 1 large flash in 5 S.L. rounds. The N.F.Q. rounds gave muzzle glows only (less than 5 c. secs.). The weight of shot was 51 lb. 12 oz. 31265

With the Q.F. 4-inch Mk. XI in a comparative trial of N.F.Q./S 198-054 and A.S.N./T 190-054 and 234-078, the N.F.Q./S rounds were all flashless while most of the A.S.N./T rounds gave full flashes together with an increased amount of smoke and with higher temperature corrections, particularly with the larger size 234-078, in which case they amounted to 21 f.s./1.15 tons for 10°F. In the Q.F. 4-inch Mk. XVI during a comparative firing in a slightly worn gun (first quarter) of 218 rounds of different lots of A.S.N./T 190-054 with 122 rounds of N.F.Q./S 164-048 the percentage of flashes with A.S.N./T was 0.92 large and 1.37 small, compared with 1.6 large and none small for N.F.Q./S. 31651 33206

In the Q.F. 40 mm. Mk. I gun a firing of A/T 099-033 (chopped) gave flashlessness when the flash eliminator was fitted and with a primer containing 64 grains of G.7. The ballistics were unsatisfactory, however, and it was recommended that further trials should be abandoned. O.B. Proc. 32369

In the Q.F. 4-inch Mk. XII and XXII guns, N.F.Q. .042 and .052 gave satisfactory flashlessness in a worn gun. A.S.N. .048 and .061 gave large flashes in about half the rounds with each size. 32707

In the Q.F. 4.7-inch Mk. IX, a comparison of A.S.N./T 190-054 with N.F.Q./S 168-048 showed that the former gave a proportion of large flashes while the latter was flashless. A further characteristic difference was that in the early stages of wear of the gun the A.S.N./T rounds showed a fall of M.V. with wear while the N.F.Q./S rounds invariably tended to give a rise. 32728

In the Q.F. 32 Pdr. gun, cordite A/T 273-091 (ann. .091) gave an unacceptably high temperature correction amounting in one instance to 22 f.s./0.6 ton for 10°F. over the range 0° - 80°F. and 53 f.s./2.6 tons over the range 80° - 100°F. Q.3826

A summary in February 1946 of the results of firing trials of cordite A.S.N. for S.S. and full charges and of N.F.Q. for S.S. charges in a number of guns gave the following conclusions:-

In all cases the smoke given with A.S.N. was about double that produced by N.F.Q. and the temperature correction figures with A.S.N. were high. Apart from this, A.S.N. was flashless and would replace N.F.Q. in the following guns:- 12 Pdr. 12 cwt. full charge and star shell charges; Q.F. 3-inch 20 cwt. S.S. charge; Q.F. 4-inch Mk. XVI S.L. full charge: Q.F. 4-inch Mk. V and star shell, S.L.; B.L. 4-inch Mk. I S.S.

Small or occasional flashes were given both by A.S.N. and N.F.Q. in the following guns:- Q.F. 4-inch Mk. V, S.S. charges F.A.; Q.F. 4-inch Mk. XVI S.S.

In the following guns while N.F.Q. was satisfactory for flashlessness, A.S.N. was unsatisfactory:- Q.F. 4-inch Mk. IV F.A. full charge; Q.F. 4-inch Mk. V full charge, F.A. 33072

In the Q.F. 3.7-inch How. AN .017 with a No. 1 Mk. II primer was found to be satisfactorily flashless as an alternative to NQ/R thickness .014 with a No. 11 Mk. I primer. With a C 9 B (smokeless) primer both propellant charges were flashless and with this primer the lowest firing intervals were obtained. The least smoke was given by NQ/R in combination with the C 9 B primer 33086

In a survey of the relative merits of AN and picrite propellants, it was pointed out that in the Q.F. 95 mm. How. a practically smokeless-flashless charge had been produced by a combination of cordite A and the C 9 A primer. For guns above Q.F. 25 Pdr. however, cordites A and AN were unsatisfactory on account of smoke or flash apart from the high temperature correction. 33158

In the Q.F. 4-inch Mk. XVI, a firing trial was conducted with A.S.N./T ann. .062 and A.S.N./S ann. .062 in comparison with N.F.Q./S 164-048. In a nearly new gun no large flashes were given with any of the propellants, but in a half worn gun, the A.S.N./S and A.S.N./T gave a large proportion of flashes while 33245
N.F.Q./S gave none. The mean temperature correction over the range 0° - 120°F. was 17 f.s./0.75 ton for 10°F. for A.S.N./T, 10 f.s./0.27 ton for A.S.N./S and 8 f.s./0.17 ton for N.F.Q./S. No further action with the A.S.N. propellant in this gun was recommended.

In the Q.F. $3\frac{1}{2}$ Pdr. automatic gun (Naval Service) trials made with N.F.Q./S 093-031 and A.S.N./T 114-038 showed that for satisfactory ignition at a temperature of -32°F. and flashlessness, 100 grains of G.P. in the primer or igniter were required. The A.S.N./T rounds gave some 50-100 per cent more smoke than the N.F.Q. rounds. O.B. Proc. 32891

In the Q.F. 17 Pdr., FNH/P .054 with 2 and 3 per cent K_2SO_4 and No. 9 Mk. III primer gave reasonably flashless results, the partly worn gun giving a rather better result than the new gun (13-21 candle secs. compared with 32-44 for the new gun). The muzzle brake in this trial had little effect on flash. Apart from the higher toxicity with this propellant the smoke was excessive and considered sufficient to mask a tracer. 22372

(b) Cordite L. For tank and anti-tank guns the smoke given by a flashless propellant was considered unacceptable. In order to provide a flashing propellant for the Q.F. 17 Pdr. to give a lower temperature coefficient than cordite A, a composition was developed in the A.R.D. designated cordite L and consisted of:- G.C. (13.1% N_2) 62, N.G. 12, D.N.T. 24, Carb. 2. It was known as LP when 1% potassium sulphate was included. A firing trial with L/M .063 and LP/M .065 in the Q.F. 17 Pdr. showed these to have temperature coefficients similar to NH viz. 16-18 f.s./0.5 ton per 10°F. in the range -4° to 120°F. (cf. p.16) O.B. Proc. 32223

(c) Nitrocellulose propellants

Granular nitrocellulose propellants (NH and FNH/P) were found to give erratic ballistics with a tendency to sporadic high pressures when fired in the Q.F. 3.7-inch Mks. I-III with a No.11 primer. Satisfactory regularity was obtained by the use of a 12-inch or 19-inch Canadian primer filled 600 grains G.7, but there was no evidence of improved flashless performance with the long primer. 33208

It was finally decided by the Army Council in November 1946 that in order to rationalise the variety of propellants so-far under consideration, picrite propellants should be generally adopted for gun ammunition and it was recommended that this policy should be also followed throughout the Empire. Q.4773 4774

Q. Safety from accidental ignition

At a conference held on 1st July, 1942 to discuss the relative safety against ignition of different propellants in ships magazines it was reported that the relative insensitivity of propellants to impact was greatest with N or NQ, intermediate with S.C. or W and lowest with FNH. –

A method devised and recommended for assessing the liability of different propellants to ignition from flash consisted in igniting a constant weight of G.P. under controlled conditions and observing the smallest distance of separation of the propellant from the flash at which ignition occurred in not more than 1 in 5 exposures. Ignition of the cordites only occurred with N cordite at very close intervals of separation from the flash 21159 compared with a distance of 18 to 21 inches with other types. O.B. Proc. 18474

A trial was conducted to determine the relative liability to ignition of charges of W.M., NQ and NH in Q.F. 2 Pdr. Mk. V cartridge cases when exposed to the impact of a .303 A.P. bullet fired at close range. With W.M./T explosions occurred with 54 per cent of the rounds, the average time from striking to explosion being 2 seconds. The remainder smouldered for some seconds. With NQ/T all the charges smouldered slightly on impact for periods up to 12 seconds and in 25 per cent of the rounds this proceeded to explosion in an average time of 5 seconds. 19184

Experiments made in the A.R.D.(77) showed that the presence of an atmosphere with a high proportion of CO_2 was very effective in inhibiting the ignition of single sticks of cordite and in extinguishing the flame when once ignited. Consideration was given to the use of CO_2 for flooding a ship's magazine by the operation of a photo-electric cell. 19353

Further trials on the sensitivity of different propellants to ignition by the impact of projectiles were conducted on 12th September, 1942 by firing .303 A.P. bullets and Q.F. 2 Pdr. A.P. shot into Q.F. 2 Pdr. cartridge cases filled with the propellant. Generally the cooler compositions NQ/T, N.F.Q. and NH proved to be less sensitive to ignition than W.M./T and S.C. 19932

The liability to ignition of propellants in ships' magazines was accordingly considered to be much less with nitroguanidine propellants than with other types. Decomposition of N.F.Q. on contact with metal at a red heat proceeded without resulting in ignition and the decomposition ceased on withdrawl from contact with the hot metal.(19) 17441

The evidence from trials made in the A.R.D. on the extra safety of picrite propellants against accidental ignition by flash, fire or heated metal particles was corroborated in the results of trials at H.M.S. Excellent and in the U.S.A.(20) 26699 32289

III. Primers and igniters[21]

(a) Land Service guns

The picrite types of flashless propellants which were approved for adoption in the Services in 1929-30 for smaller and medium size Q.F. guns differed in behaviour from the older types of cordite in requiring more powerful igniters for satisfactory ignition and acceptable firing intervals than that given by the No. 1 Mk. II primer which was in general use for the Q.F. 18 Pdr., 3-inch and similar guns. The No. 11 primer containing 6 drs. G.P., compared with 2 drs. in the No. 1 Mk. II, was accordingly adopted. This primer had always given satisfactory ignition and the extra amount of powder had helped to ensure flashlessness at the expense, however, of an appreciable increase in the amount of smoke.

The improvement in the degree of flashlessness of the propellant R.D.N./A.Q. made by the inclusion in the composition of 0.3 per cent cryolite dispensed with the need of the use of this amount of gunpowder in the primer for flash suppression.

The possibility was then investigated at length of replacing the gunpowder by a suitable nitrocellulose composition. Many powders of this type were tried in the form of either flake, chopped tube, or granulated propellant. The primer bodies employed for these fillings consisted in the first place of the No. 11 Mk. I primer with different types of liners other than paper e.g. glazedboard and metal foil. A priming of gunpowder or guncotton arranged either at the base of, or as a central core in, the primer was found necessary to overcome hangfires and to give satisfactory firing intervals. The use of primers containing guncotton priming was abandoned on account of an ignition which occurred with this design on climatic trial.

The propellants used for the primer filling which gave the most favourable results were special cordite compositions in the form of flake of 0.008" thickness or chopped tube 0.05" - 0.03" and of the following calorimetric values:-

F.503/67. G.C. (13.1 per cent N.) 37; N.C. (12.2 per cent N.) 30; N.G. 30; Carb. 3; cal. val. 1115 (W.L.)

F.503/62. G.C. (13.1 per cent N.) 36; N.C. (12.2 per cent N.) 7; N.G. 55; Carb. 2; graphite 0.3; cal. val. 1342.

F.503/89. G.C. (13.1 per cent N.) 30; N.C. (12.2 per cent N.) 20; N.G. 48; Carb. 2; cal. val. 1280.

F.503/126. G.C. (13.1 per cent N.) 24; N.C. (12.2 per cent N.) 18; N.G. 55; Carb. 3; Cryolite 1.0; cal. val. 1292 (W.L.)

and the following porous nitrocellulose compositions in tube, flake or granular form:-

F.100/59. G.C. (13.1 per cent N.) 98; Carb. 2; cal. val. 940 (W.L.)

F.100/78. G.C. (13.1 per cent N.) 58; N.C. 40; Carb. 2; cal. val. 1257 (W.L.)

A design which gave very satisfactory results and which was employed in many trials was known as the "S. of A." primer (DD/L/4634C). This consisted of a No. 11 Mk. I magazine provided with a glazed board liner. A tube $\frac{1}{4}$" diam. was fitted axially in the centre and filled with 7.5 grains of G.12 powder. The remainder of the primer was filled with 80-85 grains of F.503/62 composition in the form of flake 0.008" thick.

In addition to the brass dome primer fitted to the No. 1 Mk. II base, a large number of trials were done with cylindrical types of primers venting forward and usually without any side holes. The main variants which were investigated were length of primer which generally ranged from 1.5 to 3-inches, type of closing disc and composition of propellant filling. The tests which were made in the first place consisted of firing in a steel chamber accompanied by photography of the flash, determination of the amount of unburnt powder collected, and examination for distortion of the primer. In these rest trials measurements of the pressure in the primer were also made by connecting to a crusher gauge. The pressure so measured generally ranged from 2 to 5 tons. A further test made was to fire the filled primer in an 18 Pdr. gun with proof shot but without the cordite charge and measure the distance the shot was projected; this would usually vary from 2 to 8 feet.

Firings were then conducted in the Q.F. 18 Pdr. or Q.F. 3-inch 20 cwt. guns with a service propellant charge of R.D.N. cordite and a measurement made of the firing interval with observation of flash.

With the older R.D.N. cordite not containing cryolite a certain proportion of flashes occurred with these primers containing no, or only a few grains of, G.P. There was evidence that in many cases, flashes were associated with poor ignition as shown by long firing intervals. Though these firing intervals generally did not exceed 15 milliseconds occasional hangfires or misfires occurred with primers containing no G.P.

With regard to smoke, under favourable atmospheric conditions this was reduced to an amount not exceeding that given by a service flashing round.

The porous N.C. compositions were generally too rapid burning and caused distortion of the primer. The most satisfactory composition for the filling of these types of primers was later found to consist of Ballistite B.16 consisting of:-

N.C. (12.6 per cent N.) 60; N.G. 38; Carb. 0.5; KNO_3 1.5; Graphite 0.6.

For the Q.F. 25 Pdr. supercharge, the ignition system which was adopted in February 1938 for use with F.551/58 (R.D.Q.) propellant as giving the best compromise between good ignition and minimum of smoke was the No. 1 Mk. II primer and a supplementary igniter of F.503/126 composition in tube size .05" - .03" arranged as a core at the base of the propellant charge. O.C.Memo B 36091 and 36220

Further work on smoke reduction was discontinued on the outbreak of war as, from the result of extensive trials at Larkhill, the amount of smoke produced by gunpowder primers with flashless charges was considered not to be unacceptable for Field Army and Heavy A.A. guns. In mid-1943 it became apparent that the extra smoke given by flashless propellants with gunpowder primers was not generally acceptable for new guns which had been introduced. This applied particularly to tank and anti-tank, light and medium A.A. and Coast defence guns with which it was essential that the layer's view should not be obscured. The requirement for use at lower temperatures than those previously provided for prevented any reduction in the efficiency of the ignition.

A primer was satisfactorily developed which when used with propellant charges of NQ cordite in the Q.F. 25 Pdr. gun, Q.F. 95 mm. Tank How. and Q.F. 95 mm. Inf. How. gave satisfactory ignition at low temperatures and an amount of smoke which was generally no greater than that with a flashing propellant. This primer, known in its final form as C.9 B, was similar in design to the "S. of A."

type described above but was filled with 5.0 grams (77 grains) of ballistite B.16 and was fitted with an axial brass tube containing 5 to 10 grains of G.P. For the minimum firing intervals at low temperatures, the ignition with these primers was reinforced by the inclusion in the charge of $\frac{1}{2}$ oz. or 1 oz. of ballistite B.16 in a fabric container. While the flashlessness of these charges was satisfactory in guns not fitted with muzzle brakes, the introduction of these brakes resulted in the charges being no longer consistently flashless when using the smokeless primers. O.B. Proc.

With the introduction of multi-tubular (granular) propellant which was essential to overcome the difficulty of filling of cord or S.T. in cartridge cases which were heavily necked, e.g. Q.F. 3.7-inch Mk. VI, Q.F. 40 mm. Bofors, Q.F. 17 Pdr., it was found that a heavy ignition applied locally at the base of the charge led to the liability of sporadic high pressures.[22]

In the Q.F. 3.7-inch A.A. gun with N/A.Q./S 164-048, trials with 12 inch metal igniters and shalloon core igniters of the same length and containing 2 oz. G.P. showed no great difference in the tendency to give incipient flashes. The adoption of the core igniter was decided on. 11456

Pressure-time records made in the Q.F. 40 mm., 6 Pdr. 7 cwt., 6 Pdr. 10 cwt., 6 Pdr. 6 cwt. and Q.F. 17-Pdr. guns with piezo-electric gauges showed that a tendency for sporadic high pressures was associated with irregular pressure-time curves resulting from the use of granular charges. The irregularities in the pressure-time curves were to a large extent eliminated by the use of a long axial primer copying an American design in which the venting was more centrally disposed relative to the charge than in the Service primer. Front ignition was found to be as favourable as central ignition. Experiments showed that a dummy multitube propellant presented considerable physical obstruction to a gas surge, and hence by inference to flame or hot particles. A comparison between S.C., NH and N cordites, prepared in granular form, in the Q.F. 17 Pdr. showed that irregularity occurred with all types but was least with NH and greatest with N. The conclusion that sporadic high pressures were due to the combination of a granular charge and powerful rear ignition was confirmed by the experience with the Q.F. 3.7-inch Mk. VI gun in which the use of a supplementary bandolier igniter with 1 oz. of G.P. added to the No. 9 primer in order to ensure flashlessness had led to dangerous pressures and resulted in the adoption of the No. 9 primer alone and the inclusion of the K. salt in the propellant (cf. p.13).

With the larger sizes of Q.F. cartridges, the use of long metal igniters to give central ignition was attended by a number of objectionable features. Unless strongly supported at the base they showed a tendency to become detached during firing. In other cases fracture or distortion had occurred either through the pressure of the gunpowder or the subsequent outside pressure of the gases from the propellant. With charges giving a high density of loading, the space occupied by the metal was detrimental. These defects had been overcome by an igniter which had given promising results in which the metal igniter was replaced by a tube of combustible cordite composition. This served as a container for the required charge of gunpowder held by a closing disc. With this arrangement, venting took place both forward and axially around the fractured and burning tube. Trials conducted had indicated that the regularity and the degree of flashlessness obtainable with these igniters was at least as favourable as with the best of the metal types.

(b) Naval Service guns

For medium size Naval Q.F. guns in addition to the No. 9 or

No. 14 primers containing 1 oz. of G.P. a supplementary igniter C.B. Proc.
of from 2 to 6 oz. G.P. inserted axially as a core in the charge was found necessary to ensure flashlessness. Night firings with N.F.Q. in the Q.F. 5.25-inch, 4-inch Mk. V and 4.7 Mk. VIII showed that increasing the G.P. in the igniter reduced the incidence of sporadic flashes but increased the brightness of the muzzle glow. The high velocity star shell charges were found to require more 6167
G.P. than the older low velocity charges. 6385

For the Q.F. 4-inch Mk. XVI and 4.7-inch Mks. IX and XII the No. 24 primer was recommended to reduce the liability to occasional flashes and it was decided to retain existing primers as no unfavourable reports had been received from the Fleet. 7733

For containing the supplementary charge of G.P. the use of long steel igniters was objected to and the use of sausage-shaped 8024
fabric containers was approved.

In the Q.F. 4.7-inch Mk. XI gun N.F.Q./S 198-054 was found to give a higher degree of flashlessness when using a 6 oz. core igniter than with one of 4 oz. 14989

In the Q.F. 4-inch Mk. XVI gun with FNH/P .049, and No. 14 primer a trial of the effect of an igniter of 3 oz. G.12 placed at 16126
the top or rear of the charge showed no marked difference on ballistics or flash.

IV. Smoke with flashless propellants

O.B. Proc.

Apart from improvements still under development, the position with flashless propellants as in use in the Services up to 1943 was that, with the ignition systems which had been adopted, the smoke with flashless propellants was generally assessed as being from 50 to 100 per cent greater than that from flashing propellants. With Field guns in which, in the absence of muzzle brakes, flashlessness could be secured with smokeless types of primers, the amount of smoke varied with atmospheric conditions but in general was no greater than from a flashing propellant. Comparative trials of density and persistence of smoke were conducted at H.M.S. Excellent with N.F.Q. and S.C. cordites in the Q.F. 4-inch Mk. XVI gun fired over the sea. The relative results as shown by cine photographs varied with atmospheric conditions, but generally the difference between the two propellants, taking into account both duration and density of smoke, was negligible and could be ignored. 17534

In Q.F. 17 Pdr. and 6 Pdr. tank and anti-tank guns the position with regard to the relative obscuring effect of flash and smoke was again reviewed on 4th December, 1942. It was found that the duration of obscuration by smoke with a flashless propellant lasted for 3 to 5 secs. compared with obscuration from flash for 1 to 3 secs. A further conclusion reached was that the reduction of blast effect with a flashless propellant caused less dust to be raised from the ground. Other advantages compared with a flashing propellant were the better concealment it offered from the enemy on the ground and in the air. It was accordingly decided by the General Staff that the Q.F. 17 Pdr. and 6 Pdr. should be added to the flashless priority list.

(cf. p.16, 31 and 59)

O.B. Proc. 20719

In a further joint investigation by T.A.R. and C.D.E.S. at Porton in 1945(23) it was found that the most serious obscuration of the target during a short interval immediately after firing occurred with a flashing propellant due to shimmer arising from the refraction effect of the air which was heated by the flash. The relative merits of flashing and flashless propellants for tank and anti-tank guns accordingly remained undecided.

V. Flash extinction by external means

(a) Addition of salts to propellant charge

In order to utilise large existing stocks of flashing propellants and on account of the delay involved in introducing new types it became of urgent importance to investigate methods for the elimination of muzzle flash from the older types of cordite (e.g. M.D., W, and W.M.).

The method investigated was the application of the procedure previously employed (cf. I A), i.e. adding salts either alone or in admixture with gunpowder in packets placed behind the shot or as cords bonded by means of gum or nitrocellulose and distributed 30052
in the main propellant charge. The compounds employed included the chlorides, bromides, carbonates, bicarbonates and oxalates of sodium and potassium, cryolite, felspar, wood meal, starch, oxanilide, chalk and ethylene dibromide (in collodion vessels). The propellants used were: N.C.T., M.D., R.D.B. and W; firings were conducted mainly in the Q.F. 18 Pdr. and a smaller number in the Q.F. 4.5" How., B.L. 6-inch 26 cwt. How., B.L. 8-inch How. and the B.L. 9.2-inch How.(24)

When using cords of salts bonded with nitrocellulose a total of 500 rounds were fired during case proof in the Q.F. 18 Pdr. With M.D. cordite, consistent flashlessness was obtained by the use of 5 oz. sodium oxalate-gunpowder mixture, which corresponded to 20 per cent of the weight of propellant charge, or with 4 oz. of cryolite-G.P. mixtures (40 : 60) when contained in a shalloon bag inserted axially in the charge. Small amounts (8 to 15 grains) of cryolite or potassium bromide added to the sodium oxalate-G.P. mixtures apparently assisted flash suppression.

A firing trial was conducted in July 1938 with a worn Q.F. 3-inch gun with R.D.N./A.Q. (.052) and a No. 11 Mark I primer with and without packets of various salts inserted at the top of the charge behind the shot. The salts employed were contained in tin foil and consisted of 15 grms. of sodium bicarbonate, potassium oxalate, picrite, sodium chloride, chalk or borax. The smallest flashes were given with the borax additions.

The amount of salt needed for flash elimination or obscuration gave a prohibitive amount of smoke for use in day firing. It therefore became necessary to investigate the possibility of devising means of providing optionally flashless charges by adding or withdrawing flash-reducing substances from the propellant charge.

With fixed Q.F. ammunition this could only be done by inserting flash-reducing packets into the primer hole, thus limiting the amount of flash-reducing substances to 4-5 oz. for the 18 Pdr. With this weight of flash reducer a proportion of rounds were flashless in this gun and with the remainder some reduction in the size of flash was achieved, but it was still very vivid. Uniform success could not, however, be achieved and, after considerable research, trials with Q.F. ammunition were discontinued. 30132

With the larger field guns, i.e. the B.L. 60 Pdr. and the B.L. 6-in. 26 cwt. howitzer, a considerably larger proportion of flash-extinguishing salts could be added, but even when a packet of flash-reducing salts weighing as much as 60 per cent of the charges was employed flash extinction or drowning was not obtained and there was little hope of success in either of these pieces.

At a later period (during 1943), it was found that elimi- 22264

nation of flash in the Q.F. 2 Pdr. Mk. VIII with H.S.C.T. propel- O.C.Memo B
lant could be effected by adding 2 per cent of K. salts to the 24438
propellant charge through the primer hole provided a conical flame 25533
guard was fitted to the gun. A similar result was obtained 26626
in the Q.F. 6 Pdr. 7 cwt. in rounds filled with NH .033. Potas- O.B. Proc.
sium cryolite was found to be somewhat more efficient than K_2SO_4. Q.1237
A mixture of K_2SO_4 and G.P. was as effective as K. cryolite but
the smoke with this was excessive.

In the Q.F. 4.5-inch Mk.III, H.V.S.S. a trial was conducted
with the addition of packets of 10 oz. of potassium sulphate and
of 10 oz. of a mixture of 60/40 G.12 and potassium oxalate in
front of the charge of N.F.Q./S 198-054. The salts were unsuc-
cessful in reducing the residual small flash and produced excess-
ive smoke and fumes. 25815

In a trial in the Q.F. 25 Pdr. without a muzzle brake the
addition of 4 oz. of a 1 : 1 mixture of G.P. and K. cryolite to
charge II of W.M. propellant with a No. I primer gave suppression 33109
of flash with an increase of velocity, however, of 29 f.s. With
K. cryolite alone and with all additions tried, including potas-
sium nitrate and gunpowder, consistent flash suppression was not
obtained in charge III and supercharge. The salt was more
effective when the crystal size was increased and when placed at
the top of the charge rather than in other positions. In the
B.L. 4.5-inch Mk. II gun, 16 oz. of K. cryolite had no effect on
the flash produced by W.M. charge III.

A further procedure which was investigated for suppressing
the residual flashes which remained with certain guns was to place
a packet of starch or washing soda between the charge and the
projectile.

In a night trial in the Q.F. 4.5-inch Mk. II, no effect could
be observed with washing soda as the flashes were in all cases
very small. In the Q.F. 5.25-inch Mk. I with N.F.Q./S 198-054
the addition of 12 oz. of washing soda gave a decrease of flash.
2 large flashes in 6 rounds were obtained in the absence of the
soda and only small flashes in 5 rounds with the salt. In the
B.L. 6-inch Mk. XXIII, the addition of 20 oz. of washing soda in 27601
front of charges of N.Q.F./P gave smaller residual flashes than
either this propellant alone or N.Q.F. or H.P./P. A further A.R.D.file
trial on 7th June, 1944 with washing soda in this gun with N.Q.F./P B/19/5/4
.128 showed that no great increase of smoke resulted.

A trial with the use of starch with H.P./P .128 in the B.L.
6-inch Mk. XXIII showed that this was as effective as the soda in B19/5/24a
reducing flash while giving little increase of smoke as compared B19/5/31
with the propellant alone. In trials on 30th October, 1945 and
1st November, 1945 in the B.L. 6-inch Mk. XXIII, N.Q.F./P .128 O.B. Proc.
with 20 oz. packets of starch fired in a worn gun at night gave a 32845
considerable reduction in the brightness of the flashes compared
with those from the propellant without the starch addition. A
day firing in a new gun showed no appreciable increase in smoke
from the presence of the starch.

Filling the bore of the gun with CO_2 prior to firing gave 18042
favourable results in trials for the suppression of residual
flashes in the Q.F. 4-inch Mk. XVI with long-range star shell
charges. In a night-firing trial at Inchterf on 6th December,
1943 in the Q.F. 4.5-inch Mk. III high velocity star shell (S.L.) 9663
with N.F.Q./S 198-054 a considerable reduction of flash resulted
from the filling of the barrel of the gun with CO_2 prior to 25815
firing.

(b) Flash drowning by liquids

Trials were conducted in the Q.F. 18 Pdr., B.L. 60 Pdr. and B.L. 6-inch How. to ascertain the possibility of eliminating muzzle flash when using service flashing propellant (M.D.). It was found that by placing water in a suitably designed cardboard container, preferably held in a steel muzzle attachment, complete flash extinction resulted with ½ pint water in the Q.F. 18 Pdr. and in the B.L. 60 Pdr. with 14 pints of water or 3½ pints of potassium acetate solution and in the B.L. 6-inch 26 cwt. How. with 16 pints (20 lb.) of water.

With the B.L. 60 Pdr. it was also found that flash could be extinguished by two fire hoses with water jets crossing about 2 feet in front of the muzzle, the amount of water required, however, was about 3 gallons per second. Smaller amounts of water reduced but did not extinguish the flashes. O.C. Memo 868

The elimination of flash by the projection of sprays of liquid dopes at the muzzle of the gun was proposed and investigated by R.G.W. Norrish and collaborators. Experiments with a .303 rifle followed by a 2 Pdr. Mk. VIII gun showed that xylene was the most efficient and practical liquid. O.B. Proc. 19517 Q.741 Q.787 Q.818

As the outcome of a large number of trials at H.M.S. Excellent with the Q.F. 2 Pdr. Mk. VIII and Q.F. 6 Pdr. 7 cwt. guns it was finally concluded that as a means of flash suppression, this method was inferior to H.S.C.T./K by night but superior by day on account of the reduction of smoke. Further trials with these two guns were cancelled. Q.826 Q.836 Q.3471

VI. Theories of mechanism of flash suppression

The earliest record in scientific journals on this subject which has been noted is that of Dautriche who states that the ignition of the inflammable gases produced by the decomposition of explosives is suppressed by Na. and K. salts while Ca. and Ba. salts have little effect.[25] The measurement consisted in determining the heat evolved when nitrocellulose either in the presence or absence of excess of air was detonated in a calorimetric bomb.

Poppenberg and Stephen find that the inclusion of 3 per cent of soda in nitrocellulose powders increases the CH_4 content of the gases by 0.4 per cent.[26]

Reference may be included here to speculations in the Research Department Woolwich in 1914[1] on the cause of the efficiency of alkali metals on flash suppression; the most probable cause was considered to consist in a displacement of the water gas reaction which during cooling proceeds in the direction $CO + H_2O \longrightarrow CO_2 + H_2$. From the work of Sir J.J. Thomson[27] and H.A. Wilson,[28] activation of hydrogen was known to result from the ionising effect of the atoms of the alkali metals and this was concluded to have a retrogressive action in the progress of the above water gas reaction as cooling proceeded. (cf. p.67)

D. Riensberg[29] considers that flash is promoted by inequalities in the size of propellant, in the distribution of the ingredients and of the V.M. content. A powerful central ignition is stated to assist flashlessness.

H. Brunswig shows that an increase in the proportion of methane in the powder combustion gases tends to the reduction of muzzle flash and refers to the action of certain catalysts upon the composition of the powder gases.[30]

The analysis of gases resulting from the combustion of a powder (B.F.Pl) in a closed vessel at a density of loading of 0.2 and containing KCl is given by Fauveau and Le Paire as follows:-[31]

	CO_2	CO	H_2	CH_4	N_2
No KCl	17.2	46.6	21.9	0.5	13.8
2% KCl	17.6	44.7	20.6	0.8	16.3
5% KCl	17.7	45.3	20.8	0.5	15.7

In accordance with the view which had been accepted that the action of alkali salts is to remove the chain carriers (H.OH) in the H_2-O_2 reaction, it is shown by Pease[32] that the combination of H_2 with O_2 in silica bulbs is suppressed when the bulb is coated internally with KCl. Moreover while some H_2-O_2 can be obtained by combination on the walls of the vessel none is formed when these are coated with KCl.

Prettre finds that the presence of 3.5 mgrm. of KCl per litre, stated to be admitted as vapour, raises the ignition temperature of a mixture of 25 per cent CO and 75 per cent air from 656°C. to 1010°C., while the ignition temperature of H_2- air mixtures, which with 28 per cent H_2 is 606°C., is not affected by KCl in amounts up to 20 mgrm. per litre.[33]

A classification is made by Demougin[34] of the efficiency of a large number of anti-flash agents. Potassium salts are the most efficient; the chloride, sulphate, carbonate, oxalate and tartrate being equal. It is concluded that some substances act by lowering the temperature of decomposition of the propellant and others by increasing the volume of the gas produced or by forming a dust cloud which has an inhibiting effect on ignition by deactivating the gaseous molecules which have been activated by ionisation.

The addition of finely-divided cellulose in powders is also found to assist flash suppression.

Jorissen(35) has investigated the effect of finely-divided dusts in raising the lower explosive limit of methane in air, and finds KCl to be the most efficient.

H.W. Thompson(36) finds that with flame ignition silica dust raises the lower explosive limit of H_2 in air from 9.4 per cent to 9.55 per cent and that of CO from 16.7 per cent to 17.4 per cent. It also lowers the speed of the explosion wave with both gases. Hydrogen and oxygen mixtures explode in narrow tubes at higher temperatures than in wider vessels.

H. Muraour(37) in discussing the suppression of muzzle flash points out that methods so far employed for obtaining flashless propellants have consisted in (1) the addition of chlorides of the alkali metals and (2) the addition of combustible materials which modify the compositions of the gases and lower the temperature. The effect of the salt is attributed to the action of the large surface of the solid particles in interrupting the chain reaction by which the oxidation of hydrogen proceeds.

In tests conducted with gases arising from the combustion of propellants in closed vessels, the inflammability was lowest with compositions containing 30 per cent of nitroguanidine or with composite charges containing an addition of NH_4NO_3 and C. The results are in accordance with the minimum proportion of CO and H_2 in the products thereby obtained. A considerable proportion of methane is found to occur with compositions of lower explosion temperatures. This is considered to be formed during cooling by interaction between CO and H_2 and not to occur at the high temperature of the explosion.

P. Depreux(38) considers that alkali salts exert an inhibiting action on flash through retarding the reaction $CO + H_2O \longrightarrow CO_2 + H_2$ which proceeds as the gases cool and thereby restrict the replacement of CO by the more inflammable H_2. It is further considered that the efficiency of salts as inhibitors for the combustion of hydrogen depends on their fundamental infra-red radiation frequency being a sub-multiple of that of water thus permitting of resonance. This condition applies in the case of all the alkali salts. The fact that the efficiency of the metals increases with increasing atomic weight is attributed to the fact that a change of energy level is more easily brought about in the element with the higher atomic number. On this same basis tin should have a similar but less definite effect in inhibiting ignition of CO. It is concluded that the combustion of hydrogen is retarded by a high content of water vapour in the atmosphere while that of CO is promoted by water vapour on account of the displacement of the equilibrium of the water-gas reaction. (cf. p.66)

The above view of the effect of water vapour is concurred in by G. Debaude(39) who makes a tabulation from the results of a large number of firings in the Q.F. 37 mm. and Q.F. 100 mm. guns on different days of the number of large secondary flashes as a function of atmospheric humidity. It is concluded that for humidities below 75 per cent saturation the liability to flash is less with increasing dryness of air, while conversely with humidities above 91 per cent, the proportion of flashless rounds increases with increasing humidity. (N.B. the indications from some limited statistical results compiled in the A.R.D. Woolwich which are described below were that the incidence of flashes decreased progressively with increasing humidity.) (cf. p. 80)

In distinction from anti-catalytic agents, a very marked pro-catalytic effect on the ignition of hydrogen is found by H.B. Dixon, C.H. Gibson and C.N. Hinshelwood(40) to be exerted by the presence of traces of oxides of nitrogen. It is found that the temperature of ignition of hydrogen is depressed by over 100°C. by the addition of less than 0.1 per cent (0.7 mm.) of nitrogen peroxide but that this sensitised ignition is confined within a narrow range of concentrations of NO_2 and with amounts in excess of the optimum value of about 0.2 per cent, the ignition temperature again raises rapidly. (cf. p. 72)

This catalytic effect has been studied quantitatively by Thompson and Hinshelwood(41) and by Norrish and Griffiths(42). The influence of NO_2 is also found to cause a marked lowering of the induction period of ignition of hydrogen and oxygen and thus exercises a triple role in affecting the origin, branching and extinction of reaction chains. It is further found by Foord and Norrish(43) that very small quantities of methane have an inhibiting effect on ignition. The anti-catalytic effect of methane on the ignition of propellant gases has been further investigated by Norrish and T.M. Sugden(43a), who find that 10 per cent of methane raises the ignition point of CO-H_2 mixtures by from 40°C. to 100°C. and considerably narrows the range of mixtures which will ignite.

In view of the fact that cordite gives a certain proportion of NO_2 when burning at low pressures and of CH_4 when at high pressures, the presence of these gases may be expected to be potent factors in determining the presence or absence of muzzle flash.

VII. Photographic investigations in the A.R.D. on the nature of gun flashes

An investigation of the mechanism of flash production and of the effectiveness of flash reducing compositions was made at Woolwich by photographic means in 1928-9. For this purpose an image of the flash was projected on to a sensitised film wound on a rotating drum in such a way that the vertical motion of the film was at right angles to the horizontal axis of the gun. The film was specially treated to have the highest possible sensitivity and the drum was capable of being rotated at a uniform high speed. From the dimensions of the optical system, together with the known speed of the drum during an exposure, it was possible to determine the duration of the flash, its dimensions in the direction of the axis of the gun and the rate of propagation of the explosion wave.(44) A typical photographic record of a firing at night with a B.L. 6-inch Mk. XII gun S.S. is seen in Fig. 6. The gun was pointed in the direction of the abscissa of the Fig. while the film was rotating in the direction of the ordinate. The flash was, in this way, seen to consist of the following components:-

(a) A luminous globular discharge situated near the mouth of the gun the luminiscence of which lasted for about 0.1 m.s. and extended forwards for about 1 foot.

(b) An intermediate luminous discharge starting after an interval of about 0.5 m.s. at a point 3 or 4 feet in front of the muzzle and diffusing over a distance of about 1 foot.

(c) The main secondary flash which started after about 2 m.s. at two points about 3 and 5 feet in front of the muzzle and spread over a large area which extended for a short distance behind the original position of the muzzle of the gun. From the slope of the lines in the curves bounding the flash, though complicated by the forward movement of the gas cloud, it could be estimated that the rate of propagation of flame throughout the mass was at first slow but increased to about 400 metres per second. From an examination of the remainder of the flash record the duration of the secondary flash in this instance with the B.L. 6-inch gun was seen to be about 0.1 sec.

When similar measurements were made with the N types of propellant there remained in most instances only component (1) and the luminosity of this was reduced in proportion to the lowering of the cal. val. of the particular propellant composition used.

With a Q.F. 4.7-inch Mk. XII gun when firing S.C. cordite, cine-photographs showed that the secondary flashes were fully developed after an interval of about 0.05 second from the beginning of secondary ignition and lasted for an interval of about 0.2 to 0.25 sec. from the beginning.

In a worn Q.F. 2 Pdr. gun firing H.S.C.T./K the occurrence of a limited flash ahead of the projectile due to gases escaping past the driving band was demonstrated by light intensity-time curves by means of an oscillograph and photo-electric cell.

Measurements with a 20 mm. Hispano gun in 1943 showed that the flashes with this weapon consisted of three separate luminous regions (a) a faintly luminous glow at the muzzle, (b) a small and more diffuse luminous glow separated from the muzzle glow by several inches of dark space (c) the main secondary or "after flash" which occurred still further forward. (45), (67b), (67c). (a) and (b) were not extinguished by firing in an atmosphere of nitrogen. (b) was extinguished by xylene but increased by K.

salts and it was suggested that this component might be due to luminosity accompanying adjustments in chemical equilibria.

VIII. Measurement of gun flashes

O.B. Proc.

Methods which were employed for the assessment of gun flashes consisted mainly of the following procedures:-

(1) Stationary photographs in which, by exposing and developing under standardised conditions, comparisons could be made of the relative dimensions and intensities of small flashes during firing at night.

(2) Glowmeters based on the use of a photo-electric cell as developed in the A.R.D. Woolwich(45) and at the N.P.L. In this method the current produced in a photo-electric emissive cell, when exposed to the flash, charged a condenser giving a voltage charge which was proportional to the time integral of the light intensity and was thus a true measure of the eye's perception of the flash provided that the total time was less than about 1/10 second. Q.306 389

The voltage across the condenser was applied to the grid of an electrometer triode, and a microammeter in the plate circuit of the valve enabled a measurement of the flash to be made immediately after the gun was fired.

The instrument was placed at a fixed distance from the gun (normally 100 feet) and the readings were expressed in terms of candle-seconds.

For assessing the blinding effect of a directly viewed flash the significant quantity is the "candle-seconds per square foot" or brightness integral. This could be measured by the Glowmeter by using a lens and mask adapter arranged to allow the cell to view only a small portion of the flash where it is brightest.

For the measurement of the change of intensity with time and the peak value use was made of a system consisting of a photo-electric cell with amplifier and cathode ray oscillograph.

(3) A photographic method devised in the A.R.D.(45(a)) for the estimation of the intensity in foot-candle-seconds of flashes consisted essentially of photographing the flash directly on to a film through a stepwedge filter, without the aid of a lens. The film was calibrated by means of a standard flash of approximately the same duration as a gun flash and a correction was applied for the effect of the night sky illumination.

The gun flash and standard flash produced a number of steps of varying density on the film, and these densities were measured by any simple type of densitometer. A curve of density versus log (flash intensity) was drawn for the standard flash, and from this curve the intensity of the flash to be measured could be read off, once the density it produced on the film had been measured. The range of the instrument was practically unlimited, but a convenient working range of about 5 ft. candle seconds - 10,000 ft. candle seconds could easily be covered at a distance of 100 ft. from the gun.

With this apparatus the recorded intensity of light at the film S' was related to that at the source S by the expression $S' = \frac{S}{d^2}$, where d is the distance of the film from the light source.

IX. Laboratory investigations in the A.R.D. on anti- and pro-flash agents

Detailed laboratory investigations were conducted in the Research Department Woolwich, mainly during the period of 1933-1936[46], with the object of assessing the efficiency of a wide range of inorganic and organic materials in inhibiting the ignition of gaseous systems corresponding in composition to the muzzle gas-air mixtures arising from guns. The investigations covered three series of experiments summarised as follows:- A.R.D. file C.5899/35

(a) Ignition temperature measurements by the "Concentric Tube" method

A "Concentric Tube" apparatus of the type first developed by H.B. Dixon[47] was employed. The effect on the ignition temperature of the combustible gas in air was determined by introducing known concentrations of volatile inhibitors (e.g. ethylene dibromide, carbon tetrachloride, ethyl iodide, iodine, bromine etc. etc.) into the air stream. The influence of certain inorganic salts was investigated by spraying an aqueous solution of the salt into the air stream; the method was thus limited to trials with water-soluble salts.

It was hoped that the agents most effective in raising the ignition temperature of carbon monoxide-hydrogen mixtures would have powerful anti-flash properties in guns. It was found that on a weight for weight basis the most effective salts (e.g. KI, KBr) produced a greater elevation of ignition temperature than iodine, bromine, or organic compounds containing these elements, or "anti-knock" agents (e.g. lead tetra-ethyl, nickel carbonyl etc.)

It was clear, however, that the effects observed in these ignition experiments in the temperature range 600-700°C. would not necessarily apply to gun conditions where the inhibitor would be momentarily exposed to very high temperatures (e.g. 2500°C.) and might decompose to a large degree and interact with other products of combustion. Thus, in the ignition temperature measurements both potassium iodide and bromide were more effective inhibitors than the chloride, whereas in gun trials the chloride was shown to have clearly superior anti-flash properties. Similarly, elevations of ignition temperatures of the order of 150°C. were produced by 1 per cent of ethylene dibromide but inhibitors of this type were found to be inefficient anti-flash agents when applied "internally" in the gun.

The effect of nitrogen peroxide on ignition temperatures was specially investigated since it had been concluded from the earlier work of H.B. Dixon, C.H. Gibson and C.N. Hinshelwood[40] that the occurrence of gun flashes might be affected by traces of oxides of nitrogen such as might occur under certain conditions during the combustion of cordite. Measurements in the A.R.D. showed that as little as 0.05 per cent of nitrogen peroxide in the air stream lowered the ignition temperature of hydrogen by 150°C. and at the "optimum" concentration of about 0.2 per cent the lowering was 178°C. It was found that many compounds containing nitrogen (e.g. potassium nitrate, ammonia, aniline, acetonitrile etc.) produced traces of nitrogen peroxide when introduced into the air stream and caused the ignition temperature to be lowered. An interesting point was that the presence of ammonia in the "gas" stream, where oxidation could not proceed, raised the ignition temperature of a carbon monoxide-hydrogen mixture to a slight extent. (cf. p.18 and 68)

It was further shown that when the hydrogen content of a gas mixture exceeded 15-20 per cent the ignition temperature in air of mixtures of hydrogen with carbon monoxide or inert gases was determined almost entirely by the proportion of hydrogen rather than by the total percentage of inflammable gas (i.e. $H_2 + CO$), the carbon monoxide acting mainly as an inert diluent. This suggested that it was desirable, from a flashless point of view, for propellant compositions to be designed to produce the least possible proportion of hydrogen in the products of combustion.

(b) <u>The "Gallery" method of testing the efficiency of anti-flash materials</u>

This method consisted of a determination of the minimum weight of anti-flash agent required to prevent the ignition of an inflammable gas-air mixture when a small charge of gunpowder, stemmed with the anti-flash agent, was fired from a tube pointing axially into a gallery containing the explosive gaseous mixture. Trials were made with solids in powder form and for each material tested the limiting weights required for ignition or non-ignition of the gas mixture were determined; the mean of these limits gave the "probable" weight of material required to prevent ignition.

It was at first found that <u>cryolite</u> ($3NaF.\ AlF_3$) was more effective as a stemming material than either of its constituent salts or any other agent tested. As in gun trials, potassium salts were generally more effective than those of sodium and chlorides were superior to bromides and iodides. A sample of potassium cryolite ($3\ KF.\ AlF_3$) was found to be slightly more efficient than the natural cryolite. Salts of potassium were in the following order of decreasing efficiency: cryolite ($3\ KF.\ AlF_3$), oxalate ($K_2C_2O_4.\ H_2O$), chloride, sulphate, bromide, iodide. Certain salts, notably magnesium carbonate, magnesium oxide, aluminium fluoride, lead tartrate etc., which were not recognised as possessing any outstanding merits as anti-flash agents in guns, were unexpectedly efficient in these experiments. In considering the relation between the "Gallery" experiments and conditions in the gun it was concluded that the laboratory results were determined by the cooling effect of the agent on the flash from the gunpowder apart from the specific effects upon the limits of inflammability and the ignition temperature of the gaseous mixture. In the gun, these conditions were expected to apply mainly when using large proportions of anti-flash agents with the propellant.

It was found that when the gas mixture in the gallery was saturated at room temperature with carbon tetrachloride vapour (concentration 13 per cent) it was rendered non-explosive i.e. no stemming agent was required to prevent ignition. It was concluded, therefore, that the common fire-extinguishing agents would be effective in preventing gun-flash when applied "externally" if a practicable method of application were available.

Other experiments were carried out to determine the most inflammable mixture formed in the range of muzzle gas-air mixtures. It appeared probable that the most inflammable muzzle gas-air mixture formed from guns contained about 40 per cent of cordite gases or 20-25 per cent of inflammable gases (i.e. $CO + H_2$).

(c) The "Primer" Method of testing anti-flash materials

This method was developed with the object of testing the more effective flash reducing agents under conditions closely resembling those in a gun. Steel cylindrical primers, loaded with 5-10 gms. of a "hot" cordite composition containing incorporated anti-flash material in amounts up to 10 per cent, were fired down a steel tube 30 ins. long into a cylindrical steel boiler. The flashes produced were recorded photographically on a stationary plate or by means of a rotating drum camera.

It was shown that both a primary and secondary flash were produced in the firings, and that the secondary flash had a forward velocity of the order of 500 metres per second and remained photographically luminous for 4-10 milli-seconds. The tests confirmed the superiority of cryolite over other materials in reducing flash. Salts of potassium (e.g. oxalate, tartrate etc.) were the next most effective materials and were definitely superior to sodium salts and to compounds of tin and lead (e.g. the tartrates) which are known for their anti-knock properties.

X. The effect of propellant composition on flashlessness

Investigations in the Research Department Woolwich which commenced in 1921 (vide p. 7) were directed to modify radically propellant compositions so that the gaseous products of decomposition forming the muzzle gases contained a sufficiently low proportion of CO and H_2 so that, after admixture with air, these gases were below the lower limit of concentration necessary for inflammation at the prevailing temperature. In a composition which would be practical for service use and would meet all the exacting requirements of ballistic and chemical stability this condition of minimum inflammability of the muzzle gases together with other advantages was found to be best secured with compositions containing a high proportion of nitroguanidine. From a knowledge of the ultimate composition of a given propellant a calculation could be readily made of the gaseous products with the following assumptions (a) that complete breakdown into simple gases occurred and (b) that a known value could be assigned to the expression $\frac{CO \times H_2O}{CO_2 \times H_2} = K$ and (c) that the amount of CH_4 and NH_3 could be neglected. On these assumptions and taking for K the value of 2.5, which represents the equilibrium constant for a temperature of 1200°C., the calculated composition of the gases for the propellants of main interest and the calorimetric values are as given in Appendix G. (p.100) Apart from the composition of the muzzle gases, other factors determining the liability to flash which are given in Appendix G are the volume of gas per unit weight of propellant, which affects the temperature of the gases for a given ballistic performance, also the so-called Force Constant which is defined by the expression nRT_0, where "n" is the number of gram molecules of gas produced by 1 gram of propellant, "R" the universal gas constant and T_0 the temperature of the uncooled gases when formed at constant volume. The value of T_0 was calculated from the calorimetric value and the volume and specific heats of the gases by the simplified method of J.O. Hirschfelder and J. Sherman.[47a]

The concentration of CO + H_2 from cordite N is seen to amount to 53.8 per cent for a cal. val. of 765 compared with 58.7 per cent for S.C. of cal. val. 970 and 70.2 per cent for cordite AN of cal. val. 825.

Measurements reported in the published literature of the inflammable limits of H_2 + CO and of mixtures of these gases vary considerably according to the method of ignition used, whether the propagation of flame is in an upward or downward direction and the nature and dimensions of the enclosing vessel.

The lower limits of inflammability in air of these gases and of their mixtures in different proportions were given by W.P. Jorissen as follows:-[48]

CO	15.9;	12.0;	7.75;	4.3;	0 .
H_2	0 ;	2.7;	5.50;	7.6;	10 .

These results may be compared with the values given below by H.F. Coward, C.W. Carpenter and W. Payman:-[49]

CO	12.5;	6.1;	3.0;	1.2;	0 .
H_2	0 ;	2.0;	3.0;	3.5;	4.1.

According to a relation formulated by Le Chatelier, the inflammable limits of mixtures are of additive character.

Measurements made at the R.D. Woolwich with a rotating drum camera and with high speed cine-photographs with guns of calibres ranging from B.L. 6-inch to B.L. 16-inch showed that with a full flashing propellant (e.g. M.D.) the secondary flash commenced within 1 to 4 milli-seconds of the primary discharge. This period was presumably determined by the time required for sufficient access of air in the gas cloud to bring this below the upper limit. With firings in a B.L. 16-inch gun, however, it was seen that, when a flash (of reduced magnitude) occurred with cordite N/2P, this flash only began to develop after an interval of about 0.08 sec. (cf. p.69 & Fig.6) (cf. p.26)

From the estimate given above by Coward, Carpenter and Payman of the lower limit of inflammability of $CO + H_2$ in equal proportions - as approximately occurs with the gases from cordite N (i.e. 29% CO, 25% H_2) - it is seen that a dilution of 9 times will be required to bring the gases below the lower inflammable limit of 6%.

Measurements from cine-photographs of the volume of the smoke cloud from firings with cordite N/2P in the B.L. 16-inch gun after different intervals gave the following results:-

Time from firing (sec.)	Vol. of gas cloud ÷ Vol. of muzzle gases at N.T.P.
0.013	2.55
0.02	4.05
0.04	9.3
0.06	12.1

The delayed partial flashes which occurred during this firing may accordingly be attributed to zones of gas mixture where, through non-uniformity in the mixing with air, the concentration of the inflammable gases has not fallen below the lower limit.

In a Report by Messrs. I.C.I. Explosives Ltd.(49a) it was calculated, from data given by Lewis and von Elbe, that the effect of replacement of CO by N_2, in amounts corresponding to the differences in the muzzle gas compositions of cordites A.S.N. and N, was to raise the lower limit of inflammability of CO in air from approximately 16 per cent to 27 per cent, but that the upper limit of inflammability was unaffected by this replacement.

It was accordingly inferred that, if this upper limit is the operative factor in accordance with the view that ignition is initiated by the entrainment of air by a vortex motion along the axis of the gas cloud, the replacement of a proportion of the CO in the muzzle gases by nitrogen cannot be important and that the improved flashlessness of cordite N compared with other propellants of equivalent calorimetric value is due to some specific anti-catalytic effect of nitroguanidine. Evidence that the amount of inflammable gases is not the operative factor in producing flash was also given in firing trials of non-picrite compositions containing a high proportion of barium nitrate which gave full flashes, compared with glows only which resulted with NQ or with cordite A of higher calorimetric value and higher inflammable gas content in the muzzle gases.

In considering the temperature conditions of the muzzle gases, a calculation made in the A.R.D. from the calorimetric value of the propellant and the specific heat of the gases gave with cordite N a temperature of 2485°K. (2212°C.) for the chamber gases falling to a value of about 1950°K. at the time of shot ejection in the case of a typical medium size gun (e.g. Q.F. 4-inch Mk. XVI) while the pressure of the muzzle gases was estimated at about 700 atms.

After expansion to atmospheric pressure it was calculated, by taking a value for γ of 1.36, that the temperature would have fallen to 345°K (75°C). As the ignition temperature of the muzzle gas-air mixture at atmospheric pressure is not below 500°C. it followed that the general initiation of ignition could not result from the average temperature of the muzzle gases but must develop from local causes.

In investigations on the physical mechanism of muzzle flash from guns it was concluded by J.W. Mitchell and C.K. Thornhill[67b] and by G.M. Cooke and C.J. Laidler[67c] from the results of observations made when employing special photographic techniques that the ignition of muzzle gases after admixture with air was initiated by the high local temperatures produced by shock waves.

It was shown that as a result of the wave formations set up there were two zones of high pressure, one close to the muzzle corresponding to the Mach reflected wave and the other some distance from it and that these were separated by a low pressure region. Luminosity was associated with these regions but arose from oxidative reactions only in the second one. In accordance with this conclusion the secondary or main flash did not occur spontaneously at some distance from the muzzle but was initiated by a "leader" which started at the second compression zone and travelled forward as a narrow luminous zone. It was further concluded that this "leader" was removed and the main ignition thereby inhibited by potassium salts while organic vapours suppressed the main secondary ignition.

Ignition through the presence of incandescent solid particles may be concluded to be a further factor.

In accordance with the influence of the temperature of the muzzle gases on the liability to flash and the effect of the work expended on the projectile in lowering this temperature, it was concluded in a report by Messrs. I.C.I. of 16th February, 1945 that the relative ease of obtaining flashlessness in different guns might be evaluated by the relation maximum pressure/efficiency (in cals. grm.). The higher this ratio for a given propellant, the more difficult it should be to achieve flashlessness. With medium-size guns the easiest to make flashless according to this assessment was the Q.F. 4-inch Mk. XIX and the most difficult the Q.F. 4-inch Mk. XVI. O.B. Proc. 30641 Q.2928

In a report by C.S.A.R. of 18th December, 1944 the efficiency (E) or energy per unit weight of propellant which is converted into kinetic energy was given by the expression $\dfrac{(W + \frac{C}{3})\ V^2}{2\ C}$ Q.2894

where W is the mass of the projectile in lbs., C that of the charge in lbs. and V the muzzle velocity in f.s. If the efficiency is expressed in cals./grm. the formula becomes $E = 11.1 \left(\frac{W}{C} + \frac{1}{3}\right) \left(\frac{V}{1000}\right)^2$ cals./grm. Q.3861

From American firings with FNH propellant, it was calculated that the relation between max. press. and the critical minimum value of E to ensure flashlessness was given by the expression $\frac{\text{p. max.}}{E - 180} = 0.127$ where p. max. is in tons per sq. in. and E is in cals./grm.

For other propellants the figure 0.127 will vary with the inflammability of the gases (CO and H_2 content) while the figure 180 will vary with the cal. val. of the propellant.

The main conclusions reached from the results of firing trials were:-

(1) The higher the maximum pressure in the gun the greater the probability of a flash.

(2) Greater calibre length assisted flashlessness.

(3) Initiation of flash in an explosive mixture was often associated with local rises of temperature due to shock waves. Controlled expansion of the gases issuing from the muzzle decreased the probability of flash.

(4) The lower the temperature of the muzzle gases the less the probability of a flash. The estimated heat loss to the walls decreased from about 80 cal./grm. for a Q.F. 3-inch gun to 50 cal./grm. for a B.L. 14-inch gun when firing N or FNH.

XI. The effect of physical factors on incidence of flashes

Analysis in the A.R.D. on the effect of physical factors, e.g. state of wear of gun and the condition of the external atmosphere, dealt with a statistical survey of the results of firings during the proof of propellants and a number of early firings with experimental propellants which were on the borderline of flashlessness in the Q.F. 18 Pdr. It had been considered, from observations made during trials, that a flashless propellant would more frequently give a flash when it followed the firing of a round of a propellant giving full flashes (e.g. NH, S.C. or W.M.). In a statistical analysis of flashes at proof the evidence of interference effects from previous rounds was, however, inconclusive. Evidence for the occurrence of an effect of this nature was provided by the results of experiments of Farkas, Haber and Harteck(50) who found that hydrogen and oxygen would explode at temperatures lower than normal in silica vessels in which an explosion had previously occurred.

In the Q.F. 4.5-inch gun with N/S cordite an analysis of the results obtained with the firing of 1465 rounds showed that the proportion of flashes decreased progressively with increasing wear of gun, the proportion during rounds 1 to 100 being 7.5 per cent and during rounds 700 to 1465 falling to 0.14 per cent. O.B. Proc. 19890

A similar result of the effect of wear on the size of residual flashes was obtained in a firing in the Q.F. 5.25-inch Mk. I gun with H.V.S.S. charge. With N.F.Q./S 198-054 and 8 oz. G.12 core igniter the residual flashes had a mean value of 70c. secs. in a new gun and only 1.5 c. secs. in a gun of E.F.C. 565. 26725

In a later analysis, the effect of wear was found to be different with fixed than with separate loading ammunition. With fixed ammunition, the tendency to flash was greatest early in the gun's life, but with separate loading rounds flash tended to increase with wear at least up to E.F.C. 100-150 and then to fall off. 33590

In a gun in the early stage of wear a limited number of firings with N.F.Q./S 168-048 with propellant of R.N.C.F. manufacture (containing the normal 7.5 per cent carbamite content) gave 4 large flashes in 100 rounds with fixed ammunition and 1 large flash in 100 rounds with S.L. rounds. A higher proportion of flashes were given with R.N.P.F. propellant containing 7 per cent carbamite.

In reports on the "Incidence of flash with flashless propellant" by A.E. Jones(51) it was seen from an analysis of 13,000 rounds in the Q.F. 3.7-inch Mks. I-III that, of the total number of 104 flashes observed, the proportion of flashes at different stages of wear, as seen in the table below, was least in the middle period of the life of the gun (the life of the gun being taken as about 1600 rounds).

Round	Percentage of flashing rounds
0-400	0.4 per cent
401-800	0.27
801-1200	0.12
1201-	0.8

In the Q.F. 2 Pdr. with H.S.C.T./K, the proportion of full flashes increased from 14 per cent with a gun in the early stages of wear to 33.4 per cent with a well-worn gun while an optimum period for complete flashlessness occurred in the middle period of the gun's life. It was generally observed with all guns that where occasional flashes resulted these tended to occur in groups.

No influence of air temperature could be detected. With the Q.F. 3.7-inch Mk. I and III, Q.F. 4.5-inch and Q.F. 5.25-inch, a larger proportion of flashes were given for the newer guns. In the Q.F. 4-inch Mk. XVI, flash was promoted by the prior firings of S.C. rounds.

An analysis is given in a report on the "Effect of external factors on flashlessness"(52) of the results of firing trials at Woolwich in the Q.F. 18 Pdr. with R.D.N./A propellant and smokeless types of primers (i.e. not containing more than 0.5 grm. G.P.) over the period 1932-1934. This particular combination of gun, propellant and primer was close to the borderline of flashlessness. As far as could be assessed from a total of 750 rounds, it was seen that the proportion of flashes with guns in the early stages of wear averaged 4 per cent, increased to 21 per cent for a half-worn gun and with a very few rounds fired in a $\frac{3}{4}$ worn gun fell to zero. The period of the year (and hence the external temperature) and the temperature of the charge had no consistent effect. With rounds fired in succession, in series varying from 4 to 58 rounds, it was noticed that the average number of flashes during the first rounds (up to round 10) was 13 per cent and increased to 41 per cent for rounds 30 to 58. This effect may be expected from the increasing temperature of the gun.

Observations made during rapid fire in the Field showed that the proportion of flashes with these borderline propellants tended to become constant after firing about 10-30 rounds.

Data on the effect of wear on the incidence of flashes with cordite NQ in the B.L. 5.5-inch Mk. III gun-howitzer are given on p.34.

The effect of atmospheric humidity was found to be in agreement with previous statements that the proportion of flashes decreased with increasing atmospheric humidity: this is seen in the following table derived from an analysis of the results tabulated in the report (quoted above,(52)).

Humidity	$< 50\%$	50-65%	65-90%	$> 90\%$
Proportion of Flashes	28	16.5	15	9

These results were in agreement with the conclusion that water vapour had an inhibiting action on hydrogen-oxygen ignition(43a).

XII. Trials in the U.S.A. and Canada with picrite flashless propellants

To meet the Land Service requirements for cordite N in this country arrangements were made by the British Purchasing Commission of the Ministry of Supply in 1940-1941 for the erection of a plant at Welland, Ontario for the manufacture of nitroguanidine and for a supply of 1625 tons monthly to be made to this country from May 1941 onwards.(53) The output of this plant at the end of 1942 amounted to 1700 tons of this compound per month increasing to 2400 tons in March 1943.

The manufacture of cordite N was also investigated in Canada and later in the U.S.A. The propellant made in the first place in Canada was N/S, N/M, and N/P/M for the Q.F. 3-7-inch A.A. gun. The British method of manufacture was employed except for the solvent which consisted of acetone-alcohol in place of acetone-water in order to employ the alcohol displacement procedure for removing the water from the nitrocellulose. Satisfactory results (cf. p.12) were obtained in firing trials and apart from superior flashlessness, improved chemical stability and reduced muzzle smoke which were obtained compared with other types of flashless propellant, the use of nitroguanidine was found to have considerable advantages from supply considerations, the estimated cost of production being reported as 14 cents per lb.(54). The possibility was also (cf. p. 83) investigated at length of the replacement of nitroguanidine by nitrodicyandiamidine which, it was estimated, could be produced for 8 cents per lb. A propellant of this type was known as "Rossite". In agreement with earlier results obtained at Woolwich, these compositions were found to be of unsatisfactory stability at high temperatures and on moist storage.(55) The manufacture of cordite N from picrite supplied by Welland was undertaken in the U.S.A. A report of trials conducted at the U.S. Naval Proving Ground, Dahlgren, Va. with N/P/M, N/3P/M and N/5P/M propellants in the B.L. 6-inch/47 stated that these were markedly superior to corresponding pyro (i.e. nitrocellulose) flashless powders. Under the most severe conditions N/5P/M gave 5 to 10 per cent flashes compared with 40 to 100 per cent for pyro powders containing potassium sulphate and lampblack which had previously given the most flashless results in the B.L. 8-inch.(56)

Good flash suppression, which was markedly superior to that given with the pyro powders, was reported to have resulted from a further trial with this propellant (designated CO-270-EX) in the B.L. 16-inch/45 gun(57). In a further comparative trial in the B.L.6-inch/47 it was reported by the Bureau of Ordnance that a propellant of the N/M type but containing 1.5% K_2SO_4 and 0.3% cryolite showed, under the most severe conditions, a margin of superiority over FNH/5P and that this picrite propellant was the most promising of the flashless powders yet tested. Its defects, however, were considered to be the volatility of N.G. and the low resistance to impact at low temperatures.(58)

In a stability test of cordite N in the U.S.A., it was reported that after heating for 60 days at 65°C. (80 per cent relative humidity) no measurable fall of carbamite occurred.(59)

It was decided by the U.S. Navy that cordite N should be supplied for 25 per cent of all full charges for the 6-inch/47, 8-inch, 12-inch, 14-inch and 16-inch guns, the remaining 75 per cent to be FNH.(60)

In a review of the experience of the U.S. Navy with the use of flashless propellants in June 1945 it was stated(61) that the so-called S.P.C.G. flashless powder, which consisted of cordite N with the cryolite replaced by K_2SO_4 in amounts varying from 1.5 to 5.0 per cent (viz. nitroguanidine 55, N.C. (13.1% N_2) 19, N.G. 18.7, carb. 7.3, K_2SO_4 1.5 to 5.0 per cent), had been adopted by the U.S. Navy not only because of its desirable flashless characteristics, but also because it produced less smoke than other flashless powders. The flash was found to be negligible while the smoke was only 50% greater than with flashing powder. Although the propellant contained as an ingredient nitroglycerine which had previously been objected to in U.S. Naval propellant on account of its sensitiveness, it was reported as a result of every type of test which had been applied that the S.P.C.G. powder had proved as safe as, and in many instances safer than, present U.S. Navy smokeless powders. The comprehensive tests which had been applied included exposure to low and to high temperatures, impact tests and ignitibility. No exudation was at any time observed, and the results of tests made in the U.S. Navy confirmed the greatly reduced vulnerability of this powder to accidental ignition by flash, fire or shell fragments. O.B. Proc. 32289

In ignition trials, under conditions representing magazine storage, it was found that the effect of igniting cordite N charges in Service containers was, in all cases, very much less serious than with pyro powders.

In trials conducted by the U.S. Army, it was reported that marked advantages were shown by cordite N over other propellants in respect of improved flashlessness and chemical stability and reduced smoke on firing. The adoption of this type for Field guns in the U.S.A. was decided on.[60]

A composition designated "T.7" which was based on cordite N with a lowering of carbamite content to give a slightly higher cal. val., which was preferred, consisted of:- Nitroguanidine 54.7, N.C. (13.1% N.) 20, N.G. 19.0, carb. 6.0, cryolite 0.3. With the use of a forward venting type of primer (T.33 or M.40) with 300-400 grains of G.P., the flashless performance was found to be satisfactory in the 40 mm., 76 mm., 90 mm. and 3-inch/50 guns while in an 8-inch gun a proportion of flashes was given which it was hoped would enable an optionally flashless charge to be provided by the use or omission of a flash reducer.[62]

In the provision of a propellant for the Q.F. 3.7-inch A.A. gun, it was reported from Valcartier that "trials confirm past experience that there is little possibility of producing a cartridge of nitrocellulose powder for the Q.F. 3.7-inch A.A. gun to equal the service N/S 164-048 charge".

An arrangement was made in 1944 for the provision to the U.S. Navy of 500 to 1000 tons of N/P/M to be made in Canada for the B.L. 8-inch, 14-inch and 16-inch guns.[63]

In low temperature trials (at -40°F.) with propellants in the Q.F. 3.7-inch guns in Canada, it was reported that N/S 164-048, with a No. 11 primer and 2 oz. G.P. core, and NH/P .044 (containing 1.5 - 2.0 per cent K_2SO_4), with a 19-inch forward venting primer, were satisfactory while FNH/P .049, with a No. 11 primer and 1 oz. supplementary igniter, gave erratic ballistics and high pressures and its withdrawal from service was recommended.[64]

With a view to the improvement of the mechanical strength of cordite N and to avoid the use of N.G., extended trials were initiated in Canada and conducted with compositions in which the nitroglycerine was replaced by solid nitro compounds which were found also to possess improved gelatinising power for nitrocellulose.[65] The most suitable derivatives of this type were considered to be dinitroxyethyl nitramine ("D.I.N.A.") and tetramethylol cyclopentanone tetra nitrate ("Fivonite"). The composition most investigated was known as Albanite and consisted of nitroguanidine 55, D.I.N.A. 19.5, N.C. (12.6% N.) 20.0, O.B. Proc. 28035 30090

D.B.P. 4.0, carb. 1.5, K_2SO_4 1.5-5.0 per cent.[66] In other compositions, the D.I.N.A. was partly or wholly replaced by "Fivonite".

Large amounts of this Albanite propellant containing from 1 per cent to 5 per cent K_2SO_4 were reported in December 1945 to have been made for the U.S. Navy by E.I. du Pont de Nemours & Co. at the Burnside Laboratory[66a] and fired with satisfactory ballistic and flashless results in guns ranging from the Q.F. 40 mm. to the B.L. 16-inch/50 gun.

The cost of production of D.I.N.A. was estimated at $1.00 per lb. and that of nitroguanidine at 20 cents per lb. (cf. p.81)

Comparative trials of Albanite propellant with cordite N showed that the flashless performance of each was similar, but that the former was unsatisfactory on account of an increase in the rate of burning which occurred at low temperatures and which also resulted from submitting the propellant to cyclic temperature changes. These results were attributed to physical changes which occurred in the colloidal matrix and were in agreement with investigations made with this composition at Woolwich which concluded that the abnormalities were associated with the "flouring" or crystallisation on the surface of the D.I.N.A. after storage.[66b] O.B. Proc. 33956

The propellants with this ingredient were also found to be unstable chemically when exposed to moisture at high temperatures. (60), (62), (67).

It was concluded from trials by the U.S. Navy[66c] that Albanite in its present state of development was not suitable for large-scale production for the following reasons:-

1. Unsatisfactory ballistics - either poor regularity or high pressure or both.

2. As manufactured it was not reproducible and the ballistics were unpredictable.

3. Normal correlation between bomb test results and gun ballistics was non-existent.

4. Manufacture in pilot plants involved unacceptable hazards.

In a "Report on Muzzle Flash" by R. Ladenburg[67a] a compilation was made in April, 1944 of data and results as obtained from recent reports of the Ballistic Research Laboratory at Aberdeen Proving Ground, Frankford Arsenal, Picatinny Arsenal, du Pont Company, and the I.B. Flash Panel of the British Scientific Advisory Council.

The conclusions reached on the mechanism of the development of muzzle flash, the methods for its elimination and the degree of success obtained in new types of propellants which have been developed were in agreement with the results obtained in trials in this country.

In firing trials in the 20 mm. gun with different lengths of barrel, confirmation was obtained of the conclusions reached in the Armament Research Department that, due to the higher temperature of the muzzle gases, the flash increased with increase in the ratio of the volume of the chamber of the gun to the volume of the bore. With a number of different calibre weapons fired with the same kind of powder, results were plotted of the muzzle energy per pound of powder (in units of foot tons per lb.) as ordinates against the values of the maximum pressure in the barrel as abscissae. Flashing and flashless rounds were approximately separated by a straight line which showed that at constant maximum pressure and constant composition of the propellant the flash disappeared with increasing muzzle energy per pound of charge in accordance with the inference that the higher the muzzle energy per charge the less energy was left in the ejected gases and the lower was their temperature (cf. p. 77).

It was further found that when firing a gun rapidly flashes might appear after a large number of rounds when the gun became heated while flashes did not occur with the gun at normal temperatures.

It was concluded in the report that the effect of conical flash eliminators was to prevent or reduce the turbulence of the muzzle gases, rendering them more streamlined. The mixing of the muzzle gases with air was thereby delayed and their temperature fell considerably before the percentage of oxygen in the mixture was effective for ignition.

On the other hand, the promotion of flash, which was found to result from the use of muzzle brakes, was considered to be due, probably, to their effect in causing the muzzle gases to mix more rapidly with air by dispersal sideways and backwards and thus to retain a higher temperature when the inflammable composition of the mixture was reached.

Conclusions

From the data which are reviewed, it is seen that for all sizes of guns, including the B.L. 16-inch Mk.II, propellant charges had been developed with which the main muzzle flash was normally eliminated, though with some guns of a particular state of wear a proportion of sporadic flashes was still given. With a few guns of existing design, on account of the limitation of chamber capacity, the bulking of the flashless propellant prevented the loading of a charge sufficient to give the service ballistics and, in still more instances, though the chamber admitted readily of loading, the propellant charges could not be housed in containers of dimensions which would be accommodated by the hoists leading from the magazines to the guns, or in the rammers which load the charges in the gun.

The indications seen from the data so far surveyed, are that this flashlessness had been achieved without any diminution of ballistic regularity compared with S.C. cordite and, in the case of larger ordnance, without the production of smoke of appreciably greater obscuring effect than that of a flashing cordite.

In order to overcome the loading difficulty with certain guns (e.g. 6-inch Mk. XXIII) compositions of higher calorimetric value had been successfully applied in which the muzzle flash was not eliminated, but was reduced to an extent to avoid dazzling the observers in the vicinity of the gun.

Further important advantages which had been secured by these propellants were the greatly reduced erosive action on the guns, thereby extending their life, the smaller change of ballistics for a given state of wear of the gun compared with earlier propellants, the generally lower temperature correction and increased safety against accidental ignition in magazine through fire or heated shell fragments.

In the U.S. Navy, where this propellant had also been adopted, the results in all American guns, including the B.L. 16-inch/45 were reported to be at least as favourable as in British guns.

Investigations by special photographic methods had demonstrated that the initiation of flash due to secondary ignition of the inflammable muzzle gases after admixture with air resulted from local zones of high temperature due to shock waves which occurred in the emerging gases. The most effective remedy which had been applied for suppressing muzzle flash consisted in the devising of propellants which yielded a high proportion of nitrogen in the products of decomposition, thereby lowering the content of inflammable gases and at the same time lowering the calorimetric value of the propellants and in consequence reducing the temperature of the muzzle gases.

Use had also been made of the addition of potassium salts which acted as inhibitors in the ignition of the gases.

Acknowledgments

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APPENDIX A.

Data on "solventless" and "semi-solvent" extrusion of picrite cordites

In manufacturing and ballistic trials conducted in the R.D. and R.G.P.F. Waltham Abbey during 1927 with "solventless" and "semi-solvent" extrusion of picrite cordites, it was found advantageous, in order to facilitate the extrusion, to employ a higher ratio of N.G. to N.C. than was used with solvent cordites and to include in the composition a small proportion (up to 0.5 per cent) of candelilla wax. (cf. p.40)

The compositions most extensively investigated were F.500/43 containing 50 per cent, and F.500/57 with 60 per cent nitroguanidine. The ingredients were incorporated either with 10 per cent acetone or 8 per cent alcohol (grade II) and the gelatinised paste was then rolled about 25 times at 60°C - 85°C. The resulting sheet was then stoved at about 45°C. for 2 days, cut into discs which were then normally heated to from 75°C. to 85°C. and extruded at temperatures within this range. The effect on extrusion pressure of the amount of residual solvent is shown in Figs. 1 and 2, the influence of the wax content in Fig. 3 and the effect of temperature on extrusion pressure in Fig. 4. (cf. Appendix G)

In the process subsequently developed by S.R.N.P.F. Caerwent, use was made of the normal N.F.Q. composition and experimental trials were later extended to the picrite-oxamide composition F.560/50. O.B. Proc. 30653

The procedure employed at Caerwent consisted of the following stages:- S.R.N.P.F. Report of 7.9.'45

(a) Incorporate as for solvent picrite cordite with the addition of 0.075 per cent candelilla wax.

(b) Cold roll to reduce the dough to a sheet form.

(c) Dry to a solvent content of about 4 to 5 per cent.

(d) Roll from 8 to 15 times with a rolls temperature of about 30°C., when the solvent content is reduced to about 2 per cent.

(e) Extrude at a temperature of from 60°C. to 80°C.

(f) For S.N.F.Q./P (later designated M.N.F.Q./P) .275 a stoving period of 6 days is then required to reduce the V.M. to 0.2 per cent.

The extrusion pressures necessary for S.N.F.Q./P under the above conditions were considerably higher than those required for S.C. and could be lowered by allowing the sheet cordite to mature for a period prior to pressing or by raising the wax content, residual solvent content, or the temperature of pressing.

Satisfactory firing trials have been conducted with S.N.F.Q./P in the Q.F. 5.25-inch, B.L. 6-inch Mk. XXIII, and B.L. 16-inch guns. (cf. pps. 24, 25 and 26)

APPENDIX B

Size reduction of picrite by crystallization in presence of protective agents

It was found that the production of material in a fine state of division could be effected by the crystallization of nitroguanidine from aqueous solutions containing colloidal protective agents such as gelatin and Tylose (methylcellulose). An addition agent which was found to be particularly effective with picrite and at the same time to have no deleterious effect on its chemical stability was ammelide. The very fine material resulting from the use of this method however, showed a tendency to aggregate into lumps which were not dispersed during the incorporation process in the subsequent manufacture of propellant.

As the result of further trials with a large number of other agents it was found in 1942 that methylamine, when present to the extent of from 0.2 to 1.0 per cent of the water, was at that time the most efficient known substance in reducing crystal size.(68)

Work by the American Cyanamide Company at Welland which proceeded at the same time on this subject resulted in the observation that ethylene diamine was effective for the production of finely-divided material.

In comparative tests in the R.D. under conditions of crystallization which in the absence of the addition gave a predominating crystal size of about 0.005 mm. diam., the crystal size was reduced to 0.0005 to 0.001 mm. by 1.0 per cent of methylamine and to 0.0015 mm. by 1.0 per cent of ethylene diamine. The procedure employed in these comparative measurements was to pour a 6 per cent nitroguanidine solution at 100°C. on finely-divided ice. An investigation of the processes involved showed that interaction occurred between nitroguanidine and methylamine to give methyl nitroguanidine and ammonia, while a similar reaction which occurred with ethylene diamine resulted in the formation of ethylene nitroguanidine.

At lower concentrations however, e.g. up to 0.5 per cent, those agents were found to be approximately equally effective, the predominating crystal size being about 0.002 mm. under the same conditions of crystallization as above.

In acid solutions it was found that these reactions did not occur and the agents became ineffective in reducing crystal size. The pH value of the solution should accordingly not be below 5 and preferably 7-8.

Prior to the drying of the precipitated nitroguanidine the addition of 0.1 per cent of Aerosol D.B.A. to the wash water as a wetting-out agent was recommended by the Welland Co. to prevent agglomeration of the crystals. Perminal and Calsolene Oil H.S. have also been found to be effective in this respect.

In the course of further investigations it was found in 1944(69) that formaldehyde was still more effective than agents previously considered for crystal size reduction. The effect was found to be enhanced by the presence of ammonia, thus a solution of nitroguanidine containing 0.5 per cent of formaldehyde and 0.1 per cent of ammonia gave, by the method used in the previous tests, a predominating crystal size of 0.0005 to 0.0001 mm. diam. and 0.01 mm. length (specific surface = 80,000 sq. cm./c.c. approx.). The crystal size decreased progressively with increase in concentration of formaldehyde up to 1 per cent, but thereafter a change in crystal habit was produced.

Microscopic examination of the crystals produced by the different methods which have been investigated showed that ammelide produced a modification in crystal habit by restricting growth along a particular pair of parallel planes giving an extremely thin crystal, while the width was slightly reduced but the length almost unaffected. (cf. F in Fig. 5).

The thin crystals packed down tightly together making filtration difficult. Gelatin and Tylose on the other hand decreased the crystal length at the expense of width, giving short wide needles, the thickness apparently being little affected. Since the smallest dimension is the most important ballistically, it follows that the use of these two agents would be detrimental rather than favourable.

The crystals resulting from the use of amines were in the form of elongated rhombs, growth at all crystal faces apparently being restricted simultaneously without change in the crystal habit and resulting in no undue increase in the difficulty of filtration of the product. Similar results were obtained by the use of aqueous formaldehyde, increasing the concentration of formaldehyde causing progressive reduction up to a certain point, but at concentrations of 0.75 to 1.0 per cent in the presence of ammonia, the picrite formed incipient spherulites i.e. agglomerates of very fine needles all disposed radially.

At a concentration of 1.0 to 1.5 per cent formaldehyde true spherulitic formation occurred, the particles of about 0.01 mm. diam. being transparent and under crossed nicols appearing as white spheres or concentric coloured rings intersected by a black cross.

The product obtained by heating solid picrite with 40% formaldehyde in the presence of a small amount of ammonia as catalyst showed a pronounced change in crystal shape, the typical needle-type of picrite being replaced by barrel-shaped grains whose length was only three times the thickness. Measurements of refractive index and extinction angle showed that the product was not picrite and analytical data indicated it to be an equimolecular condensation product of picrite and formaldehyde produced without the elimination of water, i.e. probably monomethylol nitroguanidine. The reactivity of formaldehyde probably accounts for its effect on crystal size, formaldehyde molecules attaching to newly formed picrite nuclei and preventing further depositions.

A further effect of the use of methylamine or formaldehyde which was observed was that on cooling the saturated picrite solution, a state of supersaturation was maintained for a much longer period than when these additions were absent.

Diagrams of transverse cross-sections of various types of picrite crystals are given in Fig. 5. The Welland samples A to C consisted of rhombs which were undeformed or slightly truncated, while other types, though belonging to the same crystal system, were more extensively truncated. (cf. Appendix E, p. 96).

Photomicrographs of picrite recyrstallised from various aqueous solutions are shown in Figs. 11-14 together with the measured values of the specific surface (So).

APPENDIX C

Measurement of picrite particle size.[70]

An exhaustive test was made, extending over a number of years of possible methods, alternative to direct microscopic observation, which were devised in the A.R.D. and by other investigators, for assessing quantitatively the mean crystal size of the type under consideration.

Good results were obtained by optical methods based on opacity measurements of suspensions by light absorption and the adsorption of dyes from solution, and in solid form.[71]

The procedure which was finally adopted was based on a pneumatic method devised in the U.S.A. by Gooden and Smith.[72]

This method gave a measure of the total surface area of the sample and consisted in measuring the resistance offered to the passage of air by a column of the material when packed under standard conditions or alternatively by measuring the rate of flow of air through the column for a given pressure difference. By means of a relationship which was deduced and found to be applicable, the total specific surface in sq. cms. per c.c. total volume was given from the rate of air flow by a simplified formula based on the viscosity of air.[69]

Summary of Results:- No direct comparison could be made between the microscopic and pneumatic measurements without knowing all three dimensions of the crystals and, of these, the thickness could not be readily measured directly. On account of the very large spread of crystal size, microscopic observation could not be employed in practice to give reproducible results with any accuracy while with the pneumatic method, a very close agreement was obtained by different observers when using the same type of apparatus.

The results are given in Table I of measurements made in 1942 of typical early samples of the large-scale production of picrite. The values given are the predominating dimensions as measured by the microscope, the specific surface by the air-flow test and the thickness of crystal calculated from these measurements.

Table 1

Sample	Predominating dimensions by microscope, in microns. Length mm. x 10^{-3}	Breadth mm. x 10^{-3}	Specific surface, square cms. per c.c.	Thickness calculated from specific surface. mm. x 10^{-3}	Ratio of Breadth to calculated thickness	Remarks
American, box 1	200-250	6	20700	1.16	5.17	First samples from U.S.A. September, 1940
" " 2	80-100	5	20700	1.40	3.57	Made at R.G.P.F. sent to U.S.A.
W.A.95	40-50	4-5	24350	1.04	4.37	
American drum 1	50-60	1.5-2	38700	0.75	2.33	American, re-crystallised from solution containing organic amines, used for N/S at Ardeer, July, 1941
" " 2	30-40	1.5-2	47000	0.57	3.07	
" " 3	60-70	1.5-2	35300	0.85	2.06	
W.A.94	40-60	3-4	21900	1.27	2.76	Made at the Royal Gunpowder Factory
W.A.2584	50-70	3-4	25000	0.05	3.33	
W.A.92	40-60	4-5	14800	2.01	2.24	
R.N.C.F. 27	80-100	-	21800	-	-	Typical sample from R.N.C.F.
Ardeer	20-30	2	26100	1.31	1.53	Spray crystallized Ardeer process
Welland H.C.992	100	3-4	14600	2.36	1.48	Ref. R.D.C. 1383/41
" " "	"	"	14500	2.38	1.47	
Unmilled Welland 1575	40-60	4-5	11500	3.00	1.50	Ref. R.D.C. 4860/40
" " "	"	"	11600	2.96	1.52	
Welland Lot 499	85-95	6-7	13200	2.02	2.72	
" " 552	90-100	6-7	11850	2.34	2.78	
" " 555	85-95	5.5-6.5	12500	2.12	2.83	
" " C.259	80-90	5.5-6.0	11100	2.71	2.12	
" " C.260	85-95	5.5-6.0	12500	2.27	2.53	
" " C.261	85-95	5.0-5.55	14300	1.95	2.69	
Ardeer	40	2-2.5	26900	1.21	1.86	
"			26700	1.25	1.83	
"	55-65	2.5-3.5	21400	1.39	2.16	
" batch 85	50-60	2.5-3.5	20700	1.46	2.06	
" " 79	50-60	2.5-3.5	21200	1.41	2.13	
Canadian blend 227	100-110	5-6	10900	2.83	1.94	
Ardeer Lot 15	50-60	3	19500	1.60	1.87	

"R.D.C." followed by numbers denotes a file in the Armament Research Department.

APPENDIX D

The microscopic examination of flashless cordite.(17)

(cf. Figs. 7 - 9)

Thin cordite sections are cut which are then examined in their original condition and after treatment with potassium mercuric iodide solution which dissolves out picrite crystals leaving the colloid-matrix in which are embedded particles of the picrite-carbamite complex. The latter are then examined for size. Further sections are treated with alcohol which dissolves out the picrite-carbamite complex giving confirmatory information as to its state of division. To determine the degree of gelatinisation, sections are submitted to the double extraction leaving a skeleton of N.C. - N.G. colloid containing particles of chalk and cryolite. Finally, the particle size of the picrite crystals is determined by shaking a sample of the cordite with acetone followed by addition of dibutyl phthalate which dissolves out the colloid leaving the picrite crystals in a ready state for measurement.

Procedure

(a) Preparation of potassium mercuric iodide solution. 270 grms. mercuric iodide and 230 gms. potassium iodide are dissolved in 80 c.c. distilled water. The solution is concentrated by evaporation until crystallisation sets in, when it is cooled and filtered. The solubility of picrite in this solution is about 5.9 gms./100 c.c. at 20°C. The solubility of picrite in water is 0.25 gms./100 c.c. at the same temperature and its solubility in saturated potassium iodide solution (containing less potassium iodide than in the above solution) is 1.8 gms./100 c.c.

(b) Cutting of Sections. It is desirable to cut the sections as thin as possible viz. 7-10 μ and of good uniformity, in order to facilitate their subsequent extraction. It is essential to have the microtome blade very sharp in order to get the thinnest section and to avoid excessive scratch marks on the section. It is not always possible to get such thin sections with some cordite specimens owing to their brittleness; indeed the cutting operation can be an excellent guide to the degree of brittleness of the cordite. Differences between various batches of cordite N (particularly if made with picrites of different crystal size) can often be detached by this means. Occasionally it may be desirable to cut sections 10-20 μ, for example where the cordite contains large crystals which may be torn out by the blade with thinner sections. Sections must be cut longitudinally to the cord as all particles and aggregates tend to align themselves along the direction of extrusion. Two or three sections should be cut from each of several sticks chosen from the sample for greatest difference of appearance.

(c) Mounting medium. All sections whether as cut or treated are mounted in glycerol-water 1/1 by volume.

(d) Examination of section. The section after mounting is examined at a magnification of 60-100 by direct transmitted light. This reveals the presence of agglomerates of picrite and of the picrite-carbamite complex which show up dark against the light background of homogeneous composition, but these two types cannot be distinguished visually as they are very similar in appearance both under direct light and crossed nicols, both being only feebly optically active. Large picrite crystals which are lighter than the general section show up clearly, but the smaller particles are too confused for any accurate estimate of general picrite size to be formed. Large individual crystals of the picrite-carbamite complex are also easily discernible and are distinguishable from picrite by reason of their more "stubby" shape and their more clearly defined outline.

N.C. nuts normally remaining undispersed through insufficient incorporation appear as dark patches in the section, not unlike those cited above, but are distinguishable because they remain after the double extraction process described later. It is unlikely, however, that these will be met with in the present process for cordite N as operated in the factories.

(e) Extraction with potassium mercuric iodide solution. The section is transferred by means of a needle to a microscopic slide and after wetting with glycerol/water is examined under the microscope. Any alteration produced by adding drops of potassium mercuric iodide solution from a capillary to the section is then observed, particularly any solution of agglomerates or large crystals. The solution dissolves aggregates and large crystals of picrite quite readily and the progress of their solution can be followed under the microscope. Several sections are examined in this manner and their extraction completed by immersing them entirely in the solution on a microscope slide for about 5 minutes, the sections being inverted two or three times (by careful handling with a pair of needles) to promote solution of picrite. For thicker sections a rather longer time, say 10 minutes, may be necessary for total solution, but with a little experience it is easy to decide when extraction is complete, since the section initially shows entire and continuous birefringence, but finally only individual crystals of the complex against a black background (the colloid matrix) are visible. The sections are then washed in glycerol-water and finally mounted in this medium.

The crystals or agglomerates remaining after complete extraction are the picrite-carbamite complex, apart from occasional chalk or cryolite particles. The crystals are highly birefringent. Their size is determinable by observation at a magnification of about 500. In normal cordite N they should not exceed about 2-4 μ x 5-10 μ in size.

(f) Extraction of section with alcohol. Alcohol of first grade is saturated with picrite; it is convenient to leave a deposit of the crystals at the bottom of the containing vessel. Sections, first wetted with glycerol-water, are then treated with drops of the solution and the effect observed, with particular reference to any holes produced by solution of the picrite-carbamite complex. Normal cordite N undergoes no marked change by this treatment, apart from some general lightening of the section, but a cordite containing the complex in a too-coarse condition will leave a perforated skeleton. As above, complete extraction is carried out by immersing the sections for about 5 minutes in the alcohol solution contained on a slide and inverting them a few times. Finally the sections are washed in glycerol-water also on a microscope slide and mounted in that medium for examination.

(g) Double extraction with potassium mercuric iodide and alcohol. The operation described under (e) is first carried out, but after washing the sections with glycerol-water they are immersed in alcohol and subjected to the process described in (f) above. The resulting sections should be completely transparent, if the procedure has been conducted correctly, and the degree of gelatinisation can then be readily assessed by observation under crossed nicols. A few particles of cryolite and chalk remain: the former, being only feebly birefringent in the section, is not easily detectable under crossed nicols, whilst by direct light the innumerable fissures in the colloid skeleton, remaining after solution of picrite and its complex, completely obscure its presence. On the other hand, chalk particles show up dark against the matrix by direct light, whilst they display a strong yellow birefringence under crossed nicols. The addition of a dilute solution of hydrochloric acid to the section, producing ready solution of the chalk particles, is a confirmatory test.

(h) Estimation of size of picrite crystals. A sample of cordite of about 1/2-1 gm., obtained by cutting short lengths from several sticks, is placed in a "water-extract" glass-stoppered test-tube together with 10 c.c. acetone previously saturated with picrite. The tube and contents are mechanically shaken for 2-3 hours (occasional shaking over a longer period will suffice instead) and the suspension is then stirred with a with a camel-hair brush to render it homogeneous; any remaining clots of dough are readily dispersed by this process. 20 c.c. dibutyl phthalate are next added to the suspension which is again rendered homogeneous by stirring with the camel-hair brush. For the preparation of the microscope slide, it is found, in general, that one drop of this suspension stirred with five drops of D.B.P. gives a satisfactory picrite concentration.

APPENDIX E

Optical properties and crystal habits of nitroguanidine(72a)

General Nitroguanidine crystallises from water in the form of long silky needles with rhombic cross-section in the simplest type of crystals. In general, modifications to this simple form are more commonly observed by the development of crystal faces at one or both acute apices of the prism giving rise to a five or six sided cross-section. The obtuse angle of the rhomb which persists in all these modifications is 110°.

Nitroguanidine belongs to the orthorhombic crystal system, the principal axes of refraction being identical with the axes of symmetry of the simple crystal type. The refractive indices, determined by the Becke method using sodium light, have been found to be:-

α	index	1.525	Optically negative
β	"	1.715	
γ	"	1.80 (approx.)	

The α- axis is parallel to the length of the crystal, the β - and γ- axes respectively bisect the obtuse and acute angles of the rhomb section (cf. Fig. 5). These values are in good agreement with those determined in the U.S.A. at Cornell University(73).

From X-ray rotation photographs(74) the unit cell has the dimensions:-

α direction	= 3.585	Å (10^{-7} mm.)
β "	= 17.46	
γ "	= 24.77	

Since in general the direction of the greatest refractive index corresponds to the greatest dimension of the molecule it would appear that in the molecular structure of nitroguanidine the molecules are built up lengthwise across the needle, as suggested also by the X-ray observations. This laying of molecules side by side across the needle is consistent with the ease with which very long needles can be produced and with the formation of spherulites (under suitable conditions) which is usually associated with this type of growth.

Nitroguanidine has an easy plane of cleavage parallel to the length of the crystal and bisecting the obtuse angle of the rhombic section (basal pinacoidal cleavage). This property is related to the manner in which nitroguanidine often tends to grow viz. starting at one end as an individual needle and then splitting in the course of its length into three, four or more tufts. This is further evidence that the attractive forces between the head to tail configuration of the molecules are smaller than the lateral forces. The needles are extremely flexible and not easily broken.

Nitroguanidine readily undergoes change of crystal habit by the introduction of traces of certain contaminants into the crystallising solution. Usually once a change of habit has been produced in this manner subsequent recrystallisations do not remove it, presumably because the impurities are occluded in the crystal structure. Drastic chemical treatment such as dissolution in concentrated sulphuric acid followed by re-precipitation with water will, however, produce reversion to the simple rhombic type. It is considered therefore that this latter crystal form is the one assumed by pure nitroguanidine.

Polymorphs. No polymorphs of nitroguanidine have been identified and it seems extremely doubtful if any exist. Two distinct crystal forms differing in refractive index were claimed by Davis, Ashdown and Couch(75). This work was subsequently repeated in the A.R.D. with negative results, although different modifications in crystal habit were obtained by the methods described: complete identity of crystal structure both by optical measurements and by X-ray methods(74) was always observed. American researches(73) have also failed to substantiate the results of these workers. It is apparent that the observed differences relate to crystal habit and not polymorphism.

Service picrites

The crystal size of Service grades of picrite was too small for normal optical methods of examination. Samples were recrystallised from water to produce needles of thickness from 0.2-2 mm. and a large number of individual crystals were examined by mounting them in a rotation apparatus and using immersion liquids of various refractive indices. Cross-sections of crystals were also examined by embedding the needles in wax and sectioning them transversely with a microtome. By these means the crystallographic shape of the various picrites was determined. It was found that a given sample of picrite preserved the same crystallographic form independently of the number of recrystallisations from water (six or more) or the size of the crystals obtained (by various conditions) within the above measurable limits. This was also true when changing to another solvent e.g. acetone/water 80/20 parts by volume, which gave particularly large and well-formed crystals with Welland picrite. The assumption made in this investigation, that the larger recrystallised product had the same crystal shape as the original Service grade of picrite from which it was derived, appeared therefore to be justifiable.

It was found that Service picrites could be broadly divided into two groups on the basis of their transverse section:-

(1) Rhombic section or slight departure therefrom caused by development of one or two small prismatic faces. (A-C in Fig. 5)

(2) Flattened hexagonal section (D-F in Fig. 5)

Welland picrite was the sole member of class (1) the ratio crystal width/thickness varying from 0.7-1 approximately.

In the second group the width/thickness ratios were found to be:-

Ardeer picrite $1\frac{1}{2}$ - 2; R.N.C.F. picrite 2 - $2\frac{1}{2}$; Waltham Abbey 3 approximately.

These values refer to the various different batches studied, a number from each source being examined. Since the crystal forms are determined by the occluded impurities in the sample (e.g. hydrolytic products of picrite) these ratios will not be invariable, particularly if changes in manufacturing procedure are introduced.

Recrystallisation of Welland picrite from a hot aqueous solution of less than 0.05% ammelide produced the most exaggerated effect yet observed - an extremely thin ribbon-like crystal with a width/thickness ratio of 8 or 10, this value being maintained in subsequent recyrstallisations from water. In contrast to this behaviour, neither formaldehyde nor ethylene diamine (used for the production of very fine picrite) caused change of crystal habit in Welland picrite.

Little work to date has been carried out on the influence of crystal habit of picrite on ballistics. Two effects would appear to be possible:

(1) Rate of burning may differ along the three crystal axes: the cordite burning rate would then be determined by crystal habit as well as size.

(2) For a given crystal size, assessed microscopically, the second group of picrite would give faster burning cordites, since their average burning thickness would be smaller (assuming effect (1) negligible).

Recent gun trials, however, have given no observable difference in ballistics for cordites made from picrite of the same specific surface but from different sources, so that these effects would appear to be small or mutually opposed.

APPENDIX F

Influence of nitrocellulose - nitroglycerine ratios on the physical properties of picrite propellants

In the earliest firing trial with picrite propellants a composition employed contained 70 per cent nitroguanidine and 30 per cent guncotton (cf. p. 8). Apart from excessive brittleness of the cords, microscopic examination and measurements of density revealed the presence of fissures or cavities in the cords while Closed Vessel tests showed that these faults resulted in irregular and high rates of burning. The conclusions finally reached from trials with many different compositions were that this porosity and the unsatisfactory physical properties were best overcome by the following factors:-

(1) A slight lowering of the content of nitroguanidine.

(2) A reduction of the crystal size or its degree of subdivision.

(3) The use of a suitable proportion of nitroglycerine or similar liquid.

(4) The ratio of nitroglycerine to nitrocellulose to be kept within certain defined limits.

The main tests which were applied to assess the physical properties of the propellants consisted in measurements of (a) tensile strength by means of a Goodbrand machine; (b) brittleness as indicated by the diameter of the smallest circle around which the cord could be bent without breaking; (c) porosity as indicated by the determination of density and, in a further method which was employed for a time, by measuring the rate of penetration in the cordite of a dye from an aqueous solution. Methylene blue was found to be the most suitable dye for this purpose. The procedure consisted in inserting the cord in an aqueous solution of the dye and, after a definite interval, the depth of penetration of the dye in the cross section of a fractured surface was measured by a microscope. While partly a test of porosity, the differences in rates of penetration of different dyes and the fact that the rates increased progressively with increasing content of nitroglycerine showed that the solubility of the dye in the nitroglycerine was the main factor determining the penetration and this method was later abandoned.

With the use of finely-divided picrite of predominating crystal size of 0.001 to 0.003 mm. diam., a series of compositions were prepared in which the picrite content was maintained at 55 per cent. The compositions included nitrocellulose of 12.2 per cent N_2 and guncotton of 13.1 per cent N_2 content. The nitrocellulose-nitroglycerine ratios were varied and the carbamite content was adjusted with the different compositions so as to keep the calorimetric values within the range 745 to 755 except that with compositions given below as F.521/14 and F.521/19, to avoid reducing the carbamite content below 5 per cent, composition of calorimetric values of 725 and 718 (W.L.) respectively were selected.

In the table on the next page, for compositions of progressively increasing nitrocellulose content the results are given of the density, tensile strength and breaking radius for cords 0.07 ins. diam. and the rate of dye penetration, for cords 0.15 ins. diam., expressed in hundredths of an inch in 3 hours.

It is to be noted that the density and other physical properties vary with the content of residual solvent. Though this was normally reduced to below 0.5 per cent the prolonged time of stoving required for compositions of higher nitrocellulose content made it impracticable for the purpose of these tests to reduce the V.M. to this or to a constant value.

The results are also expressed as graphs in Figs. 15 and 16. The graph of theoretical densities which is shown in Fig. 15 is calculated by taking the following values for the ingredients when present in the finished cordite:-

N.C. (12.2% N_2) 1.70, N.C. (13.1% N_2) 1.72, N.G. 1.60, carbamite 1.11.

Factory No.	N.C. 12.2% N_2	G.C. 13.1% N_2	N.G.	Carb.	Density	Tensile Strength lb./sq. in ÷ 10^3	Breaking Radius Inch	Rate of dye penetration in 3 hrs. ÷ 0.01 in.
521/3	10	-	26	9	1.620	0.98	0.43	0.39
521/6	-	10	25.5	9.5	1.622	1.1	0.67	0.55
521/10	12	-	24.5	8.5	1.630	1.5	0.38	21
521/15	-	12	24	9	1.630	1.7	0.41	23
521/11	14	-	23	8	1.636	2.1	0.28	15
521/16	-	14	22.5	8.5	1.637		0.34	13
521/22	16.5	-	21	7.5	1.637	3.2	0.14	5
521/7	-	16	21	8	1.640	2.1	0.30	6
521/12	19	-	19	7	1.646	3.2	0.28	3
521/17	-	19	18.5	7.5	1.646	3.2	0.30	2
521/9	-	20	17.5	7.5	1.642	3.4	0.30	< 1
521/13	21	-	17.5	6.5	1.654	3.4	0.34	1
521/18	-	21	17	7	1.648	4.1		< 1
521/20	23	-	16	6	1.656	4.5		< 1
521/21	-	23	15.5	6.5	1.651	3.8		
521/5	25	-	14	6	1.654	5.0		< 1
521/8	-	25	13.5	6.5	1.644	4.6	0.45	
521/14	30	-	10	5	1.652	6.2		< 1
521/19	-	30	9	6	1.645			

These results indicate, in general, that with compositions containing more than about 14% N.C., the N.C. of 12.2% N_2 gave a somewhat stronger and at the same time more flexible cord than G.C. of 13.1% N_2 content and that a product of optimum density, when compared with the theoretical value, occurred with a content of about 20% N.C. These results were, however, found to be much affected by variations in the method of manufacture.

APPENDIX G (1)

COMPOSITIONS, CALORIMETRIC VALUES AND GASEOUS PRODUCTS OF CANNON PROPELLANTS

Type	Nitrocellulose		Percentage Composition					(76) CAL. VAL.		Total Gas c.c. per grm. (W.C.)	Composition of Muzzle Gases					Temperature of Chamber Gases °K.	Force Constant
	Origin	N_2	Nitro-cellulose	Nitro-guanidine	Nitro-glycerine	Carbamite	Other ingredients	W.L.	W.G.		CO	H_2	N_2	H_2O	CO_2		
I. COMPOSITIONS IN SERVICE USE																	
(a) Solvent Cordites																	
Mark I	Cotton	13.1	37		58		M.J.5	1225	1125	888	28.3	13.6	14.1	24.1	19.9	3770	2225
M.D. or M.C.	Cotton	13.1	65		30		M.J.5	1025	952	940	35.8	18.0	12.1	19.0	15.1	3250	2030
C.D.	Cotton or Wood	13.1	65		30	0.5	M.J.4.5	1035		935	35.7	17.7	12.1	19.1	15.4		
R.D.B.	Cotton	12.2	52		42		M.J.6	1000	911	960	36.1	19.8	11.7	18.7	13.7		
W	Cotton	13.1	65		29	6)		1025		910	36.5	16.2	12.8	18.1	16.4	3350	
	Wood	12.8	65		30	5)											
W.M.	Cotton	13.1	65		29.5	2	M.J.3.5	1005/ 1020	930	934	36.4	17.7	12.1	18.5	15.2	3250	2030
N.C.T.	Cotton	12.6	99.5				D.P.A.0.5		777	893	36.7	15.2	11.6	18.5	18.0		
NH (Dupont)	Cotton	13.1	86				(D.N.T.10) (D.B.P. 3) (D.P.A. 1)	740- 790		978	46.3	21.3	10.6	11.7	10.1	2700	1755 (V.M. free)
FNH (Dupont)	Cotton	13.1	84				(D.N.T.10) (D.B.P. 5) (D.P.A. 1)	750- 780		1028	48.1	23.1	10.1	10.2	8.5	2580	1723 (V.M. free)
N	Cotton	13.1	19	55	18.7	7.3	Cry. 0.3	765	700	1058	28.9	24.9	27.5	12.8	5.9	2520	1770
N.F.Q. (R.D.N./F.Q.)	Wood	12.2	16.5	55	21	7.5	Cry. 0.3	755	690	1066	29.1	25.5	27.3	12.4	5.7	2485	1750
NQ	Cotton	13.1	20.8	55	20.6	3.6	Cry. 0.3	880	805	1001	24.4	20.1	29.2	17.7	8.6	2850	1900
N.Q.F.	Wood	12.2	21	55	21	3	Cry. 0.3	885	807	1002	24.4	20.1	29.0	18.0	8.7		
A	Cotton	13.1	56.5		25.5	4.5	M.J. 3.5 D.N.T. 10	810		1026	45.7	24.5	11.1	10.7	8.0		
AN	Cotton	13.1	56.5		25.5	4.5	(M.J. 3.5) (D.N.T.10) (KNO_3 0.7)	825	783	1018	45.7	24.5	11.1	10.7	8.0		
L	Cotton	13.1	62		12	2	D.N.T. 24	790									
(b) Solventless or "Semi-Solvent" Extrusion																	
S.C.	Wood	12.2	49.5		41.5	9		970	897	957	39.4	19.3	12.3	16.0	13.0	3095	1960
H.S.C.	Wood	12.2	49.5		47	3.5		1175	1089	866	29.4	12.6	13.9	22.7	21.4		
H.S.C./K	Wood	12.2	49.5		47	3.5	K.Cry.2.25	1163	1083								
A.S.N.	Wood	12.2	49		37.25	5.5	(D.B.P.8.0) (K.Cry.4.0) (M.J.0.25)	785	728	1021	44.4	24.2	10.5	12.0	8.9		

APPENDIX G (contd.) (2)

COMPOSITIONS, CALORIMETRIC VALUES AND GASEOUS PRODUCTS OF CANNON PROPELLANTS

Type	Nitrocellulose		Percentage Composition					CAL. VAL.		Total Gas c.c. per grm. (W.G.)	Composition of Muzzle Gases					Temperature of Chamber Gases °K.	Force Constant
	Origin	N_2 Content	Nitro-cellulose	Nitro-guanidine	Nitro-glycerine	Carbamite	Other ingredients	W.L.	W.G.		CO	H_2	N_2	H_2O	CO_2		
				II.	COMPOSITIONS USED IN EXPERIMENTAL TRIALS												
						(a) Solvent Composition											
F. 463/67	Cotton	12.2	25.6	60	14.4			907	821								
F. 487/40	Cotton	13.1	18.1	60		3.8	D.G.N. 18.1	730	661		27.1	26.2	27.9	13.3	5.5	2360	1734
F. 500/11	Cotton	12.2	16	75	9				760								
F. 500/12	Cotton	12.2	21	70	9				765								
F. 500/19	Cotton	13.1	30	70					724								
F. 500/163	Wood	12.2	18	65	14	3		810	740								
F. 503/67	(Cotton (Cotton	13.1 12.2	37 30		30	3		1115									
F. 507/5	Cotton	13.1	18.5	65	12	4.5		765	695								
F. 514/1	Cotton	13.2	18.5	65	12	4.5		775									
F. 518/6	Cotton	12.2	18.5	55	18	8.5	Cry. 0.3	725									
F. 527/32	Cotton	13.1	18.5	55	18.5	2	D.B.P. 6	754	687	1061	28.6	24.9	27.0	13.4	6.1		
F. 527/127	Cotton	13.1	16.6	60	16.4	7	K.Cry. 0.5	730	670	1070	28.0	25.7	28.6	12.3	5.4	2420	1747
F. 535/2	Wood	12.9	28	40	24.5	7.5		820	750								
F. 535/32	Wood	12.9	30	40	20	10											
F. 536/38	Cotton	12.2	16	60	15	0.5	Cell. Acet.) 8.5) Cry. 0.3)	745									
F. 536/39	Cotton	12.2	14.5	55	19	0.5	Cell. Acet.) 11) Cry. 0.3)	755		1039							
R.D.N., R.D.N./A, N/A	Cotton	12.2	16.5	55	21	7.5		755	690	1066	29.1	25.5	27.3	12.4	5.7	2485	1750
R.D.N./F, N/F	Wood	12.2	16.5	55	21	7.5		755									
(F.556/1 (R.D.N./A.Q. (N/A.Q.	Cotton	12.2	16.5	55	21	7.5	Cry. 0.3	755			29.1	25.5	27.3	12.4	5.7		
(F.551/27 (R.D.H./A	Cotton	12.2	21	55	21	3		885	807	1002	24.4	20.1	29.0	18.0	8.7		
(F.551/58(R.D.Q.) (R.D.H./A.Q.	Cotton	12.2	21	55	21	3	Cry. 0.3	885	807		24.4	20.1	29.0	18.0	8.7		
H.P.	Cotton	13.1	15	65	18	2		885	805	1003	21.1	19.5	32.3	18.9	8.2	2850	1900
(H.N./P (F.563/5	Cotton	13.1	25	40	34	1	K_2SO_4 1.0	1115		908	20.1	12.8	27.5	24.4	15.2	3400	
F.560/13	Cotton	13.1	21	40	23	1	Oxamide 15) K_2SO_4 1)	783	697	988	25.2	19.3	27.0	18.7	9.8		1668
F.560/48	Cotton	13.1	19.25	50	19	1	Oxamide 10.75) K.Cry. 0.5)	790		998	23.7	19.7	29.3	18.5	8.8	2550	1700
F.560/64	Cotton	13.1	19	50	18.7	1.5	Oxamide 10.8) K.Cry. 0.5)	775	690	1011	24.3	20.4	29.2	17.7	8.4	2520	1695
F.560/72	Cotton	13.1	19.2	45.4	19.0	1	Oxamide 15.4	715	630	1010	25.3	20.6	28.1	17.6	8.4	2365	1585
F.563/9	Cotton	13.1	21.5	50	28.0	0.5	K_2SO_4 2	1055									
					(b)	Solventless or "Semi-Solvent" Extrusion											
F. 500/43	Cotton	12.2	15	50	26	9			700								
F. 500/44	Cotton	12.2	12	60	21	7			700								
F. 500/57	Cotton	12.2	12	60	21	6.5	Wax 0.5		690								
F. 503/62	(Cotton (Cotton	13.1 12.2	36 7		55	2	Graphite 0.25	1342									
F. 527/134	Wood	12.2	16.5	60	17	6.5	K.Cry.0.5	735									
F. 560/50	Wood	12.2	18	42	26	1	Oxamide 13) K.Cry.0.5)	800	711	987	24.4	19.2	27.4	19.1	9.9		
F. 560/62	Wood	12.2	18	42	25	2	Oxamide 13) K.Cry.0.5) Wax 0.15)	764	678		26.0	20.5	26.9	17.7	8.9		1662
S.N.F.Q.) M.N.F.Q.)	Chemical composition as N.F.Q.																

APPENDIX H

Flash and smoke photographs during gun-fire

The type of flash given with typical A.A. and Field guns is illustrated in Figs. 17-19 which are reproductions of War Office official photographs taken during the firing at night of batteries in action during the recent war when employing flashing W.M. cordite. With the B.L. 14-inch in a firing at night in a worn gun at Woolwich (cf. p.26) photographs are reproduced in Fig. 20 of the full flash given by a service S.C. charge, the partial flash with cordite N/2P and the small anti-blinding flashes given with F.487/40/2P and F.527/127/2P. (i.e. F.487/40 and F.527/127 with the addition of 2 per cent potassium sulphate).

In the B.L. 16-inch Mk. II frames at different intervals from rapid cinephotographs (1200 per second) when firing a charge of 600 lb. of N/5P size .280 are reproduced in Fig. 22. In this round a slight flash could be detected which lasted for the first 6 milliseconds, and again from 44 to 56 milliseconds (cf. page 26). This was a daylight trial fired at Grain on 13th June, 1945, and the photographs were taken with a Vinten high speed camera.

In the development of flashless charges giving minimum smoke for Field and anti-tank guns, the reduction of smoke which it was possible to effect in the Q.F. 95 mm. Tank How. when using NQ propellant with a smokeless C.9 type of primer is seen in Fig. 23, which reproduces photographs of the smoke given by cordite W.M., cordite NQ with a No. 11 primer and with a smokeless primer (cf. pages 16, 59).

APPENDIX I

Output of Picrite Propellants (N, N.F.Q., NQ, N.Q.F. etc.) in the U.K. during 1941-1945.

Production in tons at the Factories

Year	R.N.C.F. Holton Heath	R.N.P.F. Caerwent	Land Service Factories
1941	250		7240
1942	750	2330	33525
1943	1088	2650	25040
1944	1206	3150	21230
1945	1259	1965	14670
	4553	10095	101705

Grand total from all British Factories 116,353.

APPENDIX J

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APPENDIX K

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Cocking (Kynoch, Ltd.)	The "Axite" patents. Addition of mixtures of potassium and barium salts; tartrates, oxalates and nitrates.	15564, 15565, 15566, 1905 Br.
Duttenhofer	Addition of small quantity of fats and oils, with 1-2 per cent of such organic acids as lactic, tartaric, oxalic.	19408/06 Br.
"	Addition of 5% sodium soap as efficient as 5% vaseline plus 1% sodium bicarbonate.	791/07 Br. 364413/07 Fr.
Krupp	Addition of heavy hydrocarbons, resin, camphor, diphenylamine, sodium oxalate or bicarbonate.	16617/09 Br.
Hale	Flame-quenching material added separately.	29292/09 Br.
Robertson	N.C.(65-95), N.G.(35-5), diphenylamine (0.1-1); ether-alcohol solvent; pressed into strips; water-proofed by camphor solution and dipped into a 20% solution of pot. tartrate.	10062/12 Br. 458372/13 Fr. (Weld-Blundell)
Rottweiler Co. (Cologne)	Alkali bicarbonates: soaps of sodium, potassium, calcium, magnesium; resinate of barium or sodium.	175399/03 D.R.P. 195486/07 D.R.P.

Westf. A.S.A.G. (Berlin)	Sodium salts of organic acids added, e.g. 2-5% oxalate or citrate or tartrate.	243846/06 D.R.P.
Schlmann	Esters of organic or inorganic acids and lithium salts.	34505/10 Swedish 35011/13 "
Westf. A.S.A.G.	Addition of 0.5 - 5% pot. chloride	301659/17 German
Snelling	Addition of hydrous calcium borate, 3-25%; alternatively Gypsum.	1,464,667/23 U.S.
Nobel Ind.	Addition of carbon with pot. nitrate or bichromate.	635047/27 Fr.
Du Pont	Addition to N.C. of 4-25% of mixture of barium and potassium nitrates in ratio 2:1 otherwise addition of gun-powder or (if N.G. is present) pot. nitrate with carbon.	1,627,638-9/27 U.S. 1,627,692/27 U.S. Also see under Cocking above.
"	Addition of black powder or a mixture of sodium dichromate and charcoal.	1,627,963-4/27 U.S.
"	Addition of an oxidising and an oxidisable body, e.g., oxygen-bearing salts with carbon or hydrocarbons, such as pot. nitrate or bichromate with carbon.	298543/27 Br.
"	Mixtures of N.C. (nitrogen content above 12.9%), a polynitrotoluene (DNT in particular) and organic esters such as dialkylphthalates.	567,878/30 German
"	Pot. or sodium salts incorporated with propellant and also used separately in front of the cartridge when potassium sulphate is especially suitable, alternatives being nitrates or oxalates.	640,312/30 German
"	A flash-suppressing salt, e.g. pot. sulphate or nitrate incorporated with the powder insufficient of itself to suppress flash, together with an increment of salt in silk bags or other external addition of salt.	360,950/30 Br.
"	Partial suppression of flash by addition of less than 0.5% pot. sulphate or other anti-flash salt.	701,463/30 Fr. 1,838,347/31 U.S.
"	Addition of 0.5-2.0% (extreme limits 0.3-2.5) of pot. sulphate as anti-flash agent.	716,429/31 Fr. 366,786/31 Br. 1,838,345/31 U.S.
Hercules Powder Co., (Norton)	Addition of 5-10% of an abietate, e.g. ethyl, phenyl or benzyl abietate.	1,788,438/31 U.S.
Trojan Powder Co. (Snelling)	Nitro-starch granules rendered smoke-less and flashless by admixture with guanidine nitrate, ammonium or urea nitrate, or nitroguanidine.	1,808,613/31 U.S.

Du Pont (Woodbridge)	Addition of stannous phthalate.	1,838,346/31 U.S.
"	A small quantity of pot. sulphate or the like insufficient in itself to eliminate flash, which is suppressed by a further addition of anti-flash salt external to the powder.	1,838,347/31 U.S. See 360,950/30 Br. above.
"	0.3 - 2.0% finely divided tin oxide together with 0.3-2.0% pot. sulphate are incorporated in the powder. Other tin salts, organic or inorganic may be used; other pot. salts may be the nitrate or tartrate.	2,038,700/34 U.S.
"	Charge contains a central core of silk cloth impregnated with a flash-suppressing alkali-metal salt. A suitable dipping solution in water contains potassium sulphate and potato starch.	2,050,871/36 U.S.
I.C.I. Ltd., (Thomson and Whitworth)	Addition of 1-5% of an antimonyl compound free from halogens and containing a combined alkali metal, e.g. tartar emertic.	2,304,037/42 U.S.
M. Abelli	"Improvements in the manufacture of explosives".	Brit. Pat. No. 21529 of 1905
J.M. Skilling (du Pont)	"Progressive Nitrocellulose Powders containing Nitroguanidine".	U.S. Pat. No. 1, 454,414 (May 8, 1923)
G.C. Hale and F. Olsen	"Propellant Powder".	U.S. Pat. 1,547,808 (July 28, 1925)
	"Process for preparing propellant powders".	U.S. Pat. 1,547,809 July 28, 1925)
C.R. Franklin	"Propellant Powder."	U.S. Pat. 1,582,256 (April 27, 1926)
T.L. Davis	"Explosive and Solvent Therefor."	U.S. Pat. 1,754,417 April 15, 1930)

EXTRUSION PRESSURES AT 85°C.
F.500/43. CORD 0·08 INCH.

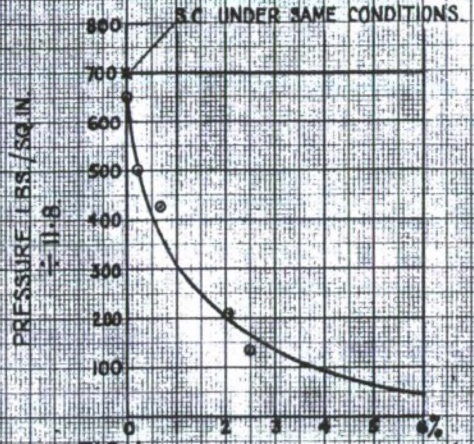


FIG 1. ACETONE (V.M. AT PRESSING)

EXTRUSION PRESSURES AT 85°C.
F.500/43. CORD 0·08 INCH.

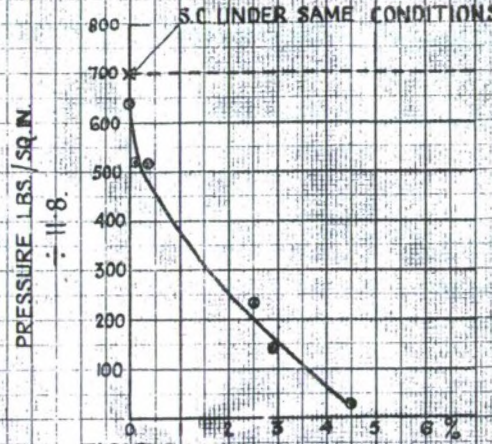


FIG 2. ALCOHOL (V.M. AT PRESSING).

LOWERING OF EXTRUSION PRESSURE BY USE OF CANDELILLA WAX.
F.500/57. CORD 0·08 INCH.

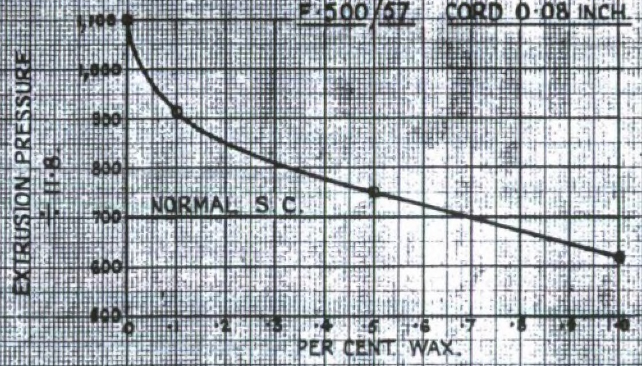


FIG 3.

PRESSURE - TEMPERATURE CURVE.
F.500/57. CORD 0·08 INCH.

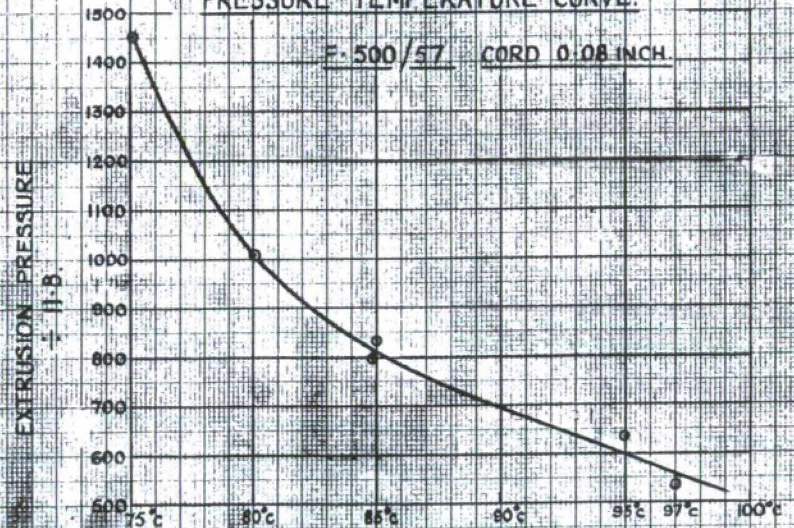
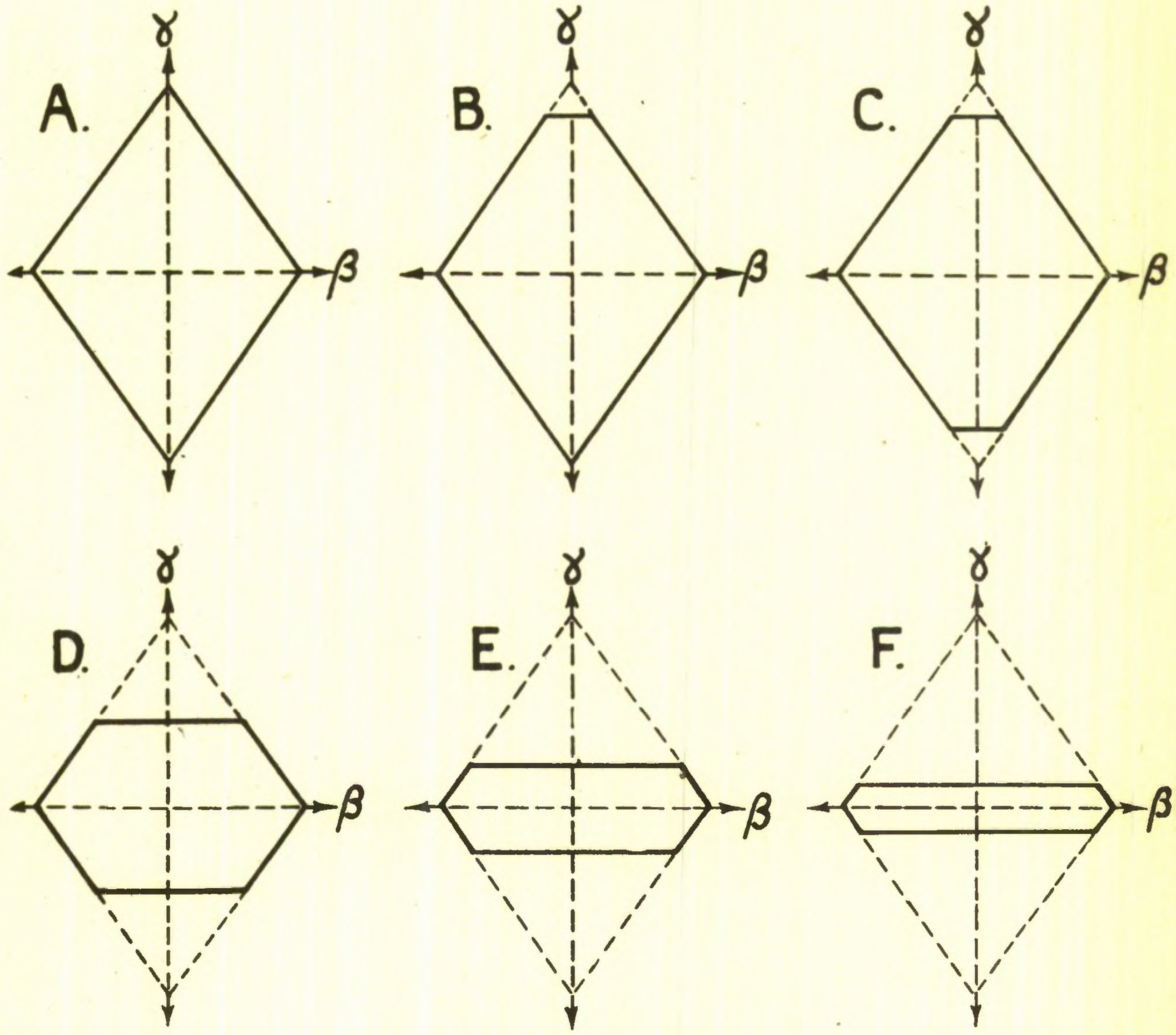


FIG 4. TEMP OF PRESSING.

TRANSVERSE CROSS-SECTIONS OF VARIOUS TYPES OF PICRITE CRYSTALS.

A-C. TYPICAL CRYSTAL SECTIONS OF WELLAND PICRITE.

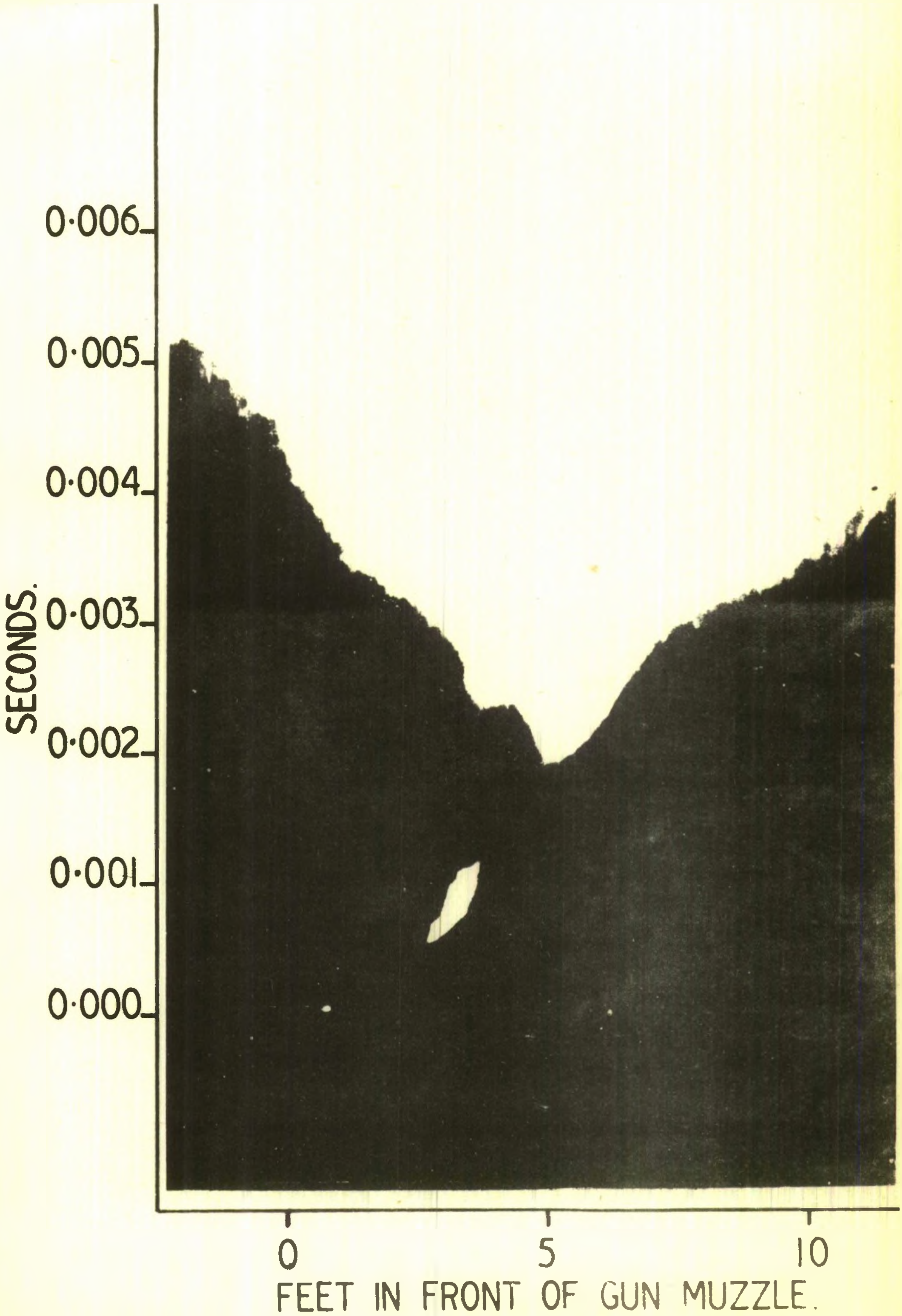


D. ARDEER PICRITE. E. WALTHAM ABBEY PICRITE. F. PICRITE (WELLAND OR WALTHAM) RECRYSTALLISED FROM 0·05% AMMELIDE SOLUTION.

THE DIRECTIONS OF THE β AND γ REFRACTIVE INDICES ARE INDICATED BY THE ARROWS. THE α INDEX IS PARALLEL TO THE LENGTH OF THE CRYSTAL.

FIG. 5.

FIG. 6. FLASH FROM B.L. 6 INCH MARK XII S.S. WITH M.D. CORDITE RECORDED ON ROTATING FILM.



FIGS. 7-9. PHOTOMICROGRAPHS OF SECTIONS OF VARIOUS PICRITE CORDITES EXTRACTED WITH POTASSIUM MERCURIC IODIDE

MAGNIFICATION 100, SECTION 10μ THICK.
TRANSMITTED LIGHT - CROSSED NICOLS.

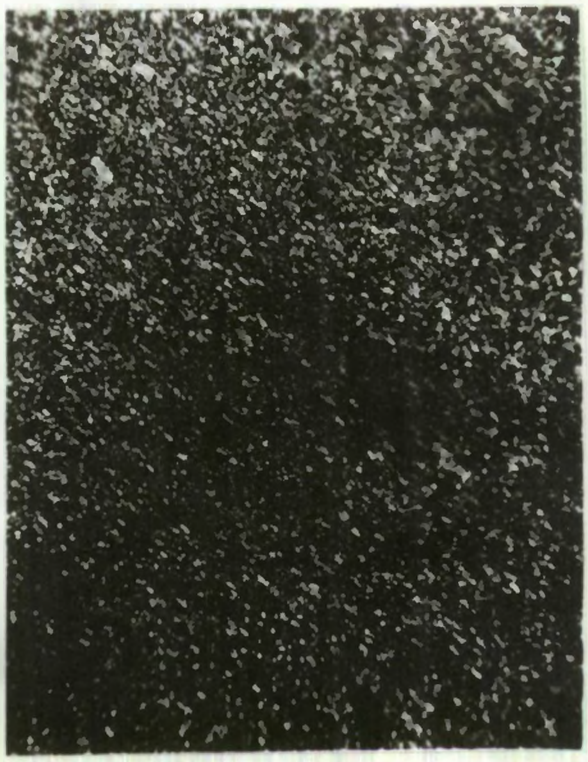


FIG. 7. NORMAL CORDITE N.

FIG. 9. F527/30
CORDITE N.
CARBAMITE DISSOLVED IN THE SOLVENT

FIG. 8. F527/44
CORDITE N.
CARBAMITE AT WET MIX STAGE

FIG. 10. PICRITE - CARBAMITE COMPLEX
(COMMON CRYSTAL FORM)

PHOTOMICROGRAPHS OF PICRITE RECRYSTALLISED FROM VARIOUS AQUEOUS SOLUTIONS

MAGNIFICATION 500 THROUGHOUT. NORMAL TRANSMITTED LIGHT

FIG. 11. R.N.C.F. NORMAL SPRAYED PICRITE So = 21,000 $cm.^3/cm.^3$

FIG. 12. R.N.C.F. PRESSURE SPRAYED PICRITE So = 38,000 $cm.^3/cm.^3$

FIG. 13. AS FIG. 11 BUT EX 1.0% FORMALDEHYDE AND 0.12% AMMONIA SOLUTION

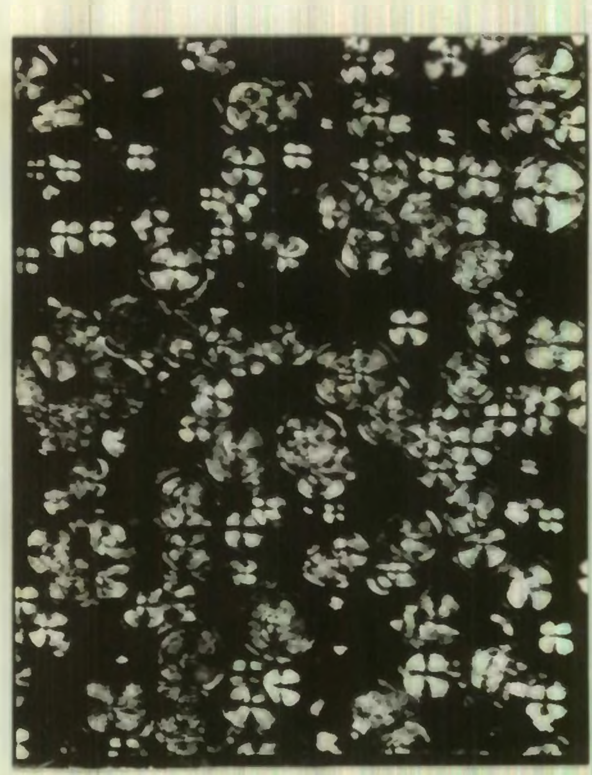


FIG. 14. SPHERULITIC PICRITE UNDER CROSSED NICOLS

PHYSICAL PROPERTIES WITH VARYING N.C. – N.G. RATIOS.

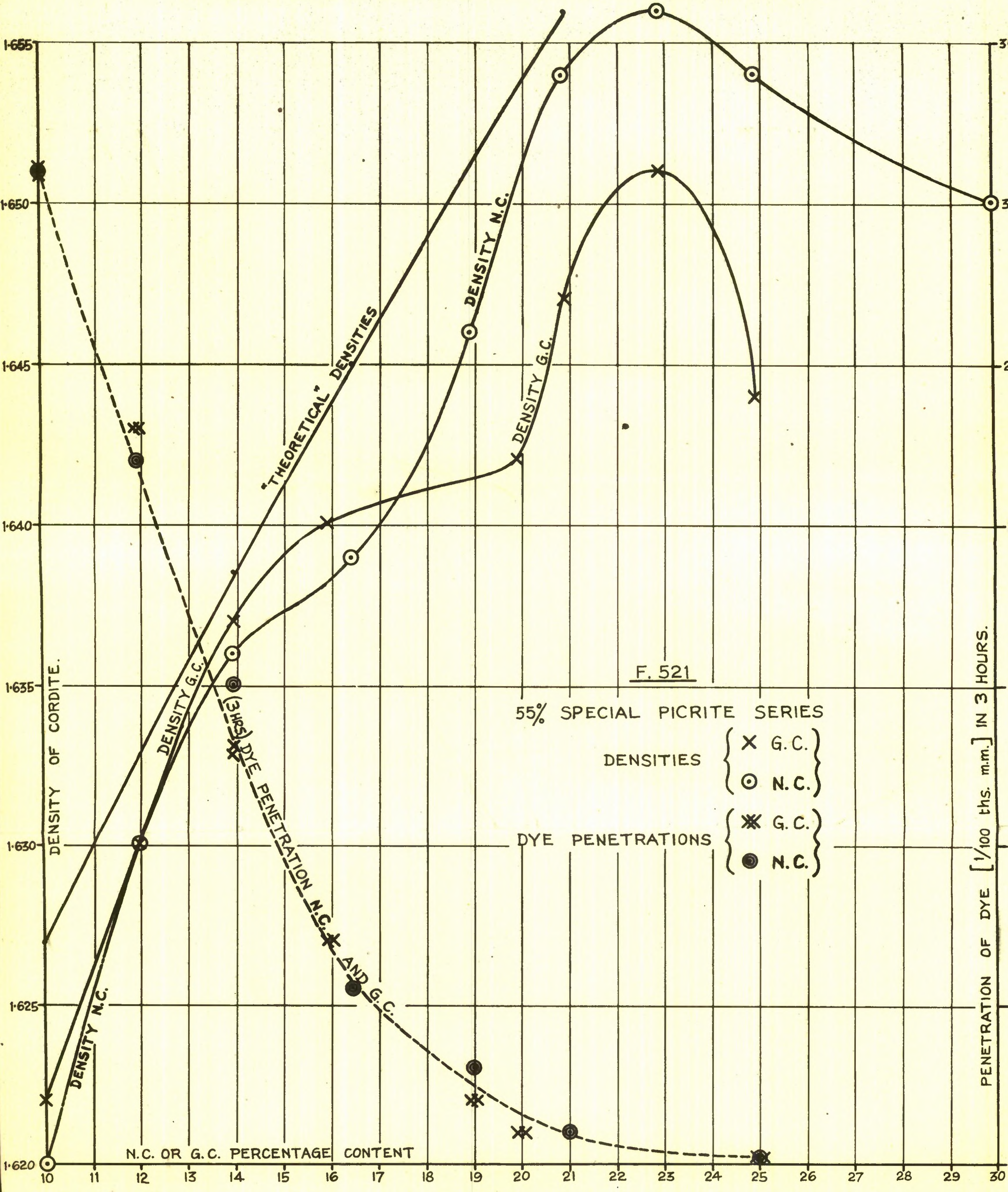


FIG. 15.

PHYSICAL PROPERTIES WITH VARYING N.C.–N.G. RATIOS.

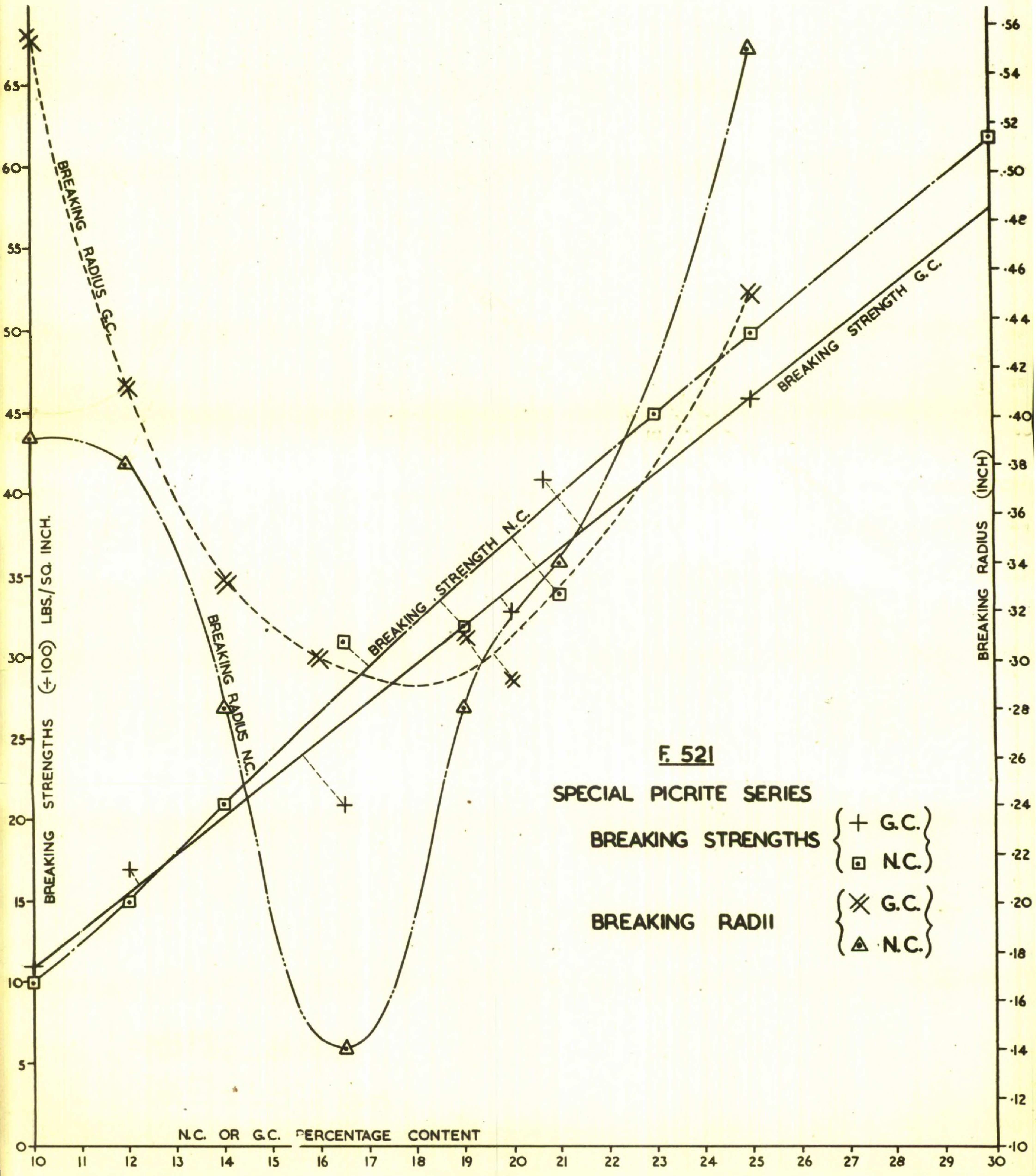


FIG. 16.

NIGHT FIRING WITH FLASHING PROPELLANT

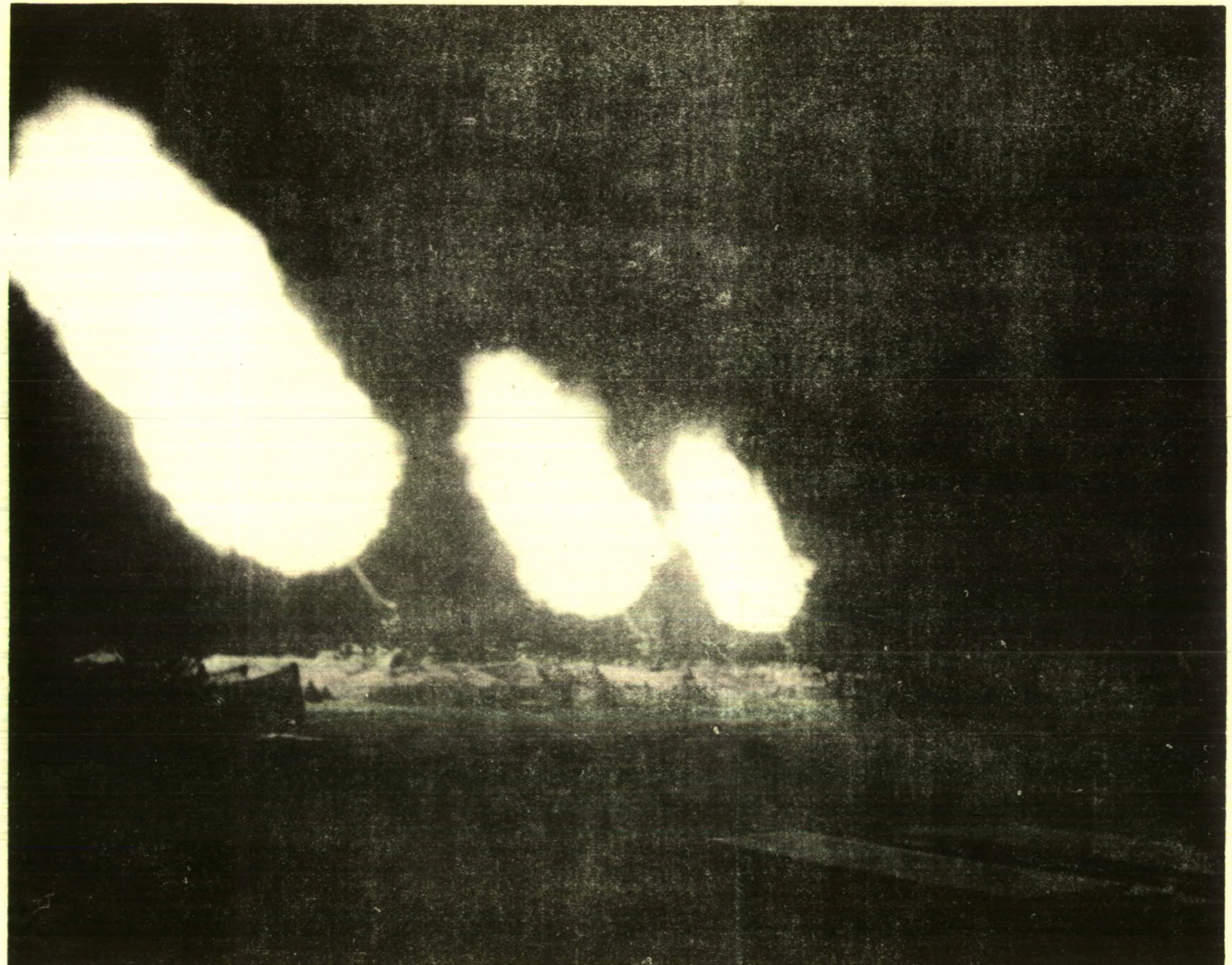


FIG. 17. 3·7 INCH A.A. BATTERY.

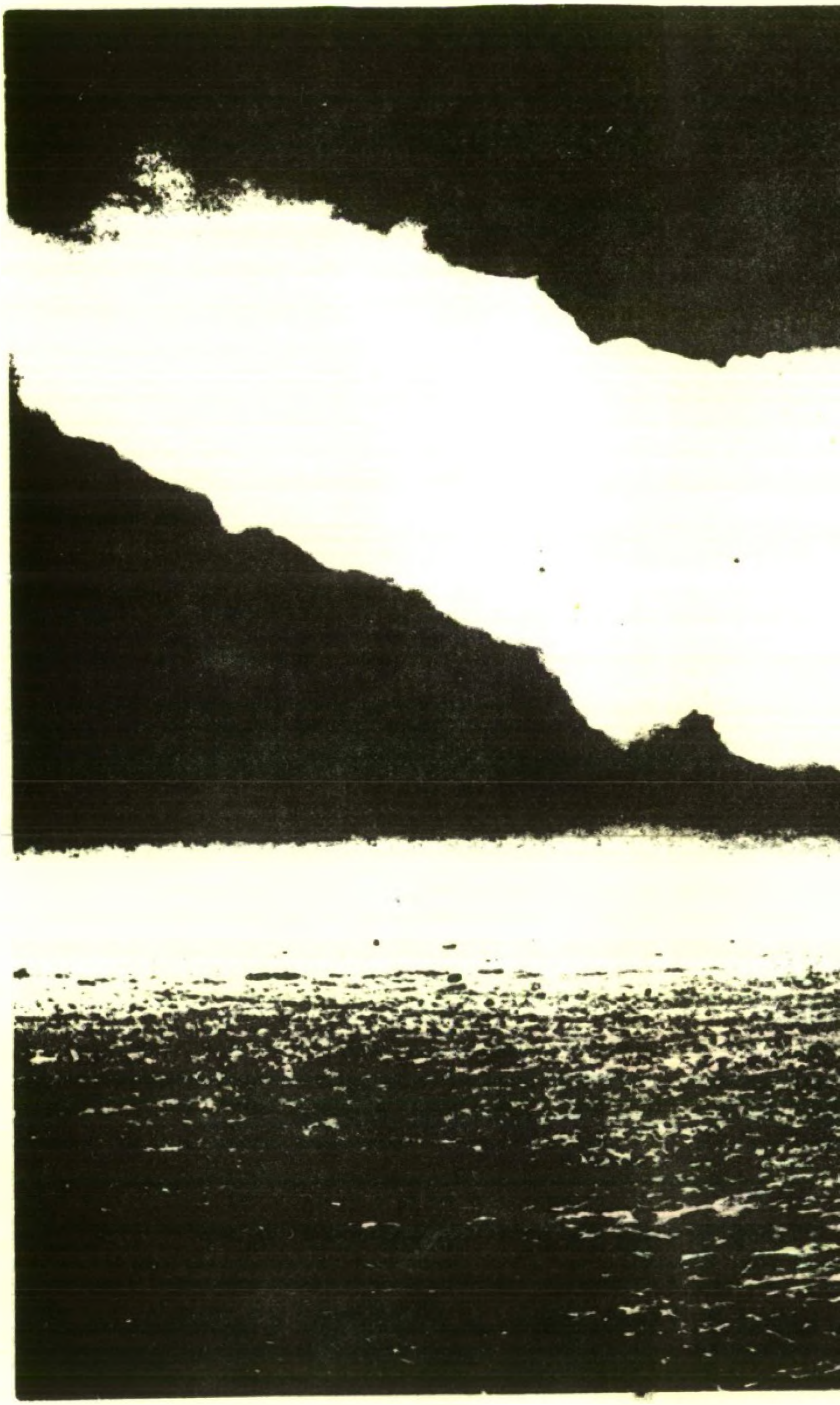


FIG. 18.

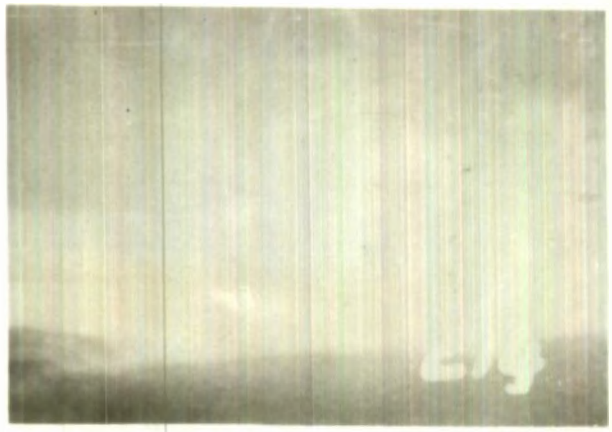
Q.F. 4·5 INCH.

FIG. 19.

Q.F. 25 Pdr.

B.L. 14 INCH MK. VII GUN (213 E.F.C.)

CORDITE S.C.
(Service Flash)

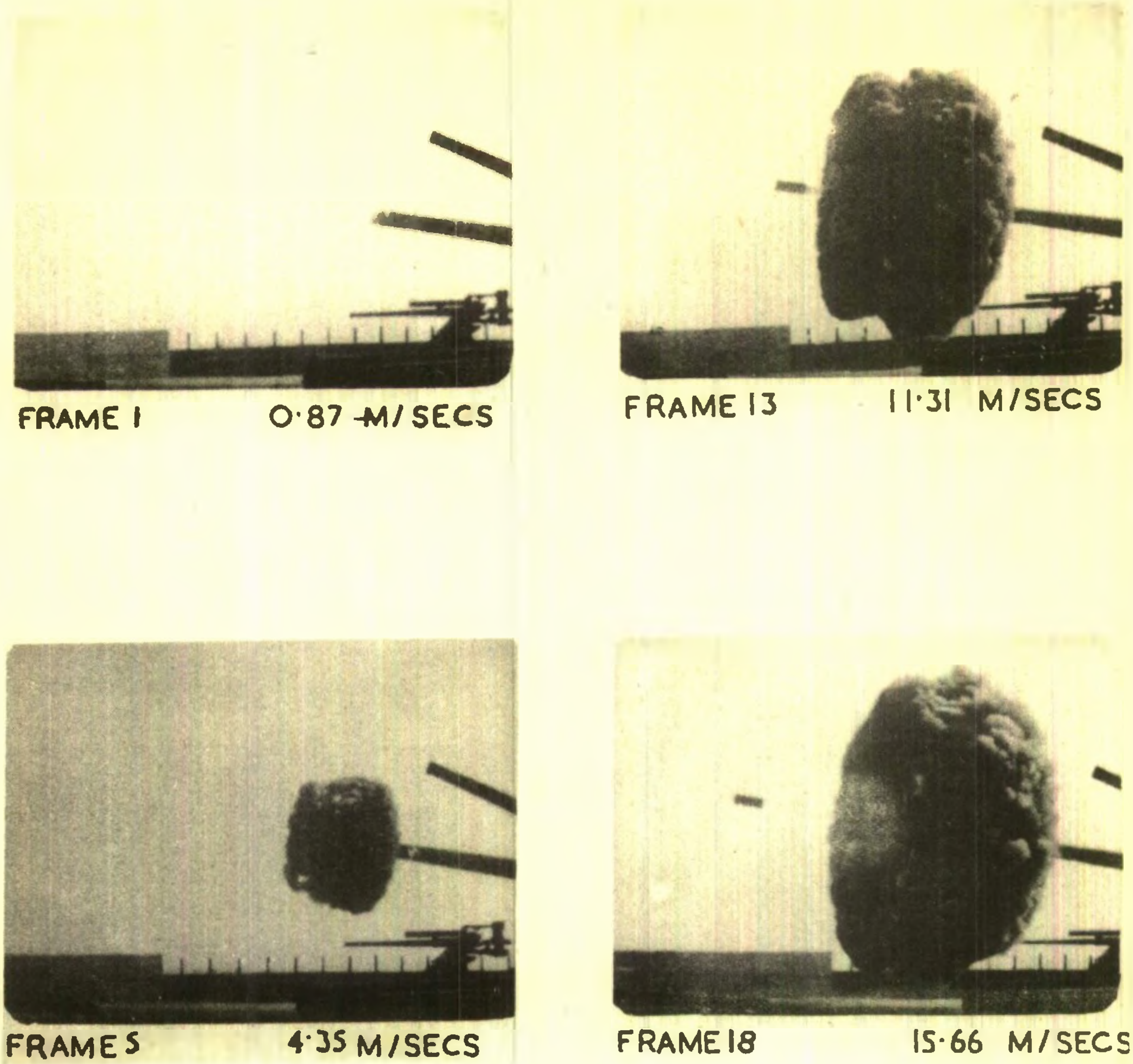


CORDITE N/2P
(Large Flash)

CORDITE F487/40/2P
(Very Small Flash)

CORDITE F527/127/2P
(Very Small Flash)

FIG. 20.



ROUND 4. 14" SHOT WB. 370lbs. N.5.P. LOT W.A.C.9.

TAKEN BY C.S.A.R. AT SHOEBURYNESS ON 15/3/45

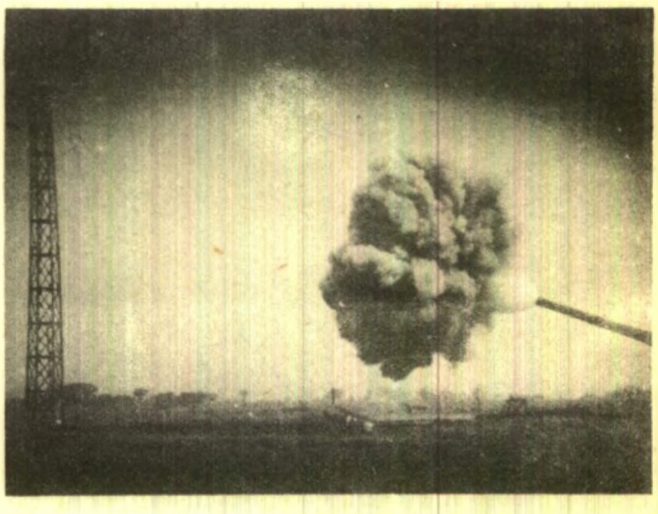
FIG. 21

FRAME 0 0.0 M/Secs.

FRAME 1 0.8 M/Secs.

FRAME 13 10.9 M/Secs.

FRAME 30 25.7 M/Secs.



FRAME 70 58.5 M/Secs.

FRAME 240 200.6 M/Secs.

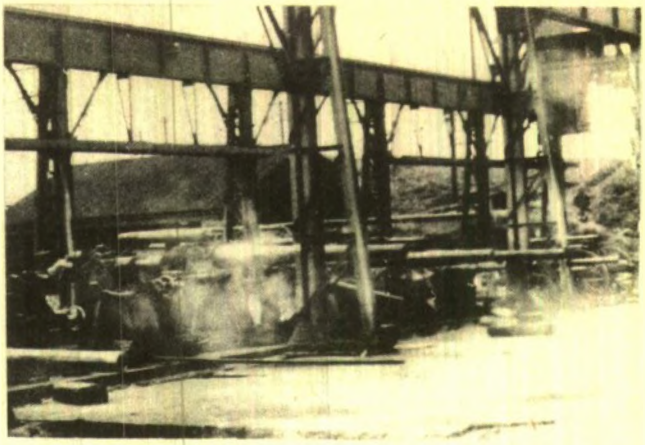
ROUND 6. 16″ GUN FLASHLESS PROPELLANTS.

TAKEN BY C.S.A.R. AT GRAIN ISLAND ON 13/6/45

FIG. 22

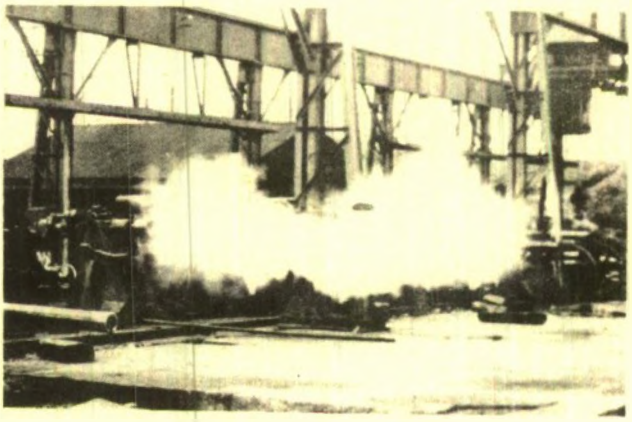
SMOKE FROM PROPELLANTS

Q.F. 95mm. TANK HOWITZER



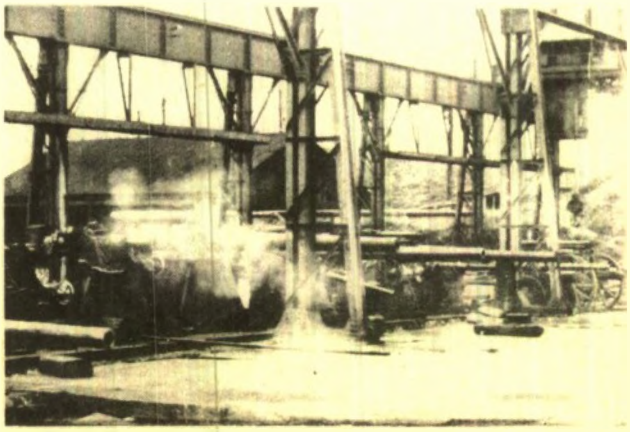
FLASHING SMOKELESS

CORDITE W.M. PRIMER No. 1



FLASHLESS SMOKY

CORDITE N.Q. PRIMER No. 11



FLASHLESS SMOKELESS

CORDITE N.Q. SMOKELESS PRIMER C9B

FIG. 23

REDUCTION OF GUN WEAR WITH FLASHLESS PROPELLANTS.
NUMBER OF FULL CHARGES FOR COMPLETE WEAR.

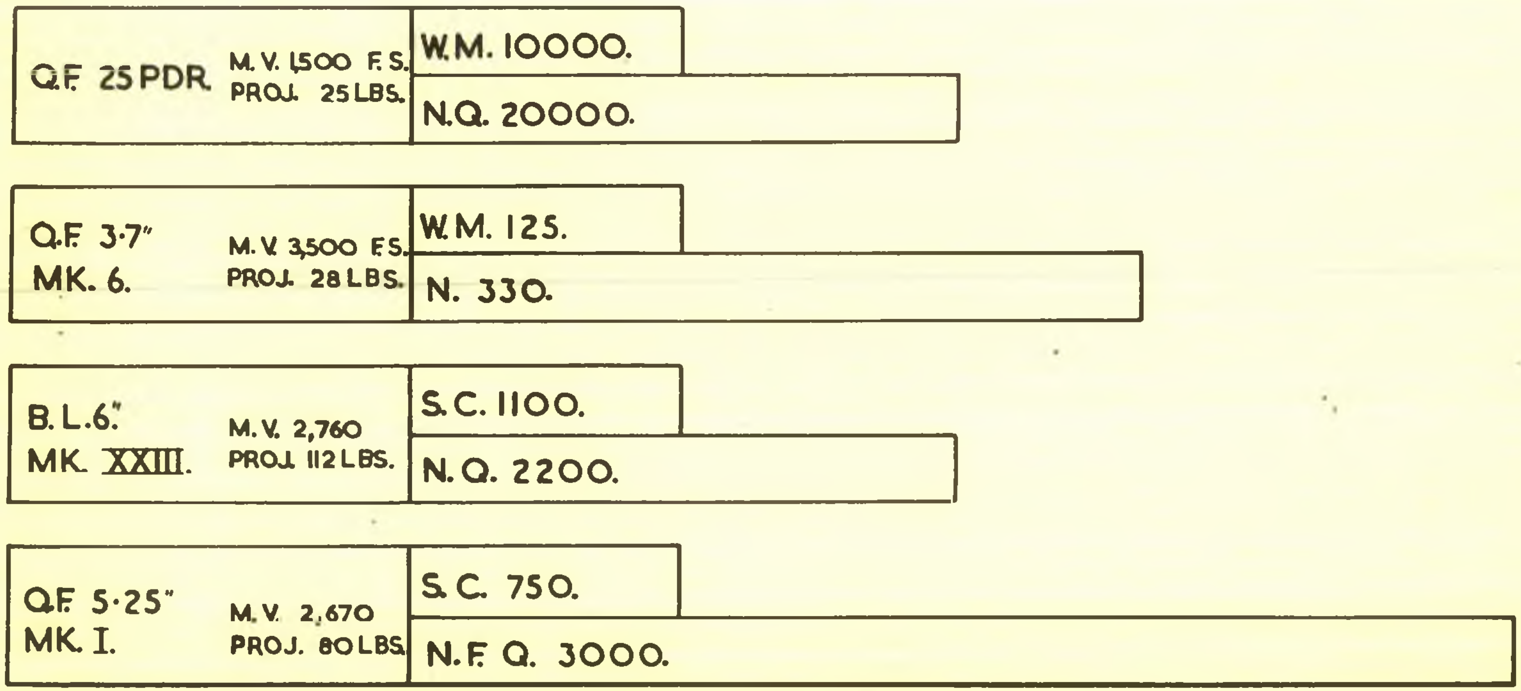


FIG. 24.

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