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Chapter 4 1945 – 1991
A RESEARCH ESTABLISHMENT – PRACTICAL ACADEMICS AND THE COLD WAR

Historical Perspective

Science: The British and German scientific and technical advances in electronics, jet power and rocketry during the Second World War (WWII)(1939-46) made it clear that post-war weapons systems would be of a completely different character; there was even talk of the demise of the manned bomber. Britain pressed ahead in those fields where it possessed expertise, and sought to recruit German rocket experts to build up a knowledge base in rocketry, where it was deficient. It failed to secure the most prominent talent, which was either bought by the Americans or kidnapped by the Russians.

Politics: Following the post war split amongst the wartime allies, the long term Cold War placed a priority on defence expenditure, and the British Government felt its world role required that it keep abreast in all relevant technologies. New research laboratories were created at Westcott and Waltham Abbey for the development of strategic and tactical missiles. Gradually Britain's changed imperial and economic position forced a withdrawal from many technical fields, and Waltham Abbey was eventually closed in 1991 after a prolonged period of decline.

Introduction

Before the end of 1944 civilians in Antwerp, London and the south-east of England had become aware of German advances in rocketry by the destructive arrival of the V1s and V2 missiles. Earlier in 1943 British ships had been attacked, and one sunk, by German Hs293 air to surface guided missiles.

British and German wartime efforts had generally kept pace with each other in jet engines, radar, aircraft navigation systems; the Germans held a superiority in basic engineering, while Britain was ahead in computers and (with the Americans) atomic power and antibiotics. But stemming from their pre-war efforts the Germans had made major advances in rocketry, producing a rocket powered fighter (Me 163) which saw operational service in 1945 and tactical and medium range missiles. They had demonstrated the potential, and before the war had ended the allies were in competition for the best talent in this area of such future significance. Many German scientists went to America, which clearly had superior economic and technical resources, but some 25 significant experts came to England.

In 1936 Britain had set up a rocketry department at Woolwich under the dominating Dr (later Sir) Alwyn Crow, but by the end of the War it had produced only the unsophisticated 2" air-to- ground rocket and the ground based ZED anti- aircraft rocket system, famed more for its noise than accuracy. Determined to do better with German help, the Government set up the Guided Projectile Establishment at Westcott, and an out-station of Woolwich, the Chemical Research and Development Department at Waltham Abbey. Both were the subject of a good deal of internal intrigue and feuding within the controlling Ministry of Supply. As a result Westcott became an outstation of the mighty Royal Aircraft Establishment Farnborough; at Waltham Abbey the politics went the other way, with the creation of the independent Explosives Research and Development Establishment.

Prior to the closure of the RGP Factory on the 28th July 1945 the site had been surveyed by staff from the Armament Research Department as a site for its explosives research and the site reopened on 30th July 1945 as an experimental station of the Armament Department with the aim of setting up a separate organisation for research into explosives and intermediates from the fundamental stages to pilot scale production.

Thus, there came into being one of the most prestigious research establishments in the field of explosives, carrying on the long tradition of the Waltham Abbey site as a centre of excellence and innovation.

On October 1st 1946 the Chemical Research and Development Department was formed with a nucleus of staff from the

Armament Research Department. These were soon joined by numbers of qualified chemists and engineers from many parts of the UK. Over the next 46 years the Establishment came under the aegis of different Ministry departments but despite this; and the many name changes (as detailed in Table 1) the basic direction of work was maintained.

Royal Powder Mills
Royal Gunpowder Factory
1787 – 1945

Experimental Station of the
Armament Research Department
1945 – 1946

Chemical Research and
Development Establishment
1948

Explosives Research and
Development Establishment
1948 – 1977

Propellants, Explosives and
Rocket Motor Establishment
1977 – 1984

NORTH SITE	SOUTH SITE
Royal Armament Research and Development Establishment 1984 – 1991	Royal Ordnance plc later British Aerospace 1984 - 1989

Table 1. Chronology of Establishment names.

Whereas previous work of the factory had been led by the need for production of a limited number of cordite compositions the new regimen opened up a large and diverse field of scientific and engineering research on all aspects of energetic material applications and other intermediates and materials with a direct relationship to service problems.

Existing buildings which had been used for the production of, firstly gunpowder and then modified for the production of cordite, were converted into laboratories and small scale experimental processes to accommodate the initial research programmes on liquid and solid propellants for both guns and rockets, high explosives, initiators and the chemical engineering needed to progress the fundamental research into viable pilot scale processes.

Propellant work was undertaken by two Propellant Branches, P1 working on nitrocellulose based materials and P2 on the newer concept of plastic and rubbery based propellants.

On the North Site the old Incorporating mills were converted into a series of interconnecting laboratories. The open loading bays were enclosed with verandahs.

Fig. 1. Existing Steam Powered Incorporating Mill on North Site converted to Laboratories.

P1 Branch:

Initially both rocket and gun propellants formulations were mainly based on nitrocellulose together with nitroglycerine or other similar nitrate esters such as ethylene glycol dinitrate and were generally termed double base. Performance and other properties were enhanced by the addition of high explosives such as picrite and RDX.
Double base gun propellants were produced in stick or granulated form but rocket propellant charges were generally cast double base compositions. Attention was also given to the production of safer, less sensitive compositions and solutions to compatibility problems that arose.

P2 Branch:
The second, Plastic Propellants, group worked on the development of composite propellants based on plastic or rubbery binders with ammonium perchlorate as oxidiser in a polymeric binder fuel matrix. Many of the early rocket motors, based on both double base and plastic propellants were developed at Waltham Abbey (Table 2).

NAME	**DESCRIPTION**
ALBATROSS	Sustainer motor for THUNDERBIRD
BANTAM	Sustainer motor for SKUA
BLACKCAP	Boost rocket motor for SEAWOLF
BUZZARD	Boost rocket motor for RED DEAN
CHICK	Booster for PETREL and SKUA
CRAKE	Sustainer motor for BLOWPIPE
CUCKOO	Solid rocket motor for SKYLARK and BLUE WATER. Also used to boost re-entry vehicle speed on BLACK KNIGHT
GOLDFINCH	Booster motor for JAGUAR and JABIRU test vehicles
GOSLING	Solid boost motor for BLOODHOUND
MAGPIE	Boost rocket motor for FIRESTREAK
NUTHATCH	Rocket motor on ALARM
RAVEN	Booster used on SKYLARK
STONECHAT	Rocket motor for FALSTAFF
SWALLOW	Sustainer motor for STOOGE
WAGTAIL	Solid Rocket Motor
WAXWING	‘Kick’ motor used for injecting satellite into orbit

Table 2. Major rocket motor compositions developed at Waltham Abbey.

A number of special applications were researched using propellants as gas generators for some specialized applications such as; aircraft escape chutes, mine lifting bags and most notably the development of KU extruded composite propellant (Fig.3) for the Blackcap boost motor for the Seawolf missile, Thunderbird 2 missile and the LAW anti-tank weapon. It was also used in the highly successful Martin-Baker aircraft seat ejector which has saved many pilot lives.


Fig.2 Ejection from Meteor

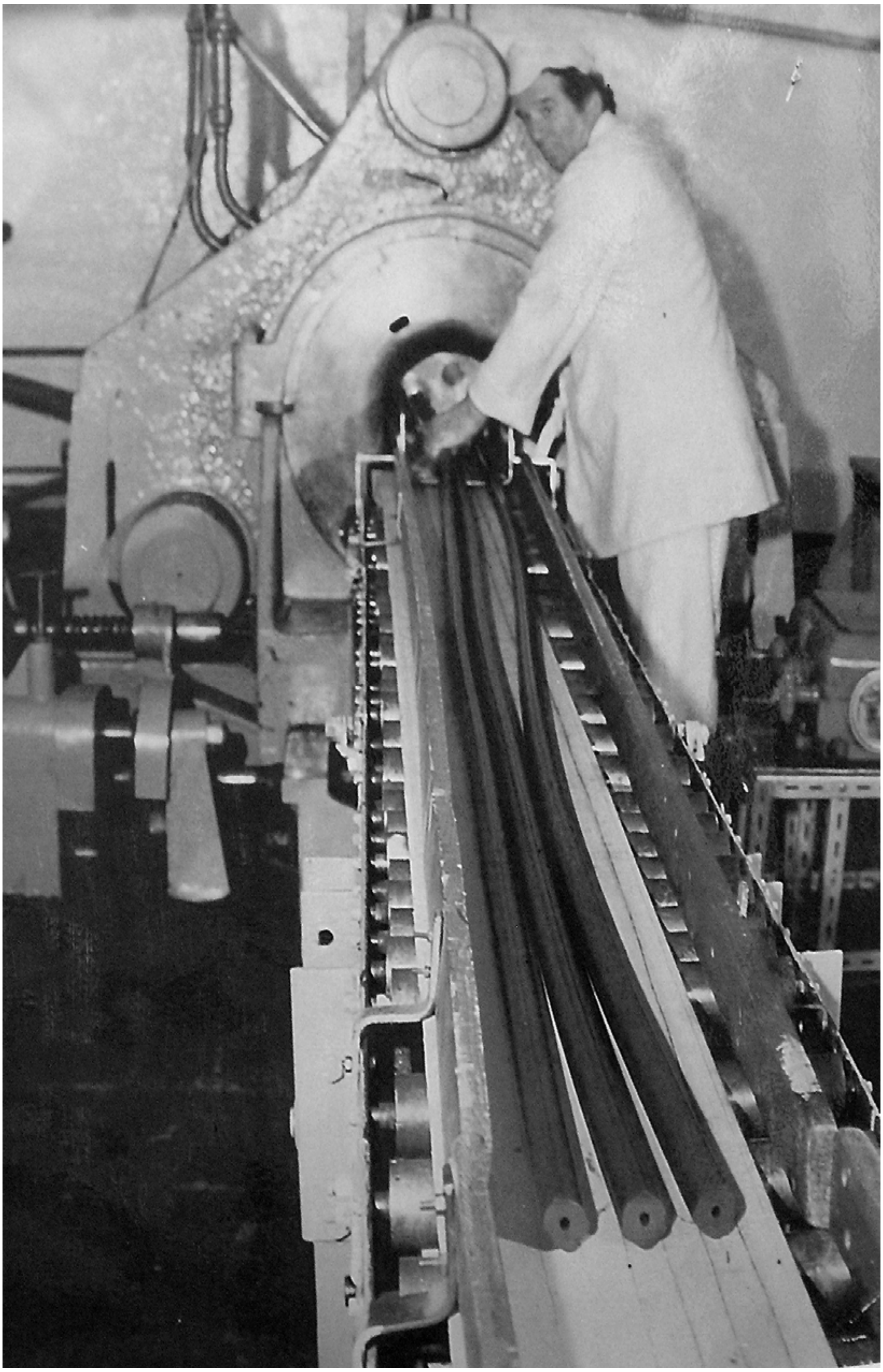


Fig. 3 Extrusion Press for KU Propellant

There was a great deal of ‘technology crossover’ and co-operation between the two groups with innovations in one area being adapted in the other.

The majority of research was on solid propellants for both guns and rockets and the following table (3.) gives the basic types of compositions.

SOLID PROPELLANTS	
GUN PROPELLANTS:	ROCKET PROPELLANTS
(Gunpowder)	(Gunpowder)
Single Base (NC)	Solvent Cordite (NC, NG, stabiliser
Double Base (NC, NG)	Solventless (as Solvent + Lead salts)
Triple Base (NC, NG, Picrite)	Cast Double Base (elastomer modified)
Composite (RDX in a Polymer matrix)	Composite-Plastic (polyIsobutene, AP)
	Composite –Rubbery (AP, polyButadienes)
	(Aluminium powder also added)
	Composite Modified Double Base (AP or RDX)

Table 3. Various propellant types.

GUN PROPELLANTS: Gunpowder was low energy, smoky and prone to unreliable ignition because of absorption of water.
Single Base (Nitrocellulose) is smokeless and still widely used in small arms.
Double Base gun propellants require a stabiliser such as carbamite and additives to reduce gun barrel wear. Picrite (nitroguanidine) is added to make 'flashless' propellants but at the cost of being smoky.
Modern high energy propellant for e.g. tank main guns use composites of RDX in a polymer matrix, which reduces impact sensitivity, and with an energetic plasticiser to boost performance.

ROCKET PROPELLANTS: Gunpowder is still used to propel pyrotechnic compositions for flares and smokes as it is low cost and of sufficient energy for the purpose.
Single Base (NC) has probably never been used as a rocket propellant but has always been plasticized with nitoglycerine (NG) or similar nitrated polyol (e.g. di - or tri - ethylene dinitrate). The NC + NG propellants are known as Double Base for obvious reasons.
1948 was a milestone in the development of Double Base propellanst when Lead Stearate was used as an ingredient to aid extrusion of 'Solventless' propellants. This additive produced 'platonised' ballistics where the burning rate remains stable over a range of pressures. Normally the burning rate increases with increased pressure and can cause catastrophic failure of the motor casing.
Extruded 'cordite' is limited in diameter by the diameter of the extrusion press. The largest press in the UK was at the Bishopton Ordnance Factory in Scotland and boasted a cylinder diameter of 22 inches (56 mm), i.e. a cross section area of 2463 cm^2.
For larger diameters a different technique was needed and Cast Double Base was developed. A casting liquid of NG, desensitiser and stabiliser was drawn up through a bed of NC granules (with additives) known as casting powderand IMS Summerfield was set up to exploit this system with ICI Nobel at Ardeer supplying the casting powders. At Waltham Abbey there were facilities for making Cast Double Base charges to develop new compositions and to help with any problems at Summerfield and Ardeer.
Composite Propellants were usually based on Ammonium Perchlorate (AP) oxidizer bonded in a polymer matrix as fuel. They offered higher energy and a more rapid delivery of that energy. Numerous binders have been studied including polyisoButene (so called Plastic Propellant), polyurethane and various synthetic rubbers (polyButadienes). Aluminium powder is often added to give more energy but the increased exhaust smoke has caused difficulty with 'line-of-sight' guided weapons. The addition of Ammonium Perchlorate to Double Base gives Composite modified Double Base but destroys platonisation. RDX can be added to Double Base with plateau retention but better physical properties can be achieved by Elastomer modification of Cast Double Base.
The activities of both Propellant Branches included experimental processing, combustion studies and ballistic properties. Fundamental research on Liquid Propellant systems at Waltham Abbey was carried out in support of work at the Rocket Propulsion Establishment at Westcott and this area of work was eventually transferred to Westcott. After several years of close association the two establishments were merged in 1973 and a re-

organisation in 1977 led to the creation of the Propellants, Explosives and Rocket Motor Establishment at Waltham Abbey and Westcott under one director.

The **Explosives Branch** dealt with the development of initiatory, high explosive and propellant compositions aimed at maximising the explosive performance. Concurrent with these activities a secondary aim was to reduce the risk of accidental initiation through shock, friction and electrostatic hazard. The Branch therefore had extensive testing facilities for hazard assessment of materials and procedures that were used by all other departments. It was responsible for all the explosive testing, both on site and for large-scale tests, at more remote ranges in the UK. A major experience at Waltham Abbey was the regular sound of 'three blasts of a klaxon' followed by a loud bang and then a single all clear blast. If one didn't note the three blast warning the often very loud bang could be quite disturbing until you heard the all clear signal.

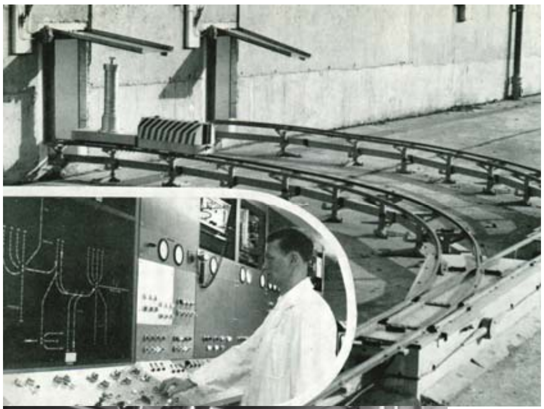
One unusual and quite spectacular facility was the underwater testing site situated to the north of the site in the wooded area. Here, a very deep pool, some forty feet deep, was used to test very large charges that could not be contained in the normal blast chambers. The sound of the explosion would not be heard as you stood safely on the bank but the resultant plume of water, rising to some forty to fifty feet high, was spectacular to say the least (Fig 2.)

Fig. 4 Underwater Explosion at Newton's Pool

The Explosives Branch also carried out noise evaluation with the measurement of impulsive noises, including those of long duration (e.g. sonic booms) and their simulation by explosives. During the development phase of Concorde the Branch successfully simulated the expected sonic boom using explosives and this was used to gauge the effect of structures to shocks of this kind.

Because of the hazardous nature of some of the new explosives being developed remote handling facilities were employed and a five-inch gauge electric railway system was used to transport hazardous materials between manufacturing, testing and storage areas (Fig. 5).

In the laboratories special armoured cupboards were used in the development and testing of explosives (Fig. 6).



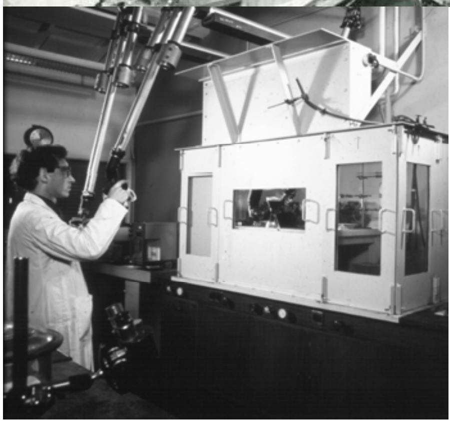


Fig. 5 Remote-Control Miniature Railway for Transport of hazardous materials.

Fig. 6 Explosives Cupboard with Slave Arm manipulators.

A major development in less sensitive explosive compositions was the development of rubbery explosives (Poly X) where the crystalline high explosive material was held in a cross linked rubbery matrix reducing the shock sensitivity of high energy compositions. The Explosives Branch carried out noise evaluation by the measurement of impulsive noises, including those of long duration (e.g. sonic booms) and their simulation by explosives. This was stimulated by the development of supersonic aircraft and successful trials were carried out on simulation of the sonic boom expected from Concorde flights.

The **Chemical Engineering Branch** was concerned with the means and equipment for processing chemicals on a production scale. Plant and facilities were designed for the manufacture of hazardous compounds and mixtures with particular emphasis on safety, remote control and instrumentation.

As new materials were researched in other branches and elsewhere, the task of the Chemical Engineering sections was to take these new materials from the laboratory to pilot plant scale. As addition to proving viable production procedures it also provided the larger amounts of any material necessary for extensive testing of properties that would be difficult to achieve in the laboratory (Fig.4).

Fig.7 Scale-up of processes to pilot scale

Successful pilot plant projects resulted in viable processes for the continuous production of TNT, separation of RDX and HMX and production processes for new explosives such as HNS and TATB. RDX and the slightly more powerful HMX are still the most powerful explosives is service today.
Research activities included studies on crystallisation and intensive drying of high boiling liquids that may be sensitive to heat or excessive turbulence.
The branch also had an Instrumentation and Glass Engineering Section for the design and construction of special electronic instrumentation systems and large-scale scientific glassware.

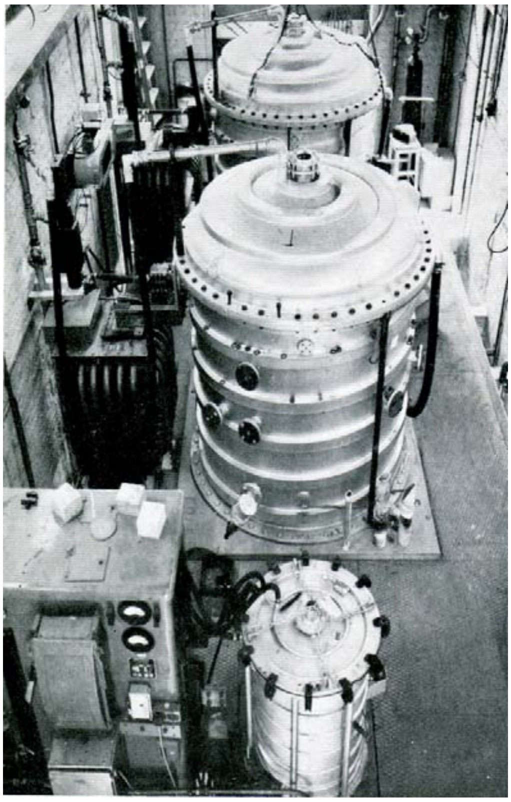
Materials Research
During the 1950s a materials department (DMXRD), the directorate of materials for explosives research and development existed within the MoD in London. The work of the technical staff was to a large extent advisory but it was realised that, to fulfil their role properly, laboratories were needed to carry out experimental work and some of the group moved, as a lodger group, to Waltham Abbey in about 1958. Some of the tasks they were involved in were; rubber Dracones for the storage of fuels, nylon driving bands for shells, paints, adhesives and the weathering of plastics. Since it was difficult to give advice on rubber and plastic components unless the department was able to mould these on a trial basis itself, a press, an injection moulding machine (Fig. 5) and a rubber mill were installed to allow the processing of rubbers and plastics.


Fig. 8 Horizontal Injection Moulding Machine

The research programme was then expanded to include the synthesis of polyesters and polytetrahydrofurans intended for use as rocket motor binders. The polymer applications side was expanded and work began on asbestos, glass and carbon fibre filled thermoplastics and investigations on the production of ethyl cellulose inhibition for Extended Double Base rocket motors were begun.
Basic studies continued on high speed impact behaviour of plastics, relationships between structure and properties of polyurethanes, moulding and moisture uptake of nylon driving bands, storage of fully cured rubber at low temperatures, basic physics of plastics, the weathering of plastics and the effect of moulding and the synthesis of novel polymer systems.
In 1980 the technology side was relocated to a larger building on the South Site to become part of the Chemical Engineering (Process Research) group and the novel polymer systems group also became attached to process research. The polymer technology group quickly became a prototype and small scale manufacturing group making specialised parts that could not be easily obtained from industry. Manufacture of ethyl cellulose tubing for EDB rockets produced by RO Bishopton became one of the early prime products and 14,000 lengths of 2” tubing were made in 2 weeks for the Falklands war. Many other products followed including- seals for gun mounts, vents for chieftain tank guns, head end liners and boots for rocket motors, Chevaline seals and in plastics various conducting ware for RO factories, the desiccators pack for LAW, protective nose cap for Stingray and the radome for Harrier jump jets plus all the associated specifications for the above.

In the 1970s a **Second Materials Branch** was set up to carry out research on fibre-reinforced materials and on the growth of ceramic whiskers.

Ceramic whiskers of high temperature materials such as silicon nitride were synthesised using high temperature furnaces to grow fibres or 'whiskers' of these materials intended to strengthen metals. Control was difficult and the furnace was dubbed the 'Bran Tub' (Fig. 9) since one never knew what the product would be until the tub was opened. This was cutting edge technology but never developed into a viable process.



The more promising research programme on fibre-reinforced plastics was transferred to the Process Research Branch and many successful products were produced using asbestos, glass and carbon fibre filled thermoplastics. Later on

Fig. 9 The 'Bran Tub' for growing 'whiskers

work on Kevlar (used for body armour) was undertaken.

To give maximum unidirectional strength for lightweight rocket motor casings it was realised that the fibres should be aligned lengthwise in the matrix and a fire alignment plant was built. These aligned fibre mats were wound on a former and impregnated with the required polymer (Fig. 10).

Fig. 10 Helical winding of rocket motor body.

Analysis and Ingredients Branch

This was formed in the early 1960s from the Analysis Groups and the Organic Chemistry Group. The Branch investigated the preparation, properties and reactions of a wide range of ingredients related to explosive, propellant and polymer technology. The Branch also offered an advisory service on the stability, compatibility and surveillance testing of propellants, explosives and other hazardous materials. New analytical methods were developed to assist quality control and a range of specialised techniques and facilities were used to provide an analytical service for the Establishment.

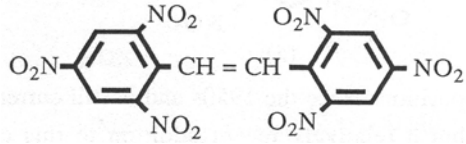
The initial synthesis of explosives and ingredients of solid propellants and polymers (fuels, oxidisers, ballistic additives, curing agents, antioxidants etc.) was undertaken on a laboratory scale and studies to optimise yield and purity and to reduce hazard (toxicity, thermal decomposition, compatibility etc.) were carried out on all new materials. Most operations were carried out in special reinforced explosive cabinets and, in some cases, using remote handling devices (Fig. 11)

Fig. 8. Explosives cabinet with remote handling.

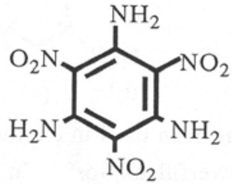
In addition to normal wet chemistry analysis a range of state of the art instrumentation (for the time) was used for the characterisation of materials. Instrumentation included Mass Spectrometry, Gas Chromatography, Infra Red Spectroscopy, Nuclear Magnetic Resonance Spectroscopy and X-Ray Crystallography.

The synthesis of novel compounds had its early beginnings in the original Organic Chemistry Group with the synthesis of such exotic materials as hydrazine diperchlorate and work on boron and aluminium hydrides. These latter compounds were being looked at in the USA as higher energy fuels for rocket motors and Waltham Abbey was associated with this programme. The stability and usability of such materials were investigated. The USA decided that boron hydrides were too costly and too toxic for use. However, carboranes, much more stable derivatives were later used in the USA and at Waltham Abbey to modify the burning rate of composite propellants. Aluminium hydride was also tried in composite propellants as a higher energy fuel than aluminium itself but proved to be insufficiently stable for long-term storage.

New explosives were being discovered in the 1970s and onwards and considerable work on these was carried out in support of the Chemical Engineering Branch scale-up. These included HNS (hexanitrostilbene), a high temperature explosive used in deep well drilling and for explosive bolts for stage separation in the space programme. Another important explosive was TATB (tetraaminotrinitrobenzene) that was a powerful yet highly insensitive explosive. Significant improvements in the synthesis and production of these materials were made.

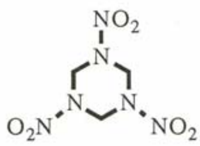


Structure of HNS

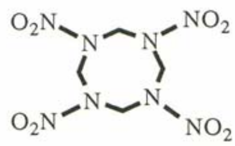


Structure of TATB

In 1980 the Organic Synthesis Group was combined with the Polymer Synthesis Group and the unit transferred to the Process Research Branch. Up until then the most powerful high explosives were RDX (cyclo-1,3,5-trimethylene-2,4,6-trinitramine) and, a closely related compound, HMX (cyclo-tetramethylene tetranitramine).

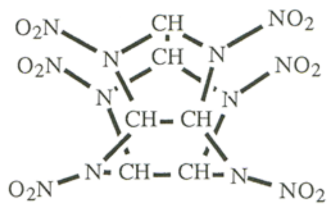


RDX



HMX

It is believed that these ring type structures with alternating carbon and nitrogen atoms confer significant stability to the nitramine class of explosive compounds and more recently a new, even more powerful explosive had been synthesised in the USA called HNIW (hexanitrohexaazaisowurtzitane).



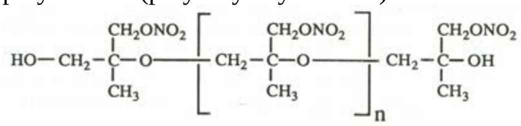
HNIW

The synthesis of this compound was a multistage process and the final nitration some difficulty presented some difficulty. At that time the Synthesis Group were exploring an hitherto neglected nitrating agent, Dinitrogen Pentoxide (N_2O_5) which offered enhanced nitrating powers at low temperatures. N_2O_5 was first discovered in the late 1890s but production of the pure material was difficult and it found little application until a simple synthesis for production of pure N_2O_5 was devised at Waltham Abbey. It was found that N_2O_5 dissolved in nitric acid was an ideal agent for the final nitration step to HNIW.

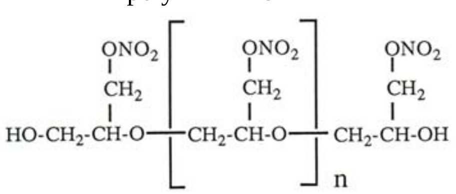
In 1984 the Establishment was split into Royal Ordnance plc on the South Site with the MoD retaining the North Site as an outstation of RARDE Fort Halstead. All propellant work and most of Process Research went to Royal Ordnance with the exception of the Synthesis and Fibre Composite work, which remained in the MoD. Eventually the Royal Ordnance site was closed (1989) and work was transferred to other Royal Ordnance sites in the UK.

At about the same time the future of the MoD site was under review and it was proposed that all the remaining work at Waltham Abbey be transferred to Fort Halstead. Since new facilities had to be built it was some years before this took place and work continued apace in the remaining sections, especially in the Synthesis Group where the work continued on the application of N_2O_5.

N_2O_5 had other unique properties in that, when dissolved in an inert organic solvent it could be used to carry out selective nitrations on molecules with more than one active site and a number of hitherto unobtainable compounds were synthesised. Concurrent with this work the polymer section was exploring a new class of energetic binders for use in high performance composite rockets and insensitive munitions and two candidates materials were identified from work in the USA. Polymeric binders used at that time were based on hydroxyterminated poly-butadiene which, being inert, diluted the overall energy of compositions. The two materials under investigation were poly-NIMMO (poly-Nitrato Methyl Oxetane) and poly-GLYN (poly-Glycidyl Nitrate).



poly-NIMMO



poly-GLYN

The basic monomers used to form these polymers (NIMMO and Glycidyl Nitrate) were difficult to obtain by conventional nitration as although the hydroxl group was readily nitrated the oxetane and oxirane rings in the molecules were cleaved in acid media and it was these ring structures that were necessary for the polymerisation of the monomers. Using N_2O_5 in an inert organic solvent at low temperature and an ingenious continuous flow reactor system, large quantities of very pure monomers were produced. This was so successful that the technology was transferred to the Office of Naval Research Establishment in Maryland USA and to ICI Nobels in Scotland where scale-up manufacture was undertaken. The work was completed to meet the deadline for closure of Waltham Abbey in 1992.

ISRG - The Inter Services Research Group

This was initially a lodger group at Waltham Abbey engaged in highly secretive work in support of Special Forces. It was a practical unit undertaking specialised tasks relating to explosives and even today much of the work carried out is classified. One activity that can be divulged is the airborne dropping trials of equipment and the packaging of sensitive materials. The Group was very much a separate entity within the Establishment.

Support Staff

All the above work was backed by the dedicated support staff in Administration, Stores, Transport Section, Library and Reports, Safety, Fire Station and Medical whose support was indispensable.

Final Closure

In 1991 the remaining staff and sections at Waltham Abbey were transferred to RARDE Fort Halstead in Kent bringing to an end nearly three and a half centuries of continuous service to the Crown. These final years of research and development continued the long tradition of excellence and innovation that has been the hallmark of the Waltham Abbey site. These last 46 years were an exciting time for the many scientists, engineers and support staff who were proud to be part of such a long-standing tradition.