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43

NORTH SITE REPRINT

CHEMISTRY & INDUSTRY 1965.

New High Explosives.

Progress report, May 1929.

321 – "premises taken over in 1945" —— not exactly – already MoS property

"first recorded NG Sobrero 1846 – NC Schönbein same year" —— <u>1845</u> & following Pelouze 1838.

a substantial portion of the pre-war RD at Wch was transferred to the site.

"Cordite ... was one of Nobel's elegant inventions" – this reverses the Court decision of 1894!

chemical interest in explosives and <u>materials</u> to cpds of elements in short periods.

"Explosion by nature vigorous reaction ... gases of low mol. wt" — too sweeping – not true of gunpowder.

team of chemists specially recruited, youngest to a Supt —— not correct – the team was three.

"lead azide, Pb trinitroresorcinate & other curiosities" — why so, tons have been made.

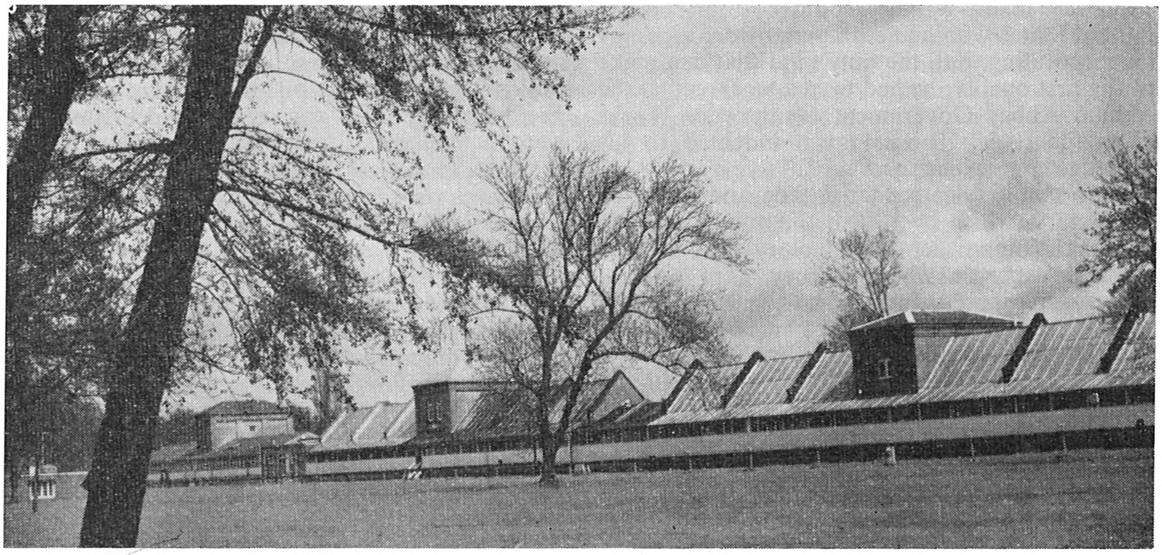
"setting-off charges ... eg RDX/TNT" —— no, tetryl between

"Some [illegible] cpds have proved to be photo conducting" etc
in need of revision — looks pretentious

REPRINTED FROM CHEMISTRY AND INDUSTRY, 1965, pp. 320—327

Research Establishments in Europe: 48

The Explosives Research and Development Establishment, Waltham Abbey



Old guncotton and cordite processing buildings which have been converted to laboratories at Waltham Abbey.

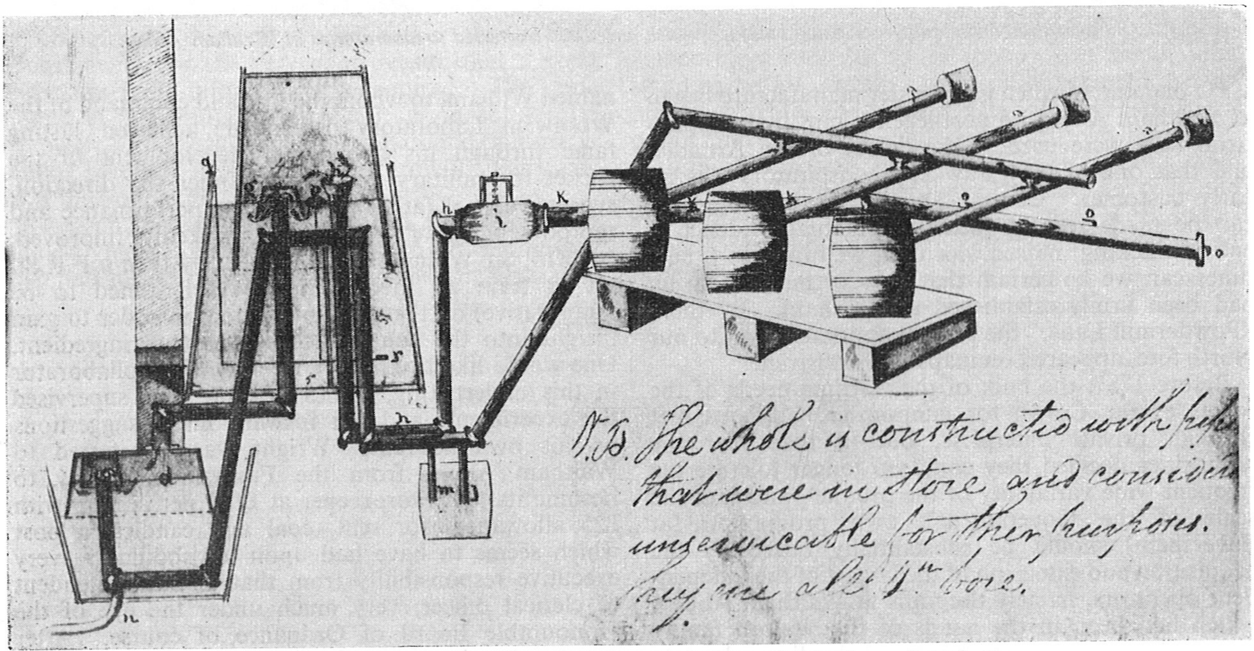
NO one knows when gunpowder manufacture began at Waltham Abbey. Local legends hint that supplies from here were used in the defeat of the Armada, and that one of Guy Fawkes's conspirators was an early customer. Circumstantially, a plausible case can be made for the latter but factual evidence is entirely lacking; indeed, not until well on into Stuart times can we be certain that powder manufacturing had been firmly established at Waltham. By then, "Powdermill Lane," the present approach road to our North Site, appeared on maps of the district.

Before 1787, the bulk of the wartime needs of the forces of the Crown for gunpowder had been met through private enterprise, but in that year the authorities decided they could no longer tolerate the frequent wide variability of the product, and that the scale of the Government's own production (at Faversham) should be substantially raised by the acquisition and extension of the largest of the independent operators, namely the mills at Waltham Abbey, which had been in the hands of the Walton family for the best part of a century. A leading advocate of this important step was Sir William Congreve, Controller of the Royal Laboratory, Woolwich, who negotiated the purchase and was responsible for the subsequent expansion of facilities. His son, also named William, to whom the title and command of the Woolwich Laboratory descended, achieved lasting fame through his spectacular development of the rocket for military purposes. Under the direction, successively, of father and son, the performance and reproducibility of gunpowder markedly improved. In 1816, Sir William Congreve, Jr., by then a F.R.S., set in train an investigation (which aimed to be quantitative) on the coking of wood, in order to gain insight into the control of the charcoal ingredient. One would like to know more about his collaborator in this undertaking, James Wright, who supervised the experiments and put forward many suggestions on his own account. Wright was transferred to Waltham Abbey from the Faversham factory to become its first Storekeeper at £150 per annum with £25 allowances for rent, coal and candles, a post which seems to have laid upon his shoulders every executive responsibility from that of Superintendent to clerical officer, very much under the eye of the Honourable Board of Ordnance, of course. After some years it seems that Wright suffered partial eclipse, owing to the Establishment's accounts being "shamefully behind." He protested, unavailingly, that he worked long hours, seven days a week; certain it is that his laboratory notes testify to meticulous care in the recording of observations. A drawing of the plant used in the initial stages of the work, which Wright called "the gasometer," is reproduced here and carries the comment: "The whole is constructed with pipes that were in store and considered unserviceable for other purposes. They are all 4-in. bore." (The Board was unaccustomed to research expenditure.) By a quirk of fate, one of James Wright's nine children, another James, who emigrated to Tennessee, was the only foreman experienced in powder-making immediately available to the Confederate authorities during the construction of the very remarkable Powder Works at Augusta, Georgia, during the Civil War:

> "But one man—Wright—could be found in the Southern States who had seen gunpowder made by an incorporating mill, the only kind that can make it of the first quality; he had been a workman at the Waltham Abbey Government Gunpowder Works in England...... I was much indebted to his knowledge and experience......"

An important service rendered time and again by the old factory (which by 1830 had assumed the title of the Royal Gunpowder Manufactory) was to send experts and expertise wherever they were wanted, notable examples occurring during the First World War in the countries of the Empire and the U.S.A.

The entry of organic nitrates into the explosives arena is a long and fascinating story indissolubly linked with the genius of Alfred Nobel. Nitrocellulose and nitroglycerine were isolated in 1846, but many years passed before means were found of bringing them into military usage. The sensitiveness of nitrocotton to friction when dry, and spontaneous explosion during storage caused its virtual abandonment by all countries during the decade following the discovery, but eventually the patient pioneer work of Sir Frederick Abel, F.R.S. (1827 to 1902), a former student of A. W. Hoffman, head of the Woolwich laboratory, brought the "smokeless powders" within the pale of acceptable ammunition fillings. His large scale experiments were done mainly at Waltham Abbey. Nobel's brilliant notion of taming the pair of dangerous nitric esters by mutual interpenetration was an essential step towards the emergence of cordite. The present South Site at E.R.D.E. was acquired in 1886 for the erection of the first cordite plant in this country.



A sketch of "the gasometer" used in Congreve's research into charcoal production.

Emergence of the Establishment

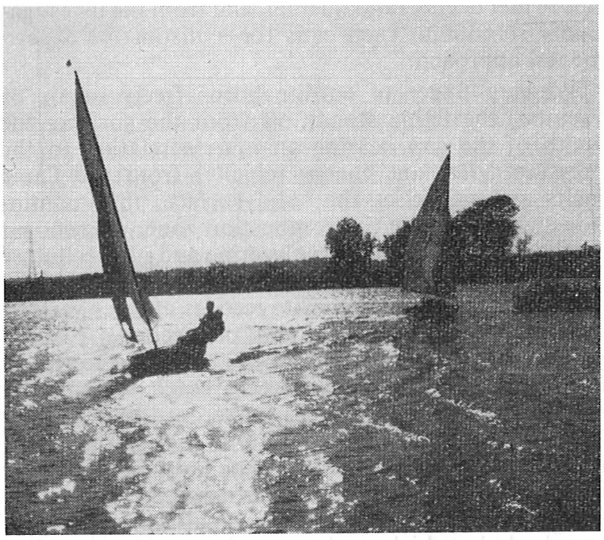
Since the take-over of the factory in 1945, a great deal has been done to effect its transformation to purposes of research and development. There was need of it. Roads were non-existent, the numerous explosives processing buildings being connected by narrow gauge railways, along which small trucks were manhandled, fitted with awnings and containing products in various stages of manufacture. Finished explosives were conveyed by barge along the network of streams and canals to and from magazines situated by the water's edge, with jetties for loading and unloading. The Old River Lee provided a link with Woolwich Arsenal through a succession of locks; to travel downstream took two days, sail being hoisted below Bromley-by-Bow

All but a few of the existing laboratories were formerly guncotton and cordite processing buildings, mostly dating from the third and fourth quarters of the last century. They are not much to look at, but they have converted well on account of their convenient dimensions. Beam engines were originally housed in the towers, for driving the paddles of "mixers"; by putting in a floor half-way up pleasant offices have been created for heads of branches.

The Author of this article, Dr. C. H. Johnson, C.B.E., relinquished the Directorship of E.R.D.E. in May, 1964. Both he and his successor Dr. L. J. Bellamy, are men of considerable academic distinction, the former having at one time been senior lecturer in inorganic chemistry at Birmingham University, while the latter is a well-known authority on infrared spectroscopy. Dr. Bellamy entered the Scientific Civil Service on completion of his Ph.D. at London University in 1939. Among his many publications, Dr. Bellamy's book entitled: "The Infrared Spectra of Complex Molecules" (Methuen, 1954, 1958) is surely the most outstanding. It has been published in German, Russian and Japanese as well as in English.

As with Government laboratories generally, an extensive range and variety of scientific equipment is installed; there are good workshops, and several professional glassblowers (directed by a chemistry graduate) are kept busy. In recent years the scientific work has tended to become predominantly physico-chemical in character and, consequently, demands on the instrumentation and electronics sections have outgrown their capacity. Steps are being taken to catch up.

Our research activities tend to be centred on North Site, which is a large park criss-crossed by streams where the old powder mills stood. Larger scale operations, pilot development and the like, are carried out mainly on the South Site; there processes are investigated and explosives compositions of all types produced in quantities sufficient for mounting field trials. The two Sites are now joined by a private road which eliminates the necessity to send explosives through the town. Much of the unusual character of the old factory (vividly described in an article in the Strand Magazine of 1898) has been retained, notwithstanding the radical changes. The Reading Room of the Library occupies a pair of early 18th century buildings, one of which is known to have been a sulphur store when the mills were owned by the Walton family, relatives of fisherman Izaak. The woods and streams are attractive in Spring and Summer and birds in great variety find sanctuary, despite the bangs, in the neighbourhood of Fisher's Green, where the Sailing Club has access to a lake.



The area around Fisher's Green, used by the Establishment's Sailing Club.

Structure and Functions of the Establishment

The Establishment is the sole Government laboratory responsible for research on, and development of, non-nuclear military explosives of every kind, and is thus concerned, at the very least in an advisory capacity, with the requirements of all three Services embraced by the new Ministry of Defence. The Establishment's larger undertakings usually require the participation of several of the eight main divisions, or branches, each headed by a Superintendent. Four are concerned with explosives, and two with non-metallic materials; the Analytical Services branch and the Chemical Engineering branch are involved right across the board. All told there are between 70 and 80 staff in the Scientific Officer grades, most of whom are chemists but include chemical engineers and physicists. There are rather more than 100 Experimental Officers of all ranks, a sprinkling of engineers and a sufficiency of laboratory assistants. The total population is around 1000, more than half of whom are industrial workers.

In describing the work carried out at Waltham Abbey, some lack of perspective is inevitable since a good slice of the programme relates to matters of military significance which cannot be taken up in this article. A fair idea of the scope of our researches in pure chemistry can be inferred from the score or more papers which appear annually in the scientific journals, though these are not yet fully reflecting the increased attention being given to non-metallic materials. We have made substantial contributions in the realms of flame chemistry, molecular spectroscopy, the organic chemistry of nitrobodies, the synthesis and (lately) degradation processes of polymers, and much else besides. A series of papers on the mechanism of stabilisation of concentrated hydrogen peroxide not only related to the problems of practice but contained a great deal of general physico-chemical interest. Some of our purer research is carried out solely to ensure, as far as possible, that the advice we give to the Service departments has a firm basis. The quality of this advice may well determine whether the taxpayer's money is to be well spent or wasted, and it is no less useful to advise correctly against substantial investment in proposed developments than to register positive achievements. In this respect, a watching brief, as it were, held even by a small team of scientists who know what they are about can be extremely effective, a thought which calls to mind nine recent papers on alkyl boranes published in *Journal of the Chemical Society*.

On the applied side, the achievements of the Establishment range from such minor tasks as the use of explosives to reproduce closely the shock front conditions of sonic booms, to major ones exemplified by the advances in plastic propellant during the 1950s, an offshoot of which was its successful use in the Skylark motor, designed for upper atmosphere research. Manufacturing processes for explosives, propellants and their ingredients are studied continuously, and, in collaboration with the Royal Ordnance Factories, improved production plants have been installed. Typical examples are the manufacture of nitroguanidine by a new process, the development of equipment for continuous crystallisation of perchlorates of the right grist and shape for explosives application, and technological improvements which allow nitric esters to be produced in better quality with less hazard. This combination of better products with less danger is also a main objective in our study of initiating explosives, and E.R.D.E. patents have been taken out for such compositions which are both safer to handle and more reliable in use. These are now operated under licence in other countries.

The Materials branches have, on the whole, been more concerned with basic than with applied problems but they have nevertheless made many useful contributions to projects such as the Dracone barges and the development of large collapsible storage tanks for petrol. Some of the basic work is now beginning to bear fruit and we are hopeful that the high strength "whisker" research which was recently discussed on T.V. will soon find some initial applications. The studies of the various ways in which polymers degrade are already pointing to new methods of prevention, and are helping to guide the choice of future programmes for the synthesis of high temperature resistant materials.

Research into Explosives

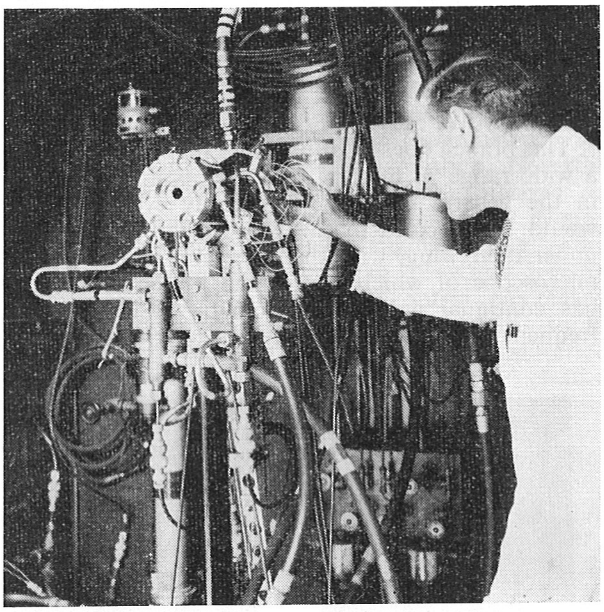
Organic chemistry figures less prominently in the explosives field than was the case a generation ago, and to maintain a knowledgeable team in the conditions of today requires an intelligent selection of research topics. Explosives undergo exceptionally vigorous reactions to yield very hot gases of low molecular weight; yet they must be possessed of pronounced stability until deliberately provoked, and it is the latter consideration which so much restricts the choice. At Woolwich during the 1920's and 30's an exhaustive exploration was made of organic explosives by a team of chemists recruited for the purpose, the youngest member of which is a Superintendent at E.R.D.E. Thermochemical determinations went hand in hand with synthesis. The trail ultimately led to R.D.X. ("Research Department Explosive"), cyclotrimethylenetrinitramine $(CH_2)_3$-$(N.NO_2)_3$, carbon and nitrogen atoms alternating in a six-membered ring. It was not an entirely original discovery, but the method of preparation worked out at Woolwich was the first which gave the prospect of extension to large scale manufacture without undue hazard. R.D.X. could be described as the high explosive of the Second World War, as T.N.T. was of the First, but at the outbreak in 1939, the only source in existence was a small pilot facility at Waltham Abbey. Chemical Engineering sections now use the mounded buildings individually.

It is possible to achieve slightly more favourable proportions of light elements than exist in the R.D.X. molecule (which is chemically balanced in respect to $3CO + 3H_2O + 3N_2$) and therefore rather greater power, but the gain will be offset by increased handling risks, and, even as things stand, R.D.X. is never used undiluted in shell fillings. It must indeed closely approximate to the optimum compromise between the two linked qualities of explosive power and hazard. Nevertheless there is still plenty of scope for investigations into the complex chemistry of nitramine compounds; for example, the reactions involved in synthesis of the six, and the analogous eight, membered ring, which should point the way to worthwhile improvements in the efficiency of production of these compounds. Our "organic" branch is also working on the non-explosive degradation of explosives in the solid state, and on initiating substances such as trinitroresorcinates, and other curious compounds. A characteristic of these "primary" explosives is that their ignition, however gently brought about, is invariably violent; hence their utilisation in setting off charges of "secondary" explosives. Some have proved to be photo-conducting, and apparatus has been set up at E.R.D.E. to measure this property as a function of light intensity with the object of obtaining quantitative information on their excition and impurity levels. Theoretical calculations of the refractive indices of azide crystals in conjunction with actual measurements are leading to deductions about the orbitals of the azide ion, which might in turn help towards an interpretation of the course of decomposition in the different planes of a single crystal.

Turning to another aspect of explosives work, two distinct types of explosion have been recognised: "deflagration" and "detonation." Judged simply from a sight of "the rocket's red glare" or of the havoc wrought by severe occurrences of either type, the distinction might seem hardly worth making. It is in fact deeply fundamental, and from the investigational standpoint each calls for a distinctive experimental approach.

When a finger of cordite burns freely in air or vacuum, the flame stands off from the surface, the width of the gap bearing an inverse relation to the pressure. Radiant energy (chiefly) from the flame melts and vaporises the solid surface, thus continuously replenishing the combustion zone. Dependent on the proportions of nitroglycerine and nitrocellulose in the composition, and on other circumstances, the surface of the burning cordite recedes at rates varying between about 0·3 and 3·0 cm. per second. Even at gun-breech pressures (3000 to 4000 atm.) the fastest burning cordites would scarcely reach 70 cm. per second. Hence, in order to make cordite deflagrate completely within a small fraction of a second, as it must do in a gun, it has to be in small pieces, presenting large surface areas at which burning can take place, such as exist, for example, in small cylinders with annular holes which can be manufactured by extruding the cordite through dies under high pressure.

Layer by layer deflagration is the type of combustion required in solid rockets, whatever their size, and one of the first decisions a designer has to make is the mass-rate of burning (lbs., or tons, per second) necessary to perform the load-carrying task specified. Ideally, the role of E.R.D.E. would be to provide a range of proved solid propellant compositions—not restricted to cordite—possessing as wide a spectrum as possible of combustion characteristics, since compromises between one feature and another are inevitable during the lengthy development of a missile: and, of course, having many other essential qualities as well. The mass-rate of burning is no less fundamental to the performance of rockets powered by liquid propellants, but in these the rates of injection of oxidant and fuel into the combustion chamber are regulated hydraulically through pumps or by gas pressure.



An instrumented laboratory rocket rig. An elaborated version of the original equipment.

The second type of explosion, that of detonation, occurs as has been mentioned earlier, whenever primary explosives such as lead azide are ignited, however softly, and when secondary explosives such as R.D.X./T.N.T. mixtures are powerfully shocked. Detonation is more readily engendered, *i.e.* by less intense shocks, when the charge is confined, as in a steel shell case, or self-confined when in bulk. Gunpowder in shell does not detonate; the fragmentation is a pressure burst. Detonation bears little obvious resemblance to flame, propagation taking the form of a chemically reactive shock front, insensitive to ambient pressure, travelling at seemingly incredible speeds of up to 10,000 metres per second, several orders of magnitude faster than that of the movement of flame on burning solid or liquid surfaces. This abrupt type of explosion, as distinct from longer-duration pressure effects, is the cause of the shattering which accompanies detonation.

Application to Flight

The divisional organisation of research and development work at E.R.D.E. is determined very largely by the differing applications of these two modes of combustion. Of the four "explosives" branches, two are entirely concerned with the deflagrating sort, the other two mainly with the detonating kind. Although solid propellant charges for rocket motors take a heavy toll of the available effort, since the guided weapons they propel fulfil diverse functions—including the artillery role for the Army—a constant stream of problems comes our way in connexion with the provision of charges for ancillary purposes, ranging from halfpenny-size shaped discs, called "snifters," for altering a space vehicle's direction when in flight, to cartridges whereby pilots strapped to their seats can be ejected from planes that have got out of control, to still larger charges for starting up cold engines, and gas generators of various types. Any mechanism (or person), in short, in need of a measured strong shove is liable to become a call on the propellant developer and manufacturer.

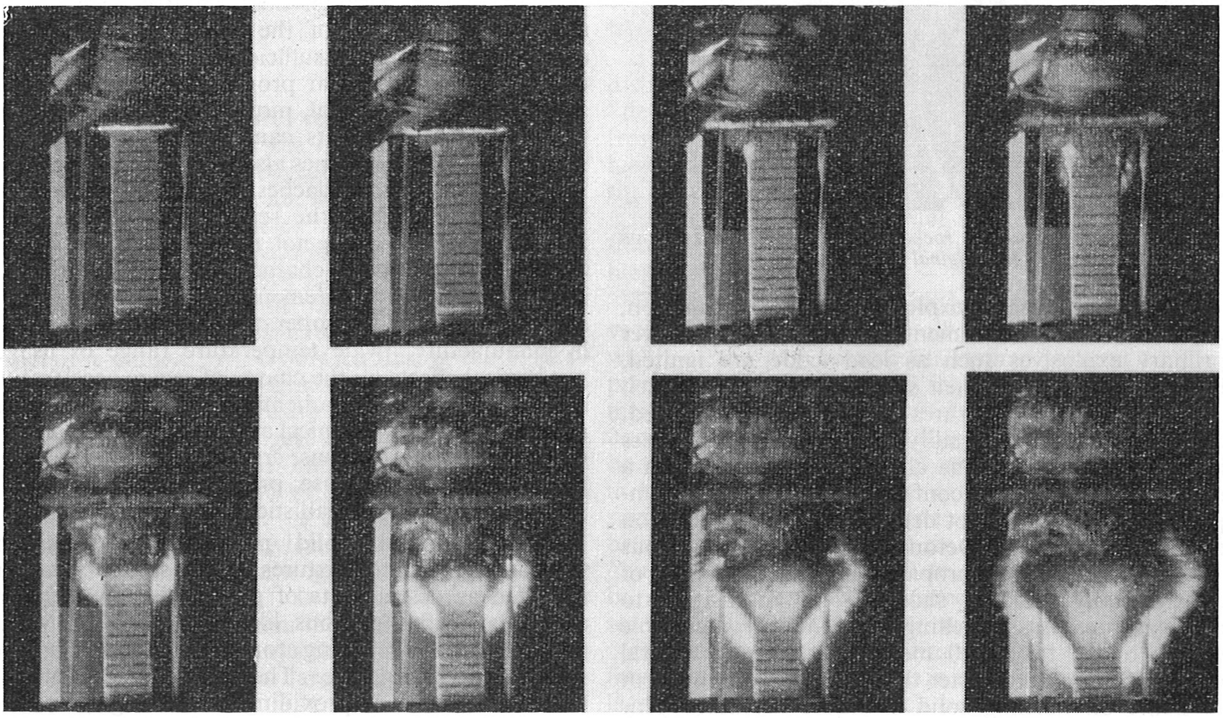
Approximate upper limits of performance of solid rocket charges are readily calculated in regard to thrust generated per unit rate of propellant consumption (commonly referred to, though ambiguously, as "specific impulse"). Until a few years ago, quoted values of specific impulse varied widely, according to the assumptions made in the calculations, and only fairly recently have rational standards of comparison been generally adopted. Unfortunately not before the impression became widespread, even amongst some professionals, that the future prospects for super-propellants were brighter than could conceivably be the case. The facts of the situation are that, by designing to employ sufficiently large charges of readily available familiar propellants, some of which are exceedingly powerful, most terrestrial tasks likely to be laid upon rockets can be accomplished, and many extra-terrestrial ones also. It may not be widely recognised that the headaches in the rocket propellant business which affect the scientist and technologist almost invariably arise, not from lack of attainment of the desired thrust characteristics, but rather in respect of other requirements imposed. Examples are: necessary but uncooperative ingredients; hazards in manufacture; wide temperature range of usage; mechanical effects on the charge of severe acceleration or of temperature gradients; ingress of traces of moisture, and slow chemical and physical deterioration signified by gas inclusions, cracking, or other "aging" phenomena which cause progressive alterations in internal and external ballistics.

Certain modern solid propellant compositions which are intimate mixtures of constituents can be regarded as descendants of gunpowder. Others are more nearly homogeneous, like cordite itself, in which the oxidising and reducing atom-groupings are part and parcel of each molecule. The variety of solid propellants is a means of providing rocket engineers with manoeuvreability in respect of the many qualities which have somehow to be combined in any given propellant charge. It takes a long time to reach the point where behaviour can be reliably predicted in almost any likely circumstances, and the systematic seeking of relevant information constitutes one of E.R.D.E.'s essential tasks.

An important aspect of explosives research, which still offers worlds to conquer, may be summed up in the word "sensitiveness," signifying the variation in susceptibility exhibited by explosives towards stimuli of different kinds; friction, shock, electric spark, and so on. Separately, nitroglycerine and dry nitrocellulose are amongst the most capricious and powerful of known explosives, but, as mentioned earlier, penetration of the fibrous "N.C." by liquid "N.G." produces a tough, horny material which can only be made to detonate when in very large bulk and very powerfully shocked! Several modern types of propellant are potentially as devastating as the high explosive R.D.X., but they, too, like cordite, are difficult to detonate. The basic problems of sensitiveness are bound up with the processes of initiation and of attainment of detonation velocity. An essential experimental tool is a very fast camera and we are fortunate in possessing both the "framing" and the "streak" instrument made by Beckman and Whitley in California, of which few others are to be found in this country. The former can take pictures at a rate of up to 1,200,000 per second, and its capability is illustrated in the figure, which displays the sequence of events at intervals of about one millionth of a second, when a block of R.D.X./ T.N.T. is subjected to a moderate shock. In the first four photographs an ordinary shock wave can be seen ravelling along the charge. Detonation occurs abruptly in the fifth frame, its onset being inferred from the sudden increase in the rate of travel of the shock wave, and the burst of light which investigation has shown to be due to the emergence of the shock front on reaching the surface of the block from the interior causing the air in the vicinity to become luminescent. The team doing this work has also made good progress in another type of investigation aimed at measuring detonation temperatures in liquid and solid explosives by the simultaneous recording of the intensity of emission from the detonating charge at six selected narrow bands in the visible and near-ultraviolet regions of the spectrum. The values of emissivity of the gaseous products have turned out to be close to unity (perhaps larger!). By further refinement of these measurements the possibility may arise of distinguishing between alternative equations of state (of the products of detonation) which theoreticians have put forward. The same branch is also responsible for assessing in semi-quantitative terms the handling hazards of all classes of explosive and for developing tests to that end.

The Analytical Services Branch

This branch does what its name suggests in applying a wide range of modern instruments and techniques in the general interest. Practically everything that would be expected in the way of equipment comes under their wing, with the exception of the electron microscope of which one of the Materials branches has continual need. Spectrometry is of course in frequent demand as an analytical tool, but examples



A block of R.D.X./T.N.T. is subjected to a moderate shock. In the first four photographs, an ordinary shock wave travels along the charge. Detonation occurs abruptly in the fifth frame.

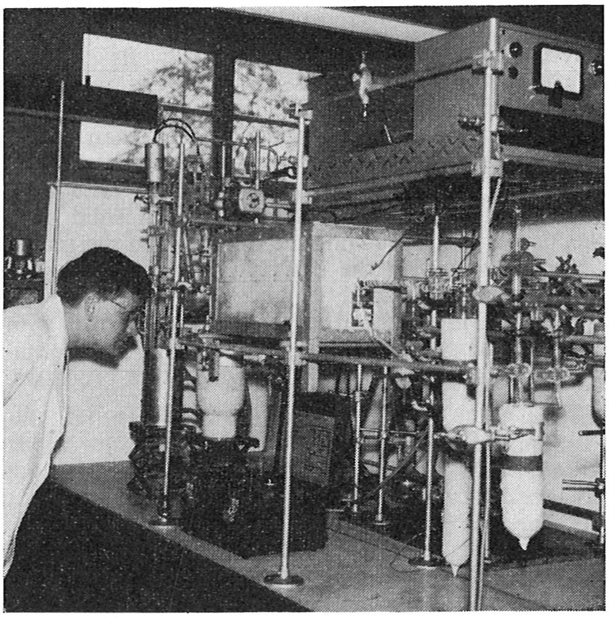
of basic research in progress are some selected studies of hydrogen bonding, and of the nature and strength of forces between molecules in the solid state and in solution. A radiochemical laboratory for tracer element applications has been set up under the *aegis* of the Analytical Services branch. The synthesis and breakdown processes of "tagged" vinyl type polymers are being investigated. A Perkin-Elmer N.M.R. machine (60 megacycles for protons) is now in operation. Far and away the simplest and most useful of the new techniques of analysis introduced at Waltham Abbey has been layer chromatography, which, amongst other things, has enabled rapid progress to be made towards unravelling the complex reactions undergone by stabiliser molecules in propellants in the performance of their stabilising functions. The great virtues of gas chromatography were brought home to us some years ago in connexion with the separation of boron hydrides.

Chemical Engineering

Our Chemical Engineering branch was set up in 1948 to investigate processes for ultimate transfer to the Royal Ordnance Factories. Today the need for this is much reduced due to changed circumstances and the contraction of the R.O.F. organisation. Nevertheless, experimental propellants and explosives are becoming more hazardous and this raises a great many queries for the chemical engineers, one section being wholly concerned with the study and development of equipment and of remote control. As regards chemical engineering research, the emphasis so far has been on problems of large scale crystallisation, such as the control of size distribution, of nucleation and of growth rates, all of which have an important bearing on the manufacture of propellant ingredients.

Several years ago, as part of a research programme on liquid rocket propellants, we took up the question of the absolute and relative contributions of radiation and convection in causing the dissipation of energy of the hot gaseous products of combustion to the motor walls. An instrumented laboratory rocket rig is shown in which measurements of radiative heat flux are currently being made and which is a much elaborated version of the original equipment. At the same time apparatus was designed, and afterwards gradually perfected, for carrying out determinations of thermal conductivity with great precision over a wide range of temperature and pressure (up to 400°C. and 300 atm.). As a result, a large amount of data of general utility has been accumulated of an accuracy certainly never bettered and perhaps unattained hitherto. This work has sprouted in two directions; a highly practical one in reference to convective heat transfer to liquids in the supercritical condition, as sometimes exists in the cooling jacket of a rocket engine, and a fundamental study of the behaviour of fluids in and around the critical state where the shape of the isotherms strongly suggests the simultaneous existence of two distinct phases. Critical phenomena seem to have been rather neglected in Britain, and offer some interesting possibilities both scientifically and technologically. The apparatus is undergoing modification to permit measurements up to 1000 atm.

Everyday concepts of explosives, or rockets, are naturally dominated by people's ideas of them as immensely powerful sources of energy. In point of fact this is only a part of the picture, and, for both solid propellants and high explosives, correct functioning is critically dependent upon the physical and mechanical properties of the charge. It is essential for rocket charges to retain their shape in all circumstances, whether in storage, in transit, or subjected to high acceleration on launching, since the carefully moulded cavity in which the combustion takes place has been designed to give a controlled programme of gas evolution. Any physical distortion or breakdown would change this radically and in most cases cause a burst, since the penalty of weight is unacceptable in rocket motor design and there is little margin of safety in the motor tube. Again, long spells at either extreme of temperature may cause permanent changes in physical properties to the detriment of reliable functioning. Therefore, in common with similar establishments in other countries, we maintain a team to work specifically on the mechanical behaviour of explosives. This work has a good deal more scientific interest than might appear at first sight, as some types of propellant have unique rheological properties. It covers such aspects as fatigue and its temperature dependence, and the measurement of tensile properties under biaxial stress, both of which are important in determining the life cycle of large rocket charges.



Apparatus used in the Materials Branch to investigate the susceptibility of polymers to attack by radicals.

Materials Research

Work on explosives cannot be wholly separated from consideration of the non-explosive components, particularly of plastics, varnishes, rubbers and adhesives, which must in any event be tested to ensure they will not react to make the explosives unsafe or reduce their performance. For this reason alone, E.R.D.E. has always maintained a small group on Materials work. Our two main Materials branches, however, have different and more generalised objectives which will now be briefly described.

Developments in modern weapons, guided missiles, and supersonic aircraft make increasing demands on materials of construction and it will be clear from information released to the Press about the Concorde and the latest American plane, which may travel even faster, that materials are becoming the limiting factor in technical advance. Both branches at E.R.D.E. are primarily concerned with studies of strength and stability of non-metallic materials used as structural components. One deals largely with high polymers, the other with inorganic or ceramic types of compound such as carbides and nitrides, of which the natural brittleness is offset by embedding them in the form of filaments or "whiskers" in a ductile matrix, which can be a plastic in the case of low temperature applications, or a metal or alloy for high temperature usage. In illustration of the improvements which these inorganic compounds offer in polyphase systems, some values of specific modulus (Young's Modulus ÷ density) may be quoted. The specific modulus of wood, aluminium, steel, magnesium, silica, and many glasses, closely approximates to 4×10^6 lb./sq. inch, which may be compared with figures of 15 to 25×10^6 lb./sq. inch for boron, beryllia, and the carbide and nitride of silicon. These latter materials suffer much smaller strains under high stresses, and thus practical use can be made of their exceptional strength with minimal dimensional distortion. This type of work is a recent innovation at E.R.D.E. and while practical objectives and engineering requirements are kept very much in mind, the immediate dividends are likely to be pointers to the way ahead rather than actual achievements, for the very good reason that a great deal more basic information is required. The same branch is beginning to interest itself in solid state chemistry, and is studying the kinetics and thermodynamics involved in the epitaxial growth of crystals from the vapour phase.

Research in the Materials branch concerned with high polymers is mainly concentrated on the mechanism and means of control of degradation processes, whether thermal, oxidative or caused by radiation of various kinds (we possess a Cobalt^{60} source of gamma radiation and have access to atomic particles through Harwell). One section is given over to autoxidation studies of model compounds and selected types of commercial polymers, and has turned up some effective antioxidants. The toluene carrier gas technique of Swarc is being used to investigate the susceptibility of polymers to attack by radicals, which should enable estimates of bond strengths to be made. The apparatus is shown in the figure opposite. Without doubt, radical formation is a first step in many natural processes of degradation. Related to this work is a general investigation of the connexion between the molecular structure of a series of well-characterised polyethers synthesised in our laboratory and a variety of physical properties which bear on inter- and intra-molecular forces. In short, we have deliberately chosen the analytical and destructive approach to the ultimate improvement of polymer properties in preference to engaging in exploratory polymer synthesis *per se*.

Conclusion

In this article we have attempted to convey an impression of the attitude towards research—no less important than the possession of elaborate equipment—at one of the smaller establishments of the Ministry of Aviation. It must again be emphasised that only research activities have been considered. The unique position held by E.R.D.E. in the small world of non-nuclear military explosives implies obligations to all three Defence Services, which is a great help when drawing up programmes of aimed research.

As regards non-metallic materials, the establishment's links with the Army Department are of long standing, and it is evident that no Government department has greater need of new materials of construction, or for that matter of improved electronics materials, than the Ministry of Aviation. This side of our work shows every sign of growing further, so that the E.R.D.E. of the future may find itself with something like equally balanced interests in explosives and in materials.

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