WASC 1607

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JRNSS Vol 22

R.L. Williams - ERDE

WASC 1607

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THE EXPLOSIVES RESEARCH AND DEVELOPMENT ESTABLISHMENT

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The Explosives Research and Development Establishment is situated in the River Lea valley some 13 miles north-east of Central London, adjacent to the well-known Waltham Abbey, which was founded in 1060. It is uncertain when gunpowder manufacture was first undertaken in this district, but there has been a long tradition of work on explosives in the neighbourhood, as is evidenced by the tombstones in the Abbey churchyard where victims of several early accidents are interred.

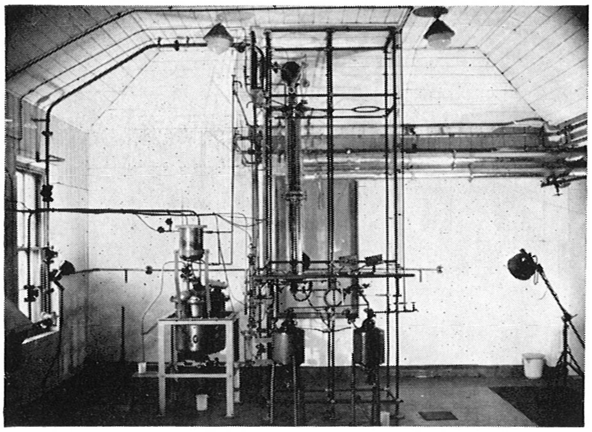
There is little doubt that gunpowder was made in Waltham Abbey about the time of the Armada, but very few records exist of the early days. This manufacture was in private hands and there were other important powder mills, notably at Faversham, Kent, by late Stuart times.

In 1787 there were complaints about the serviceability of black powder supplied to the Navy and after an enquiry, followed by firing trials conducted under the Board of Ordnance, it was established that Waltham Abbey powder was superior. It was recommended that the Powder Mills be purchased by the Government and they were taken over just in time for the Napoleonic Wars. It is probable that the gunpowder used at Trafalgar was made at Waltham Abbey. The first Superintendent was Sir William Congreve, who was succeeded in 1816 by his son who had already obtained a high reputation as a designer of rockets filled with black powder. These rockets were further developed and extensively used by both the Royal Navy and the Army until about the time of the Crimean War, when improvements in gun design caused them to become obsolete.

In this period many new powder buildings were erected at Waltham Abbey, some of which still survive, and black powder manufacture continued on a substantial scale. The manufacture of nitrocotton was undertaken in 1872, under the direction of Sir Frederick Abel and, following the work of Alfred Nobel, smokeless powder (or 'cordite') was made by about 1880. This manufacture necessitated the purchase of additional land in 1885, and the erection of new plants. There were several disastrous explosions, especially in the manufacture of nitroglycerine, and there were several Courts of Inquiry whose reports are still available in the Public Records Office. Present day segregation of explosives buildings and separating them by mounds dates from about this period. In 1909, under Sir Frederick Nathan, who was then Superintendent, a new stabilisation method in the manufacture of guncotton was worked out and this is essentially the process still in use to-day. The production of tetryl was commenced in 1912.

The heyday of the Royal Gunpowder Factory was in the 1914-18 war, when the South Site was considerably expanded and large quantities of Mark I cordite were manufactured. Some gunpowder was also produced as well as picric acid and guncotton.

In the inter-war years the factory ran down, but was reactivated in the 1930's and manufactured the Land Service cordite W (for Waltham), the Naval cordite production having, by this time, been taken over by Royal Naval Cordite Factory, Holton Heath. A plant for the manufacture of TNT was also brought into use and just prior to World War II an experimental plant for the manufacture of RDX, a new high explosive, was set up in collaboration with the Research Department, Woolwich. After the outbreak of war the factory continued in full production, employing some 6,000 people, until 1942 when it was succeeded by the new plants at Royal Naval Propellant Factory,



Plant for drying nitric esters to very low water content—this plant is operated remotely

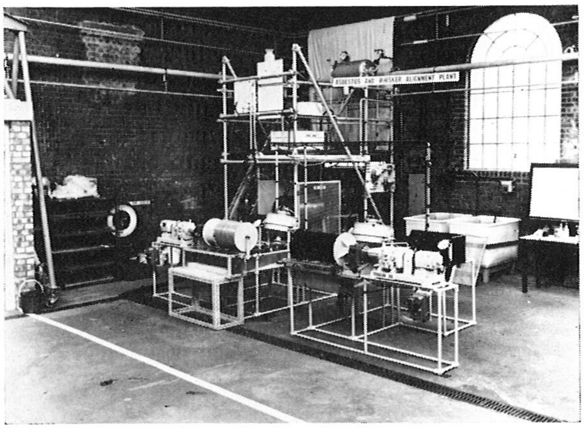
Caerwent, Royal Ordnance Factories Bishopton, Ranskill, Bridgwater and I.C.I. plants in Scotland. During this period its main claim to fame was the development of WM (Waltham Modified) cordite, and the first production of the Land Service flashless gun propellant cordite N.

There was a close association between the Royal Gunpowder Factory and the Royal Arsenal at Woolwich and the Naval Dockyards at Deptford and Chatham and with the adjacent Royal Small Arms Factory at Enfield. At one time the Metals Division of I.C.I. also had a small factory for filling rifle ammunition on the South Site. In the later part of the war, much experimental manufacture was undertaken for the Armament Research Department, and the conversion to an R. & D. Establishment in 1945 was a logical step.

The Factory was by then partly derelict, although it suffered very little damage by bombing during the war; there were only two chemical laboratories, one on each site. The first task was therefore to convert some existing processing buildings into laboratories and offices and to construct roads in the Establishment where most of the internal transport had been by barge on the numerous canals, or by narrow gauge railway. Substantial site clearance of plantations of willow and elder, previously used for charcoal manufacture, was also involved. New special purpose buildings have now been constructed for laboratory and pilot plant operations and the most recent of these have been a new Library and Lecture Theatre, a combined office and laboratory building for chemical engineering research and a new remotely controlled small scale plant for research and development work on composite high explosives.

Generally, research activities and laboratory investigations are concentrated on the North Site, whereas the pilot plant operation and work on propellants and explosives, other than on the laboratory scale, is conducted on the South Site.

Immediately after World War II, the main work of the Explosives Research and Development Establishment, as it then became, was concerned with liquid propellants, with the development of flashless gun propellants and research and development on plastic propellant, which had been introduced into the Service in the later part of the war. Another very important activity was to investigate methods for the synthesis of nitroguanidine (picrite), as this material was imported and it was desired to have an indigenous source of supply. In the early 1950's interest in liquid propellants began to wane, and the main centre of activity was transferred to the Rocket Propulsion Establishment at Westcott. Interest in gun propellant also diminished and the work on processes for the manufacture of nitroguanidine ceased although, by that time, a plant utilising the E.R.D.E. process was in course of erection at R.O.F. Bishopton. The main interest in the solid propellant field now centred on rocket applications and the work on the development of plastic propellants was extended, and facilities for the large scale manufacture of these propellants were established at R.O.F. Bridgwater based on the work carried out at



Experimental plant for alignment of whiskers and asbestos fibres.

E.R.D.E. At this time also, new facilities were brought into use for the manufacture of cast double base propellants and the plant for manufacture of extruded cordite, which had remained at the Royal Arsenal, Woolwich, was transferred to the South Site. The Establishment was thus in a position to undertake research and development on any type of solid propellant, with particular emphasis on rocket applications.

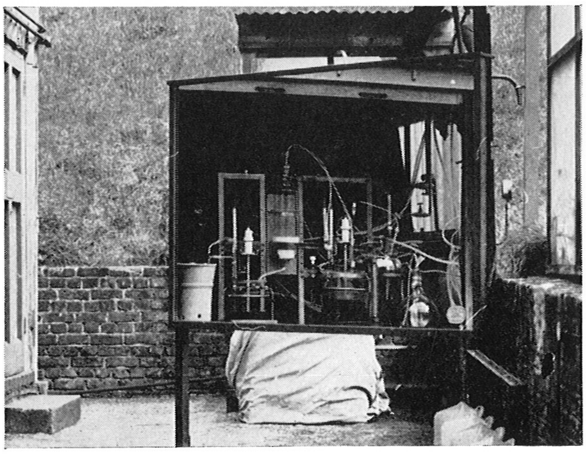
In 1956 it was decided to establish a Materials Laboratory on the North Site at E.R.D.E.—this Laboratory being mainly concerned with the application of plastics to military stores. For example, one major activity at the time was the development of nylon driving bands for shells. Recently this work has been further extended by the creation of a group to investigate the properties of high strength materials, mainly ceramic, commonly known as whiskers.

At present the Establishment is responsible for research and development of all types of military explosives and propellants, covering the requirement of all three Services. There are currently seven groups, each headed by a Superintendent. Two of these are concerned with research and development on solid propellants, one concerned with high explosives and methods of testing sensitiveness to impact, friction and the like, and two groups are concerned with non-metallic materials for any type of Service application. The two remaining are essentially service groups—the first deals with chemical and physical analysis, as required by any of the other groups and also acts in an advisory capacity on questions of compatibility with the Service Departments—laboratory scale organic preparations are also undertaken by this group. The second group deals with chemical engineering and their function is to scale-up laboratory processes and to provide pilot-scale quantities of hazardous chemicals, such as nitric esters, which may be required by the propellants or explosives groups. The total strength of E.R.D.E. is about 70 Scientific Officer grades, supported by some 110 Experimental Officer staff; most are chemists, but there are a few chemical engineers, physicists, and mechanical engineers. The present organisation is:

Director: Dr. L. J. Bellamy

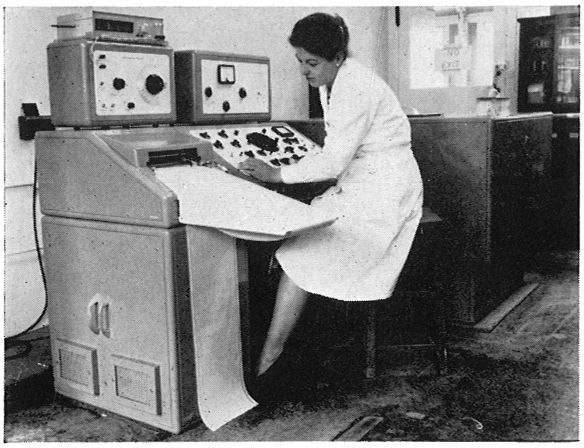
Principal Superintendent (Development)	Dr. G. H. S. Young
Individual Merit "B" Post	Mr. G. K. Adams
Superintendents	
Explosives:	Mr. E. G. Whitbread
Propellants 1:	Dr. W. G. Williams
Propellants 2:	Mr. P. R. Freeman
Materials 1:	Dr. R. L. Williams
Materials 2:	Mr. J. E. Gordon
Analysis and Ingredients:	Dr. I. Dunstan
Chemical Engineering:	Mr. R. G. Ross

The traditional propellant work of E.R.D.E., and its predecessors, is carried on in Propellants 1 Branch, which is largely concerned with colloidal propellants based on nitroglycerine and nitrocellulose. The various modifications of this propellant are manufactured by solvent, and solventless, extrusion, as well as by casting and a considerable variety of shapes and sizes is produced. These are used in small arms, mortars, guns, rockets and power cartridges. A recent development has been the design of a new cartridge for a Rocket Ejection Seat designed by Martin-Baker.



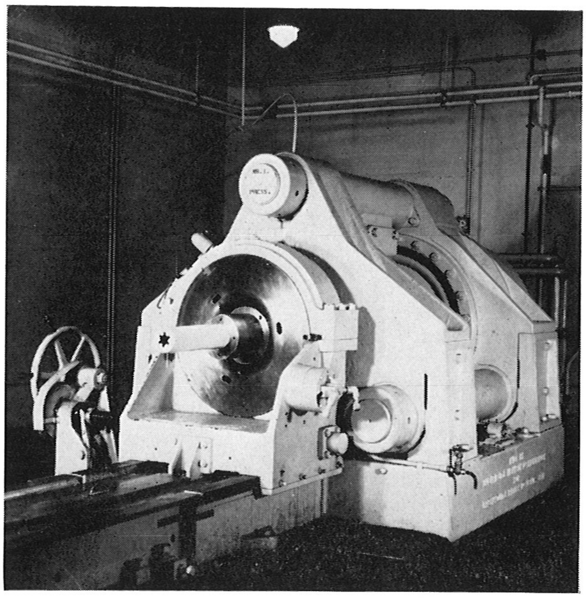
Glass plant for manufacture of hazardous chemicals.
This plant is operated remotely and is viewed from a concrete observation room by a 45° mirror.
This photograph shows the view seen in the mirror—the plant is housed in the building on the left.

There is increasing interest in the reduction of smoke and flash from rocket motors and, in addition to work on propellant compositions and inhibitors, fundamental combustion studies are in hand to determine the sources of smoke and flash and methods of eliminating them.

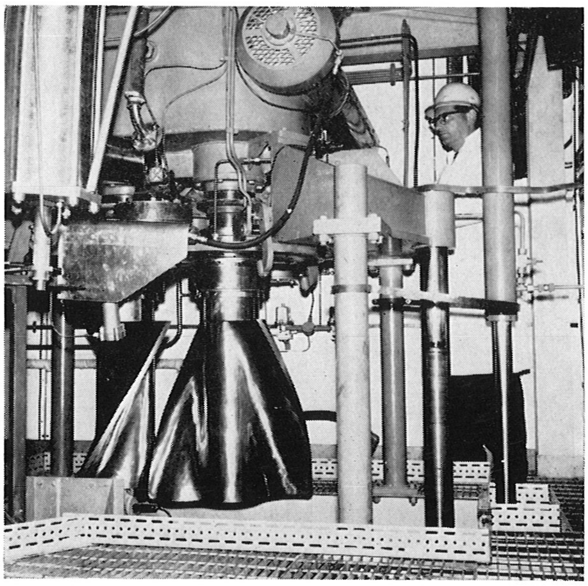


Nuclear magnetic resonance measurements on organic materials.

This Branch works in close association with Messrs. I.C.I., Ardeer and Messrs. I.M.I., Summerfield Research Station, in the development of cast double base propellants for use in weapons such as Seaslug, Seacat and Seadart. Basic work has been undertaken to establish the capabilities of case-bonded cast double base propellants as single, and dual, charges for Land Service use; new solvent systems have been developed for the manufacture of highly filled casting powders.



Large extrusion press for solventless cordite manufacture.



Vertical mixer for rubbery-type solid propellants, showing blades—the mixing pot has been lowered for removal of the propellant mix.

An improved process for manufacture of combustible cartridge cases for gun ammunition has been devised, and pilot production by this process is now being undertaken at R.O.F. Bishopton for the 105 and 155 mm. Land Service guns.

Non-destructive inspection of propellant charges is an important requirement and has been met by the installation of a 350 kV X-ray set and by the development of a pulse-type ultrasonic flaw detector; this equipment is also now installed in the R.O.F's, and is suitable for all solid propellant rocket charges currently in production.

The main work of the Propellants 2 Branch concerns composite propellants, which are the modern versions of gunpowder. There are two types currently under investigation. The first is "plastic" propellant, which consists of a mixture of polyisobutene with ammonium perchlorate as oxidiser, and other additives to alter the burning rate, or improve performance. Both small, and pilot scale, plants are operated and bulk propellant is supplied to the Rocket Propulsion Establishment for filling into motors. These are currently used for boost motors for several Land Service Weapons and for both boost and sustainer rockets for upper atmosphere research; the Skylark vehicle uses this type of propellant. More recently it has been successfully used in meteorological rockets. Another important application is for the rockets to propel the sledge on the high speed testing runway at Pendine. A possible Land Service free-flight rocket is also under investigation, in collaboration with the Royal Armament Research and Development Establishment and R.P.E.

A disadvantage of plastic propellant is that its low temperature limit of operation will not fully meet the requirements of the Royal Air Force, and an alternative composite propellant based on ammonium perchlorate with a carboxy terminated polybutadiene binder is now being studied. This type of propellant is used in the American Sparrow missile. Currently the work at E.R.D.E. is on a small scale, but a pilot plant, previously used for polyurethane propellant, is being modified for the new composition and will be brought into use later this year. The chemistry of the polybutadiene rubbers is also being studied with particular reference to the crosslinking mechanism and their ageing and oxidation characteristics.

Associated with this work there is a small section concerned with rheological and surface chemistry investigations of solid propellants, with the objective of improving their mechanical behaviour. This section also provides an advisory service for the use of adhesives, sealants and lutings in all types of conventional ammunition.

Another section is concerned with the study of heat transfer and thermal conductivity of substances of interest as rocket fuels or oxidisers. At present, work is concentrated on liquid hydrogen, where measurements of thermal conductivity in the critical region are being undertaken. Other recent investigations include measurements of the thermal conductivity of kerosene, Santowax, hydrogen chloride and ammonia over a wide range of temperatures and pressures (up to 3000 atmospheres). A test rig for the study of the combustion of gaseous hydrogen/gaseous oxygen in the region of 2-50 atmospheres is also available to provide basic design data to assist R.P.E. and others concerned with development of hydrogen rocket motors for space applications.

The Explosives Branch has been particularly concerned with the development of high explosive compositions with improved performance, especially for underwater applications. An increase in performance is theoretically possible, but is practicable only if means can be found for using combinations of ingredients which would be too hazardous for normal processing. A new facility where all weighing, mixing and filling can be conducted entirely by remote control is now being commissioned, adjacent to another remotely operated facility, under the Chemical Engineering Branch, where it will be possible to manufacture especially hazardous ingredients. It may also be possible to improve the performance of underwater explosives by correctly exploiting the mechanism of detonation. In conjunction with the Naval Construction Research Establishment, work is now in hand to tailor the shape of the underwater shock wave to produce the most damaging effect. A recent application of this work was to design special linear explosive charges to reproduce the shock wave generated by supersonic aircraft such as the *Lightning* and the *Concord*. This enables fairly cheap tests to be carried out with observers and on representative structures, such as glass windows in buildings. Rocket motor take-off blast pressures can also be simulated. Some fundamental work is carried out on the temperature and emissivity of the detonation front in liquid and solid explosives and on the kinetics and reaction mechanisms of the oxidation of alkyl and alkoxyl radicals by oxides of nitrogen. This latter is relevant to the stability of propellants and explosives.

The Branch also provides a service to the Establishment, and others, on sensitiveness testing of all types of explosives to impact, friction, shock and static electricity.

The development up to factory scale of safe and reliable means of producing initiators such as lead azide is also studied by the group. A number of satisfactory methods have been worked out, which are now used for production quantities by the R.O.F.'s and in Sweden and the U.S.A.

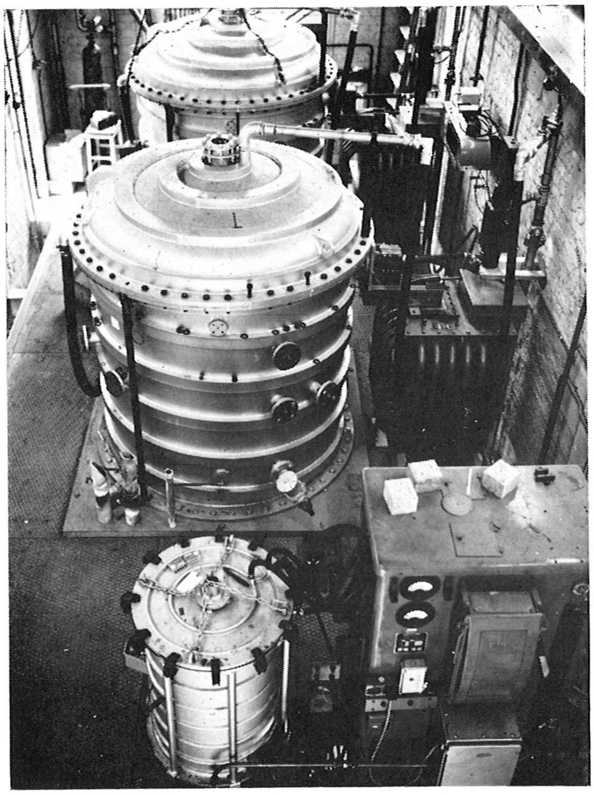
The Materials 1 Branch is concerned with the behaviour of organic non-metallic materials typified by plastics, rubbers, adhesives and fibres, in order to promote their successful use in Service equipment. All these substances are polymers and the Branch is therefore divided into sections dealing with polymer applications and development, with polymer physics, and with polymer chemistry.

The polymer applications section is almost self-explanatory. It carries out an analogous function to the Rubber and Plastics Division of A.M.L., but in this case, Army Department establishments such as R.A.R.D.E., M.E.X.E., F.V.R.D.E. and D.S.C.(D) are advised on the choice and use of polymers, and applied research is carried out on their behalf. Examples of work include the development of Dracones, flexible fuel tanks, and more recently, conducting rubber for armoured fighting vehicle tracks. The group also liaise with the producers of polymers and examines any new development in this field.

Manipulating small 10 gram mixer for sensitive high explosives. (Part of the safety screen is opened for the purpose of photographing the equipment.)

The work of the applications section is supported by the longer term research of the other sections. The polymer physics group is primarily concerned with obtaining data on mechanical properties of polymers such as the elastic moduli and ultimate strength, for use by structural engineers. Experimental work has concentrated on the effects of temperature, rate of stress application and the influence of long term loading and fatigue on these properties. End products of this section's work include the use of non-metallic driving bands and obturating rings in shells and mortar bombs, and production of a range of instruments for measuring mechanical properties.

The chemistry section studies principally the detailed mechanism of polymer breakdown under the influence of heat, radiation or atmospheric oxidation. The work is therefore complementary to that of the corresponding section at R.A.E., which tries to synthesize more thermally stable polymers. The results of the laboratory degradation studies are related to those obtained from the exposure of specimens under tropical conditions and it is hoped to suggest ways of altering the chemical structure of the polymers to improve their stability. Characterisation of the substance is carried out using infra-red and nuclear magnetic resonance spectroscopy, molecular weight determination by osmometry, viscosity and light scattering, and glass transition temperature measurements. Extensive use has also been made of gas chromatography for analysis of decomposition products.



" Bran tubs " for synthesis of silicon nitride whiskers.

Following the closure in 1958 of the Tropical Testing Establishment in Nigeria, it was decided to set up a similar unit on a slightly smaller scale in Australia. As a result the Joint Tropical Research Unit was set up in 1962 at Innisfail, Northern Queensland, and the Materials 1 Branch runs this unit in conjunction with the Defence Standard Laboratories of the Australian Department of Supply. Currently, three members of E.R.D.E. staff are stationed at J.T.R.U. The prime function of this Unit is to expose samples of polymers, paints and related materials to tropical conditions so that the effects can be compared with similar exposures carried out in simulated facilities in the U.K. The resistance of textiles to degradation by sunlight and fungi has also been studied, as well as the effect of termites on various treated timbers.

The function of the Materials 2 Group is much more specific than that of the Materials 1 section. It has been known for many years that the theoretical strengths of materials are several orders of magnitude greater than those observed in practice, but, in certain special circumstances it is possible to manufacture very fine filaments or whisker-like crystals whose strength indeed approach the theoretical values. The production and exploitation of such substances is the main aim of this section.

The problem has several aspects. First, considerable progress has been made in the production of such materials, and pilot plant apparatus has been designed and built, which produces silicon nitride whiskers in kilogram quantities. Attempts are now being made to make silicon carbide whiskers in quantity since these have better all-round properties than the nitride. The problem is now not so much to produce whiskers but to do so economically and theoretical chemical thermodynamic studies are being carried out, using a computer, to try to select the best chemical reaction for the processes.

The physical properties of these substances make them ideal reinforcing materials but they are formed in sizes ranging from a fine dust to lengths of a few centimetres and it is necessary to sort these for selected size ranges. This problem has been successfully overcome and novel ways are also being developed to orient these whiskers with their major axes parallel. The methods are of general application and have been used equally successfully with asbestos fibres.

The third field of research is in the incorporation of the whiskers as reinforcement in suitable matrices, to produce a very much strengthened material. Thermosetting and thermoplastic polymer matrices are being used to produce strong light materials which are superior to glass-reinforced laminates. A second type of matrix is a metal, whereby the strength of the metal is retained at higher temperatures than usual. For example, aluminium reinforced with silicon nitride whiskers retains its useful strength and stiffness up to at least 300°C. At temperatures greater than 1000°C, severe problems arise because of chemical reaction between the whiskers and their metal matrices and attempts are being made to overcome this. Thus, a polycrystalline alumina fibre has been developed which is stable for long periods in nickel alloys at high temperatures.

The Chemical Engineering Branch was originally set up, in 1948, to investigate pilot scale processing of explosives and intermediates prior to transfer to the R.O.F.'s or the Royal Naval Propellant Factory. This need has now virtually disappeared, and this Branch instead investigates important new requirements such as remote control of hazardous operations, the design and development of special equipment for other work in E.R.D.E. and the exploitation of whiskers. It is responsible for the provision of special electronic instrumentation as well as for the maintenance, servicing and repair of electronic instruments throughout the Establishment. There is also a Glass Engineering Section which supplies all types of laboratory glassware and has facilities for manufacture of special purpose glass plant, suitable for pilot plant operation. This Section provides training for scientific assistants and others in elementary glass working for laboratory purposes. Recently, the Section has developed mirrors of aluminium, or silver, on Mylar, or other plastic films, which are cheap and expendable, and which do not produce dangerous fragments, if broken—a very useful piece of equipment in an Establishment concerned with explosives. On the plant side, an intensive study of methods of measuring clearances in mixing machines is nearing completion, and the equipment is now being fitted to mixers used in the manufacture of rubbery propellants.

As part of the modernisation programme, this Branch has just taken over a new building specially designed for laboratory work in chemical engineering; this building also provides new offices for all the senior staff. Many old buildings are being completely overhauled. When this programme is completed, the facilities available for chemical engineering research and for pilot plant operations will compare favourably with any others in this country.

The Analytical and Ingredients Branch provides an analytical service for the whole establishment. It is similar in some respects to the General Chemistry Section of A.M.L. but the materials dealt with include explosives, propellants and initiators, polymers, and whisker materials such as silicon nitride and carbide. Some of the analyses are routine but many constitute minor researches and the group therefore develops new instrumental and practical techniques in anticipation of fresh problems.

Present interests include X-ray crystallography, infra-red and ultra-violet spectroscopy, mass-spectrometry, and the various forms of chromatography—gas, column and thin-layer. Thermal methods are becoming increasingly important. Special attention is paid to thermogravimetry and differential thermal analysis and a new highly sensitive isothermal heat flow calorimeter has been built. There is, in addition, a radiochemical laboratory and a small microanalysis unit which carries out molecular weight determination in addition to elemental analysis.

The second rôle of this division is to advise on all aspects of stability and surveillance of propellants, explosives and initiators, and on their compatibility with the materials with which they come into contact. In this respect, the group is the accepted United Kingdom authority, having final decision on difficulties arising in this field. It is not surprising therefore that there is considerable contact with many outside organisations such as British Aircraft Corporation, Ferranti, Hawker Siddeley, I.M.I. Summerfield, I.C.I. Ardeer as well as other Government departments including R.A.R.D.E., R.A.E., R.P.E., and D.C.I. This sort of work involves a large amount of routine testing but it is supported by more basic research on stabilisation mechanisms and kinetics of decomposition using 15N isotope labelling. The increasing use of polymer based propellants has also resulted in the initiation of work on the chemical stability of these systems.

A section of this branch studies the connection between the chemical constitution and the useful properties of the various substances which go to make a modern explosive. It also ensures that all necessary information is available about methods of manufacturing those which are actually or prospectively needed. Novel compounds required for the work of the other branches are made on a laboratory scale.

Research is in progress on the basic reaction mechanisms involved in the formation of RDX (cyclotrimethylenetrinitramine) by nitrolysis and of HMX (cyclotetramethylenetetranitramine) in the very complex conditions of the Bachmann process.

The aerodynamic heating of supersonic aircraft has given rise to the need for more thermally stable explosives and a number of these have been made. Hexanitrostilbene, in particular, is being more closely studied with regard to optimum yield and reliable conditions of preparation. Advice based on extensive studies has been given recently to R.O.F. Bridgwater on DATB (diaminotrinitrobenzene) manufacture.

The mechanism of thermal decomposition of high explosives is being studied and methods for measuring reaction rates based on decigram quantities of material have been developed.

To round off the picture of work at E.R.D.E. mention must be made of a small research group under the direction of Dr. L. J. Bellamy and Mr.

G. K. Adams. This undertakes a number of short term probing investigations, each usually by not more than one scientist, to decide whether or not a particular field merits more elaborate study.

Linked with these activities is another small section run by a special merit S.P.S.O. which is mainly concerned with the discovery of new additives to limit the spontaneous atmospheric oxidaton of polymers.

Other current research topics fall into three main groups. First, mathematical studies based on computers, of the theory of unsteady chemically reacting flow as in the growth of shock waves in explosives to steady detonation waves, thermodynamic calculations of explosive and propellant performance, and loudness calculations of real and simulated sonic booms.

Secondly, chemical studies on the production of potential laser materials such as the rare earth chelates, and the growth of metal oxide crystals by vapour phase transport.

Thirdly, what might be loosely termed "spectroscopic" studies. These comprise electron impact spectroscopy of organic molecules, field emission microscopy, and infra-red examination of hydrogen bonding and molecular interactions in solution.

In February 1967, following the dissolution of the Ministry of Aviation, E.R.D.E. became part of the Ministry of Technology. It is not anticipated that this change will significantly affect the type of work carried out, but a positive effort is being made to make a recognisable contribution in the civil field. As members of the Ministry of Technology Interlab scheme, the Establishment will be able to provide special facilities and advice on instrumentation to civilian industry. Local industry in the Waltham Abbey, Enfield, Hatfield and Harlow areas will be assisted. Nevertheless, the Establishment will continue to devote the bulk of its effort to research and development on explosives, propellants and non-metallic materials for the Defence Services, and will welcome enquiries from users or other Establishments on these matters.