## Chapter 16

# AMMUNITION AND EXPLOSIVES

THE manufacture of ammunition necessarily formed a large part of the munitions program, for two reasons: firstly, because of the wide variety of items that came within its scope—the ammunition for guns and rifles as well as hand grenades, land mines, naval mines and torpedoes; and secondly, because of the great quantities of each item required, running in some instances into many millions. If the extent of an industrial effort can be measured roughly by its cost, then about one third of the 1939-45 munitions effort in Australia went into ammunition: expenditure on factories and equipment for making ammunition amounted to about £45,000,000, while the cost of the ammunition itself was approximately £41,000,000.[1] It involved the Government in the construction of 11 major factories, 16 smaller ones and 90 annexes, and in the employment of over 50,000 persons.

A typical round of ammunition made at this period was that for the 3.7-inch anti-aircraft gun. The accompanying diagram shows its main components and at the same time indicates the extensive nature of the industries upon which its manufacture was based. The round will be seen to have consisted of:

(*a*) metal components: the cartridge case, shell body, primer body and fuse;

(*b*) explosive components: initiators (lead azide and mercury fulminate), igniters (gunpowder), propellant (cordite WM), booster (tetryl) and high explosives (TNT).

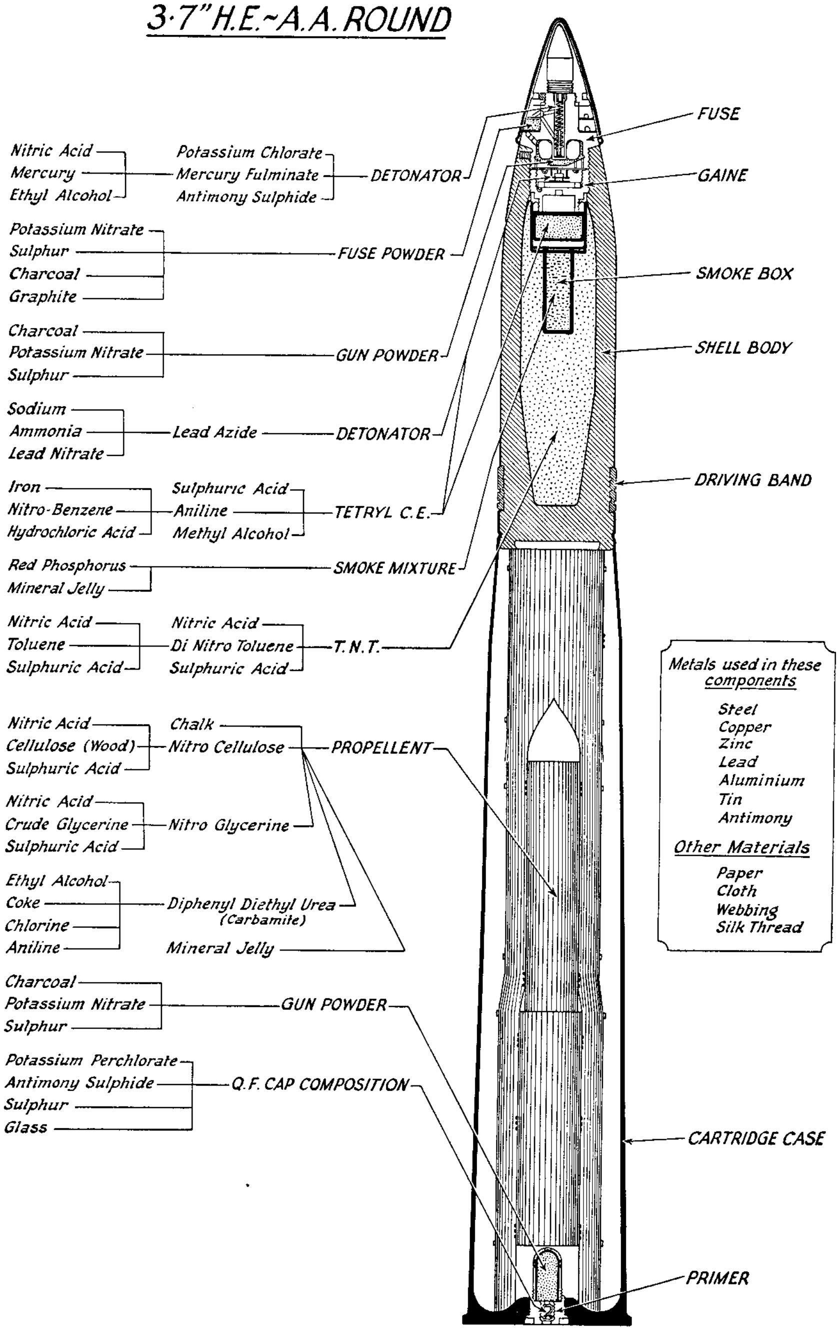
The raw materials from which these components were made are shown on either side of the diagram.

Small-arms ammunition and the cartridge cases of gun ammunition were made exclusively in the government factories, first at Footscray where the manufacturing technique for small-arms ammunition had been established in 1888. Cases were made by the traditional method of drawing in a press from a disc of brass cut from a rolled sheet. The only way of being certain that the walls of a case were of the requisite, uniform thickness and that they would retain their dimensions on storage,[2] was to begin with rolled sheet having precisely the chemical composition and physical properties specified. Manufacture of this sheet required an unusually high degree of scientific control, which was one reason why it was restricted to government factories. The capacity of the parent factory at Footscray

[1] The total expenditure on munitions was about £271,000,000 (see *Munitions Digest*, June 1945, p. 48).

[2] Unless properly treated, metals shrink and warp on long standing.

# 3·7" H.E.~A.A. ROUND




Dept. of Defence Production

proved much too small to satisfy the wartime demands, and the following factories were therefore built and began operations on the dates shown:

| | |
|---|---|
| Hendon, S.A. | Nov 1940 |
| Finsbury, S.A. | Feb 1941 |
| Rocklea, Qld | Nov 1941 |
| Welshpool, W.A. | Aug 1942 |
| Albury and Wagga, N.S.W. | Sep 1942 |
| Port Pirie, S.A. | Oct 1942 |
| Rutherford, N.S.W. | Oct 1942 |
| Goulburn, N.S.W. | Nov 1942 |
| Derwent Park, Tas | Dec 1942 |
| Broken Hill, N.S.W. | Jan 1943 |
| Tamworth, N.S.W. | Feb 1943 |
| Mildura, Vic | Mar 1943 |
| Kalgoorlie, W.A. | Oct 1943 |
| Hay, N.S.W. | Apr 1944 |

The manufacture of shell bodies by the well-established hot forging process was undertaken by the Ordnance Factory at Maribyrnong in the early thirties as part of the program to make the 18-pounder gun. As described

### GOVERNMENT AMMUNITION FACTORIES

**VICTORIA**

*Footscray*: Parent factory.
*Mildura* : Primers.

**QUEENSLAND**

*Rocklea* : ·303, ·380, ·455 Ammunition. Smoke shells-25 Pdr. Q.F. Cartridge cases

**TASMANIA**

*Derwent Park* : Cartridge cases 2 in. mortar bombs.

**NEW SOUTH WALES**

*Broken Hill* : Fuses
*Rutherford* : Cartridge cases. Shells - 4 in. Naval. 25 Pdr. 5·5 in. forging.
*Goulburn* : Shot, Fuses. Shell - 25 Pdr. Oerlikon Tracer
*Albury* : Fuses
*Tamworth* : Primers
*Wagga* : Fuses
*Hay* : Fuses

**SOUTH AUSTRALIA**

*Hendon* : ·303 Ammunition
*Finsbury* : Cartridge cases Fuses
*Port Pirie* : Shells - 25 Pdr.

**WESTERN AUSTRALIA**

*Welshpool* : ·303 Ammunition.
*Kalgoorlie* : 40 mm. A.A. Bofors shell.

earlier, a similar process capable of adaptation to the making of shell bodies was developed by Stewarts and Lloyds in their seamless tube plant at Newcastle. One of the chief problems in extending the manufacture of shell bodies to commercial industry was the provision of suitable hydraulic presses. Australia was able to import machines of the most modern design from Baldwin Omes in the United States.

The Directorate of Gun Ammunition, under the leadership of Mr W. J. Smith, one of Australia's leading production engineers, organised the manufacture of shell bodies by commercial industry with great efficiency, pressing into service the resources of all the State railway workshops, the steel industry, and other private engineering firms.

Relatively simple in design and comparatively easy to make, primer bodies were made in millions by commercial industry. So also were fuses,[3] though these were a good deal more complicated than primers.

The number of rounds of the various types of ammunition produced in Australia between 1940 and 1945 is set out below:

| | |
|---|---|
| Small arms | 1,845,000,000 |
| Light anti-aircraft | 3,784,695 |
| Heavy „ „ | 575,222 |
| Light artillery | 1,521,411 |
| Medium „ | 8,021,850 |
| Heavy „ | 131,725 |
| Mortar bombs | 3,993,011 |
| Grenades | 5,521,594 |
| Aircraft bombs (practice) | 1,840,719 |
| „ „ (service) | 147,718 |
| Mines (land) | 750,098 |
| „ (naval) | 12,336 |

While all this ammunition was manufactured in strict conformity with British specifications and designs, considerable latitude was permissible to allow for local materials and processes so long as the finished articles possessed exactly the desired characteristics. Fabrication of metal components presented few difficulties and called for very few innovations. In the manufacture of explosives on the other hand, there were many interesting technical developments and for this reason they will be discussed at some length. As these processes were potentially extremely dangerous they were confined to the government factories and to an annexe conducted for the Government by I.C.I.A.N.Z.

Until the second world war Australian commercial and military explosives were made only in Victoria.[4] In the open spaces of Deer Park on the outskirts of Melbourne the manufacture of commercial explosives was begun in 1874 in response to the needs of the flourishing gold-mining industry. Nitroglycerine formed the essential basis of explosives used in mining and quarrying. After many vicissitudes the young industry passed in 1925 into the hands of Nobels (Australia) Pty Ltd, which was later merged with I.C.I.A.N.Z. After extensions had been made to the plant in 1935, the output of explosives was greatly increased and within three years it was producing blasting gelatine, dynamite and gelignite at the rate of about 8,000 tons a year—sufficient to meet Australia's requirements of these materials.[5] Many chemical operations used in making commercial

[3] A fuse (sometimes spelt fuze) is any device for initiating the explosion of a shell, bomb, grenade, etc.

[4] Mr W. H. Coulson and Mr D. W. Finley have given me valuable help with this chapter.

[5] These explosives were all based on nitroglycerine. Their approximate compositions were as follows:

| | Blasting gelatine | Dynamite | Gelignite |
|---|---|---|---|
| Nitroglycerine | 92% | 75% | 60% |
| Collodion cotton | 8% | — | 5% |
| Kieselguhr or diatomaceous earth | — | 25% | — |

Gelignite contained in addition 27% potassium nitrate and 8% wood meal.

explosives were also used in making military explosives, and although in Australia the two industries were conducted separately in peacetime, I.C.I.A.N.Z. was able to provide valuable assistance to the Government during the war. Moreover the company could call upon the great fund of technical experience of its parent organisation, Imperial Chemical Industries, which for many years had made both industrial and military explosives on a large scale at Ardeer, in Scotland.

The manufacture of military explosives in Australia began much later than that of commercial explosives. In 1910, in pursuance of the policy of self-containment in defence, the Commonwealth Government built a factory at Maribyrnong near Melbourne for the manufacture of small-arms cordite. Like the dynamites, cordite was based on nitroglycerine. By itself, nitroglycerine was, as Nobel found when he first began to manufacture it in 1863, extremely dangerous to handle, both during manufacture and in the course of transport, and many serious accidents occurred. In 1867 he discovered that nitroglycerine could be made safer to handle by mixing it with kieselguhr, an inert substance; also, and more surprisingly, that when mixed with gun cotton (nitrocellulose), itself a powerful explosive, it formed a relatively slow-burning propellent. A colloidal dispersion of nitrocellulose in nitroglycerine formed by means of a solvent such as acetone or by mechanical working under suitable conditions of temperature and pressure, would not burn to detonation although it could be readily detonated by explosives, such as mercury fulminate, which were referred to as initiators. Until about 1930 all cordite was made by the "dry mixing" process, so called because the first step consisted of mixing dried nitrocellulose in the form of a creamy-white, friable powder, with liquid nitroglycerine. Insofar as it involved handling dry nitrocellulose there was an ever-present element of danger at this stage of manufacture. In the wet condition nitrocellulose was perfectly safe to handle; once dried it became sensitive to mechanical and thermal shock, either of which might cause it to take fire and explode. Dried nitrocellulose was always mixed by hand since the resulting paste was too sensitive to be safely handled in any form of mechanical mixing equipment. The second step in the process consisted of bringing the paste into a gelatinous condition, which was done by first moistening it with acetone, when it became less sensitive to mechanical shock, and then pounding it in a mixing machine for several hours until it was transformed into a homogeneous, yellowish-brown, translucent mass. At this point a stabiliser—mineral jelly—was added. This combined with and rendered innocuous certain substances which would be liberated by deteriorating cordite and cause a spontaneous explosion.[6] This type of cordite was discarded about 1915 because its high flame

[6] Mineral jelly owed its stabilising action to the presence in it of unsaturated hydrocarbons, the proportion of which was frequently deliberately increased by a process known as "cracking". The stabilised material, commonly referred to as "dough", was extruded in the form of cords (hence the name cordite) from which the volatile solvent (acetone) was allowed to evaporate at a temperature of not more than 43°C. This, very briefly, was the process used by the Explosives Factory Maribyrnong in 1912 when it began to manufacture cordite Mark I at the rate of about 50 tons a year for small-arms ammunition. As part of its original program the factory also made mercury fulminate, the sensitive initiatory explosive used on the percussion caps of small-arms ammunition.

temperature tended to cause serious erosion in gun barrels. This tendency was lessened by reducing the proportion of nitroglycerine in the mixture from 58 to 30 per cent, to produce cordite M.D.

As part of the program for increasing the production of munitions in the late twenties, the activities of the factory were extended to include the manufacture of a third class of explosive, namely high explosive (H.E.) used in bursting shells, bombs and mines. This differed from propellants in that its rate of burning was so rapid as to be almost instantaneous, with the result that it detonated with a shattering effect. In 1928 Maribyrnong began to make T.N.T., a substance which was still, in spite of many others that had since been developed, the most important of military high explosives. T.N.T. did not deteriorate on long storage; it melted at a relatively low temperature (80 degrees centigrade) and could be readily poured into shell bodies and other containers. It was not without drawbacks—it shrank on solidifying and thus tended to leave cavities, and it was poisonous—but these were outweighed by its advantages.

An essential quality of a military explosive was that it must not deteriorate on storage. Commercial explosives were rarely stored for long periods before use, but military explosives often were. Cordites were the most unstable explosives in common use and it was only by using raw materials of uniformly high quality, by exercising the greatest care to avoid the introduction of impurities during their manufacture and by adding to them special substances known as stabilisers, that the risk of deterioration during storage could be overcome. Though the cause can never be known with certainty, experts agree that the blowing up of the battleship *Bulwark* in 1914 and of the cruiser *Natal* a year later was due probably to a spontaneous explosion in deteriorating cordite. Testing of cordite for evidence of deterioration was therefore absolutely essential.

It was in this connection that the first scientific laboratory to be associated with the Commonwealth Department of Defence was set up in 1910 on the recommendation of Mr C. Napier Hake, Chief Inspector of Explosives in Victoria and Chemical Adviser to the Department of Defence. Located in what had been a guard house, at the south gate of Victoria Barracks, the laboratory was at first concerned almost solely with routine surveillance tests on the storage of cordite and other explosives in the various defence magazines throughout Australia.

The laboratory's activities continued until 1921, when it was included within the Munitions Supply Branch as the Explosives Section and became one of the most active and the most important units of that organisation. The section's main functions were to ensure that the products of the Maribyrnong factory conformed with Service specifications, and to study the conditions necessary for the safe storage and transport of explosives.

In 1935 the Maribyrnong factory undertook the manufacture of naval cordite (cordite S.C.).[7] This was more than simply another item on the production list: it represented a distinct advance in manufacturing achieve-

[7] SC stands for solventless, carbamite.

ment and a new level of confidence in the capabilities of the Munitions Supply Board. As already mentioned, the Australian Navy depended on Britain for all its warlike supplies, and it was reluctant to change this arrangement. The rigid system of inspection imposed by the Royal Navy applied to ammunition carried not only by its own ships but also by any ships manoeuvring with them; a ship whose magazine could not be relied on might be a danger to other ships in the vicinity, and as cordite was often stored for long periods on ships its stability had to be above suspicion.

The time required to burn a given quantity of cordite in a gun could be controlled by adjusting the ratio of its surface area to its volume. In a rifle cartridge, for example, cordite usually took the form of a bundle of fine, thin-walled tubes about the thickness of a darning needle, the wall thickness being so chosen that the charge was burnt out just before the bullet left the relatively short rifle barrel. On the other hand, in a large gun of long bore such as a naval gun a longer time of burning was called for. The charge was therefore built up of thicker cords.

When thick cords were made by the original process the time required to dry out the solvent (acetone) might be as long as several weeks which meant that large quantities of cordite had to be held in manufacture. To avoid this the Naval Cordite Factory at Holton Heath (England) introduced the solventless process, which avoided the use of a volatile solvent and had the special advantage of being much safer than the dry process because the first step consisted of mixing nitroglycerine and nitrocellulose under water.

Innovations introduced at the same time brought with them other advantages. Especially notable was the substitution of carbamite for mineral jelly as a stabiliser: carbamite was a more efficient stabiliser and also acted as a partial gelatiniser. It was added before the nitrocellulose-nitroglycerine mixture was dried, a procedure which represented a considerable gain in safety. In the second step the water was drained off and the material, in the form of a thin sheet supported on a wire gauze, was allowed to dry. Gelatinisation was completed, not by means of a solvent but simply by passing the sheet between rollers heated to 55 degrees centigrade, after which it was taken to a still higher temperature (70 degrees) and finally extruded in the form of thick cords. The increased safety of the first step was offset to some extent by the risk of fire which attended the rolling operations. The solventless process possessed still another advantage over the older process: it avoided shrinkage and distortion of the cordite. Dimensional stability was conducive to good ballistics; in other words charges of cordite which remained identical in size and shape could be relied upon to reproduce exactly a given muzzle velocity in a projectile.

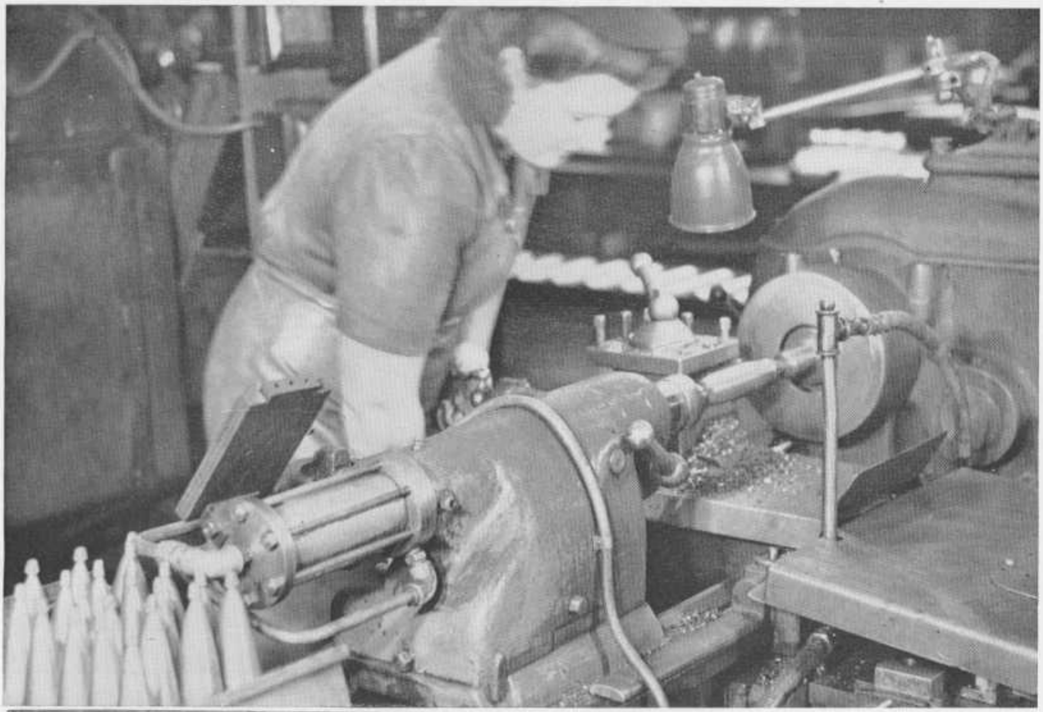
By the end of 1935 the Maribyrnong Explosives Factory, though still dependent on outside supplies for some of the raw materials, was manufacturing cordite S.C. of a quality acceptable to the Admiralty. It had also successfully developed and brought into production most of the important types of military explosive then in general use, and had assembled a staff well trained in the manufacture and in the techniques of filling ammunition. A nucleus from which a wartime explosives industry could grow was thus well established.

Calculations based on the assumption that the defence forces should be prepared for a "minor scale of attack"—the officially-accepted view—revealed that the capacity of the government factories for producing cordite and T.N.T. (which was at the rate of 1,500 and 600 tons per annum respectively) fell short of requirements. After considering several alternative proposals for decentralising the manufacture of these explosives, which up to this time had been made only at Maribyrnong, the Principal Supply Officers' Committee at a meeting on 23rd August 1938 favoured a proposal that I.C.I.A.N.Z. should be asked to build an annexe to its Deer Park factories. This proposal had much to recommend it: adequate technical staff could be provided by the company; nitric and sulphuric acids, some accessory equipment services, power and steam could be supplied from the company's neighbouring plants, and the proposed site was well suited to the purpose. Four days before the outbreak of war the Minister for Supply and Development, Mr Casey, approved the scheme, and shortly afterwards the Commonwealth Government entered into an agreement with I.C.I.A.N.Z. for the construction of an annexe (Armament Annexe No. 29—later known as No. 5 Government Explosives Factory, Albion), designed in the first instance for an annual output of 2,000 tons of T.N.T., 1,000 tons of cordite, and 250 tons of carbamite.

Carbamite, a key substance whose importance in the manufacture of cordite has already been alluded to, was new to the Australian chemical industry, but not beyond its capacity, thanks to the well-developed chlorine industry at Yarraville. One of the starting materials used in its manufacture was phosgene (a poison gas used in the first world war) which was made by the interaction of chlorine with carbon monoxide. It may help to clarify the nature of the important wartime developments in the manufacture of cordite if, at this point, the processes in operation at Maribyrnong in 1939 are briefly recapitulated, in the accompanying table.

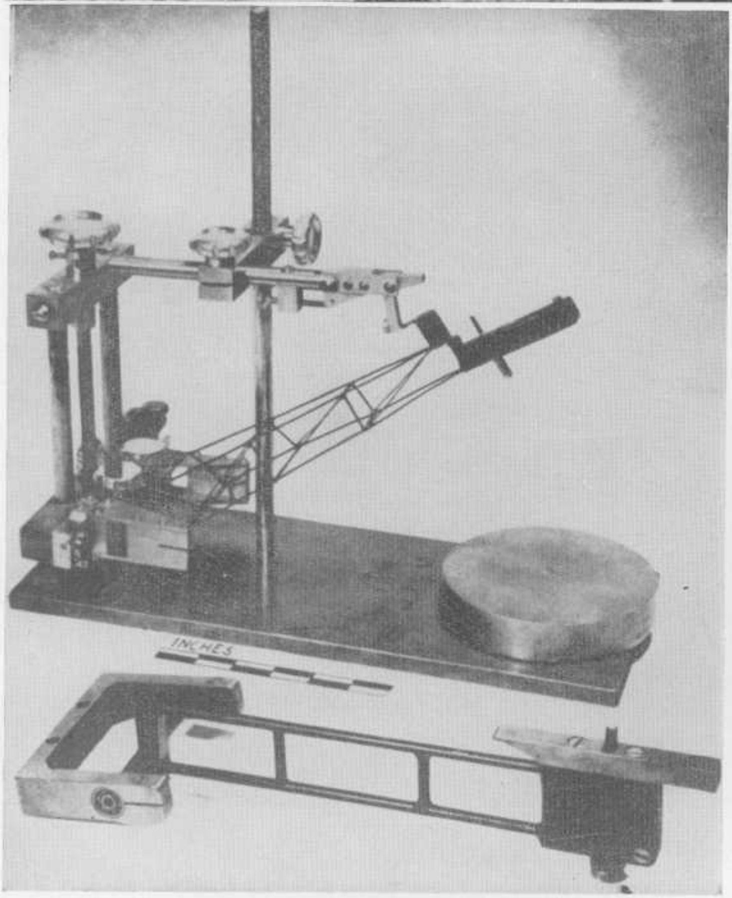
| LAND SERVICE CORDITES | NAVAL CORDITE |
|---|---|
| CORDITE MD, made by dry mixing process.<br>*Gelatinised with acetone.*<br>Stabiliser (mineral jelly) added during gelatinisation. | CORDITE SC, made by *wet mixing process.*<br>*Stabiliser (carbamite) added during wet mixing.*<br>Gelatinised by rolling at 55-75 deg C. |
| CORDITE W, made by dry mixing process.<br>Stabiliser (carbamite) added to dry mix during gelatinisation.<br>*Gelatinised with acetone.* | *Note*: The safe processes are shown in italics. |

The factory at Albion was to be used for the manufacture of cordite W, and the intention was to evolve a method which would combine the safer



*(L. J. Hartnett)*

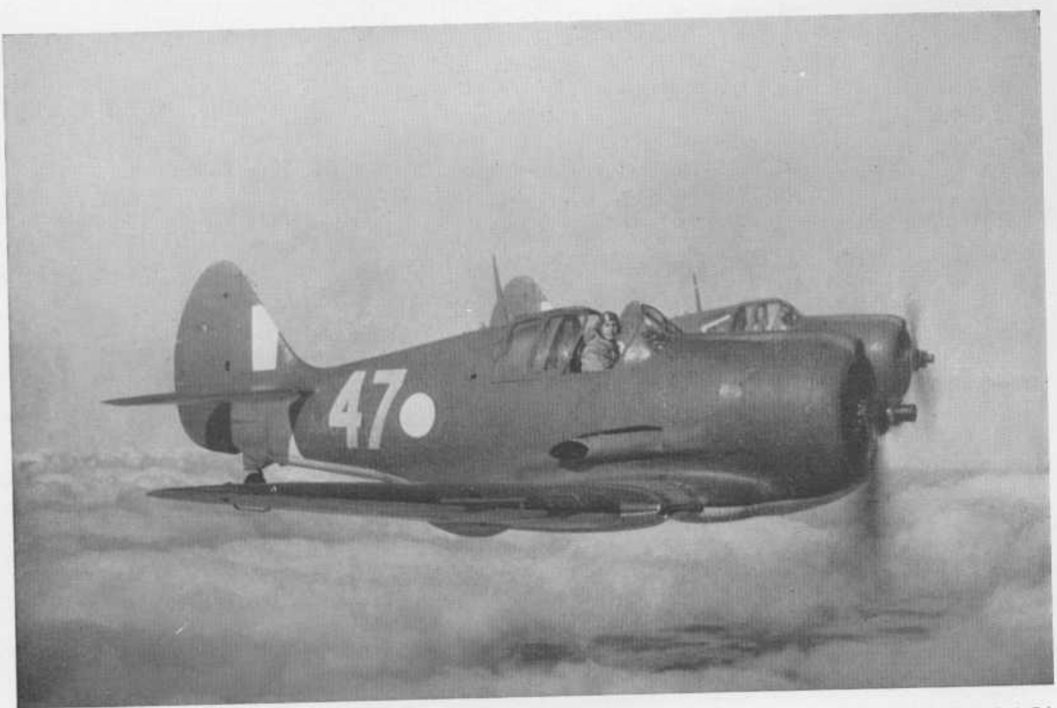
Profile turning outside of a shell.




Pendulum hammer apparatus used in experiments on the initiation of explosives.

*(From Bowden and others, CSIR Bulletin No. 173, plate 1)*

Wirraway. *(C.A.C.)*




Boomerang. *(C.A.C.)*

steps in the manufacture of the other types of cordite, namely: wet mixing using carbamite as the stabiliser; and gelatinisation by means of a volatile solvent. Such a process had been tried out in the United Kingdom some years previously but had never been used there on a large scale. There would have been little difficulty in putting it into operation at Albion had it not been for the fact that carbamite could not be imported at the time and was not yet being made locally.

A way out of this difficulty was to try to make cordite M.D. (which was an acceptable substitute for cordite W) by a wet process. Wet mixing became safer still if a stabiliser was added before the material was dried. This presented no difficulty with carbamite but at that time it had nowhere been satisfactorily achieved with mineral jelly. Mr Leighton, the Consultant on Explosives, suggested that an attempt should be made to overcome this difficulty. The problem was referred to the Developmental Laboratory at the Explosives Factory Maribyrnong where it was satisfactorily solved by a team working under the direction of Messrs Cochrane[8] and Coulson.[9] Molten mineral jelly was injected by means of steam into a well-stirred aqueous suspension of nitrocellulose. After nitroglycerine had been added the mixture was dried and gelatinised with acetone in the usual way. The new process was immediately adopted at Maribyrnong and soon afterwards at Albion. The effect of this important discovery was that it became possible to make all types of land-service cordite in the wet process plant at Albion under significantly safer conditions. By 1942 all types of cordite in production in Australia were being made by processes adapted to the initial wet mixing of nitrocellulose and nitroglycerine, a notable contribution to a higher level of safety in the industry. The absence of serious accidents from the wartime industry may be attributed in part to these technical developments.

While the Albion annexe was being built a great deal of discussion went on between the Advisory Panel on Industrial Organisation and officials of the Department of Supply, about the desirability of a second filling factory. To decentralise manufacture of military explosives but to neglect to decentralise "filling" factories was, in the eyes of the industrialists, only a half measure. Destruction of Maribyrnong filling factory, the only one in the Commonwealth, either by an accidental internal explosion or by enemy action, would, they argued, jeopardise the whole defence scheme. The panel strongly urged, therefore, the construction of a second filling factory at Albury. Department officials, on the other hand, while well aware of the force of these arguments, were anxious to defer such a step until they had provided the immediate needs of the fighting services. Their estimates were that it would be two years after beginning construction before a second filling factory would come into operation. Current expan-

[8] J. R. S. Cochrane, BSc. Asst Manager, Explosives Factory Maribyrnong, 1928-41; Manager Explosives Factory, Salisbury, 1941-45; Leader, Aust Scientific and Technical Mission to Germany, 1946-48; General Manager, Explosives Factories, 1950-55. Of Melbourne; b. Melbourne, 11 Aug 1891. Died 3 Oct 1955.

[9] W. H. Coulson. In charge of Developmental Labs Explosives Factory Maribyrnong 1938-44; Aust Munitions Representative in London 1945-50. Of Melbourne; b. London, 3 Nov 1901.

sion at Maribyrnong and at Albion, they pointed out, would make it difficult to secure the technical staff necessary to construct and operate the second filling factory.

Then there was the question of its site. Climatic conditions favoured Victoria. Some air-conditioning would be necessary wherever it was built, but it would be a good deal less in Victoria than in any other of the mainland States. Places farther north than Newcastle, New South Wales, were ruled out completely because of high temperatures and humidity. Albury, Bendigo and Ballarat were suggested, but throughout the period of the "phoney war" discussions ranged on without any decisive result. It was not until June 1940 that any positive action was taken.

Within the newly created Department of Munitions a Directorate of Explosives Supply was set up and placed under the direction of Mr Donaldson, a technical director of I.C.I.A.N.Z. Donaldson was a man with wide experience in the explosives industry at high technical and directive levels, gained first at Nobel's Ardeer factory in Ayrshire, later at the Modderfontein Dynamite Factory in South Africa, and as Technical Managing Director, Explosives Group, of I.C.I. in London. A dour Scot whose dialect was sometimes hard to follow, Donaldson had great physical and mental vigour, and outstanding administrative capacity. His immediate task was to create a large organisation capable of dealing with the many diverse problems associated with the design and erection of factories for making propellants, high explosives and pyrotechnics, as well as with the technicalities of filling and assembling ammunition. He was fortunate in having as his departmental adviser Mr Topp, who as Manager of the Maribyrnong Explosives and Filling Factory had had long experience with military explosives and knew the departmental procedures from A to Z. Mr Grist,[1] and later Mr Finley,[2] became Donaldson's personal assistant.

The Directorate of Explosives Supply differed from the other directorates of the Department of Munitions in that it was concerned entirely with designing and building factories but had no functions of management. Other directorates designed, built and managed their factories through Boards of Area Management; the factories built by the Directorate of Explosives were operated by the Department of Munitions. The purpose of this arrangement was to relieve the managements of government explosives factories from the work of designing and building new factories, so that they could concentrate on production.

Donaldson's technical experience had been gained almost exclusively with the construction and operation of plants for making commercial and military explosives. Topp, on the other hand, was experienced both in the manufacture of explosives and in the filling and assembly of the components into ammunition, and he was fully acquainted with the design of factories for making war material such as pyrotechnics, land mines and

[1] J. M. Grist. Works Manager, Nobel Explosives Factory, Deer Park, to 1945. B. Petersfield, Eng, 5 Jun 1883. Died 31 July 1951.

[2] D. W. Finley, MA, BSc. Factory Superintendent, Bogawantalawa District Tea Co Ceylon; Personal assistant to Dir Explosives Supply 1941-45; Manager, Information Service ICIANZ Ltd, since 1945. B. Ryde, Isle of Wight, 21 Jan 1912.

bombs. In many ways their experience was complementary, and each possessed a temperament that made for good team work.

Some indication of the extent of the new demand for explosives which sprang up almost overnight, may be had from the fact that tentative estimates made by the Controller of Production Orders and Statistics, Mr S. K. Menzies,[3] on advice from the Service Chiefs, called for an increase in the annual output of T.N.T. from 1,600 tons to 9,000 tons, and of cordite from 2,500 to 10,000 tons. Many other items were required, but these were the principal ones, and to provide them new factories would be needed.

The question of the adequate and continuous supply of chemical raw materials for the operation of the explosives and filling factories was now thrown into sharp relief.

> It does not require a very close examination (wrote Leighton at this time) to find that the factories now operating, small as they are compared with those that will be, already put a strain on supply. A disconcerting factor is that of surprise—one day it is glycerine, the next nitrate of soda, and so on. There seems to be no watch tower, no one to give a reliable account of how supply of armament chemicals is or will be.

The result of this memorandum was the appointment of a permanent Armament Chemicals Committee to keep watch over and report upon, and recommend measures in relation to, the supply of all chemicals needed by the Department of Munitions.[4] The need to plan supplies of raw materials for the government explosives factories had of course been recognised long before this committee came into being, but the new developments demanded a more systematic attack on what was a very much larger problem.

Those planning the new explosives factories, following the precedent set at Maribyrnong, adopted the method of making nitric acid—a key chemical of the industry—from nitrate of soda and sulphuric acid as the most practicable in the circumstances. More than thirty retorts for making nitric acid, capable of consuming between them 20,000 tons of nitrate of soda a year, were built and set up near the main factories. However the planners were fully aware that the great weakness of this arrangement was its dependence on imported Chilean sodium nitrate and the problem of disposing of "salt cake", a by-product of the process. This weakness was emphasised by the growing threat to shipping across the Pacific and the increasing difficulty of obtaining American dollars. In the course of discussions within the directorate it was pointed out that the explosives program required an annual importation of 45,000 tons of nitrate, payment for which would have to be made in dollars equivalent to £850,000 Australian.

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[3] S. K. Menzies. Executive G. J. Coles and Co 1931-39; Dir Production Orders and Statistics Dept of Munitions; and Services-Munitions Coordination Cttee, 1940-45. Of Melbourne; b. Jeparit, Vic, 23 Jul 1905.

[4] Members of the committee were: A. E. Leighton (Chairman); H. P. Breen (Asst Secretary, Dept of Munitions); H. C. Green (Controller of Materials Supply); Dr J. Vernon (representing commercial industry); Dr I. W. Wark (CSIRO); E. J. Drake (Asst Controller Industrial Chemicals) (Secretary).

At the Deer Park factory I.C.I.A.N.Z. had already begun to exploit atmospheric nitrogen as a source of nitric acid, converting it first by the Haber process to ammonia and then by atmospheric oxidation to the acid. On 12th August 1941 Donaldson presented a complete scheme for the production of nitric acid and ammonium nitrate. He proposed as a first step to erect plants for the oxidation of ammonia. The intention was to use about half the Australian output of by-product ammonia (from coke ovens and gas works) calculated to yield about 13,500 tons of nitric acid a year, until synthetic ammonia should become available. The nitric acid so obtained would be at the expense of the ammonium sulphate ordinarily used in agriculture.

After considering a recommendation by the Director-General of Munitions on 10th October 1941, the War Cabinet approved the construction of four synthetic ammonia and ancillary plants by I.C.I.A.N.Z. under the supervision of the Directorate of Explosives supply. It was decided that at the same time three units for the production of synthetic methanol and for its distillation should be built in association with the ammonia unit. The estimated cost of the whole project was £2,500,000. The installations were to be distributed as is shown in the accompanying table.

| | Synthetic Ammonia | Methanol | Ammonium Nitrate | Oxidation of Ammonia |
|---|---|---|---|---|
| Villawood . . | 1 | 1 | 1 | 1 |
| Mulwala . . | 1 | 1 | | 1 |
| Albion . . . | 1 | 1 | | 1 |
| Ballarat . . | 1 | | 1 | 1 |

In making this decision it was anticipated that with the inevitable falling off in the demand for nitric acid after the war, the ammonia plants could be turned over to the production of ammonium sulphate as a fertiliser for agricultural purposes, while the methanol plants would be of value in the plastics industry. Since, under the new scheme, sulphuric acid would not be needed for making nitric acid but only for concentrating it, there would be a smaller demand for imported elemental sulphur. Furthermore, the new industry would permanently preserve the country's capacity for making a chemical of key importance for defence.

The necessary equipment was of highly specialised and complicated design, and I.C.I.A.N.Z., as the only firm in Australia with expert knowledge concerning it, was given the responsibility of constructing four synthetic ammonia and three synthetic methanol units, together with four units for the oxidation of ammonia to nitric acid at atmospheric pressure and two for the production of ammonium nitrate. The synthetic ammonia plants were designed to have an annual capacity of 3,000 long tons of ammonia, together with 450 tons of methanol. Alternatively 900 tons of methanol could be produced if it were so desired, but at the expense of the output of ammonia, which would be reduced to 2,550 tons. It was decided to use by-product ammonia while awaiting the completion of the synthetic ammonia plants.

A survey of the capacity available in Victoria and New South Wales for the production of purified by-product ammonia having revealed that it was far from adequate to meet likely demands, additional plants were installed in the Metropolitan Gas Works in Melbourne, the Australian Gas Light Company in Sydney, and Australian Iron and Steel, Port Kembla. Arrangements were made with the Ammonia Company of Australia Pty Ltd in Sydney and the Victoria Ammonia Company in Melbourne to increase their production by about 25 per cent. Use was also made of the government annexe operated by Timbrol Ltd at Mortlake, New South Wales, to augment supplies. Oxidation of ammonia was carried out at atmospheric pressure in the presence of a platinum rhodium catalyst, a process which furnished an acid of about 50 per cent strength. Weak nitric acid from this source was later concentrated by mixing it with a strong sulphuric acid and distilling strong nitric acid from the resultant mixed acid.

The first unit for making nitric acid from ammonia was completed at Ballarat in November 1942; then followed one at Villawood (in March 1943), Mulwala (in October 1943) and Albion (in July 1944). It will be seen that most of these units were completed at the peak of the activities of the Directorate of Explosives Supply. The ammonium nitrate unit at Ballarat came into operation in March 1943 and that at Villawood in April 1943.

Owing to the uncertainty of shipping and the long delays in obtaining equipment from the United Kingdom, the Directorate of Explosives Supply decided as a matter of policy that as much as possible of the equipment for the synthetic ammonia plants should be manufactured in Australia, even though some of the items had not previously been made in this country. Australian engineers were thus committed to a somewhat daring undertaking, considering the facilities available. The Newcastle steelworks of the B.H.P., in conjunction with Australian Iron and Steel Ltd of Port Kembla, undertook the manufacture of hollow steel forgings of nickel-chromium steel for the main converters, the design of the converters being modified to meet the maximum capacities of the local steel manufacturers. The operation of piercing the 80-ton ingot poured by the B.H.P., and creating a bottleneck at both ends—one of the trickiest operations in forging—was carried out under the direction of Mr Merrett by Australian Iron and Steel. For the Australian steel industry—indeed for any steel industry—this was an achievement of a high order. It was an operation which was at that time being undertaken by only one firm in the United States, though the technique was better known in Europe. The smaller hollow nickel-chromium steel forgings were made by the Commonwealth Steel Company Ltd, while thick-walled high-pressure piping, capable of withstanding pressures of up to 300 to 400 atmospheres, was made by Stewarts and Lloyds.

The synthetic ammonia and methanol plants at Mulwala were the first to be completed (in June 1944), by which time the amount of ammonia being requisitioned was sufficient to keep only one of the four plants in operation. Consequently it was decided that as each plant was completed it would be "run in" until it was proved. Albion was ready by May 1945 and Ballarat in June 1945. While the construction of these installations was a first-class technological achievement under difficult conditions, and while it contributed greatly to the defensive potential of the country, it came too late to play any significant part in the war. Most of the 40,000 tons of nitric acid used in the explosives industry during the war came from imported Chilean nitrate; only about 10 per cent was obtained from the oxidation of by-product ammonia. The amount made from synthetic ammonia and used in war production was quite small—probably not more than 10 per cent of the acid made by the oxidation of ammonia from all sources.

One of the last recommendations made by Donaldson before he resigned the Directorship of Explosives Supply in February 1944, was that the four synthetic ammonia plants should be equipped for the production of ammonium sulphate for use as a nitrogenous fertiliser, for which there would be a large market after the war. This the Government agreed to do, allocating £400,000 for the purpose.

As explained in an earlier chapter, the conversion of glycerine, cellulose and toluene into the corresponding explosive nitro compounds entailed the use of nitric acid, together with sulphuric acid, preferably in the form of oleum—sulphuric acid containing more sulphur trioxide than corresponded with the formula $H_2SO_4$.[5] Like nitric acid, oleum was inconvenient to transport and special plants for its production had to be built as close as possible to the explosives factories. Additional plants were required in any event since the peacetime needs were only a fraction of those for war. Oleum plants using elemental sulphur as a raw material were erected by Commonwealth Fertilisers and Chemicals Ltd at Ballarat and Villawood. The 23,000 tons of oleum required each year by the Albion and Maribyrnong factories was produced in the main works of Commonwealth Fertilisers at Yarraville, Victoria, while supplies for Salisbury were obtained from Broken Hill Associated Smelters at Port Pirie. Both plants used mineral sulphides (Yarraville iron pyrites and Port Pirie zinc concentrates) as a source of sulphur.

After glycerine, toluene, or cotton had been treated with the mixture of nitrating acids (sulphuric acid and nitric acid), an appreciable proportion of the nitric acid remained unused. At the same time the sulphuric acid, which was itself not consumed in the nitration process, became diluted with water formed as a result of the chemical interaction between nitric acid and the glycerine, toluene or cotton. Before the spent acids could be used over again they had to be separated and concentrated once more. Economy in the manufacture of explosives depended to a large extent on the efficiency of acid recovery, and special equipment was installed at each of the factories for this purpose. At all factories except Albion (where Pauling pots were used) concentration of sulphuric acid was carried out

[5] As mentioned earlier, 20 per cent oleum, the strength most used in the explosives industry, consisted of 20 parts of $SO_3$ and 80 parts of $H_2SO_4$, which was equivalent to 104.5 per cent $H_2SO_4$.

by the Bamag process, then new to Australia.[6] Spent sulphuric acid was not always reconcentrated. Salisbury, for example, returned large quantities of sulphuric acid which had been diluted in the course of nitration to the superphosphate works at Wallaroo.

Distillation columns used in the separation and concentration of the nitrating acids had to withstand their highly corrosive action. For this purpose few economically available materials were so effective as a cast iron containing about 0.5 per cent of carbon and 14.5 per cent of silicon. The difficult task of casting the distillation columns—30 per cent recovery of castings was considered good under some conditions—was carried out by the W. L. Allen Foundry Pty Ltd of Melbourne, and Quality Castings Pty Ltd of Sydney. Silicon-iron cracked easily under thermal or mechanical shock, but it was almost wholly impervious to the attack of nitric or sulphuric acid in any strength and at any temperature.

In pre-war days the soap and candle industries had no difficulty in supplying glycerine for making commercial and military explosives. The amount consumed was about 1,200 tons a year—1,000 for commercial and 200 for military explosives. The estimated requirements of glycerine for 1941 and 1942 were as shown in the table.

Estimated requirements of glycerine

| | 1941 tons | 1942 tons |
|---|---|---|
| Commercial explosives . . . . . | 1,200 | 1,200 |
| Pharmaceutical and industrial uses . . | 1,500 | 1,500 |
| Military explosives . . . . . . | 1,000 | 2,300 |
| | 3,700 | 5,000 |

The figures for 1942 exceeded the anticipated combined outputs of J. Kitchen and Sons Pty Ltd (Port Melbourne) and Lever Brothers Pty Ltd (Balmain, N.S.W.) and a number of smaller firms, by about 2,000 tons a year. Several courses of action were open to the authorities. Some saving could be expected from the introduction of rationing, but since there were many industrial uses for which there was no suitable substitute for glycerine not a great deal could be hoped for from this expedient. The output of glycerine was limited by two factors: the amount of soap made, which in turn depended on the availability of soda ash and caustic soda—both in short supply; and the capacity of the stills used in making glycerine of the purity needed for explosives.

Ordinary commercial glycerine consisted of about 80 per cent glycerine and 20 per cent water. Before it could be used for making explosives it was necessary to subject it to a double distillation. Glycerine could be obtained from fats without the necessity of making soap: tallow, for example, could be split into glycerine and fatty acids by treating it with

[6] The output of a Bamag concentrator was 19 to 20 tons of sulphuric acid a day when concentrating from 63 per cent to 96 per cent strength. The numbers of units installed at each factory were: Maribyrnong 2, Villawood 8, Salisbury 6, Ballarat 12, and Mulwala 8. Together their capacity was about 600 tons of sulphuric acid a day.

superheated steam. An annexe for working this process was built by J. Kitchen and Sons at their Melbourne works. The great drawback of the process was the problem of disposing of the fatty acids.

It was also possible to make glycerine by an altogether different process —by the fermentation of raw sugar in the presence of sodium sulphite. As an insurance against a possible shortage of glycerine, Leighton arranged with the Colonial Sugar Refining Company Ltd to develop this alternative source.[7] The fermentation process had been used on a large scale in Germany during the 1914-18 war and had been a major factor contributing to Germany's ability to continue waging that war. Developmental work progressed from laboratory scale to a pilot plant capable of an output of 3 tons of glycerine a week. A major difficulty which was overcome was to purify the product of fermentation so that it would pass the stringent specification for glycerine to be used in the explosives industry. The unit functioned quite successfully, but not for long. During 1942 an unexpected windfall in the shape of several thousand tons of glycerine was received from the United States, and so from 1943 onwards there was little anxiety about the supply of glycerine. In fact, stocks banked up, with the result that some thousands of tons were declared surplus.

The lack of a well-developed organic chemical industry, particularly of a section making dyestuffs which in other countries gave considerable support to the manufacture of explosives, was one of the handicaps suffered by Australia. Fortunately, as related in the chapter on chemical industry, one company that was beginning just before the war to exploit by-products of the coal gas industry, had the foresight to begin the large-scale alkylation of aniline to provide the starting materials dimethylaniline for the manufacture of tetryl and monoethylaniline for carbamite.

The development of Australian sources of cellulose to complete independence of oversea supplies was a first-rate achievement. For many years cotton was the traditional source of cellulose for making service propellents in the United Kingdom. About 1930 the Admiralty changed from cotton to wood paper in the manufacture of nitrocellulose for naval cordite in order to obtain a more uniform raw material and to open up a fresh source of cellulose. When the manufacture of naval cordite was first begun at Maribyrnong in 1935 paper wood cellulose was imported from the United Kingdom. This would have been an undesirable state of dependence in war, and in the late 1930's a joint program of investigational work was arranged between the Maribyrnong Explosives Factory, Australian Paper Manufacturers Ltd of Maryvale, Victoria, and the Munitions Supply Laboratories.

An essential requirement in cellulose for the manufacture of nitrocellulose was that it should be free from impurities which would affect the stability of the cordite. These impurities were chiefly lignin, oxycellulose and hydroxy-cellulose. Extensive experiments were carried out

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[7] A modification of this process using molasses instead of sugar as the raw material was afterwards shown to be economical even in peace time.

on the purification of cellulose from hardwood (*Eucalyptus regnans*) but the difficulties proved so great that this raw material was abandoned in favour of softwood from *Pinus radiata,* large plantations of which were being grown in South Australia by the State Woods and Forests Department. By 1941 a stage had been reached at which the large-scale production of a suitable paper was possible. At first its use was confined to naval cordite (S.C.) but it was so obviously desirable to have only one raw material for all kinds of propellent that the experts set about achieving the widest use of the paper. Nitrocellulose for land-service propellents was nitrated to a higher degree (approximately 13 per cent of nitrogen) than that used for naval cordites (which were based on a nitrocellulose containing 12.2 per cent of nitrogen. The first step in extending the use of the paper was to develop a satisfactory method of nitrating to the higher degree. The first factory in the world to go into regular production of nitrocellulose of 12.9 plus or minus .15 per cent of nitrogen from wood cellulose by the "displacement" nitration process, was the Explosives Factory at Maribyrnong where its manufacture was begun in 1941 in order to provide nitrocellulose for Albion. A new factory at Ballarat followed some months later. By the middle of 1943 locally-produced paper-wood cellulose had displaced the imported paper altogether. Before the end of the war 10,000 tons had been produced.

One of the first matters taken up by the Director-General of Munitions after his appointment in June 1940 was the question of the second filling factory, about which he wrote to the Prime Minister as follows:

> An all-important requirement in munitions production is the filling of explosives into ammunition. Upon the figures of the advance copy of the Army Programme the cost of "filling" facilities will be £3,000,000 or more. But whatever the requirement, the capacity of the Maribyrnong Explosives Factory cannot be increased and a new factory must be erected elsewhere. The War Cabinet has decided that a site for No. 2 Filling Factory must be selected "away from the existing factories at Maribyrnong". As it is certain that a new filling factory must be erected somewhere, and quickly, the first step must be a decision as to site. As the persons to be employed, male and female, will be thousands probably, it will be obvious that only the vicinity of a large city will be suitable. Sydney and Adelaide suggest themselves immediately. . . .

The Premier of South Australia, Mr Playford,[8] was quick to point out the merits of the country near Adelaide as a site for the new factories. In addition to its strategic advantages, it offered a source of labour then largely untapped. The promise that the South Australian Government would cooperate by providing the land, an adequate water supply, bitumen roads, electric power, transport, and a means of disposing of the effluent, decided the issue. Within fifteen days of Lewis's letter to the Prime Minister a site covering approximately 4,000 acres of wheat land near the village of Salisbury, about 12 miles north of Adelaide, was chosen. There, in November 1940, was begun construction of the biggest project under-

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[8] Hon Sir Thomas Playford, GCMG. (Served 1st AIF.) MHA, SA, since 1933; Premier since 1938. Of Adelaide; b. Norton's Summit, SA, 5 Jul 1896.

taken in South Australia up to that time, an aggregation of buildings that was ultimately to cost nearly £10,000,000 and to become the largest explosives factory in Australia. It was designed for making explosives as well as for filling and assembling ammunition. Through the energy and ability of Mr Haslam,[9] senior architect of the Department of the Interior, who was in charge of the construction works, and the cooperation of Mr Chapman,[1] Chief Engineer of the South Australian Railways, and their staffs, the buildings were erected and plant and machinery installed in record time. Chapman and his staff were responsible for the steam reticulation throughout the factories, except that for the detonator section which was installed by Stewarts and Lloyds Pty Ltd. Government departments, public bodies and private firms all played their part. The South Australian Government paid the cost of bringing water supplies, roads and railways to the boundaries of the magazine and factory areas.

The buildings were required to conform in design to well-established and stringent requirements. The architectural draughtsmen were in the beginning instructed in these requirements and worked under the close supervision of the technical staff of the Directorate of Explosives Supply. In equipping the factories the help of a large number of firms in other States was enlisted to provide air conditioning, refrigeration,[2] dust exhausts, storage tanks,[3] steam reticulation,[4] compressed air, rail tank cars,[5] vacuum exhausts, pure water supplies,[6] laboratories, workshops, power, fire-fighting and air-raid precaution equipment, and many others too numerous to specify.

On 14th November 1941, just a year after constructional work had begun and in half the estimated time, the great factory at Salisbury began to operate; by August 1942 it was making T.N.T., nitroglycerine, ammonium nitrate, and several initiators, but it was not until January 1943 that the factory as originally planned was complete.

The speedy and successful completion of Salisbury can be attributed to the versatility of, and the cooperation between, the engineers, architects and chemists, who in addition to their own duties were obliged to train and instruct their staffs in the special designs for explosives factories. Many of the technicians, of necessity recruited from technical colleges and schools, revealed such adaptability and skill as the work progressed, that they were later given executive positions in the plants.

In order to lighten the complex task of the Directorate of Explosives Supply in preparing drawings and specifications of plant and machinery,

[9] W. T. Haslam. (Served 1st AIF.) Superintending Architect, Dept of Interior, Canberra, 1936-39; Liaison Officer to Dept Defence 1939-41; Superintending Architect i/c Salisbury and Cheltenham Munitions Works, 1941-43; Dir of Works, S Aust, since 1946. B. Launceston, Tas, 2 Feb 1895.

[1] Lt-Col R. H. Chapman, CMG; ME. (Served with RE 1915-19.) Formerly Chief Engineer S Aust Railways; Railways Commissioner, SA, 1947-53; B. Adelaide, 5 Jan 1890. Died 10 May 1953.

[2] Messrs W. E. Bassett and Associates.

[3] Commonwealth Oil Refineries, Ltd.

[4] Messrs Julius, Poole and Gibson, Consulting Engineers.

[5] Vacuum Oil Co Pty Ltd.

[6] Fletcher Chemical Co (Aust) Pty Ltd, consultants on the demineralisation of water; Messrs Avery and Anderson; Messrs Sydney R. Bell and Associates; and Messrs Alexander A. Stewart and Co gave considerable help in the design of plant.

the authorities enlisted the aid of industry: the Shell Company to design buildings and plant for the T.N.T. unit, and I.C.I.A.N.Z. to supervise the erection of plants for making tetryl and ammonium nitrate. Over all these activities, and many others such as the layout of roads, railways, tramways, pipe lines, power lines and lines of communication, the Director-General of Works, Mr Hoy,[7] exercised a general supervision.

The task of filling and assembling ammunition was divided into sections according to the size and complexity of the components and the sensitivity and quantities of the explosives involved. One area at Salisbury was devoted to caps and detonators, where very small quantities of highly sensitive initiators such as fulminates and azides were pressed into small metal capsules. This area included facilities for making the initiators themselves since these were not easily transported with safety.

Another section handled small components: primers and fuses, of which caps and detonators were a part. Here primers were filled with gunpowder which, despite the fact that it was the first type of explosive invented, was still the best means of igniting propellents (cordites). Fuses were filled with tetryl. This section was therefore designed for the handling of relatively small quantities of explosives intermediate in sensitivity between detonators and propellents, and high explosives.

A third and much larger section was devoted to filling cartridge cases with propellent and fitting them with primers, and to filling shell bodies with high explosive, and assembling each to form a complete round of ammunition. It was necessary to conduct these operations in a separate area owing to the large quantities of explosive used in each filling operation, and in buildings set well apart from each other to reduce damage in the event of an accidental explosion.

The large area covered by the factory—between 7 and 8 square miles—is easily accounted for by the wide dispersal of the buildings. The British Home Office scale of distances between buildings, which was enforced in Australia at this time, determined the minimum distance (usually 50 to 100 yards) between two buildings containing explosives, the maximum quantities of explosives that should be carried in the buildings, and the minimum distances between these buildings and any others inside or outside the factory boundaries.

It is not easy to convey an idea of the full extent of the constructional work done at Salisbury. Altogether there were 1,595 buildings, linked to one another and to the outside world by

| | |
|---|---|
| 41 miles of road | 150 miles of power lines (low tension) |
| 34 miles of gritless cleanways[8] | 6½ miles of underground telephone cables |
| 13 miles of water mains | 27 miles of stormwater drains. |
| 16 miles of sewers | |

[7] C. A. Hoy. Works Dir for NSW 1935-38; Asst Dir-Gen of Works, and later Dir-Gen, Dept of Interior 1938-42; Asst Dir-Gen Allied Works Council 1942-45; Asst Dir-Gen Dept of Works and Housing 1945-51. B. Sydney, 19 Aug 1888.

[8] Gritless cleanways were pathways between buildings along which operatives or explosives passed. They were of special soft-surface construction, usually wood or gritless asphalt so that friction due to grit was reduced to a minimum. Special footwear containing no nails was used, and every effort was made to keep the cleanways free from dirt and grit.

There was a certain amount of uneasiness in administrative circles early in the war concerning the planning of the explosives and filling factories at Salisbury—a feeling that perhaps it was being done upon too grand a scale. Lewis, who had had no experience in the explosives industry, found it impossible to examine the overall planning with the attention that the magnitude of the task demanded, and he therefore asked Leighton to act as his consultant.

One of the central problems in extending the military explosives industry was that of providing staff for the new factories. It was here that the Maribyrnong Explosives Factory played a role for which it had long been planned. It possessed the only body of officers trained in the manufacture of military explosives and experienced in the techniques of filling ammunition. For the first half of the war it was the school to which staff recruited for the new factories was sent for training. Maribyrnong provided the managers for these factories and also the background of practical experience which enabled them to turn out products meeting the stringent requirements of Service specifications.

It had been the intention to make nitrocellulose at Salisbury but when investigation of the local water supply revealed a fairly high proportion of chloride ion, it was decided to move the nitrocellulose plant to another site. For this Ballarat was chosen. This decision was undoubtedly a sound one, although subsequent investigation showed that contrary to expectations water supplied to Salisbury from the Barossa reservoir made satisfactory nitrocellulose and quite stable cordite. The chloride ion content would, however, have led to a most serious corrosion problem had the original plan been adhered to, and for this reason alone the decision to build a factory at Ballarat was justified. At the time little was known in Australia of the reliability and efficiency of synthetic ion-exchanging resins which might have reduced the difficulties of setting up a new plant.

By the time work on the Ballarat factory was started in September 1940 the preliminary arrangements, such as the construction of a power transmission line from Melbourne and a new water main from the Ballarat reservoir, were well in hand. Since plants for making sulphuric and nitric acids would form important units of the new factory, arrangements were made with Australian Fertilisers Ltd of Port Kembla to secure the services of its works manager, Mr Craig,[9] in designing and constructing the new factory. Craig, who had had experience in the manufacture of nitrocellulose during the war of 1914-18 (he was one of the technical men who went to England under Leighton's scheme) gave considerable help to Donaldson and Topp in planning and constructing the new factory. Within a year the Ballarat factory, then the largest of its kind in Australia, began to supply both Albion and Salisbury with nitrocellulose, which for reasons of safety was transported in the wet form.

[9] R. J. Craig, MBE; BSc. Works Manager, Aust Fertilisers Ltd, Port Kembla, 1920-40 and 1944-50; on loan to Dept of Munitions 1940-44. B. Prahran, Vic, 17 Oct 1884.

Before proceeding with an account of the building of other new factories it will be convenient to pause briefly to consider some of the new types of manufacture that were undertaken. To a very large extent these were pioneered, developed and brought into production at Maribyrnong. The range and diversity of manufacture and filling at this factory was unapproached by any other factory in the British Commonwealth, for it made and filled almost every type of ammunition. It was the essence of the general plan of expansion that the new factories were equipped to produce large quantities of a few items.

The only initiator being made at Maribyrnong before the war was mercury fulminate. For some years I.C.I.A.N.Z. had made small quantities of lead azide for use in commercial detonators at its Deer Park Factory. Here the crystals of lead azide were coated with a thin layer of dextrin in order to improve safety in handling. Dextrinated lead azide did not perform satisfactorily in some military fuses. For military use the uncoated azide, which was naturally much more dangerous to handle, was preferred; its manufacture began at Maribyrnong early in 1941. Later, lead azide and lead styphnate were manufactured in large quantities at Salisbury. The production during the war of more than two tons and a half of initiatory explosives, usually in batches of a few pounds at a time, was not the least striking achievement of the explosives industry. Their manufacture and manipulation were the most dangerous operations carried out in *any* industry.

It was difficult to bring about the detonation of T.N.T. without the use of more sensitive explosives. The usual arrangement in shells, mines and bombs was for a small quantity of an initiating explosive (mercury fulminate, lead azide or lead styphnate) to be set off by the fuse mechanism. This small explosion was picked up by what was known as a "booster" type of explosive (usually tetryl), and it was the explosion of the booster that brought about the detonation of the main bursting charge of T.N.T. Tetryl had a ready response to small initiating impulses and built up to detonation more readily than T.N.T. The inclusion of a small quantity of tetryl between the detonator and the main charge permitted the use of a smaller detonator than would otherwise be required. High explosives designed for use in shells had of necessity to be so stable that they were relatively insensitive to shock or friction; a booster was therefore essential. For these reasons extension of the manufacture of tetryl was an important development. As it was already being produced by I.C.I.A.N.Z. for commercial explosives there was no difficulty in replicating plants at Salisbury and later at Villawood. It was made by nitrating dimethylaniline, demands for which had fortunately been anticipated by Timbrol Ltd.

In the course of trials carried out to determine the effectiveness of demolition charges, it was observed that poured T.N.T. detonated with tetryl was not developing its full power. Investigations made to discover the cause of this led to the devising of a greatly improved system for bringing about the detonation of cast T.N.T.—the form assumed by molten T.N.T. after it was poured into a shell or bomb. The effectiveness of demolition charges was very considerably improved and the new system was successfully applied to a number of other projects, including anti-tank mines. Later it was demonstrated that shell could be improved in the same way but the war ended before the new system was adopted in service.

In order to eke out supplies of T.N.T. during the 1914-18 war the practice had been introduced of filling shells and bombs with intimate mixtures of T.N.T. and ammonium nitrate. Such mixtures, known as amatols, represented a great economy, for the cost of ammonium nitrate was, weight for weight, a good deal less than that of T.N.T. When efficiently detonated, amatol in a 40-to-60 mixture was only less violent than T.N.T. alone. One of the few innovations introduced at Salisbury was a plant for making ammonium nitrate by the double decomposition process. It was built by I.C.I.A.N.Z. with Mr Cresswick[1] of the Metropolitan Meat Industry Board acting as consultant. The plant was of unusual design and owing to lack of time was built without first having been tried out on a pilot scale. Very extensive phase-rule studies had been made on the ammonium sulphate-sodium nitrate system by Freeth[2] during the 1914-18 war and there was no lack of technical data. The plant gave a lot of trouble, much of which was attributed to impurities in the raw material used—ammonium sulphate from gas works. As soon as ammonium nitrate derived from the oxidation of ammonia became available the plant was closed down.

All the developments in the explosives industry described so far took place in South Australia and Victoria. The Director-General of Munitions had, however, not overlooked the necessity of building up a centre in New South Wales for manufacturing explosives and filling ammunition. Any such new development on the scale on which the explosives industry was then being expanded would require a large labour force which could be most readily obtained in the vicinity of a large city. The explosives industry was not one that lent itself to being split up into small factories distributed among a number of towns, and as there was no inland city with a big enough labour force the choice was narrowed down to sites on the vulnerable eastern seaboard. Some thought was given to the area inland from Newcastle, from which it was hoped to draw large numbers of women who could not, by reason of the heavy nature of the work, be employed in the surrounding coal and steel industries, but considerations of temperature turned the scale against any site much north of Sydney.

Sites near Sydney were the other alternative. At first a compromise was attempted by a proposal to use both areas (Newcastle and Sydney), but after all the relevant factors had been weighed—climate, labour supply, housing, water supply, disposal of effluent, proximity to residential areas,

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[1] J. A. Cresswick. Chief Chemist Metropolitan Meat Industry Board 1922-48; Consultant on ammonium nitrate to Min of Munitions and Dept of Defence Production 1940-56. Of Sydney; b. Newcastle, NSW, 27 Dec 1888.

[2] F. A. Freeth, OBE; FRS, DSc. (Major, Cheshire Regt TA.) B. Birkenhead, Eng, 2 Jan 1884.

cost of land, access by road and rail, and liability to flooding—the Sydney district was chosen. The final plan approved by the War Cabinet on 11th July 1941 was to set up a filling factory at St Mary's, on the western railway line near Sydney, and an explosives factory at Villawood on the southern line. The St Mary's Filling Factory, second in size only to the filling section at Salisbury and comprising fuse, shell-filling and other sections, was practically completed by April 1943. On account of the humid summer weather much of the factory had to be air conditioned. The cost of this alone was £140,000.

A special section of St Mary's was given over to preparing pyrotechnic compositions and filling them into their containers: shells, smoke grenades, bombs, sea markers and the like. Pyrotechnic compositions, which as a rule consisted of oxidising agents (nitrates and chlorates) mixed with combustible substances (sulphur, antimony sulphide and powdered metals such as aluminium, zinc and magnesium) burned rapidly and almost explosively in the loose condition. For use in Service stores they were moulded in presses by the addition of a binding material which caused them to burn more regularly and controllably. The handling and filling of these compositions was attended with considerable fire hazard and for this reason a separate area was set aside for them.

At Villawood, some 22 miles distant by road, factories for making oleum and T.N.T. were built by Commonwealth Fertilisers Ltd and the Shell Company of Australia Ltd respectively, and all stages of production had been tried out by 1943. Trial production of tetryl was also achieved but it was never pushed beyond this stage. The amount of T.N.T. used in the early years of the war was far less than had been anticipated. The other explosives factories were always able to keep well ahead of demand, so Villawood was closed down.

Quite early in the war there were discussions on the possibility of manufacturing "flashless" propellents in Australia. In theory the choice lay between a single-based and a double-based propellent—between F.N.H. (flashless, non-hygroscopic) powder (essentially nitrocellulose) which was in general use in the United States, and naval cordite N.F.Q. (nitrocellulose-nitroglycerine) which was in general use in British Commonwealth countries. In the early days of the war, before intense aerial bombing attacks began, the real need was for flashless propellents for naval use. The American F.N.H. powder was not suitable for use in British naval guns so that the only choice was cordite N.F.Q., which depended for its manufacture on picrite (nitroguanidine). The chances of making picrite in Australia were small and there were at first no prospects of importing it. Nevertheless the Department of the Navy was anxious to see the manufacture of flashless propellents established in Australia and when it became possible to import picrite from Canada the decision was taken to go ahead with it. The investigational work, the pilot-scale manufacture, the acceptance of the product by the Naval Inspection Branch, and the making of the special cordite dies were all completed in less than six months. Manufacture of flashless naval cordite (N.F.Q.) was well under way at Maribyrnong early in 1943.

In the meantime the possibility of making F.N.H. was being actively explored. An exchange of cables between the British War Office and the Australian Department of Munitions in September 1941 revived interest in the subject and led Donaldson to suggest that the cordite factory planned for Villawood should be abandoned in favour of one to make F.N.H. powder. On his advice a team of technical experts headed by Mr Stubbs,[3] Manager of the Villawood Factory, was sent to the United States, where it began investigations early in 1942. Meanwhile a site was chosen for the new factory. Proximity to ample supplies of water and power and ready accessibility to rail transport were among the main considerations which led to the selection of Mulwala, a town on the Murray River in New South Wales. On the basis of the information received from the United States, the Directorate of Explosives Supply began to plan the layout of the factory and the design of the buildings.

F.N.H. powder was unfortunately neither flashless (except in a few low-performance guns) nor completely non-hygroscopic. Its real advantages were that it did not require nitroglycerine, and that it was a freely flowing granular powder which lent itself to the automatic filling of cartridge cases. Although it was by no means the ideal propellent, being much less successful than picrite propellents in reducing erosion, its advantages outweighed these shortcomings and negotiations were put in hand under the Lend-Lease Agreement to acquire from Messrs E. I. Dupont de Nemours and Co a complete packaged manufacturing unit from the United States. The Directorate of Explosives Supply had merely to build a structure to house the unit, provide an acid plant, and arrange with the Victorian Government for supplies of electrical power and linking up with the State railway system. In his reminiscences of this period Sir John Jensen said: "This was the only Lend-Lease request ever to be approved without great lapse of time and much travail in argument." United States authorities gave Australia priority over their own works at Gopher, and plant began to arrive in Australia in the middle of 1942. No doubt the hope that they would be able to obtain ammunition from this source for use in the South-West Pacific Area had something to do with the speed with which the request was granted.

Unfortunately the speed with which the equipment was despatched from America was not matched by that of the factory builders. The Allied Works Council had promised to complete the buildings within six months, but they actually took more than eighteen months to finish the work. This was one of the less creditable pages in the story of the wartime explosives industry.[4] Strong representations from the Director-General of Munitions were necessary before the constructional works at Mulwala

[3] C. W. O. Stubbs, BSc. Senior chemist, Explosives Factory, Maribyrnong, to 1941, Asst Manager 1941; Manager Villawood Explosives Factory 1941-42, and Mulwala Factory 1942-51. Of Melbourne; b. Sandhurst, Vic, 30 Mar 1891.

[4] Directorate of Explosives Supply, Report No. 120, 18 Jan 1943.

could be got fully under way. Eventually a camp accommodating 3,000 men—the largest camp of its kind set up in Australia during the war—was erected and the buildings and works, costing nearly £2,000,000, were completed. The first trial runs on single units of the plant were made at the end of 1943, and in February 1944 the first samples of powder for filling cannon ammunition were submitted to the Inspection Branch. Production reached its peak about the middle of 1944.

While awaiting the arrival of plant from the United States the Munitions Department had asked Australian Paper Manufacturers Ltd to see whether it could make a still more highly purified form of cellulose, known as "alpha-cellulose board"—board, because this was the final form it assumed. Alpha-cellulose board was one of the principal raw materials that would be required for Mulwala. The use of wood pulp in making nitrocellulose had been recently developed in the United States and specifications for alpha-cellulose board for this purpose were most exacting. Although the degree of chemical purity required was considerably higher than had so far been attained by Australian Paper Manufacturers, their experience with paper-wood cellulose afforded some grounds for optimism. The company had, in point of fact, been experimenting since 1939 with the production of a high-purity alpha cellulose for Messrs Johnson and Johnson, makers of cotton wool and surgical dressings. Having failed to satisfy the requirements of a cellulose for these applications by using hardwood pulp as a source, the company turned its attention to *Pinus radiata,* as they had been forced to do in making paper wood cellulose for cordite S.C. By employing a cold refining process it was found practicable to make pulps with 92 to 93 per cent of alpha cellulose with a high degree of whiteness, but this was still not good enough to meet the requirements of the American specification. Mulwala was obliged to rely on imported alpha-cellulose board for its war production.[5]

Though completed late in the war, the building of the Mulwala factory was fully justified. One of the hopes of those who planned the factory was that it would survive the war period to become a permanent addition to the scheme for decentralising the manufacture of military explosives. This was indeed what it became.

This completes the survey of the growth of the explosives and filling factories during the war; it does not cover the network of annexes and factories in which the metal components of ammunition were made. Before the end of the war over 3,000 buildings, which with magazine areas occupied an area of more than 11,000 acres, were erected and operated, at a cost of approximately £22,000,000, for the manufacture of ammunition and explosives. Their distribution among the States is shown in the accompanying table. At the peak of their activities nearly 20,000 men and women were employed in the explosives and filling factories.

[5] Manufacture of a satisfactory material was achieved some years after the war.

## EXPLOSIVES FACTORIES IN AUSTRALIA 1939-45

(Showing principal manufactures only)

### SOUTH AUSTRALIA

SALISBURY:
- Explosives:
  - Nitroglycerine
  - Cordite
  - T.N.T.
  - Tetryl
  - Lead azide
  - Lead styphnate
  - Mercury fulminate
- Filling:
  - Shells
  - Mortar Bombs
  - Detonators
  - Percussion caps
  - Cartridges
  - Fuses
  - Primers
  - Depth Charges
- Nitric Acid
- Ammonium Nitrate

### VICTORIA

MARIBYRNONG:
- Explosives:
  - Nitroglycerine
  - Cordite
  - Nitrocellulose
  - T.N.T.
  - Mercury fulminate
  - Lead azide
- Filling:
  - Shells
  - A/C Bombs
  - Mortar Bombs
  - Pyrotechnics
  - Cartridges
  - Grenades
  - Fuses
  - Detonators
  - Primers
  - Depth Charges
  - Naval Mines
  - Demolition Charges
- Nitric acid

DEER PARK:
- Explosives:
  - Nitroglycerine
  - Gunpowders
  - Blasting Explosives
  - Lead azide
  - Tetryl
  - Lead styphnate

ALBION:
- Nitroglycerine
- Cordite
- T.N.T.
- Carbamite
- Ammonia
- Nitric Acid

BALLARAT:
- Gun paper
- Oleum
- Nitric acid
- Ammonia
- Ammonium Nitrate

### NEW SOUTH WALES

VILLAWOOD:
- T.N.T.
- Tetryl
- Ammonia
- Nitric acid

ST MARY'S:
- Filling:
  - Mortar Bombs
  - Cartridges
  - Shells
  - Pyrotechnics

MULWALA:
- Nitrocellulose powders
- Nitrocellulose
- Ammonia
- Nitric acid

The great majority of the 20,000 workers recruited for the explosives factories were entirely new to such work and had to be trained by experienced workers drawn almost entirely from the government factory at Maribyrnong. One of the considerations uppermost in the minds of those directing the factories was that of operational safety. In anticipation of rapid expansion in the manufacture of explosives, the Minister for Supply, Mr Casey, approved on 2nd October 1939 the appointment of a committee known as the Operational Safety Committee. When urging the need for such a body, Leighton had written:

> We have talked on many occasions about the need for setting up within the government factories organisation, means for securing the safety of operatives, and what is of paramount importance at the present time—the safety of factories and their continuance in operation. . . . It is unlikely in my experience that we shall continue to enjoy freedom from accidents, but it is specially necessary in our particular situation that we should not neglect precautions calculated to avoid them. In England during the last war we had accidents without number, many of them serious but none that crippled production, for the reason that in England then we usually had ten or so separate points of production. In Australia, with few exceptions, the position is that we have one point of production and therefore the need for care of what we have needs emphasising.
>
> The position of the mechanical factories for making metal components of ammunition is relatively safe and although it should be examined as soon as the opportunity offers, that of explosives and related factories should, I think, receive early attention.

The committee was charged with the duty of periodically visiting the Government Explosives Factory, Maribyrnong, and reporting on safety measures, which were to be based on those obtaining in England during the war of 1914-18.[6] The responsibilities and functions of this advisory committee were enlarged as the war progressed. Thus, once the building of the new factories was begun, the scope of the Operational Safety Committee was enlarged "to supervise the production of Service explosives in regard to public safety", which meant in effect that it examined and reported on plans of proposed new installations, factory layouts and manufacturing processes.

Among the safety precautions taken in factories which handled sensitive explosive compositions were the following: metallic articles which could cause a spark were excluded; smoking and even carrying of matches or tobacco were totally prohibited; operatives were not permitted to wear watches; clothing was held by tapes, and the use of buttons was avoided; special shoes were provided in which the soles were held together with wooden pegs instead of the usual metal brads. "Cleanways" were made of wood or asphalt and regularly hosed. Concrete in paths was often filled with gypsum in order to minimise the risk of sparks.

Just as dangerous as sparks caused by friction were those due to the building up of electrostatic charges, and many precautions were taken to minimise the danger from this source. The more sensitive the explosive the greater the precautions. In the building where mercury fulminate, lead azide and lead styphnate were handled the following stringent precautions were adopted: the door was fitted with a heavy brass handle, which was thoroughly earthed; it closed automatically and was held in position against a powerful non-sparking phosphor-bronze spring; before entering, one

[6] At the time of its first meeting on 7 Aug 1940 the members of the committee were: A. E. Leighton (Consultant on Explosives, Dept of Supply), Chairman; K. B. Straw (Chief Inspector of Explosives for Vic), Executive Member; A. A. Topp (Manager of Explosives Factory), Member; J. Wood (ICIANZ), Member; S. J. Proctor, Secretary. The following were appointed after the first meeting: A. G. Hall; J. M. Grist (ICIANZ); J. T. McCormick (Superintendent, Supply Labs.).

was required to whistle and wait for an answer in order to avoid startling the operator inside. The floor and working bench were covered with conducting rubber, and the pot containing several ounces of explosive was also of conducting rubber; the shoes provided were soled with rubber. All these precautions were essential, especially at Salisbury where the dry summer atmosphere favoured the building up of electrostatic charges.

Danger from fire and explosions, however, constituted a less important threat to the morale of workers in the industry than did hazards to health arising from the highly toxic nature of many of the substances handled.

The handling of sulphuric acid (from 63 per cent to 104.5 per cent strength) at temperatures ranging from cold to boiling point (315 degrees centigrade), of nitric acid (from very weak up to 98 per cent strength), also at temperatures ranging from cold to very hot, and of the mixed acids used for nitration, all constituted serious hazards. There were many cases of mild gassing by sulphur dioxide and oxides of nitrogen; gas masks were often used, though they were not very effective against these particular gases.

It was well known that nitroglycerine when absorbed by the body either through the skin or by inhaling the vapour, depressed blood pressure and caused violent headache which aspirin and other analgesics did little to relieve. Some men seemed either to be naturally unaffected by the nitroglycerine or to develop a tolerance to it, and these were the only people who could work in a nitroglycerine plant without acute discomfort. Paradoxically absenteeism was lower among men in the nitroglycerine section at Salisbury than among those working in less hazardous sections of the factory. One suggestion was that the men who did this job successfully had been picked out from a much larger number and were unusually strong. A more convincing explanation was that a camaraderie grew up among the men engaged in this work and it became a point of honour not to let the other fellows down. Perhaps both factors contributed.

Many individuals were prone to dermatitis caused by T.N.T. and tetryl. Methods of prevention developed in consultation with the Department of Health did much to reduce the hazard. When dermatitis persisted whatever the conditions of working, the only remedy was to transfer the victim to another section. The incidence of dermatitis was highest among workers handling tetryl, particularly in the fuse-filling and shell-filling sections where tetryl pellets or tetryl exploders were made.[7] Machines making these components created a dust which, in spite of the ventilating systems for extracting fume and dust from the air, would settle on the arms, faces and necks of the girls who did this work. Unless the dust was removed efficiently with special soaps, clothing completely changed at the end of a working section, and showers frequently taken, the incidence of dermatitis was high—often high enough to seriously impede the output of explosives. No completely satisfactory answer to the problem was ever found.

[7] Exploders were made by putting tetryl into bags about an inch in diameter and three inches long, made of heavy woollen cloth.

A greater menace to health than the dermatitis was poisoning by T.N.T., which was readily absorbed by the human body; it attacked the liver, causing serious and sometimes fatal illness. Fortunately, simple but effective tests had been devised which enabled the progress of T.N.T. absorption to be followed and which indicated when a dangerous level had been reached. They were carried out at frequent intervals on all workers handling T.N.T. Transfer to other work not involving T.N.T. usually eliminated the poison and no permanent harm was done. During the hot, humid months when excessive sweating increased the rate of absorption of T.N.T., the number of workers declared by the medical officer as unfit for duty became a serious embarrassment and led to great difficulty in maintaining production. At the worst time of the year the turnover of skilled workers in the T.N.T. filling sections at Maribyrnong and Salisbury rose to as high as 10 per cent per month and the finding of enough new workers and of employment for those declared unfit for work with T.N.T. was a major problem.

The years of careful study and building up of safety consciousness at Maribyrnong paid dividends when the new factories came into being. Their freedom from serious accident, the possibility of which was never entirely absent from the explosives industry, reflected great credit on the factory managers and on those who had laid the foundations of sound methods of training, leaders of the Australian industry from its earliest days onwards—Leighton, Brodribb, Topp and Hall.[8]

Up to the end of the war no single accident causing fire or explosion was responsible for more than two deaths. In other words, there were no really severe accidents; that is, severe as judged in the explosives industry. Safety was largely a matter of paying attention to a great number of minor details and it required much tact and patience to bring home the importance of these apparently trifling and sometimes irksome details to the new and enthusiastic recruit.

The accompanying table summarises the accidents reported in Australia over the years 1939-45.

| Group | Fatal accidents | | | Accidents causing injury but no fatality | | Accidents not causing injury | |
|---|---|---|---|---|---|---|---|
| | No. of fatal accidents | No. of persons killed | No. of persons injured | No. of accidents | No. of persons injured | No. of accidents | Total No. of accidents |
| Explosives manufacture | 6 | 6 | 11 | 10 | 11 | 57 | 73 |
| Filling stores | 3 | 4 | 4 | 51 | 67 | 82 | 136 |
| Experimental | 2 | 2 | 1 | 11 | 17 | 4 | 17 |
| TOTAL | 11 | 12 | 16 | 72 | 95 | 143 | 226 |

As the scale of manufacture increased it was inevitable that large quantities of explosives accumulated, often in the neighbourhood of wharves

[8] A. G. Hall. Assistant Manager, Explosives Factory, Maribyrnong, to 1940, Manager 1940-50. Of Melbourne; b. Elmore, Vic, 3 Oct 1883.

and in closely settled areas. The stores constituted a far graver menace to the community than did the factories. Transporting large quantities of explosives by sea and land also had its share of danger. For land transport special rail and motor vehicles were designed. On all matters relating to the packing, storing and transport of explosives the Operational Safety Committee gave invaluable advice and did much to reduce accidents to a negligible proportion. Its advice took the form of a booklet, *Information for the Guidance of Officers Engaged on the Transport of Service Explosives under War-time Conditions.* When it appeared that Australia might be invaded by the Japanese, the committee advised on methods of destroying stocks of explosives and armament chemicals without endangering the civil population.

As the constructional activities of the Directorate of Explosives Supply began to draw to an end, attention was diverted to problems of the coordination and efficiency of technical processes in the newly established factories. In a project of the magnitude of explosives supply it was obviously not enough to produce the required amounts of explosives irrespective of costs and technical efficiency. In May 1943 Donaldson put forward, with the approval of the Director-General of Munitions and of the Factory Board, an Efficiency Scheme, which followed closely a similar scheme that had been worked out in Britain during the first world war.[9] Donaldson's experience in the control of a large number of factories in England after that war had convinced him that it was a good practice to provide at each factory engineers to deal with maintenance and with work involving only a small capital expenditure, and to hold in a central organisation an experienced body of men capable of handling the major projects. He therefore built up a central engineering team which had, collectively, a detailed knowledge of the plant and machinery used in the factories, and made it part of a central Efficiency Section. This section was housed in the Melbourne headquarters of the directorate and concerned itself with and advised upon such matters as:

1. Proposals for development of improved practices in explosives technique; for the replacement of obsolescent plant, standardisation and coordination of practices in the different factories.
2. Efficient use of materials and labour.
3. Liaison with government explosives establishments in the United Kingdom, Canada and the United States in order to obtain information on the latest developments in these countries. Such information was circulated among the factories from time to time.
4. Standardisation of measures against health hazards, safety rules and general welfare practice.

The Efficiency Section settled priorities for materials, such as silicon-iron, which were in general use in all the factories, and rationed scientific instruments and special equipment in short supply. In an effort to estab-

[9] *Second Report on Costs and Efficiencies in His Majesty's Explosives Factories Controlled by the Factories Branch of the Explosives Supply, London.* HM Stationery Office (1918).

lish basic costs upon which comparisons might be made of the efficiency of factories producing the same chemicals, statistical studies were made of labour costs and of the consumption of materials. Gross differences in the costs of producing a given chemical were known to exist between the factories but it was difficult to decide how much of this was due to special local conditions and how much to real differences in efficiency. Figures were compiled by Mr Hedding[1] giving comparisons in considerable detail between English and Australian performances for various stages of filling practice. In most instances investigated the comparison was unfavourable to Australia, but it should not be inferred from this that it was true of the Australian factories in general.

There can be no doubt, however, of the general benefits accruing from Donaldson's scheme, since it did focus attention on the need for efficiency and economy. Under the scheme, for example, statistical methods of quality control were introduced. Their use in the explosives factories appears to have been one of the first instances of their extensive application in Australia. A quality-control section was later set up under Mr Wallace,[2] a chemist with considerable experience in the use of statistics. Liaison officers were appointed in each of the explosives factories and periodic visits were made by officers of the central section to explain the principles of quality control and later to give assistance in the application of the methods to specific phases of manufacturing activity.

At least a dozen different processes were studied, ranging from filling shells and bombs to assembling fuses and pressing pellets, and some remarkable economies and improvements in manufacture were effected. For instance, the number of rejects in the filling of naval shells was reduced from 6 per cent to less than 0.1 per cent; the rejection of detonators from 30 to 0.1 per cent, and of caps from 14 to 1 per cent.

Investigations and testing of explosives were carried out in the Explosives and Ammunition Section of the Munitions Supply Laboratories, which grew from a group of 12 experienced chemists into an extensive organisation with branch laboratories in each of the explosives factories and a staff which at its peak numbered 110.[3] Inspection and routine testing to see that Service specifications were being properly met formed the greater part of the work carried out in each of the branch laboratories; only at Maribyrnong itself was any extensive investigational work done, and there fourteen out of the fifty-four scientists were so engaged. An idea of the extent of the testing activities of the explosives laboratories may be gathered from the fact that during the years 1940-45 about 250,000 samples were handled.

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[1] W. A. Hedding. (Served 1st AIF.) Chemist, then Assistant Manager, Explosives Factory, Maribyrnong. B. Melbourne, 17 Apr 1897.

[2] W. N. W. Wallace, BSc. Chief Chemist, Lysaght Bros, to 1941; Head of Laboratories, Explosives Factory, Ballarat 1941-43; Head of Quality Control Dept, Dir of Explosives Supply, 1943-45; Chief Chemist, ICIANZ Biologicals Factory, Villawood, since 1945. Of Sydney; b. Sydney, 8 Nov 1908.

[3] The factories also had their own laboratories for developmental work and process control.

A great deal of the investigational work at the Munitions Supply Laboratories was of the *ad hoc* kind, designed to give quick answers to questions concerning the functioning and safe handling of explosives. Manufacturing problems were referred to this section, and also problems dealing with the causes of the defective functioning of explosives. One of its most dangerous but vitally important tasks was to make a critical study of captured enemy ammunition. There was little opportunity for fundamental research on explosives, and indeed the laboratories had not been intended for that purpose. For work of this kind we must turn to the C.S.I.R.

*The initiation and growth of explosions.* From the scientific viewpoint one of the most interesting wartime developments relating to explosives was the fundamental work on the initiation and growth of explosions carried out by Dr Bowden and his collaborators in the Lubricants and Bearing Section of the C.S.I.R. In spite of all the investigations previously made on nitroglycerine and the vast quantities of it that had been manufactured and used since Nobel first began production in 1863, the behaviour of nitroglycerine towards impact was by no means well understood even as late as 1942. Unexplained explosions at the Deer Park factory of I.C.I.A.N.Z. suggested that the sensitivity of nitroglycerine under certain conditions might be much greater than was generally supposed. It was known that liquid nitroglycerine and other similar substances could be detonated by impact if it was sufficiently violent, but little was known of the mechanism by which the mechanical energy of the blow initiated the explosive reaction. Here, then, was a problem not only of great theoretical interest but of the highest practical importance in the manufacture and safe handling of explosives.

Bowden was a first-class experimenter with a knack of devising relatively simple experiments to obtain the answers to important problems. His interests at that time lay in the study of friction (and in tribophysics generally) and since it was believed that friction had much to do with the initiation of explosions (though this appeared to be more important in regard to solids) it was not surprising that when I.C.I.A.N.Z. invited him to study the problem of the origin of unexplained explosions in nitroglycerine at Deer Park, he took up the work with great enthusiasm.[4]

Quantitative studies of detonation caused by impact were not easy to make. Some had already been carried out in England and in Germany. The usual method was to place a small amount of the explosive on a flat metal plate (anvil) and then to strike it with a flat-faced weight or hammer. The sensitivity of the explosive was expressed in terms of the potential energy of the hammer necessary to cause detonation. With mercury fulminate the limiting potential energy for regular detonation was calculated statistically to be about 500 gram centimetres (that of a 100-gram weight dropped from a height of 5 centimetres, for example).

[4] F. P. Bowden, F. Eirich, A. E. Ferguson and A. Yoffe, "The Detonation of Nitroglycerine by Impact", Bulletin 167, C.S.I.R., Melbourne, 1943.
F. P. Bowden, F. Eirich, M. F. R. Mulcahy, R. G. Vines and A. Yoffe, "Detonation of High Explosives by Impact", Bulletin 173, C.S.I.R., Melbourne, 1943.

The values found for nitroglycerine by earlier investigators differed very widely from one another but were in general very much greater (from 1,000 to 14,000 gram centimetres).

The divergence in values obtained for nitroglycerine clearly meant that the phenomenon was not thoroughly understood. Obviously there were important factors not recognised by the experimenters and therefore not properly controlled. With the help of Dr Finn[5] of I.C.I.A.N.Z., whose experience in the manufacture and handling of commercial explosives was of great value in the early stages of the work, Bowden and his collaborators began a systematic study of the detonation of nitroglycerine under various conditions of impact. Having recently developed the "hot spot" theory of friction between moving surfaces, he attempted to apply it to explain the detonation of nitroglycerine by impact. According to this theory, during the sliding of one solid over another the points of contact[6] between highly polished surfaces were at a sufficiently high temperature to cause the solid in this region to melt and the two points momentarily to weld together. The frictional force arose mainly from the making and breaking of these minute, temporary welds. Bowden failed, as he expected he would, on the basis of this theory of friction, to detonate nitroglycerine by the impact of surfaces of solids whose melting point was below 185 degrees centigrade—the temperature required for the thermal initiation of an explosion of nitroglycerine. But when, keeping all other conditions constant, he also failed to detonate nitroglycerine by fairly violent impact of surfaces of solids of melting point far above 185 degrees centigrade, he was forced to abandon this restricted form of the "hot spot" theory.

There is no space to describe the many ingenious and systematic experiments that were made in search of an alternative theory. Suffice it to say that from the mass of results two discoveries stood out from the rest. The first was that the sensitivity of nitroglycerine to impact between flat metal surfaces was markedly increased if the liquid contained small bubbles of air. Simple calculations showed that the heating of this gas caused by sudden, that is, adiabatic, compression could be quite high and well above the ignition point of the explosive. This heating was therefore sufficient to initiate the explosion.

The second discovery, which in some ways was more impressive than the first, though for a time certainly more puzzling, was known as the "cavity effect". Flat-nosed bullets attached to a pendulum hammer and allowed to fall and strike a film of nitroglycerine, failed to produce any detonation. On the other hand, when a bullet with a small circular cavity in its nose was made to strike the nitroglycerine in such a way that the complete rim of the cavity made simultaneous contact with the liquid, detonation occurred with astonishingly small energy. A bullet weighing 43 grams and falling 1.5 centimetres (potential energy 64.5 gram centimetres)

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[5] A. E. Finn, DPh. Research Chemist, Nobel's Explosives Ltd, Ardeer, Scotland, 1937-38; Superintendent Explosives, ICIANZ, Deer Park, 1939. B. Perth, WA, 9 Nov 1911.

[6] Only a small proportion of the areas of two highly polished surfaces make contact when the two are brought together.

was sufficient to cause a detonation. This was very much lower than the figure given by any previous investigator (the lowest quoted above was 1,000 gram centimetres) and was even lower than that usually given for an initiatory explosive such as mercury fulminate. In later experiments the energy required was occasionally as little as 20 gram centimetres. Under these conditions the velocity of the bullet, which was made part of a pendulum system, was very low and its impact with the anvil corresponded more to a gentle tap than a blow.

The obvious explanation of the cavity effect was that it was due to the adiabatic compression of air included within the cavity of the striker. However, this seemed to be completely ruled out by an experiment which showed that increased sensitivity could be obtained even when the cavity of the striker was carefully filled with liquid nitroglycerine before it was allowed to strike the anvil covered with the same liquid. The investigators believed that under these conditions no air was present and for a time they were completely baffled by the "cavity effect". After they had explored other possible explanations, all of which proved inadequate, they were forced to return to a more critical test of the possibility of adiabatic compression. On making a microscopic examination of the fluid in the cavity of the striker they discovered that, no matter how carefully it had been filled with nitroglycerine, at least one exceedingly small bubble was invariably present. Sudden compression of these bubbles which, as a rule, were less than one ten-millionth of a cubic centimetre in volume, was sufficient to initiate an explosion. Bubbles of this size were, of course, impossible to see with the naked eye.

Unravelling of the seeming mystery of the "cavity effect" provided striking confirmation of the importance of the role of adiabatic compression of air bubbles in initiating explosions. The scientific significance of this work was that it paved the way to a much greater understanding of the initiation and propagation of explosions in general. Bowden followed up this work at Cambridge after the war, and reached the general conclusion that initiation of explosions by impact and by friction is usually of thermal origin. His findings were embodied in a monograph which appeared some years later.[7]

On the practical side their application to safety measures, especially in the handling of liquid explosives such as nitroglycerine, was obvious. From a search through the official history of accidents, it became evident that the adiabatic effect offered a possible explanation of many otherwise mysterious explosions. Though Bowden's work does not appear to have had much influence on practice in the government explosives factories in Australia, more attention was paid to it in England. For example, members of the Cambridge School who later joined Imperial Chemical Industries Ltd assisted in applying some of the results very effectively at the Ardeer factory.

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[7] F. P. Bowden and A. D. Yoffe, *The Initiation and Growth of Explosions in Liquids and Gases*, Cambridge University Press (1952).

While Bowden and his colleagues were continuing their early studies on the origins of explosions in nitroglycerine at the University of Melbourne, Mr Bird[8] of the Maribyrnong Supply Laboratories followed, quite independently, a different line. He conceived the idea of initiating explosions by placing the explosive in a cylinder closed with a tightly fitting piston. Solid as well as liquid explosives could be detonated by suddenly compressing the air within the cylinder.

These conditions were slightly different from those used in Bowden's experiments: the air was in external contact with the explosives whereas in Bowden's experiments the air was trapped within the explosive. Nevertheless, the mechanism by which the explosion was initiated was the same —namely by the heat developed as a result of the adiabatic compression of air. Bird had in fact rediscovered a phenomenon that had been discovered independently by English, French and Italian scientists soon after the 1914-18 war. Italian scientists had attempted to apply the principle to the manufacture of fuses without detonants but had failed to obtain satisfactory build-up to detonation. Unaware of this earlier work, Bird also attempted to make "detonantless" fuses. After many trials he finally succeeded, in July 1944, in detonating a high explosive shell with a simple detonantless compression fuse, an achievement which suggested that it might be possible to devise a generally workable fuse along these lines, and thus do away with hazardous initiating explosives such as mercury fulminate and lead azide and all the complicated safety devices which had to be used with them.

[8] L. H. Bird. Chemist, Explosives and Ammunition Research Section, MSL, 1941-45; Chemist, Wheat Research Institute, Christchurch, NZ, 1945-55. Of Christchurch; b. Waimate, NZ, 29 Jun 1914.