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THE EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT
Its Historical Background

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Despite the far-reaching and wide-ranging nature of its present activities the Explosives Research and Development Establishment at Waltham Abbey occupies the site with the longest continuous association with explosives. Just after World War II the Establishment took over from the Royal Gunpowder Factory which had provided a manufacturing capability since 1787 and which in its turn was the successor to the earlier privately-owned Powder Mills.

The early history of the Powder Mills is obscured by a shadow which obscures all too many subjects of historical interest: this is the lack of authoritative records and it is from under shadows such as this that legends grow.

One legend is that some of the gunpowder used at the Battle of Crecy in 1346—the first time that gunpowder was used by English soldiers in warfare — came from Waltham Abbey where it was made by the monks. There is no evidence for this but it is known from the accounts of the Clerk of the Great Wardrobe that saltpetre and sulphur were supplied to the King for his guns.

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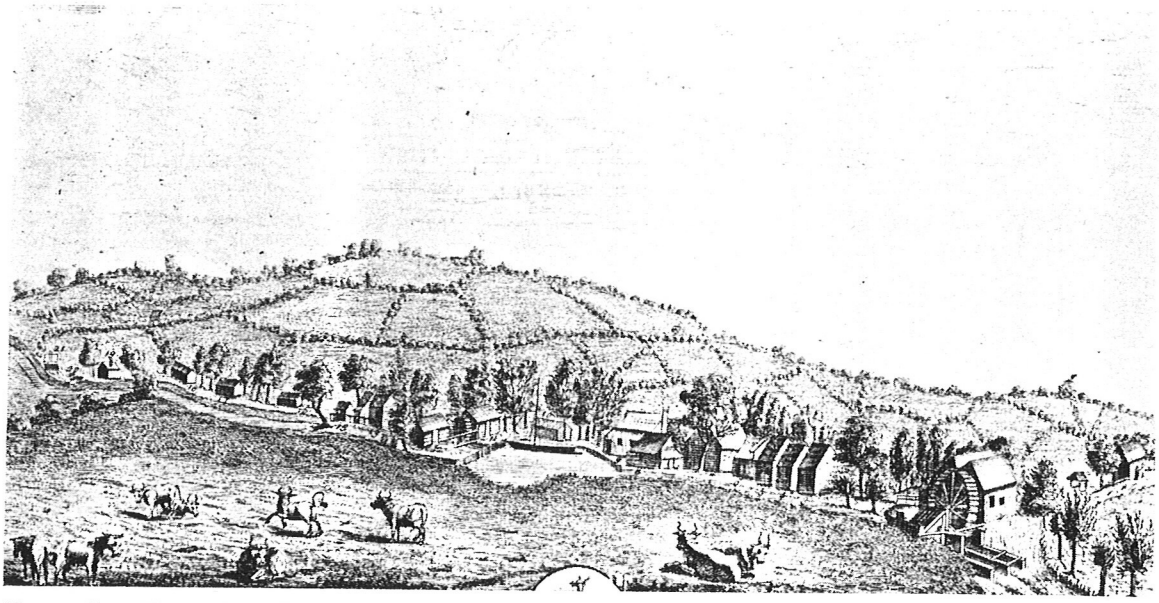
Another legend suggests that the Spanish Armada was defeated with the aid of gunpowder produced at Waltham Abbey.

Such was the state of the country's international relations in the third quarter of the 16th century and such was the scarcity of powder that Queen Elizabeth's ministers were advised that 'the Quene's Majestie should do well to macke 4 or 6 mills for the making of powder'. Here the question to be answered is 'Were the Waltham Abbey Mills in operation at this time?'—for it goes without saying that if they were their entire production would have been used to support the war effort.

Yet another legend is that Guy Fawkes and his fellow conspirators purchased their gunpowder from the mills at Waltham. Once again there is no documentary evidence—in view of the circumstances this is hardly surprising but there is circumstantial evidence to support the idea. At this time Father Henry Garnett, the Superior of the English Jesuits, was living under the assumed name of Mr. Meaze, only two or three miles away at White Webbs, where the conspirators were frequent visitors, and where they were only a few days before the 5th November, 1605. It is known from their confessions that there were at least three separate purchases of powder over several months and that it was stored in Catesby's house in Lambeth before being taken to the house rented by Percy which was next to the House of Lords. As White Webbs was in the sporting area of Enfield Chase powder could have been purchased without suspicion and then transported safely by water all the way from Waltham to Lambeth.



The earliest illustration of the Waltham Abbey Powder Mills, 1735.

But so much for legends. The first evidence of a connection between Waltham Abbey and gunpowder appears in the Calendar of State Papers of 1561 where there is mention of a contract for the supply of saltpetre and sulphur. Correspondence concerning this contract is addressed to John Tamworth at Waltham Abbey from Marco Antonio, an Italian. The letter itself gives details of the methods of payment. Tamworth was the executor of Lady Denny, the widow of Sir Anthony Denny who had been granted the Abbey lands at the Dissolution of the Monasteries and it was upon these lands that the Powder Mills were built. Tamworth was also one of the Chief Grooms of the Privy Chamber and had been granted the felling rights in the nearby Wintrie Wood.

Reference to the Mills is made by the perpetual curate of Waltham Abbey, Dr. Thomas Fuller, in his work *The History of the Worthies of England* which was published in 1662. Of gunpowder Fuller wrote that there is " more made by Mills of late erected on the river Ley, betwixt Waltham and London, than in all England besides ". He goes on to write that " 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 ".

Unfortunately it was not long after this was written that the first deaths from an explosion are recorded. The entry in the Parish register of burials for October 1665 contains an entry—

> " Tho. Gutridge, killed with a powder mill, ye 4 day. Edward Simons, carpenter, so killed, ye 5 day."

It was unusual for the cause of death to be given in the entries at this time so the tragedy must have been viewed with some concern especially so as the Plague was at its height.

Although by now the existence of the Mills had been established little is known of the owners before 27th May, 1672, when it was presented at a Court Baron that a powder mill had been erected near Hook's Marsh Bridge by one Ralph Hudson. The mill was said to be a nuisance and danger to the inhabitants of Upshire and Hallefield as they passed with their cattle. Apparently nothing was done to remove the mill and a year later Hudson was fined £10 for interfering with water supplies. There was trouble again later over water rights. In a lawsuit in 1732 brought by Charles Wake Jones against Philippa Walton, the widow of John Walton, the water intake of the mills had to be reduced. During the proceedings one of the witnesses stated that the waterways had been maintained by Mr. Hudson and since by Mr. Walton until his death and thereafter by his Widow.

By 1735 the Mills were owned by a second John Walton and were described in that year by John Farmer in his history of Waltham Abbey as being " esteemed the largest and compleatest works in Great Britain ", and although no details of manufacturing processes are given in the text it is known that the powder mills were worked by horses and that water power was being used for the corning and glazing engines. By 1770 the use of water power had spread to the powder mills. A passage in Peter Muilman's " New and Complete History of Essex " published that year, refers to " several curious gunpowder 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 Bourchier Walton, Esq." The design for the new powder mills was prepared by John Smeaton who was the leading authority on water mills.

Before this time the Government had realised the importance of controlling much of the powder production of the country and had in 1759 purchased the mills at Faversham in Kent from Thomas Pryce. But in 1783, following statements that the private merchants could make better powder than the Government and that they could make it more cheaply, the Prime Minister, Pitt, was about to recommend the sale of the Faversham Mills. Representations were then made through the Duke of Richmond, Master General of Ordnance, by Major William Congreve, who was Deputy Comptroller of the Royal Laboratory at Woolwich, to show that Government manufacture did, in fact, yield a profit, and that, if this profit were properly expended in improving the mills, it would be possible to make a powder which was more powerful and more durable than had ever been made previously. Fortunately and justifiably—as shown later —he received a sympathetic hearing and not only were the Faversham Mills reprieved but negotiations were opened with yet another John Walton for the purchase of the Waltham Abbey mills. On the 11th October, 1787, the minutes of the Honourable Board of Ordnance record the receipt of a letter from Walton expressing his willingness to dispose of the powder mills for £10,000. His offer was accepted and by the 22nd October, Major Congreve had taken over. Congreve was active even before the mills had been taken over officially and had eployed Daniel Cornish, a carpenter, to recruit the best of the millmen and labourers who had been working for Walton. These men were to be paid nine shillings a week and Cornish 15 shillings a week. Other men were drawn from Faversham and on the 18th November, 1787, James Wright was appointed Storekeeper at £150 per annum to be in charge of the new Royal Powder Mills under Major Congreve. The mills under John Walton had fallen into neglect and although the purchase price was £10,000 another £35,000 was spent in improvements and enlargements. All this took time and although Congreve sent processing instructions to the Master Worker, William Newton, in July 1788 directing him to use the proportions of ingredients of gunpowder of saltpetre 75 lb, sulphur 10 lb, and charcoal 15 lb it appears that no powder was made until 9th February, 1789—only to be followed on the 12th February by the first explosion. Fortunately this did little damage and the mill where the incident occurred was working the next day. Minor explosions were frequent and this fact was recognised insofar as the buildings were built of light, easily-replaced materials. Congreve was also responsible for the Faversham Mills and it was from there that he issued the first set of gunpowder factory rules. These rules, covering safety and discipline, coupled with processes designed to produce a uniform product, form the basis of the improvement in quality and cost of the powder from the Royal Mills. Congreve, in 1811, was able to justify his actions in 1783 in keeping the Faversham Mills and the purchase of the Royal Gunpowder Factory by publishing a statement of the savings arising from the manufacture of gunpowder at the Royal Mills. Between 1789 and 1810 407,408 barrels of powder each of 100 lb. were produced at Waltham Abbey and Faversham. The savings to the Government, being the difference between the Merchants' price and actual cost, amounted to £288,357 6s. 0¼d. Taking the Royal Gunpowder Factory alone, even after deducting the £45,000 spent on the mills, a saving of over £50,000 was made.

Experiments were made at this time both to improve the quality of the product and, once it had been improved, to maintain uniformity of this quality. This was a most important consideration, for when used in service action one batch of gunpowder should provide a bullet or shell with the same range as the next batch. To maintain this uniformity it was essential

to use pure ingredients and the greatest attention was paid to the refining processes and to the processes designed to give a stable and lasting powder.

Congreve was able to demonstrate the improvements in the powder by trials carried out on Marlborough Downs where 10-inch shells were fired by 9 lb lots of gunpowder from different makers including six private merchants. That from the Royal Gunpowder Factory had the greatest range of 4,430 yards exceeding its closest private rival by 160 yards and most of the others by over 500 yards.

General Congreve, as he then was, was created Baronet in 1812. His son, another William Congreve, followed his father's footsteps very closely, entering the Artillery, joining the Royal Laboratory and in 1814 succeeding his father as 2nd Baronet and as Comptroller of the Royal Laboratory. It was the son who in 1805 developed the famous Congreve rocket for military purposes. This gunpowder-propelled missile had terror and incendiary value as its qualities rather than accuracy but it is responsible for the words " the rockets' red glare " in the United States national anthem, recording the use of the Congreve rocket in 1814 against Fort McHenry and in the battle of Bladensburg. William Congreve Junior also continued the experiments at the Royal Gunpowder Factory where they were supervised with great resourcefulness by James Wright, the Storekeeper. These experiments might almost be taken for granted nowadays and, even though Congreve was a Fellow of the Royal Society by this time, it must be remembered that theoretical chemistry was still in its infancy.

These were the years of the Napoleonic wars and production of the Royal Gunpowder Factory was mounting. By 1809, 20,000 barrels were produced, by 1811 21,000 and by 1813 it had risen to 22,000. Even this rate was increased during the first few months of 1814 but after Wellington's victory every effort was made to cut down and only 10,000 barrels were produced.

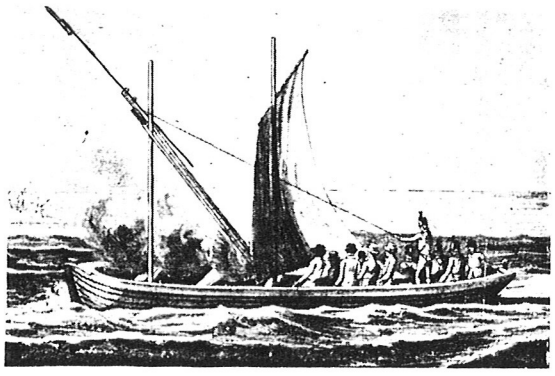
Napoleon's escape from Elba in 1815 resulted in the Mills' production being maintained and nearly 16,000 barrels of powder were made that year. Immediately after Waterloo output was reduced drastically to 4,000 barrels in 1816 and to 1,000 barrels and less in 1819 and the following years.

Employment in the Factory had been 250 in 1813 but by 1822 the figure was down to 34. Waltham Abbey survived this contraction but the other Government factories at Faversham and at Ballincollig in Ireland were sold back into private ownership.

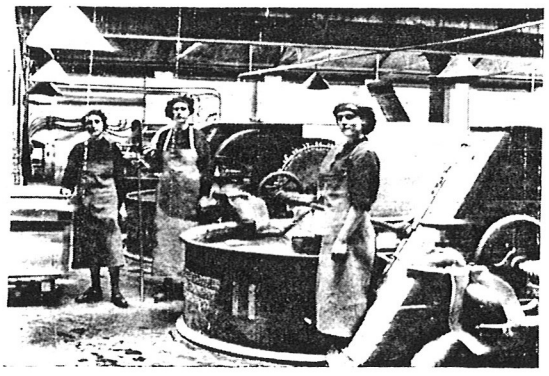
At this stage it would be useful to say something about the manufacture of gunpowder which is an intimate mixture of the three ingredients: saltpetre, sulphur, and charcoal. Saltpetre was imported from India and by the time it reached the Factory it had been refined once. In this state it was known as Grough saltpetre and had to be further refined by recrystallization.

This was achieved by dissolving two tons of the Grough material in 270 gallons of water, boiling the solution, then filtering free of scum and deposits before cooling in long rows of vats. The crystals were stirred and were produced in the form of fine flour.

Sulphur, imported from Sicily, was refined by distillation.



Use of Congreve Rockets from boats.



Guncotton pulping.

About 6 cwt of the sulphur was placed in an iron pot heated by a furnace. The first yellow vapour evolved passed into sublimation domes but when reddish brown fumes appeared they were led into receiving pots. When cooled sufficiently the sulphur was ladled by hand into wooden tubs.

The charcoal was produced from three woods: the alder, willow, and black dogwood. Some of the wood was grown in plantations within the factory, the rest was bought in 3 ft lengths and stored in the woodyard before being converted into charcoal in iron retorts or cylinders heated by a furnace.

The three ingredients were ground separately, sieved and mixed in batches of about 42 lb. When mixed it was known as a " green charge ". The next process, " incorporation ", was the most important step in the manufacture of gunpowder. This was carried out in incorporating mills — the early ones being worked by horses, later by water power and later still by steam. A central water-wheel drove a pair of these mills, which consist of an iron or stone circular bed 7 ft in diameter, around which were driven two stone runners, 18 in. thick and 6 ft in diameter, each weighing about four tons. A 42 lb batch of green charge was spread evenly over the bed, moistened with water, and worked under the millstones for about four hours. The runners have a three-fold action: firstly, crushing, from the sheer weight of them, secondly, grinding from the twisting motion of revolving so large a wheel in so small a circle and lastly mixing which is brought about by the other two. At the end of the running time the charge was taken off as " mill-cake " in a layer of about $\frac{1}{4}$ to $\frac{1}{2}$ in. thick. This mill cake was then broken down to a convenient size for the hydraulic press in which it was pressed into oblong slabs of about $\frac{1}{2}$ in. thick known as " press cake ".

The press cake had then to be broken down into the different grain to sizes required. This was done in the granulating machine, an invention of William Congreve, Junior. The press cake was broken as it passed through the rollers and separated into the required sizes by sieves—large grain for cannon powders and fine grain for rifle powders. Granulation produced dust which had to be removed because if it were left on the surface of the grains, it would quickly absorb moisture from the atmosphere. The dusting was carried out in long cylindrical reels covered with canvas or silk screens which allowed the dust to pass through as they revolved.

After being stoved, or dried, for 24 hours in a building heated by steam pipes, the powder was dusted once more to remove all traces of dust and to impart the final glaze. The gunpowder was then ready for use and was stored in barrels holding 100 lb. The barrels were taken in a powder barge, through the Factory waterways, down the River Lea and then along the Thames to Woolwich.

The detail of these processes is contained in a pamphlet by Major Fraser Baddeley entitled " The Manufacture of Gunpowder, as carried on at the Government Factory, Waltham Abbey ", and published in 1857.

It is significant that this pamphlet could have affected world history. At the beginning of the American Civil War only three powder mills are known to have been in existence in the Southern States. Major George Washington Rains was given the task of supplying the Confederate Army with gunpowder and it is recorded by him that he had the " great good luck " to come by Baddeley's Pamphlet, which draws attention to the importance of very careful purification of the ingredients and describes the process of incorporation—two of the main reasons for the high quality of Waltham Abbey powder. Both Rains himself and the United States Ordnance Manual of 1862 express the opinion that nobody makes better powder than the British.

The one drawback of Baddeley's pamphlet is that, whilst it gives precise details of the processes, it contains no drawings of machinery or equipment, but Major Rains was fortunate in that he was able to employ the services of James Wright, the grandson of the earlier James Wright, the first storekeeper of the Waltham Mills. Of this later James, who had emigrated to Tennessee, Rains wrote: " But one man — Wright — could be found in the Southern States who had seen gunpowder made by an incorporating mill, the only kind that can make it of first quality; he had been a workman at the Waltham Abbey Government Gunpowder Works in England . . . I was much indebted to his knowledge and experience . . . "

But the Royal Gunpowder Factory appeared to have been backing both sides for it is known that Antoine Biderman and his nephew Lammot du Pont, both of the large Northern powder company of Du Pont, paid separate visits to Waltham Abbey *before* the Civil War.

Mention has been made of the accidental explosions referred to by Fuller and the first recorded fatal accident. Although other explosions did occur in the era of private ownership very little is known about them, but from the time that the Government took over the Mills the records of explosions are virtually complete. There is a change of attitude from one of the inevitability of explosions to one of understanding why they took place. In the early years of Government ownership regulations were made tighter and precautions were introduced whenever they were seen to be necessary. Advice was sought from the leading authorities in the country.

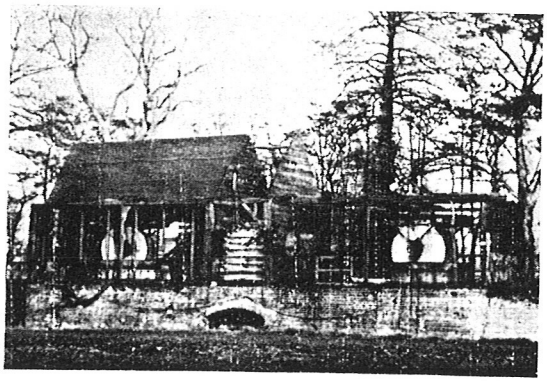
Explosions in the incorporating mill were frequent but usually not serious because the "green" charges had weaker explosive power, and did not damage the machinery. Flimsy walls were soon replaced and the mills were working again after a very short time. It was in the later stages of manufacture that the possibility of a serious explosion was greatest.

The first of these occurred in 1801 when a corning mill blew up killing nine men and four horses. After this incident an approach was made to the Royal Society to suggest the best floor coverings and a visit was made to the mills by a party which included the President, Sir Joseph Banks, Count Rumford and Henry Cavendish. Their report stated that there was no hazard from electrical excitations in the practice of rolling barrels on floors covered with hide nor from the use of silk dusting screens, but recommended the use of painted floor cloth to cover the whole floor.

Another serious explosion destroyed a press house and a corning house in November, 1811, when eight men were killed. A committee was set up to recommend the best construction for the new buildings. A further recommendation was for the use of hydraulic presses, as described earlier, instead of the older screw presses.

With the run down on production following the Napoleonic War there were few accidents but in 1843 yet another press house and corning house exploded killing seven men. On this occasion Michael Faraday was called upon to enquire into the causes of the explosion.

Another step towards safer manufacture was taken in 1858 when Sir William Snow Harris visited the Royal Gunpowder Factory to make recommendations for a system of lightning conductors for all the buildings.



The ruins of the last pair of mills, 1956.

In 1893 after an explosion in a building in which granulated powder was being pressed had caused the loss of nine lives, there was serious public concern. The Press was critical and questions were asked in the House of Commons. The report of the Committee of Enquiry, which included Lord Sandhurst and Sir Frederick Abel, can be said to be the basis of modern safety practice in explosives manufacture, for not only did it indicate the probable causes of the incident, but it discussed at some length the deficiencies of procedures and regulations.

For centuries the entire production of the Factory had been gunpowder, or blackpowder as it was sometimes called, but by the middle of the 19th century there was a growing interest in Europe in two new explosives: guncotton and nitroglycerine.

Guncotton had been made by Schönbein of Basle in 1846 by the action of nitrating acids on cotton, and a plant for its production was set up at Faversham, now once again in private hands.

Unfortunately, a serious explosion destroyed the plant and following explosions elsewhere in Europe little interest was shown in guncotton except in Austria where the processes were improved. So much so that the Austrian Government offered the details to the British Government and Frederick Abel, the War Office Chemist, was instructed to examine these improvements. Abel commenced experimental production at Waltham Abbey in 1863 according to the Austrian recipe. Later, he developed his own process for pulped guncotton which could be compressed into any desired shape suitable for use in mines and torpedoes or for blasting purposes In 1872, he was authorized

to set up a plant to produce 250 tons a year. Eventually this plant proved to be inadequate to meet an ever-increasing demand and a new site on the southern side of Waltham Abbey was acquired.

The Abel guncotton process consisted of raking a charge of 1¼lb of purified cotton waste into a bath of nitrating acids and allowing the charge to remain for eight minutes. The charge, now weighing about 15 lb, was removed to be cooled for 12 hours before having most of the acid removed in centrifugal machines. The guncotton was then immersed in a tank of water which was drained and filled about six times to wash away the acid after which it was boiled and pulped in beating machines. The very finely divided guncotton was then run into moulds, strained, and consolidated under hydraulic pressure.

In 1872 Colonel Younghusband, the Superintendent of the Royal Gunpowder Factory, wrote: "A great future may fairly be anticipated for Guncotton. As regards safety in manufacture, storage, transport and use, it is unrivalled by any other explosive, while in power it has not been surpassed by any substance with which it has been compared."

Nitroglycerine, a liquid explosive, first made by Sobrero in 1847 by the action of nitrating acids on glycerine, was the subject of much experimentation by Alfred Nobel but after several accidental explosions its importation and manufacture were prohibited by several Governments. Nobel's experiments were directed towards making nitroglycerine more easily handled than it was in its liquid state and one product he prepared was a mixture of nitroglycerine, soluble nitrocellulose and camphor. At this point Abel took up the story for the Government and made a mixture of nitroglycerine, guncotton and mineral jelly which gave promising results. This mixture which could be made into a charge of cords or rods received the name cordite. In 1891 a nitroglycerine plant was erected at the Royal Gunpowder Factory together with the necessary buildings for the making of cordite. A second plant was built shortly afterwards and during the Boer War the production of nitroglycerine was about 18½ tons per week.

Cordite was prepared by first mixing nitroglycerine with unpressed guncotton and then incorporating the mineral jelly with the necessary solvent, acetone, in machines of the type used by bakers for mixing dough. After the incorporation had been completed the mixture was subjected to pressure and extruded into cords of the required diameter which were placed on reels and sent to the drying house where the acetone was expelled.

Modifications to the original processes have been introduced for all three products, guncotton, nitroglycerine and cordite, and for cordite there have been variations in the ingredients. Production of cordite was about 40 tons per week in 1907 but at the height of the 1914 - 18 war it was about 64 tons per week.

The years between the wars were lean years for the Factory but even with a depleted staff research continued and improvements ensued, including the introduction of nitroguanidine, or picrite, into the cordite to lessen flash and smoke. Also a solventless process, which had the advantages of being safer and eliminating the drying stage, was introduced.

Although Colonel Younghusband had spoken in 1873 of the potentialities of guncotton as an explosive in such glowing terms this did not prevent the search for other explosives for shells and demolition purposes. Abel comes back on to the scene again for it was he who suggested "picric powder", a mixture of saltpetre and ammonium picrate, and arranged for its manufacture at Waltham Abbey. It was being made up to the 1914 - 18 war but was being replaced by then by tetryl as a booster explosive, when this came into production.

TNT, probably the most widely known high explosive, is made from the action of nitrating acids on toluene, but, although it came into use in the British Services in the First World War, it was not until 1933 that it was made at the Royal Gunpowder Factory.

At this time the Factory was a production unit, whilst at the Research Department at Woolwich, work was being carried out to improve old processes and to introduce new explosives. One line of research led to RDX, which stands for Research Department Explosive, and plant for its production was set up at Waltham Abbey in 1938. RDX, or cyclotrimethylene trinitramine, has been called *the* high explosive of World War II. It is therefore significant that for the first years of the war the Waltham plant was this country's only source of production.

As the war continued so other Ordnance Factories took over the production of the various explosives and the contribution of the Royal Gunpowder Factory decreased. In the winter of 1940 - 41 an enemy land mine put out

of action the last of the powder mills and the production of gunpowder which had given the factory its name was not resumed. Towards the end of 1943 most of the plant was being run down and on the 28th July, 1945, the Royal Gunpowder Factory was formally closed after nearly 160 years.

However in 1944 the factory site had been surveyed and a report submitted recommending the use of the site as an Experimental Station of the Armament Research Department at Woolwich. On the 1st October, 1946 there came into being the Chemical Research and Development Department with a nucleus of scientific staff drawn from the explosives and propellant branches of the Armament Research Department. Thus the link with Woolwich, which had begun with Sir William Congreve, was continued.

In 1947 the name of the Department was changed to the one by which it is known today, the Explosives Research and Development Establishment. Conversion of the old factory site to the new Establishment was an immense task but gradually rehabilitation proceeded. Now ERDE exists as a centre for chemical research concerned with rocket propellants, explosives, initiatory and pyrotechnic compositions and for their development to meet the present and future requirements of the Services. With similar objectives investigations are also carried out with polymeric materials and high-strength reinforcement with short or chopped fibres.

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The early history of the Powder Mills is obscured by a shadow which obscures all too many subjects of historical interest: this is the lack of authoritative records and it is from under shadows such as this that legends grow.

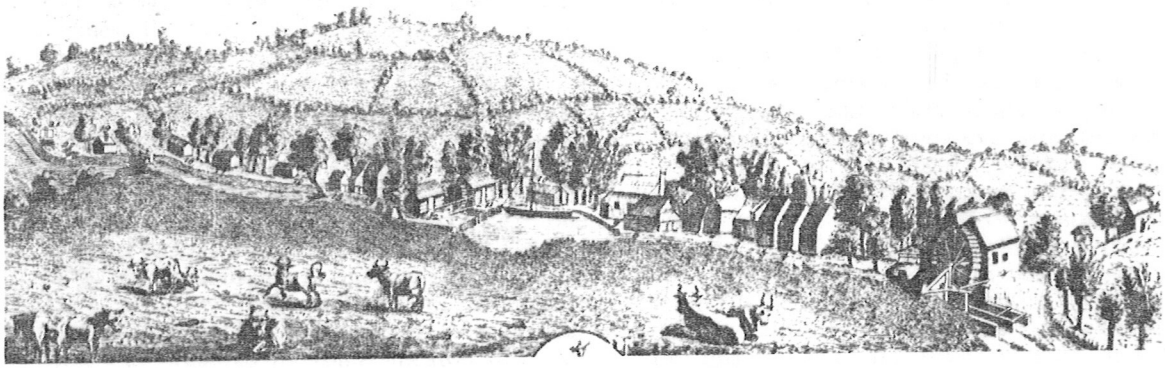
One legend is that some of the gunpowder used at the Battle of Crecy in 1346—the first time that gunpowder was used by English soldiers in warfare—came from Waltham Abbey where it was made by the monks. There is no evidence for this but it is known from the accounts of the Clerk of the Great Wardrobe that saltpetre and sulphur were supplied to the King for his guns.

The Gunpowder Plot conspirators.

Another legend suggests that the Spanish Armada was defeated with the aid of gunpowder produced at Waltham Abbey.

Such was the state of the country's international relations in the third quarter of the 16th century and such was the scarcity of powder that Queen Elizabeth's ministers were advised that 'the Quene's Majestie should do well to macke 4 or 6 mills for the making of powder'. Here the question to be answered is 'Were the Waltham Abbey Mills in operation at this time?'—for it goes without saying that if they were their entire production would have been used to support the war effort.

Yet another legend is that Guy Fawkes and his fellow conspirators purchased their gunpowder from the mills at Waltham. Once again there is no documentary evidence—in view of the circumstances this is hardly surprising but there is circumstantial evidence to support the idea. At this time Father Henry Garnett, the Superior of the English Jesuits, was living under the assumed name of Mr. Meaze, only two or three miles away at White Webbs, where the conspirators were frequent visitors, and where they were only a few days before the 5th November, 1605. It is known from their confessions that there were at least three separate purchases of powder over several months and that it was stored in Catesby's house in Lambeth before being taken to the house rented by Percy which was next to the House of Lords. As White Webbs was in the sporting area of Enfield Chase powder could have been purchased without suspicion and then transported safely by water all the way from Waltham to Lambeth.



The earliest illustration of the Waltham Abbey Powder Mills, 1735.

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It was unusual for the cause of death to be given in the entries at this time so the tragedy must have been viewed with some concern especially so as the Plague was at its height.

Although by now the existence of the Mills had been established little is known of the owners before 27th May, 1672, when it was presented at a Court Baron that a powder mill had been erected near Hook's Marsh Bridge by one Ralph Hudson. The mill was said to be a nuisance and danger to the inhabitants of Upshire and Hallefield as they passed with their cattle. Apparently nothing was done to remove the mill and a year later Hudson was fined £10 for interfering with water supplies. There was trouble again later over water rights. In a lawsuit in 1732 brought by Charles Wake Jones against Philippa Walton, the widow of John Walton, the water intake of the mills had to be reduced. During the proceedings one of the witnesses stated that the waterways had been maintained by Mr. Hudson and since by Mr. Walton until his death and thereafter by his Widow.

By 1735 the Mills were owned by a second John Walton and were described in that year by John Farmer in his history of Waltham Abbey as being " esteemed the largest and compleatest works in Great Britain ", and although no details of manufacturing processes are given in the text it is known that the powder mills were worked by horses and that water power was being used for the corning and glazing engines. By 1770 the use of water power had spread to the powder mills. A passage in Peter Muilman's " New and Complete History of Essex " published that year, refers to " several curious gunpowder 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 Bourchier Walton, Esq." The design for the new powder mills was prepared by John Smeaton who was the leading authority on water mills.

Before this time the Government had realised the importance of controlling much of the powder production of the country and had in 1760 purchased the mills at Faversham in Kent from Thomas Pryce. But in 1783, following statements that the private merchants could make better powder than the Government and that they could make it more cheaply, the Prime Minister, Pitt, was about to recommend the sale of the Faversham Mills. Representations were then made through the Duke of Richmond, Master General of Ordnance, by Major William Congreve, who was Deputy Comptroller of the Royal Laboratory at Woolwich, to show that Government manufacture did, in fact, yield a profit, and that, if this profit were properly expended in improving the mills, it would be possible to make a powder which was more powerful and more durable than had ever been made previously. Fortunately and justifiably—as shown later—he received a sympathetic hearing and not only were the Faversham Mills reprieved but negotiations were opened with yet another John Walton for the purchase of the Waltham Abbey mills. On the 11th October, 1787, the minutes of the Honourable Board of Ordnance record the receipt of a letter from Walton expressing his willingness to dispose of the powder mills for £10,000. His offer was accepted and by the 22nd October, Major Congreve had taken over. Congreve was active even before the mills had been taken over officially and had eployed Daniel Cornish, a carpenter, to recruit the best of the millmen and labourers who had been working for Walton. These men were to be paid nine shillings a week and Cornish 15 shillings a week. Other men were drawn from Faversham and on the 18th November, 1787, James Wright was appointed Storekeeper at £150 per annum to be in charge of the new Royal Powder Mills under Major Congreve. The mills under John Walton had fallen into neglect and although the purchase price was £10,000 another £35,000 was spent in improvements and enlargements. All this took time and although Congreve sent processing instructions to the Master Worker, William Newton, in July 1788 directing him to use the proportions of ingredients of gunpowder of saltpetre 75 lb, sulphur 10 lb, and charcoal 15 lb it appears that no powder was made until 9th February, 1789—only to be followed on the 12th February by the first explosion. Fortunately this did little damage and the mill where the incident occurred was working the next day. Minor explosions were frequent and this fact was recognised insofar as the buildings were built of light, easily-replaced materials. Congreve was also responsible for the Faversham Mills and it was from there that he issued the first set of gunpowder factory rules. These rules, covering safety and discipline, coupled with processes designed to produce a uniform product, form the basis of the improvement in quality and cost of the powder from the Royal Mills. Congreve, in 1811, was able to justify his actions in 1783 in keeping the Faversham Mills and the purchase of the Royal Gunpowder Factory by publishing a statement of the savings arising from the manufacture of gunpowder at the Royal Mills. Between 1789 and 1810 407,408 barrels of powder each of 100 lb. were produced at Waltham Abbey and Faversham. The savings to the Government, being the difference between the Merchants' price and actual cost, amounted to £288,357 6s. 0¼d. Taking the Royal Gunpowder Factory alone, even after deducting the £45,000 spent on the mills, a saving of over £50,000 was made.

Experiments were made at this time both to improve the quality of the product and, once it had been improved, to maintain uniformity of this quality. This was a most important consideration, for when used in service action one batch of gunpowder should provide a bullet or shell with the same range as the next batch. To maintain this uniformity it was essential

to use pure ingredients and the greatest attention was paid to the refining processes and to the processes designed to give a stable and lasting powder.

Congreve was able to demonstrate the improvements in the powder by trials carried out on Marlborough Downs where 10-inch shells were fired by 9 lb lots of gunpowder from different makers including six private merchants. That from the Royal Gunpowder Factory had the greatest range of 4,430 yards exceeding its closest private rival by 160 yards and most of the others by over 500 yards.

General Congreve, as he then was, was created Baronet in 1812. His son, another William Congreve, followed his father's footsteps very closely, entering the Artillery, joining the Royal Laboratory and in 1814 succeeding his father as 2nd Baronet and as Comptroller of the Royal Laboratory. It was the son who in 1805 developed the famous Congreve rocket for military purposes. This gunpowder-propelled missile had terror and incendiary value as its qualities rather than accuracy but it is responsible for the words "the rockets' red glare" in the United States national anthem, recording the use of the Congreve rocket in 1814 against Fort McHenry and in the battle of Bladensburg. William Congreve Junior also continued the experiments at the Royal Gunpowder Factory where they were supervised with great resourcefulness by James Wright, the Storekeeper. These experiments might almost be taken for granted nowadays and, even though Congreve was a Fellow of the Royal Society by this time, it must be remembered that theoretical chemistry was still in its infancy.

These were the years of the Napoleonic wars and production of the Royal Gunpowder Factory was mounting. By 1809, 20,000 barrels were produced, by 1811 21,000 and by 1813 it had risen to 22,000. Even this rate was increased during the first few months of 1814 but after Wellington's victory every effort was made to cut down and only 10,000 barrels were produced.

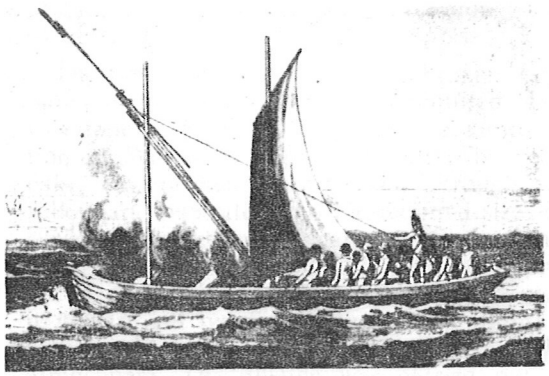
Napoleon's escape from Elba in 1815 resulted in the Mills' production being maintained and nearly 16,000 barrels of powder were made that year. Immediately after Waterloo output was reduced drastically to 4,000 barrels in 1816 and to 1,000 barrels and less in 1819 and the following years.

Employment in the Factory had been 250 in 1813 but by 1822 the figure was down to 34. Waltham Abbey survived this contraction but the other Government factories at Faversham and at Ballincollig in Ireland were sold back into private ownership.

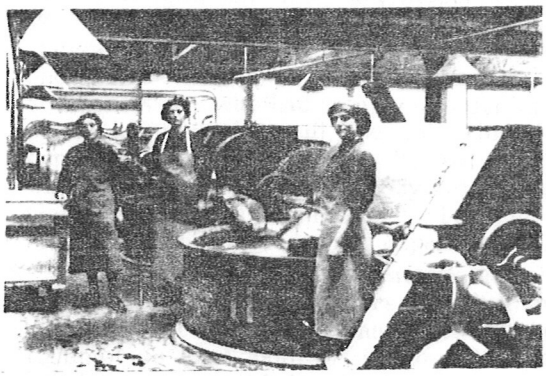
At this stage it would be useful to say something about the manufacture of gunpowder which is an intimate mixture of the three ingredients: saltpetre, sulphur, and charcoal. Saltpetre was imported from India and by the time it reached the Factory it had been refined once. In this state it was known as Grough saltpetre and had to be further refined by recrystallization.

This was achieved by dissolving two tons of the Grough material in 270 gallons of water, boiling the solution, then filtering free of scum and deposits before cooling in long rows of vats. The crystals were stirred and were produced in the form of fine flour.

Sulphur, imported from Sicily, was refined by distillation.



Use of Congreve Rockets from boats.



Guncotton pulping.

About 6 cwt of the sulphur was placed in an iron pot heated by a furnace. The first yellow vapour evolved passed into sublimation domes but when reddish brown fumes appeared they were led into receiving pots. When cooled sufficiently the sulphur was ladled by hand into wooden tubs.

The charcoal was produced from three woods: the alder, willow, and black dogwood. Some of the wood was grown in plantations within the factory, the rest was bought in 3 ft lengths and stored in the woodyard before being converted into charcoal in iron retorts or cylinders heated by a furnace.

The three ingredients were ground separately, sieved and mixed in batches of about 42 lb. When mixed it was known as a " green charge ". The next process, " incorporation ", was the most important step in the manufacture of gunpowder. This was carried out in incorporating mills — the early ones being worked by horses, later by water power and later still by steam. A central water-wheel drove a pair of these mills, which consist of an iron or stone circular bed 7 ft in diameter, around which were driven two stone runners, 18 in. thick and 6 ft in diameter, each weighing about four tons. A 42 lb batch of green charge was spread evenly over the bed, moistened with water, and worked under the millstones for about four hours. The runners have a three-fold action: firstly, crushing, from the sheer weight of them, secondly, grinding from the twisting motion of revolving so large a wheel in so small a circle and lastly mixing which is brought about by the other two. At the end of the running time the charge was taken off as " mill-cake " in a layer of about $\frac{1}{4}$ to $\frac{1}{2}$ in. thick. This mill cake was then broken down to a convenient size for the hydraulic press in which it was pressed into oblong slabs of about $\frac{1}{2}$ in. thick known as " press cake ".

The press cake had then to be broken down into the different grain to sizes required. This was done in the granulating machine, an invention of William Congreve, Junior. The press cake was broken as it passed through the rollers and separated into the required sizes by sieves—large grain for cannon powders and fine grain for rifle powders. Granulation produced dust which had to be removed because if it were left on the surface of the grains, it would quickly absorb moisture from the atmosphere. The dusting was carried out in long cylindrical reels covered with canvas or silk screens which allowed the dust to pass through as they revolved.

After being stoved, or dried, for 24 hours in a building heated by steam pipes, the powder was dusted once more to remove all traces of dust and to impart the final glaze. The gunpowder was then ready for use and was stored in barrels holding 100 lb. The barrels were taken in a powder barge, through the Factory waterways, down the River Lea and then along the Thames to Woolwich.

The detail of these processes is contained in a pamphlet by Major Fraser Baddeley entitled " The Manufacture of Gunpowder, as carried on at the Government Factory, Waltham Abbey ", and published in 1857.

It is significant that this pamphlet could have affected world history. At the beginning of the American Civil War only three powder mills are known to have been in existence in the Southern States. Major George Washington Rains was given the task of supplying the Confederate Army with gunpowder and it is recorded by him that he had the " great good luck " to come by Baddeley's Pamphlet, which draws attention to the importance of very careful purification of the ingredients and describes the process of incorporation—two of the main reasons for the high quality of Waltham Abbey powder. Both Rains himself and the United States Ordnance Manual of 1862 express the opinion that nobody makes better powder than the British.

The one drawback of Baddeley's pamphlet is that, whilst it gives precise details of the processes, it contains no drawings of machinery or equipment, but Major Rains was fortunate in that he was able to employ the services of James Wright, the grandson of the earlier James Wright, the first storekeeper of the Waltham Mills. Of this later James, who had emigrated to Tennessee, Rains wrote: " But one man — Wright — could be found in the Southern States who had seen gunpowder made by an incorporating mill, the only kind that can make it of first quality; he had been a workman at the Waltham Abbey Government Gunpowder Works in England . . . I was much indebted to his knowledge and experience . . . "

But the Royal Gunpowder Factory appeared to have been backing both sides for it is known that Antoine Biderman and his nephew Lammot du Pont, both of the large Northern powder company of Du Pont, paid separate visits to Waltham Abbey *before* the Civil War.

Mention has been made of the accidental explosions referred to by Fuller and the first recorded fatal accident. Although other explosions did occur in the era of private ownership very little is known about them, but from the time that the Government took over the Mills the records of explosions are virtually complete. There is a change of attitude from one of the inevitability of explosions to one of understanding why they took place. In the early years of Government ownership regulations were made tighter and precautions were introduced whenever they were seen to be necessary. Advice was sought from the leading authorities in the country.

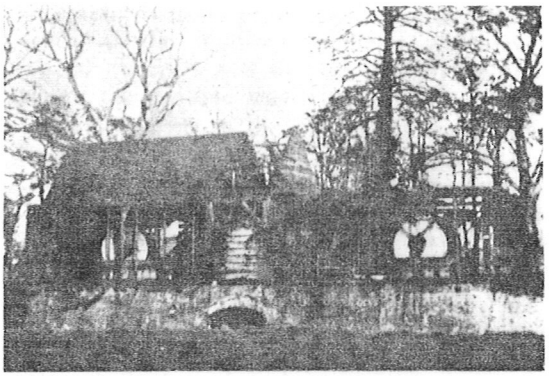
Explosions in the incorporating mill were frequent but usually not serious because the "green" charges had weaker explosive power, and did not damage the machinery. Flimsy walls were soon replaced and the mills were working again after a very short time. It was in the later stages of manufacture that the possibility of a serious explosion was greatest.

The first of these occurred in 1801 when a corning mill blew up killing nine men and four horses. After this incident an approach was made to the Royal Society to suggest the best floor coverings and a visit was made to the mills by a party which included the President, Sir Joseph Banks, Count Rumford and Henry Cavendish. Their report stated that there was no hazard from electrical excitations in the practice of rolling barrels on floors covered with hide nor from the use of silk dusting screens, but recommended the use of painted floor cloth to cover the whole floor.

Another serious explosion destroyed a press house and a corning house in November, 1811, when eight men were killed. A committee was set up to recommend the best construction for the new buildings. A further recommendation was for the use of hydraulic presses, as described earlier, instead of the older screw presses.

With the run down on production following the Napoleonic War there were few accidents but in 1843 yet another press house and corning house exploded killing seven men. On this occasion Michael Faraday was called upon to enquire into the causes of the explosion.

Another step towards safer manufacture was taken in 1858 when Sir William Snow Harris visited the Royal Gunpowder Factory to make recommendations for a system of lightning conductors for all the buildings.



The ruins of the last pair of mills, 1956.

In 1893 after an explosion in a building in which granulated powder was being pressed had caused the loss of nine lives, there was serious public concern. The Press was critical and questions were asked in the House of Commons. The report of the Committee of Enquiry, which included Lord Sandhurst and Sir Frederick Abel, can be said to be the basis of modern safety practice in explosives manufacture, for not only did it indicate the probable causes of the incident, but it discussed at some length the deficiencies of procedures and regulations.

For centuries the entire production of the Factory had been gunpowder, or blackpowder as it was sometimes called, but by the middle of the 19th century there was a growing interest in Europe in two new explosives: guncotton and nitroglycerine.

Guncotton had been made by Schönbein of Basle in 1846 by the action of nitrating acids on cotton, and a plant for its production was set up at Faversham, now once again in private hands.

Unfortunately, a serious explosion destroyed the plant and following explosions elsewhere in Europe little interest was shown in guncotton except in Austria where the processes were improved. So much so that the Austrian Government offered the details to the British Government and Frederick Abel, the War Office Chemist, was instructed to examine these improvements. Abel commenced experimental production at Waltham Abbey in 1863 according to the Austrian recipe. Later, he developed his own process for pulped guncotton which could be compressed into any desired shape suitable for use in mines and torpedoes or for blasting purposes In 1872, he was authorized

to set up a plant to produce 250 tons a year. Eventually this plant proved to be inadequate to meet an ever-increasing demand and a new site on the southern side of Waltham Abbey was acquired.

The Abel guncotton process consisted of raking a charge of 1¼lb of purified cotton waste into a bath of nitrating acids and allowing the charge to remain for eight minutes. The charge, now weighing about 15 lb, was removed to be cooled for 12 hours before having most of the acid removed in centrifugal machines. The guncotton was then immersed in a tank of water which was drained and filled about six times to wash away the acid after which it was boiled and pulped in beating machines. The very finely divided guncotton was then run into moulds, strained, and consolidated under hydraulic pressure.

In 1872 Colonel Younghusband, the Superintendent of the Royal Gunpowder Factory, wrote: "A great future may fairly be anticipated for Guncotton. As regards safety in manufacture, storage, transport and use, it is unrivalled by any other explosive, while in power it has not been surpassed by any substance with which it has been compared."

Nitroglycerine, a liquid explosive, first made by Sobrero in 1847 by the action of nitrating acids on glycerine, was the subject of much experimentation by Alfred Nobel but after several accidental explosions its importation and manufacture were prohibited by several Governments. Nobel's experiments were directed towards making nitroglycerine more easily handled than it was in its liquid state and one product he prepared was a mixture of nitroglycerine, soluble nitrocellulose and camphor. At this point Abel took up the story for the Government and made a mixture of nitroglycerine, guncotton and mineral jelly which gave promising results. This mixture which could be made into a charge of cords or rods received the name cordite. In 1891 a nitroglycerine plant was erected at the Royal Gunpowder Factory together with the necessary buildings for the making of cordite. A second plant was built shortly afterwards and during the Boer War the production of nitroglycerine was about 18½ tons per week.

Cordite was prepared by first mixing nitroglycerine with unpressed guncotton and then incorporating the mineral jelly with the necessary solvent, acetone, in machines of the type used by bakers for mixing dough. After the incorporation had been completed the mixture was subjected to pressure and extruded into cords of the required diameter which were placed on reels and sent to the drying house where the acetone was expelled.

Modifications to the original processes have been introduced for all three products, guncotton, nitroglycerine and cordite, and for cordite there have been variations in the ingredients. Production of cordite was about 40 tons per week in 1907 but at the height of the 1914 - 18 war it was about 64 tons per week.

The years between the wars were lean years for the Factory but even with a depleted staff research continued and improvements ensued, including the introduction of nitroguanidine, or picrite, into the cordite to lessen flash and smoke. Also a solventless process, which had the advantages of being safer and eliminating the drying stage, was introduced.

Although Colonel Younghusband had spoken in 1873 of the potentialities of guncotton as an explosive in such glowing terms this did not prevent the search for other explosives for shells and demolition purposes. Abel comes back on to the scene again for it was he who suggested " picric powder ", a mixture of saltpetre and ammonium picrate, and arranged for its manufacture at Waltham Abbey. It was being made up to the 1914 - 18 war but was being replaced by then by tetryl as a booster explosive, when this came into production.

TNT, probably the most widely known high explosive, is made from the action of nitrating acids on toluene, but, although it came into use in the British Services in the First World War, it was not until 1933 that it was made at the Royal Gunpowder Factory.

At this time the Factory was a production unit, whilst at the Research Department at Woolwich, work was being carried out to improve old processes and to introduce new explosives. One line of research led to RDX, which stands for Research Department Explosive, and plant for its production was set up at Waltham Abbey in 1938. RDX, or cyclotrimethylene trinitramine, has been called *the* high explosive of World War II. It is therefore significant that for the first years of the war the Waltham plant was this country's only source of production.

As the war continued so other Ordnance Factories took over the production of the various explosives and the contribution of the Royal Gunpowder Factory decreased. In the winter of 1940 - 41 an enemy land mine put out

of action the last of the powder mills and the production of gunpowder which had given the factory its name was not resumed. Towards the end of 1943 most of the plant was being run down and on the 28th July, 1945, the Royal Gunpowder Factory was formally closed after nearly 160 years.

However in 1944 the factory site had been surveyed and a report submitted recommending the use of the site as an Experimental Station of the Armament Research Department at Woolwich. On the 1st October, 1946 there came into being the Chemical Research and Development Department with a nucleus of scientific staff drawn from the explosives and propellant branches of the Armament Research Department. Thus the link with Woolwich, which had begun with Sir William Congreve, was continued.

In 1947 the name of the Department was changed to the one by which it is known today, the Explosives Research and Development Establishment. Conversion of the old factory site to the new Establishment was an immense task but gradually rehabilitation proceeded. Now ERDE exists as a centre for chemical research concerned with rocket propellants, explosives, initiatory and pyrotechnic compositions and for their development to meet the present and future requirements of the Services. With similar objectives investigations are also carried out with polymeric materials and high-strength reinforcement with short or chopped fibres.