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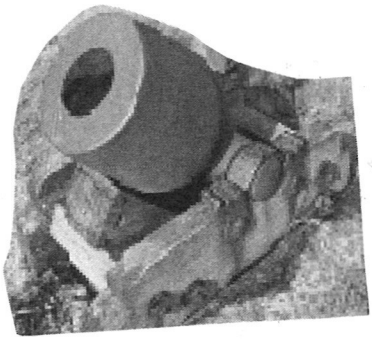
MORTAR EPROUVETTE



[ALSO ON FRONT COVER OF THE GUNPOWDER INDUSTRY WASC 1468 WAI]

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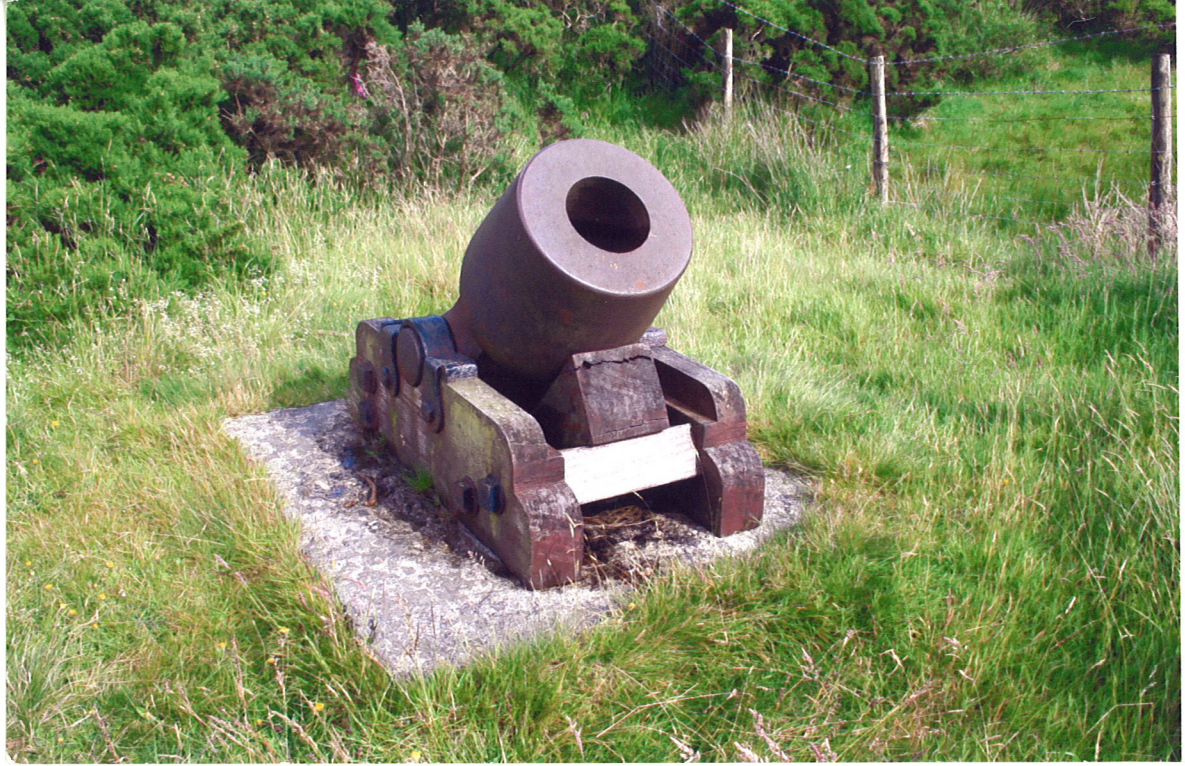

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The Gunpowder Industry

Gunpowder is a mixture of saltpetre, charcoal and sulphur. Until the middle of the nineteenth century it was the only explosive available either for firing guns or for blasting in mines and quarries. This book outlines the history of its manufacture, from the development of gunpowder as a propellant in the fourteenth century, through its adoption as a blasting agent in the seventeenth, to the introduction of improved varieties shortly before its eclipse by high explosives. Methods of obtaining saltpetre, the major problem facing the early powder makers, are described together with the various stages of processing and combining the ingredients and producing the final black powder. Because of the dangerous nature of their work gunpowder mills were typically situated on spacious, well wooded sites in rural seclusion. Many are now obliterated but some substantial remains can still be identified and a few structures have been preserved.

Glenys Crocker lives at Guildford in Surrey, near the site of the Chilworth powder mills, which were started by the East India Company in 1625. She was born and brought up in Lancashire, read geography at Sheffield University and formerly worked as a librarian. She has written booklets on the history of the Basingstoke Canal and Chilworth gunpowder and has collaborated with her husband, Alan, in writing a research volume on an early mill site at Godalming. They have also been involved in setting up a national Gunpowder Mills Study Group and are trustees of the Godalming Water Turbine Trust and active members of the Surrey Industrial History Group.

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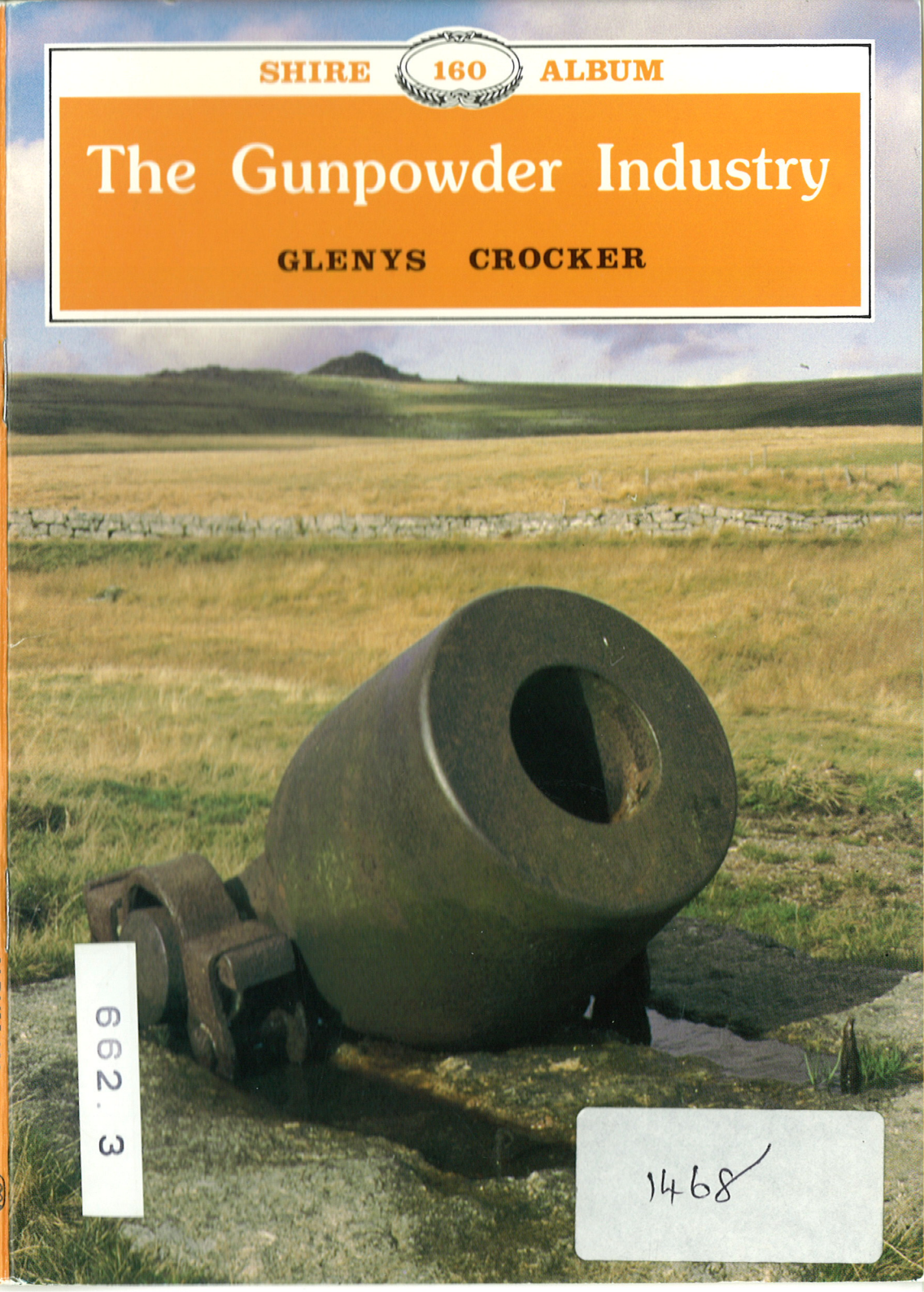
The Gunpowder Industry

GLENYS CROCKER



Gunpowder workers at Chilworth, Surrey, about 1913. The works operated around the clock and the men worked twelve hour shifts. They were searched on arrival and were issued with working clothes without pockets to guard against dangerous articles being brought on site. The tramlines are part of five miles (8 km) of 2 foot 7½ inch (800 mm) gauge track which, together with punts on the millstream, provided transport around the works.

THE GUNPOWDER INDUSTRY

Glenys Crocker

Shire Publications Ltd

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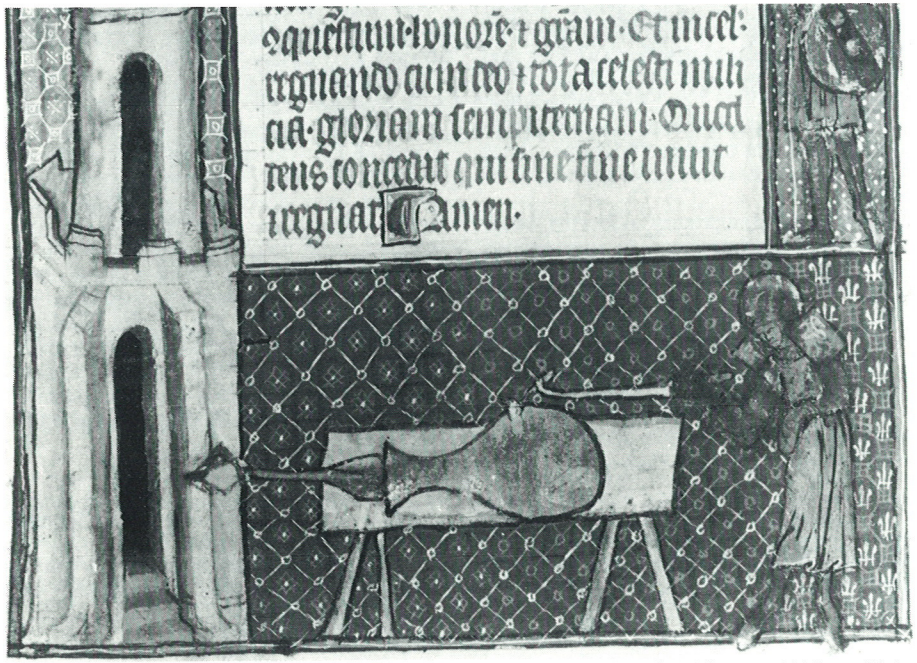
COVER: *A mortar for testing gunpowder at Powdermills, Two Bridges, Devon, where blasting powder was made in the nineteenth century. The mortar has an 8 inch (200 mm) bore.*

BELOW: *A typical street name in the vicinity of a gunpowder works. This example is near the site of the former Hounslow mills in west London.*



The earliest representation of a gun, from the manuscript of Walter de Milemete, 1326, at Christ Church, Oxford (MS 92, fol.70v).

THE INVENTION OF GUNPOWDER

Gunpowder is a mixture of saltpetre, charcoal and sulphur, usually in the proportions of 75:15:10. The saltpetre, or potassium nitrate, supplies oxygen and the other constituents provide fuel, the sulphur serving to inflame at a relatively low temperature. The formula has varied and in general the earlier compositions contained less nitrate.

The early developments took place in China, where deflagrating mixtures of the three ingredients were known to alchemists by the ninth century AD. The first known written formula appeared in the *Wu Ching Tsung Yao*, a treatise on military techniques which was completed in 1044. By that time the Chinese were using saltpetre mixtures of low nitrate content in simple bombs and grenades and in flame throwers made from hollow stems of bamboo. The next step was to shoot projectiles, such as fragments of metal and arrows, from a tube and this was followed in about 1280 by the true gun, with a metal barrel and a projectile which closely fitted the muzzle.

The West had a wide range of incendiary devices which required atmospheric oxygen in which to burn, including the distilled petroleum product known as 'Greek fire', which was introduced in Byzantium in the seventh century AD. The use of saltpetre represented a completely different development, which was introduced to Europe from China via the Arab world in the first half of the thirteenth century.

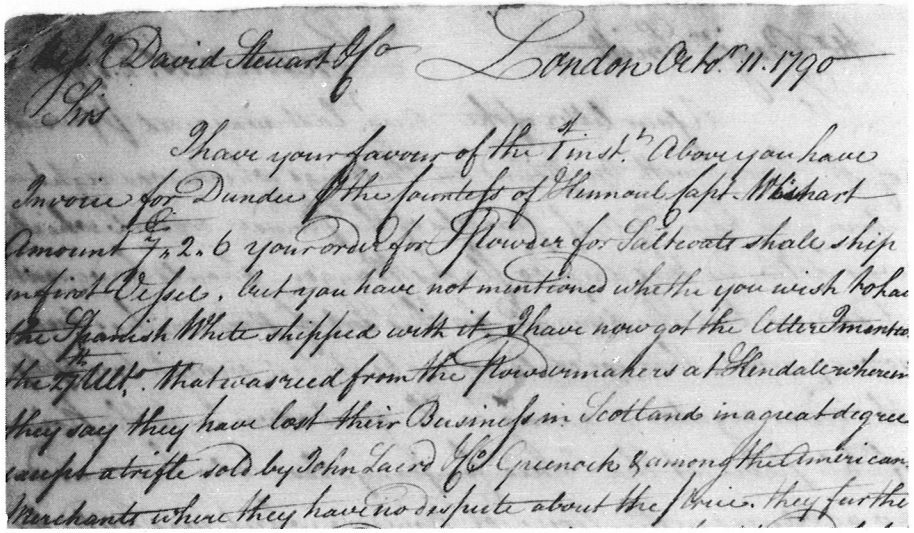
A method of purifying saltpetre was

solution and the resulting liquor was boiled down and allowed to cool so that crystals of saltpetre precipitated.

Until the East India Company established a steady import trade in Indian saltpetre in the second half of the seventeenth century, the collection of sufficient manure presented a perennial problem. Saltpetre men were therefore appointed who had the right to enter and dig in buildings such as dovehouses and stables. Under James I a system of weekly quotas was introduced and, although provision was made for the repair of damage and exemption of inhabited dwellings, in practice the efforts of the collectors to fulfil their obligations resulted in many grievances. When the import trade with the East developed it was dominated by England and the Netherlands and in other countries the burden of collection remained. In France, for example the *sâlpetriers* had extensive rights, which continued to cause great resentment until the revolution of 1789.

In the nineteenth century a method was developed, using potassium chloride, of manufacturing potassium nitrate from sodium nitrate or Chile saltpetre, which was readily available from South America and was cheaper than the Indian variety.

Part of a letter from William Tinkler, powder maker, of Chilworth, Surrey, to a customer in Scotland, 1790, from a document in the Guildford Muniment Room (132/1) '...[Above you have] Invoice for Dundee ff the Countess of Kennoul Capt Wishart Amount £7-2-6 your order for Powder for Saltcoats shall ship in first Vessel. but you have not mentioned whether you wish to have the Spanish White shipped with it. I have now got the letter I mentioned the 27th Ult that was recd from the Powdermakers at Kendale wherein they say they have lost their Business in Scotland in a great degree except a trifle sold by John Laird & Co Greenock & among the Americans Merchants where they have no dispute about the price ...' Orders were supplied from the firm's central magazine at Barking Creek on the Thames estuary. 'Spanish White' was a form of talc used for cleaning. Competition was increasing in the late eighteenth century as new mills were being set up in the north of England and Scotland. Prices were agreed by the powdermakers after the East India Company's sale of saltpetre in March and September and there had been a complaint about underselling.


David Stewart Esqr London Octr 11. 1790

Sir

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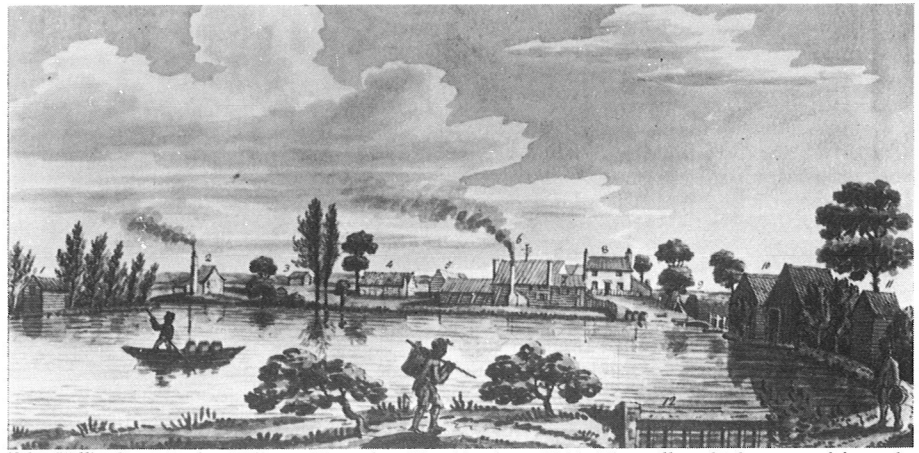


'Mr. Hill's Gunpowder Mills on Hounslow Heath', about 1800. The mills, which operated from the seventeenth century until 1926, were situated on the river Crane in the area occupied by the modern Crane Park in west London. The firm of Curtis's and Harvey, which took over many factories throughout Britain in the course of the nineteenth century, was established at the site in 1820. The mills in the illustration are water powered and the chimneys are associated with drying kilns and saltpetre refining.

HISTORY OF THE GUNPOWDER INDUSTRY

The first recorded use of gunpowder by English soldiers was at the battle of Crecy in 1346, during the Hundred Years War with France, and accounts from the Tower of London show that powder was by then being made in England.

The early makers did not have sophisticated plant but made relatively small quantities of powder by hand with a pestle and mortar. Much of the manufacture was carried out by gunners in the arsenals and some powder was made in the field as it was needed because the early product tended to separate into its constituent ingredients during transit.

Water-driven powder mills are known in Britain from the sixteenth century onwards. One existed on the Thames at Rotherhithe by 1543 but there is a lack of firm evidence for other early sites. Several were probably built after 1560 for in that year the government was advised that 'four or six' were needed and in 1561 instructions for making saltpetre were purchased.

The supply of powder was, however, very inadequate when the Spanish Armada attempted to invade England in 1588. It was therefore decided to introduce a proper system of contracting with manufacturers and, beginning in 1589, certain makers were licensed by royal letters patent. The Evelyn family of Tolworth and later of Godstone and Wotton in Surrey then began a long period of prominence in the industry, as holders of appointments under Elizabeth I and of the monopoly introduced by her successor. In 1621 James I appointed the Lords of the Admiralty as Commissioners for Saltpetre and Gunpowder. The kingdom was divided into districts for the collection of saltpetre and a series of three-year contracts was made with John Evelyn to manufacture gunpowder. The contract of 1621 was for 120 lasts, of 144 tons, annually, to be delivered to the Tower of London, which held the main gunpowder store. This quantity was doubled in the contract of 1624. Two-thirds of the powder was for the King's stores and the rest was assigned to merchant seamen and other private subjects.

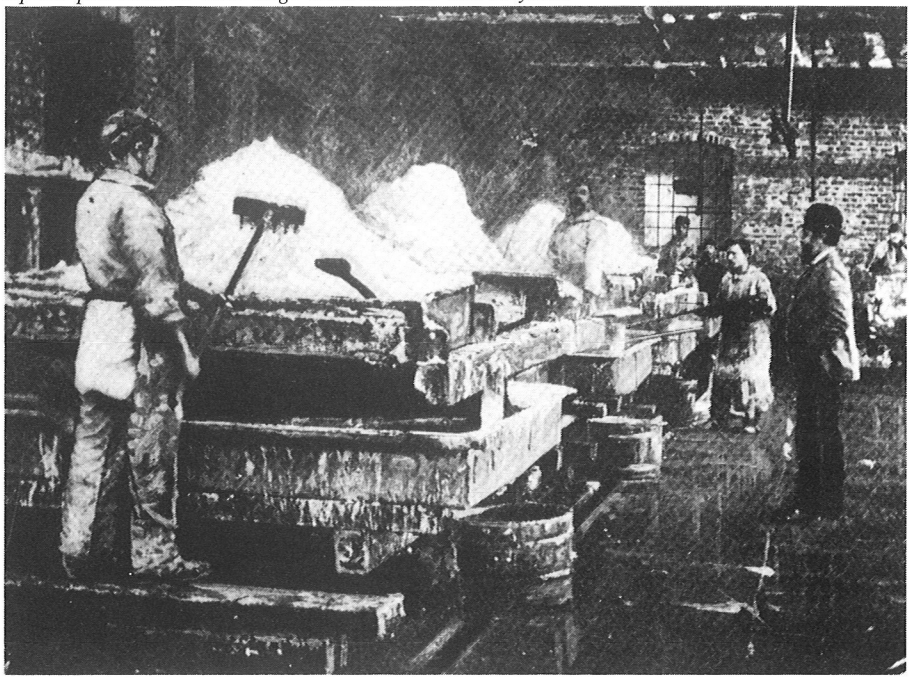
Although the industry was in principle a monopoly, several other factories were operating, some under licence. Illicit powder making was carried on in Southwark and Lambeth, in Sussex, Devon and

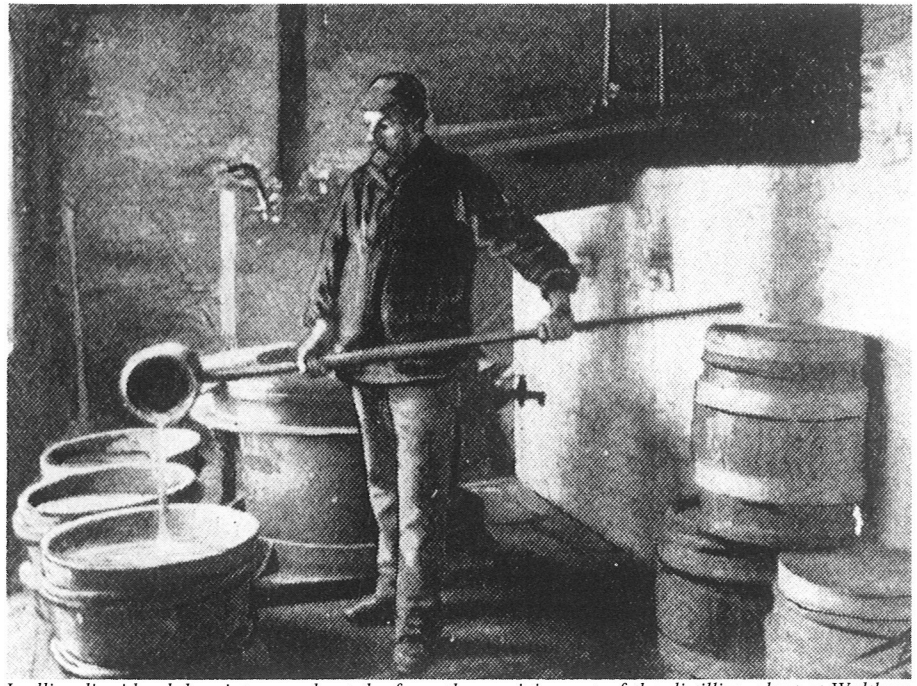
miner's safety fuse in 1805 by William Bickford of Tuckingmill in Cornwall. Bickford was concerned to reduce the toll of accidents caused by crude and unpredictable fuses made from reeds and goose quills. Together with a local miner, Thomas Davey, he developed a textile fibre fuse with a uniform core of powder which burnt at a determinate rate. The fuse was made in a rope walk, the powder being trickled into a bundle of fibres as these were being twisted. More fibres were wound around in the opposite direction, to counter the twist, and a varnish of tar and resin was applied.

Bickford fuse soon acquired a world-wide market and factories were opened in several countries for its manufacture. The product was adapted for use in different climatic conditions and for special purposes such as underwater blasting. Another type of fuse was developed, notably by the Cornish firm of Tangye, in which the powder was contained in a lead or composition pipe. The manufacture of fuse continued in Cornwall until the 1960s, long outlasting the traditional gunpowder industry in the county.

New gunpowder mills were started in the mid nineteenth century in the west of Scotland, Wales, Devon, Cornwall and the Lake District. Many technical improvements were made but at the same time a new high explosives industry based on more modern chemical technology was making rapid progress. Gunpowder, or black powder as it became called, to distinguish it from newer products, eventually became obsolete for most purposes. Before describing these developments, it is necessary to explain how it was made.

The saltpetre refinery at the Royal Gunpowder Mills, Waltham Abbey, 1895. 'Grough' saltpetre was dissolved in water in 500 gallon (2300 litre) coppers, boiled, skimmed and run through filter bags into the cooling vessels shown here. The solution was agitated as it cooled so that small, pure crystals formed. These are being raked out on to drainers before being transferred to washing vats. The liquors produced at each stage were retained and recycled.





Ladling liquid sulphur into wooden tubs from the receiving pot of the distilling plant at Waltham Abbey, 1895.

THE MANUFACTURE OF BLACK POWDER

The first stage was preparing the raw materials by refining the saltpetre and sulphur, manufacturing the charcoal, pulverising the ingredients separately and mixing them in the required proportions. The gunpowder was then incorporated by mechanically grinding and crushing the ingredients into an intimate mixture. At this stage the gunpowder was in the form of a damp paste known as mill cake. This was pressed into hard slate-like sheets of press cake, corned or formed into grains of various sizes, dusted, glazed and finally dried.

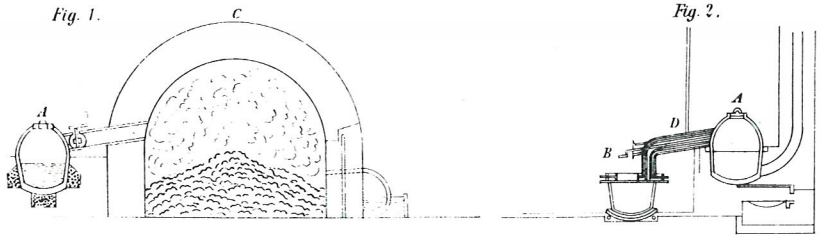
PREPARATION

The crude or 'grough' saltpetre, which was imported or made in local nitre beds, was dissolved in water, boiled and recrystallised. Saltpetre was also extracted from old powder which had deteriorated. Sulphur, which was imported from Italy and Sicily, was distilled.

Charcoal was the variable factor in the composition and its preparation involved selection of the wood to be used and control of the burning process. The traditional method of charring wood in stacks made excellent charcoal for fuel but the product was too impure and uneven as an ingredient of gunpowder. A new method of distilling wood in sealed retorts was therefore developed in the late eighteenth century.

Coppices were planted around powder mills to supply the necessary wood. The preferred trees were alder, willow and alder buckthorn, which was commonly known in England as 'dogwood', and juniper was used locally in the Lake District.

Saltpetre in the form of fine crystals could be used straight from the refinery but the charcoal and sulphur had to be



Sulphur refining apparatus, late nineteenth century. Grough sulphur is heated in the melting pot (A) and the initial yellow vapour is led into the subliming chamber (C) where it falls down as flowers of sulphur. This was not used in the manufacture of gunpowder but was returned to the melting pot. As heating continues, the subsequent brown vapour flows through the cold water jacket (D) to condense in the receiving pot (B).

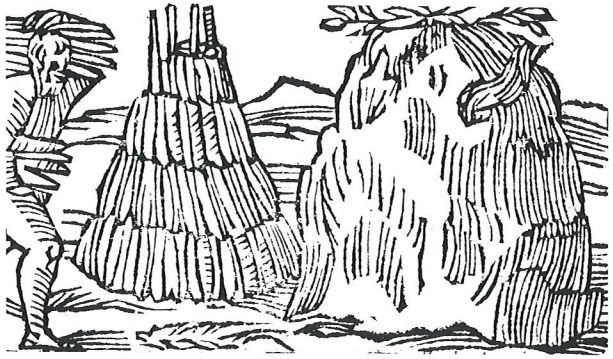
pulverised. This was done traditionally in crushing mills with stone edge runners rolling upon a circular bedstone and in the nineteenth century machines similar to giant coffee grinders were introduced for pulverising charcoal.

The powdered ingredients were each sieved to ensure uniformity and to remove any gritty particles which might cause an explosion during manufacture. The saltpetre, charcoal and sulphur were then weighed out, normally in the proportions 75:15:10, and mixed in a revolving drum to produce the 'green charge' for the incorporating mills.

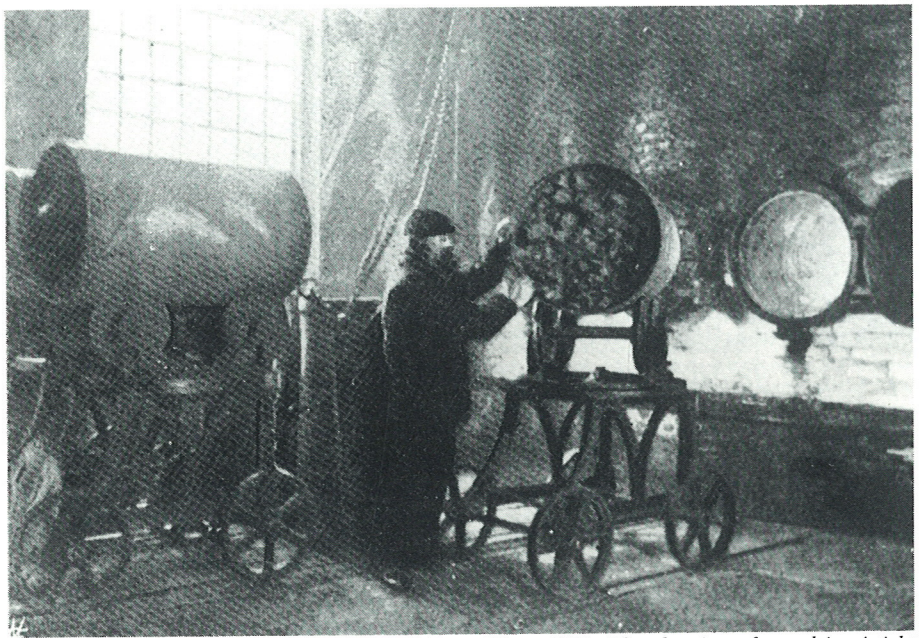
INCORPORATING

The early method of incorporating was by pestle and mortar, worked by hand or with the aid of a spring beam and then by a water-driven camshaft. Incorporating mills with stone edge runners were introduced in Britain in the early eighteenth century and in 1772 pestle mills were in general made illegal on grounds of safety, although exemption was granted to the Sussex mills which made the fine 'Battle' powder for fowling. The charge was moistened and kept damp throughout the incorporating process, which lasted for about two hours for common blasting powder and eight hours or more for the finest sporting grades. Production was continuous, with the workforce operating a shift system.

In the nineteenth century steam engines and later water turbines were introduced to drive incorporating mills and other equipment. Improvements were made in the design of machinery and this enabled a larger charge to be processed. The charge for incorporating mills was limited by law to 40 pounds (18 kg) in 1772 and 60 pounds (27 kg) in 1860.

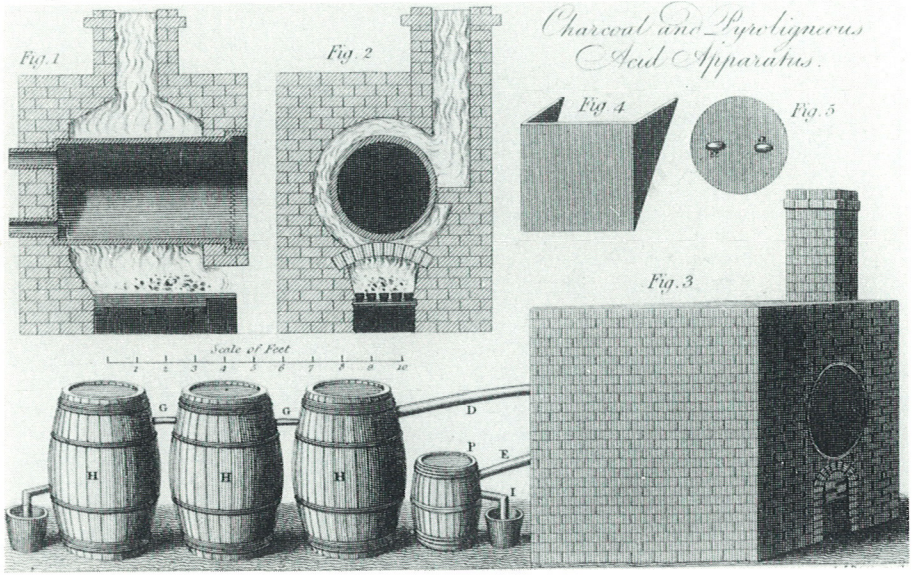


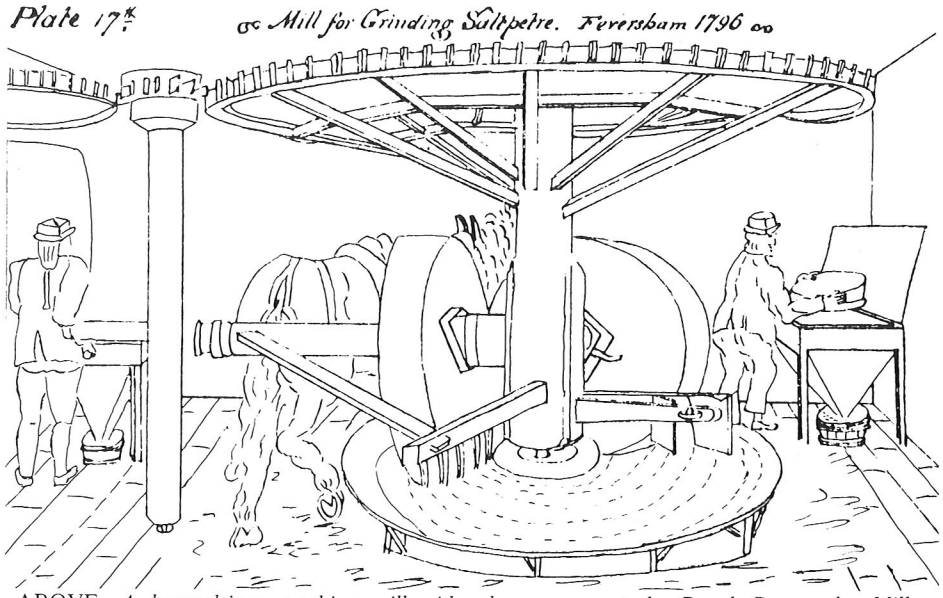
The traditional method of charcoal burning, from Biringuccio's 'Pirotechnia', 1559.



ABOVE: *Making cylinder charcoal at Waltham Abbey, 1895. The charring of wood in airtight cylinders, from which the by-products of combustion were extracted, was developed for the government factories in the late eighteenth century by Richard Watson, Professor of Chemistry at Cambridge and absentee Bishop of Llandaff.*

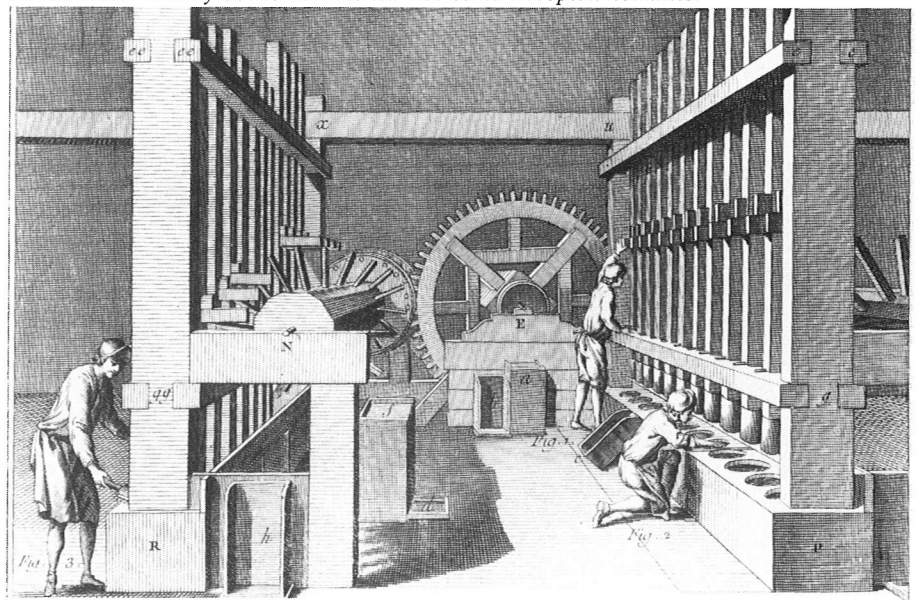
BELOW: *Diagram of charcoal cylinders from Parkes's 'Chemical Essays', 1815, showing the arrangement of flues and the barrels for collecting tar and pyroligneous acid.*

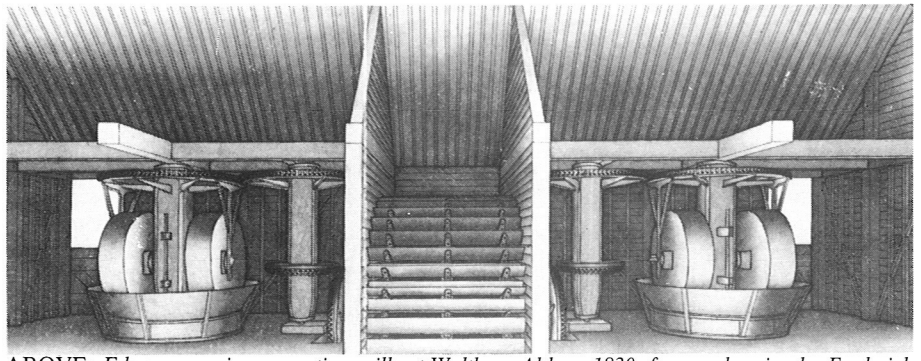




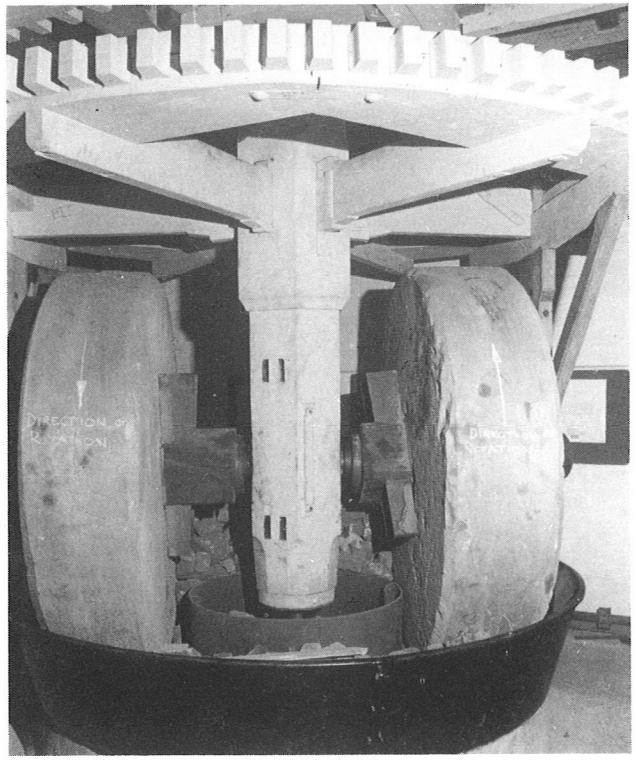
ABOVE: *A horse-driven crushing mill with edge runners at the Royal Gunpowder Mills, Faversham, 1796. The drawing shows the crushing of saltpetre which had been cast into round cakes. Similar equipment was used for pulverising charcoal and sulphur before mixing the charge for the incorporating mills.*

BELOW: *Pestle incorporating mills, from Diderot's 'Encyclopédie', 1762-77. Rows of stamps are operated by a cam shaft. Pestle mills were in general made illegal in Britain in 1772 but survived into the nineteenth century in North America and some European countries.*

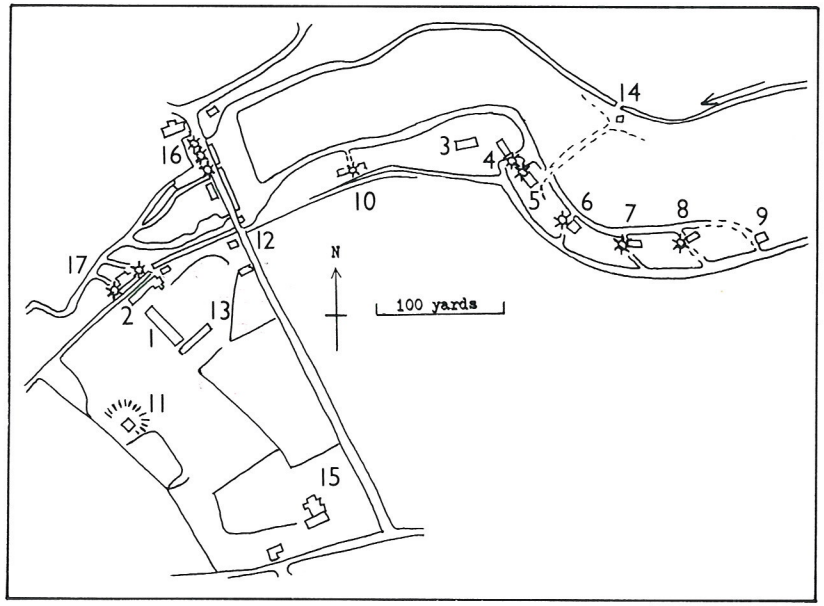




ABOVE: *Edge-runner incorporating mills at Waltham Abbey, 1830, from a drawing by Frederick Drayson in the Public Record Office (M.P.II.15). The drawing shows a typical construction of a pair of mills driven by a central water wheel and geared from above. Later mills, particularly those driven by steam, were geared from beneath so that the machinery was less vulnerable to destruction in an explosion. The bedstone is enclosed in a curb to contain the charge which weighed 40 pounds (18 kg). The stone edge runners are mounted asymmetrically on the shaft and are preceded by ploughs which push the charge into their path to give a combined crushing, grinding and mixing action. In the late nineteenth century, incorporating mills were made of iron and the edge runners were suspended slightly above the bed instead of resting upon it, allowing a larger charge of 60 pounds (27 kg) to be processed safely.*

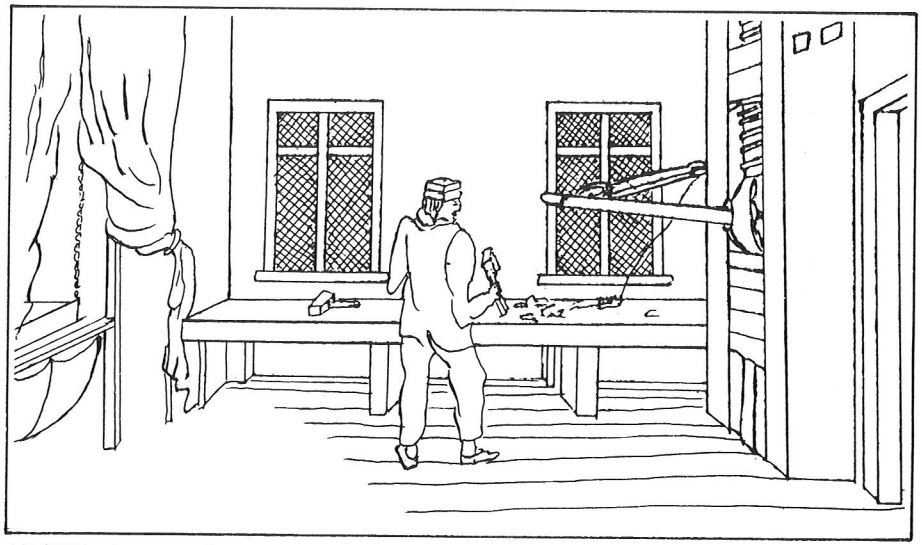


RIGHT: *A restored incorporating mill at Faversham, Kent, dating from the period of the Napoleonic Wars at the beginning of the nineteenth century.*



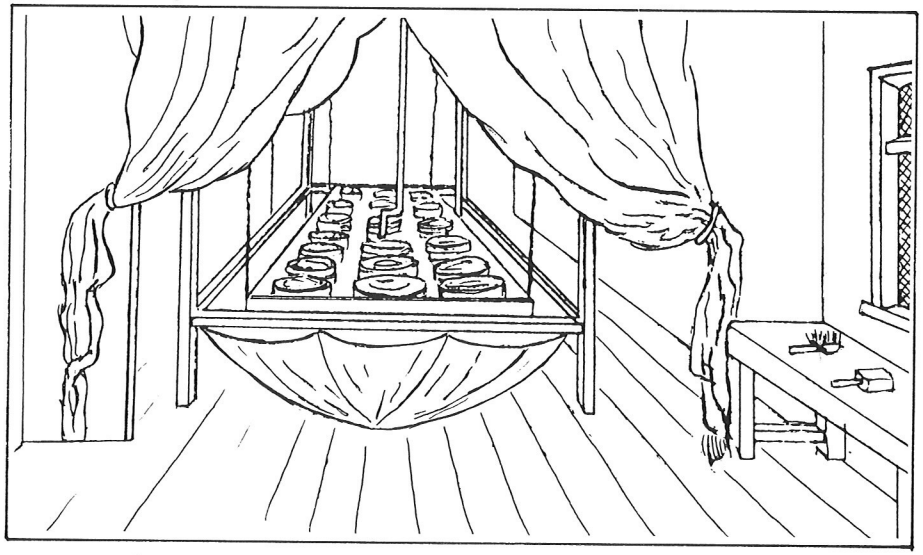
ABOVE: *Powder mills at Waltham Abbey in 1735, from John Farmer's 'History'. From the right the buildings are: 1 Horse mill; 2 Corning and glazing engine; 3-5 Three horse mills; 6 Stables; 7 Coal (charcoal) mill and composition house; 8 Carpenters' and millwrights' workhouse; 9 Clerk's counting house and watch house; 10 Loading house; 11-12 Two stamping mills; 13-14 Two dumb mills; 15 Charging house; 16 Old composition house; 17 Store house; 18 Dusting house; 19 Little stove; 20 Three sun stoves or drying leads; 21 Great stove. The drawing shows the transition from stamping or pestle mills to incorporating mills with edge runners, here described as 'dumb mills' because of their quiet operation. The mills were situated on the river Lea which provided transport to the Thames as well as water power. This was supplemented by horse mills, as shown in the drawing, as late as the period of the Napoleonic Wars in the early nineteenth century, when the factory was owned by the government.*

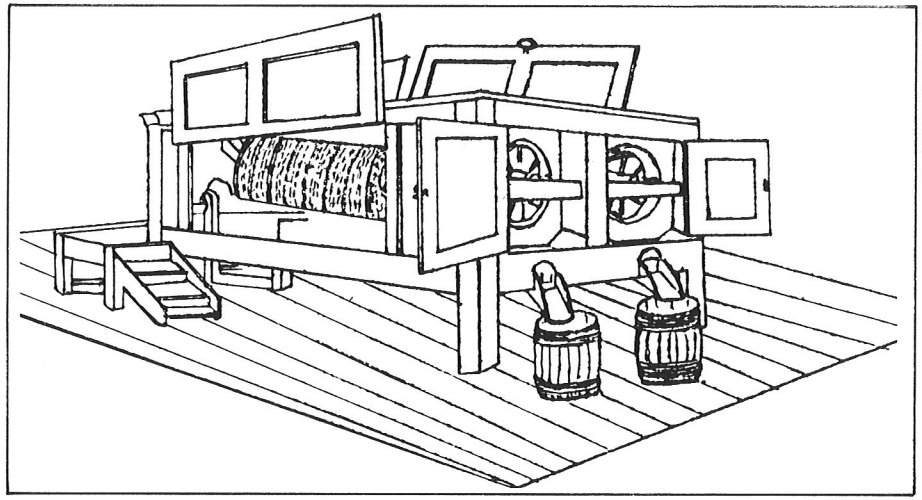
OPPOSITE: *Sketch map of the Chilworth powder mills near Guildford, Surrey, in 1728. 1 Saltpetre earth house; 2 Saltpetre boiling house; 3 Charcoal house; 4 Coal (charcoal) and brimstone mill; 5-8 Four powder mills; 9 Proposed new mill; 10 Corning house; 11 Stove; 12 Coopers' shop; 13 Carpenters' and millwrights' workhouse; 14 Watch house; 15 Dwelling house; 16,17 Paper mills. The plan shows a typical powder mill lay-out, with buildings spaced out along a valley and served by a series of short mill races. The works had been more extensive in the late seventeenth century but had recently contracted and some of the former powder mills had been converted to paper making. The saltpetre earth house shown in the plan was still being used in 1790 although imports by the East India Company provided the major source of saltpetre.*



ABOVE: *A gunpowder screw press at Faversham, 1796. Mill cake was broken up and placed in layers between the copper plates of the press on the right. It was compacted to about half its original thickness to form slabs of hard press cake about ½ inch (13 mm) thick. These were removed with copper utensils, broken into small pieces with wooden mallets and taken to the corning machine on the left. Pressing was one of the most dangerous operations and safer hydraulic presses were used in the nineteenth century.*

BELOW: *Front view of corning machine, Faversham, 1796. Rows of sieves containing discs of lignum vitae, which break up the powder, are attached to a water-powered shaking frame. The sieves are double. The inner one is made of parchment with holes ⅛ inch (3 mm) in diameter and the outer one is made of finer reel cloth, which retains the grain and allows the dust to pass through. The grain size of cannon powder, or large grain, was 8 to 16 meshes to the inch (25 mm) and that of musket powder, or fine grain, was 16 to 36.*





Slope reel for dusting, Faversham, 1796. Corned powder was loaded at the higher end and tumbled through the cylinder as it rotated. Remaining dust passed through the silk covering of the reel and was collected for reprocessing.

PRESSING AND CORNING

Pressing the mill cake to increase its specific gravity was introduced in the eighteenth century when pestle mills were being replaced by edge runners.

Corning was an earlier introduction. Originally gunpowder was simply incorporated and dried but in this form it did not explode consistently and the ingredients tended to separate out again. The practice therefore began in the sixteenth century of forcing it through punched parchment sieves to form 'corn powder'. The loose type then became known as serpentine powder, after guns of the period. As with incorporating, the early method of corning by hand was first mechanised and then replaced by a more modern process. Later granulating machines had toothed rollers which cut the press cake into pieces. After it was corned, remaining dust was removed by tumbling the powder in gauze-covered revolving cylinders.

GLAZING AND DRYING

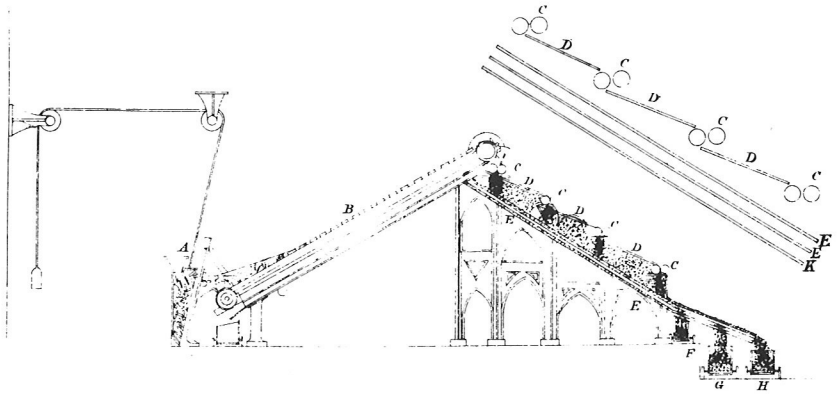
Glazing the powder, by tumbling it in barrels, was practised from about 1680 onwards in order to round the grains and cause inferior ones to disintegrate. In the nineteenth century the process became more sophisticated with the use of black lead to coat the grains of powder and make them resistant to moisture.

Some kinds of powder were effectively dried during glazing but traditionally powder was dried in heated stoves or even in the open air. Early 'gloom' stoves were heated by a fireplace but heating by steam pipes was introduced in the late eighteenth century. After it was dried the powder was given a final dusting before being packed for distribution.

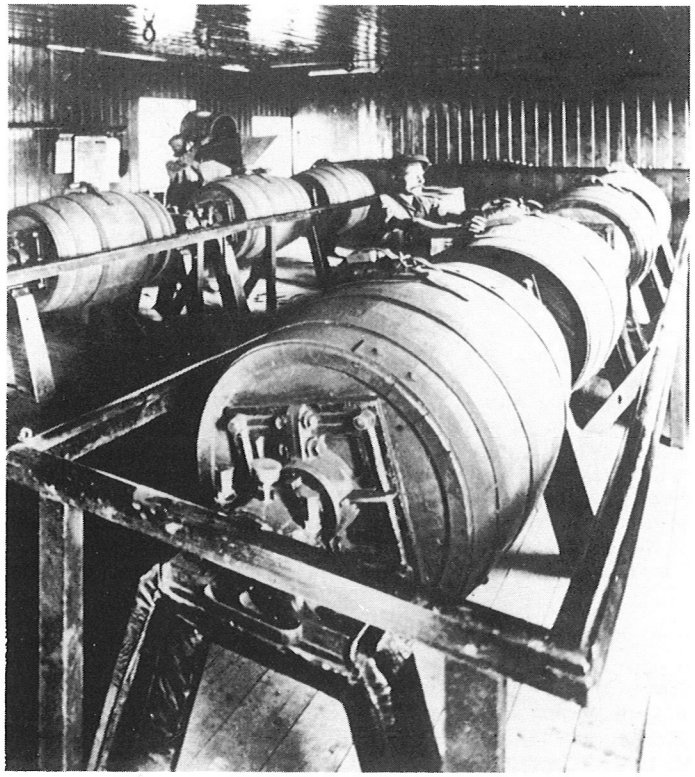
PROOF

Samples of gunpowder were regularly tested for quality and consistency by a variety of devices usually known by the French term *éprouvettes*. Vertical ratchet testers and pistol *éprouvettes* were in use in the seventeenth century. Other early methods used the distance of penetration of projectiles into clay or stacks of wooden boards and another measured the range of cannonballs fired from a small mortar.

A breakthrough came in 1742 with the invention by Benjamin Robins of the ballistic pendulum, which enabled the muzzle velocity of projectiles to be measured with considerable accuracy. This provided a scientific basis on which to



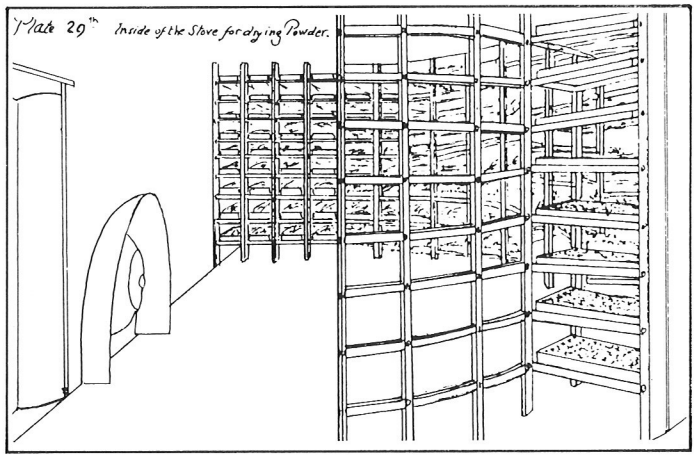
A. Hopper with raising arrangement.
B. Endless band
CCCC. Four pairs of rollers
DDD. Short screens.
EE. Long Screens
F. Box for dust
G. Box for grain
H. Box for chucks
K. Bottom board



ABOVE: *A nineteenth-century granulating machine. This type of machine, with pairs of toothed gunmetal rollers, was designed by William Congreve the younger in 1815. Press cake was cut and automatically sorted into grain, dust and chucks, which went through the process again.*

LEFT: *Glazing barrels at Waltham Abbey, late nineteenth century. The barrels were 5 feet (1.5 m) long and each held 400 pounds (180 kg) of powder. Some types of powder were tumbled for 3 or 4 hours at 34 revolutions per minute. Black lead was added towards the end of the process to coat the grains and make them moisture resistant.*

The interior of a gloom stove at Faversham, 1796. The powder was spread out to dry on the shelves and the chamber was heated by the back of a cast iron fireplace, shown on the left, which glowed red hot. By this date, gloom stoves were beginning to be replaced by safer stoves heated by steam pipes.



develop standards for the composition and grain size of gunpowder. Electrical testers were developed in the nineteenth century. The most successful of these was the Boulengé chronograph, in which a projectile broke two wire screens a given distance apart.

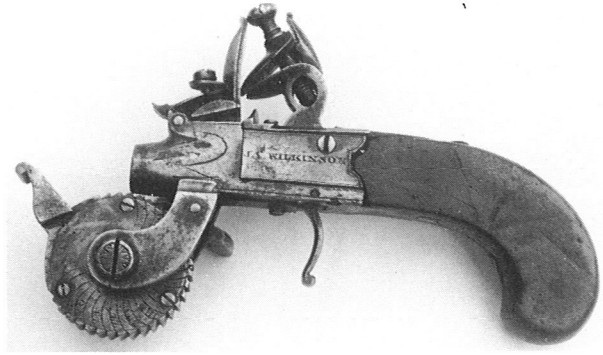
PACKING AND TRANSPORT

Gunpowder was traditionally packed in oak barrels and kegs of various sizes, the 100 pound (44 kg) barrel being used as the standard unit of weight in marketing. Most powder mills had their own cooperage and this employed a large proportion of the workforce. At the Roslin works in Lothian in the 1840s, for instance, half the sixty employees were coopers. Small quantities of powder were sold in metal flasks and canisters and products such as cartridges were packed in boxes.

For transport within factories, punts were used on mill streams wherever possible and tramways were laid to connect the different buildings, with the trams pulled by horses or pushed by workmen.

Gunpowder was stored in factory magazines while awaiting dispatch. An Act of Parliament of 1772 required private firms to maintain magazines on the Thames below Blackwall or in other licensed places. Many of these warehouses were situated on the Thames estuary in Kent and Essex and there were others at Bristol and Liverpool. The government factories had magazines at Purfleet in Essex and an Act of 1851 provided for floating magazines to be established for the Ordnance on the Mersey at Liverpool.

Carriage was at first by packhorse and, as transport systems developed, wagons,



A gunpowder proving pistol in Hastings Museum, Sussex, from the nearby powder mills at Battle.

Coopers of the Elterwater Gunpowder Company in the late nineteenth century. The Elterwater factory, which operated from 1824 to 1928, was one of a group in southern Cumbria which made blasting powder for home and export markets. Powder was delivered by horse and cart to the local Langdale slate quarries and Coniston copper mines and sent by rail to Liverpool for export, much of it to West Africa.

canal barges and railways were in turn adopted. There was also a considerable coastal traffic in gunpowder. For transport inland, waterways provided a particularly suitable means of transport and the government and several private firms maintained their own fleets of sailing barges.

EXPLOSIONS

Minor accidents were commonplace and most mills would experience a fatal explosion occasionally. Fortunately the number of casualties was not usually large, in comparison with, for example, mining disasters, but details are invariably gruesome.

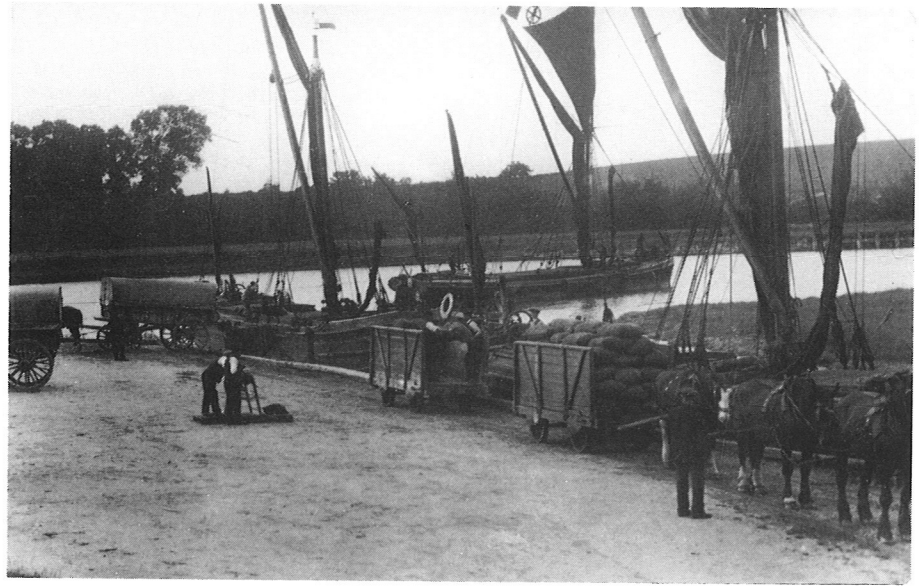
Most manufacturing accidents occurred in incorporating mills but those in press and corning houses were more serious in terms of loss of life and injury. The worst were multiple accidents such as that at Kames in Strathclyde in 1863 in which a granulating house, press house, glazing house, dusting house, double press house and glazing house exploded in succession, killing seven men and injuring eight others.

Early legislation was concerned only with the needs of the state for supplies and the first Act of Parliament to deal with public safety was that of 1719 which regulated the carriage of gunpowder in London and Westminster. Similar provisions were made for the rest of Great Britain in 1771 and the first Act to cover manufacturing practices was passed in the following year. This introduced manufacturing licences, prohibited pestle mills in general and limited the quantities of powder to be incorporated and dried at one time. It controlled the storage of powder and required magazines to be provided remote from the mills.

Safety measures involved taking steps to avoid bringing dust and grit into contact with gunpowder and guarding against sparks from iron objects and heat caused by friction. It became the practice to cover the floors of danger buildings with tanned hides and for the men to change into special slippers on entering. Copper and wooden utensils were used instead of iron, and copper was used for metal parts and fittings. When carrying powder, containers and wagons were

ABOVE: *Packing gunpowder at the Oare works, Faversham, about 1925. Powder is being packed into flasks and canisters. The large labelled boxes contain blasting pellets.*

BELOW: *Powder barges at Oare Creek, Faversham, about 1925. Powder was carried from the works to the wharf in the covered horse-drawn wagons on the left and taken by sailing barge to magazines on the Thames at Tilbury. The barges are flying the red flag to show they have explosives on board.*



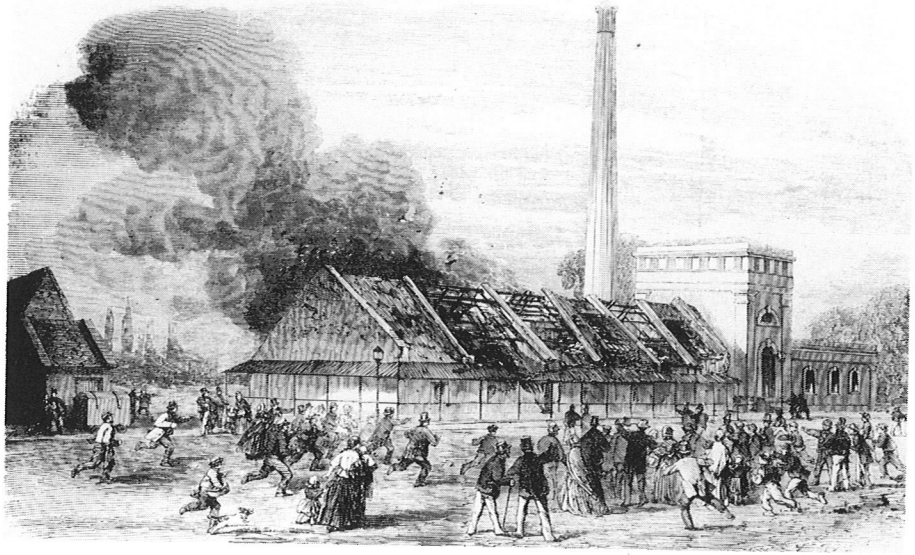
covered with leather to prevent spillage. Danger buildings were surrounded on three sides with massive earth embankments and partially built of flimsy materials, to control the effect of any blast. Buildings were widely spaced to prevent explosions from spreading and trees were used as shock absorbers.

However, although sound practices evolved, rules were not always observed. The next major legislation was passed in 1860 and was soon found to be inadequate, partly because it was overtaken by the development of new products but also because of the difficulty of enforcing its provisions. A disastrous explosion of a magazine at Erith in south-east London in 1864 highlighted the need for change. A subsequent report on the state of the Thames embankment in the area, where many magazines were situated, gave a startling account of careless attitudes and practices. A partial system of inspection and inquiry into major accidents was started and was later made comprehensive and permanent by the Explosives Act of 1875.

Meanwhile, in 1874, another salutary incident occurred when one of a convoy of five narrow boats, which was bound for the Midlands, exploded while passing beneath a bridge on the Regent's Canal in London. It was carrying a mixed cargo containing both gunpowder and benzolene and vapour from the latter was ignited by a naked flame in the cabin.

The new Act introduced a list of authorised explosives and a licensing system for factories and stores based on the submission of detailed plans and the practice of inspection. In the field of transport, model codes of bylaws were prepared for the use of railway, canal and harbour companies. All accidents were required to be notified and the number of deaths and injuries was substantially reduced. For the explosives industry as a whole, fatalities declined from forty-three per annum in England and Wales before 1870 to approximately seven per annum in the United Kingdom after 1878.

An explosion at the incorporating mills, Waltham Abbey, 1861. Workmen had neglected to place the customary piece of leather under the edge runners when they were being moved for cleaning and a spark ignited the powder. Four men were badly burnt and one of them died from his injuries. The picture shows a typical arrangement of six incorporating mills powered by a steam engine, in this case a beam engine in the tall engine house. A covered tram can be seen at the left of the picture.



Powder punts on the mill stream at Chilworth, Surrey, 1913. The leats of water-powered mills provided a convenient means of transport within factories. The photograph shows the leather covers on the barrels which were used to prevent powder from being spilt.

THE FINAL PHASE

With advances in the design of guns in the second half of the nineteenth century, corresponding improvements were needed in the manufacture of powder for specific purposes. This was made possible by better methods of testing which allowed greater control to be exercised over, for example, the properties of the charcoal used and the density of the finished product.

Slow-acting charges were needed both for rifled guns and for the heavy artillery which was made to penetrate armour plating on ships. The density of the powder was therefore increased, first by cutting press cake into ½ inch (13 mm) cubes instead of granulating it, to produce 'pebble powder', and later by using a hydraulic press or a cam press to mould powder into cylinders and prisms. Some products also had a reduced sulphur content to slow down combustion.

A problem with black powder was the amount of smoke it created, obscuring the target from view. To overcome this, an almost smokeless powder, known as brown prismatic or 'cocoa' powder, was produced by using brown charcoal made from straw.

Blasting charges were also made in the form of compacted 'bobbin powder', perforated cylinders of ¾ inch to 1½

inches (19 to 38 mm) in diameter which when in use were threaded on to lengths of fuse. A later product, 'bobbinite', was an adaptation of the black powder formula for use in coal mines where there was a risk of firedamp.

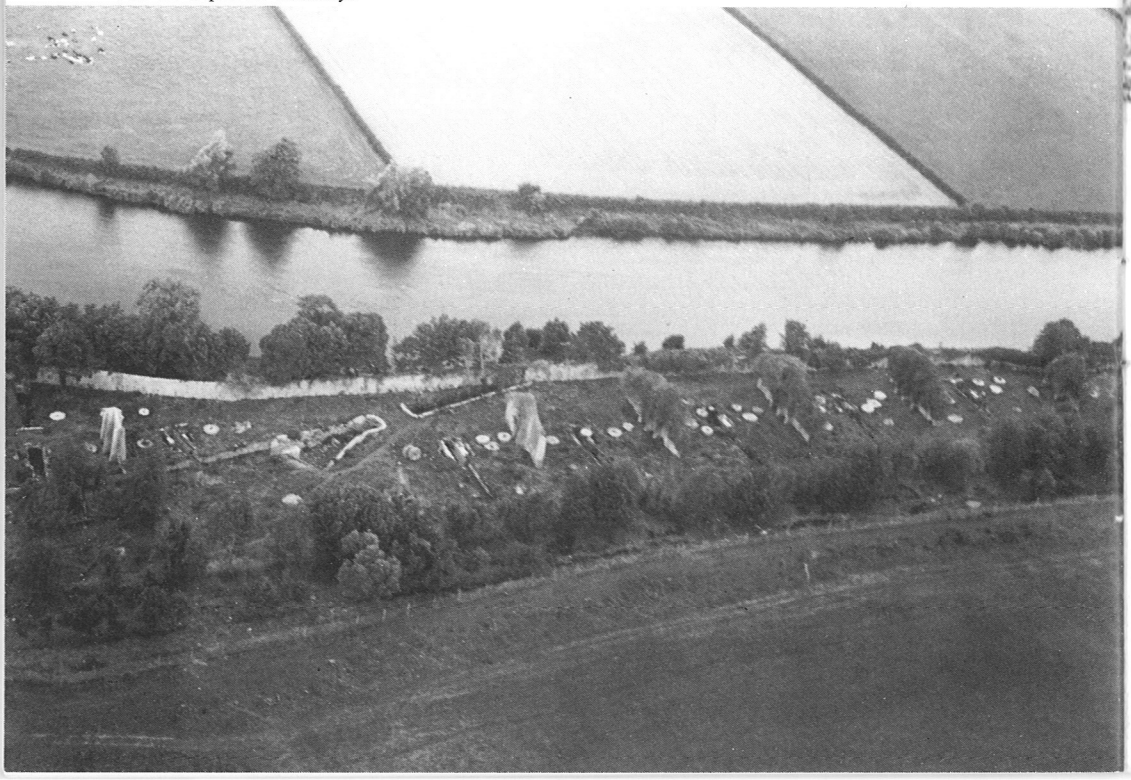
During the nineteenth century some firms began to expand, notably Curtis's and Harvey, which was established at Hounslow in 1820 and proceeded to take over other companies throughout the British Isles. The industry also acquired an international dimension when in 1885 a subsidiary of a German company took over the Chilworth works in Surrey for the manufacture of brown prismatic powder.

Meanwhile the modern high explosives industry had been undergoing rapid development. The new technology, which was based on the nitration of glycerine, cellulose and other organic compounds, had begun experimentally in Italy and Switzerland in the 1840s and, after a protracted development stage, blasting agents had gone into regular production in the 1860s. The zenith of black powder technology was reached just as a breakthrough was being made in controlling the power of the new explosives for ballistic use.

The new products included dynamite, blasting gelatine and the propellant ballistite, all patented by the Swedish inventor Alfred Nobel, and the propellant cordite, which was developed under the auspices of the British government. Nobel set up companies to manufacture his products in several countries and one of these, the British Dynamite Company, opened a factory at Ardeer on the Ayrshire coast of Strathclyde in 1872.

Many existing gunpowder factories were redeveloped and extended to manufacture the new products. The manufacture of black powder ceased in Cornwall and Devon by the end of the nineteenth century, its end hastened by a slump in the mining industry. The explosives industry as a whole, however, expanded, with the workforce in the United Kingdom increasing from 7,500 in the late 1870s to 14,500 at the end of the century. Dramatic expansion, on an international scale, occurred in the years leading up to the First World War of 1914-18. After the armistice, when demand suddenly fell, the successor of the British Dynamite Company arranged a merger of explosives firms in Britain. In the rationalisation which followed, most of the factories closed and the manufacture of explosives became largely concentrated at Ardeer. The new company, Nobel Industries Limited, itself became part of Imperial Chemical Industries in 1926.

Black powder was still used for fuses and fireworks and for blasting in slate quarries, where it was favoured for its clean, heaving action. It continued to be made at Faversham in Kent and at several sites in the Lake District. In 1934 however, when the political situation in Europe was again deteriorating, the Faversham business was moved to Ardeer. The last of the Lake District mills, Gatebeck, closed in 1937. Production ceased at the government factory at Waltham Abbey when plant was destroyed by enemy action in the Second



Incorporating mills at Ballincollig, County Cork. The aerial photograph shows part of a row of twelve pairs of mills along the bank of the river Lee. Each pair has a central water wheel pit and is separated from the next by a high blast wall with buttresses. In 1983 work began on conserving the site as a public amenity.

Ruins of water-powered incorporating mills at Kennall Vale, Ponsanooth, Cornwall. The empty shells of several pairs of mills, served by a sequence of leats at different levels, are ranged along the side of a steep, wooded valley. Since 1985 the site has been managed as a nature reserve.

ABOVE: *A saltpetre boiling pan in a garden at Battle, Sussex. The bowl is 52 inches (1.3 m) in diameter and 33 inches (0.85 m) deep. A similar pan can be seen at Hastings Museum.*

LEFT: *Charcoal cylinders at Gatebeck, Cumbria. The site of the Gatebeck factory, which closed in 1937, has been developed as a holiday caravan site and the cylinders, which are approximately 8 feet (2.5 m) long, have been erected as gate posts.*

Powder mills, Dartmoor. The chimney shaft was probably associated with the preparation of raw materials. The pairs of incorporating mills or 'wheel houses' in the background were served in turn by a long leat which carried water across the moor from the river East Dart.

Excavations at Wilmington, Dartford, by the Kent Archaeological Rescue Unit in 1983. Remains of the Dartford mills, which operated from 1732 until the early twentieth century, were discovered during industrial redevelopment of the area and plans were modified in order to preserve foundations of incorporating mills.

World War. It continued at Ardeer until 1976, with some processes being carried out at Roslin in Lothian until 1954.

Black powder is nowadays imported into Britain mainly from West Germany and one factory is still operating in North America. Powder is supplied to the fuse and fireworks industries and some is used for blasting, mainly in stone-cutting. The chief market is in sporting powder for users of antique firearms.

FURTHER READING

For the early history of gunpowder see: Needham, J., 'The Guns of Khaifêng-fu: China's Development of Man's First Chemical Explosive', *Times Literary Supplement,* 11th January 1980; Partington, J. R., *A History of Greek Fire and Gunpowder,* Heffer, 1960.

For the history of the industry see: Hodgetts, E. A. B. (editor), *The Rise and Progress of the British Explosives Industry,* Whittaker, 1909; Reader, W. J., *Imperial Chemical Industries: A History, Volume I: The Forerunners 1870-1926,* Oxford University Press, 1970; the *Victoria County History of Surrey,* 1902-12, volume 2.

Useful works on technology include: Fitzgerald, W. G., 'How Explosives Are Made', *Strand Magazine,* volume 9 (1895) 307-18; Howard, R. A., 'Black Powder Manufacture', *Journal of the Society for Industrial Archaeology,* volume 1 (1975) 13-28; Smith, F. M., *A Handbook of the Manufacture and Proof of Gunpowder,* HMSO, 1871; Wardell, W. H., *Handbook of Gunpowder and Guncotton,* HMSO, 1888.

The following deal with particular sites and regions and provide further bibliographical references: Blackman, H., 'The Story of the Old Gunpowder Works at Battle', *Sussex Archaeological Collections,* volume 64 (1923) 109-22; Buchanan, B. J., and Tucker, M. T., 'The Manufacture of Gunpowder: A Study of the Documentary and Physical Evidence Relating to the Woolley Powder Works near Bath', *Industrial Archaeology Review,* volume 5 (1981) 185-202; Crocker, G., *Chilworth Gunpowder,* Surrey Industrial History Group, 1984; Earl, B., *Cornish Explosives,* Trevithick Society, 1978, Fairclough, K., 'Early Gunpowder Production at Waltham', *Essex Journal,* volume 20 (1985) 11-16; Harris, H., *The Industrial Archaeology of Dartmoor,* David and Charles, 1972; Marshall, J. D., and Davies-Shiel, M., *The Industrial Archaeology of the Lake Counties,* second edition Michael Moon, 1977; Over, L., *The Gunpowder Mills on Hounslow Heath,* Richmond upon Thames Friends of the Earth, 1984; Percival, A., 'The Faversham Gunpowder Industry and Its Development', *Industrial Archaeology,* volume 5 (1968) 1-42; Philo, P. and Mills, J., 'The Bedfont Gunpowder Mills', *London Archaeologist,* volume 5 (1985) 95-102; Philp, B., *The Dartford Gunpowder Mills,* Kent Archaeological Rescue Unit, (1984); Pritchard, T., *et alii, The Old Gunpowder Factory at Glynneath,* Merthyr Tydfil and District Naturalists' Society, 1985; Simmons, W. H., *A Short History of the Royal Gunpowder Factory at Waltham Abbey,* Royal Ordnance Factories, 1963.

Other important sources are the government documents held by the Public Record Office, Kew, under the classification Supply 5 and the annual reports of Her Majesty's Inspectorate of Explosives in *Parliamentary Papers* from 1875 onwards.

Further information may be obtained from the Secretary, Gunpowder Mills Study Group, c/o Society for the Protection of Ancient Buildings (Wind and Watermill Section), 37 Spital Square, London E1 6DY.

PLACES TO VISIT

Intending visitors are advised to find out the times of opening of museums before making a special journey.

MUSEUMS IN BRITAIN

Chart Gunpowder Mills, Faversham, Kent. (Restored incorporating mill.) Enquiries to the Fleur de Lis Heritage Centre.

Fleur de Lis Heritage Centre, Preston Street, Faversham, Kent. Telephone: Faversham (0795) 534542. (Displays cover the local explosives industry.)

Science Museum, Exhibition Road, South Kensington, London SW7 2DD. Telephone: 01-589 3456. (Space Technology Gallery.)

MUSEUMS IN OTHER COUNTRIES

Frederiksvaerk Museum, Torvet, 3300 Frederiksvaerk, North Zealand, Denmark.
Hagley Museum, PO Box 3630 Greenville, Wilmington, Delaware 19807, USA.
Penny Royal Gunpowder Mills, Launceston, Tasmania, Australia.

INDUSTRIAL ARCHAEOLOGY

When powder mills closed danger buildings were gutted and cleaned out in the interests of safety. Many sites were then abandoned to the processes of decay and dereliction.

Several sites are being conserved, some as public amenities. Roslin, south of Edinburgh (National Grid Reference NT 268627), has been opened to the public by Midlothian District Council. In west London, Crane Park (TQ 129729), the site of the Hounslow mills, is open as a public park and an area is being managed as a nature reserve. Some conservation and amenity projects are still in progress and enquiries about access in these cases should be made at local libraries, museums and tourist offices. At Dartford in Kent (TQ 548730), excavated remains are to become a feature of a riverside walkway planned by Dartford Borough Council. Remains on Dartmoor in Devon are visible from a footpath from Higher Cherry Brook Bridge (SX 635770). However, the structures are on private land and are being conserved and visiting is not encouraged. A proving mortar can be seen on the approach to craft workshops adjoining Powder Mills Farm (SX 627768). The best preserved site in Cornwall, Kennall Vale (SW 750375), is managed as a nature reserve by the Cornish Trust for Nature Conservation. In the Republic of Ireland, the extensive Ballincollig site, 5 miles (8 km) west of Cork city, is being conserved by Cork County Council as the focus of a regional park.

Some sites have been reused for holiday accommodation and non-residents should obtain permission to visit these. There are caravan sites at Sedgwick (SD 508877), Gatebeck (SD 544855) and Blackbeck (SD 335855) on the edge of the Lake District and at Cosawes (SW 768377) in Cornwall. The Forestry Commission has developed the Herodsfoot site in Cornwall (SX 205608) as Deerpark Forest Cabins. The best preserved site in the Lake District, Elterwater (NY 327052), and the Melfort site in Argyll (NM 840145) have become holiday time-share developments.

In south-east England, there are remains at East Bedfont in Hounslow, west London, which are accessible by footpaths leading north from Baber Bridge (TQ 112746), at Chilworth in Surrey (TQ 024475), where access is permitted by Guildford Borough Council, and in East Sussex at Battle (TQ 742146) and Sedlescombe (TQ 781176), both in private gardens. The Sedlescombe remains and a dam and former millpond at Peppering-Eye (TQ 743139) are visible from public footpaths. The Waltham Abbey factory in Essex has become a research establishment to which entry is strictly controlled for reasons of security.

In Wales, there is a site at Glyn Neath, West Glamorgan (SN 911080), on which information may be obtained from the Tourist Information Centre, Aberdulais; telephone Neath (0639) 53531. There are also remains near Dolgellau (SH 735270).

In Scotland, there are substantial remains on private land of nineteenth-century mills at Clachaig (NS 120814), Furnace (NN 022005) and Kames, Kyles of Bute (NR 958707), all in Strathclyde, and of a Second World War factory near Wigtown (Dumfries and Galloway) (NX 425595).