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A SHORT HISTORY OF THE ROYAL GUNPOWDER FACTORY AT WALTHAM ABBEY

BY

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FOREWORD

Three hundred years of the science and art of the manufacture of explosives is related in this short history of the Royal Gunpowder Factory at Waltham Abbey. The author outlines the technical development of the factory throughout the centuries to meet the changing requirements for military explosives of novel natures. Quotations and extracts from relevant publications and early factory documents are used to give interesting glimpses of the changing social and industrial relationships.

Considerable research into ancient records and local lore has been made by the author in his efforts to achieve historical accuracy and he has presented his findings in a manner which makes this a factual, interesting and very readable history of the Royal Gunpowder Factory.

R. RATCLIFFE
Controller,
Royal Ordnance Factories

Northumberland House, W.C.2.
April, 1963.

AUTHOR'S PREFACE

The Royal Gunpowder Factory at Waltham Abbey is an Institution which holds a unique place in the hearts of all those who have ever worked there - It was therefore with great pleasure and even more diffidence that I accepted an invitation from Dr. Bowden, then Director of Ordnance Factories Explosives to compile its history.

The work was very slow and much interrupted by other duties. It has involved the reading of a mass of letter, books and other documents removed from Waltham Abbey as well as other relevant documents. The writer has been greatly helped and encouraged by the interest and understanding shown by the many people on whose time and patience he has trespassed. It is perhaps, invidious, to mention individuals among so many helpers but I feel it essential to put on record my debt to Mr. T. H. Barry, who first catalogued the mass of documents removed from Waltham and now in the Public Record Office, Mr. Elliot L. Blee, Danger Building Officer at Waltham during two Wars, who made a valuable collection of notes on the first 20 years or so of Waltham's existence as a Government Factory, Mr. J. F. Lawrence, of Bridgwater, whose skill as a Palaeographer has helped so much to elucidate the mysteries of the much quoted Elizabethan documents, and Mr. B. R. Pearn of the Foreign Office, formerly Professor of History at Rangoon University, whose helpful criticism has done so much to keep this history on the right lines. Finally I must acknowledge the encouragement and help received from many libraries and librarians, from Mr. W. R. Powell, the Editor of the new edition of the Victoria County History of Essex and from Dr. C. H. Johnson, C.B.E., the Superintendent of the present Research Establishment at Waltham Abbey.

W. H. Simmons, M.B.E., F.R.I.C.
Bridgwater

"A mill for making of gunpowder's there,
And water flows amazing and more rare;
Which from a model on river's took
Of worthy Walton's works; (whose soul can't brooke
With thing that's mean; but like a generous heart
Encourages all learning, honesty, and art)"

"PHILOTECHNOS"
(A local poet, 1735)

OFFICERS IN CHARGE OF THE R.G.P.F.

James Wright	1787 - 1805	Storekeepers under the Comptroller of the Royal Laboratory, Woolwich.
H. S. Mathews	1805 - 1818	
E. Middleton	1818 - 1825	
C. Wilks	1825 - 1831	

SUPERINTENDENTS

Lt. Col. C. T. Moody R.E.	1832 - 1845
Capt. A. T. Tulloh R.A.	1845 - 52
Capt. C. C. Dickson R.A.	1852 - 54
Col. W. H. Askwith R.A.	1854 - 68
Col. C. W. Younghusband R.A.	1868 - 75
Lt. Col. Young R.A.	1875 (died)
Col. R. J. Hay	1875 - 80
Col. C. B. Brackenbury R.A.	1880 - 85
Col. W. H. Noble R.A.	1885 - 92
Lt. Col. W. Mc. Clintock R.A.	1892 - 94
Col. J. B. Ormsby	1894 - 1900
Bt. Col. Sir F. L. Nathan R.A.	1900 - 1909
Major F. T. Fisher R.A.	1909 - 17
Lt. Col. P. H. Evans R.A.	1917 - 34
R. C. Bowden Ph.D., M.Sc., F.I.C., M.I. Chem. E.	1934 - 39
P. G. Knapman B.Sc., F.I.C.	1939 - 43

ASST. SUPERINTENDENTS *

Capt. A. T. Tulloh	1840 - 45
Major Badeley	1855 - 60
Major G. C. Henry	1860 - 66
Capt. F. M. Smith	1866 - 71
Major S. P. Morgan	1871 - 76
Major W. H. Wandall	1876 - 78
Major Tweedie	1878 - 79
Major W. H. Wandall	1879 - 81
Capt. H. S. S. Watkin	1881 - 84
Major F. W. J. Barker	1885 - 92
Major F. L. Nathan	1892 - 1900
Major E. S. Cooper	1900 - 1904
Capt. W. H. W. Hope	1904 - 1907
Capt. S. C. Halse	1907 - 11
Major R. Waring	1911 - 15
Bt. Maj. P. H. Evans	1915 - 17
Major A. H. Fraser	1917 - 19
Capt. F. O. Field	1919 - 24

* Some times known by other titles, such as "Inspector of Gunpowder", but the duties seem to have been very similar.

CHAPTER I

THE EARLY DAYS OF THE ROYAL GUNPOWDER FACTORY

The history of the Waltham Abbey Powder Mills, later known as the Royal Gunpowder Factory, forms a major chapter in the history of explosives manufacture in England. Waltham was among the earliest powder factories, and it continued its existence as an explosives factory for three hundred years. The date at which its operations commenced is not known with any certainty, but in 1662 it had already been in operation for some years. The early history of the factory is obscure, and most writers on the subject have drawn extensively on the first attempt at a comprehensive account of its origin and growth, namely, Winters' 'Centenary Memorial', (Ref. 1) published in 1887, one hundred years after the establishment had been taken over by the Government.

Winters was an interesting character who worked in his youth in the factory itself and later became a bookseller and Pastor of the Particular Baptists' Ebenezer Chapel in the town of Waltham. He wrote a number of books, mainly of local historical or religious interest, which he published himself. In his Centenary Memorial he gives a mass of historical information compiled from the records of the factory, to which he seems to have had free access, and from manuscript sources in the Public Record Office and the British Museum.

Most of the few accounts of the history of the factory which have since appeared quote freely from Winters. In particular the article in the 'Victoria County History of Essex' (1907), written by Colonel F. L. Nathan, (Ref. 2) then Superintendent of the Factory, follows Winters very closely: Nathan mentions in a footnote that much interesting though wholly undigested information is to be found in Winters' book, and certainly Winters was a most diligent historian to whom the present writer is greatly indebted. His work nevertheless needs to be treated with caution: his judgment was not always free from bias, and he was inclined to make categorical statements without stating the evidence on which he based them. For example, he states baldly that John Walton, who owned the factory in 1735, was a relative of Isaac Walton, 'the celebrated Angler;' yet in the brief genealogy of John Walton, taken from the Parish Registers, which his book contains, there is no mention of Isaac Walton and no indication of any connexion between his family and that of John Walton.

When, therefore, Winters asserts that the Waltham factory existed at least as early as the time of Elizabeth I, his statement cannot be accepted without confirmation. Certainly the secret of the manufacture of gunpowder originally the only product of the factory, had been known in England long before that time. Roger Bacon wrote his famous account of it as early as 1242, though he concealed the details cryptically because, as he explains, he firmly believed scientific knowledge to be hurtful to the people: 'the Crowd,' he says, 'is unable to digest scientific facts, which it scorns and misuses to its own detriment and that of the wise. Let not pearls, then, be thrown before swine.' So effective was his cypher that it was not till 1904 that a clear rendering of the important passage was given by Colonel W. H. Hime, (Ref. 3). Despite Bacon's knowledge of the process too, it was not till a hundred years after his time that any trace can be found of the purchase in England of the materials needed for gunpowder manufacture. Then, in 1346, the accounts of John Cook, the Clerk of Edward III's Great Wardrobe, show that 912 lbs. of saltpetre and 886 lbs. of quick sulphur were supplied to the King for his guns, (Ref. 4).

Other small purchases are recorded in the ensuing two hundred years, but such manufacture as there may have been in this country seems to have been on a very small scale, and most of the gunpowder that was used was imported. During the reign of Elizabeth I the gravity of this situation, in view of the threatening aspect of the country's foreign relations, began to be perceived, and 1560 Gresham wrote to Cecil saying that in view of 'the great scarssite of powdyr that ys here to be hade, the Quene's Majestie should do well to macke out of hands, iiij or vi milles for the macking of powdre for the servise of her Highness' turne, if the warres contynew, or this breach of amytie should chance betwixt her Majestie and King Philipe' (Ref. 5).

By this time, it is known, at least one gunpowder factory was in existence, though not at Waltham, for in 1554/5 Henry Lee (Ref. 6) was accused of having erected a gunpowder mill at Rotherhithe on land to which he had no title. This was apparently the mill referred to by Thomas Lee in 1533, (Ref. 7) who claimed that he and his father had made gunpowder there for twenty years, though they had had no proper lease in spite of a request from Henry VIII in 1536 to the Abbot of Bermondsey, the owner of the land, to make out a lease for them.

Whether, however, as Winters claims, there was at that period a factory at Waltham is open to doubt. He says categorically that 'The Waltham Works are the oldest of the kind in England. They were in existence in 1560, but how long before that time it is difficult to say,' and his view has been generally accepted by later writers without, it would seem, any serious attempt at confirmation. Thus in the 'Victoria Country History of Essex', Nathan likewise says that 'The earliest English Powder Mill of any consequence was, without doubt (notwithstanding statements sometimes made to the contrary), that situated in the valley of the River Lea, in the south west corner of Essex'.

Both these writers adduce as evidence a number of references in State Papers to a contract for the supply of saltpetre, sulphur and bowstaves to the Government; some of this correspondence is addressed to John Thomworth at Waltham Abbey, and both writers seem to have assumed that Thomworth was the owner or manager of a powder mill there.* Certainly Thomworth was the executor of Lady Denny, (Ref. 8) whose husband Sir Anthony Denny, had been granted the Abbey lands by Henry VIII at the Dissolution, and certainly the factory was built on land that formerly belonged to the Abbey, but Thomworth had other interests, not connected with Waltham. He was one of the chief Grooms of the Privy Chamber to Queen Elizabeth (Ref. 9), and it seems probable that he was concerned with the contract in an official capacity on behalf of the Queen and not on his own account and that, therefore, the contract had no relation to Waltham. This supposition is confirmed by the terms of the contract itself, for it provides for the supply of sulphur, saltpetre and bow-staves, which last though still at that time an important munition of war, could not possibly be needed in a gunpowder factory. Winters attempts to overcome this obstacle to his theory by speaking of 'bow-staves for barrels' but reference to the original contract (Ref. 10) disproves his thesis. The contract reads as follows:

> "The Stranger Mark Antonio is agreed to deliver theas parcelles following at suche pryces as are mencyond wythe theis particulars following viz:-
>
> 'Fyrst bow-staves of good stuff and not hollow, of the leynght of vj foote and hallf at the lest at ix li to the C. Itm. vj m. bowes redy made and doble ceasoned savying the hornying at xiij li. xs. the C.
>
> 'Itm. the saltpeter of Naples so it be of lyke goodnes to the sample herwyth to be shewed at iij li. v. s. the C.
>
> 'Itm the brymstone so it be of lyke goodnes to the sample herewythe to be shewyd at xiijs the C."

It is, to say the least, improbable that so elaborate a specification would have been prescribed for staves for barrels whereas it would be normal in respect of the supply of bows. Up to the very end of the sixteenth century the long bow remained the most important hand weapon; little wood suitable for bow-staves grew in England, however, and staves were normally imported at prices which, indeed, put them beyond the reach of the average man and made Government purchase unavoidable. Pulling on an average 100 lbs., the war bow was six feet long and usually self-nocked; i.e. the notches for the string, at top and bottom, were integral parts of the bow itself. Fancier bows had horn or ivory nocks fastened to the ends of the bow limbs (Ref. 11), and this is probably what is meant by 'hornyng' in the contract.

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* This theory appears to originate in a brief note to the same effect in F. M. Smith's "Handbook of the Manufacture of Gunpowder" (1870).

On the face of it, this contract for expensive bow staves, despite the conjunction of saltpetre and brimstone, cannot be taken as evidence that the staves were to be used for making barrels for the storage of gunpowder, a purpose for which far less costly timber could have been used and for which 6' 6" lengths would have been quite ridiculous. Thus there is nothing in Thomworth's contract to show that gunpowder was being made at Waltham at the time suggested.

Winter also adduces, apparently in confirmation of his theory of the early origin of the factory, the legend that the remains of the old central tower of the Abbey Church at Waltham were blown up by gunpowder in 1556. The great Abbey Church at Waltham Holy Cross and St. Laurence, built by King Harold, was at the time of the Reformation one of the largest and most beautiful churches in the country. Henry VIII intended to turn it into a Cathedral, (Ref. 12). It was not until 1540 that the Abbey was dissolved, the last in the country to suffer this fate. After that, demolition of the monastic buildings and part of the church east of the central tower was commenced, and this evidently weakened the structure of the tower itself. So, according to Strype (Ref. 13),'on February 9, 1552, between 7 and 8 of the clock in the evening, the great steeple of Waltham Abbey in Essex, fell down to the ground, and all the great bells, and the choir, and much of that stately church demolished with it.' Not all the church collapsed, however, for the part west of the central tower, known as Harold's Nave, which had always been used by the people, stands today as the Parish Church with a new tower, built in 1556-58, at the west end.

Evidently the collapse left the remaining part of the tower in a dangerous condition and it was necessary to demolish it, this being done in 1556. Whether, however, gunpowder was used in the demolition is another matter. Winters does not give any source for his statement, but it seems likely that he drew on Farmer's 'History of the Town and Abbey of Waltham,' (Ref. 14) published in 1735, which gives the following extract from the Churchwardens' Accounts, copied from Fuller's "History of Waltham Abbey" (1655):

'Anno 1556 Mariae 3. Imprimis, for coals to undermine a piece of the steeple which stood after the first fall, two shillings.'

Farmer goes on to explain that 'the steeple formerly stood in the middle of the church, now at the East end of the Church, and, being ruined past possibility of repair fell down of itself, only a remaining part was blown up by miners.' But the reference in the Churchwarden's Accounts to the purchase of coal for the underminers indicates that Farmer and presumably Winters after him, misunderstood the matter, for the use of coal shows that the underminers acted in the normal way by first using timbers to shore up the foundations and afterwards setting fire to them. Unfortunately the volume of the Churchwarden's Accounts containing this reference is no longer extant, so that it is not possible to confirm with certainty that there is no mention of 'blowing up' in them; but 1556 would have been a remarkably early date for the use of gunpowder for demolition work. Indeed Guttmann in his book on Blasting* stated that for three Centuries after its invention (according to him 1310-1320), the sole use of gunpowder was in firearms. He says that the first recorded use of gunpowder for throwing down rock in mining work was made by Gaspar Weindl at Schemnitz in Hungary in 1627. In spite of the fact that an illustration, dated 1570, in the same Author's 'Monumenta Pulveris Pyrii' clearly shows a tower in a besieged fortress being blown up, it seems improbable that Gunpowder was used for civil demolition work at this period and that therefore Winters' statement that gunpowder was used to blow up the Tower was mistaken.

The statement so often made that Waltham started operations in the middle of the 16th Century thus lacks confirmation. There are other claimants to a similar antiquity. Hart, who was a member of the staff of the Public Record Office, wrote in 1855 (Ref. 4) that 'the first establishment of Gunpowder Mills, of any importance, appears to have been at Long Ditton in Surrey, by George Evelyn, Grandfather of the celebrated Sir John Evelyn. He also had mills at Leigh Place near Godstone in the same County. The mills at Faversham in Kent were in operation as far back as the time of Elizabeth, but we cannot say which actually had precedence.'

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* "Blasting" by Oscar Guttmann. London: Chas. Griffin & Co., Ltd. 1906.

A footnote by John Evelyn at the beginning of his diary says "The reste of my Unkles and Aunts, surviving, had considerable estates left and settled upon them, whereof one was John of Godstone, sole master of the Powder Works, of which my Gr. Father had a pattent, derived I think from my Great Gr. Father, who is said to be the first who brought that invention into England out of Flanders, from whence and from Genoa we bought powder at excessive rates. And this manufacture continued in the above named family until the Civil Wars and late Rebellion; when it was taken from it and made a droug by several undertakers."

As Evelyn was born in 1620 and his diary records events from 1641 onwards this lends colour to the supposition that Evelyn's mills started at a very early date, and a chronological table in "The Rise and Progress of the British Explosives Industry" (Ref. 15) asserts that Evelyn's Mills were started about 1561. It is also stated in this book, among some notes contributed by private explosives manufacturing firms, that the factory at Chilworth in Surrey is supposed to have started in 1570, and that the mill at Faversham was, if not the oldest in the Country, at any rate the second oldest.

It seems to be clear that even if any of these mills actually started operations in the middle of the 16th Century they very soon ceased again, for in 1575, Francis Lee, who was then owner of the Rotherhithe Mills previously mentioned and one of the four Master Gunners in the Tower of London, in words that go far towards clarifying the position at that time petitioned the Privy Council for permission to import saltpetre and restart the manufacture of gunpowder (Ref. 16). Although we have not succeeded in tracing any reply to this petition and after the date of it no more is heard of Lee or of the Rotherhithe mill we feel it is worth quoting in full.

"To the Lords and others of the Queen's most honourable Privy Council, Francis Lee, gunpowder maker, wisheth all health and felicity.

"1 Samuel. Chap. 13. Verse 19. "There was no Smith found throughout the land of Israel lest the Hebrews should make them swords and spears".

"So now no powder made for her Highness in England, but provision made out of foreign parts as of late from Barbary, Hamburg and Antwerp which provisions in the time of the Duke D'Alva were cut off.

"In which extremity your petitioner did make 100 lasts * of powder from saltpetre gathered in this realm to the profit of her Highness for he delivered Serpentine at 8d a pound and corn powder at 9d which was £40 a last cheaper than the foreign provision - Yet it is now thought by Her Highness and Council better to pay £10 more a last for foreign provisions than to have her subjects houses digged - Whereupon groweth this further inconvenience that they send over powder made of unrefined saltpetre which at first appears very good but soon appears moist and filthy to the loss of the money laid forth and disappointment of her Majesty's affairs.

"This may be avoided by the provision of saltpetre from overseas which can be stored and turned into gunpowder when necessary, in this way avoiding the risks of fire, lightning and other mishaps (which God forbid), for a fire of saltpetre may be put out, whereas a spark in Gunpowder overwhelmeth all.

"Whereas it is alleged that Her Majesty might suffer great loss by the running out or wasting of saltpetre if it were stored, the truth is that losses of this kind which have happened have only been by want of skill in him that made choice thereof - One skilful man can preserve the petre and deliver powder weight for weight and as cheap as the saltpetre is bought and then Her Majesty shall be furnished with good stuff and shortage, danger and digging avoided.

"In proof whereof and in recompense for the £4000 saved in the making of the 100 lasts above mentioned your petitioner desireth that he may be licensed to make provision of 20 or 30 lasts of saltpetre yearly from overseas till he shall have brought in 100 lasts to set himself and his factory to work as he has no other trade, free or living. The price of the powder shall be but 10d a pound which is the general price for all powder brought in by the merchants.

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* A "last" was a unit of weight which varied according to the district and the materials, but in the case of gunpowder was usually 2400 lbs.

"Your petitioner prayeth that if any objection be raised against him he may be tried touching skill, antiquity, workmanship and price by the accounts of your Majesty's provision wherein it shall be found that for the last fifty years your petitioners father, brother and himself have been the greatest dealers therein and no man in all that time has made better stuff nor served her Majesty so cheap.

"He humbly prayeth also that this trial may be made as he has no other trade and he is possessed of implements for the purpose which have cost much money and shall otherwise stand him in no stead as also and chiefly because all faith, service and duty to Her Majesty and his native country to both of which he shall herein do acceptable service."

The reference to the Queen's objection to having her subjects houses "digged for saltpetre" is one of the earliest mentions of the much disliked activities of the saltpetre men. In the early part of the sixteenth century gunpowder manufacture was beginning to become increasingly important and the supplies of saltpetre, never abundant, more and more difficult.

Saltpetre is formed by the decomposition of animal and vegetable matters under suitable conditions, and it forms an efflorescence on the ground. In countries warm enough to accelerate the decomposition and having long and regular dry seasons, sufficient material can accumulate to make its collection worth while; thus North Africa, India and China were for long the principal producers; but as every country needed a sufficient supply in time of war, Governments encouraged its production under less suitable conditions. In England the workers used the earth of stables, sheep pens, cellars and pigeons houses, and the plaster and rubbish produced when houses were pulled down. Earth mixed with such materials, ashes and lime was stored in well ventilated heaps in barns where it was turned over from time to time and watered with urine and stable drainings. The nitrate so formed was scraped off the surface and extracted with water.

Evelyn's claim that his ancestor had been the first to bring "that invention" (gunpowder) to England from Flanders probably refers to large scale manufacture for, as already mentioned, some powder was made here in the 14th Century, and in 1515 Hans Wolf was appointed to be one of the King's Powder Makers at the Tower and "to go from shire to shire to find stuff to make saltpetre of, where he and his labourers shall labour, dig or break in any ground", and in 1531 Thomas Lee, one of the King's gunners, was appointed principal searcher and maker of gunpowder. Continuing shortages made it necessary to grant licenses to certain individuals giving them special privileges in specified areas which enabled them to dig up the floors of stables, dovecotes and even dwelling houses as they thought fit, and without compensation to the owners, and to demand waggons to carry the material from place to place as required, at the rate of 4d. per mile for a load of one ton.

These very wide privileges were, very naturally, grossly abused. Both Hart (Ref. 4) and "Rise and Progress" (Ref. 15) quote interesting examples showing the widespread discontent thus caused which continued for many years. Even in 1630 a complaint was made to the Lords of the Admiralty that two saltpetre men had been digging in all places without distinction, as in parlours, bedchambers, threshing and malting floors, and even in churches; 'they respect not times, digging in the breeding time in dove houses whereby the flight of doves are destroyed, and in malting houses when green malt is upon the floor'.

In 1589 Queen Elizabeth granted the Evelyn family a monopoly for gathering and working saltpetre for the whole of the South of England and the midlands except the City of London, and this saltpetre was to be made into gunpowder for the Queen's service.

None of the drastic measures taken seem to have produced satisfactory results, for complaints of the shortage of powder recurred. In 1607 the patent was transferred to the Earl of Worcester, whose efforts appear to have been successful, since in 1610 the store was so replenished that he was licensed to transport 'to such parts beyond seas that are in amity with us' any surplus not required in the King's stores. In 1620 Worcester relinquished his patent and Evelyn came into the picture again; but by 1627 the Earl of Totnes, Master of the Ordnance, was complaining that the office was never so weak in powder as now. The fact that Evelyn was protesting at frequent intervals about difficulty in obtaining payment for the

powder he had supplied to the King may have had some bearing on the shortage, but it was also due in some part to the difficulty in obtaining saltpetre for, owing to the continued disorderly conduct of the saltpetre men, 'all men endeavoured to destroy the generation of saltpetre within their possession'. (Ref. 17).

During the seventeenth century, following on the commencement of saltpetre importation and gunpowder manufacture by the East India Company * in 1626 and the abolition of the monopolies of saltpetre and gunpowder in 1641, powder mills seem to have been erected in many parts of the country, and when the Company's charter was renewed in 1693 it was stipulated that there should be an annual provision of 500 tons to the Ordnance (Ref. 18).

It is not until 1662 that we have found any definite record of the Waltham Abbey Factory. In that year Fuller (Ref. 19) who had become perpetual curate of the Abbey in 1648 wrote as follows:

"Gunpowder:- Why hereof in this rather than in other Counties? Because more made by mills of late erected on the river Ley, betwix Waltham and London, than in all England besides. It consisteth of three essential ingredients:-

1. Brimstone, whose office is to catch fire and flame of a sudden and convey it to the other two.

2. Charcoal pulverised, which continueth the fire and quencheth the flame, which otherwise would consume the strength thereof.

3. Salt-Petre, which causeth a windy exhalation and driveth forth the bullet.

This gunpowder is the emblem of politic revenge for it biteth first and barketh afterwards, the bullet being at the mark before the report is heard; so that it maketh a noise not by way of warning but triumph. It is questionable whether the making of gunpowder be more profitable or more dangerous. The mills in my parish have been five times blown up within seven years, but, blessed be God, without the loss of any one man's life".

The quotation is the first clear and definite record of powder mills at Waltham. It seems to indicate that the mills were started about 1650, for if the mills had existed prior to his own time, Fuller would surely have mentioned the point. It is also significant that the first deaths from an explosion at the powder mills recorded in the register of burials of the parish of Waltham Holy Cross occur in October 1665, as follows:-

"Tho. Gutridge, killed with a powder mill, ye 4 day:

Edward Simons, carpenter, so killed, ye 5 day".

The absence of earlier references to such catastrophes lends colour to the view that the starting date of the mills was about 1650, for had the mills been in operation during the previous hundred years there must surely have been other deaths from the same cause, though admittedly earlier records in the parish registers only give names with no information about occupation or mode of death.

A further reason for thinking that the factory is more likely to have started in the 17th Century then the 16th is that a map of the district of about 1590 in the collection of the Marquess of Salisbury shows a fulling mill near the Powder Mill Lane entrance, but makes no mention of any powder mill.

In 1672 one Ralph Hudson seems to have owned the mills (Ref. 2); it is recorded among the manor rolls that, at a Court Baron held on 27th May, 1672, the jury presented that he had erected a powder mill near Hook's Marsh Bridge, to the great nuisance and danger of the inhabitants of Upshire and Hallefield, daily passing with their cattle, the way leading from Hook's Marsh to Edmondsey being obstructed. Hudson was ordered to remove the mill and

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* An interesting account of the manufacture of saltpetre in India is given in A. G. Marshall's "Explosives" Vol. I (London:- Churchill, 1917)

restore the road without delay. A year later, a complaint was made that he had done nothing about it and had, on the contrary, caused further trouble by interfering with water supplies. He was fined £10, but no record is available of his remedying the cause of complaint. The position described is some 500 yds. upstream from the centre of the Factory as shown in Farmer's illustration and later maps, and it may well be that the Hooks Marsh Bridge site (now known as Fishers Green) was the original one and that Hudson moved further downstream as a result of the complaint. Colour is lent to this assumption by the report of a lawsuit (Ref. 20) over water rights in 1731-2 between Charles Wake Jones (joint owner of the Abbey Corn Mill) and Philippa Walton, widow, the owner of the powder mill. One witness deposed that he had known the current called Thoroughgood's Ditch for upwards of 50 years and that the wharfing at the mouth thereof at the River Lea etc., were always, during his memory, repaired and cleaned at the cost of Mr. Hudson, formerly proprietor of the said mills, and since by Mr. Walton, late husband of the said Mrs. Walton, and by Mrs. Walton since his death. He also remembered there being a powder mill at the point under discussion where the intake from the old River Lea to the Mill Head Stream was. The unfortunate widow, Philippa, was required to restrict severely the size of her water intake trough, which she had apparently been enlarging a little at a time for some years.

The effect does not seem to have been as serious as might have been expected, for Farmer in 1735 wrote in his 'History', that 'Near the Town', on one of the rivers are curious gunpowder mills, which supply the nation with great quantities of gunpowder, being esteemed the largest and completest works in Great Britain, and are now the property of Mr. John Walton, a gentleman of known honour and integrity'. He gives in his book a drawing of the factory lay-out, which shows twenty-one buildings. He gives no details of the process used in manufacture, but he does tell us that in the making 'there require three essential ingredients'.

Farmer's reference to the size and excellence of the factory is confirmed by a 'New and Complete History of Essex', published in 1770 (Ref. 21), which refers to 'several curious powder mills, upon a new construction, worked by water, (the old ones having been worked by horses). They are reckoned the most complete in England and will make near one hundred barrels weekly for Government Service, each barrel containing one hundred weight. They are now the property of Bouchier Walton, Esq.'

The use of water power was not entirely new in 1770, for Farmer's 1735 drawing clearly shows corning and glazing engines and stamp mills being operated by water wheels. The employment of water power caused continual difficulties about supply; in 1739 a bill was introduced into Parliament for the improvement of the Lea Navigation and the preservation and improvement of the supply of water to the New River, which had supplied London with good and wholesome water since the time of James I. The bill was resisted by interested parties, among them John Walton of Waltham Abbey who gave evidence on the second reading in the House of Lords. Nevertheless, the bill received the Royal Assent on June 14th, 1739.

Largely because of water shortages horse mills were not entirely discarded until 1814 and it was by the use of horses for the production of one third of the entire output, that output kept pace with demand during the Napoleonic Wars. But water power was always favoured for gunpowder incorporation and continued to be used for that purpose right up to the very end, the last two waterdriven mills being finally put out of action by a land mine on 15th November, 1940.

From the various references quoted it is possible to compile a chronological list of the private owners of the factory with dates at which they were active:-

Ralph Hudson	1672
John Walton I	1675
William Walton	-
Philippa Walton (his widow)	1731
John Walton II (died 1757 without issue)	1735

Bouchier Walton (Grandson of Philippa)	1770
John Walton III	1787

Before leaving the period of private ownership completely some explanation of the curious piece of verse by "Philotechnos", which appears in the front of this volume is due to readers. It is quoted in Farmer's History and, indeed, there seems some reason to believe that "Philotechnos" was no other than Farmer himself. The verse appears to refer to a wonderful musical clock, or Microcosm, built by a local carpenter, one Henry Bridges. This clock struck the hours in the notes of a cuckoo and the dial was illustrated with astronomical signs while the lower part was adorned with representations of rural scenery with a picture in miniature of the Gunpowder Mills. The work occupied Mr. Bridges for nine years and earned him the unstinted admiration of "Philotechnos", who said of him:-

"Nor need you fear the want of being known,

Since Britain's masterpiece in yours is shown".

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CHAPTER II

THE GOVERNMENT TAKES OVER THE FACTORY

The Government seems to have realized the advantages of owning at least a considerable proportion of the production capacity of gunpowder at an early date, and in 1760 Charles, Duke of Marlborough, Master-General of the Ordnance, bought from Thomas Pearse the factory at Faversham previously referred to, which thus became the first Royal factory. His Majesty's Storekeeper was in charge and the output of the factory was about 80 barrels of service powder a week.

In 1781 the corning house and dusting house of this factory, situated almost within the town, blew up, killing three men and doing much damage in the Town, including the destruction of a Church tower at the nearby village of Davington. In 1783, when the fate of the factory had been under discussion for a considerable time, Pitt was on the point of recommending to Parliament the sale of the Faversham Mills, it having been represented to him that the Powder Merchants could make better powder and much cheaper than Government servants. The Duke of Richmond, Master General of the Ordnance, at the behest of Major Congreve, the Deputy Comptroller of the Royal Laboratory, Woolwich, brought forward evidence that Government manufacture of powder was and could be a very profitable proposition, with the result that the scheme was abandoned, and the buildings which housed processes considered dangerous were rebuilt in 1786 further from the Town of Faversham, and negotiations were commenced for the purchase of the privately owned mills at Waltham Abbey. On 11th October, 1787, the minutes of the Honourable Board of Ordnance record receipt of a letter from John Walton of Waltham Abbey, signifying his willingness to dispose of the powder mills, refining house, and fisheries at Waltham Abbey, together with the loose utensils, implements etc. specified in the enclosed inventory, for £10,000 to be paid when Parliament votes the money. His charcoal etc. to be taken away within one month unless purchased by the Board. The offer was accepted and Major Congreve instructed to take over the property. A minute of 22nd October records that he had done so, but from the wages accounts, etc. it is evident that the Board had been employing workers on site for some time before actually completing the purchase.

This is Major Congreve, who became Comptroller of the Royal Laboratory in 1789, rose to the Rank of Lt. Gnl. and was created Baronet in 1812. His son, also William Congreve, was born in 1772 and entered the Artillery as his father had done, after being educated at the Royal Military Academy, Woolwich. He was attached to the Royal Laboratory in 1791 and in 1805 invented the Congreve Rocket, a weapon which, though far from completely successful, remained a service weapon for many years and was the forerunner of all rocket weapons. He was made an F.R.S. in 1811 and entered Parliament the next year. In 1814 he succeeded his father as 2nd Baronet and as Comptroller of the Royal Laboratory. He wrote many economic and scientific works and was a personal favourite of George IV. Both father and son, who for the sake of brevity and clarity we refer to as Wm. Congreve I and Wm. Congreve II, wrote pamphlets about their work at Waltham Abbey. Wm. Congreve I, though the Dictionary of National Biography regards him as a lesser man than his son, was a greater one as far as Waltham Abbey Powder Mills were concerned, but it was not till 1811 that he was able to publish his justifications of himself, which we reproduce as Appendix I, the "Statments of Facts relative to the savings which have arisen from manufacturing gunpowder at the Royal Mills". The economic arguments are unanswerable and the accounts of technical improvements introduced show him to have been a man of great ability.

Wm. Congreve II likewise wrote an account (Appendix II) of the improvements he introduced, being largely an account of a new type of Granulating Machine he patented (No. 3937 of 1815), but he does not impress in the way his father does. It is sad to relate that this man, so distinguished in his day, appears to have got mixed up in some shady financial transactions connected with a mining company and fled the Country early in 1828, dying in Toulouse a few months later. His obituary notice in the "Gentleman's Magazine" for August, 1828 tells also that one of the French papers reported that he had left a widow, several children and an immense fortune, but adds that this may be seriously doubted as he was not married till 1824.

Though the Waltham Mills had been in operation many years prior to the purchase by the Government it seems probable that they had suffered some neglect and a great deal of work was put in to improve them and increase their capacity. Some £35,000 or 3½ times the purchase price was spent in expenses, repairs and improvements including the purchase of the water of the Cheshunt and Waltham Abbey corn mills, a deal which increased the capacity of the works from 15,000 to 20,000 barrels a year.

On 17th September, 1787, nearly a month before the takeover became official, Congreve was already busy putting his new command in order for he wrote as follows to Mr. Daniel Cornish, Carpenter.

"I am directed by his Grace the Duke of Richmond to desire you will immediately hire the best of the millmen and labourers who lately worked at Mr. Walton's powder mills. They will be paid nine shillings per week for month certain, and for every week they may be continued in Powder Mills if they should be purchased by the Government; and the above men will be allowed every advantage that has been hitherto given to the millmen and labourers who work in the Royal Powder Mills at Faversham. Mr. Cornish, you will be paid fifteen shillings a week from the date hereof for one month certain. (Signed) Wm. Congreve, Major of Artillery, Waltham Abbey.
N.B. The Duke of Richmond may be seen at Whitehall on Sunday morning at 10 o'clock".

The first Cash Book of the factory opens on 31st October, 1787 with a petition for wages.

"Daniel Cornish, Carpenter of this Place, Humbly prays an allowance of the undermentioned sums, the same being his pay from 21st September to the 18th October, 1787, both days inclusive and prior to his being put on the List of Artificers and Labours employed at this place. Viz:-

September 30th	To 8 days pay at 2/6 per day	£1.	0.	0.
October 18th	To 16 " " at ditto	£2.	0.	0.
		£3	0.	0.

Humbly Certified
Willm. Sutton
Acting Overseer
Under Mr. Bennet"

Bartholemew Bennet was Clerk of Works at Faversham, and the letter books contain many communications from him which show that he took a very active and personal interest in the new factory, giving much sound advice and technical information.

The first wages list of the same date includes Edward Jones, Millwright at 3/6 per day, three carpenters (including Cornish) at 2/6, four sawyers at 2/6 and thirty-two labourers at 1/6. Pay dates from 19th September, 1787. The second list includes seven carpenters, and in the third, three more millwrights appear. It is interesting to note that, of the thirty odd labourers only six or seven sign their names. Wages do not appear to have been paid at regular intervals - the first pay days being 31st Oct., 13th November, 26th Nov., 30th Nov., 10th Dec., 20th Dec., 31st Dec.

On 18th November 1787, James Wright was appointed Storekeeper and was in effective charge of the factory. Men were sent to Faversham to learn to make powder for the Government Service. At the end of the year Wright sent in a demand for "Stationery judged necessary for carrying on his Majesty's service at this place on its first establishment and for the current year" as well as demands for materials and stores, all with details of the buildings in which they were to be used, so that he must have spent a remarkably busy six weeks, getting settled into his new job. He also sent in an account of his disbursements and a demand for travelling expenses.

He undoubtedly received a great deal of help from Faversham but his achievement was a very real one and he may well be regarded as one of the builders of Waltham.

All the time Major Congreve was pushing for an early start to production and asking what progress was being made; e.g. on 18th December, 1787, he asks how long it will be before the new press is put up in the corning house and whether the canvas glazing and dusting reel is nearly complete. He had given his first operating instructions on 25th October 1787, stating that the proportion of ingredients was to be 75 lbs. Saltpetre, 10 lbs. Sulphur and 15 lbs. Charcoal and adding:-

"In order that Gunpowder may be made as soon as possible the mode of working it for the present must be as formerly practised by the Merchants except that each charge of green Composition must not be worked less than four hours".

The optimistic point of view which gave rise to expectations of an early start proved to be ill-founded. It appears that the amount of work necessary to put the mills into good working order and, in particular, to control the water supply had been greatly underestimated.

An ample supply of water for transport and power was of course a major necessity to the powder manufacturer. While the water supply at Waltham Abbey was adequate for the factory's needs it was not under proper control. The locks were in a serious state of disrepair, causing great waste of water, and, at times, serious flooding. For many years the Board was engaged in constant warfare with this unruly element, to say nothing of legal squabbles concerning fishing rights, responsibility for maintenance and so forth. Two letters of December 1810 give very full details of all the stoppages of the water driven mills from various causes between 1804 and 1810 and it is clear that the position was still far from satisfactory.

The first letter recorded in the "Letters Received" book is one from Major Congreve insisting that no gardens may be allowed on the banks of the Powder Mill stream because they would damage the banks by loosening the earth, and on 11th January, 1788 Storekeeper Wright complains that he could not get supplies in, as the whole country was under water from the late great floods. On 26th March, he is still busy cleansing the river and tail stream bed. "I wish you could look in on us" he writes to Major Congreve, "as we have some difficulties to go through, but if I cannot have that pleasure, I hope we shall accomplish this work so as to meet your approbation". In a report dated 17th January, 1788 Congreve says that £7,988. 18. 8¾d. had already been spent on putting the works into proper condition.

Extensive alterations and repairs had been settled on and a new mixing house and saltpetre refinery were to be built, but in spite of all efforts progress seems to have been remarkably slow, owing to the arguments about water supplies and the difficulty in securing much needed repairs to the locks on the river Lea. About the middle of 1788 it seems that they were again optimistic about an early start for Congreve wrote to Mr. William Newton, who by then had been appointed Master Worker, on 8th July of that year.

"Sir,

You will make use of the proportion of ingredients in the Gunpowder which you manufacture at Waltham Abbey until further orders.

Saltpetre 75 lbs.

Sulphur 10 lbs.

Charcoal 15 lbs.

You are to corn your powder from cake and dust of the mill charges pressed together a sufficient time to bring it into a firm body - The dust which is produced from corning this first powder, called the first dust, after having the fine grain separated from it, also to be pressed and corned. Great care must be taken that both dusts are pressed sufficiently firm to prevent the powder from being of a rotten grain. The remains of the dust after working the second dust into gunpowder is to have the fine grain separated from it and is then to be sent to a mill to be worked for one hour and a half. You must be particularly careful that the several ingredients are pulverized as near as possible to the same degree of fineness. They are to be put into a charge tub in alternate layers, to be well blended with a stirrer and then to be passed through a

fine wire sieve to make as intimate a mixture as possible. Your charges of green composition are never to be worked less than three hours exclusive of the time required to load and unload the mills and as much longer as you may find it necessary from time to time to bring it into a proper state. After the powder is corned it is to be moderately glazed. It is then to be stove dried with such a degree of heat that the thermometer in the door of the stove may not be less than 90 degrees when the stove is at its hottest. The Powder is never to be barrelled up from the stove until it is sufficiently cool and has been passed through a powder screen.

(Signed) William Congreve"

But with all this no powder seems to have been made that year and on 6th February, 1789, Wright and Clowdesley, the Clerk of Cheque, wrote to Congreve as follows:

"Sir,

We have (by a messenger) received your directions to set the Mills to work, we beg leave to acquaint you we mean to begin on Monday morning and it will take up all day tomorrow to provide the horses for grinding the composition and various other small matters it will be necessary to adjust before we begin.

We beg to inform you that we have your directions of 8th July on the Mode of Working but you took back the paper which you gave the Storekeeper wherein the manner of marking the barrels were inserted. We likewise beg to acquaint you that we have no Cooper which Mr. Forman intimated would be sent from the Laboratory.

We have no mode of drying mill samples at present as the cylinder is not set in the proof house, neither does Mr. Sutton know it is to be fixed, therefore the Master Worker thinks to work 35 and 32 pound charges until the samples can be tried and proved that some conclusion may be drawn on working 38 lb. charges.

(Signed) Jas. Wright.

Jno. Clowdesley.

So at last a start was made, presumably on Monday, 9th February, but on the 12th we find a Report of the first "blow-up".

"My Lord Duke and Rt. Honourable and Honourable Gents,

We beg leave to report that last night at 6 o'clock, the second of the No. 16 Head Mills blew up. The charge had not been on the bed more than five minutes. As the mill did not receive any injury it was set again to work this day at 10 o'clock.

We are,

Your most faithful obedient Servants,

Jas. Wright, Jno. Clowdesley

His Grace the Duke of Richmond and the Honourable Board of Ordnance".

Even then teething troubles were not at an end, for we find a note dated February 27th sent to Woolwich asking if they can supply the bearer (the newly appointed Cooper) with three bundles of hoops for powder barrels "as we have powder ready for heading up and no barrels to put it in".

After this unfortunate start things seem to have progressed and though "blow-ups" were frequent no serious damage is reported. When an inspection was made by order of Major Congreve by the Fire Masters and Assistant Firemasters on 18th August, 1789 they reported that the saltpetre refining and the manufacture of Gunpowder was being conducted in a highly satisfactory manner and that the various buildings appeared to be well calculated for the purpose for which they were intended.

According to present day standards this appears a very charitable view of the position for "blow-ups" were frequent occurrences and seem to have been taken almost as a matter of course. Generally they were due to the charge on the bed of the mill firing, and provided no one was near at the moment little damage resulted.

It is necessary, however, when dealing critically with these records to keep in mind the contemporary state of knowledge; Lavoisier's "Traite Elementaire de Chimie" was published in the year 1789 and Dalton's "New System of Chemical Philosophy" in 1808. It was many years before the full implications of the theory of combustion and of chemical combination were fully realised. Without clear ideas on these matters it was quite impossible to make much headway in the systematic study of explosions or to evolve a well defined system of safety measures.

The state of knowledge at this period is clearly shown by a quotation from a paper given to the Royal Irish Academy in 1788 by the Honourable George Napier, who had been Comptroller of the Royal Laboratory at Woolwich, (1782/3) and entitled "Observations on Gunpowder".

> "It does not always follow that the purest nitre produces the strongest powder. In Russia I am informed they seldom refine their nitre more than twice, and having analysed some very excellent Russian powder, I found the saltpetre contained a considerable portion of marine salt and magnesia. It is difficult to account for this phenomenon, as marine salt both impedes the ignition and lessens the explosion of gunpowder; and I believe it may be demonstrated that magnesian or calcareous nitre produces at least the last of these effects, if we consider the faintness of its own detonation, when it has any; and that deliquescent quality, which must communicate a degree of humidity of the composition, inimical to a forcible explosion; and (what is in my opinion of much greater consequence) which must be noxious in the extreme to the durability of gunpowder: I have reason to believe (as far as my experience can establish the fact) that powder made with saltpetre, oftener than four times refined, is of inferior strength, though probably more durable, that that which has been only twice depurated. If the elastic and expansive fluid contained in nitre partakes of all of a spirituous nature, may not repeated evaporation liberate a portion of it?
>
> Stahl asserts that the nitrous acid is a combination of the vitriolic acid with the principle of inflammability, effected by the agency of putrefaction; and Piatch of the Berlin Academy seems to prove this theory by his experiment of moistening a calcareous stone with vitriolic acid and wine, which being exposed for some time to the action of the atmosphere was found to be strongly impregnated with nitre. If the aforesaid experiment be accurate we must admit that saltpetre is a compound substance, and it may not be a very improbable deduction to suppose that elization in part deprives this salt of that elastic fluid which constitutes the strength of gunpowder.
>
> I cannot in this place omit noting the paradoxical peculiarities of this extraordinary fossil (saltpetre) which, generated by a combination of animal and vegetable putrefaction exhibits the most energetic of antiputrescent principles, and, though classed among the coolest of the saline genus, is replete with vehement and irrestible fire".

The Congreves, father and son, were far in advance of this curious mixture of tradition and empiricism, almost worthy of an alchemist, and the men who were chosen to run the Royal Gunpowder Factory seem to have been forward-looking.

In 1794 the Government took a further step away from dependence on private producers by establishing a third Royal Factory at Ballincollig, near Cork, on land adjacent to the Cavalry Barracks and with very excellent water-power provided by the river Lea, but this factory was closed during the period of retrenchment which followed the Napoleonic Wars.

CHAPTER III

THE MANUFACTURE OF GUNPOWDER

For a full understanding of the problems of the hundred years or so during which gunpowder was the sole or main manufacture of the Royal Gunpowder Factory it is necessary to have a general idea of the processes involved and how they are and have been carried out.

In this chapter an attempt is made to provide this information briefly but clearly. Gunpowder is an intimate mixture of saltpetre, charcoal and sulphur in proportions which may vary over a considerable range, but are normally 75, 15, 10. It was usual for the saltpetre to be purified by recrystallization, and the sulphur by sublimation in the gunpowder factory. The charcoal was usually made in woods near the factory, principally from alder, willow and dogwood and the old method of burning in heaps under carefully controlled conditions did not produce a sufficiently uniform product to make good gunpowder, but was not superseded, as will be seen, till the beginning of the 19th Century.

The methods by which the processes of manufacture are carried out have changed slightly during the centuries as more experience was gained and more suitable machinery became available, but basically there has been little change since the 16th Century when "corning" was introduced. The original gunpowder, called "serpentine powder" was merely a loose mechanical mixture of the three ingredients. Its combustion was slow and irregular and much gas escaped through the vent of the gun so that a very low velocity was imparted to the shot. Corned powder consists of hard compressed grains of controlled and regular size and it was this feature that made gunpowder such a suitable material as a propellant for use in guns that it remained unchallenged till the end of the Nineteenth Century.

The three ingredients are first ground separately, foreign matter being removed by sieving and are then weighed out in the correct proportions and given a preliminary mix in a cylindrical drum on the axle of which are mounted a number of radial arms - the drum and the arms rotate in opposite directions at different speeds. A few minutes mixing, followed by another sieving to remove hard lumps that might cause an explosion during subsequent operations, suffices to prepare the mixture for incorporating or milling, the first real gunpowder process, which is carried out in iron edge runner mills of the type formerly used for mortar mixing.

These mills were continually increased in size and those in use at Waltham when gunpowder manufacture was discontinued had runners about 8 feet in diameter weighing some 5 tons each. These runners are supported in such a way as to allow independent vertical motion but to prevent actual contact with the bed plate. Two wooden ploughs covered with leather stir up the charge and prevent it from accumulating at the centre and edge of the bed plate. The most usual method of driving these mills was by water wheel, normally one wheel situated between two mills, but horse mills were used at various times and steam mills were introduced in 1856.

The mills were isolated from each other by strong masonry walls and the charge kept damp during milling. Automatic drowning arrangements were a further safety measure, but the risks of milling, which must originally have been very considerable, were greatly reduced by improved mill construction.

Earlier edge runner mills, such as those used at the time of the factory becoming Government property were built either of cast iron or stone and the runners rode freely on the bed plate. Even earlier, stamp mills had been used. The usual type of construction was a large block of granite with a number of basin shaped depressions in it. The powder was placed in these basins and pounded by a cam operated series of heavy wooden uprights. At the time the factory was started hand operated mortars and pestles were used, the pestle being sometimes hung from a spring beam. Such appliances must have been extremely dangerous and it is perhaps as well that the high price and scarcity of saltpetre prevented the use of a recipe for gunpowder that would develop the maximum strength.

The product of milling is known as "mill-cake". It contains hard pieces of material formed under the weight of the runners which may adhere to the bed plate. Great care has to be exercised when the mill is being emptied and only wooden tools are used.

The mill cake was broken up by hand with wooden mallets and put on sieves agitated in such a way that a flat circular piece of lignum vitae in each sieve took a sufficient velocity to break up the lumps of powder and force it through the sieve. These pieces were separated from dust by further sieving and were hardened and had the rough edges taken off by being given a treatment in a closed revolving cylindrical reel.

It was not possible to produce a really hard compact grain by this method and round about the time the Waltham factory was taken over by the Government, presses, at first screw, and later hydraulic, were beginning to be used to produce a hard dense "press cake".

A press charge is built up of a number of layers of powder on copper sheets. These layers are "struck off" level in a wooden frame, which is then removed so that the powder is not confined during pressing. The copper plates may be as much as 30" square and the charge of 1" thick layers of powder may weigh 1000 lbs. The usual pressure is 600-800 lbs. per square inch on the powder. Pressing is one of the most dangerous operations in gunpowder manufacture and is remotely controlled.

The press cake was at first broken up and sieved in just the same way as mill cake had been, but improved methods were soon forthcoming.

The press cake was fed into a granulating machine where it passed between three or four pairs of rolls, toothed, serrated and smooth. One of each pair of rolls was mounted on sliding bearings held by springs, so that if an extra hard piece of cake or a foreign body was found it would pass through without producing excessive friction or heat. Between each pair of rolls automatic sieves sort out material of different sizes. Dust or fine powder is collected and returned for reincorporation and pressing. This type of granulating machine was invented by Wm. Congreve II, the Comptroller of the Royal Laboratory, in 1815 (see Appendix II) and, while improved in detail, has never been completely superseded.

Owing to the continually increasing size of artillery weapons a demand arose for powder in larger and more regular grain sizes. Cubes were first cut from press cake and in the 1880's cylinders and hexagonal prisms were pressed from broken press cake.

Powder corned by the standard method may require to be dusted especially if made from dogwood, an operation normally carried out in a dusting reel, a cylindrical reel set at a slight angle to the horizontal and covered with fine gauze. Slow burning powders are glazed by rotating in a wooden drum with a little graphite, and the powder is finally dried in a steam heated stove at 40°C to about 1% moisture.

Before the advent of steam, heating powder was dried in an alarming apparatus known as a "gloom stove". It consisted of a large cast iron vessel projecting into one side of a room and heated from the outside by a fire. A sheet of copper was placed over the pot when the powder was charged or discharged and this again was covered with a canvas screen. Some idea of the size of the glooms may be gathered from the fact that Winters says the covers for the first glooms were 10 feet by 12 feet. Earlier methods of drying seem somewhat obscure, but the view of the factory in Farmer's "History of Waltham" (1735) shows a "little stove" and a "Great stove", both brick buildings complete with chimneys and three "Sun stoves or drying leads" which look rather like garden frames.

The manufacture of Gunpowder was from the earliest times regarded as something of a black art and the amount of authentic published matter on the subject is small, so that the very full collection of record books, correspondence etc. from Waltham, now indexed in Public Record Office under the generic reference "Supply 5" is a valuable contribution to knowledge.

Richard Coleman, who was graded as a Clerk, and earned £70 a year, kept a diary of interesting things that happened in the factory from 1793 to 1796, which is a valuable source of information for that period. He also gave a paper before the Askesian Society in May, 1801 describing the manufacture of gunpowder in some detail. This was published in the Philosophical Magazine for 1801 and is reproduced as Appendix III. It is quite remarkably well informed, and contains a good account of gunpowder manufacture as then carried out and interesting speculations on its explosive force. The next and most complete record we have is the very remarkable "Treatise on Gunpowder" by Frederick Drayson (Supply 5/762). This is a beautifully handwritten folio volume

containing 79 pages of text and 37 detailed drawings giving plans, sections and perspective views of all buildings and drawings of the utensils used in them. Every building is fully described in the text and all the processes including the refining of nitre and sulphur, the burning of charcoal, the regeneration of damaged gunpowder and the recovery of saltpetre from unserviceable powder are dealt with in detail. There are observations on each building and process and suggestions for improvements and a report on the condition of the factory with plans for its extension, repair and improvement.

It is described as being written for the Honourable Board of Ordnance by their authority dated 13th August, 1830, that is, only a year after the position had been investigated by a committee appointed for the purpose of reporting on the improvements necessary to bring the factory to a state of high efficiency. Just who Frederick Drayson was is not at all clear*, as no other reference to him has been found except two rather obscure remarks in Winter's History:-

"1830 August 5th Mr. Drayson. Letter proposes a place of corning powder."

"1831 January 25th Mr. Drayson's method not approved of by the Board."

If this last remark is of general application Drayson must have been a very disappointed man. There can be no doubt that he had worked hard and made a very good job of describing the process as it then existed. He summarized his suggestions for improving the process as follows:

"1. The process of refining nitre may be rendered less expensive and that the ingredient need not be melted, thus exposing it to the liability of receiving injury.

2. That the charcoal may be produced of far superior quality and at less cost than that now used.

3. The sulphur may be rendered perfectly pure by a process not so expensive as the one to which it is now submitted, and which only removes half the impurities from it.

4. That the process of amalgamation may be much improved.

5. That the danger and expense of granulating may be greatly reduced and the operation rendered much less complex.

6. That the mode of drying the powder may be improved.

7. The ingredients may be prepared and mixed in such a manner as either greatly to increase the strength of gunpowder or to diminish the time required for its amalgamation.

8. There is 43 per cent of grain, superior to either the cannon or musket powder now produced, which is contained in the dust and sent to be reworked, but which might be separated from it without again undergoing the processes of amalgamation, pressing and granulation which alone I trust is a suggestion entitled to a favourable consideration."

If indeed these suggestions, which are fully detailed in the text, were turned down in the brusque manner Winters appears to suggest, one feels he must ever after have been a man with a grievance.

* He may well have been related to William Drayson who was Clerk of Works in 1827.

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(Supply 5/762)

CHAPTER IV

CHARCOAL AND BISHOP WATSON

The importance of charcoal, the most variable of the three ingredients of gunpowder, has already been mentioned and both Congreve I (Appendix I) and Coleman (Appendix III) refer in glowing terms to the improvement brought about in the first few years after the Government took over the factory by the introduction of "cylinder charcoal". Congreve says this improvement was first suggested by Dr. Watson, "the celebrated chemist".

Investigation has shown that Dr. Watson was no other than the Right Reverend Richard Watson, D.D., F.R.S., Lord Bishop of Llandaff. This very remarkable man was born, the son of a Westmorland schoolmaster, in 1737. He went to Trinity College Cambridge on an Exhibition in 1764 and commenced his studies with great eagerness, his father having died the previous year and left him only £300, so that as soon as his education was complete he would have to rely entirely on his own efforts.

Two and a half years later he secured a scholarship and took his first holiday, visiting his elder and only brother. Of him he says, "He was the first curate of a new chapel at Kendal, to the structure of which he had subscribed liberally. He was a man of lively parts, but being thrown into a situation where there was no great room for the display of his talents, and much temptation to convivial festivity, he spent his fortune, injured his constitution and died when I was about 33, leaving a considerable debt, all of which I paid immediately though it took almost my all to do it."

He returned to Cambridge and in view of his straitened circumstances became mathematical tutor to two other students of the year below his, although he really wanted the time to study.

He was a hard worker. He felt he never really understood a proposition in mathematics or natural philosophy till he was able, in a solitary walk, to draw the scheme in his head and go through every step of the demonstration without book, pen or paper (He found Euclid, Book XII, Conic Sections and Newton's "Principia", very difficult). He became a good classicist and was very interested in logic.

He took his B.A. in 1759 and was second Wrangler of the year. He felt he had been wronged over this and the senior position was his of right. He was later to take effective steps to stop such honours being granted by favour rather than according to merit.

In October, 1760 he was elected a Fellow of Trinity and continued as a tutor, refusing one or two offers of curacies. He took his M.A. in 1762 and was made Moderator for Trinity College the next year.

In 1764 he heard that an old friend had separated from his wife and gone abroad. He immediately set off for Paris somewhat inadequately equipped with a French Dictionary and a borrowed £50. He found his friend and after a variety of accidents and great fatigue (including crossing the Channel 4 times in a fortnight) brought him back to his country and family in time to squash scandal and prevent him from being thrown out of the House of Commons.

On 19th November the same year he was elected by the Senate Professor of Chemistry. Of this appointment he says in his autobiography:-

"At the time this honour was conferred upon me, I knew nothing at all of Chemistry, had never read a syllable on the subject; nor seen a single experiment in it; but I was tired with mathematics and natural philosophy, and the "vehementissima gloria cupido" stimulated me to try my strength in a new pursuit, and the kindness of the University (it was always kind to me) animated me to very extraordinary exertions. I sent immediately after my election, to Paris for an operator. I buried myself as it were in my laboratory, at least as much as my other avocations would permit; and in fourteen months from my election, I read a course of chemical lectures to a very full audience, consisting of persons of all ages and degrees, in the University. I read another course in November, 1766, and was made Moderator, for the fourth time, in October, 1765."

He tells us that there was no stipend attached to the Professorship at that time nor anything furnished by the University except a room to read lectures in. He sent a petition to Lord Rockingham, a Minister, for a stipend from the Crown. The latter gave it to the Duke of Newcastle to forward and much delay ensured but by firmness and persistence Watson managed to see Lord Rockingham who was 'on the point of going out of office', but undertook to ask the King and offered to have the £100 a year Watson asked for settled on him for life. He refused this saying he only wanted it while he remained Professor of Chemistry.

He seems to have done a great deal towards putting the affairs of the University in order as the following passage shows.

"In January every year, when the Bachelors of Art take their degrees, one of the two Moderators makes a sort of speech in Latin to the Senate; I made this speech three times: the last was in 1766. I had, in a former speech, taken the liberty to mention, with great freedom, some defects in the University education, especially with respect to Noblemen and Fellow-Commoners: and strongly insisted on the propriety of obliging them to keep exercises in the schools, as the other candidates for degrees did. In this last speech I recommended the instituting of public annual examinations, in prescribed books, of all the orders of students in the University. I mentioned also the necessity of allowing more time for the examination, and of appointing more examiners, and of particularly distinguishing, by separate honours, the best proficients in several branches of science; that those who could not excel in the abstract sciences, or natural philosophy, might have some chance for distinction in ethics and metaphysics."

At the same time his interests continued to widen and he tells the following anecdote:

"Whilst I was Professor of Chemistry, I dissected a subject which I had procured from London, in order to perfect myself in Anatomy; my laboratory was my theatre, and Professor Waring, known to Europe by his mathematical publications, and my old friend Preston (afterwards Bishop of Ferns), were my assistants. When we had finished the business we put what remained of the body into a box, and commissioned an old soldier to bury it in the fields. The man thought the box was worth something, and instead of burying it he opened it, and poured the contents into the Cam, and as there happened then to be a great flood, some of them drifted on shore and excited a great suspicion of murder having been committed; but as no person was either taken up or suspected of it, we carefully kept our secret, and thus probably escaped being stoned, like anatomists of old, by a superstitious populace."

He became a Head Tutor in 1767. At this period of his life he worked prodigiously. He read three public lectures daily in Trinity College beginning at 8 O'Clock. He then spent 4-5 hours with his private pupils and 5-6 more in his laboratory.

In 1768 he sent in a paper to the Royal Society about the phenomena attending the solution of salts and was elected F.R.S.

The next year the Regius Professor of Divinity died and Watson was encouraged to put himself forward for this, the first office for honour in the University. He tells us that he was momentarily puzzled by the fact that he had no Divinity degree, which was absolutely necessary for the job. He had only seven days to transact the business in, but "by hard travelling and some adroitness" accomplished his purpose and obtained the King's mandate for a Doctor's degree and was created a Doctor with a day to spare.

When he got the job he applied himself with equal eagerness to the study of divinity and participation in politics. He wrote letters and sermons and expressed his views very strongly on a variety of subjects. He was a Whig, a great lover of personal liberty, and he opposed the American war as not only inexpedient, but unjust.

He never hesitated to speak his mind even when it was to his own disadvantage. He was soon at loggerheads with the Archbishop and roundly accused the King (George III) of breaches of the Royal Perogative (he had appointed Lord Sherborne to the Treasury on the death of Lord Rockingham without waiting for the recommendation of the Cabinet). Some of his political maxims are worth remembering.

"Patriotism is a scandalous game played by public men for private ends and frequently little better than a selfish struggle for power."

"To forget all benefits and to conceal the remembrance of all injuries, are maxims by which political men lose their honour, but make their fortunes."

In 1782 when the opportunity arose he did not scruple to make use of his political and titled ex-pupils to secure for himself the Bishopric of Llandaff. In this post he remainded till his death in 1816, political pressure preventing further promotion for a man who supported the French Revolution, Catholic and Nonconformist emancipation and electoral reform, and who violently opposed slavery.

Nevertheless, in 1786 he was asked by the Government if he could give any advice relative to improving the strength of gunpowder and he suggested making charcoal by distilling the wood in closed vessels, a method of manufacture suggested some time previously by George Fordyce, M.D., F.R.S., an eminent physician and the author of several chemical treatises. His own account of the result of this suggestion is as follows:

"The suggestion was put in execution at Hythe, in 1787, and the improvement has exceeded my utmost expectation. Major-General Congreve delivered to me a paper, containing an account of the experiments which have been made with the cylinder powder, (so called from the wood being distilled in iron cylinders), in all of which its superiority over every other species of powder was sufficiently established. In particular, a given quantity of gunpowder, made with this kind of charcoal, threw a ball of sixty-eight pounds weight, two hundred and seventy-three feet; whilst the same mortar, at an equal elevation, and charged with an equal weight of gunpowder made with charcoal prepared in the best of the ordinary ways, threw an equal ball only one hundred and seventy-two feet. In this experiment, the strength of the cylinder, estimated by the horizontal range, is to that of the best sort of other powder, as 100 to 63. By experiments with the Eprouvette, the proportion of the strength of the cylinder to other powder was that of 100:54. In round numbers, it may perhaps be near enough to the truth to say, that the strength of the cylinder powder is to that of other powder, as 100:60, or 5:3. One of the clerks in the laboratory at Woolwich desired a gentleman, in 1803, to inform me, (as he suspected I did not know it), that I had for several years saved to the government one hundred thousand pounds a year. I have never inquired whether this information is correct; nor if it should turn out to be so, have I any intention of applying for a reward. My country is welcome to my services in every way; but if, in the vicissitudes incident to all families, my posterity should be my misfortune, not occasioned by vice or indiscretion, reduced to beggary, I would advise them to petition the House of Commons for a remunderation; they may do it with a just confidence of being listened to. At a levee, soon after the experiments on gunpowder had been made, I happened to be standing next to the Duke of Richmond, then Master General of the Ordnance, and the duke informed His Majesty, that they were indebted to me for a great improvement in its fabrication. On my saying that I ought to be ashamed of myself, inasmuch as it was a scandal in a Christian Bishop to instruct men in the mode of destroying mankind, the King answered, "Let not that afflict your conscience, for the quicker the conflict, the less the slaughter," or in words to that effect. I mention this to do justice to the King, whose understanding it was the fashion to decry. In all the conversations I had with him, he appeared to me not at all deficient in quickness or intelligence."

One is left wondering whether any of this remarkable Bishop's descendants were ever reduced to petitioning the House of Commons as he suggested and what success they had.

It was some considerable time before powder containing cylinder charcoal was introduced into the service for it is stated in Coleman's diary referred to in the last Chapter that a barge loaded with the first freight of cylinder coal returned to the factory on April 6th, 1794. Undoubtedly some of the intervening time must have been spent in the development of suitable plant to carry out the Bishop's suggestion and there may well have been opposition to the introduction of a novelty. Once difficulties had been overcome the advantages of cylinder charcoal were so obvious that pit charcoal went completely out of use. Early in the new Century the Government dealt drastically with the problem of supplies of cylinder charcoal by establishing two cylinder charcoal works in the Sussex Weald at Fernhurst and Fisher Street.

They were in charge of the Storekeeper at Waltham who visited them frequently and some of the buildings at both places still exist, converted into cottages (Transactions, Newcomen Society, 1938, p.61). Cylinder burning was transferred to Faversham after the Napoleonic Wars, when these two small works seem to have been closed down, and to Waltham in 1831.

As far as one can tell from his book, Bishop Watson seldom visited his diocese and never lived there. He had to give up his Cambridge appointment in 1787 because of his health and then went to live in Westmorland and occupied himself as an improver of land and planter of trees. His health improved and he made money, which gave him satisfaction in that he had by his own efforts counteracted the effects which might otherwise have followed the neglect he experienced from the Court or its Ministers, so that he was able to pity and forgive the littleness of mind which occasioned it.

He did not believe in Christian Missionaries ("they are more interested in bringing over dissenters to episcopacy than in converting the Heathen") but believed that Christianity would be better propagated by the extension of science and commerce. He thought Russia would Christianize Japan, China and Tibet, and England would do the same for India.

He continued to publish sermons and pamphlets such as one in 1796 "An Apology for the Bible", being a defence of that Holy Book against the scurrilous abuse of Thomas Paine. He continued to press for an understanding with France and for an honourable Union on equitable terms with Ireland, which took place in 1800.

He became an authority on agriculture and pressed for £10 million or more to bring into cultivation all the waste land in the Country and for the tax to be taken off coal carried coast wise and used in burning lime for agriculture.

When he heard that the poet Cowper was in a very depressed state of mind he wrote a letter to him, although he did not know him personally, speaking of the great pleasure he had derived from a re-reading of the poems which impressed by the way they supported the cause of piety and virtue and invited him to come and enjoy the hospitality of Calgarth Hall, his home in the Lake District.

When his son married in 1805 he wrote to the Duke of York asking his protection for him in view of all he (the Bishop) had done to support the religion and constitution of the Country. This solicitation of favour was a success and the son was promoted from Major to Lt. Col. in the 3rd Dragoon Guards.

This remarkable man continued, in spite of failing health, in good works of all kinds. In 1805/6 he planted 22,500 larches on the shores of Windermere and improved over 150 acres of land not worth 2/- an acre. He wrote a paper on this work for the Board of Agriculture and was given a gold medal inscribed "Private Wealth and Public Strength". He worked for the gradual abolition of the slave trade and slavery. His idea was to refuse to allow the importation of more slaves and to liberate all children of existing slaves at the age of 21.

He thought the education of the children of the poor deserved the consideration of the Government inasmuch as a proper education is the parent of piety and good morals. He did not think this education should be free and felt that very few parents could not spare 3d. a week for 2-3 years for the education of each of their children.

He was asked to write a refutation of Malthus' "Essay on Population" but replied that he had only read far enough to discover that the author was trying to show the utility of bringing the population of the earth down to the level requisite for its support whereas he thought that he would have been better employed in investigating means of increasing the subsistence to the level of the population.

His opposition to what the Whigs regarded as the increased and increasing influence of the Crown apparently annoyed the King greatly and when an opportunity arose for his translation to the Archbishopric of York, Pitt let him know that although he was the most suitable candidate the King would not hear of it. He finishes this anecdote by saying "I ought to say with St. Paul Thou shalt not speak evil of the Ruler of the people."

In 1809 he records that he visited his diocese and went over the mountains from Neath to Merthyr Tydvil where no confirmation had ever been held before. In his time it had grown from a small village to a great town of 10-12 thousand inhabitants. His host was Mr. Crawshaw, one of the most intelligent and opulent iron-masters in Europe. In bidding the bishop farewell he said "If ever you have occasion for 5 to 10 thousand pounds, I am entirely at your service". He says he was more pleased with this substantial proof of the disinterested approbation of an iron-master than he could have been with an archbishopric obtained by selfish subserviency to the despotic principles of a court.

In the next few years he suffered a succession of mild strokes and, while his bodily activity was restricted, his mind seems to have been as alert and vigorous as ever. A typical remark of this period in answer to a query about reform in the representation of the people was "I have never seen a plan calculated to do much good. As the old Duke of Newcastle said 'it is cheaper to buy the elected in the House of Commons than the electors in rotton Burghs'".

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CHAPTER V

PROGRESS - FROM THE TAKE OVER TO THE TURN OF THE CENTURY

It has already been shown that the works at Waltham were not in particularly good condition when they were taken over by the government. No contemporary account has been found of just what was taken over, but Frederick Drayson's 1830 "Treatise on Gunpowder" previously referred to contains an introduction which says:

"When purchased by the government in 1787, the Factory consisted of a saltpetre refinery, since pulled down, a composition mill worked by horses, a mixing house, seven gunpowder mills, a corning house worked by horses (destroyed in 1801 by an explosion and not rebuilt), a dusting house and two gloom stoves. It might be considered capable of producing 6000 barrels of gunpowder annually. It drew only a small proportion of the stream of the River Lea, the remainder being divided between the Cheshunt and Waltham Abbey Corn Mills. These were eventually purchased and more gunpowder mills etc., erected, and in 1813 25,000 barrels were made."

One of the first steps taken by Congreve towards increasing the capacity of the factory was to build new gloom stoves, a surprising step for a man with such an advanced outlook, for in E. Jacobs' "History of the Town and Port of Faversham" (1774) it is stated that in the works at Oare (privately owned and never part of the Royal Factory "the act of drying the gunpowder is effected by the means of a constant stream of hot water, conveyed under the copper frame whereon it is placed to dry. This new contrivance is said to answer the purpose exceeding well".

Be that as it may, gloom stoves were successfully used for many years and we have no record of any accidents due to them in spite of the somewhat alarmist view taken by Coleman (Appendix 3), but risks must have been considerable as the following letter shows:

Royal Powder Mills,
Waltham Abbey,
25th November, 1791

"To the Comptroller of the Royal Laboratory.

Sir,

We beg leave to report the following particulars respecting the lower powder stove upon the bank at this place.

Soon after the purchase of these premises the upper of the Chimney was observed to be cracked but as it had been many years in the same condition it was not supposed to be of dangerous consequence.

On Tuesday last (the stove being set and a fire lighted) the stoveman thought he saw smoke come through the tiles. As soon as the heat of the stove was reduced and the stoving of powder drawn, the Storekeeper got into the loft over the stoke hole and observed that a wall plait of fir was laid into the chimney and if continued must be very near the flue and thus dangerous. The brickwork of the chimney appeared to be in bad condition.

We therefore thought it right to take down the chimney and found the wall plate and ends of the rafters (which support the roof over the drying room) burnt to a charcoal, there being only a single brick laid lengthways between the fire, which sometimes rises to a considerable height in these chimneys, and the wall plate and rafters. There was a half inch opening between the heads of two bricks, there being no mortar between them, just at the part where the wood is burnt, the plait was likewise laid within two inches of the flue at the angles of the chimney.

We are using every dispatch to get this chimney rebuilt as we want the use of this stove very much and shall, with the advice of Barnes make a safe and compleat job of it.

The chimney in the stove near Gallows Gate is built upon a different plant. We mean to inspect it more particularly tomorrow after a stoving of powder is drawn.

We hope that you will approve of the steps we have taken. It really appears miraculous that the stove should escape taking fire.

We are, etc., etc.,
James Wright, Jno. Clowdesley."

By the reference to the lower powder stove upon the bank it is not entirely clear what building is referred to but the juxtaposition of the "stove near Gallows Gate" seems to indicate that the trouble was in the building referred to by Farmer as "the little stove". It is possible that these two stoves were still operating on the old principle and the "glooms" set up by Congreve in 1788 had not yet entirely displaced them, but in any case the problem of making a flame and spark proof joint between the brickwork and the cast iron gloom must have been well nigh insoluble.

By the time production started up in 1789 there were ten serviceable incorporating mills working 30-36 lb. charges at 6 r.p.m. for four hours, horse mills for charcoal, sulphur, and saltpetre, and a horse driven corning house. There were also the necessary buildings for refining sulphur and saltpetre, and charcoal was burnt by the pit process in the factory.

A return of "Officers, Artificers, Labourers etc., necessary for carrying on His Majesty's Service at the Royal Powder Mills at Waltham Abbey" reads as follows:

Respective Officers	(Storekeeper	1 at £150 p.a.
	(Clerk of Cheque	1 at £90 p.a.
Clerks		(1 at £70 p.a.
		(1 at £60 p.a.
Master Worker		1 at £90 p.a.
Surgeon		1 at £54.15 p.a.
Mixing House Man		1 at 21/- per week
Labourers for the Mixing House		3 at 10/6 per week
Millwright		1 at 21/- per week
Carpenter		1 at 17/6 per week
Cooper		1 at 17/6 per week
Storehouse Man		1 at 14/- per week
Stovemen		2 at 10/- per week
Millmen		12 at 12/- per week
Labourers for corning house & glazing engine		11 at 10/6 per week
Saltpetre millmen		2 at 10/6 per week
Charcoal & sulphur millmen		2 at 10/6 per week
Dusting Housemen		2 at 10/6 per week
Office keeper		1 at 12/- per week
Bargemen		(1 at 10/6 per week
		(1 at 9/- per week
Labourers	(To mark powder barrels	1 at 10/6 per week
	(To set and draw stoves, weigh powder, etc.,	3 at 10/6 per week
	(To assist the bargemen to cut weeds, etc.,	3 at 10/6 per week
Charcoal burners		2 at 10/6 per week
Wardens		3 at 10/6 per week
Watchmen		6 at 1/- per night each

Horsekeeper (to be found by contractor)	1 at 8/- per week
Refiner of Saltpetre	1 at 17/6 per week
Labourers to refine saltpetre	6 at 10/6 per week

Apprentices

To Master Worker	1 at 7/- per week
To Refiner of Saltpetre	1 at 7/- per week
" Mixing House Man	1 at 7/- per week
" Millwright	1 at 7/- per week
" Carpenter	1 at 7/- per week

Extra Allowances to Officers, etc.,

Storekeeper for house rent, coal and candles	£25 p.a.
Clerk of Cheque " " " " "	£20 p.a.
Clerks " " " " "	£15 p.a.
Master Worker in lieu of coals and candles	£5.5. p.a.
Refiner of Saltpetre in lieu of coals and candles	£4.4. p.a.
Extra pay to stovemen for night work	6d. per night each
" " " millmen " " "	3d. per night each
Extra pay to bargemen when employed in the barge and absent from the mills.	1/6 per day
Extra pay to charcoal burners when in the country charring wood.	Foreman 1/6 per day Assistant 1/- per day

In October 1785 the Comptroller issued from Faversham a set of "Orders" which formed, in effect, the first factory rules. They are so sound that they are worth quoting in full as showing they way in which they have formed the basis of all later rule books and much good explosives practice.

1. If any workman belonging to the Royal Mills wears his slippers out of those parts of the Works where they are intended to be used for safety, or wears his own shoes into any of the said works, any such workman is to be chequed a days pay for the first offence and if they should so far forget the duty they owe their country as a second time to run the risque of blowing the works up, through such negligence they are to be discharged and on no account to be entered again.

2. The respective officers will please to give the strictest orders for having the several works cleaned out whenever they require it, and the cleaning is not to be confined to the floors only but to every part of the machinery and buildings to prevent any accumulation of dust, which in a powder manufactory must be attended with the greatest danger.

3. The hinges of all doors and window shutters are to be kept weel oiled, also the pulleys over which the window lines go and the grooves in which the sashes slide to be brushed and scraped as often as occasion requires to prevent any dangerous friction. The cogs, axles and other parts of the machinery to be kept well soaped and oiled hitherto been the custom.

4. The Pulleys belonging to the valves of the Powder Stoves must be carefully examined and if there is a possibility of the ropes rubbing against wood or if the sheaves of the pulleys are made of wood they must be altered, so that the ropes may rub against copper, and the sheaves be made of the same metal.

5. Whenever the Powder Tumbrils are required to come near a building in which powder is contained, brick rubbish must be laid on the ground after it has been very carefully examined that no flint or other stones remains therein.

6. Each of the corning houses are to be completed with canvas receivers in the dust troughs and a canvas curtain similar to that ordered for No. 1 corning house.

7. When barrels of gunpowder are lifted out of boats to be stored in the magazines or powder vessels, the strictest attention must be paid to have them brushed all over with a soft brush to prevent any grit hanging to them. The wheelbarrows on which they are to be carried, the hold of the vessel in which it is to be laid to be cleaned in the same manner.

8. All the wheelbarrows which are used to carry powder are to be fitted with copper hoops and gudgeons instead of iron.

9. The floors of the cooperage must be kept as clean from sand or gravel as the magazine and the coopers must work in their magazine slippers to prevent any grit adhering to the barrels or charge tubs, and before any of the articles are issued from the cooperage they must be well brushed and cleaned."

Great efforts were being made at this period to tighten up discipline, particularly with regard to timekeeping and locking up of buildings. The roofs of buildings were whitewashed and the building of traverses started. Frequent reports occur of men being taken off their watch and having their pay checked for arriving at work drunk, being absent without leave, fighting or having nails in their shoes. An order was issued in December, 1789 that no strangers were to be admitted without a written order from an Ordnance Board Office. This instruction is repeated from time to time in the following years and appears to have been difficult to enforce.

1790, the year in which Burke's "Reflections on the French Revolution" was published, was a quiet one at the Factory. Negotiations were in hand for the purchase of the Waltham Abbey and Cheshunt Corn Mills, so that possibly the troubles to come and the need for increased output were foreseen in Government circles. There were two or three mill explosions which did no serious damage but at least roused the Storekeeper to protest about an order that the fire engines were to be sent to the Tower to be repaired and to suggest that, in the interests of safety, they should be inspected and put into order on the spot. The Comptroller saw fit to congratulate the factory on the quality of the powder they were making, so that it is clear that the strenuous efforts being made to improve conditions were having some effect.

The next year or two was a period of consolidation and preparation for more intensive production. Discipline, safety, methods of working and production capacity continued to engage the attention of the officials.

Perhaps one of the most striking instructions of the period and one that has never yet been rescinded in the Explosives Royal Ordnance Factories was one from Major Congreve on May 17th, 1791 that men were not to be employed on task (i.e. piece) work "because it is a dangerous temptation for the labourers to slight their work". Traverses were erected for the first time, more frequent and drastic action was taken against men found with nails in their shoes or coming to work in liquor.

The Surgeon who, as we have seen, received almost exactly the same pay as a mixing house man and rather less than the lowest paid clerk, also received from each employee the sum of 6d. per month, for which he undertook to look after them in all sickness, his official duty being solely to take care of them "in cases of Surgery such as being burnt or any hurt they might receive in the Service".

At the beginning of 1793, England together with Prussia, Austria, Spain and Piedmont, was at war with France, but in a somewhat half-hearted way, as half our Army was away in the West Indies there to die of fever, and Prussia was much more interested in capturing Poland, with whom she was not at war, than in earning the subsidies we were paying her to fight France.

One interesting sidelight on the effect of the situation on the factory is a letter dated 20th July, 1793 to the Duke of Richmond asking for protection against being "detained by the Impress Office" (i.e. press-ganged) for three bargemen constantly employed in the transport of gunpowder between Waltham and Woolwich.

By the middle of 1793 Sunday working was introduced, in the first place because of shortage of water, but continued as the demands for gunpowder continued to rise.

In May, 1794 the Waltham Abbey Volunteers were formed "to learn the Management of Field Pieces - in order that they may be serviceable as artillerists in case of invasion or other civil commotion". The men unanimously voted in favour of joining and to learn the job after working hours in the evening without pay. A smart uniform no doubt helped as also did one guinea levy money paid to each man.

One wonders whether pressure of volunteer duties was in any way responsible for a series of complaints about the quality of the powder being made at Waltham which commenced about October, 1794 and went on well into 1797. The quality of the charcoal was generally blamed and teething troubles with the introduction of cylinder burnt charcoal seem likely to have played some part.

There is quite a batch of correspondence with regard to an allowance to be paid to one John Hart, a local tradesman, who had supplied the factory with clocks and timepieces (time or rather revolution indicators driven by the wheels of the water mills, an early type of instrumentation) for five years. He visited the factory at least twice a week to regulate and inspect these instruments, only charging for such repairs as were found necessary. In January 1794 he asked for a yearly stipend to be allowed for this duty and no reply was received till November, by which time he had been languishing in prison for debt for several months. He was doubtless gratified to receive 2/- a week retrospectively and it may be hoped that this was enough to discharge his debts.

The end of 1794 and beginning of 1795 seems to have been a period when a variety of troubles descended on the unfortunate Storekeeper. Major Congreve had been ordered to Flanders a year earlier to command the force of Artillery so that the factory seems to have had very little guidance or help from outside. On December 1st he writes that all work was stopped on account of a most astonishing flood, and again on January 15th on account of frost. Flood and frost seem to have alternated right up to the middle of February and to have been exceptionally severe, holding up manufacture and transport.

In France the Reign of Terror was at its height and there were repercussions here. A fire at the Faversham works and an explosion at the magazines at Dartford were supposed to have been the work of incendiaries.

Extra watchmen were taken on at Waltham and everyone warned to be on the alert. Further, three sober and steady men were employed as "rounders", one each night alternately, to go round the premises at various hours of the night and see that the watch and millmen were alert at their duty, for which service a proper allowance was considered to be 1/6 a night when on duty.

The spirit among the men does not seem to have been too good, for when three extra men were employed as "occasional millmen" to fill in duties when the ordinary millmen were sick or absent a series of attempts was made to sabotage their work by adding water to the charge just before it was due to come off. One millman was discharged for frequently being absent without leave and leaving his mill running without attendance while he went into the town and got drunk. He got his own back to some extent by accusing one of the new millmen (not without justification) of sealing wood from the factory.

Technical progress was being made. A steam stove was completed and put into operation in June, 1795. The first load of cylinder charcoal was received in April 1794, presumably from Hythe, as mentioned by Bishop Watson (Chap. IV). It was not till August 1795 that the charcoal works at Fisher Street in Sussex were erected, those at Fernhurst following in May, 1796. The change-over to cylinder burnt charcoal together with, perhaps, the division of effort and

attention to volunteer duties, seems to have involved a certain amount of teething troubles for there are many complaints of poor quality gunpowder at this period. It was not till March 1800 that a letter was received from the Board of Ordnance expressing gratification that Rifle Powder similar to that made at Battle could be manufactured at Waltham Abbey. Thereafter complaints are very few.

In a paper read before the Newcomen Society in December 1937 Messrs. Dickinson and Straker state that in the course of researches on the Sussex Iron industry they found, still in existence, buildings that had obviously housed the charcoal works at Fernhurst and Fisher Street, now turned into cottages. They are still (1962) there and look firm substantial buildings. Bricked up arches are still visible and tradition is preserved in names, for the Fernhurst site, on the main road (A 286) halfway between Haslemere and Midhurst is named "Cylinders" on the 1" Ordnance map and the Fisher Street site (about 1 mile North of North Chapel on the A 283 road) is down a side turning known locally as "Cylinders Lane".

In the second edition of Arthur Young's "Agriculture of Sussex" (1808) there is quite a detailed description of the operation of the Fisher Street plant and this is reproduced as Appendix IV.

CHAPTER VI

GUNPOWDER FROM 1801 TO THE COMMENCEMENT OF GUNCOTTON MANUFACTURE

On April 18th, 1801, there took place the first major explosion which had occurred since the factory came into government hands. This is described in some detail in Chapter XII. The accident, in which nine men and four horses were killed, caused a certain amount of disquiet among the workers and a petition from the foreman and men of the Corning house asked that the floor of that building might be covered with tanned hides as was done in the magazines. Congreve I, the Comptroller, refused this request on the grounds that he thought the hides would not be so safe as a boarded floor frequently sprinkled with water. At the same time he asked the Board of Ordnance to apply to the Royal Society to suggest the best floor covering. A committee was appointed to vist the Mills, and Messrs. Angell and Son were ordered to send down some refreshment for the Committee at their meeting. Unfortunately their bill has not been traced, so that we are never likely to know the extent of government hospitality provided for these very distinguished visitors.

The visit duly took place and the Committee, headed by Sir Joseph Banks, the President, and including Count Rumford and Henry Cavendish, expressed the opinion that no danger was to be apprehended "from such excitation as can be produced by walking or rolling barrels upon hides as now used to cover the floors of the Magazines etc., even when used without being previously wetted, nor will there be any danger of explosion from electrical excitation from the use of silk dusting reels in the manufacture of gunpowder." They went on to say that for other parts of the works, hides had the disadvantage of affording a lodgement for the dust of the powder as they did not lie close upon each other or upon the floor. They thought that some uniform material of sufficient size to cover the whole floor, such as painted floor cloth would be preferable.

By 1804 there was again a shortage of powder and in September the Board approved a scheme for the erection of six horse mills and stables with the greatest expedition. By October, three more horse mills, a new magazine and enlargements to the mixing house were also approved. By the end of the year it was estimated that 20,000 barrels could be manufactured annually including Sunday work. Although horse mills had been commonly used in Walton's time it was found necessary to write to Faversham for full instructions for the setting up and operation of horse mills. Their very detailed reply even states that the manure should be equally divided between the Storekeeper and the Clerk of Cheque. The new magazine above referred to (the "Grand Magazine"), built on Paine's Island for 1,500 barrels of gunpowder, was still in use (as a Tetryl Box Store), when the factory closed.

Towards the end of 1804 Mr. Hilton, the Factory Surgeon, asked if he could be supplied with the apparatus "for the recovery of the apparently drowned" recently approved by the Royal Humane Society. It was promptly secured and is still preserved at the Establishment. It is contained in a baize lined, brass bound polished mahogany box with the Board of Ordnance Arms engraved on a brass medallion on top. In addition to a large pair of bellows there are bottles labelled "Spirits of Hartshorn", "Cordial Mixture", "Camphorated Spirit" and "Emetic Tartar", a lead box labelled "Tobacco", a pewter box marked "Common Salt", a tinder box, a flint and steel, various nozzles and flexible connected tubes ingeniously contrived out of wire bound leather, a small ivory syringe, a boxwood funnel for blowing by the mouth and a perforated brass box covered with wood with connections at top and bottom intended for burning tobacco or other herbs.

The instruction sheet reads as follows:

Description and Directions
for the use of
The Apparatus for the Recovery of the Apparently Drowned
recommended by
The Royal Humane Society
and made (by their appointment) by
J.H. Savigny
Surgeon's Instrument Maker, 28 King Street, Covent Garden

"The instrument parts contained in these chests being intended for the double purpose of inflating the lungs and conveying the fumes of tobacco or other herbs into the body, it may be necessary to explain the mode of connecting them in order that these effects may be produced: for the former, the short thick ivory pipe constructed to occupy the whole of one nostril, while the other is closed by the pressure of the fingers, is to be screwed into one end of the short flexible tube and the box mouthpiece (if the breath of a healthy person is employed), or the bellows (should atmospheric air be employed) to the other. If, from contraction or adhesion of the epiglottis, the introduction of the short ivory pipe into the nostril should prove insufficient, it is to be removed and the curved silver tube screwed on in its place; which introduced through the nostril or mouth, and passing beyond the glottis, overcomes every impediment and accomplishes the intention. For the latter, the bellows or mouthpiece, whichever may be preferred, or at leisure is to be connected with the upper part of the brass box (enclosed in wood), filled with herbs or tobacco, whose lower extremity must be fixed to one end of the long flexible tube, and, to the other, one of the ivory pipes for the rectum, as the most convenient size shall determine. The herbs being lighted by the insertion of a piece of lighted tinder, or by the flame of a candle directed upon them with the curved silver tube, their fumes will be ejected by the action of the bellows or breath. Under the bellows will be found a syringe with a flexible tube, for conveying a small quantity of stimulating liquor into the stomach of the patient. The other compartments, boxes and bottles in the chest are intended to contain the necessary spirits, drugs, salt, cloth etc. that may be required."

The problem of public access to the factory still seems to have been acute and in April 1805 Congreve gave instructions that there was to be a daily Warden at the Watch House on Paine's Island to prevent improper people going near the magazine and to suffer no one to carry a gun across the Island or to smoke pipes thereon. The Wardens were not to carry firearms but pikes and sea service hangers.

At the same time the Storekeeper, James Wright, whose salary had been increased to £300 a year with a rent free house, and who seems to have been Superintendent, Principal Clerk, Chief Engineer, and Production Manager all in one, under the Comptroller of the Royal Laboratory, was told by the Board that his accounts were shamefully behind, rendering the office liable to all censure. He mildly replied that he was already working ten hous a day seven days a week and that it was ever his wish to discharge business with care and faithfulness. He must have been a busy man for he also visited from time to time the charcoal works in Sussex.

At this time too comes the first mention of Factory Clothing, for in the accounts we find:-

To:	Thos. Coleman for 27 White Russia Frocks at 6/6d. each	£ 8	15	6
	25 prs. Trousers at 5/- each	£ 6	5	0
	23 dyed drab frocks at 11/6d. each	£13	4	6
To:	Ann Rolfe, collarmaker, to goods	£19	17	1
To:	John Carr, for 36 prs. shoes at 7/-	£12	12	0
To:	Isaac Ireland, to 2 doz. gloves	£ 1	8	0

Petitions for increases of pay were made occasionally but seem to have had little effect. For instance on January 1st, 1806, the Board announced that they did not approve of double pay for mere working on Sunday but in 1808 it was agreed that factory workmen acting as watchmen were not to be employed more than half the night and were to be paid 1/6d.

Water shortages continued and the Cheshunt and Waltham Abbey Corn Mills were eventually purchased and closed to ensure an adequate supply for factory purposes. These drastic measures seem to have been effective for production in 1809 was 20,050 barrels, in 1810 20,688 barrels, in 1811 21,252 barrels and in 1812 21,033 barrels. In 1813 the maximum of 22,398 barrels was reached. To achieve these results more land had had to be bought and buildings erected and extended, and in 1814 and estimated production of 30,000 barrels was to have resulted from a further total expenditure of £51,122. 6. 10d. Wellington's defeat of Soult at Toulouse in April, and the deposition of Napoleon quickly changed the picture and by May the best way of reducing the establishment was under discussion. Only 10,161 barrels were actually made.

Staff had not only increased greatly, but wartime conditions had caused considerable rises in pay. There were about 250 men employed in 1813 and the wages bill amounted to £17,212. The Storekeeper now received £350, the Clerk of Survey £200 and the Clerk of Cheque £150, the master worker got £130 and the surgeon £63.17.6d., with, in most cases, additional allowances for coals, candles and house rent. Foremen received about 4/- a day, millmen 3/-, 2/8, coopers and coppersmiths 4/6. In addition most of the men engaged on production were allowed to do watch duty every third night at 1/6d. a night and millmen working at night were allowed an extra sixpence.

Trouble in Europe was not entirely over, however, and in March 1815 Napoleon escaped from Elba and re-entered Paris, not being finally defeated by Wellington at Waterloo till June of that year. Waltham thus remained busy and 15,790 barrels of powder were made. Thereafter production was greatly reduced and for the next few years was in the neighbourhood of 1,000 barrels.

The factory, though its staff was reduced, was not entirely neglected. A new type of granulating machine designed by Congreve II was installed in 1816 and during that year several houses were bought for employees. A certain amount of that would now be called civil work was undertaken, 1,000 tons of sulphur being refined and cast into rolls in 1818. The corn mill bought several years earlier was reopened for its original purpose and produced a revenue of £2,000 a year.

In spite of these efforts to ease the effects of low production, in October 1820 it was decided to work only four days a week, the foremen and labourers being encouraged to try to get work elsewhere on Mondays and Tuesdays. Further redundancies took place in 1822 when a total establishment of 34 was decided on. Pay for labourers was also reduced from 14/- a week to 12/- and this in spite of the fact that refined saltpetre was being made for the trade and the cooperage was kept busy making cement casks for Harwich. An attempt to reduce the £50 paid to the Curate of Waltham Abbey for the performance of Divine Service on Sunday evenings for the benefit of the men who were liable to be employed on Sundays was not successful and this allowance continued for at least another 60 years.

In 1826 a complaint was received from Woolwich that the service powder had lately been found inferior. A select Committee was appointed to enquire into this and eventually reported that it was due to either the powder itself or the charcoal having lain in store too long. The Board ordered that an annual report should be made on the strength of the powder and that a mortar and gun eprouvette should be installed at Waltham Abbey. These complaints persisted for another year or two and then died out, without any further apparent action having been taken.

In 1825 the old government factory at Faversham was leased to Messrs. Hall, who had another factory nearby, thus leaving Waltham in a rather isolated and responsible position. Money for keeping it in order was severely rationed and in 1829 a Committee was appointed to report on the improvements necessary to bring the Royal Factory to its utmost efficiency. Three officers, Col. J. T. Jones, C.B., R.E.; Col. Sir Hugh Frazer, K.C.B., R.A. and Major Thomas Moody, R.E. comprised this committee and their very business-like report showed that water power shortage was still one of the main problems to be faced.

In the first months of 1814 production at the rate of 25,000 barrels a year had been achieved, the available water power being assisted by 50 horses. Without these animals only 15,000 could have been made. After the war two old water mills, 9 horse mills, 2 corning houses worked by horses were taken down and none of five existing horse composition mills were serviceable at the date the Committee reported - The only machinery in a condition to work consisted of:-

5 Gunpowder Mills in a state to do the work of 4 efficient ones
1 " " fitted up as a composition mill
½ " " fitted up to break mill cake
3 Corning Houses
1 Glazing Mill
1 Dusting Mill

The gunpowder mills were all much worn and unstable and some were erected on defective principles. It was pointed out that the very limited expenditure, authorised by the Board since the war had been judiciously applied by the executive officer to keeping the more serviceable machinery of each nature of operation so far efficient as to ensure some power of reviving the manufacture should service demands require it.

The establishment of workmen was altogether unequal to the full employment of the machinery so that maximum possible annual output was not more than 3,500 barrels.

As there were no arrangements for charring wood at Waltham Abbey, it was recommended that the cylinders at Faversham should be removed there (those in Sussex had been closed after the war and Faversham had supplied Waltham's needs).

Other recommendations were:-

1. All new mills should be placed angularly and not directly opposite each other on their respective banks of the mill head.

2. The water wheels and shafts should be made of cast iron instead of wood.

3. Powder should be glazed in barrels instead of reels.

4. Maximum and minimum thermometers to be introduced into the stoves.

5. Steam stoves to be used rather than gloom stoves.

6. As the chief of each division or branch of the manufactory regulates his practice on partial instructions or established usage and there is no unified control it is recommended that some one person, under the title of Superintendent, living on the spot should have general control, but each Master Worker or Refiner should, by means of instructions from the Board specifying his responsibility be protected from all possibility of wanton innovation or vexatious interference on the part of the Superintendent.

It is perhaps hardly surprising to discover that, on October 28th, 1831, Lt. Col. Moody, R.E. was appointed Superintendent, the Office of Storekeeper being abolished. It is, however, less easy to understand the fact that in the same year the other Royal Factory, at Ballincollig, was sold.

As may well be imagined the limitation of the Superintendent's powers suggested in recommendation 6 does not seem to have worked too well and in 1840 an order was issued that the officers at the Head of Departments should all be subject to the Superintendent and not any outside body. Another committee, a year later, seems to have restored a measure of power and freedom of action to the Commanding Royal Engineer and this was a source of trouble for many years.

An example of the sort of thing that happened can be seen in the events following a serious explosion (seven lives lost) of a corning house and press house in April 1843. Col. Cockburn, the Superintendent of the Royal Laboratory, held an enquiry into the circumstances and Faraday was brought in as a consultant. The day after the enquiry the Superintendent (Col. Tulloh) wrote to Col. Hague, the C.R.E., expressing his regret that he had not come to the enquiry with Cockburn and Faraday.

Col. Tulloh seems to have been an energetic and forceful character. He asked that he should be allowed to see plans and proposals for the new buildings to replace those damaged, but the C.R.E. refused to allow this until he received a direction from the Board of Ordnance. Tulloh notes that a zinc roof was proposed and very sensibly wrote to Faraday for his views on this proposal. The latter replied that any metal roof would be dangerous as perfect metallic contact could not be guaranteed permanently. Though this information was passed on at once Tulloh found out accidentally that it was intended to use galvanized iron and another letter to Faraday and an instruction from the Board were necessary before it could be stopped.

He also had a tremendous struggle to bring enough pressure to bear to prevent buildings being replaced exactly as before, though the vast amount of damage done and the fact that the press house was set off by the corning house explosion showed clearly that safety distances were not great enough and the traverses quite inadequate. He recommended the purchase of more land to prevent the right of public access to the immediate vicinity of buildings which rendered the prevention of smoking impossible and made it easy for ill-disposed persons to throw grit or stones on the platforms. It was many years before this was fully implemented.

Wages at this period were on the upgrade as the following list shows:

Master worker	£160 p.a.
Master Refiner Saltpetre	45/- per week.
Master Mixer	28/- per week.
Foreman Cylinder House	28/- per week.
Foreman - Stores	25/- " "
Foreman - Sulphur Refinery	24/6 " "
Senior Foreman - Corning House	24/6 " "
Junior " " "	22/6 " "
Foreman, Glazing House	22/6 " "
Foreman, Plantations	18/- " "
16 Labourers - Corning and Granulating Houses	18/- " "
10 Mill men	16/6 " "
1 Stoveman	16/6 " "
2 Coopers	21/- " "
12 1st Class Labourers	15/- " "
14 2nd Class "	14/- " "
2 Apprentices } for training as	23/- " "
1 Apprentice } masters	12/- " "

Colonel Tulloh took his job seriously and in 1848 he wrote to the Board at great length making a case for the reoccupation of the Faversham works to supplement Waltham's output when Messrs. Halls' lease expired in 1853. Even if contractors were used to make the powder the government could not be sure of getting saltpetre of the high grade they required unless they refined it themselves and the capacity at Waltham was quite inadequate to meet any increase in output (then 18,000 barrels of gunpowder a year).

Though no action seems to have been taken this output was greatly exceeded in 1855, during the Crimean War.

Little can be said about technical progress at this period. The first steam mill was built in 1856 and some time previous to this hydraulic presses had completely replaced the screw type. Improvements were made in the dusting and glazing houses in 1846, but most improvements seem to have been matters of detail, not principle.

In 1858, The Secretary of State for War asked Sir William Snow Harris, F.R.S., to prepare a statement of his views on the protection of buildings from lightning. He visited the factory and made recommendations for a system of lightning conductors for all buildings which were subsequently accepted. It is interesting to note that the latest War Office Code of Practice for Lightning Protection (November 1961) says that, on the whole, his recommendations were practicable and had a solid scientific foundation.

Conditions of employment seem to have changed very little, and what change there was was not always for the better. For instance Col. Hay (Superintendent 1875-1880) took away the privilege that all established men had had for many years of having a rent-free plot of government land for a garden. This seems to have followed closely on an order he issued that men were not to cut vegetables on these plots on Sundays!

Police were first stationed in the factory in 1860 and the night "rounders" and watchmen were then dispensed with. These duties had been paid for, so the arrival of police must have meant a reduction of pay for many of the men.

In 1869 Dr. Priest, a local practitioner who served as "acting surgeon" to the factory started a series of annual reports. He was having a drive against the terribly unsanitary conditions prevailing in the factory and in Waltham New Town, where many of the men were living. The level of the cess pits of their houses was normally only inches above the level of the surrounding streams, and in the flood conditions that prevailed nearly every winter they lived in a lake of sewage. The local authorities refused to take action and made great difficulties and delays even when he spurred them on by writing to and visiting the Local Government Board and Members of Parliament. He won in the end but it was a long and hard struggle.

In 1871 he reports that "a case of small-pox has occurred in the family of Mr. Richard Adams, master worker. The patient has been placed in an upper room isolated as much as possible and Mr. Adams directed to reside in the factory and hold no communication with his family until the infection danger is at an end".

Dr. Priest was clearly a man of intelligence with the courage of his convictions. It was long after 1872 before the dangers of nitrous fumes were generally realised, but in his report for that year he says "The employment of men and boys in the guncotton factory has not harmed their health, but I fear it may unless means can be found to carry off or decompose the gases, as a man's lungs cannot bear with impunity the breathing of nitrous acid fumes for any length of time".

In 1877 the approved list of articles required in a factory accident ward was as follows:

Basins and Jugs
3 Holdalls
Scissors
Tweezers
Flannel, red
Corkscrew (for opening bottles of brandy etc. to be used as medical comforts).
Holland
Thread, white
Pins & needles
Skin, gold-beaters
Ink, marking (for writing labels on holdalls).

In 1870 the factory contained 32 pairs of incorporating mills, some driven by water and some by steam. They could incorporate annually materials for about 27,580 barrels of large grain or 13,690 barrels of fine grain gunpowder. The number of men employed was about 150. All the processes preparatory to the actual manufacture of the powder were carried on in the factory in order to ensure absolute purity of the finished article. These processes included the refining of Sulphur and Saltpetre and burning of charcoal in cylinders.

In 1872 modern explosives manufacture began. A guncotton factory was erected in buildings which abutted onto the principal street of the town and had formerly been the saltpetre refinery. From this time onwards the history of the factory is so closely allied with that of the manufacture of the main modern military explosives that it can best be summarized in a brief history of those materials.

CHAPTER VII

"A DANGEROUS RIVAL TO GUNPOWDER"

On August 25th, 1846, Christian Friedrich Schönbein, Professor of Chemistry at Basle, used these words in a letter to Faraday with reference to the guncotton he had just been demonstrating at Woolwich Arsenal. On May 27th of that year he had announced at a meeting of the Society of Scientific Research in Basle that he had produced a powerful new explosive by the action of a mixture of sulphuric and nitric acids on cotton.

A month or two earlier he had sent samples to Faraday, Herschel and Grove in England and the last named demonstrated some of its properties at the British Association Meeting at Southampton. The Inventor came to England in August and demonstrated the new material at Woolwich Arsenal so successfully that further demonstrations for which the government paid £1,500, were arranged. They took place in October and aroused great interest in mining and Army circles.

Thus opened the era of high explosives. Great interest was aroused in France, England and Germany. An English patent (No. 11407) was taken out in the name of John Taylor, of Adelphi, on 8th October, 1846, describing the manufacture in considerable detail. Böttger, Professor of Chemistry at Frankfurt, had independently discovered guncotton shortly after Schönbein, and the two collaborated in negotiations with John Hall and of Faversham, with the result that on 18th October an agreement was signed for the erection of the first guncotton factory there. The date on which operations were commenced is not clear but G.W. MacDonald in his *"Historical Papers on Modern Explosives"* quotes the following advertisement dated 19th November, 1846:

"Very numerous applications having been made to us for a supply of Patent Guncotton (for sporting and blasting purposes), we deem it necessary to inform the public that extensive preparations are in progress for the manufacture of this article, which will shortly be completed, when due notice will be given to gun makers and mine agents, who may be desirous of obtaining a supply. Persons detected in making, using, or vending an imitation of the patent article, will be proceded against on all occasions.

Messrs. John Hall & Son, the patentees and sole manufacturers of Schönbein's patent guncotton, respectfully state that they are now prepared to supply the patent guncotton (compressed for convenience of carriage), in round and square paper cases of four ounces each, packed in boxes containing 50 and 100 cases each, at the price of three shillings per pound, for ready money. Also in tubes or cartridges of 1, 1⅛, 1¼, and 1½ inches diameter, containing 2, 4, 6 and 8 ounces each, at the additional charge of 1, 1½, 2, and 2½ pence, each tube. For blasting in state quarries, paper tubes will be supplied three feet in length, containing one ounce of the patent guncotton per foot. Four ounces of guncotton are equal in powder to 24 ounces of blasting gunpowder, as proved in mortars, similar to those used by the Board of Ordnance, for the proof of gunpowder."

This remarkable example of English commercial enterprise did not, however, meet with the reward it deserved for on 14th July, 1847, little more than a year after the first announcement of the invention, a disastrous explosion destroyed the factory with the loss of some 20 lives. Letters, also quoted by MacDonald, give some indications of the difficulties these pioneers must have had to contend with and make it seem remarkable to us that manufacture was able to continue as long as it did without serious accident. Schönbein was of the opinion that the explosion occurred as a result of "some inadvertence or other having occurred during the operation of drying the cotton." As Messrs. Hall had referred in their report of the accident to Schönbein to the difficulty men had in sustaining respiration in the drying and packing departments and as Schönbein appears to have given no indication of suitable temperatures for drying this explanation was doubtless the correct one, though perhaps not so precise as we would expect today.

The method of drying used at Faversham is not known, but it does appear that the drying of guncotton was not regarded as a dangerous operation. Although steam stoves had been used for gunpowder for many years we find in MacDonald's book the following contemporary description of the way in which drying was carried out even as late as 1862.

"The manufacture of guncotton in Hirtenburg consists of a number of perfectly harmless operations: and it is remarkable that, contrary to what happens with gunpowder, if fire be not actually applied explosion is impossible. All operations are so arranged that the material acted upon is in a moist or wet condition - hence not explosive. Drying takes place in a capacious building, open to the air on every side. The last process of drying is carried out in the drying-chamber, when it is effected by a stove situated on the outside, distributing its heat to the building by earthenware pipes - drying being thus ensured by a gentle warmth. In Prussia a drying chamber has recently blown up; but they have worked for eight years with guncotton, and not a single explosion has occurred except the last named. In the Prussian drying chamber referred to, a stove with an iron smoke pipe was used - a sufficient explanation of the misfortune."

This early disaster was a demonstration of the facility with which the full development of a discovery may be retarded by hasty attempts to apply it to practical purposes before its nature has been sufficiently studied and determined, a lesson of particular importance in explosives manufacture and one which has always received particular attention at Waltham Abbey.

The interest roused by the new invention was great and research work was actively persued from a very early period. Teschemacher already in 1846 showed that although mixed acid had to be used in the nitration process only the nitric acid went into combination. Ransome in the same year prepared and analysed guncotton, studying the yield and the nitrogen content. Crum in 1847 undertook a thorough chemical investigation of guncotton and devised and standardized the nitrometer. Gladstone investigated the solubility of guncotton in various organic solvents.

After Hall's explosion and three serious explosions in 1847/8 in France, little interest was shown anywhere for some years except that, after the material had been reported on unfavourably by a Committee appointed for its investigation by the German Confederation, one of its members, Baron Von Lenk, continued to devote himself to its study, and with such success, it appears, that a Committee was eventually appointed by the Austrian Government in 1852, to inquire fully into the merits of the material. A sum of money was paid to Schönbein and Bottger in recognition of the value of their discovery, and an experimental manufactory of guncotton was established at the Castle of Hirtenberg, near Vienna. A particular form of gun was devised by Baron von Lenk for employment with guncotton, of which a 12-pounder battery was established. The performance of these guns were considered sufficiently satisfactory to warrant the preparation of four more batteries, which did not go into active service. It appears that in consequence of a want of uniformity in the effects of the guncotton the material fell into disfavour, and its application in cannon was abandoned but was returned to for a brief period at the close of the Italian War. In July 1862 an explosion occurred in a magazine at Hirtenberg, where guncotton and gunpowder were stored together.

The cause of this explosion was never discovered, but a committee of investigation, consisting of eminent military and scientific men, eventually reported highly in favour of the stability and important properties as an explosive agent of guncotton, and this favourable opinion was supported by most of the Austrian Engineers, in whose name Baron von Ebner prepared a very complete and interesting report on the properties of this material with special reference to mining, submarine, and other engineering operations. However, after a further serious explosion in October 1865, the manufacture of guncotton was officially forbidden in Austria.

In February, 1862 the Austrian Government had spontaneously offered to communicate to the British Government details of the improvements in manufacture and application of guncotton made by Baron von Lenk, and Mr. Abel, the War Office Chemist, was instructed to examine these improvements and investigate the stability of the guncotton produced. Mr., afterwards Sir Frederick, Abel was probably the best man who could have been found for this job. In the

autumn of 1846 he had made a few pounds according to Schönbein's recipe and his interest had naturally continued when he was appointed lecturer at the Royal Military Academy and, subsequently, adviser in chemical matters to the War Office.

Major C. F. Young, R.A., was sent with Abel to Vienna to inspect Von Lenk's experimental manufacture of guncotton at Hirtenberg and collect all possible information from the Austrians. As a result of this joint effort Abel commenced to make guncotton at Waltham Abbey in the spring of 1863, in spite of the explosion at Hirtenberg a few months earlier.

Abel described the Von Lenk system of manufacture before the Royal Society on 19th April, 1866, and laid special stress on the purification of the final product, then accomplished by long washing in cold water, followed by boiling for 14 minutes in a dilute solution of potassium carbonate. He realised, and was probably the first to do so, that an alkaline boiling was the most important part of the purification process and that its function was not so much to neutralise and remove residual traces of nitrating acid as to dissolve small quantities of unstable bodies produced by the action of the nitrating acid on impurities retained by the tubular cotton fibre.

This was the real beginning of safe guncotton manufacture. There can, in fact, be little doubt that most of the previous disasters were due to the spontaneous decomposition of unstable compounds. It is clear that Abel had this question of purification very much in mind for in 1865 he took out English Patent 1102, which had for its object the reduction of guncotton to a pulp and forming from this pulp grains suitable for propulsive purposes. But the pulping process also had, he claimed, the advantage that the guncotton, being divided into very minute fragments, and at the same time violently agitated with a large volumn of water, which is afterwards thoroughly expressed when the pulp is converted into cylinders or other forms, receives a more thorough purification than is possible by any other means.

Although the pulping and granulation of guncotton did not succeed in transforming it into a satisfactory propulsive explosive, the greater purity of the material resulting from the pulping process, re-established confidence in guncotton for both military and technical purposes, and in 1871 a Select Committee on guncotton was appointed. Its terms of reference were "to consider and report on the manufacture, storage and use of guncotton etc.," It reported that Abel's compressed guncotton was quite safe and required no special treatment or storage, though it thought that the question of drying might require further consideration. In his evidence Abel said that he began to devote special attention to guncotton in 1862, having been instructed to investigate the Von Lenk process. He commenced experimental manufacture at Waltham Abbey in 1863 and from 1863 to 1868 made 1000-2000 lbs. each summer. He then got experience in the application of the material and developed his own process at Woolwich between 1865 and 1868. He also put forward the idea of what he called "nitrated guncotton", that is, guncotton impregnated with and containing up to 30% of saltpetre..

At this period of his life Abel must have been a disappointed man. Although he had been elected a Fellow of the Royal Society in 1860 his favourable report on the Von Lenk process in Austria had roused little interest in official circles in spite of his continual efforts to show that guncotton was of vast potential importance. Two important papers he had read before the Royal Society (1866 and 1867) on the manufacture and composition of guncotton and its stability respectively had roused little interest outside scientific circles.

He continued however to push his case and the foundation of the Select Committee above referred to was undoubtedly the result of a strongly worded report dated 18th November, 1870 in which he remarks rather pathetically that, in devoting his energies unceasingly to the successful manufacture and application of guncotton, he not only received but scanty encouragement at the hands of the Authorities but also had to contend continually against very strong prejudices until about two years earlier when the attention of several foreign governments had been attracted to the results he was obtaining with compressed guncotton, and Messrs. Prentice of Stowmarket, who had long been trying to overcome the difficulties interent in the Austrian process of manufacture, had been allowed to work his process under license with the stipulated agreement that H.M. Government should have full use of his patent without any drawback.

This firm had commenced the manufacture of guncotton according to the Von Lenk process in 1863 but very soon had a serious accident. With great courage they had rebuilt and enlarged their factory two years later, this time including the use of Abel's improvements. Abel in his report went on to recommend that the Government should accept help from Prentice's in starting a guncotton factory and pointed out how his pulped guncotton could easily be formed by hydraulic pressure into dense compact masses of any desired shape suitable for use in mines and torpedoes or for blasting purposes. These shapes could be stored wet for any desired period, and, according to a recent discovery by E.O. Brown of Woolwich Arsenal, could be fully detonated, wet and unconfined, by fulminate of mercury.

At last Abel was to reap some reward for his long and devoted service. The Select Committee reported in his favour and in 1872 a factory to produce 250 tons a year was erected at Waltham. The fact that the factory was located in old buildings, which, once part of the Saltpetre refinery, abutted on the main street of the town showed considerable confidence in Abel, particularly as 15 tons of guncotton had exploded spontaneously in a magazine at Stowmarket in August 1871.

The Abel process of manufacture held almost undisputed sway for many years. It was essentially a modification of the Von Lenk process. Mixed acid consisting of 3 parts of 96% Sulphuric Acid to 1 part of 91% Nitric Acid was run into cast iron dipping pans holding about 220 lbs. The pans were supported in an iron tank through which cold water circulated to keep the temperature at 70°F and were provided at the back with gratings on which to press out some of the acid from the charge.

The charge of purified, dried and cooled cotton waste weighing 1 lb. 4 ozs. was raked into the acid as rapidly as possible and allowed to remain there 8 minutes. It was then transferred to the grating and as much acid as possible squeezed out by an iron lever with a plate on one end. After a charge had been removed from the dipping pan about 13¾ lbs. of mixed acid was run into it to replace the acid removed with the charge. The charge with its adherent acid, now weighed about 15 lbs., and was transferred to an earthenware pot with a cover and placed in the cooling pit through which a stream of cold water flowed and where it remained 12 hours. The contents of the pots were then transferred to centrifugal machines which extracted the bulk of the acid. The guncotton was then placed in galvanised iron pans with long handles - these pans, when full, were carried quickly across to the immersing tank and the guncotton thrown into a large bulk of water, the workmen standing by the tank and pushing the guncotton at once under the water with a stout wooden paddle, the immersing had to be done as quickly as possible, as if the guncotton was allowed to come gradually in contact with the water it was liable to fume off. The immersing tank was fitted with a perforated copper plate to allow the water to overflow so that fresh water was constantly passing through the tank. When 2 cwt. had been immersed the inflow of water was stopped and the tank drained down. It was then refilled and drained again six times or until the cotton no longer tasted of acid. Then, after a further washing with water in a centrifugal the guncotton was fit for boiling and pulping.

Though the process produced good guncotton it was an expensive one. Labour and acid usage were very high, maintenance and renewals of plant were very heavy and decompositions at all stages of the nitration process were frequent.

In spite of these serious defects the Abel process was very widely worked and it was long before any improvement was made. Nobels at Ardeer were probably the first to break away from it when they introduced their "direct dipping" process. Here iron pots known as "dippers" were provided with fume offtakes and 4½ lbs. cotton used to 127 lbs. of mixed acid. The time of immersion could be varied from 8 to 24 hours, the amount of nitric in the mixed acid being varied accordingly. When the nitration was complete the dippers, covered with light aluminium covers, were trucked to centrifuges into which the contents were tipped. After wringing, the guncotton containing about its own weight of acid, was drowned in water (a process so unpleasant that the operators had to wear hoods with compressed air attachment), and drained, centrifuged and washed before boiling.

On the continent centrifugal nitration had a certain vogue but before the development of acid-resisting steels the process must have had considerable drawbacks. The most satisfactory type of machine had two speeds, a slow one of 20-30 r.p.m. and a normal high speed. While the basket was revolving at the slow speed the acid was run in and cotton gradually added. After an hour the high speed was turned on and the acid wrung out, the guncotton being drowned as previously described.

Right up to 1886 when the first smokeless powder was invented in France, the uses of guncotton were comparatively limited for no means had been found of moderating its force and rendering it useful as a propellant. Gunpowder continued to fight hard for survival and a number of improvements in the manufacture were introduced. These are summarized in a paper read by Col. C. B. Brackenbury, the Superintendent of the Royal Gunpowder Factory, before the Royal United Service Institution on February 29th 1884, with the intriguing title "Gunpowder, considered as the Spirit of Artillery, with the results which have followed and will follow this view of its Position". The improvements he mentions include the introductions of cylindrical or prosmatic powder, which burnt more regularly and with better late effects in the gun and made up into a better cartridge than pebble powder; the control of density by the rate of drying and reducing the original moisture content, blending to increase uniformity, the reduction of sulphur content to decrease erosion and finally the introduction of brown or cocoa powder, using charcoal made from rye straw.

In an interesting aside in his paper he tells us that the electric light had been in use at Waltham for two or three years past, a completely safe arrangement having been designed by his ingenious friend, Major Watkin. "The incandescent lamp (anybody's will do) is plunged in a large glass vessel of water and hermetically sealed. The light can be used where any other type has to be avoided and thus are secured at once longer working for several houses, and brilliant illumination with perfect safety."

The writer has been told by old gunpowder workers at the factory that at night it was frequently possible from inside a gunpowder mill, to tell that these lights, which were outside the windows, were safely alight.

But not even with all these improvements in gunpowder manufacture could the progress of guncotton and its eventual use in propellants be delayed. The old guncotton factory was soon found to be inadequate for the increasing demand and new land further away from the town (the Quinton Hill site) was acquired in 1885. A new cotton factory working on the Abel system was built on it, manufacture there commencing in 1890. But the Abel process was doomed, for it was not only laborious and expensive in acid, but involved considerable health risks. Acid fumes filled the air and fume-offs were uncomfortably frequent.

A great deal of thought was being given to improved methods of manufacture, but it was not until 1905 that any real improvement was made. In that year J. M. Thomson, who had come to the factory as manager from Ardeer when the manufacture of nitroglycerine was started in 1890 (see next Chapter) and his younger brother, W. T. Thomson, who was Chemist in Charge of guncotton manufacture, invented by a stroke of sheer genius the displacement process. It is so well known and has been so often described in the literature that it is not necessary to describe it in detail. The cotton is pushed in handfuls below the surface of mixed acid contained in conical based stoneware pan with a bottom outlet covered by a perforated false bottom. Each handful is immersed by the use of an aluminium fork and when the charge is complete it is covered with sectional perforated plates and a layer (½ inch or so) of water gently run on top. This effectively keeps down fumes. After 2½ hours standing the gentle water flow on top is started again and a corresponding amount of spent acid run out at the bottom, the whole of the acid being eventually displaced by water. This very ingenious process was a vast improvement on anything that had gone before and it remained for many years the standard process for the production of guncotton for cordite manufacture. The advantages gained by the use of the process as listed by Nathan in 1909 were as follows:

1. Great simplicity as compared with the Abel process.

2. The dipping process is much less laborious and the heavy labour of squeezing out excess acid is done away with.

3. Loss of acid and guncotton due to fumeoffs and broken pots together with the danger of nitrous fume poisioning almost entirely eliminated.

4. The process is remarkably free from fumes as compared with Abel's.

5. Acid usage much less and less pollution of escaping wash water.

6. Recovered waste acid much cleaner.

7. Mechanical losses of guncotton much reduced.

8. A more thorough washing is obtained with the use of one-fifth the water and less boiling is required.

9. Saving in power for centrifugals.

10. Maintenance is very low.

11. Labour is only one third that previously required.

12. A more stable guncotton, of more uniform composition is produced. It is cleaner and contains less mineral matter.

13. The reduction in cost was approximately 50%

The guncotton factory at Quinton Hill was considerably enlarged in 1904/5, being simultaneously converted to the displacement system of nitration, and thereafter served to produce the entire guncotton requirements of the factory. It was further enlarged in 1915 and, even as late as 1940 was producing guncotton at the rate of 120 tons a week.

Of recent years the Thomson displacement process has been improved in small ways, but the principle introduced at Waltham Abbey in 1905 was the method by which the guncotton requirements of the fighting services of this country in two World Wars were supplied. It was adapted for the nitration of wood pulp paper in place of cotton with equally satisfactory results.

Purification Processes

It has already been said that Abel recognised at a very early stage the importance of purification of guncotton. When manufacture was started at Waltham in 1872 stabilization was effected by a long washing with cold water followed by a short alkaline boil. In the middle of 1873 boiling vats were erected, so that it seems clear that the R.G.P.F. again pioneered a method of stabilization that has since been universally adopted. The times of boiling underwent many changes in the succeeding years and it was not until 1905 that a systematic study of the subject was made by Dr. (afterwards Sir Robert) Robertson, then a chemist at Waltham Abbey. He found that long boils at the commencement enabled the stable condition to be reached earlier. This was a complete reversal of the conditions used up to that time. He also found that it was advantageous to allow the first long boil to take place under acid conditions as in this way the unstable sulphuric ester is decomposed. This method of boiling remained unchanged for many years, and the Waltham system of boiling (2 x 12 hour boils, the first being acid and the second almost neutral, 4 x 4 hour and 1 x 2 hour alkaline boils with displacement washing between each) has been accepted as an ideal standard, which can usually be relaxed especially when cordite containing an efficient stabilizer is being made.

The pulping process carried out in the beating engine as used in paper mills was another of Abel's introductions that is still in universal use. Unlike the paper makers the guncotton maker desires to cut his fibres into short lengths and not open them up. To do this it is necessary to keep the beater blades sharp. The rolls that carry the blades are heavy and bulky and here again a Waltham Abbey man, A. W. Williamson, in 1903, designed and

patented a portable milling cutter, driven off the beater shaft, which enabled the job to be done *in situ*.

The next process, potching, was again copied from the paper making industry and for many years their methods were followed. They were not entirely satisfactory, however, and efforts were made to devise a machine that could be constructed of non-corrodible materials without being impossibly expensive. In 1935 the first Bowden-Parsons Tangential Potcher was constructed at Waltham Abbey and this type of machine was used in all the new British factories. Essentially it consists of a cylindrical tank with a conical bottom and central outlet to a centrifugal pump which returns the pulp through a tangential inlet at the level of the top of the cone. The tank is readily constructed of either lead, aluminium or light gauge stainless steel supported in a suitable framework. It can be as large as is desired and two or more pumps can be used. Circulation and washing are excellent and maintenance is low.

It would be out of place in this history to go into detail of the many improvements in minor details of manipulation that have been made at Waltham Abbey as well as elsewhere, but it is clear that all the major developments have come from that factory and that Waltham's method were copied, both by the trade in this country, and by other countries.

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CHAPTER VIII

THE DEVELOPMENT OF NITROGLYCERINE MANUFACTURE

Ascanio Sobrero, Professor of Applied Chemistry at the University of Turin, in February 1847, presented a paper to the Turin Academy describing three new substances he had prepared, nitroglycerine, nitromannite and nitro-lactose. He investigated the chemical and physical properties of these materials and noted their explosive power. He appears to have thought that nitromannite, being a solid explosive, would be more useful than nitroglycerine, but a spontaneous explosion of the former in Turin Arsenal caused him to lose interest in these materials.

The danger of using a liquid explosive was so obvious and the difficulty of producing an explosion by any practical and reliable means so great that nitroglycerine attracted little attention from workers in the explosives field. It could not be caused to explode with a fuze as could gunpowder and guncotton and no practicable means of producing the necessary conditions to cause an explosion were known. Its use in medicine was discovered in Holland in 1855, the discoverer, J. E. de Vrij, losing his sight for some time as a result of an accidental explosion while making small quantities for experimental purposes.

At the beginning of the Crimean War in 1854 Alfred Nobel and his father were running an engineering business in St. Petersburg and the Russian Government entrusted them with a mine-laying programme. In this connection two Russian Professors, Zinin and Trapp, drew their attention to the possibilities of nitroglycerine as a powerful explosive which would be more effective than gunpowder in mines. Nothing came of this immediately but the interest of the Nobels was aroused and in 1862 the father added 10% of nitroglycerine to gunpowder. When freshly made this mixture produced a sensibly more powerful explosion than plain gunpowder, but in a few hours was fully absorbed in the pores of the powder and the mixture became less active.

Alfred Nobel continued these researches and raised the nitroglycerine content up to 30%, but still was not completely successful in ensuring detonation. He therefore turned his attention to this problem, and, towards the end of 1863 succeeded in detonating nitroglycerine by a small gunpowder charge fired by a fuze or a percussion cap containing mercury fulminate. He still saw clearly the defects of liquid nitroglycerine and experimented with various absorbents, eventually patenting the use of Kieselguhr, the porous silica he was using as a packing for his tins of nitroglycerine, in the year 1867.

As soon as a practicable method of detonating was found, nitroglycerine began to be used in the Swedish mining industry and very quickly a demand for the material arose. A laboratory for the manufacture of nitroglycerine had been set up in a building close to Nobel senior's house in Heleneborg near Stockholm in 1863 and by the beginning of 1864 was making considerable quantities. On September 3rd of that year an explosion occurred which killed Emil Nobel, Alfred's younger brother; the chemist; the handy man, and a workman who happened to be passing. The father had a stroke a month later from which he never completely recovered.

A statement the father made to the police after this event said that he had not considered it necessary to notify the authorities that he was making the substance and it was quite harmless. He thought his son had been trying to simplify the method of production and had thereby produced a violent reaction which raised the mixture to the temperature at which it would explode.

Not unnaturally the manufacture was prohibited within the city area and it was difficult to find a site in the neighbourhood. Alfred Nobel was not daunted by these disasters and difficulties and transferred the manufacture to a pontoon moored in the Malar Lake, only 2 miles from Stockholm, until a new factory could be built at Winterviken. In the next few years the Nobel business spread with amazing rapidity all over the world, in spite of many accidents and much prejudice. The Nobel factory at Ardeer produced nitroglycerine for the first time in January 1873, after a prolonged struggle to find a way round an Act of 1869 which forbade the manufacture or import of nitroglycerine.

Nobel, in spite of his business and financial preoccupations did not give up his scientific work and in 1875 he patented blasting gelatine in which soluble nitrocellulose was gelatinized by nitroglycerine. Both this material and dynamite are suitable only for blasting purposes, but by increasing the percentage of nitrocellulose from 7% to 45% and adding 10% of camphor he produced in 1888 a smokeless powder he called Ballistite.

This followed hard on the heels of the French invention of "Poudre B" and, as will be seen in the next chapter, the British Government had appointed an "Explosives Committee" under Abel to consider new inventions in the explosives field. This Committee's invention of cordite in 1889 made the production of nitroglycerine at Waltham a matter of urgency, particularly as their work had been done at Woolwich with nitroglycerine extracted from Blasting Gelatine, and little attention seems to have been paid to nitroglycerine manufacture. Arrangements were hastily made for Col. Noble (the Superintendent) to visit the nitroglycerine works at Opladen in Germany, and on 7th July, 1889 he submitted a report on his visit together with rough estimates for buildings and machinery, it being proposed that the greater part of the latter should be obtained in Germany. This was approved by the Secretary of State, together with plans for the buildings, but before very long doubts as to the wisdom of proceeding with the erection of the plant without expert knowledge seem to have arisen, for Mr. George McRoberts, the manager of Nobel's Ardeer factory, was present at a meeting on 21st January, 1890, when many points in connection with the installation were approved, and among other things, it was agreed that the method of introducing the glycerine into the mixed acid practiced at Ardeer should be followed, Mr. McRoberts furnishing detailed drawings of his injector. At the same time he was asked to furnish the names of two men he would recommend as N.G. foremen, and, as a result, Messrs. Thomson and Taylor of the Ardeer Factory were engaged on 12th October, 1890.

At a further meeting on January 28th drawings submitted by Mr. McRoberts were approved for immediate action, and the position and pay of the man in charge of the Factory were discussed. It was decided that he should hold the position of an Assistant Manager, directly responsible to the Superintendent and independent of the Master Worker, with pay at the rate of £400 a year. An assistant with £4 a week was to be appointed in addition. Mr. J. M. Thomson, from Ardeer, thus became the first Manager.

The position of Mr. George McRoberts in this matter is a little obscure. He was the Manager of Nobel's Ardeer Factory, but he seems to have acted privately as a Consultant, as all his correspondence is addressed from a private house in Ardrossan, Ayrshire. He does not appear to have had a very high opinion of the German plant, for on April 4th, 1890, he writes to the Superintendent:-

> "I have carefully avoided altering the plant you have already got because I think it can be used perfectly well and with safety, although, had I been designing the plant, I should have had it different. The plant is not the best, but it will do till it is worn out and then it can be replaced by plant of superior design at small cost. To substitute, at present, plant of my design would be an unnecessary extravagence. I am anxious, since you have consulted me, to have the plant fitted up at as small a cost as is consistent with efficiency and safety."

Thomson, however, was not satisfied with the plant received from Germany. It had suffered considerable damage on the journey and he almost completely reconstructed it, following the methods adopted at Ardeer as closely as possible.

The erection of the factory appears to have proceeded smoothly and McRoberts gave much useful information as to its fitting up, though curiously, the correspondence with him appears to die out about the end of April, 1890 and he is not mentioned again.

In the early part of 1891 the plant was approaching completion and draft specifications for raw and finished materials approved. There is recorded on 24.2.91 a telephone message from Superintendent R.G.P.F. to D.G.O.F. "Have you purchased Glycerine for making Cordite?" Half an hour later D.G.O.F. replied "No Glycerine for making Cordite has been ordered, but we have ordered glycerine for making N.G. for Cordite as approved by your telephone message of to-day". Apart from the somewhat heavy humour of this reply it is of interest to note the

careful way in which conversations on the telephone were recorded at the time, and that both R.G.P.F. and Woolwich Arsenal were so advanced in outlook as to have had that new and strange instrument installed at such an early date.

On March 16th Mr. Skerman (the Foreman of the Woolwich Cordite Factory) and six men arrived at Waltham Abbey ready for the start-up of the cordite plant, and on that day the first charge appears to have been nitrated, though it has not been possible to trace any definite record of that interesting event.

Production continued without any events of special interest for three years; then on May 7th 1894, a disastrous explosion took place, starting in the wash house. The Court of Enquiry which followed suggested a number of possible sources of danger in the plant (See Chapter XI) and, while it was rebuilt quickly in such a way as to avoid repetition of the worst of these errors, a great deal of work was put in on the subject of possible further improvements.

After this explosion Col. McClintock, the Superintendent, retired and for a time Col. Nathan, the Danger Building Officer, was Acting Superintendent. In this period a number of meetings were held to discuss the reconstruction and rearrangement of the Cordite Factory. In the July a new Superintendent, Col. Ormsby, was appointed, and he seems to have regarded the matter from a broader viewpoint than had hitherto been taken, for on 3rd January, 1896, he wrote to Dr. Anderson, Director General of Ordnance Factories, a personal letter so remarkable as to deserve quoting at length.

"Now I want to bring before you a new suggestion - I do not know what you will think of it, but to me it seems a good one from several points of view.

It arose from my incidentally hearing in the R.E.D. the other day that all the 12 pdr. Batteries are now being converted to pole draught which I presume means cordite ammunition, and the setting free of a considerable quantity of S.P. powder, which, with the conversion of 6" B.L. to Q.F., setting free of large quantity of E.X.E. seems to reduce the chance of any orders worth speaking of for powder to an almost vanishing quantity. Of course I do not know what the orders to Powder will be, but I anticipate that they will be so small as to make our prices, with our present staff etc., quite prohibitive. Even now our prices are, I know, above those of private firms. The utility of a Government powder factory seems to me to be at an end. It is not required as a main source of supply. It cannot manufacture as cheaply as private firms, and is therefore without the power to control prices. It must in any case come to an end in a short time, and now, when we are thinking of making new cordite Press Houses, and are putting up a new N/G Factory, seems to be a good time to consider our position. If it should be agreed to close our G/P Works as a large source of supply, the whole of the cordite plant might be removed to the Upper Works, with probably less immediate expense than would be involved in the proposed replacement of the Cordite Press Houses; with a very large consequent reduction of expense, and with greatly increased facilities in manufacture. Sufficient G/P plant would remain to enable us to do repairs, and to execute small orders. One very large item that might be struck out of next year would be the proposed look on the Mill Head stream.

A point for consideration also is that of supervision. With the N/G Factory at one end of the Works and all the rest of the Cordite plant, the laboratory etc. at the other end, it would be difficult for Nathan and Mr. Thomson to exercise as close supervision as they now do; whereas if the change be made all their work would be together except the guncotton, and that does not require at all such close attention as the others.

In that case the second D.B.O. might be dispensed with - I know that this is a large question, but it will have to be faced some day before long, and facing it now would save our running into considerable expense, that when the change does come would be thrown away, and get rid of several difficulties and inconveniences in working. I propose the question in the first case privately. If you do not agree, no harm is done; if you do agree, I am ready to put forward a complete plan. Nathan and I have been through all the details both of the houses and of the working, and everything seems to fit in easily and well".

This letter seems to have been written out of the blue and after some 18 months of discussion on other sites, Col. Ormsby striving diligently the whole time for a more convenient layout and greater distances between buildings. His new scheme seems to have had no acknowledgement at all till 21st March, when D G.O.F. informed him that it had been before the Military Authorities since 22nd January, and that he was hopeful of a decision soon.

On 9th July, the Director General of Ordnance Factories and the Superintendent of Building Works visited the factory and inspected with the Superintendent the buildings it was proposed to convert. It was agreed that estimates should be submitted, and on the 8th April, 1897, D.G.O.F. gave his verbal approval to go ahead. Work then proceeded without delay, the factory being taken into use in 1898. It appears that the growing power of the Building Works Department, so bitterly complained of by Col. McLintock, at the enquiry on the 1894 explosion, was broken and the views of the Superintendent received first consideration.

During the Boer War both nitroglycerine plants appear to have worked steadily and to have produced between them an average of 18½ tons of N.G. per week. There were no incidents and no explosions, until 1901 when an explosion occurred in one of the bottom cocks of a nitrator after the charge had been run off. Following this, means of eliminating cocks became a matter of urgent concern and a patent (E.P. 15983 of 8th August, 1910) was taken out in the names of Nathan, Thomson and Rintoul. The plant described is the nitrator-separator which has continued in use ever since, and has only recently been displaced by systems of continuous nitration.

In the original plant the glycerine was injected below the surface of the nitrating acid contained in a cylindrical lead vessel provided with cooler coils and air agitation. There was a domed cover with glass inspection windows and a fume pipe and, at the bottom two stone-ware cocks, one for drowning the charge and the other for running it to a separating tank. This was a conical bottomed vessel with thermometers, fume pipe and air agitation and cooling coils. A glass window just above the outlet cock enaeled the operador to see the line of demarcation between acid and nitroglycerine when the vessel was emptied.

The nitrator separator is a lead vessel with a bottom sloping in one direction. It is fitted, as in the older plant, with cooling coils and air agitation. A two way bottom outlet communicates on one branch to a drowning tank, and on the other forms an inlet for either mixed acid or spent acid. The vessel is filled with mixed acid and glycerine injected with brine circulating in the cooling coils. A 1,400 lb. charge of glycerine takes about 45 minutes to nitrate and some 20 minutes later the nitroglycerine is nearly all separated into an oily layer on the surface of the spent acid. This is displaced upwards by admitting spent acid at the bottom of the vessel and a glass window at the top of the conical cover of the vessel enables the operator to see when all the N.G. has been removed.

The advantages of the Nathan-Thomson-Rintoul plant as compared with the Nobel plant previously in use may be summarized as follows:

(1) Greatly reduced height and floor area.

(2) Fewer pieces of apparatus.

(3) Abolition of all cocks through which nitroglycerine has to pass.

(4) Introduction of labyrinths for all wash waters.

(5) Removal of N.G. from contact with acid as it separates from it.

(6) Presence of cooling coils during separation.

(7) The undesirable operation of running a mixture of acids and N.G. down an exposed gutter is avoided.

(8) Less labour required.

(9) Removal of acid and N.G. fumes to an extent not previously deemed possible.

(10) Increased yield of about 15%.

Another improvement introduced at the same time was the addition to the waste acid after completion of separation of 5% of water. This has the effect of increasing the solubility of the nitroglycerine in the waste acid so that no further separation takes place.

The new plant was taken into use at Quinton Hill on 5th May, 1903 and after a trial there manufacture was transferred to the new factory at Edmonsey and the Quinton Hill plant put into reserve. The last charge there was nitrated on 27th August, 1903. At the beginning of the 1914-18 War Waltham Abbey was the only Government Explosive Factory in the Country. The "new" nitroglycerine plant at the Upper Works (Edmondsey) had to meet the demand without help, and in 1916 an average weekly output of 46 tons was reached with many extensions to the plant. Other factories were then coming into operation and Waltham gave them all great assistance by training new staff and seconding experienced men and chemists.

The plant worked right through the First World War without accident, and during the slump years from 1919 to 1935 only an occasional batch was made. In 1936 output increased considerably and by the declaration of war in 1939 it had been stabilized at 75 tons of Cordite a week, equivalent to 25 tons of nitroglycerine. In the first few months this old factory, with so much obsolete plant and machinery, had once again to take the foremost place in explosives production, but, fortunately for the Country, other and larger factories in safer and more suitable areas were well advanced, and Waltham Abbey did not remain for two years the sole source of Government-made Cordite as it had done in 1914-16.

None the less Waltham played a very important part in filling the gap, once again helping to train new staff and to provide the leaven of experience which did so much to help the new factories get away to a good start.

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CHAPTER IX

CORDITE

On July, 10th, 1888 The Secretary of State appointed a committee to consider questions relating to new explosive agents and to new applications of, or improvements in, the production and application of, known explosive agents. This committee, known as the Explosives Committee, had Sir Frederick Abel as its President with Professor J. Dewar and Dr. A. Dupré as its Members, the Secretary being Capt. J. H. Thomson, R.A. It was a committee which acted with remarkable speed and efficiency and interpreted its duties more widely than might have been expected.

Their first meeting was held within a week of appointment and on 20th August, 1888 they wrote to the Director of Artillery, stating that their entry upon work necessitated early consideration of the following functions not specifically dealt with in the Circular of Instructions issued to them:-

1. To examine into and report on the novelty and merits of explosive inventions.

2. To afford advice and assistance in connection with new applications or modifications of known explosives.

3. To watch the progress of invention and keep the authorities informed and advised with regard to recommended course of action in regard to fresh advances here or abroad.

4. To pursue experimental investigations having for their object the advancement of knowledge of explosives and the originating of improvements and inventions in their manufacture and use.

The Committee were of the opinion that No. 4, represented their most important duty, but pointed out that any success they had would not be regarded with favour by the explosives makers, and that they would inevitably come under the stigma of not being impartial judges and of profiting by information imparted in confidence. They pointed out that no facilities or resources were being given them and that there was not even any possibility of secrecy, and that therefore they could only secure to the Government the practical results of their official investigations by taking out patents.

They stated that it was essential that regulations should be laid down under which all officials producing inventions bearing on service requirements would have the right to take out patents with the approval of the Government, securing them in the public interest, but giving the inventor the option of taking out foreign patents at his own expense in all cases in which the Government does not consider it necessary in the interests of the Service to secure secrecy.

To this very reasonable suggestion no reply was received, but there can be no doubt that the present procedure with regard to such patents is based on it.

There can be little doubt that one of the reasons for the appointment of this committee was the fact that in 1886 the French had brought out the first successful smokeless propellant, the famous "Poudre B". This was made by gelatinizing a mixture of guncotton and collodion cotton with alchohol and working up the paste to small squares of a dry horn-like material. For some 30 years Abel and others had been trying to moderate the force of nitro-cellulose so as to apply it to ballistic purposes, but the French material was the first which gave good results. There can be little doubt that the Service Authorities in this Country were seriously disturbed by this spectacular advance.

The Committee examined all the many powders which were being hawked about and for which startling and totally unsubstantiated claims were being made. They turned down one after another after fair but rigorous trial. In December 1888, however, Nobel submitted two samples of an entirely new type which gave very promising results. These had been manufactured at Nobel's factory at Honfleur. They were, in fact, the first samples of "Ballistite" and consisted of a mixture of nitro-glycerine and soluble nitro-cellulose with camphor as a plasticizer. The material was not affected by damp, but evaporation of the volatile camphor on exposure to the air rapidly affected the ballistic results. In every other way the powder gave the sort of results the Committee was looking for. On receipt of a report to this effect on 25th April, 1889 Nobel promised to submit samples in which camphor had been replaced by some substance not liable to evaporation. He did not do so, and, according to the Committee, did not appear to realize sufficiently the importance of what they had told him.

The Committee thereupon took steps to investigate experimentally the production of a substitute containing no volatile ingredients. They used guncotton instead of soluble nitro-cellulose and adopted a method of manufacture slightly different from Nobel's in that the ingredients were kneaded together with a solvent such as acetone, afterwards removed by stoving, instead of being worked between steam heated rollers without a solvent. They quickly obtained promising results and also hit on the idea of making up the charge in the form of a bundle of wires or rods of a length to occupy the whole of the powder space of the cartridge. The material was produced in this form by forcing the preparation while in a suitable plastic state through a die of the requisite diameter.

The mixture, numbered 128 in the original series, became "Cordite, Mark I". Its composition was:-

Nitroglycerine	58
Trinitrocellulose	37
Vaseline	5

The name "Cordite" appears to have been first used in the Proceedings of the Committee for 5th June, 1889. Before that the material had been referred to as "Cord powder" or "The Committee's modification of Ballistite". On 27th March a meeting between the Director-General of Ordnance Factories, the Superintendent, R.G.P.F. and the President of the Explosives Committee had taken place to consider the manufacture at Waltham Abbey, and it may well be that the more convenient name had been suggested at that meeting.

Exactly how the work of the Committee was being financed is a matter of conjecture. The Director of Artillery on 4th April, 1889 approved the further expenditure of £100 to cover expenses of manufacture at Waltham Abbey. When that was exhausted he would require a progress report and a statement of further requirements. The committee replied that progress was such that they anticipated the amount would be considerably exceeded in the current year, but they would report in due course. In June the President forwarded to D. of A. a letter from Messrs. Easton and Anderson (Engineers) describing in general terms the machinery they had designed for the manufacture of Cordite. The cost was to be about £100. This modest expenditure was forthwith approved and work proceeded.

Abel and Dewar patented their invention of Cordite, British Patents 5,614 and 11,664 of 1889. This is not the place to go into the involved story of the repercussions, but there were several patents which claimed to anticipate them; Nobel's Ballistite patent, one by Engel, one by Maxim and lastly one (B.P. 13,308/1888) by Mr. A. Anderson of the Royal Laboratory, Woolwich, and Mr. I. M. T. Anderson of the New Explosives Co., Ltd., Stowmarket. The last seems to have been particularly annoying to Abel & Dewar. To quote from their report ..... "This patent was taken out in November 1888 by special permission of the War Office, upon the recommendation of the late Director General of Ordnance Factories (Dr. W. Anderson) and without any conditions being imposed, for the production of a smokeless powder from gun-cotton gelatinized by means of a solvent. The complete specification of this patent was lodged some time after the Committee had been engaged in experiments in the Arsenal on the production of Cordite, the nature of which could not but become known to Mr. A. Anderson in his official capacity in the Department where part of the Committee's work was carried on and it included a claim which

was not indicated in the provisional specification, namely that of employing explosives generally in the form of threads, strips, cylinders and tubes produced by squirting materials through holes or slits in metal or other plates". Such a serious view of the possibilities of this specification was taken that the Cordite Patent was kept secret lest possible proceedings by the Andersons might have led to the disclosure of details of manufacture not enlarged upon in the specification.

Opposition came, however, not from any of the surprisingly numerous Andersons, but from Alfred Nobel, who claimed that the Cordite Patents infringed his Ballistite patent (B.P. 1471/1888) and that, in evidence he had given Abel's Committee, he had revealed manufacturing details of Ballistite that had been of great service to the Committee in evolving the manufacture of Cordite, but there seems to be no evidence that what he told them was of any real value to them. Although the War Office offered Nobel a joint interest in the discoveries of both sides, negotiations came to an end and the case eventually came before the Courts in the form of a friendly action. Nobel lost the case and Mr. Justice Romer said in his judgement that Abel and Dewar had solved the problem Nobel had left unsolved, that of making a good powder of insoluble nitrocellulose and nitroglycerine. It would be an unwarrantable extension of Nobel's patent to hold that it covered the use of guncotton when the patentee had expressly limited himself to the use of soluble nitrocellulose.

At this period of his life Nobel was involved in a series of misfortunes. Both his mother and his elder brother died, his own health was bad, political and economic difficulties had assailed his French company and his neglected mistress was having a child by an Austrian Officer. Schuck and Sohlmann quote the judgment in the case in full and there seems no doubt that it was a just one, but Nobel bitterly resented it and carried the case to the Appeal Court and the House of Lords, thereby incurring costs to the tune of £28,000. Still indignant, he started to write a satirical play called "The Patent Bacillus", but he seems to have had little grounds for complaint as his company received orders from the Government for making cordite and were also allowed to make it for various foreign governments including the Japanese.

The erection of the first cordite factory at Waltham Abbey and its start up ran parallel to the manufacture of nitroglycerine there, and this has already been fully detailed. The first nitroglycerine made was immediately incorporated with guncotton and left Waltham by barge on 21st March, 1891, to be pressed at Woolwich. At this time experimental work was still going on and specifications were still incomplete. Abel had written to D.G.O.F. on 12th March that the nitroglycerine used should be purified "to an extent which would enable it to comply with the standard adopted by Nobels' for nitroglycerine used in the manufacture of blasting gelatine". Pressure was being put on the Superintendent to try the use of spirit dried guncotton almost immediately, when it must have been quite difficult enough to get manufacture going with stove dried guncotton.

By 11th May, 1891 complaints were already being received of irregular performance of W.A. Cordite and the Superintendent wrote in reply to an Ordnance Committee minute that he was really not surprised at irregular results as arrangements were far from satisfactory. "It is incorporated here, pressed at Woolwich, mixed here - for you cannot call it blending - and, so far as I am aware, never tested before it is issued."

By 20th May, however, a considerable degree of success had been achieved for we find Thomson (the Manager) asking Skerman (the foreman imported from Woolwich) how many men and boys he would require to press, reel and cut two tons of cordite a week, if he had enough presses, etc. Pressing started at Waltham on 17th June, and on the 7th July the Explosives Committee paid their last visit of inspection to Waltham. Cordite had been well and truly launched by this band of pioneers.

A day or two later (10th July) D.G.O.F. wrote to Superintendent saying that it was absolutely necessary that energetic steps should be taken at once to ensure a considerable and regular output.

The Superintendent, not without reason, seems to have been more than a little annoyed. He wrote a long and somewhat heated reply showing how much he had done and continuing "I must, however, impress upon you the absolute necessity of having my demands met with a greater degree of promptitude than has hitherto been the case". He showed how his demands were held up at Woolwich whatever their nature, quoting examples of steam pipes, an enlarged porch for

the dry guncotton stove, trucks for transport of cordite and additional presses for the manufacture of rifle material, and said that these instances showed how no amount of energy on his part could avail so long as such a state of things was allowed to exist. The minute received an unpromising reply, but ten days later the Director-General visited the factory and settled all outstanding matters to the satisfaction of the Superintendent. On the 5th August, however, we find the Superintendent writing to Superintendent of Building Works to point out that he could not proceed with the manufacture of Cordite at night until the new electric lamps were put into the press house.

In spite of all these difficulties progress seems to have been good and a fair amount of experimental work was done, for by the middle of August it had been decided that the spirit drying process for gun-cotton was not a success and authority was being sought for the purchase of more land at Quinton Hill as no suitable site for more drying stoves could be found "owing to the dangerous nature of this process and the proximity of adjacent buildings."

In September Capt. Thomson, R.A. (not to be confused with J. M. Thomson, the Manager) who had been Secretary of the Explosives Committee, was appointed Experimental Officer for Cordite, his duties being to carry out and record all experiments with Cordite required by D.G.O.F., reporting the results to him. This appears to have been a further blow to the authority of the Superintendent as apparently he was not even to be informed of the results of experiments.

In spite of all difficulties and opposition the triumphant march of Cordite continued and on 6th October, 1891 the Superintendent wrote a long minute to D.G.O.F. setting out his requirements to make 2 million pounds of cordite a year, only to be informed that "there is no doubt that half the supply of Cordite will be obtained from the trade." The equivalent of the make of black powder ar Waltham would be half the quantity mentioned, and the Superintendent was to supply details of modifications required to bring output up to that figure. The acquisition of additional land for this purpose (Cob Mead) was approved by the middle of October and by the end of the month the Superintendent was able to detail his requirements without, however, assigning positions to buildings until he knew just how much land it was proposed to acquire and until the results of a proposal to deliberately fire a cordite stove were known. It is clear that, although operations had been so far carried through without accident, the dangerous nature of the manufacture was becoming clearly recognised and more detailed information on the risks involved demanded.

The general manufacture of cordite by private firms, apparently imminent in 1891, did not commence until 1894, when the National Explosives Company and Kynoch Ltd. were each given a contract for 600 tons to be delivered over three years at a price of 2/10½d. a pound, although in 1891 Superintendent Waltham had reported his cost to be 2/- to 2/6 a pound and improvements to reduce that figure considerably could be foreseen. The highest tender sent in was 4/3 and 2/10½ was the lowest so the bargain was perhaps not an unreasonable one.

The firms were also appraently allowed to sell cordite elsewhere if they could and Kynochs were soon to supply the Japanese Navy with it. But when the contract was placed they had not as much as a hut or a field, let alone the plant for manufacture. They commenced by placing a contract with Nobels to supply the Cordite paste and only did extrusion, drying, and blending themselves, though apparently they soon started making nitroglycerine and guncotton for some part of their output. In 1900 they admitted at the enquiry of the Select Committee on War Office Contracts that they were importing guncotton from Germany, and by that time the price was down to 1/10½.

Nobels had built a cordite factory at Ardeer in 1893/4 and the loss of the sole contract must have been something of a blow to them, but they appear to have started exporting at an early date and, after the nitroglycerine explosion at Waltham in May 1894, Nobels and the others came to the assistance of the Government and took Waltham guncotton for impregnation with N.G., thus enabling the Government to produce between that date and June 1898, 1000 more tons of cordite than they would otherwise have done, but it was not until January 1899 that Nobels received another order for Cordite from the British Government, and it is hardly surprising to see that in 1900 they were not very enthusiastic when the Government started to press for greatly increased output and in their reply stated that they would want early notice of requirements as they had had to accept orders from Foreign Governments who were willing to pay higher prices. They would, however, if it were made worthwhile, decline such business and restrict their manufacture largely to the requirements of the British Navy and Army.

Although one of the factors that had decided the Explosives Committee to standardize on the use of Mineral Jelly in cordite, was the lessening erosion and corrosion in guns, it was found in the Boer War that this was still serious and in 1901 Cordite M.D. was introduced to effect a further improvement. In this the proportions of guncotton and cordite were practically reversed, thus making the composition:-

Guncotton	65
Nitroglycerine	30
Mineral Jelly	5

This considerably reduced the temperature of explosion with greatly improved results as far as the expectation of life of guns was concerned, and M.D. remained the standard cordite until 1915 when circumstances compelled a further change.

When M.D. was introduced the output of the factory was considerably increased by increasing the guncotton plant and acquiring fresh land for the erection of cordite stoves to the South of Quinton Hill. These extensions were completed by 1906.

It was not very long after the introduction of Cordite M.D. that the first serious accident in cordite manufacture at R.G.P.F. took place. On 15th December, 1902 an incorporating machine blew up, killing three men. No entirely satisfactory explanation was forthcoming, but the occurrence led to a further tightening up of regulations particularly as regards inspection and mixing of the paste and ingredients, and nothing of the sort ever took place again.

In 1901-2, two of the very remarkable team of Chemists then employed at the Factory under the inspiring leadership of Sir Frederick Nathan, Dr. R. Robertson and Mr. W. Rintoul, commenced experimenting on the recovery of acetone from the cordite stoves by the bisulphite process. It was not until 1906 that a plant on these lines was completed and put into operation. It proved very successful, saving about 50% of the acetone used and was in operation until 1918.

At the outbreak of the 1914-1918 War the output of cordite was 26 tons a week. This was stepped up immediately to 57 tons and by March 1915 had reached 64 tons. This was all done without any new plant, but in the Autumn of 1914 orders had been received to increase production of rifle cordite to 20 tons a week and cannon cordite to 120. This was completed within a year of the outbreak of the War. At this point, in August 1915, the factory was transferred to the Ministry of Munitions and by various extensions the capacity was increased to 200 tons of Cordite M.D. About the end of 1916 the shortage of acetone compelled the new Cordite R.D.B. to be used for all large sizes. R.D.B. was a wartime development and consisted of 52% Collodion Cotton, 42% Nitroglycerine and 6% Mineral Jelly, ether-alcohol being used as a solvent.

The years between the wars were years of depression at the R.G.P.F. but the small staff remaining there did a great deal of valuable work with the very limited means at their disposal. Not only was the plant maintained in good order but much investigational work was carried out. Solventless cordite and flashless cordite owe much to the early plant work that was carried out by the staff in those critical years, but perhaps the most outstanding feature was the development of "Cordite W". Between 1928 and 1932 guncotton was made with a mixture of 50% linters and 50% cotton waste. In 1932 it was found that cordite made from it gave corrosion spots on climatic trial which definitely shortened the life of the cordite. It was decided to revert to the use of cotton waste only but possible dangers had been shown up. The corrosion usually centred round foreign bodies and a new type of straining arrangement was designed which led to greater freedom from foreign matter in the cordite. It was also felt that a more efficient stabilizer than mineral jelly was required and as a result of experiments carried out by H. A. Phillips and P. G. Knapman it was decided to use 6% of "carbamite" (diphenyl diethyl urea). This cordite was first produced in 1933, and proved very much superior to its predecessors as regards stability.

At the same time other qualities were being called for in cordite. Freedom from flash and smoke became of increasing importance as also did more rapid methods of manufacture which did not demand extended periods of stoving.

The first of these problems was solved by the use of "picrite" (nitroguanidine) which was suggested by the Research Department at Woolwich. A cordite containing 55% of this material was made at Waltham in 1928. Various compositions of this type were tried and eventually wartime manufacture settled down to compositions containing approximately:

55% Picrite
20% Guncotton
20% Nitroglycerine
4.7% Carbamite
0.3% Cryolite

Such compositions are stable enough to allow the use of wood and straw cellulose in place of cotton and give almost complete freedom from flash and smoke.

The "solventless" process, by eliminating the use of volatile solvents such as acetone, does away with the necessity of stoving and the large ground area and many buildings required for it. The time occupied in drying cordite, particularly the large sizes, is very considerable and when production is urgent this can be a serious drawback. Compositions made in this way normally contain nitrocellulose (12.2% N_2) and its gelatinization by nitroglycerine is enhanced by the presence of carbamite. A further advantage of the solventless process is the much greater safety resulting from the fact that a wet slurry of guncotton is mixed with nitroglycerine and thus the drying of guncotton and dry mixing are completely avoided.

In addition to its duties as a producing factory Waltham continued to do a great deal of experimental and pioneering work on various types of cordite right up to the time it closed in 1943.

CHAPTER X

HIGH EXPLOSIVES AND SUNDRY MANUFACTURES

While Waltham Abbey was essentially a propellant factory it played a by no means inconsiderable part in the development of high explosives. A Royal Engineer Committee reported in 1870 that compressed guncotton fired with detonating fuzes was a most valuable explosive and that it should form a portion of the R.E. equipment in the field. For many years guncotton was only made for such purposes at Waltham, and about the time its use in cordite was discovered, investigations were also going on with a view to finding other explosives for shell filling and for demolition purposes.

The Abel Committee on Explosives which invented cordite was also keenly interested in the development of high explosives. Abel had previously tried to rouse interest in picric acid and various compositions containing picrates, and among the many inventors the Committee had to deal with was Turpin, the Frenchman, who had put forward picric acid under the name of "Melinite" as a shell filling. He had been in communication with the Admiralty who carried out some tests at Lydd and invented the name "Lyddite". The Committee discovered that the "Melinite" then being used by the French Government was not, in fact, plain picric acid, but contained a proportion of collodion. Although Turpin had had a reward from his Government for suggesting the use of picric acid in shells, his invention had merely served as a starting point.

Abel, in July 1870, had put forward 'picric powder', a mixture of three parts of saltpetre with two of ammonium picrate. It could be readily prepared by the methods used for gunpowder and could be pressed and granulated without difficulty. It gave excellent results in a variety of tests.

Manufacture was undertaken at the R.G.P.F. and on 19th May, 1874. the Superintendent reported that a green charge had exploded on a mill without serious damage or injury. After the explosion an iron nail was found on the mill bed, and this may have fallen from the roof after the explosion. After this no further untoward incidents seem to have occurred; but it is by no means clear how much picric powder was manufactured.

The amount cannot, however, have been large, for when some was demanded in April 1895 manufacturing instructions had to be obtained from the W.D. Chemist "as the powder had not been made for many years and no records of its manufacture have been kept". General information was forthcoming and investigations at Waltham soon produced a practicable process (this time fully recorded). Difficulty was found in getting supplies of ammonium picrate and when a further order was received three years later a plant was erected at Quinton Hill for making it from Picric Acid. This plant worked quite satisfactorily and was used during the first World War for the same purpose. This picric powder was used as a "booster" for picric acid which, under the name of "Lyddite" remained the principal shell filling in this country until the 1914-1918 War. The United Kingdom had at this time only a very weak organic chemical industry with the inevitable result that progress in such matters was very slow.

TETRYL

About 1910 Tetranitrodimethylaniline, also known as Composition Exploding (C.E.) and Tetryl, came into use as a booster in place of picric powder. Manufacture on a very small scale commenced at Waltham in that year and did not increase until the outbreak of War in 1914. Then continual uncertainty and fluctuation in requirements even while plant was being erected led to piecemeal extensions which were far from satisfactory. It is typical that in 1916 a nitrating plant capable of producing 5,000 lbs. a week was improvised out of lead and old acetone drums, and was actually producing within 24 hours of the order to proceed being received. It was not till 1917 that other factories came to the aid of Waltham, and then only after a number of serious fires had shown the undesirability of depending for supplies of this important material on one factory. The water boiling process for purification was put on a satisfactory manufacturing basis in 1917 and a new plant was completed just before the Armistice. This was not used till 1935, and again, at the outbreak of War, at first the Waltham plant had to carry

the whole burden of Tetryl manufacture though other factories were able to relieve the pressure by 1942. Never the less insufficient supplies of corned and granulated material necessitated the continued use of the old dilapidated and improvised plant at Waltham till the end. It was, in fact, one of the very last Waltham plants to close down.

T.N.T.

The importance of T.N.T. as a military explosive today is such that it is difficult to realize that it was not used at all in the British Services before 1914. It had been employed as a shell filling in Germany in 1902, but it was not till after the beginning of the first World War that its importance was fully realized in this country.

When the need was realized manufacture quickly started, though it had previously been little more than a laboratory operation. The Woolwich Research Department rapidly established suitable conditions for efficient nitration and plants were established later in new Government Factories and in industrial concerns, notably Chance & Hunt Ltd. at Oldbury.

A three stage batch nitration process was generally used, using the waste acid from the last stage for the earlier stages, but a continous counter-current process was developed at Chance & Hunts. It had not been called to produce Grade I. T.N.T. continuously by the end of the war and considerable doubts had been expressed as to whether it would be possible for it to do so.

With the curbs on Government expenditure which followed the war no development work was carried out until 1930 when the staff of the Directorate of Ordnance Factories was augmented to consider the steps to be taken with regard to increasing the facilities for the manufacture of munitions in the event of war, and a special section to review the production of explosives and chemicals was formed. To this section Dr. R. C. Bowden was appointed from Walthan Abbey and Mr. T. A. Smith was appointed from outside the Civil Service.

With regard to explosives the duties of this section were specially to review the processes used in the last war, and to select the processes to be adopted in the event of it being necessary to build further factories.

The production of T.N.T. was one of the first subjects to be considered and an extensive review of all available literature and war records was undertaken. Certain changes in the position since the last war particularly with regard to T.N.T. manufacture had taken place. The chief of these was the situation brought about by the turn-over to the production of nitric acid by the oxidation of synthetic ammonia instead of its production from Chile saltpetre and sulphuric acid. This use of sulphuric acid had formed an outlet for the weak acid produced in the T.N.T. process which started with concentrated sulphuric acid in the form of oleum. Without such an outlet it would be exceedingly difficult to continue the manufacture of T.N.T. on a war scale and the demands for oleum would be excessively high and large new plants would have to be erected. Under the new conditions of manufacture it was therefore necessary to find a means of closing the sulphuric acid cycle.

After an exhaustive study of all processes known to have been used, both at home and abroad, it was not found possible to select one likely to be at all useful as no effort had been made to close the cycle, there having been, during the first war, the outlet for weak acid in nitric acid manufacture, and during peace it was possible to dispose of the small amount of weak acid arising from the small scale manufacture in the production of fertilisers.

The plant which showed more promise of meeting requirements was the continuous counter current process developed during the last war at Oldbury, and with the development and operation of which Mr. Smith has been associated. This plant had never been called on continuously to produce Grade I T.N.T. and there were doubts as to whether it could be relied on for this purpose. There were also other features that it was considered essential to avoid in view of the conditions arising from the use of untrained labour under war conditions.

The Director of Ordnance Factories decided, however, to erect a new plant at Waltham Abbey on lines proposed by the Development Section and £5,000 was allocated for this purpose by the three Services. This new design incorporated the following features:

1. Separator vessels were reduced in size so that the amount of nitrobody in the plant was considerably lessened, with a view to reduction in risk. This was made possible by a new design of separator and a new design of transfer equipment.

2. All connections were above the level of the liquids and accessible for cleaning.

3. Provision for regular removal of sludge from the plant was made.

4. Valves were avoided.

5. Flow was visible and capable of being controlled.

6. The arrangement was such that failure of one part of the plant did not put the whole plant out of commission.

7. The possibilities of the use of non-corrosive materials in plant construction were carefully considered.

8. Means were provided for re-circulating the contents of any one pot and preventing the nitrobody passing forward from pot to pot if the required degree of nitration had not been effected.

9. Simplicity of plant design facilitated rapid replacement due to loss by enemy or other action.

10. The process uses 96% Sulphuric Acid for making mixed acid and this enables the cycle to be closed. The spent acid (72%) is concentrated to 96% and all of this goes back to the nitration stage.

The proposed arrangement had the approval of the Research Department, Woolwich, and the Principal Supply Officers Committee through the Explosives Sub-committee.

A plant erected to produce 2 tons per week showed itself capable of producing this quantity of the right quality (approved to Specification by W.D. Chemist) continuously, and formed the basis of the design of future plants. A patent (Specification No. 381291 of 1932) for this design of plant was taken out in the names of G. S. Witham, T.A. Smith and R.C. Bowden and assigned to the Secretary of State for War. A full scale unit of nominal capacity of 25 tons per week was erected at Irvine to give experience in continued running and also to meet demands which were being placed for T.N.T.

This unit was sufficiently succesful for all subsequent units erected to be almost complete replicas of it, and such a unit has shown itself, with enlarged transfer equipment, to be capable of producing 90 tons T.N.T. per week.

In all 24 such units were erected in British T.N.T. factories and upwards of 270,000 tons T.N.T. produced on them during the 2nd World War. The total home production in the 1914-18 War was 238,364 tons.

R.D.X.

The manufacture of R.D.X. (Cyclonite, cyclo-trimethylene-trinitramine) was developed into a practical operation in the Woolwich Research Department during the years between the Wars. The material, which is one of the most powerful and safest high explosives, had been known as a laboratory curiosity for many years but it was not until the advent of synthetic methanol and ammonia that its large scale manufacture had become a practical proposition. It had the further advantage that it was a truly synthetic compound requiring no imported materials as it was made by treating hexamine with excess of nitric acid under suitable conditions. The hexamine was made from ammonia and methanol, both derived from coal, air and water and the nitric acid from the oxidation of ammonia.

The Woolwich process, devised by Drs. Elwyn Roberts and Aquila Forster, was a singularly smooth and successful one and is probably still the cheapest method of production, though it suffers from the defect that it requires the concentration to nearly 100% of large quantities of nitric acid and this, in turn, requires the concentration of even larger amounts of sulphuric acid, involving the use of very large amounts of fuel. In 1938 it was decided to erect a small pilot plant, capable of producing about five tons of R.D.X. a week, at Quinton Hill. This work started early in 1939, and no serious difficulties were met with in operation. For two years after the war started this small plant was the country's only source of this most powerful explosive, and it was pressed so hard for output that it was not possible to carry out nearly as much development work as had been hoped. Much good work was done, however, and staff were trained and gained experience in the manufacturing operations before new factories were ready to take over manufacture on a much larger scale.

FUZE POWDERS

Until August 1915 shells, and consequently fuzes and fuze powders, had been produced in such small quantities that no serious difficulties had arisen. The sudden enormous increase in demand immediately found weak spots. New fuzes and guns were designed and the fuze powders formerly used caused blinds to be experienced at gunproof. Waltham, then the sole producer, faced with the total collapse of previous methods of manufacture, and little time for experimenting, rose to the occasion and a new method was devised and proved successful. This process was considerably improved as time went on, and it was possible to do more experimental work. This was continued between the wars and culminated in the production of methods of manufacture in which all factors were completely under control. In the second World War this manufacture was taken over by the filling factories.

These remarks apply to the Gunpowder type of fuze powder. A slow burning fuze powder, for use particularly in A.A. shells, became increasingly demanded, and one of the first development jobs between the Wars was the installation of a plant for the manufacture of R.D. 202, a mixture of ammonium perchlorate, charcoal and starch, in 1925. The manufacture ran well, in spite of the difficulty and danger of first grinding ammonium perchlorate to pass through a 240 mesh sieve and then incorporating with the other ingredients. As the second war approached and the demand increased, the factors controlling time of burning were clarified and defined and, finally, it was possible to hand the process over to the filling factories as one which would give them no difficulty.

NITROGUANIDINE

Nitroguanidine, also known as Petrolite and Picrite, is used as an ingredient of flashless cordite. A plant for its manufacture by methods developed at Woolwich Research Dept. was erected at Waltham Abbey in 1925. The method proved to be capable of being very greatly improved and Waltham developed it into an extremely neat and trouble free process with interesting chemical engineering features which it would be out of place to discuss here. The plant continued in operation till 1941 when other sources of supply became available.

MISCELLANEOUS

In addition to such operations as the burning of charcoal and refining of sulphur the Royal Gunpowder Factory for many years had its own Gas Works. This only ceased operation about 1905, a year or two later than the distillation of acetone from grey acetate of lime.

Soon after the introduction of cordite it became clear that operations could not be economically carried on unless the factory had its own acid plant. Previously mixed acid had been imported into the factory and no attempt made to recover waste. The acid plant kept well abreast of the times and pioneered in more than one direction.

A Guttman plant for nitric acid production from Chili saltpetre and sulphuric acid was started up in December 1897. This plant had vertical air cooled condensers with acid lutes leading to common collecting channel pipes. This very troublesome condenser system was

replaced in 1913 by silica coils sprayed with water, through which the nitric vapours pass upwards and down which the condensed acid flows to a suitable receiving system. This type of condenser which can readily be run with two or more coils in parallel proved much more satisfactory and remained in use until the factory closed.

Sulphuric acid concentration was carried out by Kessler Concentrators which were installed at much the same time as the nitric acid plant. The Kessler plant, now almost, if not quite obsolete, is described fully in many text books.

It is built of Volvic lava, an acid-proof and easily workable stone found in the Puy-de-Dome area of France, and consists of a rectangular basin into the top of which hot gases from a producer gas furnace are introduced. The gases are brought into contact with a shallow layer of acid in the "saturex" as it is called, by walls of the same stone hanging from the cover and reaching to acid level. The weak acid is fed in at the other end of the Saturex down a short recuperator tower consisting of trays of Volvic lava drilled with holes fitted with porcelain bubble caps. The whole apparatus is kept under suction by an ejector (or lead covered fan) and the gases finally emerge through a coke scrubber.

The apparatus was completely dependent on a supply of Volvic lava and during the 1920's it was realized that this might not be a very desirable state of affairs in the event of war; and the building of a Kessler in substitute materials was given serious consideration.

Acid resisting bricks made in England are as good as any in the world and considerable thought and ingenuity was expended in building a similar type of concentrator in these bricks. A design was eventually proposed by Dr. R.C. Bowden in which the saturex was built in several layers of brickwork jointed with glass powder and pumice damped with a little silicate of soda. The recuperator tower was constructed likewise in brick with internal arches bonded to the walls and containing holes at their outer edges, each arch being surmounted by two half arches with central holes. There was thus a continuous back and forth flow both of acid down and hot gases up and the result was a concentrator made of home produced materials, quickly and cheaply build and in many ways superior to the Kessler.

It was only killed by the vastly increased demand for acid concentration during the War and the fact that pot concentrators could destroy all organic matter in acid fed to them and produce concentrated acid without the very objectionable exit gases that were characteristic of all concentrators in which hot furnace gases were brought in direct contact with the acid.

This "Evans-Bowden" concentrator was not only used at Waltham Abbey, but a number were erected elsewhere both in Government and in private factories.

CHAPTER XI

EXPLOSIONS AND THEIR PREVENTION

It will be observed that so far little reference has been made to accidental explosions. Their repercussions and the alterations to manufacture made as a result of them are so important that the stories concerning them, as far as they are known, have been brought together.

In the early days of the factory and, indeed, of all gunpowder factories, explosions were frequent. They seem to have been regarded as inevitable and little effort was apparently made to enquire into causes or take steps to prevent a recurrence until the Government took over the factory. The lack of scientific control or understanding of underlying causes of explosions as well as the somewhat unpredictable habits of gunpowder encouraged a fatalistic attitude. Such explosions as we know of seem to have been slight, e.g. Tom Fuller's reference to the mills having been five times blown up within seven years, without loss of life, and an entry in the Annual Register dated December 3rd, 1765, "Two powder mills blew up at Waltham Abbey but happily no lives were lost."

More serious explosions undoubtedly did occur, for in an account of a Corning House explosion in the "Gentleman's Magazine" for 1801 there is brief reference to a similar explosion which had occurred sixty-two years earlier (1739) when one of the men killed was "so completely destroyed that only his clothes were found on Galley Hill".

From the time the Government took over in 1787 the records of explosions seem to be fairly complete. There were many explosions of "green" or partly milled charges in the mills and they were usually without very serious results and the following examples show:

"Sept. 9th, 1789. This morning, at 11 o'clock, the two new or Iron mills blew up. Tho. Runball, the millman on duty, had just liquored the charge, and happened to be outside; he received no hurt. The Master Worker says this mill has fequently blown up."

"Feb. 4th, 1790. This morning, at 1 o'clock, one of the Queens Mead mills blew up, which entirely unroofed same. The charge had been worked an hour. Thos. Graylin, millman on duty, set fire to his jacket; but he received no bodily harm".

"April 2nd, 1790 - Explosion of two mills, at 11 o'clock. No one hurt".

"May 22nd, 1790. Hoppit Mills blew up, no one hurt".

Explosions were, in fact, so frequent that we can only refer to a few of the more serious ones or those possessing features of special interest.

In 1793 it would appear that steps began to be taken to tighten up regulations and made the manufacture safer. On Feb. 23rd, for instance, an order was issued that no beer admitted to be drunk at any part of the manufactory, nor any dogs admitted "up the Bank". On Feb.27th, gravel was discovered "at the bottom of a shoe belonging to a labourer at New Corning House", and the master mixer was instructed to go and examine the shoes at frequent intervals. Following this instruction we note many references to men being stopped a day's pay for not obeying orders with regard to shoes.

On May 28th a piece of hard flint was found on the sieves at the Old Corning House, having gone through the press and corning frame sieves. Orders were issued that the charges should always have covers on them when removed.

On May 29th two Engineer Officers arrived "to set out the proposed traverses". This appears to be the first mention of the traverses now so universally used to confine the effects of accidental explosions. No record elsewhere at an earlier date is known to exist.

In the following years the factory was working under considerable pressure owing to the Napoleonic wars and a practice seems to have grown up among the millmen of increasing the mill charge. Several explosions were ascribed to this cause and steps were taken to decrease the charge. The following extracts from factory records on three successive days seem to be last on this topic:

Dec. 3rd, 1798: Lower Queen's Mead Mill blew up. It was violent, much injury done. The shock was felt all over the town, and gave greater alarm than ever was heard of before. It was supposed that more than the ordinary quantity of powder had been put in the mill." Dec. 4th: "Letter from Major Congreve directing the mill charges to be reduced to 38 lbs. and 40 lbs. Suspicion that millmen have added to the charges, and this caused great injury at the explosions." Dec 5th: "Mill blew up. Very violent. Caused by practice of putting more powder on the beds than allowed."

The first serious explosion after the mills became Government property occurred, as already mentioned (Chap. VI), on April 18th, 1801. The new Corning House on Horse Mill Island blew up, killing nine men and four horses. The official view was that it was impossible to say the cause and that there was no powder in the buildings except what was in process of graining. The account given in the "Gentleman's Magazine" however goes into more detail -

"April 18th, between 3 and 4 in the afternoon the Corning Mill at Waltham Abbey, blew up, with a great explosion which was sensibly felt all round the neighbourhood. Eight men were blown to pieces in the adjoining meadow, and four horses much mangled were left near the mill wheels; fragments of a ninth man were found on the 3rd day. This fatal accident is ascribed to the overheating of one of the gudgeons of the mills, and had nearly happened a fortnight before. Three of the men have left families and the others only widows. One of them was substituting for another who had narrowly escaped in a previous explosion and was on leave. The mill was being worked for the last time previous to a complete overhaul. The magazine of dry powder was not 200 yards distant and 400 barrels of powder had been removed from the mill in a boat not long before it blew up.

On June 16th of the same year when this Corning House was under repair a fire occurred and seven men were badly burnt. It was ascribed to the blow of a copper hammer on a pit wheel. The fact that it was a copper hammer seems to show that some precautions were taken, but later it was discovered that many of the copper implements were contaminated with iron. It sounds too as if the precautions of thorough washing down and wetting down had not been carried out effectively.

Compensation in the case of this accident seems to have been on a comparatively generous scale; the widow of the foreman received half her husband's pay of 13/6 a week (she had two children). The widow of a labourer with seven children and disabled from earning her living received his full pay of 12/- a week and another widow, who was about to have her first child, 6/- a week. Nearly a hundred years later, in 1894, it was stated in the House of Commons, in reply to a question, that regulations permitted a maximum grant to a widow with one child of £10 a year with £15 in respect of the child.

Safety seems to have been given a good deal of consideration about this time for on July 15th, 1801 a committee of the Royal Society visited Waltham to investigate matters which the Board of Ordnance had referred to them regarding the floors of the Powder Magazines. On July 24th they reported that no danger was to be apprehended from electrical excitation in rolling barrels of powder on leather covered floors in magazines but that painted floor cloth was more suitable for other buildings. Such floor cloth was delivered to the factory in May, 1803.

On November 27th, 1811, No.4 Press House on Lower Island exploded and the ensuing fire communicated to the Corning House and Reel House which also went up. Eight men were killed in this disaster. The Board of Ordnance was appealed to for funds to bury the dead in a plain, decent manner, and for some mark of merit to be granted to Wm. Peyton, Carpenter, who, after the explosion, extinguished a fire brand which fell near the door of the Magazine which had a quantity of powder in it. The door of the Magazine had been forced open by the explosion.

He received a donation of £20.

The magnitude of this explosion is shown by the account of it in the "Cambridge Chronicle" of the following day and headed "A Dreadful Accident". "A powder mill at Waltham Abbey was blown up on Wednesday last, 8 lives were lost and seven of the persons left families. The whole of the town of Waltham was in great danger, as it was thought the magazine would have been blown up. A man was, in consequence, sent through the streets to warn the inhabitants to leave their houses instantly. At Stepney, a mirror of plate glass was broken by the shock; at Hackney several panes of glass were forced in and at Blackwall the windows throughout a whole street were shattered. Near the New Road Marylebone, several of the houses were much broken and the labourers who were excavating in the park felt the ground shake where they were at work. Even ships on the River were shaken. Some of the morning papers mistook it for an earthquake."

In June 1812 a Committee of Engineers were appointed "to consider the best means of establishing the works destroyed by the late explosion". Their recommendations include the provision of half doors to buildings to prevent dust and stones being blown in from the paths. They also suggested that, as the glass in many of the windows was exposed to the free action of the sun, it might, in some cases, from the accidental irregularities of the surface, concentrate its rays into a focus sufficiently powerful to explode in a state of high inflammability, particularly when the glass, the windows and all woodwork were covered with an inpalpable dust of powder ready to ignite by the slightest possible cause. To counter ct this, linen blinds stretched in frames outside were recommended to be applied to windows so situated. Larger traverses were also recommended.

A further recommendation was that Bramah's Hydraulic Presses should be used instead of screw presses. This does not seem to have been implemented completely, for Drayson's "Treatise on Gunpowder" (1830) refers to screw presses as being used with the old type shaking frames and Bramah presses with the Congreve Granulator which was installed in 1816 at the Lower Island Works. The very limited expenditure authorized by the Board evidently prevented extension of these improvements.

There followed a lond period of peace and a very low level of work in the factory and no further serious explosions took place till 1843. On April 13th of that year at 2.50 p.m. another Corning House working on the old system exploded violently. The explosion was communicated over the traverse to the press house and another corning house and press house were set on fire and burnt out. Seven lives were lost and the explosion was felt more or less severely for miles around; many doors and windows were blown out and broken in the Magazines and houses near. In the town an old wall was blown down and an immense number of windows broken. Pieces of broken beams etc. were found upwards of a mile off in the direction of Enfield Lock; large pieces of the presses were found at a distance of 220 yards, and the Mill Head was covered with debris.

An enquiry into this accident was held by Col. Cockburn and Mr. Faraday, and is referred to in Chapter VI.

By this time explosions were beginning to excite some public interest and the "Illustrated London News" published what they described as a "series of graphic sketches illustrative of the deplorable event and its consequences".

In the account of a very minor explosion some six years later, reference is made for the first time to one of the greatest safety precautions in gunpowder manufacture, the tanks of water arranged above the mills on hinged boards, so as to be overturned in the event of an explosion. On this occasion, and on many other subsequent ones, it is stated that they worked well and prevented serious damage.

In 1856 one or two minor explosions took place during the working of experimental compositions and some of this work seems to have been undertaken rather casually. The Crimean War was then keeping the factory very busy, and like later wars, seems to have stimulated research. The following quotation shows what is meant:

"On 19th April, 1856 an experiment for Capt. Boxer was being carried on in No. 4 Mill when it exploded. The composition was: Sulphate of Lead 48, Charcoal 6. The runners had not been round more than three times when it burnt up more than it exploded. Three other mills were just going to work on this composition, which were immediately stopped. Experiments were made immediately to ascertain whether this composition was highly explosive, which was found to be the case, in fact went off when struck by iron hammers on an anvil every time like detonating composition. No-one was hurt and little damage was done".

To go blindly into an experiment of this sort and start up four mills together seems a curious way to go to work. Likewise the somewhat crude attempt to find out if the material was dangerous after the event seems odd to us, although if the composition is correctly given in the records there was no obvious reason to anticipate danger.

In 1857 an event took place which showed clearly the need for safety rules of a stringent character. During the morning of June 1st a stoker in the Saltpetre Refinery was lighting one of the copper fires by carrying a shovel of hot coals from another fire. Before he could shut the fire door fire ran up the side of the copper and communicated with the filter and thence to the beam and a wooden trough. This could easily have been put out but the Master Refiner, an old man, lost his head and seized one end of the trough telling another man to do the same. Together they carried it out of the building with a view to dropping it in the river. To do this they had to step on to a boat which was alongside, and which contained 13 barrels of damp gunpowder which had been brought up for extraction.

A piece of the lighted wood fell from the burning trough into the boat and exploded it, together with four or five barrels left on the quayside from a previous load which had been partly dried out in the powerful sun.

The boat was blown to pieces and four or five men greatly shaken, Mr. Knowler, the Master Refiner, was seriously injured, and his nephew, who had helped him to carry the trough, so badly burnt that after a year in bed he was quite incapacitated for the service. Another man had his leg so badly shattered that immediate amputation was necessary and one other badly burnt.

Quite a full inquiry was held into this accident and it seems to have been decided that the cause was ineffective damping of the gunpowder. Instructions were issued that material for extraction was to be mixed with water to a thick paste before being brought to the Refinery for extraction.

At this period it seems to have been the beginning of the realization that explosions might be preventable. A slight explosion on July7th, 1857 is recorded together with a note:- "In consequence however of so many explosions in these four mills, they received a thorough overhaul, and it was deemed advisable to re-cut and polish all the runners and beds, which had become very rough and fix gun-metal cheeses in places of the iron ones which appeared to be particularly the cause of frequent explosions in these mills."

An explosion on May 27th, 1861, showed, however, that a great deal of laxity and carelessness still prevailed. A mill had been stopped for repairs and four experienced millmen had been sent in to clean it. While moving the runners off the cake it exploded, and four other mills in the group of six followed rapidly (the remaining one had just been cleaned). It appeared that the ordinary precautions of using leathers to prevent contact of the runners with the bed or of damping the runners and bed had not been taken. As a result three of the men were badly burnt and the fourth died of his injuries. At the inquest the following verdict was returned by the jury: "we find that the deceased met his death by an explosion of gunpowder, at the Works at Waltham Abbey, caused by not using the hide leathers provided for use in moving the runners, and the jury would recommend that the foreman be instructed to see that the leathers are used by the men and any other precautionary measures be adopted the Authorities may deem fit.

It is clear that by now the public conscience was beginning to be affected by the continual explosions and the "Morning Chronicle" of June 3rd reported this inquest with a headline "Singular Neglect in a Government Establishment".

In the report of a small explosion in 1864 we find for the first time a mention of a man whose face and hand were burnt but "the fireproof clothing saved any part of his body being burnt". It looks as is this is the first mention of lasting cloth for factory wear and its use may have been connected with a remark at the inquest on the 1861 explosion that the men's clothing was saturated with gunpowder and took fire very rapidly.

In spite of the obvious advantages of fireproof clothing, it does not appear to have been universally used. An explosion which occurred in a press house on Lower Island on June 16th, 1870 caused the deaths of five men, and it was pointed out at the inquest that if the men had had fireproof clothing they would have been saved from the terrible burns they suffered. The lack of fireproof clothing is curious for Capt. F. M. Smith in his "Handbook of Gunpowder Manufacture at Waltham Abbey", published in the same year states very definitely that no workman is allowed to enter any powder building without putting on a working dress of incombustible material. The explanation given of this explosion after a good deal or cross questioning, as that a flash had been accidentally produced by some foreign substances, such as sand being present while powder was being unloaded in the press. The Coroner's Jury returned the usual verdict of "accidentally killed by an explosion of Gunpowder" with a rider to the effect that the magazine should be placed as far as possible from those parts of the Works where powder is made. The Jury, made up of Townsfolk, were not unnaturally disturbed by the revelations that the next door building to the one which exploded was a magazine containing five or six thousand pounds of gunpowder, and that after the explosion this had been emptied into the river through the efforts of half-a-dozen men who braved the flames and glowing embers to save the possibility of a worse disaster.

After this explosion a fund for the benefit of the relatives of victims was raised locally The need for it was shown in a revealing paragraph in the "Waltham Abbey and Cheshunt Weekly Telegraph":- "Deprived in an instant of their sole means of support, the widows and orphans are at present entirely dependent on the bounty of others. We say, at present, because the aid which Government may and, we sincerely trust, will give to the widows of those who died in execution of their duty, must be the subject of protracted correspondence and may indeed, after all, be insufficient to maintain them."

In the following years serious efforts seem to have been made at last to elucidate the cause of all explosions, and to disprove a remark made by Sir Frederick Abel, who, in the course of expert evidence at the Coroner's inquest after the 1870 explosion had said:- "However careful men are, it is impossible for these explosions to be guarded against". About this period, too, explosions of modern explosives started. The first of which we have record was on 8th April, 1873, when a guncotton press exploded. Three 5" discs, separated by steel plates, were being pressed in the same mould, and when pressure was put on, the press exploded violently. The explanation given at the time was that the long travel of the "piston" would cause serious friction if it was the least degree out of truth, and that this friction must have been enough just to dry and then ignite some of the particles of guncotton in close proximity. Such an eminently reasonable explanation is a pleasant change from the long series of "no known cause" in Gunpowder accidents. The precautions taken seem to have been sensible for the Superintendent decreed that, in future, only one disc should be pressed in each bush, thus giving the "piston-head" a shorter travel, and that the presses should be removed to a separate building.

Nevertheless a similar explosion took place on August 2nd, 1877, and further precautions were introduced. Just what they were cannot now be traced, but it is believed that the practice of surrounding the press with rope mantlets dates back to this period.

A century of Government occupation ended without further explosions of general interest. As will be seen from the foregoing, some progress had been made and both the public and the official conscience was beginning to revolt against the idea that accidental explosions were natural and inevitable. Capt. Smith's 1870 "Handbook" previously referred to contains a summary of the "Rules for the Prevention of Accidents" many of which have survived unchanged to the present time. They were hung up in every house and the foremen were instructed to read them to their men once a week. The first factory rule book was published in 1884 and covers the same ground with some additions. The use of "clean" shoes and lasting cloth

clothing and the cleanliness of buildings are insisted on. It is surprising but logical to find a rule that men must be careful to keep hair and beard cut short to avoid introducing particles of sand or grit. In this issue too appears the famous rule that "no undue haste must ever be made and no greater force employed than is absolutely necessary." Such rules as "No implements are to be used in any Powder House, Mill or Boat, except those provided", and that requiring stoppage of machinery during a thunderstorm are standard in explosives factories to-day, and it is evident that this rule book represents a great deal of progress and a real effort to make the factory all that it should be.

It was a start, but more explosions were to occur before the factory reached a state where good discipline and scientific control reduced the number and frequency to a point at which Explosives manufacture could compare favourably from the safety angle with most other industries.

For some twenty years all went well and then on August 22nd, 1890 at 6.30 a.m. the peace of Waltham Abbey was once again shattered by a loud explosion. The explosion occurred in No. 1 Breaking Down House where millcake was ground to powder between two slowly moving phosphor bronze rollers, driven by a water wheel. The process is normally a very safe one, and at the inquest on the two men who were in the building at the time no evidence came to light as to the cause of the accident. A boatman had delivered twelve barrels of powder to the house half-an-hour earlier, the machines were apparently in good order and the men were reliable and experienced. The surrounding trees appear to have acted as a traverse and saved the external damage from being more serious than it was and the factory Fire Brigade was quickly in action.

Evidence was given at the inquest that the men were wearing non-inflammable clothing and felt shoes. The local paper describes in some detail the safety arrangements to prevent an explosion spreading from one compartment to another under the same roof. "A shaft runs the length of the building and connected with this are arranged above each pair of rollers a 30 gallon water tank and a shutter. Should an explosion take place in any one roller house, the shutter in it would be shot up, and this would capsize the contents of each water tank in the other houses, saturating and rendering harmless the gunpowder beneath."

The two men killed, William Napthan and William Maynard had both been employed at the factory for about 18 years. Both were married men with families and both widows received a pension of 4s. 0d. a week, and "a small amount from the Factory Benevolent Fund towards which several subscriptions have been received during the week." At this time the public purse was being safeguarded with more zeal than discretion but that the excellent discipline of the factory was fully appreciated is shown by the following correspondence which was posted on the Factory Notice Board:-

War Office, Pall Mall
29th August, 1890.

Sir,

I am directed by the Secretary of State for War to convey to you his appreciation of the courage and discipline exhibited by the officers and men employed at the Royal Gunpowder Factory at the time of the late accident, attended by the lamentable loss of two excellent workmen. He is very sensible of the devotion to duty exhibtion by those who so promptly extinguished the fire in the exploded building, no less than by those who remained at their posts, according to regulations, during the trying moments of suspense when it was uncertain whether other buildings would not be exploded. The methodical way in which the work of the factory was resumed also speaks highly for the training of the men employed in a manufacture in which a strict observance of regulations and prompt action in the moment of danger are essentially necessary to the safety of those employed.

I am, Sir, your obedient servant,
(Signed) W. St. J. Brodrick.

Major-General Noble,
Superintendent, Royal Gunpowder Factory,
Waltham Abbey.

Royal Gunpowder Factory,
Waltham Abbey.

30th August, 1890.

Sir,

I have the honor to acknowledge the receipt of your letter dated 29th August, 1890, in which the Secretary of State for War conveys his appreciation of the courage and discipline exhibited by the officers and men employed at this factory at the time of the recent explosion, and on their part and my own I beg to thank you. We one and all only did our duty; but it is very gratifying to receive such an expression of approval.

I am, Sir, your obedient servant,

(Signed) W.H. Noble, Major-General,

Superintendent, R.G.P.F.

The Honourable W. St. John Broderick,
Financial Secretary,
War Office, S.W.

Further proof that safety in gunpowder manufacture had by no means been secured came in the early norming of December, 13th, 1893, when one of the worst accidents recorded at Waltham Abbey took place. At 2.35 a.m. during stormy wintry weather a mild explosion or severe fire occurred in the Cam House on Lower Island, a building in which granulated powder was pressed into small prisms in a cam action press. The original hydraulic presses had been replaced by cam action machines in 1887. Eleven men were in or near the building at the time and only one escaped uninjured. One was killed outright, eight died of their injuries within a few days and one man was injured and recovered.

By now serious concern was being manifested by the public. The papers, both local and national, were critical of the state of affairs in the factory; the inquest on the victims did not pass off quite as smoothly as the Authorities would have liked for an open verdict was returned with a rider criticizing the grouping of cam houses in sets of four, suggesting that night work was dangerous and should be abolished, that steel tools should only be allowed in these houses in the hands of experienced mechanics and that machines should be stopped when powder boats are alongside. The Jury also asked that these points might be strongly represented to the Home Office. Questions were asked in the House of Commons and in some instances received evasive replies, as, for example, when Mr. Hanbury asked if the factory was carried on under the provisions of the Explosives Act, whether it was inspected by the Home Office Inspectors and whether conditions were as good from the safety point of view as would be insisted on for a private factory, Mr. Campbell-Bannerman explained that by Section 97 of the Act, Government Factories were exempted from the provisions of the Act, but carried on their business in correspondence and communication with the Chief Inspector and adopted all improved arrangements introduced from time to time. Mr Hanbury complained that this did not answer his question, but got no satisfaction.

An official enquiry was held into the accident and the local paper was indignant that its sittings were held in private and suggested that its report would be of the usual soothing character. But for once the "Weekly Telegraph" was wrong. The Committee, presided over by Lord Sandhurst, Parliamentary Under Secretary of State for War, and consisting of Sir Frederick Abel, Col. V.D. Majendie (Chief Inspector of Explosives), and Major-General F.T. Lloyd, Deputy Adjutant-General of Royal Artillery, with Mr. R.H. Brade as Secretary, was far from being a body of "Yes-Men". Their enquiry was full and elaborate; their report damning but full of valuable suggestions for future safety. In fact, it may well be said that this report is the foundation stone of modern safety practice in explosives manufacture.

The Committee, in the first place, visited the factory and inspected the scene of the accident. They afterwards held meetings at the War Office and examined the Superintendent and other members of the Staff of the Factory, besides a number of men employed in the class of work which was being carried on in the building destroyed, including the only man who succeeded in escaping without injury.

The building was about fifty years old at the time and had originally been an incorporating mill. It was made entirely of wood with the exception of a brick wall at the South end and the roof was boarded over, fastened with iron screws and covered with tarred felt. Roof and walls were lined with varnished matchboard and the floor covered with hides fastened by copper nails. There were four machines in the building driven by a centrally placed water wheel. At the time of the accident all the machines were working and a boat was alongside from which two boatmen were supplying the house with powder. The normal hours of the night shift were 6 p.m. to 6 a.m. but at this time of year they were working an extra hour on each end of the shift to make up time and enable them to take a holiday on Boxing Day, which was not a Government holiday.

The succession of events at the time of the accident appears to have been that a flash was seen from the South end of the house and was followed rapidly by three mild reports and a very intense fire. One of the machine operators at the South end claimed that he had seen the flash coming from his machine. The only man of the ten in and around the building who was killed on the spot was also in the South end and was rolling in a barrel of powder. All the other men succeeded in escaping from the building, but with terrible burns. Most jumped into the adjacent river and must have suffered severely from exposure which probably hastened their deaths.

The wooden building caught fire immediately but the roof remained on and the walls standing. The tarred felt roof caught fire but the factory fire brigade prevented blazing pieces being blown about in the high wind. The water wheel continued to revolve till jammed by falling debris and the machines went on working some time after the building took fire. A screw, perhaps from outside the inner roof, was afterwards found to have fallen into one of the bushes of No. 2 machine and broken the plunger.

The Committee found rather contradictory indications as to the probable cause of the accident. They considered that the actual causes might be found among the following:

1. Defective working of the machine.
2. Use or fall of a tool or implement.
3. Lucifer match.
4. Presence of grit or other foreign substance.

As regards (1), they agreed that a good deal of evidence had been heard which was unfavourable to the cam type of press, but thought that probably the general efficiency of the machines after the accident could be accepted as conclusive evidence that the explosion was not the result of their having been clogged. The screw in the bush of No. 2 machine almost certainly got there in the course of the fire.

The use of steel tools in the building was, it appeared from the evidence, quite the usual practice and such tools were used by unskilled workers to adjust the machines while powder was in the house. This breach of the Explosives Act received severe criticism from the Committee.

Turning to No. 3 on the list of possible causes the possibility of the presence of a lucifer match could only be disregarded if the precautions taken were such as to render its presence a physical impossibility. The Committee considered that the precautions adopted at Waltham fell very far short of this standard. Searching by the Police at the Gate was not nearly thorough enough, examination of clothing for pockets by shifting house attendants was practically non-existent and search by the foreman at the places of work was an absolute farce. The Committee expressed their opinion that under the conditions then prevailing at Waltham it was quite possible for the accident to be due to the presence of a match.

The precautions for the prevention of grit and other foreign substances were by no means adequate. There were long uncovered gangways onto which grit could be blown or deposited, there were "dirty" mats at the doorways and "clean" mats in the shoe holes; the shoe hole was used on occasions for taking meals and there was no means of stopping dirty or gritty sponge cloths from re-entering buildings.

These last three causes, says the Committee's conclusion, almost certainly include the actual cause of the accident. The Report goes on to give the Committee's recommendations for the prevention of similar accidents.

The Committee were of opinion that the very grave defects in the system of discipline and precautions were to some extent connected with frequent changes of Superintendent (there had been 4 in 20 years), saying that a newly appointed officer could hardly be expected to revise and overhaul regulations made and accepted by his more experienced predecessors. In explosives factories want of familiarity with detail may impair production efficiency and imperil the lives of workpeople. In spite of a recent decision (Art. 317 of Royal Pay Warrant) that appointments in the Ordnance Factories should be subject to review every five years, the office of Superintendent should not be subject to frequent avoidable change and particular fitness and technical qualifications for the post should be primary governing considerations in determining continued occupancy of the post.

They also thought that, if the War Office found it impossible to secure by independent action results corresponding to those which H.M. Inspectors of Explosives had obtained in private factories, then the question of subjecting Government Explosives establishments to the Inspection of H.M. Inspectors of Explosives should receive serious consideration.

They then reviewed the more prominent of the defects their enquiries had brought to light, pointing out emphatically that this list was by no means exhaustive. The list was as follows:

1. The excessively large number of persons present within a single danger risk.
2. Defective system of searching to secure exclusion of matches, pockets, etc.
3. Absence of any system of effective visitation or inspection of danger buildings.
4. The system under which repairs and adjustments of machinery were made (sometimes by unskilled men) without clearing the house, or even the machine, of powder.
5. Defective arrangements for the removal of oily sponge cloths.
6. Defective arrangements for the exclusion of grit.
7. The practice of taking meals in the shoe holes should be absolutely prohibited.
8. The rules were imperfect and not properly impressed on the work-people.
9. There were no effective penalties for breaches of rules except dismissal and even this did not apply in the case of Contractors men.
10. The explosives limits did not include material in process of removal from the house and neither they, nor the house rules, were posted in the houses.
11. Evidence was laid before the Committee of a Granulating house in the factory with an unlined roof. They held that the Superintendent had been right in refusing to use this house.
12. Lastly, the Committee were not satisfied that the arrangements under which houses were handed to the Works Dept. for repair or alteration and restored to use as danger buildings afterwards were satisfactory.

We have dealt with this report at considerable length as it is clear it constitutes the real beginning of Safety practice in the Government factory. The exemption granted under Section 97 of the Explosives Act, 1875, appears to have been grossly abused at this period, and the Sandhurst Committee did a remarkably good job in drawing attention to this fact and making sound recommendations for future improvements. Their report was dated April 24th, 1894, and only a fortnight later, on Monday, May 7th, the country was again shocked by the news of another serious accident at Waltham Abbey, this time at the newly established Nitroglycerine Factory.

Four persons were killed and these included the chemist on duty at the time, the foreman, the foreman plumber and one workman. Twenty other people were injured, mostly not seriously. The same Committee was asked to enquire into the occurrence and, again, their report was masterly. They examined witnesses who were in the vicinity at the time, members of the

Managing and Administrative Staff, Dr. Dupré, Dr. Kellner, Sir Benjamin Baker, Mr. G. MacRoberts, Mr. O. Guttmann and Mr. Lundholm.

The explosion took place at 4.8 p.m. in the Quinton Hill Nitroglycerine Factory. There were two explosions separated by a very short interval of time, the first in the washing house and the second in the nitroglycerine store. The Committee concluded that it was impossible to say what was the actual cause of the explosion but thought it was among the four special risks detailed below. The original explosion was followed almost at once by the explosion in the store and this was probably due to the crushing and breaking up of the building through the blast of the first explosion. The traverses, though calling for material improvement in design (most of the injuries were caused by flying bricks from the traverses) did valuable service, but the supervision and precautions called for modification and improvement though no special blame could be attached to anyone.

The "special risks" referred to above were as follows:

1. Risks from a blow or friction due to the fall or violent movement of the skimmer.
2. Risk from the use of earthenware cocks.
3. Risk from friction established by the leaden air pipe.
4. Risk from the fall or use of some article commonly present in the washing house.

In addition, the Committee considered that the risks referred to in their previous report existed in the present case, sometimes in an exaggerated form and that a further source of risk was presence of a public right-of-way open at weekends, within a few yards of the buildings concerned, and the extremely insufficient protection against the presence in the factory of unauthorized persons.

It was considered that the least improbable of the four special risks was the first. The skimmer was a lead perforated bowl weighing about 36 lbs., connected to the outlet with a rubber tube and suspended by a cord from a pulley above the washing vat. The fall or rapidly dangerous descent or accidental swing of this skimmer, though unlikely, could undoubtedly have caused the explosion.

No. 2., the earthenware cock, was not considered a probable cause in view of the weather being too warm for the nitroglycerine to freeze, but it was pointed out that, if the cock stuck, any application of force must be attended by grave risk.

The third possible reason was one which attracted the attention in particular of Dr. Dupré, the chemical adviser to the Explosives Dept. of the Home Office. The air pipes had been renewed on the Saturday before the accident and were fixed only at the top. When air was sent through them there was nothing to stop them vibrating and rubbing against the bottom or even knocking against the side of the vessel. In the highly heated state of the nitroglycerine (it was washed at 50°C.) Dr. Dupré held that this was a very dangerous state of affairs.

The risk from the use or fall of some loose article could not be ignored, said the Committee. A glance at the 'Use List' shows an extraordinary profusion of articles including 5 wooden buckets, 1 glass beaker, 2 glass sample bottles, 1 phosphor bronze key, 1 wood maul, 1 lead maul, 2 copper rings, 2 framed slates, 1 earthenware skimmer, 2 lead weights, so that the chances of something falling accidentally were by no means negligible.

With regard to general risks, the Committee pointed out that several of those referred to in their previous report still existed, some being even worse. The Committee's report had not, before the date of the explosion, got into the hands of the factory staff. Searching had improved but was still not satisfactory, workmen wore boots without nails, but were allowed to wear them outside the houses. Apart from the risk of introduction of grit, a match could easily be introduced on a man's boot and could quite likely be picked up on the footpath adjacent to the building which had been used by the public the day before.

The Committee believed that, in several details, the system of manufacture and supervision, the precautionary regulations and details, the distribution, and to some extent, the protection of the buildings called for modification and improvement. All the comments with regard to factory discipline made in connection with the previous explosion still appeared to hold, and one witness, Mr. McRoberts, in his evidence, suggested the possibility of the accident having occurred as the result of some incautious act of a workman with a view to repairing a sudden leak or fracture of the apparatus.

In the course of the evidence at the enquiry it transpired that the Building Works Department was under the control of its own Superintendent, who was not responsible to the Superintendent of the Factory. In fact, it was clear that he was about to reconstruct the buildings on the same sites in the same way as before and that the unfortunate Superintendent had not even seen the drawings.

The Committee expressed the opinion that the buildings were far too close together and that if they were to be reconstructed on the same sites the output must be reduced to the absolute necessary minimum. They suggested, too, that it was unwise to surround danger buildings with uninterrupted traverses or mounds or to place them in pits (the N.G. Store was built in this way). They recommended a type of construction of buildings light enough to yield easily to suction or pressure, and were of the opinion that no N.G. store was necessary, but that successive batches of purified material should be forthwith absorbed in Guncotton.

Finally, they said "But the Committee are of opinion that a factory like Waltham Abbey, and more especially that branch which deals with chemical explosives, should have the constant services of a chemist of high standing and long special experience in these departments of chemical industry, and that this official should have responsible control over all the manufacturing operations, as well as over the quality of materials used, in that branch which deals with chemical explosives.

Thus was laid the foundation of that modern practice which has made explosives manufacturing a really safe industry. Many old ideas were swept away and much new blood was brought in. Col. McLintock, the Superintendent, was one of the first to go; in fact, he had gone before the Committee's report appeared (on July 12th, 1894) and Capt. F. L. Nathan, the Officer-in-charge of Danger Buildings, was Acting Superintendent, and probably gained at this period much of the experience which made him later one of the greatest Superintendents. In July Col. Ormsby became Superintendent and he appears to have carried on the good work of reform with great vigour.

At this period the morale of the factory must have been at a low ebb and one curious attempt at boosting it was the publication in the popular "Strand Magazine" in March 1895, of an illustrated article by Wm. J. Fitzgerald entitled "How Explosives are Made". This was a fairly detailed description of the factory and the manufacture of gunpowder therein, but the very journalistic approach and the insistence on the risks involved can have done little to help. This article is reproduced as Appendix V.

Improved discipline and the strict application of the recommendations of the Sandhurst Committee were daily rewarded. The Boer War came and went with R.G.P.F. carrying the brunt of cordite manufacture without any accident, but on 15th December, 1902 a cordite incorporating machine blew up and caused the deaths of three men. At the Coroner's inquest which followed no satisfactory explanation was found. The accident occurred just as a machine was started with a fresh charge. Major Nathan, who was by then Superintendent, gave as possible explanations the possibility of some foreign substance either in the paste or in the machine, or the fracture of one of the cast iron arms of the machine. The Foreman of the jury, at the conclusion of the inquest, said that he thought Major Nathan had given every facility for holding the enquiry and that the fact that nine years had elapsed since the previous explosion was very creditable to officials and workmen. The local newspaper the "Weekly Telegraph", however, said "Whether all was said that would have been uttered had not Major Nathan remained sitting at the Coroner's elbow, is purely a matter for speculation. At all events we do not hesitat to say that it would have been more satisfactory, and would have set much doubt at rest if during the recital of the chargeman's evidence, all the factory officers had withdrawn b earshot. We have no wish to cavil at the congratulatory observations of the foreman c Jury."

Before the inquest there had been stories of rushed work and of complaints from workers as to the condition of the plant. The local paper had recommended the jury to press for answers to questions on these points, suggesting that by so doing they would undoubtedly "do a service that will be appreciated by hundreds of men who cannot speak for themselves, but who have to groan under conditions which would not for a moment be tolerated in any respectable manufactory or workshop".

Nothing that transpired at the inquest could be said to lend colour to such comments and if Major Nathan was an autocrat, he was an enlightened and even benevolent autocrat. Even if the cause of this explosion did not transpire at the inquest there can be no doubt that its lessons were learned, for it was to be almost 40 years before trouble came again.

Even the 1914-18 war with the immense output that Waltham produced did not shake the safety record. The dull period after that war and the period of increasing output from 1935 onwards, all passed safely. The second World War started and on the first day of it Waltham had its first (false) air raid alarm. The phoney war period proceeded and in the morning of Thursday, 18th January, 1940, the neighbourhood was startled into believing that a real raid had started. It was, however, an explosion at an N.G. mixing house. The morning was intensely cold and the subsequent enquiry left little doubt that some nitroglycerine had been handled in the frozen condition. Three men who were present in the building were killed as also were two others who were killed by blast just outside the traverse as they were bringing more paste. Three other men, working in an N.G. washing house only 100 yards from the explosion, continued at work in spite of damage to the building and services until the operation was completed. For this typical example of the working of the tradition that had by this time grown up in Waltham Abbey, they were awarded the Empire Gallantry Medal.

It need hardly be added that by this time compensation to relatives of the deceased men was on a much more generous scale than was the case in the previous incidents we have recorded, but, nevertheless, an emergency relief fund was opened and over £100 quickly subscribed.

Only three months later, on Saturday, 20th April, 1940, a very similar accident occurred in another mixing house. Again, five men were killed, and, as in the previous case, rumours of sabotage were rife. On this occasion there was no icy blizzard to freeze nitroglycerine, and, indeed, all conditions appeared to be favourable. No explanation was found by the Court of Enquiry on which the explosion could definitely be blamed.

After this very disquieting pair of accidents work at the Royal Gunpowder Factory continued without further explosions until the factory was finally closed down. Production was very little hindered by enemy action and, though Waltham was in a well bombed area. the amount of damage in the factory was quite slight and the loss of life due to enemy action very small indeed.

CHAPTER XII

THE ROYAL GUNPOWDER FACTORY

THE LAST PHASE

In the year 1934 an entirely new era in the history of the Royal Gunpowder Factory opened, for in that year Dr. R. C. Bowden was appointed Superintendent, the first civilian to hold such a post. There then commenced the work of rehabilitation of the factory for rearmament after many years of idleness and neglect caused by short sighted economy.

It was quickly realized that nothing could be done to turn Waltham into a large scale and economical producing unit. Efforts were concentrated on getting the available facilities working quickly and at the same time planning the removal of the main production to less vulnerable sites, and the training of staff to operate new factories.

The first step in this direction was the opening in 1938 of the Royal Ordnance Factory at Irvine to operate the new continuous T.N.T. process already described. The major problem was, however, the siting of the new propellant factory. The authorities were very properly pressing for a site in one of the depressed areas to be chosen. Dr. Bowden, assisted by the Building Works Surveyor at Waltham and the Land Agent for Scotland surveyed some 4,000 square miles and finally recommended a 2,500 acre site at Bishopton in Renfrewshire. No alternative being offered, the recommendation was approved and a planning staff engaged and located, under Superintendent, R.G.P.F., at Waltham. The construction of the Factory was undertaken by His Majesty's Office of Works and it was brought into operation in 1939 when Dr. Bowden was transferred there.

Several other factories followed, both for propellants and high explosives, and they all relied very largely on Waltham for experienced staff.

So the spirit and tradition of Waltham lived on and still lives on in various parts of the country but as the war progressed and the newer and larger Ordnance Factories came one by one into production and full operation, it was felt that Waltham's thriving and growing offspring should shoulder more of the burden of production and relieve the authorities of the responsibility of having to carry on dangerous work in such a vulnerable area. R.D. 202 was discontinued in January 1943, Guncotton in August, and Nitroglycerine in September of the same years. By October 1943 the R.G.P.F. had ceased to be a production unit and a history of continuous manufacture of explosives for about 300 years, half of which was under Government control, came to an end.

The site has not, however, been entirely divorced from Explosives Work as it became the Headquarters of the Explosives Research and Development Department and many of the old buildings have been adapted for purposes far removed from those for which they were originally used.

Roads have been built all over the site and drainage and transport facilities improved out of all recognition, so that one may well wonder whether, in spite of war risks, it might not have been advisable to retain this very conveniently sited factory for the manufacture of explosives.

APPENDIX I

STATEMENT OF FACTS RELATIVE TO THE SAVINGS WHICH HAVE ARISEN FROM MANUFACTURING GUNPOWDER AT THE ROYAL POWDER MILLS AND THE IMPROVEMENTS MADE SINCE 1783

Published by Wm. Congreve (I) Comptroller of the Royal Laboratory, by permission of Lord Mulgrave, Master General of the Ordnance in the Year 1811

"In the year 1783, Mr. Pitt intended to have recommended to Parliament the sale of the Royal Powder Mills at Faversham, it having been represented to him that the powder merchants could make better gunpowder, and much cheaper, than the King's servants; fortunately, however, for the country, His Grace the late Duke of Richmond, then Master General of the Ordnance, attended to the representations which Gen. Congreve, at that time Comptroller of the Laboratory, thought it his duty to make; by which it was proved, that there existed a profit on the powder manufactured at the King's Mills; and that if this profit were for a few years properly expended in improving the works, the Ordnance would be enabled to make both stronger and more durable Gunpowder at the Royal Powder Mills, than had ever been previously made. This statement was confirmed by a course of experiments, proposed and carried on by the Comptroller; and in consequence, the idea of disposing of the Royal Powder Mills was not only abandoned, but the improvements suggested were carried into effect; with what benefit to the country, both as to economy, and as to the improvement of this most important article of war, will be provided by the estimates, and other statements contained in this Pamphlet, which have now stood the test of more than twenty years' experience. With reference to the first point, it is shewn that there has been saved to the country no less a sum than one million forty-five thousand four hundred and ninety-four pounds; and with respect to the latter, it is sufficient to state, that such has been the increase of strength in the gunpowder, that it was found necessary to reduce the charges for the service of the navy, from one-half the weight of the shot to one-third; so that, not only has there resulted a saving in the price of the article, but in the actual consumption also.

It is needless here to dilate upon the state of the gunpowder in the British service previous to this period, since it is notorious, that the inferiority of the English gunpowder to that of the enemy, was the constant subject of complaint both in the navy and army; and it is a fact, that, when the fleet was disarmed at the conclusion of the American war, in some of the line-of-battle ships, there were not ten barrels of powder fit for service:- how much its condition has been since improved, will be seen in the sequel. In the first place, however, the following detailed estimate is set forth to prove the extent of the savings to the country made in this article.

AN ESTIMATE

OF

SAVINGS MADE TO THE ORDNANCE,

In consequence of the several improvements introduced by Lieutenant-General Congreve, Comptroller of the Royal Laboratory, in the manufacture of new Gunpowder:- in extending the powers of the mills:- in recovering the strength of that which has been rendered defective on board the Royal Navy:- in extracting the Saltpetre from damaged Gunpowder, etc. etc. - viz.

	£	s.	d.
1st item. - Profit to the ordnance, in manufacturing, between the 1st of January, 1789, and the 31st August, 1810, 407,408 barrels of gunpowder, of 100 lbs. each, at the Royal Powder Mills at Waltham Abbey and Faversham, being the difference between what that number of barrels cost manufacturing at the King's mills, and the sum that would have been paid if supplied by the merchants ...	288,357	6	0½
Carried forward	288,357	6	

	£	s.	d.
Brought forward	288,357	6	0¼
2nd. - Profit to the ordnance in recovering the strength of gunpowder, (returned from the royal navy, etc.) by re-stoving and dusting, at the Royal Powder Mills at Faversham and Waltham Abbey, and mixing at Purfleet, the operation having been performed with 127,419¾ barrels of gunpowder, of 100 lbs. each, between the 1st of January, 1790, and the 31st of August, 1810, which, at 8s. 4d. per barrel, amounts to	53,091	11	3
3rd. - Profit to the ordnance in recovering the strength of 62,338½ barrels of gunpowder, of 100 lbs. each, by dusting, re-stoving, and mixing, at the Royal Powder Works at Portsmouth and Plymouth, between the 1st of July, 1804, and the 31st of August, 1810; which, but for these works, must have been performed at Faversham, and of course been subject to the additional charge of freightage from those places to Purfleet and from thence to Faversham, as well as other expenses, and the loss of gunpowder from damage in its transit backwards and forwards; nor could it have been in so good a condition for service, as it must be by the gunpowder being recovered on the spot as it now is. The above number of barrels therefore, at 8s. 4d. per barrel, amounts to	25,974	7	6
4th. - Profit to the ordnance, in consequence of the improvements in the manufacture of new gunpowder, by which its strength has been so much increased, that it was found necessary, in the year 1796, to reduce the charge of gunpowder for ordnance one-third in weight, by which two barrels will go as far as three barrels did previous to that period; since which there have been manufactured at the King's Mills, and received from the merchants, between the 1st of January, 1797, and the 31st of August, 1810, 371,880 barrels of large grain gunpowder, of 100 lbs. each, which, valued at £5 per barrel only, the profit upon each will be one-third of that sum, viz. £1. 13s. 4d. per barrel, and amounts to the sum of	619,800	0	0
5th. - Profit to the ordnance in extracting saltpetre from 137,993 barrels of unserviceable gunpowder, of 100 lbs. each, by the adoption of Gen. Congreve's new-invented press*, between the 1st Of January, 1785, and the 31st of August, 1810, as, before this press was used, only 65 lbs. of saltpetre were procured from each barrel of gunpowder; but during the above period, 71 lbs. have been obtained, (in consequence of the improvement) which is a saving of 6 lbs. of saltpetre upon each barrel:- the whole quantity saved amounts to 827,961 lbs. - the profit, at 9d. per lb. to	31,048	10	9
Carried forward	1,018,271	15	6¼

* A press with two moveable side cheeks operated by screws in which bags of gunpowder soaked in hot water could be squeezed for removal of the soluble nitre, (W.H.S.)

	£.	s.	d.
Brought forward	1,018,271	15	6¼
6th - Profit to the ordnance from the 1st of March, 1794, to the 31st of August, 1810, by issuing to the merchants, as recommended by General Congreve, refined, instead of grough saltpetre, as formerly; since this period there have been delivered into store, at Purfleet magazines, 241,980 barrels of gunpowder, of 100 lbs. each, for which the merchants would have been allowed, if the existing arrangements had not been adopted, at the rate of 80 lbs. of refined saltpetre per barrel; whereas, for each barrel manufactured during the above period, they have received upon an average only 77 lbs. there is, therefore, a saving of 3 lbs. of treble-refined saltpetre upon each of the above barrels, besides the more important object gained by the ordnance, of being certain that this most essential ingredient is perfectly divested of all impurities, by refining it themselves. This item amounts to 725,940 lbs. weight; which, at 9d. per lb. is	27,222	15	0
Total of savings	£1,045,494	10	6¼

By the foregoing estimate, therefore, the amount of this important saving is proved, as above stated, to be no less than one million forty-five thousand four hundred and ninety-four pounts, ten shillings, and six pence. Some further explanation, however, of the sources from which it has flowed may be necessary. They are as follows:

1st. – The extension of the powers of the Royal Powder Mills at Faversham and Waltham Abbey

On this point it is to be observed, in addition to what has already been stated as to Gen. Congreve's having prevented the sale of the Faversham Powder Mills in 1783, that it was in consequence of his repeated remonstrances that the Mills at Waltham Abbey were purchased: and here, therefore, it is proper, with regard to these Mills, separately to state how the account stands; to wit, that, after paying off £45,622. 12s. 4d. the whole amount expended in the original cost, in extensions of the works, in repairs, and improvements, there is a balance, in favour of these new Mills alone, of £50,096. 13s. 5d. Now much having been said respecting the money laid out at the Royal Powder Mills at Waltham Abbey, it is important that this statement should be made known; and indeed it is further to be observed, that the purchase of the water of the Cheshunt and Waltham Abbey corn mills was the only additional purchase recommended by Gen. Congreve, the necessity of which has been sufficiently justified; as, previous to this power being obtained, 15,063 barrels of gunpowder only were made in one year; but subsequently, 20,401 are manufactured per ann. by the same mills, making an increase of 5,338 barrels annually; and as the quantity of water is considerably more than could be used by the former establishment, the Ordnance are still further enabled to build additional mills upon that head, and increase the manufacture of gunpowder to a much greater extent. From this circumstance, therefore, it will evidently appear, that the purchase was not advised without due consideration. It is true there may be some reason for regret, that this was not done in 1789, when it was first recommended by Gen. Congreve, as at that time it might have been obtained for about £9,000, instead of the sum which it eventually cost; and as it would further have enabled the Ordnance to have had the arrangements of the manufactory complete, and in the full power of work, some years sooner. They could then have sooner resisted the extravagant demands of the powder merchants, who, previous to this purchase, asked an increase of 18s. 6d. upon each barrel of gunpowder, though they afterwards consented to take 8s. 6d.

The second source of the savings above stated is –

The recovery of old powder by the process of dusting and re-stoving it

This important arrangement was introduced by General Congreve prior to the year 1790; since which period no less than one hundred and eighty-nine thousand barrels of old powder have been rendered serviceable by this simple and unexpensive process.

Previous, however, to His Grace the Duke of Richmond's time, all gunpowder which had been formed into lumps, from the damps in His Majesty's ships of war, on which upon its return from a foreign station would not raise the vertical eprouvette to 1 inch 8 tenths were sold. Thus, between the 1st of January, 1771, and the 31st of December, 1779, the powder merchants purchased 19,070 whole barrels of gunpowder, which had been only one voyage to a foreign station, and they did not pay more than 56s. per barrel. The gunpowder thus purchased from the Ordnance department for exportation, procured the purchaser in the first instance, 4s. 6d. per barrel drawback at the Custom-House, the exporter only being called upon to swear that such powder was of British manufacture. So that there was not only in the first instance the loss upon the powder itself, which might have been so easily restored, but in the second instance, the country lost the drawback also.

Before the 1st of April in the year 1783, a powder merchant (Mr. Hill) purchased 5,150 whole barrels of foreign gunpowder from the Ordnance, for 37s. per barrel, because it did not raise the vertical eprouvette to the proof standard, when similar gunpowder has been found to make ranges very sufficient for many cases of service.

But, in fact, these are not the only advantages of this new system of repairing gunpowder; for it must be evident, that one hundred and eighty-nine thousand barrels of new powder, the place of which has thus been supplied by recovering the old powder, could not have been obtained in the time, without very greatly enhancing the price of the commodity in the market; not to mention, indeed, that the great consumption of the period if question could not, in fact, have been adequately provided for, had not this arrangement been adopted!

The third source of economy has been seen to be -

The increased strength of the powder, and the consequent reduction of the charges

Under this head it has been already stated, that two barrels of the powder now manufactured are equal to three of that which used to be made; a circumstance, the advantage of which are not merely confined to the reduction of the consumption, but embraces still more important considerations, in the proof it establishes of the superior excellence of the powder itself, and the great additional powers thereby given to His Majesty's arms, both by sea and land; and indeed it has been proved, by a variety of experiments, that whereas the English gunpowder was formerly very inferior to that of the enemy, there is no powder belonging to any nation, which will give any thing like the ranges which the British powder now produces.

The next source is -

The improved mode of extracting saltpetre from damaged powder

From this it appears that there is a saving of 6 lbs. of saltpetre upon every barrel extracted; to which it may be added, that a further saving has resulted from the removal of the operation, as proposed and carried into effect by Gen. Congreve, from Woolwich to Faversham, where it is performed at a considerably reduced expense.

The last source of advantage stated in the foregoing estimate, is -

The issuing of refined saltpetre to the merchants, instead of giving it to them in the impure state, as formerly

Gen. Congreve was induced to propose this arrangement, and to recommend the Ordnance to refine their own saltpetre, for two reasons: first, that they might be certain of having it properly purified; and secondly, with a view of reducing the loss sustained by the government, in allowing 15 per cent. for refinement on the quantity issued. He had indeed, from repeatedly analysing the contractors' powder, convinced himself, that although this allowance was made, the saltpetre was very imperfectly refined, so as not only most materially to deteriorate the powder, but to give the contractors a profit on this allowance to which they were not entitled; as, in fact, there is not a loss of more than 7 per cent. in treble-refining the most impure saltpetre that comes to this country, and not more than 5 per cent. on an average; so that, even if the contractors had brought the saltpetre to its most refined state, there was still an average loss to the country of 10 per cent. on the quantity issued.

Such, then, is the recapitulation of the sources of advantage from Gen. Congreve's arrangements in the department of the Powder Mills, as stated in the foregoing estimate; and to these may be added the following, viz:

First, that the present Comptroller introduced the system of producing the fine-grained as well as the large-grained powder in the process of the manufacture, so as to be able to issue a description of small-grained powder for small arms, and for priming of cannon, and of large-grained for the cannon themselves; having ascertained by experiment, that although the small-grained powder is stronger in small quantities, and therefore fitter for musquetry, the large-grained powder is better for the charges of cannon, independent of the great certainty of not missing fire, which arises from priming the locks, whether for small arms or cannon, as now used in the navy, with this fine-grained powder.

But in fact, a further profit might be carried to the credit of the account, as this priming and small-arm ammunition would be charged for by the merchants at a much higher rate than has been allowed for it in the estimate, where the same price only is taken for both sorts; exclusive also of the above-mentioned powder, a considerable saving might be reckoned in the manufacturing 2,791½ barrels of rifle gunpowder, of 100 lbs. each, at the King's Mills, which has only been estimated at the price of the common sorts; because, if the Ordnance were to purchase this species of gunpowder of the powder merchants, who retail it at about 3s. per lb. it is reasonable to suppose that they must have been paid at the rate of £10 per barrel, whereas it does not cost government, by manufacturing it themselves, much more than half that sum.

The next point to be stated is -

The great durability that has been given to the British gunpowder.

This is one of the most important improvements made in the manufacture by Gen. Congreve. It depends on a variety of circumstances, viz. - The great care now taken to render the ingredients most perfectly pure - the increased attention paid to working the powder under the runners - to the pressing of it - and to the improved modes of dusting and glazing it.

The following table of practice, carried on at Marlborough Downs some time since, will shew the extraordinary durability of which good gunpowder is capable. Some of the Faversham gunpowder, fired in these experiments, was made under the immediate inspection of the Comptroller of the Laboratory, in 1785, and has been kept in common wooden barrels upwards of twenty-four years.

Ranges of a 10-inch shell from a sea-service mortar, loaded with 9 lbs. of gunpowder, Marlborough Downs, 1809 and 1810.

		Range
		Yards
Faversham Gunpowder, made in	(1785)	4319
	(1809)	4360
Waltham Abbey, in	1809	4430
Contractors' Gunpowder, made in 1809	(Pigou	4270
	(Bridges	3898
	(Taylor and Co.	3861
	(W. Taylor	3922
	(Mr. Butts	4187
	(Mr. Kitchener	3801

Notwithstanding, however, the extraordinary preservation of this gunpowder, shewn by the above table, it is much to be wished that the Ordnance would devise the means of providing thoroughly seasoned wood for the construction of powder barrels, to prevent the possibility of that damage, which the powder now frequently receives from the acid of green wood. It is also very desirable, that proper powder vessels should be constructed for the better security of the powder barrels from damp in their passage to the magazines at the outports.

The comparisons afforded by this table are an additional proof of the good policy and importance of the retention of the King's Powder Mills at Faversham, and the purchase of those at Waltham Abbey.

There is another point which must not be passed over in this history of the transactions of this department, viz. -

The idea of this improvement was first suggested by Dr. Watson, the celebrated chemist, and has been carried into full effect by the present Comptroller, who has by this means brought to perfection a new description of gunpowder, called Cylinder Powder, from the form of the retort in which the process of charring is performed. The form of this retort was first recommended by Dr. George Fordyce, and afterwards improved upon by Gen Congreve; and the powder made with charcoal so produced, greatly exceeds the strength of the common powder. It is, therefore, not only of great consequence in a variety of cases of service, but in the repairing of old powder, by mixing a certain proportion of this strong powder with it.

Such then is the outline of the improvements that have been made in the gunpowder department within the last thirty years, and of the important benefits that have arisen from them, both to His Majesty's service, and to the public purse. It is only necessary further to state, that in consequence of the present powerful condition of the King's Mills, so great a quantity of powder is manufactured by the Ordnance themselves, that they are enabled to keep the contractors in order, both as to price, and to the quality of the powder received from them; which, by the regulations of Gen. Congreve, is now submitted to the most severe trials. These trials, moreover, are now made to correspond with the description of use to which the powder is to be applied in actual service; the large-grained powder being now proved by comparative ranges with the King's powder, out of a mortar; and the small-grained powder by the comparative penetration of a bullet fired from a musquet barrel: whereas nothing could be more deceptive than the former mode by the vertical eprouvette, in which a soft and rotten-grained powder would produce a much greater effect than the hard and good serviceable powder; and the results of which would be continually at variance with the effects in the modes of actual service. In short, the powder that is now received from the merchants, is much more powerful than any in possession of the enemy, and is a firm-grained, clean, and durable powder. And this has been the great object of the Comptroller not to deprive the contractors of their employment, or of their profits, but to make them do their duty - to improve as much as possible the powder made at the King's mills - and to compel the merchants to imitate these improvements; for which purpose they have access to the King's works whenever they please.

That General Congreve has well succeeded in these objects, it is hoped the foregoing statements will have abundantly proved. To have so succeeded for the good of the service, and of his country, constitutes his greatest pride, and brings with it its own reward; for he has sought no other recompense.

Royal Laboratory.
April 20, 1811.

A SHORT ACCOUNT OF THE IMPROVEMENTS MADE BY SIR Wm. CONGREVE (II) IN THE MANUFACTURE OF GUNPOWDER

(Including the Substance of British Patent Specification No. 3937.)

Published by T. Egerton, Military Library, Whitehall
in 1818

In the first place - as the due mixture of the ingredients of Gunpowder, namely, the saltpetre, sulphur, and charcoal, is of the utmost importance in producing the strength of the compound; and as, at present, little pains are taken in this first mixture before the composition is placed under the runners; I have invented a machine for this purpose, to bring the operation to as great perfection and certainty as possible, in the first instance.

This Mixing Machine is thus constructed:- three hoppers, for the three ingredients, are fixed in a frame, close together, in a horizontal line, and a cylindrical brush, either of hair, wire or other suitable material, about three inches in diameter, and six or eight inches long, is then fitted on an axis into an oblong aperture, of the same dimensions, in the bottom of each hopper. On this cylindrical brush the composition in the hopper lies, so that when the brush is made to revolve on its axis, the composition will be drawn out in a fine stream of the same breadth as the brush; and on the same principle as cotton thread is drawn by the revolutions of the rollers in the cotton mill: the fineness of the stream being adjusted by the closeness with which the cylinder is fitted to the aperture of the hopper.

With this arrangement it follows, therefore, that the quantity of composition drawn out in a given time, depends upon the number of revolutions made by the roller in that time; and consequently, any required proportion of the different ingredients may be drawn from each different hopper, according to the proportionate velocities with which the brush rollers are made to revolve, and these being regulated according to the due proportions required for Gunpowder, and their motions being sustained by a mechanical action, we have thus the means of keeping up streams of the three ingredients, having the proportionate quantity of each, exactly what is required. This, therefore, is the first part of the process.

Again, beneath these hoppers and rollers, on the same frame, a broad endless band of leather, canvas, or any other suitable material, is fixed on rollers, so as to have a continued horizontal motion, sustained by the same action as supports the motion of the discharging rollers of the hopper; and on this band, so in motion, are received the three proportionate streams of composition above described, as issuing from the three hoppers. In proportion, therefore, as the velocity of this band's motion is increased, with respect to the velocity of the issuing streams, so will these streams be reduced in thickness, drawn out by this second process, and carried away upon the band, in lamina, thinner and more attenuated than as they issue from the hoppers. It follows, therefore, as the band passes with the same velocity under each of the hoppers, that it will be covered with a stratum of composition composed of the three ingredients, uniting upon the band in the due required proportions, and attenuated by a sufficient velocity in the band, so as to bring the falling particles of each ingredient into a due and almost mathematical juxtaposition, with those of the other two; and in the predetermined proportions, regulated by the velocities of the extracting rollers. It is almost needless to add, that the combination of particles thus collected, is detached from the band where it turns over the end roller, and is there gathered into a single receiver.

In this way every mill charge may be mixed separately, or in greater quantities, according to the size of the apparatus; and although the mixture thus obtained may be considered as nearly perfect, still, as a few small lumps will sometimes escape the revolving brushes, I have considered it advisable to pass the composition from this receiver through another machine, for the purpose of breaking down any such irregularities, and for the more complete incorporation of the ingredients.

This second machine is somewhat similar, but consists of a single hopper only, having a larger cylindrical brush at the bottom of it; the lower part of which acts against a fine wire sieve, embracing half the brush.

By this means, the contents of the hopper, consisting of the compound of ingredients, united as above described, are forcibly driven through the sieve, and reduced to the finest powder; so as, by a few repetitions of the process, completely to remove any imperfections that may remain after the first mixture. The repetition of this operation to any desired extent, in one continued process, I have effected by letting the contents of the hopper fall into the inside of a vertical drum, fitted with ledges. This drum works round the hopper, so that, when revolving, it carries the composition received from the hopper at the bottom round to the top, and drops it back again into the hopper from the ledges as fast as it issues; and for as long a time, or as frequent repetitions of its passage through the brush and sieve, as may be wished, by keeping the machine at work.

Such, therefore, is the process of mixing which I adopt previously to working the Powder under the runners; and as the great end of the working under the runners is the due mixture and incorporation of the ingredients, it follows that much of this operation, which, from the present imperfect mode of previous mixture, is tedious, laborious, expensive, and dangerous, may be saved by the simple, secure, and easy previous admixture here provided for. Indeed, it is difficult to say, with the present experience, to what extent the latter of these operations may not ultimately be substituted for the former.

We now proceed to the Press House; where, instead of the present mode of throwing the mill cake under the press as it comes from the mill, by which means large intervals are left in the mass, so as to form a very soft and brittle cake in the parts near those intervals, the mill cake is broken down by passing it through brass rollers with coarse teeth; by which it is brought into such a state, that it can be distributed so regularly in the press as cannot fail to produce an equal and thoroughly well-pressed cake. Instead also of being laid between a few copper-plates, as at present, so as to turn out from under the press in cakes of two and a half or three inches in thickness, it is laid, with much nicety, between an increased number of plates, at gauged distances, so as to turn out in cakes, the average thickness of which does not much exceed one-eighth of an inch. It is needless to say, that a much more regular and uniformly pressed cake is thus produced.

But the object of this arrangement does not rest here. It anticipates an entirely new mode of granulating the powder, by which not only the danger of the Corning House is obviated, but many other imperfections attaching to the present system of granulation avoided.

The new Granulating Machine, for which the press cake is thus prepared, is formed as follows.

It consists of three parts, which are placed in three distinct rooms, one principal and two adjoining rooms, having a strong brick wall between them, to act as a traverse to each. In the principal, or middle room of the three, the actual granulating apparatus is placed.

In the first of the adjoining rooms is contained a large hopper, in which the pressed cake is deposited, in quantity not exceeding a barrel at a time, to supply the machine in the second or middle room; while the third room contains a bin into which the powder passes as fast as it is granulated in the second, and is thence carried away, at stated periods, to a magazine, to prevent any accumulation in the granulating house.

Such is the general arrangement. The Granulating Machine itself, in the middle room, consists of two sets or pairs of brass rollers, about two feet six inches in length, and two inches in diameter, supported in the middle, and divided into teeth (as will hereafter be more particularly described); each pair working together by means of a pinion or nut at the end of each roller, so that they draw inwards like the rollers of a flatting mill, or those of a cotton mill.

The teeth of these two sets of rollers are of different degrees of fineness, and the rollers are set at different distances; the coarsest so far apart as readily to draw in the thin pressed cake above described. These pairs of rollers are set in a strong frame of cast iron or wood, about six feet high, and eight or ten feet long, more or less; so that the upper and coarser pair are at the top of the frame, about eighteen inches or two feet higher than the other pair. They are then connected either by a double crank, or by a rod and pinion, or any other way, so that when one pair is set in motion by the principal mover of the machine, whatever it may be, water, or horse, or any other power, the other pair will also move: and they are, moreover, so arranged, whether in a direct position over one another or obliquely placed, that whatever passes through the upper or coarser pair, shall pass also through the finer or lower pair.

Now the teeth of the coarse pair of rollers are so constructed, that the thin press cake, being brought gradually into a hopper surmounting those rollers, is immediately drawn through them, and broken into irregular fragments, or heads; which fragments, again passing through the lower or finer rollers, are finally and at once reduced into the most perfect grains of every different size required; which are separated in one operation, by falling from the lower pair of rollers, upon a series of wire sieves, calculated according to the different sorts required. These sieves being of a sufficient length, from four to six feet, are placed obliquely, and kept in motion by the common mover, so that the different grains pass from top to bottom of these sieves in the act of separation, which, at the same time, cleanses the powder from the dust.

Now these different sorts of powder and their dust, having thus been separated and carried to the bottom of the sieves by their motion and obliquity, are, from each respective sieve, delivered into a flat funnel, which disposes of each sort upon a horizontal endless band of canvas, or other material, running from the foot of the Granulating Machine, in a flat trunk through the traverse wall into the bin above mentioned, as being provided in one of the adjoining rooms for receiving the powder when granulated: there being as many bands and as many compartments in the bin, as sorts of powder, including the dust, and these bands being kept in constant motion by the first mover, so as to carry off every grain of powder and dust as fast as it is formed, and thereby prevent any accumulation about the machine, in the act of granulation.

It remains now only to describe how the machine is fed with the cake, that also being done by a mechanical process, to prevent the necessity of any person being near when actually at work.

This is, in fact, performed by nearly the same operation as that by which the powder is carried off after it is grained: that is to say, by bands of canvas, or any other suitable material, passing from the hopper in the outer room, through the traverse wall, into the hopper over the upper set of granulating rollers, in the middle room; these bands, however, are stronger, more tightly strained, and have straps of leather, or cords, or small rods, sewed flat, or otherwise secured, upon them, every nine or ten inches, to raise the cake out of the hoppers, the back of which being placed at an angle of forty-five degrees of inclination, and the band moving up that back, the cake, although thrown indiscriminately into the hopper, is, nevertheless, drawn out of it in single pieces, lying flat upon the band, any surplus not actually raised and supported by the cross staps on the band, falling or sliding back from the great inclination at which the strap moves in its progress up the back of the hopper. Having surmounted this, however, with its due load, namely, covered with a single layer of cake, the band takes a horizontal course through the traverse wall, until it reaches the edge of the hopper of the granulating machine, and there discharges its load in regular quantities between the upper set of rollers for granulation, as already specified.

It is almost needless to say, that these feeding bands are also kept in a constant uniform action by the common moving power: and, I believe, the only remaining detail of the machinery necessary to be described, is the form of the teeth of the rollers:- they are of various sorts, either grooved horizontally, so as to bring the teeth to sharp edges, or in spiral grooves, and either crosscut, or not, into rings, leaving void spaces between them,

equal in breadth to the rings of the teeth themselves, and so arranged on the reciprocal rollers, that the rings of the teeth on one roller shall work in the void spaces of the other, and vice versa, but no part of the rollers or teeth actually touching in any case; thus arranged, the teeth never clog. Here also it must be stated, that the teeth of the large rollers in the Press House, for breaking down the preparing the mill cake, are formed on similar principles to those of the granulating rollers, only coarser in proportion, as the mill cake is thicker than the press cake.

The advantages of this Granulating Machine are numerous: in the first place, the whole operation being as above described, performed by mechanical means requires no person to be present in either of the rooms except at the moment of the discharging the powder from the bin and of replacing the cake in the hopper, which is performed at the same time, during which the machine is stopped: and, moreover, as no accumulation can take place in any part, it follows, that there is no personal danger to any one, neither can any serious mischief happen to the machine itself, with the traverse walls, if the quantity of cake put in at each charge be limited, as above stated, to a barrel at a time; the small quantity which can ever exist in the principal room protects the machine itself, while the adjoining buildings being of a slight and temporary nature, an explosion with the quantity limited would be of little consequence, no persons being, as before stated, required in the buildings when the work is going on.

The next great advantage of this machine is the extraordinary quantity of work of which it is capable with a very moderate power. From the very nature of the machine working so much by mechanical means, it is evident that very few persons are required to attend it. And when it is stated that a machine of the dimensions above stated has been found capable of making upwards of six barrels of powder in an hour, the saving of labour and power, and its consequent economy, must be self-evident to all persons at all conversant with the present mode.

But the economy does not rest here; the proportion of dust to grain made in this machine is not above one twentieth, whereas, in the common mode, it is full one-half; so that independent of the quantity of material absolutely lost in the old mode in dust, such is the great proportion of dust to grain produced, that, on an average, every barrel of powder manufactured may be said to be pressed twice, and a considerable portion of it to be twice worked under the runners: whereas, it is evident, that the small quantity of dust produced in the machine is hardly worthy of a consideration as to re-pressing, and leaves none to be re-worked under the runner.

But there are other advantages not to be passed over; in the first place, the grain is more uniform and more dense from being made out of the thin cake: in the next place, from the same cause, it contains more smooth and less broken surface, and is, therefore, on both these accounts, less liable to wear into dust; in addition to which, the grain must be cleaner and more free from foreign matter, a considerable quantity of which is collected by friction from the soft substances of the parchment sieves, &c. as well as gathered up with the dust; all of which is evidently avoided by the construction, materials, and mode of operation of this machine.

It remains now only to be stated, that as the preservation of the Gunpowder from the moisture of the atmosphere, is as important to its strength as the due mixture and incorporation of its ingredients, or any other process attaching to it, my system is to inclose it in wooden barrels, lined with thin metallic linings, either of copper, lead, or pewter, or any other sufficient substance, so as to form one entire barrel, of the exterior and lining, perfectly air and water tight, having an aperture at one end so contracted, that the inclosure may be made perfect by a luting of bees-wax and tallow, or a mixture of rezin and tallow, or any other sufficient luting; this aperture and luting being further secured by a false head to the wooden barrel, the interior of which is completely supported and protected by the exterior from being bruised or otherwise injured: and this mode will be found to be much less expensive than any system of barrel made wholly of metal, without an exterior of wood, can be, on account of the difference of the quantity and nature of the metallic substances required: while the slight lining, as a preservative, is equally as efficient as the most expensive metallic case alone. For the greater stowage, in particular situations, I have substituted rectangular cases, lined with different metallic materials, on the same principles as the barrels.

APPENDIX III

ON THE MANUFACTURE AND CONSTITUENT PARTS OF GUNPOWDER

A paper read before the Askesian Society in May, 1801 by Mr. R. Coleman of the Royal Mills, Waltham Abbey and published in the Philosophical Magazine, 1801, pp. 355-365.

The process of manufacturing gunpowder is so inaccurately described in every author which I have seen, and in many instances so extremely absurd an account is given, that I am induced to hope that a true account thereof will not be unacceptable; and more particularly as I apprehend nothing can tend more to establishing a true theory of the combustion of gunpowder, than a knowledge of the ingredients it is composed of, and the manner of their combination.

Gunpowder is made of three ingredients, saltpetre, charcoal, and brimstone. They are combined in the following proportions: to each 100 parts of gunpowder, saltpetre 75, charcoal 15, and sulphur 10.

The first thing to be attended to, it is evident, is the purity of these articles; for, if they are defective, the gunpowder can never be good, though ever so well manufactured.

The saltpetre is either that which has been imported, principally from the East Indies, or that which has been extracted from damaged gunpowder. It is refined by solution, filtration, evaporation, and crystallization; after which it is fused, taking care not to use too much heat, that there may not be any danger of decomposing the nitre; by this means it is not only rendered more pure, but the water of crystallization more certainly got rid of. The principal object in refining the nitre is, to get it free from the earths and salts it is combined with in its grough * state, and which by deliquescing would render the gunpowder liable to injury by attracting moisture, and, thereby decomposing the accurate mixture of the composition, rendering it unfit for use.

The sulphur used is that which is imported from Sicily, and is refined by melting and skimming: the most impure is refined by sublimation.

The charcoal formerly used in this manufacture was made by charring wood in the usual manner. This mode is called charring in pits. It consists in the wood being cut into lengths of about three feet, and then piled on the ground in a circular form (three, four, or five cords of wood making what is called a pit), and covered with straw, fern, etc., kept on by earth or sand to keep in the fire, giving it air by vent-holes as may be found necessary. This mode of charring is uncertain in its operation, and defective in every respect for the purpose of making good charcoal; and therefore no dependance could ever be placed on the charcoal so made.

The method now adopted for making charcoal for gunpowder, consists in distilling (if I may so call it) in iron cylinders and collecting the pyro-ligneous acid, the carbon remaining in the cylinder or retort. The wood to be charred is first cut into lengths of about nine inches, and then put into the iron cylinder, which is placed horizontally. The front opening of the cylinder is then closely stopped: at the further end are pipes leading into casks. The fire being made under the cylinder, the pyro-ligneous acid, attended with a large portion of carbonated hydrogen gas, comes over. The gas escapes, and the acid liquor is collected in the casks. The fire is kept up till no more gas or liquor comes over, and the carbon remains in the cylinder.

This, it is evident, is a more eligible method than the former; and, indeed, the only proper one. The difference in the strength of the powder made from the two sorts of charcoal will be more particularly mentioned hereafter. I shall here only remark, that the proportion of powder used for the several pieces of ordance by the navy, etc. has been reduced one-third in consequence of the increased strength of the composition into which this cylinder charcoal enters.

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* This is the term used for the nitre as imported.

The wood, before charring, has the bark taken off; for which purpose it is felled in the summer season, when the sap is up, and it will flow clean. One reason for taking off the bark is, that it would render the powder therefrom full of sparks; which would be of course injurious, and dangerous in the use.*

The wood made use of is either alder, willow, or (black) dog-wood; but the distillation in the cylinders making the charcoal of different woods nearly alike, it is not, I believe, material as to the sorts of wood made use of.

The several ingredients being thus prepared, are ready for manufacturing. They are, 1st, separately ground to a fine powder: 2nd, mixed together in the proper proportions: 3rd, the composition is then sent to the gunpowder-mill, which consists of two stones vertically placed, and running on a bed-stone. On this bed-stone the composition is spread, and wetted (not with sal-ammoniac, urine, etc. as some authors state) but with as small a quantity of water as will, together with the revolutions and weight of the runners, bring it into a proper body, but not into a paste. After the stone runners have made the proper number of revolutions over it, and it is in a fit state, it is taken off.

A powder-mill is a slight wooden building and boarded roof. Only about 40 or 50 lb. of composition is worked here at a time, as an explosion will sometimes happen from the runners and bed-stone coming in contact, and other causes. These mills are either worked by water or by horses.

4th, The composition taken from the mills is sent to the corning-house to be corned or grained. Here it is first pressed into a hard and firm body, broken into small lumps, and the powder then grained, by these lumps being put into sieves, in each of which is a flat circular piece of lignum vitae. The sieves are made of parchment-skins, having round holes punched through them. Several of these sieves are fixed in a frame, which by proper machinery has such a motion given to it, as to make the lignum vitae runner in each sieve go round with a quick velocity, breaking the lumps of powder, and forcing them through the sieves, forming grains of several sizes. The grains are then separated from the dust by proper sieves and reels.

5th, They are then hardened, and the rougher edges taken off by being run a sufficient length of time in a close reel, having a proper circular velocity given it.

The powder for guns, mortars, and small arms is generally made at one time, and always of the same composition. The difference is only in the size of the grains, which are separated by the sieves of different fineness.

6th, The gunpowder, thus corned, dusted, and reeled, (which is called glazing, as it puts a small degree of gloss on it) is sent to the stove and dried; taking care not to raise the heat so as to decompose the sulphur. The heat is regulated by a thermometer placed in the door of the stoves, if dried in a gloom-stove **.

A gunpowder stove either dries the powder by steam or by the heat from an iron gloom, the powder being spread on cases, placed on proper supports, round the room.

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* This is clearly seen by the combustion of charcoal, with the bark on, in oxygen gas.

** This species of stove consists of a large cast-iron vessel projecting into one side of a room, and heated from the outside till it absolutely glows. From the construction it is hardly possible that fire can be thrown from the gloom, as it is called; but stoves heated by steam passing through steam-tight tubes, or otherwise, ought surely to be preferred; for the most cautious man may stumble; and if he has a case of the powder in his hand, some of it may be thrown upon the gloom; and it is surely possible that in this way some of the accidental blowing up of powder mills may have been occasioned.

If gunpowder is injured by damp in a small degree, it may be recovered by re-stoving it; but if the ingredients are decomposed, the nitre must be extracted and the gunpowder re-manufactured.

There are several methods of proving and trying the goodness and strength of gunpowder. This it is not the object of this paper to describe; but I shall just mention one, by which a good idea may be formed of the purity of the gunpowder, and also some conclusion as to its strength.

Lay two or three small heaps (a dram or two) on separate pieces of clean writing-paper; fire one of them by a red-hot iron wire: if the flame ascends quickly, with a good report, leaving the paper free from white specks, and does not burn it into holes; and if sparks fly off, setting fire to the adjoining heaps, the goodness of the ingredients and proper manufacture of the powder may be safely inferred: but if otherwise, it is either badly made or the ingredients impure.

OBSERVATION

If the composition on a mill explodes by any accidental cause, shortly after it has been put on the stones, it goes off with a very slight explosive force, principally in flame; but if it has been on an hour or two under the runners, and then explodes, it more or less destroys the mill, throwing the boards of the covering and sides to a considerable distance.

I shall here state a circumstance that happened, which, although not immediately connected with the subject, may serve as a strong illustration of one branch of philosophy. On the explosion of the powder in a mill which had been on about two hours, the mill was wholly unroofed and the sides blown out. The doors and windows of the mills on the opposite side of the stream were forced open *outwards*, and the nails, etc., drawn.

I shall now beg to submit some ideas that occur to me from a consideration of the whole of the circumstances I have related, and from what may be deduced from an examination of the component parts of gunpowder - It appears to me that no part of the explosive force consists in elastic vapour, found, by the combustion from water contained in it - so small a portion of water is in the ingredients, and I have observed that not any is gained in the manufacturing, that I cannot conceive any water is carried off undecomposed, but that it is converted into hydrogen and oxygen gases. I am of the opinion that the explosive force of gunpowder consists wholly in the several gases formed by the combustion; and that, the quicker it takes fire, the more gas is generated in a given time and its force consequently greater.

It seems therefore that the combustion is carried on by the oxygen supplied from the nitre; that this gas is instantly taken up by the sulphur and carbon; and, converting those substances into carbonic and sulphureous acid gases, agotic gas being at the same time liberated from the nitre, the water which may be in the nitre; and also that which is in the charcoal is decomposed: and the oxygen taken up by the carbon and sulphur, and the hydrogen set free. The force arising from these gases, with the increased elasticity they receive from the increase of temperature caused by the combustion, is surely sufficient to account for the effects we observe in gunpowder.

"THE MANUFACTURE OF CYLINDER CHARCOAL IN SUSSEX."

From Young's "Agriculture of Sussex" (1808)

The manufacture of charcoal is an object of some consequence in such a county as Sussex. Large quantities are annually sent to London by land-carriage. The old process in burning has been lately laid aside, and a new method substituted; as, after various experiments, the powder made upon this new principle, has, upon proof of its strength been found much superior to that which was made in the old way. And accordingly this ingenious mode has been suggested to Government, by the Bishop of Llandaff, of making the charcoal in iron cylinders, of such a construction, as effectually to exclude the air, and to preserve all the tar acid which is extracted from the wood in the course of burning.

Adjoining the turnpike at North Chappel, and within five miles of Petworth, Government has lately purchased a small piece of land of Lord Egremont, and upon it have erected this charcoal manufactory. The cylinder room is 60 feet in length and proportionately high and wide: three sets of iron cylinders are placed in a very thick wall, or bed of brick-work, built nearly along the centre of the house; each of them contains three cylinders, each being six feet long and two feet diameter. To prevent every possibility of air being admitted, iron stops are contrived, 18 inches in length, and the size of the inner circumference of the cylinder, which are placed in the mouth, and are filled and rammed down with sand: besides which, sand-doors (as they call them) are made to project obliquely over the front or opening of the cylinder, and are entirely filled with sand, and the stops covered with it. At the back part of the building are copper-pipes projecting seven feet in length, communicating at one extremity with the far end of the cylinder, and at the other extremity immersed in half-hogshead barrels. These pipes serve to draw off the steam or liquid, which flows in large quantities into the tar barrels during the process of charring. Sea-coal fires are made under them, one to each set; and in order to convey the heat as equally as possible to all parts of the cylinder alike, four flues or cavities equidistant from each other in the brick-work, spirally encircle the cylinders, and conduct the heat over every part. The position of the grate was at first under the centre cylinder. Various alterations have since been made, as it was found that this method did not answer so as to heat all the cylinders equally. The grate is now placed under the outside cylinder in each of the sets; and by the flues being so conveyed, it follows, that the further cylinder is first heated, and that which is nearest the fire, last. Each set holds 5 cwt of wood; so that when all three are in full work, the daily consumption is 15 cwt of wood, which makes 4 cwt of coal; it loses nearly three parts out of four in charring; and if all the three sets were at constant work, the annual consumption would be nearly 550,000 cwt-27,500 ton.

The process of this novel and valuable operation may be thus explained: very early in the morning the first thing done by the workmen is to take the doors down, by a pulley suspended at the ceiling, remove the sand, and also to take the sand out of the stops, previous to being drawn out and suspended; large tin coolers are then brought up to the mouth of the cylinder, and the charcoal of the preceding day is then drawn with a rake into the cooler, and shut up close. As soon as the cylinders are emptied, the workers are employed in recharging them. For this purpose the sorts of wood are various, but withy and elder are the best: the cordwood is about 18 inches long, but before it is placed in the furnace, they cut it into five lengths, and all the black knots are cut away. In the act of filling, the largest pieces are placed in the centre, and the smaller adjoining the rim; when it is charged, the iron stop is let down by the pulley, put into its place, and the sand rammed into the front; the doors are then hung over the mouth, and filled up with sand, and the fire is kindled and fed till the wood is completely charred, which is known by the tar ceasing to flow through the copper pipes. If the fire is lighted about half six o'clock in the morning, it will take from two to two hours and a half before the wood is at all heated, and the liquid begins to flow. At this time the fume becomes extremely offensive, and soon after almost intolerable to any but the workmen. The time required is eight hours, but this depends upon the size of the wood.

During the operation, attention is paid to the pipes, which are inspected, lest any air might be accidently admitted, which would infallibly stop the pipes from working. The fires are kept up as strong and as bright as it is possible; though the waste of sea-coal is not considerable; about eight bushels to each set daily. When the wood ceases to work, and the tar to flow, the fire is gradually extinguished, which concludes the day's work, the furnaces remaining in the same state till the next morning, in order to give them time to cool; and when drawn, they are replenished in the manner before-mentioned; but are always cleaned each day, and the pipes once a month.

The wood for this manufactory comes out of the neighbourhood, and is bought in at 24s. per stack (fell, flaw and stack), besides the carriage. Large quantities of wood are kept in the yard, and stand about a year before using: the stack is here twelve feet long, three feet ten inches high, and three feet six inches over, and from each is extracted about 55 gallons of tar-liquor. This tar acid they daily draw from the barrels, but into a large tub, and preserve it in hogsheads, but at present it cannot be used, because a patent is out for the monopoly of the sale. It is worth 6d. per gallon. The charcoal goes to Waltham and Faversham.

THE MANUFACTURE OF GUNPOWDER AT WALTHAM ABBEY

By William Fitzgerald, "The Strand Magazine" March 1895

The famous Royal Gunpowder Factory, whose main gate is almost under the shadow of the ugly Norman Tower of Waltham Anney is the most extraordinary factory in the world.* Factory is quite a misnomer applied to this lovely and picturesque domain. The establishment consists of about four hundred acres of wooded land, intersected by four miles of crystal streams, which would fill the angler's heart with delight.

Passing in at the gate we beheld an avenue of stately poplars, at the end of which the Union Jack floated proudly from a flagstaff. This gave rise to a train of thought from which we were rudely aroused by a sharp challenge from the inspector of police. We were then requested to enter the police quarters, where we were plied with questions as to our business, and whether we possessed any matches, pipes, or steel implements. Then we turned out our pockets, just as Lord Sandhurst had to do when he visited the factory for the purpose of opening the hospital. In fact, all comers, from the Prince of Wales down to the humblest factory lad, are interrogated by the police at the gate with a strict regard for duty that reminded us of certain anecdotes in our school books.

Colonel Ormsby, the Superintendent, assured us that the way was long, and therefore it would be better for us to set off on our personally conducted tour at once. He was right. The buildings seemed to be scattered far and wide as though it were the primary intention of the authorities to occupy every available square foot of land. We walked miles; we plunged into thickets, crossed innumerable streams, and occasionally glided from one building to another in a swift electric launch,+ the panting of whose screw scared the birds and rabbits that abound in this extraordinary place.

But we must commence ab initio. The first place we visited - and we were calm and appreciative then, not knowing the extent of the appalling task that lay before us - was the saltpetre refinery. The saltpetre comes from Scinde in bags of 100 lb., and in this state it contains about 5 per cent of impurities. It is dissolved in large quantities in water heated to 230 degrees, and, after careful skimming, the solution is pumped into coolers. The saltpetre crystallizes in these coolers, and is then raked from the bottom in the form of wet snow, which is piled up, and subsequently undergoes a washing process by means of a continuous stream of water. There are four refining coppers and seven evaporating pots in the refining room. The saltpetre is ultimately sent to the mixing house in barrels, with a certificate showing that it contains between 3 and 6 per cent of water. The saltpetre refuse is bought by farmers for from 8/- to 12/- per ton.

We next called at the sulphur refinery but found it almost impossible to breathe within its evil smelling precincts. As regards the worthy man we found there, he was as unconcerned as though he were inhaling the ozone on Brighton Pier; more, he proceeded to give us, out of the fulness of his twenty-six years' experience, a few details concerning his own department in quite a graphic manner. Six hundredweight and a half of Sicilian sulphur is shot into the

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* A curious opening. The bulk of the structure of the Abbey is Norman work at its best, but the Tower, built in 1556/8, is not even an imitation of Norman work.

\+ "The 'Spark', built at the Factory in July 1886, to the designs of the Superintendent, Col. W. H. Noble, R.A., mainly as a means of lighting up some of the powder houses in the factory which are at a considerable distance from the dynamos used for general electric lighting services. The lighting and motive powers of the boat are derived from a battery of accumulator cells, stowed under cover amidships, and a small 1½ horsepower motor which turns the shaft to which the screw propellor is attached. The speed is 5 - 6 knots and the vessel is 25 ft long and 5 ft beam" (Winters)

retort, and after it has remained there about three hours it passes in vapour from the retort, through cold water jacketed pipes, into the receiving pot, where it arrives in a treacly mass. Our friend ladles this viscous matter into the casting tubs, in which it is left for about eighteen hours. Next morning these tubs are emptied, and out of each comes two hundredweight of purified sulphur, which resembles a monstrous custard. This also goes to the mixing room, after having been ground in the sulphur mill.

There remains one other constituent of powder to be investigated namely, charcoal. Why, we asked, are there such extensive groves and forests of willow, dog-wood, and alder within the boundaries of this strangest of factories? One reason is that the wood is converted into charcoal; and another, that a dense growth of trees serves to locate the effects of a possible explosion. After being seasoned in stacks for 3-10 years, the wood is placed in cylindrical drums, and the latter are then run into furnaces shaped to receive them, by means of travelling cranes. After from three to eight hours of very great heat, during which time the very gases from the burning wood are utilized as fuel in the furnace below, the drums are withdrawn and their contents shot into air-tight iron vessels to cool for four hours. The charcoal is subsequently removed to smaller coolers, where it remains another twelve hours, after which it is taken by boat to the store. Here it remains for a day or two before being picked over by hand, in order to see that there are no nails or pieces of iron in it. The responsibility of this last mentioned work may be judged when we state that, if the smallest particle of gritty matter of any sort is inadvertently passed over, it infallibly means an awful explosion and certain loss of life.

The sulphur is ground so as to pass through a sieve having 36 openings to the square inch; the charcoal is passed through a mesh 32 to the inch. Now we are ready for the mixing room. Grimy men flitted through an almost tangible gloom; and in one corner an expert was weighing up the saltpetre, sulphur and charcoal in parts of 75, 10 and 15 respectively. For powder for big guns, however, the proportions are 79, 3 and 18. These constituents were shot into a revolving drum fitted with blades inside. The mixture is afterwards packed in half charge sacks of 60 lb, and sent to the incorporating mill - the first of the "danger buildings."

The incorporating mills are built in groups of six and are worked by independent machinery. Except for the division walls, these mills are constructed of the flimiest material possible, the roof being of wood, and the fronts of canvas, buttoned on to a slight iron framework; this is in order that no resistance may be offered to a possible explosion. Yet the interior of any one of the incorporating mills is not calculated to strike awe or terror into the heart of the visitor. There is nothing in the place but a big circular iron bed, round which revolve two enormous wheels, each weighing four tons.

Into this bed is shot the contents of the half-charge sack brought from the mixing house. A wooden "plough" is then fixed from the centre, so as to keep the powder continually under the rollers, and then all is ready for starting the machinery. Even in this stage the mixture is highly inflammable, and therein lies the raison d'être of the "flash-board", over the bed. In the event of an explosion, either through the wheels meeting with gritty particules in the mixture, or from other causes, this board would be violently thrown upwards on hinges, and in its descent backwards would automatically overturn tanks of water, not merely on its own bed, but also on the beds of its working neighbours, who might otherwise be tempted to join in the riot.

Indeed, the risk is so great, that in order to start the incorporating mill, the operator prudently draws down the flaps of his cloth helmet, puts on his gauntlets, and retires outside. The man is clothed in a suit of "lasting" that curious leathery material affected by the London apprentices in the days of Queen Elizabeth. There are no pockets in this suit, and the buttons are of bone; no powder adheres to this material. The men are even forbidden to cultivate long beards, lest perhaps these hirsute appendages should contain particules of grit, harmless enough in themselves but more deadly than cholera bacilli when introduced into a powder mill.

After being three and a half hours beneath the incorporating rollers, the mixing becomes "mill cake," and is removed in covered trucks to the breaking down house. This building, in common with most of the other danger buildings, is lighted at night by electric lamps,

immersed in water, and placed outside the windows. In the breaking down house the mill cake is placed in a hopper, drawn up on an endless band, and crushed into meal powder by two pairs of gun metal rollers. Only twelve charges of 120 lb. each are allowed in this house at one time.

The next department is the press house. Here the machine house and the mens' retiring room are separated by a "traverse", a mighty mass of masonry, concrete, and earth, which is intended to protect the workmen; these latter are compelled to remain in the lobbies while the machinery is in motion. In the press house one of the most dangerous operations takes place. Copper plates are fixed in a rack in a huge iron box, and about 750 lb of meal powder is strewn between them. A hydraulic ram of from 63 to 500 tons pressure is then brought to bear upon the plates for half an hour, during which time the men are congregated in the shoe-room on the other side of the traverse. It is no exaggeration to say that there is an awful uncertainty about this operation.

A bell rings when the pressure gauge reaches a certain point, and the men then return to the machine room and remove the "press cake," as it is now called, from the plates. The regulations caution the men against "undue haste" in removing the cake, and the authorities have thoughtfully provided deep wells outside each danger building, into which men who have been badly burnt may plunge. No more than 900 lb. of powder may be kept in the press-house at one time.

The press-house is the parting of the ways, so to speak, of the various kinds of powder, which are made from press-cake treated in different ways. For pebble powder the press-cake - which, by the way, resembles thick black slate - is cut into strips, and these strips are further cut into "5/8 cubes." The rest of the cake is reduced to coarse powder by three pairs of graduated rollers.

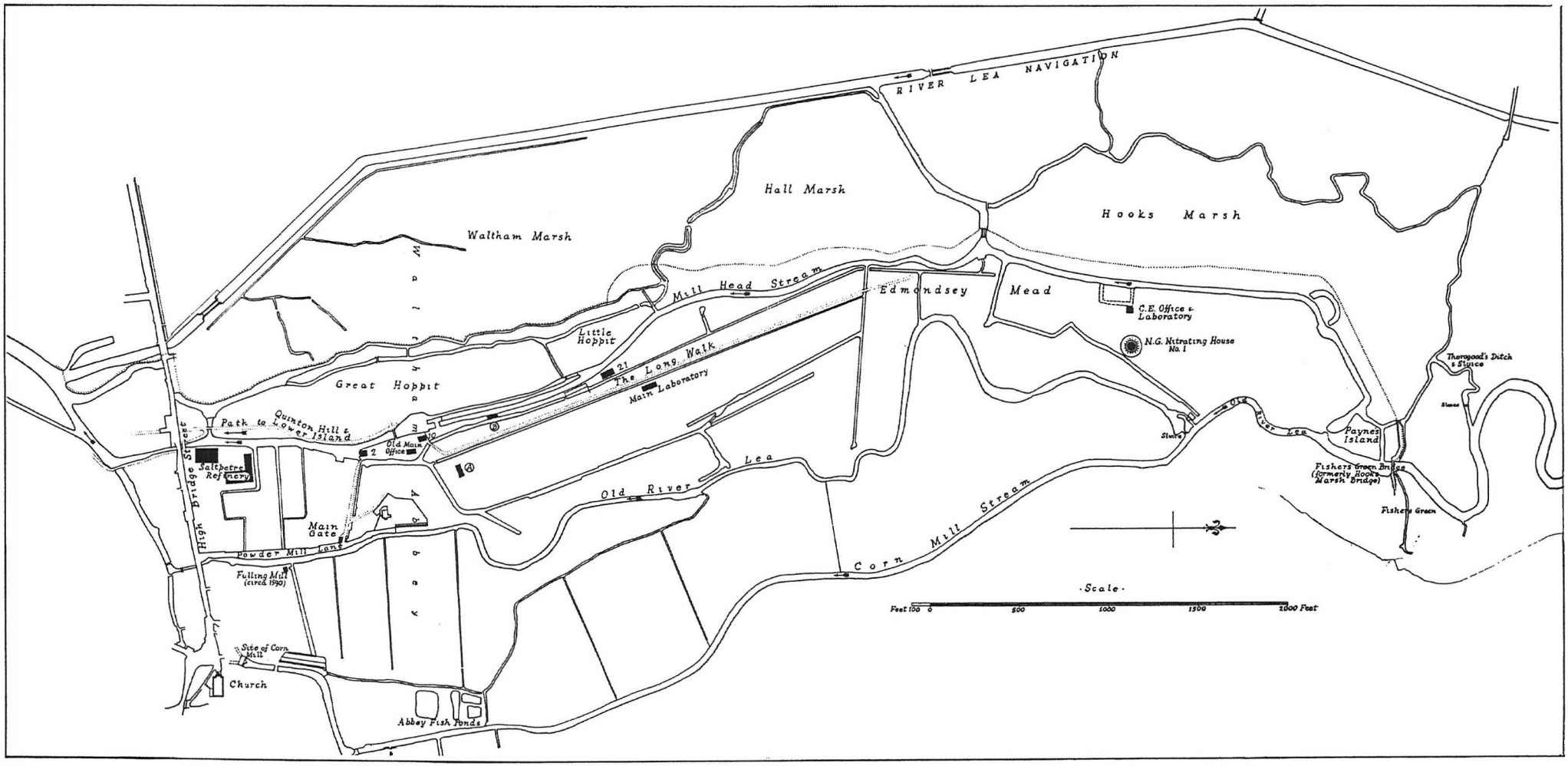
All sorts of fearsome notices and cautions abound in the retiring room of the press-house. A rigorous line of demarcation is formed by an upright board, before passing which every visitor, from the Government inspector downwards, is compelled to put on a pair of enormous boots over his own. This precaution is taken in order that no gritty particles may be introduced on to the soft leather floor of the danger buildings. Having put on these boots, you shuffle shamefacedly round the traverse to the machine room. We say shamefacedly advisedly, for we defy any man to walk a dozen yards in these safety-boots and yet maintain a semblance of dignity.

The glazed and granulated powder (the dust from which has been removed by another process and sent back to the incorporating mills) is now ready for moulding into prisms for the built up charges used in big guns. In the moulding room coarse-grained powder is fed into the compartments of a wheeled tray and it is then pushed under the hydraulic press, which has corresponding plungers. The hexagonal prisms emerge in batches of sixty-four or 13,000 per day. A skilled workman weighs a specimen from each batch in air and mercury, and "if the scale do turn (literally) but in the estimation of a hair", the whole batch is rejected. In the drying rooms, ordinary grain powder is left for from one to three hours; pebble powder, however, takes from twenty-four to forty hours to dry and S.B.C. ("slow burning cocoa") for 110 ton guns, about sixty hours.

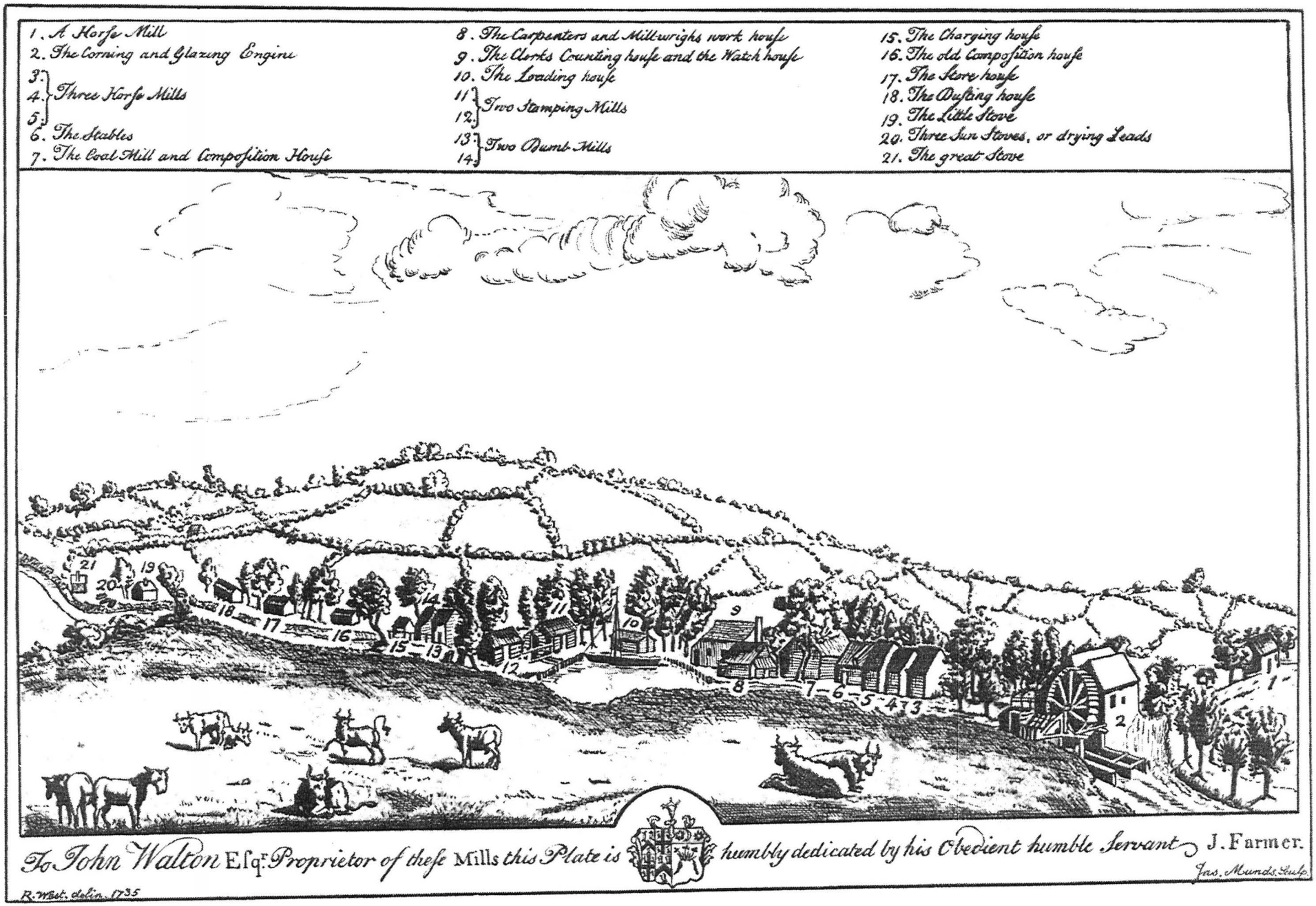
The last mentioned powder is proved in 11 in. guns with a charge of 360 lb. and gives a muzzle velocity of from 2,010 ft. to 2,050 ft. per second. Finished powder of all sorts is sent to the splendidly-fitted laboratory to undergo various tests; it is then proved in the guns at the butts attached to the establishment. Finally, large quantities of each kind are blended so as to give uniformity, and the powder is then conveyed to Purfleet and Woolwich in special barges, which fly a red flag and can be sunk in five minuted.

Altogether there are about 900 men employed in the factory, and the annual wages bill comes nigh unto £70,000. One thousand four hundred tons of saltpetre are stocked; 100 tons of sulphur; and enough wood to make 40,000 barrels of powder. The annual consumption of

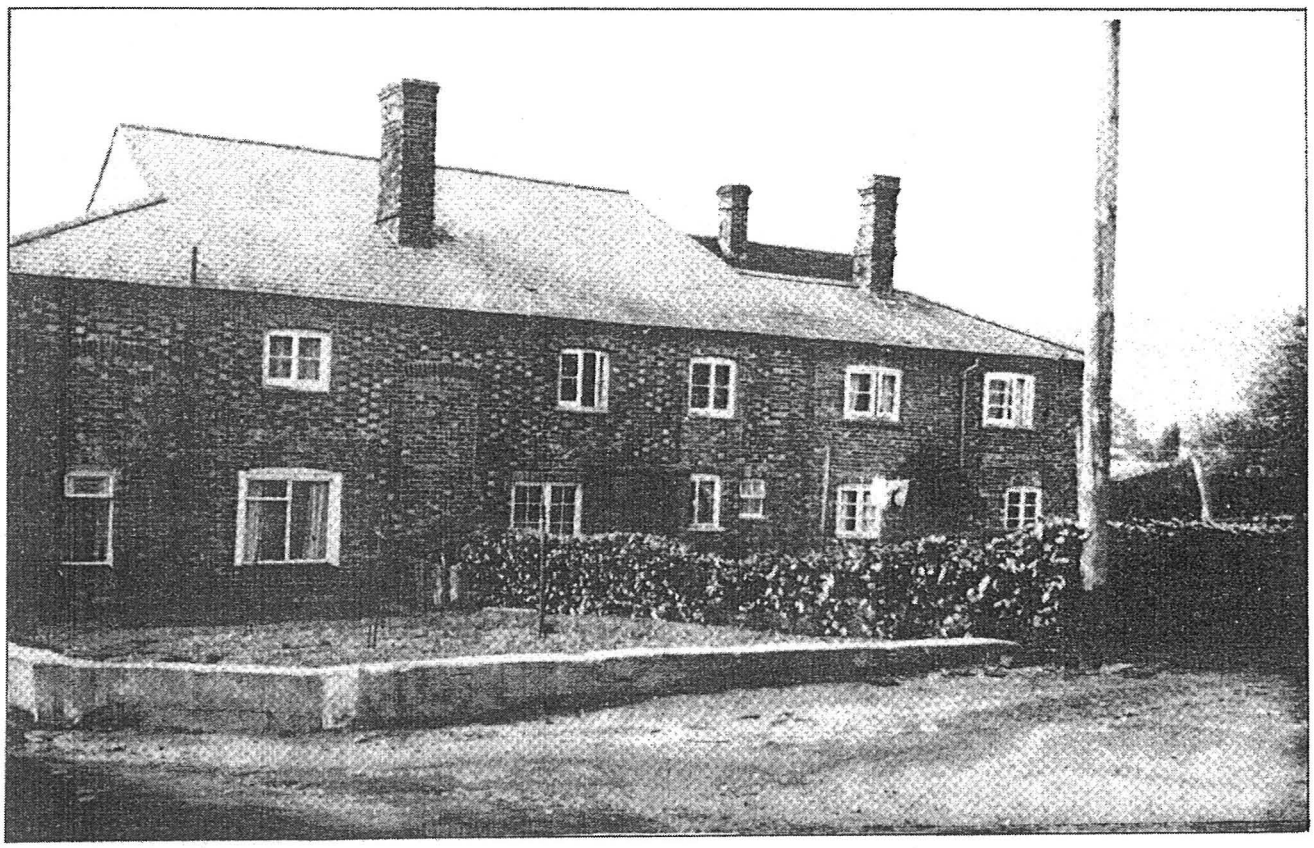
coal ranges from 8,000 to 10,000 tons. A little hospital has been opened by Lord Sandhurst quite recently. The hospital stands close to one of the myriad streams that intersect the vast grounds of the factory, and is intended solely for the benefit of injured workmen. By the way, it seems strange that, in spite of innumerable precautions and all that science can do, frightful explosions should take place - explosions as disastrous as they are inexplicable. Truly, these grave, quiet men, who are turning out by day and by night material for the defence of our country, "know not the day nor the hour."



MAP OF FACTORY AREA (NORTH SITE) AND SURROUNDINGS SHOWING VARIOUS BUILDINGS AND AREAS MENTIONED IN THE TEXT. BUILDINGS MARKED 2,10, & 21 ARE THUS DESIGNED IN FARMER'S SKETCH (A) IS THE SITE OF THE EXPLOSION OF 27th MAY, 1861, AND (B) THAT OF THE LAST INCORPORATING MILLS (SE PHOTOGRAPHS)

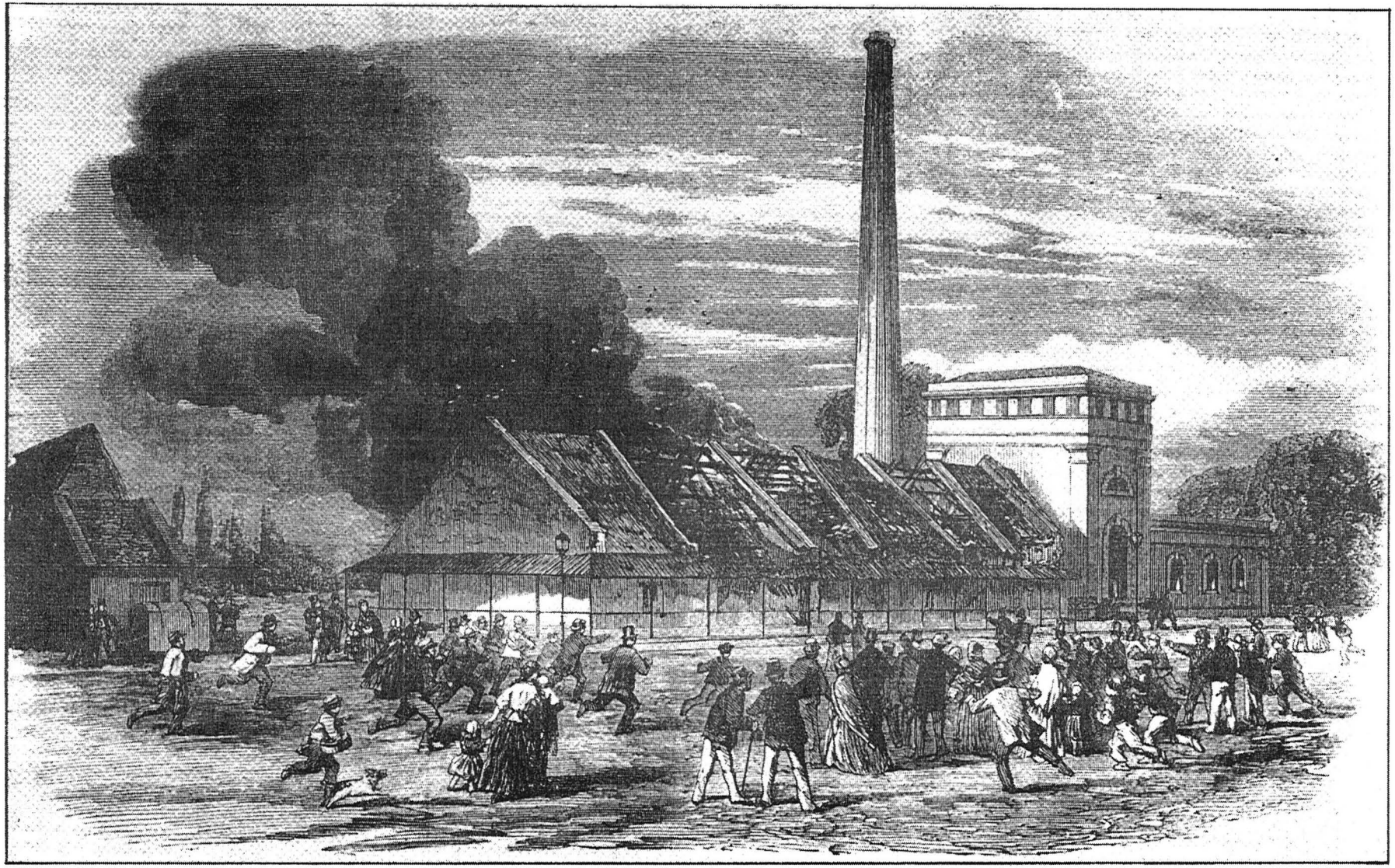


GENERAL VIEW OF THE FACTORY IN 1735
(FROM FARMERS "HISTORY")

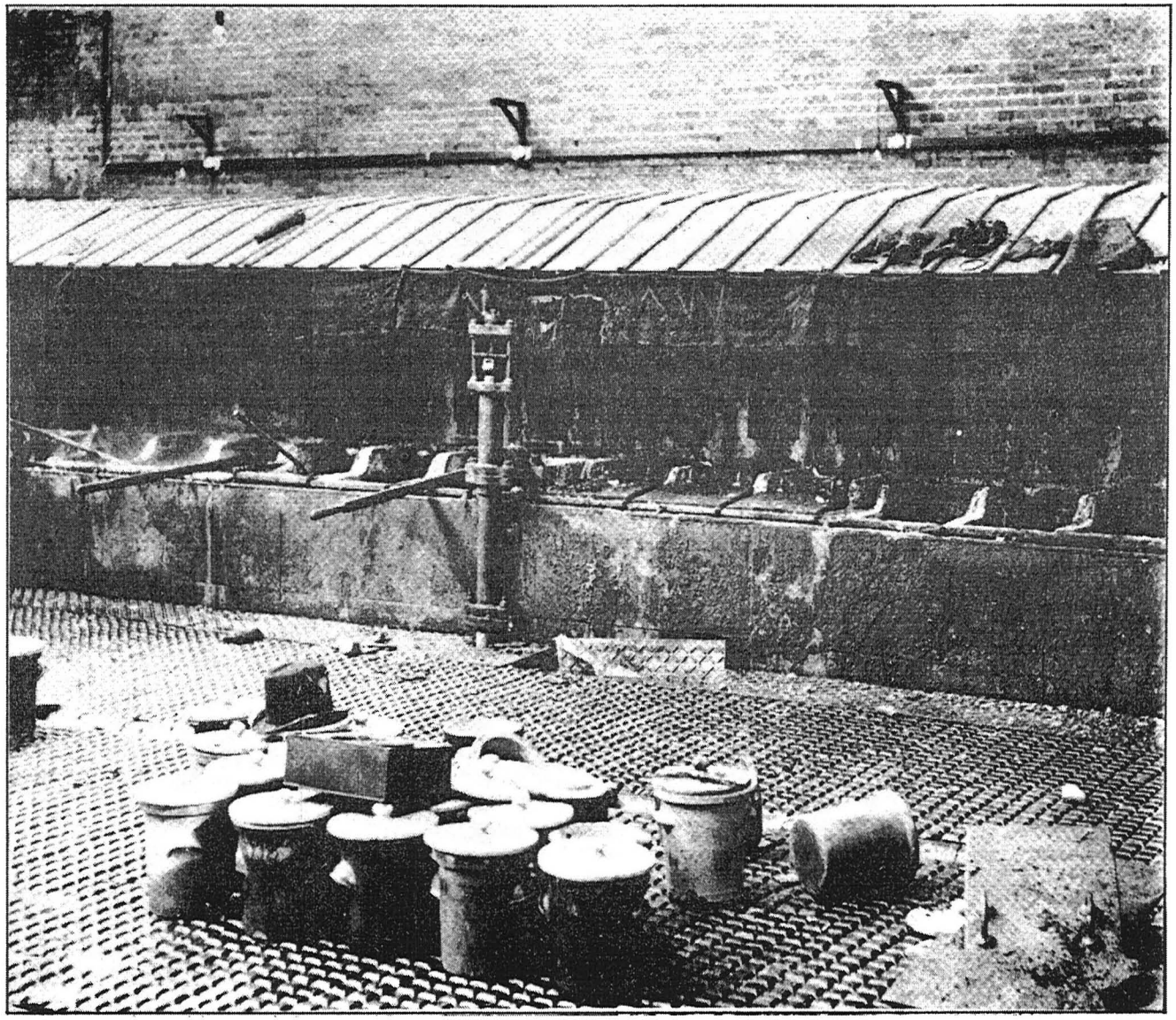


COTTAGES AT FERNHURST, SUSSEX
(Formerly Charcoal Cylinder House,

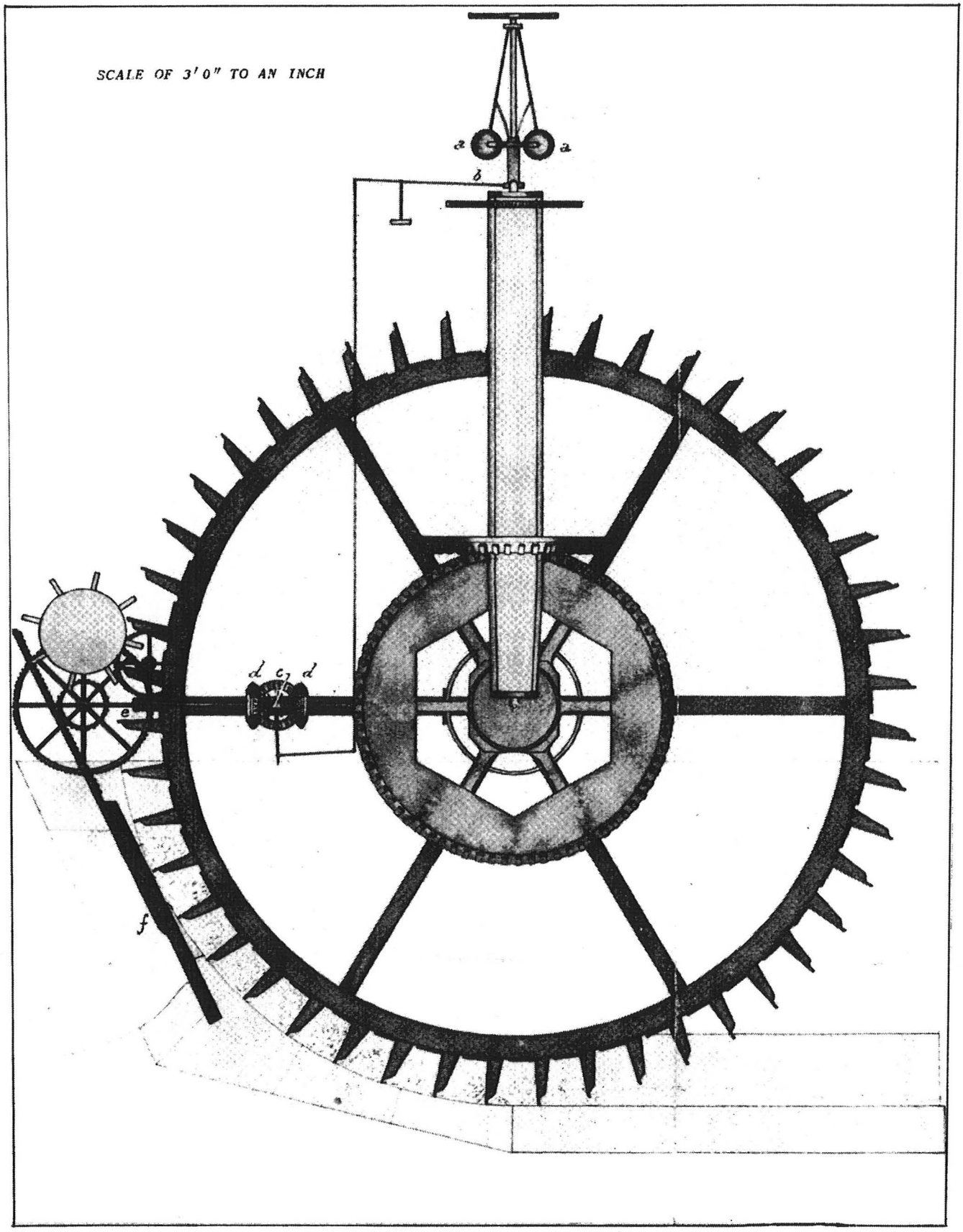
THE OLD CENTRAL OFFICE (JOHN WALTON'S HOUSE). DRAWN BY J. BELL. 1851



EXPLOSION AT INCORPORATING MILL, 27th MAY, 1861
(By Courtesy of Illustrated London News)



EXPLOSION AT GUNCOTTON DIPPING ROOM, 1st MARCH 1894
(SAID TO BE DUE TO AN ATTEMPT TO INCREASE NITROGEN CONTENT
OF GUNCOTTON BY RENITRATING IT)



A DRAWING FROM FREDERICK DRAYSONS "TREATISE ON GUNPOWDER" (1830) SHOWING REGULATOR USED ON GUNPOWDER MILLS.

"WHEN THE MACHINERY MOVES WITH TOO GREAT VELOCITY, THE BALLS MARKED a EXPAND, RAISE THE LEVER b, AND CAUSE THE CLUTCH c TO CATCH ONE OF THE SMALL WHEELS d, WHICH TURN THE MULTIPLIER e, AND WHICH TURNING THE OTHER WHEELS SO AS TO RAISE THE WATER GATE f, ADMIT A LESS QUANTITY OF WATER ON TO THE WATER WHEEL".

THE LAST PAIR OF MILLS - FROM A PAINTING BY E. A. MONRO, 1956