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Explosives - The
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W. D. Cocroft

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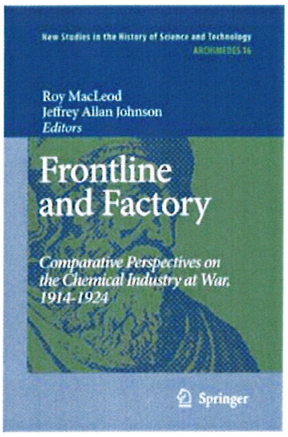

Roy MacLeod; Jeffrey Allan Johnson (Eds.)

Frontline and Factory

Comparative Perspectives on the Chemical Industry at War, 1914-1924

The First World War is often called the 'chemists' war'. But few realise precisely how, or the extent to which modern chemistry became a significant factor in the struggle, and would be in turn deeply shaped by it. Gathering momentum at first, by 1916, success in applying scientific knowledge to 'frontline and factory' became a measure of a nation's capacity to win an industrial war. In the end, the titanic contest was won in large part through the command of raw materials and industrial output. This book represents a first considered attempt to study the factors that conditioned industrial chemistry for war in 1914-18. Taking a comparative perspective, it reflects on the experience of France, Germany, Austria, Russia, Britain, Italy and Russia, and points to significant similarities and differences. It looks at changing patterns in the organisation of industry, and at the emerging symbiosis between science, industry and the military, which contributed to the first 'academic-military-industrial' complex of the 20th century. At the same time, it reflects on the world's first, and ultimately unsuccessful attempt to monitor 'dual-use' chemical technologies, and so restrict the proliferation of an important category of weapons of mass destruction.

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WAYNE D. COCROFT

FIRST WORLD WAR EXPLOSIVES MANUFACTURE — THE BRITISH EXPERIENCE

INTRODUCTION

On the eve of war in August 1914, military explosives manufacture in Great Britain was split between the State enterprises at the Royal Arsenal, Woolwich, and the Royal Gunpowder Factory, Waltham Abbey, and around ten private producers. The principal needs of the services were for a propellant and shell fillings, and for other explosives in lesser quantities. Cordite filled the first role; black powder and picric acid or lyddite — a high explosive[1] — the second. It was an industry developed to supply the relatively modest needs of a small regular army, which trained for mobile open warfare and was mainly engaged in policing the empire. The Royal Navy was entrusted with guarding the country against invasion and securing the sea-lanes of the empire, and, although it was rarely in action, its guns consumed large quantities of explosives.

In the autumn of 1914 as the western front campaign in Belgium and northern France opened, the type of war for which the British army was prepared, and which it had envisaged, quickly stagnated into a static war, waged from parallel series of heavily fortified trench systems. To break this impasse, Field Marshall Sir John French, Commander-in-Chief of the British Expeditionary Force, declared in February 1915 that 'the problem set is a comparatively simple one, munitions, more munitions, always more munitions'.[2] In particular, the army required vast quantities of high explosive shells to break through German trench lines.

PROPELLANTS

From its introduction in the 1890s as the principal British service propellant, an assured supply of cordite was of vital strategic interest to the government. Clive Trebilcock has described the way in which the British government carefully nurtured the development of the cordite industry. By alternating the award of cordite contracts between different firms, it was able to create extra capacity by effectively compelling the companies to erect the necessary plant at their own expense.[3]

Before the war, the yearly demand for cordite stood at around 3600 tons (3657.6 tonnes); the Royal Gunpowder Factory at Waltham Abbey supplied about one third, and seven trade factories the remainder, most of that went to the Royal Navy.[4] Cordite factories were some of the largest and most complex explosives factories. They required large areas of flat land, a reliable water supply, good transport links, a large workforce, and plant to concentrate sulphuric acid and to manufacture nitric

R. Macleod and J.A. Johnson (eds.), Frontline and Factory, 31–46.

acid, as well as facilities to recover spent acids. Units were also needed to produce guncotton and nitroglycerine before the manufacture of cordite could begin (See Figure 1).

In the early stages of the war, cordite production was increased by extensions to existing factories. Plant was also used more effectively with the introduction of shift working. prior to the declaration of war the largest private explosives producer,

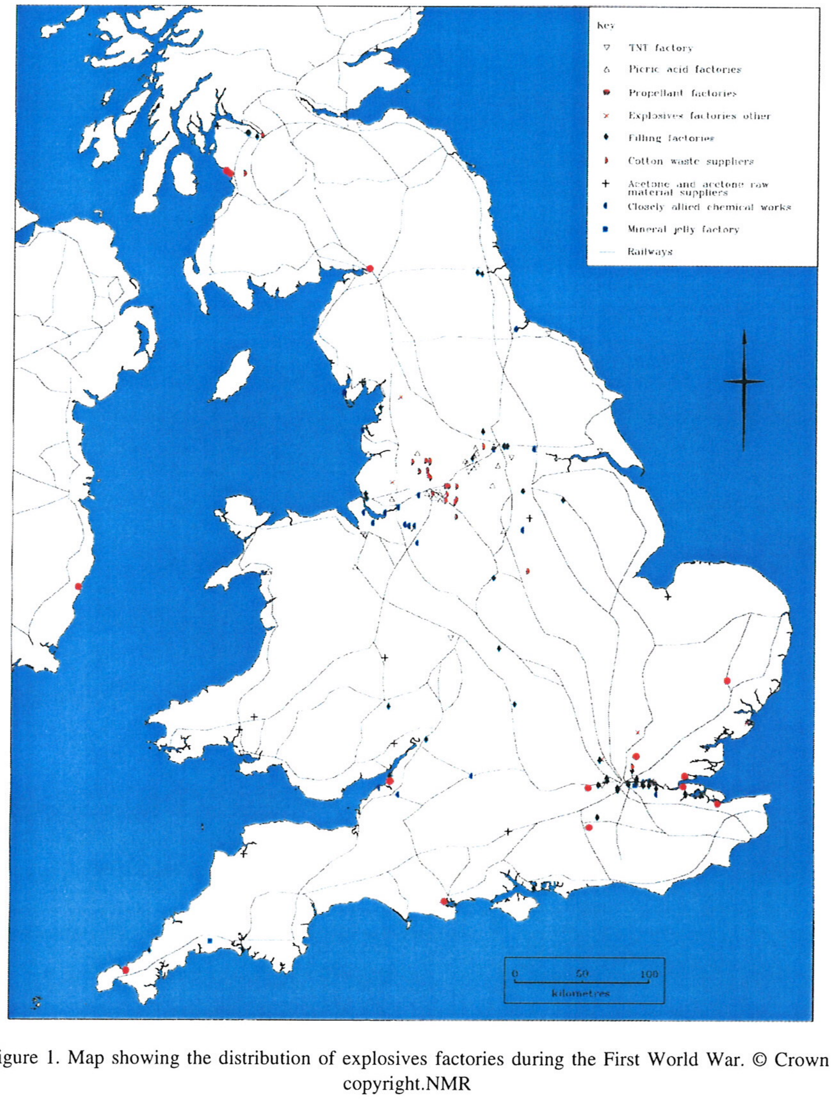

Figure 1. Map showing the distribution of explosives factories during the First World War. © Crown copyright.NMR

Nobel's, had already planned to increase cordite production by building a new factory at Pembrey in South Wales. Its design, entrusted to Sir Frederic Nathan, later informed the design of the new cordite factory adjacent to Nobel's Ardeer factory in North Ayrshire, and later the government factory at Gretna. Nathan's career illustrates the close links that developed between the government service and the private manufacturers. He had joined the Royal Artillery in 1879, and rose to become the Superintendent of the Royal Gunpowder Factory at Waltham Abbey, before joining Nobel's in 1909. He returned to government service in 1915, and took charge of the construction of the new Royal Naval Cordite Factory at Holton Heath, Dorset, before his great organizational skills were harnessed as Controller of Propellant Supplies at the Ministry of Munitions.[5]

A key part of the cordite manufacturing process was the incorporation of the cordite paste — a mixture of highly nitrated (insoluble) guncotton and nitroglycerine — using acetone as the solvent. Britain's reliance on cordite made a secure supply of acetone critical. Before the war, acetone was derived mainly from the destructive distillation of wood, and much was imported from Austria and the United States of America. One of the most innovative processes devised during the war (and one with the most far-reaching consequences) was the synthetic manufacture of solvents using a bacterium to ferment acetone and butanol from starch sources, including potatoes, maize and chestnuts. The process has been closely associated with Chaim Weizmann, although it was the product of the pre-war work of around fifteen scientists working in research laboratories set up around the turn of the century.[6] Remarkably, part of the acetone plant at the former Royal Naval Cordite Factory at Holton Heath survives (See Figure 2) and is now protected as a scheduled monument. Study of its fabric has revealed the careful attention paid by the construction engineers to the pipework's seals, an essential feature to maintain the sterility of the operation.[7]

As a further step to conserve supplies of acetone-based cordite — due to its stability and uniformity of effect, the preferred choice for naval gunnery — the Research Department at the Royal Arsenal at Woolwich devised a new type of cordite for land service. This was known as cordite RDB. In place of highly nitrated insoluble guncotton, soluble nitrocellulose was substituted, and ether-alcohol was used as the solvent. This resulted in scarcity and higher prices for ether-alcohol, produced by the alcohol distilleries. Despite this, and although it was more expensive to manufacture, cordite RDB was accepted for use in May 1915, and put into production as a war emergency measure.[8]

However, this innovation had consequences. Notably, it increased demand for glycerine. To maintain ballistic performance, it was necessary to raise the nitroglycerine content to 42 per cent compared to the 30 per cent content of pre-war cordite MD.[9] Sections of the Royal Gunpowder Factory were converted to manufacture cordite RDB, and plans for the new cordite factory at Gretna were redrawn to include additional facilities for the production of the new type of cordite. Yet another adjustment — in this case, to conserve supplies of cordite for use in larger guns — was the substitution of single-based propellants for use in rifle cartridges,

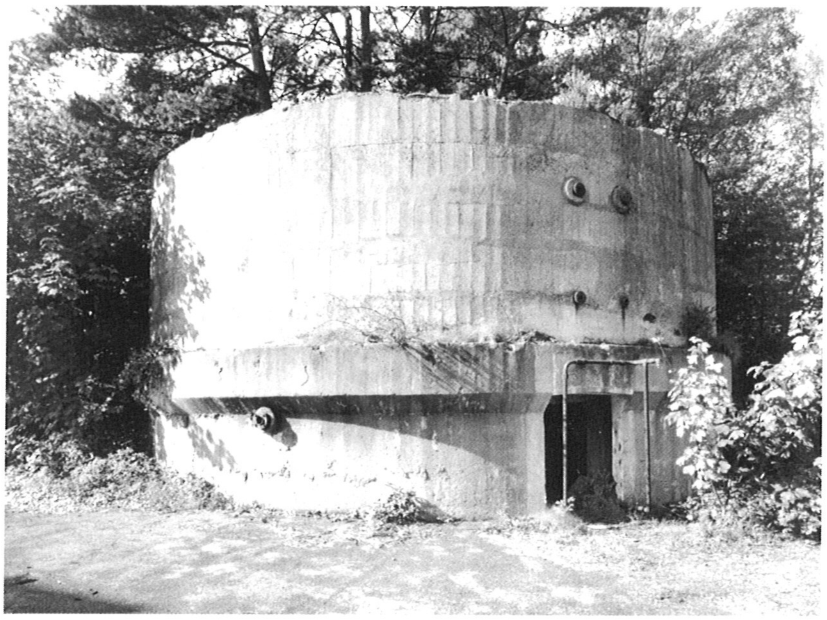

Figure 2. Royal Naval Cordite Factory, Holton Heath, Dorset, remains of the fermentation vessels used for the production of acetone (BB94/16943) © Crown copyright.NMR

a large quantity of which were imported from America.[10] New factories were also built at Irvine in Scotland and at Henbury, near Bristol, to manufacture nitrocellulose powders.

HIGH EXPLOSIVES

In contrast to the case of cordite, whose manufacture was well developed and understood, the capacity to produce large quantities of high explosive had to be built up almost from scratch. Before August 1914, the types of operations in which the British Army was predominantly engaged, called for anti-personnel shrapnel shells, exploded by a blackpowder charge. The smaller numbers of high explosive shells used by the army were filled from the mid-1890s with lyddite. Soon after the outbreak of war, trinitrotoluene (TNT) — which had been in use in Germany since the turn of the century — was recommended as the preferred type of shell filling. TNT, although less powerful than lyddite, used smaller amounts of raw materials in its manufacture, which made it cheaper to produce. It could also be used in a less than pure form, and further savings in raw materials could be made by diluting TNT with ammonium nitrate to form 'amatol', which produced a relatively cheap shell filling.[11]

In the production of high explosives, Britain was in a strong position. Her coal by-products industry and town gasworks were able to supply a large proportion of the raw materials for the country's lyddite and TNT requirements. Nevertheless, this took prodigious quantities of coal. To produce a typical weekly output of TNT in wartime, for example, required 720 tons of toluene, which in turn required 600,000 tons of coal. Geographically, the production of high explosives and their precursors was concentrated in the north of England, between Manchester and Leeds, in an area closely associated with the manufacture of synthetic textile dyes and other coal tar derivatives. Another significant group of factories was located along the river Thames, close to London (see Figure 1).

Before the war, the manufacture of TNT was restricted to two private companies, the Clayton Aniline Company and Nobel's, the latter having a capacity of just ten tons per week.[12] In comparison with other areas of munitions supply (especially shells, whose manufacture was often organized by locally self-appointed committees) the supply of high explosives was in November 1914 put into the hands of a newly-appointed Committee on High Explosives, under the chairmanship of the lawyer, Lord (Fletcher) Moulton, FRS.

Moulton quickly instigated a survey of private chemical works capable of producing, or being adapted to manufacture, high explosives. In addition to these private concerns, the government itself also entered into bulk high explosives manufacture for the first time. On Moulton's initiative, an exemplary national TNT plant was constructed adjacent to Messrs. Chance's factory at Oldbury, near Birmingham, supervised by chemists from the Research Department at Woolwich.[13] Following established practice at the Royal Gunpowder Factory, the Oldbury TNT factory was open for private producers to inspect what was considered to be best practice. By May 1915, it was producing 100 tons (101.6 tonnes) of TNT per day.[14]

At the beginning of the war, the manufacture of TNT was poorly understood. The main risk was thought to come from its flammability, and, as a result of the urgency to increase production, some factories were built in inappropriate urban locations. Almost inevitably, this had tragic consequences. For example, a factory in a former textile mill at Ashton-under-Lyme, Greater Manchester, and a factory constructed in a former caustic soda plant at Silvertown, in London, both blew up with heavy loss of life. Less visible as catastrophes were the fatalities and sickness caused by TNT poisoning.

One of the most important technical challenges put to the British explosives industry was the need to devise methods to increase the ratio of ammonium nitrate to TNT in 'amatol'. British manufacturers soon managed to raise the proportion to 80 parts ammonium nitrate to 20 parts TNT, resulting in significant savings in raw materials. German industry, desperately short of toluene supplies, never succeeded in increasing the proportion beyond 40 parts ammonium nitrate.[15] A new industry developed to supply ammonium nitrate, led by the great alkali concern of Brunner Mond and Company, located in the north-west of England.[16] Their chief chemist, Dr Francis A. Freeth, developed a process for the industrial manufacture of ammonium nitrate, based on the work of Dutch chemists, which was patented in 1910.[17]

Through the technical expertise of Brunner Mond's research workers and plant managers, the production of ammonium nitrate was raised from around 1000 tons (1016 tonnes) per year, to an output of over 200,000 tons (203,200 tonnes) between and 1915 and 1918.

THE FILLING FACTORIES

During the first months of the war, with the exception of explosives production, the coordination of munitions supply suffered from the absence of strong leadership and direction. This culminated in May 1915 in the 'shells scandal', when it was claimed in *The Times* that the shortage of high explosives and shells had contributed to the lack of progress and heavy loss of life on the Western Front.[18] Partly in response to this criticism, a newly formed coalition government under Herbert Asquith created the Ministry of Munitions in June 1915, which was to be responsible for all areas of munitions supply and manufacture. Under the new ministry, directed by David Lloyd George, a system of national factories was planned. The selection of sites, design of factories, and manufacture of process plant and machinery, together with the recruitment and training of a labour force, was a complex task. Nevertheless, by spring 1916, the first of the new national factories was in production, in readiness to equip Kitchener's New Armies and in preparation for the Somme offensive of that summer. Most of the new factories were working by 1917, and by the end of the war, the Ministry of Munitions was operating around 200 factories, manufacturing everything from aircraft, explosives and shells to boxes and concrete slabs.[19]

To ensure a steady supply of shells for the front, one of the most pressing needs was for 'filling factories' — where the various components and explosives were brought together for assembly. Under strong central direction, the emergence of standardized factory designs and plant might be expected. In practice, considerable latitude was given to individual preference. At Chilwell, in Nottinghamshire, Viscount Chetwynd, a former steelworks manager with no previous experience of handling explosives, took a novel approach to the design of a factory to fill shells with amatol. After visiting a number of French explosives factories, and unimpeded by convention, he adapted coal-crushing, stone-pulverising, sugar-drying, paint-making and sugar-sifting machinery, and used porcelain rollers usually found in flour mills to grind TNT. Contrary to normal practice in the explosives industry, he built multi-storey mills similar to those used for milling flour. Despite being a government factory, Chilwell so closely identified with Chetwynd that a monogram of crossed 'C's was applied to lamp posts and the ironwork of buildings' balconies (Figure 3). The factory filled prodigious quantities of munitions, including over nineteen million shells, 25,000 sea mines, and 2500 aerial bombs.[20] It was also the scene of the worst accidental explosion of the war, in 1918, when 134 people were killed.

At Greenford, West London, a similar arrangement was entered into, whereby A.G.M. Chalmers was asked to undertake the design, construction and management of a factory for filling gas shells. There, H.M. Office of Works designed the

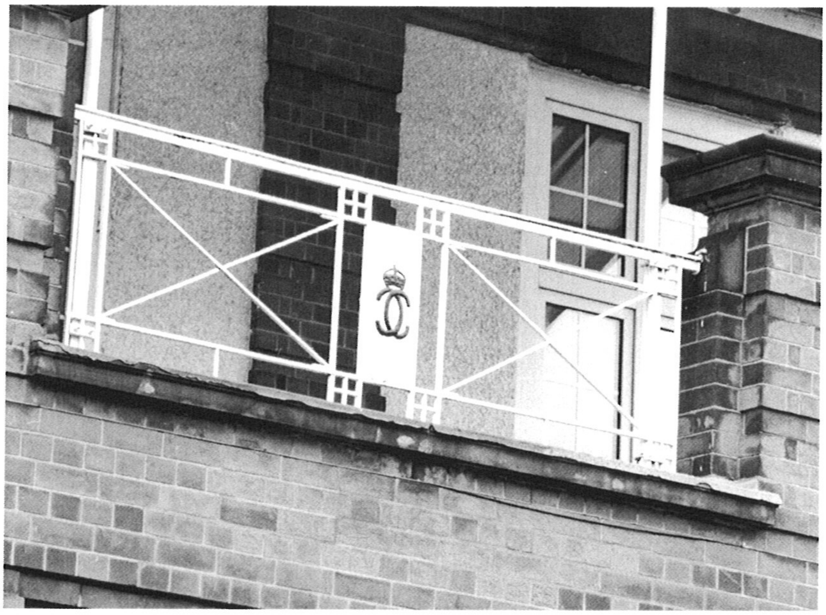

Figure 3. Chilwell, Nottinghamshire, National Filling Factory No.6, balcony of the officers' mess and main offices showing Chetwynd's crossed 'C's monogram, but beneath a King's crown (AA96/3561). © Crown copyright.NMR

buildings, while Chalmers was responsible for the machinery and its arrangement, and later for the management of the factory.[21] By 1918, the Ministry of Munitions operated twenty-two national filling factories, together with other specialized filling factories — for example, designed for the needs of the Trench Warfare Department. The policy of permitting strong local or individual control led to a multitude of factory designs, often resulting in plants that were closely designed around a specific production process, with little flexibility for adaptation.

CONTINENTAL AND EMPIRE CONNECTIONS

During the late 19th century, the development of the British explosives industry was heavily reliant on foreign expertise. This know-how was brought by individuals, such as the Hungarian Oscar Guttmann, but was also represented in factories established by continental companies — most notably by Nobel's, but also smaller concerns producing patent explosives. This dependence on foreign specialists continued throughout the war. Some links — such as the continuing employment of German workers by the Chilworth Gunpowder Company, a firm partly owned by the Vereinigte Rheinisch-Westfälische Pulverfabriken — finally ceased in 1915, when the links within the Nobel Dynamite Trust were also cut.

Despite the efforts of Britain's chemists, the country was short of 'chemical engineers' with the skills to build the new munitions factories, and of factory chemists, and their assistants, to manage the factory sections and to undertake quality control. Fortunately, Britain was able to make up part of this shortfall by chemists drawn from the empire.[22] Amongst their number was the chemical engineer Kenneth B. Quinan, who made the single greatest contribution to the British war effort. Quinan was an American, who before the war had been employed by the Cape Explosives Works in South Africa. He designed some of the largest government plants erected during the war, including the factory at Queensferry in North Wales, which was capable of producing staggering amounts of explosives, including 500 tons (508 tonnes) of TNT and 250 tons (254 tonnes) of nitrocellulose per week.[23]

Even larger was the cordite factory he designed on the English and Scottish border close to the village of Gretna. As the largest explosives factory in the empire, this covered 9000 acres (3642.3 hectares) and stretched for seven miles (12 km) and employed nearly 20,000 people.[24] Gretna had a maximum production capacity of 1000 tons (1016 tonnes) of cordite per week and, given economies of scale, was able to produce cordite at a price around 25 per cent lower than before the war.[25] Such factories were not only remarkable for their scale, but also for the use of innovative chemical technology. At Gretna and Queensferry, this included the manufacture of sulphuric acid by the contact process developed by continental acid producers.[26] At Gretna, too, Quinan introduced his patent guncotton stoves, a number of which survive. They combined the twin advantages of a faster drying time with improved safety, as there was less guncotton in a stove at a given time, as compared with older designs.

Continental expertise was also drawn upon to build the smaller raw materials plants, which were also critical to production. In early 1915, a distillation plant owned by Shell, which was capable of producing toluene from Borneo petroleum, was brought from Rotterdam and re-erected at Portishead, near Bristol. Soon afterwards, an almost identical plant was constructed at Barrow-in-Furness in Cumbria. During the war, these two factories produced almost the same amount of toluene as the entire British coal-gas industry. Under Shell's chief engineer, W.R. Aveline, company chemists, who included Dutch citizens, also assisted in the construction of the nitration and TNT plants at Oldbury and Queensferry.[27]

Another example of resourcefulness in drawing on expertise was the National Ammonium Perchlorate Factory, established in 1916 at Langwith in Derbyshire, which similarly relied upon technology supplied by Carlson's of Stockholm.[28] Another, although unfinished, factory was intended to produce nitric acid, which was essential for the production of most explosives, and which was throughout the war produced from sodium nitrate from Chile. This source was vulnerable to interception by German U-boats, and also occupied valuable shipping space in a three-month round journey.[29] To lessen this dependence, plans were drawn up to build a synthetic ammonia plant at Billingham, Teeside, using the Haber-Bosch process devised by German chemists before the war. However, the development was incomplete at the time the war ended.[30]

ALTERNATIVE PERSPECTIVES

The production of munitions in Britain during the First World War is comparatively well documented. Sources include the official twelve volume *History of the Ministry Munitions* published in the early 1920s, individual factory histories, and unpublished records held by the Public Record Office, along with secondary histories derived from these. The Ministry of Munitions, and later the Department of Scientific and Industrial Research, commissioned William Macnab to document some of the most innovative processes devised during the war.[31] Nevertheless, sources and resources have not been exhausted; and questions can change and enlarge. Many local archives remain unexplored, and often contain material not found in national archives. Other sources, beyond what may be regarded as traditional areas of documentation, may also be used to increase our understanding of production processes, factory architecture, working conditions, and the social context of manufacturing activity.

Few wartime participants remain alive, but the sound archive of the Imperial War Museum, London, holds many interviews with former munitions workers. Some of the most valuable untapped sources of information are contemporary photographs. These were taken for a variety of reasons; some to document construction work, others consciously commissioned as a historical record.

One of the most important collections was produced in anticipation of the foundation of a National War Museum (later renamed the Imperial War Museum). Its subcommittee was established to record the contribution of women to the war effort, and photographers were appointed to record their work.[32] Official statistics generally reveal few facts about factory life, beyond perhaps the percentage of female staff employed. Photographs can be used to uncover valuable information on working conditions, the roles and activities undertaken by men and women, their ages, clothing, and machinery and plant, which rarely survive as historical artefacts (Figure 4).[33]

The images of large numbers of women in British factories contrast with the French experience, where numerous wounded and convalescent servicemen were employed in the munitions industry.[34] Contemporary photographs are also often the only evidence of the appearance of munitions factories, especially where they were hastily erected in timber and quickly dismantled after the end of the war.

The construction of new munitions factories represented just one element of the militarization of Europe's landscape. There was a grim symmetry, hinging on the Western Front, of munitions factories, depots and supply lines delivering armaments to the killing fields.[35] It is only now, after the end of the Cold War, that much of this land is being returned to civilian use, thereby giving access to many previously restricted installations, and creating opportunities to study their physical fabric.[36] This approach is able to open up new sources of information, avenues of research and perceptions about this great enterprise over and above what is available from traditional documentary sources.

Even in the countries with best documentation, factory plans and drawings of plant may be lacking. This may be partly remedied by archaeological survey, such

Figure 4. In this view of the top floor of the Cunard's Shellworks, Liverpool the women are working on 4.5-inch shells. In the foreground the operator is cutting a groove at the base of the shell ready to accept the copper driving band. On the adjacent lathe the operator is using a gauge to test the depth of the cut and on the centre bench the dimensions of the shell are being checked with another gauge (BL24001-21). © Crown copyright.NMR

as the recent identification and record of wartime extensions to the Chilworth gunpowder works in Surrey. While some structures or groups of buildings leave distinctive footprints, ascribing functions without supporting documentation is often problematic. Among the features that munitions manufacture brought to 20th-century factory design was the application of scientific management to factory layout and the improved organization of the workforce. Whereas, before the war, a skilled worker might have carried out a number of tasks, the policy of dilution broke down the manufacturing process into a series of repetitive tasks that could be carried out by unskilled, and often female, labour. Because of these developments, spatial analysis has become one of the most rewarding ways of studying large factory complexes. Plans may reveal the incremental growth of a factory. Even where wartime factories represent a single phase of activity, simple block plans may be used to study organizational structure and production processes (see Figure 5). Moreover, as surviving original drawings of structures and plant within factories are comparatively rare, careful recording work in the field can often allow the manufacturing process to be reconstructed. Some of the most revealing evidence

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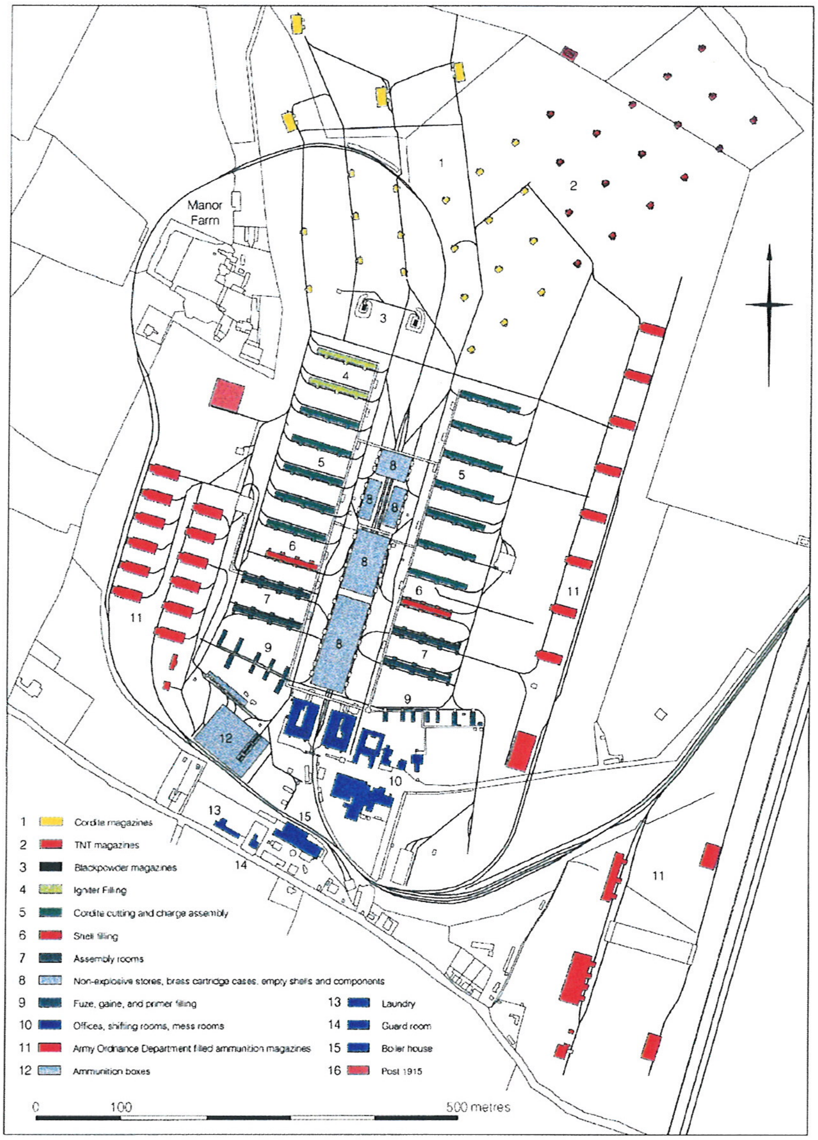

Figure 5. Quedgeley, Gloucestershire, National Filling Factory No.5, block plan illustrating the main activities of the building within the factory. Site plan redrawn from Ordnance Survey, Gloucestershire, 1923, 25-inch, Sheets XXXIII.10 and XXXIII.14. © Copyright.NMR

Figure 6. Royal Gunpowder Factory Waltham Abbey, Essex, examples of excavated earthenware taps and pipes used in the acid factory. Before the development of acid resistant metals, the chemical industry was reliant on suppliers of specialist earthenwares (BB94/7995). © Crown copyright.NMR

of former production activities is to be found in dumps of industrial earthenware, an adequate supply of which was in itself a limiting factor in the expansion of chemical production (see Figure 6).

In addition to chemists, wartime government departments employed teams of architects, some of them eminent in their profession. At the Ministry of Munitions, the head of the design team of the Explosives Supply Department, which was responsible for design of HM Factory, Gretna, was Raymond Unwin. At HM Office of Works, Frank Baines was the principal architect, and amongst his work was the lyddite factory at Rotherwas in Herefordshire. The designs they produced — especially for the public or accessible face of these factories — sought to convey a deliberate image. At the beginning of the 20th century, many prestigious factories — such as Marconi's works erected in 1913 at Chelmsford, Essex — were fronted by grand and ornate administrative ranges, expressing the international standing of the company. During the war, neo-Georgian buildings became what could be regarded as the official style. It was more restrained than pre-war styles and, in contrast to contemporary buildings in an Arts and Crafts style, many of its elements such as sash windows could be prefabricated as standardized units. Nevertheless, the construction of imposing entrances and offices represented a considerable investment in skilled labour, construction time, and materials.

Their design raises the question of what these buildings, built at time when the country was locked in a deadly struggle, actually represented. Some of the new

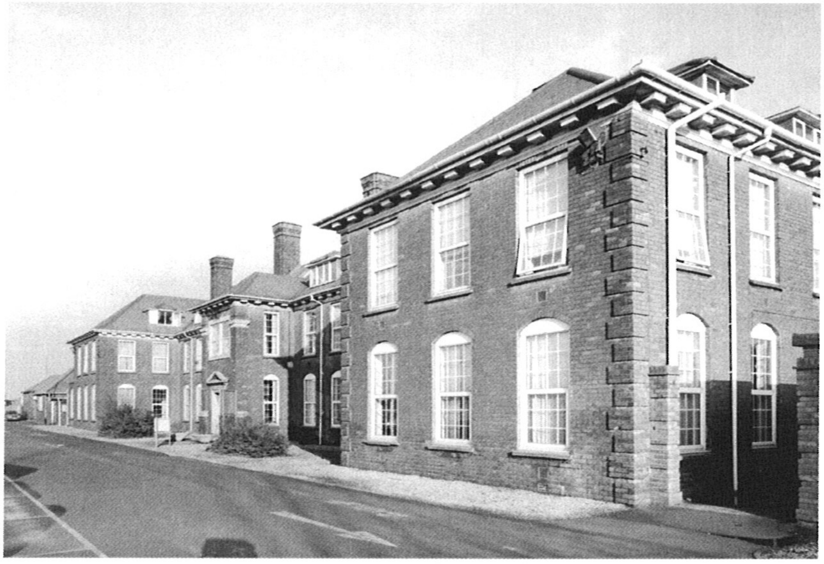

Figure 7. His Majesty's Factory Avonmouth, near Bristol, office building of a factory initially built to produce picric acid, it was later converted manufacture produce mustard gas. The windows are modern replacements (BB97/117). © Crown copyright.NMR

factories, such as the Royal Naval Cordite Factory at Holton Heath, were intended to be permanent establishments; grand style was a reflection of the pride and patriotism inherent in a 'national' factory. In most instances, however, new factories were erected to fulfil short term needs, with little thought to future demands. Even in such cases, such as at the picric acid factory at Avonmouth, Bristol (see Figure 7), there was an impressive neo-Georgian frontage — a style closely associated with the Liverpool School of Architecture, which produced facades behind which factory owners hid the unpleasant realities of the early 20th century.[37]

The style had a particular resonance in the area of munitions, for it was the same architectural style that was associated with the expansion of the Board of Ordnance sites a century earlier, when the country was locked in war with revolutionary France. Outwardly, architectural standards were maintained to the war's end. The National Machine Gun Factory at Burton-on-Trent, Staffordshire, whose construction was approved in 1917, was given an imposing three-storey range resembling a country house; but steel framing, concrete and slab filling were used to speed up construction. Some private manufacturers who benefited from wartime expansion also enhanced their factories with impressive gatehouses, medical centres and administrative blocks, such as those built at Kynoch's Witton cartridge factory, Birmingham, in 1915. Elsewhere, factories were erected quickly, using timber or corrugated iron. Surprisingly, given its comparative cheapness and ease of use, concrete was rarely employed.

LEGACY

Discussions about the future of the explosives industry began well before the end of the war, with the growing realization that there would be massive over-capacity.[38] With large remaining stocks of explosives, and the belief that a major war in Europe was unlikely in the next ten years ('the 10-year rule'), there could be no justification in maintaining the large network of explosives factories, and most of the new factories were destined for closure.

The government relinquished its control of armaments production, and the Cessation Act wound up the Ministry of Munitions in 1921. Government explosives production and research retreated to Waltham Abbey, Holton Heath, and the Royal Arsenal, with its enlarged Research Department. Nearly all the national factories were closed; some sites were soon cleared, and returned to agricultural use. There was a similar picture of closures amongst the trade factories, and by 1920 most had amalgamated to form Nobel Industries Limited, which was absorbed into ICI in 1926. Under a drastic restructuring scheme, blackpowder manufacture was consolidated at a handful of sites, and commercial chemical explosives manufacture was concentrated at Ardeer in Scotland. Specialist explosives plants offered few opportunities for conversion to peaceful purposes, but other types of munitions factories with large, flexible, covered, open spaces (such as filling and projectile factories), as well as other engineering concerns, were put to new uses.

In particular the emerging automotive industry benefited from the legacy of newly-built munitions factories; elsewhere the orderly layouts of these factories were easily adapted to trading estates with premises for small businesses.[39] Of more enduring use have been the residential estates, many of which were originally built to house munitions workers.

The victors also had opportunities to inspect enemy plant. Of particular interest was the German synthetic ammonia factory at Oppau. Despite the obstructions placed in their way, the visit convinced the directors of Brunner Mond that they should acquire the part-finished artificial nitrate plant at Billingham, thereby forming the basis of the modern chemical industry on Teeside.[40] It was also as a result of contact with German wartime practice that the Royal Naval Cordite Factory began experiments in the 1920s with wood (in the form of paper) as a cellulose source in place of imported cotton. The most important legacy of the vast munitions programme, however, was the experience that it gave government experts who became responsible for armaments production during the 1930s.[41]

In the context of modern conservation agendas in England, this work on the physical remains of the industry has played a central role in informing English Heritage's assessment and designation programmes for the gunpowder — and, more recently, the chemical industry — including chemical explosives.[42] Parts of the legacy are accessible and interpreted to the public, notably within the displays at Waltham Abbey's Royal Gunpowder Mills. But these can give only a limited impression of the scale of the national endeavour, the ingenuity and organization upon which it drew, and the experience of the many thousands whose contribution to the war to end all wars was the labour, and sometimes the lives, they gave to munitions production. For our generation, the physical remains of locations, sites, buildings and artefacts continue to provide distinctive insights not available from other sources.

ACKNOWLEDGEMENTS

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NOTES

[1] When used as a shell filling in British service, Picric acid was known as lyddite, after Lydd in Kent, where it was first tested. In other countries, it was variously called melinite, shimose, pertite and picrinite.

[2] V.B. Lewes, 'Modern Munitions of War', *Journal of the Royal Society of Arts*, LXIII (1915), 821.

[3] R.C. Trebilcock, 'A "Special Relationship"—Government and Rearmament, and the Cordite Firms', *Economic History Review*, Series 2, (19), (1966), 364–379.

[4] Public Record Office (Kew) (afterwards, PRO), MUN7/555, 'Reduction in Output at Royal Gunpowder Factory Waltham Abbey and Question of Future of Factory', 1918–1919.

[5] William Rintoul, 'Frederic Lewis Nathan, 1861–1933', *Journal of the Chemical Society*, 1 (1934), 564–565.

[6] Robert Bud, *The Uses of Life: A History of Biotechnology* (Cambridge: Cambridge University Press, 1994), 37–45; and Roy M. MacLeod, 'The Chemists go to War: The Mobilization of Civilian Chemists and the British War Effort, 1914–1918', *Annals of Science*, 50 (1993), 455–481.

[7] Wayne Cocroft, *Dangerous Energy: The Archaeology of Gunpowder and Military Explosives Manufacture* (Swindon: English Heritage, 2000), 158–159.

[8] PRO SUP5/436, Establishment: Gretna Committee (W.3504), 1919–1920.

[9] John Reader, *Explosives* (Harmondsworth: Penguin, 1942), 112.

[10] HMSO, *History of the Ministry of Munitions* (London: HMSO, 1922), Vol. 10, 3.

[11] Reader, *op. cit.* note 9, 125; MacLeod, *op. cit.* note 6.

[12] PRO MUN7/36, Minister's Queries on Report of the Committee on the Silvertown Explosion, 23 February 1917–9 October 1919; Alan Cartwright, *The Dynamite Company: The Story of the African Explosives and Chemical Industries Ltd* (London: Macdonald, 1964), 136; Luit Haber, *The Chemical Industry, 1900–1930* (Oxford: Clarendon Press, 1971), 189.

[13] Hampshire County Record Office (Winchester), 109M91/RM9, 'Memo on HE by Lord Moulton', 16 June 1915.

[14] Anon., 'Birmingham and the Production of Munitions No. 1', *The Engineer*, 29 March 1918, 270–271.

[15] S. Levy, *Modern Explosives* (London: Pitman & Sons, 1920), 12.

[16] John Watts, *The First Fifty Years of Brunner Mond and Company* (Winnington: Brunner Mond and Company, 1923), 52–54.

[17] Francis Freeth, 'Ammonium Nitrate and TNT in World War I', *New Scientist*, 270 (1962), 157.

[18] *The Times*, 14 May 1915; See MacLeod, *op. cit.* note 6.

[19] PRO MUN5/146/1122/8, 'List of Factories operated by the Ministry of Munitions in March 1918'.

[20] M. Haslam,*The Chilwell Story: VC Factory and Ordnance Depot* (Nottingham: Boots Company, 1982), 1–70.

[21] PRO MUN5/154/1123.3/39, 'History of NFF Greenford, Middlesex (Chemical Shell)', November 1918.

[22] Roy MacLeod, 'The Industrial Invasion of Britain: Mobilising Australian Munitions Workers, 1916–1919', *Journal of the Australian War Memorial*, 27, (1993), 37–46.

[23] Levy, *op. cit.* note 15, 92.

[24] HMSO, *op. cit.* note 10, 3.

[25] PRO MUN7/555, *op. cit.* note 4.

[26] D. Hardie, and J. Davidson Pratt, *A History of the Modern British Chemical Industry* (Oxford: Pergamon Press, 1966), 99.

[27] P.G.A. Smith, *The Shell that Hit Germany the Hardest* (London: Shell Marketing, 1919), 5–11; see also Ernst Homburg in this volume.

[28] PRO MUN 5/294, HM Explosives Factory, Langwith, Nottinghamshire, January–November, 1918; Personal communication, Whaley Thorns Heritage Centre to author.

[29] Robert Robertson, 'Some War Developments of Explosives', *Nature*, 107 (2695), (1921), 524.

[30] Tony Travis, 'The Haber-Bosch Process: Exemplar of 20th-Century Chemical Industry', *Chemistry and Industry*, 15 (1993), 581–585.

[31] Anon., 'The Manufacture of Explosives', *Nature*, 109 (2739), (1922), 541–544.

[32] Gareth Griffiths, *Women's Factory Work in World War I* (Stroud: Alan Sutton, 1991); Gaynor Kavanagh, *Museums and the First World War* (Leicester: Leicester University Press, 1994), 138–143.

[33] Wayne Cocroft and Ian Leith, 'Cunard's Shellworks, Liverpool', *Archive*, 11 (1996), 53–64.

[34] Guy Hartcup, *The War of Invention: Scientific Developments, 1914–18* (London: Brassey's, 1988), 55.

[35] Nicholas Saunders, 'Excavating Memories: Archaeology and the Great War, 1914–2001', *Antiquity*, 76 (2002), 101–108.

[36] See Marie-Luise Buchinger, *Stadt Brandenburg an der Havel Teil 2: Äussere Stadtteile und eingemeindete Orte* (Worms am Rhein: Wernersche Verlagsgesellschaft, 1995), 212–219; Malcolm Bowditch and Lesley Hayward, *A Pictorial Record of the Royal Naval Cordite Factory Holton Heath* (Wareham: Finial Publishing, 1996); Cocroft, *op. cit.* note 7, ch. 6; Sebastian Kinder, 'Brandenburg an der Havel Der Industriestandort Kirchmöser von der Pulverfabrik bis zum Ausbesserungswerk der Reichsbahn', *Brandenburgische Denkmalpflege*, 1, (2000), 4–16; and Stuart Foreman, 'Nitroglycerine Washing House, South Site, Waltham Abbey Royal Gunpowder Factory, Essex', *Industrial Archaeology Review*, 23 (2), (2001), 125–142.

[37] Simon Pepper and Mark Swenarton, 'Neo-Georgian Maison Type', *Architectural Review*, 168 (1002), (1980), 92.

[38] PRO MUN7/555, *op. cit.* note 4.

[39] Paul Collins and Michael Stratton, *British Car Factories from 1896: A Complete Historical, Geographical, Architectural and Technological Survey* (Godmanstone: Veloce Publishing, 1993), 46, 68, 162, 173, 196, 200, 219, 237.

[40] Francis Freeth, 'Explosives for the First World War', *New Scientist*, 402, (1964), 275; ?, *op. cit.* note 30, 585.

[41] PRO CAB102/627, D. Mack Smith, 'Construction of the Filling Factories'. unpublished narrative, ca. 1945/6.

[42] Gould Shane, *Monuments Protection Programme: The Gunpowder Industry* (Combined Steps 1–3 Report, typescript report for English Heritage, 1993); David Cranstone, *Monuments Protection Programme: Chemical Industry* (Steps 1 Report, typescript report for English Heritage, 2002).