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RCHME

1993 SURVEY

[WITH INDEX]

SAME AS WASC 2167-01

THE ROYAL GUNPOWDER FACTORY,

WALTHAM ABBEY, ESSEX

AN RCHME SURVEY, 1993

ROYAL
COMMISSION
ON THE HISTORICAL
MONUMENTS
OF ENGLAND

INDEX

RCHME SURVEY 1993 ON THE ROYAL GUNPOWDER FACTORY WALTHAM ABBEY

WASC 2167-01

COMPILED BY IRIS & MARK BAILEY, 2009

The Royal Gunpowder Factory,

Waltham Abbey, Essex

An RCHME Survey, 1993

A mill for making Gunpowders there,
And Water flows amazing, and more rare;
Of worthy Walton's Works.

Philotechnos, a local poet (1735)

... there were rumours of Martians ...
and news of the destruction of Waltham Abbey Powder Mills
in a vain attempt to blow up one of the invaders.

H G Wells *The War of the Worlds* (1898)

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Designed and produced by the RCHME

Contents

Section 3 Analytical Report

Plans and illustrations (bound separately)

Status and organisation of report

This report has been written to form the deposited archive account for the National Monuments Record (NMR) covering RCHME's field survey and associated research on the site of the Royal Gunpowder Factory at Waltham Abbey and of subsequent production facilities on that site. As such it constitutes the core of the NMR record for NMR site numbers TL 30 SE *** and TL 30 SE *** , respectively Waltham Abbey RGPF (gunpowder factory) and Waltham Abbey RGPF (explosives factory) and TL 30 SE *** Lower Island. It also contains reference to and information about TQ 30 NE *** South Site, which as part of the extended factory for producing chemically based explosives and propellants has been investigated to a lower level of detail, without original topographical survey.

Buildings and features within those sites are treated here as **components** of the larger site rather than monuments in their own right. Where individual buildings have been recorded in detail by RCHME architectural staff, the resulting descriptions are incorporated within the structure of this report as adjuncts to the component sheets (see below). In that they will also enter the NMR's MONARCH record system as records of individual monuments with their own reference number, they will be attached to the site record in a 'parent-child' relationship, as that computerised system allows.

Though created for this primary purpose, the report is designed to be made available, in whole or in part, as a word-processed product to directly interested parties. It is not a formal publication, however. RCHME is considering the options for such publication as a separate matter.

The report is organised in four numbered **Sections**. They are:

1. an introductory section including the circumstances and methods of the survey, and a summary;
2. a history of Waltham Abbey RGPF plus a description of the field remains recorded through the survey task;
3. an analysis of the development and functioning of the RGPF as exemplified by the recorded remains;
4. the collection of component sheets, which represent the 'professional papers' or detailed catalogue, building by building and feature by feature, that underpin the site description. These are in practice bound separately in groups corresponding to the topographical and functional areas through which the site is described, and are represented in the report itself only by a listing and a sample. They contain contact prints of record photographs and appended to them in relevant cases are the selected detailed building descriptions by RCHME architectural field staff (as above).

Supporting this report and especially **Section 2** is a separate A3 binding of plans. The bulk of this comprises RCHME's surveyed site plan of the North Site and Lower Island, reproduced at 1:1 250 scale and broken down into the topographical areas by which the site is described in **Section 2**.

Behind this, and intended to form a supporting package of deposited information and resource in the National Monuments Record, lies an overall site plan surveyed at 1:1 000. This is held both as 16 original hard-copy field sheets and as a multi-layered digital data-set created within a CAD environment. The deposit also includes copies of a large selection of historic maps and drawings of the site, historic and modern site photography, aerial photographic recording of the site, and copies of technical manuals and other specialist publications, all of which do not directly form part of the report but whose scope is indicated in its bibliography.

The report is therefore the tip of an iceberg of information resulting from the survey. In all its richness and diversity it reflects the complexity and importance of the field archaeology of the Royal Gunpowder Factory at Waltham Abbey.

Circumstances and methods of the survey

The remains of the former Royal Gunpowder Factory at Waltham Abbey encompassing the manufacture of both gunpowder and chemically-based explosives extend for over 4 km along the valley of the River Lea. They lie at 19-21 m above OD, on the sand-and-gravel terraces of the east side of the Lea's broad flood-plain (BGS 1978). This locates them entirely in the county of Essex but abutting on its borders with Hertfordshire and historic Middlesex (Greater London).

Development of production facilities over at least three centuries created this extended layout. Reflecting that historical development, they are most readily understood as three topographically distinct entities, which are identified by their traditional names of **North Site**, **Lower Island** and **South Site** (see Figs 1, 2). The E-W cross-valley routes conveniently divide them in the modern landscape. North Site lies north of the long-established crossing of the Lea valley from Waltham Cross to Waltham Abbey by the causeway of Highbridge Street: it extends continuously some 2 km northwards to the site's Grand Magazine (TL 37636 02580) at a point where waterways divide near Fishers Green. Lower Island lies south of Highbridge Street and is now separated from South Site by the intrusion of the line of the M25 motorway. Though thus topographically separate, these sites were integrally linked in a changing pattern of manufacturing flowlines within Waltham Abbey RGPF.

RCHME's survey of the North Site was initially prompted by its national importance as a site of gunpowder production being formally drawn to the attention of RCHME in the summer of 1992 by Professor RA Buchanan, at that time an RCHME commissioner. He recommended that survey and recording be considered by RCHME, particularly in the context of potential land-use changes resulting from the closure in 1991 of the government research establishment (RARDE) hitherto occupying the site. Advice from the principal special interest group, the Gunpowder Mills Studies Group, urged the same perceived importance. A combined site visit in September 1992 by RCHME and English Heritage staff for the first time gave an insight into the remarkable range of structures and earthwork features and even vulnerable artefacts and fittings preserved within the site, and not least within its heavily wooded northern half. Information about their date, functions and inter-relationships was at that stage rudimentary or nonexistent. A formal project proposal for RCHME fieldwork was put to RCHME Commissioners at their meeting on 24.11.92. English Heritage, who had a concurrent need to assess the site for designation (either or both listing and scheduling as appropriate) also asked if a survey programme could serve a second, short-term purpose in informing them through its results of the location and significance of the site's built and buried features. This formed an agreed purpose in the fieldwork and English Heritage made a contribution to the survey costs.

RCHME fieldwork began on 4 January 1993. It was timetabled for the first three months of the year when ground conditions were most suitable for survey: any later in the year the northern part of the site is covered by dense undergrowth. That area's status as a SSSI brought other practical constraints on the survey programme. Its primary product was a survey plan of the whole North Site at a scale of 1:1 000. This drew for its technical framework on a topographical survey of the site commissioned by MoD in connexion with an active programme of demolition and decontamination works being carried out by MoD through the agency of Royal Ordnance. Under this survey scheme, National Grid co-ordinates were brought onto the site from the Monkham Hall Pillar (TL51/1) and were tied out on PTS 85 in Highbridge Street, Waltham Abbey. The main traverses were observed in November 1992 using Leica T1000/DI1000 total stations equipment. The specifications for the survey included a plot scale of 1:500. Through the generous cooperation of MoD and their contractors, Milton Keynes Surveys, plots at a scale of 1:1 000 from this survey were made available to RCHME on a rolling programme through January, February and March 1993 for field enhancement with archaeological detail. Archaeological detail was surveyed using standard graphical methods supplemented by additional control points within the control survey established by use of Wild self-reducing alidade and plane-table. The arrangement had the important additional virtue of thereby making the archaeological planning inherently compatible with the plans that form the basis of modern site management. The surveyed information has subsequently been drawn up by RCHME in a CAD environment under Autocad version 11.

The site plan was supported by at least a minimum description of all buildings, structures and selected earthwork features, to form a record of all site components at RCHME level 1 or better, and a field photographic record of all buildings and structures by 35mm black-and-white coverage. This has been supplemented by architectural recording of selected larger buildings by RCHME Threatened Buildings staff, namely 1 Grand Magazine, A200, A201, A202, A210, A214, A221, A230, A231, A232, A233, A234, A238/A268, A269, H7/H8, H10, H12, H25, H26, L122, L145, L148, L149, L153, L157, L167, L168, L176. RCHME professional photographic coverage has extended selectively to those buildings and to other features surveyed, employing large-format photography in black-and-white and colour as appropriate to record all the important structures within the factory.

To complement the ground-based survey, a series of low-level oblique aerial photographs have been taken of the RGPF, covering both North Site and South Site. This photography has provided general views of the site, medium-focus views illustrating the relationships between groups of buildings, and photographs of individual buildings. Photography taken on an initial sortie in less than ideal conditions in early June 1993 will be retaken during winter 1993-4. The resulting images will be lodged in the National Library of Air Photographs, RCHME Swindon, and may be consulted through the established public access facilities.

It was recognised at an early stage in planning the survey project that there was likely to be an archive of graphical material - maps, plans, drawings and photographs - acquaintance with which was essential to any clear understanding of the development of the factory. Three principal archives were identified as holding material from the site; (1) the Public Record Office at Kew principally in the SUPPLY/5 deposit and in unaccessioned material in its store at Hayes, (2) the Epping Forest District Museum at Waltham Abbey, and (3) the Ministry of Defence at Chessington. Enquiries also established that no relevant site-specific records are held by MoD at Fort Halstead. The survival of such a quantity of visual records greatly enhances the importance of the site because of the level of understanding of the field evidence that can be achieved through them. Its survival owes much to the foresight and energy of Malcolm McLaren, former librarian/archivist with RARDE. Access at short notice for RCHME project staff to these three sources was facilitated by Miss Margaret Condon, Head of the Maps and Prints Department at the PRO, by Susan Dalloe and her colleagues at EFDM, and by David Stanners at MoD Chessington. All three archives were visited and relevant material - comprising original maps and plans, buildings drawings, historic photographs, journal articles and official handbooks - has been indexed at a basic level against the components of the site. With such voluminous source material the searches were necessarily swift and selective, their aim limited to understanding the development of the factory as a whole and to explaining the functioning of the individual field monuments. Some copying by xeroxing and photography took place to secure working materials and to augment the RCHME archive deposit.

Other documentary sources have been pursued to very limited extents. Because the Waltham Abbey factories were a focus of technological development and innovation as well as bulk production, many contemporary technical articles, handbooks and manuals are based on and illustrate its equipment and practices. These have been sought out for their direct evidence relating to physical remains, both via library loans and by consulting the Nathan collection of publications on gunpowder and high explosives in the library of the Royal Chemical Society.

Information about all individual buildings and features on the site - bridges, water courses, power lines, pipe lines and buried features - was brought together on what have been termed component sheets for the purposes of this project. An example is appended to the end of **Section 4**. For all the buildings on the site this will at minimum constitute a RCHME level 1 record. In addition to the recording of basic information on function and location, all known historic sources have been related to a particular component and the different elements of the RCHME survey. Here, too, cross-references to the National Building Record numbers of the extended reports by RCHME Threatened Buildings Section, to RCHME photography by negative numbers, and related information may be found. Information from a visit by Fred Walker, naval architect at the Royal Maritime Museum at Greenwich, to inspect the remains of powder barges on the site in August 1993 has been drawn into the report and archive. Creation of this consolidated archive formed the first stage in the post-survey process. Its results duly informed English Heritage staff in their assessment of the site and was drawn on as documentation for their designation proposals.

From June to December 1993 has seen the second stage of post-survey work in the writing of the archive report itself and preparation of supporting graphical materials. In parallel, and often in consequence, new information has fed into the archive through enhancements to the component sheets.

Running in parallel with RCHME's survey project was an active programme of demolition, decontamination and clearance carried out by the MoD through Royal Ordnance. Information and discoveries resulting from this that emerged while RCHME staff were on site is incorporated in the report. From June 1993 a site archaeologist, Adam Ford, was employed by MoD to advise them and liaise with Royal Ordnance activities. His direct use of the RCHME archive and good communication with the RCHME Keele staff have resulted in some subsequent discoveries being noted in the report where they add uniquely to understanding, but not in systematic up-dating since that is a continuing process whereas the RCHME survey was a single event.

The decontamination programme and beneficial reuse studies of themselves gave rise to a series of specialist reports about the North Site, which were made available to RCHME staff for information. Where relevant, they are included in the Bibliography at the end of **Section 1**.

A series of studies of the natural history and ecological importance of the North Site were undertaken in 1992 and 1993 with MoD funding and in consultation with English Nature. They extended to the whole of North Site and were not confined to the SSSI that occupied its northern, wooded half: Dr Bob Stebbings of Robert Stebbings Consultancy was the consultant. A tree survey was undertaken in 1992 by Higson Pearson Landscape Architects, with plans at 1:500.

This variety of activities and interests was brought together in a Liaison Committee, convened by CIVIX acting as MoD's planning consultants, which first met in December 1992.

During the course of the survey, RCHME staff became aware that the area of the Lower Island Works lying to the south between Highbridge Street and the M25, which from the beginning of the 19th century was an integral part of Waltham Abbey RGPF, survives as earthworks and buried remains. The area of survey was extended to cover this section of the factory, with the same survey procedures and standards except that the topographical control was supplied by Ordnance Survey 1:1 000 mapping via SUPERPLAN rather than data from Milton Keynes Surveys.

The southern part of Waltham Abbey RGPF was South Site on Quinton Hill, now lying to the south of the M25. It was developed only from 1885 onwards, and remained outside the RCHME survey project area in 1993. Limited large-format ground photography was taken of a few buildings on this site, principally to inform the recording of structures on North Site and to illustrate their functioning.

List of RCHME staff involved in the project

Project leader (responsible for on-site fieldwork, archive and report preparation)	Wayne Cocroft, Keele
Archaeological fieldwork, from	Adam Ford, casual Keele Jane Kenney, Cambridge Simon Loaring, period Keele Alastair Oswald, Cambridge Paul Struth, Cambridge Cathy Tuck, Keele
Architectural fieldwork	Robyn Burgess, Cambridge Keith Falconer, Salisbury
Photography	Dank Silva, Cambridge
Aerial photography	Roger Featherstone, Swindon
Graphics	Philip Sinton, York
Liaison/oversight/report editing	Paul Everson, Keele

Summary

Essex	**Epping Forest District**	**Waltham Abbey Parish**
TL 30 SE **	**Waltham Abbey RGPF (gunpowder factory)**	**TL 376 015**
TL 30 SE **	**Waltham Abbey RGPF (explosives factory)**	**TL 376 015**
TL 30 SE **	**Lower Island gunpowder works**	**TL 3763 0001**

Waltham Abbey Royal Gunpowder Factory was the location of gunpowder and latterly chemical-based explosives and propellants manufacture throughout a period of over 300 years. Within that period, it moved from private ownership into state hands in 1787. Following the Second World War, after manufacturing ceased in 1943, it became a research rather than a production centre and finally until its closure in 1991 the Royal Armaments Research and Development Establishment (RARDE).

Its position on the River Lea gave it abundant facilities to exploit water power that is typically the prime mover in early gunpowder production. The scope, too, for water-borne transport within the factory was thoroughly and characteristically exploited. It also throughout its life gave it ready access by water to the Thames estuary both for the import of raw materials and for the safe transportation of finished products to installations on the estuary such as the Royal Arsenal at Woolwich and the great late 18th-century gunpowder magazines at Purfleet (SAVE 1993, 51-61, 68). The development of navigation of the Lea (Fairclough 1992) was important to this factory as it was to others, like the Royal Small Arms Factory at the Brimsdown Works in Enfield on the opposite bank less than a mile to south (Putnam and Weinbren 1992, 5; SAVE 1993, 64-65).

Gunpowder production had evidently begun on the site by the mid 17th century, centred on a late medieval fulling mill. From its early origins the works quickly expanded into a purpose-built manufactory as reflected in Farmer's engraving in 1735 (Fig. 15), and during the 18th century became one of the principal suppliers of gunpowder to the Board of Ordnance. Government concern about the quality, quantity and reliability of gunpowder supplied by the private trade led to the establishment in 1759 of a first Royal Gunpowder Factory at Faversham in Kent by purchase of the Home Works, followed in 1787 by Waltham Abbey. This purchase by the government coincided with a periodic up-turn in the demand for gunpowder in the wake of the French Revolution and later stimulated by the Napoleonic wars. After an unprecedented period of expansion, which included the development of **Lower Island** as an ancillary part of the factory, the 1820s brought in a period of retrenchment with little new investment through to end of the 1840s. In contrast to the first half of the century the second half saw continual expansion and innovation. Many of the changes were inspired by the need to produce cannon powders for ever larger guns, and especially to manufacture moulded powders in large quantities.

The second half of the 19th century also saw experimentation with new chemically-based explosives, in the first instance guncotton. This was joined by cordite in the last decade of the century, which replaced gunpowder as the main service propellant by 1900. Around this date the majority of the former gunpowder buildings on the **North Site** and **Lower Island** were converted to cordite production. Despite this, some gunpowder continued to be produced until the end of the First World War for use as fuse powders.

With the shift to chemically-based products, in the 1880s the factory expanded its production facilities greatly by creating the **South Site** on Quinton Hill. Initially this provided more space for guncotton production in a specially-built complex that survives: a nitroglycerine and cordite factory were quickly added, however. With developments in the 1890s that established an acid factory and nitroglycerine plant on Edmonsey Mead towards the north end of **North Site**, the changeover to cordite production had effected a repolarisation of the factory. Prior to this date the manufacturing flowlines within the factory could be seen as operating from south to north, ending with finished products in the Grand Magazine at the extreme northern end of the factory. Now, wet guncotton was brought to and stored in the Grand Magazine and moved southwards during its manufacture into cordite. Peaks of production and refurbishment were naturally prompted by the First and Second World Wars: during the former the work-force rose to a peak of 5000, the majority women working shifts to secure continuous production.

Although not a high explosives factory, Waltham Abbey RGPF manufactured picric powder in the 1870s and 1890s, initially for the filling of shells and later for use in detonators. Production was first carried out in former gunpowder mills on North Site and Lower Island. Around 1910 the first plant in Britain for the manufacture of tetryl (C. E.) was established on North Site, later augmented by a second plant during the First World War. Between the wars, manufacture of picrite, used in flashless cordite, began along with RD202, a slow-burning fuse powder. Important work was also carried out on South Site in developing safe and efficient manufacturing processes for TNT and RDX.

Explosives manufacture at Waltham Abbey ceased in 1943 in favour of factories in the north and west of Britain further from the continent and airborne military threats. In 1945 the factory was taken over as a government research establishment, for a time with interests in the development of rockets and their propellants, which it remained until closure in 1991.

It was that closure and the moves to find a viable and beneficial reuse for the site that led in 1993 to the archaeological survey by the Royal Commission on the Historical Monuments of England that is reported here (see **Circumstances and methods of the survey** above). The survey concentrated in its detailed recording on the **North Site**, which encapsulates the location of the earliest gunpowder production facilities centred on the Millhead Stream as well as a wide range of later developments. It was extended in similar detail to take in the area of **Lower Island**, where earthworks mark the location of gunpowder and later production facilities that formed part of Waltham Abbey RGPF from the beginning of the 19th century. The **South Site** or Quinton Hill, added to the complex in the 1880s, remained outside the fieldwork remit, though a level of understanding of the processes and facilities there is necessary since it formed an integral part of the production cycle of the factory.

North Site covers 75 hectares (185.25 acres): during RCHME's survey 205 roofed buildings were identified ranging in size from large 19th-century steam incorporating mills to small early post-war locker magazines. A further 44 buildings survive as roofless ruins and another 95 building sites were identified from concrete floor slabs. It is also believed that around 125 buildings, including remains of the earliest mills on the site, survive as buried archaeological features within the bounds of the site. The **Lower Island** works cover about 3.5 hectares (8.65 acres) and there are thought to be the remains of 30 buried gunpowder processing building within its boundaries. These crude numbers conceal the common phenomenon that buildings and structures were often adapted and reused several times over in successive phases of the factory's activities. The buildings were linked by an extensive canal and leat network that in 1900 stretched to over 5 miles. This system survives partly as open waterways, partly as earthwork features, while other waterways have been filled and are lost as surface features. The communications system was augmented in the later 19th century by a tramway network, small sections of which remain in place and part of which gave a link under Highbridge Street to **South Site**. Power systems on the site changed from muscle and water, to steam, hydraulic, gas and electric, commonly employed in combination.

Of specific importance are the very full range of gunpowder processing facilities that survive or can be identified on site. Some, especially the earliest in the millhead area, are buried features with excellent archaeological preservation; others are standing buildings with machinery *in situ*. Of these, the water-driven pump and hydraulic press [L103] preserves an early form of hydraulic power system that pre-dates the application of a centralised hydraulic power system on site. Also the group of steam-driven incorporating mills, with underdriven power systems intact, in their scale and production capacity are unparalleled elsewhere in England and, in that they were built in groups successively over a period of years between 1857 and 1889, each exhibits design changes. Equally, if not more significant are the remains of chemical-based explosives production, which include complete complexes of self-contained chemical plant, through which processes can be followed and understood by reference to contemporary manuals and technical papers.

The importance of the site's having been in government hands for the last two centuries cannot be underestimated. Latterly its use as a research establishment has prevented casual access and vandalism, and in many instances has led to a remarkable degree of survival of unique buildings and pieces of machinery. Government ownership has also ensured that documentation has been preserved throughout that two hundred years, that allows an exceptional insight both into the technological and historical processes that have moulded the development of this factory. Complementing the written and drawn archive is an extensive photographic archive dating from the 1860s. The majority of early photographs were taken after explosions as part of the subsequent investigations and often usefully show machinery within buildings. As the premier gunpowder producing factory in Britain, many of the advances made in gunpowder production were initiated by developments at Waltham Abbey. This is especially true in the second half of the 19th century when much effort was devoted to the production of specialised powders in truly industrial quantities evidently to meet the demands of developments in armaments.

Later in the 19th century Waltham Abbey RGPF was closely associated with the Royal Laboratory at Woolwich as the leading centre for research into guncotton before it was accepted for service use. Waltham then became the sole government factory manufacturing guncotton, and many of its innovations were taken up by commercial manufacturers. In the early 1890s Waltham Abbey was the first plant to produce the new service propellant cordite: again much of the initial research work carried out here was passed onto the commercial producers. The pre-eminence of this work is illustrated by the fact that all the official handbooks on explosives manufacture used Waltham Abbey RGPF as their source and exemplar, often describing and illustrating in great detail the processes carried out here. The factory was internationally important, too, in particular influencing the development of the American gunpowder industry and early production of guncotton in Germany. To go beyond that simple assessment requires a wider study. For example, to set the solutions arrived at in Britain for the production of the specialised powders for large-bore guns in the late 19th century in a wider context one needs to look at the work being carried out in the state factories in Europe and America. Similarly the introduction of guncotton might be discussed in relation to work being carried out in Europe, in particular Austria. The introduction of cordite as a nitroglycerine-based explosive is tied to the development work carried out by Nobel and the Nobel Explosives Trust established between the explosives manufacturers of Europe. These research matters are, of course, additional to the contribution Waltham Abbey RGPF made directly to supplying Britain's armed forces with explosives in every major conflict for nearly three hundred years, and indirectly since 1945 through the products developed at the research establishment.

The importance of the remains of Waltham Abbey RGPF lie therefore in a combination of factors. In its early creation and successful development in commercial black powder production in the 17th and 18th centuries; in the context for investment, large-scale production and innovation over an extended time-span that its transfer into state hands gave from 1787; in the resultant survival of good documentation; in the 300-year continuum for gunpowder to chemically-base explosives; and in the totality of the site in the landscape. Though many of the buildings are individually unique, their importance is much enhanced by belonging to a wider context of structures and features that may be related to given production processes. Additional depth is given to these relationships through the detailed documentation surviving from the factory, which allows these connections to be seen set against time as new buildings or processes are introduced. The connections are physically manifest in the canal and tramway networks, the power transmission lines and steam heating pipes linking the factory together. The factory is therefore more than a collection of interesting buildings. It is a dynamic landscape that is capable of explanation through time as it developed from the mid 17th century. It is also a dynamic landscape in that it is capable of explanation through the flow materials between the various process buildings, which is also varied by time as new processes and products are introduced.

Within the study of the gunpowder industry in Britain, Waltham Abbey RGPF has a special place as one of a handful of very long-lived production centres of large physical extent. It is quite exceptional as a factory in state hands and devoted to production for military uses to have had its field archaeology recorded and studied in detail. The survival and recording of the later remains of chemical-based explosives production is to date without parallel.

Acknowledgements

A survey project as extensive as that at Waltham Abbey has drawn on the expertise and cooperation of many people within RCHME and outside.

Some have known the site at first hand for many years and have long valued its historical interest. Pre-eminent is Malcolm McLaren, formerly RARDE librarian, who added to his previous efforts in cataloguing and in many cases saving material relating to the former Royal Gunpowder Factory both by guiding us to the dispersed archives and by contributing to our understanding through his own knowledge. RCHME would also like to thank Dr Ken Bascombe, Chairman of the Waltham Abbey Historical Society and also a former employee of RARDE, for his advice and interest. Several members of the Gunpowder Mills Study Group took an early interest in the project and set us on the way with relevant information, including Professor Alan Crocker and Mrs Glenys Crocker, Keith Fairclough, John Boyes, and Dr Jenny West. We are also grateful to Tim Smith for his interest in the use of hydraulic power on the site in the 19th century and continuing discussions on the subject. Dr John Becklake at the Science Museum in London has responded to enquiries about post-War rocket and propellant research at Waltham Abbey and at Westcott, Bucks. Dr Mark Newell of the University of South Carolina has shared his knowledge of the Confederate Powder Mills at Augusta in Georgia in correspondence.

For making access possible to archives split between three principal locations, we are indebted to the individuals responsible in each case. At the Public Record Office at Kew, Miss Margaret Condon, Head of the Maps and Plans Department, kindly arranged direct access to unaccessioned material held in store at Hayes. Equally helpfully, Kate Carver and Susan Dalloe from Epping Forest District Museum facilitated work on archival deposits, especially historic photography, within their care. With many drawings of the individual buildings retained by the Ministry of Defence, we are especially grateful to David Stanners of the Defence Land Services (Central Disposals Unit) for granting access to this material and permitting selective copying. Staff at Fort Halstead responded to enquiries about holdings specific to Waltham Abbey that might exist in MoD hands. The staff at the library of the Royal Chemical Society gave helpful access to the important collection of papers on explosives gathered and deposited by F L Nathan, former superintendent of the Royal Gunpowder Factory.

Staff of Essex County Council Archaeology Section put us in touch with the valuable work done by Fred Nash, working as their consultant on the Second World War defences of the county, in locating the surviving land defences around Waltham Abbey RGPF. This work complements that of RCHME, whose survey was restricted to the confines of the factory.

Practical arrangements for site access were made through CIVIX, planning consultants to MoD, acting in a liaison capacity. Our thanks go particularly to Dan Bone of CIVIX for his help. On site, RCHME field staff benefited from the sensible guidance and goodwill of British Aerospace Defence/ Royal Ordnance Division through their site manager Graham Vincent and his deputy Trevor Wilson and from the practical help afforded by Alan Heath. The survey of the Lower Island works was made possible through the kind permission of Ed Andrews, manager of the southern half of the former RGPF.

We are grateful to the Ministry of Defence for agreeing RCHME's use of the survey data produced by their contract with Milton Keynes Surveys. Paul Bennett of Milton Keynes Survey and their project leader Stuart Dimond made the arrangement work by providing a flow of working plots, often at very short notice, and on completion supplying the electronic data on which the RCHME CAD diagram is based.

This project has seen excellent and effective working relationships with staff of English Heritage, notably with Dr Martin Cherry (Listed Buildings branch) and David Stocker (MPP) in the first instance over designation and latterly with Deborah Priddy and Oliver Pearcey, who are responsible for management issues.

The support of RCHME's Chairman and Commissioners has been essential to the project, since the work is undertaken on their behalf. In particular, those Commissioners with specialist knowledge of industrial archaeology, successively Professor RA Buchanan and Dr Marilyn Palmer, have given the work their every encouragement.

The survey was undertaken by RCHME field teams from offices at Cambridge and Keele; Jane Kenney, Simon Loaring, Alastair Oswald, Paul Struth and Cathy Tuck. The project relied heavily on the hard work of Adam Ford, acting as researcher, fieldworker and record compiler. The selection of more complex buildings were recorded by Robyn Burgess from RCHME Threatened Buildings Section, under the guidance of Keith Falconer, who also lent both advice as RCHME's industrial archaeological specialist and his enthusiastic support throughout the project. Dank Silva was responsible for the large-format photography, taking photographs both in difficult light conditions forced by the winter timetable and in unpleasant confined spaces within the buildings. He was also responsible for copying a number of archive drawings, in varied and less-than-optimum conditions. Low-level oblique photography of the site has been taken by Roger Featherstone of RCHME Air Photography Unit. The CAD-based archive diagram and maps supporting the report were produced by Philip Sinton at York, and Suzanne Ferguson at Southampton produced trial plots that contributed to the integrity of the final products. Mhairi Handley of NAR archives section handled a large volume of photographic negatives from the field, and arranged for the transportation and copying of a fragile glass negative collection from Epping Forest District Museum.

The principal day-to-day burden of the project fell on Wayne Cocroft, in supervising the on-site fieldwork, organising the resultant archive preparation, and researching and writing the report. Paul Everson acted as 'fixer and checker', dealing with liaison between the numerous external bodies and with the different RCHME sections and handling the voluminous amount of correspondence generated. He also edited the report.

Financial support from CIVIX/MoD in producing multiple copies of the report is gratefully acknowledged.

Bibliography

Cartographic Sources (listed chronologically)

ERO T/M 125	c1590	Copy map of Waltham Holy Cross, Epping and Loughton (Original at Hatfield House)
WASC 900/1	1783	'A Plan of the Powder Mills at Waltham and the Fishery on the River Lea the Property of Walton Esq.' (Surveyed 1783 additional information May 5 1836) Scale 10 Chains to approx 2.85" {Also PRO Kew MR 593}
WASC 900/1a	1783	'A Plan of the Royal Powder Mills at Waltham Abbey with part of the Land belonging thereto' Scale 1:900
WASC 900/58	1801	'Plan describing the whole of the land and its situation at Waltham Abbey belonging to the Board of Ordnance' (Tracing 1902) No Scale {also PRO Kew MR 580
WO78/1352	1806	'Map of the whole site including Lower Island' Scale ? {also PRO Kew MR 580 PFN/555}
WASC 900/4	1827	'Plan of several works and Buildings of the Royal Gunpowder Manufactory Waltham Abbey; required by the Board's Order of 5th Dec 1827 L/969, with an accompanying Report of their present State and appropriation' T Austen from a survey in 1821 Scale 200ft to 1" {also PRO Kew MPHH/271}
WO55/2694	1830	'Plan Shewing the Buildings and Land attached to the Gunpowder Manufactory at Waltham Abbey' Thomas Moody, Royal Engineers No Scale
WASC/5	1830	'Plan of the Royal Gunpowder Manufactory, Waltham Abbey' F Drayson Scale 800ft to 1"
WASC 900/7	c1835	'Extract form Holyfield Upshire and Waltham Tithe Apportionment, shewing in emerald green the position and present appropriation of Tithe Lands' Scale 1:2 500
OS	1844	Ordnance Survey 1st edition 1" sheet LXXII Brentwood north-west
WO55/3027	1851	Map accompanying 'Statements of lands and Buildings owned and hired by Ordnance' Vol 918
WASC 900/10	1861-8	'A Survey of the Lands and Buildings the property of the Ordnance at The Royal Powder Works Waltham Abbey, made in compliance with the Master General and Boards Order 6th June 1821' (Updated from 1821) Scale 200ft to 1"
WASC 900/13	1865	'Royal Powder Factory, Waltham Abbey General Plan' sheets 1 & 2 (Surveyed 1863 corrected May 1866) Scale 1:2 500
WASC 900/14	1870	'Royal Powder Factory, Waltham Abbey' (Surveyed 1863 corrected 1870) Scale 1:500 Covers both sides of the Long Walk
SUPP5/682	1871	No Title Scale 1:2 500
OS	1886	Ordnance Survey 1st edition 25" Essex XLIX.10 Scale 1:2 500

WASC 900/38	1888	'Royal Powder Factory, Waltham Abbey General Plan' sheets 1 & 2 (Surveyed 1863 corrected May 1888) Scale 1:2 500 {also PRO Kew SUPP5/682}
WASC 900/41a	1888	'Royal Powder Factory, Waltham Abbey' (Surveyed 1863 corrected Jan 1888) Scale 1:500 Covers both sides of the Long Walk
WASC 900/42	1888	'Royal Powder Factory, Waltham Abbey General Plan' (Surveyed 1863 corrected 1888) Scale 1:2 500 North Site and inset of Quinton Hill
OS	1897	Ordnance Survey 2nd edition 25" Essex XLIX.10 Scale 1:2 500
OS	1897	Ordnance Survey 2nd edition 25" Essex XLIX.10 Scale 1:2 500
WASC 900/79	c1900	'Royal Gunpowder Factory' Scale 1:2 500
SUPP5/361	c1900	'Bridge over River Lea at Hooks Marsh Bridge' Scale ? (N tip of RGPF only)
WASC 900/65	c1910	'RGPF Boundary, Notices, Fences, Booms and Telephonic Fire Alarm' Scale 1:2 500
WASC 900/70	1917	'Royal Gunpowder Factory Waltham Abbey' (June 1917) Scale 1:2 500
WASC 900/72	1917	'Royal Gunpowder Factory Waltham Abbey' (Sept 1917) Scale 1:2 500
WASC 900/74	1919	'Royal Gunpowder Factory Waltham Abbey' sheet 1 (1917, revised March 1919) Scale 1:2 500
WASC 900/80	c1920	'Royal Gunpowder Factory Waltham Abbey' Scale 1:2 500
WASC 900/84	1923	'Royal Gunpowder factory Waltham Abbey' (13th Sept 1917 revised March 1919, March 1923) Scale 1:2 500
WASC 900/87	1932	Royal Gunpowder Factory Waltham Abbey' (June 1932) Scale 1:2 500
WASC 900/91a	1940+	'Royal Gunpowder Factory Waltham Abbey' Scale 1:2 500
A - B.34	1954	No title Scale 1:2 500 (Held by MOD Chessington)
WASC 900/94	c1960	'Explosives Research and Development Establishment' Scale 112ft to 1"
Drg No.LSG/6	1960	'Waltham Abbey ERDE Record Survey' Scale 1:500
Drg No.LSG/7	1960	'Waltham Abbey ERDE Record Survey' Scale 1:500
Drg No.LSG/8	1960	'Waltham Abbey ERDE Record Survey' Scale 1:500
Drg No.LSG/9	1960	'Waltham Abbey ERDE Record Survey' Scale 1:500
Drwg No.P16	nd	'Royal Gunpowder Factory Waltham Abbey Plan of Portions of N.G. & C.E. Factories Edmonsey' (circa 1960? reusing earlier base plan?) Scale ? On-site working map collection
WASC 900/97	c1963	No title Scale 1:2 500 ERDE North Site
OS	1967	Plan TL 37 00 NE Scale 1:1 250
WASC 900/102		1972 'ERDE Waltham Abbey' (April 1972 OS sheet TL 30 SE) Scale 1:2 500

WASC 900/104	1972	'ERDE Waltham Abbey' (Updated from April 1972) Scale 1:2 500
WASC 900/113	1976	'PERME Waltham Abbey' (Updated from april 1972) Scale 1:2 500

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War Office	1907	*Treatise on Service Explosives* HMSO London
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Statutes at Large 1756, **29 George II, ch 16**; An Act to impower His Majesty to prohibit the Exportation of saltpetre; ....

Statutes at Large 1772, **12 George III, ch 61**; An Act to regulate the making, keeping and carriage of gunpowder within Great Britain, and to repeal the laws hereto made for any of those purposes

Public General Statutes 1860, **23 and 24 Victoria, ch 139**; An Act to amend the law concerning the making, keeping, and carriage of gunpowder and compositions of an explosive nature, and concerning the manufacture, sale and use of fireworks

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Supply 5 863	1940-1941	Photograph Album - RGPF Damage by Enemy Action
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The Royal Gunpowder Factory,

Waltham Abbey, Essex

An RCHME Survey, 1993

SECTION 2
DESCRIPTIVE REPORT

Contents

Essex	**Epping Forest District**	**Waltham Abbey Parish**
TL 30 SE **	**Waltham Abbey RGPF (gunpowder factory)**	**TL 376 015**
TL 30 SE **	**Waltham Abbey RGPF (explosives factory)**	**TL 376 015**
TL 30 SE **	**Lower Island gunpowder works**	**TL 3763 0001**

Introduction (Figs 1, 2)

Waltham Abbey Royal Gunpowder Factory (RGPF) lies to the north-west of the town of Waltham Abbey in Essex, in the valley of the River Lea or Lee (Fig. 1). The river and its canalised successors flow south to reach the River Thames and its estuary some 15 miles (24 km) away below Blackwall. This waterway has been historically navigable by sailing barge and has been subject to periodic improvement works for navigation and flood-water control up to the present day (Fairclough 1992 and references given there). Such water-borne access for raw materials and egress for finished products has been an essential aspect of the development of the factory and is typical of large-scale gunpowder production.

This report is principally directed at describing the northern part of Waltham Abbey RGPF, historically known as **North Site**, its southern limit defined by Highbridge Street TL 3768 0059 and to the north by the factory's Grand Magazine at TL 3762 0264 (Fig. 2). Also included within the account is a description of the part of the factory known as **Lower Island**, that lies between TL 3769 0055 on the south side of Highbridge Street and TQ 3770 9973 now just to the south of the line of the M25 motorway. An equally extensive part of the RGPF now to the south of the M25 motorway was known as the Quinton Hill Factory or more colloquially as **South Site**: it was developed only from the 1880s onwards. Though an integral part of the factory from this date, South Site lay outside the scope of RCHME's 1993 survey; in this report, therefore, reference will be made to South Site/Quinton Hill only where it is necessary to understand the processes carried out on North Site and its production flowlines.

The total factory extends for over 4km in a north-to-south orientation within the flood plain of the River Lea over recent alluvial deposits (BGS 1978), and the North Site alone for more than 2 km of that. The landfall is between 21m above OD at the northern end of the site to 19m above OD at the south end. The strong linearity of the factory, typical of many gunpowder works and created by the course of the river valley and exploitation of water as the principal power in the early factory, was reinforced by the need to space buildings for reasons of safety. The western boundary of North Site is defined by Horsemill Stream, a canalised and widened successor to a stream known as variously as Royal Powder Mill Head Stream, Mill River, The Gunpowder Mill Head and Millhead Stream. On its east, North Site is bounded by Cornmill Stream, also an artificial channel built to serve the medieval fishponds and watermills of the Augustinian abbey at Waltham (Huggins 1972, fig. 2), and further south by the Old River Lea snaking through the centre of the factory before emerging near the **Press House** [103] as the eastern boundary. The area of New Hill, extending to around 12 ha (30 acres) on the east side of Cornmill Stream was added to the factory only in 1940.

The series of interconnecting canals and leats crucial to the functioning of North Site will be discussed in the descriptive and analytical texts below and in Section 3. Their essence, however, is that they operated at two levels, high and low, with a vertical height difference of approximately 2m (6 feet) to give sufficient head to power the water mills in gunpowder production. Sluices, eg at Newton's Pool [276] and by the Water-Watchman's House [L102] reflect this difference directly. In their role as on-site transport arteries the levels came to be interlinked by locks and to the river outside the site. It seems probable that the two fundamental elements of the high level, namely Cornmill Stream and Millhead were both inherited from the monastic water engineering.

Much of the northern half of North Site is heavily wooded and has the status of SSSI. Some of this vegetation represents recent invasive colonisation of derelict sections of the factory and is heavily dominated by sycamore trees: but at the core of other sections of woodland is historic planting associated with the production of charcoal for gunpowder. The preferred woods for gunpowder charcoal include willow, alder and black dogwood (*Rhammus Frangula*). Grown-out coppiced woodland containing these species may be found across large parts of this northern area. Historic photographs show that pollarded trees extended down into the Lower Island Works. The wooded appearance of the northern area is therefore not unlike its appearance when the factory was in full operation. For coppice growth was encouraged not only for charcoal production but also as a elastic blast containment screen between danger buildings. Another interesting plantation established at Waltham Abbey early in the 19th century was one of walnut trees (Winters 1887, 66). The walnut wood was required for gunstocks at the Royal Small Arms Factory at Enfield.

The detailed core of this report lies in three principal sections; Site History and Description in **Section 2** and Analysis in **Section 3**. Each section has been written as a free-standing piece of text: some repetition of information may therefore be encountered in a reading from cover to cover. Bound separately in support of the report are A3-size extracts of the archive plan reproduced at a scale of 1:1 250 and organised in relation to areas defined on Figure 3, together with other maps and illustrations.

Throughout the text of the report the identifying numbers assigned to buildings and features may be cited in square brackets [ ]. The same identifying numbers are used on the 1:1 250 plan extracts: numbers with RCHME prefixes appear in italic on the plan extracts. All numbers cross-refer to the relevant component sheet. These in turn have been brought together in bindings or volumes by area of the site as defined on Figure 3 to form the archive resources lying behind **Section 4** of the report. A full list of the volumes in Section 4 provides a key to these.

References attributed to the Waltham Abbey Special Collection (WASC) refer the archive formerly held at the factory and now split in deposits of material held by Epping Forest District Museum and unaccessioned material held by the Public Record Office at Kew in their Hayes repository. Listings of this material are contained within RCHME's site archive.

The bibliography for the report is bound in **Section 1**.

Site history

Early history: private ownership c1650-1787

The land on which the Royal Gunpowder Factory now sits formerly belonged to Waltham Abbey; it passed to Sir Anthony Denny after the dissolution of the monasteries in 1535 (VCH 1907, 452). This tenuous connection between the abbey and the powders mills may in part lie at the origin of the persistent legend that the monks of Waltham Abbey were engaged in gunpowder making (Gray et al 1982, 3388). Despite continued antiquarian interest in this question since the 19th century no documents have been produced to support the proposition and remains a perhaps attractive but unsubstantiated legend. Equally persistent but inconclusive is the quotation of correspondence in State Papers concerning the negotiations between John Thomworth of Waltham Abbey and an Italian Marco Antonio Erizzo for the supply of saltpetre and sulphur - the two principal ingredients of gunpowder - and bowstaves to the government as evidence for the early establishment of the gunpowder industry in Waltham Abbey (*Cal State Papers 1561-1562*, 1; Winters 1887, 17). Thomworth, however, was not a producer gunpowder but an prominent figure at the court of Queen Elizabeth and was probably involved in some financial duties including trade: it is in this context that the correspondence with Erizzo is recorded with no implication of local gunpowder manufacture (Fairclough 1993, 3). In the late 16th century three water mills were documented at Waltham Abbey, a fulling mill and two other watermills (Winters 1887, 15). The existence of two of the mills is confirmed by a map 1590 (ERO T/M 125) that shows a fulling mill probably at the head of Millhead Stream and a mill close to the abbey church.

The earliest production centre for the manufacture of gunpowder within the parish was probably at Sewardstone, two miles south of the abbey church. Production began there in the 1640s and continued until around 1715 when the mills were converted to other uses (Fairclough 1985, 11-13). It is probably about these gunpowder mills that Dr Thomas Fuller, curate of Waltham Abbey, commented in the middle of the century that 'more (gunpowder) made by mills of late erected on the River Lea, betwixt Waltham and London, than in all England besides ... the mills within my parish having been blown up within seven years' (Fuller 1662, 165).

Within Waltham Abbey, the fulling mill identified as lying at the head of Millhead Stream had during the first half of the 17th century been converted into an oil mill. A deed of 1669 described the mill as 'all that heretofore an Oyle Mill and now lately converted into two powder mills ... with all necessary outhouses for grindinge boylinge corninge and drying of powder ... now in the tenure and occupation of Samuel Hudson or his undertenants'. It is uncertain when the latter took the tenancy on this mill, although they may be shown to have held the tenancy of the abbey mills between 1643 and 1673 (Fairclough 1985, 14). On present evidence it appears that the manufacture of gunpowder at Waltham Abbey started between the Civil War and the early Restoration period. In common with many other gunpowder works the initial development made use of a pre-existing mill, in this case an oil mill. Confirmation of the manufacture of gunpowder by 1665 comes from two sources. One is the first recorded death in the parish attributed to an accidental explosion within a mill: secondly, also in that year a contract was signed between Ralph Hudson, brother of Samuel and sub-tenant of the Waltham mills, to supply gunpowder to the government (Winters 1887, 18).

Increased demand prompted by the Third Dutch War of 1672-4 probably led to the building of new mills at Hooks Marsh Bridge, adjacent to the present Grand Magazine [1]. Complaints were brought against Ralph Hudson at the manor court in 1672 about these new mills, that were seen as a nuisance and a danger to the local inhabitants (VCH 1907, 452). Though he was ordered to remove them they were still standing in 1676, but Farmer's engraving of 1735 (Fig. 15) shows they had been removed by the early 18th century. Ralph Hudson died in 1676 and was described as an active powder-maker: the business passed to his son Peter. It was nearly twenty years, however, until he received a contract to supply the Ordnance Office with 500 barrels per year. Even this was a relatively small amount when the capacity of the works was estimated at 168 barrels per month or 2,016 per year and was judged to be the seventh largest in the kingdom in 1687. This compares to the 1,000 barrels per month that the largest gunpowdermaker at Chilworth in Surrey was able to produce at this date (Tomlinson 1979, 117). However, Peter Hudson's political sympathies lay elsewhere and during this period he supplied William Duke of Orange with 400 barrels of powder. His support was rewarded in 1689 with a contract to supply the Ordnance with 1,000 barrels over a six-month period. This lucrative contract continued until July 1693, for in that year a Treasury official recommended that he be prosecuted for supplying bad powder. Though the prosecution was dropped through Hudson's lobbying, he received no more government contracts. It is uncertain for how much longer after the loss of the Ordnance contract Hudson remained in business at Waltham Abbey, for by 1702 William Walton had taken over the works and signed a contract with the Ordnance. This was an fortunate moment to enter the business with a periodic upturn in demand caused by the War of Spanish Succession of 1701-15, through which Walton rose to be one of the principal suppliers to the Ordnance (Fairclough 1985, 15). On his death in 1733 his wife Philippa took over the business, which she managed, latterly with her son John, until her death in 1749 aged seventy four. Farmer in 1735 noted that the 'curious Gunpowder Mills, which supply the nation with great quantities of gunpowder, being esteemed the largest and completest works in Great Britain, and are now the property of Mr John Walton' (Hodgetts 1909, 318). Gunpowder was an uncertain business in many ways; setting aside the dangers inherent in manufacture, the market presented particular problems. In times of peace the producers were forced to rely virtually entirely on private markets, in particular the merchants and the mining industry, while in times of war they were pressed by the government to increase both the quantity and quality of their output. The Waltons' business was no exception, since they acted as contractors in time of war and indeed proposed that they should solely make powder for the Board for a number of years and no powder for private sale without the Boards permission (West 1991, 73-4). Work for the Board also involved the reworking or repair of damaged powder stored by the Board, in order that it could be returned to service (West 1991, 27).

The Waltons' mills were one of around ten supplying gunpowder to the Ordnance Office and as such employed the most up-to-date methods of manufacture. Peter Muilman in his *New and Complete History of Essex* in 1770 wrote of the factory of 'several curious gunpowder mills, upon a new design, 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' (VCH 1907, 453). A few years later the engineer and pre-eminent improver of mills of late 18th century, John Smeaton, was engaged to draw up plans and elevations for new mills at Waltham Abbey (Wilson 1957, 41). The business passed through the family to Philippa's great grandson, John Walton, who entered into negotiations with the government in 1787 regarding the sale of the works (West 1991, 209-210).

Government ownership 1787-1945: The Royal Gunpowder Factory

The government's purchase of the factory at Waltham Abbey had a background of concern about the quantity and quality of powder supplied by private manufacturers that dated back to the Seven Years War of 1756-63. The government at first tried to improve supply by limiting private trade in saltpetre and gunpowder (George II 1756). They also tried to lessen their dependence on the private producers with the purchase of the Faversham Mills in 1759 (West 1991, 149). In that case, the early years saw production increase, although the quality remained poor, often below that of many of the private producers (West 1991, 218). However, a large proportion of the work at Faversham was directed at the reworking or repair of unserviceable powder from the Greenwich magazine (West 1991, 162). In 1783, in an attempt to reduce government spending, Prime Minister Pitt had been about to recommend the sale of the Faversham factory after representations from the private manufacturers claimed that they could produce powder in greater quantities and of better quality. This was rebuffed by the Board of Ordnance chiefly through the efforts of Major Congreve, who was able to show that gunpowder manufacturing in government hands could be a profitable proposition (Simmons 1963, 11; West 1991, 167). Not only were the Faversham Mills saved but negotiations were put in hand with view to acquiring the factory at Waltham Abbey, well known to the Board as one of its largest suppliers in time of war. The final settlement of the contract for the purchase of the factory between John Walton and the government was not signed until 1795 (West 1991, 210), although the government had been active at the factory since 1787 (Simmons 1963, 11-16). Waltham Abbey thereby joined the mills at Faversham to become the second government owned gunpowder factory, and a third Royal Gunpowder Factory was established at Ballincollig near Cork in 1804 (Kelleher 1993, 32). Links between the two English factories were close: workmen were sent to Faversham to learn how to make gunpowder, and runners (millstones) were brought from the Faversham works for use at Waltham Abbey (Winters 1887, 28-30). Men from Faversham were also transferred to work at Waltham Abbey and to establish the working procedures practised at Faversham (WASC 1007, 1406). Those transferred in the early years included the master worker Mr Newton (WASC 1408), who occupied the former **Turnpike and Chequer Inn** [RCHME 304] as a private residence and gave his name to **Newton's Pool** [RCHME 276]. The mills at Waltham Abbey were put under the command of Major William Congreve, Deputy Comptroller of the Royal Laboratory at Woolwich, the day-to-day running of the factory under the supervision of James Wright, storekeeper. Congreve quickly set about the refurbishment of the mills, spending £35,000 on this work - a considerable sum when set against the purchase price of £10,000. The scale of this refurbishment may also be measured by the fact that production did not resume until February 1789 (Simmons 1963, 12). New construction work included a new Mixing House and Saltpetre Mill opposite the Master Worker's house, Walton's House and new gloom stoves (Winters 1887, 29). No formal description of the factory that was made when it was taken over by the government is known to exist: however Frederick Drayson begins his *Treatise* of 1830 with a brief account of the acquisition (PRO Supply 5/762). In this he says there were ... one saltpetre refinery, one horse composition mill, one mixing house, seven gunpowder mills, one corning house worked by horses, a dusting house and two gloom stoves. By 1789 when production resumed under government control there were ten operating gunpowder mills, horse mills for the initial processing of sulphur, saltpetre and charcoal, a sulphur and saltpetre refinery, a horse corning mill and a charcoal pit (Simmons 1963, 28).

The time at which the government took over the works coincided with an almost continuous period of warfare in the aftermath of the French Revolution in 1789. This led to a considerable expansion in the size of the works, with enlargement of the canal system and many new buildings being added. Technological improvements in gunpowder manufacture caused the adoption of cylinder charcoal in place of pit-burnt charcoal in 1794, at this date brought to the factory by barge at first from Fisher Street and Fernhurst, Sussex and later from Faversham, Kent (Winters 1887,40). In 1795 experiments were under way with a steam stove for the drying of gunpowder in preference to gloom stoves (Winters 1887, 46): the Steam Stove was at first applied drying damp powders returned from Naval ships. A purchase of twelve millstone runners and six bedstones in 1796 may further imply the construction of three new double mills or else it may simply represent refurbishments of older mills (Winters 1887, 52).

Such was the demand at this time for powder that in September 1804 the Board of Ordnance approved the construction of six horsemills and stables, followed in October by approval to build a further three horsemills, to enlarge the Mixing House and to build a magazine capable of holding 1500 barrels (Winters 1887, 62). The horse mills were a war-time expediency, and had by 1806 filled Horsemill Island, lying to the west of Millhead Stream

(WO78/1352). An engraving of the powder works from the west in Dr Hughson's *Description of London* published in 1808, shows the nine horsemills in place with the stables to the south and three small charge houses. The use of horsemills had the twin advantages of being less costly to erect than water-driven mills and, probably more importantly, of not putting any more demand on the flow of water through the site. Concern about water rights and the supply to the mills led in 1805 to the purchase of Cheshunt cornmill to the north and Waltham Abbey cornmill, adjacent to the abbey church, in 1809 (Winters 1887, 64, 66). During this period two horse corning mills were added at the end of new canal cuts east of Millhead Stream and another steam stove.

In addition to the expansion around the old works, a new works - the Lower Island Works - was established in the early years of the 19th century between 1801 and 1806 (see figures 2, 6-7). Initially three mills were constructed on the central island: by 1827 two additional mills had been built to the east and a new sulphur refinery had been added to the north along with a group of store buildings on the south side of Highbridge Street (WASC 900/04).

The improvements to the Waltham Abbey RGPF under the direction of William Congreve were continued by his son, also William, who succeeded him in 1814 as 2nd baronet and Comptroller of the Royal Laboratory at Woolwich. Included in his duties was the supervision of the government gunpowder factories. William was a noted inventor, whose most noted invention was the Congreve rocket. He was also active in the development of new machinery for gunpowder manufacture. In 1815 he took out patents for a machine to mix the ingredients of gunpowder in as near-perfect a mixture as was possible and for another to granulate the powder once it had been pressed (*Gents Magazine* 1828, 178-9). Both machines were introduced at Waltham Abbey. The mixing machine ensured that a consistent charge of powder was supplied to the mills for incorporation : the granulating machine had advantages in terms of the safety of the workers, as it could be left without supervision and was able to produce a more uniform powder grain more efficiently than the previous hand methods. The granulating machine was installed one of the Lower Island mills, remaining in service until at least the 1840s (Winters 1887, 83).

A list of works and repairs proposed to be carried out at Waltham Abbey in 1814 provides a useful snapshot of the full war-time establishment of the factory. To ensure the purity of the ingredients the Board refined its own saltpetre within its own refinery on site. Surprisingly, no mention is made of a sulphur refinery at this date, although sulphur mills are shown on near-contemporary maps and additionally Coleman in his description of the manufacture of gunpowder in 1801 states that the sulphur was refined at the Waltham Abbey factory. The most logical explanation is that the refining of sulphur took place within another building that was identified under a different name. Cylinder charcoal was at this date manufactured in Sussex, although only Fisher Street was mentioned by name as a works where expenditure was required. The gunpowder was mixed in one of five composition mills and incorporated in one of eleven water-powered mills or nine horse-powered mills that were in operation. Additionally another two water-powered mills of unspecified function are described as lying on Millhead. Further processing took place in the four Corning Houses, before the powder was dusted and glazed and finally dried either in one of the two Gloom Stoves or in the more advanced Steam Stove. Four receiving magazines, six charge magazines and the Grand Magazine were provided for the temporary storage of powder. A figure is also quoted for the erection of four water-driven mills for grinding charcoal and an associated reservoir. The gunpowder was moved between the process buildings by a flotilla of boats, comprising five barges, nine powder boats, two ballast barges and six punts. Also attached to the factory were a number of ancillary buildings made up of store houses and lodgings (Winters 1887, 78).

At the height of war-time production 250 men had been employed at the factory in 1813. The total collapse of demand for gunpowder at the end of the Napoleonic Wars caused the work force to be reduced to 34 by 1822 (Winters 1887, 89). This is also reflected in the production figures that reached a wartime peak of 22,398 barrels per year in 1813 (Winters 1887, 74) but declined to 988 barrels per year in 1819 (Winters 1887, 86). The figure for newly-manufactured powder fell even more in the 1820s, although more powder was regenerated. By the end of the decade the decline of the factory had reached such a pitch that a committee was established to finds ways of improving its efficiency. It reported that two old water mills (probably those at the head of Millhead), nine horsemills and two horse corning mills had been demolished at the end of the war and that many of the remaining structures were unstable or worn out. The stock of the factory at this date was five gunpowder mills, one composition mill, a breaking down mill, three corning houses, a glazing house and a dusting house (Simmons 1963 35). Around this time also, Frederick Drayson produced his remarkable *Treatise* accompanied by finely detailed plans and elevations of the buildings of the factory and the machinery and utensils (PRO Supply 5/762 and MPII.15). This was in part a record of the practices on the site at this time and in part a proposal on how the processes could be improved. This included suggestions for constructing ten new gunpowder mills on Queens Mead east of Millhead with five new charge magazines (PRO MP 11.15, 37). None of these particulars were implemented and it is uncertain if any of his other suggestions were acted on either. The committee's recommendations were largely concerned with the internal workings of the factory rather than new building. They did nevertheless recommend that the charcoal cylinders at the Faversham factory be brought to Waltham Abbey.

These minor works were very much in the spirit of retrenchment prevalent in the Board of Ordnance at this date. In 1825 the Home Works part of the Royal Gunpowder Factory at Faversham had been sold to John Hall. John Hall gained control of all the Faversham factories when he leased the Marsh Works from the Board in 1832, buying them outright in 1854 (Percival 1986, 11). The Royal Gunpowder Mills at Ballincollig Ireland were similarly investigated by the Board of Ordnance in 1828, though no immediate decision was made on their fate. In November 1831 the board decided to move some of the machinery from

Ballincollig to Waltham Abbey and this was completed by the following March. The mills were sold a few years later to a partnership Horsfall, Tobin and Company, known two years later as Ballincollig Royal Gunpowder Mills Company (Kelleher, 1993, 35-45). By this date Waltham therefore became the sole Royal Gunpowder Factory and with the Royal Laboratory at Woolwich the centre of government explosives research and development.

The period following the committee's report saw little development on the site and apparently little technological progress in the manufacture of gunpowder. Gloom stoves remained standing if not in use within the factory and screw presses also continued in use, despite their danger. The most notable technical advance at this time was the building of the new charcoal cylinder house at Waltham, albeit at the expense of the Faversham works. This gave Waltham Abbey RGPF for the first time the ability to produce its own cylinder charcoal, and experienced cylinder house staff were transferred to the factory to operate the plant (Winters 1887, 102). Whether any use was made of the machinery from Ballincollig is uncertain: no increase in the number of buildings is suddenly evident around this date, but it may have been used to refurbish existing buildings. A short account of the works in 1838 by Antoine Bidermann (Bidermann 1838) describes no new features, not even the Bramah hydraulic presses that had certainly been installed in the Lower Island mills, which may suggest that his access was restricted. Some work was carried out in the 1840s, as a new granulating machine at a cost of £2000 was constructed and improvements were recommended for the Dusting and Glazing Houses. Correspondence in 1845 refers to the erection of five incorporating mills and the laying of two hydraulic pipes and in 1847 a new iron mill (Iron Duke) was finished (Winters 1887, 108-9). Even with these minor improvements the future of the factory throughout this period remained uncertain, for in 1845 an order, never apparently carried out, was received for its closure (Winters 1887, 108). The low level of activity is further confirmed by the sale of nine mill stones for £90 to the powder manufacturers Messrs Hall in 1848 (Winters 1887, 110). Around the middle of the century, water-driven hydraulic pumps were introduced for the pressing of gunpowder in place of manually operated presses. One survives as L103.

This picture of relative inactivity before about 1850 contrasts with one of continual growth and expansion throughout the remainder of the century. This strikingly illustrated by the production figures: in 1853 the factory was capable of producing of 10,000 barrels of gunpowder, compared to the 27,580 of large grain or 13,690 barrels of fine grain gunpowder it was capable of producing by 1870 (VCH 1907, 454). The demands placed on the factory were also far greater. During the Crimean War the largest gun in use on land or at sea was a smooth-bore 68-pounder taking a charge of 16 pounds of black powder. This contrasts with thirty years later when the largest guns afloat at 110 tons were using a charge of 960 pounds in weight of prismatic gunpowder (Lewes 1915, 821). This represents a sixty-fold increase in the amount of powder required for the largest guns. Each 960-pound charge represented just over 19 production charges from an incorporating mill, since individual mills were restricted to working no more than 50 pounds of government powder at any one time.

The lessons learnt from Britain's poor military performance in the Crimean War proved to be a catalyst for reform in the Army and its supply. Developments at Waltham Abbey RGPF were intimately connected, therefore, with rapid advances in other fields notably the heavy engineering industry, which was able to manufacture ever larger guns with rifled bores and huge and specialised appetites for gunpowder. The mechanisation of parts of the gunpowder process through the introduction of steam power, too, was mirrored in other military manufacturing such as the Royal Small Arms Factory at Enfield, that was completely remodelled at this period too (Putnam and Weinbren 1992, 32).

While the Congress of Paris was meeting at the close of the Crimean War, the foundation stone was laid of the first steam-driven gunpowder incorporating mills on Queens Mead, followed a few years later by another group on Lower Island. The use of steam power liberated the milling process from the vagaries of water supply and that at a time when increasing demands were being placed on the waters of the Lea for by other users, especially the water companies. Over the next thirty years a further five steam incorporating mills were built on North Site in addition to the group at the northern end of the Lower Island Works. By 1870 there were thirty-two pairs of incorporating mills working within the factory powered by water and steam (Simmons 1963, 38). The adoption of steam power also saw the canal network supplemented by a tramway system to move the gunpowder between the various process buildings. The trucks were propelled around the site either by men or, as at the turn of the century, by boys (Arkas 1900, 417).

As the first half of the century had been characterised by relatively little change in the way powder was manufactured, the second half of the century witnessed increased experimentation in improving the performance of gunpowder. Not only did the larger guns of the late 19th century require a far greater charge of powder, they also required specialised powders where the rate of burning was controlled. Experiments were also taking place with different types of powders and the moulding of gunpowder into differing shapes (pellet, pebble and moulded powders are discussed in the Appendix). It was to address these needs that the major refurbishment of the factory took place in the late 1870s. At this date there was a marked expansion in the high-level canal system and new buildings were introduced which increased the capacity of the factory and gave it the ability to produce the specialised moulded gunpowders for use by the services. The requirements for the operation of the new moulding and press machines within the factory led to the introduction of a centralised hydraulic power system. By this date hydraulic systems were a tried and tested technology having been widely used in docks since the 1850s (Richie-Noakes 1984, 121-8; Smith 1991, 64-88). The investment required in the system and the specialised forms of gunpowder produced by the presses ensured that it was a technology that was very restricted in its application and found little use amongst the private manufacturers. Running side-by-side with the introduction of moulded powders were experiments with 'brown' or 'cocoa' powder, where burnt rye straw was substituted for wood charcoal, also used in moulded form in large bore guns. Brown powders were first introduced from Germany in 1883 and production started at Waltham Abbey RGPF in 1885 (VCH 1907, 455). Waltham Abbey RGPF, along with the Chilworth Gunpowder Company in Surrey - acquired in 1885 by the German Company Koln-Rottweiler specifically to produce brown powders for the British market (Reader 1970, 131) - and the Tonbridge works of Curtis Harvey's Ltd, became the only English manufacturers of moulded brown powders (Hodgetts 1909, 357). These new slower-burning powders, in releasing energy not only at the point of ignition, where it would exert great force on the breech block, but along the whole length of the barrel, presented new opportunities to the armament manufacturers. The most notable advance was the adoption by Britain of breech-loading weapons designed by Armstrong and Woolwich, and as early as 1883-4 the army was provided with field guns of this new design (Newbold, 1916, 27, 43). The moulded and brown powders represented the end of the road for gunpowder as a propellant and were superseded within the decade by chemically-based propellants.

Throughout this period when a more scientific methodology was brought to the production of gunpowder, it is extremely fortunate that the processes were detailed in a series of handbooks and pamphlets published by the staff of Waltham Abbey RGPF. The earliest of these, written by Major Baddeley in 1857, was produced as an *aide memoire* for the officers of the factory and was privately published. From 1870 onwards with the publication of Captain Smith's handbook, the books were published under the auspices of the War Office. In addition to acting as manuals about the manufacture of gunpowder, these handbooks were also intended to inform officers in other branches of the services about explosives. In doing so they detailed the processes carried out at Waltham Abbey RGPF, often providing line illustrations of the machines used within a particular process building. From 1888 the manufacture of guncotton was also included. From the late 1890s the manuals were updated at regular intervals and were known initially as a *Treatise on Service Explosives* and later as the *Text Book of Explosives*. The description of the manufacture of gunpowder remained virtually unaltered from the 1888 handbook, but those of the manufacture of high explosives were continually updated as new products and processes were introduced at the factory. The swansong for gunpowder production at Waltham Abbey appears in an article written for the *Strand Magazine* (Fitzgerald 1895, 307-18). In this piece the atmosphere of working in the factory during the last few years of gunpowder production is captured even as the change-over to chemically-based explosives was taking place.

The improvements introduced by successive superintendents and the standards to which gunpowder was produced at Waltham Abbey RGPF played a important part in the world-wide reputation for the quality of British powder. In the period since the government acquired the factory, the charge of gunpowder was reduced from half the weight of the cannon ball to less than one third. Two barrels were used in place of three previously, allowing more powder to be stowed on board ship or taken into the field. There was also a corresponding increase in the range achieved by the powder from 190 feet to 268 feet. The RGPF also acted as a model mill, whose products set standards for the industry and acted as bench-mark against which the price for powder paid by the government could be judged

(Wynter 1858, 246-7). In this manner the RGPF acted in the same way as the Royal Small Arms Factory at Enfield, that was seen by the Board of Ordnance as acting as 'a check on the trade' (Putnam and Weinbren 1992, 21).

The reputation that the RGPF had gained by this date may partly be judged by the high regard in which it was held by foreign producers, in particular the Americans. In 1858 the American blackpowder manufacturer, Lammot Du Pont, visited Europe including England. As the principal contractor to the United States government, Du Pont was particularly interested in the manufacture of cannon powders. He had Waltham Abbey RGPF high on the list of the places he wished to inspect, therefore, having also seen a number of provincial mills, as the Waltham Abbey works had a unique expertise in that sphere. Indeed, for the certain periods during the Crimean War of 1854-56 the sole output of Waltham Abbey RGPF was cannon powder (*ILN* 1854, 479). In his tour of the factory he was especially impressed by the new granulating machine, of which he remarked 'decidedly the best granulating machine in England and Europe' (Wilkinson 1975, 94). This may be identified as the machine installed in 1845 at a cost of £2,000 and known as Granulating Machine number 2 in 1866 (Winters 1887, 108).

Shortly after his return to America, the Du Pont factories were supplying gunpowder to the Unionist forces during the Civil War. The influence of Waltham Abbey RGPF on the American Civil War was not be one-sided, however; for Major George Washington Rains, charged with supplying the Confederate side with powder, recorded that he had the 'singular good fortune' to come into possession of a copy of Major Baddeley's (misrendered 'Bradley's') pamphlet on gunpowder manufacture (Rains 1882, 8). He noted that the processes and machinery at Waltham Abbey RGPF were 'the best existing in any country', but regretted the absence of drawings of the buildings and machinery. This view was shared by his enemies on the Unionist side, the United States Ordnance Manual of 1862 being of the opinion that British gunpowder was the best available (McLaren 1975, 180). The Confederate side also employed a former workman from Waltham Abbey, a man named Wright 'sadly defective in a certain way' (Rains 1882, 8), at their Manchester powder works and their principal Confederate Powder Mills at Augusta. How far the design of the new steam-driven mills in England influenced the design of the incorporating mills at Augusta is unclear. Construction probably began on those mills late in 1861 or early 1862 and they appear to have had some similarities of layout and details. The main incorporating mills were driven by a 130 hp steam engine, placed centrally with six mills bays to either side: as in [L168] at the Waltham Abbey factory, the mill bays faced alternately in opposite directions. Further similarities included an underground drive shaft placed in a tunnel and a drenching tub over each incorporating machine (Rains 1882, 18-19). Rains also experimented with improving on the Waltham Abbey processes. He felt that the pressure the powder was subjected to beneath the incorporating mills was sufficient to dispense with the need for pressing, although he retained two hydraulic presses. He also aimed to save time by combining the glazing, drying and dusting processes into one operation using a heated glazing barrel (Rains 1882, 23).

At Waltham Abbey RGPF, from 1862 development of more potent chemically-based explosives, described in the next section, ran in parallel with the advances in the production of gunpowder. It was not until 1889, however, that a usable alternative was found to gunpowder in the form of cordite - a mixture of guncotton, nitroglycerine and mineral jelly. Within the decade cordite had virtually superseded gunpowder as the main service propellant, except for the needs of a number of obsolete artillery pieces. By 1898 the majority of the gunpowder processing buildings had been adapted for the production of cordite. By 1907 the factory was producing around 2,000 tons of cordite, 200 tons of gunpowder and 150 tons of guncotton per year. It had expanded to cover 411.25 acres (160.5 hectares) by developing the South Site and occupied three hundred separate buildings served by around five miles of navigable waterways, with a workforce of 1200-1300 (VCH 1907, 455).

Small amounts of fine-grained gunpowder did continue to be produced in the old mills along Millhead for use as fuse powders for the initiation of chemically-based explosive charges. Until at least 1920 the whole of this remaining gunpowder facility was active (Blee 1959, 243): but archive photographs show piecemeal demolition of gunpowder buildings between the wars. Other process buildings such as the water-driven hydraulic Press House [L103], although still standing, appear semi-derelict in photographs taken in 1940. The capacity of Waltham Abbey RGPF to produce gunpowder was finally ended in 1941 when the last pair of powder mills were severely damaged by enemy bombing (Gray et al 1982, 3395). Although in a bomb-damaged state, buildings on Millhead Stream remained standing until 1956, when superstructures were demolished and foundations were covered with a levelling of earth (Simmons 1963, 113).

Development of the chemical explosive industry at Waltham Abbey RGPF 1862-1945

Alongside the development of new types of gunpowder in the late 19th century ran experimentation into chemically-based explosives and the advancement of the chemical industry. Generally, however, it was many years after initial discoveries before practical applications could be found and safe and efficient manufacturing processes devised. Indeed to many contemporary scientists it might have appeared that improvements in gunpowder technology was the only way forward in developing more effective propellants.

In 1846 Professor Schobein of Basle University had announced his discovery of guncotton, created by the action of a mixture of nitric and sulphuric acid on cotton (Simmons, 1963, 39). John Hall and Son of Faversham were quick to obtain the British patent and in the autumn of the same year established the first guncotton factory in the world at their Marsh gunpowder works at Faversham (TR 06 SW 64). This early enterprise was abruptly halted by a disastrous explosion on 14 July 1847, in which twenty people lost their lives (Percival

1986, 11). In consequence, and coupled with a series of explosions at French guncotton factories, interest in guncotton as an explosive declined. Research was nevertheless continued by Baron von Lenk, an Austrian artillery officer, under the aegis of the German Confederation and achieved some success in the use of guncotton as a propellant. Interest in Britain was rekindled in 1862 by an offer from the Austrian government to communicate the process of manufacture devised by von Lenk. Dr (later Professor Sir Frederick) Abel as the War Office chemist and Major Young travelled to Vienna to inspect the von Lenk plant. Early in the following year Abel was directed by the Secretary of State for War to investigate the manufacture of guncotton and its composition when manufactured on an extensive scale (Abel 1866, 273). To this end an experimental plant was established at the Waltham Abbey RGPF in the old **Saltpetre Refinery**, adjacent to the Highbridge Street entrance: analysis of the products was largely carried out at the Royal Laboratory at Woolwich. In this work great emphasis was placed on the purity of the product, the aim of research being to produce grains that could be used as a propellant. Parallel research was also being conducted in the private sector, notably by Messrs Prentice at the Great Eastern Chemical Works at Stowmarket, where they began to manufacture guncotton on 26 January 1864 (Earl 1978, 147). The innovation of pulping the guncotton in order that it could be moulded by hydraulic presses introduced by Abel was of particular importance. This gave guncotton the potential for use in torpedoes, mines and blasting charges. The problem of detonating guncotton was solved by research work at Woolwich, which identified fulminate of mercury as a suitable initiatory explosive. After ten years of research the manufacturing process had been developed to a stage where full production could commence and the properties of guncotton were sufficiently understood for it to enter into service use. Production began in a group of buildings formerly occupied by the **Saltpetre Refinery** (Simmons 1963, 40-43). The early hopes that guncotton might be used as an alternative propellant to gunpowder were not realised. Its principal use was as an explosive in the form of compressed slabs or discs in mines and torpedoes and where rapid demolition was required on land or underwater (Wardell 1888, 76).

The discovery of other powerful chemical explosives was announced by the Italian chemist, Professor Sobero, in 1847. The three substances were nitroglycerine, nitromanite and nitrolactose. It was through the development work of Alfred Nobel, however, and his discovery that nitroglycerine could be detonated by fulminate of mercury, that the full potential of nitroglycerine as an explosive was realised. Its extreme sensitiveness prevented its transportation in liquid form; but Nobel was able to solve this problem by infusing a silicious earth '*kieselguhr*' with nitroglycerine, creating dynamite (Wardell 1888, 85-6). He went on to develop blasting gelatine, in which soluble nitrocellulose was gelatinised by nitroglycerine. The ferocity of explosions created by all these compounds nevertheless made them unsuitable for use as propellants as they would burst the barrel of the gun. Elsewhere in Europe the search for a smokeless powder had concentrated on nitrocellulose products. Colonel Schutze, an Austrian, produced a smokeless powder based on nitrated wood fibre and in 1884 a Frenchman, Vielle, produced a nitrocellulose powder known as Poudre B that was accepted by the French authorities (Reader 1970, 140). Nobel's researches continued and he found he was able to moderate the explosive effects of guncotton by the addition of nitroglycerine. This explosive was called 'Ballistite' and was composed of 45% nitrocellulose, 10% camphor and 45% nitroglycerine. Ballistite was first patented in France in 1887 and experimental production began in Nobel's Italian factory in 1888. It was against this background that the British government set up the Explosives Committee in 1888 under Professor Sir Frederick Abel, War Office chemist, Professor James Dewar and Dr August Dupre to advise the War Office on smokeless powders. The committee took evidence from a wide range of people working in the field including Nobel and within six months of their appointment patented a substance known as 'cordite' in April 1889. This consisted of 58% nitroglycerine, 37% trinitrocellulose (guncotton) and 5% vaseline, the mixture being blended together using acetone. The speed at which the committee had come to its results essentially through using the work of others and the patent arrangements whereby the members of the committee were allowed to take out and personally benefit from the foreign patents of their invention became known as the 'Cordite Scandal' (*The Times* 1893, 4). Nobel brought an action against the British government for infringement of patent, but the case was lost as cordite used a nitrocellulose of a higher degree of nitration known as 'insoluble' compared to Nobel's use of 'soluble' nitrocellulose (Reader 1970, 142-3).

Cordite had the advantage over contemporary alternatives that it produced a greater muzzle velocity than that of ballistite, but had the drawback of creating more barrel erosion (Roos 1894, 5). It also proved to possess a further advantage over the nitrocellulose powders in that it was found to be more stable under service conditions. This was graphically illustrated by accidental explosions in ships of two of the powers that had adopted nitrocellulose powders. In 1898 the American ship the 'Maine' was lost in Havanna harbour and later the French ship the 'Liberte' was also destroyed in an accidental explosion. In both instances the cause of the explosion was attributed to an attack by organisms on the nitrocellulose powder that had caused decomposition within the explosive (Hall 1915, 55).

Growth in the military demand for guncotton led in 1885 to purchase of land to the south of Lower Island known as Quinton Hill for the construction of a new guncotton factory. The purpose-built Guncotton Factory was completed by 1889 and production began in 1890. Research work into cordite had until this date relied on extracting nitroglycerine from blasting gelatine: the break-through with cordite and plans to produce it in quantity demanded that a nitroglycerine plant be established at Waltham Abbey RGPF. At this date too, therefore, an area for producing cordite was established on the new site to the south of the Guncotton Factory. Such was the urgency that Colonel Noble, superintendent of the RGPF, was dispatched to inspect the plant of the Rheinische Dynamitfabrik at Opladen near Cologne, part of the Nobel group. The plant used in the construction of the first nitroglycerine factory on the South Site was also imported from Germany (Simmons 1963, 47-50).

Such was the War Office's confidence in cordite that it displaced gunpowder almost overnight as the main service propellant. In November 1891 cordite was adopted as propellant for the .303 cartridge for the Lee-Enfield rifle (Hogg 1963, 1414), the principal service rifle, and rapidly thereafter replaced gunpowder in large-bore armaments. More production capacity was needed, and was achieved by converting the majority of the gunpowder processing buildings on the North Site to cordite production. This was supplemented by a massive building campaign started in 1896, which included a new acid factory alongside Millhead stream on the north-west side of North Site and a new nitroglycerine factory to its east on Edmondsey Mead (see bindings of component sheets as 'Acid and tetryl factories' and 'Area E') . Groups of guncotton drying stoves were also constructed and were supported by extensive additions to the canal system. This phase of development lasted until around 1910, although refinements were being made continuously to the manufacturing process thereafter, often leaving little direct archaeological evidence.

Unlike gunpowder, the market for cordite was highly specialised as the government dominated it. In other areas of explosives manufacture, private firms could look to overseas markets to absorb spare production capacity. This was not so with cordite as foreign governments typically either controlled their own explosives manufacture and more pertinently had adopted explosives other than cordite as their service propellant. The Germans, Austrians, Swedes and Norwegians used a form of ballistite, while the French, Russians and Americans used nitrocellulose powders, leaving Britain, Japan and some of the South American countries using cordite (Reader 1970, 143-4). The British government therefore needed carefully to control the cordite industry by letting out contracts to encourage the private producers to invest in the plant that would serve to create the extra capacity needed at times of tension. The relationship benefited the explosives manufacturers in many other ways, however, and it has been shown that the small group of manufacturers awarded government munitions contracts gained much from 'spin-offs' into other areas of their business (Trebilcock 1969, 485).

It had been decided by government at the outset that only a proportion of the services' demands for cordite would not be met solely by Waltham Abbey RGPF. The remainder would be supplied by private firms under contract. The first commercial contract for cordite was awarded in 1894 to the National Explosives Company at Hayles in Cornwall, who in the previous year had undertaken the speculative development of a cordite factory in anticipation of future government contracts (Earl 1978, 212-3; Earl and Smith 1991, 10). This was soon followed by a major government contract for cordite to the firm of Kynoch's, which at that time had no cordite manufacturing capacity (Trebilcock, 1966, 374). The contract encouraged them to establish a large cordite factory at Arklow on the east coat of Ireland (Kelleher 1993, 91-113), providing the necessary safeguard against loss of production at Waltham Abbey RGPF. This was later followed by the same firm's factory on the Thames estuary at Kynochtown near Corringham in Essex (now demolished). It is believed that the plant at Kynochtown was closely modelled on that at Waltham Abbey RGPF. This example illustrates another recurring theme, whereby Waltham Abbey acted as a pilot plant for the development of manufacturing techniques that were then passed on to commercial producers or other government factories. The cordite production capacity at Waltham Abbey was itself another means whereby the government could attempt to exercise the necessary control over the private manufacturers in a market dominated by Nobel's, as it had done with the gunpowder manufacturers earlier in the century, using the factory as a yardstick against which private producers' costs could be judged, despite their complaint that a realistic cost of production was never arrived at and too many costs were hidden (Trebilcock 1966, 373). The government also recognised that the private manufacturers had developed a particular expertise in the production of chemical explosives that was lacking amongst staff of the RGPF. Outside experts that were recruited to manage the new government factory included Messrs Lundholm and McRoberts from Nobel's Ardeer factory and Oscar Guttman, a Hungarian by birth, who had wide experience in the explosives industry elsewhere in Europe and had been responsible for the overall design of the National Explosives Company's factory at Hayle (Earl 1978, 185, 213).

The impact of two World Wars

Though primarily concerned with the manufacture of propellants, Waltham Abbey RGPF nevertheless played an important part in the development of a number of high explosives, of which guncotton was the most widely used. Others manufactured there included 'picric powder', a mixture of two parts ammonium picrate and three parts saltpetre using a manufacturing technique similar to gunpowder. Production began in 1874 but appears to have been discontinued, for in 1895 instructions regarding its manufacture were requested from the War Office chemist. Production was evidently started again by 1896 when 60lbs of picric powder exploded in a mill on Mill Head, and was later transferred to a new plant on South Site. Picric powder was used a booster for picric acid ('Lyddite'), the principal shell filling used by the British throughout the First World War (Simmons 1963, 59).

By 1910 a plant had been established immediately north of the acid factory for the manufacture of a substance called trinitro-phenyl-methy-nitramine, more commonly known as 'Tetryl' or 'Composition Exploding' alias 'C.E.'. This was used within an exploder system as an intermediary between a sensitive mercuric fulminate detonator and the main charge to ensure the complete detonation of the main charge (HMSO, 1938, 143-7). During the First World War another tetryl plant was created on the eastern side of the site, but was built too late to see much use before the signing of the armistice. Production was resumed in 1935 in the by-then outdated plant, and for the first few years of the Second World War Waltham Abbey RGPF was the sole manufacturer of tetryl, before new factories in the west of Britain were brought into production (Simmons 1963, 60).

By 1909 the RGPF was producing cordites MD, MDS, MDT and MK1, various gunpowders, fuse powders, picric powder and various guncottons: in 1911 tetryl was added to the list of products (Supply 5/435). The First World War as in all other aspects of munitions production saw an unprecedented expansion. Production was increased both by the construction of additional buildings and for two and a half years of the war by round-the-clock production. Output of cordite rose from 26 tons per week at the outbreak of war to 140 tons per week within a year (PRO Supply 5/453). There was also a corresponding rise in the workforce from a pre-war total of around 1200 to around 5,000, half of whom were women (RARDE 1987). Prior to the war, few women had been employed at the factory, and those in the rather menial job of picking over the cotton waste looking for foreign objects before it entered the guncotton factory. In contrast during the war contemporary photographs show women engaged in nearly all aspects of guncotton and cordite production. All the surviving photographs of the light railway system during the First World War, for example, show it being operated by women.

During the inter-war period a number of experimental production plants were established at Waltham Abbey RGPF after initial research at the Royal Laboratory at Woolwich, and these acted as models for plant at new factories established in the west of Britain during the rearmament programme of the late 1930s and in the early war years. Such Royal Ordnance factories in Britain are said in turn to have acted as models for the construction of explosives factories in the former British empire and dominions. The experimental production plants were all constructed on South Site of the RGPF, but the processes may have placed increased demands on the acid factory within North Site, perhaps stimulating some of the new construction work traceable there around this date. TNT, trinitrotoluene or 'Troyl' had been used as shell filling by the Germans since 1902 but it was not until 1914 that it came into use by the British (HMSO 1938, 129-42). In the 1930s the Directorate of Ordnance Factories began looking into the most efficient way that TNT could be produced and the design of a model plant that could be replicated in other ordnance factories should the need arise. The First World War factory of Chance and Hunt at Oldbury was selected as the pattern for the new plant and was considerably improved upon in research work at Woolwich. A plant to the new design was set up on South Site in the 1930s and served as the model for 24 such units built during the Second World War in Britain (Simmons 1963, 60-1).

In 1938 work started on a plant for the production of cyclo-trimthylene-trinitramine or 'Cylonite', more usually known as RDX ('Research Department composition X'). RDX was produced from the treatment of 'hexamine' with excess nitric acid. Hexamine itself was produced from ammonia and methanol, both derived from coal, air and water, and the nitric acid from the oxidation of ammonia. RDX was a particularly important development since it was an entirely derived from synthetic compounds that did not require any imported materials. In explosive force it was half as powerful again as TNT (Gibbs 1961, 168): its principal use was as a high-explosive shell filling and as such it remains in use today. As with TNT, initial research work into the most efficient production processes was carried out at Woolwich before an experimental production plant was established at Waltham Abbey RGPF, again located on South Site. As with tetryl, the RGPF plant was the sole producer of RDX during the first two years of the Second World War before plants elsewhere came into operation (Simmons 1963, 62).

Although the use of gunpowder as a propellant had ceased by the end of the 19th century, there was still a demand for fine-grained gunpowder as a fuse powder, for priming cordite, cartridges, picric powder, nitric acid, nitroglycerine, and guncotton in mines and torpedoes. During the First World War Waltham Abbey RGPF was the sole manufacturer of fuse powders, but by the Second World War production was undertaken by the filling factories. In 1925 a plant was established in the north-west corner of South Site to manufacture RD (Research Department) Composition No. 202. This consisted of a mixture of 77% ammonium perchlorate, 20% charcoal and 3% starch: its chief application was in the time rings of long-burning fuses used in anti-aircraft shells (Simmons 1963, 62; HMSO 1938, 153). Manufacture of nitroguanidine, also known as 'Petrolite' and 'Picrite' and used in smokeless cordite, was again first developed at Woolwich. Buildings' drawings were prepared by late 1924 and full production started in 1925 at Waltham Abbey RGPF, where the processes were refined and later replicated elsewhere (Simmons 1963, 62).

The outbreak of the Second World War found the RGPF utilising production plant for the most part dating back at least to the First World War, while some of the 19th-century watermills may have remained in use producing fuse powders. Nevertheless with the new products outlined above, the RGPF played a vital part in Britain's war effort in the first few years of the war. Not only did it in supply the services with the most up-to-date explosives, but it also produced trained staff to take their expertise in explosives manufacture to new factories being established around the country. The early war period also witnessed a flurry of building activity on North Site, including the erection of a complete new nitroglycerine factory on New Hill, on land lying east of Cornmill Stream taken in for that purpose. The widespread use of breeze block distinguishes these buildings, although brick and concrete were also employed still. Despite all this new construction, production of explosives ceased in 1943 in favour of the new factories built in the late 1930s and early war years in west of Britain. These factories were purpose-built, located at the extreme range of continental bombers and offered an integrated network of explosives manufacturing sites linked by rail to the filling factories. What had been Waltham Abbey's early geographical advantages in its proximity to London and waterborne connections to the Thames now played a part in its closure. In the contemporary situation it was isolated in the south-east of England, poorly served by rail transport and vulnerable to enemy bombing, with manufacturing plant over thirty years old. On its closure many of the staff were transferred to the Bishopton factory near Glasgow.

Surprisingly in view of the importance of the RGPF's production facilities to Britain's ability to wage war, the factory does not appear to have been directly targeted by the Luftwaffe.

On the 5 October 1940 No. 15 Cordite Stove on South Site was destroyed by enemy bombing (WASC 1333) and while other parts of the site were cratered. A month later on 15 November a parachute bomb caused extensive damage in the Mill Head area, reportedly putting the last water-driven mills out of action. Later in the war a V2 rocket fell in Highbridge Street demolishing some of the residences of the principal officers (Blee 1970, 84), and another fell close to the RDX plant on the South Site (Supply 5/435). More damage than this evidently opportunistic bombing by the Germans was inflicted on the factory in two apparently accidental explosions early in 1940. The first took place in **Cordite Mixing House** [63] in January and the other in **Cordite Mixing House** [46] in April. In both explosions a large part of the northern area of North Site was devastated, bringing production to a halt. These explosions highlighted the vulnerability of the whole plant in its reliance on a single nitrator and prompted the development of the New Hill nitroglycerine factory later in the year. Many of the older buildings in the northern area were damaged beyond repair and they were reconstructed using breeze block, concrete and asbestos sheets.

Defensive protection was given to the factory, but was pushed away from the perimeter fence. On the west a line of pillboxes existed to the west of Horse Mill Stream, only one of which now survives. In the south, Quinton Hill was ringed by pillboxes, but as yet none have been discovered up the east side of the factory. Anti-aircraft defence was generally placed at a distance from the site, also protecting the armaments factories at Enfield and the approaches to north-east London. One large battery was sited on the rising ground over one kilometre to the east of the factory at Daillance Farm (TL 393 021). Closer to the perimeter fence was an **Alan-Williams Turret** [RCHME 335] sited west of the **Grand Magazine** [1], and more substantial anti-aircraft defence was provided by two octagonal emplacements [RCHME 345 and RCHME 346], one in the grounds of the **Senior Officer's House** [A221] and the other immediately north of the **Grand Magazine** [1]. These were open to the sky, with a central mounting for a weapon of unknown type and surrounded by a low blast wall and ammunition lockers. In addition to extra demands placed on the workforce by the increased production, many of the employees gave up their spare time to the 56th Essex Battalion Home Guard (WASC 180-3).

The formal closure of Waltham Abbey RGPF took place on 28 July 1945.

Post-war government research establishment

The factory site reopened on 30 July 1945 as an experimental station of the Armament Research Department: the aim was to create a separate organisation for research into explosives and intermediaries and their production (RARDE 1987, 14). The Chemical Research and Development Department (CRDD) was established as a separate body on 1 October 1946, with the intention that it should employ around one third of the parent body's staff, around 173 people. North Site provided the new body with laboratories and other buildings that could easily be converted for laboratory use. One of the first priorities was research into liquid fuels for rockets and other purposes, and a proof stand was quickly built by adapting **Cordite Reel Magazine** [H12]. A plant was also established for the pre-production manufacture of plastic propellants for use in rocket motors. In collaboration with Woolwich, work also included a pilot plant to manufacture cast double-base rocket motors based on work pioneered in the United States. In this process a nitrocellulose-based casting powder was introduced into the outer casing of the rocket motor, and was combined with a nitroglycerine-based casting liquid: after curing, this would form a solid propellant within the casing (Gordon 1987, 311). Other early priorities identified were research into non-erosive propellants for guns, chemistry of high explosives and initiators, study into keeping explosives and propellants under tropical conditions, and the cartridging and packing of these substances. Other activities were also undertaken within the new establishment. Research was continued on South Site into improved production methods for RDX and into the production of picrite (nitroguadine) as a shell or bomb filling (CRDD 1947, 1-12). In 1948 the establishment changed title twice, first to the Chemical Research and Development Establishment and secondly to the Explosives Research and Development Establishment (ERDE), the title it retained until 1977. Work at Waltham Abbey concentrated on research into explosives and propellants while rocket propellant research was transferred in the early 1950s to the Rocket Propulsion Establishment at Westcott in Buckinghamshire.

By the 1960s Waltham Abbey was the sole government laboratory responsible for research and development of non-nuclear explosives of every kind. The establishment was divided into a number of branches. The main research areas of Explosives Branch lay in the degradation of explosives, initiating substances, and deflagration and detonation, along with solid propellant charges. Another important area was 'sensitiveness', that is the study of the variation of different explosives to varying stimuli, for example friction, electric sparks and shock. Much of the laboratory work was done in converted buildings from the former factory, while test explosions were conducted in purpose-built firing points. An essential piece of equipment for this work were high-speed cameras capable of taking pictures at the rate of up to 1,200,000 exposures per second. These instruments were constructed by Beckman and Whitley in California and were amongst a very small group of such instruments available in England. Research was also conducted into the establishing quantitatively the risks in the handling of explosives. Allied to investigation into the explosives elements within weapons systems was work on the non-explosive components. This involved research into paints, varnishes, rubbers and adhesives, for example, to ensure they did not create any adverse reactions with the explosives substances or impair their performance. It extended, for example, to collaboration between ERDE, the rocket motor manufacturing and research station at Summerfield in Worcestershire, and Ciba-Geigy into the development of a bonding agent for use in rocket motors (Gordon 1987, 318). The Materials Branch was also concerned with research into the suitability of different materials in guided missiles and aircraft. In addition, basic research was carried out into the use of polymers. The Chemical

Engineering Branch set up in 1948 initially worked closely with Royal Ordnance factories in refining the manufacturing processes of various explosives, but was also involved in projects as diverse as the development of liquid rocket propellants and remote handling equipment. Supporting these branches was the Analytical Services Branch, which included a radiochemical laboratory. South Site at this period was used for larger-scale operations, pilot development work and the manufacture of products for field trials. Limited production was undertaken where only small amounts of a given substance were required by the services (Johnson 1965, 321-27).

During the 1970s Propellants 1 Branch was concerned with the development of propellants from nitroglycerine and nitrocellulose. Small amounts of nitroglycerine were manufactured on the site reusing the old Edmonsey Mead nitroglycerine factory centred on the **Nitrator** [E2]. This plant had been refurbished in the early 1960s, the former **Washing House** [E5] being used for the Schid continuous nitration process. By the 1970s, however, the nitroglycerine required in the production processes was extracted gelignite. Weapons systems introduced through the research and development at Waltham Abbey included the British anti-tank missiles Swingfire and Vigilant and the Giant Viper, used in minefield clearance. Work on the long term stability of explosives under different conditions also continued through trials and storage. Propellants 2 Branch was concerned with composite explosives of two main types, namely plastic and rubbery. A plastic propellant has malleable qualities while rubbery propellants retain their shape: the development of the former was almost entirely confined to Britain. Applications included guided missiles, rockets for British research in the upper atmosphere and space, and service motors. The Process Research Branch developed specialised materials required by the Ministry of Defence and production where only small quantities were required. The work begun on polymers in the 1960s continued to grow in importance. The interests of the General Chemistry Branch lay in studying the decomposition reactions and stability of various explosives and propellants, for an explosive that becomes inert through time is almost as dangerous in service use as one that becomes unstable. Long-term research into rubbers and plastics was conducted by the Non-Metallic Materials Branch, which for instance studied the effects of tropical exposure and weathering. Research programmes at ERDE included developing a plastic pump and fan for the Chieftain tank and a clear ammunition box lid for the same tank. An ethyl cellulose tube developed for the Giant Viper complemented the work of Propellants Branch on that system. The early post-war links were reforged with Westcott when both establishments were brought together again in 1977 as the Propellants, Explosives and Rocket Motor Establishment (Walton 1977, 26-8). The Advance Explosives Research Branch was also conducting experiments into the remote handling of explosives, which included the construction of a five inch gauge railway on South Site with an engine and truck to move the explosives around the process plant (WASC 1126/29-34).

The early 1980s saw a final change of title to the Royal Armament Research and Development Establishment (RARDE). The early 1980s was also a period of contraction and uncertainty. The **Nitrator** [E2] on Edmondsey Mead was finally decommissioned after nearly a century of service and further parts of the site fell out of use. The link between North Site and South Site was broken in 1984 when South Site and the area of the Lower Island Works were transferred to Royal Ordnance plc in the lead-up to privatisation. North Site remained under the control of the Ministry of Defence. Research work during the final years of the establishment's history concentrated on the chemistry and physics of energetic materials and propellants: research into polymeric and composite materials for use in weapons systems also continued. 1987 marked the bicentennial of Waltham Abbey RGPF that was commemorated by the publication of a small booklet (RARDE 1987) and exhibitions. It was also the year that final closure proposals were announced, although discussions about the future of the site and the preservation of some of the buildings had already commenced. On 30 June 1991, after over two hundred years of service to the Crown, the establishment was closed. In 1992 a decontamination programme began on North Site, to satisfy the requirements of the Explosives Inspectorate and to allow the site to be put to beneficial reuse.

Site description

The factory may be conveniently described using the areas defined by the current Ministry of Defence prefixed numbering system. These areas will be roughly adhered to within the description for ease of use by the many agencies familiar with the current designations. Additional areas have been defined outside these boundaries to describe the remainder of North Site: Figure 3 acts as a key to their extent. Buildings and features are referred to by their current prefixed MoD number where available; if not, by the 1923 numbering system as designated on map WASC 900/84. Buildings or features not covered by the current or 1923 numbering system have been allocated an RCHME number: they are often buried buildings or earthwork remains, including sections of watercourse, tracks and tramways that link buildings together. In the text of the report they are cited in square brackets [ ]. Individual buildings and other components were originally linked by a complex series of watercourses, tracks and tramways as well as power systems. It is these linkages and groupings rather than individual items, along with the principal concentrations of buried features, that will be dealt with in the description.

The northern part of North Site divides into topographic units based on current building numbering systems less easily than the southern part of North Site. But in order to maintain consistency a numerically based division of the site has largely been adhered to. Readers may therefore find that odd buildings do not comply with the general numbering system within an area. Careful reference should therefore be made to Figure 3 to note in which area a particular building lies.

The description and analysis relies for its supporting detail on the **Inventory** that is available for professional consultation in the form of what are termed for the purposes of this project 'component sheets'. A sheet has been prepared for every standing building, the principal buried remains, other monuments and the principal earthwork elements of the factory. This system has also been used to record all the water courses and smaller components worthy of fuller descriptions. Each component sheet identifies the individual component by function and/or name, aiming to chart any change of function through time by cartographic and documentary searches. Its immediate associations with other components are noted and a brief field description given. A number of the structurally more complex buildings were investigated by RCHME Threatened Buildings Section, whose reports are appended to the relevant component sheets. References to RCHME photography are divided into four categories: (1) 35mm field photography, (2) large format photography, (3) 35mm Threatened Buildings notebook photography, (4) aerial photographs. The information contained on these sheets will be freely utilised without reference beyond a relevant component sheet number.

The numbers found on the 1:1 250 plan extracts refer to the relevant component sheet, and extend to current, 1923 and RCHME numbered items, which are distinguished by italics.

Buried buildings are marked on the plans by an encircled cross or target with associated number.

Component sheets have been brought together in bindings or volumes by area of the site rather than by overall numerical listing, so 1923 and RCHME numbers are bound with prefixed component sheets or other groupings within whose area they lie. A full list of the volumes forms the content of **Section 4**, as a key to them. In practice, they correspond to the subdivisions of the site description in **Section 2** and to the divisions mapped in Figure 3, with some additions as for the Millhead area or the barges as a distinctive type of evidence.

In general terms and with limited deviation,the description proceeds from south to north. It therefore deals first with Lower Island, which at present appears as a misleadingly detached area.

Lower Island (Figs 1-2, 6-7)

The site of the Lower Island Works situated south of Highbridge Street lay outside the initial RCHME project objective of recording the northern part of Waltham Abbey RGPF, ie North Site, owned by the Ministry of Defence. Ownership of Lower Island and the southern part of the RGPF, South Site or Quinton Hill, in 1993 lay with Royal Ordnance. Though the topographical survey at 1:1 000 scale was extended to this area, resources allowed only a lower level of documentary search and recording. This has nevertheless sought to establish a building date for all of the structures and principal changes of use in the same manner as on North Site, and interpretation is supported by a volume of component sheets.

For the purposes of this description the area of Lower Island is defined as lying between, in the north, a gated entrance on the south side of Highbridge Street at TL 3769 0055 and, in the south, where Cobbins Brook joins the Rammey Marsh Flood Relief Channel, at TQ 3763 9974. The brook, which is now canalised for most of its length along the southern foot of the M25 embankment, also formed the northern boundary of South Site. The western side of Lower Island is defined by the River Lee Navigation which lower downstream joins with the flood relief channel. The eastern side is also delimited by a water course, in this case a modern narrow drain. To its east, the area known as Town Mead was quarried away by a gravel pit shown active on various aerial photographs between 1964 and the 1970s when the area has been reinstated as playing fields. The gravel pit extended up to the present site boundary and is presumed to have destroyed any buried remains beyond it, principally a mill tailrace.

It is more than usually difficult in this area to relate the modern topography to the historic mapping, for example Fig. 4, because of major changes in the watercourses. The area can be thought of as two narrow linked islands, lying in north-south alignment. In its southern half, few topographical features correlate with the mapped layout of the Lower Island Works as the waterways were modified or filled during the construction of the Rammey Marsh Flood Relief Channel. As the area occupied has largely been dumped over through that construction rather than quarried away, however, the potential for buried remains is high. In the northern half, all of the structures have been demolished and at best remain as a few brick courses, but the foundations of many of the other structures probably remain as well-preserved buried features. It is therefore apposite to begin with a brief description of the physical form of the Lower Island Works before their demolition taken from cartographic sources before describing their present condition.

The Lower Island Works (see Fig. 4) were established between 1801 and 1806 on a meander of the River Lea by-passed by a canal constructed by 1783 (ECRO T/M 335). This is represented by the southern half of the later Lower Island site. The mills were powered by the head of water from the level of the Old River Lea, that is the lowest level on North Site, taken off from the east side of the river in a straight cut to act as a head leat. The necessary fall to what was therefore the lowest level in the factory was created by 'The Tumbling Bay' at the northern end of the canal cut, the canal being maintained at a higher level than the old river meander. The fall was also marked the Rammey Marsh Lock at the southern end of the canal cut, and later a lock [RCHME 350] was placed at the southern end of the eastern head leat. Originally there were three mills with ancillary buildings [394, 395, 397, 398 and 399] powered by the eastern head leat tipping water into the lowest stretch of water beneath The Tumbling Bay. To these were later added two further mills [RCHME 308 and RCHME 309] placed on the east side of the header leat. They occupied a narrow island or platform, its line roughly represented by modern track, with water from the header leat tipping into a tailrace to their east. A pair of **Charge Magazines** [RCHME 347] were sited to their north. These two mills were shortlived although the **Charge Magazines** survived. Otherwise, the mills on Lower Island remained in use until the end of gunpowder manufacture.

At the southern end of Lower Island and to the north of the former **Lock** [RCHME 350] were four small structures, a **Loading Stage** [401], a **Shoe Room** [402], a **Magazine** [403] and an **Earth Closet** [404]. All four buildings have been demolished and have left no surface trace. To their north again was a **Press House** [399], initially with hand-operated screw presses that were replaced after 1812 with a press powered by a Bramah hydraulic pump (see discussion of 'Infrastructure' in **Section 3**), and on the opposite side of its northern traverse a water-powered **Corning and Granulating House** [395-398], housing from 1814 Sir William Congreve's granulating machine. To its north was **Incorporating Mill** [394], also water-powered, and two **Magazines** [392 and 393]. At the very northern tip of Lower Island was a millman's cottage [389]. Through the 19th century these mills changed their function on a number of occasions, often involving a change in machinery that is not manifest in the cartographic sources.

At the southern edge of the surveyed area a canal branch led off Cobbins Brook and into the South Site. It survives as an open channel for about 25m: beyond it has been filled. The northern end of the channel is spanned by a wrought-iron **Footbridge** [RCHME 266]. Between this footbridge and the M25 motorway is an area of rough ground, left from when the valley of the River Lea was bridged by the M25. Historic mapping and aerial photographs suggest that this piece of land appears to be archaeologically sterile.

North from the M25 motorway to the point where the strip of land adjacent to the river narrows opposite to the modern flood control gates, TQ 3760 0010, there is a large smoothed earthwork bank up to 12m in width and 1m in height. Between its eastern base and the western edge of the track lies the course of the header leat serving the mills on Lower Island, now buried and unrecognisable as a surface feature. Beneath the mound and along the eastern edge of the flood relief channel are the sites of the mills detailed above. The survival of subsurface features is confirmed by two brick outlet leats with walls lying 2.5m apart at TQ 37607 99987, identified as lying within building [394], an **Incorporating Mill and Cam House**. The remains of early 19th-century mill buildings may also lie buried to the east of this bank. Part of the mound itself may even be composed of the demolished mills and the massive brick traverse that screened the mills (see photographs WASC 809, 810). Final demolition of the remaining traverse took place only in June and July 1981 (WASC 1051) while construction work was under way on the M25 motorway. Slightly further north, a number of buildings were probably destroyed during the cutting of the flood relief channel, notably the **Millman's Cottage** [389] and perhaps the **Charge Magazines** [392 and 393], their small size making an exact siting from historical maps difficult. The foundations of the two early water-powered **Incorporating Mills** [RCHME 308 and RCHME 309] and the **Charge Magazine** [RCHME 347] on the east side of the header leat may lie buried beneath the modern track. The present boundary ditch separating Lower Island from the playing fields roughly marks the line of the former eastern tailrace, though air photographs suggest that the original feature has been destroyed.

The northern half of the area, to the north of the flood control gates, was not developed with buildings in the early 19th century except for the **Sulphur Refinery** [375, 376] at its north end. From cartographic evidence this may be shown to be a two-phase structure, the western side being the earlier. The refinery survives as a few brick courses to the west and east with a single row of bricks linking the either end. The form of this structure and the processes carried on within it are known in some detail from later 19th-century official gunpowder manuals. The area is strewn with river gravel and rubble dumps perhaps masking further features. Sometime after 1850, and perhaps directly linked to the creation in 1859 of the Group B incorporating mills that it served, a straight canal and mill head leat was constructed on a north-east/south-west orientation. It closely followed the course of an earlier road and appears to have been linked in to the north end of the earlier header leat to its south to form a distinctive angled waterway (see Figs 4 and 5). The eastern tailrace of the mills to the south was available to act as its tailrace, too. A linear hollow lying parallel to and west of the modern track, up to 6m in width, marks the course of this former mill head leat. Along its western side, between TQ 37605 00202 and TQ 37691 00386, is a bank at least 6m wide and up to 0.75m in height. It is composed of river gravel and brick, which may in part comprise demolition rubble as fragments of building debris including a section of leather floor with copper nails was found in its make-up. It is unclear whether this bank is an original canal side-bank or whether it is composed solely of demolition rubble. To the west of the bank is the site of the 19th-century **Proof Butts** [RCHME 305]. The surface between the bank and the flood relief channel is covered by a layer of river gravel that obscures any remains that may lie in this area.

Along the eastern side of the header leat/canal towards its southern end, the principal buildings were the Group B **Gunpowder Incorporating Mills** [387] and its **Boiler House** [385], constructed in 1859. Despite their construction in sequence with the steam-driven incorporating mills in Area L on North Site (see below), these mills were principally water-driven from the header leat. A map of 1886 (WASC 900/42) shows a tailrace emerging from the centre of the building. In addition to the water power the mills could also be driven by an auxiliary steam engine when water levels were low (Smith 1870, 40). A number of minor buildings were also associated with these buildings. Although all of these structures have been demolished, their foundations may survive as buried features beneath the modern track or along its margins.

The primary means of communication between the Lower Island Works and the remainder of the factory was waterborne: this was later supplemented by the narrow gauge railway. The railway emerged through a tunnel beneath Highbridge Street on the east bank of the lower reaches of Millhead Stream and crossed the Old River Lea by bridge. The line then roughly followed the course of the modern track. The construction of the present road took place during the 1960s to provide a closed link between North Site and South Site: it was at this date that the modern road bridge at TQ 37718 00425 across the Old River Lea was constructed. To its east on either side of the river are the steps and piers of a former **Footbridge** [RCHME 268] . Adjacent to the southern pier is a small **Observation Post** [OP 13], probably constructed during the Second World War, commanding views along the Old River Lea and controlling access across the footbridge.

North of the road bridge are the foundations of two ranges of parallel store buildings, [344-352] to the east and [353-362] to the west, bounded on the east by the continuation of Millhead Stream. On the west the west wall of the buildings survives to a few courses in height marking the site boundary, and within a few stone floor slabs remain *in situ*. The eastern range may be traced as a brick wall foundation with sandstone door thresholds, presumably to facilitate loading from the waterway. North of the easterly range was another group of store buildings [339-343]: the northern part of these buildings has been retained to eaves height as the northern boundary to the site. The road is now closed at its northern end by steel gates.

The majority of the buildings on Lower Island survived until after the Second World War, although most had been converted to other functions than gunpowder manufacture by this date. Their gradual run-down and demolition may be charted through post-war aerial photography. Buildings on Lower Island remained roofed into the 1950s although the area was heavily overgrown. In the late 1950s or early 1960s the building were fired and remained as roofless ruins until at least 1966: a number of the traverses survived until 1981. The Group B **Incorporating Mills** [387] and their associated buildings stood until 1963 when they were demolished and the modern link road between North Site and South Site was constructed. Between 1966 and 1970 the area was altered out of all recognition by the construction of the Rommey Marsh Flood Relief Channel. Also at this time the gravel pit was active on Town Mead, which has subsequently been filled and turned into playing fields. During this operation the former header leat and the tailrace below The Tumbling Bay were filled. The area was further transformed in the early 1980s with the demolition of the last surviving traverses and with the construction of the M25 embankment and the bridge carrying it across the Lea valley.

Area A (Figs 3, 8)

Area A lies in the south-east corner of North Site, bounded to the east by Powdermill Lane and to the west by the lower reaches of Millhead Stream. To the north the area is delimited by the lower section of the canal [RCHME 156]. Its southern limit for the RCHME survey was taken as Powdermill Lane and the back gardens of the early 1950s housing estate. The boundary of North Site originally extended southwards to Highbridge Street encompassing the area of the housing estate. This part of the factory site was further affected during the early 1970s by the construction of a round-about at the west end of the Waltham Abbey By-pass. No surface remains of any historic buildings survived in this area. Its early 19th-century use may be characterised as a series of small store buildings and artisans shops interspersed with factory cottages and gardens. As a result no attempt has been made to compile a systematic record of the buried archaeology in this area. Two important buildings, though now buried, do merit attention. These are the 19th-century **Saltpetre Refinery**, a U-shaped building numbered [278-282], and a building immediately to its south [RCHME 316] used in the early years of guncotton manufacture. Both buildings lay close to the edge of Millhead Stream and may remain as buried features beneath the gardens backing onto the stream. The location of the Saltpetre Refinery, together with the Sulphur Refinery on the opposite side of the lower Millhead stream at the southern end of area H, is typically at the riverine entrance to the early factory.

Area A has two distinctive attributes. First, from the earliest historic mapping in the late 18th century it has provided the road access to the site, off Powdermill Lane earlier known as Threshings Lane. This road ran north at right angles off Highbridge Street along the west bank of the Old River Lea to reach a site entrance after some 200 metres. In association with early canals lying east-west off the lower reach of Millhead Stream, this in turn created a east-west rectangular arrangement of buildings between Powdermill Lane and Millhead Stream that, despite functional changes, has been very persistent. The buildings here have generally fulfilled administrative and service functions detailed below.

Secondly, within area A are some of the earliest remains of the powder factory shown on the engraving of 1735 in Farmer's *History of Essex*. Beneath the present-day administrative buildings [A230-A234] may lie the remains of a **Horse Mill** [RCHME 321], shown on Farmer's engraving of 1735 as mill 1 (Fig. 15). The other area of intensive early activity lay on the promontory, latterly known as The Island, on which the **Lecture Theatre** [A203] sits. The principal early structures in this area were two horse-driven mills [RCHME 321], a **Saltpetre Mill** [226] and **Charcoal Mill** [227] with their associated stables and a number of ancillary buildings. At the southern tip of the promontory is the site of an early water-powered **Corning and Glazing House** [234]. The exact siting of this mill is open to question as it relies the evidence of Farmer's engraving and its true site may lie slightly further to the south, perhaps closer to the **Barge House** [[RCHME 322]. As shown by Farmer in 1735 this mill as powered by an undershot wheel dipping into the lower reaches of Millhead Stream. This mill may overlie the site of the **Fulling Mill** shown in 1590 (ERO T/M 125) or even be that mill, which was later converted into an oil mill before forming the core of the early gunpowder factory (Fairclough 1985, 14). It appears to have gone out of use as a mill from the late 18th century, being used thereafter for a variety of purposes. The original mill was demolished during the 19th century and was replaced by building [234] on an almost identical ground plan. This building was latterly used as a **Sieve and Reel Shop** and stood until the late 1950s. During the construction of the lecture theatre in December 1963, the remains of two circular structures were uncovered and were presumed at the time to be the remains of the horse mills [RCHME 321] (WASC 176). It is believed that the remains were simply buried and the **Lecture Theatre** [A203] built over the top of them, which may have sealed them intact.

Amongst the earliest standing buildings on North Site is **Walton's House** [A200], the main offices for the factory constructed in the late 18th century soon after the government purchased the factory in 1787. Opposite **Walton's House**, between it and the pool below Millhead, stand two other building of the same era, namely the **Mixing House** [A201] and the **Sulphur Store** [A202]. All three were recorded in detail by RCHME Threatened Buildings surveys. The promontory was linked at its southern end to the store buildings by the Powdermill Lane gate originally by a 'brick bridge of carriages' (MPHH 271 1827). This was replaced in 1832 by the present **Cast Iron Bridge** [RCHME 132]. This alteration coincided with the digging of the canal [RCHME 278] from the lower reach of Millhead Stream to the **Charcoal Cylinder House** [RCHME 333] and facilitated the passage of river barges into the canal.

This bridge giving access to the promontory linked the buildings there to the rectangular layout associated with the site access from Powdermill Lane, where further buildings date from the early years of the 19th century. These include buildings abutting on Powdermill Lane and forming a sort of entrance frontage. [A269] was constructed in c1807 as an **Engineers Office** and **Clerk of Works House**, comprising a central four-bay block of two storeys plus attic and basement with single storey wings of one bay to north and south. Originally building [A268/ A238] was of one storey and was built at a similar date as **General Storehouses**. It was raised to two storeys in two phases in the 1880s and was used as a **Library** and **Police Quarters** with the **Police Lodge** at its the north end. Between these blocks was a gated entrance on Powdermill Lane [RCHME 131], with a double gate flanked by pedestrian entrances and the piers protected by a pair of upturned cannons. This formed the access to the Engineers Yard, where buildings generally comprised various store rooms and other ancillary functions. The yard was a formally rectangular space defined on the north by the present administrative buildings [A230-A234] along with some demolished buildings at their western end, including an early 19th-century **Barge House** [RCHME 322]. To the south and lying parallel to [A230-A234] a demolished range [A259 and A265] formed the other side of the Engineers Yard. These demolished buildings [A259 and A265] were identical in form to the surviving range and were similarly used as stores (Drayson 1830, drwg. 36). They occupied the ground between the floor slab [A266] and partly underlay the west end of the **Social Club** [A250]. They were demolished in the late 1950s probably around the same time as the **Social Club** [A250] was under construction. Within the yard area, two small buildings were a **Glue House** [A263] and a **Sawpit** [249b]. The south-eastern part of the Engineers Yard was during the Second World War and shortly afterwards infilled by a group of pre-fabricated concrete single-storey office buildings [A266, A271, A272, A273, A282, A283, A284, A285 and A289]: all had been demolished in late 1992 before the RCHME survey.

To the north and running parallel to the administrative buildings [A230-A234] was a **Canal** [RCHME 356], possibly created to serve that range of store buildings along the northern side of the Engineers Yard. This connected to a **Leat** [RCHME 357] that roughly followed the line of the boundary around the **Senior Officers House** [A221]. Both features have been filled and there was no surface trace of either. The line of the **Canal** [RCHME 356] was relocated during the decontamination work in 1993 and was found to be revetted with wooden sides. Further canals lay to the south at right angles to the lower Millhead stream, between the Engineer's Yard and the **Saltpetre Refinery** [278-282] (Figs 4,5).

The northern part of area A throughout the 19th century remained relatively undeveloped, its western and northern fringes covered by woodland. To the east of the area, a large residential house [A221] built in the early 19th century was latterly occupied by the director. The northern-most section of area A was developed by the outbreak of the First World War as the site of the principal factory **Power House** [A210], with a tall chimney in the angle of the building on its south side. Associated with this was the hydraulic **Accumulator Tower** [A214] and its engine house. Further buildings added to this complex, **Water Softening**

Buildings [A211 and A212] and **Tanks** [A213], were all reduced to floor slab level immediately prior to the RCHME survey.

The outbreak of the Second World War prompted further development in the area with the construction of **Telephone Exchange** [A219] and **First Aid Dressing Centre** [A220]: both these buildings, too, had been razed to their concrete floor slabs by the time of the RCHME survey. Also at this date an octagonal brick anti-aircraft emplacement [RCHME 345] was built in the garden of the Director's House [A221]. This structure is identical to another [RCHME 346] to the north of the **Grand Magazine** [1], that is now demolished but visible on historic aerial photographs.

Millhead (Figs 3, 9-10)

An area called Millhead is defined for the purposes of this description as lying between the northern limit of area A to the south and **Corning House** [97] to the north. The western side is bounded in the north by the modern course of Horsemill Stream, but cuts in eastwards along the buried canal [RCHME 301] on the north side of the **Ballistics Laboratory** [H67], and from this point uses the eastern edge of area H along Millhead Stream as its limit. The eastern limit of Millhead is taken as The Long Walk and at its northern end those features lying west of the leat [RCHME 119]. This defines the core of the early water-powered black powder factory as depicted in Farmer's engraving of 1735 (Fig. 15). The modern flood relief channel now known as Horsemill Stream was historically known as Millhead Stream as far north as the **Grand Magazine** [1]: in this description, Millhead Stream will be retained only for the section of the stream either buried or surviving as an earthwork between **Heading-up House** [RCHME 274] and the former sluices [RCHME 135].

Included in this area is a part of the factory historically known as Little Hoppit. This lay to the north of the infilled canal [RCHME 301], in the triangular-shaped piece of ground between Horsemill Stream and Millhead Stream. This area of ground is level and featureless except for two dumps of river gravel along its western edge. A systematic search through all the available historic mapping has failed to reveal any buried features within this area. Historically this low-lying area was used as a willow plantation to provide wood for charcoal.

Apparently with the exception of [S34] adjacent to Newton's Pool and facilities on Lower Island, the head of water provided by Millhead Stream was utilised to generate motive power for all the water-driven mills within the Royal Gunpowder Factory throughout its existence. It represents a substantial engineering feat, re-using or developing a medieval monastic construction. North of the **Grand Magazine** [1] the River Lea split into two and was carried along two artificially engineered channels, to the west Millhead Stream and to the east Cornmill Stream. Maintained at a lower level was the former course of the river, the Old River Lea, with water sluiced into it at **Newton's Pool** [RCHME 276] if the water in

Cornmill and Millhead Streams was at sufficient height. Associated with Millhead Stream was a network of canals developed piecemeal from the early 19th century that facilitated access between buildings and provided power to a number of process buildings located away from the header leat. Below this system at the same level as the Old River Lea was a network of leats into which water was discharged through the mill wheels. The head of water between the two levels was six feet (1.8m), surface to surface. This figure appears to have remained constant throughout the operation of the factory. For in 1771 John Smeaton records a head of six feet for the mill [197] he constructed (Wilson 1957, 41); while over a century later, drawings of the new aqueducts [RCHME 112 and 214] also show a difference of six feet between the two levels.

To maintain this head of water against the surrounding ground surface it was necessary to contain Millhead Stream within an earthwork embankment. This embankment is clearly mapped by the Ordnance Survey in 1897, which shows Millhead Stream from the **Grand Magazine** [1] raised in an earthwork embankment for a distance of at least 1500m to the **Sluices** [RCHME 135] and site of the former head mills. The western side of the embankment has been entirely removed by the canalisation of the present Horsemill Stream and survives only at the southern end of the former Millhead Stream. The line of the eastern embankment has been covered in the far north by dumping of river gravels and further southwards has been lost beneath the Acid and Tetryl Factories. South of the modern sluices in Horsemill Stream the embankment has been lost through canalisation, although the height of the stream is maintained by modern dumping which may in places embody the original embankment. But south of the site of the **Heading-up House** [RCHME 274], the embankment of Millhead Stream may still be followed as a well-preserved earthwork feature, most conveniently described from south to north.

The southern end of Millhead Stream has been filled but its line may be followed as a linear earthwork hollow around 11m in width. To either side of the channel is a level platform, up to 10m in width on the western side and probably slightly less to the east, on which the mill buildings sat. To either side of the platforms and at a lower level to Millhead Stream were two tailraces [RCHME 119 and RCHME 301]. At the very southern end of the high-level section of Millhead Stream are the brick **Sluices** [RCHME 135]. These consist of four narrow channels that could be blocked by inserting boards into sloping slots within the brickwork. There was no means of access between the high- and low-level water systems for the barges at this point. Immediately north of the **Sluices** the western side of the Millhead is clearly defined by a line of bricks marking the edge of the towpath. The eastern side is less clearly defined by a shallow earthwork. The line of the stream is lost to either side beneath the road leading off westwards from the roundabout. North of here the stream channel may be followed as a linear earthwork hollow 11m in width as far as the road to [H67]. Either side of the channel is the level platform on which the mill buildings were located. Along the eastern side this platform is revetted by a brick wall with the tailrace [RCHME 119] still an open water-filled channel, while along the western side the tailrace

[RCHME 301] may be traced as a slight linear hollow 6m in width for 92m. The tailrace was held against the local ground surface by a slight flat topped bank on its western side. Again the line of the stream is lost as it passes under the road to [H67]. Between this road and the **Dusting House** [159] the Millhead Stream was filled with a mixture of concrete and breeze-block building fragments and research establishment waste probably dating from the 1960s. This was removed early in 1993 revealing the sides of the stream revetted with corrugated iron. Beyond the **Dusting House** [159], the stream remains as an open earthwork channel, partly water-filled during periods of heavy rainfall and with sides similarly revetted by corrugated iron. Northwards from the entrance to the **Radio Chemistry Laboratory** [L128] the channel is once again filled, its line visible on the eastern side where its subsiding fill has revealed the corrugated iron revetment.

This southern end of Millhead Stream contains the densest, potentially earliest and most complex buried remains on the site. Between the **Sluices** [RCHME 135] and the **Dusting House** [159], a distance of around 250m, are the sites of eleven water-powered **Incorporating Mills** besides other facilities. The actual number of structures may be far higher as the limited excavation of mill [197] showed a succession of mills dating between the late 17th century and 19th century on the same site. Farmer's depiction of the Millhead in 1735 (Fig. 15) argues that remains on the east side of the stream may be earlier than those on the west. Nevertheless, the majority of the mills within this area may be shown at least to occupy the sites of mills depicted in the 18th century. The only mill building that has been sampled archaeologically, [197], revealed a sequence of structures dating back to the late 17th century.

The mill buildings were located on the level platforms between the stream itself and the tailraces to either side: each mill had a central wheel pit set at right angles to the stream that powered machinery in mill buildings on both sides of the central spill-way. The only exceptions to this general arrangement were the two head mills [211 and 211a] and the former mill [234] below the **Sluices**.

On either side of the **Sluices** [RCHME 135] at the southern end of Millhead Stream were two mill buildings designated by the later numbers [211 and 211a]. Mills on this site are shown on an engraving of 1735 as **Stamp Mills** (Farmer 1735, nos 11 and 12; see Fig. 15). This early method of incorporating gunpowder by means of a series of mechanised pestles falling onto a row of mortars containing the gunpowder seems from the engraving to have been driven by a side wheel. These two mills were apparently demolished early in the 19th century and their sites remained vacant for some time until the **Charcoal Store** [211] was built on the west bank. The **Charcoal Store** may be traced on the ground as brick foundations with an internal 18-inch gauge rail inside the building. The rail is wood with an L-iron metal sheath fitted to its inner upper side. **Incorporating Mill No.1** [211a] was built on the site of the demolished **Stamp Mill** [Farmer No.11], and its site was in turn subsequently partly covered by the **Central Solvent Store** [A292]. It appears that the

Incorporating Mill was driven by water being culverted from Millhead Stream beneath the building and turning either a wheel or possibly a turbine. When the concrete floor slab of [A292] was lifted during decontamination works in 1993 and loose rubble removed, a brick channel and at least three phases of brickwork were exposed down to a depth of 2m.

As described above, the western edge of Millhead Stream is defined by the brick-edged towpath: this also marks the position of mill [RCHME 272], last used as **Mixing House No.2**, and attached to its south side was a small **Saltpetre Store**. The northern wall and western edge of the building are also visible as brick foundations. The mill was driven by a central wheel. It was served by barges unloading material on its west side using the low-level water system to communicate with the **Sulphur Refinery** [375, 376] and **Saltpetre Refinery** [278-82] to the south and the **Charcoal House** [RCHME 333] to the east. Directly across the header leat from this mill are the buried remains identified as Smeaton's Mill [197/198], thought to have been designed by the eminent late 18th-century engineer John Smeaton. The location is labelled as 'Smeaton's Mill' on a map of 1783 (WASC 900/01). The brick foundations of the mill are visible on the surface and a brick revetment wall survives along its eastern side. Associated with mill [197/198] was a small **Lobby** [196], its site lying beneath the road from the roundabout. Smeaton's Mill [197/198] is the only mill building within the factory that has been subject to any archaeological excavation (Cherry, 1974, 132; Bascombe and Smith 1973). In the early 1970s a small excavation indicated that the mill was at least a three-phase structure, the present brick revetment wall replacing an earlier timber revetment. The underlying bank was thought to date from around 1700. Also found during the excavation were elm posts over 2m in length that formed a support for the internal machinery.

The extent of John Smeaton's work at Waltham Abbey RGPF may, however, have been greater than this one identification suggests. Original drawings preserved in his folios at the Royal Society Library (Smeaton 1771) show the design for two mill buildings for the factory. Drawings 36-38 show the design for a powder mill on the *west* side of the mill pond. It is conventionally arranged with a central wheel pit: but the mill is shown as being underdriven, with its wooden gearing housed in a massive vaulted brick chamber beneath the mill. The flow of water on the drawings also confirms its intended position on the west side of the stream. A possible location for these mills may be indeed on the west side of the stream but slightly to the north, beneath mills [182] which were labelled as the 'New Mills' in 1783 (WASC 900/01), that is less that ten years after Smeaton's designs. The closeness in time of this map to the drawings would also tend to confirm that mill [197/198], too, was indeed built to a design by Smeaton. Drawing 33 shows another mill, again arranged around a central wheel. In this instance the wheel was apparently intended to power two incorporating mills either side of the central pit, the wheel driving one mill directly off a spur wheel and the second via a long shaft with gears at either end. Since no building corresponding to such a ground plan is evident on the 1783 map, this may best be regarded as a proposed rather than an executed design. If this is so, it may also throw the status of the other drawings into question.

To the north of mills [RCHME 272 and 197/198], two further former mills were situated roughly beneath the modern road leading off from the west side of the roundabout. On the western side of the Millhead Stream was **Hoppit Mill** [RCHME 353] and on the eastern side **Queens Mead Mill** [RCHME 349]. Late 18th-century maps show that both mills were of the characteristically centrally driven form: they were demolished shortly before 1840. The site of **Queens Mead Mill** [RCHME 349] may partly be overlain by two later buildings, namely a **Charge Magazine** [190] and a **Loading Stage** [187]. North again of these buildings were two pairs of **Incorporating Mills**, [183] and [181]. The central wheel pits of both these mills are visible in the brick revetment wall of the eastern tailrace **Leat** [RCHME 119] and odd stretches of brick foundations are visible on the level platform between the stream and the tailrace. Also lying close to the surface are fragments of limestone edge runners. As the brick revetment approaches the modern road to [H67], its line is lost but it re-emerges north of the road as the eastern wall of [165], a building last used as a **Barrel House**, although in the early part of the 19th century it served as a temporary **Dusting House**. On the western side of Millhead Stream was a similar pattern of **Incorporating Mills** [191, 182 and 165a], each arranged around a central wheel. No earthwork evidence survives fixing the precise positions of these mills, but the fact that the platform on which they sat may be followed as an earthwork would point to the presence of below-ground deposits. If we are correct in supposing that the 'New Mills' identified in 1783 were built by Smeaton to his design drawing, then a below-ground structure in excess of 15 feet (4.57m) might be expected. The drawings also show that the foundations were piled, which ought to offer the potential for dendrochronological dating if these mills were ever excavated. Separating mills [191] and [192] was a small **Magazine** [184].

North of the modern road to [H67] where Millhead Stream remains as an open earthwork, this improved state of preservation is also reflected in the few buildings that were ranged along either side of the stream. On the eastern side of the stream is the **Dusting House** [159]. This is the only example of the characteristic centrally-driven water-powered gunpowder mill building to survive on the surface within the factory. In the centre of the building is a wheel pit, retaining on the stream side a metal tumbling bay and shuttle and plates that controlled the flow of water through the low breast-shot wheel. On either side of the wheel pit the slots for the pit wheels survive: they provided power to the mill building either side of the central pit. The mills were formerly covered by timber-framed superstructures set on brick foundations. These rectangular brick bases survive probably to their full height, although in places disturbed by tree roots. Within the former buildings are sandstone and concrete bases, and set within them vertical mounting bolts to which the machinery was attached. Later in the history of this building free-standing traverses of mass concrete were added to either end. A traverse also existed opposite to the **Dusting House** on the eastern edge of leat [RCHME 119]: this has been removed but a concrete revetment along the leat edge marks its position. At the northern edge of the traverse was a small **Shoe**

Room [157] linked to the **Dusting House** by a **Footbridge** [RCHME 223].

To the north of the **Dusting House** [159] is a **Expense Magazine** [155]. This is a small single-storeyed vaulted structure with a porch on its west side, through which it was supplied exclusively by barges on the Millhead Stream. The magazine originally had a raised timber floor, which has been lost inside the magazine but survives in a rotten condition in the porch, where also some of the leather floor covering fixed with copper nails is extant. To its north is a building [L128] raised on concrete legs to the level of the stream. It had originally been built as a **Fuse Powder Magazine,** supplied from Millhead Stream through a covered porch: it has subsequently been converted for use as the **Radio Chemistry Laboratory**. Associated with this building is a small **Magazine Solvent Store** [L123] to its north. The **Radio Chemistry Laboratory** [L128] may overlie the site of an 18th-century **Gloom Stove** [RCHME 349].

During ground clearance work between [L128] and [155] early in 1993, twelve small sandstone millstones [RCHME 258] were recovered. The stones are between 52cm and 69cm in diameter and between 24cm and 31cm in thickness: the majority were grooved with a circular central hole. It is unlikely that these stones were used for the production of gunpowder as sandstone was avoided because of its tendency to spawn grit. The stones may perhaps originate from one of the workshops on the site, where they might have been used for sharpening tools: but alternatively a more likely source, because of their numbers, may be the Royal Small Arms Factory at Enfield a few miles down the River Lea, where grinding stones were in constant use.

Running along the base of the eastern embankment as Millhead Stream curves westward north of the **Dusting House** [159] is a shallow ditch. [L128] and [155] appear to built into and over it, and it is by leat [RCHME 119] close to the **Dusting House**, which itself continues straight northwards on a line diverging from Millhead Stream. The ditch peters out to the north of the **Solvent Store** [L123]. It appears to be an earlier phase of tailrace, already superseded by 1827 (Fig 4).

Set on the western embankment of Millhead Stream north of the road to [H67] are the brick foundations of a building last used as a **Barrel House** [RCHME 218]. The western side of the building forms the edge of the infilled western tailrace [RCHME 301], while its eastern side is encased within the later revetment of Millhead Stream. It was used in the first half of the 19th century as a temporary **Dusting House**. The only feature surviving within the structure that hints at a degree of sophistication beyond that of a simple store is a small brick culvert running north to south beneath the western side of the building. Immediately to the north of the **Barrel House** is a brick **Weir** [RCHME 219] used to regulate the depth of water in Millhead Stream. The weir consists of a vertical brick wall at either end, with a gently sloping brick surface in between partly laid in a herringbone pattern. The flow of water into the weir was latterly blocked by the reinforcement of the revetment along the side of

Millhead Stream. At that date, regulation of water in the high and low systems probably being more effectively controlled by the **Lock** [RCHME 222]. This lock, of brick with cast-iron sluices by Frederick Bird of London, was constructed in 1896-7. The new lock facilitated access between the high- and low-level water systems, allowing barges to move between Millhead Stream and the lower reaches of Millhead Stream beneath the **Sluices** [RCHME 135] along the western tailrace [RCHME 301]. It also created access westwards to the earlier Horsemill Stream along the western side of the factory. The east-west leat lying north of the **Ballistics Laboratory** [H67], an extension of [RCHME 301] that forms the north limit to area H, is now infilled and impinged on by structures in area H ancillary tot he laboratory. A linear earthwork hollow is all that marks the north-south section of the low-level leat [RCHME 301], the eastern side bounded by the embankment of Millhead Stream. In the fill of this leat fragments of acid processing earthenware were seen.

North of the **Lock**, the western embankment is largely featureless and there is no direct evidence of structures here. Opposite the **Expense Magazine** [155] is a sub-rectangular scarp defining a level area at the base of the embankment, but with no known function. The embankment may then followed for a further 60m northwards until the former line of the stream is lost beneath dumped gravels and the western perimeter road. The featureless triangle of land against Horsemill Stream is Little Hoppit.

Northwards of this point the former western edge of Millhead Stream has entirely been swept away in the canalisation of the Horsemill Stream. On the eastern bank was a **Heading-up House** [RCHME 274], in which gunpowder was barrelled: although no surface remains are traceable, its site may survive beneath the modern perimeter road. On the opposite side of the stream was a group of buildings [148, 149 and 150] surrounded by two traverses. They originally formed a gunpowder **Gloom Stove** and were later converted into a gunpowder **Drying Stove**, utilising steam heating as opposed to the direct heat of the gloom. Any remains of these buildings seem likely to have been swept away with the canalisation of Horsemill stream, but fragments may survive buried on the new western and eastern stream banks. Northwards again, no other buildings of the gunpowder factory were placed on the western bank of Millhead Stream until the area later occupied by the Acid Factory.

The eastern bank between the **Heading-up House** [RCHME 274] and the east-west canal [RCHME [294] has been considerably altered by this side of the stream being cut back eastwards and by the dumping of river gravel as embankment for the new Horsemill Stream. Within this dump of river gravel are fragments of brick and breeze-block structures. A small **Magazine** [132] was certainly destroyed when the river was widened. North of it, the **Granulating and Dusting House** [125] lay close to the stream's edge, so that it is possible that parts of the east side of this building may lie beneath the modern perimeter fence and track. Its location is indicated by the tailrace leading away from the centre of this building as an earthwork and discharging into leat [RCHME 119]. North of the **Granulating and Dusting House** the linear dump of gravel continues, in part filling the leat [RCHME 119].

brick walls seen during the re-excavation of service trenches in this area were probably part of that feature.

With the exception of a small **Guncotton Drying Shed** [RCHME 343] constructed sometime after 1862, Great Hoppit was largely featureless until the end of the 19th century when **Sandhurst Hospital** [H26] was built in 1894. The area to the north of the hospital developed after the turn of the century with the expansion of the cordite processing capacity of the factory. The layout then remained fairly static until after the Second World War when the needs of the new government research establishment initiated a new phase of building activity.

To the west of Great Hoppit was a narrow island called Horse Mill Island (see Figs 4 and 5) extending for nearly 500m between the **Gloom and Gunpowder Stove** [148/149/150] at its northern end and a former **Stables** [RCHME 317] at its southern end. The island was formerly separated from Great Hoppit by a narrow stream called Horsemill Stream and was delimited on its western side by a further un-named narrow stream. The island took its name from nine horse-powered gunpowder mills that were constructed on it during the early years of the 19th century, as shown on Ellis's engraving of 1808 in Hughson's *Description of London*. These mills were demolished at the end of the Napoleonic wars, but a number of associated buildings were retained until the early 1900s. Working from south to north the principal buildings retained were the **Stables** [RCHME 317], converted to a **Sulphur Store** in the early 19th century and at the beginning of the 20th century to an **Acetone Store**. To its north were two **Dwellings** [RCHME 318 and 319] for factory employees and to their north a **Watch House** [RCHME 320]. At the northern end of the island was a **Gloom Stove** [148/149/150], later converted to a steam-heated **Gunpowder Powder Drying Stove No.2**. Between the **Watch House** and the **Gloom Stove** was a horse-powered **Corning House** [RCHME 359]. This building was probably constructed shortly after the government took over the factory. It was destroyed in an explosion on 18 April 1801 and was apparently not rebuilt.

The island survived until around 1950 when Horsemill Stream separating it from Great Hoppit was canalised. This both straightened its course and widened the channel, probably shaving some ground from the eastern side of Horse Mill Island. The majority of the island however survived as a wooded area within the security fence of the factory; the sinuous course of the western stream is visible on aerial photographs as an earthwork. By 1980 this part of the North Site had been relinquished and an access road constructed along the western bank side of Horsemill Stream. Depending on the construction methods used in building it, the foundations of all the buildings described above, along with the early **Horse Mills**, may survive as buried features beneath the road along the western side of Horsemill Stream.

The development of the area known as Great Hoppit did not begin until the end of the 19th century with the construction of **Sandhurst Hospital** [H26] in 1894. Opposite to **Sandhurst Hospital** [H26] is the **Womens Hospital** [H25] and its associated **Earth Closet** [H25a], both constructed during the First World War. North of **Sandhurst Hospital** [H26] is a small single-storey **Office** [H23]. To its north, a U-shaped scarp probably represents the northerly extent of tipping during the remodelling of the southern gate area in the 1960s. Between this scarp and the fence just over 50m north again is the site of a large building, the women's **Shifting and Dining Rooms** [H19], also constructed during the First World War. The ground surface in this area is covered by long coarse grass and no surface remains of this building are visible. Its eastern limit may nevertheless be marked by the linear scarp oriented north to south. If so, this would also mark the line of part of the narrow gauge railway network in this area. To the east of [H19] were two buildings, [H21/1 and H22], of unknown function; the northerly of them, [H21/1], was possibly screened by an earthwork traverse. To the south-west of [H19] is the small **Sewage Pump House** [H24].

The northern part of area H was developed around the turn of the century during the expansion of the cordite manufacturing capacity of the factory. Immediately north of the fence is a large floor slab measuring 45m x 33m, the remains of a First World War **Cordite Press House** [H16]. To its west were three further buildings of uncertain function [RCHME 340, RCHME 341 and RCHME 342]. At the northern end of the area are two **Cordite Drying Stoves** [H7 and H8], set within massive subrectangular earthwork traverses around 3m in height with a basal width of up to 10m. The traverses are entered at opposing corners through vertical concrete revetment walls leading to a timber loading porch at either end of the brick built stove. These porches were formerly served by the narrow gauge railway. The entrances to the magazines are protected by low red-painted toe boards defining dirty and clean areas; shoe boxes were also provided where the workers were required to change into magazine shoes before entering. Associated with these stoves is the free-standing former **Cordite Reeling House** [H10] and the **Cordite Reel Magazine** [H12]. The **Cordite Reel Magazine** is enclosed within an earthwork traverse up to 3m in height with a maximum basal width of 10m. The traverse is entered from the northern side through two parallel vertical concrete revetment walls. This entrance also was formerly used by the narrow gauge railway system.

Few traces now survive of the narrow gauge railway network that linked the cordite processing buildings within area H. The line was connected to the South Site by a single line that ran through a tunnel beneath Highbridge Street. This line emerged on the east bank of lower Millhead Stream, where it ran through the **Saltpetre Refinery** [278-82] before crossing the stream by means of a swing bridge located to the north of **Sandhurst Hospital** [H26]. The remains of the bridge [RCHME 100], consist of a central concrete pier, the western pier and a short length of earthwork embankment. Further remnants of the network in this area include the **Locomotive Shed** [H13] and a short section of *in situ* track to the east of [H65]. Between [H17] and [H8] a Y-shaped scarp with steep well-defined sides is a section of railway embankment. The only other clues to its former routes are the concrete entrance portals through the earthwork traverses.

This pattern of buildings within area H remained fairly static for the remainder of the factory's life, except for the addition of the **Air Raid Shelter** [H15] during the Second World War. Subsequent to the closure of the RGPF in 1945 and its re-establishment as a research station, many of the factory buildings in this area were adapted for new uses and additional ones were constructed. Also during this period much of the redundant infrastructure designed to serve the factory was dismantled, in particular the narrow gauge railway system. New services were required, including a steam heating system supported on steel piers and served from the central **Power House** [A210]. The lines of the steam pipes were marked by concrete bases with steel pipes set into them: these have been removed in decontamination work immediately following the RCHME survey. Adaptations of the existing buildings included the conversion of the **Reel Magazine** [H12] into **Proof Stand No.1** for propellant testing. Access to the **Proof Stand** was along raised earthwork paths closed by a lifting barrier arm with a red light to warn of a test firing. This facility was served by three new structures, the **Dithekite Fuel Store** [H65] and the **?Switch Room** [H14] and a building [H54] of unknown function and with no surface remains at the waterside to its east. Raised earthwork causeways were constructed to link the new buildings, although the causeway to the south of [H14] may have reused a former railway embankment. The former **Reeling House** [H10] was converted into a **Laboratory**. This in turn gave rise to an accretion of minor buildings around the original core. **Offices** [H71] were added to its western end and additional office space was provided by the porta-cabin [H32]. Explosives research within the **Laboratory** led to the construction of a small **Magazine** [H21] to the north and **Locker Magazine** [H66] to the south. Also to the south of [H10] are the concrete floor slabs of three **Store** buildings [H1, H2, and H3]. Adjacent to these are two prefabricated cast-concrete garages [H5 and H6], also used as **Stores**. Associated with this group but perhaps earlier in origin is [H11], a concrete shelter of semi-circular section latterly used as a **Chemical and Solvent Store**. Isolated from the main group of buildings in this group is the **Solvent Store** [H30] at the north end of the **Locomotive Shed** [H13].

The largest new building project in the northern area of H was the **Ballistics Laboratory** [H67] and its associated structures in the late 1950s. Behind the laboratory was an area delimited by a low post-and-wire fence, access into which was controlled by two lifting barriers across the footpaths. Within this enclosure were ancillary structures associated with the laboratory. In the centre is the concrete **Test Bed** [H68], with two firing bays separated by a central control room. To its east are a **Magazine** [H69] and a **Solvent Store** [H70]. At the northern end of the enclosure a **Firing Tunnel** [68a] had been constructed from pre-cast concrete pipes joined together and mounted on breeze-block and timber supports, and in part overlay the filled east-west section of canal [RCHME 301].

The remaining buildings in area H are two **Sewer Pumping Houses,** [H17] and [H31]; these are associated in function with two **Sewer Pump Houses** in area L, [L126] and [L170].

Area L (Figs 3, 9-10)

Area L, see Figure 3, is bounded to the south by area A, to the east by the Old River Lea and to the west by the eastern edge of Millhead. The northern limit of this area is taken as leat [RCHME 296] on the line of an outflow channel from **Corning House** [97] at the northern extremity of the Millhead area.

Much of this area was known historically as Queens Mead and for the first half of the 19th century was covered by willow plantation cut by a number of low-level leats (Fig. 4). The present land-use shows a marked division between a heavily wooded northern half with dense summer undergrowth, north of canal [RCHME 300], and an open southern half to which the name Queens Mead has latterly been restricted.

Early developments in the southern part of this area included the digging of the canal [RCHME 278] to serve the **Charcoal Cylinder House** [RCHME 333]. The major development, however, took place with the construction of the **Steam Incorporating Mills** beginning in 1857 with the **Group A mills** [L168, L169 and L176]. This group of mills comprised a surviving detached boiler house [L176], with a (demolished) tall chimney between it and the engine house [L168], supplying steam to the engine in the eastern end of [L168]. The western side of the [L168] was occupied by a machine shop that utilised power from the engine. The incorporating mills themselves were arranged in six interlocking trapezoidal-shaped bays to the east of the engine house. The separating walls were constructed from solid brick three feet thick; the fourth and widest side of each bay and the roof were of corrugated iron and glass (Wynter 1858, 244) to provide a side of least resistance in the event of an explosion. Just such an accident is vividly captured in an engraving for the *Illustrated London News* of 8 June 1861. These mills, like their successors, were under-driven and original builders' drawings indicate that they were powered by a compound steam engine of thirty horsepower supplied by the Soho Ironworks of Bolton. Lammot du Pont on his visit to the Waltham Abbey RGPF in 1858 noted in his journal that the mills were 'driven by a double-cylindered, high-pressure steam engine powering a single drive shaft that passed through an arch beneath the floor of each mill. The roll wheels were a 'light' 5-1/2 tons each, six feet in diameter, and with a face of 17-1/8 inches'. He also noted the safety device of having drenching tubs containing three cubic feet of water above each mill that would be automatically upset if one of the mills exploded. He was also impressed by the adjacent **Machine Shop** [L168] with its horizontal boring mill capable of turning the large iron rolling wheels and bed plates for the rolling mills (Wilkinson 1975b, 27-8). The original mill buildings were demolished in the 1950s the present concrete floor [L169] relates to a modern building constructed then. It may therefore perhaps cover and preserve the foundations of the mills and in particular the underground drive shaft alley.

This Group A was followed in area L in succession by the **Group C mills** [L157] in 1861, **Group D mills** [L153] in 1867, **Group F** [L145] and **Group E** [L149] (originally constructed as a **Pellet Powder House**) in 1878. The complex, organised on a north-south alignment alongside canal [RCHME 300], was completed by the addition of **Group G mills** [L148] in 1889. Associated with these mills were a number of small **Expense Magazines** the surviving examples comprising [L170a], [L154] and [L141]. The **Group B mills** [387] were those constructed in 1859 on Lower Island (see above).

All these steam-driven incorporating mills with the exception of the earliest, **Group A** [L168, L169, L176], were T-shaped in plan. At the rear of the buildings was an enclosed coal yard and a tall chimney. The rear wing of each mill was a boiler house containing two Lancashire boilers raising steam for a centrally-placed beam engine (Johnson 1965, 321) formerly housed within the tall axial tower. The engines were secured to bed stones surrounded by a floor supported on cast-iron beams. To either side of the engine and below the floor level of the building was a segmental cast-iron fly wheel. The engine powered a central horizontal drive shaft housed in a tunnel, termed a drive shaft alley, beneath the floor of the mill bays, three bays either side of the engine house. In mills [L145], [L149] and [L157] the tunnel was constructed from cast iron plates while the tunnel beneath [L153] uniquely was brick vaulted. [L148] was unavailable for investigation during RCHME fieldwork. Beneath each of the mill bays, the drive shaft alley widened out to form a circular chamber in which was housed a horizontal gear wheel driven by a pinion wheel attached to the drive shaft. This wheel was engaged by means of a friction clutch controlled from the outside of the mill (see Fitzgerald 1895, photo 8). In mills [L148], [L149] and [L153] the drive shafts, clutches and pinion wheels remain *in situ*. The only subfloor engine compartment that was available for investigation was beneath [L153]. Here the original cast-iron floor beams of the engine house had been retained to support the modern floor. The subfloor area was filled with loose brick rubble and some artefacts including leather fire buckets. Below the floor the engine bases, of brick with a stone cap, survived and other pieces of gearing and pipes were visible protruding from the rubble. The cast-iron segmental fly wheel also survived, the top third of the wheel having been removed. The engine bases and gearing may also survive in the other mills, as in [L149] and [L157] the fly wheels were visible at the ends of the drive shaft alleys backed by loose brick rubble. The incorporating mill machinery sat on the floor above the chamber with a drenching tub over the machinery to douse the mill in water in the event of an explosion.

At the end of the 19th century the **Steam Gunpowder Incorporating Mills** were converted into **Cordite Incorporating Mills**. The gunpowder mills were removed by the simple expedient of cutting the vertical drive shaft and allowing the horizontal gear wheels to drop into the subfloor chamber where the majority of them remain today. The below-floor shaft was replaced by an overhead drive shaft powering belt-driven cordite incorporating machines. The bearing boxes of the overhead drive shaft as it passed through the partition walls and end walls are still visible on a number of the mills, along with the sawn off girders. It appears that at least for the early years of this century the central steam engines were retained to power the overhead drive. It also appears that the drive shafts were linked between the buildings, for when mill [L148] was involved in an accidental explosion in 1902 it was being driven from [L153] (Nathan 1902, 6). The considerable collateral damage caused to the surrounding buildings probably prompted the construction of the mass concrete blast wall along the west side of mills [L149] that is visible in early photography (see PRO Supply 5/861 photo 217). A traverse was also erected between the engine houses of [L153] and [L148]. It is unclear whether a series of structures shown on plans to the west of the main west range of mills also represent concrete blast walls (WASC 900/84, 1923). All traces of these traverses and blast walls have been removed.

The **Steam Incorporating Mills** and the **Magazines** were served by a tramway system (Jenkins 1989, 387). A few remains of this system were found in the RCHME survey. To the west of mills [L145-L153] on the open ground known as Queens Mead a low linear bank around 5m in width and oriented north-north-west to south-south-east marks the course of the line; while during removal of contaminated earth adjacent to the west frontage of the mills a row of brick pier bases formerly supporting the trestle on which the tramway sat was revealed. A low scarp running parallel to the mills here marks the limit of the tramway. The trestles served to raise the railway to the level of the working floors of the incorporating mills and to raise it above the level of any winter flood waters in Queens Mead. The height of the tramway is also betrayed by the raised doorway of **Expense Magazine** [L154] and on its eastern elevation the scar of a brick trestle support is visible. The early tramway rails were described as 'tramway irons' (Jenkins 1989, 387) and were illustrated on a number of the contemporary builders' drawings for the incorporating mills. A section of this early type of rail about 2m in length was recovered during the emptying of canal [RCHME 278].

Also cutting across Queens Mead in the later part of the 19th century was a canal or leat [RCHME 355]. The feature has subsequently been filled leaving no visible surface trace, but its eastern end lies beneath the **Incorporating Mill** [L148] and the railway that served it.

Further developments taking place in this area at the end of the 19th century included the construction of [L167], a building whose early use is uncertain but which was later converted to a **Cordite Reel Drying Stove** and later again to a **Dining Room and Store**. The **Guncotton Press House** [L137] and two associated **Magazines** [L107 and L138] and the **Tray Magazine** [L135] were also added in the late 19th century, as production turned from gunpowder to newer explosives. Other new buildings in the area included the **Laboratory** [L122] and the **Managers Office** [L119]. The Great War led to an unprecedented demand for cordite and prompted the construction of **Cordite Press Houses** [L134 and L159] and the **Cordite Incorporating Houses** [L143, L146, L151 and L155] to north and south of the **Group E Incorporating Mills** [L149] on the eastern side of the canal [RCHME 300]. Like the incorporating mills, these are all long buildings divided into bays by brick partition walls and were formerly closed by timber walls. Also at this time a purpose-built **Mineral Jelly Store** [L165] was constructed, mineral jelly being used during the incorporation of cordite.

Throughout the latter part of the 19th century the factory **Gas Works** [RCHME 333] was situated at the end of canal [RCHME 278] adjacent to the earlier **Charcoal Burning House** [RCHME 333]. The **Gas Works** was demolished and the canal was filled, probably after the Second World War, and subsequently it has had a car park laid out over the top of it. During the early part of 1993 the car park was dug up and the material filling the canal removed. The material in the canal included fragments of breeze-block and concrete structures, some light railway track and strands of cordite in the upper layers. Also exposed during this operation were the timber revetments along either side of the canal.

The reuse of Waltham Abbey RGPF as a research establishment after the Second World War saw the conversion of the majority of the pre-existing buildings within the southern part of area L to laboratories and associated buildings. **Group D, F and G mills** [L145, L148 and L153] were linked together into a continuous range. A scatter of minor ancillary buildings were also added to the pattern. This is most apparent at the northern end of the present Queens Mead near the **Laboratory** [L122]. The many minor earthworks linking the buildings in this area are the remains of a network of footpaths. New **Stability Laboratories** [L191 and L198] were constructed and an old timber hut [L185] was used as a **Laboratory**. Associated with the laboratories were **Stores** [L120, L125 and L196], **Preparation Room** [L118] and a **Toilet Block** [L121]. The buildings to the east of [L122] occupied the positions of a small group of timber sheds earlier associated with the main laboratory, including a small electric **Accumulator House** [140] and **The Silvered Vessel House** [144b] used in the testing of cordite (HMSO 1938, 116). A distinctive type of building constructed at this time were the **Locker Magazines** [L117, L186, L188, L192, L193 and L194]. These are single-storey structures with doors to either end; along one wall were ranged up to six metal lockers in which explosives were stored for use within the surrounding laboratories. All the **Locker Magazines** were heated by steam pipes and later by electric heaters. As explosives stores, all the **Locker Magazines** were protected by lightning conductors connected to a copper band running around the building and joining to the individual lockers.

The wooded northern part of area L may conveniently be divided into two, east and west, by the former canal [RCHME 179]. This canal was constructed during the extension of the high-level canal system in 1878 and was carried by an earthwork embankment raised above the surrounding ground surface. The canal survives as a open earthwork feature at its northern end with the remains of the timber board-walk to either side; it is carried over low-level leat [RCHME 181] on a brick aqueduct [RCHME 180]. To the south of the entrance to the **Cordite Paste Store** [L105] the canal has been filled and a tarmac road laid over its line, although in places the timber revetments of the canal are visible. The canal served the **Blank Cutting House** [L109] and a **Magazine** [L133]. Later a second **Cordite Paste Store**

[L108] was added to its west bank. It is uncertain whether or not the canal directly served the **Cordite Paste Store** [L105] as there are no apparent loading facilities at this point. These stores were also served by the light railway system that ran along the western towpath of the canal. The rails have been removed for most of its length but a short section remains *in situ* to the rear of [L108] and to the north of the entrance to [L105].

At the southern end of canal [RCHME 179], a short section of the canal remains as an open earthwork as it approaches the canal **Lock** [RCHME 225], despite its use as a casual dump in the recent past. The canal **Lock** [RCHME 225] controlled access between the upper and lower water systems. It is brick-built with timber gates remaining *in situ* at the either end. Below the lock the lower canal system remains water-filled southwards. Canal [RCHME 179] terminated in a dead-end immediately north of the **Remote Accumulator Tower** [L136] to serve the **Magazine** [L133]. This section of canal also survives as an open earthwork partly filled by rubbish. The low-level canal and leat to the east and north of the lock [RCHME 156] are water-filled but clogged with vegetation and casually dumped rubbish from the research establishment. Stranded in this stretch of canal between the **Lock** [RCHME 225] and **Magazine** [L111] are the decaying remains of four powder barges [RCHME 157-160].

To the west of the canal [RCHME 179], the area between it and the Long Walk was formerly part of Queens Mead. The land northwards between the east-to-west road south of **Climatic Test Cubicles** [L190] and the earthwork leat [RCHME 181] is covered by an alder plantation at least a century old. Running on the east side and parallel to the Long Walk is an earthwork leat [RCHME 299], which is part of the low level water system. This appears on the ground as a linear ditch with a bank on its eastern side, that converges southwards with the Long Walk and is perhaps overlain by it. This leat formerly continued south of [L190], although now no surface evidence remains for the feature. Within the alder plantation are many minor earthworks; they are interpreted as local water-management features for the alders and the result of natural mounding around the tree roots. Towards the end of the 19th century encroachments were made into the south of the plantation with the construction of the **Magazine** [L114] and the **Photographic House** [L116]. Later additions to this pair were the **Air Raid Shelter** [L115] during the Second World War and the **Climatic Testing Cubicles** [L190] during the 1960s. Immediately to the north of the alder plantation is a **Cordite Paste Store** [L105] set within a massive earthwork traverse up to 14m in width and 2.5m in height. To the north of [L105] and to the west of the concrete floor slab of [L104] a short earthwork bank represents the remains of a 19th-century footpath leading to the lifting **Footbridge** [RCHME 177].

To the east of canal [RCHME 179] in a roughly rectangular-shaped piece of ground defined by that canal and canal [RCHME 300], the leat [RCHME 181] and the Old River Lea to the east, the most prominent feature is a large post-war concrete and steel pile **Firing Point** [L189] surrounded by an earthwork traverse. To its north is a further **Firing Point** [L199] constructed from steel piles and concrete. These features are connected by footpaths raised on narrow earthwork banks. The entrance to these footpaths at the west and east sides were controlled by a barrier and telephone box. To the south of [L189] are the earthwork remains of a sub-rectangular pond [RCHME 155], measuring 30m x 21m with a small sub-rectangular mound 11m x 8m positioned slightly off centre. To its south is large gravel traverse [RCHME 228] revetted on its southern side in timber, this formerly shielded the northern side of the late 19th-century **Gunpowder Moulding House** [L130] situated on the south bank of the east-west stretch of canal [RCHME 300]. About 20m due east of [L199] is the site of the **Experiment House** [RCHME 303], but the ground surface in the area is covered by a dump of river gravel. The concrete floor slab a similar distance north-west of [L199] is the site of **Drying Stove** [L106], which was linked to the Tetryl to the east of the Old River Lea by the light railway system during the Second World War. The line of the railway is marked by the curving raised path to its east.

To the north of this area the line of the east-west leat [RCHME 181] may be followed to the east of canal [RCHME 179] as a linear earthwork hollow with a low bank on its northern side. The eastern end of this feature was buried by a dump at the time of survey, but after the removal of this dump in April 1993 its line may be traced for its full length eastwards. Between the ditch and the fence defining the southern edge of the Burning Ground a group of amorphous earthworks probably represent former mounding around tree roots and perhaps quarry pits for the embankment of canal [RCHME 294].

The major east-west canal [RCHME 294] formed one of the early extensions to the high-level system, having been created in the first decade of the 19th century to serve a horse-driven **Corning House** [103] adjacent to the Old River Lea at its eastern extremity. It was fed from the west by Horsemill Stream and carried on an embankment 250m due east to terminate in a wide basin that was evidently part of its original design (Figure 4). The early building halfway along its south side was a **Magazine** [105], that later served the **Press House** [103/104]. The canal survives as an open earthwork feature at its west end, although partly truncated and filled during the canalisation of Horsemill Stream. When the north-south low-level leat [RCHME 119] was created and crossed near its west end, [RCHME 294] was carried over it by a brick **Aqueduct** [RCHME 170]. The nearby section of the canal in front of [107/108] has recently been partly re-excavated, although some waste does remain in the base of the feature. Lying within this stretch is a powder **Barge** [RCHME 169].

All that remains of buildings [107/108] is a mass concrete E-shaped traverse that formerly surrounded two timber **Moulding Houses**, additions to the gunpowder production cycle of the 1880s. Their brick foundations survive, and in [108] a cast-iron hydraulic press base remains in place. West of the **Moulding Houses** is an **Earth Closet** [108a]. To the east of the present track the canal was formerly crossed by a lifting footbridge [RCHME 177]. The lifting mechanism was on the northern bank within a wooden compartment and on the southern bank was a metal locking mechanism on to which the bridge dropped. East of this point the canal has been filled to the level of the Burning Ground and is not visible as surface feature. Its southern embankment does survive between the **Cordite Paste Store** [L101] and the canal [RCHME 179], where the southwards bulge at the west end indicates the sites of **Magazines** [105 and 106]. The foundations of these magazines may survive as buried features as the wall lines of [106] can be seen as a row of bricks close to the surface. At its eastern end the embankment is overlain by the earthwork traverse surrounding the former **Cordite Paste Store** [L101]. This building is surrounded by a **U**-shaped traverse up to 14m in width and 3m in height, the northern ends revetted by vertical concrete walls. It was formerly served by canal [RCHME 294].

The early **Corning Mill** at the east end of canal [RCHME 294] was replaced in the mid 19th century by **Hydraulic Pump and Press House** [103/104], alias gunpowder **Press House No.2** . The high-level basin on the west of the buildings provided the head of water to power the a low breast-shot wheel on the southern side of [103]. This drove a hydraulic pump housed within the building, which in turn powered a hydraulic gunpowder press housed within [104]. Both the water-wheel and the pump mechanism and a hydraulic press survive *in situ*. The **Pump House** roof although collapsed may retain its original 19th-century corrugated iron roof. The corrugations distinctively are far wider than would be expected on more recent sheeting. The earliest proposed use of corrugated iron at Waltham Abbey RGPF was in 1845 (WASC 901/112). Snow Harris in his paper on lightning conductors (1858b, 129-32) believed that corrugated iron used 'in the new works by the water wheel' would provide effective protection against disruptive electrical discharge. Scattered around the **Press House** are fragments of slate around 1cm in thickness with drilled screw holes, some retaining brass screws. The function of these pieces is unknown but they may have been part of an attempt at fire-proofing parts of the building. Also around the building and fixed to the exterior of the **Pumphouse** are the remains of a danger building lighting system. This consisted of small-bore iron piping that contained the wiring and the remains of light fittings that were suspended outside the windows and fragments of the glass globes that encased the lights. These two building are separated by an oval brick traverse with battered walls, a remnant of an early horse **Corning Mill** that formerly occupied the same site. The canal basin and the area to its south have in the post-war period been used as a convenient dumping ground that has recently been cleared down to the original ground surface. Among portable finds made during the re-excavation of the canal basin, two copper press plates were recovered that were used to separate the layers of powder within the press. One of the plates was square, while the other was rectangular and narrower than the first. It is suggested that this narrower plate was used to produce presscake for use in the pebble powder cutting machine, for that process required a smaller cake (see Appendix to **Section 3** for discussion of pebble powders). Also recovered was a brass chisel formerly used to separate the gunpowder from the copper sheets after pressing. To the east of the **Press House** is a concrete shelter with a semi-circular section [RCHME 167], similar in form to [H11] and the demolished building [L197].

The final and northernmost part of area L lies to the north of canal [RCHME 294] and is bounded to the east and north by the Old River Lea and leat [RCHME 296] and to the west by canal [RCHME 209]. It contains the triangular area of ground known as the Burning Ground, used in the post-war period for the destruction of dangerous substances by detonation or fire, whose southern edge overlies the central section of canal [RCHME 294]. Defining the western edge of the Burning Ground is canal [RCHME 289], part of the extended high-level system. The road **Bridge** [RCHME 112] under which it passes and its own cast-iron **Aqueduct** [RCHME 113] over the Old River Lea carry dates respectively of 1878 and 1878-9. This canal was used in the post-war period for dumping research establishment waste but during current decontamination work has recently been cleaned out to the clay lining. It served two **Magazines** on its eastern bank, [L102] and [L103]; these are separated by a concrete traverse and screened to the west by an earthwork traverse on the western canal bank. The northern edge of the burning ground is defined by a raised embankment carrying a roadway over **Bridge** [RCHME 113]. To the north of the embankment were two ponds divided by earthwork embankment carrying a footpath to canal **Bridge** [RCHME 117], also dated 1878. These two ponds have also been partly filled with rubbish in the post-war period, which was largely cleared out in the early part of 1993. Adjacent to **Bridge** [RCHME 113] is the **Dining Room** [96], a derelict single-storey structure on the verge of collapse.

The present road to the east of the Burning Ground is a relatively recent creation. It overlies the filled canals [RCHME 181 and 294] to the west of the **Press House** [103/ 104] and is raised on an embankment to rise over the canal bridge [RCHME 117], superseding the earlier raised footpath described above. The area between this road and the Old River Lea is largely featureless, with the exception of some short linear scarps interpreted as tree-planting ridges and a linear earthwork hollow oriented north-east to south-west that is the remains of a leat shown on 19th-century maps.

The Acid and Tetryl factories (Figs 3, 12)

The Acid Factory (see Figure 3) was developed on a narrow strip of land on the east bank of Horsemill Stream in the 1890s to serve the needs of the new Nitroglycerine Factory in Area E immediately to its east. The factory was initially situated between canal [RCHME 288], where its **Boiler and Engine House** [80 and 86a] lay on the south bank, and **No.1 Steam Stove** [RCHME 330]. The eastern side of the factory is defined by the line of the present north-to-south road and the western edge by the course of Horsemill Stream. The construction of the factory involved the demolition of a small building of unidentified function at the junction between Horsemill Stream and canal [RCHME 288]. The **No.4 Granulating House** [AF4 formerly 56] was retained and converted into a **Plumbers Shop**, and the traverse to its north was retained. At this date a sub-rectangular pond [RCHME 354] with two small circular islands to the south of the **Granulating House** that its tail race tipped into was filled and built over. The early Acid Factory was housed within around eight substantial buildings. During its construction a culvert [RCHME 183] was built. This was in part open, but the remainder was culverted beneath the factory and joined with an older north-south leat [RCHME 119] south of canal [RCHME 288]. The factory underwent further expansion prior to and during the First World War, to extend as far south as [87] as a result.

To the north of the Acid Factory, a factory was created at this date for the production of Tetranitro-methyl-aniline, more commonly known in the services as Tetryl or Composition Exploding 'C.E.'. The construction of this plant involved the demolition of the early 19th-century **Steam Stove** [RCHME 330] and loss of its surrounding canal. Infilling by buildings also occurred between the original Acid Factory and the Tetryl Factory effectively covering the whole of this area. Further expansion took place during the Second World War when the area of the factory was extended as far south as [H87]. Two buildings, the **C.E. Grade 1a Purification and Absorption Towers** [39 and 39a], were placed on the west bank of Horsemill Stream, linked to the main factory by a bridge. The remains of these buildings are presumed to have been lost during the widening of Horsemill Stream. Also constructed at this time was the new **Engine House** [83b] and an **Air Raid Shelter** [ARS 2] to the east of the factory.

The site of the Tetryl Factory had been cleared by the time of the RCHME survey in 1993 and no surface field remains were recorded. The majority of the Acid Factory had been demolished after the Second World War, leaving only the floor slabs of the buildings in place. Many of these slabs are wholly or partly buried, although a number have been re-exposed as part of the decontamination programme. It is clear from contemporary mapping of the acid factory, however, that more building slabs remain buried in this area. On the slab bases details of the internal divisions of the buildings can be discerned, but on the slabs planned little intelligible evidence remained to indicate the processes within each building. Rarely, for example in **Acid and Glycerine Shed** [72], the position of the doors on the eastern side where the railway entered can be made out and the line of the rails leading into the building.

Few buildings remain standing on the acid factory site. In the south are two small **Toilet Blocks** [U4 and U7] and the former Nitroglycerine Nitrating **Engine House** [83b], stripped of its plant and latterly used as a warehouse. To the north of the Acid Factory the **Nitrate Soda Store** [E10] remains; it was a specialised building with battered concrete walls, a tramway line running north to south through eastern aisle of the building.

In the south-west of the Acid Factory was the old gunpowder **Dusting House** [84] and to its north a **Barrel Store** [79]. With the construction of the factory both buildings were converted for use as **Shifting Rooms**. It seems probable that both buildings were removed when Horsemill Stream was canalised although fragments of the **Dusting House** may remain buried on the edge of the stream. The former tailrace from the **Dusting House** [84], running from [84] to approximately the site of the chimney base [83], may survive as a buried archaeological feature. Between these buildings and the leat [RCHME 119] were two large **Boiler Houses** [80 and 86a]; the positions of these buildings are indicated by their floor slabs although the majority of [80] is buried beneath up to 0.5m of overburden. The bases of the brick chimneys associated with the boiler houses survive up to 1m in height. At the northern end of the leat [RCHME 119] are the concrete remains of the **Oil Separator Tanks** [78f]. The tanks are rectangular in shape, 12.7m in length, 4.6m in width and 1.4m in height overall, and are divided internally into six tanks. To the east of the leat a further number of floor slabs have been recently exposed although others lie buried up to 0.5m below the surface. North of the filled canal [RCHME 288] are a series of floor slabs, but understanding of the former functions of the buildings they supported is supplied by contemporary mapping rather than by the physical form of the features.

Area E (Figs 3, 12)

For the purposes of this description area E is taken as the area of the late 19th-century Nitroglycerine Factory, which was superimposed on a complex pattern of earlier canals and production buildings. It will include all those structures lying within the area prefixed E and a small group of associated structures to the east (see figure 3). On the western side the area is bounded by the Acid Factory and to the east by canal [RCHME 289]. In the north-east the boundary turns along the east-west leat [RCHME 283], out to Cornmill Stream, then back along the south-eastern side of Newton's Pool [RCHME 276] to **Aqueduct** [RCHME 250]. The northern limit is set by canals [RCHME 284] and the later canal cut [RCHME 290]. Cutting through the centre of this area is the Old River Lea, a meander in which forms the southern boundary. The area may be broken up into a series of topographic units using the lines of the watercourses that criss-cross it.

The area in which the structures prefixed E lie is triangular-shaped and bounded by the Old River Lea to the east and the Acid Factory to the west. Its northern side is defined earthwork canal [RCHME 284]. This area was sub-divided into three in the late 19th century by arms of the developed high-level canal system. In the south, [RCHME 288] led to the former **Press House** [76] and form a T-junction with canal [RCHME 291] west of the Press House. Canal [RCHME 288] is now largely filled and has been partly covered by a track. The section to the east of the road defining the east side of the Acid Factory was emptied in the later part of 1992 to remove contaminated waste but not so thoroughly as to expose the clay lining. Canal [RCHME 291] was an early part of the high-level system fed from Millhead Stream (see figure 4), whose elevation is betrayed on the east side by its raised embankment. This southerly part of canal [RCHME 291] survived as a waterway until after the Second World War, when it was filled by material dumped by the research establishment. This contaminated material was similarly cleared during the latter part of 1992 as part of the decontamination work; here, too, without exposing the clay lining.

The northern section of [RCHME 291] was filled probably after the Second World War northwards from the bend marked by the site of two magazines, **No.1 Press House Magazine** [54] and **No.1 Granulating House Magazine** [50]. Both sat on the west bank of the canal; no surface remains of [54] are discernible, whereas the brick foundations of [50] can be made out on the surface. From this point marked by the **Magazines**, an early section of canal [RCHME 291] formerly connected westwards to Millhead Stream about 70 metres south the former **Steam Stove** [RCHME 333], but was filled in the 19th century leaving no surface trace. From the **Magazines** [50 and 54] a 19th-century rerouting of canal [RCHME 291] formerly led north-east to the **Granulating House** [S34], its line now followed by a tarmaced path between the **Nitrator** [E2] and **Washing Houses** [E5] and [E3]. North of [E3] the line of this canal may be traced once again as an earthwork feature. Adjacent to the **Nitrator** [E2] are the remains of a rectangular **Boathouse** [44]. They consist of the foundations of three brick walls with the eastern, canal side open; the centre of the building is hollowed where the filling material has settled. When this canal was filled, the northern section of canal [RCHME 289] between [E3] and [E5] was also filled. The line of this canal between its former T-junction with canal [RCHME 291] and the **Aqueduct** [RCHME 214] is recoverable as an earthwork feature marked by a linear hollow where the filling material within the canal has settled.

The small triangular area to the south of canal [RCHME 288] is largely featureless; a narrow raised bank crossing the area roughly north to south marks the line of a footpath depicted on 19th-century maps. A later path leads from building [87] in the Acid Factory towards **Mixing House** [E14]. This path was also shared by a steam pipe that ran along the southern side of the path also towards [E14]. On the opposite side of the Old River Lea is a subrectangular area defined by the river and canals [RCHME 107] and [RCHME 289]. A narrow ditch cuts off the southern part of this area against the river. This equates with a boundary mapped in the 19th century (WASC 900/38, and see figure 4), showing a plantation to the north and an open area, possibly a garden, around a **Watch House** [RCHME 108]. The site of this building is visible on the surface as brick foundations. The land to the north of this building has a smoothed hollow crossing it, perhaps a former river channel, and to its north a sunken area of amorphous hollows perhaps created by extraction of material for use in canal banks and traverses. Crossing the area are a series of overhead transmission lines, some dating from the late 19th century.

Against the road close to the Acid Factory are two standing buildings, an **Air Raid Shelter** [ARS2] and a **?Transformer House** [U5], both of which were associated with the Acid Factory, along with an open **Well Shaft** [78e]. Adjacent to [ARS 2] is the concrete floor slab of a demolished building. The most substantial building in this sector is **Mixing House** [E14] of Second World War date, set within a U-shaped earthwork traverse up to 10m in width and 3m in height. The north-eastern side of the traverse is closed by a breeze-block wall that both screens the building and forms a landing stage served by canal [RCHME 288].

On the opposite side of the canal are the remains of a **Press House** [76], served by a wide canal basin. Its most prominent feature is an oval brick traverse, originally constructed in the early 19th century to serve a horse **Corning Mill**, which was the facility that the high-level canal [RCHME 291] link from Millhead Stream was built to serve. This was subsequently converted into **No.1 Press House**. The arrangements in this were identical to those within the surviving **No.2 press House** [103 and 104] in area L. On the south-west side of the traverse was a hydraulic **Pump House** powered by a waterwheel by the head of water in canal [RCHME 288]. The **Pump House** was demolished when canal [RCHME 107] was cut through it towards building [88a] in 1940. A short length of its north-eastern wall may be seen in the canal bank. The **Press House** was located on the opposite side of the traverse. The brick foundations of this house survive and sections of a concrete floor possibly related to its later use as a **Cordite Mixing House**; attached to the canal side wall are a number of pipes, possibly associated with the hydraulic press. Marooned in the basin in front of the **Press House** is a well-preserved powder **Barge** [RCHME 101].

To the north of the **Press House** are a group of scarps defining a Y-shaped channel apparently tipping into a sub-rectangular pond, 32m x 15m. The westerly arm of the Y is overlain by the bank of canal [RCHME 291]. No features are portrayed in this area on the available mapping although some of the scarps may relate to an earlier meander of the Old River Lea. Heading off from the eastern bank of the canal [RCHME 291] is a raised earthwork path leading to **Earth Closet** [73].

To the west of canal [RCHME 291] is an area of ground whose surface appears to have been almost entirely covered by dumped material, partly as a general spread and more immediately to the east of the Acid Factory as a levelling layer. The only standing buildings in the area are [E12], a partly demolished **Shift House**, and a **Pump House** [E13]. To the south of these buildings there is the concrete floor slab of a demolished building. To the east of [E12] and [E13] are two breeze-block blast walls, [RCHME 185] and [RCHME 186], screening the Acid Factory from **Mixing House** [62]. To the north of [E12] there is a slight east-to-west linear hollow forming a T-junction with a linear earthwork hollow running parallel to the modern track. At the northern end of this feature is a sub-rectangular bank forming a right angle to the hollow.

The most prominent features in area E, and indeed on the whole of the northern part of North Site, are the **Nitrator** [E2] and its associated **Washing Houses** [E3] and [E5], forming the core of the Nitroglycerine Factory. Each is enclosed within circular protective earthwork traverse known within the factory as 'Hills': from this the term 'Hillmen' was derived, describing those workmen who worked within these structures. The primary key to the understanding of this group of monuments is the flow of liquids by gravity between the various structures. Where liquids were required to move against gravity compressed air was introduced. The **Nitrator** [E2] at the beginning of the process occupies the highest position, while the **Washing Houses** [E3] and [E5] are positioned slightly lower, and below them are the **Mixing Houses** and the **Wash Water Settling House**. As described above, the **Nitrator** [E2] was originally separated from the two **Washing Houses** [E3] and [E5] by canal [RCHME 291], and the **Washing Houses** were in turn separated from each other by canal [RCHME 289] leading from the **Cast Iron Aqueduct** [RCHME 214]. These canals have subsequently been filled and a road surface laid over sections of them.

The **Nitrator** [E2] is a large circular mound, 42m in diameter and 6m in height. In the centre of the mound is a circular, vertical brick revetting wall formerly surrounding the **Nitrator** itself, which was housed within the traverse in a free-standing timber framed building. Dug into the north-west side of the mound is a concrete revetted indentation formerly housing the timber superstructure of the acid lift. Ascending the mound on the western side of the acid lift was a flight of stairs leading to the **Charge House** on the top of the mound. This building has been demolished although its concrete base survives. The base of the **Nitrator** is revetted in concrete on the western side between the Acid Lift and the entrance. This may represent a cutting back of the original mound during a later refurbishment. The **Nitrator** was entered on its south-west side along a curving tunnel sealed by a red-painted wooden-slatted door. At the end of the tunnel the free-standing timber roundhouse, which in this instance had facetted sides for half its circumference, was linked to the tunnel by a covered porch. In the concrete base of the **Nitrator** is an oval pit that formerly housed the drowning tank; into this the nitroglycerine would be discharged if the temperature within the **Nitrator** rose above a critical point. The nitration process took place within tanks set on raised platforms within this building. The only remaining evidence of their positions are a number of sawn-off girders fixed into the surrounding wall indicating the former floor levels within the **Nitrator**. Piercing the revetting wall on the west side are two holes containing cast-iron pipes and above them a brick-lined tunnel, now blocked. This was formerly used to channel waste acid back to the Acid Factory for reprocessing. A number of pipes and other fittings remain attached to the revetment wall and probably relate to the last phase of use. From the **Nitrator** the partly washed nitroglycerine was run by gravity in a covered lead-lined gutter through a brick lined tunnel on the south-east side of the mound towards the two **Washing Houses** [E3] and [E5]. The positions of wooden gutters are marked by a line of rusty bolts on either side of the tunnel walls. As the gutters emerged from the **Nitrator** they were carried on timber trestles to the two **Washing Houses**.

The **Nitrator** was formerly surrounded by four ponds, three of which were described as Borrow Pits (Drwg P.16). To the north are the remains of two trapezoidal ponds, the original plan-form of both ponds have been considerably altered by the dumping of waste materials from the research establishment. The third pond to the west of [E1] has been completely filled. The fourth pond to the south-west of the **Nitrator** was the waste nitroglycerine drowning pond, and this pond still retains water.

To the west of the **Nitrator** are a small group of buildings associated with the refurbishment of the **Nitrator** in the early 1960s. Furthest away is the **Remote Control Room** [E6] and adjacent to it the **Compressor House** [E15]. At the foot of the **Nitrator** is the **Refrigeration House** [E9], the successor to an identically-numbered building within the Acid Factory area. Associated with these structures is an overhead pipeline [RCHME 273] to the south of [E6] and [E9]. In addition to the overhead pipe the line also supported a sealed metal conduit containing control wires leading from the **Remote Control Room** [E6] to the **Nitrator** [E2]. At the foot of the **Nitrator** the pipes rose over the surrounding track before ascending the side of the traverse. At the top of the mound the pipes led to an circular insulated tank on the top lip of mound. At the western foot of the **Nitrator** is the concrete floor slab of the **Acid House** [E1].

The **Washing Houses** each performed the same function of washing the acids from the nitroglycerine collected during the nitration process. Their slightly differing physical form is attributable to later modifications. Each of the houses was surrounded by an earthwork mound 30m in diameter and 3.8m in height. In the centre of each of the mounds was a timber roundhouse surrounded by a circular brick revetment wall. [E3] was approached from the north through a curving brick-lined tunnel sealed by a red-painted, slatted wooden door. The upper courses of the entrance are covered by a more recent concrete capping. Attached to the east wall are a group of modern electrical switch boxes. At the end of the tunnel was a free-standing roundhouse; and although the house has been demolished the slightly raised concrete floor remains. In its present form the nitroglycerine was run into the building along a gutter within a concrete channel, but this probably represents a late modification to the structure. The washing process was undertaken within tanks inside the house. The only evidence for the internal arrangements of the building are two bed stones set into the revetment wall, that formerly supported a raised platform within the building. The revetment wall on the west side was also pierced by a single earthenware pipe containing a cast-iron pipe. The washed nitroglycerine was originally channelled to **Mixing House** [46] along a gutter set within a circular depression within the revetment wall. This arrangement was later formalised when the depression was infilled with concrete with a central covered tunnel. As the gutter emerged from the tunnel it would have been supported on a timber trestle before being carried over the Old River Lea over a pipe bridge [RCHME 253] supported by brick piers on either bank. The contaminated water from the **Washing House** was channelled along a lead gutter supported by a wooden shelf through a brick-lined tunnel in the south side of the mound to the **Wash Water Settling House** [E4]. The exit portal to this tunnel has been modified by the addition of a concrete capping: on the eastern side of the tunnel the wooden shelf remains *in situ*. As the gutter emerged from this exit portal it was similarly supported on a timber trestle as it headed for bridge [RCHME 212] across the Old River Lea.

The other **Washing House** [E5] was identical in plan-form to [E3], although differing in orientation. It was entered through a curving brick tunnel from the west, sealed by a red-painted wood slat door, and in the centre of the building was a timber round house, set on a circular concrete slab. In the centre of this building, and possibly a modification to the original structure, is a tall steel girder frame. Around the foot of the frame traces of the lead floor that would have originally covered the whole floor were found. In other respects, the building exhibits similar signs of modification as [E3]. The entry channel on the north-west side has been replaced in concrete and the curving depression on the side closest to the mixing house filled with concrete with a tunnel at its centre. The contaminated waters were similarly channelled through an arched brick tunnel towards the **Wash Water Settling House** [E4] across bridge [RCHME 212]. The washed nitroglycerine was channelled to **Mixing House** [62] from **Washing House** [E5] through a concrete tunnel on the south side of its mound. **Mixing House** [62] is also enclosed by a circular earthwork traverse, 25m in diameter and 2m in height. After the explosions in **Mixing Houses** [46 and 63] in 1940, three traverse walls were built around [62], on its eastern side a breeze-block wall [RCHME 188] and on the opposite side of the canal to the west two breeze-block walls [RCHME 185] and [RCHME 186]. The **Mixing House** was served by barge along the canal [RCHME 291]. The barges were unloaded at a covered porch attached to a timber roundhouse in the centre of the earthwork traverse. The nitroglycerine was channelled from [E5] along wooden trestles and through the concrete tunnel on the east side of the mound. The fixing bolts for the wooden shelving remain *in situ* on the southern side of the tunnel. The internal arrangements of the building are similar to [46A], described below. In the floor the fixing bolts for the nitroglycerine tank remain in place and in front of them is an L-shaped depression. This building however differs from the others in that only enough feet holes were seen for two mixing tables rather than three as in the other buildings. Between the **Wash Water Settling House** [E4] and the **Mixing House** [62] is a small breeze block building [U3] of unknown function.

The **Wash Water Settling House** [E4] was formerly a timber-framed building set on brick foundations within a concrete cellar. Contaminated water was collected from the **Nitrator** [E2] and the two **Washing Houses** [E3 and E5] for filtration within this building.

Three circular purpose-built **Mixing Houses** [46, 62 and 63] originally lay to the north-east and south-west of the **Wash Water Settling House**. Two former gunpowder buildings, the **Press House** [76] and the **Granulating House** [S34] were also converted into **Cordite Mixing Houses**. **Mixing Houses** [46 and 63] were destroyed in accidental explosions in 1940, [63] in January and [46] in April. Little surface evidence remains for either structure bar a light surface scatter of shattered bricks and asbestos fragments.

The area was quickly brought back into production with the construction of two new **Mixing Houses** [46A] and [46R]. It is probably at this time also that the northern end of canal [RCHME 289] leading to **Aqueduct** [RCHME 214] was blocked by placing corrugated iron sheets across the channel and infilling the canal. The line of the canal may be followed on the ground as a linear scarp on its eastern side caused by the infilling material sinking. The **Aqueduct** [RCHME 214] was converted into a road bridge by the insertion of a timber deck within the trough. To the west of the canal a massive breeze-block and earthwork traverse [RCHME 213] was constructed to shield the **Wash Water Settling House** [E4] from the new **Mixing House** [46A]. At the southern end of this traverse are the brick foundations of the timber-framed **Tool Shed and Mud Hut** [E16].

The new **Mixing House** [46A] is circular in shape and surrounded by an earthwork traverse, whose inner revetment wall is constructed from breeze block. Nitroglycerine was run into the building along a gutter from **Washing House** [E3], over the Old River Lea across bridge [RCHME 253] and through a tunnel in the north side of the traverse. Inside the traverse was a circular timber-framed building perhaps clad in sheet asbestos, the roof supported by a central post. The internal arrangements of the building are largely recoverable through the impressions laid in the concrete floor. As the nitroglycerine entered the building it would initially have been stored in a tank fixed to the floor, the fixing bolts for which remain next to an L-shaped depression in the floor. In this depression the nitroglycerine was run on to guncotton contained in rubber bags. The next stage was the thorough mixing of the of the resulting paste on one of three tables, the leg holes of which may clearly be seen in the concrete floor. As with the other danger buildings, it is probable that this building originally had a lead-covered floor. The **Mixing House** was served by a loading stage connected to the timber roundhouse by a long covered porch, and a new loop was added to canal [RCHME 290] to serve this building. To the south the small island created by this loop is filled by a breeze-block and earthwork traverse [RCHME 216] screening the loading stage. A small building of unknown function [RCHME 215] was constructed at the western base of the **Mixing House** traverse, partly over the filled portion of canal [RCHME 289], into which it is now sinking.

The traverse surrounding the other new **Mixing House** [46R] is bulb-shaped in plan. It consists of an inner breeze-block revetment wall surrounded by earth. The traverse was entered through a tunnel on the southern side. On the floor of the tunnel narrow-gauge rails remain *in situ*, the metal rails giving way to ?teak rails as they approach the loading porch. The **Mixing House** was a circular roundhouse with a loading porch on its south side. The internal arrangements within this house differed from [46A] in that there was no tunnel through which the nitroglycerine could be channelled. In this house the nitroglycerine was apparently channelled into the building beneath the traverse through a lead pipe with a bore of 39mm, that emerged in the gully between the roundhouse and the revetment wall. The pipe then passed beneath the roundhouse wall and into the building. Unfortunately the floor of this building was largely covered by humic material at the time of the RCHME survey, but the foot positions of at least one mixing table were seen. The **Mixing House** was heated by a single steam pipe fixed to the apex of its roof. Warm air was blown from a small brick **Fan House** [U2] to the north-east, and the pipe was carried down the side of the mound supported in iron hoops on concrete stanchions.

The buildings of the Nitroglycerine Factory were laid out over a section of the North Site previously engaged in the production of gunpowder. The principal building from that phase in the area was **Granulating House No.4** [RCHME 275]. Its position may be traced on the ground by a length of brick wall revetting the west side of canal [RCHME 289] opposite the end of the east-west leat [RCHME 293] and probably representing a landing area. In the centre of the building was a central wheel pit, visible on the ground as a rectangular-shaped brick-lined pit. The entrance to the pit on the canal side has been sealed with corrugated iron sheeting and the wheel pit filled. Slight scarps either side of this feature may mark the position of the **Granulating House** walls. The central wheel pit was powered by water from the high-level canal [RCHME 289] passing through the wheel and then out into a spill way, which survives as an earthwork hollow, 40m in length and 9m in width, tipping down westwards to the Old River Lea. The purpose of the other earthwork hollows connecting into the spill way is unclear. The **Granulating House** was served by a **Magazine** [74] to its south, also on canal [RCHME 289].

When this area was incorporated into the Nitroglycerine Factory the **Granulating House** was demolished and its southern end was probably partly overlain by the **Mixing House** [63]. Its former **Magazine** [74] was converted into an **Engine and Fan House** for a new **Guncotton Stove** [75] built to its south and separated from it by a mass concrete traverse. Also added at this date was the small **Earth Closet** [73], now surviving as a partly derelict structure and renumbered X18. Extending south from the **Granulating House** [RCHME 275] and passing immediately to the east of the **Earth Closet** [73] is a low earthwork bank, interpreted as the line of a former footpath. At the southern tip of this area in the angle between canals [RCHME 289] and [RCHME 107] is the roofless shell of **Mixing House No.6** [88a]. The **Mixing House** is surrounded by a U-shaped earthwork traverse 10m in width and 3m in height and revetted by vertical concrete walls on the south side. In the concrete floor of the building are impressions of the feet holes for the cordite mixing tables. As built, it was lit on three sides by window openings. These have subsequently been boarded up and provided with a single artificial light to either side and double lights on the rear wall. The use of 'Maxlume' lighting boxes suggests this modification was carried out during the Second World War. In common with the lighting systems in other danger buildings, the wires between the lights were encased in small-bore metal pipes fixed to the outside of the wall. Originally this building was served by a short canal spur [RCHME 107] off canal [RCHME 289], built at the turn of the century, from a covered timber landing stage whose foundations may be seen. It was later incorporated within the Tetryl Factory and became a **Tetryl Magazine**. In 1940 a **Fan House** [88b] was added on the west side of the traverse, allowing the warm air to be pumped into the **Mixing House** through a pipe laid up the side of the traverse. This is the only **Fan House** on site that retains its original fan.

Area E underwent considerable redevelopment in 1940 after the destruction of **Mixing**

Houses [46] and [63]. As described above, the new **Mixing Houses** [46A and 46R] were constructed. The **Guncotton Drying Stove** [75] and its **Engine House** [74] suffered extensive collateral damage in the explosions and were demolished with their traverse. In its place a new **Guncotton Stove** [S28] was constructed; this, too, had a traverse of breeze-block and earthwork construction, whose northern edge partly overlies the concrete traverse of a former **Guncotton Stove** [75]. Its entrance was screened by a long earthwork traverse or blast wall [RCHME 207], 51m x 14m and around 2.5 in height, on the opposite bank of canal [RCHME 289]. Access was from the east side of the canal [RCHME 289] via a extant wooden bridge: this blocks the canal for barge traffic and must therefore be a post-war facility. The **Guncotton Stove** was served by a **Fan House** [RCHME 208] situated to its north and surviving as a small cluster of concrete slabs. To the south of [S28] a curving scarp follows the base of the traverse, overlying a subrectangular hollow. Moving southwards beyond where canal [RCHME 289] veers westwards, a breeze-block and earthwork traverse [RCHME 115] was constructed screening the entrance to [S30] on the opposite side of the canal. Running into the rear of this traverse is a raised earthwork footpath oriented roughly east to west and heading towards the concrete **Aqueduct** [RCHME 106]. Also running into the rear of the traverse is an earthwork ditch, 52m in length and falling towards the Old River Lea. A new link [RCHME 107] was cut in the canal system to join the earlier canal spur adjacent to [88a] to canal [RCHME 288] next to the **Mixing House** [76], thereby removing the remains of the former gunpowder **Pump House**. This new link in the canal system was carried over the Old River Lea in a concrete **Aqueduct** [RCHME 106], with the date 1940 cast into its side.

North Area [buildings 1-40] (Figs 3, 13)

The northern section of North Site is the shape of a billhook blade and is defined as lying to the north of the Tetryl Factory and north of canal [RCHME 284], the western edge is bounded by Horsemill Stream and the eastern edge by Cornmill Stream and Newton's Pool [RCHME 276]. The early name for this area was Edmonsey Mead. Included within this area is a description of the buildings adjacent to Newton's Pool [S34, S35, S36, S37, S38, S50 and RCHME 337], which lie outside the numbering sequence that defines the area.

At the very northern end of North Site is the **Grand Magazine** [1] or factory magazine, where the finished powder was stored before being moved by river barge down to government magazines at Purfleet on the north bank of the Thames estuary. The **Grand Magazine** was constructed around 1800, but the present structure represents a later 19th-century rebuilding of the earlier structure. A **Wet Guncotton Magazine** [2a] was later added to the south side of the **Grand Magazine**; the timber superstructure of this magazine has been demolished leaving a concrete floor slab. To the east of the **Grand Magazine** are the remains of a small office-like building [2]. The **Grand Magazine** was located on an artificial island known as Paynes Island. This island was created by three inlets or channels springing westward off the River Lea, a single main channel at this point (see map of 1827 figure 4). All three channels contributed to supplying water into MillHead Stream (now superseded by the widened Horsemill Stream), the high-level feed of the Royal Gunpowder Factory's canal system. The inlets were located about 190m and 40m to the north and 40m to the south of the **Grand Magazine** [1], approximately along the line of the modern eastern boundary fence. The **Grand Magazine** was thereby served on its western side by Millhead Stream acting as a canal system; in the latter part of the 19th century its porch was protected by a cover extending over part of the stream. The topography of this part of the site has been altered out of all recognition, probably in the late 1960s when canalisation of Horsemill Stream destroyed the northern part of Millhead Stream. Both the inlets to the north and south of the **Grand Magazine** have been filled, and no surface remains are visible. At the eastern entrance to the southern inlet were two small buildings, a **Sluice House** and a **Water Warden's/Police Hut** [5]. No surface evidence for the positions of these structures survives. Similarly, the northern section of Millhead Stream has been completely filled to the west of the **Grand Magazine**; the ground surface here has been additionally built up with the deposition of dredged river gravels.

On the west bank of Horsemill Stream opposite to the **Grand Magazine** an **Alan-Williams Turret** [RCHME 335], a domed revolving steel turret manned by two men with light armaments for anti-aircraft defence, was constructed during the Second World War. At the grid reference cited it is probable that it was removed during the engineering works of the early 1970s; at best it may survive buried beneath the deposited river gravel. To the north of the **Grand Magazine** was an octagonal **Anti-aircraft Emplacement** [RCHME 346] similar to [RCHME 345] in the grounds of the **Directors House** [A221]. This is presumed to have been demolished during the widening of Horsemill Stream, but its foundations, too, may remain buried beneath the road north of the **Grand Magazine**.

The earliest buildings in this northernmost area were concentrated along the eastern bank of Millhead Stream, ie are now on the eastern bank of Horsemill Stream. The largest of these structures is the large oval brick traverse [26], a stone plaque above whose eastern entrance records **'No.4 Steam Stove 1885'**. The traverse originally housed a boiler to raise steam used to heat the **Drying Stoves** [25 and 28] to either side. These stoves were supplied by barges unloading and loading beneath covered porches spanning waterways to north and south; for in common with the other stoves within the RGPF, [S90 and RCHME 330], the complex was surrounded by a U-shaped canal fed from Millhead Stream. The traverse was later converted to act as an **Engine and Fan House** for **No.1 Guncotton Stove** [27] constructed to its south-west, of which no surface traces survive. The brick traverse was then again adapted in the post-war period as a **Firing Point**. This entailed the construction of a steel compartment in the centre of the traverse and a reinforced concrete wall at the eastern end. The interior of the traverse has suffered considerable damage from these activities, as if from shrapnel. The only remaining upstanding part of this group of buildings is the brick traverse [26] itself, and this has been partly buried by the dumping of river gravel. The site of the **Gunpowder Drying Stove** [28] on its south side is covered by dumped gravel. On its north side, the lines of the brick foundations of the **Gunpowder Drying Stove** [25] may be followed on the surface as may the remains of its boat porch attached to its north wall. No surface remains are visible of the rectangular **Guncotton Stove No.1** [27], but its foundations may remain at the stream edge beneath the modern track.

To the north of the **Gunpowder Stove** [26], two further structures along the stream edge, were a **Barrel House** [RCHME 329] and a **?Magazine** [RCHME 328]. Both buildings were served from Millhead Stream, and their entrances were protected by covered porches extending over the stream. The two buildings were demolished at the turn of the century when the guncotton stoves (below) were constructed in the area. Their sites lie beneath an extensive dump of gravel alongside Horsemill Stream. The only other buildings that appear in this area on 19th-century maps are a **Watch House** [RCHME 326] and a **Dining Room** [RCHME 327]; no surface remains were found of either of these structures.

The present arrangement of this area of the factory north of canal [RCHME 284] is largely the result of the construction of a coherent network of **Guncotton Drying Stoves** and associated canals around the turn of the century. Although exempt from the explosives legislation (Victoria 1875, ch 17), the Royal Gunpowder Factory adhered to the spirit of the legislation and kept all gunpowder danger buildings at least one hundred and forty yards away from the factory magazine [1]. The nearest danger buildings, the **Granulating House** [S34] and the **Steam Stove** [26], were in fact over twice the recommended distance from the **Grand Magazine** [1]. Its change of function to the **Wet Guncotton Magazine** also changed its status to that of a large expense magazine, thereby allowing the construction of process buildings closer to it.

The majority of the **Guncotton Stoves** were surrounded by a circular earthwork traverse around 25m in diameter and 2m in height, which was supported internally by a circular brick revetment wall. This is the characteristic form of their surviving remains. The **Guncotton Stoves** themselves were circular timber roundhouses, the roof supported by a central post or a group of four smaller posts that also served to support a central warm-air pipe in a number of stoves. The roofs were wooden boards covered by galvanised metal sheeting. The interiors of the stoves were zinc-lined with lead-covered floors in an attempt to prevent the accumulation of guncotton dust and to reduce the risk of objects sparking together. Three earlier stoves went against the developed form in this area and were rectangular in plan. The stoves sat on a concrete floor separated from the revetment wall by a narrow gully. In this gully a circular segmental cast-iron pipe with a series of elbow joints was placed horizontally to feed the warm air into the base of the stove. Access into the gully, to control external vent panels and service the external danger building lights, was by means of timber steps generally placed on the opposite side of the mound to the barge porch. The artificial lighting to the stoves, at least during their later history, was provided by 'Maxlume' lights. In this system the light bulbs were suspended outside, their small reinforced glass lights in enamelled boxes joined by wires encased in small-bore metal pipes. The stoves were served by barge from one of the canals or Millhead Stream. The loading and unloading operation was protected by a barge porch over the canal and a covered porch linking the barge porch to the stove.

The stoves were generally arranged in pairs; in the centre of each pair was an **Engine and Fan House** that blew warmed air into the stoves to dry the guncotton. The **Engine and Fan Houses** were served by a network of steam pipes carried originally on tarred wooden posts and later suspended from reinforced concrete posts. Steam was carried in small-bore iron pipes, lagged with asbestos protected by a cover like roofing felt. Typically in this block of **Guncotton Drying Stoves** the central **Engine House** is now represented by a concrete floor slab. To either side of this are a series of concrete blocks that formed the base of a covered belt race, whose belts were powered from the centrally placed **Engine Houses**. At the end of each belt race was a **Fan House** pushing air through two adjacent heaters and into the **Drying Stoves**. Presumably the **Engine Houses** were electrically driven, although there is no direct evidence for this beyond a network of transmission lines; but in practice the distinction between electric and telephone lines is difficult on field evidence alone.

The stoves were served by two canals, [RCHME 283 and RCHME 285], set at right angles to canal [RCHME 284] and north of it. The easterly canal [RCHME 283] may be traced for 280m as an open earthwork feature around 9m in width at the top, except in the centre close to a **Footbridge** [RCHME 264] where it has been filled. The northern end of the canal has also been filled. The sides of the canal were battered, with a timber walkway built out over the bank. The canal was crossed by two semi-circular wrought-iron **Footbridges** [RCHME 255 and RCHME 264]. At the foot of each bridge was a boot scraper to prevent grit being trodden onto the bridge that might then have fallen onto a passing explosives barge. The line of canal [RCHME 285] has entirely been lost at its southern end beneath a dump of river gravel. The line of the feature may then be picked up from the partly-buried **Footbridge** [RCHME 182]. From this **Footbridge** northwards the canal survives as an open earthwork feature for 70m adjacent to the **Quinan Stove** [22a]; it is then lost again, before being picked up for a further 50m between **Guncotton Stoves** [18a and 16a]. Northwards of these stoves the line of the canal is entirely covered by a gravel dump, estimated at over 1m in depth.

Originally five **Guncotton Stoves** were placed on the west bank of the easterly canal [RCHME 283]; this number has been reduced to four surviving examples by the demolition of the northernmost stove [8]. The site of **Guncotton Stove** [8] may be seen as a slight curving scarp marking the southern edge of its traverse. This stove shared an **Engine and Fan House** [9] with its partner to the south **Guncotton Stove** [14]; the **Engine and Fan House** remains as a series of concrete bases with associated concrete pipe supports. Adjacent to [14] is a small breeze-block building [RCHME 259] of unidentified function. Progressing southwards, the next pair of **Guncotton Stoves** are [18 and 22], sharing **Engine and Fan**

House [19]. **Guncotton Stove** [22] has had the southern half of its traverse removed, revealing the stepped construction of the revetment walls. Linking the four stoves described above is a narrow bank along their western sides marking a former path; from this path other paths run at right angles westwards to the **Air Raid Shelter** [ARS1] and **Engine and Fan House** [17]. Following all of these paths were steam pipes either supported on tarred posts or suspended from concrete posts. At the southern end of canal [RCHME 283] is **Guncotton Stove** [29], later modified to become a **Picrite Stove**. This originally acted in tandem with **Guncotton Stove** [22a/a] and was served by **Engine and Fan House** [28a]; it was latterly served exclusively by **Engine House** [33] to its south-west. A small scarped bank leading from the base of the wooden steps on the south-west side of the **Guncotton Stove** may have led to this **Engine House**. Presumably because of its conversion and late use, metal drying racks and other fittings survive in **Guncotton Stove** [29]

The westerly canal as described above is largely filled. Originally three circular **Guncotton Stoves** were placed along its eastern bank. They were reduced to two, [16a] and [18a], when stove [22a/a] was demolished to make way for the **Quinan Stove** [22a] in 1935. Around two-thirds of the centre of the original stove [22a/a] remains visible as foundations on the east side of the **Quinan Stove** and the foundations of its porch on the platform west of the **Quinan Stove**. The **Quinan Stove** was screened by two traverses [22a/1] and [22a/2], placed to the south and west of the stove and constructed from corrugated iron sheets and old rails. The stove [22a] was served by a **Fanhouse** [22a/3] on the west side of traverse [22a/1]. The **Quinan Stove** [22a] itself is a technically interesting structure for more effective drying of guncotton, physical details of whose operation are well preserved. These are most conveniently described in the analytical report of **Section 3**. North of the **Quinan Stove** the traverses to two **Guncotton Stoves** [16a and 18a] remain intact, separated by the concrete bases of their shared **Engine and Fan House** [17a].

Ranged alongside Millhead Stream, ie now Horsemill Stream, north from **Gunpowder Stove** [26] were another three pairs of **Guncotton Stoves**. The first two, [27 and 20], were unusual in that they each had an individual **Engine and Fan House**. As described above, [27] made use of the central traverse of the former **Gunpowder Stove** [26] to house its **Engine and Fan House**. **Guncotton Stove** [20] was originally surrounded by an earthwork traverse, but this has been demolished leaving only its concrete floor slab to mark its position. The site of its **Engine House** [21] to the east of the stove is marked by a single concrete block partly buried beneath a dump of river gravel. Northwards there was no surface evidence for the site of the circular **Guncotton Stove** [17]. This stove shared an **Engine House** [16], visible as a few concrete blocks protruding from the gravel, with the rectangular **Guncotton Stove** [11], which survives as a rectangular concrete floor slab. North again and past the point where canal [RCHME 285] formerly joined with Millhead Stream, were a final pair of **Guncotton Stoves** [4 and 10]. There is no surface evidence for stove [4], but stove [10] is perhaps marked by a slight rise in the gravel surface. These stoves were served by **Engine House** [7], whose position is marked by a couple of concrete blocks.

Between canal [RCHME 283] and Newton's Pool [RCHME 276] are two further **Guncotton Stoves** [23] and [36]. Stove [23] was served from canal [RCHME 283] while stove [36] was served by canal [RCHME 284]. The two stoves are joined by a raised strip of ground between two large hollows. Neither of these hollows appears as a topographical feature on the early maps of the area and they may be better interpreted as borrow pits to produce the spoil for the nearby mounds rather than as ponds. Between the two stoves are the concrete bases of the **Engine House** [U1], and sufficient of the superstructure remains here to indicate that the bases were formerly covered by a timber-framed superstructure covered by asbestos sheets. In their original state both the stoves conformed to the general pattern described above. However, both stoves had subsequently undergone a degree of modification. **Guncotton Stove** [23] had its porch modified so that the stove could be served both by the canal [RCHME 283] and by a spur off the light railway system approaching it from the north along the canal bank. This 50m spur of light railway track [RCHME 263] remains *in situ*. This stove is also notable for its horizontal warm air inlet pipe, because this is constructed from sections of rivetted sheet metal rather than the more usual cast-iron sections. This rivetted pipe is a unique survival amongst the guncotton stoves, although sections of rivetted pipe are visible elsewhere on historic photographs. **Guncotton Stove** [30] was reconstructed in 1940 after receiving extensive collateral damage from the explosions in **Mixing Houses** [46 and 63]. The stove was rebuilt with an internal revetment wall of concrete surrounded by an earthwork traverse. In place of the more usual circular timber stove, a rectangular timber-framed building with an asbestos skin was constructed. This was divided into two rooms each heated by a separate radiator. These were supplied by a small-bore steam pipe from **Fan House** [U1] rather than by the more usual large diameter warm air pipes.

At the core of the buildings on the north side of Newton's Pool is a brick traverse, that is the only standing remains of a **Gunpowder Granulating House** [S34], incorporated into the traverse surrounding the later development of [S34]. This **Gunpowder Granulating House** is poorly documented in comparison with many of the other process buildings on the site, to such an extent that the method of powering the machinery within this building is not known through the documentary record. However, late 19th-century mapping shows a leat carried off Cornmill Stream 22m north of the sluice gates into Newton's Pool [RCHME 276]. A building, probably now lying beneath [S34], is shown as sitting over this leat, adjacent to a longer rectangular building north-east of the traverse. The juxtaposition of these two buildings strongly suggests that a water-wheel was housed in the smaller building to power granulating machinery within the larger building. This deduction may be reinforced by the absence of the small building over the leat by 1923 (WASC 900/84), by which time the buildings either side of the traverse had been converted to other uses. On the south-west side of the traverse a small square building was also shown. A connection between this building and the one on the north-east side of the traverse was made through a small arched brick tunnel beneath the southern end of the traverse. It is unclear whether the cast-iron pipe within the tunnel supplied steam heat or power to the **Granulating House** or whether some form of remote control rod was housed in it so that the machinery within the **Granulating House** could be controlled from relative safety behind the traverse. The *Illustrated London News* of 1854 (*ILN* 1854, 478) describes a method of turning machines on and off by means of a rope passing through a wall. The **Gunpowder Granulating House** was later absorbed into the Nitroglycerine Factory and converted into a **Cordite Mixing House**. Also associated with these buildings is an **Earth Closet** [41] to the south-west .

The **Gunpowder Granulating House** was formerly served by canal [RCHME 287], a dead-end branch of the high-level canal system. This canal survives as an earthwork hollow with raised towpaths to either side for around 30m to the west of [S34]. The eastern section of the canal has been filled and a tarmac and concrete surface laid over its line.

The present building [S34] and its surrounding breeze-block and earthwork traverse were built in 1940 after the original buildings received collateral damage with the accidental explosion of **Mixing House** [63]. The earthwork traverse to the south of [S34] overlies and fills the leat shown on the 19th-century maps and may overlie the foundations of the suggested water-wheel house. During this phase of use as a **Cordite Mixing House**, the principal entrance of [S24] remained on the north side through double doors adjacent to the traverse, which were served from canal [RCHME 287]. The building was additionally serviced by the light railway system by a spur off the main north-to-south line running parallel to Cornmill Stream (see figure 5). The railway approached the building along a short tunnel cut through the eastern side of the traverse, where the positions of the rails remain visible in the tunnel floor. By the tunnel portal is a small brick bunker [S38] of a similar date to [S34]; its original function is unknown.

Newton's Pool [RCHME 276] derives its name from a Mr W Newton who was brought from the Royal Gunpowder Factory at Faversham to act as the Master Worker at Waltham Abbey in 1788 (Winters 1887, 30). He lived for some time in the former **Turnpike and Chequer Inn** [RCHME 304] on the eastern side of the pool. Limited archaeological excavations in 1972 found a brick-lined pit and within its fill a half-penny of 1806 (Cherry 1973, 104). To the south of this building for a short time at the beginning of the 19th century was the **Stables** [RCHME 358] for the contract horses.

The present arrangements around **Newton's Pool** [RCHME 276], however, relate to the activities of the post-war research establishment. During this period of Newton's Pool was used to test the effectiveness and reactions of explosive charges under water. [S34] was converted into a **Control Room** and [S38] appears to have been used as **Switch Room**. A number of small buildings were also erected at this time; a **Store** [S35] that only survives as a concrete floor slab, a **Day Detonator and Explosives Magazine** [S36], a steel gantry [S37] on the north side of the pool and a **Control/Observation Room** [S50] like a sentry box. Also associated with this phase of activity are two small structures of the south side of

Newton's Pool. The former **Fan House** [U2] was converted into an office and concrete bases [RCHME 337] supported a steel pole, from which a wire was attached to the northern shore; the wire was then used to suspend explosive charges into the pool.

Guncotton Drying Stoves [74-98] (Figs 3, 11)

This second group of **Guncotton Drying Stoves** are sited on the west bank of Cornmill Stream adjacent to the later New Hill Nitroglycerine Factory. The stoves were constructed in the first decade of this century in an area of the factory previously used for growing dogwood, which was burnt to produce charcoal for use in gunpowder. The only building in the area prior to the construction of the stoves was the **Water Wardens Cottage** [102], built in 1878 in the south-east corner of the plantation adjacent to a weir between the high-level water system of Cornmill Stream and the low level of the Old River Lea. The **Water Wardens Cottage** was surrounded by a domestic garden and approached by a single footpath between it and the **Gunpowder Stove** [S90]. This was the only mapped feature in the area until the construction of the stoves. The line of this path between [S90] and the north-west corner of the **Water Wardens Cottage** [102] may be followed for 215m, the majority of its former length as a linear earthwork bank 3.5m in width. It may clearly be seen to have been overlain by railway embankments and overlain by stoves [93a and 96a]; between [96a and 98a] it is additionally overlain by a small embankment carrying an earthenware pipeline. It appears that the path may have partly been reused between stove [96a and 93a], since it seems to form the link to their central **Fanhouse** [93b], and to the west of [98a] a short path was constructed linking it to the **Fanhouse** serving that stove.

The **Gunpowder Drying Stoves** are similar in form to the circular stoves described in the northernmost area of North Site. They differed from those, however, in that they were served by a section of the light railway system rather than by the canal network. Connections between the canal network and the light railway were nevertheless essential to move the wet guncotton from the **Wet Guncotton Magazine** [1/2] to the stoves for drying. It was then necessary to move the dried guncotton to the **Weighing House** [S27] on the south side of the east-west leat [RCHME 283] and on by barge to the cordite mixing houses. Connections were made with the canal system at a landing stage [RCHME 114] at the angle of canal [RCHME 289] north-east of the **Steam Stove** [S90] and at the **Weighing House** [S27] at the northern end of this area. The layout of the railway network may be reconstructed from the earthwork embankments and tallies closely with that mapped (see figure 5). The railway was based on two parallel lines; the eastern line ran from [S27] in the north and then along the west side of stoves [74a to 96b]. Parallel to this, the second line ran along the east side of stoves [98a to 93a] and to the landing stage [RCHME 114]. The course of both lines may be followed as embankments for most of their lengths, except to the north where they are disturbed and overlain by the modern track. The two parallel lines were originally linked sections of track running between [96b] and [96a] and from [76a] in the direction of [S90] (see WASC 900/84 of 1923). These were supplemented by another two slanting links placed between them (see figure 5). All these links may be traced as earthwork embankments. An early modification to the original system may have been the construction of two lines, south of [96a] and north of [93a], westwards into the adjacent Tetryl Factory (see below). The rails were laid on pressed steel sleepers, a number of which survive *in situ* on top of the embankments. Beneath the porches adjacent to the **Guncotton Stoves** the rails were laid on horizontal wooden sleepers. It is not known whether the rails directly in front of the stoves were of wood as has been found at the entrance to other danger buildings within the factory.

Between the railway embankments and certainly beneath the later links of the system are a series of amorphous hollows. They exhibit no discernible forms and it seems probable that they represent borrow holes where the material was dug to construct earthwork traverses and railway embankments. An alternative explanation might view them as a means of maintaining the waterlogged conditions preferred by the dogwood plantation.

The **Stoves** were surrounded by a circular earthwork traverse with an external diameters of around 23m, built around a circular brick revetment wall 2m in height with an internal diameter of 10.8m. In the centre of this revetment wall the wooden **Guncotton Stoves** formerly stood, separated from the wall by a narrow gully. In stove [96a] the gully was housed a circular, segmental cast-iron pipe, to which elbows were bolted to feed warm air into the stoves. The remainder of the stoves employed a sheet metal pipe of large diameter, insulated by asbestos held in place by chicken wire and covered by galvanised metal sheets. This was fixed to the apex of the conical roof of each of the stoves. Historical photographs show that this pipe was supported on four posts beneath the roof centre. It is unclear whether the reason for employing differing methods of introducing warm air into the stoves was chronological or whether the use of the larger pipe led to an improvement in their operation. Three of the stoves [93a, 96a and 96c] were used for drying Tetryl. The method of introducing hot air into the stove was identical for both guncotton and Tetryl, but stove [96a] as the only stove in this complex with its pipe in the gully is included within the group of **Tetryl Drying Stoves**. The other surviving stoves in the group [76a, 92a, 93c, and 98a] were used for exclusively for drying guncotton; [98a] preserves a set of metal drying racks. **Guncotton Stove** [74a] at the north end of the eastern row was destroyed as a result of the explosion of **Mixing House** [63] in January 1940; its **Motor House** [75a] and partner **Guncotton Stove** [76a] were also badly damaged. **Stove** [74a] was rebuilt and **Motor House** [75a] and **Stove** [76a] were restored. **Stove** [74a] was probably demolished around 1970 when **Cattlegate Bridge** [RCHME 238] was renewed. The site of the stove is marked by uneven ground and a scatter of brickwork, including sections of the inner curving revetment wall.

Each stove was served by the local tramway network through a covered porch on the front of the building, connecting to the roundhouse. The porch was supported over the section of track immediately in front of the stove by two timber posts standing on concrete bases on the opposite side of the track. The stoves were lit from the exterior by means of electric lights encased in 'Maxlume' green enamelled metal boxes; these were suspended outside the small windows around the top of the roundhouse. Power was supplied along overhead lines. One line ran along the base of the railway embankment of the easterly line, as indicated by a pole with Cordeaux-type porcelain insulators placed opposite to the entrance of each of the stoves. The westerly stoves were supplied by an overhead powerline running along the line of their western bases. The earliest dates seen on the poles were of the 1890s.

To the east of this group of stoves, Cornmill Stream has been terraced into the gently westward-falling ground. On the west bank of the stream a broken scarp marks the line of its earthwork embankment. The **Guncotton Stoves** have overlain this scarp where they impinge on it. The scarp also appears to have been partly modified to act as a link between the stoves, forming a connecting path with their **Fan Houses**. As in the northern area, each pair of **Guncotton Stoves** was served by a central **Motor House**; it is interesting to note that the distinction is made between the term 'Engine House' as applied to the northern group of stoves and the term 'Motor House' used in this group of stoves. Presumably there was a steam chest in each of these buildings, where air was passed over hot pipes before it was blown into the stoves. The steam was generated centrally either in the main **Power House** [A210] or within one of the **Boiler Houses** within the Acid Factory. The arrangement of the stoves was as follows; stoves [74] and [76a] were served by **Motor House** [75a], stoves [92a] and [93c] shared **Motor House** [92b], and stoves [93a] and [96a] shared **Motor House** [93b]. Two stoves were left out of this pairing and were served by their own individual **Motor Houses**, [96b] by **Motor House** [93d] and [98a] by a **Motor House** at the foot of its traverse on the west side. A network of steam pipes either suspended from reinforced concrete posts or supported on tarred posts formerly crisscrossed the area, connecting the **Motor Houses** to the central steam supply. A number of pipe runs were recorded in the field prior to removal in the decontamination programme: the original form of others may be seen in historic photographs (WASC 499, photo 13).

Associated with this group of **Guncotton Stoves** are two small building [91a] and [U9]. [91a], now ruinous, was described as a **Hose House** and may be associated with a cast-iron telephone column on the opposite side of the track. [U9] is a small breeze-block building of unknown function, probably constructed during the Second World War; it has a single door and a blocked window.

At the north end of their respective north-south railway lines were the two points of interchange with the high-level canal system. On the western line this was the landing stage [RCHME 114] at the marked elbow of canal [RCHME 289] immediately north-east of [S90]. It is marked by timberwork of the landing stage and a surviving length of track immediately adjacent that terminates in a buffer stop. On the eastern line it was **Weighing House** [S27], which is located further north and to the east of canal [RCHME 289] and is served by a short east-west spur [RCHME 293] from this canal. The surviving remains are the breeze-block and earthwork traverse that formerly surrounded a timber-framed building. This structure overlies an earlier **Weighing House** [52] on the same site that was badly damaged in the explosions in the nearby Mixing Houses in 1940. The only above-ground trace of this earlier structure is a length of brick wall incorporated into the south wall of the later reconstruction. The canal-side entrance to the **Weighing House** on its north side is screened by a breeze block blast wall [RCHME 205]. Associated with the **Weighing House** were a small brick building [RCHME 201] adjacent to its southern entrance and a building razed to its concrete slab [X19].

Tetryl factory [S26-S90] (Figs 3, 11)

The area occupied by this group of numbered buildings is ill-defined topographically. The numbering sequence relates primarily to an area of the site devoted to the production of Tetryl, in some instances adapting structures formerly used in the production of gunpowder. The extent of this area is bounded to the west by the Old River Lea and canal [RCHME 289], formerly part of the high-level system and now a dry earthwork feature: the eastern side is marked by the line of **Guncotton Stoves** [98a to 93a]. The southern boundary is marked by a watercourse linking Cornmill Stream to the Old River Lea via a weir next to the **Water Wardens Cottage** [102].

This area was developed for the production of Tetryl during the First World War, but the plant was completed only shortly before the signing of the armistice and saw little use. During the inter-war period the plant was mothballed and began production again in the late 1930s, when the RGPF was the only manufacturer of Tetryl (Simmons 1963, 60). As with the area to the east occupied by the **Guncotton** and **Tetryl Stoves**, this area was previously used as dogwood plantation. Earlier development for gunpowder production was restricted to the side of canal [RCHME 289]. The Tetryl plant was therefore developed in two main phases, initially during the First World War, followed by further building in the late 1930s or the early years of the Second World War.

The buildings were linked by an extension of the light railway system from the area of the **Guncotton Stoves** to the east. Links were effected to the south of **Guncotton Stove** [96a] and to the north of **Guncotton Stove** [93a], and the route of these lines may be followed as earthwork embankments utilised by the modern tracks. The remainder of the early network may similarly be followed as earthwork embankments leading to the **Tetryl Corning House** [S32] and the **Tetryl Incorporating House** [S33]. From these buildings the lines converged to form a Y-junction east of [S31], which was by this date in use as a **Tetryl Packing House**, the line from [S33] passing the **Tetryl Cleaning Houses** [S39 and S40] and their ?**Fanhouse** [RCHME 150]. At [S31] a connection would have been possible with the canal system; alternatively a connection could be made with the canal system via the spurs close to the **Guncotton Stoves** and back towards the landing stage [RCHME 114]. The system had been extended southwards by the Second World War to link [S32] to the **Tetryl Store** [U10]. This building was screened on its south side by a breeze-block traverse [RCHME 142] and a corrugated iron traverse filled with gravel [RCHME 140] on its west. From this building the line passed the **Shifting Room** [104a] in making its way south-west to **Stove** [L106] in the north end of Area L (see above).

A railway branch was also laid eastwards towards the **Water Wardens Cottage** [102] to provide a link to a new group of **Tetryl Drying Stoves** [S46-S49]. This group of stoves was arranged in two pairs separated by a central breeze-block blast wall [RCHME 140]. Each pair of stoves was served by a central **Fan House** [RCHME 138 and RCHME 139]. The fanhouses were supplied with steam heating from the north along pipeline runs supported on concrete stanchions, which rise over the railway serving the stoves before entering the **Fan Houses**. Warm air was then blown from the **Fan Houses** into pipes along the base of the southern walls of the stoves. This group of **Stoves** [S46-S49] and their associated **Fan Houses** remain largely intact while the rest of the buildings of this Tetryl plant have been razed to their concrete floor slabs.

On the east bank of the Old River Lea are two small **Earth Closets** associated with the Tetryl Factory; [RCHME 149] in brick and a dilapidated timber structure [RCHME 148]. To the north of the closets is a small breeze-block building [U8], a **Bunker** probably of Second World War date. Surrounding these buildings and covering much of the ground surface between [S33] and the Old River Lea is a dump of steel barrels [RCHME 147].

As stated above, the area of this Tetryl Factory incorporated two buildings, [S31] and [S90], that previously formed part of the gunpowder manufacturing process. Both were set along the side of canal [RCHME 289]. To the south of [S31], this canal was carried over the Old River Lea by a **Cast Iron Aqueduct** [RCHME 112], one of a pair on the site (see also [RCHME 214]). It was cast in 1877-78 as part of a major extension to the factory canal network. The canal opens out on its eastern side to form a broad basin serving [S31]. Some 50m further north, opposite the T-junction with canal [RCHME 107], a well-preserved powder barge [RCHME 104] lies within the canal, impaled by sycamore growth.

[S31] was initially built in 1879 as a **Gunpowder Press House**, probably powered by the factory's central hydraulic system supplied from the engine house and accumulator in [L149], 570m to the south. It was subsequently converted to a **Gunpowder Moulding House**, a process also utilising hydraulic power. It has been suggested (pers comm T. Smith) that the vertical rivetted iron girders to the south of the building may have acted as the supports for a local hydraulic accumulator. By the turn of the century, the building is described as a **Cylinder Cutting House**, perhaps associated with the Cordite Factory established by this date. It underwent a further transformation when it was incorporated into the new Tetryl Factory as a **Packing House**. The structure is U-shaped in plan, with an imposing entrance on the southern side consisting of a central brick tunnel flanked by two brick semi-circular arched portals. These portals were originally open but have subsequently been blocked and the upper parts glazed. The other sides of the structure consisted of a traverse formed from mass concrete faced on the inside with brick and protected by an earthwork bank around the exterior. The process building was set in the centre of this structure on flimsy brick foundations that probably indicate a timber superstructure. The canal side was open, with a timber landing stage set into the walls of the traverse.

To the south of [S31] a number of structures were added when the Tetryl Factory was constructed. The most distinctive of these is an hexagonal concrete base raised on concrete legs, the remains of the **Tetryl Purification Plant** [95a]. To the rear or north of this building is a small timber-framed shed covered by asbestos sheeting [U6]. Between it and [S31] was **Boat House** [94], the brick footings of which may be seen on the surface. Other footings in the area are presumed to relate to the **Tetryl Purification Plant**. A capped well shaft to the south of [S31], was probably sunk to provide an independent water supply for the Tetryl plant. To the east of the modern road, between this group of buildings and [S39] is a concrete floor slab marking the position of the **Fire Engine House** [95b].

North of [S31] along canal [RCHME 289] are the remains of a **Gunpowder Drying Stove** [S90] arranged identically to the early **Steam Stove** [RCHME 330] and **No.4 Steam Stove** [26] in the northern area. As in those cases, in the centre of the stove are the remains an oval brick traverse, which consists of an inner vaulted brick chamber and an outer battered wall of brick, with the core filled with concrete. This structure was originally covered by a slate roof and had a tall chimney on top of the central flue. Inside the traverse was a boiler to raise steam to heat the drying stoves sited on either side of it. Access through round-headed doorways at either end. The doorway at the south-east side has collapsed while that at the opposite end has been blocked and the exterior covered by a later earthwork traverse. In its original form the traverse sat between two rectangular buildings, **Gunpowder Drying Stoves** [89 and 91], to its south-west and north-east; each stove was heated by steam generated within the boiler encased in the traverse. Attached to the ends of the stoves furthest away from the traverses were boathouses where the gunpowder could be unloaded and loaded into barges under cover. The two boathouses were linked by a U-shaped canal, which thereby enclosed the whole of the **Gunpowder Stove**. Along the canal side were two small buildings [87 and 88] of uncertain function, that were possibly used as coal stores. Around the turn of the century the group was converted to a **Cordite Tray Stove**, with a similar requirement for a central heating source and drying sheds to either side.

This group suffered considerable collateral damage with the explosion of **Cordite Mixing House** [63] (WASC 499, photo 9). This at least prompted the demolition of the southern stove [91] and its boathouse. They were replaced by a massive breeze-block and earthwork traverse abutting against the central traverse [S90]. In the centre of this traverse was placed a timber-framed **Tetryl Magazine** [S30], which may be traced as a concrete floor slab.

Associated with this magazine was a screening **Traverse** [RCHME 115] immediately to the north on the opposite side of the canal (see Area E), and two small breeze-block buildings, a **Detonator Store** [S29] and a **Shelter** [S29a]. The latter was served by a spur from the light railway network in the area of the guncotton drying stoves. Traces of the earlier gunpowder structure may be found to the north-east of the traverse, where the brick footings of the stove and boat house are visible and a battered earthwork hollow marks the line of the encompassing canal. The curve of the modern road follows the outside of its line. The position of the surrounding canal is also clearly marked on the south side by an embankment, which emphasises how the canal was raised above the surrounding ground surface. At the southern corner of the surrounding canal is a denuded gravel mound, the remains of an earthwork traverse. To the south-west of the traverse a sections of brick wall footings are visible around the base of the earthwork traverse.

In its final phase of use the boiler traverse was used a **Firing Point**. During this period the interior was lined with steel plates and a small breeze-block **Control Room** [S90a] was constructed in front of the south-eastern entrance to the traverse. This was protected on the traverse side by thick steel plates, with a small hole through which control wires could pass. Use as a **Firing Point** has had a detrimental effect on the structure, in that the internal flue opening has been partly brought down and part of the south-east exterior has come away revealing the inner mass concrete core.

New Hill Nitroglycerine Factory (Figs 3, 14)

New Hill Nitroglycerine Factory was developed in 1940 in response to the two disastrous explosions that occurred in the early part of that year in **Mixing Houses** [46 and 63] within the earlier Nitroglycerine Factory in Area E. The New Hill was an extension to North Site, and lies on the eastern side of the main factory site (see figure 3) on 13 hectares (32.11 acres) of what until 1940 had been open farmland. Two of the former east-to-west hedgelines survive as denuded features within the factory and in its southern part the traces of slight straight agricultural ridging are overlain by the factory structures. It appears from the information of former employees at North Site that although the Nitroglycerine Factory was completed technical problems prevented the operation of the plant.

The New Hill factory was approached from the old factory site across Cattlegate Bridge, originally sharing it with the light railway system. The present bridge is a Mk II Bailey Bridge [RCHME 238] erected in 1971. The site could also be entered from the north-east through a gate controlled by a **Police Post** [S9 and S42] and open-topped **Pillbox** [S43].

As in the earlier plant (the group of structures around [E2]), the nitroglycerine and the wash waters were moved around through the force of gravity along covered gullies and additionally within this plant along earthenware-lined drains. The New Hill factory was built on the gently sloping ground to the east of Cornmill Stream and was able to take advantage of the natural ground fall from east to west.

On the eastern side of the factory, the **Nitrator** [S16] is located at the highest point within the system. In contrast to the late 19th-century **Nitrator** [E2], [S16] at the heart of the factory is sub-square in plan. It was housed within a square pit with battered concrete walls surrounded by an earthwork traverse. The **Nitrator** was approached through a curving tunnel on the north-west side of the mound. On the eastern side of the mound are two brick piers supporting a concrete slab, on which was placed two earthenware fume towers. The remains of these towers lie in a heap at the base of the piers. On the south side of the mound, supported on concrete legs set in the mound of [S16], is the concrete floor slab to [S18]. On top of this slab there was formerly a large timber shed covering the acid and wash water tanks serving the **Nitrator**. The wash water tanks also served the other buildings within the complex, since [S18] was the very highest point within the complex. Also associated with the **Nitrator** is the small **Plenum Heater House** [S17] at its entrance and a hexagonal-shaped building foundation [U??] of unknown function to its north-east. To the north of the **Nitrator** is a small toilet block [S14]. A small circular earthwork pond [RCHME 234] surrounded by a continuous bank may be the **Nitroglycerine Drowning Pond**.

From the **Nitrator** [S16], lead-lined gutters supported by a wooden shelf fixed to concrete stanchions carried the nitroglycerine through a tunnel leading through the west side of its traverse to the **Washing House** [S19]. Contaminated water from the **Nitrator** was taken south-west to the **Wash Water Settling House** [S23]: the concrete stanchions between these buildings remain in place although the wooden gutter supports have been removed. A third gravity-fed link is made from the base of the **Nitrator** on its southern side by a half-open brown-glazed earthenware pipe that falls gently over a distance of 115m to the **Flume House** [S25] (see below). The pipe is set at the bottom of an earthwork cutting with banks to either side.

Like the **Nitrator**, the **Washing House** [S19] is set within a square-shaped concrete-revetted traverse surrounded by earth. It is approached through a concrete-lined service tunnel on the north side, at the entrance to which is a small building originally housing a **Plenum Heater** [S20]. Nitroglycerine was received from [S16] into [S19] along a tunnel through the eastern side of its mound. Contaminated wash waters were sent to the **Wash Water Settling House** [S23] along a gutter in a tunnel through the southern side of the mound: as the gutter emerged from the tunnel it was again supported on a row of concrete stanchions that remain in place. The washed nitroglycerine was run westwards along a tunnel through the west side of the mound to the **Pouring On House** or **Mixing House** [S21]. The link was made, as between [S16] and [S19], by a lead-lined gutter supported on a timber shelf. The stanchions for the gutter survive on the south side of the path connecting the two buildings and until late 1992 the timber shelf remained intact. Fortunately a section of the wooden shelf remains in place along the tunnel into [S21] and corresponds to a contemporary drawing of a gutter (S.19.B.27). The tunnel floor is raised considerably above the level of the floor of the **Mixing House** so that the nitroglycerine was able to enter the upper part of the house. The **Mixing House** [S21], in common with the other structures in the complex, was screened by a battered concrete wall surrounded by a square-shaped earthwork traverse. The **Mixing House** itself was a free-standing timber-framed building set on a low concrete plinth in the centre of the traverse. It was served on its west side by the light railway, which entered the traverse through concrete portals to north and south. The 18" gauge rails remain *in situ* in the southern tunnel for most of its length. As the iron rails emerge from the tunnel they are replaced by teak rails directly in front of the **Mixing House** itself, and the entrance to the building was protected by a porch.

The **Mixing House** [S21] was warmed by a **Plenum Heater House** [S22] situated by the southern tunnel portal. The railway serving the **Mixing House** approached the building in a cutting from Cattlegate Bridge [RCHME 238], which was terraced into the gently rising hill side above Cornmill Stream. The upcast from the cutting was dumped on the lower western scarp to create an earthwork bank. On the top of the bank is a small **Toilet Block** [S26].

The contaminated water from both the **Nitrator** [S16] and the **Washing House** [S19] was channelled along raised wooden gutters to the **Wash Water Settling House** [S23], entering the house along either side of the tunnel through the north side of its traverse. The building was set at a lower level than the two entry pipes, within a rectangular concrete revetment surrounded by a earthwork traverse. The exit from the building was along a tunnel through the south-east corner of the traverse. At the outer entrance to this tunnel is the **Plenum Heating House** [S24] that served the **Wash Water Settling House**. Along the eastern side of the tunnel and the pathway southwards is a half-open white-glazed earthenware pipe. This pipe then forms a **Y**-junction with the pipe direct from the **Nitrator** [S16] 8m to the north-east of [S25]: from this point it is a single half-open white-glazed pipe leading into the **Flume House** [S25]. It is unclear what process went on with this building, but it is presumed to be a final filtration of contaminated water before it was discharged directly into Cornmill Stream. To the west of the **Flume House**, a half-open brown-glazed earthenware pipe is set within an earthwork cutting with banks to either side and falls gently towards Cornmill Stream. In this section a length of galvanised metal pipe set in clay remains *in situ* within the earthenware pipe. This may indicate that the other earthenware pipes, too, originally contained metal pipes rather than being open to the air.

The intention was that this new Nitroglycerine Factory would be supplied by pipeline from the Acid Factory on the west side of North Site, a distance of around 600m. The pipeline was to carry mixed acids, compressed air and steam heating into the new plant. There was also a return pipe through which waste acid from the **Nitrator** would be taken back to the Acid Factory for reprocessing. The course of the pipeline [RCHME 102] may be traced for most of its length from north-west ofthe former **Press House** [76] within Area E, where it crosses the River Lea by bridge to the north-east of [76], to a bridge across Cornmill Stream to the south of the **Pump House** [S1]. From this point the line of the feature is lost, but it may be picked up again as an earthwork cutting south-east of [S3] heading towards the **Nitrator** [S16]. Contemporary photography preserved within the Public Record Office shows a row a concrete pipe stanchions in the base of the cutting. A layer of cork formerly used to insulate the pipes was found in the base of the cutting during fieldwork.

Adjacent to the road running along the northern perimeter of New Hill are a series of ancillary building connected with the new Nitroglycerine Factory. Unfortunately, as a consequence of the failure of this plant no documentation has been found describing the intended use for many of these buildings. This is because, despite the fact that many of the builders' drawings survive, the buildings are referenced by number rather than by function. Those that may be identified include a small group around the north-east gate, [S9], [S42] and [S43] comprising a **Police Post**. Adjacent to Cornmill Stream is a **Pump House** [S1] taking water directly from the stream; but it is unclear where and for what purpose the water was being used. The power supply for the new factory was regulated through the **Transformer House** [S2], which retains all its 1941 transformers and switch gear. Power was distributed around the factory by overhead transmission lines, a number of which survive around the factory from the 1940s. By this date the lines were using small brown Sinclair-Aitken insulators, generally dated to 1940 and 1941, which were supplemented by larger white insulators dated in the late 1930s. The other buildings [S5, S6, S10, S11, S12 and S13], although associated with the factory, have no clear diagnostic features to indicate their original functions. At least two buildings within this area have been demolished, [S3] and [S7]. Their remains may be traced as concrete floor slabs. A further unexplained structure is [X3]. This is constructed out of cement-filled sand bags; it is square in plan with a former entrance on the north side. This entrance has subsequently been blocked and the interior filled with sand.

When the government research establishment was set up after the Second World War, many of the buildings in this area were converted to serve new purposes. Many of those along the northern perimeter road were converted to **Laboratories** with supporting ancillary buildings. The conversions often increased the number of windows within individual buildings and saw the construction of minor additions. The concrete and earthwork traverses of the Nitroglycerine Factory were adapted as **Firing Points**. Original buildings within the traverses were demolished and in [S16] and [S19] steel firing points were constructed. The northern entrance tunnel of [S21] was converted into a firing point by blocking either end of the tunnel with steel plates and constructing a concrete test bed within the tunnel. Many of the former **Plenum Heater Houses** were converted to act as electrical switch rooms for the firing points. The only new building constructed was an **Expense Magazine** [S15] associated with the **Firing Point** in [S16].

The Royal Gunpowder Factory,

Waltham Abbey, Essex

An RCHME Survey, 1993

SECTION 3
ANALYTICAL REPORT

Contents

Introduction

The analytical description of the site presented below is archaeological. That is the principal source of information is the physical remains of the factory and the analysis is concerned with explaining the physical development of the factory both topographically and technologically. The analysis has nevertheless been informed and strengthened by reference to the wealth of historic cartographic, documentary and photographic sources that survive. It is this depth and range of evidence that has allowed the development of the factory to be articulated in such detail. While recognising that complex historical processes in many fields - technology, armaments development, foreign affairs and the interrelationships of government departments - were often behind many of the changes described below, it is beyond the scope of this report to explore these avenues of research. It is also significant that many of the greatest upheavals at the factory were pushed through by the talent, energy and determination of individual officers; notably the Congreves in the early 18th century and Sir Frederick Nathan in the later 19th century, in order to increase its efficiency or adapt to new products.

For the purposes of this analytical section of the report, the development of the factory has been split into ten chronological or functional phases. The parallel avenues of explosives research at Waltham Abbey RGPF are indicated in the overlapping divisions of the later periods. This represents a refinement of the broader periods defined in the history of the site as presented in the report's **Section 1** and reflects better the topographical development of the factory. To the ten phases has been added a substantial section on the factory's infrastructure in the key areas of power, transport and safety: this has been positioned between the closure of the factory and the description of the site's post-war existence as a government research establishment. Finally a short postscript notes developments during the search for an appropriate re-use for the site.

More detailed descriptions of the principal manufacturing processes have been brought together in **Appendix 1**, which also serves as a commentary on a set of flow diagrams outlining the main stages of those manufacturing processes in **Appendix 2**.

The early development *c*1650-1787

In attempting to reconstruct the early post-medieval topography of the site currently occupied by North Site within Waltham Abbey Royal Gunpowder Factory, we are fortunate in the survival of map of c1590 preserved at Hatfield House (ERO T/M 125). At the southern end of the site, four streams are shown joining to form the River Lea south of Highbridge Street. Reading east to west, these may be reconciled with Cornmill Stream, Old River Lea, Millhead and perhaps a channel approximately on the line of the later Lea Navigation. However, to the north where the Lea splits to form the four channels it is difficult to fit the pattern of channels known from later mapping. Snaking through the centre of the site is the Old River Lea; its present course may be seen to follow its 16th-century line apart from some minor straightening north of **Press House** [76]. The lower section of the river as it approached the town also appears to have been straightened, but before any of the available mapping. To the east and west of the old river were two artificial channels. The eastern one was Cornmill Stream, engineered to serve the former corn mill immediately to the west of the abbey church in the centre of Waltham Abbey. Its northern section followed the course of the Old River Lea until below **Newton's Pool** [RCHME 276] where it was terraced into the contour of the gently rising valley, its down-slope western side retained by an earthwork embankment. The water level within this channel was controlled by a 'turnpike' at the head of **Newton's Pool** [RCHME 276]; 'turnpike' in this context probably refers to a moveable dam with guillotine gates (Fairclough 1992, 6). By 1827 a further sluice had been added adjacent to the later **Water Wardens Cottage** [102] in order further to regulate the flow of water within this channel. To the west of the Old River Lea the channel was Millhead Stream. For most of its length it, too, was held within an earthwork embankment to maintain its level above the flood plain. The main inlet sluice into Millhead Stream was about 200m north of the **Grand Magazine** [1], with an overshot immediately to its north and another sluice to its south. The construction of Millhead Stream around one kilometre in length and Cornmill Stream over one kilometre in length in raised earthwork embankments represents a considerable capital investment and exercise of engineering skill. Although it is not directly documented, it is tempting to see Millhead as monastic in origin as well as Cornmill Stream, which more certainly is (Huggins 1972, esp. figure 1). At least by 1590 Millhead Stream powered a fulling mill, later converted to an oil mill before conversion again to gunpowder milling by 1669 (Fairclough 1985, 14). Though the arrangement of machinery within late medieval fulling mills is poorly documented the basic configuration of rising and falling hammers was probably not unlike those of gunpowder stamp mills with their pestles and mortars. If this late medieval fulling mill is correctly equated with mill 2 as shown on Farmer's engraving in 1735 (Fig. 15), it might imply the earlier demolition of a mill located on the end of the leat of Millhead by the present sluices [RCHME 135], otherwise the fall in the water level at this point is difficult to explain.

It is against this basic framework of the Old River Lea and the two channels parallel to it, with a similar six foot head of water in both Millhead Stream and Cornmill Stream, that the factory developed.

Within the perimeter of the later factory adjacent to the sluices at **Newtons Pool** [RCHME 276] was the **Turnpike and Chequer Inn** [RCHME 304], that was later at the end of the 18th century used by the master worker brought from Faversham, Mr W Newton.

By the third quarter of the 17th century there were two centres to gunpowder production locally. The earlier made use of a former oil mill and had with it ancillary buildings for the grinding, boiling, corning and drying of powder. The site of the original oil mill may coincide with the **Corning and Glazing Engine** [RCHME 234] shown with a large low breast-shot wheel by Farmer in 1735 (Fig. 25), and formerly located immediately to the south of the modern **Lecture Theatre** [A203]. Secondly, a smaller group of mills had also been established at Hooks Marsh Bridge, immediately north of the **Grand Magazine** [1]. This enterprise was relatively short-lived, for by the early 18th century an embryonic factory was emerging at the head of Millhead Stream.

The methods of manufacture described by Sprat in 1667 (described in the **Appendix 1**) are mirrored sixty years later in Farmer's view of the factory in 1735 (Fig. 15). By this date a clear south-to-north production flowline had been established and implies a unity of layout either as a purpose-built factory or as a rationalisation of earlier structures. This south-to-north flow remained in place until the end of gunpowder production although modified as new processes were introduced into an ever more crowded site. It is likely that the horsemills (3,4,5) shown by Farmer at the southern end of the site were used in the initial pulverisation of the saltpetre, charcoal and sulphur before mixing. A pair of the stamp mills is shown at the head of Millhead Stream. A possible innovation by this date are a pair of mills named as 'Dumb Mills', which are interpreted as the forerunners to the centrally-driven water-powered mills later to become the characteristic form in the industry. Mill 2 is described as a 'Corning and Glazing engine', which meant that another refinement had been added to the process as described by Sprat. During glazing, a surface finish was imparted to the gunpowder grains either by the action of friction as the grains rubbed against one another in a revolving barrel or by the addition of graphite. Removed at the north end of the works at a safe distance from the mills were stoves, including three sun stoves with drying leads, and a dusting house.

The topography of the factory altered little throughout the remainder of the 18th century. There was, however, a marked infilling between the buildings in the Millhead area. By 1783 seven pairs of water-driven mills were in place and all appear to have had a centrally-placed wheel with mills to either side. This arrangement also seems to apply to the **Head Mills**; by this date the use of stamp mills had been prohibited by legislation of 1772 (12 Geo III, ch 61). Another effect of this act of parliament was to limit the amount of powder that might be stored within any one process building. This might in part explain the appearance of the magazine on the east side of Millhead, north of the mills. In 1771 the eminent 18th-century engineer John Smeaton produced a series of drawings for new mills at Waltham Abbey (Smeaton 1771). Smeaton was a noted improver of watermills and his mills are recognised as being at the pinnacle of technology as regards the wooden wheel (Wilson 1957, 37). These drawings included proposals for a remarkable underdriven mill with the mechanism encased in a brick vault, and a design for a centrally-driven mill with two pairs of incorporating mills to either side. It is not known if any of the mills shown in the drawings were actually executed at Waltham Abbey RGPF, since elsewhere some of his most careful designs were never used and mills are known to have been built where there are no known surviving drawings (Wilson 1957, 25-6). It is known from Smeaton's own reports, however, that he did construct at least one mill at Waltham Abbey (Wilson 1957, 43) and a mill on the east side of Millhead [197] is marked as 'Smeatons Mill' on a site map of 1783. Two further pairs of mills on the west side of Millhead are marked as 'The New Mills' in 1783 and may also have been executed to Smeaton designs. By this date the former corning house is described as 'Old Engine House' and it had been replaced by a hand-crank corning house to the north of the main group of mills. To its north were two buildings described as **Running House** and **The Old Running House**; they appear to occupy the site of later **Dusting House** [159] and it may be that **Running House** was an 18th-century term for dusting. Similarly a building on Millhead to its north shown as **Tumbling Room** may be equated with the later **Corning House** [116, 117]. A further innovation that may have been introduced by 1783 was a large **Saltpetre Refinery** [RCHME 311] to the south of the mills; although the building shown on plan was not named at this date, it was later identified as the **Saltpetre Refinery**.

The early years of government ownership 1787-1816

The acquisition of the factory by the government in 1787 made little immediate impact on the overall topography of the site. The considerable expenditure undertaken was directed at the refurbishment of the existing factory rather than any extensive building programme. A few new buildings were constructed at this date and fortunately three of them remain as standing structures. **Walton's House** [A200] is described at this period as the **Master Workers House**; later it was used as the factory office. Opposite to **Walton's House** are two stoutly constructed buildings, a **Mixing House** [A201] and a **Saltpetre Mill** [A202], later identified as a **Saltpetre Boiling and Melting House**. Other buildings new at this period included a new **Gloom Stove** [148, 149, 150] and a new **Magazine** [RCHME 218] on the west bank of Millhead Stream north of the mills. The **Saltpetre Refinery** [RCHME 311] is first positively identified as such at this date although, as discussed above, it may have been functioning from an earlier date. The layout of the factory inherited from the Walton family, however, remained static until after the turn of the century.

The Napoleonic Wars created an unprecedented demand for gunpowder. This was partly met by increased output from private contractors, but also by increased capacity at the existing government factories and through the purchase of the factory at Ballicollig in southern Ireland in 1804 (Crocker 1988, 52). At Waltham Abbey RGPF the years between 1801 and 1806 saw a flurry of building activity. At the northern tip of the site the **Grand Magazine** [1] was constructed on Paynes Island, an artificial creation by the inlets to Millhead Stream. Though the magazine at this date had a similar plan to the present structure it was described in contemporary ledgers as being built of brick and boards. The **Grand Magazine** served the needs of powder barges along Millhead Stream, and had a connection through the lock on Powdermill Cut to the River Lea Navigation (see figure 4). To the south along Millhead stream a **Steam Drying Stove** [RCHME 330] was added, with a U-shaped canal enclosing the structure. Two canal branches [RCHME 291 and RCHME 294] were constructed off Millhead Stream within raised embankments to maintain their height as part of the high-level canal system. Both canals led to horse-driven **Corning Mills** [76 and 103]; it therefore appears unlikely that at this date the canals were being used to power any machinery within those mills. The mills consisted of two buildings separated by an oval brick traverse, both of which survive. Each of the **Corning Houses** was served by a **Receiving Magazine** [54 and 105], in which powder was stored either before or after processing. This reflected the provisions of the 1772 Act, which made it illegal to store more powder than was required for the immediate work within a mill. As with the later explosives acts, Waltham Abbey RGPF was free from its statutes as it lay on Crown land, but it appears largely to have followed its recommendations as examples of good working practice. The head of Millhead Stream by this date was densely packed with mills and offered little scope for further development, nor did the area around **Walton's House** [A200], which was surrounded by horsemills and ancillary buildings.

The canal system was further extended by a link [RCHME 301] dug westwards towards Horsemill Island. The small streams either side of this island were also probably enlarged at this date to allow for the passage of gunpowder barges. The canal at the southern end of Horsemill Island was also linked to the Old River Lea by a channel running to the west of the **Saltpetre Refinery** [RCHME 311]. These extensions allowed freer movement of powder barges around the southern end of the site, between the initial processing of the ingredients and mixing houses adjacent to **Walton's House** [A200] and along the western tail race and over to Horsemill Island. It was at this date when the factory was driven by the wartime demand for powder that Horsemill Island was developed. At the northern end of the island the **Gloom Stove** [148, 149, 150] remained in place while on the rest of the island nine horsemills were constructed with associated **Charge Magazines** and **Stables** [RCHME 317]. From the available evidence it appears that this was the first use of horses for incorporating gunpowder since perhaps the early 18th century. Previously horses had been used to power the initial grinding and composition mills close to **Walton's House** [A200] while incorporation of gunpowder had been carried on exclusively by the water-powered mills on Millhead Stream.

The almost continual warfare with France until 1815 led to a period of continuous growth within the factory. One of the more lasting developments was the construction of the Lower Island Works. These included two gunpowder **Incorporating Mills** [394 and 395], a **Corning House** [399b] and the **Press House** [399]. Two more **Incorporating Mills** [RCHME 308 and RCHME 309] and a **Receiving Magazine** were later added to their north. To the north of the mills a new **Sulphur Refinery** [375, 376] was constructed and at about the same time, and a series of **Store** buildings [339-362] were built at right angles to the Highbridge Street flanking the entrance to the Lower Island Works.

It was also during the early period of government ownership that Powdermill Lane, then known as Threshings Lane, was developed as the principal road entrance to the factory. Nevertheless, the primary route in and out of the factory for raw materials and finished gunpowder was by river and remained so until the end of explosives' production. Inside the Powdermill Lane entrance an Artificers Yard, later the Engineers Yard, was built between 1801 and 1806. During its construction an old **Horse Mill** [RCHME 321] was swept away and replaced by a range of **Store** buildings incorporated into the present administrative buildings [A231 and A234]. The hipped roofs of these buildings with trusses formed from a tie beam and kingpost with an expanded head and foot and raking struts may be paralleled in a number of contemporary ancillary building constructed at the Royal Gunpowder Factory at the Marsh Works in Faversham (TR 06 SW 64). The present administrative buildings [A231 and A234] were mirrored to the south by a further pair of store buildings now demolished [A259 and A265]. At the entrance to the yard was another **Store** building [A238/A268] and on the opposite side of the gate the **Clerk of Works House and Engineers Office** [A269].

During the early years of government ownership the quality of powder produced at the royal factories was gradually improved under the energetic and inventive Comptroller of the Royal Laboratory, William Congreve. Two of the most important properties of good military powder was that it should have a consistent and reproducible action. To achieve this the manufacturers had to ensure that the ingredients of saltpetre, charcoal and sulphur were of a consistent purity and that each batch of powder was manufactured in an identical way. Strict control over the refining process also helped to ensure that no grit or other foreign bodies entered the ingredients before incorporation, where they might have catastrophic results. Probably the most important innovation introduced during the 1790s has left no archaeological trace; that was the substitution of charcoal produced in cylinders against the old pit method of production. Experiments had been conducted in the 1780s by Bishop Watson into producing gunpowder with a reproducible performance (*Gents Magazine* 1816, 274-8; Gray et al 1982, 3389). The quality of the charcoal was recognised as one of the variables that had to be controlled, and Watson's solution was the distillation of charcoal within closed iron cylindrical vessels or retorts. So marked was the increase in performance of gunpowder using charcoal produced in this way that charges in some ordnance pieces were reduced by up to one third (Coleman 1801). Cylinder charcoal was introduced at Waltham Abbey RGPF in 1794 (Winters 1887, 41), but at this date it was produced at Fisher Street and Fernhurst in Sussex and transported to Waltham by barge. Such cylinder-fired charcoal continued to be imported onto the site until 1830. However, the attention paid to the refining of sulphur and saltpetre is manifest in the new buildings devoted to these processes. (For more detailed descriptions of the processes, see **Appendix 1**). Additional **Saltpetre Refining Buildings** [RCHME 313, RCHME 315] were added to the north of the **Saltpetre Refinery** [RCHME 311] and were associated with these improvements. Indeed the processing of saltpetre had probably been moved into the new buildings completely, for the old building [RCHME 311] was named as the **Grand Storehouse** by 1806 (WO78/1352). Further capacity for refining saltpetre was acquired with a major new **Saltpetre Refinery** [278-82] built on the opposite side of lower Millhead Stream to the old **Saltpetre Refinery** [RCHME 311] by 1827. It is also during this period that the **Sulphur Refinery** [375, 376] may be identified as a separate building. The original building was smaller than its final form or it consisted only of the western side [376]. Prior to this date sulphur refining may have taken place alongside saltpetre refining in building [RCHME 311]. For a period after the construction of the new **Sulphur Refinery** some sulphur refining continued to take place in a building, [RCHME 313], just off the Highbridge Street entrance to the factory.

To the east of the **Saltpetre Refinery** [278-82], a number of dwellings were built or acquired and much of the area was divided up into allotments for the benefit of the workers. Further buildings were added to the Engineers Yard on Powdermill Lane and a dwelling built for the senior officer [A221]. In addition to the increased gunpowder incorporating capacity gained by the construction of the mills on Lower Island and Horsemill Island, the Millhead area was remodelled. An further pair of mills [182] were constructed on the west side of Millhead Stream and a pair of mills [181 and 183] described as 'erected in 1814 on an improved principle' (WASC 900/04) came in on the eastern side. Further northwards the **No.1 Corning House** [116, 117] was built, perhaps on the site of an earlier structure, and to its north **No.2 Corning House** [97,98] with a tail race [RCHME 296] tipping into the Old River Lea. To cope with its increased production capacity a number of small new **Receiving Magazines** were scattered around the factory. At its northern end a **Stables** [RCHME 358] was constructed for the contract horses to the south of **Newton's Pool** [RCHME 276] and the former **Turnpike and Chequer Inn** [RCHME 304] was inhabited by the master worker from Faversham, Mr W Newton, and his family.

In addition to improving the quality of British service powder, Congreve also helped to maintain the supply of powder by reworking old powder by dusting it and then re-stoving. Powder that had deteriorated to such an extent that it was no longer useable had the saltpetre extracted from it in a special press designed by Congreve (Congreve 1811). These and other early improvements to the quality of powder were carried through utilising the pre-existing buildings and had no marked effect on the topography of the factory. Another such innovation was the first mentioned use of iron bedstones and runners in 1801 (VCH 1907, 453). This highlights a continuing problem in any attempt to put a precise date on the introduction of many innovations in gunpowder production from field archaeological or cartographic sources alone. For until a particular process is deemed to be of such importance to have a building named after it or built specially for it, it is uncertain by documentary means alone if the process was in use.

Curiously, not all the developments in the factory appear to have employed the latest methods of manufacturing technology. For example, the construction of a new **Gloom Stove** [148, 149, 150] would appear to be a retrograde step, for a steam drying stove is known to have been in use as early as 1776 at the privately owned Oare Works in Faversham (RCHME 1991, 43) and Smeaton had produced a proposal for a steam drying stove at Worcester Park, Tolworth as early as 1772 (Smeaton 1772). The use of steam stoves had the twin advantages that they were less likely to overheat and cause the powder to ignite, and there was also less likelihood of a rapid rise in temperature that might cause the sulphur to sublime out of the powder (Rees 1820, 143). The reasons for the choice of gloom stoves may lie in the personal preferences of Congreve, for the Royal Gunpowder Mills at Faversham persisted in the use of gloom stoves, too (Hodgetts 1909, fig. 17). Also pressed into service at this date as a **Stove** was the **Old Engine House** [A234], although the method for drying gunpowder it employed is unknown. But a **Steam Gunpowder Drying Stove** [RCHME 330] was also introduced at this period to supplement the existing gloom stoves.

Many of the improvements introduced by William Congreve and his son, also William, as successive Comptrollers of the Royal Laboratory either remained in place or directly influenced later practice. The refining houses for sulphur and saltpetre established during this period remained in operation until the end of gunpowder production, the method of refining sulphur changing little. The younger William, who succeeded his father as Comptroller in 1814, was no less inventive than his father and in 1815 patented a machine for granulating powder. A machine of this type was installed in the Lower Island **Corning House** [399b] in 1816 (Winters 1887, 83). William Congreve's machine was mentioned by name until 1841 (WO55/2856) and may have survived longer; certainly the design was used throughout the 19th century (Smith 1870, figs. 18 & 19) and, as noted above, made a distinct impression on the American powder maker Lammot du Pont during his tour of European mills. At the same time Congreve introduced a mixing machine that ensured the precise proportions of saltpetre, charcoal and sulphur were blended within a charge prior to incorporation. The Congreves also brought a more scientific approach to the manufacture of gunpowder, as is illustrated by their introduction of the quantification of the effectiveness of different batches of powder and establishment of a proof house for this purpose.

Other developments during the Napoleonic Wars were transitory and had no lasting impact on the factory. This included the use of horse-powered **Incorporating Mills**, and **Corning Mills** which appear to have been an expediency forced on the factory by the war. Prior to this occasion horse power appeared only to have been used in the initial processing of the ingredients.

Retrenchment 1816-*c*1850 (see Figure 4)

In contrast to the previous thirty years that had seen a period of continuous expansion, the cessation of hostilities in 1815 brought an abrupt end to any further large-scale development. Some of the increased capacity acquired during the war was lost, notably all nine horse mills on Horse Mill Island, and a large **Stables** [RCHME 317] on the island was converted into a **Sulphur Store**. Also the two horse **Corning Houses** [76 and 103] were demolished and with the loss of these buildings the necessity for the extra **Stables** [RCHME 358] to the south of **Newton's Pool** ceased and they were demolished. The number of incorporating mills at the head of Millhead stream was almost halved with the loss of the two former **Stamp Mills** [211 and 211a], followed later by the demolition of the two water-powered incorporating mills known as **Queens Mead Mill** [RCHME 349] and **Hoppit Mill** [RCHME 353]. Also lost during this period were two water-powered **Incorporating Mills** [RCHME 308 and RCHME 309] within the Lower Island Works.

In the midst of a typical periodic down-turn in the gunpowder market it is hardly remarkable that no apparent improvements took place in the manufacturing techniques. The existing factory seems to have coped adequately with the low demands made upon it for new powder and for the reworking of damaged powders. Probably the most significant advance came at the end of the 1820s with the construction of the **Charcoal Cylinder House** [RCHME 333]. Until then Waltham Abbey RGPF had been dependent on other producers for a supply of high-quality retort-burnt charcoal (see above). It is unclear whether the equipment for this building was moved from the Faversham works as a committee at the time recommended (Simmons 1963, 36) or whether the staff were simply transferred to the new building. The **Charcoal Cylinder House** [RCHME 333] was located on the eastern side of North Site in a meander of the Old River Lea and was linked to the lower reaches of Millhead Stream by a new canal [RCHME 278]. It is probably in connection with this new canal that the **Cast Iron Bridge** [RCHME 132], which has the date 1832 cast into its side, was built to replace an earlier 'brick bridge for carriages' (PRO MPH 271) in order that barges could pass beneath it.

After nearly twenty years of little or no investment in new machinery and buildings some refurbishment did start to take place in the 1840s. A new granulating machine costing £2000 was installed in [97, 98] in 1845 (Winters 1887, 108): this was in response to an explosion that destroyed the earlier building, however. Correspondence at this period also discussed the erection of five incorporating mills and two hydraulic pipes. Unfortunately it is not known whether this work was carried out or if it represented the rebuilding of mills on earlier sites. In 1847 the iron mill 'Iron Duke' was described as being newly finished (Winters 1887, 109), but it is unclear which mill this description was applied to and, once again, it may refer to the rebuilding of a mill on a pre-existing site.

Improvements were also carried out to the flow of water around the factory. The tailrace along the eastern side of Millhead Stream [RCHME 119] was extended as far northwards as the high-level canal [RCHME 288]. **Corning House No.4** [97, 98] on Millhead Stream that had formerly tipped water into the Old River Lea now used a shortened tailrace [RCHME 296], the old tailrace [RCHME 297] perhaps being reopened at a later date. At the northern end of leat [RCHME 119] a former barrel storehouse [84] was converted into a water-powered **Dusting House**, its central wheel tipping into the newly extended tailrace. Part of the objective of these developments may have been to increase the flow of water into the lower reaches of Millhead Stream. Also during this period a new canal cut [RCHME 288] was made towards the former **Corning House** [76] and the old canal leading to it [RCHME 291] was filled to the north of magazine [54]. The remodelling of the canal system in this area was probably connected with the conversion of the old **Corning House** [76] into water-powered hydraulic **Press House No.1**, either at the very end of this period or shortly after 1850.

Despite these piecemeal improvements the majority of the plant within the factory by the 1840s was becoming antiquated. The **Corning House** [97, 98] that blew up in 1843 was still using a hand-operated screw press and a shaking frame for the granulation of powder (Winters 1887, 106; *ILN* 1843, 275-6). **Gloom Stoves** also remained in use for most of this period. The large **Gloom Stove** [148, 149, 150] was converted into a **Steam Drying Stove** in 1840 (WASC 901/111) but one other **Gloom Stove** may have remained in use into the 1850s, for Snow Harris in his paper on lightning conductors (1858a, 129-30) describes two of the stoves as 'the upper and lower' and a further stove as the 'old stove house'.

The final phase of gunpowder: development and demise 1850-1898

The reinvestment in Waltham Abbey RGPF begun in the 1840s gained increasing momentum in the second half of the century, driven by the needs of ever larger ordnance. Not only were far greater quantities of gunpowder required, but also more specialised forms including pellet, pebble and moulded powders that demanded new types of process buildings. (For a more detailed discussion of these forms of powder, see **Appendix 1**). The armaments industry at home and abroad was developing new alloys and engineering techniques for the production of ever larger guns, as the imperial powers strove to outgun their rivals. The response of the powder makers to these advances was very much reactive, and not until the development of chemically-based explosives were the propellant manufacturers able positively to feed back into the development of improved ordnance. At Waltham Abbey RGPF the later 19th century saw an infilling of the existing factory area on North Site and the application of new technologies to the manufacture of gunpowder. The innovation lying in the application rather than the technology itself. Steam-powered grinding mills and centralised hydraulic systems, for example, were established technologies within other large industrial complexes. The period from 1850 to the end of large-scale gunpowder production in 1898 saw the factory transformed from an essentially late 18th-century manufactory to an up-to-date factory producing gunpowder on a truly industrial scale. This was most evident in the incorporation of gunpowder, where the traditional paired water-powered mills were superseded by steam engines each driving groups of six mills. The change was gradual, however, and cumulative in contrast to the total remodelling that the Royal Small Arms Factory at Enfield underwent around this date (Putnam and Weinbren 1991, 36-7). The very nature of gunpowder manufacture made the ideal of a mechanised integrated factory an undesirable end because of the distances required between buildings as dictated by the needs of safety. Also at this date the use of composite wrought- and cast-iron roof trusses was introduced at the RGPF, though they had been in use naval dockyards and some textile mills as a fire-proofing measure since the beginning of the century (Falconer 1993, 18). Although some centralisation of the power supplies of hydraulic, gas and electric was achieved by the end of the century, production largely remained in individual buildings each with an autonomous source of power.

The Crimean War of 1854-56 had exposed many weaknesses in the British Army and its suppliers, who were little reformed from the Napoleonic era. This neglect was also evident in the RGPF, where little development took place for almost four decades previously. The end of the Crimean War and the construction of the new Group A steam-driven **Incorporating Mills** [L168, L169, L176] in 1856 marked the start of a period of unprecedented growth in the size of the factory. These first Group A mills differed from the later mills in that they were L-shaped in plan, with a detached **Boiler House** [L176] that served a beam engine within the **Engine House** [L168]. Attached to western side of this building was an **Engineers and Carpenters Shop** also utilising the power of the beam engine. The **Incorporating mills** [L169] were to the east of the engine house and were powered by an underground drive shaft. The six mills were served by two small free-standing **Charge Magazines** [170a and RCHME 193] at the eastern end. It was also at this date that the tramway was introduced to serve the new mills by linking them to the water-powered **Charcoal and Mixing House** [197] on Millhead Stream. The tramway was raised on wooden trestles to lift it to the height of the working floors in the steam-driven mills, which was determined by their need to accommodate the drive-shaft alley beneath their floors.

North of Group A, work started on the Group C mills [L157] in 1861, Group B mills having been constructed on Lower island in 1859. The T-shaped plan of the Group C mills was to become the characteristic form of the later mills. To the rear of the building was a boiler house serving a central engine house. The early drawing for this group (L157/3) shows that the original intention was to have two pairs of mills either side of the engine house; this was later increased to three either side. To the south of the boiler house was a coal yard and a tall chimney connected to the boiler house by a flue. [L157] was followed by a mill group of identical plan [L153] immediately to its north in 1868. In response to the introduction of pellet powders for use in large charges in 1867 (Smith 1868, 132), construction work began at the RGPF to ensure the large supplies required by the services. For this work the **Pellet Powder House** [L149] was constructed. It consisted of a boiler house to the south with an engine house and hydraulic accumulator tower to the north (L149.B.15). No press was shown in the building nor would there have been any room for one; it is therefore presumed to have been sited elsewhere in an unlocated building. This building's construction may have been somewhat premature, for in 1869 a committee under Colonel Younghusband found that 'pebble powders' gave superior results to 'pellet powders' (Morgan 1875, 2). In 1877 work began to convert the building into a more standard T-shaped gunpowder incorporating mill. The central engine house and hydraulic accumulator tower were retained, while a new boiler house was added to the eastern end of the existing boiler house and three incorporating mill bays were added to either side of the engine house. At this date also, the northernmost Group F mills [L145] was built; they differed only the architectural treatment of the central engine house. The final mills, Group D [L148], completed the programme only in 1888. As the groups of mills were built so the tramway system was extended, including the construction a lifting bridge to form a link to [L149] (Jenkins 1989, 389). Although these gunpowder mills were exempt from the provisions of the 1860 Act (Victoria ch139) as they lay on Crown lands, they nevertheless fulfilled the one of the provisions of the Act, which required groups of Incorporating Mills to have **Charge Magazines** so that powder not beneath the mill runners could be stored in safety. Two **Charge Magazines** were originally provided for the complex, one of which [L154] survives.

It was probably at the very end of the 1840s or more likely in the early 1850s that the two former horse **Corning Houses** [76 and 103] were converted into **Hydraulic Press Houses**. By the time of its introduction at Waltham Abbey RGPF it was probably a proven technology, as a water-driven gunpowder press is documented at the privately owned Oare Works in Faversham from at least 1846 (RCHME 1991, 41). The presses were powered by a hydraulic pump driven by a water wheel that utilised the head of water in the high-level canal system. It was probably in response to the reuse of the former **Corning House** [76] that the more direct canal route [RCHME 288] was excavated. It is shown as being in place by 1851 (PRO WO55 3027), which may provide a *terminus ante quem* for the introduction of water-driven hydraulic power within the factory.

Between the end of the Crimean War and the concerted expansion of the factory in 1878 some piecemeal development had occurred in the northern part of the site, including the construction of a new water-powered **Granulating House** [S34] in 1857. The mill powered by the fall of water from Cornmill Stream into **Newton's Pool**. Also connected with the construction of this **Granulating House** was the extension of the canal [RCHME 291] from the **Magazine** [54] north-eastwards as a new canal [RCHME 287] to serve it and link it conveniently to its new **Expense Magazine** [50], which was constructed adjacent to [54]. The construction of the **Granulating House** may be connected with the conversion of [76] into a hydraulic **Press House**, that had probably occurred a few years earlier. A further water-powered **Granulating House** [AF4 formerly 56] was constructed in 1875 on the eastern bank of Millhead Stream, now therefore adjacent to Horsemill Stream, and the structure was later engulfed within the Acid Factory and used as the **Plumbers Shop**. This mill was powered by the fall of water from Millhead Stream into a newly constructed rectangular pond [RCHME 354].

During 1878 and 1879 a massive redevelopment of the factory was under way. The impetus behind the programme at this date appears to have been the need to produce moulded powders for use in large-bore ordnance. (A fuller discussion of moulded powders, together with pebble powders and brown or cocoa powders is contained in **Appendix 1**). The **Accumulator** building or **Pellet Powder House** [L149] was converted into a characteristic T-shaped steam-powered **Gunpowder Incorporating Mill**, but its accumulator was retained to power the new centralised water hydraulic system. This now worked in conjunction with a **Remote Accumulator Tower** [L136], that served to regulate and to maintain pressure within the system. From this tower a network of moulding houses were supplied with hydraulic power. At first it may have served only the new **Press House** [S31]; however, the network quickly expanded to include the **Moulding House** [L130] and the pair of **Moulding Houses** [L107 and L108] constructed in the early 1880s. In the Lower Island Works a number of the old water-driven incorporating mills were converted for use as **Cam Press Houses** [394 and 395]. For the machines in these, the compression was supplied by means of a cam or eccentric on a shaft driven either by steam or a water-wheel; in these cases it was by water. The finished prism was regarded by some to be of a superior quality than hydraulically produced prisms (Wardell 1888, 62). The large hydraulic presses used on North Site and the smaller cam presses used on Lower Island were both supplied by Taylor and Challen of Birmingham (Guttmann 1895, fig.128 and Supply 5/862 photos 45-49)

Central to expansion of the factory in 1878 was the extension of the high-level canal system fed from Millhead Stream. Two arms of the extended system were taken off **Canal** [RCHME 294] leading to the **Press House** [103]. One arm went off southwards [RCHME 179], its height maintained in a raised embankment. This canal terminated in a dead end at the **Remote Accumulator Tower** [L136], but a branch was taken off to the **Canal Lock** [RCHME 222], and this provided a connection from the high-level system to the lower level of the canal system. The low-level **Canal** [RCHME 300] that passes north-south through the complex of steam incorporating mills was probably constructed early on in the third quarter of the century. It does not appear to have served the steam incorporating mills directly, as the powder was moved by tramway from the **Composition Mill** [RCHME 272] to the mills and by the same tramway to **Magazine** [L133] at the southern end of canal [RCHME 179], prior to transfer to the canal system. The canal may nevertheless have been used to carry coal to the coal yards at the rear of each of the mills. **Canal** [RCHME 300] was certainly used to convey material to and from the **Guncotton Press House** [L137], however, connecting it to the early guncotton factory by the present Highbridge Street gate. It also supplied the gunpowder **Moulding House** [L130], which was probably not constructed before 1878.

Opposite the northern end of canal [RCHME 179] was the start of **Canal** [RCHME 298] going north-east, which was also carried within an earthwork embankment to maintain its level. This canal crossed over the Old River Lea in two places, carried within **Cast Iron Aqueducts** [RCHME 112 and RCHME 214] at both points; both the aqueducts have the royal cipher and the date 1878-9 cast into their sides. At its northern end, canal [RCHME 279] formed a T-junction with canal [RCHME 287]. It was perhaps at this time also that the canal [RCHME 284] was dug to ensure an adequate supply of water into the extended high-level system.

Associated with the extension of the canal system was a sustained building programme. The **Remote Accumulator Tower** [L136] at the end of the new southern canal arm [RCHME 179], as described above, was part of this; adjacent to it and supplied by the canal was **Magazine** [L133]. North of these two, the early use of building [L109] is unclear; it was screened by a traverse on its north and south sides, however, which indicates a danger building of some form. A further clue to its use comes from a map of 1886 (WASC 900/38) that apparently shows a tail leat on its eastern side, perhaps indicating the presence of water-driven process machinery.

Along the new northern arm [RCHME 289] a number of substantial process buildings were added for the manufacture of traditional black powder. Immediately north of the new **Aqueduct** [RCHME 112] a new **Press House** [S31] was constructed in 1879: it was surrounded on three sides by a massive brick, concrete and earthwork traverse and supplied by a wide canal basin on its west side. The **Press House** was served by a **Magazine** [L102] to its south on the canal side, also built in 1878. To its north a new **Steam Stove** [S90] was built in a form virtually identical to the earlier stove [RCHME 330] constructed fifty years previously. The central steam-raising boiler was enclosed in a concrete and brick traverse with drying rooms to either side. These were supplied by barges unloading and loading beneath covered boat sheds at either end of the building. The whole complex was surrounded by a U-shaped canal. At the northern end of canal [RCHME 289] the head of water within the canal was used to power **Dusting House No.4** [RCHME 275] via a central wheel discharging westwards into an earthwork leat and thence into the Old River Lea, six feet below the level of the canal. To the south of the **Dusting House**, two **Charge Magazines** [74 and 75] were constructed to regulate the amount of powder that was in the dusting house at any one time. The distribution of these buildings along this new canal appears to be somewhat arbitrary. Prior to their construction a rough south-to-north flowline may be seen in the manufacture of black powder (see **Appendix 1**). The positioning of these new buildings would seem to introduce the necessity for many more boat movements to and fro between process buildings.

The pace of technological change continued to quicken and within five years of these extensive works the factory was enlarged yet again to embrace the manufacture of brown or 'cocoa' powders (see **Appendix 1**). In place of wood charcoal these powders used carbonised straw, giving them their characteristic brown colour. They were developed for use exclusively in large-bore guns and were formed in pellets or prisms before being packed into charge bags. It was the necessity of providing moulding houses for these powders that sparked off a spate of building activity in the early 1880s. It seems that the **Press House** [S31] was converted into a **Moulding House**; it is shown as such in 1886 (WASC 900/38), although the stone plaque on its wall clearly states its original function as 'No.4 Press House 1879'. A new **Moulding House** [108] surrounded by a U-shaped mass concrete traverse was constructed in 1882 near the west end of canal [RCHME 294]. The original structure was extended in 1884 by the addition on its east side of **Moulding House** [107] to create the E-shaped plan it has today. An additional **Magazine** [L103] was constructed alongside [L102] on canal [RCHME 289] to store powder for these moulding houses; the two magazines were separated by a mass concrete traverse. It was probably at this date also that an additional **Press House Magazine** [106] was constructed next to [105], but these two magazines were left unprotected by a dividing traverse.

At the northern end of the factory a fourth **Steam Stove** [26] was added on the east side of Millhead Stream. This followed the plan of two of the earlier stoves [RCHME 330 and S90], with a central boiler house within a traverse, drying rooms to either side served by covered boat sheds, and surrounded by a U-shaped canal. The increased drying capacity was probably required because of the greater drying times required by the moulded prismatic powders as much as increased production.

As described above, the expansion of the **Steam Incorporating Mills** had continued with the construction of [L148] in 1888. Other buildings added at this time included a new **Charcoal Store** [L167] at the southern end of the main complex of incorporating mills. The **Charcoal Cylinder House** [RCHME 333] was also enlarged during this period to include a **Gas Works** with two, and later three, gasometers to its north. A **Coal Store** [L160] was added in 1887, its lower concrete walls distinctively buttressed against the weight of material within the building. Though called a **Coal Store**, [L160] is probably better interpreted as a **Charcoal Store**. The word coal was often used throughout the 19th century to describe charcoal, and little purpose would be served by storing mineral coal under cover.

This period also saw a major remodelling of the Lower Island Works that formed them into a larger, almost self-contained unit. At the northern end of these works the **Sulphur Refinery** [375, 376] was enlarged and a small **Proof Range** [RCHME 305] established immediately south of it. In the wake of the first group of new steam incorporating mills on North Site, drawings were prepared in 1857 for a new group of mills at the northern end of the Lower Island Works (WASC 901/1-2). These Group B **Incorporating Mills** [387] were in operation by 1859. They appear to be unique amongst the mills at Waltham Abbey RGPF as their prime mover was water power, with an auxiliary steam engine for times of water shortage. The Group B mills were supplied by a new header leat, which may still be traced for part of its length as an earthwork hollow. This leat also provided a route by which gunpowder could to be taken to and from the mills by the internal canal network. It was at the same level as the lowest level of water on North Site and tipped through the mill to the tailrace on the eastern side of the Lower Island works (see figure 4). Because of their restricted location these mills took a different form to those on North Site described above. They consisted of a central engine house with a pair of incorporating mills to either side; the boiler house and coalyard were placed in a line north of the building. On the island the former **Incorporating Mills** [394] were converted into **Cam Houses**, housing presses used in the production of moulded gunpowders, while to the south [395] remained as a **Breaking Down House** and [399 and 399a] retained their functions as **Granulating House and Press House**.

Following the conversion of a large part of Waltham Abbey RGPF to cordite production from the late 1880s, gunpowder production capacity was retained only for use in fuses used in the detonation of chemical explosives. The surviving facilities were concentrated in the old water-driven mills along Millhead. Also retained along Millhead was the **Breaking Down House** [116,117] and the **Granulating House** [125] and the **Press House** [103]. The reduced capacity only justified the retention of one **Drying Stove** [148, 149, 150]. Gunpowder production was thereby concentrated exclusively along the western margin of the factory. In addition, the **Saltpetre Refinery** [278-82], **Sulphur Refinery** [375, 376] and the **Charcoal Burning Houses** [RCHME 333] remained in production. Though no change in their plan form may be perceived at this date, production must have been severely reduced. Though the former gunpowder **Steam Drying Stove** [S90, 89 and 91] was converted at the turn of the century for use as a **Cordite Tray Stove**, [S90] was converted back to gunpowder drying probably by the First World War, and building [89] was used as a **Fuse Powder Magazine**. Further losses to the gunpowder section of the factory occurred with the conversion of **Granulating House No.2** to tetryl production by 1940.

Another explosive introduced in this period was Picric Powder, a bright yellow-coloured powder consisting of a mixture of two parts ammonium picrate and three parts saltpetre (Wardell 1888, 88). It was manufactured in a similar way to gunpowder and could be corned and pressed without difficulty. Sir Frederick Abel in July 1870 had proposed the use of picric powders for filling shells (Simmons 1963, 59) and its use in this role had been patented in 1871 (*The Times* 1890b, 4). Manufacture began at Waltham Abbey RGPF in 1874 but appears to have declined in importance quickly. Interest in its explosive effects were rekindled by an explosion in a Manchester dye works in 1887 where picric acid was used as a dying agent, its most common use until this date. When production recommenced at Waltham Abbey RGPF in 1895, instructions for its manufacture had to be requested from the War Office Chemist 'as the powder has not been made for many years and no records of its manufacture have been kept' (Simmons 1963, 59). In the late 19th century the introduction of picric powders had little effect on the physical development of the site as former gunpowder buildings were used for its manufacture. This was graphically illustrated in 1897 when **No.5 mill** [182] on Millhead Stream exploded while milling 60lb of picric powder. A new store for ammonium picrate [275] was built to the north of the **Saltpetre**

Refinery [278-82], and was shown as disused by 1923. On Lower Island, mill [397] was used for blending picric from 1889. In 1898 production of picric powder was transferred to South Site and production continued there into the First World War. By this date it was primarily used a booster in conjunction with picric acid or Lyddite, the principal British shell filling.

New developments: guncotton 1860-1888

Guncotton is an explosive substance produced from cotton by the action of nitric acid or a mixture of nitric and sulphuric acid (Cavendish nd, 126); a fuller definition and discussion of the manufacturing process of guncotton may be found in **Appendix 1**. Early in 1863 Sir Frederick Abel was instructed by the Secretary of State for War to undertake a detailed investigation into the manufacture of and composition of guncotton when produced on an extensive scale. Manufacture of guncotton was carried out at Waltham Abbey RGPF, while most of the chemical analysis was undertaken at the Royal Laboratory at Woolwich. Guncotton used in the research was procured from Hirtenberg in Austria, from Messrs Prentice's at Stowmarket, and from Waltham Abbey, the output from the latter being of particular importance as it was here Abel was able to vary the production procedures and study their effects on the finished product (Abel 1866, 269-308; Abel 1867, 181-253). As with all new explosives guncotton underwent extensive trials, in particular to study its reactions to light and heat before fullscale manufacture for service use began at Waltham Abbey RGPF in 1872. The first guncotton factory was located in the old **Saltpetre Refinery** [288, 291, 291a RCHME 313] by the present south/Highbridge Street entrance to North Site. The factory also occupied a large building [RCHME 316] immediately south of the **Saltpetre Refinery** [278-82]. Along Highbridge Street was a **Boiler House** [294] that was probably used to raise steam both to power engines within the factory and to provide heat for boiling and drying the guncotton. Ancillary structures included a **Guncotton Drying Shed** [RCHME 343] within the present Area H and **Guncotton Presses** [L137] in Area L, north of the steam-driven incorporating mills. The original **Guncotton Press House** [L137] consisted of two separate building at either end of the present structure, but by 1897 these two buildings had been joined together probably by the core of the present building. The **Press House** was served by two **Magazines** [L107 and L135] with loading platforms at the canal edge. It is uncertain at this date whether or not the **Guncotton Press House** was also associated with the **Moulding House** [L130] and the **Magazine** [L135] or whether they were devoted with gunpowder production. The **Guncotton Press House** was probably located in this position to take advantage of the hydraulic power supply from the **Accumulator Tower** in [L149].

The growth in the demand for guncotton by the early 1880s could no longer be met by the plant in the old **Saltpetre Refinery**. In 1885 land on Quinton Hill to the south of the Lower Island Works was bought for the erection of a new, purpose-built Guncotton Factory. Work on the factory buildings situated on the south side of Cobbins Brook had begun by 1888 and production commenced in 1890 (Nathan 1909a, 178). This was soon supplemented by a nitroglycerine factory to underpin the manufacture of cordite. From this date the Quinton Hill factory on South Site provided all the guncotton used in the production of blasting charges and for incorporation into cordite.

New developments: nitroglycerine and cordite 1889-1914

As late as 1888 Wardell was able to write of guncotton that 'we may well doubt whether it has any future as a propelling agent' (Wardell 1888, 75). The search for the so-called 'smokeless' powders using a chemical base, notably nitroglycerine, was soon to revolutionise military propellants and in turn present the armament manufacturers with the opportunity to develop smaller and more powerful weapons. In 1887 Nobel had patented an explosive known as 'Ballistite', a preparation based on nitrocellulose and nitroglycerine. The British government had in response to this invention set up an Explosives Committee under Abel, Dewar and Dupre to investigate smokeless powders. The committee quickly reported and in 1889 Abel and Dewar patented 'Cordite' (Reader 1970, 141). Cordite, too, was a mixture of nitrocellulose and nitroglycerine; its principal distinguishing property was that it used an 'insoluble' nitrocellulose and that in its production acetone was used as a solvent. Cordite was quickly adopted as the principal service propellant and had virtually superseded gunpowder within the next decade. (Descriptions of the manufacture of guncotton, nitroglycerine and cordite may be found in **Appendix 1**, along with their manufacturing flow lines in **Appendix 2**).

In order to put cordite into production at Waltham Abbey RGPF, a nitroglycerine factory was set up on the newly-established South Site or Quinton Hill section of the factory. The design of this plant was partly based on the nitration plant used at Nobel's Ardeer Works and partly on the plant at Opladen in Germany. The early form of this plant is described and shown diagrammatically in the 1895 *Service Treatise* and in the report on a disastrous explosion at the plant in 1894. The plant was soon rebuilt but following a different design. A number of the buildings from this rebuilding survive largely intact on the South Site, including notably the **Washing House** [483], which retains many of its internal fittings from the turn of the century. To its south is a timber **Mixing House** [486], also largely intact but lined with galvanised metal probably during the Second World War. Also surviving from the original 1891 factory is a partially derelict **Guncotton Stove** [494].

The explosion of 1894 at Quinton Hill highlighted the dangers of having all the production of nitroglycerine focused on a single plant. One of the recommendations of the committee looking into the explosion was 'establishing a duplicate factory on some suitable and separate site'. The site chosen was Edmonsey Mead towards the northern end of North Site. In conjunction with the nitroglycerine factory an acid factory was built along the east bank of Millhead Stream - its location is now the east bank of Horsemill Stream. This plant was provided to ensure the high concentration and purity of the acids used in the nitration of glycerine that could not be assured from commercial sources. The early acid factory complex consisted of a **Nitric Acid Factory** [68], **Sulphuric Acid Concentration House** [64] and an **Acid and Glycerine Store** [72] along with a number of ancillary buildings. Some recovery of the acids used in the nitration process was carried on in the **After Separating House** [48] and the **Denitrating House** [71]. The working yards around the guncotton and nitroglycerine factories were dominated around the turn of the century by row upon row of large dark green bottles covered in wicker, known as carboys, in which the acids were brought to the RGPF. After the construction of the acid factory they were still used to move acid around the site. The glycerine continued to be acquired from normal commercial sources and was delivered to the RGPF in large iron tanks (Arkas 1900, 420).

At the centre of the nitroglycerine factory was the **Nitrating House** [E2] and to its east across the canal [RCHME 287] two **Washing Houses** [E3 and E5]. The existence of two **Washing Houses** was in response to the findings of the report into the explosion in the Quinton Hill plant (on which see the section on nitroglycerine in **Appendix 1**). Whereas in the original Quinton Hill plant a number of batches of nitroglycerine were stored in tanks in a single building, each batch was now sent to a separate **Washing House** and then to the **Mixing Houses**, where it was immediately mixed with guncotton to produce the relatively inert cordite paste. Also associated with the nitroglycerine factory was the **Wash Water Settling House** [E4] occupying the position if not the actual structure of a building of otherwise unknown function, perhaps constructed in the early 1890s. It is unclear whether the gunpowder **Dusting House** [RCHME 275] found a new role at this date or whether it was by then derelict. A **Mud Washing Shed** was constructed at this date, and is probably represented by the footings of [E16].

The creation of this nitroglycerine factory had a profound effect on the whole structure of North Site, for the purpose of its construction was to implement large-scale production of cordite. By 1898 the whole RGPF was being moved over from gunpowder to cordite production. Introduction of cordite entirely removed the need for either brown powders and moulded gunpowder and freed large numbers of buildings for conversion. As a consequence, the majority of the former gunpowder processing buildings were converted, including even the most up-to-date examples.

From 1890 guncotton was produced at Waltham Abbey RGPF entirely in the purpose-built **Guncotton Factory** [G418 and G431] at the northern end of South Site (see map, figure 2). The makeshift arrangements for manufacturing guncotton in the old buildings by the Highbridge Street entrance ended by this date. Before the guncotton was mixed with nitroglycerine to form cordite paste it first had to be dried. This drying was achieved by warm air heated by steam in a heat exchanger before it was blown into the guncotton drying stoves. At first it was carried out in one of three **Stoves** on South Site that included the sole surviving example of a circular timber **Guncotton Drying Stove** [494]. Other batches were moved north by barge to **Drying Stoves** [11, 20, 27] constructed in 1894 on North Site along Millhead Stream, ie now located along Horsemill Stream. [11 and 20] had their own **Engine Houses** [16 and 21], while **Stove** [27] made use of the former **Gunpowder Drying Stove** [26] which was probably used to house a fan and engine house. These early stoves were rectangular in plan and were surrounded by rectangular earthwork traverses. An outlier from this early group was **Guncotton Drying Stove No.4** [75], built adjacent to the former **Dusting House Magazines** on canal [RCHME 289]. This stove was also rectangular in shape and was screened by a mass concrete traverse to either end. It is uncertain how these stoves fitted into the production process, as at this date nitroglycerine was produced only on the South Site. There would appear to be little logic in drying the guncotton at the northern end of the RGPF, only then to move it in a more dangerous dried state south again for mixing. For in the early years the manufacture of cordite was exclusively carried out on South Site, in buildings between the **Guncotton Factory** [G419 and G431] and the canal known as Black Ditch. On North Site, the earliest pair of circular **Guncotton Drying Stoves** [22 and 29], built in 1897, formed the model for the majority of the later stoves, although at this date each stove may have been heated by a single **Engine House**. To these were added five more **Stoves** [4, 8, 10, 14 and 18] in 1903. This group of stoves was divided into pairs and heated by a centrally-placed **Engine House**, which by means of a belt drive powered fan houses to either side, that drove air over two heaters and warmed air into the drying stoves. A building programme in the following year added another three stoves [17, 23 and 36]. Further extensions were made to this group probably between 1908 and 1914 when **Stoves** [16a, 18a and 22a] were constructed. Also probably laid out at this time was the second complex of **Stoves** along the western bank of Cornmill Stream [74a, 76a, 92a, 93a, 93c, 96a, 96b and 98a], with their associated centrally-placed **Engine Houses**. This complex of stoves differed from the others in that they were supplied by a new tramway system rather than by the canal network around which the earlier, more northerly complex was arranged. Canals and tramway were nevertheless linked.

The circular stove warmed by an engine house remained the standard method of drying guncotton until the construction of the **Quinan Stove** [22a] in 1936, details of whose operation are discussed under cordite in **Appendix 1**. Two principal types of circular guncotton stoves were in use at Waltham Abbey RGPF. Those in the northern area normally had a single central post, presumably supporting a roof crown at the apex of the conical roof as is found in the sole surviving example [494] on South Site. In this type of stove the warm air was generally fed into the base of the building via a horizontal pipe set in a gully around the roundhouse, with a series of elbows attached to the side of the buildings. Two types of pipe were in use; the more common was formed from sections of cast-iron pipe, the other was formed from rivetted iron sheet with cast-iron elbows. In the second type of stove the roof was supported by four thin posts, to which was attached a single galvanised sheet-metal pipe at the apex of the roof. Two types of **Fan or Engine Houses** have also been recognised. In the northern group the arrangement was generally a central motor house that drove two fan houses, one to either side, by means of a belt drive. The belt covered by a long wooden shed termed the belt race. The fan houses sucked air in and blew it over a pair of heaters before it was blown into the stoves. In the other type of fanhouse, characterised by those along Cornmill Stream, there was a single central fanhouse (WASC 499, photo 12), probably with two electrically-driven fans or blowers (similar to the one surviving in building [88b]) that blew the air directly over the heaters thereby doing away with the need for the belt races.

To produce cordite it was necessary to blend the dried guncotton with nitroglyerine. Latterly the guncotton from the stoves was taken to a weighing house: whether such a specialist facility was in use in the early years of cordite production is uncertain. From the weighing house it went to **Mixing Houses**. The earliest **Mixing Houses** on North Site were in two former gunpowder processing buildings, **Press House** [76] and **Granulating House** [S34]. After conversion these buildings were presumably connected to the **Wash Houses** [E3 and E5] by gutters along which the nitroglycerine could be run. The resulting mixture of guncotton and nitroglycerine was known as cordite paste and was stored in designated paste magazines until room was available in one of the incorporating mills. At an early date storage may have been in former gunpowder magazines such as [L133].

During 1898 all the former steam-powered **Gunpowder Incorporating Mills** in Area L at the southern end of North Site were given over to the production of cordite. The gunpowder incorporating mills were stripped out and was replaced by cordite incorporating machines in three of the mill groups [L145, L148, L149], where the cordite paste was mixed with acetone and mineral jelly added. During the conversion the earlier underfloor gearing was cut away and replaced by an overhead drive shaft and belt drives to power the incorporating machines. Mills [L153 and L157] were converted to **Cordite Press Houses**, where the mixed cordite paste was extruded into long cords under hydraulic presses. The rate at which the cordite burned was controlled by the thickness of the cords, and generally the larger the gun the thicker cords that formed the charge bag. It is likely that the former **Guncotton Press House** [L137] was also taken over by the cordite factory at this date for extruding cordite paste, as was the former **Gunpowder Moulding House** [L130].

After pressing, the cordite was either wound onto small reels or the larger sizes of cordite were cut to into shorter lengths for making up into charge bags. Drying was carried out in the old gunpowder **Drying Stoves;** [S90] became **Cordite Tray Stoves 8 & 9**, [RCHME 330] **Cordite Tray Stoves 6 & 7**, and probably also [26] **Tray Stoves 10 & 11**. The lower numbered tray stoves in this sequence are presumed to have existed on the South Site. It is probable that the old gunpowder drying stoves retained their central boilers serving steam pipes to either side and that the newer stoves made use of some steam supplied from a central source, possibly one of the former gunpowder stoves. After drying, the cordite was blended so that cordite from different batches was mixed together to ensure a uniform and repeatable ballistic product. On North Site this was done in the former gunpowder **Moulding Houses** [107 & 108], now designated **No.3 Cordite Blending House**. Alternatively the cordite might be dried in the **Reel Drying Stove** [L167], also converted from a gunpowder processing building. From here the reels could easily be moved to the **Reeling House** [L168], a former steam-driven gunpowder **Incorporating Mill**.

Two other buildings [L109 and S31] also had a documented change of function at this date, but the use to which the buildings were put is obscure. [L109] became a **Blank Cutting House** and [S31] a **Cylinder Cutting House**.

These rather *ad hoc* arrangements supported British forces in the Boer War, when Waltham Abbey RGPF was one of the principal suppliers of cordite to the British army. Shortly afterwards production of cordite was transferred entirely to North Site. Production on South Site was now restricted to the manufacture of guncotton, which was then moved northwards for storage and mixing. The southern area of the Quinton Hill site, south of Black Ditch, was developed with **Stove Magazines** for drying the cordite manufactured on North Site. This move to North Site occurred at the same time as the nitroglycerine content of cordite was reduced from 58% in Cordite MKI to 30% in Cordite M. D. (Modified). The needs of the cordite production could therefore be met from the output of the single **Nitrator** [E2] on Edmonsey Mead. The move also coincided with the conversion of the Edmonsey **Nitrator** [E2] to the Rintoul-Nathan method of nitration (see the description of the early nitration processes in **Appendix 1**). The older of the two Quinton Hill **Nitrators** [476] was demolished, while the second one was used until the end of 1904 and then it was mothballed and never re-activated. Additionally three new circular **Mixing Houses** [46, 62 and 63] were constructed in a group around the **Nitrator** [E2]. They were of a similar design to the guncotton stoves, with a timber roundhouse in the centre of a circular brick and earthwork traverse, differed only in the provision of a covered tunnel through the traverse protecting the nitroglycerine gutter. Construction of **Mixing House** [63] necessitated demolition of the **Gunpowder Dusting House** [RCHME 275], but the **Mixing Houses** converted from former gunpowder buildings [76, S34] continued in use until the Second World War. Extra **Guncotton Stoves** were also added at this date, and these have been described above.

It was in the consolidation at this date that the northern end of Area H was also developed. At its north end two **Reel Drying Stoves** [H7 and H8] were built to replace the early **Stove** [L167] converted from a former gunpowder building. These stoves were constructed at the same time as the **Acetone Recovery Plant** [571] on South Site was built and building [249] in the Engineers Yard was converted for use as an **Acetone Recovery Plant**. It is not known whether the new **Reel Drying Stoves** in Area H from the first included the plant necessary for the recovery of acetone vapour (described in **Appendix 1**). The lessons learned from the explosion on South Site in 1894, when it was found that the solid parts of the traverse had added considerably to the damage caused by the explosion, were applied to the form of the new traverses. As a result the traverses around [H7 and H8] were earthworks except where the tramway passed through, and this passage was revetted by a vertical concrete face. **Reeling House** [H10] to the south of the stoves was where the reels were wound on to larger spools to produce thicker cords. Finished reels were stored in the **Reel Magazine** [H12]. These buildings were linked by the tramway system to the **Cordite Incorporating Mills** to their east in Area L, although it is unclear at this date how far south the system extended. The new buildings in Area H had repercussions on the converted gunpowder **Incorporating Mills** in area L. The construction of a purpose-built **Reeling House** [H10] allowed the former **Reeling House** [L169] to be converted again into a **Cordite Press House**. The construction of the new drying stoves did away with the need for [L167], which was converted into a **Mineral Jelly Store and Dining Room**. Other changes included the alteration of the **Cordite Press House** [L153] into a **Cordite Incorporating Mill**. New buildings in Area L constructed at the turn of the century included the **Managers Office and Laboratory** [L119], along with a small **Laboratory Magazine** [L114] to its north. They were soon supplemented by the timber-framed **Laboratory** [L122] and a **Photographic House** [L116].

Also around the turn of the century an **Acetone Factory** [288, 291] was established in the old **Guncotton Factory** at the south gate to North Site. Acetone was used in large quantities for the incorporation of cordite. It had initially in 1889 been extremely expensive, when supplies were entirely dependent on the German chemical industry; but its price fell by over 75% in the first decade of production. Acetone was produced by the distillation acetate of lime, which in turn came from the combination of pyroligneous acid resulting from the distillation of wood with lime. In the 1890s an experimental plant was set up at Woolwich, taking advantage of the waste wood from its sawmills and workshops (Anderson 1898, 123-4). The plant established at Waltham Abbey RGPF to produce acetone is described and illustrated by Guttman (1895, 117-21). To serve the **Acetone Factory,** the old **Sulphur Store** [RCHME 317] was converted into an **Acetone Store** as were the former **Boiler House and Gunpowder Incorporating Mills** [385 and 386] on Lower Island.

Further developments within the cordite factory prior to the First World War included construction of three virtually identical **Cordite Paste Stores** [L101, L105 and L108]. They were all served by the canal network and positioned at the northern end of canal [RCHME 179]; in them the mixed paste was held before it was brought down to the **Cordite Incorporating Mills** [L145, L148, L149 and L153]. Two of the **Stores** [L101 and L105] were surrounded by earthwork traverses, revetted in concrete only where a vertical face was required. **Paste Store** [L108] was left unscreened, probably because of its remoteness from other structures. At this date also a further **Mixing House** [88a] was added. This building was similar in design to the **Paste Stores**, although with additional windows. It, too, was surrounded by an earthwork traverse. The former **Cylinder Cutting House** and earlier **Press House** [S31] changed its function yet again to join [107 and 108] in becoming a **Cordite Blending House**.

The move to the production of nitroglycerine and cordite on North Site prompted further extensions to the canal system in addition to the new buildings. There was now a greater flow of barge traffic between South Site, where the guncotton was produced, and North Site, initially to the **Grand Magazine** [1] where it was stored wet until being moved to a stove for drying. Probably during the First World War the capacity of this magazine was extended when a timber-framed **Wet Guncotton Magazine** [2] was added to the original structure. On Millhead Stream a **Lock** [RCHME 222] was constructed in 1896 to facilitate movement between the upper and lower water systems within the factory. It may also be at this date that a **Lock** was inserted at the southern end of the header leat serving the Lower Island Works. To the north of the **Nitrator** [E2] two parallel canals were dug to supply the newly constructed **Guncotton Stoves**, the easterly canal [RCHME 283] probably around 1897 and the westerly canal [RCHME 285] between about 1908 and 1914. Around this date also, a short spur [RCHME 107] was cut westwards from canal [RCHME 289] to serve the **Cordite Mixing House** [88a]. About 1914 a short diversionary canal [RCHME 290] was cut between canals [RCHME 289 and RCHME 284] to keep barge traffic away from nitroglycerine factory. The new link [RCHME 290] was carried over the Old River Lea in a composite cast-iron and steel girder **Aqueduct** [RCHME 250]. There were also some minor losses to the canal network, when the U-shaped links that surrounded the former **Gunpowder Drying Stoves** [RCHME 330 and 26] were filled.

The tramway system in the early years of cordite production remained little altered from the system that had served the steam-driven gunpowder incorporating mills at the south end of North Site. Two other tramway networks did develop on the site. The first linked the acid factory to the nitroglycerine factory. Along it bogies of acid and glycerine were pushed towards the **Nitrator** [E2], where they were raised on a lift on the side of the traverse for their contents to flow by gravity into the storage tanks in the building. The second independent tramway serviced the complex of **Guncotton Stoves** on the west side of Cornmill Stream; it was linked to the canal network by a small landing stage [RCHME 114] and at the **Weighing House** [S27]. This network was later extended to encompass the new tetryl plant built nearby to the south-west during the First World War. Meanwhile the system around the former steam gunpowder incorporating mills was extended northwards on the embankment of canal [RCHME 179] to serve the **Cordite Paste Stores** [L105 and L108]. This system was also extended westwards into Area H to supply the cordite processing buildings added in 1904. It was subsequently linked southwards by a tunnel beneath Highbridge Street to South Site and to exchange sidings with the standard gauge lines through the Royal Small Arms Factory at Enfield. Until this date trucks had been pushed by hand between buildings; during the First World War small electric and oil-fuelled locomotives were introduced (Jenkins 1989, 404-410, Clarke nd, 3-5). These were housed in the small, newly-built **Locomotive Shed** [H30]. It appears, however, that the locomotives only worked as far north as Area H and the remainder of the systems on North Site remained hand-powered.

Gunpowder production at the Lower Island Works was similarly run down. By 1908 the **Steam Gunpowder Incorporating Mills** [387] and its former **Boiler House** [385] were stripped out and converted to **Acetone Stores**. On the island on which the water-driven mills were located buildings apparently retained their late functions, [394] as an **Incorporating Mill and Cam House**, [395] a **Granulating House**, [397] a **Picric Blending House** and [399] a **Press House**. The presence of the **Picric Blending House** [397] suggests, however, that they were being used for the production of picric powder rather than gunpowder.

High explosives 1910-1945

High explosives never formed a large percentage of the output of Waltham Abbey RGPF. The factory was, however, one of the few British plants to manufacture trinitro-phenyl-methyl-nitramine, more commonly known as tetryl or C.E. Its principal use was as an intermediary between an initiating fulminate detonator and the main charge. A plant for the manufacture of tetryl was established by 1910 to the north of the acid factory on the west side of North Site. To make way for its construction the old gunpowder **Drying Stove** [RCHME 330] was demolished. It was by this date around 100 years old and its later use as **Cordite Drying Stove** had been superseded by the new **Cordite Drying Stoves** in Area H. By the time RCHME's site survey took place in 1993, the area of the tetryl factory had been entirely cleared and all surface traces removed. Judging from available aerial photographs this factory consisted of a group of small and undistinguished buildings.

A second tetryl plant was established during the latter part of the First World War partly in new buildings and partly in buildings belonging to the cordite factory, some of which had in turn been converted from gunpowder processing buildings. This factory was located between the leat south of the **Water Wardens Cottage** [102] and canal [RCHME 289], adjacent on their south-west side to the later complex of guncotton drying stoves. New buildings included the **Tetryl Corning House** [S32], **Tetryl Incorporating House** [S33], **Tetryl Cleaning Houses** [S40] and a **Tetryl Purification Plant** [95a]. Three of the former **Guncotton Stoves** [93a, 96a and 96b] were converted for use as **Tetryl Drying Stoves** (later referred to as **Stores**). The two **Cordite Blending Houses** [S31 and 107/108] were converted to **Tetryl Packing Houses**. The tramway system to the east of the new plant was extended to link the buildings and form a connection with the canal system at [S31]. At some later stage but before 1925 the relatively newly-built **Cordite Mixing House** [88a] was converted for use as a **Tetryl Magazine**. The new eastern tetryl plant was further extended during the Second World War. To the south a new **Tetryl Store** [U10] was built, screened by a breeze-block traverse [RCHME 142] and a corrugated iron and earth traverse [RCHME 140]. Adjacent to the **Water Wardens Cottage** [102] two pairs of **Tetryl Drying Stoves** [S46, S47, S48 and S49] were constructed, each pair heated by a central **Fan House**. This group serviced by a new branch off the tramway network. A further new tramway branch linked the **Tetryl Store** [U10] to another new **Tetryl Store** [L106] 160m to its west in the north end of Area L. The former gunpowder **Drying Stove** [89] was for some time used as a **Tetryl Magazine**; after collateral damage caused by the explosion of **Mixing House** [63] in 1940 the southern part of the **Drying Stove** was rebuilt as **Tetryl Magazine** [S30]. By 1940 **Tetryl Magazine** [88a] was back in use as a **Cordite Mixing House**. The small **Magazine** [111] adjacent to [107/108] had by this date been taken into use as **Tetryl Store**. To its north the former gunpowder **Granulating House** [97, 98] was converted to a **Tetryl Still and Purification House**, thus creating an east-to-west band of buildings solely concerned with the manufacture of tetryl.

In 1925 a small experimental plant for the production of Picrite, also known as Petrolite or Nitroguanidine, was erected at Waltham Abbey RGPF. It is not known where this plant was located, but probably either in the acid factory or on South Site. On North Site **Guncotton Stove No.12** [29] was converted into a **Picrite Store**. This seems to have caused little physical alteration except for the addition of a porch with concrete walls and a timber superstructure; otherwise the remains of the **Picrite Store** appear identical to the other guncotton stoves in the area. Production of all the other new explosives manufactured at the RGPF, such as TNT and RDX, was carried out on South Site and seems not to have had any impact on North Site.

The First World War and its aftermath 1914-1939

The First World War placed an unprecedented demand on Waltham Abbey RGPF, that was met through a vast increase in the workforce, a large proportion of whom were women. Much of the increase in production capacity is undetectable archaeologically as it was achieved by increased shift working. There were nevertheless some new building projects. Few technological innovations were introduced at Waltham Abbey RGPF during the First World War, except perhaps in the manufacture of different types of cordite. In the northern part of North Site, a bypass canal [RCHME 290] was cut around the Edmonsey nitroglycerine factory and a new tetryl plant was built in the east near Cornmill Stream later in the war, as described above.

The capacity of the factory to produce cordite was greatly expanded by the construction of new **Cordite Incorporating Mills** [L143, L146, L151 and L155]. These are single-storey structures divided into bays of a similar design to that of the steam-driven gunpowder incorporating mills. The incorporating machines were powered from an overhead drive shaft, the bearing boxes of which may be seen in a number of the bay walls. Presumably the drive shafts were belt-driven from electric motors housed either in the end bays of the buildings or in small external lean-tos. Such an arrangement is illustrated in a paper written in 1898 (Anderson 1898, pl. 2) and is a standard method of powering overhead drive shafts in later explosives processing buildings elsewhere.

To meet the increased demand for mineral jelly used in the incorporation of cordite, **Mineral Jelly Store** [L165] was added to the north of the original **Steam Incorporating Mills**

[L168/L169] to support the **Mineral Jelly Store** in [L167]. To the north and south of the new **Cordite Incorporating Mills**, two new **Cordite Press Houses** [L134 and L159] were also added. A further large **Cordite Press House** [H16] was constructed in the centre of Area H. During the war the **Cordite Reel Drying Stove** [H7] was converted into a **Laundry**. This apparent anomaly whereby cordite production capacity was being increased while drying capacity was being reduced may be explained by the large group of **Tray Drying Stoves** built on South Site during the early years of the century. These forty-four stoves are virtually identical in form, with a rectangular ground plan surrounded on three sides by an earthwork traverse. The fourth side of the traverse is open and was served by the canal network linking the stoves to North Site.

There is circumstantial evidence that during the war the list of explosives produced at the factory was expanded to included cordite R. D. (Research Department) B. This innovation was an attempt to overcome the shortage of the solvent acetone. It used a so-called 'soluble' nitrocellulose that contained only 12.2% of nitrogen and was capable of being dissolved in ether/alcohol in place of acetone (HMSO 1938, 105). The evidence for its manufacture at Waltham Abbey is found on a series of drawing prepared in 1918 (WASC 901/300-1) for an ether pipeline leading from the **Mineral Jelly Store** [L165].

Prior to the war it is unclear where the electricity was being generated, although it had been used on the site since at least the 1880s. The addition of a **Switch Board House** [L177] to the **Boiler House** [L176] in 1902 may suggest that generators had been installed in there, but this cannot be confirmed from other sources. Later in the decade some of the electricity needs of North Site may have been met by the newly-built **Power House** [410] within South Site. The increasing use of electricity to power process machinery on North Site led to the construction of the **Power House** [A210] sometime between 1908 and 1915. A **Hydraulic Accumulator Tower and Engine House** [A214] was placed adjacent to the **Power House** to take advantage its steam-raising facilities. Its position also conveniently served the needs of the adjacent **Cordite Press Houses** [L157, L159 and L169], although the hydraulic power could have been transferred much further if it was required.

The employment of large numbers of women during the First World War necessitated the provision of facilities for their use. In the south of Area H a large **Shifting and Dining Room,** incorporating a **Boot Changing Room** [H19], was provided solely for the use of the female employees. Adjacent to the original factory hospital, **Sandhurst Hospital** [H26], a new timber-framed Y-shaped **Womens Hospital** [H25] and associated **Toilet Block** [H25a] were constructed during the war.

Some of the changes made to the physical appearance of the factory are largely unrecoverable using field and cartographic evidence. This is particularly true of the many sand-bagged air raid shelters that were built towards the end of the war. These structures are clearly visible on contemporary photographs but do not appear to have been mapped in any systematic way.

The armistice brought a rapid run-down and demobilisation of the armed forces and with it went the need for large quantities of explosives. Amongst the private sector producers of explosives it was a time of amalgamation and rationalisation, with many of the new wartime factories closing. Production at Waltham Abbey RGPF continued in the interwar period on a much-reduced scale and probably much of the plant was moth-balled or restricted to manufacturing intermittent batches. The only demolition work carried out during this period appears to have been on old gunpowder buildings; there is photographic evidence for the demolition of the **Incorporating Mills** [181] in 1936. Nevertheless some research work continued at Waltham Abbey, including the development of a new form of cordite, Cordite W. ('W.' for Waltham), developed between by H A Philips and P G Knapman. In this variant carbamite (diphenyl diethyl urea) was used a stabiliser in place of mineral jelly (Simmons 1963, 57). Production of Cordite W commenced in 1933. In the late 1920s the production of picrite began, probably on South Site although the former **Guncotton Stove No.12** [29] on North Site was converted to picrite drying. [29] is one of two **Stoves**, along with [98a], to retain metal drying racks with galvanised wire shelves.

Though Waltham Abbey RGPF was rehabilitated during the desparate rearmament programme of the late 1930s, it was realised that it could be nothing more than a stop-gap and that modern purpose-built factories were required to meet the needs of the services in wartime circumstances. The old factory was brought back into production, but little new building work took place on North Site with the exception of the **Quinan Stove** [22a] for drying guncotton. The **Quinan Stove** replaced an earlier **Guncotton Stove** of standard circular pattern with the same number, cutting through its porch area. The **Quinan Stove** brought the twin advantages of a faster drying time and safety benefits as less guncotton was in the stove at any one time. It continued to be supplied by the canal network through two loading bays at its north and south end. (For a fuller explanation of the workings of the **Quinan Stove**, see the section on the manufacture of cordite in **Appendix 1**).

Another important innovation made at the factory during the inter-war period was the 'Evans-Bowden' acid concentrator (HMSO 1938, fig. 10.5). This replaced the acid concentrator designed by Kessler in the early years of the century. The 'Evans-Bowden' concentrator had the advantage over the early system that it used home-manufactured acid-resistent bricks in its construction in place of Volvic lava and was quicker and cheaper to produce - £40 for bricks as opposed to £600 for Volvic lava (HMSO 1938, 72; Simmons 1963, 63). The design was later taken up by other government and private factories.

Within the guncotton factory on South Site research was carried out into the development of a new potcher used in the final purification of guncotton. The potchers in use until the 1930s were essentially machines based on those used in the paper industry and had remained virtually unchanged from the late 19th century. The new machines, known as the 'Bowden-

Parsons Tangential Potcher', consisted of a cylindrical tank with a conical base and central outlet. A swirl of water in the tank was achieved that allowed the water to run tangentially into the tank. As with many of the innovations made at the RGPF, the 'Bowden-Parsons Potcher' was widely used elsewhere in British explosives factories (HMSO 1938, 90 fig13.7; Simmons 1963, 45). Crucial work was also carried out on South Site into production methods for TNT and RDX, the technology then being transferred to other government and private factories. This research into TNT and RDX is more fully discussed in the history of the factory in **Section 2**.

The Second World War 1939-1945 (see Figure 5)

The outbreak of war once again led to an increased demand for explosives from Waltham Abbey RGPF. The North Site factory that entered the Second World War was essentially the factory that had been mothballed in 1919, little or no new investment having taken place during the 1930s. The pressure placed on the workforce to increase output was cited as one of the possible causes of two serious explosions that rocked the factory early in 1940. The two apparently accidental explosions occurred in **Cordite Mixing Houses** [46 and 63] and resulted in the devastation of a large number of buildings in the northern part of North Site. The destruction caused by these explosions seems to have acted as the catalyst for much of the building work carried out in the cordite factory in the latter half of 1940. The first explosion took place in **Mixing House No.5** [63] on 18 January 1940 and obliterated the building. Collateral damage spread as far as **Mixing House No.4** [76]. The **Wash Water Settling House** [E4] was badly damaged, as was the **Weighing House** [S27] and the roof was ripped off the **Tetryl Magazine** [89]; **Guncotton Stove** [74a] was destroyed and its **Engine House** [75a] and its neighbouring **Stove** [76a] were gutted. Rebuilding work was under way when this section of the factory was shaken by a second explosion as **Mixing House** [46] blew up on 20 April 1940. Collateral damage extended northwards to the **Grand Magazine** [1] and southwards to **Guncotton Stove** [96a]. The **Wash Water Settling House** [E4] that had been badly damaged in the earlier explosion was again ruined, as were the **Guncotton Weighing Houses** [S27 and S34]

The reconstruction work undertaken during the Second World War is characterised by the use of breeze block, which forms a distinctive 'type fossil' for building work carried out at this date. Although using new materials, the plans adhered to were essentially those of the turn of the century guncotton stoves and mixing houses. Work began to bring the nitroglycerine factory back into operation; the two **Mixing Houses** [46 and 63] were replaced by new **Mixing Houses** [46A and 46R]. **Mixing House No.4** [76], a former gunpowder building, had also been badly damaged and was replaced on a different site by a new building [E14]. The **Wash Water Settling House** [E4], having been destroyed twice in one year, was given a breeze-block and earthwork **Traverse** [RCHME 213] to screen it from the two new mixing houses. The old **Guncotton Weighing House** [S34] was demolished and a new building erected on its site, surrounded by a breeze-block and earthwork traverse. It is unclear whether it resumed its previous function as a **Guncotton Weighing House** or whether it was used as an additional **Mixing House**. The other **Weighing House** [53a], badly damaged in both explosions, was demolished and replaced by a new building. Similarly the **Guncotton Stove** [75] was demolished and replaced by a new circular **Guncotton Stove** [S28] to the south of the old site. **Guncotton Stove** [36] was also rebuilt, this time following a different pattern. The **Tetryl Store** [89] had its roof blown and it is likely that it was demolished shortly afterwards. Its partner [91], formerly a **Fuse Powder Store,** was demolished and replaced by a new **Tetryl Magazine** [S30] surrounded by a breeze-block and earthwork traverse and screened to the north by a linear **Traverse** [RCHME 115].

The largest positive development during the Second World War was the construction of a new nitroglycerine factory. This was begun on the recommendation of the Court of Enquiry into the explosion of April 1940. Known as New Hill, it was constructed on just over twelve hectares of farmland adjoining Cornmill Stream on the eastern side of the factory (see figure 3). Construction work probably began late in 1940 and continued into 1941. Photographs of the site taken in August 1941 (PRO Supply 5/863) show the majority of the buildings in place and surrounded by earthwork traverses, although fitting out had still to take place. The New Hill factory was built as an entirely self-sufficient unit. Along the north edge of the new perimeter was a **Transformer House** [S2] and other ancillary buildings. The intention was that the **Nitrator** [S16] should be supplied with acids from the old acid factory on the west side of North Site by means of a pipeline. This pipeline [RCHME 102] was laid across the centre of the factory, crossing the Old River Lea, canal [RCHME 289] and Cornmill Stream by bridge; the pipe, supported on stanchions, then ran from near [S3] along the earthwork hollow towards the **Charge House** [S18] on the **Nitrator**. In addition to acids, this pipeline was also intended to carry steam for heating and compressed air, and waste acids back to the acid factory for reprocessing. The **Charge House** [S18] was placed on top of the **Nitrator** mound so that the acids and other liquids could pass into the **Nitrator** by force of gravity. In it the acids, glycerine, brine for the cooling pipes and clean wash waters were stored before being let down into the **Nitrator**. If a similar arrangement was followed to that in the older nitrator [E2], then the charge house would also store all the wash waters used in the other process buildings for distribution also by gravity. From the **Nitrator** some of the less contaminated water, possibly the cooling brine, could run directly to the **Flume House** [S25] along an earthenware gutter. If wash waters were being distributed from **Nitrator**, the channel may have been used for this function. The waters used to 'wash' the nitroglycerine were channelled along a covered lead-lined gutter supported on concrete stanchions to the **Wash Water Settling House** [S23], where any remaining nitroglycerine was collected before the water was discharged. The main charge of nitroglycerine was run in a covered lead-lined gutter supported on concrete stanchions to the **Washing House** [S19]. In this building the nitroglycerine underwent further washing to remove any trace of the nitrating acids, before being again moved by gravity along a covered lead-lined gutter to the

Pouring On House [S21], i.e. **Mixing House**. The waste water from the **Washing House**, contaminated with acids and possibly small amounts of nitroglycerine, was meanwhile moved along a covered gutter to the **Wash Water Settling House** [S23]. From the **Wash Water Settling House** the 'cleaned' water was run along a half-open earthenware pipe to the **Flume House** [S25], and joined by a pipe from the **Nitrator** [S16] 8m north-east of the building. Presumably the final filtration of the waters took place in the **Flume House** before they were discharged into the Old River Lea. The nitroglycerine entry pipe from the **Washing House** [S19] was so arranged that it entered the **Pouring On House** at head height, probably to be stored in a tank before measured amounts were removed for mixing with guncotton. A light railway line was laid to bring the dried guncotton from the other side of Cornmill Stream; the resulting cordite paste was to be removed by the same method. Associated with all the main process buildings on New Hill were small **Plenum Heater Buildings**, in which steam heat was used to warm air before it was blown into the process buildings.

It is thought that this plant was still to operate on a batch system of production rather than the newer Schmid process. The Schmid process was used in a dozen plants around the world by 1937; its distinctive feature was the continuous nitration of the glycerine, which gave a number advantages during processing (War Office 1938, 84; and see **Appendix 1**). In the event, it is believed that the New Hill plant was never put into production. Information from former employees of the factory suggests that the principal reason for the failure of the factory was a problem in the flow of acid along the pipeline. Whether this was the reason is uncertain; it may simply be that events overtook the commissioning of the plant. For in September 1943, nitroglycerine production ceased at the factory (Simmons 1963, 77).

Minor changes were also made to the canal network at this date. A short cut was made to extend canal [RCHME 107] from [88a] to [76] via a concrete **Aqueduct** [RCHME 106] dated 1940, probably to link it to the new **Mixing House** [E14]. This cut through the former **Hydraulic Pump Room** of the gunpowder **Press** [76]. It was also probably at this date that the northern end of canal [RCHME 289] was blocked by corrugated sheeting and the canal filled adjacent to the new **Mixing House** [46A]. A small breeze-block shelter [RCHME 215] was constructed over the fill and has subsequently subsided into the material filling the canal. Concrete stanchions carrying steam heat to the new **Mixing House** [46A] were set across the line of the former canal. Probably, too, the **Aqueduct** [RCHME 214] had timber decking inserted into the trough to create a footbridge across the Old River Lea, but whether the remainder of canal [RCHME 289] was filled between the **Wash Houses** [E3 and E5] at this date or later is not known. When this canal was sealed a short loop was dug at the southern end of canal [RCHME 290] to serve the new **Mixing House** [46A], the entrance of which was screened by a breeze-block and earthwork traverse [RCHME 216]. Other work to the canal system in this area included the sealing of the entrance to the former wheel pit of the gunpowder **Dusting House** [RCHME 275] with corrugated iron sheeting.

Extensions were also made to the tramway system. The two branches added to the eastern tetryl factory have been described previously. A new line was also run along the western side of Cornmill Stream linking the **Grand Magazine** [1] and the **Wet Guncotton Magazine** [2A] to the **Guncotton Weighing Houses** [S27 and S34]. A branch was laid to **Guncotton Stove** [23] and a line laid across Cornmill Stream to supply the new **Mixing House** [S21] on New Hill.

Additions were made to the acid factory during the Second World War. The majority of the building erected had a relatively limited lifespan and no records have been located to define their use. For example, at the southern end of the factory are three large concrete floor slabs [H87, RCHME 192 and RCHME 193]; opposite them is the Second World War **Air Raid Shelter** [ARS2] and adjacent to it another floor slab [RCHME 194]. North of the floor slabs and still surviving, the **Nitroglycerine Nitrating Engine House** [83b] also was constructed during the early part of the war. At the northern end of the acid factory a **Refrigeration House** [E9] was built for the **Nitrator** [E2]. To the east of the factory the **Changing Rooms** [E12] were probably also built at this time. Other minor buildings added the density rather than the extent of the acid factory.

As described in the earlier section on high explosives, Waltham Abbey RGPF remained the sole supplier of tetryl to the services until 1942. Most of this production was carried out in old and dilapidated plant dating back to the First World War and before; the additions made during the Second World War have been described in the discussion of the eastern tetryl factory.

Other new structures reflected the conditions of war and the threat of aerial bombardment. They included a number of new concrete air raid shelters dotted around the factory; the five with surviving superstructures are, from north to south, [ARS1], [ARS2], [L115], [L150] and [H15]. A further two shelters, [L104] close to the burning ground and [L163] adjacent to the old **Gas Works** [RCHME 333], have been demolished. Few active anti-aircraft measures seem to have been put in place at the factory during the war. The only features visible on the early post-war aerial photographs of the site are two small octagonal structures, [RCHME 335] to the north of the **Grand Magazine** [1] and [RCHME 343] east of the **Senior Officers Quarters** [A221]. An Allan-Williams steel turret pillbox [RCHME 334] is reported to have survived close to the **Grand Magazine** [1] into the 1970s (Wills 1985, 85). The western side of the site was defended by a line of pillboxes west of Horsemill Stream, all but one of which have been removed. South Site was similarly defended by pillboxes pushed away from the perimeter, and internal communications were controlled by a number of small observation posts. Active anti-aircraft defence for the RGPF was subsumed within a wider scheme to protect the north-eastern approach to London by large anti-aircraft artillery parks, which were located some distance from the factory (pers. comm. F Nash).

Explosives production ceased at Waltham Abbey RGPF in 1943 (Simmons 1963, 77) in favour of newer factories constructed during the late 1930s and early war years in the west of the country at the extreme range of bombers flying from the continent. Many of the staff from Waltham Abbey transferred to the new propellant works at Bishopton in Renfrewshire. Though decommissioned, most of the buildings of the cordite factory survived as roofed structures into the 1960s. It is not known how much of the plant was removed for use elsewhere, or how much went for scrap, as the majority of the machinery was of First World War vintage or earlier with the exception of the New Hill factory.

Infrastructure: power, transport, safety

Power Networks: Muscle

Muscle power, both animal and human, played a small but significant part in the manufacture of gunpowder throughout the history of the factory. As with many early developments within the factory, Farmer's engraving of 1735 (Fig. 15)) is the first reliable evidence of the early use of animal power. It clearly marks three horse mills (3, 4 and 5) along with a stables roughly beneath the present **Lecture Theatre** [A203]. During construction work in December 1963 two circular brick bases were uncovered and it was presumed that they represented the remains of the horsemills [226 and 227]. In 1783 (WASC 900/1) they were mapped in use as a charcoal mill and composition house. This, coupled with the fact that the gunpowder incorporating mills were all water-powered, may suggest that horse power was as a general rule only used in the initial pulverising and mixing of the ingredients. The use of horse mills for grinding the ingredients was also a feature of the Royal Gunpowder Works at Faversham, where a 1796 manual shows a horse mill in use for grinding saltpetre (Crocker 1986, 14). A further horse mill [RCHME 321] was shown by Farmer beneath the present administrative buildings [A232]; unfortunately there is no evidence to suggest what this mill was used for.

By the end of the 18th century a horse-powered **Corning House** was in operation on Horsemill Island (formerly west of Area H). This mill exploded in 1801 with the loss of nine lives and four horses (Winters 1887, 57); it apparently was never rebuilt. Use of horse power at the RGPF reached its peak during the early years of the 19th century. During that period nine horse-powered incorporating mills and a purpose-built stable block [RCHME 317] were constructed on Horsemill Island, and illustrated by an engraving in Hughsons *Description of London* 1808. Horse were also used to power two **Corning Houses** [76 and 103]. Though the need for increased capacity at the factory was clearly dictated by the demands of the Napoleonic Wars, the reasons for the use of horse in preference to water power are unclear. It may in part have been financial, as horse mills require less gearing and no water engineering works. Horse mills also had the advantage of placing no additional demands on the water supply within the factory network. Some if not all of the horse-powered incorporating mills used iron beds and runners. The horses were also equipped with a special harness with bells on and as they passed round they struck a small bell so that the heads of the factory department could be certain that their work was regular and at the correct speed (Winters 1887, 62-3).

Though the country was still at war with France, it was ordered in 1814 that water power should be used instead of horse power (Smith 1870, 7). This would coincide with the construction of two new water-powered **Incorporating Mills** [181 and 183] on Millhead in 1814. Also in that year preparations were in hand to convert the former **Stables** [RCHME 317] on Horsemill Island into a **Sulphur Store**. The horse-powered **Corning Houses** [76 and 103] survived until 1819, when they were sold to Mr Philpot of Stanford-street (Winters 1887, 86). At the same time the **Stables** for contract horses south of **Newton's Pool** was demolished. Though the initial capital investment in water-powered mills was probably greater than for a horsemill, they had the advantage over horses in that in periods of slack demand that there was not the continuing feed bill incurred even if the horses were idle. By the 1820s horse power had been entirely displaced by water power for incorporating gunpowder and subsequent processing. Horse power may nevertheless have remained in use for the initial grinding of charcoal and sulphur, for mill [226] was still described as a **Saltpetre Mill** and [227] as a **Charcoal Mill** in 1830 (WO55/2694), neither building having any other obvious power source.

Human muscle power was used to a limited extent in the processing of gunpowder and was increasingly replaced by other sources of power. As in most early industry it was muscle power that moved and lifted the materials between processes, the weights generally not being too large. Charge sizes were restricted to forty pounds and later fifty pounds within the danger buildings by law. Muscle power was also used to turn the early screw presses introduced soon after the government took over the factory. These were later replaced by various forms of hydraulic press that were both safer and able to exert far greater pressures. It also appears that men were employed to haul or punt the powder boats around the factory. In the few historic photographs of the barges no horses are in evidence, and within the ledgers from the mid 19th century onwards no references are found to stables. Men and boys were also employed to push the tramway powder wagons between the various process buildings (Arkas 1900, 416). Manpower was sufficient to move these wagons around and remained in use until the First World War, when the longer and more frequent trains carrying guncotton and cordite, and the extended link to South Site, required the introduction of other motive power.

Power networks: Water

The ready availability of water power on the site was probably the principal reason why the gunpowder mills were established at Waltham Abbey. As described in the early history of the factory, the early gunpowder works were set up in a former fulling mill, converted to an oil mill in the 17th century before it became a gunpowder mill. This mill may be identified as the one shown at the head of Millhead Stream in 1590 (ERO T/M 125).

The artificial leat of Millhead Stream extended around 1.8km in length along the west side of the site. The leat took its water from an inlet just north of the **Grand Magazine** [1] and from two inlets to the north and south of Payne's Island, on which the **Grand Magazine** was located. The ground fall between the north of Payne's Island and Highbridge Street at the southern end of the site is around 2 metres, between 21m OD and 19m OD. This corresponds well with the 6 foot head of water that John Smeaton described as being available in the late 18th century (Wilson 1955, 41). It can be independently verified by measuring the height difference between the former water level in the cast-iron aqueducts of the upper-level water system and the Old River Lea. In the simplest terms, the water system within North Site appears to have operated on two levels, termed here the higher and the lower. The high-level system was fed by the two artificial channels raised in earthwork embankments. Millhead Stream was carried down the west side of the factory in an earthwork embankment, which is clearly depicted on the 1897 Ordnance Survey 25" map sheet, Essex XLIX.14. The embankment has largely been buried by later accretions or removed during the widening of Horsemill Stream. That is except for the section south of the **Radio Chemistry Laboratory** [L128], where it survives as an earthwork. The similar artificial leat of Cornmill Stream powered the cornmill adjacent to Waltham Abbey Church. This, too, was raised in an earthwork embankment and in part terraced into the rising ground to the east. Cornmill Stream was at the same height as Millhead Stream, but not apparently until the 1850s was it used to power any gunpowder processing building, when the **Granulating House** [S34] was constructed on the north side of **Newton's Pool**. Water controlled by sluice gates was directed into the low-level water system within North Site at two points, at **Newton's Pool** [RCHME 276] and adjacent to the **Water Wardens Cottage** [L102].

The densest concentration of water-powered mills lay at the southern end of Millhead Stream close to the site of the original fulling mill. In Farmer's print of 1735 (Fig. 15) there are four water powered mills, two of them stamp mills and two mills that are thought to have been driven by a central wheel powering mills with edge runners. At the height of the Napoleonic Wars the number of **Incorporating Mills** at the southern end of Millhead rose to nine and a **Dusting House** [159], also powered by a central wheel, had been added to their north. Water was also taken off the east side of Millhead Stream further north to power two **Corning Houses** [97 and 116]. Further demands were made on the water supply within Millhead Stream when the **Dusting House** [84] and **Granulating House** [AF4] were added later in the century, though by this date a number of the early **Incorporating Mills** had been demolished.

The high-level water system was extended between 1801 and 1806 when canals [RCHME 291 and RCHME 294] were cut to convey powder to the horse-powered **Corning Houses** [76 and 103/104]. At this date they were evidently dug to act as a communications link rather than a power source, that was provided by the horses. However, when these buildings were converted into **Hydraulic Gunpowder Presses**, probably in the early 1850s, the head of water in the canals was used to power water-driven hydraulic pumps. Probably also at this date canal [RCHME 288] was dug to provide a more direct link and more reliable water supply from Millhead Stream to [76].

The expansion of the factory in 1878 was accompanied by a corresponding growth in the high-level canal system in the northern part of the factory. Again the emphasis was on communication, but the potential for power was exploited, too. The expanded network provided a link from canal [RCHME 294] southwards along canal [RCHME 179] to the lower-level system through canal **Lock** [RCHME 225]. Along this section of canal the only building that may have been powered by water was [L109], although unfortunately its early use is unknown. Another high level canal [RCHME 289] was taken off canal [RCHME 294] northwards and was carried over the Old River Lea at two points in cast-iron **Aqueducts** [RCHME 112 and RCHME 214]. In addition to providing access to the **Press House** [S31] and the **Steam Stove** [S90], it also provided a head of water to turn the central wheel of **Dusting House** [RCHME 275]. This system was further expanded around the turn of the century to supply the guncotton stoves at the northern end of the site by barge. About the time of the First World War a short diversion [RCHME 290] was constructed around the Edmonsey nitroglycerine factory; it was carried over the Old River Lea by a composite cast-iron and steel girder **Aqueduct** [RCHME 256].

To achieve the necessary fall to power the various water wheels it was necessary to have a lower-level water system to carry the used water away. The water in this system was at the same level as the water in the Old River Lea and fell gently from north to south. The only connection between the river and the low level system within the factory appears to have been below bridge [RCHME 230]. Here the tailrace from the **Corning House** [97] joined with the river, although below the bridge are slots in which boards could be placed to seal the tailrace. The low-level leat system within the factory also acted to drain the site as much of it lies close to the water table and is still prone to flooding during periods of exceptional rainfall. The southern part of the low-level system was also used as part of the canal network, but until 1878 when **Lock** [RCHME 226] was constructed there was no direct link between the two systems.

The low-level system of the northern part of the factory in turn provided the motive power for the mills on Lower Island (see figures 4, 5). Water was brought along a central canal, that also acted as the head leat; this tipped to the west and east into lower level tailraces. The tailrace to the west was created by a tumbling bay at its northern end. The southern end of the central canal was at first controlled by a sluice house and later a lock was added. To the south-east of the southern end of Lower Island there was a lock on the River Lea Navigation where it dropped to the level of the water in the tailraces. The lower level within the Lower Island area was at the same level as Cobbins Brook that entered from the east and the same level as the canal system laid out for the southern part of the RGPF, ie South Site.

Power networks: Steam

Prior to the construction of the first steam-driven gunpowder incorporating mills in 1856, steam-raising facilities had only existed to dry gunpowder in **Steam Drying Stove** [RCHME 330]. The use of steam power at gunpowder factories elsewhere in Britain was by this date fairly well established. As early as 1806 a Boulton and Watt steam engine was under construction for the Seddlecombe gunpowder works (Crocker 1988, 27). Du Pont writing in 1858 described four steam engines in use at the Dartford Works of Pigou and Wilks, although there they were held in reserve against low water levels. At the Kames Powder Company in Scotland, which he visited at the same time, steam was one of the prime movers along with water power (Wilkinson 1975a, 11, 21). Unfortunately no material is readily available that describes the detailed operation of any of these mills.

The first steam-powered gunpowder mills at Waltham Abbey RGPF were the Group A Mills [L168, L169 and L176], whose foundation stone was laid on 1 March 1856 in the closing month of the Crimean War. The Group A Mills were originally designed with the beam engine house [L169] placed in its present position but with the six mills placed side by side, separated by partition walls (see drwg. L169/6) and powered by two underfloor drive shafts. An similar arrangement for the transmission of power was employed by Shirley's bone mill in Stoke-on-Trent, also constructed in 1856. In this mill a single gear wheel attached to the flywheel of the beam engine drove two parallel drive shafts in a groundfloor shaft room with a pan room above, which housed the grinding pans (Green et al 1986, 57-70). The use of horizontal drive shafts within the basements of textile mills had been used to a limited extent from the early years of the century in an attempt to mitigate the effects of accidental fire (Falconer 1993, 21-3). The executed plan of the Group A Mills (drwg. L169/2), carried out under the supervision of I Randel as Clerk of Works, however, had a single drive shaft with the mills ranged in a line above the shaft. Captain Smith, Assistant Superintendent, commented that this is 'an objectionable arrangement' (1870, 40) but did not elaborate why. The incorporating mills were each housed in a trapezoidal-shaped bay, each bay facing in the opposite direction to its neighbour. The builder's drawings for the Group A Mills also rarely furnish some detail about the engines they intended to use; the earlier drawing (drwg. L169/6) was annotated 'thirty horse condensing engine', while the second plan (L169/2) described the motive power as a 'thirty horse power compound engine'. In 1861 the Group A mills were rocked by a fearful explosion, in which four out of the six bays were destroyed. The cause of was thought to be the neglect of safety procedures by workmen in not placing hide leathers beneath the runners in one of the mill bays when they were removing them for maintenance, rather than an inherent design fault within the mills (*ILN* 1861, 537).

The Group B mills [387] were constructed in 1859 at the northern end of the Lower Island Works. Their elongated plan was dictated by the confined site that was chosen for their construction. The mills followed the early pattern of the later steam-driven mills on North Site, with a central engine house and two incorporating mills to either side within parallel sided bays; the **Boiler House** [385] for the mills was detached northwards. This group may be those that are described as a 'group of iron mills driven by water power with an auxiliary steam engine' (Smith 1870, 40). Such an interpretation is also borne out by the cartographic evidence (WASC 900/42 1888), which shows a tailrace emerging from the centre of the mills, as they are positioned between higher and lower watercourses.

The preferred plan form for the steam-driven mills was to become the T-shaped mill built of a buff coloured brick with red brick details. The earliest examples of these T-shaped mills, [L157] built in 1861 and [L153] built in 1867, were originally constructed with two pairs of incorporating mills either side of the central engine house (Smith 1870, 40); this was only later increased to three either side. The change is graphically illustrated on the original plan of [L157], where a piece of paper has simply been stuck to the drawing to add the extra bay. In the rear of the mill was a boiler house with a pair of Lancashire boilers covered by a roof supported by wrought iron tension rods, king rods with decorative cast-iron compression members, and cast-iron ventilators. Adjacent to the boiler house was a tall brick chimney 75' (22.86m) in height surrounded by a walled coalyard. In the centre of the incorporating mill was the engine house. This was a two-storey structure, originally open to the roof in order to house a beam engine. It is not known if beam engines were used in all of the mills or if, by 1889 when the last group [L148] was constructed, a horizontal engine was employed. The original drawing of the last group (drwg. L148/4) shows a similar open two-storey structure. If the engine house was not built to accommodate a beam engine, the sole reason for such a design must have been to maintain the outward architectural harmony of the group.

The beam engines were mounted on stone blocks supported by brick piers over a concrete foundation. The floor around the engine, probably a cast-iron grill, was supported by cast-iron floor beams. Either side of the engine mainly below floor level was a segmental cast-iron flywheel connected to the below-ground drive shafts on either side of the engine house. Each drive shafts powered three incorporating mills. The drive shaft was contained in an underground tunnel termed the 'shaft alley'. In all of the mills investigated and from drawing of [L148] and [L168] the shaft alley was constructed from cast-iron plates: the only exception to this rule was [L153], where the shaft alley was a vaulted brick tunnel. [L153] also differs from the others in the group in that the drive shaft was slung low down in the tunnel: in the other mills the drive shaft was supported on bearing arms at shoulder height. Beneath each of the mills the alley widens out into a circular chamber, in which was a cast-iron shoulder supporting a large gear wheel. The drive shaft was connected to this wheel by a friction clutch attached to a small pinion wheel. This was controlled by means of a rod that passed up through the alley roof to the outside platform of the building, where it was activated by a wheel that can be seen in an illustration in the *Strand Magazine* (Fitzgerald 1895, photo 8). Above each chamber was an incorporating mill. Each mill consisted of a circular iron bed on which turned two vertically mounted cast-iron runners between three and a half and four tons in weight, each set at a different distance from the central vertical turning shaft. This ensured that all parts of the pan were covered by the edge runners. The powder within the pan was also constantly turned by a pair of ploughs located between the runners. The amount of powder beneath any pair of mill wheels was restricted to fifty pounds by act of parliament (Victoria 1860, ch139), and it remained under the runners for between three and five hours. Over the period of one year it was calculated that a pair of steam-driven mill wheels would produce a third more powder than an equivalent pair of stone wheels driven by water power (Smith 1870, 41).

The incorporating mills for reasons of safety were each accommodated in an individual bay separated from their neighbour by a brick partition wall in English bond. The open sides of the bay were filled by a light timber boarding over an iron frame. The roof was of a similar light iron frame construction braced by wrought iron tension rods. The design was to ensure that the force of any accidental explosion would be carried to the front and the rear rather than to the neighbouring mill. Other safety features included in the design were a copper drenching tub above the mill, which would dowse it in water in the event of an explosion. Artificial lighting was provided by a lantern set into the wall of the building, with any maintenance of the light carried out from the exterior. In the base of the lantern a layer of water was constantly maintained. It is uncertain from the drawings whether oil or gas lamps were used; electric lighting was certainly in use in a number of the danger buildings by the 1880s. The remainder of the steam-driven mills followed the T-shaped pattern, and the last of the seven steam mills built in 1888 gave Waltham Abbey RGPF a total of forty individual mills powered by steam.

As noted above, the use of steam power at Waltham Abbey RGPF was not particularly early. It is, however, the size and the architectural pretension of the gunpowder **Incorporating mills** and the scale on which he technology was applied at Waltham Abbey that sets these mills apart from all the other powder manufacturers in Great Britain. In England their closest parallel postdates them by almost three decades. That was the single row of six bays constructed in 1885 for the Chilworth Gunpowder Company in Surrey (Crocker 1884, 15). Those mills, however, lacked the architectural brick styling of the Waltham Mills and were constructed simply in utilitarian mass concrete. Though the design of the steam-driven mills failed to make an immediate impact on the design of gunpowder mills in England, in America their design was apparently closely followed by the steam incorporating mills built at the Confederate Powder Works at Augusta in Georgia around 1861 (Rains 1882, 18-19). These mills were demolished in 1880 to make way for a cotton mill, but parts may survive as archaeological remains (pers. comm. M Newell, University of Carolina). The design of the individual opposed trapezoidal bays in which the incorporating mills stood, like the Group A mills, was copied in 1858 at the New Sedgwick works in the Lake District, however. But in that example the mills were driven by an underfloor shaft powered by a water wheel (pers. comm. Professor Alan Crocker). While the mills at Waltham Abbey RGPF and New

Sedgwick are the only known examples of trapezoidal-shaped incorporating mills, the shape was used in other danger buildings in the industry, for example the corning house at the Lowwood works in the Lake District.

Steam power was apparently not extended to all the other aspects of the gunpowder processing right through to the end of production. It was applied to the generation of hydraulic power used in the processing of pressed gunpowders, however. The steam-raising facilities in **Incorporating Mill** [L149] were used to maintain the pressure in the weight-loaded accumulator at the front of the building. Also when the **Power House** [A210] was constructed, its steam-raising facilities were employed to power the engine adjacent to the weight-loaded accumulator [A214]. The use of hydraulic power is more fully discussed below. Steam was also used in generating electricity, in the late 19th century perhaps powering dynamos attached to existing steam engines and later in the purpose-built **Power House** [A210]. The generation and use of electricity is also discussed more fully below.

Steam power was probably also used in the early guncotton factory located in the former saltpetre processing building by the Highbridge Street gate. Though there is little direct evidence for the power source, steam appears to be the only viable option. Within the processing building, power was required for the mechanical teaser, beaters and potchers, which all needed a rotative movement that could conveniently be supplied by an overhead drive shaft and belts. A disused **Boiler House** [294] on Highbridge Street on the east bank of Millhead Stream is described in the 1908 ledger, and it probably produced the steam for the engines in the buildings.

Steam heat was another requirement of the guncotton factory. This was secondary product, however, Younghusband describing the steam for heating as 'waste steam from the boiler house' (Younghusband 1873, 1).

Steam power in the former gunpowder **Incorporating Mills** probably lingered on for the first decade after their conversion to **Cordite Incorporating Mills and Presses**, with the steam engines harnessed to the overhead drive shafts as opposed to the underfloor drive shaft. Around 1908 (WASC 1509, 1908, 17) the boilers were removed from mills [L145, L148, L153 and L157]. The boilers were retained in [L149], however, as they were needed to work the engine in association with the weight-loaded hydraulic accumulator and in [L176], where they provided power for the beam engine in [L168] that powered the adjacent machinery shop. It is presumed that where steam power was removed it was replaced by electric motors.

Power Networks: Hydraulic

The purpose of this section is to draw together the evidence for the use of hydraulic power at Waltham Abbey RGPF and discuss its development. Hydraulic power may be defined as 'a system for transmitting energy through the medium of water or other incompressible fluid'. Those machines worked through the pressure of the water as opposed to the motion of water are more correctly hydrostatic machines (Jarvis 1985, 3). Before the invention of the hydraulic press by Bramah, patented in 1795, the only press available was the screw press capable of exerting a load of no more than 20 or 25 tons (McNeil 1972, 23-34). The use of a hand-driven hydraulic press allowed far greater pressures to bear on materials within a press, acting on the principle that a small force acting on a piston of small area over a long travel will create a large force on a piston of large area over a short travel (Jarvis 1985, 2).

Screw presses had increasingly been used throughout the 18th century to increase the density of gunpowder before granulation. There was a screw press at the RGPF at Faversham by 1762, which was still in operation in 1798 (Hodgetts 1909, fig.13). A screw press was installed at Waltham Abbey RGPF when the mills were bought by the government in 1787 (West 1991, 171), probably installed in building [97, 98]. A new **Press House** [395, 396, 397] was constructed at Waltham Abbey in the new Lower Island Works between 1801 and 1806. Although hand-operated Bramah hydraulic presses were employed elsewhere at this date for 'throwing of light articles into small bulk', e.g. baling or for expressing vegetable oils (McNeil 1972, 34), it appears that screw presses were installed. However, after a devastating explosion in a press house at Waltham Abbey in 1811, Sir William Congreve substituted a Bramah press for the screw press formerly in use (Hodgetts 1909, 320). Confirmation of the use of Bramah hand-powered hydraulic presses is provided in Drayson's treatise of 1830 (Supply 5/762, drwg.17). In his report, which seems to have been largely ignored by the Board of Ordnance, he recommended that screw presses be introduced instead of Bramah's hydraulic presses. He gave no reason for the recommendation, which ignored the advantage of Bramah presses that they could be worked remotely from behind a traverse. The Bramah presses survived at least into the 1850s, when the building was described as 'containing two hydraulic presses' in the 1851 factory ledger (WO55/3027). Screw presses remained in use until the 1840s when the last one was destroyed in an explosion in 1843 (Winters 1887, 106); this press was probably the housed in building [97, 98] along Millhead Stream.

The introduction to Waltham Abbey RGPF of hydraulic pumps powered by water also appears to have lagged behind their use elsewhere. It is suggested on the basis of cartographic evidence that water-powered hydraulic pumps may have been in use at the Oare Gunpowder Works at Faversham as early as 1844 (RCHME 1991, 19). The water-driven hydraulic presses at Waltham Abbey were certainly in use by 1854, when they were briefly described in a journal article (*ILN* 1854, 478). The two new **Press Houses** [76 and 103,104] were constructed reusing the traverses from two disused horse corning mills. Each of these buildings lay at the end of a high-level canal and was able to make use of the six-foot head of water in the canal system. In the **Press and Pump House** [103,104] much of the machinery survives intact, but the superstructure and internal fittings were lost when the building was fired. A low breast-shot water wheel powered a hydraulic pump, which in turn supplied hydraulic power to the press at up to 70 tons per square foot in the adjacent building screened from it by a brick traverse. The pump could also be operated manually if required (Baddeley 1857, 15). Smith (1870, 44-9) and Guttman (1895, 206-10) both give detailed contemporary descriptions of the pressing process. Before the Second World War an electric pump was placed in the former shoe room at the west end of the **Pump House** to provide a supplementary power supply. **Press House** [76] remained in operation until around 1898, when the building was converted into a cordite **Mixing House**; the other **Gunpowder Press and Pump House** [103, 104] remained intact, although out of use and in a derelict condition by 1940.

By 1850 the industrialist William Armstrong had developed the weight-loaded hydraulic accumulator. In this system water was pumped into a cylinder by a steam engine; the water in the cylinder acted on by a ram with a yoke and weight bin attached to it. Such a system had the advantages of providing a power source independent from the needs of a water-powered pump; it also provided a constant supply of water at high pressure (potentially over 600psi) and effectively stored power against demand (Richie-Noakes 1984, 123). It had the added advantage over water-driven pumps that it able to deliver a far more constant pressure compared to the cyclical variation produced by pumps. The first weight-loaded accumulator was installed at Waltham Abbey RGPF in 1869 in building [L149]. This consisted of a boiler house, engine house, accumulator tower, chimney and coalyard and was described as the **Pellet Powder Building**. No press room was shown on the original plan and it is presumed that the press lay elsewhere.

The full advantages that could be gained from a hydraulic system, although in common use in docks by this date, were not exploited for another decade at the RGPF. A hydraulic system offered factory engineers a system whereby power could be moved around to locations free from mechanical linkages and a means of moving power with little transmission loss except friction between the fluid and pipe sides. It also offered explosives makers a safe power source that was in itself free from the risk of initiating an explosion. During the remodelling of the factory in 1878 the **Pellet Powder Building** was reconstructed and converted into an **Gunpowder Incorporating Mill**, but the engine and weight-loaded accumulator were retained to power a wider network of hydraulic machines. To cope with the increased demands on the system, a receiver or **Remote Accumulator** [L136] was added; this acted as a storage device and a means of regulating and maintaining pressure within the system.

The centralised hydraulic system was probably introduced along with other developments in the late 1870s within the factory to meet the demand for the moulded powders required for the increasingly larger guns coming into service at this date (Wardell 1888, 61-2; see also Guttman 1895, 247-59). It does not appear to have been used for the initial pressing of powder, although it may have supplied power to **Press House** [S31], built in 1879 and converted to a **Moulding House** by the 1880s. It has been suggested (pers. comm. T Smith) that the two rivetted iron stanchions in front of the building may have formed part of a small weight-loaded accumulator. This need not preclude the provision of hydraulic power from the central system, since the small accumulator might act as a power store or regulator within the system. If it was part of a free-standing system it would have required its own engine house to power the pumps to maintain the pressure within the system, but no engine houses are shown on any historic maps of the area and it is unlikely that an engine would have been situated in the neighbourhood of a **Press House**, which was recognised as one of the most dangerous processes. The other **Moulding Houses** built around this date were [107, 108] and [L130]. **Moulding Houses** [107, 108] would have required around 300 metres of pipe to link it to the **Remote Accumulator** [L136], while [S31] would have required 400 metres; the **Remote Accumulator** was itself 150 metres away from the **Weight Loaded Accumulator** in [L149]. One reason for siting the **Guncotton Press House** [L137] close to [L149] was probably to take advantage of the readily available hydraulic power needed for the pressing of guncotton into cylinders.

Hydraulic power was also required in the manufacture of cordite, where it was used to squeeze the incorporated paste into the distinctive strands that gave the substance its name. It was applied to loading the cylinder in which the cordite paste was placed and to squeezing it through a die of the required diameter. Three different types of presses were used for this process, a screw press, a combined screw and hydraulic press, and a hydraulic press. At Waltham Abbey RGPF it was found that the mains pressure supplied by the East London Water Company at 135 lbs. per square inch was sufficient to power the presses (Anderson 1898, 81). A pumping station was conveniently situated on the opposite bank of the River Lea to the Quinton Hill Factory on South Site at TL 3753 0031.

It appears, however, that the increased demands placed on the system on North Site with the construction of new **Cordite Press Houses** during the First World War were beyond the capacity of the existing system. By this date the original system was nearly forty years old and may have been suffering from faults experienced by other systems, including underground leaks and power loss through scale build up in the pipes. To supplement the old system a new **Weight Loaded Accumulator and Engine House** [A214] was constructed adjacent to the **Power House** [A210]. The hydraulic system presumably remained in use until the end of explosives production in 1945. After the war the accumulator in [L149] was removed and the tower floored to create offices. The **Remote Accumulator Tower** [L136] was similarly floored over and converted to office accommodation. The later **Accumulator and Engine House** [A210] was stripped out in the 1950s and converted into toilets and wash rooms.

Power Networks: Gas and Electricity

The **Gas Works** [RCHME 333], established between 1850 and 1870, were placed adjacent to the **Charcoal Cylinder House** at the eastern extremity of North Site in Area L. The **Gas Works** may have been placed here to take advantage of the wood gas produced as a by-product of the burning of charcoal in closed cylinders. Equally it may have been placed here to share the canal link [RCHME 278] with the **Cylinder House**. To the north of the **Gas Works** were by two gasometers, a third was added by 1897. Gas was produced on the site until 1905 (Simmons 1963, 62), when presumably use was made of the town gas supplies. The **Gas Works** was still identified on the 1923 map (WASC 900/84), but perhaps referring only to the three gasometers. No direct evidence has been found of the purposes the gas was used for but presumably solely for lighting buildings and roads within the factory.

Electric lighting for the factory was probably introduced in the 1880s, for in 1885 Colonel Watkin had invented a lamp containing an electric bulb suitable for use near the danger buildings (Jenkin 1891, 372). The arrangements for lighting the danger buildings are described in a paper published in 1891 (Jenkin 1891, 367-79). The light bulbs were enclosed in glass globes, the bottom of which was filled with a layer of water, with a small amount of glycerine added to prevent freezing. This was a tried and trusted system for containing lights and had been employed at Waltham Abbey RGPF at least since the 1850s for oil lights (*ILN* 1854, 478). A similar system was also employed to light the magazine rooms on board warships. Great care was also taken to case all the wires in wrought iron steam pipes and to have the switches and fuse boxes at a safe distance from the buildings, judged to be fifty yards. The novelty of using electric lighting at this date is perhaps reflected in the precautions of placing the electric lamps on posts away from the buildings. This seems to differ from the earlier practice of setting an enclosed lamp in the wall of a danger building, with provision for the servicing of the lamp to be carried out from the outside. A contemporary drawing of the arrangements in one of the **Incorporating Mills** [L148], built in 1889, shows such a copper lamp with a small chimney, presumably indicating the use of oil or gas. A similar arrangement was later adopted for the danger buildings and survives in part on the exterior of the **Press House and Pump House** [103 and 104]. On this building a small-bore wrought iron pipe was attached to the exterior of the building at window height, and over the west window of the **Pump House** [104] the top of a lamp survived that lit the building from the outside. Amongst the demolition debris of the **Press House** was a danger building light similar to that illustrated by Jenkin (1891, fig. 6) and odd fragments of the glass globe that enclosed the bulb. On South Site the **Washing House** [483] constructed in 1894 retains most of its original electrical fittings. Electricity was supplied along overhead lines by wires fixed to Cordeaux-type insulators (Pope 1973, 372), the wires connecting to a wooden pole with a cast-iron switch box. From the switch box the wires were led inside wrought iron pipes around the roof of the building to three lamps set inside glass globes, the glass enclosed in chicken wire. This method of lighting danger buildings continued into the 20th century, so that around many of the structures built or refurbished during the Second World War are the remains of 'Maxlume' lamp boxes. These consist of a green enamelled metal lamp case with a white interior; one side was open where it was fixed to a glass pane on the exterior of the building thereby illuminating the interior of the building. The bulb was changed by means of a hinged door on the rear of the lamp case. Wires between the lamps were encased in small-bore iron pipes. A complete lighting circuit remains in place on the former **Mixing House** [486] on South Site with 'Maxlume' lamp boxes and encased pipes. On North Site the **Mixing House** [88a] retains its lighting to three windows, where the earlier window opening are blocked by wooden boarding and the interior is lit by white-washed windows with 'Maxlume' light boxes fixed to the exterior and covered by a blackout cloth.

Though it is reasonably certain that electric lighting was in use by the late 1880s at the RGPF and that it was generated by a number of dynamos (Winters 1887, 131), it is less certain where these dynamos were located. A likely place would be next to one of the existing steam engines on the site. The annotation of 'Electric Machine House' next to the **Boiler House** of [L148] offers the only documented evidence in the 1880s. The factory ledger of 1908, too, offers a little evidence to solve this problem; only two buildings on North Site have suggestive names, an **Electric Accumulator House** [140] adjacent to the **Laboratory** [L122], and amongst the Group A buildings the building abutting the **Boiler House** [L176] is described as a **Switch Board House** [L177] and one of the rooms in building [L168] with a beam engine is described as a motor room. A further possibility is that electricity was supplied for a time from the South Site **Power House** [410] constructed in 1905. The erection of the main **Power House** [A210] on North Site may be dated between 1908 and 1915. Though the building drawings are dated 1915, a contemporary photograph of the interior (Supply 5/861, no.237) showing three generators by Bruce Peebles & Co Ltd is dated 1908. This may also be supported by the demolition of the **Cordite Incorporating Mills** chimneys, which may imply that they were converted to another mode of power supply at this date. Drawings accompanying the 1902 explosion report (Nathan 1902) show electric lighting in use through the **Cordite Incorporating House** [L148]. Hodgetts (1909, 323) in his description of the factory states that electrical power was almost universally employed and that the factory was lighted from the same source. He described the central power generating station as housing three 200 K.W. generators and three smaller ones with a boiler house containing fifteen Lancashire boilers measuring thirty feet by eight feet at 100 lbs pressure. It is unclear if he is describing the power house on North Site as he goes on to say that the boilers were also used for supplying steam to the guncotton factory. It is also uncertain at what voltage electricity was operating or whether the whole factory operated at the same voltage. Amongst the objects from the factory at the Epping Forest District Museum is a 'Stella' light bulb rated at 110v (WASC 39).

Also of interest in the history of power supply within the factory is the **Transformer House** [S2] on New Hill, since that retains its transformer equipment dating to 1941.

Electricity was moved around the site by overhead transmission lines. The poles for supporting these lines survive as intermittent runs in the northern part of North Site, but many were unfortunately removed immediately prior to the RCHME survey. The widespread adoption of electric power for lighting may have occurred with the conversion of many of the former gunpowder buildings to cordite production in the late 1890s. Dating evidence for the introduction of the overhead transmission lines includes dates carved into the poles; the earliest date seen was 1892 near the **Press House** [S31]. These dates may only be regarded as a *terminus post quem*, however, as dates of 1897 were seen on poles erected to supply the **Guncotton Stoves** built around 1910 along Cornmill Stream. Dating evidence also exists in the pottery insulators themselves; Cordeaux-type insulators bearing the War Office broad arrow were seen with dates between 1897 and 1917, with large numbers dated between 1914 and 1917. A major refurbishment of the overhead transmission lines took place early in the Second World War using smaller brown insulators of the Sinclair-Aitken type (Pope 1973, 373) dated 1940 and 1941 and larger white insulators with dates from the late 1930s. Electricity, certainly by the First World War, had become the prime mover on the site along with hydraulic power. It additionally provided all the lighting needs of the factory.

The possibility also exists that some of the lines carried telegraph or telephone wires; indeed where multiple insulator brackets are present both types of wires could have been carried. In other instances their use for transmission of electricity can be confirmed through the presence of cast-iron junction and fuse boxes. The willingness to adopt new devices is illustrated by the record of a telephone conversation between the superintendent of the RGPF at Waltham Abbey and the Director General of Ordnance Factories at Woolwich as early as February 1891 (Simmons 1963, 48).

Finally, stored electrical power in the form of batteries was used in the factory from the 1880s, when the superintendent, Colonel Noble, launched a small electric boat named the 'Spark'. The barge was both electrically powered and carried lights to light inaccessible powder buildings not connected to the dynamos (Winters 1887, 130-1). Provision for storage of batteries was made by the conversion of [A234] into a **Battery Store**. Battery power is again in evidence from the First World War when a number of battery-powered narrow gauge railway engines were introduced (Jenkins 1989, 405-10). Charging was done in the **Locomotive Shed** [H13], which retains a notice from this date giving advice about the treatment of electric shocks.

Transport: the tramways

Descriptions of the surviving evidence of tramways within North Site will be found within the relevant sections of the report. More detailed studies of the tramway system have been published (Clarke nd; Jenkins 1989, 385-415), and they also include a description of the locomotives and rolling stock in use at the factory. The object of this section is to provide a short overview of the tramway network and to discuss briefly some of the surviving remains that have been found on the site.

The earliest confirmed use of a tramway at Waltham Abbey RGPF came with the construction of the steam-driven **Incorporating Mills**, starting in 1856. On a number of the builders' diagrams for these mills are drawn sections of 'tram iron' that was to be used on the raised working platform. The early network was hand-propelled and is thought to have operated on a 2' 3" gauge line. This tramway linked the new steam incorporating mills with Millhead Stream and was gradually extended as more mills were added to the group. The tramway operated on raised trestles, designed both to raise it to the height of the working bays within the mills and to raise it above winter flood waters. This accounts for the raised doors of a the small **Expense Magazines**, as they were designed to be at the same level as the tramway. Tramways were also used within the new guncotton factory on the South Site in the late 1880s. The extent of this system is depicted on a map accompanying the report into an explosion in 1894 (Sandhurst 1894). It was also probably during the 1890s that the 18" gauge line replaced the 2' 3" as standard.

On North Site the original network was extended to embrace the new cordite buildings within Area H. Two new independent systems were also established. One lay within the acid factory, to transport chemicals around that complex and acids and glycerine to the **Nitrator**. When the new group of guncotton stoves adjacent to the Cornmill Stream were built in Area 74-98, a second self-contained tramway system was established to serve their needs. Until the First World War the tramway systems on North Site and South Site had developed as independent networks. When cordite production became focused on North Site and to aid in the quicker movement between the two sections of the factory, principally moving guncotton from South Site northwards, a line was constructed through the Lower Island Works and through a tunnel beneath Highbridge Street. It emerged on the east bank of lower Millhead Stream and crossed onto Great Hoppit and Area H by means of a swing bridge [RCHME 100]. Further extensions were made to the tramway system serving the guncotton stoves along Cornmill Stream, too, linking it to the new tetryl plant adjacent to its south-west. Also during the First World War locomotive haulage was introduced, although it was probably restricted to South Site and Area H. A **Locomotive Shed** [H13] was built to house the locomotives.

It was also during the First World War that the RGPF was connected to the standard gauge railway network. Exchange sidings were built by the acetone recovery plant in the south-west corner of the South Site. This gave access to the Great Eastern Railway mainline to Cambridge through the Royal Small Arms Factory at Enfield.

The North Site tramway systems had further piecemeal extensions during the Second World War principally in the northern part of the site, the final extent of which is illustrated in figure 5. A new line was constructed along the west bank of Cornmill Stream between the **Grand Magazine** [1] and the New Hill Nitroglycerine Factory. Spurs were taken off this line to the **Guncotton Stove** [23] and the **Cordite Mixing Houses** [S34] and [46R]. At its southern end the line extended over Cornmill Stream into the New Hill Nitroglycerine

Factory to the **Pouring-On** or **Mixing House** [S21]. The tramways survived in use into the early post-war period until 1954.

Despite the former extent of the tramways comparatively little physical evidence survives to mark the routes of the lines. In Area H the concrete piers of the swing bridge [RCHME 100] remain in place and a small section of the earthwork embankment to its north. Also within area H is the **Locomotive Shed** [H13] and to its east a short length of tramway remains *in situ*. Between the **Laboratory** [H10] and the **Magazine** [H8] a Y-shaped earthwork marks the line of the embankment. Around the laboratories in Area L few traces of the tramway survive, but the line of the trestles is marked by a low earthwork across Queens Mead. Elsewhere, as described above, the line of the tramways may be followed by the raised doorways of the **Expense Magazines**. Further north a section of tramway that ran along the west bank of canal [RCHME 179] survives *in situ* at the rear of **Cordite Paste Store** [L108].

On the eastern side of North Site, the embankments of the network serving the **Guncotton Stoves** along Cornmill Stream survive as earthwork banks. Within this section occasional pressed steel sleepers remain and give way to longitudinal timber sleepers beneath the porches of the **Guncotton Stoves**. A short length of rail and buffer stop just north-east of [S90] mark the canal-side interchange point [RCHME 114] at the elbow of canal [RCHME 289]. Across Cornmill Stream in the New Hill Nitroglycerine Factory the branch line may be followed as an earthwork cutting leading towards the **Mixing House** [S21]. In the southern tunnel of this building the steel rails remain *in situ* and give way to teak rails adjacent to the former loading porch. Along the western side of Cornmill Stream short lengths of rails survive next to the **Weighing House** [S27] and **Mixing Houses** [46R and S34]. A 50m length of line [RCHME 263] leading to the **Guncotton Stove** [23] was revealed by clearance of surface litter and soil, which may indicate that more of the tramway networks might remain elsewhere.

Virtually no evidence survives for the tramway system in the acid factory except for the position in the floor of the **Acid and Glycerine Store** [72] where the lines entered the building.

During RCHME's survey and resulting from the continuing decontamination programme a number of artefacts relating to the tramways have come to light. In particular they confirm the types of rail used within the system. Jenkins (1989, 386) was, for example, unsure whether the hollow U-shaped tramway irons illustrated on the early builders' drawings had actually been used; that use was confirmed when a length of tramway iron was discovered during the re-excavation of canal [RCHME 278]. Elsewhere on the site conventional flat-bottomed steel tramway rails were employed, laid, in the sections that survive, on pressed steel sleepers. Another type of rail that was in use utilised a timber rail with an L-shaped metal sheath along its inner running edge; a short length of such a rail remains in place on building foundation [211]. Where rails entered or ran alongside danger buildings it appeared to be a common practice to replace the steel rail with a wooden, probably teak, rail to reduce the risk of sparking. Sections of wooden rails remain in place in the **Mixing Houses** [S21, S34 and 46R]. There was some discussion in the late 19th century about the advisability of using brass rails inside danger buildings. The Director General of Ordnance Factories, however, considered them unnecessary and the Superintendent issued instructions that 'it would be better to use wooden rails if not brass' (Jenkins 1989, 392). Nevertheless during decontamination work a section of brass rail came to light and at least suggests perhaps limited use within North Site. The remains of a single truck were found close to the **Tetryl Drying Stove** [S49]; off site one complete truck is preserved as a display item at the Ministry of Defence research establishment at Fort Halstead.

Transport: water transport and the barges

River barges were used from the early history of the powder works to transport the raw materials up the River Lea and the finished powders down to the government magazines at Purfleet and the Royal Laboratory at Woolwich on the Thames. In Farmer's print of 1735 (Fig. 15) a barge is shown moored at the Loading House on Millhead; just under a century later what was by then Waltham Abbey RGPF had five barges, nine powder boats, two ballast barges and six punts (Winters 1887, 78). The smaller powder barges were increasingly used throughout the 19th century as the internal canal network spread, and by 1907 there was around five miles of navigable waterways around the factory (VCH 1907, 455). The powder barges were employed to move gunpowder and later guncotton between the various process buildings and magazines; the majority of the process buildings were exclusively supplied by barge until the introduction of the tramway in the last quarter of the 19th century and even then a large percentage of the internal movement in the factory until its closure was by barge.

Until 1878 the high- and low-level canal systems within the factory were isolated, except by the circuitous route of using Powdermill Cut and the River Lea Navigation down to Waltham Wharf to the north of the Lower Island Works. This had the effect of separating those barges carrying the basic raw materials and those barges plying between the danger buildings with gunpowder. The first internal link between the two systems was made in 1878 with the construction of **Lock** [RCHME 225], probably in response to the construction of the **Moulding House** [L130] since it thereby allowed powder to be brought there for pressing and pressed powders to be moved back northwards for further processing. A further link was created in 1896 with the construction of **Lock** [RCHME 222] on Millhead. This was probably built partly in response to the shift away from gunpowder to cordite production on North Site. This shift generated far more barge traffic, as all the guncotton used on North Site was manufactured on South Site and moved for storage in the **Grand Magazine** [1] at the northern tip of the factory. It was also probably at this date that a lock was inserted in the southern end of the Lower Island Works to provide a through link to South Site, since the canal network there operated on a lower level than the lowest level on North Site.

By the late 19th century two types of barge were used for internal communications within North Site. The first type was 'ship-shaped', with a prow to either end, up to 10.5m in length and with a beam of 2m; the second type were flat- or 'swim'-ended and shorter in length at around 6m. Both types were carvel-built in timber and had barrel-shaped roofs; phosphor bronze nails and fittings were used throughout, and the barges were also partly covered in leather or cloth to prevent explosive dust adhering to their structure. The barges were divided into three distinct areas, with open wells to either end connecting to the covered section by wooden doors. In the centre of the covered section was a loading area with openings to either side. To use barge [RCHME 101] as an example, it is described as utilising typical 19th-century canal shipwright technology, its weight was estimated to be around 2.25 tonnes and would have been capable of transporting a cargo of up to 5 tons (Walker 1993). The barges were poled around the system or pulled by men on the banks; no evidence has been to found to suggest that horses were used. In addition to these barges Colonel Noble, superintendent from 1885 to 1892, had a powered barge called 'The Spark' constructed for his internal communications around the factory. It was also equipped to provide electric lighting to buildings that were not connected to the dynamos (Winters 1887, 130-1). Another specialised barge in use on the factory's canal system was dredger with a grabbing crane built by Priestman Brothers of Hull and London (PRO Supply 5/861 photos 380-2).

In addition to the barges used to move materials around the factory another group of larger barges rigged with sails were employed to transfer finished gunpowder down to the Purfleet Magazines and to the Woolwich Arsenal. The last wooden sailing barge, called 'The Lady of the Lea', was built in 1931 and is known to have survived into the 1970s; her subsequent fate is not known. It is also believed that a river-going barge may survive as a wreck, sunk within North Site in the southern section of Millhead Stream immediately south of the cast-iron bridge [RCHME 132].

The flotilla of barges remained in operation until the closure of Waltham Abbey RGPF in 1945. At this date a number were sold. A few were used as maintenance barges along the River Lea Navigation and may have survived into the 1970s. Another three of the barges were sold to the Great Western Railway for use on the Kennet and Avon Canal and later passed to the British Waterways Board. One of these was broken up in the 1950s, while another passed into private ownership and survived into the 1960s before it, too, was broken up. The third barge was deliberately sunk in about eight feet of water near Newbury Wharf, where it is believed to survive as a wreck (pers. comm. Mr John Gould MBE).

Abandoned around North Site, and most strikingly within the drained high-level canal system, are the remains of seven ship-shaped barges and three swim-ended barges. A number still retain their superstructure, although all are in a poor state of preservation. A further ship-shaped barge is stored as a display item at the Ministry of Defence research establishment at Fort Halstead and remains in reasonable condition. Original builders' drawings survive in the various archive repositories, unfortunately all undated, and in Epping Forest District Museum are a number of barge models.

The archaeology of safety

To the early powder makers the risk of explosions was almost regarded as an unavoidable hazard of the trade. Progressively through the 18th century it became recognised that these risks could be minimised and this was gradually reinforced by statute. In the early factory there was an attempt to separate the most dangerous operations away from the main factory area by placing the drying stoves at the northernmost end of layout, although the incorporating mills remained grouped close together on Millhead Stream. From the late 18th century the gunpowder industry was increasingly regulated to ensure that it did not create an undue hazard to itself or to its neighbours. The manifestation of the legislation is found in the increase in provision for charge magazines in the factory and in the spacing of buildings within the factory. Working alongside the legislation were rules and regulations specific to a given factory that laid down procedures designed to minimise the risk of explosions. Though Waltham Abbey RGPF was exempt from the legislation pertaining to the manufacture of explosives (George III 1772 ch 61; Victoria 1860 ch 129; Victoria 1875 ch17), it does appear to have followed best practice and was often in advance of private manufacturers in the provision of safety devices. It is not the purpose of this section to deal exhaustively with the working practices within Waltham Abbey RGPF, which are better studied by consulting the 19th- and 20th-century factory regulations. Many of the working practices are unrecoverable archaeologically; others have left physical traces, however, and they are drawn together in this section.

The occurrence of traverses to deflect the blast in the event of an explosion is one of the distinctive aspects of the developed gunpowder industry. At Waltham Abbey RGPF they were first used during the Napoleonic Wars, when brick traverses were built next to the two **Horse Corning Mills** [76 and 103]. A traverse was also constructed to separate the hydraulic **Press House** [399] from its Washing Up Room, containing the hand-powered presses. This method was also used to separate the **Granulating House** [S34] from it neighbour, probably a retiring room for the workmen. A pipe passing beneath the traverse was possibly a means to control the machinery within the building remotely. For the *Illustrated London News* (1854, 478) describes how the machinery within some danger buildings could be started and stopped by means of a rope passing through the wall. When the **Horse Corning Mills** were reused as **Press Houses** around 1850 the traverses were retained to separate the press house from the building containing the pumps and men's retiring room. A similar solution was employed when the first **Steam Drying Stove** [RCHME 330] was built, although in this instance the steam-raising boiler was actually placed inside the traverse with drying rooms to either side. This became the standard pattern for **Steam Drying Stoves** and was repeated when the **Stoves** [26 and S90] were constructed later in the century.

The use of a brick and earthwork traverse around buildings was a relatively late introduction, first deployed during the 1878 enlargement of the factory. The **Press House** [S31] was enclosed on three sides by a brick and earthwork traverse, while the fourth, open side was directed at a piece of woodland. An L-shaped traverse was used to surround the **Moulding House** [L130], although a linear traverse was erected on the opposite side of the adjacent canal to cover one of the open sides. A few years later a new type of mass concrete traverse was constructed around the new **Moulding Houses** [107 and 108]; these buildings were surrounded on three sides, the fourth side being open to facilitate loading. Mass concrete was also used to create a traverse between two **Magazines** [L102 and L103] and around the **Dusting House** [159]. After the devastating explosion in the Quinton Hill nitroglycerine factory in 1894, the investigating committee found that the solid traverses were a danger in themselves as their disintegration produced large quantities of flying debris. The original decision to use solid traverses is somewhat puzzling, since 19th-century field fortification engineers had recognised the advantage of using earthworks to absorb incoming shot and blast damage. They did occupy relatively more ground area, however. The traverses constructed in the early years of the 20th century, for example around the **Cordite Reel Drying Stoves** [H7 and H8], were entirely of earth except where it was necessary to have a vertical face for the tramway to pass through.

The circular buildings of the nitroglycerine factory also followed this general principle; although their interior was revetted in brick, this was encased within earth to minimise the sideways projection of the blast. The buildings of the New Hill nitroglycerine factory constructed during the Second World War were similarly surrounded by earthwork traverses; in this case the interior walls were of concrete but slightly battered outwards. A less expensive form of traverse of this period was formed out of corrugated iron sheets reinforced with old rails and angle irons, the interior packed with gravel and earth. Blast walls added at this time were also constructed from breeze block, sometimes backed by earth. Even timber-revetted traverses were used during the Second World War and survive at the rear of [RCHME 167] and by the **Tetryl Store** [U10]. The value of trees as a means of limiting explosions was recognised from an early date, as they acted as an elastic barrier to absorb the force of an explosion.

Many of the safety features included in process buildings were common to a number of processes and can be dealt with generically using particular buildings as examples of features that might be found included in other structures. Where brick walls were required within structures, English bond was employed; although more expensive in bricks used, a strong wall resulted. Roofs tended to be flimsy so as to offer the least resistance to explosion and also to minimise the danger from flying debris. Galvanised metal became a common roof covering at the end of the 19th century as well as corrugated iron, in preference to tarred roofing felt that offered the danger of fire. Slates were curiously used to roof the steam-driven gunpowder incorporating mills, despite the danger they might create in an explosion. The superstructures generally of many of the danger buildings were flimsy, constructed from either light timber and in some instances canvas so as to offer the least resistance to explosion. In contrast the magazines and boiler houses associated with the gunpowder steam drying stoves were well-built brick structures with brick vaulted roofs covered by slates. These buildings were designed to protect their contents from explosions in other buildings rather than yield to explosions within the building. The nails and screws used in most of the building were made from bronze, as were the fittings such as locks and hinges. This was both to prevent the creation of accidental sparks and to ensure no sparking should occur in the event of a nail or screw falling into one of the machines. Doors on all the danger buildings in the factory were arranged to open outwards to facilitate rapid egress in the event of an emergency.

Lightning conductors were in use from the early 19th century. The earliest form was a post or spar erected some distance from the building it was designed to protect. In 1858 after the publication on his paper on the application of lightning conductors to magazines (Snow Harris 1858a, 55-63) Sir W Snow Harris was asked to look at the measures utilised at Waltham Abbey RGPF to protect against lightning. He recommended that the old system of lightning conductors should be replaced by a conductor placed at each end of a building and joined by a metallic strip, and that any tall features such as stove chimneys ought to be protected by conductors (Snow Harris 1858b, 129-32). This good practice employed at Waltham Abbey RGPF was two years later extended to the rest of the industry by statute (Victoria 1860, ch 139), which required that all stores or magazines where gunpowder was kept were required to have thunder rods or lightning conductors. Ornate lightning conductors remain on the roofs of many of the North Site buildings, and are attached to copper strips on the exterior of the buildings secured by lead bands.

Great care was also taken of the floor surfaces within buildings; all were required to be kept clean at all times. For this purpose areas were designated as 'clean' and 'dirty'. The clean areas were usually marked at the entrance to a building by a toeboard, sometimes painted red. This not only provided a physical reminder of the clean area but also provided a physical barrier to prevent grit getting inside buildings. Toilets can also occur in pairs, one 'clean' the other 'dirty'. To work in side the 'clean' areas the workers were required to put on large leather 'magazine shoes' with no nails in their soles. Pocketless leather clothing was also provided for the danger building operatives during the 19th century. Scattered around the factory were a number of **Shifting Rooms**, where the workers could change into factory clothing and deposit contraband items. Additionally at the entrance to many of the buildings a shoe room was provided for changing. Where there was insufficient room, a shoe box and changing seat was provided and in the case of the **Tetryl Drying Stoves** [S46-S49] a small fold-down step was provided over the toeboard. Grit was a constant danger around the factory: other attempts to reduce it included boot scrapers at the entrance to buildings, one of which survives *in situ* outside the **Press House** [S31]. Boot scrapers were also provided at the bottom of the footbridges in an attempt to prevent grit from the bridges falling onto the barges. In the 19th century a further attempt was made to minimise the risk from sparking by covering the floor surfaces with leather hides nailed down with copper nails kept moist at all times (Smith 1868, 112). Fragments of such leather floors fixed with copper nails survive in the porches of **Magazines** [155 and L135]. The accumulation of dust within buildings was another hazard, especially of dry guncotton. In an attempt to overcome this problem buildings within the nitroglycerine and cordite factories had floors of lead sheet. As a valuable commodity, lead was removed before the firing of all of the buildings, but a fragment was discovered surviving in the **Washing House** [E5]. To prevent dust settling in crevasses in walls buildings were lined with matchboard or with painted calico sheeting; peeling sheets remain in the **Quinan Stove** [22a] and in the **Cordite Paste Stores** [L105 and L108]. As with the gunpowder buildings, those associated with guncotton were regularly swept and the floors kept damp. Around the interior of the **Quinan Stove** is a gully to allow for regular washing of the floor. A further danger lay in the introduction of contraband items into the factory, for example lucifer matches or metallic items that might cause a spark. This was partly controlled by police body searches at the gate, but within the factory hinged metal boxes remain attached to a number of buildings, for example the **Locomotive Shed** [H13] and the **Gunpowder Press House** [S31], where contraband items could be placed before leaving to work on the railway or enter a process building.

The T-shaped gunpowder incorporating mills built from 1861 onwards included many features to ensure the safe working of the mills or at least to minimise the effects of an accidental explosion. Each of the incorporating mills was housed in a bay separated from its neighbour by a partition wall in English bond. The intention was that any explosion would be directed forwards and backwards away from the neighbouring mill machinery. Above each of the mills was a drencher tank that would automatically tip water into the affected bay and adjoining bays in the event of an explosion. Drenching tubs had been in use at Waltham Abbey RGPF since at least 1854 (*ILN* 1854, 478), but the earliest recorded use of drenching tubs was at the Tonbridge Mills of Messrs Barton in 1819, when the manager at the time, Mr Monk, was presented with a silver medal and prize of 20 guineas for the invention of an improved gunpowder mill incorporating a drenching tub (Trans Soc Arts 1820, 161-7). The arrangement of the processing building into isolated bays with the provision of drenching machinery remains a feature of the explosives industry today. The mills were powered by an underground drive that had the twin advantages of protecting the shaft from damage and removing the danger of objects falling into the mill machinery.

Future clearance or archaeological excavations may reveal traces of deep wells which 'the authorities have thoughtfully provided ... outside each danger building, into which men who have been badly burnt may plunge' (Fitzgerald 1895, 311).

Government Research Establishment 1945-1991

The post-war activity on the site may conveniently be divided up into the adaptive reuse of former explosives manufacturing buildings and newly-erected buildings tailored to the needs of the research establishment. One of the early priorities of the research establishment was liquid fuels for use in rockets and other purposes. For this important work conversion work began in 1946 on the former **Cordite Reel Magazine** [H12] for use as a **Proof Stand**. Three walls of the original building were retained; within these was inserted a central T-shaped control room and a firing bay to either side, both of which could be observed through armoured glass from the control room. Ancillary cubicles were set around the exterior of the building within an earthwork traverse. The **Proof Stand** was additionally supported by a **Store** [H14] and a **Dithekite Store** [H65] for liquid fuel.

By the summer of 1946 work was also under way on the conversion of all the former **Cordite Incorporating and Press Houses** into laboratories, with the possible exceptions of [L155] and [L159] which may not have been converted until the 1950s. It was not until the 1960s that the bedstones for the beam engine in [L168] were stripped out and replaced by **Whisker Furnaces** used in the study of inorganic and ceramic compounds as materials for specialised structural components (Johnson 1965, 327). It was probably also at this date that the original Group A mill buildings with its trapezoidal bays was demolished and replaced by a building last used as a **Store**. Machinery was stripped from the bays in the **Incorporating Mills**; in some instances the metal bearing boxes from the overhead drive shafts were filled and in other cases removed altogether, the two girders set into the partition walls above the incorporating machinery were cut off flush with the wall and may be seen in many of the bay walls. The protection afforded by the partition walls to the explosives processing machinery was also ideally suited to the hazardous nature of many of the experiments carried out by the new research establishment. The machinery from the engine houses was finally removed at this date and a floor inserted into each of the towers to create additional office space. The verandas of the buildings were closed to form a convenient access corridor between the various bays. Links were also built between a number of the mills to create longer ranges linked by a single corridor. Demolition of some of the infrastructure of the mills took place with the removal of the **Tramway**, a number of small **Expense Magazines** and a concrete **Traverse** in front of [L149]. The former **Reeling House** [H10] was also converted to laboratory with a later addition [H71] constructed on the west side of the building.

In the northern part of North Site the majority of the cordite and tetryl manufacturing buildings remained standing until the 1960s. Some of the buildings have documented reuse by the research establishment while others may have had casual reuse. The two surviving oval steam boiler house **Traverses** [26 and S90] were converted into **Firing Points**. The interiors were partially lined with thick steel plates and in [26] concrete support bases were constructed. At the south-eastern end of [S90] a small breeze-block building [S90a] was placed at the entrance to act as the control room for experiments within the **Traverse**. The majority of the **Magazines and Cordite Paste Stores** that had survived into the Second World War were retained as **Magazines**. The acid and tetryl factory on the west side of North Site was progressively demolished from the early 1950s. By 1952 the tetryl factory had been reduced to floor slabs and by the early 1960s few buildings of the acid factory survived, only the **Soda Store** [E10] and the former **Engine House** [83b] remaining until the closure.

The nitroglycerine factory of New Hill was seemingly left unused until the late 1950s with the exception of the **Mixing House** [S21] that was converted into a **Proof Stand** in 1949. The conversion involved sealing of the northern tunnel leading to the building and construction of concrete bases within the tunnel. The main series of drawings relating to the conversion of the other buildings do not date before the late 1950s, when it is presumed that the work was carried out. The former **Nitrator** [S16] was converted into **No.1 Firing Point** for unobserved firing, with a large steel gantry constructed in the centre of the traverse and protected by an armoured canopy. The **Washing House** [S19] was converted into **No.2 Firing Point**; an armoured chamber was constructed in the centre of the traverse and this was surrounded on three sides by an observation room with armoured glass windows built into the walls of the chamber. Some of the small buildings associated with the proposed nitroglycerine factory were converted into electrical switch rooms or control rooms. The buildings along the northern perimeter of New Hill became part of the testing facility, [S10] was converted for the use of the sensitiveness section in 1962 and [S5] was used for the charge machinery block. Other buildings were utilised as stores.

In addition to reusing available facilities on North Site a number of new and purpose-built structures were constructed. In 1954 work began on a new **Firing Point** [L189]; at the core of the structure was a steel pile and armour-plated chamber with a control room and camera room to either side. This was supplemented a few years later by another **Firing Point** [L199]. Also constructed in this northern part of Area L was the **Climatic Test Cubicles** [L190]. Around the laboratories converted from the former cordite processing buildings a new **Stability Test House** [L191] and **Stability Laboratory** [L198] were added. Scattered around the site close to the laboratories a series of **Locker Magazines** were built in the late 1950s. These were single-storey brick structures with an asbestos roof and doors at either end. Inside were between three and six steel lockers in which explosives could be stored for use in the laboratories.

A problem faced by the research establishment in North Site was the difficulty of access. The factory had hitherto relied heavily upon waterways and tramways to move material around the site. The high-level canal system fell out of use and by the early 1950s aerial photographs show fresh work along Horsemill Stream, including dumps of material sealing the entrances to the canal network either side of the acid factory, into canal [RCHME 294] and into the remains of Millhead Stream. From this date onwards the dry canal beds became convenient dumping grounds for the rubble from demolished buildings and of waste materials generated by the research establishment. A number of canals were completely filled, leaving little or no surface traces. These included the former link [RCHME 278] to the **Gasworks** [RCHME 333], which was re-excavated in 1993, and canal [RCHME 288] leading to the former **Press House** [76]. The majority of the canal [RCHME 294] leading across the Burning Ground was also filled. Other canals such as [RCHME 289 and 291] had been partly filled but the line of the banks were still visible. In some instances, where the canal was filled and overlain by a road, the line of communication was retained although the mode of transport changed. So, for example, he majority of canal [RCHME 291] was filled and had a road laid over it when the **Nitrator** [E2] was brought back into use in the early 1960s. The tramway system, too, was removed leaving only scattered fragments to mark its former course. To replace the old communications network a new perimeter road was laid around North Site. Along the west side it utilised the Long Walk and a pre-existing road along the east side of the acid factory; north of this point it became a dirt track following the perimeter fence. Along the east side it followed the line of the tramway laid during the Second World War from the **Grand Magazine** [1] south to [S90]; from there a new section of road was laid to the **Press House** [103] reusing **Bridge** [RCHME 117] but on a new alignment on an embankment south of the bridge. From this point it rejoined a pre-existing perimeter road.

Within North Site the area most extensively and heavily redeveloped was at the northern end of Area H. By 1956 construction work was under way on a new **Ballistics Laboratory** [H67] and a number of associated structures. In a fenced area behind the main laboratory a new concrete **Test Bed** [H68] was built and a **Magazine** [H69] along with a **Solvent Store** [H70]. A horizontal **Firing Tunnel** [H68a] was probably also constructed at this date. At this time, too, the east-west section of canal [RCHME 301] along the northern edge of the fenced enclosure was filled. The last surviving **Powder Mill** [182] was demolished in 1956 and the southern end of Millhead Stream filled in and grassed over.

In 1961 the rehabilitation of the Edmonsey nitroglycerine factory began, to allow production of small quantities of nitroglycerine for use within the research establishment. Presumably the raw materials for manufacture, ie principally concentrated nitric acid, sulphuric acid and glycerine, were brought in from outside as most of the acid factory had been demolished by this date. The **Nitrator** [E2] was brought back into use, but whether new plant was installed or the plant designed by Nathan at the turn of the century was recommissioned is not known. The two **Washing Houses** [E3 and E5] were also brought back into use, but [E5] had plant installed for the continuous nitration of glycerine known as the Schmid Process (see War Office 1938, 84). The **Wash Water Settling House** [E4] and the **Tool Shed and Mud Hut** [E16] retained their original functions. New access roads were constructed into the plant and the canal [RCHME 291] that had formerly separated the **Nitrator** from the **Washing Houses** was filled and a road surface laid over its course. New ancillary buildings were also constructed to the west, namely a remote **Control Room** [E6] and a **Compressor House** [E15]. A **Refrigeration House** [E9] was later added to this pair after the original

Refrigeration House also numbered [E9] was demolished when Horsemill Stream was widened. In addition a new **Acid Mixing House** [E1] was built at the base of the Nitrator's mound.

With the exception of the buildings grouped around the **Power House** [A210], the buildings in Area A were principally concerned with the administration of the research establishment. The early 19th-century **Store** buildings [A231 and A232] were converted into **Offices**, while the other sections of this range remained as stores. The early 19th-century buildings along Powdermill Lane also became offices. Behind them a small group of prefabricated office buildings were added; some were of wartime construction while others had been added in the early post-war years. On the western side of Area A a new **Canteen and Social Club** [A250] was constructed in 1960 partly over the sites of two **Store** buildings [247 and 248], and it is probably at this time that the range of store buildings parallel to [A230-A234] were demolished. In the early 1950s the area between these buildings and Highbridge Street was cleared and the **Saltpetre Refinery** [278-282] demolished. A small housing estate was constructed in the western half of the area. The southern edge of the site was further encroached upon when the Waltham Abbey by-pass was constructed in the early 1970s. During its construction a row of labourers cottages provided for workers at the factory were lost at the entrance to Powdermill Lane. The buildings around **Waltons House** [A200] were also converted into offices. [A201] became a **Surgery**, while [A202] was turned into the establishment's **Library** and connected to a new **Lecture Hall** [A203], constructed in 1965 and resulting in the loss of a number of early buildings. During the construction work the foundations of two of the three horse mills depicted by Farmer in 1735 (Fig. 15) were located and recorded (WASC 176).

In the late 1960s the area around **Newton's Pool** [RCHME 276] was modified to act as an underwater test facility. Test firings were undertaken, notably on the explosive Torpex, which was a mixture of RDX, TNT and aluminium powder and was the most powerful underwater explosive produced in Britain during the Second World War (Gibbs 1961, 168). The former **Guncotton Weighing House** [S34], constructed during the Second World War, was converted into a **Control Room** and the **Bunker** [S38] at its eastern end into a **Switch Room**. The former **Fanhouse** [U2] on the opposite side of the pool was converted for use as an **Office**. The north-eastern end of canal [RCHME 287] was filled and a road surface laid over it; concrete steps were also constructed to aid access to the pool side. New buildings included a **Shed** [S35] and a small **Blast and Splinter Proof Control Point** [S50]. A small breeze-block **Day Expense Magazine** [S38] was added to the north-west of the complex. Explosive charges were suspended in the pool by a rig attached to a steel framework [S37] on the north shore and a steel pole on the south side [RCHME 337] for detonation underwater.

By the late 1960s all the principal building work and modifications to pre-existing buildings had taken place. Piecemeal minor modifications continued into the 1980s, but rarely leaving any substantial physical evidence. Progressively from the 1960s demolition work took place on the buildings of the old cordite factory as buildings were stripped out and fired. Casual dumping of waste continued to fill the canals, the borrow pits around the **Nitrator** group and in dumps around the Burning Ground.

Postscript

On the closure of the research establishment in 1991 stripping-out work began on the former laboratories and on the other remaining buildings on the site. In September 1992 a visit was made to North Site by staff of RCHME and English Heritage to evaluate the site and this gave rise to RCHME's detailed survey, begun in January 1993. In the intervening period stripping-out work continued on site and some of the physical evidence of the factory's infrastructure was removed before a record could be made. In Area H and Area L the principal loss was overhead steam heating pipe runs and some telegraph poles: a number of minor buildings of Second World War or post-war date were also demolished in these areas. In the northern part of North Site, including the north end of Area L and the area of the former tetryl factory, S26-S90, most of the steam pipe lines linking the buildings were removed along with many telegraph/electricity poles dating from the late 19th century. In the New Hill Nitroglycerine Factory there was a similar picture of the removal of steam pipelines and overhead supply lines, but also the wooden shelves that were designed to carry the nitroglycerine and waste wash waters between the buildings. Additionally the shattered remains of the earthenware fume tower at the base of the nitrator [S16] was cleared away. As the decontamination programme began to empty canals during this period from autumn 1992, a collection of the more interesting artefacts discovered was started by the workmen. The importance of this unofficial policy was reinforced by arrangements made by RCHME as the survey proceeded; it now forms the basis of a coherent retention policy under the supervision of the site archaeologist, appointed in June 1993.

Appendix 1 The technology of explosives manufacture

The purpose of this appendix is not to produce a detailed manual on the manufacture of gunpowder and chemical-based explosives, but rather to provide a straightforward description of the processes involved as a commentary on the flow diagrams for each of the principal products (**Appendix 2**) and as a background to the physical remains encountered on the North Site. Particular emphasis is given to the technology in use and developed at Waltham Abbey RGPF. Modern summaries of gunpowder manufacture may be found in Crocker 1986, Pye & Robinson 1990, and West 1991, while detailed accounts of the manufacturing methods used at Waltham Abbey RGPF from the mid 19th century are listed in the section of the bibliography entitled 'Official Publications'. Little secondary literature exists on the manufacture of chemical explosives outside generalised chemistry textbooks: the accounts below are based almost exclusively on those given in the official publications.

A Manufacture of gunpowder

By the late 19th century gunpowder was divided into three groups: Class A 'granulated', Class B 'cut' and Class C 'moulded'. From the flow diagram (**Appendix 2**) it is clear that the manufacturing process will vary depending on the class of powder to be produced. After the initial refining of the ingredients, manufacture of gunpowder may be broken down into ten distinct processes.

1) Mixing the ingredients
2) Incorporating or milling
3) Breaking down the mill cake
4) Pressing
5) Granulating
6) Dusting
7) Glazing
8) Stoving or drying
9) Finishing
10) Blending

After Wardell 1888, 46.

Introduction

Gunpowder is a mechanical mixture of three ingredients; saltpetre, charcoal and sulphur. The proportions of the ingredients in English powder had by the 18th century become fairly standardised at a ratio of seventy-five parts saltpetre, fifteen parts charcoal and ten parts sulphur. This was capable of variation, however, depending on the application to which the powder is to be put and differed from the proportions used by continental manufacturers

(Baddeley 1857, 2). In early accounts of gunpowder manufacture (Norton 1628, 144-5; Sprat 1667, 277-83), the exact proportions of ingredients were not yet fixed and both writers recognised that it was best left to the empirical experience of the powder maker. They did nevertheless recognise the importance of using pure ingredients and described the refining processes then in use. After initial refining the sulphur and charcoal were pulverised under stone in horsemills; the resulting products were then sieved. Sprat notes that the saltpetre was boiled to the 'thickness of hasty-pudding'; it is described by later writers as saltpetre 'snow or flour'. Next, the ingredients were mixed and taken to the incorporating mills, which were, as Sprat comments, 'seldom made to move with any thing but water'; but Norton also refers to the use of horses. Early gunpowder or 'Serpentine' powder was simply mixed together, often on the battlefield. As a mechanical mixture it was liable revert to its constituent parts if shaken during transport. Certainly by the 16th century stamp mills were in use in England to pound the ingredients together (Hodgetts 1909, 17). It is such a mill that Sprat described in use in the late 17th century. In these mills the water-wheel was used to turn a cam shaft, to which was attached a series of pestles that fell on the powder contained within a mortar. The powder might remain in this process for up to thirty hours, during which time some 'liquor' would be added to prevent it becoming too dry. The powder was taken from the mills to the corning house, where it was rubbed through sieves to produce grains of varying sizes. Norton described only the sun drying of powder 'or in a warm place' (Norton 1628, 145), however Sprat described a stove that would later be recognised as a gloom stove, in which a cast-iron fireback was set into a wall of the drying room. From the stove the powder was resieved to grade the powder in terms of size and to remove any dust.

Refining of Ingredients

Charcoal

The preferred woods for charcoal for gunpowder production were black dogwood (*Rhamnus frangula*) for small arms powders, and alder and willow for cannon powders (Smith 1870, 57). Plantations of all these woods were maintained around the factory to supply the charcoal burners. The greater part of wood used by the factory was brought in, however; from Sussex fine willows and alders, while additional supplies of wood were imported from Belgium and Holland (Smith 1868, 110). Young wood less than ten years old was generally preferred, between one and four inches in diameter. From an early date the charcoal was burnt in pits, but from the 1790s charcoal produced in iron retorts was favoured as it could be relied upon to produce a more predictable ballistic result. After cooling, the charcoal was ground in an upright mill resembling an old-fashioned coffee mill, from which it passed into a slope reel. Any large fragments were returned for remilling. For almost four decades until 1830 Waltham Abbey RGPF was dependent on external suppliers for its supply of retort-burnt charcoal. However in 1830 the Charcoal Cylinder House was transferred from the Royal Gunpowder Factory at Faversham, thereby enabling the Waltham Abbey factory to furnish its own requirements. Milling of the charcoal was carried out in the three buildings [225-7] alongside the lower reaches of Millhead Stream identified by Farmer as horsemills in 1735 (Fig. 15), although not all three acted as such for all their history. The lack of a head of water in this area would also imply that the milling was all done by horsepower, perhaps later replaced by a small stationary engine.

Saltpetre
By the 19th century the crude saltpetre used at the RGPF was entirely imported from India, principally Bengal and Oude (Smith 1870, 11); some saltpetre was also derived from reworking unserviceable powders. As imported, the saltpetre, known as 'grough saltpetre', contained organic and inorganic impurities amounting to between 5 and 10 lbs per 112 lbs; they needed to be removed for before use. Following the government's acquisition of the Waltham Abbey factory William Congreve became concerned about the purity of the saltpetre used in gunpowder and aimed to guarantee it by refining in government-controlled premises. In addition to supplying the RGPF, the refinery also supplied saltpetre to some private manufacturers with government contracts in order to ensure the purity of their ingredients and thereby improve the quality of their products (Baddeley 1857, 21-2). This move would also ensure that the maximum amount of pure saltpetre was recovered from the imported 'grough'. A building [RCHME 311] was identified as a **Refinery** in 1783 (PRO MR593), and was later confirmed as the **Saltpetre Refinery** (WASC 900/58); this illustrates that some refining of the ingredients had taken place even while the factory was in private hands. In this period this building may also have housed the **Sulphur Refinery** as no building was specifically dedicated to this function in the late 18th century. Congreve's desire to improve the quality of saltpetre manifested itself in the construction between 1801 and 1806 of new **Saltpetre Refinery** adjacent to the present Highbridge Street entrance to North Site, replacing the old structure. By 1827 this had in turn been superseded by a newer **Saltpetre Refinery** [278-82] on the opposite side of Millhead Stream, which survived until the end of gunpowder production. Its final demolition took place shortly after the Second World War. At the end of the 18th century saltpetre was purified by a method that required it to be crystallised three times. Around 35 hundredweight of saltpetre was put in a copper containing 270 gallons of water. This was boiled and impurities skimmed off the top; after about three to four hours the liquor was pumped out and filtered before it was allowed to run into casting pans. This was repeated a further twice and in the last filtration the liquor was also passed through charcoal. After the final crystallisation the saltpetre was melted and cast into cakes weighing 38lbs (Baddeley 1857, 3-4). This process was carried out in two buildings, the **Saltpetre Boiling and Melting House** and the **Saltpetre Crystallisation House,** the latter a long open building (Drayson 1830 drwgs 1, 2, 33).

As discussed in relation to the earlier periods, not all the changes and developments in the factory are recoverable through the archaeological study of buildings or cartographic study. Where processes took place within unspecialised spaces, on floor surfaces, and within containers, it is likely that some of the changes will have left no archaeological trace that even careful excavation of the buildings would be able to recover. For example, in the

1850s a new method of refining saltpetre following the French practice had been adopted (Smith 1870, 12); Baddeley writing in 1857 said it had 'only just been adopted'. The first part of the process was similar to the old method of three recrystallisations, described above, in that 40 hundredweight was boiled in 270 gallons of water and the scum skimmed off the top. After boiling, the liquor was filtered and collected in troughs, where it was allowed to crystallise; during this stage the liquor was subjected to constant agitation to encourage crystallisation and to prevent the formation of large crystals. The resulting crystals had the appearance of snow or flour. They were raked onto a wooden frame over a copper sieve and then into the washing cisterns. After washing, the saltpetre was placed on copper trays for drying to reduce the moisture content to between 3% and 5%. This new method reduced the production time for pure saltpetre from six days to one day and was thought to reduce the labour and coal input by one half (Baddeley 1857, 4-5). The saltpetre was used straight from the refinery although it was usually allowed to stand for four or five days first.

Sulphur

The value of sulphur as an ingredient is due to the low temperature at which it inflames, which facilitates ignition and accelerates combustion (Smith 1868, 109). Sulphur, like saltpetre, had to be imported and the sole source for Waltham Abbey RGPF was Sicily. As with saltpetre the sulphur as purchased was known as 'grough sulphur' and contained many impurities that had to be removed before use. Coleman in his account of the factory in 1801 describes the refining of sulphur by two methods. The first method was simply to melt the sulphur and skim the impurities of the top, while the most impure sulphur was purified by sublimation. Drayson illustrates both these two methods of sulphur refining in his treatise on gunpowder manufacture produced in 1830. The first, by fusion, is identified with building [RCHME 313] on the north side of Highbridge Street. Refining by sublimation took place at the northern end of the Lower Island Works within buildings [375, 376]. Drayson also produced another drawing, entitled 'Sulphur Refinery on a New Principle' (drwg 29), in which he shows a subliming dome and casting pot similar to that described and illustrated by later writers. The grough sulphur as imported contained around 3-4% of earthy impurities that the gunpowder manufacturers had to remove before use. This was achieved by placing around six hundredweight of sulphur in a covered iron pot or retort, which was then heated. Connected to the pot were two outlets, one leading to the sulphur dome and the other to the casting pot. As soon as yellow vapour began to be given off, the outlet to the dome was opened and the sulphur sublimed or condensed on its walls as a fine powder known as 'flowers of sulphur'. This is unsuitable for powder-making owing to its acid content and was collected for laboratory use or mixed with grough sulphur for reprocessing (Baddeley 1857, 9). After about three hours the vapour turned a deep iodine colour; the outlet to the dome was closed and the outlet to the casting pot opened. The vapour passed through pipes jacketed by cold water, causing it to condense and run into the casting pot where it formed as clear yellow crystals. After cooling the crystalline sulphur was ground in a mill before being taken to the **Mixing House** (Smith 1870, 22-25).

Mixing

Mixing was the process whereby the three ingredients were combined in the correct proportions ready for incorporation. By the 19th century it was done by machine. Sir William Congreve II was a pioneer in inventing a machine to mix the ingredients in the correct proportions; but this appears to have been abandoned and a return was made to carefully weighing the ingredients on scales. After weighing, the powder passed to the mixing machine itself. This consisted of a drum with a metal shaft with arms or fliers that revolved in opposite directions. By the later 19th century such machines were powered by an overhead belt drive (Smith 1879, pl.8). The powder in this state was known as 'Green Charge' and was held in an expense magazine until required by the incorporating mill. Mixing was carried out at the southern end of Millhead Stream in the purpose-built **Mixing House** [A201]. This was joined, and later superseded, by the **Water Composition Mill** [RCHME 272]. In this mill it appears that the powder was not only mixed but run under edge runners, albeit of smaller size than found in the incorporating mills.

Incorporation

Incorporation was the singular most important process in the manufacture of gunpowder, wherein by continual grinding the mixed ingredients appeared as a new compound. The ingredients actually remained as separate elements and may be observed as such under a microscope; gunpowder is therefore a mechanical mixture rather than a chemical compound and is liable to disintegration if not handled properly. In the later middle ages incorporation was by a simple hand process by pestle and mortar or spring beam. The process was mechanised by the use of a cam shaft attached to a water-wheel powering a row of pestles to fall on a series of mortars. It is probably this form of mill that was first used as the head mills at Waltham Abbey. In Farmer's view of the factory in 1735 (Fig. 15) he shows two stamp mills at the head of Millhead Stream on the site of the later mills [211 and 211a]. These probably remained in use until 1772, when their use was prohibited by act of parliament (George III, 1772). In France, stamp mills or *Moulins a Pilons* continued in use to the mid 19th century along with *Moulins a Tonneaux*, in which the ingredients were shaken up in wooden barrels along with metal balls (Smith 1868, 113).

The method of incorporation that was universally adopted in England was the use of heavy edge runners, and it was thought that it was this method of incorporation that gave English powder its particular potency. In this process the powder was ground together beneath two vertically mounted stone runners revolving on a circular bedstone. At Waltham Abbey RGPF black Derbyshire limestone was preferred for edge runners as its fine grain took a high polish and did not produce any potentially damaging grit. Iron bedstones and runners were introduced at the RGPF in 1801 (VCH 1907, 453); but how successful the experiments with iron runners were at this date is unclear for Bidermann's account of the factory in 1838 describes only stone runners. Cast-iron runners and beds were nevertheless employed in the steam-driven incorporating mills introduced after 1856. The edge runners employed weighed between three and a half tons and four tons and were up to seven feet in diameter (Smith 1870, 39), although slightly smaller runners were preferred as they were less likely cause excessive strain on the turning mechanism. The edge runners turned on a bedstone, or iron bed if iron runners were in use, set on a deep brick foundation. A number of millstones have survived within North Site. In the Millhead area fragments of edge runners are visible on the surface by the sites of mills [181] and [183], and to their north is a broken edge runner [RCHME 257]. Two complete edge runners [RCHME 224] formerly set into the floor of [L162] were removed when the canal [RCHME 278] which it overlay was re-excavated. A third complete edge runner [RCHME 262] was found during decontamination work near **Sandhurst Hospital** [H26], where it had been reused as a capstan base.

Whether the motive power was horse or water, the early edge runner mills were generally powered from above and connected by overhead spur wheels. At Waltham Abbey RGPF it seems that the process of incorporation was generally carried out by water-powered mills, while the crushing mills using a similar mechanical arrangement but with smaller stones were horse-powered. The internal arrangements of the water-powered mills appears to have become fairly standardised within the industry at an early date. That preferred in Britain was a central wheel set at right angles to the header leat and powering a mill to either side. The 'Dumb Mills' marked by Farmer in 1735 (Fig. 15) are taken to be early examples of this form of mill, 'dumb' because they made little noise in comparison to the hammering of the stamp mills that were still then in operation. The general arrangement of all mills is illustrated by the sole surviving above-ground example in the factory, the **Dusting House** [159]. The mill was driven by a central wheel set in a deep brick channel between the two bays; the flow of water was controlled by metal sluice plates on the head leat side. Within the building on either side of the wheel was a vertical pit wheel and above these horizontal wallowers. The wallowers could be raised or lowered to engage or disengage the spur wheels within each mill. The arrangement of the central wheel and gearing was virtually identical in all the mills, even where they carried out differing functions.

In 1771 John Smeaton was asked to prepare designs for improved incorporating mills at Waltham Abbey. These plans included a design for a water-driven mill powered by an under-floor shaft and a plan for a mill with two incorporating mills within a one bay, perhaps similar to the continental practice illustrated by Diderot (1774, Tome VI pl.VI). No building similar to this design is known from later mapping and it is probable that it was never executed. Similarly it is not known whether or not the design of the under-driven mill was carried through: if it was, it may lie buried beneath one of the later structures.

The water-powered incorporating mills were joined from 1857 by a series of steam-driven mills; these are described in detail in the section on steam power in the analytical description of **Section 3**. It was calculated that a pair of water-turned stone runners could produce 660 barrels of cannon powder or 330 barrels of small-arms powder per year. By contrast, steam-driven mills with iron runners could turn out 990 barrels of cannon powder or 473 barrels of small-arms powder per year (Smith 1870, 41-2). Whereas the mixed powder was known as 'green charge' at the beginning of the process, after incorporation it was known as 'millcake' and was moved on to the **Breaking Down House**.

Breaking down and Pressing

Breaking down is not a primary process in the manufacture of gunpowder but rather a preliminary stage before pressing. The millcake as it left the incorporating mill was soft and dusty, although it hardened if left. The purpose of breaking down was to reduce the cake to a powdery substance for ease of loading into the press. The Breaking Down houses were powered by a central wheel in a similar fashion to the incorporating mills described above. In these buildings the millcake was loaded into a hopper and passed between two pairs of grooved gunmetal rollers that rendered it into a fine meal. In the earlier history of the factory the mill cake was simply broken up with malls before it was taken to the press (Bidermann 1838), but at Waltham Abbey RGPF mechanised breaking down machines were in use certainly by 1830 (Drayson 1830, MP II 15, drwg.14). The factory was served by two **Breaking Down Houses**, [395] on the Lower Island Works and [116] at the northern end of the Millhead group of mills but south of canal [RCHME 294] that led to **Press House** [103/4] and canal [RCHME 288] that led to **Press House** [76].

One of the most important early innovations that government ownership brought to the manufacture of gunpowder was the use of a screw press to increase the density of the powder after incorporation and before it was granulated (West 1991, 171). The press at this date would have been hand-operated and probably similar in design to one illustrated in a contemporary technical manual compiled at Faversham Royal Gunpowder Factory in 1798 (Hodgetts 1909, fig. 13). The early hand-operated press had a brass screw fitted to a wooden saddle. Pressure was applied at 113lb/square foot to a wooden trough measuring three foot long, one foot six inches wide and two foot deep, which was packed with layers of broken millcake separated by copper sheets (Bidermann 1838). The pressure was applied by a lever or capstan. In the drawing of a press at the Faversham factory a lever is clearly shown, whereas Drayson's drawing of 1830 of **Press House** [97] shows a capstan in use at the Waltham Abbey RGPF.

In addition to hand-operated screw presses, Bramah hand-operated hydraulic pumps were in use. In Drayson's depiction of **Press House** [399b] the pumps are shown housed in a room termed the **Wash-up House**, perhaps a predecessor to the shifting or changing room. This was separated from the press room by an brick traverse and the hydraulic pipe passed beneath it. The Bramah press in this building may have been an innovation shortly after 1812 in the aftermath of a press house explosion, for the investigating committee of Engineers recommended that Bramah presses should be introduced. Hand presses nevertheless remained in use side-by-side with hydraulic presses and as late as 1830 in the

Corning and Press House [97, 98] screw presses were still in place next to the old-fashioned shaking frames used in the corning of gunpowder (Drayson 1830, Drwg 14). Curiously, in his report Drayson recommended that fourteen screw presses be introduced instead of Bramah hydraulic presses, without giving any explanation of his preference (1830, 71). The importance placed on the pressing of the powder may be judged from the investment put into this part of the manufacturing cycle. Pressing was seen to endow the powder with many qualities, the most important of which was the increase in its specific density. It also helped to compact the ingredients of the gunpowder further, making it less likely to separate into its constituent parts if it was roughly treated during transport. Pressing additionally made a powder less hydroscopic and less likely to produce dust during corning or granulation. When fired a pressed powder produced a greater volume of flammable gas than an unpressed powder. Its one drawback is that more of the powder is blown out of the gun unignited thereby shortening the range of the gun. This was not considered a great disadvantage, however, as unpressed powder would soon lose its effective range because of the effects of damp (Baddeley 1857, 15).

It was probably in the early 1850s that the two former horse **Corning Houses** [76 and 103] were converted in **Hydraulic Press Houses**. By the time of its introduction at Waltham Abbey RGPF, this was probably a proven technology in the industry as a water-driven press is documented as early as 1846 at the privately owned Oare Works at Faversham (RCHME 1991, 41). On North Site, the presses were powered by a hydraulic pump driven by a water-wheel utilising the head of water in the high-level canal system. The hydraulic pipe passed beneath the brick traverse of the former Corning House to the **Press House**. In this building the gunpowder was pressed between copper plates, about 800lb of powder at one time, with the press exerting a pressure of 700 tons/square foot on the powder. The powder remained at this pressure for fifteen minutes (Baddeley 1857, 15). The section on hydraulic power in the analytical description of **Section 3** contains a fuller discussion of this subject.

Granulating

The objective of granulation, also known as corning, was to render the presscake into grains or pieces of various sizes and shapes. The term 'corning' was acquired from the early process of breaking the powder down with shaking frames, while granulating was applied after the introduction of Sir William Congreve's granulating machine. Before the introduction of pressing, the millcake from the incorporating mills would be taken straight to the granulating house. The range of grain sizes required by a government factory producing only cannon and small-arms powders was relatively narrow and more waste in the form of small grains was rejected. This would either be sent back to the press house or, in the case of dusty powders, back to the incorporating mills for reworking. The rejection rates amongst the private-sector producers was far lower, as they had other markets such as sporting or blasting powders that used fine-grained powders.

Early methods of corning employed a parchment sieve through which the millcake was forced by hand. By the end of the 18th century this process had been mechanised with the use of a shaking frame; an example in use at the Royal Gunpowder Factory at Faversham is illustrated by Hodgetts (1909, fig. 14). This consisted of a rectangular frame suspended from the ceiling by ropes, with a crank beneath it to cause it to oscillate. On the frame were placed double sieves of parchment, the upper with wider holes of the required grain size and the lower one with small holes to catch the grains and let the dust through. On the top sieve was placed a 'cheese' of *Lignum vitae*: as the 'cheese' oscillated around the sieve so the cake was broken up and forced through.

Prior to government ownership a single hand-cranked corning house was identified in 1783 (WASC 900/1). The new corning houses built after the government acquired the factory probably conformed to the model illustrated from Faversham. By 1807 (WO55/2351) four **Corning Houses** may be identified, probably only differing in their motive power. A horse **Corning House** [RCHME 359] on Horsemill Island had been destroyed in an accidental explosion in 1801. The **Corning House, Press House and Wash-up House** [399b] on Lower Island and [116] north of the incorporating mills on Millhead were powered by central water-wheels. The other two **Corning Houses** [76 and 103] were horse operated; but these, too, were demolished around 1819 and after that date all corning was water-powered, including an additional **Corning House** [97]. The shaking frame remained in use at Waltham Abbey until 1843 when the last **Corning House** [97] with one in use was destroyed by an explosion.

In 1815 William Congreve, Comptroller of the Royal Laboratory at Woolwich, patented a new machine for granulating powder. The machine was designed to crush the presscake between toothed gunmetal rollers, which could be interchanged depending on the type of powder required. The rollers were set at a slant in a tall framework of triangular section, the rollers being set along the diagonal of the frame. Between and beneath the rollers were a series of graded screens that sorted the powder into different grain sizes and passed the rejected grains on to the next set of rollers. The sorted powders descended into separate boxes at the base of the machine, along with the rejected powder and the rejected grains or 'chucks'. The machinery is illustrated by Smith (1870, figs 18 & 19). This type of machine was first installed in the Lower Island **Corning House** [399b] in 1816 where it was powered by a water-wheel. It was widely adopted by other powder makers in Britain and modified versions corned all the powder at Waltham Abbey RGPF until the end of production. The new **Granulating Houses** constructed at the RGPF for this purpose, [395] on Lower Island and [AF4 formerly 56] and [S34], were all water-powered.

Pebble and Moulded Powders

The increase in the size of ordnance in the later 19th century placed new demands on the powder makers and the result was a period of intense experimentation and innovation. As the guns became larger and bolt-shaped projectiles replaced the cannonball, a powder was required that was slower burning and took a greater time to exert its maximum pressure. The solution lay in making the grains larger so it took the flame longer to reach the centre from the surface (*Encyclopaedia Britannica* 1950, 3). A special committee under Colonel Askwith, the then superintendent at Waltham Abbey RGPF, was set up in 1858 to study this problem (Morgan 1875, 1-28). Abroad the Russians were experimenting with moulded prismatic powders (see below also), while the Belgians were probably the first country to introduce pellet-shaped powders (Smith 1870, 75). In its final report the committee recommended that extensive and systematic experiments with pellet powder should begin. Experiments took place in 1865-6, and in 1867 it was accepted for as the service powder for all large charges (Smith 1868, 132). A hydraulic press for its manufacture was designed by Anderson of the Royal Laboratory at Woolwich; this was in use at Waltham by 1870 and probably remained in operation until the 1880s (Smith 1870, 74-80; Guttmann 1895, 258-9). Pellet powder was pressed into small cylinders with a small hollow or indentation in its upper surface. It was meal powder that was used for pressing, that is powder from the **Breaking Down House**: pellet powders dispensed with the need for all the other processing of conventional powders and probably only required stoving before packing (Smith 1868, 132-3).

Pebble powders were a 'cut' powder, later termed Class B (Wardell 1888, 56), and were cut from pressed powder (see flowline). Initially around 1870 all pebble powders were cut by hand using gunmetal knives, by cutting the presscake first into strips and then into 'pebbles'. This system was improved by Captain Smith, who devised an implement with knife blades arranged around a roller that would cut the blocks in one direction only. By 1872, however, Captain Morgan had invented a machine with cutting rollers set perpendicular to one another that would cut the presscake into cubes (Morgan 1875,3-12; Wardell 1888, 56-59). The larger pebble powders were still cut by hand using a gunmetal blade hinged at one end of the bench similar to an old-fashioned paper guillotine. The size of the 'pebbles' roughly corresponded to the size of the gun in which they were used. Originally all 'pebbles' were 0.5" square; this was later increased to 1.25" for thirty-eight ton guns and 1.7"-2" for eighty-one ton guns (*The Times* 1879, 3). Pebble cutting machines were located in the **Breaking Down House** [117] and a pebble cutting machine survived in **Press House** [103] until at least 1940 adjacent to the surviving press. After cutting, the 'pebbles' were glazed, which also removed any sharp edges that might break in transit; they were then dried in a stove for thirty-six hours in the case of smaller 'pebbles' and one hundred and twenty hours for the largest powders (Wardell 1888, 59).

Waltham Abbey RGPF was the primary producer in Britain of pebble powders, though some private producers such as the Kennall Vale Powder Company in Cornwall were producing pebble powders by the late 1880s, probably for government contracts (Earl 1978, 52). Pebble powders appear to have been a peculiarly British solution to the problem of producing a suitable charge for large-bore cannon. In America General Rodman was conducting experiments from the 1850s into the use of compressed powder for large-bore guns, which was known as Mammoth powder. In his early experiments Rodman used perforated compressed discs of gunpowder the same diameter as the bore of the gun. At the beginning of ignition, the disc presented a minimal burning surface but this constantly increased as the grain burned, thereby building up the production of gases as the space in the barrel behind the moving projectile increased (Guttmann 1895, 236). It is likely, however, that it was through his visit to Waltham Abbey that Du Pont was able to take back many ideas about pebble powders that led to his successful collaboration with Rodman (Wilkinson 1985, 44).

An alternative solution was moulded prismatic gunpowder. By the 1860s the Russians, who were the first to introduce prismatic powders (*The Times* 1890a, 14), and later Prussians were successively experimenting with the use of prismatic powders moulded with hydraulic presses. Smith (1870, 74-80) described the manufacture of pellet powders in some detail; his cursory coverage of prismatic powders suggests that they had yet to assume prominence at Waltham. It was nevertheless the need to produce moulded powders that drove the redevelopment of the site in 1878. In manufacture, moulded powders followed the production of granulated powders until the glazing stage, when it was removed for moulding. They differed slightly in composition, however. For moulded powders the proportions of 79% saltpetre, 18% charcoal and 3% sulphur were used, and for brown prismatic powder straw charcoal was substituted for wood charcoal (Wardell 1888, 61). The powder was moulded under either hydraulic or cam presses and was then moved for stoving.

Brown or Cocoa Powders

An area in which Britain started to lag behind the continental manufacturers in the second half of the 19th century was in the use of 'brown or cocoa' powders. These powders were also designed to overcome the problems of the larger charges in ever larger-calibre guns. In place of wood charcoal they used a lightly browned carbonised rye straw. The proportions of their ingredients were 79% saltpetre, 3% sulphur and 18% brown charcoal. The resulting powder was moulded into prisms 24.8mm in height with a central hole 10mm in diameter using the same methods as for black powder. Brown powder was found to have a slower rate of burning. This, combined with the perforated prism, resulted in a diminution in the initial pressure in the gun; the perforation in the prism then served to build up the gaseous pressure as with black powder. Brown powder was also found to give off less smoke than conventional black powders (Deering, 1889, 2-7). Brown powders had been introduced in Germany as early as 1875 and into Britain in 1881, when Heidemann and Duttenhofers had been invited to undertake its manufacture at Waltham Abbey RGPF for instructional purposes. In 1882 a British patent was taken out by J N Heidemann and a specification was finally approved by the British government in 1886 (Deering 1889, 1; Newbold 1916, 43; Wardell 1888, 110-113). Initially large quantities of black and brown prismatic powders were procured from Germany by the British government, until full production of these types commenced at Waltham Abbey RGPF in 1885 (Wardell 1888, 29;

Supply 5/435).

Dusting and Glazing

The grains from the granulating machines termed 'foul grain' was angular and dusty; dusting and glazing aimed to round the grains and through glazing make them less hydroscopic. Dusting was carried out in reels, of which there were two types - horizontal and sloping. In each type the reel consisted of a frame covered by canvas and wire cloth. In the sloping reel the grains passed from end to end and were collected in a barrel at the end. In the horizontal reels the powder was turned for a given length of time, differing grain sizes requiring slightly different treatment. In the 18th century an early form of dusting screen consisted of a slanted screen, down which the powder was tumbled so that the dust dropped through the screen (Hodgetts 1909, fig. 16). Sloping reels, however, had been introduced at Faversham by the end of the century and are illustrated in use at Waltham Abbey RGPF by Drayson in 1830. The dusting houses were powered from a central wheel with the building on each side housing up to six reels. This arrangement is clearly illustrated by **Dusting House** [159] on Millhead Stream, where the internal mounting blocks for the reels remain in place. At the northern end of the factory a similar pattern is repeated by **Dusting House** [RCHME 275], where its central wheel pit is clearly visible and the buildings to either side survive as earthworks.

In the **Glazing House** the powder was placed in stout wooden barrels by a small door on the barrel's side: the barrels were supported on their central axis. As the grains revolved in the barrel the action of rubbing together would round its edges and impart a glaze to the grain. A small amount of graphite was sometimes added to the powder to give a harder glaze. This was generally only done to the larger grains as it acted as an inhibitor to the ignition of the powder. While this was a desirable effect in cannon powders it was inappropriate for small-arms powders.

Stoving

Some moisture from the powder was lost during the dusting and glazing processes through heat generated by friction; the remaining moisture was reduced through stoving. The earliest form of drying was simply to lay the gunpowder in the open air and allow the circulating air and sun to dry it. While this method may have worked in southern Europe, it is unlikely that it ever widespread or successful in England. However, three sun stoves or drying leads are shown in the engraving of the Waltham Abbey factory by Farmer in 1735 (Fig. 15). By this date **Gloom Stoves** were also in use for drying powder at Waltham Abbey. A gloom stove consisted of two chambers, a fire room and a drying room. Set into the back of the fire was a large cast-iron fireback that protruded into the drying room, in which the gunpowder was laid out on shelves to dry. In the late 18th a new and safer method was devised for drying gunpowder, which consisted of stoves heated by steam. The RGPF persisted with gloom stoves, however, and indeed a new large **Gloom Stove** [148, 149, 150] was built shortly after the government took over the works even though the technology of steam stoves was available.

The first **Steam Stove** [RCHME 330] was constructed at Waltham Abbey RGPF by 1827 towards the northern end of Millhead Stream. The stove consisted of a central circular brick traverse enclosing a further oval shaped wall and at the centre a steam boiler with a chimney above. This boiler supplied drying stoves to either side with steam through a network of pipes to dry the powder spread out on a series of racks (illustrated by Drayson 1830, fig. 22). The drying rooms were each served by a loading room leading onto a covered loading stage where the powder was brought by barge. This stove formed the model for the other two almost identical **Drying Stoves**, [S90] built in 1879 and [26] built in 1884. The former **Gloom Stove** was also converted into a **Steam Stove** around 1840, but its ground plan remained unaltered.

Finishing, Blending and Packing

After drying, the large-grained powder was sent to the **Heading-up House**, where it was sealed into barrels for issue. Finer-grain powders were returned to the dusting house, and there any last traces of dust was removed in horizontal reels before it, too, was barrelled for issue. By the end of the 19th century all powders were finished to remove any lingering dust (Wardell 1888, 53). Blending was carried out before stoving, before finishing, and finally before it was barrelled. In this way batches from different incorporations were mixed to ensure that a uniform product was produced that could be relied upon to give uniform ballistic results. From the **Heading up House** the barrelled powder was taken to the factory magazine, **The Grand Magazine** [1]. When 500 barrels had accumulated there they were removed by barge to the government magazines on the north bank of the Thames estuary at Purfleet (Wynter 1858, 246).

Examination and Proof

The aim of a good gunpowder maker was to produce an 'equal' powder, that is one where an equal charge will produce an equal result every time. This was recognised as an impossible ideal owing to the many variables in manufacture and because of the differing methods between manufacturers. Gunpowder after finishing should have the appearance of uniform, angular crisp grains that are sharp to the touch. It should also be durable in handling and able to withstand differing atmospheric and transport conditions without deterioration; and its specific gravity should be not less than 55lb to the cubic foot (Baddeley 1857, 20).

Proving of gunpowder was carried out at Waltham Abbey RGPF from at least 1807 (WO55/2351), when two small sheds for the proof mortar and proof carbine may be identified close to the former **Administrative Buildings** [A230-A234]. Drayson in his treatise of 1830 illustrates a vertical eprouvette, that moved a weight up a vertical column when the gunpowder was ignited, and a gun eprouvette (Drwg.27). The gun eprouvette consisted of a small cannon suspended on a carriage, with what appears to be a graduated scale to measure the amount of swing as the cannon was fired. This probably corresponds with the 1-pounder gun pendulum described by Baddeley (1857, 27) whereby the velocity of a cannon ball could be computed from its recoil. The use of the eprouvette had fallen out of favour at the RGPF by the middle of the century (Baddeley 1857, 26), and Baddeley had little faith in the pendulum method either. Proof was also undertaken by firing a measured amount of powder: in the middle of the 19th century an 8-inch mortar charged with 2oz of powder was reckoned to throw a 68-pounder shot in the range of 270-300 feet (Baddeley 1857, 20). In the second half of the 19th century **Proof Butts** [RCHME 305] were established at the northern end of the Lower Island Works to the south of the **Sulphur Refinery** [375, 376], as illustrated by Smith (1870, pl. 25). By the end of the century, gunpowder was tested for seven attributes; a visual inspection, a 'flashing' test to check it was properly incorporated, sifting to check size and shape, density, uniform action when fired, correct proportions of ingredients, and that it was able to withstand absorption of a given amount of water (Smith 1870, 81).

B *Manufacture of chemically-based explosives*

[a] Guncotton

Celluloses under the action of strong nitric acid (usually with sulphuric acid as a dehydrating agent) form the nitric esters known as nitrocellulose: where cotton is the cellulose the result is guncotton. The term nitrocellulose is a misnomer, as the compounds formed by the action of nitric acid on celluloses are nitrates or nitric esters and not nitro bodies. A more accurate term for these compounds would be cellulose nitrates; the term nitrocellulose is retained, however, through historic usage (HMSO 1938, 86). Nitrocellulose may be referred to as 'soluble' or 'insoluble'. Insoluble nitrocellulose contains more than 12.8% of nitrogen and is only soluble to a limited extent in ether-alcohol. By contrast, the lower nitrates are entirely soluble in ether-alcohol (HMSO 1938, 93).

Although the manufacture of guncotton has left relatively few physical remains on North Site, a brief description of the manufacturing procedure will serve to underline the importance of Abel's work at Waltham Abbey in its development. A flow diagram summarising the processes of manufacture in the production of guncotton may be found in **Appendix 2**.

The properties of guncotton were known about from the 1840s, but interest waned after a series of explosions during its manufacture. The first English factory to produce guncotton, the Marsh Works (TR 06 SW 64) at Faversham in Kent owned by John Hall and Son, ceased production after less than a year when some twenty people lost their lives in an explosion in 1847 (Percival 1986, 11). General von Lenk nevertheless persevered with his experiments at Hirtenberg in Austria and produced a serviceable guncotton. His principal precautions in producing a strongly nitrated cotton included; cleansing and desiccation of the cotton, use of the strongest acids available, steeping the cotton in fresh strong acids after the first emersion and its continuance for forty-eight hours. The final stage was a thorough rinsing of the cotton to remove all traces of acid by washing it for several weeks in a stream of water and finally in a solution of potash (Cavendish nd, 129). It was this basic recipe that Abel took and began work on at Waltham Abbey RGPF. Abel's researches quickly bore fruit and in 1864 he patented the pulping and pressing of guncotton (Hodgetts 1909, 56). The pulping of the guncotton after its nitration and preliminary washing ensured that the later washing removed all traces of the acids used during nitration and that the resulting pulp could easily be tested for its purity. Earlier methods of washing had failed to remove all traces of the nitrating acids that could lead to decomposition and ultimately to an explosion of the nitrocellulose. This pulp could then be moulded into cylinders or discs using hydraulic presses. At this date, too, Abel was still hoping to make the breakthrough that would allow him to granulate the guncotton so that it could be used a propellant (Nathan 1909a, 178). Abel's method also meant that cotton waste could be used as the basic raw material as opposed to the more expensive skeins previously found necessary, thereby reducing the cost of the finished guncotton. Through the initial teasing of the cotton that he introduced, he was able both to remove foreign objects and to open it out, thereby ensuring that a maximum surface area was available to the action of the acids. One of Abel's team, Mr E O Brown, in 1869 made the further discovery that guncotton could be detonated in the wet and compressed state by the use of a primer of dry guncotton and a detonator. The importance of this discovery was that it enabled guncotton to be used in a wet state, in which it was uninflammable and relatively safe to transport. Detailed accounts of the early manufacturing process of guncotton may be found by Younghusband 1873 and in Wardell's handbook of 1888.

Abel's work re-established guncotton as a practical military explosive and led to the commencement of guncotton production on a large scale at Waltham Abbey RGPF. The influence of his work also spread to private manufacturers, who quickly took up his patent of 1864. Notable among them were Messrs Prentice at Stowmarket, who had been using the von Lenk system since 1861. As the New Explosives Company, the Stowmarket factory continued the Abel method of guncotton into the 20th century (Nathan 1909a, 178). The influence of Abel's work also spread to the continent. For after the erection of the guncotton factory at the southern end of Area H at Waltham Abbey, representatives of the German government inspected the plant and were later to establish a plant along similar lines at Kruppamuhle in Silesia (Hodgetts 1909, 59). Development work continued to take place after the production began at Waltham Abbey, with the result, for example, that about the middle of 1873 the boiling of guncotton after nitration to effect its stabilisation was introduced, a process then widely adopted elsewhere (Nathan 1909a, 183).

The process of guncotton manufacture devised by von Lenk and improved upon by Abel remained in use at Waltham Abbey RGPF for around thirty years. The most important change came in 1905, however, when the guncotton factory, now on the South Site, was enlarged and in August of that year the displacement method of nitration was introduced. The older method used by Abel involved the laborious movement of the cotton between the various dipping pans, nitrating pots and later washing tanks. In the displacement system devised by J M Thomson and W T Thomson of the RGPF, the cotton was immersed in an earthenware pan containing the mixed acids and weighed down with a perforated earthenware plate; it was left for two and a half hours to nitrate, the whole covered by a fume hood. The acids were then run off through a drain cock at the base of the pan, and the cotton was washed through by water. The guncotton was next removed from the displacement tanks and taken over to the boiling vats. The new system was hailed as a great advance on the old nitration system in terms of cost savings in labour, power used, acid recovery and the less frequent need to replace the plant (Nathan 1909, 182-3); a 170% improvement in yield was claimed and a more stable guncotton was produced. This method remained in use with minor modifications throughout the First World War and into the Second World War, when the RGPF was producing 120 tons of guncotton per week in 1940 (Simmons 1963, 44).

From the nitrators the guncotton underwent a number of purification processes, beginning with boiling to remove any traces of acids; it was then pulped in the beaters between rotating knife blades, before being run over a grit trap and blanket run to remove any foreign matter still remaining in the pulp. From here it was run into the potchers, where it received a final washing, before it was mixed with guncotton from the other nitrators in a tank capable of holding four tons. From there it passed to the presses (HMSO 1938, 86-92).

[b] **Nitroglycerine**

The principal sources for the study of the technology of the nitroglycerine and cordite manufacture lie in official handbooks and technical papers produced around the turn of the century, the most influential of which emanated from Waltham Abbey RGPF itself. The purpose of this section is to describe in layman's terms the production of these explosives and the developments that took place, and this simply emphasises the importance of the Waltham plant in the development of the industry.

The adoption of propellants based on nitrocellulose and nitroglycerine marked a complete break in the propellants industry, which was traditionally based upon black powder and latterly brown powders. The plant needed for its production was that of the high explosives industry, which was producing guncotton and nitroglycerine-based products for demolition and blasting purposes. The advantages of cordite compared to gunpowder as a propellant may be judged by the comparison between the largest 110-ton, 16.25 inch gun of the 1880s that required a charge of 960lb of prismatic powder, and the 100-ton, 15 inch guns of the super-dreadnoughts of the First World War which used a 400lb charge of cordite MD to project a far heavier shell at almost twice the muzzle velocity (Lewes 1915, 823).

Such was the perceived urgency to establish a nitroglycerine plant that Colonel Noble, the factory's superintendent, was sent to Oplagen in Germany to inspect the plant there. He returned with sketches for the plant and recommended that the machinery for it should be bought from Germany. In the meanwhile advice was sought from Mr McRoberts of Nobel's Ardeer factory, where nitroglycerine had been manufactured since 1873. He suggested a number of modifications to the German plant, in particular that the glycerine should be injected into the mixed acids as at Ardeer. It therefore appears that the plant that was in operation by March 1891 was a modified version of the Oplagen plant rather a direct copy (Simmons 1963, 47-51). This first nitroglycerine factory was built on the Quinton Hill site, ie South Site, south of the newly completed guncotton factory. A useful section through this plant is shown in the 1895 service treatise (pl XIV) and a plan of the original plant is shown in appendices 1 and 2 of the 1894 Sandhurst Committee's report into the explosion at the first Quinton Hill plant.

Nitroglycerine is formed by the nitration of glycerine in a mixture of nitric and sulphuric acid. The nitroglycerine factory was so arranged that the chemicals could largely flow by gravity: where it was necessary to move chemicals against gravity compressed air pipelines were used. At the centre and highest point of the Quinton Hill factory were two **Nitrators** [476, 477] each surrounded by a solid brick traverse. In between and above the **Nitrators** was the **Charge House**; in this building were two tanks, one containing mixed acid (nitric and sulphuric) and the other glycerine. The acids were moved to the tank under compressed air injected into an **Acid Egg**, an egg shaped iron tank. From the **Charge House** a charge of 1054lb of nitric and 1785lb sulphuric acid was let into the nitrating vessel. This consisted of a cylindrical lead vessel with a sloping base and lead cooling coils in the interior, through which passed cooling waters or brine. The acids would be cooled to 16°C before the glycerine was sprayed into the base of the nitrating vessel. If the temperature during nitration rose above 22°C, the whole charge was 'drowned' in a drowning tank of water situated below the nitrating vessel. As the glycerine was nitrated it was displaced through the acids forming an oily layer at the top of the tank. A charge of 350lb of glycerine would take around forty-five to sixty minutes to be nitrated.

After nitration the whole charge was discharged through an earthenware cock lubricated with vaseline at the base of the nitrating vessel into the separating tank. This was a square-shaped tank with a sloping base, where the charge was held for around forty to forty-five minutes while the nitroglycerine was displaced to the surface forming a layer about 4.5 inches thick. This vessel, too, was connected to the drowning tank in case the temperature rose too high. By means of earthenware cocks at the base of the vessel the waste acids were run off to the **After Separating House**, where those acids could be recovered. After all the acids had been discharged, the nitroglycerine was run into the prewash tank and there it was washed in water four times, the last time with warm soda water. The wash waters were discharged to the **Wash Water Settling House**, where any remaining nitroglycerine was removed.

From the **Nitrator** the nitroglycerine was run along a covered lead-lined gutter to the **Washing House** [483] and into two lead-lined barrels containing a solution of soda water to remove any acids still adhering to the nitroglycerine. The nitroglycerine sank to the bottom of the barrels. The barrels were supported on a raised platform; under it was a drowning tank, into which the charge would be tipped if the temperature rose above 50°C. In the barrels up to 750lb of nitroglycerine was washed by mixing it with water using a compressed air supply. When the compressed air supply was turned off the nitroglycerine sank to the bottom of the barrel, where it was let out through the lower of two taps. The upper tap was used to discharge the waste wash waters to the **Wash Water Settling House**. The nitroglycerine was then filtered through salt to remove any remaining water. From the **Washing House** the waste water was sent to the **Wash Water Settling House** and the nitroglycerine flowed along another lead-lined covered gutter to the **Weighing House**. In the **Weighing House** it came into two lead tanks each capable of holding 2200lb of liquid nitroglycerine. The practice at this time was to bring dried guncotton to the **Weighing House** where the nitroglycerine was poured onto it; the resulting paste was then taken to a **Mixing House** before it was delivered to the **Incorporating House**. Storing such large quantities of liquid nitroglycerine seems to have been a practice peculiar to Waltham Abbey. For after an explosion in the **Washing House and Nitroglycerine Store** in 1894 the investigating committee remarked that private factories would not be allowed under Home Office Licence to store nitroglycerine in this manner and recommended that in future it should immediately be mixed with guncotton (War Office 1895, 81-8; Sandhurst 1894). The Royal Gunpowder Factory was exempted from the regulations laid down by the 1875 Act (Victoria 1875, Ch 17) that applied to private producers.

Waltham Abbey RGPF in the early 1890s was the only producer of cordite in the country and service needs dictated that the nitroglycerine facility damaged in this explosion be brought back into immediate operation. The original nitration plant was retained, the **Washing House** [483] was rebuilt using a new design of a circular structure partly sunk into the ground and surrounded by an earthwork traverse. The use of an earthwork was preferred as it would result in less flying debris should a building explode. Remarkably, this **Washing House** dating from 1894 survives intact on South Site with the two washing barrels and other interior fittings *in situ*. The dangerous practice of storing liquid nitroglycerine was replaced by a system where the nitroglycerine was mixed almost immediately with guncotton in the **Mixing Houses** [485 and 486] to produce relatively inert cordite paste.

Another recommendation of the Sandhurst Committee was the establishment of a duplicate factory (Sandhurst 1894, xx). This need was partly met by encouraging the private manufacturers Kynochs to establish a cordite factory at Arklow in Ireland in 1895 (Kelleher 1993, 91-113), followed two years later by Kynochtown on the Thames estuary at Corringham in Essex. The National Explosives Company at Hayle in Cornwall also were awarded a government contract for cordite, while Nobel and Company failed to secure an early contract (Trebilcock 1966, 368). Reliance on the Quinton Hill plant was also reduced by the construction of a new nitroglycerine factory at Waltham Abbey on an area in the area of North Site known as Edmonsey Mead. The design of this new installation followed the principles established in the reconstruction of the Quinton Hill factory. The buildings were enclosed by high earthwork traverse mounds, their centres revetted by a brick wall, and the entrances to the enclosed buildings were along curving tunnels through the traverse mound. To overcome the problem of reduced production created by the elimination of a liquid nitroglycerine store, the **Nitrator** [E2] was now served by two **Washing Houses** [E3 and E5], each of which eventually served several **Mixing Houses** [S34, 46, 62, 63, and 76]. The nitration and purification processes described above were followed in the new buildings (War Office 1900, plate XX section through Edmonsey factory), although the arrangements of acid and glycerine supply to the **Nitrator** were altered. Prior to the construction of the Edmonsey factory, acids had been acquired commercially; but to ensure the high concentration and purity required for nitration, a purpose-built acid factory was constructed to the west of the nitroglycerine factory. The concentrated nitric and sulphuric acid along with glycerine was originally stored in separate tanks in building [72]. When the chemicals were required they were loaded into small tramway 'bogies' and pushed to the base of the **Nitrator**. At the base of the **Nitrator** was a lift to raise the bogie to the top of the mound, where it was held under cover in the charge house on top of the mound. The contents of the bogies were discharged by gravitation into the nitrating vessel, and the mixing of the nitric and sulphuric acids took place at this stage. The glycerine was discharged into a separate tank in the **Nitrator** building before it was sprayed into nitrating vessel. The remainder of the process was as described before, with the important improvement that the nitroglycerine was mixed almost immediately with guncotton. The nitroglycerine was thereby stored as cordite paste rather than in liquid form.

The use of earthenware cocks at the base of the nitrating vessel and the separating and washing tanks was recognised as a possible danger if the taps stuck because of differential warming of the parts. The validity of these concerns was borne out with a minor explosion in No.2 Nitration House on Quinton Hill in 1901 that happened in one of the earthenware cocks (Nathan and Rintoul 1908, 199). The solution to this problem was to remove the earthenware cocks from the base of the tanks and discharge the nitroglycerine from the top of what was now termed the 'nitrator separator'. To achieve this, waste acid from the previous charge was stored in tanks on top of the mound. At the end of a nitration cycle, a charge of waste acids was let into bottom of the nitrator separator so as to push the nitroglycerine to the top of the tank and over into a gutter connecting it to the prewash tank. The operation was controlled by observing glass windows in the side of the tank that allowed the division line between the acids and nitroglycerine to be seen. The waste acids were left in the nitrator separator until the next charge was ready as it was found this prevented erosion through action of acid fumes. The cocks were also removed from the base of the pre-wash tank and the nitroglycerine was now run out along a rubber tube to the lead-lined and canvas-covered gutter leading to the **Washing House**. It is uncertain whether the method of delivering mixed acid and glycerine to the **Nitrator** also changed at this date or was a later modification. For a plan of the nitroglycerine factory (P16), unfortunately undated but perhaps originating around 1940, shows that the acid tower lift had been demolished and replaced by an acid pipeline leading from building [72] to the **Nitrator**, through which the acids were forced against gravity by compressed air.

The wooden lead-lined washing barrels were replaced by lead tanks without cocks, in which the nitroglycerine was filtered through a flannel bag containing salt to remove any traces of water. All the wash waters and soda solutions were prepared in the charge house on top of the **Nitrator** and run into the nitrator separator and wash houses as required. A further refinement added to the process was the filtration and purification of the wash waters to remove limescale caused by the local hard waters. All the washing waters were collected in the **Wash Water Settling House** [E4], where any remaining nitroglycerine was collected. The resulting mud was removed at the end of each week and washed in the **Mud Hut** [E16] to remove any nitroglycerine still clinging to it and to render it alkaline, converting the sulphates into carbonates. The resulting residue was mixed with paraffin and burnt (War Office 1907, 88-90; Nathan & Rintoul 1908, 193-205; War office 1938, 80-83). This, the

Nathan and Rintoul method, became the preferred method of manufacture at Waltham Abbey from 1903 when No.1 Nitration House on Quinton Hill was converted to the new process: the Edmonsey plant was converted in 1904. After this date all nitroglycerine production was transferred to Edmonsey; the newer Quinton Hill plant was mothballed never to be used again, while the older Quinton Hill plant was demolished. This also coincided with a reduction of the nitroglycerine content of cordite by almost 50%, thereby considerably reducing the demands placed on the nitrators. The Nathan and Rintoul method of manufacture appears to have remained unaltered until the closure of the factory and may have still been employed when small-scale production started up again in the early 1960s, although by this date experiments were taking place in [E5] using the Schmid method of continuous nitration (HMSO 1938, 84) in place of the earlier batch methods.

[c] **Cordite**

A flow diagram showing the manufacturing process of cordites M.D. and W. is included in **Appendix 2**.

Cordite is a propellant consisting of a uniform colloidal mixture of nitrocellulose and nitroglycerine with the addition of a stabiliser. The name 'cordite' originates from the cord-like strands it was usually pressed into before being tied together in silk charge bags or pressed into rifle cartridges. It was first recommended for service use in 1888 and by 1890 a plant had been established on the South Site at Waltham Abbey RGPF. In 1891 cordite was accepted into service use for .303 rifle cartridges (Hogg 1963, 1414). Cordite Mark I consisted of 58% nitroglycerine, 37% nitrocellulose and 5% stabiliser (mineral jelly). Experience gained during the Boer War between 1899 and 1901 found that the high nitroglycerine content caused the charge to burn with such great heat that it resulted in excessive barrel erosion. This was overcome by reducing the nitroglycerine content to 30% to produce what was known as Cordite M.D., ie modified (Nathan 1909b, 443; War Office 1938, 99-101). Cordite was further developed after the First World War at Waltham Abbey RGPF in an attempt to produce a propellant free from smoke and flash. The resulting product was known as Cordite W., 'W.' standing for Waltham since it was developed there in the 1930s, using carbamite as the stabiliser in place of mineral jelly (War Office 1938, 15). Cordite M.D. remained in use for rifle-sized charges while Cordite W. was used for cannon sizes. Other important variants included Cordite R.D. (Research Department) B., developed during the First World War to overcome the shortage of acetone used as a solvent in other types of cordite. A further variation called Cordite S.C., ie solventless carbamite, was developed as a naval propellant, though no evidence has been found that this variant was produced at Waltham Abbey RGPF.

The manufacturing of guncotton is briefly described in **Appendix 1** B section [a] above. It appears that at the turn of the century the wet guncotton was sent in an uncompressed state for drying and then mixing to produce cordite (Engelbach 1899, 407). This potentially hazardous method of working with loose dry guncotton was later replaced by using compressed blocks of guncotton. After the guncotton had been pressed into cylinders known as primers, measuring three inches in diameter and six inches in length, this wet guncotton, which contained around 30% of moisture, was moved to one of the wet guncotton magazines for storage (HMSO 1938, 102). Guncotton required by the cordite processing facilities on North Site was moved by barge from South Site to the **Wet Guncotton Magazines** [1 and 2a] at the very northern tip of the factory. The **Grand Magazine** [1] therefore underwent a subtle change from the factory magazine where finished gunpowder was stored to a large expense magazine where wet guncotton was stored prior to further processing. From the **Wet Guncotton Magazine** the guncotton was taken by barge and later perhaps by the tramway to one of the batteries of **Guncotton Drying Stoves**. The primers were dried on galvanised wires supported on wooden frames; in the only two instances where these fittings survive, stoves [29] and [98a], the racks are metal. Drying was by hot air supplied by a **Fanhouse**. In the earlier, northern complex of stoves separate **Engine Houses** were provided to power a belt drive to the fanhouses, which blew air over heaters and into the stoves; whereas in the later stoves it appears that there was a single heat exchanger within the central fanhouse along with the blowers. In the heat exchanger air was passed through pipes surrounded by steam in a chamber known as a heater; the moisture content of the air was reduced to 10% before it was blown into the stoves (War Office 1895, 89). Steam heat for the drying stoves was probably produced in **Boiler Houses No.1 and No.2** [80 and 80a] in the acid factory, later supplemented by **Boiler House No.3** [86a]. Each centrally placed **Fanhouse** or **Engine House** usually served a pair of stoves. The warmed air was then blown into the stove by a powerful fan through lagged pipes. In the earlier buildings the warmed air was distributed around the stove via a horizontal pipe lying in the gully between the stove and the revetment wall of the traverse: these appear to have been replaced in a number of the stoves by a single, large-diameter, lagged sheet-metal pipe attached to the apex of the stove's conical roof. Refinements were made to the recommended drying temperatures as the process became better understood, so that by 1938 5000lb of guncotton in a single stove was dried for sixty hours with an initial inlet temperature of 70°C later brought down to 35°C (War Office 1938, 101). After drying, the guncotton was left in the stove, which now functioned as a store or magazine, obviating the need to unload the stove until the dried guncotton was required.

In 1936 a new type of guncotton stove, the **Quinan Stove** [22a], was built replacing an earlier drying stove also numbered 22a. This pattern of stove had been patented around the turn of the century by W P Quinan, an American and sometime manager of De Beers explosives factory at Somerset West in Cape Province, South Africa (Reader 1970, 156). The basic principle of the unit was to dry the guncotton in small quantities. Hot air was generated in a similar manner to that of the earlier **Fanhouses** by forcing air through a heater warmed by steam in a **Fanhouse** [22a/3]. From there it was blown along the principal air main into one of the fifteen bays within the stove. In each of these bays stood a pan with a retaining screen seated in it, on which the charge of wet guncotton on a cloth sheet was placed. Warm air was blown into the pan and up through the screen onto the underside of the guncotton charge. At the end of the drying process the warm air pipe could be closed by a valve operated by a wire from inside the building. If the guncotton was required for immediate use, the guncotton could be cooled by opening a second pipe containing compressed air, that would cool as it left the pipe and expanded. The dried guncotton was lifted out still on its cloth sheet, thereby reducing the handling of the now more hazardous dry guncotton. The Quinan type of stove therefore had the advantages over the older form of **Guncotton Drying Stove** of reducing the amount of guncotton in a stove at any one time and also reducing the amount of drying time, thereby compensating for the smaller individual load in a greater through-put of material (Fraser & Chalmers 1908; War Office 1938, 101-2).

The report into the explosion at **Mixing House** [46] in April 1940 (No author 1940) usefully described the procedures involved in the mixing of cordite paste. Washed nitroglycerine was run down from one of the **Washing Houses** [E3 and E5] along a lead-lined and covered gutter and into one of the **Mixing Houses**, where it was stored in a lead-lined tank capable of holding around 1200lb of nitroglycerine. After the guncotton had cooled in the **Drying Stoves**, the dry guncotton primers were roughly broken up and placed in india rubber bags for transport by barge to the **Weighing House** [S27], where it was weighed into rubberised bags containing 39lb of guncotton and moved to one of the **Mixing Houses** [46, 62 and 63, and later 46A and 46R]: for a time [L101] was also used as a **Mixing House**. In the **Mixing Houses** 18lb of nitroglycerine was run into a lead burette for pouring onto a sack of dry guncotton, which was then tied. The guncotton and nitroglycerine was mixed by hand on one of the lead tables within the building before being forced through a 1/2 inch mesh brass sieve into a calico bag. The combination of nitroglycerine and guncotton was now known as cordite 'paste'. Not all the mixing was done in the **Mixing Houses** with the nitroglycerine tanks; some might also be moved to other ancillary **Mixing Houses** [76, 88a and S34 and later E14] which were a greater distance from the **Washing Houses**. Later the distinctive role of the **Mixing Houses** in which the nitroglycerine was first poured onto the guncotton was reflected in the more specific name of **Pouring on House**. Samples were taken both from the nitroglycerine tank and the mixed cordite to the Laboratory for testing.

From the **Mixing Houses** the paste was taken either directly to the **Cordite Incorporating Mills** or to a **Paste Store**. Many of these stores were added to the factory around 1910 and elsewhere former gunpowder expense magazines were converted to paste stores. The incorporation of the cordite was at first carried out in three converted **Gunpowder Incorporating Mills** [L145], [L148] and [L149]; [L153] was later added to this group. A further group of purpose-built **Cordite Incorporating Mills** [L143, L146, L151 and L155] were added during the First World War. Again, a report into an accidental explosion, in this case **Cordite Incorporating Mill** [L148], provides useful details of the machinery and procedures in use in a cordite incorporating mill (Nathan 1902). A by-now familiar theme of the borrowing of proven technology from other industries was repeated with the use of incorporating machines manufactured by Werner, Pfleiderer and Perkins that were similar to those used by bakers for mixing bread dough for the incorporation of cordite paste. At first two sizes of machine were used at Waltham Abbey RGPF, one capable of incorporating 75lb and the other 150lb of cordite (War Office 1895, 93): by the turn of the century a medium-sized machine had been introduced for handling 120lb of cordite (Nathan 1902, 6). Each mill consisted of a tub with two spindles, each with two blades. Each incorporating machine had a drenching tub placed over it in a similar arrangement to that fitted over the earlier gunpowder mills. The **Cordite Incorporating Mills** were powered by an overhead drive shaft running through the buildings: this passed through the bay walls in a bearing box and the machines were connected to the drive shaft by leather belts. For at least the first decade of cordite incorporation the central engine houses and boiler houses of the former gunpowder mills remained in use and probably retained the original engines. Certainly in 1902 when the Group G mills [L148] exploded four out of the five chimneys were in operation that morning. It appears, too, that the drive shafts were connected between the mills, for when mill [L148] exploded it was being driven from the engine in [L157]. Around 1908/9 the tall chimneys in the yards of the incorporating mills were demolished. This almost certainly indicates a change in motive power and probably a conversion to electric power. This may coincide with the construction of the main **Power House** [A210]; unfortunately the date of this building is not known precisely but may be bracketed between 1908 and 1915.

In the production of Cordite M.D. a portion of the solvent acetone was poured into the incorporator before a charge of paste weighing 57lb was tipped into the machine. The machine was then started and allowed to mix the initial batch for a minute or two before the remaining cordite paste was added. A total of 50lb 4oz of acetone was used for a 150lb charge of cordite (War Office 1895, 94). After about three and a half hours 6lb of mineral jelly was added. The mineral jelly was initially an attempt to prevent fouling of the gun barrels by deposition of a metallic coating from the shot as it passed along the barrel. It was later found that the mineral jelly had the additional property of acting as a chemical stabiliser within the cordite (Nathan 1909b, 443-4). There is circumstantial evidence that Cordite R.D.B. was manufactured at Waltham Abbey RGPF during the First World War. This used a soluble nitrocellulose with a lower nitrogen content soluble in ether/alcohol rather than the scarcer acetone that the non-soluble nitrocelluloses required. When this variant was produced, the cordite remained in the incorporator for another three and a half hours, giving a total of seven hours in all. For the production of Cordite W., carbamite was used in place of the mineral jelly, the whole required amount being placed in the incorporator at the beginning of the operation (War Office 1938, 102).

From the **Incorporating House** freshly mixed cordite paste was taken to one of the **Press Houses**. Three types of presses were used at Waltham Abbey RGPF for extruding cordite paste, namely screw, screw plus hydraulic, and hydraulic (War Office 1895, 95). Screw presses were generally found to be best for the smaller diameters of cordite required for rifle cartridges, although they utilised hydraulic rammers to load the pressing cylinder. For the cords of larger diameter used in the large guns a hydraulic press was employed. After pressing, the small-diameter cords were wound onto reels for drying while the larger cordite was cut to the required lengths. From the **Press House** the cordite was moved on to the **Drying House** and there it was dried for between three and a half and fifteen days depending on size. The **Drying Houses** were heated by steam pipes, whose sawn-off remains may be seen on the exteriors of these buildings. The object of the drying was twofold; first to remove any remaining moisture in the cordite and secondly to drive off the acetone used during incorporation. Dried reels were moved to the **Reeling House**, where the small cords were stranded together to form an untwisted rope of sixty strands. This sixty-strand rope ensured that the batches were adequately blended together to guarantee an average product giving uniform ballistic results. Larger cord sizes were blended by hand. The finished cordite was finally moved to the **Cordite Reel Magazine** for shipment off site and for use in cartridge- or charge-packing factories (Anderson 1898, 69-129).

An important technological innovation introduced around 1905 was the recovery of the acetone used as a solvent in the production of cordite. For this the stove in which the cordite was initially dried was sealed except for a small opening at the door. The excess air and the acetone vapour was drawn across a stream of sodium bisulphate solution, which caused the acetone to combine with it to form a bisulphite or soluble salt. From this compound it was estimated that around 50% of the acetone used during the incorporation process could be recovered by this method. After this initial drying the cordite was then removed for final drying, and no attempt was made to recover any more acetone as the amounts were too small to be economical (War Office 1938, 103).

[d] Trinitro-phenyl-methy-nitramine, aka Tetryl or Composition Exploding (C.E.)

A flow diagram for the manufacture of tetryl is included in **Appendix 2**, and a detailed account of its manufacture in the 1938 War Office *Textbook of Explosives.* As discussed in the analytical description of North Site, the manufacture of tetryl has left relatively few physical remains on the site. A brief outline of its processes is included to place the Tetryl Factory alongside Horsemill Stream and more particularly the surviving components of the later factory on the east side of North Site between the Old River Lea and Cornmill Stream within a manufacturing context.

The manufacture of tetryl may be divided into two main stages, the nitration of dimethyl aniline and the purification of the crude tetryl. The sulphation of the dimethyl aniline was carried out in a cast-iron pot fitted with cooling coils and stirring gear. The pot contained 1500lb of 94% sulphuric acid into which 96lb of dimethyl aniline was introduced, the temperature not being allowed to rise beyond 30°C. The dimethyl aniline sulphate was then run into lead pots containing 800lb of 90% nitric acid and here the temperature was allowed to rise to 70°C. After cooling, the charge was filtered through quartz filters before passing to settling tanks, where the crude tetryl formed on the surface of the acid and could be skimmed off. The tetryl was washed in water, followed by boiling, before it was placed in a centrifuge and the water content was reduced to around 5%.

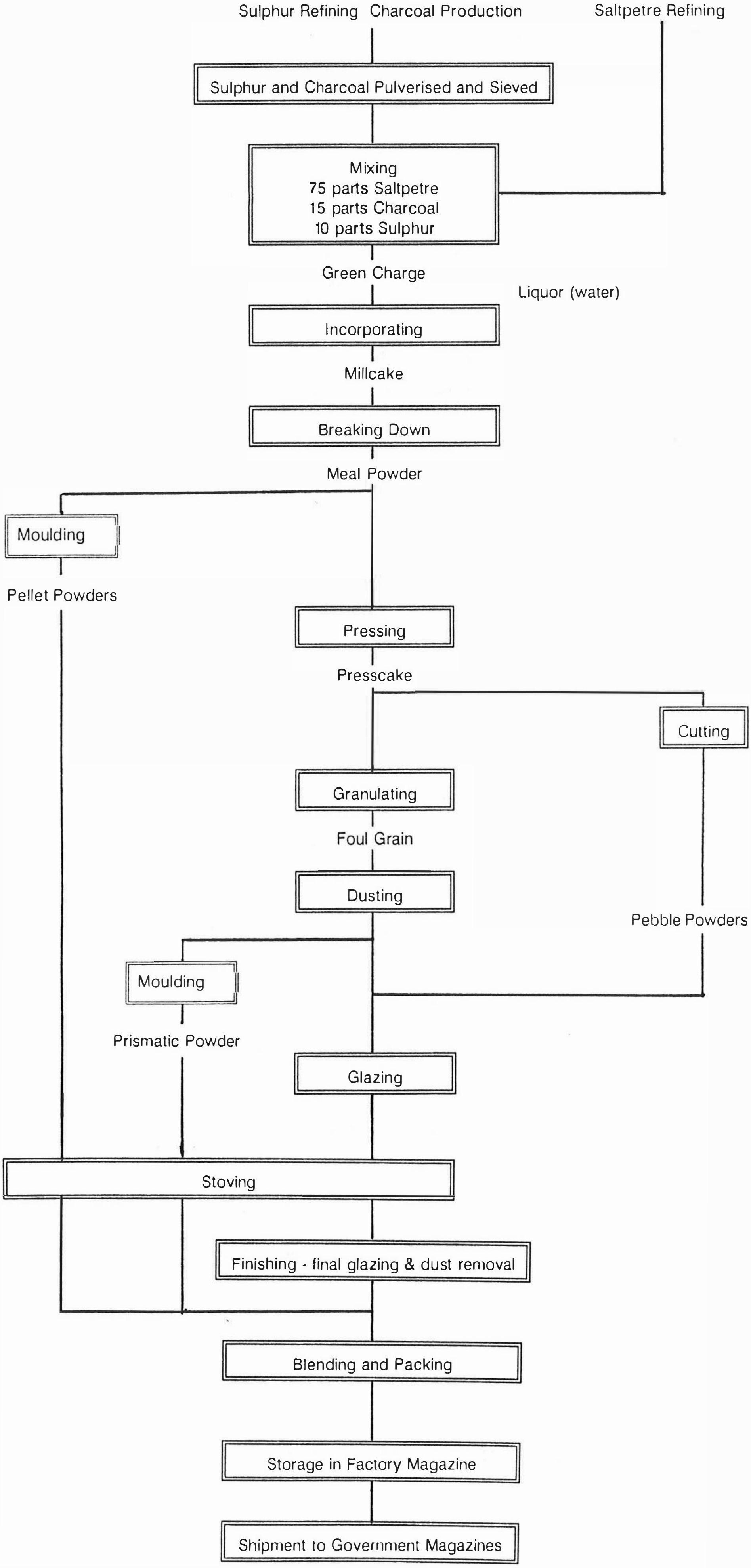
The crude tetryl was then ready for the second stage of the process, that is purification. From the initial 96lb of dimethyl aniline a charge of 200lb of crude tetryl resulted. The crude tetryl was dissolved in 400lb of anhydrous acetone and the resulting solution was run into 300lb of water; from this process 173lb of pure tetryl was precipitated from the solution. This was placed on trays and dried in air ovens at 80°C for forty hours: the result was 147lb of pure tetryl. The tetryl was then mixed with gum arabic in an incorporating machine similar to that used for cordite, before it was corned and dried at 90°C for three days to reduce the water content to 2%.

Appendix 2 Manufacturing flow diagrams

Black Powder
Nitrocellulose for cordite M. D. or guncotton
Cordites M. D. and W.
Nitroglycerine
Tetryl

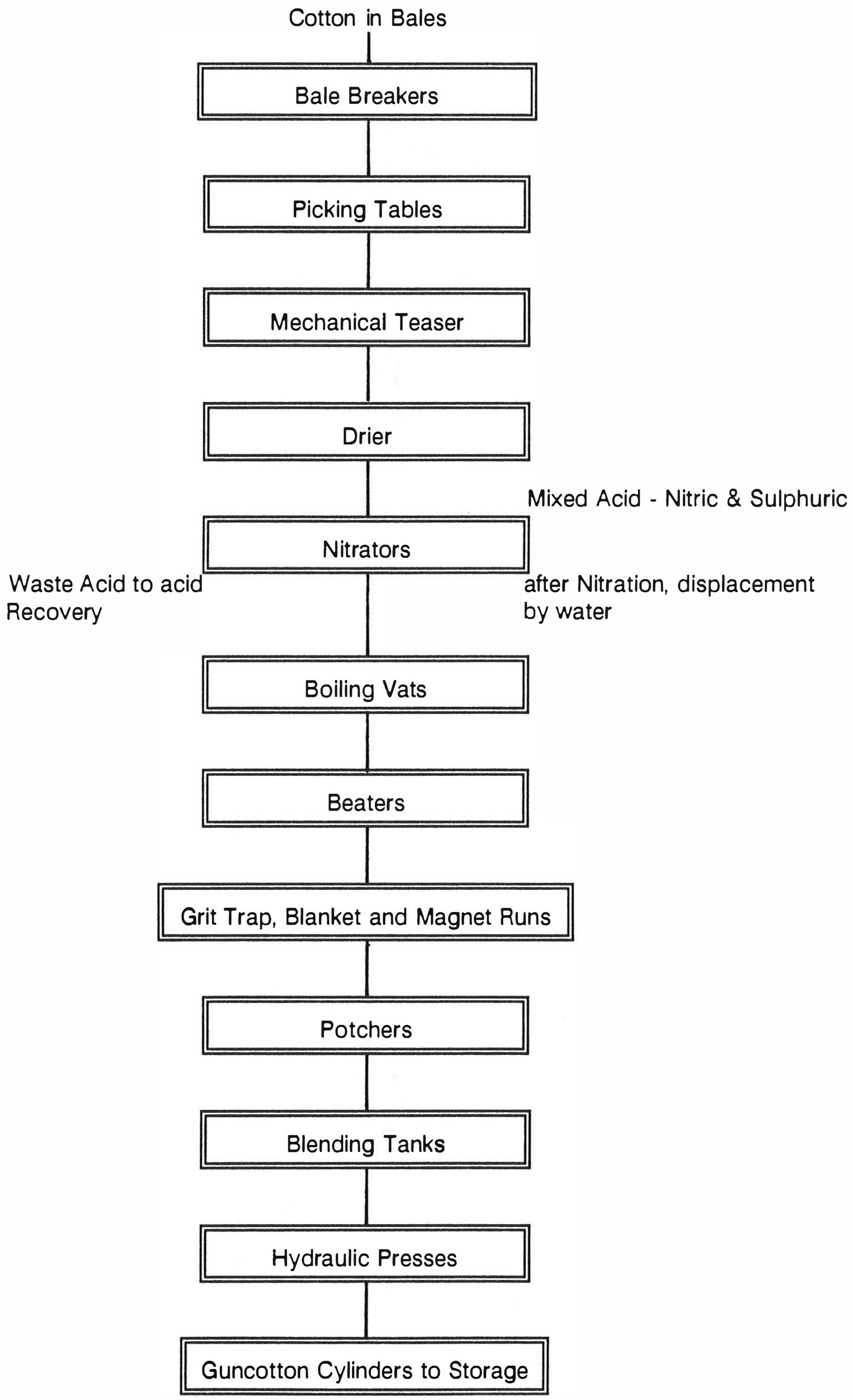
For descriptions amplifying and elaborating these diagrams, see **Appendix 1**.

Flow Diagram for the Manufacture of Black Powder



after: Wardell W H 1888 Handbook of Gunpowder and Guncotton HMSO

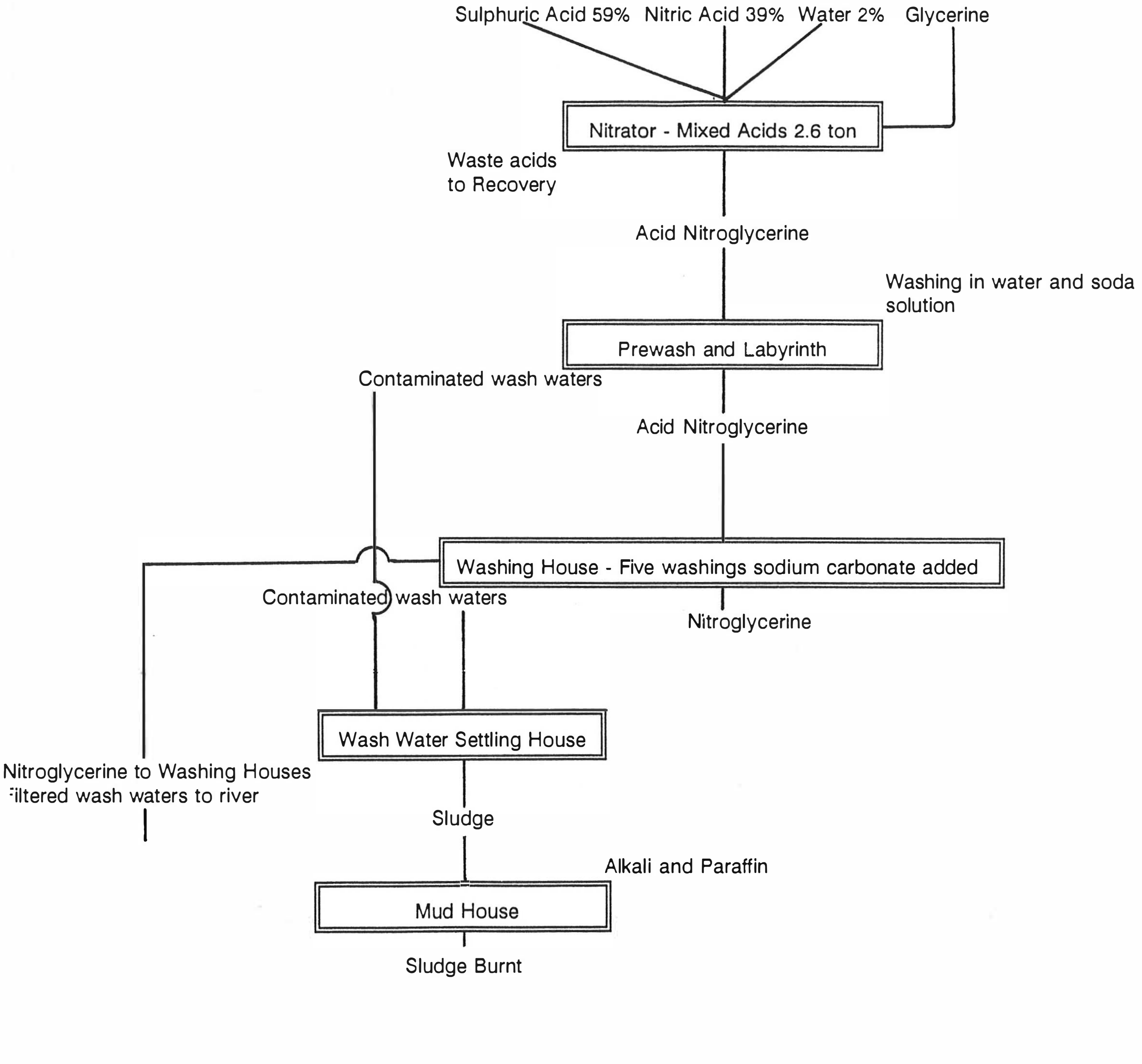
Flow Diagram for the Manufacture of Nitrocellulose. For Cordite M.D. or Guncotton



after: War Office 1938 Text Book of Explosives used in the Service

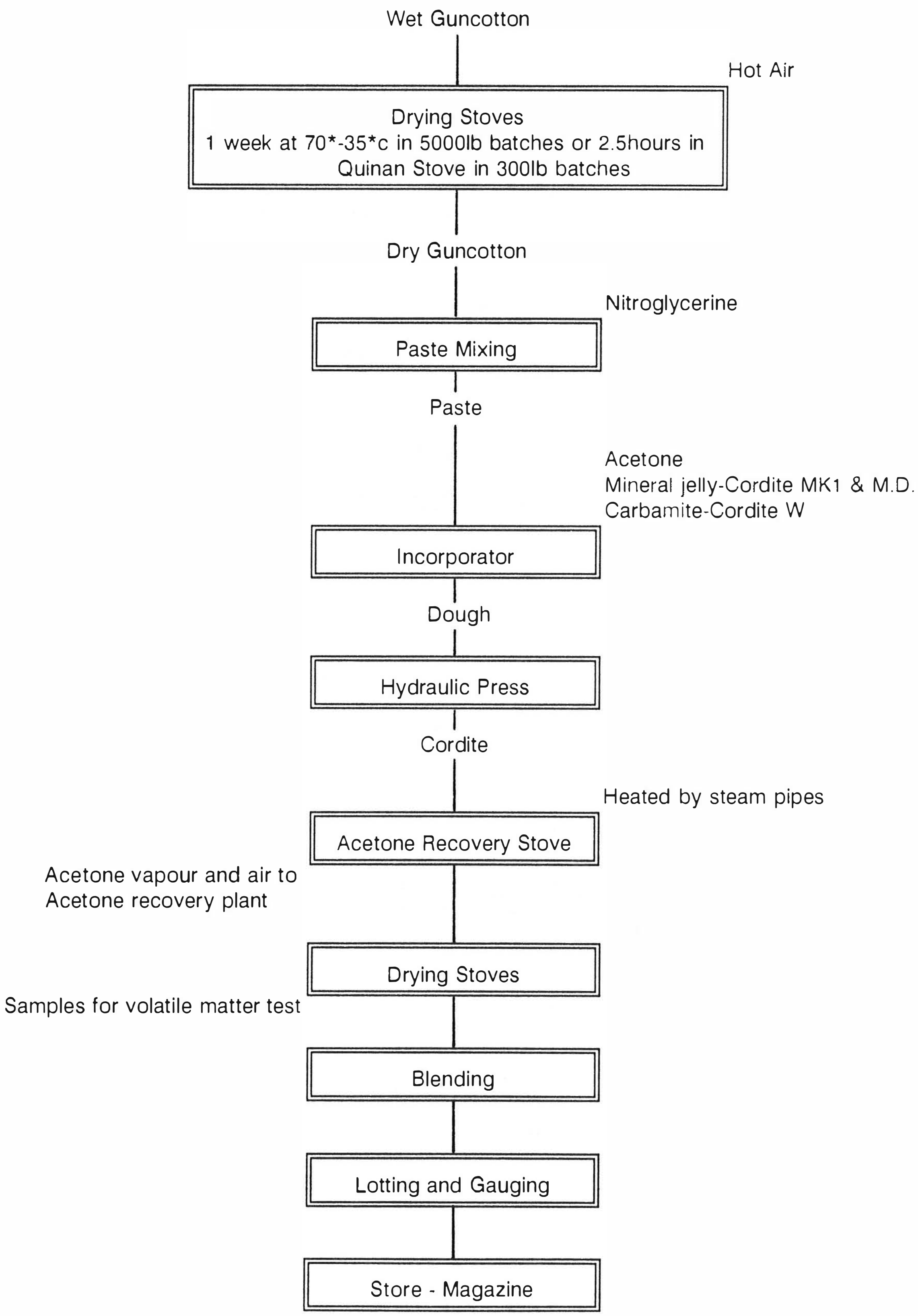
Flow Diagram for Manufacture of Nitroglycerine

Rintoul-Nathan Process



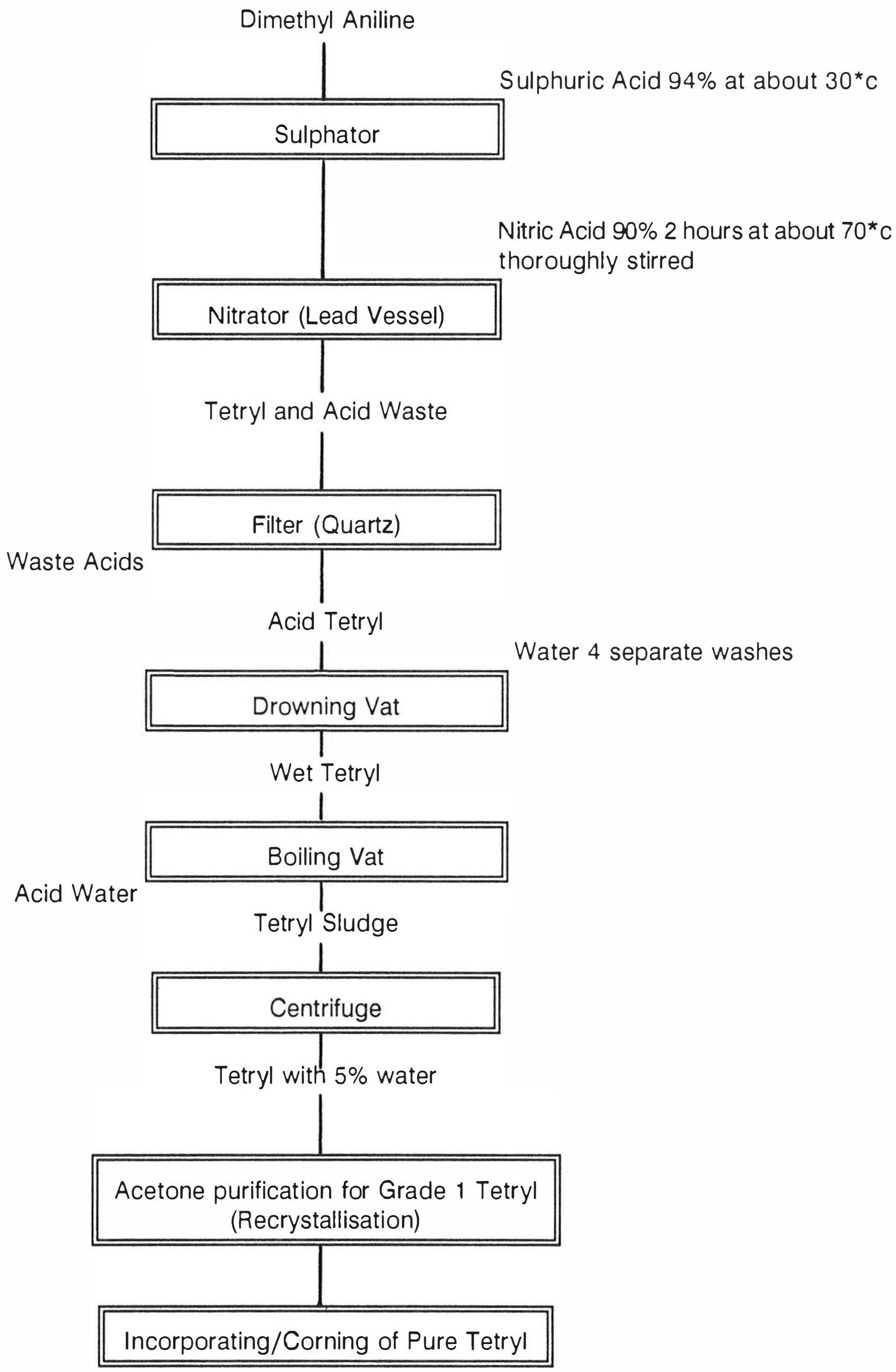
after: War Office 1938 Text Book of Explosives used in the Service

Flow Diagram for Manufacture of Cordites M.D. and W



after: War Office 1938 Text Book of Explosives used in the Service

Flow Diagram for the Manufacture of Trinitro-phenyl-methyl-nitramine (aka Tetryl or Composition Exploding C.E.)



after: War Office 1938 Text Book of Explosives used in the Service

The Royal Gunpowder Factory,

Waltham Abbey, Essex

An RCHME Survey, 1993

SECTION 4
PROFESSIONAL PAPERS

Listing of volumes of component sheets from RCHME 1993 survey

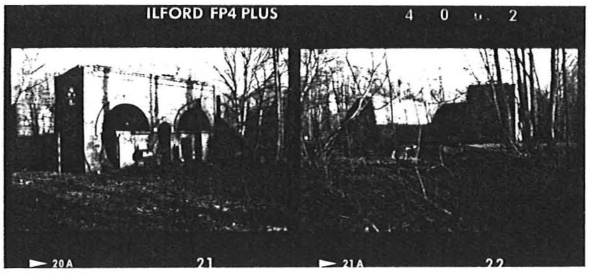
Acid and Tetryl Factories
Aqueducts, Bridges, Canals and Leats
Area A
Area H
Area L
Barges
Buildings 1-40
Guncotton Drying Stoves 74-98
Lower Island Works
Millhead
New Hill Nitroglycerine Factory
Nitroglycerine Factory E1-E16
Quinton Hill - South Site
S27-S90

An example of a component sheet is appended.

THE ROYAL GUNPOWDER FACTORY - WALTHAM ABBEY

NUMBER	OLD SERIES	RCHME NUMBER	N.G.R.
S31	93		TL 37600 01844

NAME/FUNCTION	START DATE	END DATE
Press House No.4	1879	by1886
No.1 Moulding House	by1886	1898?
Cylinder Cutting House	1898?	by 1908
Cordite Blending House	by1908	1917?
CE Packing House	1917?	by 1940
CE Store No.1	by 1940	1945



CARTOGRAPHIC DEPICTION

1886	WASC 900/38 + SUPP5 975 ; No 1 Moulding House
1886	WASC 900/41A
1886	WASC 900/42
1886	WASC 900/41A No1 Moulding House
1897	WASC 900/53C
c1900	WASC 900/79 Cylinder Cutting House
c1910	WASC 900/65
c1910	WASC 900/79
1917	WASC 900/70
1917	WASC 900/72
1919	WASC 900/74
c1920	WASC 900/80
1923	WASC 900/84 ; CE Packing House
>1940	WASC 900/91A
1940	Proc Court Inquiry 20-Apr-1940 appendix I CE Store No.1
1954	A - B.34 ; S31
c1960	WASC 900/94 ; S31
c1963	WASC 900/97 ; S31
1972	WASC 900/102 ; S31
1972	WASC 900/104 ; S31
1976	WASC 900/113 ; S31

DOCUMENTARY REFERENCES

Plan and elevation

date?	No.1 Moulding House- shows timber framed building in centre of traverse, small rooms on south elevation west side Shoe Room east room Store, both lit by circular slights RCHME Neg. BB92/26362
1908	RGPF Ledger WASC 1509 + WASC 1764 ; Blending House and Shoe Room built 1879 p9
c1925	RGPF Ledger WASC 1680
c1945	RGPF Ledger WASC 1508 ; Blending House and Shoe Room
1972	ERDE List ; Asbestos Hut
1991	Mott McDonald survey
1992	RARDE List ; Demolished gunpowder store/retaining walls only

PHOTOGRAPHY HISTORIC	PHOTOGRAPHY RCHME
PRO Supply 5/861 349 (1918?)	1) 206/H/21 From South 206/H/22 From West 206/H/36 From South 201/O/23 Pole dated 1892 Powerline leading to S31 2) BB92/26106 View from South East BB92/26107 View from East BB92/26108 View from East BB92/26345 New Press House 9.4.? BB92/26362 Plan and Elevation date ?

RELATIONSHIPS WITH OTHER MONUMENTS

ASSOCIATED WITH: L149?, L136?, RCHME 289, Tetryl Factory post 1917

CONDITION Fair

DESCRIPTION

1) CONSTRUCTIONAL MATERIAL
Brick, concrete, earthwork

2) ROOF MATERIALS AND STRUCTURE
Part brick vaulted

3) POWER SOURCE
Hydraulic from L149?

4) DIMENSIONS i) L 23.4m ii) W 9.65m iii) HT 5.35m

5) The Press House has been demolished however a substantial contemporary traverse remains. The south elevation is in buff coloured brick with red brick details. This elevation has two bays separated by a brick entrance tunnel, these openings have semi-circular heads with red brick detail. Over the entrance tunnel is stone plaque inscribed 'No.4 press House 1879'. Running along the top of this elevation is a brick dentil course. Each of the bays was formerly open but they have been blocked by brick walls the curve of the arch covered by a glazed? timber frame. Doors have been knocked into these two rooms from the entrance tunnel, roof vents also have been added. Attached to the this elevation is a metal contraband box and below this a boot scraper. In from of the building are two vertical riveted iron girders. Attached to the Southwest corner of the building is a klaxon and four late nineteenth century type pottery overhead line insulators.

The Presshouse was entered through the tunnel described. It sat at the centre of a massive traverse, the traverse consists of a brick facing laid in English bond with a concrete backing enclosed on the north and east sides by an earthen traverse. The loss of earth on the southern part of the earthen traverse had been removed by about 1917 (Supply 5/861 349). The Presshouse was served from the west by canal RCHME 289. Within the traverse are the partly buried brick footings of a building. On the internal southern wall of the traverse leading to the eastern bay is a small segmental headed arch, height 0.355m width 0.32m this may represent position of hydraulic pipe used to power the press.

ROYAL
COMMISSION
ON THE HISTORICAL
MONUMENTS
OF ENGLAND