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ERDE BOOKLET c. 1968  
Activities + Facilities



# Explosives Research & Development Establishment

## **Research and Development Activities and Facilities**



glBromberger :



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**EXPLOSIVES  
RESEARCH & DEVELOPMENT  
ESTABLISHMENT**

**RESEARCH and DEVELOPMENT  
ACTIVITIES and FACILITIES**



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# HOW TO CONSULT ERDE

ERDE is able to offer a limited, free consultative service to industrial undertakings on problems related to expertise available in the Establishment.

Problems involving more extensive investigations or the use of equipment and special facilities may be undertaken for a fee, subject to the demands of the Establishment's research and development programme.

Enquiries may be made

- (a) by letter, addressed to The Director  
ERDE  
Ministry of Technology  
Waltham Abbey, Essex;
- (b) by telephone, asking for Heads of specific branches or ERDE Industrial Liaison Officer (01-97 23688).

## ERDE TELEPHONE NUMBER

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# INTRODUCTION

The primary function of the Explosives Research and Development Establishment is to undertake research on, and development of, explosives, propellants and related exothermic compositions to meet the present and future requirements of the three Services. The Establishment is also actively engaged on materials work, concerned principally with the chemistry and physics of polymers, and with new engineering materials based on refractory fibres.

To exercise these functions, ERDE maintains a staff of scientific, technical and engineering personnel representing a wide range of disciplines but with particular expertise in chemistry, chemical engineering and physics. Research and development tasks are shared by seven technical branches supported by drawing office, machine shop, electronics and glass engineering facilities, and by appropriate library and information services.

It is the purpose of this book to give a brief outline of the work of the technical branches, especially those aspects involving expertise, facilities or equipment which are likely to be of interest to industrial undertakings.



# MANAGEMENT ORGANIZATION

Director	Dr. L. J. Bellamy
Principal Superintendent/Development	Dr. G. H. S. Young
Special Merit 'B' Post	Mr. G. K. Adams
Heads of Branches	
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	Prof. J. E. Gordon
Analysis and Ingredients	Dr. I. Dunstan
Chemical Engineering	Mr. R. G. Ross
Chief Engineer	Mr. S. J. Lowdell
Chief Safety Officer	Mr. J. V. Griffiths
Chief Administrative Officer	Mr. S. F. M. Whiteside
Individual Merit Scientists	Dr. A. W. H. Pryde (Chemical Engineering)
	Mr. G. W. C. Taylor (Initiator Explosives)
	Dr. N. Uri (Autoxidation)
	Mr. H. Ziebland (Heat Transfer)





# EXPLOSIVES

Head of Branch    E G WHITBREAD

The Explosives Branch deals primarily with the development of sensitive, initiatory explosives and high explosive and propellant compositions of improved performance. Trials are performed to assess sensitiveness and hazards associated with all explosive materials.

## ACTIVITIES AND FACILITIES

### Explosive Risk

Standard tests designed to evaluate and to compare the explosive risk of materials are based on impact and friction sensitiveness, ease of ignition, susceptibility to burn to detonation, and shock sensitiveness. Results enable recommendations to be made regarding type of hazard, degree of protection and appropriate storage requirements.

*Armoured cupboards for small-scale tests (up to 30 g) and instrumented firing site facilities for larger quantities (up to 4.5 kg). Firing site for small-scale underwater tests.*

### Electrostatic Risk

Electrostatic risks associated with handling explosive powders, vapour/air, and gas/air mixtures are assessed by measuring

- (a) electrostatic voltages and charges on transferring solids or liquids, or on separating surfaces;
- (b) comparative electrification of materials, especially fabrics and plastics;
- (c) electrical resistance of floors, footwear and items of equipment;
- (d) susceptibility to ignition by capacitor type discharge.

*Electrostatic voltmeter (30—18 000 volts); resistance meters (up to  $10^{16}$  ohms); facilities for measuring electrostatic spark sensitiveness of powders.*

### High Speed Photography

This technique is used to record mechanical and explosive phenomena, to investigate shock initiation of explosives and to determine propagation velocities.

*Portable 16 mm ciné camera (100—18 000 frames/sec): framing camera (25 frames at 150 000 —  $4 \times 10^6$  frames/sec), installed in 2.25 kg explosives test facility; streak camera (writing speed 0.7 mm—9 mm/microsec), installed in 4.5 kg explosives test facility. Printing facilities include conversion of 35 mm frames into animated 16 mm film, and colour printing of negatives of explosive phenomena with particular reference to correct colour balance.*

## Noise Evaluation

Measurement and analysis of impulsive noises including those of long duration (e.g. sonic booms), and their simulation by explosives. Techniques for generating a wide range of pressure waveforms in air may be applied to studying the behaviour of structures to shocks of this kind.

*Apparatus to record shock waves in air down to  $5 \text{ N/m}^2$  ( $0.1 \text{ lbf/ft}^2$ ).*

## Remote Control Methods

Development of remote control methods for manufacturing and testing dangerous explosive materials.

*Process bays (limit 7.25 kg TNT equivalent) in which hazardous operations can be performed by remote control. Remotely operated mixing, extruding and injection moulding unit (4.5 kg) with temperature, vacuum and shear rate controls on mixer (viscosities 2—3 000 poise). Strong bay (limit 1.35 kg TNT equivalent) with master slave manipulators (3.5 m extended reach), X-ray facility (250 kv), and armoured viewing window. Capability for melt-mixing and moulding, or for pressing explosives, and for carrying out basic machinery operations on explosive charges by remote control. Closed circuit TV available to position all remotely-controlled operations.*

## Gas Kinetics

Kinetics and mechanisms of gas-phase reactions and general free radical chemistry using static and discharge-flow techniques. Reactions of alkyl and alkoxy radicals, nitrogen oxide and nitrogen dioxide. Mechanisms of gas-solid reactions.

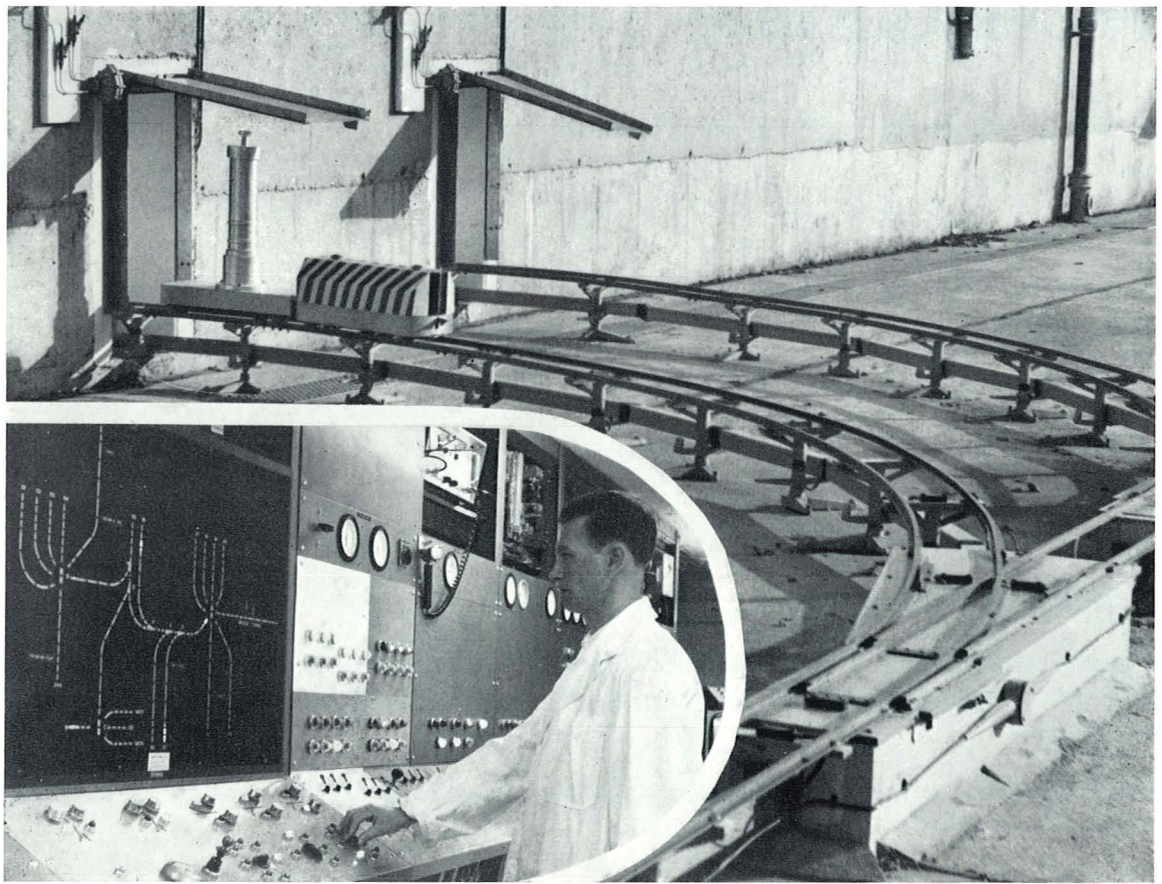
*High vacuum techniques and product analysis by vapour-phase chromatography, infra-red and mass spectrometry. Emission spectroscopy.*

## Polymer Technology

Cure chemistry of polyurethane elastomers prepared from di-isocyanates and hydroxy-terminated polyesters and polyethers; optimization of physical properties of heavily-loaded rubbers.

*Small scale plant facility for development work; laboratory equipped to study physical properties and ageing characteristics.*





REMOTE-CONTROL TRANSPORTATION OF HAZARDOUS MATERIALS

A five-inch gauge electric railway system used to transport hazardous materials between manufacturing, testing and storage areas.

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# PROPELLANTS 1

Head of Branch     W G WILLIAMS

Propellants 1 Branch is largely concerned with the development of propellants based on nitrocellulose. Work is undertaken on methods for controlling ballistics, and to devise ballistic assessment techniques. Attention is also given to the quality control of propellants by non-destructive tests involving X-ray or ultrasonic inspection.

## ACTIVITIES AND FACILITIES

### Propellant Processing

Experimental processing of nitrocellulose-based propellants poses problems similar to those involved in processing plastic materials, especially consideration of viscosity control and particle size.

*Plant for rolling and extrusion of incorporated materials; preparation of felted paper tubes with high length/diameter ratios.*

### Combustion

Investigations of propellant combustion using techniques equally applicable to combustion of fuel oils and gases. High temperature degradation of organic materials, research capable of being extended to flammability and flame-proofing of plastics.

*Equipment to measure temperature profiles at burning surfaces, and appropriate instruments (infra-red and ultra-violet spectrophotometers and gas chromatographs) for flame decomposition product analysis.*

### Ballistic Properties

Burning rates and calorimetric measurements. Experimental techniques are available to study solids, liquids, and gases, and to determine precise heats of combustion, formation and wetting.

*Equipment to measure static and dynamic pressures for fractions of a second or longer in ranges up to  $31 \text{ MN/m}^2$  (4500 psi). Calorimeters with platinum resistance thermometry systems (precision better than  $1 \times 10^{-3}^\circ\text{C}$ ).*

### Non-Destructive Testing

The integrity and bonding of propellants are inspected by radiographic and ultrasonic test methods which may also be used to investigate conventional plastics and bonded systems.

*Radiographic (400 kV) and ultrasonic (375 kc/sec through transmission) inspection equipment.*





#### PRECISION CALORIMETRY

An NPL-pattern bomb calorimeter for determining heats of combustion with an accuracy approaching 1 part in  $10^4$ .



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# PROPELLANTS 2

Head of Branch     P R FREEMAN

Propellants 2 Branch is responsible for research and development on composite propellants based on plastic or rubbery binder systems. The facilities include laboratories for quality control, including ballistic and physical property assessment, together with small- and large-scale manufacturing plants.

Basic and applied research on rheology and adhesion is performed to improve the mechanical behaviour of solid propellants and to provide an advisory service on the use of sealants, adhesives and lutings. A Section concerned with heat transfer and low temperature research uses specialized engineering techniques to study heat transfer parameters of materials under conditions encountered in liquid propellant rocket engines.

## ACTIVITIES AND FACILITIES

### Thermal Conductivity

Precision measurements of thermal conductivities of liquids, gases, and supercritical fluids ( $12^{\circ}$ — $650^{\circ}\text{K}$ ; up to  $300\text{ MN/m}^2$ ); facilities equally suitable for measuring viscosity, dielectric constant, etc. over wide ranges of temperature and pressure.

*Air conditioned laboratory for precision temperature measurement; protected annexe for compressing gases and liquids; thermal conductivity cells: Phillips helium-filled cryogenerator ( $12^{\circ}$ — $90^{\circ}\text{K}$ ); liquid nitrogen-filled metal thermostat ( $90^{\circ}$ — $220^{\circ}\text{K}$ ); recirculating Turbotherm-filled liquid thermostat ( $300^{\circ}$ — $650^{\circ}\text{K}$ ).*

### Convective and Radiative Heat Transfer from Flames and Gases

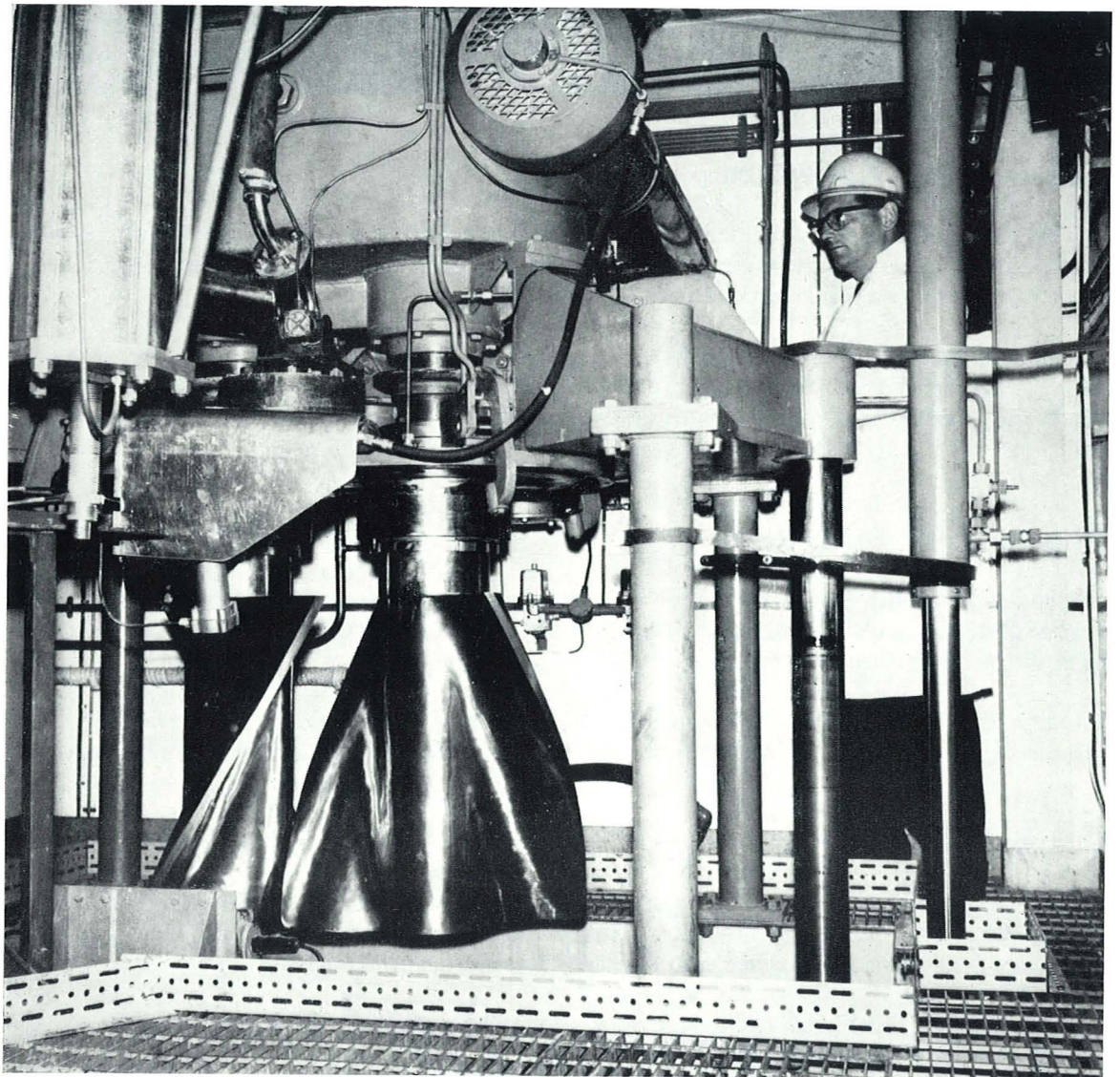
Studies of convection and radiation from flames and combustion gases (up to  $3800^{\circ}\text{K}$ ;  $10\text{ MN/m}^2$ ); radiative emissivity of water vapour ( $1500^{\circ}$ — $3500^{\circ}\text{K}$ ;  $0.5$ — $10\text{ MN/m}^2$ ).

*Two instrumented test cubicles; water-cooled combustion chambers; black-body furnace to calibrate radiation sources.*

Heat transfer from heated gas under disturbed or under-developed flow conditions; effects of burner head design and Reynolds number.

*Horizontal tubular test rig using electrically heated nitrogen as heat transfer fluid (maximum temperature,  $620^{\circ}\text{K}$  at  $10\text{ kW}$  energy dissipation; maximum pressure,  $6\text{ MN/m}^2$ ).*

Design, construction and operation of high-pressure combustion chambers; novel techniques for cooling surfaces; measurement of convective heat transfer from dissociating gases; instrumentation to measure temperature, flow rates, electrical energy, and small pressure differences at high static pressures.



VERTICAL MIXER FOR RUBBERY-TYPE SOLID PROPELLANTS  
The mixing pot has been lowered for removal of the propellant mix.

### Convective Heat Transfer to Cryogenic Fluids

Convective heat transfer to fluid hydrogen in the vicinity of the critical point and at supercritical pressures; fluid dynamics of cryogenic fluids.

*Remotely-operated test rig in which cryogenic fluids flow through asymmetrically heated rectangular ducts (maximum energy dissipation, 40 kW; maximum pressure, 5 MN/m<sup>2</sup>).*

### Convective Heat Transfer to Liquids

Convective heat transfer from electrically heated surfaces to aviation kerosine under subcooled, boiling, and supercritical conditions.



*Closed-loop apparatus with rectangular test-section channel containing heated tube (maximum power, 10 kW; maximum pressure, 10 MN/m<sup>2</sup>; maximum fluid flow rate, 1.2 kg/sec). Photographic observation using Fastex ciné camera (18 000 half-frames/sec) and 0.2  $\mu$ sec argon flash lamp.*

## Sealants and Adhesives

Development of lutings and cements for threaded joints, etc., and adhesives for metal, plastics, paper, and leather; study of tensile and shear strength, and of stress-strain behaviour of adhesives, joints and solid propellants ( $-50^{\circ}$  to  $60^{\circ}\text{C}$ ).

*Instron universal testing machine (load,  $10^{-3}$  — 5000 kg; cross-head speed,  $10^{-3}$  — 10 mm/sec; cross-head travel, 1 m) with thermostatic chamber. Hydraulically-operated high-speed test machine (strain rate up to 10 cm/sec); Sanborn twin-channel recorder (10 ms response) and Tektronix oscilloscope. Test rigs for joint strengths.*

## Rheology of Stiff Pastes

Dependence of rheological behaviour of highly concentrated solid-in-liquid dispersions on nature of solids, solids loading, magnitude and distribution of particle size, nature and viscosity of liquid, temperature and test methods.

*Plastometers to study flow and deformation behaviour including fatigue effect of cyclic compression and extension, effect of imposed hydrostatic pressure, and response to biaxial strain. Brittle point apparatus.*

## Surface Chemistry

Surface tensions of highly viscous organic liquids; effect of molecular weight and temperature. Study of contact angles and interfacial tensions between viscous liquids and inorganic salts, and their dependence on surface contaminants (moisture, surfactants).

*Equipment for surface tension and contact angle measurement; thermal siphoning technique for growing large perfect crystals of inorganic salts.*

## Particle Size Analysis

Measurement of size and size distribution of particulate solids (0.1 — 150 $\mu$ ).

*Sharples Micromerograph (humidity- and temperature-controlled); photo-extinction sedimentometer; gas adsorption and various types of gas permeability apparatus for surface area measurement.*

## Technology of Pastes and Slurries

Formulation, manufacture, and handling of stiff pastes based on curable and non-curable liquid organic polymers.

*Vertical mixers (capacity, 300 kg; maximum viscosity, 20 000 poise); horizontal mixers (150 kg; 10<sup>7</sup> poise); de-aerating pug-mills; hydraulic processing and small-scale extruding equipment.*



# MATERIALS 1

Head of Branch     R L WILLIAMS

Materials 1 Branch undertakes basic and applied research on the chemistry and physics of polymers with particular regard to synthesis, characterization, degradation, and mechanical behaviour under a range of test conditions. The Branch offers an advisory service on the applications of polymers, and supervises long-term environmental testing at the Tropical Research Unit, which is a joint project with Australia.

## ACTIVITIES AND FACILITIES

### Polymer Physics and Engineering

Study of the physical properties of non-metallic materials and reinforced plastics: stress-strain curve, strength, fracture energy, damping capacity, creep, fatigue, stress relaxation, and dimensional stability. Effects of rate of deformation, temperature and moisture. Stress relaxation tests on rings and beams; dynamic mechanical properties of discs. Compression cell to study effects of dynamic, static, and creep loading.

*Hounsfield apparatus (extension rate, 0.0013 — 50.8 cm/min; temperature, — 80° to 80°C); Baldwin machine; Goodbrand machine (fibre test). Avery Izod impact machines (capacity 17 kg.m; maximum loading rate,  $18 \times 10^2$  kN/sec; photographic recording with 35 mm. streak- or 12 000 frames/sec Fastex-cameras). Flywheel machine (fracture energies at impact velocities of 130—1 300 cm/sec). Ultrasonic equipment (150 kc/sec—2 Mc/sec; up to 80°C). Rotating beam machine (fatigue properties).*

### Polymer Chemistry—Synthesis, Characterization, and Stability

Investigation of novel and potentially useful polymer systems; monomer and polymer synthesis, polymer fractionation, mechanism and kinetics of polymerization, reactions of polymers.

Characterization of polymers by molecular weight (viscometry, osmometry, light scattering, and end-group analysis), spectroscopy (IR, UV and NMR), dilatometry, bulk viscometry, compressibility and thermal expansion measurements, and by optical examination of polymer morphology.

Stability of addition and condensation polymers to heat, ultra-violet light, and high energy radiation; effects of chemical structure, impurities and environment. Mechanism and kinetics of degradation and its effect on molecular weight and physical properties.

*MOLECULAR WEIGHT Hewlett-Packard 502 high-speed membrane osmometer (maximum operating temperature 130°C); Brice-Phoenix Series 2000 Universal light scattering photometer with MSE high-speed centrifuge.*

*BULK PROPERTIES Epprecht Viscometer (0.1— $10^6$  poise, 0°—180°C); linear expansion apparatus for glass transition temperatures; pressure balance (temperature controlled to  $\pm 0.001^\circ\text{C}$ ).*



#### AVERY IZOD PENDULUM IMPACT APPARATUS

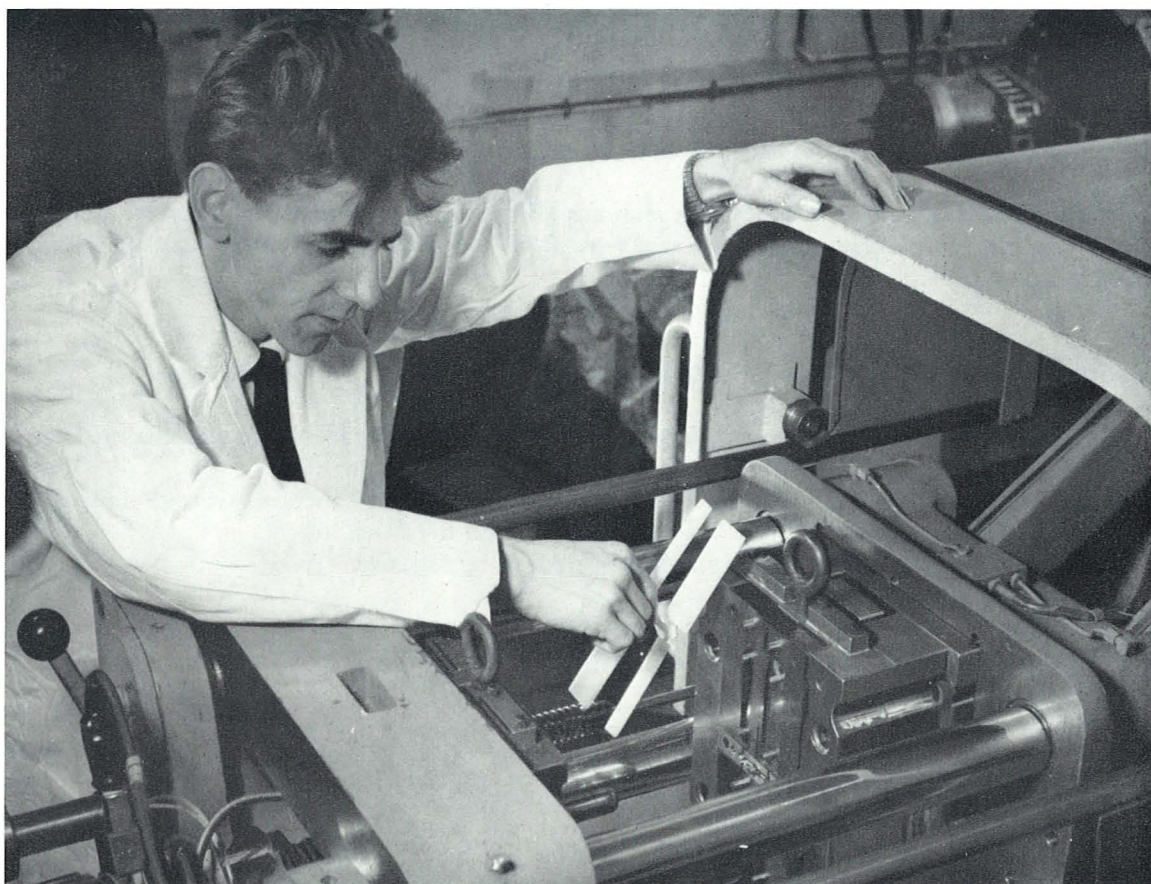
A pendulum impact tester modified for tensile and flexural impact tests to investigate the engineering life of non-metals.

#### NUCLEAR MAGNETIC RESONANCE MEASUREMENT

This 60 M/c instrument is used for characterization and structure determination of a wide range of organic compounds.







HORIZONTAL INJECTION MOULDING MACHINE

Test pieces for mechanical property assessment being produced in a constant torque, injection moulding machine.

SPECTROSCOPY *PE R10 60 M/c NMR spectrometer (variable temperature probe, spin decoupling unit, probes for  $^1\text{H}$ ,  $^{11}\text{B}$ ,  $^{19}\text{F}$ , and  $^{31}\text{P}$ ; PE 337 grating spectrometer (4000—400  $\text{cm}^{-1}$ , ATR attachment); Unicam SP 500 spectrometer.*

MICROSCOPY *Gilett and Sibert time-lapse microscope (35 mm and 16 mm (ciné) photographic recording).*

DEGRADATION *Mercury lamp, xenon arc, molten salt- and fluidized sand baths.*

GAS CHROMATOGRAPHY *PE Model 801 (dual column analytical instrument, linear programming); Pye Model 105/15 (automatic preparative gas chromatograph, linear programming).*

## Polymer Development and Applications

Processing and curing of new rubbers and thermoplastics by injection moulding, extrusion, milling, and compression moulding. Measurement of physical properties, and the effect of contaminants (e.g. explosives, propellants, petrol, etc.). Accelerated and tropical ageing trials to assess useful life. Investigation of failures. Manufacture of special components; antistatic and conducting rubbers.

Proofed fabrics: preparation, mechanical properties, and advice on the design of proofed fabric structures.

*PROCESSING* Wide range of mills, mixers, hydraulic presses and injection moulding machines. Facilities for the synthesis of polyester-polyurethane rubbers. Small-scale equipment for preparing proofed-fabric samples.

*TESTING* Physical properties; permeability of materials to organic fluids and water; ageing ovens to simulate hot/dry and hot/wet conditions; continuous and intermittent stress relaxometers. Carbon arc equipment for special exposures.

## **Joint Tropical Research Unit, Queensland**

Four sites are available for the exposure of small specimens to atmospheric weathering.

- (a) **INNISFAIL** Latitude  $17^{\circ} 32'$  S. Average annual rainfall 140 inches. Average daily mean temperature  $74^{\circ}\text{F}$ ; relative humidity 83 to 87. Sites are
  - (i) Hot/wet, jungle, i.e. sunlight screened off by foliation.
  - (ii) Hot/wet, clearing.
- (b) **CLUMP POINT** Similar latitude and conditions to Innisfail but the site is
  - (iii) Marine.
- (b) **CLONCURRENCY** Latitude  $20^{\circ} 43'$  S. Average annual rainfall 17 inches. Average daily mean temperature  $78^{\circ}\text{F}$ ; relative humidity 39. The site is designated
  - (iv) Hot/dry.



# MATERIALS 2

Head of Branch J E GORDON

Materials 2 Branch carries out research and development on fibre-reinforced materials and on the growth of ceramic whiskers.

## High Temperature Equipment

*Furnaces of various types for operation up to about 1600°C; high frequency heating equipment; temperature measuring devices.*

## Fibre Processing Plant

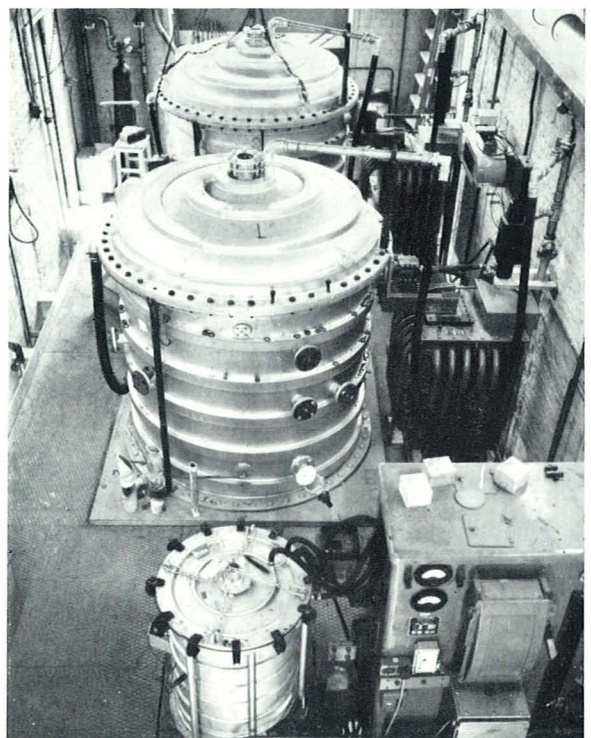
*Equipment for sizing whiskers and other short fibres.*

## Fibre Testing Equipment

*Marsh micro-testing machine and various macro-testing machines.*

## Microscopes

*A range of optical microscopes and a J.E.M. 7 electron microscope.*



**'BRAN TUBS'**

High temperature furnaces for synthesis of silicon nitride whiskers.

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# ANALYSIS AND INGREDIENTS

**Head of Branch**     **I DUNSTAN**

The Analysis and Ingredients Branch investigates the preparation, properties and reactions of a wide range of ingredients related to explosive, propellant and polymer technology. The Branch offers an advisory service on the stability, compatibility and surveillance testing of propellants, explosives and other hazardous materials. New analytical methods are developed to assist quality control, and a range of specialized techniques and facilities are used to provide an analytical service for the Establishment.

## ACTIVITIES AND FACILITIES

### Synthesis and Characterization

Synthesis of explosives and ingredients of solid propellants and polymers (fuels, oxidizers, ballistic additives, stabilizers, curing agents, antioxidants, etc.); studies to optimize yield and purity and to reduce hazard (toxicity, thermal decomposition, etc.).

*General techniques of preparative chemistry, and supporting facilities: armoured cupboards; PE Model 237 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ); Unicam SP 500 spectrometer; various refractometers and optical microscopes, including Kofler hot-stage instruments; molecular weight determination by semi-micro ebulliometry and micro-cryoscopy.*

### Stability and Compatibility

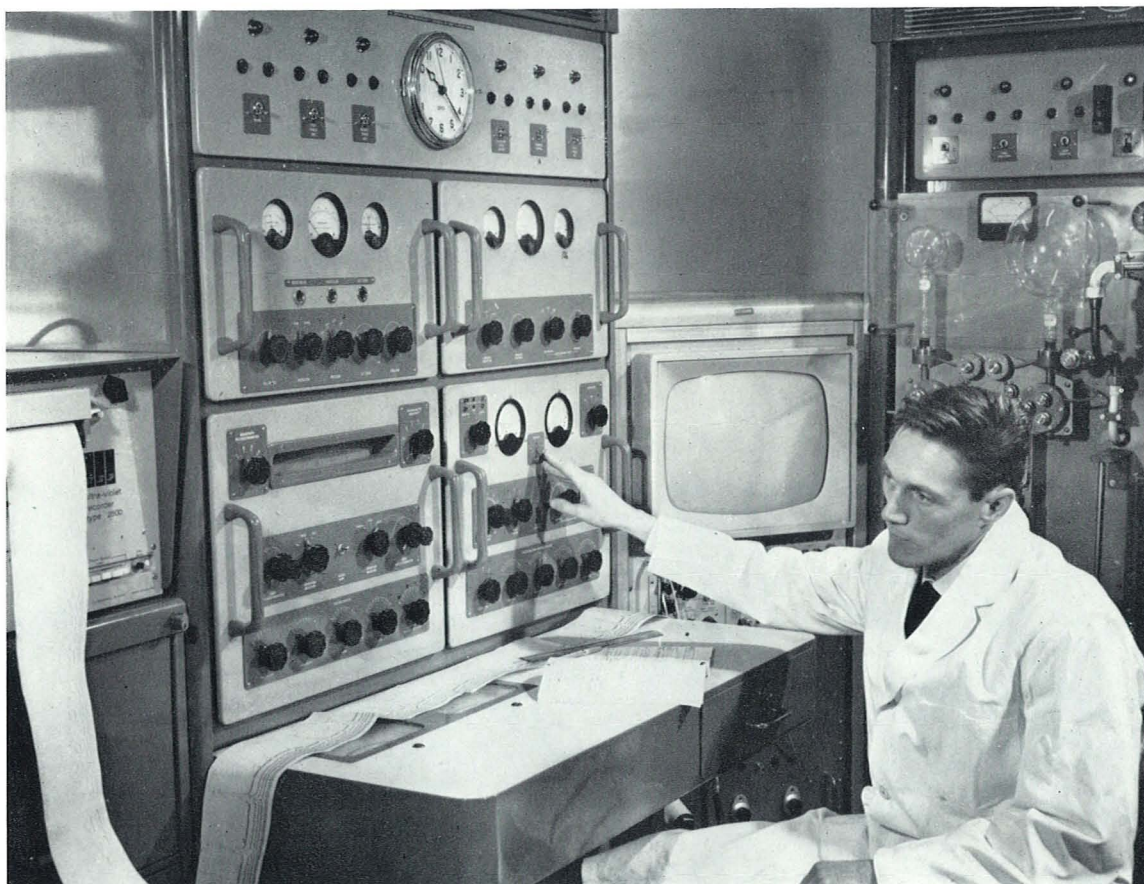
Kinetics and mechanism of thermal decomposition of explosives and exothermic compositions; ignition phenomena and build-up to low order detonation; compatibility of explosives, propellants, etc. with materials (e.g. polymers, plastics, metals, adhesives, varnishes and paints); effect of severe environmental conditions on storage stability. New techniques to investigate thermal stability.

*Environmental testing ovens and standard stability test facilities. Master slave manipulator. Stanton thermogravimetric balance (maximum temperature,  $250^{\circ}\text{C}$ ); PE differential scanning calorimeter, Model 1 ( $-100^{\circ}$  to  $500^{\circ}$ ); heat flow calorimeter (sensitivity,  $30\text{ }\mu\text{watts}$ ); multirange temperature recording equipment ( $-200^{\circ}$  to  $500^{\circ}\text{C}$ ). Photomicroscopy of samples heated in vacuum. Advance Model TC 2A electronic timer counter ( $1\text{ }\mu\text{sec}$ ).*

### Chemical Analysis and Physical Methods

Separation, identification, and analysis of the constituents of explosives, propellants, polymers, rubbers, etc.; determination of functional groups, elemental composition, and molecular weight; trace metal analysis. Estimation of purity, and investigation of quality control and specification tests. Studies concerned with gas and solvent vapour analysis; molecular and crystal structure; thermochemical characteristics (phase changes, low temperature behaviour and thermal decomposition); cure- and post-cure chemistry of polymeric systems; non-aqueous titration; mass spectrometric and polarographic analysis.





#### MASS SPECTROMETRY

An AEI Model MS2H mass spectrometer capable of performing isotopic and chemical analyses on very small quantities of material, including solids.

**CHROMATOGRAPHY** *Wide range of standard equipment for analytical- and preparative-scale column- and thin layer chromatography; Craig counter-current extraction apparatus; Varian Aerograph Model 1522 gas chromatograph (dual column, linear programming); PE Fraktometer; pyrolysis attachment.*

**SPECTROSCOPY** *PE Model 257 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ) ATR attachment, micro- and heated cells; modified Grubb Parsons S3A spectrometer ( $3500\text{--}250\text{ cm}^{-1}$ ); PE Model 137 UV spectrometer; Unicam SP90 atomic absorption spectrophotometer.*

**MASS SPECTROMETRY** *AEI Model MS 2H*

**MICROANALYSIS** *Combustion equipment (C, H, N); Schöniger flask (S, halogens); Mechrolab Model 302 vapour pressure osmometer (molecular weights up to 20 000).*

**POLAROGRAPHY** *Beckman Electroscan 30 (various electrometric analysis techniques).*

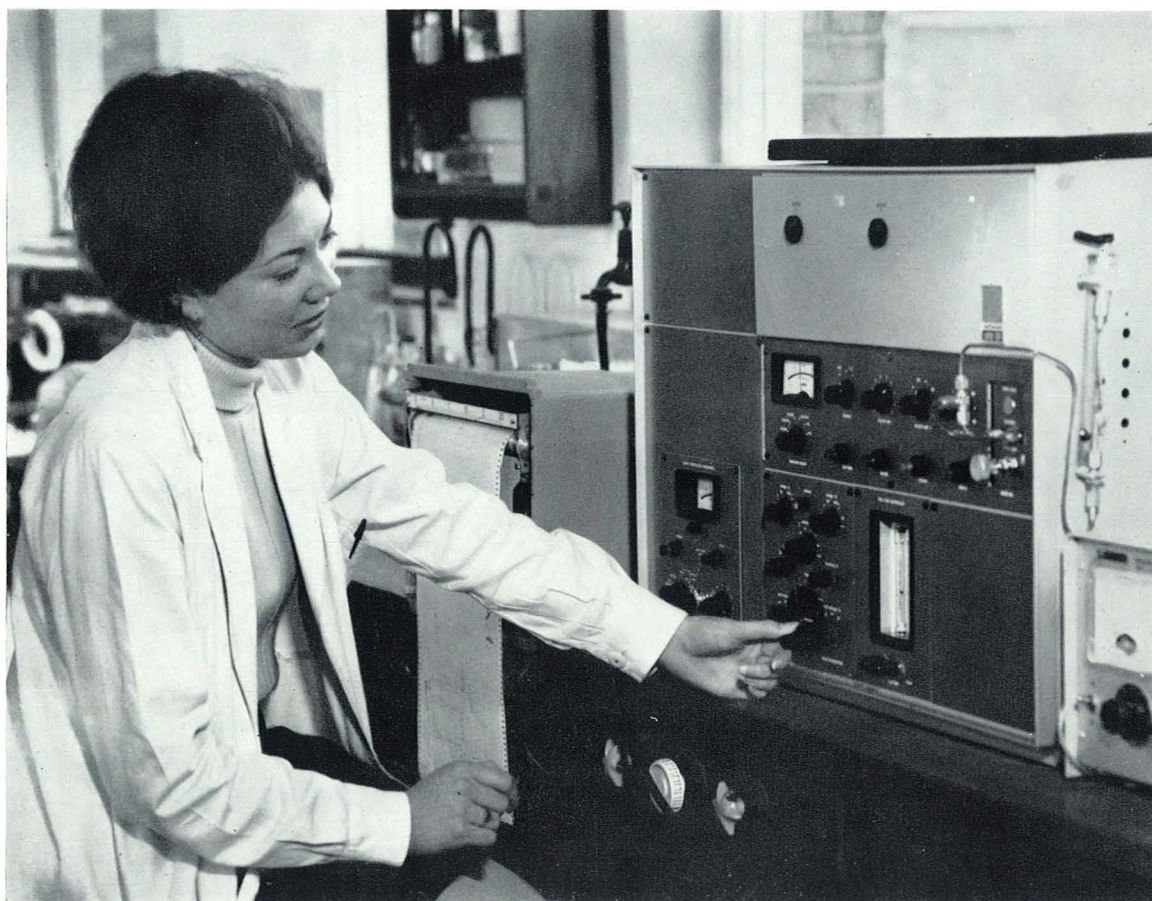
**RADIOCHEMISTRY** *Tracer laboratory; Panax standard- and low background Geiger counters; Isotope Development Ltd. solid and liquid scintillation counters.*

**THERMOCHEMICAL ANALYSIS** *see Stability and Compatibility.*

## Crystallography

Application of optical and X-ray diffraction to identification and characterization of compounds; phase analysis of mixtures, polymorphism, crystal orientation, and crystal structure analysis.

*Equipment includes three X-ray generators, one being a high-power rotating anode set, X-ray powder cameras, goniometers (Weissenberg, oscillating crystal and optical), an X-ray powder diffractometer, and polarizing microscope with heating stage.*



## GAS CHROMATOGRAPHY

This technique is particularly useful for identifying and estimating volatile constituents of complex mixtures.



# CHEMICAL ENGINEERING

Head of Branch     R G ROSS

The Chemical Engineering Branch is concerned with means and equipment for processing chemicals on a production scale. Plant and facilities are designed for the manufacture of hazardous compounds and mixtures with particular emphasis on safety, remote-control, and instrumentation. The Branch has special interests in unit operations such as crystallization and mixing, and in the development and application of instruments and apparatus based on electronic and glass engineering techniques.

## ACTIVITIES AND FACILITIES

### Large-scale Production

Development of laboratory syntheses on to pilot- and full-scale processes; pilot plant operation; manufacture of experimental chemicals and materials, including high explosives, polymer and rocket ingredients, whiskers and aligned inorganic fibres.

*Protective enclosures, with remote control, for processing experimental quantities of dangerous chemicals (i.e. fire, explosion, toxicity risks): one for large laboratory-scale glass plant; another for 2.5 kg pilot plant scale, equipped with a closed circuit television loop.*

*A wide range of pilot-scale plant, including: plant for concentrating nitric acid free from nitrous acid; nitration and sulphonation unit with brine cooling, remote control and acid mixing plant; glass-lined oil heated reactors for polymer manufacture; and plants to classify and align asbestos and other whiskers for making composite materials.*

*Separators such as decanters; pressure-, vacuum- and rotary filters; batch and continuous stainless steel centrifuges; liquid centrifuges; and dry powder sieves.*

*Dryers, including hot air-, vacuum tray- and rotary-steam tube types.*

*Grinding plant, including jaw crusher; roll mill; edge-runner mill; hammer mills; and 'micronizer' fluid energy mill.*

*Mixers: double cone powder blender; medium and heavy paste mixers.*

*Packed, gas-liquid absorption towers.*

*Distillation: a 5-cm glass 'molecular' still; a 50-litre glass batch distillation unit; glass distillation column of high efficiency for high vacuum and 150°C; similar unit in stainless steel for pressure distillation up to 1 MN/m<sup>2</sup>.*

### Crystallization

Studies of nucleation and crystal growth; control of crystal shape, size, and size distribution.

*Laboratory equipment for measuring nucleation and crystal growth rates in a stirred cooling crystallizer.*

*Pilot crystallizers: Kestner evaporative; Oslo type; and pulsed tube type, for performance studies and production of crystalline products.*

## **Intensive Drying or Stripping**

The intensive drying (or stripping) of high boiling liquids which may be sensitive to heat or excessive turbulence.

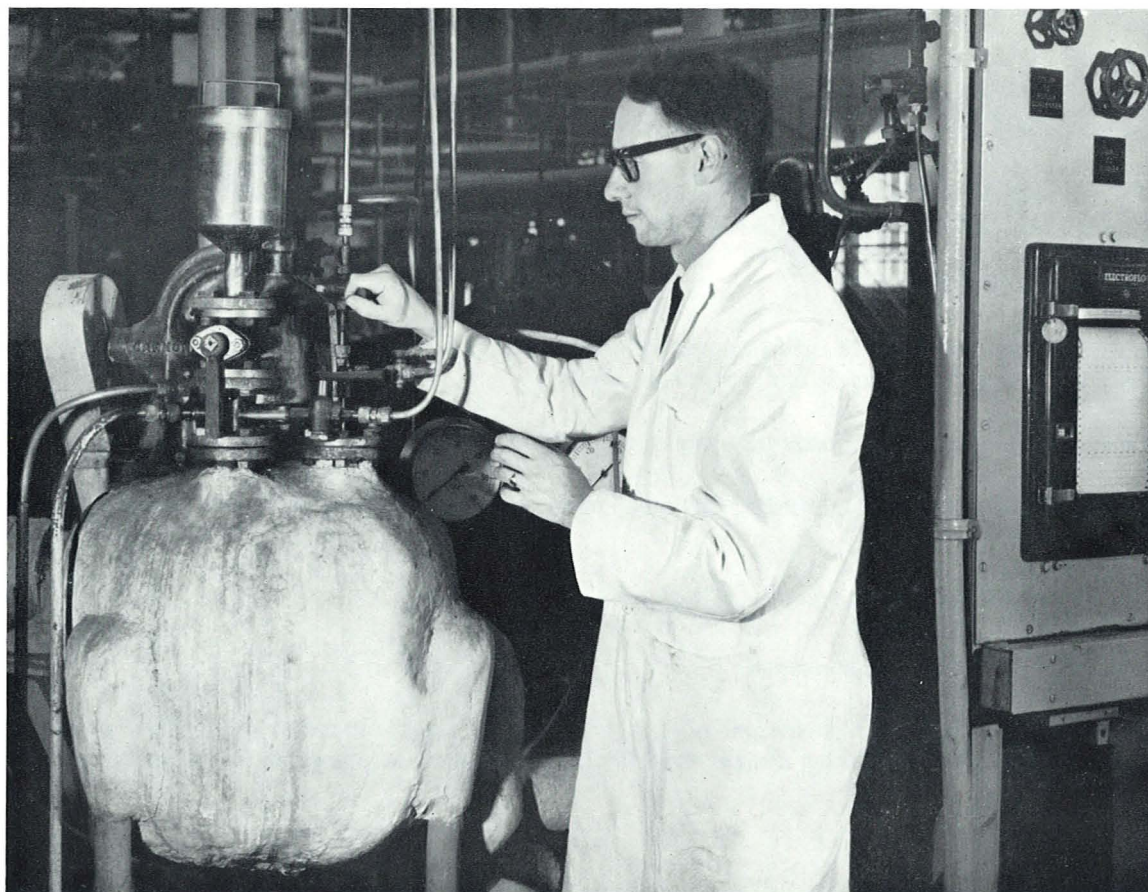
*Continuous plant (11.5 kg/h), based on single passage of liquid down a column packed with a battery of vertical helical coils.*

## **Equipment Design**

Remote control devices for safe handling and processing of hazardous substances. Theory and practice of mixing stiff pastes: performance and safety of mixers, blade clearances, shaft seals.

## **Instrumentation and Glass Engineering**

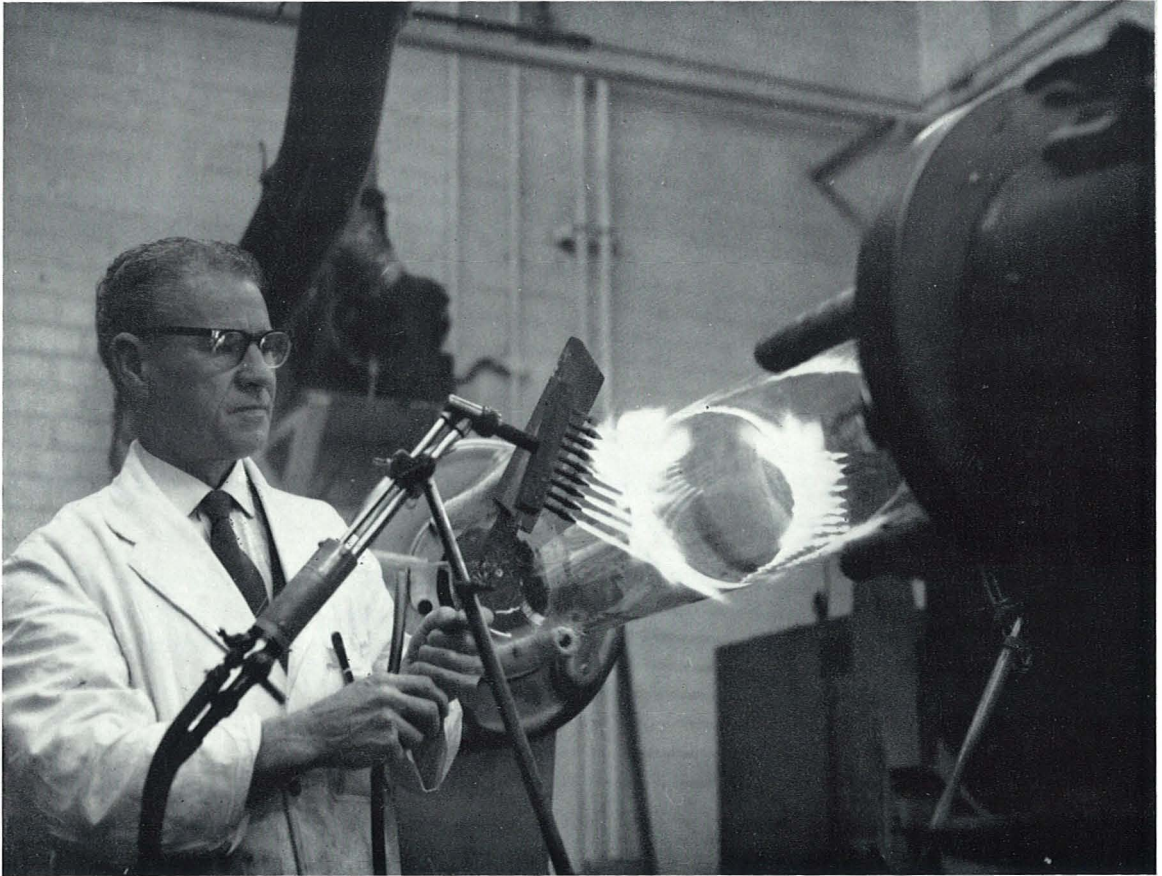
Design and construction of special electronic instrumentation systems and scientific glassware.



PLANT FOR POLYESTER MANUFACTURE

An example of the development of laboratory syntheses on to pilot-scale processes.





GLASS ENGINEERING

The glass engineering workshop is equipped to undertake construction of scientific glassware ranging from special laboratory articles to the large-scale item shown here.



# MISCELLANEOUS RESEARCH ACTIVITIES

In addition to research and development work performed by the Branches described above, certain specialized or exploratory research topics are undertaken by small groups under the direction of Dr. L. J. Bellamy, Mr. G. K. Adams, and Dr. G. H. Young.

## Spectroscopy

Studies of factors affecting infra-red absorption spectra of complex molecules; assignment of absorption bands and interpretation of spectra.

*Unicam SP 100 spectrometer (3650—300  $\text{cm}^{-1}$ ); Grubb Parsons GS2 grating spectrometer (4000—650  $\text{cm}^{-1}$ ); Unicam SP 700 spectrometer (55000—4500  $\text{cm}^{-1}$ ); attachment to determine emission spectra in the visible region; time-resolved luminescent spectroscopy in the visible region (resolution, 1  $\mu\text{sec}$ ).*

## Flame and Explosion Phenomena

*A small computer installation is being planned, and computer programmes are available for calculation of flame and explosion properties, and the thermodynamic properties of two-phase, multi-element systems in chemical equilibrium.*

## Autoxidation and Antioxidants

Kinetics and mechanism of free radical chain reactions in solution; catalysis of oxidation-reduction reactions by heavy metals; effect of oxidative degradation, light, and ionizing radiation on polymeric materials. Research aimed at preventing or inhibiting oxidative degradation. Design and assessment of new antioxidants; mechanism of antioxidant action, particularly synergistic effects (mixtures of free radical acceptors; free radical acceptor and chelating reagent or S-containing peroxide decomposer); inhibition of autoxidation by metal chelates.

*Warburg apparatus and equipment for automatic recording of oxygen uptake; facilities for photochemistry and radiochemistry.*

# INDEX OF ACTIVITIES

Titles of branches have been abbreviated as follows:

E	Explosives	M1	Materials 1
P1	Propellants 1	M2	Materials 2
P2	Propellants 2	AI	Analysis and Ingredients
CE	Chemical Engineering	Misc. Res.	Miscellaneous Research

ADHESIVES		CRYSTALLOGRAPHY	
Development, application and strength	P2	Identification, phase analysis, crystal structure	AI
AGEING			
Non-metallic materials	M1	DEFORMATION	
Explosives and propellants	AI, P1	Non-metallic materials	M1
ANTIOXIDANTS	Misc. Res.	DIFFERENTIAL THERMAL ANALYSIS	AI
ASBESTOS REINFORCED MATERIALS	M1, M2, CE	DISTILLATION	
ATOMIC ABSORPTION SPECTROPHOTOMETRY	AI	Fractional, pilot-scale, 'molecular'	CE
AUTOXIDATION	Misc. Res.	DRYING AND STRIPPING	
		Heat-sensitive liquids	CE
BALLISTIC ASSESSMENT	P1, P2		
BURNING RATE DETERMINATION	P1, P2	ELASTICITY AND ELASTOMERS	M1
		ELECTROMETRIC ANALYSIS	AI
CALORIMETRY, PRECISION	P1	ELECTRONIC INSTRUMENTATION	CE
CARBIDES		ELECTRON MICROSCOPY	M2
High temperature materials	M2	ELECTROSTATIC RISK	
CERAMIC MATERIALS	M2	Generation of electric charge, electrical resistance measurement, susceptibility to ignition	E
CHEMICAL ANALYSIS		EMISSION SPECTROSCOPY	
Instrumental, elemental and functional group	AI	Visible region	Misc. Res.
CHEMICAL MANUFACTURE		ENVIRONMENTAL TESTING	
Laboratory investigations	AI	Effect of contaminants and climatic conditions on polymers	M1
Pilot-scale processes	CE	Explosives and propellants	AI, P1
CHROMATOGRAPHY, SOLUTION		EXPLOSIVES EVALUATION	
Analytical and preparative scale, column and thin layer, counter-current extraction	AI	Type of hazard, degree of protection and storage requirements	E
CLIMATIC EFFECTS		EXPLOSIVES SYNTHESIS AND MANUFACTURE	AI, E, CE
Non-metallic materials	M1		
Explosives and propellants	AI, P1	FATIGUE	
COMBUSTION		Non-metallic materials	M1
Solid propellants and organic materials	P1	FIBRE REINFORCED MATERIALS	M2
Liquid propellants	P2	FLAME AND EXPLOSION PHENOMENA	
COMPATIBILITY TESTING		Combustion	P1
Effect of contaminants and climatic conditions on hazardous materials	AI	Detonation	E
COMPOSITE MATERIALS	M1, M2, CE	Theory	Misc. Res.
COMPRESSION TESTS	M1	FLUID DYNAMICS	
CREEP TESTING		Cryogenic fluids	P2
Non-metallic materials	M1	FREE RADICAL CHEMISTRY	E, Misc. Res.
CRYOGENIC FLUIDS			
Fluid dynamics and heat transfer	P2	GAMMA IRRADIATION	Misc. Res.
CRYSTALLIZATION TECHNOLOGY	CE	GAS CHROMATOGRAPHY	
CRYSTAL GROWTH		Analytical	AI, M1, P1, E
From vapour	M2	Preparative	M1
From solution	CE, P2	GAS KINETICS	E

GLASS ENGINEERING			
HAZARD APPRAISAL			
Impact and friction sensitiveness, ease of ignition, burning to detonation, shock sensitiveness, electrostatic risk			
Thermal stability and self-heating			
HEAT RESISTANT MATERIALS			
Polymers			
Composites			
HEAT TRANSFER			
Convective and radiative, flames and combustion gases, liquid fuels, cryogenic fluids			
HIGH SPEED PHOTOGRAPHY			
Explosive phenomena			
Mechanical testing			
HYDROGEN, LIQUID			
IGNITION			
Hazardous materials			
IMPACT TESTING			
Polymers			
INFRA-RED SPECTROSCOPY			
Qualitative and quantitative analysis			
Polymer characterization			
Gas kinetics research			
Combustion			
Basic studies			
INITIATORY EXPLOSIVES			
JOINT STRENGTH			
LIQUIDS			
Critical point phenomena			
LOAD CELLS			
MASS SPECTROMETRY			
MATERIALS			
Non-metallic			
Composites			
MECHANICAL TESTING			
Non-metallic materials			
Composites			
Adhesives			
Propellants			
MICROANALYSIS			
MICROSCOPY			
Crystal morphology			
Polymer crystallization			
Fibres and ceramic whiskers			
MIXERS, DESIGN AND OPERATION			
Performance, safety, application to hazardous materials			
NITRIDES			
High temperature materials			
NITROCOMPOUND CHEMISTRY			
	CE	NOISE EVALUATION	
		Measurement and simulation of impulsive noises, sonic bangs	E
		NON-AQUEOUS TITRIMETRY	AI
		NON-DESTRUCTIVE TESTING	
	E	Radiographic and ultrasonic inspection	P1
	AI	NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY	
		Analysis and structure determination	M1
		NUCLEATE BOILING	P2
	M1		
	M2	OXIDATION INHIBITORS	Misc. Res.
		PARTICLE SIZE ANALYSIS	P2
		PASTES, STIFF	
	P2	Processing and rheology	P2
		PLASTICS	
	E	Chemistry and physics	M1
	M1	POLAROGRAPHY	AI
	P2	POLYMER CHEMISTRY	
		Synthesis, characterization, stability	M1
	E, AI	POLYMERIZATION KINETICS	
		Basic studies	M1
	M1	Applied studies	M1, P2, E, AI
		POLYMER PHYSICS AND ENGINEERING	
	AI	Non-metallic materials and reinforced plastics, physical properties and engineering data	M1
	E		
	P1	POLYMER TECHNOLOGY	
	Misc. Res.	Curable and non-curable polymers	M1, P2
	E	Heavily-loaded thermo-plastic rubbers	P2
	P2	Polyurethane elastomers	M1, CE, E
		PRESSURE MEASUREMENT	
		Explosions	E
	P2	Rocket motor firing	P1, P2
	M1	Liquid flow	P2
		PROOFED FABRICS	M1
	AI	PROPELLANT PROCESSING	
		Nitrocellulose-based	P1
		Rubber-based	P2, E
	M1	PYROLYSIS	
	M2	Polymers	M1, AI
		Organic materials	P1
	M1		
	M2	RADIOCHEMISTRY	AI
	P2	RADIOGRAPHIC INSPECTION	P1, E
	P1, P2	REFRACTORY MATERIALS	M2
	AI	REMOTE CONTROL METHODS	
		Mixing, extrusion, injection moulding	E
	AI, CE	Manufacture of hazardous chemicals	CE
	M1	Closed circuit TV	E, CE
	M2	RHEOLOGY	
		Polymers and composite materials	M1
		Adhesives	P2
	CE	Solid propellants	P2
		Stiff pastes	P2
		Fibres	M1, M2
	M2	RUBBER, SPECIAL APPLICATIONS	
	AI	Conducting, antistatic, proofed fabric	M1



SAFETY	
Manufacture, handling and storage of hazardous materials	E, CE, P1, P2
SEALANTS	
Lutings and cements for threaded joints	P2
SHEAR TESTS	
Joints	P2
SONIC BANGS	
	E
SPECTROSCOPY	
Fundamental studies	Misc. Res.
Qualitative and quantitative analysis	AI
Application to combustion	P1
gas kinetics	E
polymers	M1
SURFACE CHEMISTRY	
Surface tension, contact angles	P2
SYNTHETIC CHEMISTRY	
	AI
TEMPERATURE MEASUREMENT	
Combustion and calorimetry	P1
Thermal conductivity	P2
Thermochemical analysis	AI
High temperatures	M2
TENSILE STRENGTH TESTING	
	M1, M2
THERMAL CONDUCTIVITY	
Liquids, gases, supercritical fluids	P2
THERMAL STABILITY	
Polymers, degradation studies	M1
Hazardous compounds	AI
THERMOCHEMICAL ANALYSIS	
Differential scanning and heat flow calorimetry, thermogravimetry	AI
THERMOCHEMICAL DATA	
Heats of formation, combustion and wetting	P1
ULTRA-VIOLET SPECTROMETRY	
Qualitative and quantitative analysis	AI, M1
VAPOUR PHASE CHROMATOGRAPHY	
	AI, M1
VISCOMETRY	
	M1
VULCANIZATION	
	M1
WHISKERS, CERAMIC	
Production, processing and testing	M2
Classification and alignment	M2, CE
X-RAY CRYSTALLOGRAPHY	
Powder diffraction photography, single crystal analysis	AI

# INDEX OF FACILITIES

ABSORPTION TOWERS			MICROCOMBUSTION EQUIPMENT	AI
Packed, gas-liquid	CE		MICROSCOPES	
ARMoured CUPBOARDS AND PROTECTIVE ENCLOSURES			Time-lapse, photographic recording	M1
Small scale tests and preparations	AI, E		Projection	CE, M2
Large scale manufacture	E, CE		Hot-stage polarizing	AI
ATOMIC ABSORPTION SPECTROPHOTOMETER	AI		Electron	M2
AUTOXIDATION LABORATORY			MIXERS	
Oxygen uptake measurement	Misc. Res.		Powder blending	CE
			Heavy paste	CE, P1, P2, E
CALORIMETERS			MOLECULAR WEIGHT APPARATUS	
Precision	P1		Viscometry, osmometry and	
Differential scanning and heat flow	AI		light scattering	M1
CHEMICAL PLANT			Vapour pressure osmometry,	
Nitration, sulphonation, acid			ebulliometry and cryoscopy	AI
concentration, polymer manufacture,				
fibre and whisker classification				
and alignment	CE			
CREEP TESTING EQUIPMENT	M1		NUCLEAR MAGNETIC RESONANCE SPECTROMETER	M1
DISTILLATION EQUIPMENT			PARTICLE SIZE EQUIPMENT	
Fractionating columns, pilot-scale			Gas adsorption and permeability,	
and 'molecular' stills	CE		micromerograph, sedimentometer	P2
DRYERS			PLASTOMETERS	
Hot air, vacuum, steam	CE		Flow and deformation, brittle point	P2
			PHOTOGRAPHIC EQUIPMENT	
ENVIRONMENTAL TEST FACILITIES			High speed streak and framing	
Climatic chambers	P1		cameras	E, M1, P2
Ageing ovens	AI, M1		Time-lapse photomicroscopy	M1
Tropical test site	M1		Hot-stage photomicroscopy	AI
EXTRUSION PLANT			POLAROGRAPH	AI
Propellants and explosives	P1, P2, E		PRESSURE SENSORS	
Polymers	M1		Explosion and noise	E
			Propellant impulse	P1, P2
			Liquid flow	P2
FURNACES			RADIOCHEMICAL TRACER LABORATORY	AI
High temperature, laboratory and			REACTION VESSELS, PILOT-SCALE	CE
pilot-scale	M2		REMOTE CONTROL FACILITIES	
			Process bays and equipment design	CE, E
GAS CHROMATOGRAPHS			Master slave manipulators	E, AI
Analytical	AI, M1, P1, E		RHEOLOGICAL TEST FACILITIES	
Preparative	M1		Static, dynamic and creep loading	M1, P2
GRINDING PLANT			Impact, flywheel and rotating beam	
Jaw crusher and various mills	CE		machines	M1
			Microtest	M2
HEAT TRANSFER TEST RIGS			Variable environment	M1, P2
Variable pressure, temperature and				
flow rates	P2		SEPARATORS	
			Decanters, sieves, filters, and	
IMPACT TESTERS			centrifuges	CE
Polymers	M1			
INFRA-RED SPECTROMETERS			THERMAL CONDUCTIVITY CELLS	
General purpose			Variable pressure and temperature	P2
instruments	AI, M1, P1, E		THERMOCHEMICAL ANALYSIS INSTRUMENTS	
High resolution	Misc. Res.		Differential scanning and heat flow	
			calorimeters, thermogravimetric	
MASS SPECTROMETER	AI		balance	AI

THERMOMETERS		
Platinum resistance		P1
Multirange recording		AI
ULTRASONIC INSPECTION EQUIPMENT		
Propellants		P1
Polymers		M1
ULTRA-VIOLET SPECTROMETERS		
General purpose		AI, M1
Continuous scanning	AI, Misc. Res.	
VISCOMETERS		
Bulk viscosity		M1, P2
Intrinsic viscosity		M1
X-RAY EQUIPMENT		
Radiographic inspection		P1, E
Crystallographic analysis		AI











# Explosives Research & Development Establishment

## **Research and Development Activities and Facilities**



# **EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT**

*circa 1968  
(Open days)*

**RESEARCH and DEVELOPMENT  
ACTIVITIES and FACILITIES**



# HOW TO CONSULT ERDE

ERDE is able to offer a limited, free consultative service to industrial undertakings on problems related to expertise available in the Establishment.

Problems involving more extensive investigations or the use of equipment and special facilities may be undertaken for a fee, subject to the demands of the Establishment's research and development programme.

Enquiries may be made

- (a) by letter, addressed to The Director  
ERDE  
Ministry of Technology  
Waltham Abbey, Essex;
- (b) by telephone, asking for Heads of specific branches or ERDE Industrial Liaison Officer  
Waltham Cross 23688; (STD) 97-23688 Inner London; (STD) 0992-23688 Outside London.

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# INTRODUCTION

The primary function of the Explosives Research and Development Establishment is to undertake research on, and development of, explosives, propellants and related exothermic compositions to meet the present and future requirements of the three Services. The Establishment is also actively engaged on materials work, concerned principally with the chemistry and physics of polymers, and with new engineering materials based on refractory fibres.

To exercise these functions, ERDE maintains a staff of scientific, technical and engineering personnel representing a wide range of disciplines but with particular expertise in chemistry, chemical engineering and physics. Research and development tasks are shared by six technical branches supported by drawing office, machine shop, electronics and glass engineering facilities, and by appropriate library and information services.

It is the purpose of this book to give a brief outline of the work of the technical branches, especially those aspects involving expertise, facilities or equipment which are likely to be of interest to industrial undertakings.



# MANAGEMENT ORGANIZATION

Director	Dr. L J Bellamy
Deputy Director	Dr. G H S Young
Special Merit 'B' Post	Mr. G K Adams
Heads of Branches	
Explosives	Mr. E G Whitbread
Propellants 1	Dr. W G Williams
Propellants 2	Mr. P R Freeman
Non-metallic Materials	Dr. B L Hollingsworth
General Chemistry	Dr. I Dunstan
Process Research	Mr. H Ziebland
Chief Engineer	Mr. R Fisher
Chief Safety Officer	Mr. J V Griffiths
Chief Administrative Officer	Mr. S F M Whiteside
Individual Merit Scientists	Dr. A W H Pryde (Chemical Engineering) Mr. G W C Taylor (Initiator Explosives) Dr. N Uri (Autoxidation)



# EXPLOSIVES

Head of Branch    E G WHITBREAD

The Explosives Branch deals primarily with the development of sensitive, initiatory explosives and high explosive and propellant compositions of improved performance. Trials are performed to assess sensitiveness and hazards associated with all explosive materials.

## ACTIVITIES AND FACILITIES

### Explosive Risk

Standard tests designed to evaluate and to compare the explosive risk of materials are based on impact and friction sensitiveness, ease of ignition, susceptibility to burn to detonation, and shock sensitiveness. Results enable recommendations to be made regarding type of hazard, degree of protection and appropriate storage requirements.

*Armoured cupboards for small-scale tests (up to 30 g) and instrumented firing site facilities for larger quantities (up to 4.5 kg). Firing site for small-scale underwater tests.*

### Electrostatic Risk

Electrostatic risks associated with handling explosive powders, vapour/air, and gas/air mixtures are assessed by measuring

- (a) electrostatic voltages and charges on transferring solids or liquids, or on separating surfaces;
- (b) comparative electrification of materials, especially fabrics and plastics;
- (c) electrical resistance of floors, footwear and items of equipment;
- (d) susceptibility to ignition by capacitor type discharge.

*Electrostatic voltmeter (30—18 000 volts); resistance meters (up to  $10^{16}$  ohms); facilities for measuring electrostatic spark sensitiveness of powders.*

### High Speed Photography

This technique is used to record mechanical and explosive phenomena, to investigate shock initiation of explosives and to determine propagation velocities.

*Portable 16 mm ciné camera (100—18 000 frames/sec): framing camera (25 frames at 150 000 —  $4 \times 10^6$  frames/sec), installed in 2.25 kg explosives test facility; streak camera (writing speed 0.7 mm—9 mm/microsec), installed in 4.5 kg explosives test facility. Printing facilities include conversion of 35 mm frames into animated 16 mm film, and colour printing of negatives of explosive phenomena with particular reference to correct colour balance.*



## Noise Evaluation

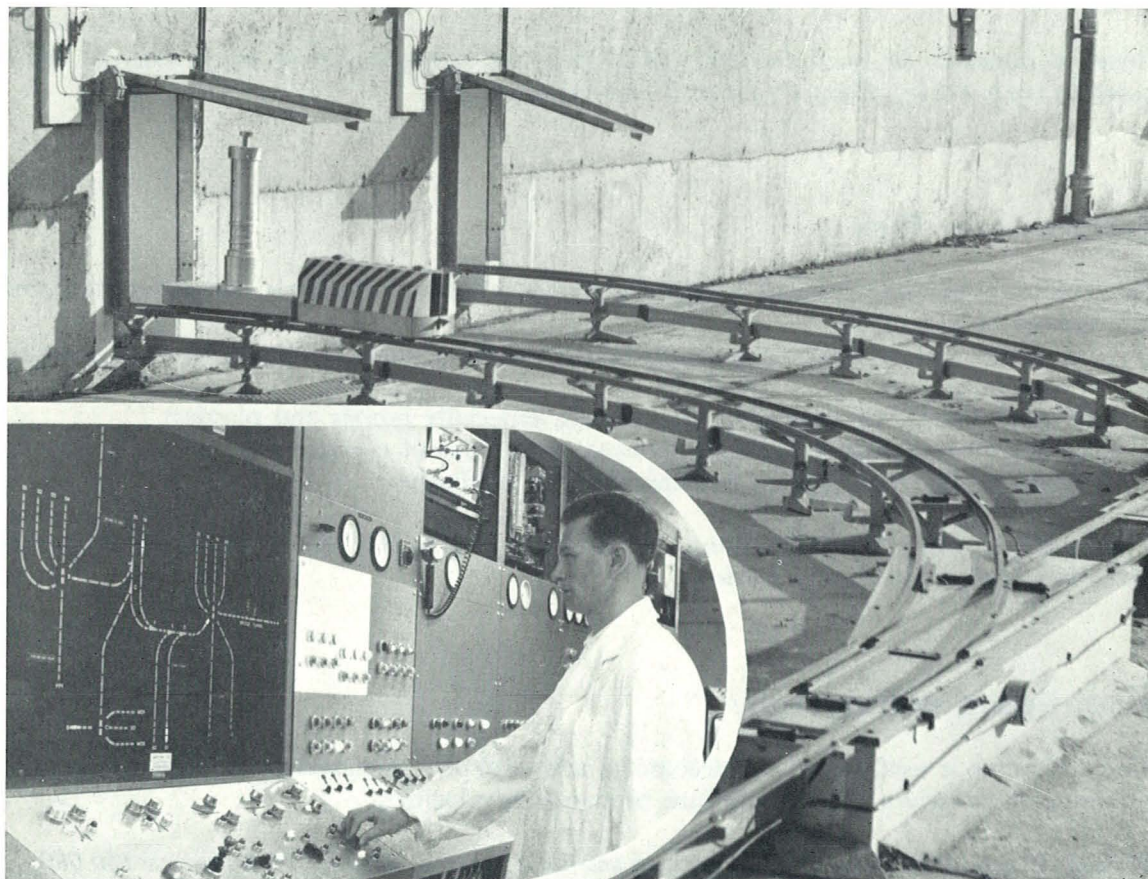
Measurement and analysis of impulsive noises including those of long duration (e.g. sonic booms), and their simulation by explosives. Techniques for generating a wide range of pressure waveforms in air may be applied to studying the behaviour of structures to shocks of this kind.

*Apparatus to record shock waves in air down to  $5 \text{ N/m}^2$  ( $0.1 \text{ lbf/ft}^2$ ).*

## Remote Control Methods

Development of remote control methods for manufacturing and testing dangerous explosive materials.

*Process bays (limit 7.25 kg TNT equivalent) in which hazardous operations can be performed by remote control. Remotely operated mixing, extruding and injection moulding unit (4.5 kg) with temperature, vacuum and shear rate controls on mixer (viscosities 2—3 000 poise). Strong bay (limit 1.35 kg TNT equivalent) with master slave manipulators (3.5 m extended reach), X-ray facility (250 kv), and armoured viewing window. Capability for melt-mixing and moulding, or for pressing explosives, and for carrying out basic machinery operations on explosive charges by remote control. Closed circuit TV available to position all remotely-controlled operations.*



723/2 + 3

### REMOTE-CONTROL TRANSPORTATION OF HAZARDOUS MATERIALS

A five-inch gauge electric railway system used to transport hazardous materials between manufacturing, testing and storage areas.

## **Polymer Technology**

Cure chemistry of polyurethane elastomers prepared from di-isocyanates and hydroxy-terminated polyesters and polyethers; optimization of physical properties of heavily-loaded rubbers.

*Small scale plant facility for development work; laboratory equipped to study physical properties and ageing characteristics.*

# PROPELLANTS 1

Head of Branch    W G WILLIAMS

Propellants 1 Branch is largely concerned with the development of propellants based on nitrocellulose. Work is undertaken on methods for controlling ballistics, and to devise ballistic assessment techniques. Attention is also given to the quality control of propellants by non-destructive tests involving X-ray or ultrasonic inspection.

## ACTIVITIES AND FACILITIES

### Propellant Processing

Experimental processing of nitrocellulose-based propellants poses problems similar to those involved in processing plastic materials, especially consideration of viscosity control and particle size.

*Plant for rolling and extrusion of incorporated materials; preparation of felted paper tubes with high length/diameter ratios.*

### Combustion

Investigations of propellant combustion using techniques equally applicable to combustion of fuel oils and gases. High temperature degradation of organic materials, research capable of being extended to flammability and flame-proofing of plastics.

*Equipment to measure temperature profiles at burning surfaces, and appropriate instruments (infra-red and ultra-violet spectrophotometers and gas chromatographs) for flame decomposition product analysis.*

### Ballistic Properties

Burning rates and calorimetric measurements. Experimental techniques are available to study solids, liquids, and gases, and to determine precise heats of combustion, formation and wetting.

*Equipment to measure static and dynamic pressures for fractions of a second or longer in ranges up to  $31 \text{ MN/m}^2$  (4500 psi). Calorimeters with platinum resistance thermometry systems (precision better than  $1 \times 10^{-3}^\circ\text{C}$ ).*

### Non-Destructive Testing

The integrity and bonding of propellants are inspected by radiographic and ultrasonic test methods which may also be used to investigate conventional plastics and bonded systems.

*Radiographic (400 kV) and ultrasonic (375 kc/sec through transmission) inspection equipment.*





# PRECISION CALORIMETRY

An NPL-pattern bomb calorimeter for determining heats of combustion with an accuracy approaching 1 part in  $10^4$ .

John Littlefair 723/4 + 5  
 Bob Forbes

# PROPELLANTS 2

Head of Branch     P R FREEMAN

Propellants 2 Branch is responsible for research and development on composite propellants based on plastic or rubbery binder systems. The facilities include laboratories for quality control, including ballistic and physical property assessment, together with small- and large-scale manufacturing plants.

Basic and applied research on rheology and adhesion is performed to improve the mechanical behaviour of solid propellants and to provide an advisory service on the use of sealants, adhesives and lutings.

## ACTIVITIES AND FACILITIES

### Composite Propellant Formulation, Manufacture and Assessment

Formulation and manufacture of paste-like and rubbery composite propellants, assessment of ballistic properties by strand burning and static firing of small rocket motors. Compositions of high energy are available covering a wide range of burning rates.

*Comprehensive facilities for the manufacture of propellants and filling of small rocket motors. Strand burning bombs and small static proofstand.*

### Sealants and Adhesives

Development of lutings and cements for threaded joints, etc., and adhesives for metal, plastics, paper, cloth and leather; study of tensile and shear strength, and of stress-strain behaviour of adhesives and joints.

An advisory service is offered on all aspects of bonding and hermetic sealing of joints, and on joint design.

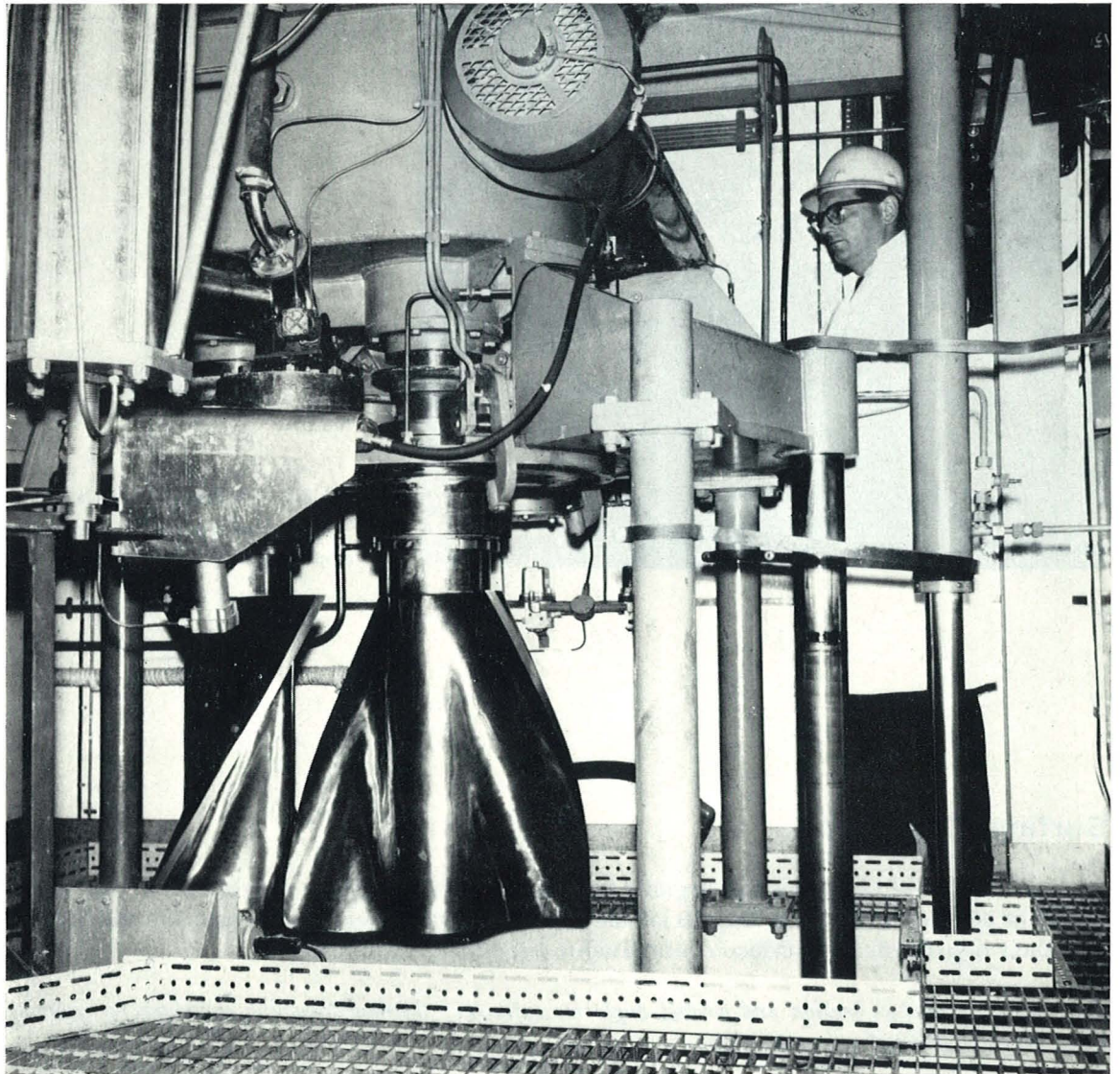
*Instron universal testing machine (load,  $10^{-3}$ —5000 kg; cross-head speed,  $10^{-3}$ —10 mm/sec; cross-head travel, 1 m) with thermostatic chamber ( $-50^{\circ}$  to  $60^{\circ}\text{C}$ ) and automatic integrator. Hydraulically-operated high-speed test machine (strain rate up to 10 cm/sec); Sanborn twin-channel recorder (10 ms response) and Tektronix oscilloscope. Figs for the preparation and testing of joints; equipment for preparation of proofed fabrics; viscometers, plastometers; facilities for storage at controlled humidities and temperatures.*

### Rheology of Stiff Pastes and Highly Filled Rubbers

Dependence of rheological behaviour of highly concentrated solid-in-liquid dispersions on nature of solids, solids loading, magnitude and distribution of particle size, nature and viscosity of liquid, temperature and test methods. Mechanical behaviour of highly filled rubbers by tensile testing over a wide range of temperatures and strain rates. Construction of master curves of mechanical behaviour by time-temperature superposition.



*Plastometers to study flow and deformation behaviour including fatigue effect of cyclic compression and extension; fatigue by flexing; effect of imposed hydrostatic pressure; response to biaxial strain. Brittle point apparatus. Tensile testing apparatus.*



VERTICAL MIXER FOR RUBBERY-TYPE SOLID PROPELLANTS  
The mixing pot has been lowered for removal of the propellant mix.

*Gordon Brumberger*





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MEASUREMENT OF CONTACT  
ANGLE OF WATER ON A  
CONTAMINATED STEEL SURFACE

## Surface Chemistry

Surface tensions of highly viscous organic liquids; effect of molecular weight and temperature. Study of contact angles and interfacial tensions between viscous liquids and inorganic salts, and their dependence on surface contaminants (moisture, surfactants).

*Equipment for surface tension and contact angle measurement; thermal siphoning technique for growing large perfect crystals of inorganic salts.*

## Technology of Pastes and Slurries

Formulation, manufacture, and handling of stiff pastes based on curable and non-curable liquid organic polymers containing a high proportion of solid inorganic filler.

*Vertical and horizontal mixers of various capacities capable of processing mixes up to  $10^7$  poise viscosity; de-aerating pug-mills and pressure extrusion equipment.*

# NON-METALLIC MATERIALS

Head of Branch     B L HOLLINGSWORTH

The Non-metallic Materials Branch undertakes basic and applied research on the chemistry and physics of polymers with particular regard to synthesis, characterization, degradation, and mechanical behaviour under a range of test conditions. The Branch offers an advisory service on the applications of polymers, and supervises long-term environmental testing at the Tropical Research Unit, which is a joint project with Australia.

## ACTIVITIES AND FACILITIES

### Polymer Physics and Engineering

Study of the physical properties of non-metallic materials and reinforced plastics: stress-strain curve, strength, fracture energy, damping capacity, creep, fatigue, stress relaxation, and dimensional stability. Effects of rate of deformation, temperature and moisture. Stress relaxation tests on rings and beams; dynamic mechanical properties of discs. Compression cell to study effects of dynamic, static, and creep loading.

*Hounsfield apparatus (extension rate, 0.0013 — 50.8 cm/min; temperature, — 80° to 80°C); Baldwin machine; Goodbrand machine (fibre test). Avery Izod impact machines (capacity 17 kg.m; maximum loading rate,  $18 \times 10^2$  kN/sec; photographic recording with 35 mm. streak- or 12 000 frames/sec Fastex-cameras). Flywheel machine (fracture energies at impact velocities of 130—1 300 cm/sec). Ultrasonic equipment (150 kc/sec—2 Mc/sec; up to 80°C). Rotating beam machine (fatigue properties).*

### Polymer Chemistry—Synthesis, Characterization, and Stability

Investigation of novel and potentially useful polymer systems; monomer and polymer synthesis, polymer fractionation, mechanism and kinetics of polymerization, reactions of polymers.

Characterization of polymers by molecular weight (viscometry, osmometry, light scattering, and end-group analysis), spectroscopy (IR, UV and NMR), dilatometry, bulk viscometry, compressibility and thermal expansion measurements, and by optical examination of polymer morphology.

Stability of addition and condensation polymers to heat, ultra-violet light, and high energy radiation; effects of chemical structure, impurities and environment. Mechanism and kinetics of degradation and its effect on molecular weight and physical properties.

**MOLECULAR WEIGHT** *Hewlett-Packard 502 high-speed membrane osmometer (maximum operating temperature 130°C); Brice-Phoenix Series 2000 Universal light scattering photometer with MSE high-speed centrifuge.*

**BULK PROPERTIES** *Epprecht Viscometer (0.1—10<sup>6</sup> poise, 0°—180°C); linear expansion apparatus for glass transition temperatures; pressure balance (temperature controlled to  $\pm 0.001^\circ\text{C}$ ).*





#### AVERY IZOD PENDULUM IMPACT APPARATUS

A pendulum impact tester modified for tensile and flexural impact tests to investigate the engineering life of non-metals.

*Charlie Munns.*

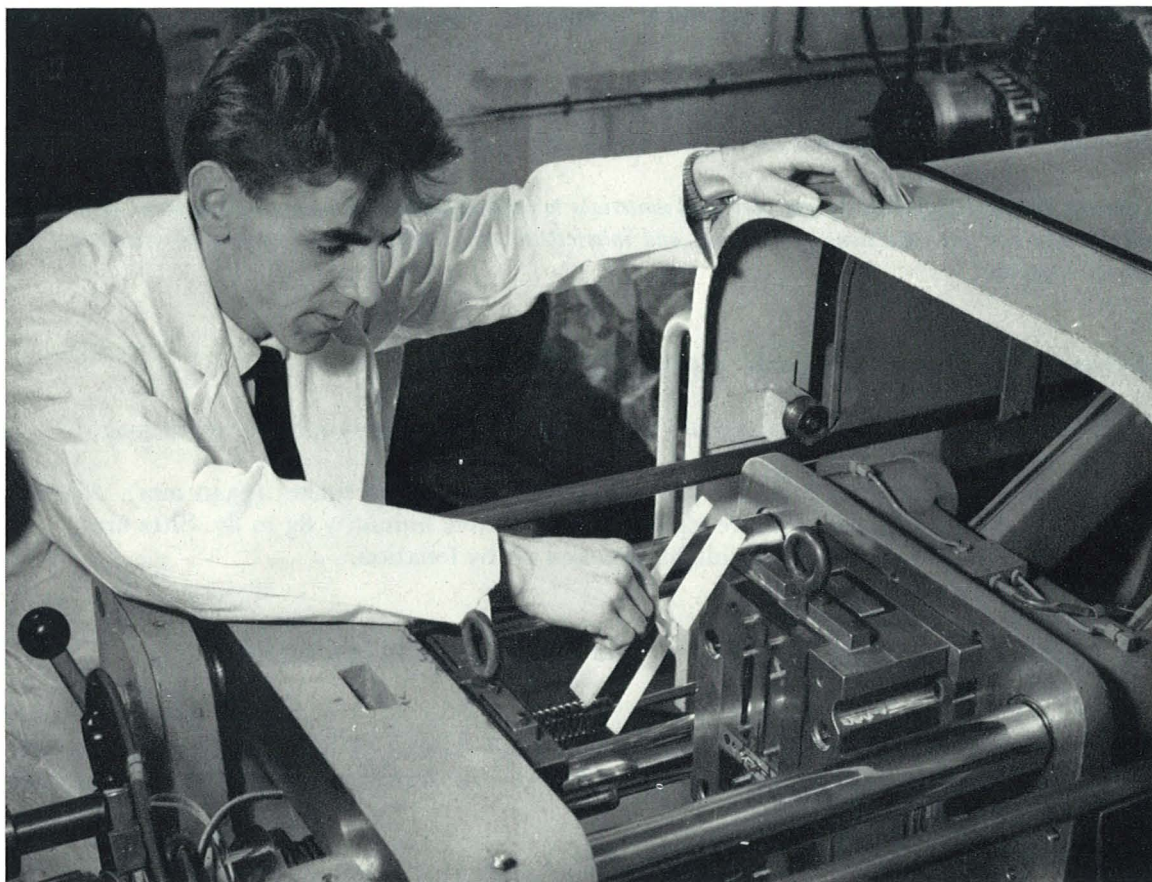
#### NUCLEAR MAGNETIC RESONANCE MEASUREMENT

This 60 M/c instrument is used for characterization and structure determination of a wide range of organic compounds.



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HORIZONTAL INJECTION MOULDING MACHINE

Test pieces for mechanical property assessment being produced in a constant torque, injection moulding machine.

*Keith Ledbury.*

*723/10*

SPECTROSCOPY *PE R10 60 M/c NMR spectrometer (variable temperature probe, spin decoupling unit, probes for  $^1\text{H}$ ,  $^{11}\text{B}$ ,  $^{19}\text{F}$ , and  $^{31}\text{P}$ ; PE 337 grating spectrometer ( $4000\text{--}400\text{ cm}^{-1}$ , ATR attachment); Unicam SP 500 spectrometer.*

MICROSCOPY *Gilett and Sibert time-lapse microscope (35 mm and 16 mm (ciné) photographic recording).*

DEGRADATION *Mercury lamp, xenon arc, molten salt- and fluidized sand baths.*

GAS CHROMATOGRAPHY *PE Model 801 (dual column analytical instrument, linear programming); Pye Model 105/15 (automatic preparative gas chromatograph, linear programming).*

## Polymer Development and Applications

Processing and curing of new rubbers and thermoplastics by injection moulding, extrusion, milling, and compression moulding. Measurement of physical properties, and the effect of contaminants (e.g. explosives, propellants, petrol, etc.). Accelerated and tropical ageing trials to assess useful life. Investigation of failures. Manufacture of special components; antistatic and conducting rubbers.

Proofed fabrics: preparation, mechanical properties, and advice on the design of proofed fabric structures.

**PROCESSING** *Wide range of mills, mixers, hydraulic presses and injection moulding machines. Facilities for the synthesis of polyester-polyurethane rubbers. Small-scale equipment for preparing proofed-fabric samples.*

**TESTING** *Physical properties; permeability of materials to organic fluids and water; ageing ovens to simulate hot/dry and hot/wet conditions; continuous and intermittent stress relaxometers. Carbon arc equipment for special exposures.*

## **Joint Tropical Research Unit, Queensland**

Four sites are available for the exposure of small specimens to atmospheric weathering.

- (a) **INNISFAIL** Latitude  $17^{\circ} 32'S$ . Average annual rainfall 140 inches (3540 mm). Average daily mean temperature  $74^{\circ}F$  ( $23^{\circ}C$ ); relative humidity 83 to 87. Sites are
  - (i) Hot/wet, jungle, i.e. sunlight screened off by foliation.
  - (ii) Hot/wet, clearing.
- (b) **CLUMP POINT** Similar latitude and conditions to Innisfail but the site is
  - (iii) Marine.
- (c) **CLONCURRY** Latitude  $20^{\circ} 43'S$ . Average annual rainfall 17 inches (430 mm). Average daily mean temperature  $78^{\circ}F$  ( $25^{\circ}C$ ); relative humidity 39. The site is designated
  - (iv) Hot/dry.

# GENERAL CHEMISTRY

Head of Branch I DUNSTAN

The General Chemistry Branch investigates the preparation, properties and reactions of a wide range of ingredients related to explosive, propellant and polymer technology. The Branch offers an advisory service on the stability, compatibility and surveillance testing of propellants, explosives and other hazardous materials. New analytical methods are developed to assist quality control, and a range of specialized techniques and facilities are used to provide an analytical service for the Establishment.

## ACTIVITIES AND FACILITIES

### Synthesis and Characterization

Synthesis of explosives and ingredients of solid propellants and polymers (fuels, oxidizers, ballistic additives, stabilizers, curing agents, antioxidants, etc.); studies to optimize yield and purity and to reduce hazard (toxicity, thermal decomposition, etc.).

*General techniques of preparative chemistry, and supporting facilities: armoured cupboards; PE Model 237 grating spectrometer ( $4000-650\text{ cm}^{-1}$ ); Unicam SP 500 spectrometer; various refractometers and optical microscopes, including Kofler hot-stage instruments; molecular weight determination by semi-micro ebulliometry and micro-cryoscopy.*

### Stability and Compatibility

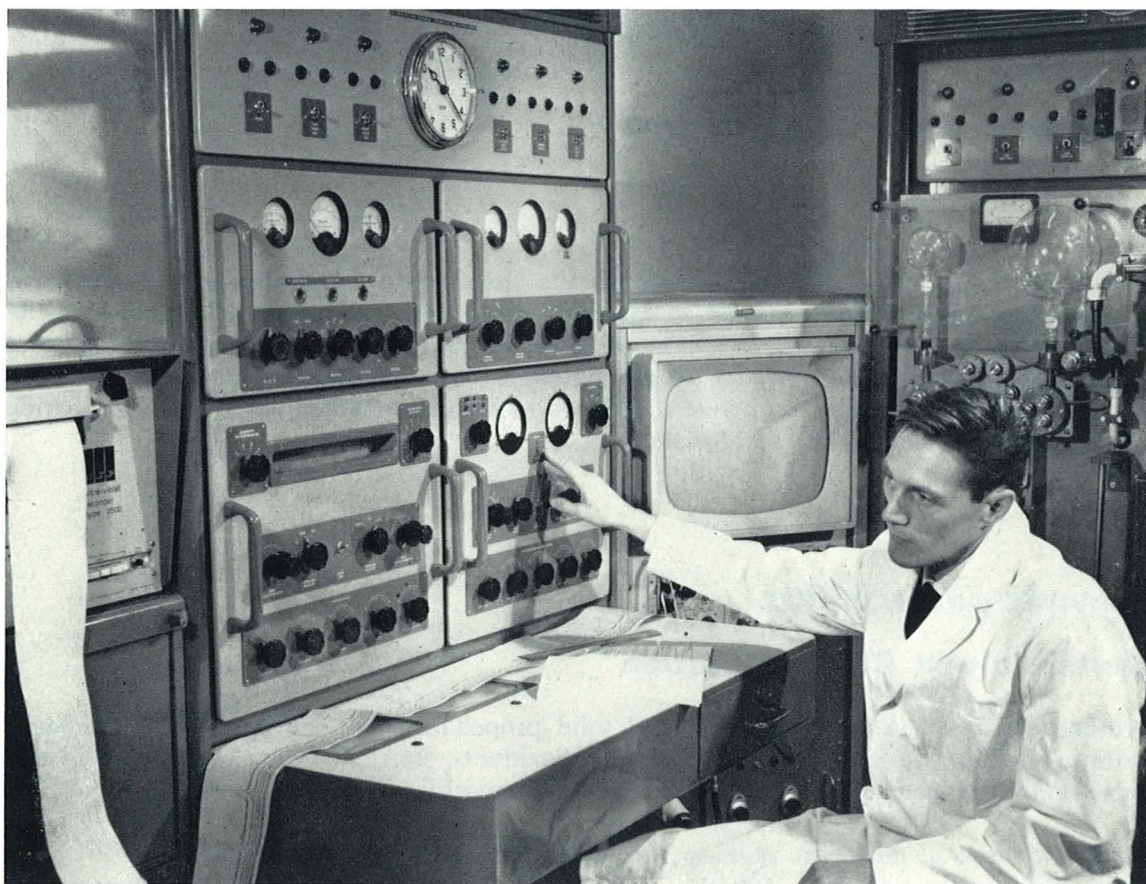
Kinetics and mechanism of thermal decomposition of explosives and exothermic compositions; ignition phenomena and build-up to low order detonation; compatibility of explosives, propellants, etc. with materials (e.g. polymers, plastics, metals, adhesives, varnishes and paints); effect of severe environmental conditions on storage stability. New techniques to investigate thermal stability.

*Environmental testing ovens and standard stability test facilities. Master slave manipulator. Stanton thermogravimetric balance (maximum temperature,  $250^{\circ}\text{C}$ ); PE differential scanning calorimeter, Model 1 ( $-100^{\circ}$  to  $500^{\circ}$ ); heat flow calorimeter (sensitivity,  $30\text{ }\mu\text{watts}$ ); multirange temperature recording equipment ( $-200^{\circ}$  to  $500^{\circ}\text{C}$ ). Photomicroscopy of samples heated in vacuum. Advance Model TC 2A electronic timer counter ( $1\text{ }\mu\text{sec}$ ).*

### Chemical Analysis and Physical Methods

Separation, identification, and analysis of the constituents of explosives, propellants, polymers, rubbers, etc.; determination of functional groups, elemental composition, and molecular weight; trace metal analysis. Estimation of purity, and investigation of quality control and specification tests. Studies concerned with gas and solvent vapour analysis; molecular and crystal structure; thermochemical characteristics (phase changes, low temperature behaviour and thermal decomposition); cure- and post-cure chemistry of polymeric systems; non-aqueous titration; mass spectrometric and polarographic analysis.





#### MASS SPECTROMETRY

An AEI Model MS 2H mass spectrometer capable of performing isotopic and chemical analyses on very small quantities of material, including solids.

*Norman Paul 723/11*

**CHROMATOGRAPHY** *Wide range of standard equipment for analytical- and preparative-scale column- and thin layer chromatography; Craig counter-current extraction apparatus; Varian Aerograph Model 1522 gas chromatograph (dual column, linear programming); PE F11 gas chromatograph; pyrolysis attachment.*

**SPECTROSCOPY** *PE Model 257 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ) ATR attachment, micro- and heated cells; modified Grubb Parsons S3A spectrometer ( $3500\text{--}250\text{ cm}^{-1}$ ); PE Model 137 UV spectrometer; Unicam SP90 atomic absorption spectrophotometer.*

**MASS SPECTROMETRY** *AEI Model MS 2H*

**MICROANALYSIS** *Combustion equipment (C, H, N); Schöniger flask (S, halogens); Mechrolab Model 302 vapour pressure osmometer (molecular weights up to 20 000).*

**POLAROGRAPHY** *Beckman Electroscan 30 (various electrometric analysis techniques).*

**RADIOCHEMISTRY** *Tracer laboratory; Panax standard- and low background Geiger counters; Isotope Development Ltd. solid and liquid scintillation counters.*

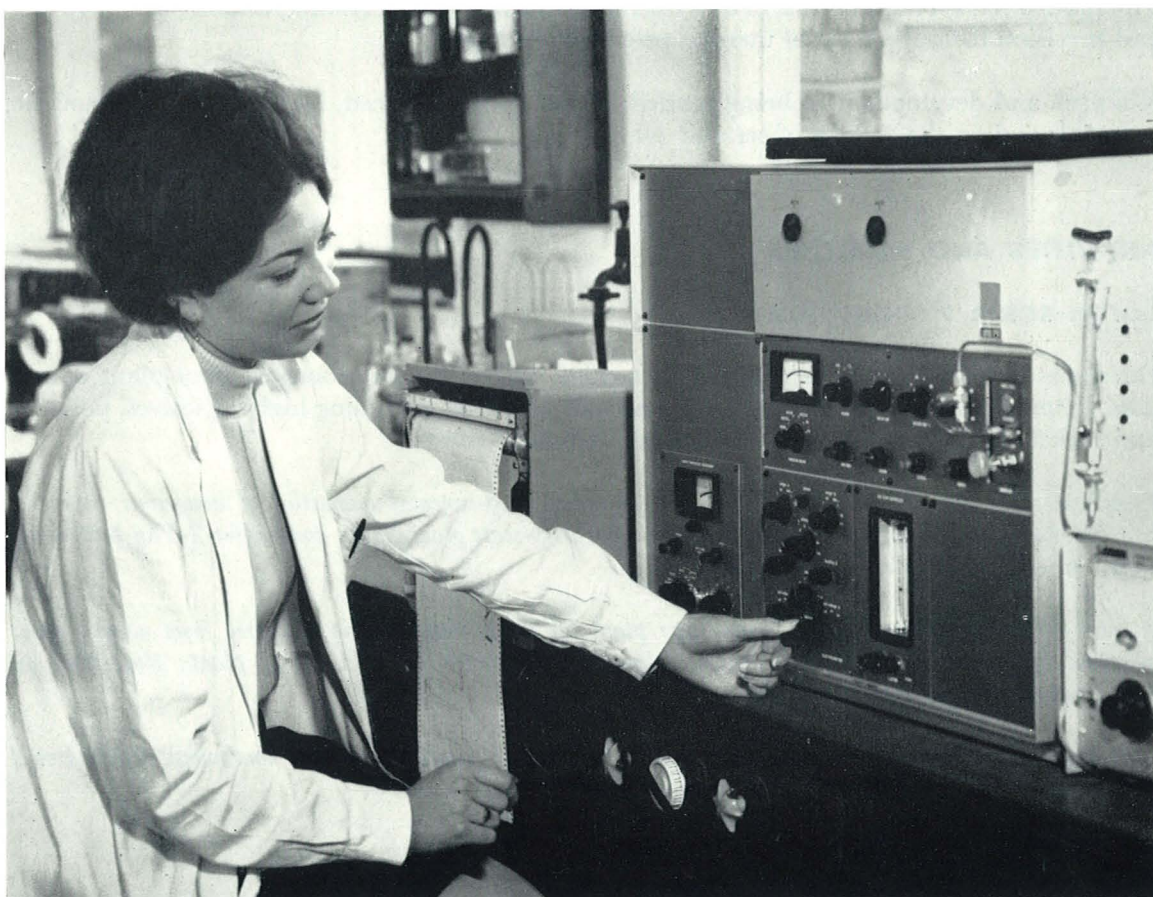
**THERMOCHEMICAL ANALYSIS** *see Stability and Compatibility.*

**PARTICLE SIZE ANALYSIS** *Sharples Micromerograph (humidity- and temperature-controlled); gas adsorption and various types of gas permeability apparatus for surface area measurement.*

## Crystallography

Application of optical and X-ray diffraction to identification and characterization of compounds; phase analysis of mixtures, polymorphism, crystal orientation, and crystal structure analysis.

*Equipment includes three X-ray generators, one being a high-power rotating anode set, X-ray powder cameras, goniometers (Weissenberg, oscillating crystal and optical), Hilger-Watts 4-circle, single crystal automatic diffractometer, an X-ray powder diffractometer, and polarizing microscope with heating stage.*



Mary Bent

? becomes Frank Carter wife

## GAS CHROMATOGRAPHY

This technique is particularly useful for identifying and estimating volatile constituents of complex mixtures.

723/12

## Gas Kinetics

Kinetics and mechanisms of gas-phase reactions and general free radical chemistry using static and discharge-flow techniques. Reactions of alkyl and alkoxy radicals, nitrogen oxide and nitrogen dioxide. Mechanisms of gas-solid reactions.

*High vacuum techniques and product analysis by vapour-phase chromatography, infra-red and mass spectrometry. Emission spectroscopy.*



# PROCESS RESEARCH

Head of Branch     H ZIEBLAND

The Process Research Branch is concerned with means and equipment for processing chemicals on a production scale. Plant and facilities are designed for the manufacture of hazardous compounds and mixtures with particular emphasis on safety, remote-control, and instrumentation. The Branch has special interests in unit operations such as crystallization, mixing, heat transfer, and precision measurements of thermal properties of fluids.

Research and development is being carried out on fibre-reinforced, metallic and non-metallic materials and on the growth of ceramic whiskers.

## ACTIVITIES AND FACILITIES

### Large-scale Production

Development of laboratory syntheses on to pilot- and full-scale processes; pilot plant operation; manufacture of experimental chemicals and materials, including high explosives, polymer and rocket ingredients, whiskers and aligned inorganic fibres.

*Protective enclosures, with remote control, for processing experimental quantities of dangerous chemicals (i.e. fire, explosion, toxicity risks): one for large laboratory-scale glass plant; another for 2.5 kg pilot plant scale, equipped with a closed circuit television loop.*

*A wide range of pilot-scale plant, including: plant for concentrating nitric acid free from nitrous acid; nitration and sulphonation unit with brine cooling, remote control and acid mixing plant; glass-lined oil heated reactors for polymer manufacture.*

*Separators such as decanters; pressure-, vacuum- and rotary filters; batch and continuous stainless steel centrifuges; liquid centrifuges; and dry powder sieves.*

*Dryers, including hot air-, vacuum tray- and rotary-steam tube types.*

*Grinding plant, including jaw crusher; roll mill; edge-runner mill; hammer mills; and 'micronizer' fluid energy mill.*

*Mixers: double cone powder blender; medium and heavy paste mixers.*

*Packed, gas-liquid absorption towers.*

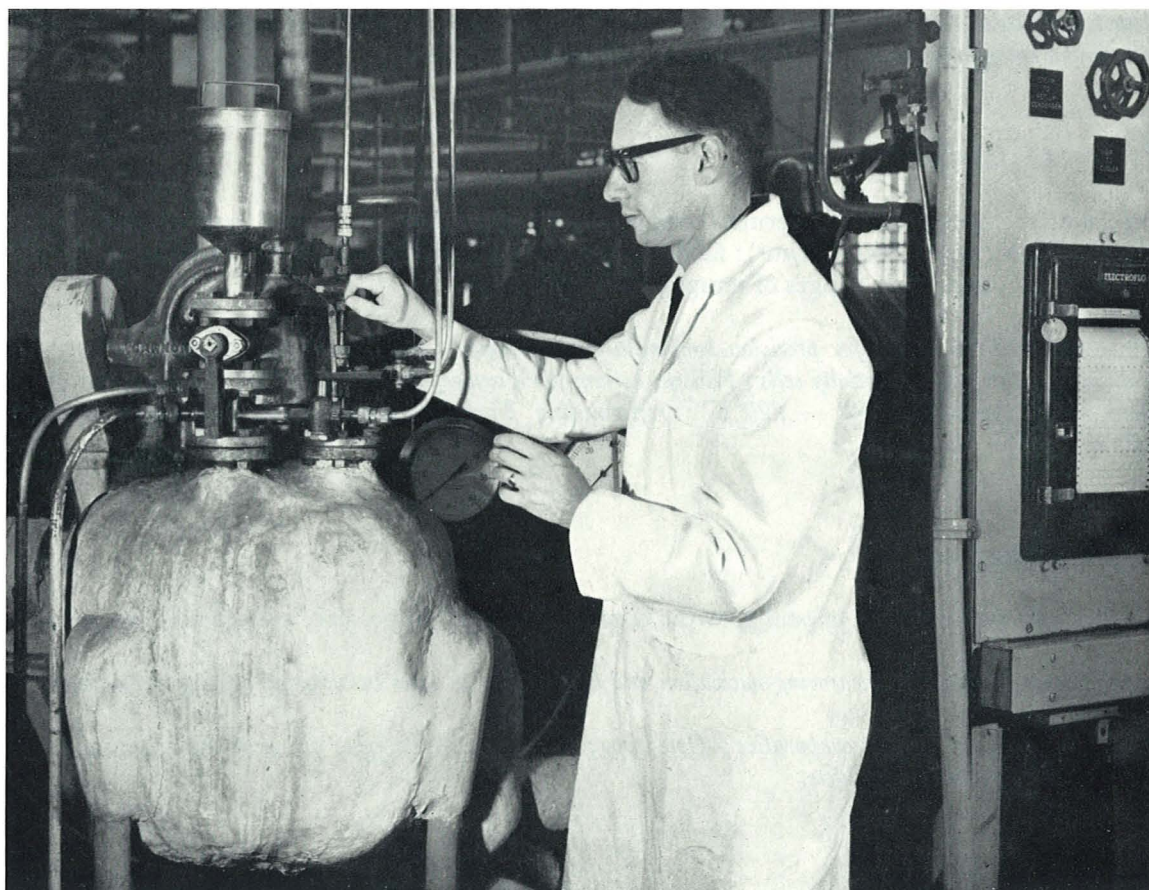
*Distillation: a 5-cm glass 'molecular' still; a 50-litre glass batch distillation unit; glass distillation column of high efficiency for high vacuum and 150°C; similar unit in stainless steel for pressure distillation up to 1 MN/m<sup>2</sup>.*

### Intensive Drying or Stripping

The intensive drying (or stripping) of high boiling liquids which may be sensitive to heat or excessive turbulence.



*Continuous plant (11.5 kg/h), based on single passage of liquid down a column packed with a battery of vertical helical coils.*



PLANT FOR POLYESTER MANUFACTURE

An example of the development of laboratory syntheses on to pilot-scale processes.

*Les Dingle*  
*723/13*

## Convective and Radiative Heat Transfer from Flames and Gases

Studies of convection and radiation from flames and combustion gases (up to 3800°K; 10 MN/m<sup>2</sup>); radiative emissivity of water vapour (1500°—3500°K; 0.5—10 MN/m<sup>2</sup>).

*Two instrumented test cubicles; water-cooled combustion chambers; black-body furnace to calibrate radiation sources.*

## Convective Heat Transfer to Liquids

Convective heat transfer from electrically heated surfaces to aviation kerosine and other liquids under sub-cooled, boiling, and supercritical conditions.

*Closed-loop apparatus with rectangular flow channel containing heated tube (maximum power, 10 kW; maximum pressure, 10 MN/m<sup>2</sup>; maximum fluid flow rate, 1.2 kg/sec). Photographic observation using Fastex ciné camera (18 000 half-frames/sec) and 0.2 μsec argon flash lamp.*

## Convective Heat Transfer to Cryogenic Fluids

Convective heat transfer to fluid hydrogen in the vicinity of the critical point and at supercritical pressures; fluid dynamics of cryogenic fluids.

*Remotely-operated test rig in which cryogenic fluids flow through asymmetrically heated rectangular ducts (maximum energy dissipation, 40 kW; maximum pressure, 5 MN/m<sup>2</sup>).*

## Thermal Conductivity

Precision measurements of thermal conductivities of liquids, gases, and supercritical fluids (12°—650°K; up to 300 MN/m<sup>2</sup>); facilities equally suitable for measuring viscosity, dielectric constant, etc. over wide ranges of temperature and pressure.

*Air conditioned laboratory for precision temperature measurement; protected annexe for compressing gases and liquids; thermal conductivity cells: Phillips helium-filled cryogenerator (12°—90°K); liquid nitrogen-filled metal thermostat (90°—220°K); recirculating Turbotherm-filled liquid thermostat (300°—650°K).*

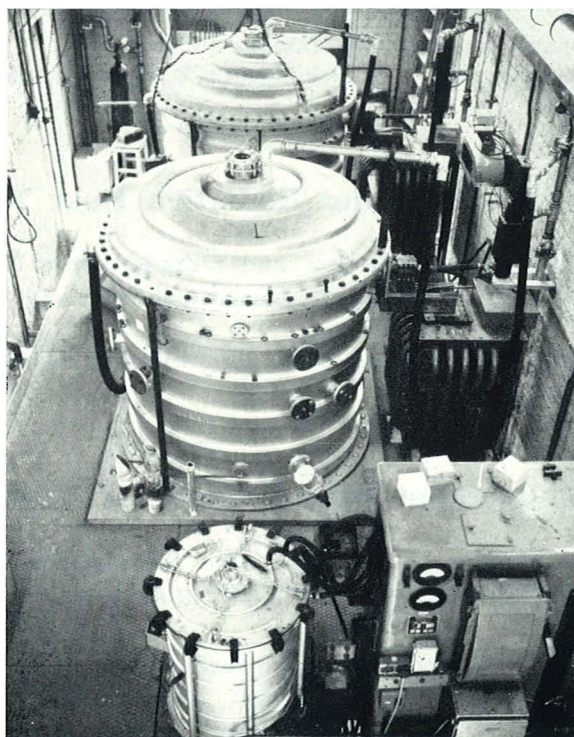
## Crystallization

Studies of nucleation and crystal growth; control of crystal shape, size, and size distribution.

*Laboratory equipment for measuring nucleation and crystal growth rates in a stirred cooling crystallizer.*

*Pilot crystallizers: Kestner evaporative; Oslo type; and pulsed tube type, for performance studies and production of crystalline products.*

723/1



'BRAN TUBS'

High temperature furnaces for synthesis of silicon nitride whiskers.



## High Temperature Equipment

*Furnaces of various types for operation up to about 1600°C; high frequency heating equipment; temperature measuring devices.*

## Fibre Processing Plant

*Equipment for sizing whiskers and other short fibres and plants to classify and align asbestos and other whiskers for making composite materials.*

## Fibre Testing Equipment

*Marsh micro-testing machine and various macro-testing machines.*

## Microscopes

*A range of optical microscopes and a J.E.M. 7 electron microscope.*

## Instrumentation and Glass Engineering

This Section, part of the Engineering Branch, is responsible for the development and application of instruments and apparatus based on electronic and glass engineering techniques.



### GLASS ENGINEERING

The glass engineering workshop is equipped to undertake construction of scientific glassware ranging from special laboratory articles to the large-scale item shown here.

723/14



# MISCELLANEOUS RESEARCH ACTIVITIES

In addition to research and development work performed by the Branches described above, certain specialized or exploratory research topics are undertaken by small groups under the direction of Dr. L. J. Bellamy, Mr. G. K. Adams, and Dr. G. H. Young.

## Spectroscopy

Studies of factors affecting infra-red absorption spectra of complex molecules; assignment of absorption bands and interpretation of spectra.

*Unicam SP 100 spectrometer (3650—300  $\text{cm}^{-1}$ ); Grubb Parsons GS2 grating spectrometer (4000—650  $\text{cm}^{-1}$ ); Unicam SP 700 spectrometer (55000—4500  $\text{cm}^{-1}$ ); attachment to determine emission spectra in the visible region; time-resolved luminescent spectroscopy in the visible region (resolution, 1  $\mu\text{sec}$ ).*

## Flame and Explosion Phenomena

*An Elliot 903 computer is in use, and computer programmes are available for calculation of flame and explosion properties, and the thermodynamic properties of two-phase, multi-element systems in chemical equilibrium.*

## Autoxidation and Antioxidants

Kinetics and mechanism of free radical chain reactions in solution; catalysis of oxidation-reduction reactions by heavy metals; effect of oxidative degradation, light, and ionizing radiation on polymeric materials. Research aimed at preventing or inhibiting oxidative degradation. Design and assessment of new antioxidants; mechanism of antioxidant action, particularly synergistic effects (mixtures of free radical acceptors; free radical acceptor and chelating reagent or S-containing peroxide decomposer); inhibition of autoxidation by metal chelates.

*Warburg apparatus and equipment for automatic recording of oxygen uptake; facilities for photochemistry and radiochemistry.*

## INDEX OF ACTIVITIES

Titles of branches have been abbreviated as follows:

E	Explosives	NM	Non-metallic Materials
P1	Propellants 1	GC	General Chemistry
P2	Propellants 2	Misc. Res.	Miscellaneous Research
PR	Process Research	IGE	Instrumentation and Glass Engineering Section

ADHESIVES		CRYSTALLOGRAPHY	
Development, application and strength	P2	Identification, phase analysis, crystal structure	GC
AGEING			
Non-metallic materials	NM	DEFORMATION	
Explosives and propellants	GC, P1	Non-metallic materials	NM
ANTIOXIDANTS	Misc. Res.	DIFFERENTIAL THERMAL ANALYSIS	GC
ASBESTOS REINFORCED MATERIALS	NM, PR	DISTILLATION	
ATOMIC ABSORPTION SPECTROPHOTOMETRY	GC	Fractional, pilot-scale, 'molecular'	PR
AUTOXIDATION	Misc. Res.	DRYING AND STRIPPING	
		Heat-sensitive liquids	PR
BALLISTIC ASSESSMENT	P1, P2		
BURNING RATE DETERMINATION	P1, P2	ELASTICITY AND ELASTOMERS	NM
		ELECTROMETRIC ANALYSIS	GC
CALORIMETRY, PRECISION	P1	ELECTRONIC INSTRUMENTATION	IGE
CARBIDES		ELECTRON MICROSCOPY	PR
High temperature materials	PR	ELECTROSTATIC RISK	
CERAMIC MATERIALS	PR	Generation of electric charge, electrical resistance measurement, susceptibility to ignition	E
CHEMICAL ANALYSIS		EMISSION SPECTROSCOPY	
Instrumental, elemental and functional group	GC	Visible region	Misc. Res.
CHEMICAL MANUFACTURE		ENVIRONMENTAL TESTING	
Laboratory investigations	GC	Effect of contaminants and climatic conditions on polymers	NM
Pilot-scale processes	PR	Explosives and propellants	GC, P1
CHROMATOGRAPHY, SOLUTION		EXPLOSIVES EVALUATION	
Analytical and preparative scale, column and thin layer, counter-current extraction	GC	Type of hazard, degree of protection and storage requirements	E
CLIMATIC EFFECTS		EXPLOSIVES SYNTHESIS AND MANUFACTURE	GC, E, PR
Non-metallic materials	NM		
Explosives and propellants	GC, P1	FATIGUE	
COMBUSTION		Non-metallic materials	NM
Solid propellants and organic materials	P1	FIBRE REINFORCED MATERIALS	PR
Liquid propellants	PR	FLAME AND EXPLOSION PHENOMENA	
COMPATIBILITY TESTING		Combustion	P1
Effect of contaminants and climatic conditions on hazardous materials	GC	Detonation	E
COMPOSITE MATERIALS	NM, PR	Theory	Misc. Res.
COMPRESSION TESTS	NM	FLUID DYNAMICS	
CREEP TESTING		Cryogenic fluids	PR
Non-metallic materials	NM	FREE RADICAL CHEMISTRY	GC, Misc. Res.
CRYOGENIC FLUIDS			
Fluid dynamics and heat transfer	PR	GAMMA IRRADIATION	Misc. Res.
CRYSTALLIZATION TECHNOLOGY	PR	GAS CHROMATOGRAPHY	
CRYSTAL GROWTH		Analytical	GC, NM, P1
From vapour	PR	Preparative	NM
From solution	PR, P2	GAS KINETICS	GC

GLASS ENGINEERING		IGE	NOISE EVALUATION	
			Measurement and simulation of impulsive noises, sonic bangs	E
HAZARD APPRAISAL			NON-AQUEOUS TITRIMETRY	GC
Impact and friction sensitiveness, ease of ignition, burning to detonation, shock sensitiveness, electrostatic risk		E	NON-DESTRUCTIVE TESTING	
Thermal stability and self-heating			Radiographic and ultrasonic inspection	P1
HEAT RESISTANT MATERIALS		GC	NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY	NM
Polymers		NM	Analysis and structure determination	PR
Composites		PR	NUCLEATE BOILING	Misc. Res.
HEAT TRANSFER			OXIDATION INHIBITORS	
Convective and radiative, flames and combustion gases, liquid fuels, cryogenic fluids			PARTICLE SIZE ANALYSIS	GC
HIGH SPEED PHOTOGRAPHY		PR	PASTES, STIFF	
Explosive phenomena			Processing and rheology	P2
Mechanical testing		E	PLASTICS	
HYDROGEN, LIQUID		NM	Chemistry and physics	NM
		PR	POLAROGRAPHY	GC
			POLYMER CHEMISTRY	
			Synthesis, characterization, stability	NM
IGNITION			POLYMERIZATION KINETICS	
Hazardous materials		E, GC	Basic studies	NM
IMPACT TESTING			Applied studies	NM, P2, E, GC
Polymers		NM	POLYMER PHYSICS AND ENGINEERING	
INFRA-RED SPECTROSCOPY			Non-metallic materials and reinforced plastics, physical properties and engineering data	NM
Qualitative and quantitative analysis		GC	POLYMER TECHNOLOGY	
Polymer characterization		NM	Curable and non-curable polymers	NM, P2
Gas kinetics research		GC	Heavily-loaded thermo-plastic rubbers	P2
Combustion		P1	Polyurethane elastomers	NM, E, PR
Basic studies	Misc. Res.	E	PRESSURE MEASUREMENT	
INITIATORY EXPLOSIVES			Explosions	E
			Rocket motor firing	P1, P2
			Liquid flow	PR
JOINT STRENGTH		P2	PROOFED FABRICS	NM
			PROPELLANT PROCESSING	
LIQUIDS			Nitrocellulose-based	P1
Critical point phenomena		PR	Rubber-based	P2, E
LOAD CELLS		NM	PYROLYSIS	
			Polymers	NM, GC
MASS SPECTROMETRY		GC	Organic materials	P1
MATERIALS			RADIOCHEMISTRY	GC
Non-metallic		NM	RADIOGRAPHIC INSPECTION	P1, E
Composites		PR	REFRACTORY MATERIALS	PR
MECHANICAL TESTING			REMOTE CONTROL METHODS	
Non-metallic materials		NM	Mixing, extrusion, injection moulding	E
Composites		PR	Manufacture of hazardous chemicals	PR
Adhesives		P2	Closed circuit TV	E, PR
Propellants		P1, P2	RHEOLOGY	
MICROANALYSIS		GC	Polymers and composite materials	NM
MICROSCOPY			Adhesives	P2
Crystal morphology		GC, PR	Solid propellants	P2
Polymer crystallization		NM	Stiff pastes	P2
Fibres and ceramic whiskers		PR	Fibres	NM, PR
MIXERS, DESIGN AND OPERATION			RUBBER, SPECIAL APPLICATIONS	
Performance, safety, application to hazardous materials		PR	Conducting, antistatic, proofed fabric	NM
NITRIDES				
High temperature materials		PR		
NITROCOMPOUND CHEMISTRY		GC		



SAFETY	
Manufacture, handling and storage of hazardous materials	E, PR, P1, P2
SEALANTS	
Lutings and cements for threaded joints	P2
SHEAR TESTS	
Joints	P2
SONIC BANGS	
	E
SPECTROSCOPY	
Fundamental studies	Misc. Res.
Qualitative and quantitative analysis	GC
Application to combustion	P1
gas kinetics	GC
polymers	NM
SURFACE CHEMISTRY	
Surface tension, contact angles	P2
SYNTHETIC CHEMISTRY	
	GC
TEMPERATURE MEASUREMENT	
Combustion and calorimetry	P1
Thermal conductivity	P2
Thermochemical analysis	GC
High temperatures	PR
TENSILE STRENGTH TESTING	
	NM, PR
THERMAL CONDUCTIVITY	
Liquids, gases, supercritical fluids	PR
THERMAL STABILITY	
Polymers, degradation studies	NM
Hazardous compounds	GC
THERMOCHEMICAL ANALYSIS	
Differential scanning and heat flow calorimetry, thermogravimetry	GC
THERMOCHEMICAL DATA	
Heats of formation, combustion and wetting	P1
ULTRA-VIOLET SPECTROMETRY	
Qualitative and quantitative analysis	GC, NM
VAPOUR PHASE CHROMATOGRAPHY	
	GC, NM
VISCOMETRY	
	NM
VULCANISATION	
	NM
WHISKERS, CERAMIC	
Production, processing and testing	PR
Classification and alignment	PR
X-RAY CRYSTALLOGRAPHY	
Powder diffraction photography, single crystal analysis	GC

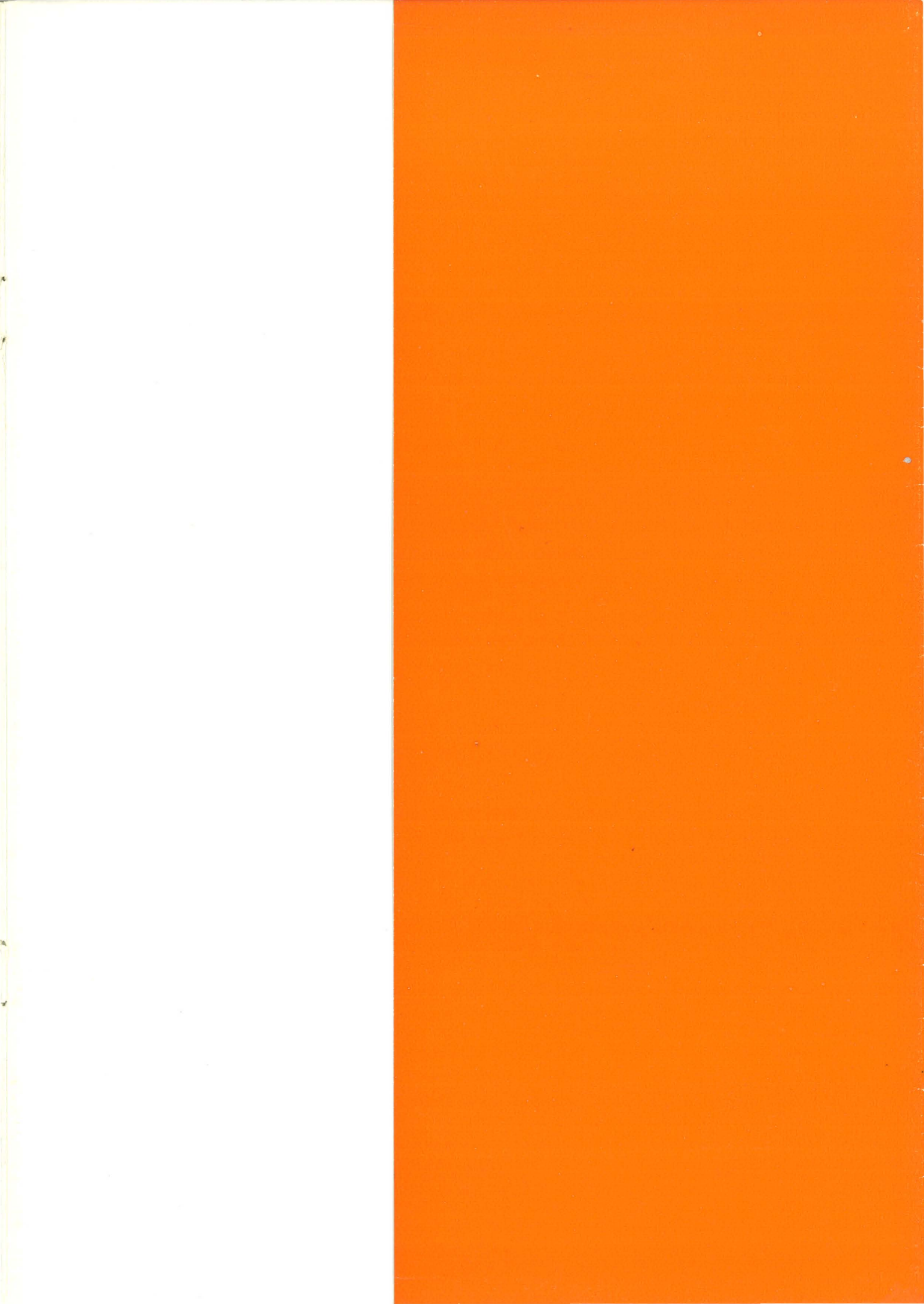
# INDEX OF FACILITIES

ABSORPTION TOWERS			MICROCOMBUSTION EQUIPMENT	GC
Packed, gas-liquid	PR		MICROSCOPES	
ARMoured CUPBOARDS AND PROTECTIVE ENCLOSURES			Time-lapse, photographic recording	NM
Small scale tests and preparations	GC, E		Projection	PR
Large scale manufacture	E, PR		Hot-stage polarizing	GC
ATOMIC ABSORPTION SPECTROPHOTOMETER	GC		Electron	PR
AUTOXIDATION LABORATORY			MIXERS	
Oxygen uptake measurement	Misc. Res.		Powder blending	PR
			Heavy paste	PR, P1, P2, E
CALORIMETERS			MOLECULAR WEIGHT APPARATUS	
Precision	P1		Viscometry, osmometry and light scattering	NM
Differential scanning and heat flow	GC		Vapour pressure osmometry, ebulliometry and cryoscopy	GC
CHEMICAL PLANT			NUCLEAR MAGNETIC RESONANCE SPECTROMETER	NM
Nitration, sulphonation, acid concentration, polymer manufacture, fibre and whisker classification and alignment	PR			
CREEP TESTING EQUIPMENT	NM		PARTICLE SIZE EQUIPMENT	
			Gas adsorption and permeability, micromerograph, sedimentometer	GC, P2
DISTILLATION EQUIPMENT			PLASTOMETERS	
Fractionating columns, pilot-scale and 'molecular' stills	PR		Flow and deformation, brittle point	P2
DRYERS			PHOTOGRAPHIC EQUIPMENT	
Hot air, vacuum, steam	PR		High speed streak and framing cameras	E, NM, P2
ENVIRONMENTAL TEST FACILITIES			Time-lapse photomicroscopy	NM
Climatic chambers	P1		Hot-stage photomicroscopy	GC
Ageing ovens	GC, NM		POLAROGRAPH	GC
Tropical test site	NM		PRESSURE SENSORS	
EXTRUSION PLANT			Explosion and noise	E
Propellants and explosives	P1, P2, E		Propellant impulse	P1, P2
Polymers	NM		Liquid flow	PR
FURNACES			RADIOCHEMICAL TRACER LABORATORY	GC
High temperature, laboratory and pilot-scale	PR		REACTION VESSELS, PILOT-SCALE	PR
GAS CHROMATOGRAPHS			REMOTE CONTROL FACILITIES	
Analytical	GC, NM, P1		Process bays and equipment design	PR, E
Preparative	NM		Master slave manipulators	E, GC
GRINDING PLANT			RHEOLOGICAL TEST FACILITIES	
Jaw crusher and various mills	PR		Static, dynamic and creep loading	NM, P2
HEAT TRANSFER TEST RIGS			Impact, flywheel and rotating beam machines	NM
Variable pressure, temperature and flow rates	PR		Microtest	PR
			Variable environment	NM, P2
IMPACT TESTERS			SEPARATORS	
Polymers	NM		Decanters, sieves, filters, and centrifuges	PR
INFRA-RED SPECTROMETERS			THERMAL CONDUCTIVITY CELLS	
General purpose instruments	GC, NM, P1		Variable pressure and temperature	PR
High resolution	Misc. Res.		THERMOCHEMICAL ANALYSIS INSTRUMENTS	
MASS SPECTROMETER	GC		Differential scanning and heat flow calorimeters, thermogravimetric balance	GC

THERMOMETERS		
Platinum resistance		P1
Multirange recording		GC
ULTRASONIC INSPECTION EQUIPMENT		
Propellants		P1
Polymers		NM
ULTRA-VIOLET SPECTROMETERS		
General purpose		GC, NM
Continuous scanning	GC, Misc. Res.	
VISCOMETERS		
Bulk viscosity		NM, P2
Intrinsic viscosity		NM
X-RAY EQUIPMENT		
Radiographic inspection		P1, E
Crystallographic analysis		GC











# Explosives Research & Development Establishment

## **Research and Development Activities and Facilities**



# **EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT**

**RESEARCH and DEVELOPMENT  
ACTIVITIES and FACILITIES**

ERDE MINISTRY of

DEFENCE

WALTHAM ABBEY ESSEX



# HOW TO CONSULT ERDE

ERDE is able to offer a limited, free consultative service to industrial undertakings on problems related to expertise available in the Establishment.

Problems involving more extensive investigations or the use of equipment and special facilities may be undertaken for a fee, subject to the demands of the Establishment's research and development programme.

Enquiries may be made

- (a) by letter, addressed to The Director  
ERDE  
Ministry of ~~Technology~~ <sup>DEFENCE</sup>  
Waltham Abbey, Essex;
- (b) by telephone, asking for Heads of specific branches or ERDE Industrial Liaison Officer  
Waltham Cross 23688; (STD) 97-23688 Inner London; (STD) 0992-23688 Outside London.

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# INTRODUCTION

The primary function of the Explosives Research and Development Establishment is to undertake research on, and development of, explosives, propellants and related exothermic compositions to meet the present and future requirements of the three Services. The Establishment is also actively engaged on materials work, concerned principally with the chemistry and physics of polymers, and with new engineering materials based on refractory fibres.

To exercise these functions, ERDE maintains a staff of scientific, technical and engineering personnel representing a wide range of disciplines but with particular expertise in chemistry, chemical engineering and physics. Research and development tasks are shared by six technical branches supported by drawing office, machine shop, electronics and glass engineering facilities, and by appropriate library and information services.

It is the purpose of this book to give a brief outline of the work of the technical branches, especially those aspects involving expertise, facilities or equipment which are likely to be of interest to industrial undertakings.



# MANAGEMENT ORGANIZATION

Director	Dr. L J Bellamy
Deputy Director	MR G K ADAMS
<del>Special Merit 'B' Post</del>	<del>Mr. G K Adams</del>
Heads of Branches	
Explosives	DR C A BECK
Propellants 1	DR C G LAWSON
Propellants 2	Mr. P R Freeman
Non-metallic Materials	Dr. B L Hollingsworth
General Chemistry	DR A R OSBORN
Process Research	Mr. H Ziebland
Chief Engineer	Mr. R Fisher
Chief Safety Officer	Mr. J V Griffiths
Chief Administrative Officer	Mr. S F M Whiteside
Individual Merit Scientists	Dr. A W H Pryde (Chemical Engineering)
	DR D H RICHARDS (POLYMER CHEMISTRY)
	Dr. N Uri (Autoxidation)



# EXPLOSIVES

Head of Branch

DR C A BECK

The Explosives Branch deals primarily with the development of sensitive, initiatory explosives and high explosive and propellant compositions of improved performance. Trials are performed to assess sensitiveness and hazards associated with all explosive materials.

## ACTIVITIES AND FACILITIES

### Explosive Risk

Standard tests designed to evaluate and to compare the explosive risk of materials are based on impact and friction sensitiveness, ease of ignition, susceptibility to burn to detonation, and shock sensitiveness. Results enable recommendations to be made regarding type of hazard, degree of protection and appropriate storage requirements.

*Armoured cupboards for small-scale tests (up to 30 g) and instrumented firing site facilities for larger quantities (up to 4.5 kg). Firing site for small-scale underwater tests.*

### Electrostatic Risk

Electrostatic risks associated with handling explosive powders, vapour/air, and gas/air mixtures are assessed by measuring

- (a) electrostatic voltages and charges on transferring solids or liquids, or on separating surfaces;
- (b) comparative electrification of materials, especially fabrics and plastics;
- (c) electrical resistance of floors, footwear and items of equipment;
- (d) susceptibility to ignition by capacitor type discharge.

*Electrostatic voltmeter (30—18 000 volts); resistance meters (up to  $10^{16}$  ohms); facilities for measuring electrostatic spark sensitiveness of powders.*

### High Speed Photography

This technique is used to record mechanical and explosive phenomena, to investigate shock initiation of explosives and to determine propagation velocities.

*Portable 16 mm ciné camera (100—18 000 frames/sec): framing camera (25 frames at 150 000 —  $4 \times 10^6$  frames/sec), installed in 2.25 kg explosives test facility; streak camera (writing speed 0.7 mm—9 mm/microsec), installed in 4.5 kg explosives test facility. Printing facilities include conversion of 35 mm frames into animated 16 mm film, and colour printing of negatives of explosive phenomena with particular reference to correct colour balance.*



## Noise Evaluation

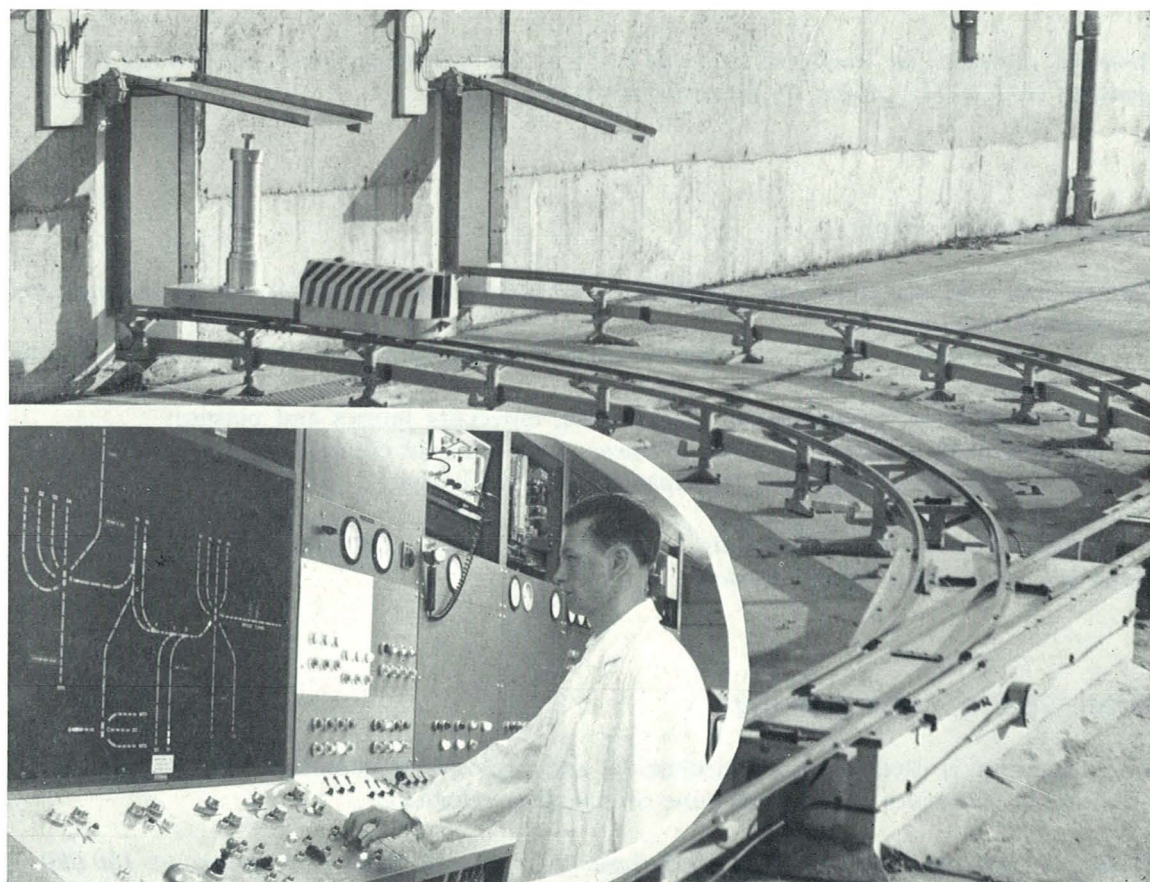
Measurement and analysis of impulsive noises including those of long duration (e.g. sonic booms), and their simulation by explosives. Techniques for generating a wide range of pressure waveforms in air may be applied to studying the behaviour of structures to shocks of this kind.

*Apparatus to record shock waves in air down to  $5 \text{ N/m}^2$  ( $0.1 \text{ lbf/ft}^2$ ).*

## Remote Control Methods

Development of remote control methods for manufacturing and testing dangerous explosive materials.

*Process bays (limit 7.25 kg TNT equivalent) in which hazardous operations can be performed by remote control. Remotely operated mixing, extruding and injection moulding unit (4.5 kg) with temperature, vacuum and shear rate controls on mixer (viscosities 2—3 000 poise). Strong bay (limit 1.35 kg TNT equivalent) with master slave manipulators (3.5 m extended reach), X-ray facility (250 kv), and armoured viewing window. Capability for melt-mixing and moulding, or for pressing explosives, and for carrying out basic machinery operations on explosive charges by remote control. Closed circuit TV available to position all remotely-controlled operations.*



### REMOTE-CONTROL TRANSPORTATION OF HAZARDOUS MATERIALS

A five-inch gauge electric railway system used to transport hazardous materials between manufacturing, testing and storage areas.

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## **Polymer Technology**

Cure chemistry of polyurethane elastomers prepared from di-isocyanates and hydroxy-terminated polyesters and polyethers; optimization of physical properties of heavily-loaded rubbers.

*Small scale plant facility for development work; laboratory equipped to study physical properties and ageing characteristics.*

# PROPELLANTS 1

Head of Branch

W DR C/G LAWSON

Propellants 1 Branch is largely concerned with the development of propellants based on nitrocellulose. Work is undertaken on methods for controlling ballistics, and to devise ballistic assessment techniques. Attention is also given to the quality control of propellants by non-destructive tests involving X-ray or ultrasonic inspection.

## ACTIVITIES AND FACILITIES

### Propellant Processing

Experimental processing of nitrocellulose-based propellants poses problems similar to those involved in processing plastic materials, especially consideration of viscosity control and particle size.

*Plant for rolling and extrusion of incorporated materials; preparation of felted paper tubes with high length/diameter ratios.*

### Combustion

Investigations of propellant combustion using techniques equally applicable to combustion of fuel oils and gases. High temperature degradation of organic materials, research capable of being extended to flammability and flame-proofing of plastics.

*Equipment to measure temperature profiles at burning surfaces, and appropriate instruments (infra-red and ultra-violet spectrophotometers and gas chromatographs) for flame decomposition product analysis.*

### Ballistic Properties

Burning rates and calorimetric measurements. Experimental techniques are available to study solids, liquids, and gases, and to determine precise heats of combustion, formation and wetting.

*Equipment to measure static and dynamic pressures for fractions of a second or longer in ranges up to  $31 \text{ MN/m}^2$  (4500 psi). Calorimeters with platinum resistance thermometry systems (precision better than  $1 \times 10^{-3}^\circ\text{C}$ ).*

### Non-Destructive Testing

The integrity and bonding of propellants are inspected by radiographic and ultrasonic test methods which may also be used to investigate conventional plastics and bonded systems.

*Radiographic (400 kV) and ultrasonic (375 kc/sec through transmission) inspection equipment.*





PRECISION CALORIMETRY

An NPL-pattern bomb calorimeter for determining heats of combustion with an accuracy approaching 1 part in  $10^4$ .

# PROPELLANTS 2

Head of Branch     P R FREEMAN

Propellants 2 Branch is responsible for research and development on composite propellants based on plastic or rubbery binder systems. The facilities include laboratories for quality control, including ballistic and physical property assessment, together with small- and large-scale manufacturing plants.

Basic and applied research on rheology and adhesion is performed to improve the mechanical behaviour of solid propellants and to provide an advisory service on the use of sealants, adhesives and lutings.

## ACTIVITIES AND FACILITIES

### Composite Propellant Formulation, Manufacture and Assessment

Formulation and manufacture of paste-like and rubbery composite propellants, assessment of ballistic properties by strand burning and static firing of small rocket motors. Compositions of high energy are available covering a wide range of burning rates.

*Comprehensive facilities for the manufacture of propellants and filling of small rocket motors. Strand burning bombs and small static proofstand.*

### Sealants and Adhesives

Development of lutings and cements for threaded joints, etc., and adhesives for metal, plastics, paper, cloth and leather; study of tensile and shear strength, and of stress-strain behaviour of adhesives and joints.

An advisory service is offered on all aspects of bonding and hermetic sealing of joints, and on joint design.

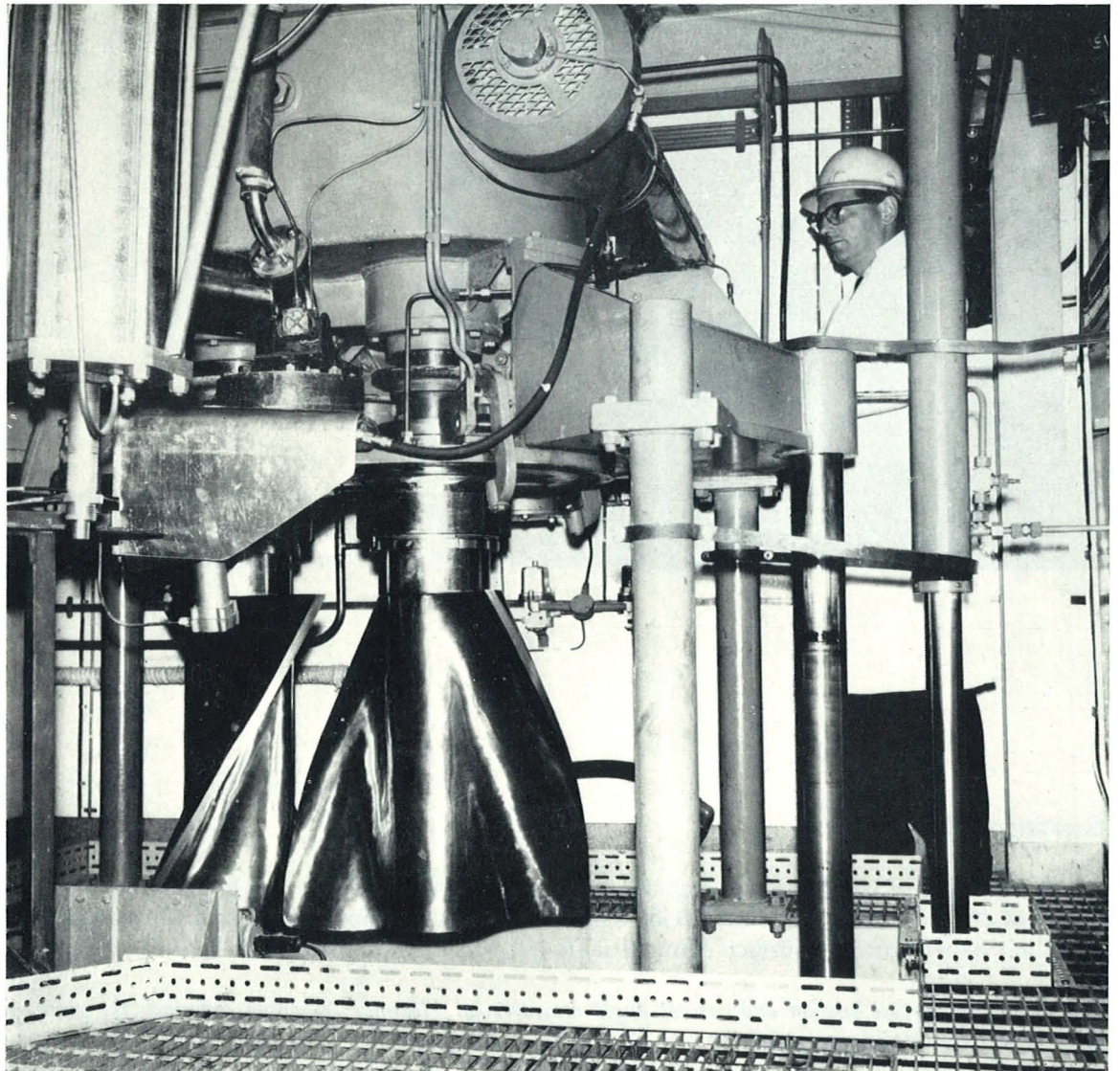
*Instron universal testing machine (load,  $10^{-3}$ —5000 kg; cross-head speed,  $10^{-3}$ —10 mm/sec; cross-head travel, 1 m) with thermostatic chamber ( $-50^{\circ}$  to  $60^{\circ}\text{C}$ ) and automatic integrator. Hydraulically-operated high-speed test machine (strain rate up to 10 cm/sec); Sanborn twin-channel recorder (10 ms response) and Tektronix oscilloscope. Jigs for the preparation and testing of joints; equipment for preparation of proofed fabrics; viscometers, plastometers; facilities for storage at controlled humidities and temperatures.*

### Rheology of Stiff Pastes and Highly Filled Rubbers

Dependence of rheological behaviour of highly concentrated solid-in-liquid dispersions on nature of solids, solids loading, magnitude and distribution of particle size, nature and viscosity of liquid, temperature and test methods. Mechanical behaviour of highly filled rubbers by tensile testing over a wide range of temperatures and strain rates. Construction of master curves of mechanical behaviour by time-temperature superposition.



*Plastometers to study flow and deformation behaviour including fatigue effect of cyclic compression and extension; fatigue by flexing; effect of imposed hydrostatic pressure; response to biaxial strain. Brittle point apparatus. Tensile testing apparatus.*



VERTICAL MIXER FOR RUBBERY-TYPE SOLID PROPELLANTS  
The mixing pot has been lowered for removal of the propellant mix.





MEASUREMENT OF CONTACT  
ANGLE OF WATER ON A  
CONTAMINATED STEEL SURFACE

## Surface Chemistry

Surface tensions of highly viscous organic liquids; effect of molecular weight and temperature. Study of contact angles and interfacial tensions between viscous liquids and inorganic salts, and their dependence on surface contaminants (moisture, surfactants).

*Equipment for surface tension and contact angle measurement; thermal siphoning technique for growing large perfect crystals of inorganic salts.*

## Technology of Pastes and Slurries

Formulation, manufacture, and handling of stiff pastes based on curable and non-curable liquid organic polymers containing a high proportion of solid inorganic filler.

*Vertical and horizontal mixers of various capacities capable of processing mixes up to  $10^7$  poise viscosity; de-aerating pug-mills and pressure extrusion equipment.*

# NON-METALLIC MATERIALS

Head of Branch     B L HOLLINGSWORTH

The Non-metallic Materials Branch undertakes basic and applied research on the chemistry and physics of polymers with particular regard to synthesis, characterization, degradation, and mechanical behaviour under a range of test conditions. The Branch offers an advisory service on the applications of polymers, and supervises long-term environmental testing at the Tropical Research Unit, which is a joint project with Australia.

## ACTIVITIES AND FACILITIES

### Polymer Physics and Engineering

Study of the physical properties of non-metallic materials and reinforced plastics: stress-strain curve, strength, fracture energy, damping capacity, creep, fatigue, stress relaxation, and dimensional stability. Effects of rate of deformation, temperature and moisture. Stress relaxation tests on rings and beams; dynamic mechanical properties of discs. Compression cell to study effects of dynamic, static, and creep loading.

*Hounsfield apparatus (extension rate, 0.0013 — 50.8 cm/min; temperature, — 80° to 80°C); Baldwin machine; Goodbrand machine (fibre test). Avery Izod impact machines (capacity 17 kg.m; maximum loading rate,  $18 \times 10^2$  kN/sec; photographic recording with 35 mm. streak- or 12 000 frames/sec Fastex-cameras). Flywheel machine (fracture energies at impact velocities of 130—1 300 cm/sec). Ultrasonic equipment (150 kc/sec—2 Mc/sec; up to 80°C). Rotating beam machine (fatigue properties).*

### Polymer Chemistry—Synthesis, Characterization, and Stability

Investigation of novel and potentially useful polymer systems; monomer and polymer synthesis, polymer fractionation, mechanism and kinetics of polymerization, reactions of polymers.

Characterization of polymers by molecular weight (viscometry, osmometry, light scattering, and end-group analysis), spectroscopy (IR, UV and NMR), dilatometry, bulk viscometry, compressibility and thermal expansion measurements, and by optical examination of polymer morphology.

Stability of addition and condensation polymers to heat, ultra-violet light, and high energy radiation; effects of chemical structure, impurities and environment. Mechanism and kinetics of degradation and its effect on molecular weight and physical properties.

**MOLECULAR WEIGHT** *Hewlett-Packard 502 high-speed membrane osmometer (maximum operating temperature 130°C); Brice-Phoenix Series 2000 Universal light scattering photometer with MSE high-speed centrifuge.*

**BULK PROPERTIES** *Epprecht Viscometer (0.1—10<sup>6</sup> poise, 0°—180°C); linear expansion apparatus for glass transition temperatures; pressure balance (temperature controlled to  $\pm 0.001^\circ\text{C}$ ).*





#### AVERY IZOD PENDULUM IMPACT APPARATUS

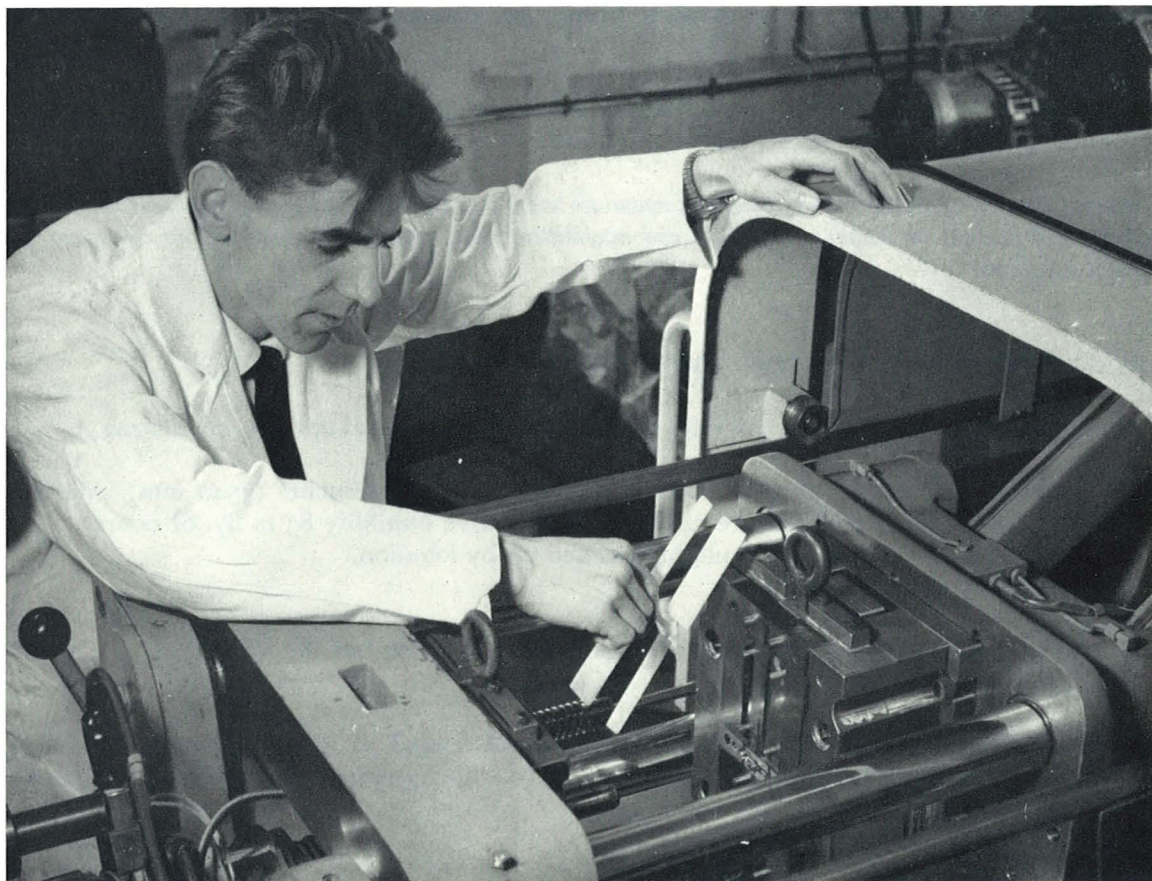
A pendulum impact tester modified for tensile and flexural impact tests to investigate the engineering life of non-metals.

#### NUCLEAR MAGNETIC RESONANCE MEASUREMENT

This 60 M/c instrument is used for characterization and structure determination of a wide range of organic compounds.







HORIZONTAL INJECTION MOULDING MACHINE

Test pieces for mechanical property assessment being produced in a constant torque, injection moulding machine.

SPECTROSCOPY *PE R10 60 M/c NMR spectrometer (variable temperature probe, spin decoupling unit, probes for  $^1\text{H}$ ,  $^{11}\text{B}$ ,  $^{19}\text{F}$ , and  $^{31}\text{P}$ ; PE 337 grating spectrometer ( $4000\text{--}400\text{ cm}^{-1}$ , ATR attachment); Unicam SP 500 spectrometer.*

MICROSCOPY *Gilett and Sibert time-lapse microscope (35 mm and 16 mm (ciné) photographic recording).*

DEGRADATION *Mercury lamp, xenon arc, molten salt- and fluidized sand baths.*

GAS CHROMATOGRAPHY *PE Model 801 (dual column analytical instrument, linear programming); Pye Model 105/15 (automatic preparative gas chromatograph, linear programming).*

## Polymer Development and Applications

Processing and curing of new rubbers and thermoplastics by injection moulding, extrusion, milling, and compression moulding. Measurement of physical properties, and the effect of contaminants (e.g. explosives, propellants, petrol, etc.). Accelerated and tropical ageing trials to assess useful life. Investigation of failures. Manufacture of special components; antistatic and conducting rubbers.

Proofed fabrics: preparation, mechanical properties, and advice on the design of proofed fabric structures.

*PROCESSING* Wide range of mills, mixers, hydraulic presses and injection moulding machines. Facilities for the synthesis of polyester-polyurethane rubbers. Small-scale equipment for preparing proofed-fabric samples.

*TESTING* Physical properties; permeability of materials to organic fluids and water; ageing ovens to simulate hot/dry and hot/wet conditions; continuous and intermittent stress relaxometers. Carbon arc equipment for special exposures.

## **Joint Tropical Research Unit, Queensland**

Four sites are available for the exposure of small specimens to atmospheric weathering.

- (a) **INNISFAIL** Latitude  $17^{\circ} 32'S$ . Average annual rainfall 140 inches (3540 mm). Average daily mean temperature  $74^{\circ}F$  ( $23^{\circ}C$ ); relative humidity 83 to 87. Sites are
  - (i) Hot/wet, jungle, i.e. sunlight screened off by foliation.
  - (ii) Hot/wet, clearing.
- (b) **CLUMP POINT** Similar latitude and conditions to Innisfail but the site is
  - (iii) Marine.
- (c) **CLONCURRY** Latitude  $20^{\circ} 43'S$ . Average annual rainfall 17 inches (430 mm). Average daily mean temperature  $78^{\circ}F$  ( $25^{\circ}C$ ); relative humidity 39. The site is designated
  - (iv) Hot/dry.

# GENERAL CHEMISTRY

Head of Branch

DR A R OSBORN

The General Chemistry Branch investigates the preparation, properties and reactions of a wide range of ingredients related to explosive, propellant and polymer technology. The Branch offers an advisory service on the stability, compatibility and surveillance testing of propellants, explosives and other hazardous materials. New analytical methods are developed to assist quality control, and a range of specialized techniques and facilities are used to provide an analytical service for the Establishment.

## ACTIVITIES AND FACILITIES

### Synthesis and Characterization

Synthesis of explosives and ingredients of solid propellants and polymers (fuels, oxidizers, ballistic additives, stabilizers, curing agents, antioxidants, etc.); studies to optimize yield and purity and to reduce hazard (toxicity, thermal decomposition, etc.).

*General techniques of preparative chemistry, and supporting facilities: armoured cupboards; PE Model 237 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ); Unicam SP 500 spectrometer; various refractometers and optical microscopes, including Kofler hot-stage instruments; molecular weight determination by semi-micro ebulliometry and micro-cryoscopy.*

### Stability and Compatibility

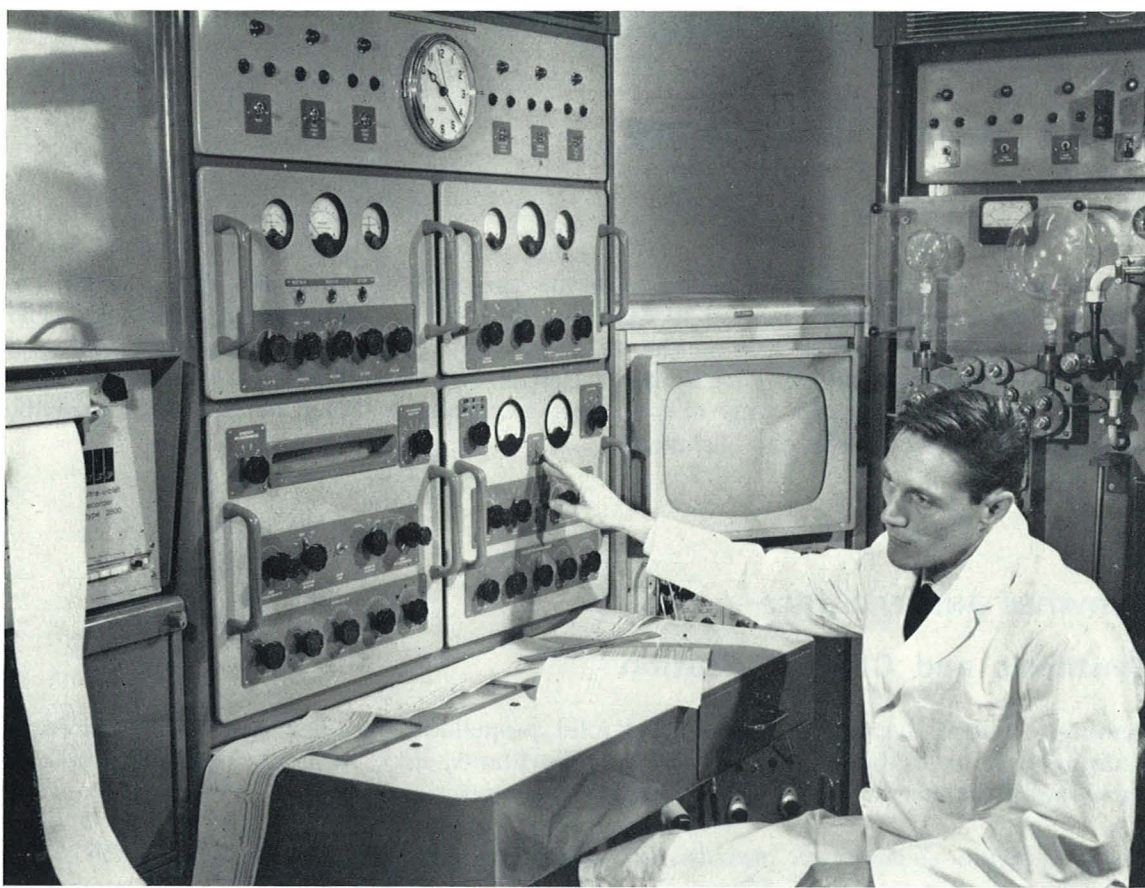
Kinetics and mechanism of thermal decomposition of explosives and exothermic compositions; ignition phenomena and build-up to low order detonation; compatibility of explosives, propellants, etc. with materials (e.g. polymers, plastics, metals, adhesives, varnishes and paints); effect of severe environmental conditions on storage stability. New techniques to investigate thermal stability.

*Environmental testing ovens and standard stability test facilities. Master slave manipulator. Stanton thermogravimetric balance (maximum temperature,  $250^{\circ}\text{C}$ ); PE differential scanning calorimeter, Model 1 ( $-100^{\circ}$  to  $500^{\circ}$ ); heat flow calorimeter (sensitivity,  $30\text{ }\mu\text{watts}$ ); multirange temperature recording equipment ( $-200^{\circ}$  to  $500^{\circ}\text{C}$ ). Photomicroscopy of samples heated in vacuum. Advance Model TC 2A electronic timer counter ( $1\text{ }\mu\text{sec}$ ).*

### Chemical Analysis and Physical Methods

Separation, identification, and analysis of the constituents of explosives, propellants, polymers, rubbers, etc.; determination of functional groups, elemental composition, and molecular weight; trace metal analysis. Estimation of purity, and investigation of quality control and specification tests. Studies concerned with gas and solvent vapour analysis; molecular and crystal structure; thermochemical characteristics (phase changes, low temperature behaviour and thermal decomposition); cure- and post-cure chemistry of polymeric systems; non-aqueous titration; mass spectrometric and polarographic analysis.





#### MASS SPECTROMETRY

An AEI Model MS 2H mass spectrometer capable of performing isotopic and chemical analyses on very small quantities of material, including solids.

**CHROMATOGRAPHY** *Wide range of standard equipment for analytical- and preparative-scale column- and thin layer chromatography; Craig counter-current extraction apparatus; Varian Aerograph Model 1522 gas chromatograph (dual column, linear programming); PE F11 gas chromatograph; pyrolysis attachment.*

**SPECTROSCOPY** *PE Model 257 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ) ATR attachment, micro- and heated cells; modified Grubb Parsons S3A spectrometer ( $3500\text{--}250\text{ cm}^{-1}$ ); PE Model 137 UV spectrometer; Unicam SP90 atomic absorption spectrophotometer.*

**MASS SPECTROMETRY** *AEI Model MS 2H*

**MICROANALYSIS** *Combustion equipment (C, H, N); Schöniger flask (S, halogens); Mechrolab Model 302 vapour pressure osmometer (molecular weights up to 20 000).*

**POLAROGRAPHY** *Beckman Electroscan 30 (various electrometric analysis techniques).*

**RADIOCHEMISTRY** *Tracer laboratory; Panax standard- and low background Geiger counters; Isotope Development Ltd. solid and liquid scintillation counters.*

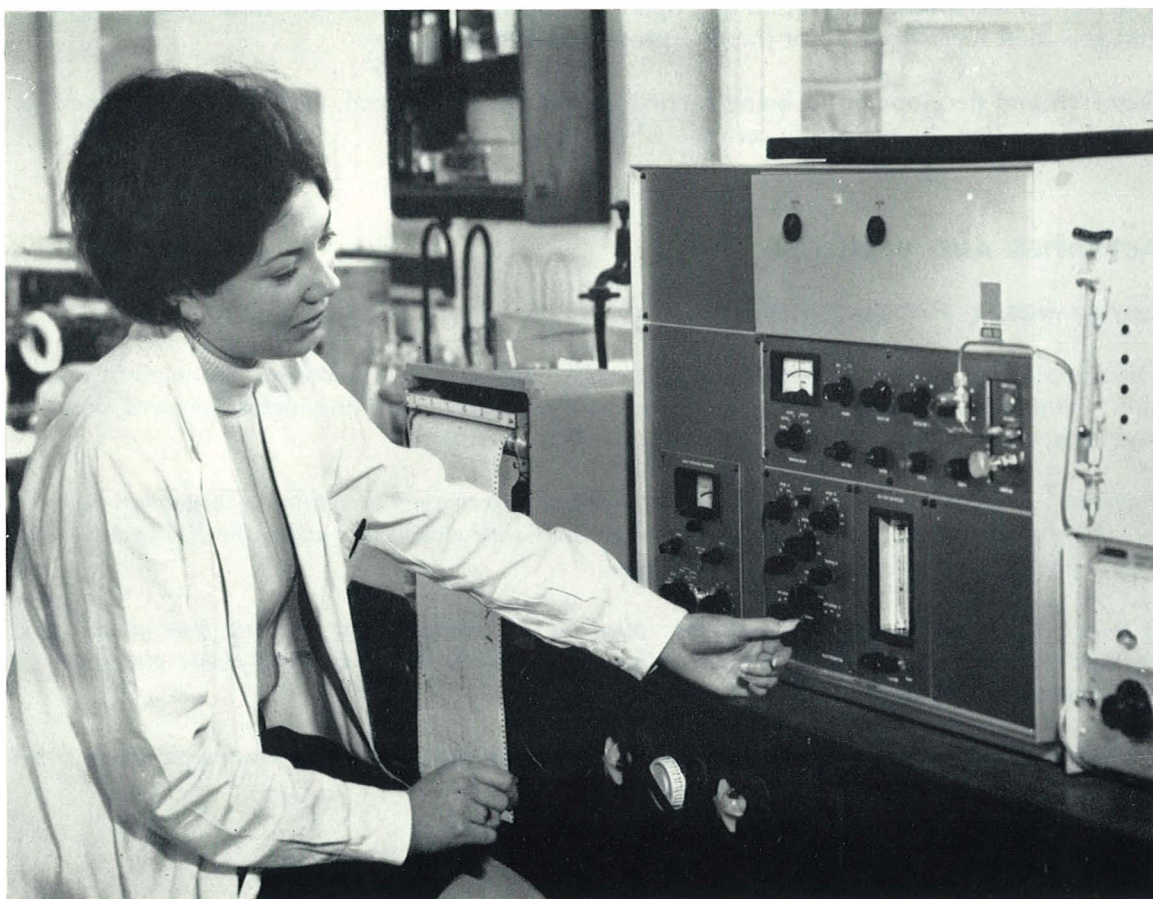
**THERMOCHEMICAL ANALYSIS** *see Stability and Compatibility.*

**PARTICLE SIZE ANALYSIS** *Sharples Micromerograph (humidity- and temperature-controlled); gas adsorption and various types of gas permeability apparatus for surface area measurement.*

## Crystallography

Application of optical and X-ray diffraction to identification and characterization of compounds; phase analysis of mixtures, polymorphism, crystal orientation, and crystal structure analysis.

*Equipment includes three X-ray generators, one being a high-power rotating anode set, X-ray powder cameras, goniometers (Weissenberg, oscillating crystal and optical), Hilger-Watts 4-circle, single crystal automatic diffractometer, an X-ray powder diffractometer, and polarizing microscope with heating stage.*



## GAS CHROMATOGRAPHY

This technique is particularly useful for identifying and estimating volatile constituents of complex mixtures.

## Gas Kinetics

Kinetics and mechanisms of gas-phase reactions and general free radical chemistry using static and discharge-flow techniques. Reactions of alkyl and alkoxy radicals, nitrogen oxide and nitrogen dioxide. Mechanisms of gas-solid reactions.

*High vacuum techniques and product analysis by vapour-phase chromatography, infra-red and mass spectrometry. Emission spectroscopy.*



# PROCESS RESEARCH

Head of Branch     H ZIEBLAND

The Process Research Branch is concerned with means and equipment for processing chemicals on a production scale. Plant and facilities are designed for the manufacture of hazardous compounds and mixtures with particular emphasis on safety, remote-control, and instrumentation. The Branch has special interests in unit operations such as crystallization, mixing, heat transfer, and precision measurements of thermal properties of fluids.

Research and development is being carried out on fibre-reinforced, metallic and non-metallic materials and on the growth of ceramic whiskers.

## ACTIVITIES AND FACILITIES

### Large-scale Production

Development of laboratory syntheses on to pilot- and full-scale processes; pilot plant operation; manufacture of experimental chemicals and materials, including high explosives, polymer and rocket ingredients, whiskers and aligned inorganic fibres.

*Protective enclosures, with remote control, for processing experimental quantities of dangerous chemicals (i.e. fire, explosion, toxicity risks): one for large laboratory-scale glass plant; another for 2.5 kg pilot plant scale, equipped with a closed circuit television loop.*

*A wide range of pilot-scale plant, including: plant for concentrating nitric acid free from nitrous acid; nitration and sulphonation unit with brine cooling, remote control and acid mixing plant; glass-lined oil heated reactors for polymer manufacture.*

*Separators such as decanters; pressure-, vacuum- and rotary filters; batch and continuous stainless steel centrifuges; liquid centrifuges; and dry powder sieves.*

*Dryers, including hot air-, vacuum tray- and rotary-steam tube types.*

*Grinding plant, including jaw crusher; roll mill; edge-runner mill; hammer mills; and 'micronizer' fluid energy mill.*

*Mixers: double cone powder blender; medium and heavy paste mixers.*

*Packed, gas-liquid absorption towers.*

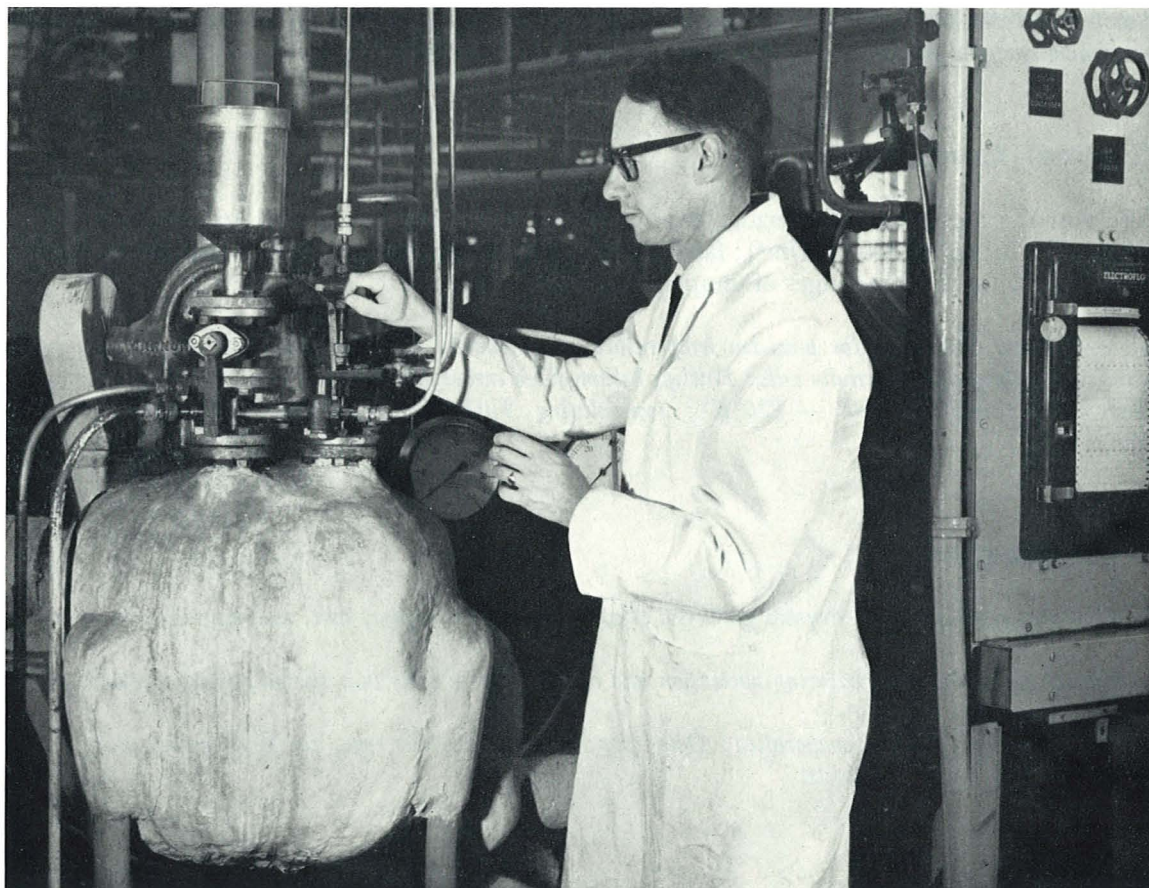
*Distillation: a 5-cm glass 'molecular' still; a 50-litre glass batch distillation unit; glass distillation column of high efficiency for high vacuum and 150°C; similar unit in stainless steel for pressure distillation up to 1 MN/m<sup>2</sup>.*

### Intensive Drying or Stripping

The intensive drying (or stripping) of high boiling liquids which may be sensitive to heat or excessive turbulence.



*Continuous plant (11.5 kg/h), based on single passage of liquid down a column packed with a battery of vertical helical coils.*



PLANT FOR POLYESTER MANUFACTURE

An example of the development of laboratory syntheses on to pilot-scale processes.

## Convective and Radiative Heat Transfer from Flames and Gases

Studies of convection and radiation from flames and combustion gases (up to  $3800^{\circ}\text{K}$ ;  $10\text{ MN/m}^2$ ); radiative emissivity of water vapour ( $1500^{\circ}$ – $3500^{\circ}\text{K}$ ;  $0.5$ – $10\text{ MN/m}^2$ ).

*Two instrumented test cubicles; water-cooled combustion chambers; black-body furnace to calibrate radiation sources.*

## Convective Heat Transfer to Liquids

Convective heat transfer from electrically heated surfaces to aviation kerosine and other liquids under sub-cooled, boiling, and supercritical conditions.

*Closed-loop apparatus with rectangular flow channel containing heated tube (maximum power,  $10\text{ kW}$ ; maximum pressure,  $10\text{ MN/m}^2$ ; maximum fluid flow rate,  $1.2\text{ kg/sec}$ ). Photographic observation using Fastex ciné camera ( $18\,000$  half-frames/sec) and  $0.2\text{ }\mu\text{sec}$  argon flash lamp.*

## Convective Heat Transfer to Cryogenic Fluids

Convective heat transfer to fluid hydrogen in the vicinity of the critical point and at supercritical pressures; fluid dynamics of cryogenic fluids.

*Remotely-operated test rig in which cryogenic fluids flow through asymmetrically heated rectangular ducts (maximum energy dissipation, 40 kW; maximum pressure, 5 MN/m<sup>2</sup>).*

## Thermal Conductivity

Precision measurements of thermal conductivities of liquids, gases, and supercritical fluids (12°—650°K; up to 300 MN/m<sup>2</sup>); facilities equally suitable for measuring viscosity, dielectric constant, etc. over wide ranges of temperature and pressure.

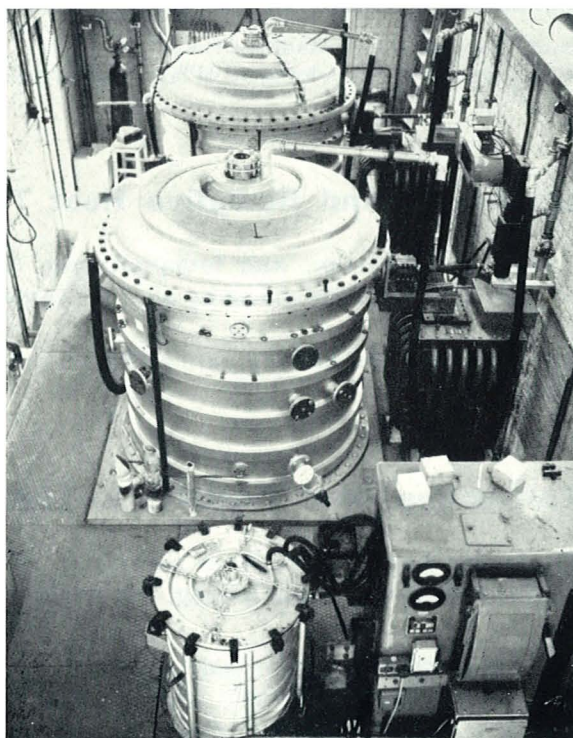
*Air conditioned laboratory for precision temperature measurement; protected annexe for compressing gases and liquids; thermal conductivity cells: Phillips helium-filled cryogenerator (12° — 90°K); liquid nitrogen-filled metal thermostat (90° — 220°K); recirculating Turbotherm-filled liquid thermostat (300° — 650°K).*

## Crystallization

Studies of nucleation and crystal growth; control of crystal shape, size, and size distribution.

*Laboratory equipment for measuring nucleation and crystal growth rates in a stirred cooling crystallizer.*

*Pilot crystallizers: Kestner evaporative; Oslo type; and pulsed tube type, for performance studies and production of crystalline products.*



**'BRAN TUBS'**

High temperature furnaces for synthesis of silicon nitride whiskers.



## High Temperature Equipment

*Furnaces of various types for operation up to about 1600°C; high frequency heating equipment; temperature measuring devices.*

## Fibre Processing Plant

*Equipment for sizing whiskers and other short fibres and plants to classify and align asbestos and other whiskers for making composite materials.*

## Fibre Testing Equipment

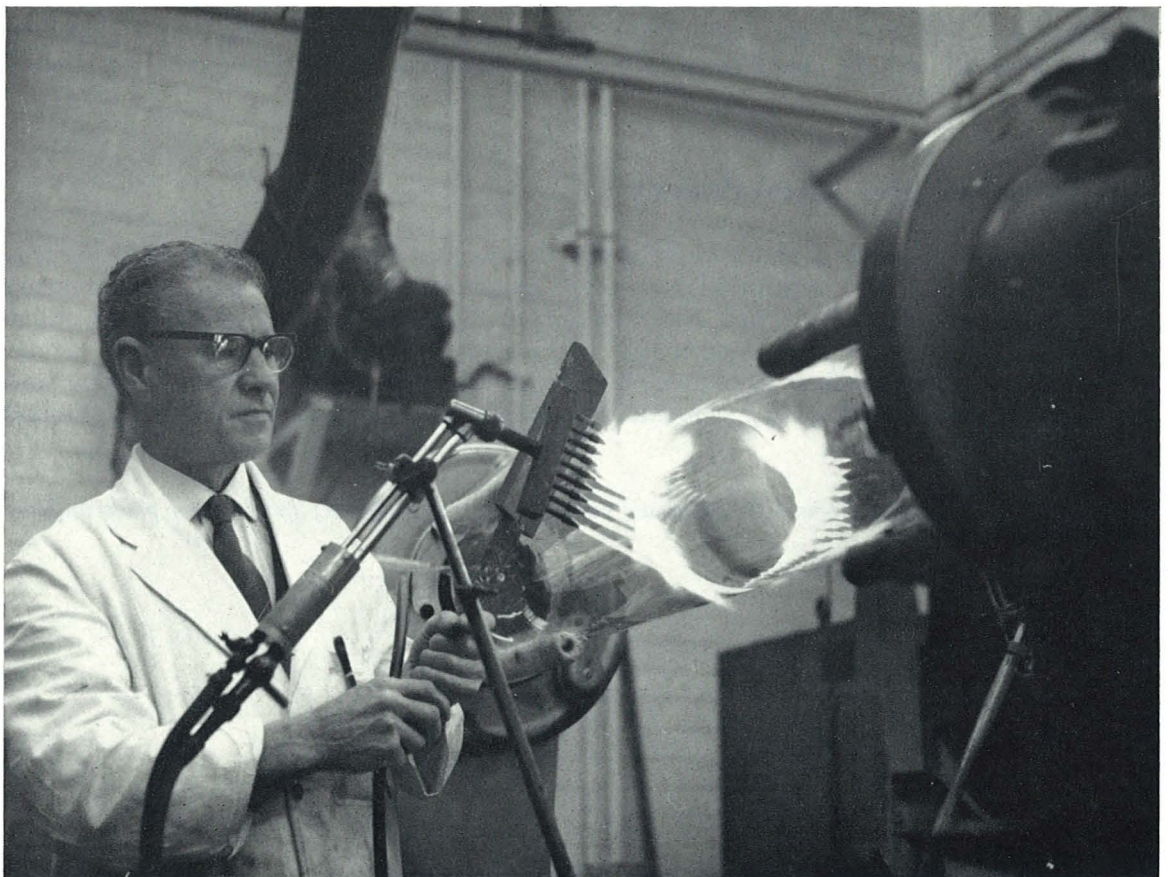
*Marsh micro-testing machine and various macro-testing machines.*

## Microscopes

*A range of optical microscopes and a J.E.M. 7 electron microscope.*

## Instrumentation and Glass Engineering

This Section, part of the Engineering Branch, is responsible for the development and application of instruments and apparatus based on electronic and glass engineering techniques.



### GLASS ENGINEERING

The glass engineering workshop is equipped to undertake construction of scientific glassware ranging from special laboratory articles to the large-scale item shown here.



# MISCELLANEOUS RESEARCH ACTIVITIES

In addition to research and development work performed by the Branches described above, certain specialized or exploratory research topics are undertaken by small groups under the direction of Dr. L. J. Bellamy, Mr. G. K. Adams,

## Spectroscopy

Studies of factors affecting infra-red absorption spectra of complex molecules; assignment of absorption bands and interpretation of spectra.

*Unicam SP 100 spectrometer (3650—300  $\text{cm}^{-1}$ ); Grubb Parsons GS2 grating spectrometer (4000—650  $\text{cm}^{-1}$ ); Unicam SP 700 spectrometer (55000—4500  $\text{cm}^{-1}$ ); attachment to determine emission spectra in the visible region; time-resolved luminescent spectroscopy in the visible region (resolution, 1  $\mu\text{sec}$ ).*

## Flame and Explosion Phenomena

*An Elliot 903 computer is in use, and computer programmes are available for calculation of flame and explosion properties, and the thermodynamic properties of two-phase, multi-element systems in chemical equilibrium.*

## Autoxidation and Antioxidants

Kinetics and mechanism of free radical chain reactions in solution; catalysis of oxidation-reduction reactions by heavy metals; effect of oxidative degradation, light, and ionizing radiation on polymeric materials. Research aimed at preventing or inhibiting oxidative degradation. Design and assessment of new antioxidants; mechanism of antioxidant action, particularly synergistic effects (mixtures of free radical acceptors; free radical acceptor and chelating reagent or S-containing peroxide decomposer); inhibition of autoxidation by metal chelates.

*Warburg apparatus and equipment for automatic recording of oxygen uptake; facilities for photochemistry and radiochemistry.*

# INDEX OF ACTIVITIES

Titles of branches have been abbreviated as follows:

E	Explosives	NM	Non-metallic Materials
P1	Propellants 1	GC	General Chemistry
P2	Propellants 2	Misc. Res.	Miscellaneous Research
PR	Process Research	IGE	Instrumentation and Glass Engineering Section

ADHESIVES		CRYSTALLOGRAPHY	
Development, application and strength	P2	Identification, phase analysis, crystal structure	GC
AGEING			
Non-metallic materials	NM	DEFORMATION	
Explosives and propellants	GC, P1	Non-metallic materials	NM
ANTIOXIDANTS	Misc. Res.	DIFFERENTIAL THERMAL ANALYSIS	GC
ASBESTOS REINFORCED MATERIALS	NM, PR	DISTILLATION	
ATOMIC ABSORPTION SPECTROPHOTOMETRY	GC	Fractional, pilot-scale, 'molecular'	PR
AUTOXIDATION	Misc. Res.	DRYING AND STRIPPING	
		Heat-sensitive liquids	PR
BALLISTIC ASSESSMENT	P1, P2		
BURNING RATE DETERMINATION	P1, P2	ELASTICITY AND ELASTOMERS	NM
		ELECTROMETRIC ANALYSIS	GC
CALORIMETRY, PRECISION	P1	ELECTRONIC INSTRUMENTATION	IGE
CARBIDES		ELECTRON MICROSCOPY	PR
High temperature materials	PR	ELECTROSTATIC RISK	
CERAMIC MATERIALS	PR	Generation of electric charge, electrical resistance measurement, susceptibility to ignition	E
CHEMICAL ANALYSIS		EMISSION SPECTROSCOPY	
Instrumental, elemental and functional group	GC	Visible region	Misc. Res.
CHEMICAL MANUFACTURE		ENVIRONMENTAL TESTING	
Laboratory investigations	GC	Effect of contaminants and climatic conditions on polymers	NM
Pilot-scale processes	PR	Explosives and propellants	GC, P1
CHROMATOGRAPHY, SOLUTION		EXPLOSIVES EVALUATION	
Analytical and preparative scale, column and thin layer, counter-current extraction	GC	Type of hazard, degree of protection and storage requirements	E
CLIMATIC EFFECTS		EXPLOSIVES SYNTHESIS AND MANUFACTURE	GC, E, PR
Non-metallic materials	NM		
Explosives and propellants	GC, P1	FATIGUE	
COMBUSTION		Non-metallic materials	NM
Solid propellants and organic materials	P1	FIBRE REINFORCED MATERIALS	PR
Liquid propellants	PR	FLAME AND EXPLOSION PHENOMENA	
COMPATIBILITY TESTING		Combustion	P1
Effect of contaminants and climatic conditions on hazardous materials	GC	Detonation	E
COMPOSITE MATERIALS	NM, PR	Theory	Misc. Res.
COMPRESSION TESTS	NM	FLUID DYNAMICS	
CREEP TESTING		Cryogenic fluids	PR
Non-metallic materials	NM	FREE RADICAL CHEMISTRY	GC, Misc. Res.
CRYOGENIC FLUIDS			
Fluid dynamics and heat transfer	PR	GAMMA IRRADIATION	Misc. Res.
CRYSTALLIZATION TECHNOLOGY	PR	GAS CHROMATOGRAPHY	
CRYSTAL GROWTH		Analytical	GC, NM, P1
From vapour	PR	Preparative	NM
From solution	PR, P2	GAS KINETICS	GC

GLASS ENGINEERING			
HAZARD APPRAISAL			
Impact and friction sensitiveness, ease of ignition, burning to detonation, shock sensitiveness, electrostatic risk			
Thermal stability and self-heating			
HEAT RESISTANT MATERIALS			
Polymers			
Composites			
HEAT TRANSFER			
Convective and radiative, flames and combustion gases, liquid fuels, cryogenic fluids			
HIGH SPEED PHOTOGRAPHY			
Explosive phenomena			
Mechanical testing			
HYDROGEN, LIQUID			
IGNITION			
Hazardous materials			
IMPACT TESTING			
Polymers			
INFRA-RED SPECTROSCOPY			
Qualitative and quantitative analysis			
Polymer characterization			
Gas kinetics research			
Combustion			
Basic studies			
INITIATORY EXPLOSIVES			
JOINT STRENGTH			
LIQUIDS			
Critical point phenomena			
LOAD CELLS			
MASS SPECTROMETRY			
MATERIALS			
Non-metallic			
Composites			
MECHANICAL TESTING			
Non-metallic materials			
Composites			
Adhesives			
Propellants			
MICROANALYSIS			
MICROSCOPY			
Crystal morphology			
Polymer crystallization			
Fibres and ceramic whiskers			
MIXERS, DESIGN AND OPERATION			
Performance, safety, application to hazardous materials			
NITRIDES			
High temperature materials			
NITROCOMPOUND CHEMISTRY			
IGE			
NOISE EVALUATION			
Measurement and simulation of impulsive noises, sonic bangs			
NON-AQUEOUS TITRIMETRY			
NON-DESTRUCTIVE TESTING			
Radiographic and ultrasonic inspection			
NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY			
Analysis and structure determination			
NUCLEATE BOILING			
OXIDATION INHIBITORS			
PARTICLE SIZE ANALYSIS			
PASTES, STIFF			
Processing and rheology			
PLASTICS			
Chemistry and physics			
POLAROGRAPHY			
POLYMER CHEMISTRY			
Synthesis, characterization, stability			
POLYMERIZATION KINETICS			
Basic studies			
Applied studies			
POLYMER PHYSICS AND ENGINEERING			
Non-metallic materials and reinforced plastics, physical properties and engineering data			
POLYMER TECHNOLOGY			
Curable and non-curable polymers			
Heavily-loaded thermo-plastic rubbers			
Polyurethane elastomers			
PRESSURE MEASUREMENT			
Explosions			
Rocket motor firing			
Liquid flow			
PROOFED FABRICS			
PROPELLANT PROCESSING			
Nitrocellulose-based			
Rubber-based			
PYROLYSIS			
Polymers			
Organic materials			
RADIOCHEMISTRY			
RADIOGRAPHIC INSPECTION			
REFRACTORY MATERIALS			
REMOTE CONTROL METHODS			
Mixing, extrusion, injection moulding			
Manufacture of hazardous chemicals			
Closed circuit TV			
RHEOLOGY			
Polymers and composite materials			
Adhesives			
Solid propellants			
Stiff pastes			
Fibres			
RUBBER, SPECIAL APPLICATIONS			
Conducting, antistatic, proofed fabric			



SAFETY	
Manufacture, handling and storage of hazardous materials	E, PR, P1, P2
SEALANTS	
Lutings and cements for threaded joints	P2
SHEAR TESTS	
Joints	P2
SONIC BANGS	
	E
SPECTROSCOPY	
Fundamental studies	Misc. Res.
Qualitative and quantitative analysis	GC
Application to combustion	P1
gas kinetics	GC
polymers	NM
SURFACE CHEMISTRY	
Surface tension, contact angles	P2
SYNTHETIC CHEMISTRY	
	GC
TEMPERATURE MEASUREMENT	
Combustion and calorimetry	P1
Thermal conductivity	P2
Thermochemical analysis	GC
High temperatures	PR
TENSILE STRENGTH TESTING	
	NM, PR
THERMAL CONDUCTIVITY	
Liquids, gases, supercritical fluids	PR
THERMAL STABILITY	
Polymers, degradation studies	NM
Hazardous compounds	GC
THERMOCHEMICAL ANALYSIS	
Differential scanning and heat flow calorimetry, thermogravimetry	GC
THERMOCHEMICAL DATA	
Heats of formation, combustion and wetting	P1
ULTRA-VIOLET SPECTROMETRY	
Qualitative and quantitative analysis	GC, NM
VAPOUR PHASE CHROMATOGRAPHY	
	GC, NM
VISCOMETRY	
	NM
VULCANISATION	
	NM
WHISKERS, CERAMIC	
Production, processing and testing	PR
Classification and alignment	PR
X-RAY CRYSTALLOGRAPHY	
Powder diffraction photography, single crystal analysis	GC

## INDEX OF FACILITIES

ABSORPTION TOWERS			MICROCOMBUSTION EQUIPMENT	GC
Packed, gas-liquid	PR		MICROSCOPES	
ARMoured CUPBOARDS AND PROTECTIVE ENCLOSURES			Time-lapse, photographic recording	NM
Small scale tests and preparations	GC, E		Projection	PR
Large scale manufacture	E, PR		Hot-stage polarizing	GC
ATOMIC ABSORPTION SPECTROPHOTOMETER	GC		Electron	PR
AUTOXIDATION LABORATORY			MIXERS	
Oxygen uptake measurement	Misc. Res.		Powder blending	PR
			Heavy paste	PR, P1, P2, E
CALORIMETERS			MOLECULAR WEIGHT APPARATUS	
Precision	P1		Viscometry, osmometry and light scattering	NM
Differential scanning and heat flow	GC		Vapour pressure osmometry, ebulliometry and cryoscopy	GC
CHEMICAL PLANT			NUCLEAR MAGNETIC RESONANCE SPECTROMETER	NM
Nitration, sulphonation, acid concentration, polymer manufacture, fibre and whisker classification and alignment	PR			
CREEP TESTING EQUIPMENT	NM		PARTICLE SIZE EQUIPMENT	
			Gas adsorption and permeability, micromerograph, sedimentometer	GC, P2
DISTILLATION EQUIPMENT			PLASTOMETERS	
Fractionating columns, pilot-scale and 'molecular' stills	PR		Flow and deformation, brittle point	P2
DRYERS			PHOTOGRAPHIC EQUIPMENT	
Hot air, vacuum, steam	PR		High speed streak and framing cameras	E, NM, P2
ENVIRONMENTAL TEST FACILITIES			Time-lapse photomicroscopy	NM
Climatic chambers	P1		Hot-stage photomicroscopy	GC
Ageing ovens	GC, NM		POLAROGRAPH	GC
Tropical test site	NM		PRESSURE SENSORS	
EXTRUSION PLANT			Explosion and noise	E
Propellants and explosives	P1, P2, E		Propellant impulse	P1, P2
Polymers	NM		Liquid flow	PR
FURNACES			RADIOCHEMICAL TRACER LABORATORY	GC
High temperature, laboratory and pilot-scale	PR		REACTION VESSELS, PILOT-SCALE	PR
GAS CHROMATOGRAPHS			REMOTE CONTROL FACILITIES	
Analytical	GC, NM, P1		Process bays and equipment design	PR, E
Preparative	NM		Master slave manipulators	E, GC
GRINDING PLANT			RHEOLOGICAL TEST FACILITIES	
Jaw crusher and various mills	PR		Static, dynamic and creep loading	NM, P2
HEAT TRANSFER TEST RIGS			Impact, flywheel and rotating beam machines	NM
Variable pressure, temperature and flow rates	PR		Microtest	PR
			Variable environment	NM, P2
IMPACT TESTERS			SEPARATORS	
Polymers	NM		Decanters, sieves, filters, and centrifuges	PR
INFRA-RED SPECTROMETERS			THERMAL CONDUCTIVITY CELLS	
General purpose instruments	GC, NM, P1		Variable pressure and temperature	PR
High resolution	Misc. Res.		THERMOCHEMICAL ANALYSIS INSTRUMENTS	
MASS SPECTROMETER	GC		Differential scanning and heat flow calorimeters, thermogravimetric balance	GC

THERMOMETERS		
Platinum resistance		P1
Multirange recording		GC
ULTRASONIC INSPECTION EQUIPMENT		
Propellants		P1
Polymers		NM
ULTRA-VIOLET SPECTROMETERS		
General purpose		GC, NM
Continuous scanning	GC, Misc. Res.	
VISCOMETERS		
Bulk viscosity		NM, P2
Intrinsic viscosity		NM
X-RAY EQUIPMENT		
Radiographic inspection		P1, E
Crystallographic analysis		GC











# Explosives Research & Development Establishment

## **Research and Development Activities and Facilities**

MINISTRY of

DEFENCE



*Amendments in Blue Made 21 June 1974*

**EXPLOSIVES  
RESEARCH & DEVELOPMENT  
ESTABLISHMENT**

**RESEARCH and DEVELOPMENT  
ACTIVITIES and FACILITIES**



# HOW TO CONSULT ERDE

ERDE is able to offer a limited, free consultative service to industrial undertakings on problems related to expertise available in the Establishment.

Problems involving more extensive investigations or the use of equipment and special facilities may be undertaken for a fee, subject to the demands of the Establishment's research and development programme.

Enquiries may be made

- (a) by letter, addressed to The Director

ERDE

Ministry of ~~Technology~~ <sup>DEFENCE</sup>

Waltham Abbey, Essex; **EN 9 1BP**

- (b) by telephone, asking for Heads of specific branches or ERDE Industrial Liaison Officer  
Waltham Cross 23688; (STD) 97-23688 Inner London; (STD) 0992-23688 Outside London.

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# INTRODUCTION

The primary function of the Explosives Research and Development Establishment is to undertake research on, and development of, explosives, propellants and related exothermic compositions to meet the present and future requirements of the three Services. The Establishment is also actively engaged on materials work, concerned principally with the chemistry and physics of polymers, and with new engineering materials based on refractory fibres.

To exercise these functions, ERDE maintains a staff of scientific, technical and engineering personnel representing a wide range of disciplines but with particular expertise in chemistry, chemical engineering and physics. Research and development tasks are shared by six technical branches supported by drawing office, machine shop, electronics and glass engineering facilities, and by appropriate library and information services.

It is the purpose of this book to give a brief outline of the work of the technical branches, especially those aspects involving expertise, facilities or equipment which are likely to be of interest to industrial undertakings.



# MANAGEMENT ORGANIZATION

Director	Dr. L J Bellamy
Deputy Director	<div>Mr G.K. Adams <del>MR R HERON</del></div>
<del>Special Merit 'B' Post</del>	<del>Mr. G K Adams</del>
Heads of Branches	
Explosives	<div>DR C A BECK</div>
Propellants 1	<div>DR C G LAWSON</div>
Propellants 2	Mr. P R Freeman
Non-metallic Materials	Dr. B L Hollingsworth
General Chemistry	<div>DR A R OSBORN</div>
Process Research	Mr. H Ziebland
Chief Engineer	Mr. R Fisher
Chief Safety Officer	Mr. J V Griffiths
Chief Administrative Officer	Mr. S F M Whiteside
Individual Merit Scientists	Dr. A W H Pryde (Chemical Engineering) Mr. G W C Taylor (Initiator Explosives) Dr. N Uri (Autoxidation) <div>DR D H RICHARDS (POLYMER CHEMISTRY)</div>



# EXPLOSIVES

Head of Branch

DR C A BECK

The Explosives Branch deals primarily with the development of sensitive, initiatory explosives and high explosive and propellant compositions of improved performance. Trials are performed to assess sensitiveness and hazards associated with all explosive materials.

## ACTIVITIES AND FACILITIES

### Explosive Risk

Standard tests designed to evaluate and to compare the explosive risk of materials are based on impact and friction sensitiveness, ease of ignition, susceptibility to burn to detonation, and shock sensitiveness. Results enable recommendations to be made regarding type of hazard, degree of protection and appropriate storage requirements.

*Armoured cupboards for small-scale tests (up to 30 g) and instrumented firing site facilities for larger quantities (up to 4.5 kg). Firing site for small-scale underwater tests.*

### Electrostatic Risk

Electrostatic risks associated with handling explosive powders, vapour/air, and gas/air mixtures are assessed by measuring

- (a) electrostatic voltages and charges on transferring solids or liquids, or on separating surfaces;
- (b) comparative electrification of materials, especially fabrics and plastics;
- (c) electrical resistance of floors, footwear and items of equipment;
- (d) susceptibility to ignition by capacitor type discharge.

*Electrostatic voltmeter (30—18 000 volts); resistance meters (up to  $10^{16}$  ohms); facilities for measuring electrostatic spark sensitiveness of powders.*

### High Speed Photography

This technique is used to record mechanical and explosive phenomena, to investigate shock initiation of explosives and to determine propagation velocities.

*Portable 16 mm ciné camera (100—18 000 frames/sec): framing camera (25 frames at 150 000 —  $4 \times 10^6$  frames/sec), installed in 2.25 kg explosives test facility; streak camera (writing speed 0.7 mm—9 mm/microsec), installed in 4.5 kg explosives test facility. Printing facilities include conversion of 35 mm frames into animated 16 mm film, and colour printing of negatives of explosive phenomena with particular reference to correct colour balance.*



## Noise Evaluation

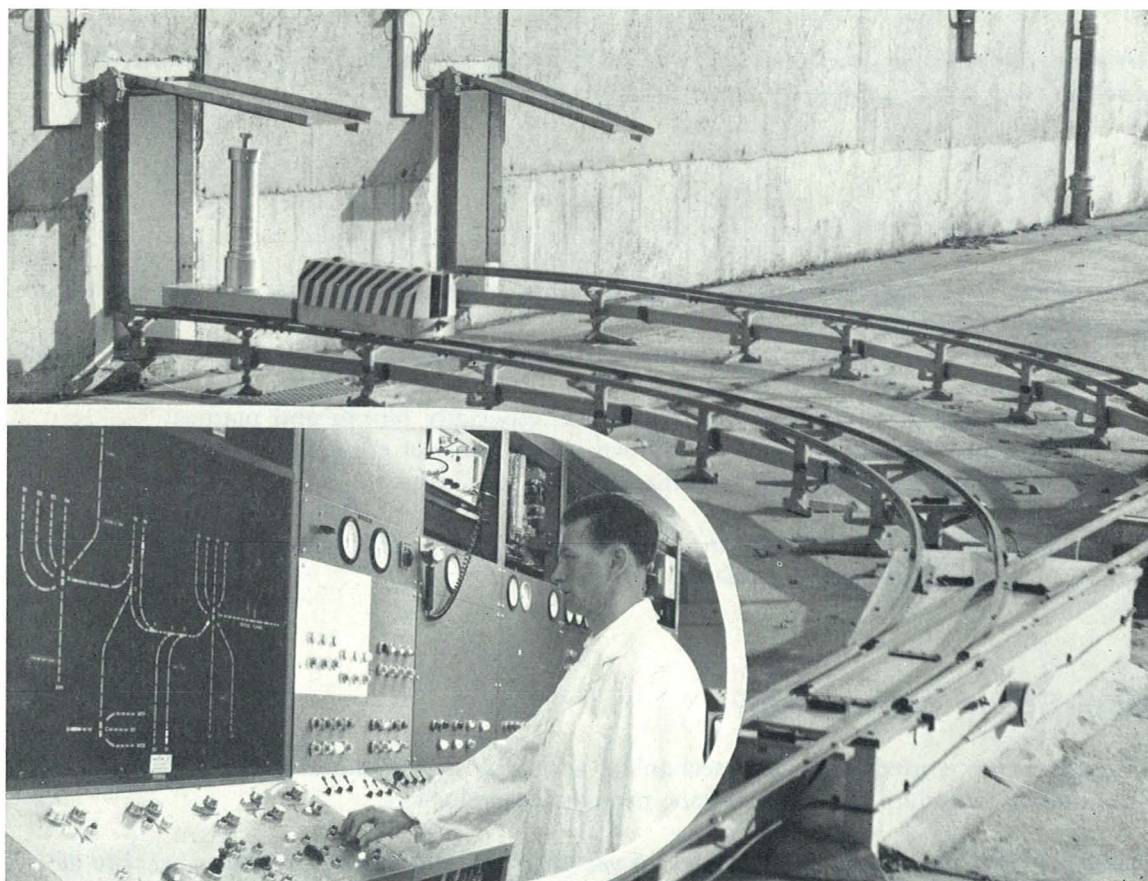
Measurement and analysis of impulsive noises including those of long duration (e.g. sonic booms), and their simulation by explosives. Techniques for generating a wide range of pressure waveforms in air may be applied to studying the behaviour of structures to shocks of this kind.

*Apparatus to record shock waves in air down to  $5 \text{ N/m}^2$  ( $0.1 \text{ lbf/ft}^2$ ).*

## Remote Control Methods

Development of remote control methods for manufacturing and testing dangerous explosive materials.

*Process bays (limit 7.25 kg TNT equivalent) in which hazardous operations can be performed by remote control. Remotely operated mixing, extruding and injection moulding unit (4.5 kg) with temperature, vacuum and shear rate controls on mixer (viscosities 2—3 000 poise). Strong bay (limit 1.35 kg TNT equivalent) with master slave manipulators (3.5 m extended reach), X-ray facility (250 kv), and armoured viewing window. Capability for melt-mixing and moulding, or for pressing explosives, and for carrying out basic machinery operations on explosive charges by remote control. Closed circuit TV available to position all remotely-controlled operations.*



### REMOTE-CONTROL TRANSPORTATION OF HAZARDOUS MATERIALS

A five-inch gauge electric railway system used to transport hazardous materials between manufacturing, testing and storage areas.

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## Polymer Technology

Cure chemistry of polyurethane elastomers prepared from di-isocyanates and hydroxy-terminated polyesters and polyethers; optimization of physical properties of heavily-loaded rubbers.

*Small scale plant facility for development work; laboratory equipped to study physical properties and ageing characteristics.*

# PROPELLANTS 1

Head of Branch

DR C G LAWSON

Propellants 1 Branch is largely concerned with the development of propellants based on nitrocellulose. Work is undertaken on methods for controlling ballistics, and to devise ballistic assessment techniques. Attention is also given to the quality control of propellants by non-destructive tests involving X-ray or ultrasonic inspection.

## ACTIVITIES AND FACILITIES

### Propellant Processing

Experimental processing of nitrocellulose-based propellants poses problems similar to those involved in processing plastic materials, especially consideration of viscosity control and particle size.

*Plant for rolling and extrusion of incorporated materials; preparation of felted paper tubes with high length/diameter ratios.*

### Combustion

Investigations of propellant combustion using techniques equally applicable to combustion of fuel oils and gases. High temperature degradation of organic materials, research capable of being extended to flammability and flame-proofing of plastics.

*Equipment to measure temperature profiles at burning surfaces, and appropriate instruments (infra-red and ultra-violet spectrophotometers and gas chromatographs) for flame decomposition product analysis.*

### Ballistic Properties

Burning rates and calorimetric measurements. Experimental techniques are available to study solids, liquids, and gases, and to determine precise heats of combustion, formation and wetting.

*Equipment to measure static and dynamic pressures for fractions of a second or longer in ranges up to  $31 \text{ MN/m}^2$  (4500 psi). Calorimeters with platinum resistance thermometry systems (precision better than  $1 \times 10^{-3}^\circ\text{C}$ ).*

### Non-Destructive Testing

The integrity and bonding of propellants are inspected by radiographic and ultrasonic test methods which may also be used to investigate conventional plastics and bonded systems.

*Radiographic (400 kV) and ultrasonic (375 kc/sec through transmission) inspection equipment.*





PRECISION CALORIMETRY

An NPL-pattern bomb calorimeter for determining heats of combustion with an accuracy approaching 1 part in  $10^4$ .

# PROPELLANTS 2

Head of Branch     P R FREEMAN

Propellants 2 Branch is responsible for research and development on composite propellants based on plastic or rubbery binder systems. The facilities include laboratories for quality control, including ballistic and physical property assessment, together with small- and large-scale manufacturing plants.

Basic and applied research on rheology and adhesion is performed to improve the mechanical behaviour of solid propellants and to provide an advisory service on the use of sealants, adhesives and lutings.

## ACTIVITIES AND FACILITIES

### Composite Propellant Formulation, Manufacture and Assessment

Formulation and manufacture of paste-like and rubbery composite propellants, assessment of ballistic properties by strand burning and static firing of small rocket motors. Compositions of high energy are available covering a wide range of burning rates.

*Comprehensive facilities for the manufacture of propellants and filling of small rocket motors. Strand burning bombs and small static proofstand.*

### Sealants and Adhesives

Development of lutings and cements for threaded joints, etc., and adhesives for metal, plastics, paper, cloth and leather; study of tensile and shear strength, and of stress-strain behaviour of adhesives and joints.

An advisory service is offered on all aspects of bonding and hermetic sealing of joints, and on joint design.

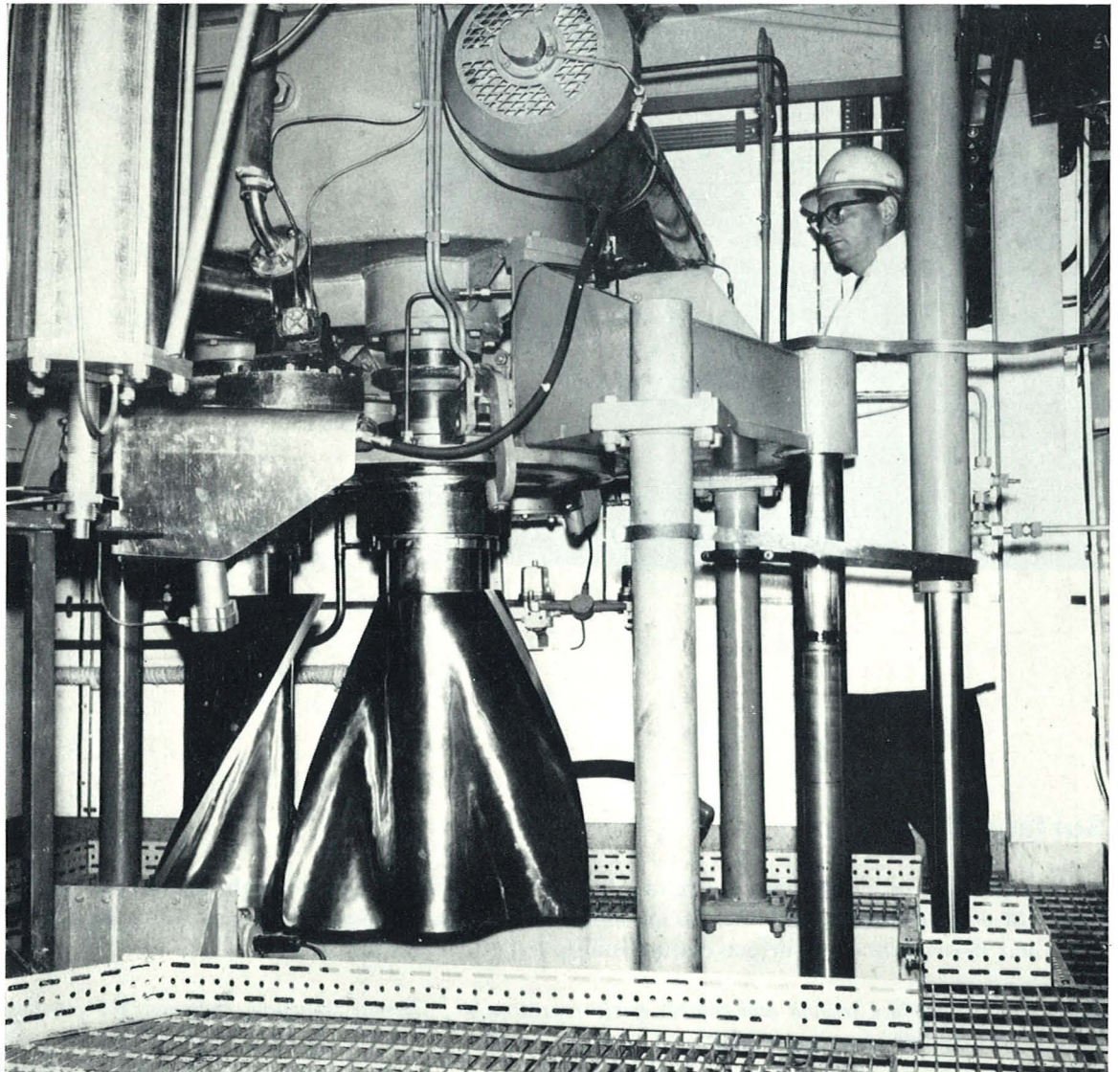
*Instron universal testing machine (load,  $10^{-3}$ —5000 kg; cross-head speed,  $10^{-3}$ —10 mm/sec; cross-head travel, 1 m) with thermostatic chamber ( $-50^{\circ}$  to  $60^{\circ}\text{C}$ ) and automatic integrator. Hydraulically-operated high-speed test machine (strain rate up to 10 cm/sec); Sanborn twin-channel recorder (10 ms response) and Tektronix oscilloscope. Jigs for the preparation and testing of joints; equipment for preparation of proofed fabrics; viscometers, plastometers; facilities for storage at controlled humidities and temperatures.*

### Rheology of Stiff Pastes and Highly Filled Rubbers

Dependence of rheological behaviour of highly concentrated solid-in-liquid dispersions on nature of solids, solids loading, magnitude and distribution of particle size, nature and viscosity of liquid, temperature and test methods. Mechanical behaviour of highly filled rubbers by tensile testing over a wide range of temperatures and strain rates. Construction of master curves of mechanical behaviour by time-temperature superposition.



*Plastometers to study flow and deformation behaviour including fatigue effect of cyclic compression and extension; fatigue by flexing; effect of imposed hydrostatic pressure; response to biaxial strain. Brittle point apparatus. Tensile testing apparatus.*



VERTICAL MIXER FOR RUBBERY-TYPE SOLID PROPELLANTS  
The mixing pot has been lowered for removal of the propellant mix.





MEASUREMENT OF CONTACT  
ANGLE OF WATER ON A  
CONTAMINATED STEEL SURFACE

## Surface Chemistry

Surface tensions of highly viscous organic liquids; effect of molecular weight and temperature. Study of contact angles and interfacial tensions between viscous liquids and inorganic salts, and their dependence on surface contaminants (moisture, surfactants).

*Equipment for surface tension and contact angle measurement; thermal siphoning technique for growing large perfect crystals of inorganic salts.*

## Technology of Pastes and Slurries

Formulation, manufacture, and handling of stiff pastes based on curable and non-curable liquid organic polymers containing a high proportion of solid inorganic filler.

*Vertical and horizontal mixers of various capacities capable of processing mixes up to  $10^7$  poise viscosity; de-aerating pug-mills and pressure extrusion equipment.*

# NON-METALLIC MATERIALS

Head of Branch     B L HOLLINGSWORTH

The Non-metallic Materials Branch undertakes basic and applied research on the chemistry and physics of polymers with particular regard to synthesis, characterization, degradation, and mechanical behaviour under a range of test conditions. The Branch offers an advisory service on the applications of polymers, and supervises long-term environmental testing at the Tropical Research Unit, which is a joint project with Australia.

## ACTIVITIES AND FACILITIES

### Polymer Physics and Engineering

Study of the physical properties of non-metallic materials and reinforced plastics: stress-strain curve, strength, fracture energy, damping capacity, creep, fatigue, stress relaxation, and dimensional stability. Effects of rate of deformation, temperature and moisture. Stress relaxation tests on rings and beams; dynamic mechanical properties of discs. Compression cell to study effects of dynamic, static, and creep loading.

Hounsfield apparatus (extension rate, 0.0013 — 50.8 cm/min; temperature, — 80° to 80°C); ~~Baldwin machine~~; ~~Goodbrand machine (fibre test)~~. Avery Izod impact machines (capacity 17 kg.m; maximum loading rate,  $18 \times 10^2$  kN/sec; photographic recording with 35 mm. streak- or 12 000 frames/sec Fastex-cameras). ~~Flywheel machine (fracture energies at impact velocities of 130—1300 cm/sec)~~. Ultrasonic equipment (150 kc/sec—2 Mc/sec; up to 80°C). Rotating beam machine (fatigue properties). *Automated*

*Creep Measurement Equipment*

### Polymer Chemistry—Synthesis, Characterization, and Stability

Investigation of novel and potentially useful polymer systems; monomer and polymer synthesis, polymer fractionation, mechanism and kinetics of polymerization, reactions of polymers.

Characterization of polymers by molecular weight (viscometry, osmometry, light scattering, and end-group analysis), spectroscopy (IR, UV and NMR), dilatometry, bulk viscometry, compressibility and thermal expansion measurements, and by optical examination of polymer morphology.

*New Polymer Stability Section*

Stability of addition and condensation polymers to heat, ultra-violet light, and high energy radiation; effects of chemical structure, impurities and environment. Mechanism and kinetics of degradation and its effect on molecular weight and physical properties.

MOLECULAR WEIGHT *Hewlett-Packard 502 high-speed membrane osmometer (maximum operating temperature 130°C); Brice-Phoenix Series 2000 Universal light scattering photometer with MSE high-speed centrifuge.* *Waters DPL*

BULK PROPERTIES *Epprecht Viscometer (0.1—10<sup>6</sup> poise, 0°—180°C); linear expansion apparatus for glass transition temperatures; pressure balance (temperature controlled to  $\pm 0.001^\circ\text{C}$ ).*





#### AVERY IZOD PENDULUM IMPACT APPARATUS

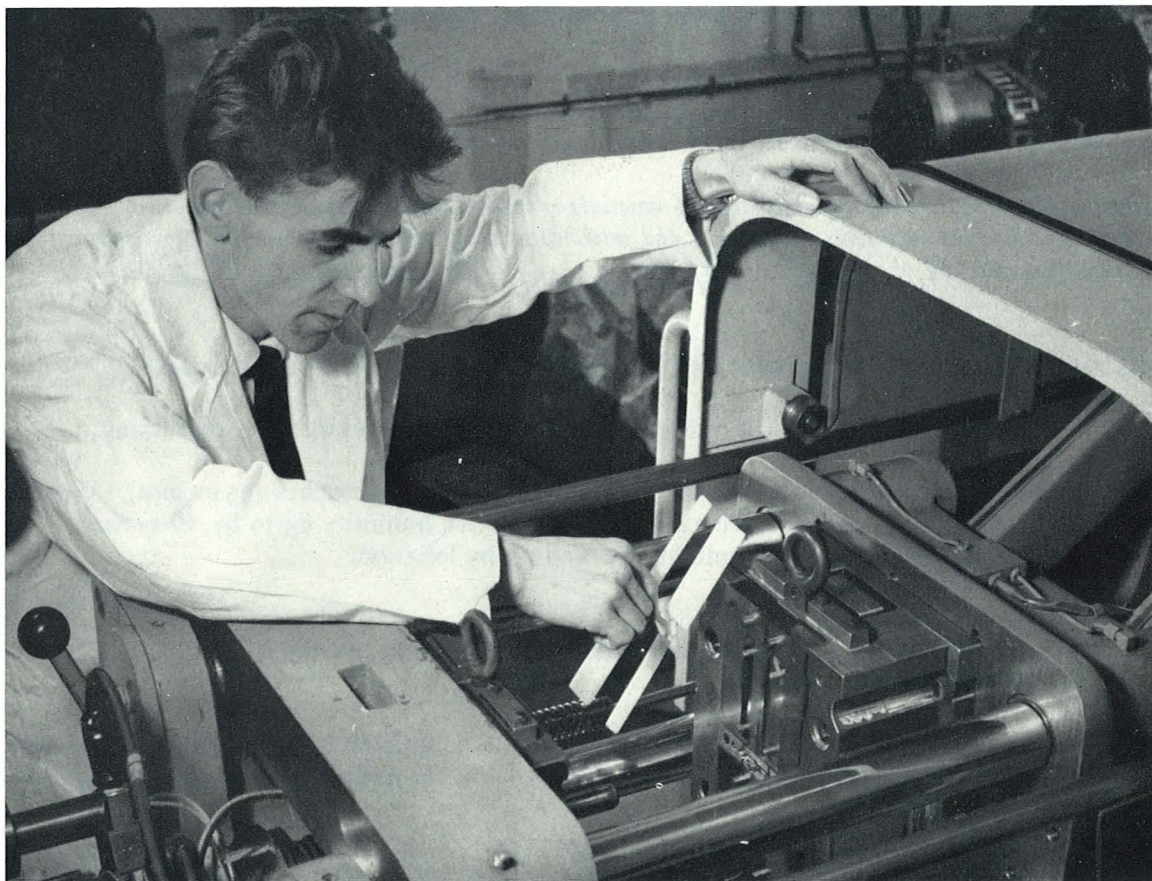
A pendulum impact tester modified for tensile and flexural impact tests to investigate the engineering life of non-metals.

#### NUCLEAR MAGNETIC RESONANCE MEASUREMENT

This 60 M/c instrument is used for characterization and structure determination of a wide range of organic compounds. *Superseded by JEOL 100 MHz instrument*







HORIZONTAL INJECTION MOULDING MACHINE

Test pieces for mechanical property assessment being produced in a constant torque, injection moulding machine.

*JEOL 100 MHz*

SPECTROSCOPY ~~PE R10 60 Mc~~ NMR spectrometer (variable temperature probe, spin decoupling unit, probes for  $^1\text{H}$ ,  $^{11}\text{B}$ ,  $^{19}\text{F}$ , and  $^{31}\text{P}$ ; PE 337 grating spectrometer ( $4000\text{--}400\text{ cm}^{-1}$ , ATR attachment); Unicam SP 500 spectrometer.

MICROSCOPY Gilett and Sibert time-lapse microscope (35 mm and 16 mm (ciné) photographic recording).

DEGRADATION Mercury lamp, xenon arc, molten salt- and fluidized sand baths. *Climatic Weathering Chamber*

GAS CHROMATOGRAPHY PE Model 801 (dual column analytical instrument, linear programming); Pye Model 105/15 (automatic preparative gas chromatograph, linear programming).

## Polymer Development and Applications

Processing and curing of new rubbers and thermoplastics by injection moulding, extrusion, milling, and compression moulding. Measurement of physical properties, and the effect of contaminants (e.g. explosives, propellants, petrol, etc.). Accelerated and tropical ageing trials to assess useful life.\* Investigation of failures. Manufacture of special components; antistatic and conducting rubbers.

*\* Now in Polymer stability Section.*

Proofed fabrics: preparation, mechanical properties, and advice on the design of proofed fabric structures.

**PROCESSING** Wide range of mills, mixers, hydraulic presses and injection moulding machines. Facilities for the synthesis of polyester-polyurethane rubbers. Small-scale equipment for preparing proofed-fabric samples.

**TESTING** Physical properties; permeability of materials to organic fluids and water; ageing ovens to simulate hot/dry and hot/wet conditions; continuous and intermittent stress relaxometers. Carbon arc equipment for special exposures.

*Climate UV/Fluorescent weathering chambers*

## Joint Tropical Research Unit, Queensland (JTRU) (Polymer Stability Section)

Four sites are available for the exposure of small specimens to atmospheric weathering.

- (a) **INNISFAIL** Latitude  $17^{\circ} 32'S$ . Average annual rainfall 140 inches (3540 mm). Average daily mean temperature  $74^{\circ}F$  ( $23^{\circ}C$ ); relative humidity 83 to 87. Sites are
  - (i) Hot/wet, jungle, i.e. sunlight screened off by foliage.
  - (ii) Hot/wet, clearing.
- (b) **CLUMP POINT** Similar latitude and conditions to Innisfail but the site is
  - (iii) Marine.
- (c) **CLONCURRY** Latitude  $20^{\circ} 43'S$ . Average annual rainfall 17 inches (430 mm). Average daily mean temperature  $78^{\circ}F$  ( $25^{\circ}C$ ); relative humidity 39. The site is designated
  - (iv) Hot/dry.

*Small no. of staff are attached to JTRU for 3 years. Tours  
Polymer Stability Section*

*In addition to the work referred to above under this section's activities, the Section runs a world-wide solar UV radiation monitoring program at more than 20 stations roughly from the Arctic Circle to the equator, in both Hemispheres. The results enable predictions to be made of the damaging effects of UV on paints, textiles, plastics, rubber and ~~Human Skin~~, as well as indicating the lifetime of oil slicks at sea.*



# GENERAL CHEMISTRY

Head of Branch

DR A R OSBORN

The General Chemistry Branch investigates the preparation, properties and reactions of a wide range of ingredients related to explosive, propellant and polymer technology. The Branch offers an advisory service on the stability, compatibility and surveillance testing of propellants, explosives and other hazardous materials. New analytical methods are developed to assist quality control, and a range of specialized techniques and facilities are used to provide an analytical service for the Establishment.

## ACTIVITIES AND FACILITIES

### Synthesis and Characterization

Synthesis of explosives and ingredients of solid propellants and polymers (fuels, oxidizers, ballistic additives, stabilizers, curing agents, antioxidants, etc.); studies to optimize yield and purity and to reduce hazard (toxicity, thermal decomposition, etc.).

*General techniques of preparative chemistry, and supporting facilities: armoured cupboards; PE Model 237 grating spectrometer ( $4000-650\text{ cm}^{-1}$ ); Unicam SP 500 spectrometer; various refractometers and optical microscopes, including Kofler hot-stage instruments; molecular weight determination by semi-micro ebulliometry and micro-cryoscopy.*

### Stability and Compatibility

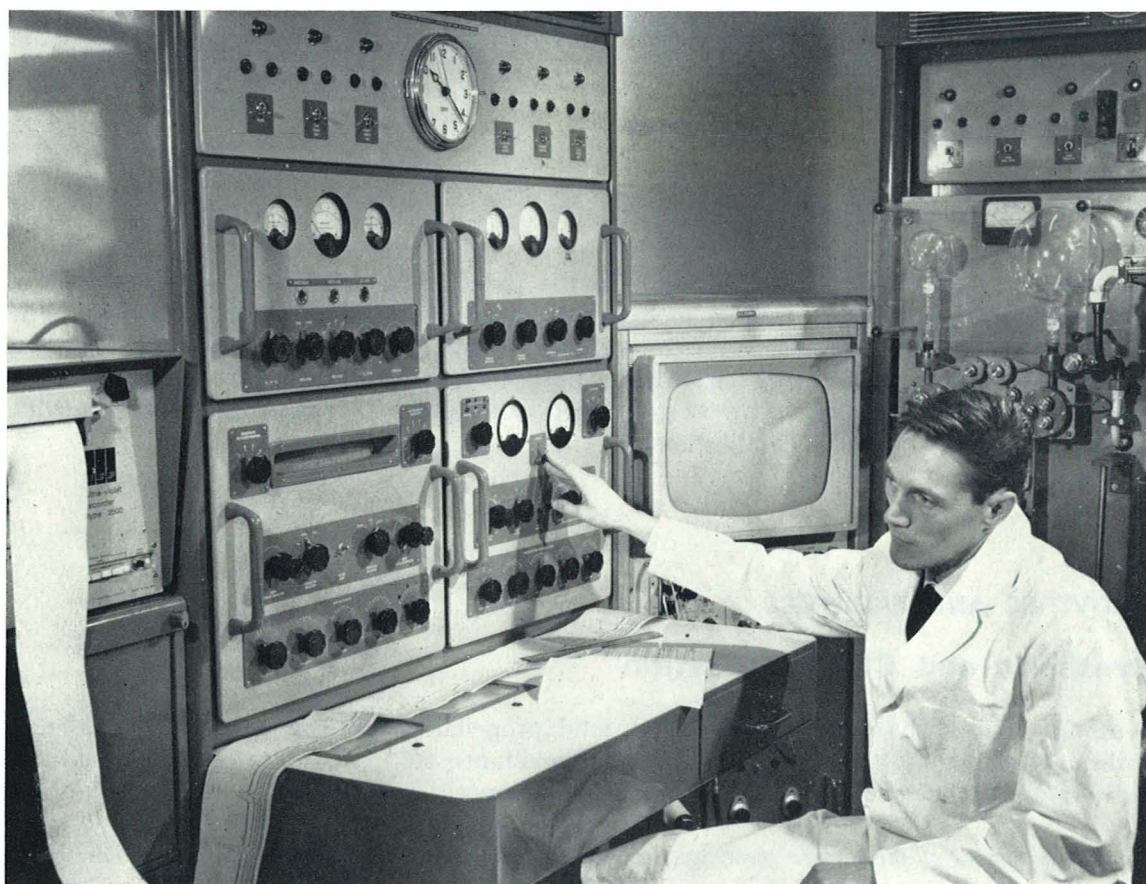
Kinetics and mechanism of thermal decomposition of explosives and exothermic compositions; ignition phenomena and build-up to low order detonation; compatibility of explosives, propellants, etc. with materials (e.g. polymers, plastics, metals, adhesives, varnishes and paints); effect of severe environmental conditions on storage stability. New techniques to investigate thermal stability.

*Environmental testing ovens and standard stability test facilities. Master slave manipulator. Stanton thermogravimetric balance (maximum temperature,  $250^{\circ}\text{C}$ ); PE differential scanning calorimeter, Model 1 ( $-100^{\circ}$  to  $500^{\circ}$ ); heat flow calorimeter (sensitivity,  $30\text{ }\mu\text{watts}$ ); multirange temperature recording equipment ( $-200^{\circ}$  to  $500^{\circ}\text{C}$ ). Photomicroscopy of samples heated in vacuum. Advance Model TC 2A electronic timer counter ( $1\text{ }\mu\text{sec}$ ).*

### Chemical Analysis and Physical Methods

Separation, identification, and analysis of the constituents of explosives, propellants, polymers, rubbers, etc.; determination of functional groups, elemental composition, and molecular weight; trace metal analysis. Estimation of purity, and investigation of quality control and specification tests. Studies concerned with gas and solvent vapour analysis; molecular and crystal structure; thermochemical characteristics (phase changes, low temperature behaviour and thermal decomposition); cure- and post-cure chemistry of polymeric systems; non-aqueous titration; mass spectrometric and polarographic analysis.





#### MASS SPECTROMETRY

An AEI Model MS 2H mass spectrometer capable of performing isotopic and chemical analyses on very small quantities of material, including solids.

**CHROMATOGRAPHY** *Wide range of standard equipment for analytical- and preparative-scale column- and thin layer chromatography; Craig counter-current extraction apparatus; Varian Aerograph Model 1522 gas chromatograph (dual column, linear programming); PE F11 gas chromatograph; pyrolysis attachment.*

**SPECTROSCOPY** *PE Model 257 grating spectrometer ( $4000\text{--}650\text{ cm}^{-1}$ ) ATR attachment, micro- and heated cells; modified Grubb Parsons S3A spectrometer ( $3500\text{--}250\text{ cm}^{-1}$ ); PE Model 137 UV spectrometer; Unicam SP90 atomic absorption spectrophotometer.*

**MASS SPECTROMETRY** *AEI Model MS 2H*

**MICROANALYSIS** *Combustion equipment (C, H, N); Schöniger flask (S, halogens); Mechrolab Model 302 vapour pressure osmometer (molecular weights up to 20 000).*

**POLAROGRAPHY** *Beckman Electroscan 30 (various electrometric analysis techniques).*

**RADIOCHEMISTRY** *Tracer laboratory; Panax standard- and low background Geiger counters; Isotope Development Ltd. solid and liquid scintillation counters.*

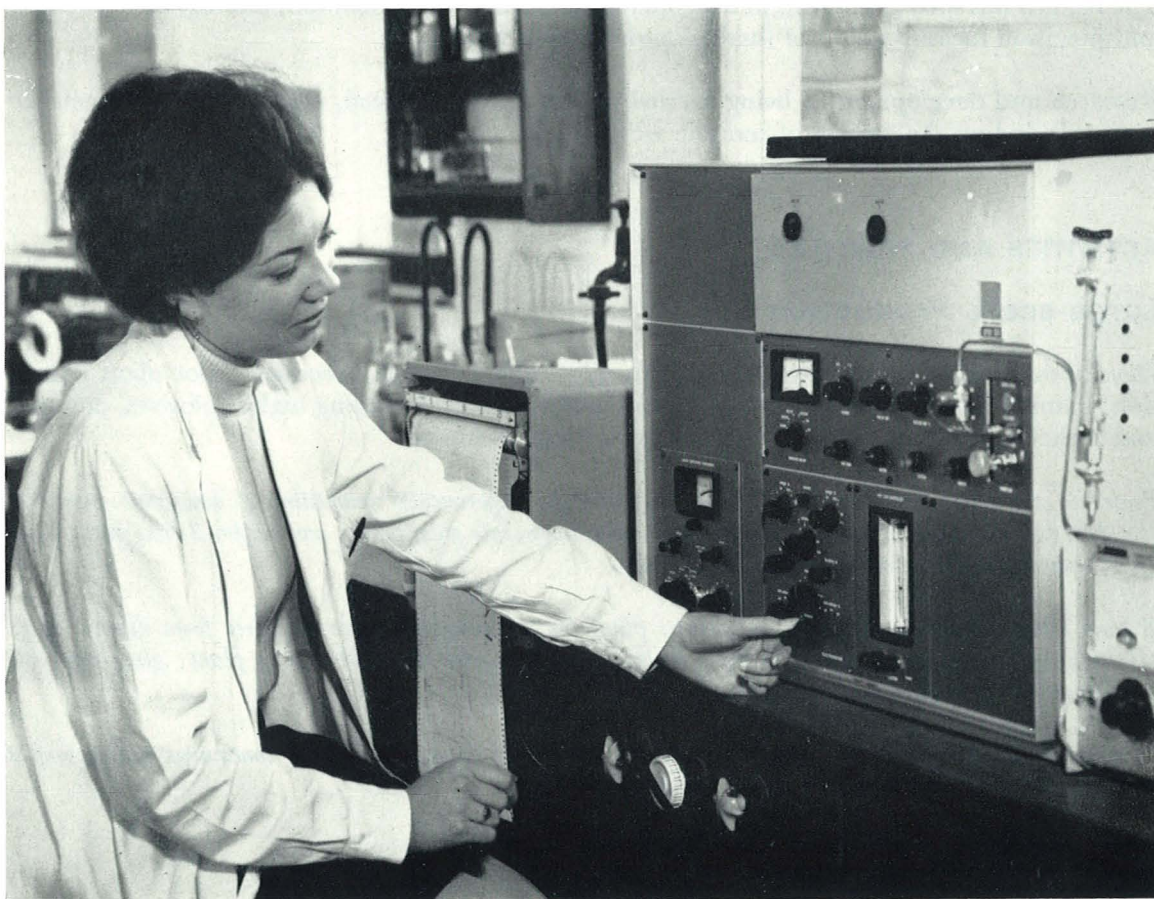
**THERMOCHEMICAL ANALYSIS** *see Stability and Compatibility.*

**PARTICLE SIZE ANALYSIS** *Sharples Micromerograph (humidity- and temperature-controlled); gas adsorption and various types of gas permeability apparatus for surface area measurement.*

## Crystallography

Application of optical and X-ray diffraction to identification and characterization of compounds; phase analysis of mixtures, polymorphism, crystal orientation, and crystal structure analysis.

*Equipment includes three X-ray generators, one being a high-power rotating anode set, X-ray powder cameras, goniometers (Weissenberg, oscillating crystal and optical), Hilger-Watts 4-circle, single crystal automatic diffractometer, an X-ray powder diffractometer, and polarizing microscope with heating stage.*



### GAS CHROMATOGRAPHY

This technique is particularly useful for identifying and estimating volatile constituents of complex mixtures.

## Gas Kinetics

Kinetics and mechanisms of gas-phase reactions and general free radical chemistry using static and discharge-flow techniques. Reactions of alkyl and alkoxy radicals, nitrogen oxide and nitrogen dioxide. Mechanisms of gas-solid reactions.

*High vacuum techniques and product analysis by vapour-phase chromatography, infra-red and mass spectrometry. Emission spectroscopy.*



# PROCESS RESEARCH

**Head of Branch     H ZIEBLAND**

The Process Research Branch is concerned with means and equipment for processing chemicals on a production scale. Plant and facilities are designed for the manufacture of hazardous compounds and mixtures with particular emphasis on safety, remote-control, and instrumentation. The Branch has special interests in unit operations such as crystallization, mixing, heat transfer, and precision measurements of thermal properties of fluids.

Research and development is being carried out on fibre-reinforced, metallic and non-metallic materials and on the growth of ceramic whiskers.

## ACTIVITIES AND FACILITIES

### Large-scale Production

Development of laboratory syntheses on to pilot- and full-scale processes; pilot plant operation; manufacture of experimental chemicals and materials, including high explosives, polymer and rocket ingredients, whiskers and aligned inorganic fibres.

*Protective enclosures, with remote control, for processing experimental quantities of dangerous chemicals (i.e. fire, explosion, toxicity risks): one for large laboratory-scale glass plant; another for 2.5 kg pilot plant scale, equipped with a closed circuit television loop.*

*A wide range of pilot-scale plant, including: plant for concentrating nitric acid free from nitrous acid; nitration and sulphonation unit with brine cooling, remote control and acid mixing plant; glass-lined oil heated reactors for polymer manufacture.*

*Separators such as decanters; pressure-, vacuum- and rotary filters; batch and continuous stainless steel centrifuges; liquid centrifuges; and dry powder sieves.*

*Dryers, including hot air-, vacuum tray- and rotary-steam tube types.*

*Grinding plant, including jaw crusher; roll mill; edge-runner mill; hammer mills; and 'micronizer' fluid energy mill.*

*Mixers: double cone powder blender; medium and heavy paste mixers.*

*Packed, gas-liquid absorption towers.*

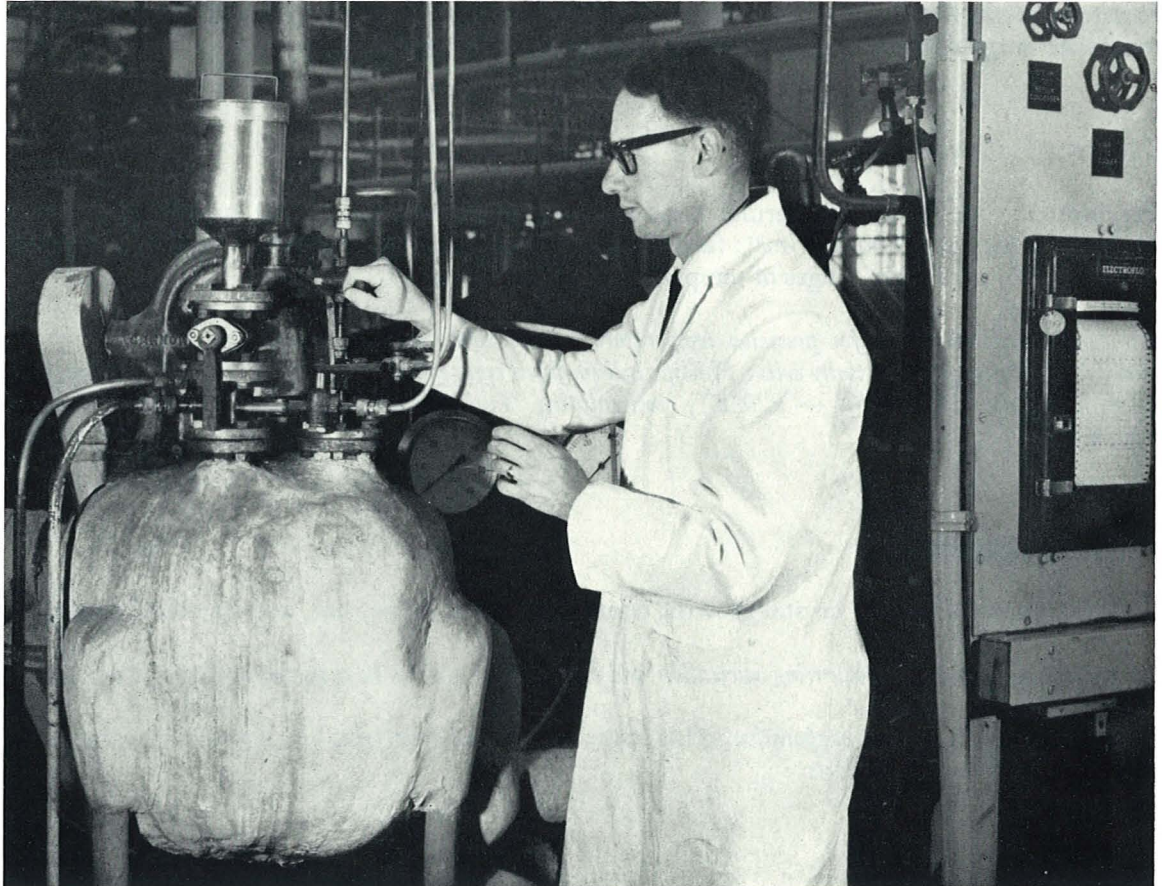
*Distillation: a 5-cm glass 'molecular' still; a 50-litre glass batch distillation unit; glass distillation column of high efficiency for high vacuum and 150°C; similar unit in stainless steel for pressure distillation up to 1 MN/m<sup>2</sup>.*

### Intensive Drying or Stripping

The intensive drying (or stripping) of high boiling liquids which may be sensitive to heat or excessive turbulence.



*Continuous plant (11.5 kg/h), based on single passage of liquid down a column packed with a battery of vertical helical coils.*



PLANT FOR POLYESTER MANUFACTURE

An example of the development of laboratory syntheses on to pilot-scale processes.

## Convective and Radiative Heat Transfer from Flames and Gases

Studies of convection and radiation from flames and combustion gases (up to 3800°K; 10 MN/m<sup>2</sup>); radiative emissivity of water vapour (1500°—3500°K; 0.5—10 MN/m<sup>2</sup>).

*Two instrumented test cubicles; water-cooled combustion chambers; black-body furnace to calibrate radiation sources.*

## Convective Heat Transfer to Liquids

Convective heat transfer from electrically heated surfaces to aviation kerosine and other liquids under sub-cooled, boiling, and supercritical conditions.

*Closed-loop apparatus with rectangular flow channel containing heated tube (maximum power, 10 kW; maximum pressure, 10 MN/m<sup>2</sup>; maximum fluid flow rate, 1.2 kg/sec). Photographic observation using Fastex ciné camera (18 000 half-frames/sec) and 0.2 μsec argon flash lamp.*

## Convective Heat Transfer to Cryogenic Fluids

Convective heat transfer to fluid hydrogen in the vicinity of the critical point and at supercritical pressures; fluid dynamics of cryogenic fluids.

*Remotely-operated test rig in which cryogenic fluids flow through asymmetrically heated rectangular ducts (maximum energy dissipation, 40 kW; maximum pressure, 5 MN/m<sup>2</sup>).*

## Thermal Conductivity

Precision measurements of thermal conductivities of liquids, gases, and supercritical fluids (12°—650°K; up to 300 MN/m<sup>2</sup>); facilities equally suitable for measuring viscosity, dielectric constant, etc. over wide ranges of temperature and pressure.

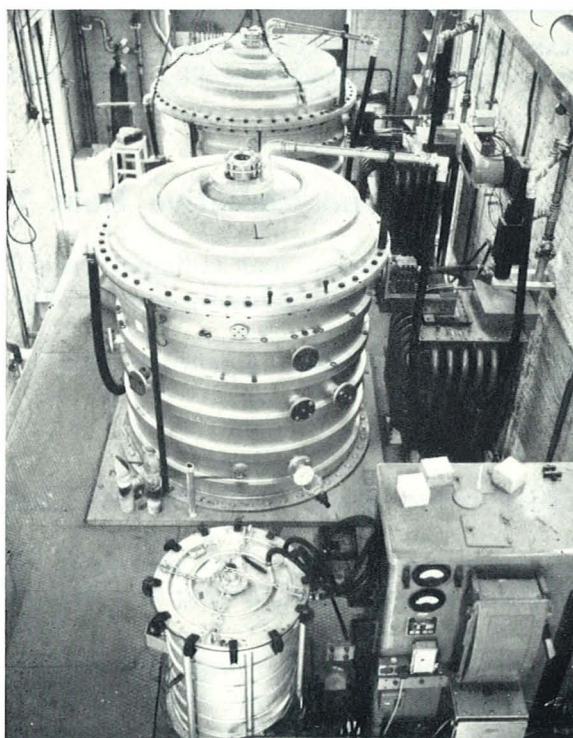
*Air conditioned laboratory for precision temperature measurement; protected annexe for compressing gases and liquids; thermal conductivity cells: Phillips helium-filled cryogenerator (12°—90°K); liquid nitrogen-filled metal thermostat (90°—220°K); recirculating Turbotherm-filled liquid thermostat (300°—650°K).*

## Crystallization

Studies of nucleation and crystal growth; control of crystal shape, size, and size distribution.

*Laboratory equipment for measuring nucleation and crystal growth rates in a stirred cooling crystallizer.*

*Pilot crystallizers: Kestner evaporative; Oslo type; and pulsed tube type, for performance studies and production of crystalline products.*



‘BRAN TUBS’

High temperature furnaces for synthesis of silicon nitride whiskers.



## High Temperature Equipment

Furnaces of various types for operation up to about 1600°C; high frequency heating equipment; temperature measuring devices.

## Fibre Processing Plant

Equipment for <sup>sizing</sup> whiskers and other short fibres and plants to classify and align asbestos and other Fibres. Whiskers for making composite materials. Preparation of complex shapes in carbon fibre reinforced resin composites. Whisker reinforcement of metals

## Fibre Testing Equipment

Marsh micro-testing machine and various macro-testing machines.

## Microscopes

A range of optical microscopes and a J.E.M. 7 electron microscope.

## Instrumentation and Glass Engineering

Now Under General Chemistry

This Section, part of the Engineering Branch, is responsible for the development and application of instruments and apparatus based on electronic and glass engineering techniques.



### GLASS ENGINEERING

The glass engineering workshop is equipped to undertake construction of scientific glassware ranging from special laboratory articles to the large-scale item shown here.



# MISCELLANEOUS RESEARCH ACTIVITIES

In addition to research and development work performed by the Branches described above, certain specialized or exploratory research topics are undertaken by small groups under the direction of Dr. L. J. Bellamy, Mr. G. K. Adams, and Dr. G. H. Young.

## Spectroscopy

Studies of factors affecting infra-red absorption spectra of complex molecules; assignment of absorption bands and interpretation of spectra.

*Unicam SP 100 spectrometer (3650—300  $\text{cm}^{-1}$ ); Grubb Parsons GS2 grating spectrometer (4000—650  $\text{cm}^{-1}$ ); Unicam SP 700 spectrometer (55000—4500  $\text{cm}^{-1}$ ); attachment to determine emission spectra in the visible region; time-resolved luminescent spectroscopy in the visible region (resolution, 1  $\mu\text{sec}$ ).*

## Flame and Explosion Phenomena

*An Elliot 903 computer is in use, and computer programmes are available for calculation of flame and explosion properties, and the thermodynamic properties of two-phase, multi-element systems in chemical equilibrium.*

## Autoxidation and Antioxidants

Kinetics and mechanism of free radical chain reactions in solution; catalysis of oxidation-reduction reactions by heavy metals; effect of oxidative degradation, light, and ionizing radiation on polymeric materials. Research aimed at preventing or inhibiting oxidative degradation. Design and assessment of new antioxidants; mechanism of antioxidant action, particularly synergistic effects (mixtures of free radical acceptors; free radical acceptor and chelating reagent or S-containing peroxide decomposer); inhibition of autoxidation by metal chelates.

*Warburg apparatus and equipment for automatic recording of oxygen uptake; facilities for photochemistry and radiochemistry.*

# INDEX OF ACTIVITIES

Titles of branches have been abbreviated as follows:

E	Explosives	NM	Non-metallic Materials
P1	Propellants 1	GC	General Chemistry
P2	Propellants 2	Misc. Res.	Miscellaneous Research
PR	Process Research	IGE	Instrumentation and Glass Engineering Section

ADHESIVES		CRYSTALLOGRAPHY	
Development, application and strength	P2	Identification, phase analysis, crystal structure	GC
AGEING		DEFORMATION	
Non-metallic materials	NM	Non-metallic materials	NM
Explosives and propellants	GC, P1	DIFFERENTIAL THERMAL ANALYSIS	GC
ANTIOXIDANTS	Misc. Res.	DISTILLATION	
ASBESTOS REINFORCED MATERIALS	NM, PR	Fractional, pilot-scale, 'molecular'	PR
ATOMIC ABSORPTION SPECTROPHOTOMETRY	GC	DRYING AND STRIPPING	
AUTOXIDATION	Misc. Res.	Heat-sensitive liquids	PR
BALLISTIC ASSESSMENT	P1, P2	ELASTICITY AND ELASTOMERS	NM
BURNING RATE DETERMINATION	P1, P2	ELECTROMETRIC ANALYSIS	GC
CALORIMETRY, PRECISION	P1	ELECTRONIC INSTRUMENTATION	IGE
CARBIDES		ELECTRON MICROSCOPY	PR
High temperature materials	PR	ELECTROSTATIC RISK	
CERAMIC MATERIALS	PR	Generation of electric charge, electrical resistance measurement, susceptibility to ignition	E
CHEMICAL ANALYSIS		EMISSION SPECTROSCOPY	
Instrumental, elemental and functional group	GC	Visible region	Misc. Res.
CHEMICAL MANUFACTURE		ENVIRONMENTAL TESTING	
Laboratory investigations	GC	Effect of contaminants and climatic conditions on polymers	NM
Pilot-scale processes	PR	Explosives and propellants	GC, P1
CHROMATOGRAPHY, SOLUTION		EXPLOSIVES EVALUATION	
Analytical and preparative scale, column and thin layer, counter-current extraction	GC	Type of hazard, degree of protection and storage requirements	E
CLIMATIC EFFECTS		EXPLOSIVES SYNTHESIS AND MANUFACTURE	GC, E, PR
Non-metallic materials	NM	FATIGUE	
Explosives and propellants	GC, P1	Non-metallic materials	NM
COMBUSTION		FIBRE REINFORCED MATERIALS	PR
Solid propellants and organic materials	P1	FLAME AND EXPLOSION PHENOMENA	
Liquid propellants	PR	Combustion	P1
COMPATIBILITY TESTING		Detonation	E
Effect of contaminants and climatic conditions on hazardous materials	GC	Theory	Misc. Res.
COMPOSITE MATERIALS	NM, PR	FLUID DYNAMICS	
COMPRESSION TESTS	NM	Cryogenic fluids	PR
CREEP TESTING		FREE RADICAL CHEMISTRY	GC, Misc. Res.
Non-metallic materials	NM	GAMMA IRRADIATION	Misc. Res.
CRYOGENIC FLUIDS		GAS CHROMATOGRAPHY	
Fluid dynamics and heat transfer	PR	Analytical	GC, NM, P1
CRYSTALLIZATION TECHNOLOGY	PR	Preparative	NM
CRYSTAL GROWTH		GAS KINETICS	GC
From vapour	PR		
From solution	PR, P2		

GLASS ENGINEERING		IGE	NOISE EVALUATION	
			Measurement and simulation of impulsive noises, sonic bangs	E
HAZARD APPRAISAL			NON-AQUEOUS TITRIMETRY	GC
Impact and friction sensitiveness, ease of ignition, burning to detonation, shock sensitiveness, electrostatic risk			NON-DESTRUCTIVE TESTING	
		E	Radiographic and ultrasonic inspection	P1
Thermal stability and self-heating			NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY	
HEAT RESISTANT MATERIALS		GC	Analysis and structure determination	NM
Polymers			NUCLEATE BOILING	PR
Composites		NM		
HEAT TRANSFER		PR	OXIDATION INHIBITORS	Misc. Res.
Convective and radiative, flames and combustion gases, liquid fuels, cryogenic fluids			PARTICLE SIZE ANALYSIS	GC
HIGH SPEED PHOTOGRAPHY			PASTES, STIFF	
Explosive phenomena		PR	Processing and rheology	P2
Mechanical testing			PLASTICS	
HYDROGEN, LIQUID		E	Chemistry and physics	NM
		NM	POLAROGRAPHY	GC
		PR	POLYMER CHEMISTRY	
			Synthesis, characterization, stability	NM
IGNITION			POLYMERIZATION KINETICS	
Hazardous materials		E, GC	Basic studies	NM
IMPACT TESTING			Applied studies	NM, P2, E, GC
Polymers		NM	POLYMER PHYSICS AND ENGINEERING	
INFRA-RED SPECTROSCOPY			Non-metallic materials and reinforced plastics, physical properties and engineering data	NM
Qualitative and quantitative analysis		GC	POLYMER TECHNOLOGY	
Polymer characterization		NM	Curable and non-curable polymers	NM, P2
Gas kinetics research		GC	Heavily-loaded thermo-plastic rubbers	P2
Combustion		P1	Polyurethane elastomers	NM, E, PR
Basic studies		Misc. Res.	PRESSURE MEASUREMENT	
INITIATORY EXPLOSIVES		E	Explosions	E
			Rocket motor firing	P1, P2
			Liquid flow	PR
JOINT STRENGTH		P2	PROOFED FABRICS	NM
			PROPELLANT PROCESSING	
LIQUIDS			Nitrocellulose-based	P1
Critical point phenomena		PR	Rubber-based	P2, E
LOAD CELLS		NM	PYROLYSIS	
			Polymers	NM, GC
MASS SPECTROMETRY			Organic materials	P1
MATERIALS			RADIOCHEMISTRY	GC
Non-metallic		NM	RADIOGRAPHIC INSPECTION	P1, E
Composites		PR	REFRACTORY MATERIALS	PR
MECHANICAL TESTING			REMOTE CONTROL METHODS	
Non-metallic materials		NM	Mixing, extrusion, injection moulding	E
Composites		PR	Manufacture of hazardous chemicals	PR
Adhesives		P2	Closed circuit TV	E, PR
Propellants		P1, P2	RHEOLOGY	
MICROANALYSIS		GC	Polymers and composite materials	NM
MICROSCOPY			Adhesives	P2
Crystal morphology		GC, PR	Solid propellants	P2
Polymer crystallization		NM	Stiff pastes	P2
Fibres and ceramic whiskers		PR	Fibres	NM, PR
MIXERS, DESIGN AND OPERATION			RUBBER, SPECIAL APPLICATIONS	
Performance, safety, application to hazardous materials		PR	Conducting, antistatic, proofed fabric	NM
NITRIDES				
High temperature materials		PR		
NITROCOMPOUND CHEMISTRY		GC		



SAFETY	
Manufacture, handling and storage of hazardous materials	E, PR, P1, P2
SEALANTS	
Lutings and cements for threaded joints	P2
SHEAR TESTS	
Joints	P2
SONIC BANGS	
	E
SPECTROSCOPY	
Fundamental studies	Misc. Res.
Qualitative and quantitative analysis	GC
Application to combustion	P1
gas kinetics	GC
polymers	NM
SURFACE CHEMISTRY	
Surface tension, contact angles	P2
SYNTHETIC CHEMISTRY	
	GC
TEMPERATURE MEASUREMENT	
Combustion and calorimetry	P1
Thermal conductivity	P2
Thermochemical analysis	GC
High temperatures	PR
TENSILE STRENGTH TESTING	
	NM, PR
THERMAL CONDUCTIVITY	
Liquids, gases, supercritical fluids	PR
THERMAL STABILITY	
Polymers, degradation studies	NM
Hazardous compounds	GC
THERMOCHEMICAL ANALYSIS	
Differential scanning and heat flow calorimetry, thermogravimetry	GC
THERMOCHEMICAL DATA	
Heats of formation, combustion and wetting	P1
ULTRA-VIOLET SPECTROMETRY	
Qualitative and quantitative analysis	GC, NM
VAPOUR PHASE CHROMATOGRAPHY	
	GC, NM
VISCOMETRY	
	NM
VULCANISATION	
	NM
WHISKERS, CERAMIC	
Production, processing and testing	PR
Classification and alignment	PR
X-RAY CRYSTALLOGRAPHY	
Powder diffraction photography, single crystal analysis	GC

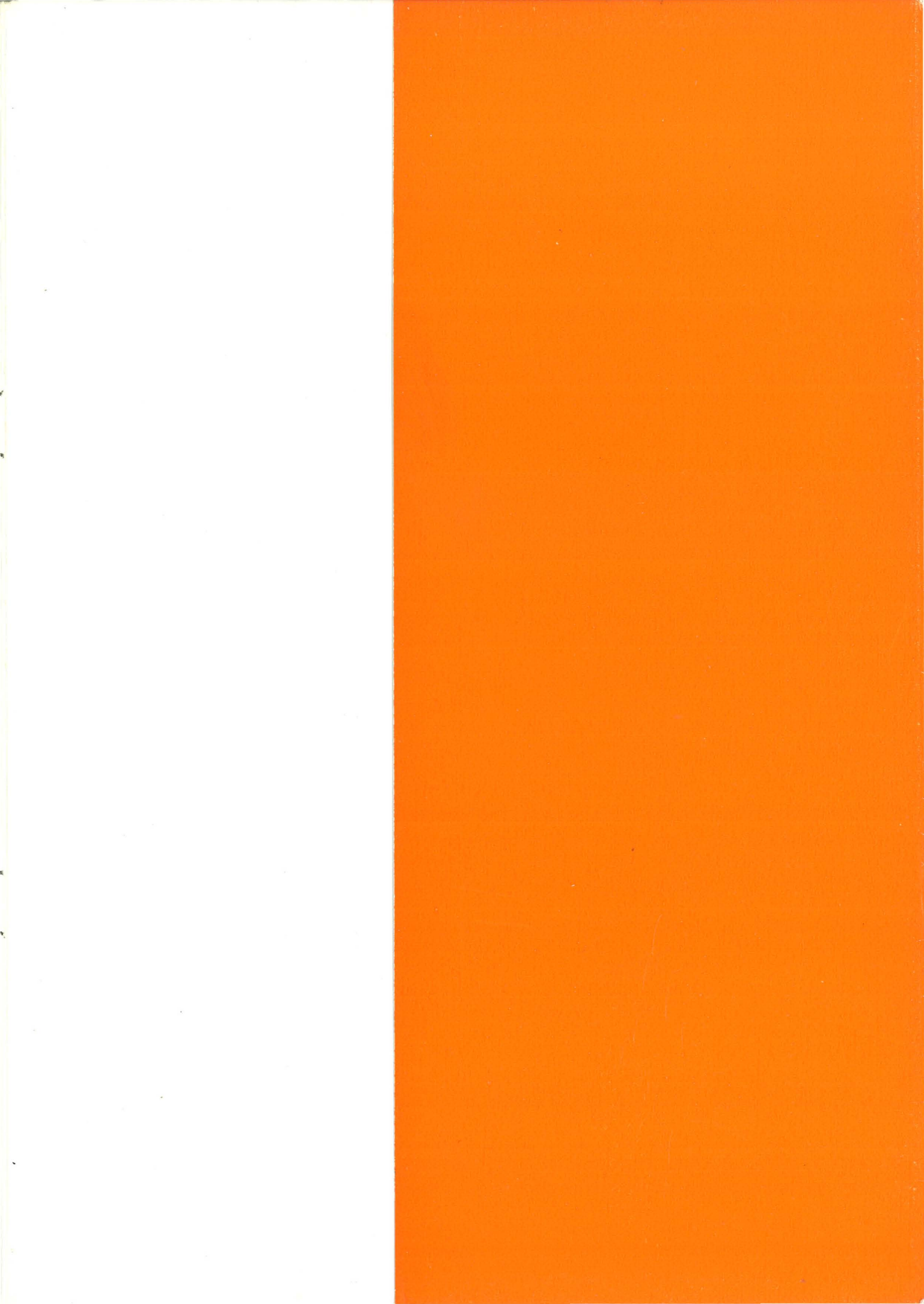
## INDEX OF FACILITIES

ABSORPTION TOWERS			MICROCOMBUSTION EQUIPMENT	GC
Packed, gas-liquid	PR		MICROSCOPES	
ARMoured CUPBOARDS AND PROTECTIVE ENCLOSURES			Time-lapse, photographic recording	NM
Small scale tests and preparations	GC, E		Projection	PR
Large scale manufacture	E, PR		Hot-stage polarizing	GC
ATOMIC ABSORPTION SPECTROPHOTOMETER	GC		Electron	PR
AUTOXIDATION LABORATORY			MIXERS	
Oxygen uptake measurement	Misc. Res.		Powder blending	PR
			Heavy paste	PR, P1, P2, E
CALORIMETERS			MOLECULAR WEIGHT APPARATUS	
Precision	P1		Viscometry, osmometry and light scattering	NM
Differential scanning and heat flow	GC		Vapour pressure osmometry, ebulliometry and cryoscopy	GC
CHEMICAL PLANT			NUCLEAR MAGNETIC RESONANCE SPECTROMETER	NM
Nitration, sulphonation, acid concentration, polymer manufacture, fibre and whisker classification and alignment	PR			
CREEP TESTING EQUIPMENT	NM		PARTICLE SIZE EQUIPMENT	
			Gas adsorption and permeability, micromerograph, sedimentometer	GC, P2
DISTILLATION EQUIPMENT			PLASTOMETERS	
Fractionating columns, pilot-scale and 'molecular' stills	PR		Flow and deformation, brittle point	P2
DRYERS			PHOTOGRAPHIC EQUIPMENT	
Hot air, vacuum, steam	PR		High speed streak and framing cameras	E, NM, P2
ENVIRONMENTAL TEST FACILITIES			Time-lapse photomicroscopy	NM
Climatic chambers	P1		Hot-stage photomicroscopy	GC
Ageing ovens	GC, NM		POLAROGRAPH	GC
Tropical test site	NM		PRESSURE SENSORS	
EXTRUSION PLANT			Explosion and noise	E
Propellants and explosives	P1, P2, E		Propellant impulse	P1, P2
Polymers	NM		Liquid flow	PR
FURNACES			RADIOCHEMICAL TRACER LABORATORY	GC
High temperature, laboratory and pilot-scale	PR		REACTION VESSELS, PILOT-SCALE	PR
GAS CHROMATOGRAPHS			REMOTE CONTROL FACILITIES	
Analytical	GC, NM, P1		Process bays and equipment design	PR, E
Preparative	NM		Master slave manipulators	E, GC
GRINDING PLANT			RHEOLOGICAL TEST FACILITIES	
Jaw crusher and various mills	PR		Static, dynamic and creep loading	NM, P2
HEAT TRANSFER TEST RIGS			Impact, flywheel and rotating beam machines	NM
Variable pressure, temperature and flow rates	PR		Microtest	PR
			Variable environment	NM, P2
IMPACT TESTERS			SEPARATORS	
Polymers	NM		Decanters, sieves, filters, and centrifuges	PR
INFRA-RED SPECTROMETERS			THERMAL CONDUCTIVITY CELLS	
General purpose			Variable pressure and temperature	PR
instruments	GC, NM, P1		THERMOCHEMICAL ANALYSIS INSTRUMENTS	
High resolution	Misc. Res.		Differential scanning and heat flow calorimeters, thermogravimetric balance	GC
MASS SPECTROMETER	GC			

THERMOMETERS		
Platinum resistance		P1
Multirange recording		GC
ULTRASONIC INSPECTION EQUIPMENT		
Propellants		P1
Polymers		NM
ULTRA-VIOLET SPECTROMETERS		
General purpose		GC, NM
Continuous scanning	GC, Misc. Res.	
VISCOMETERS		
Bulk viscosity		NM, P2
Intrinsic viscosity		NM
X-RAY EQUIPMENT		
Radiographic inspection		P1, E
Crystallographic analysis		GC



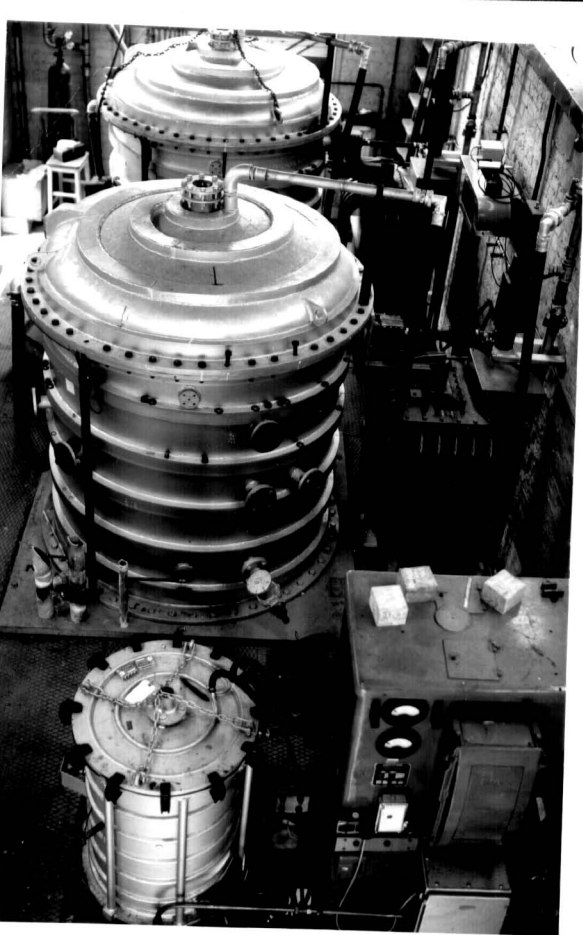


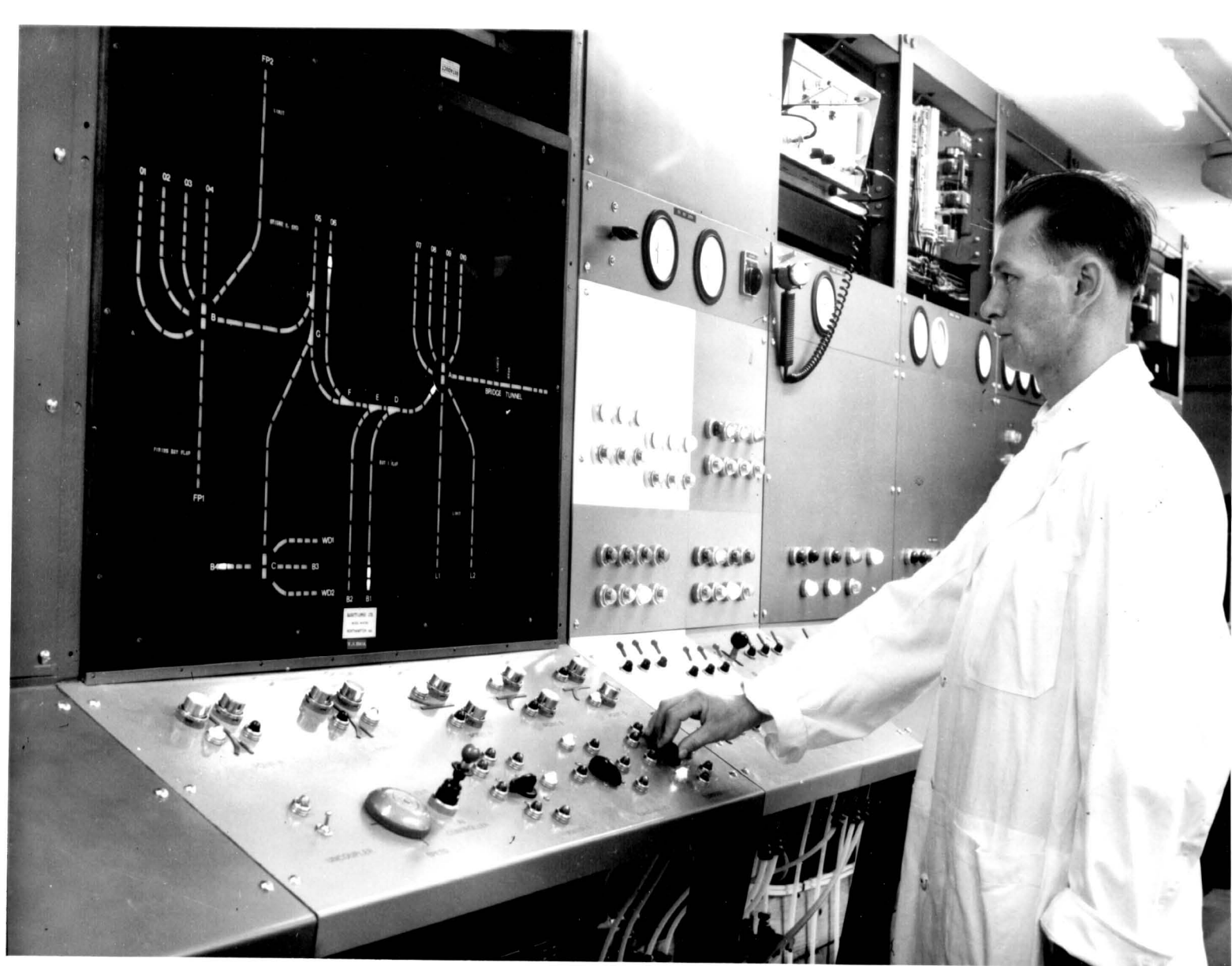


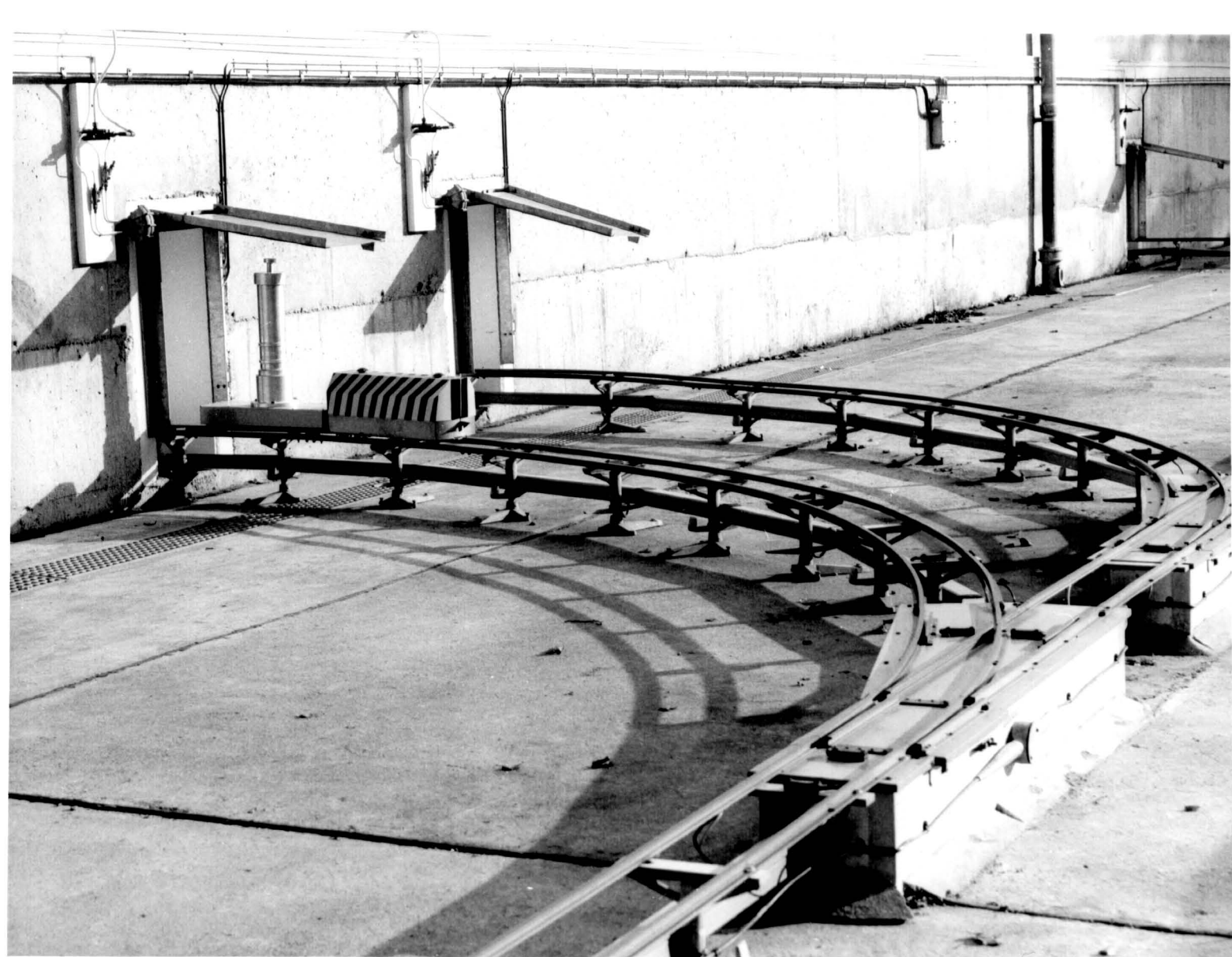




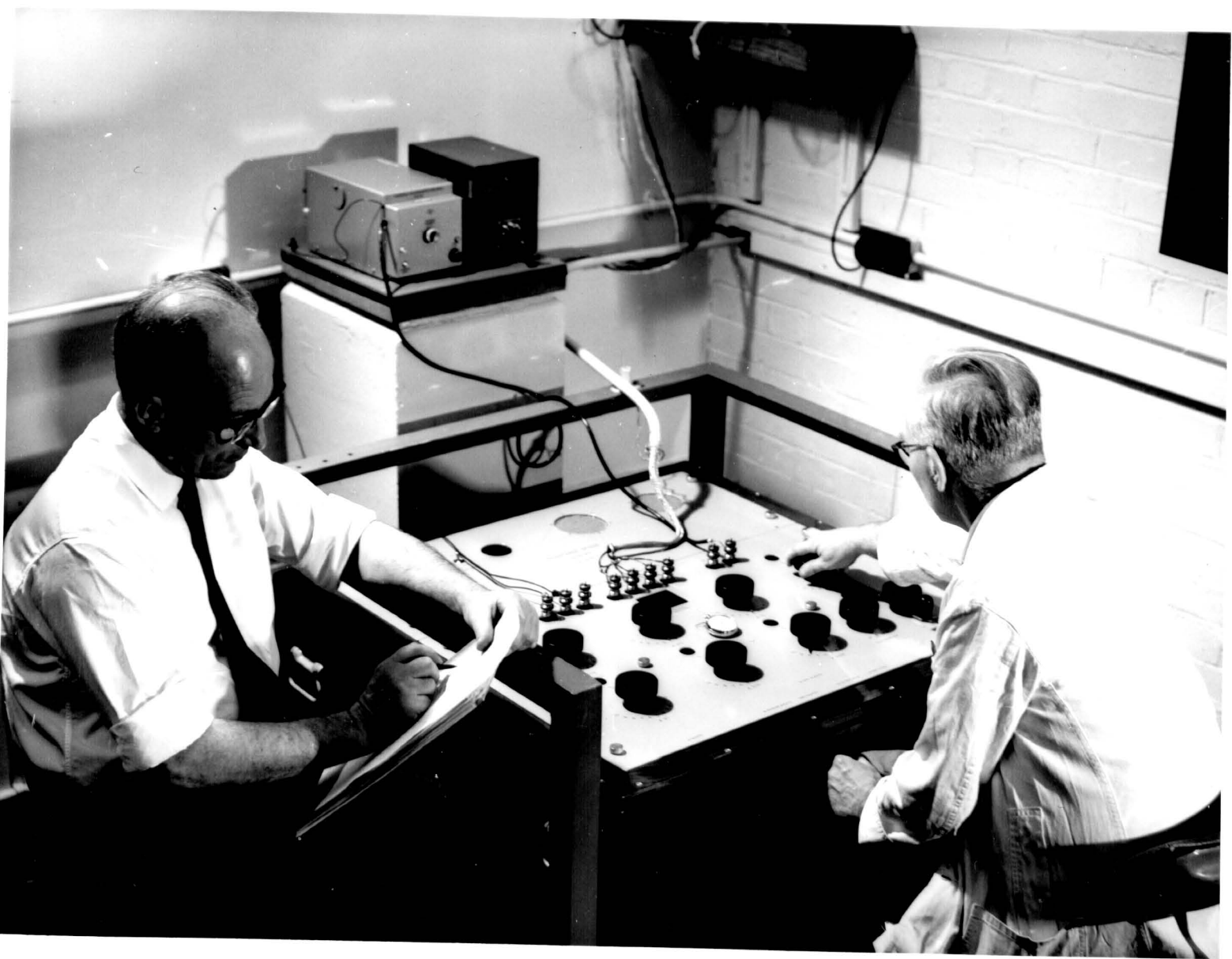












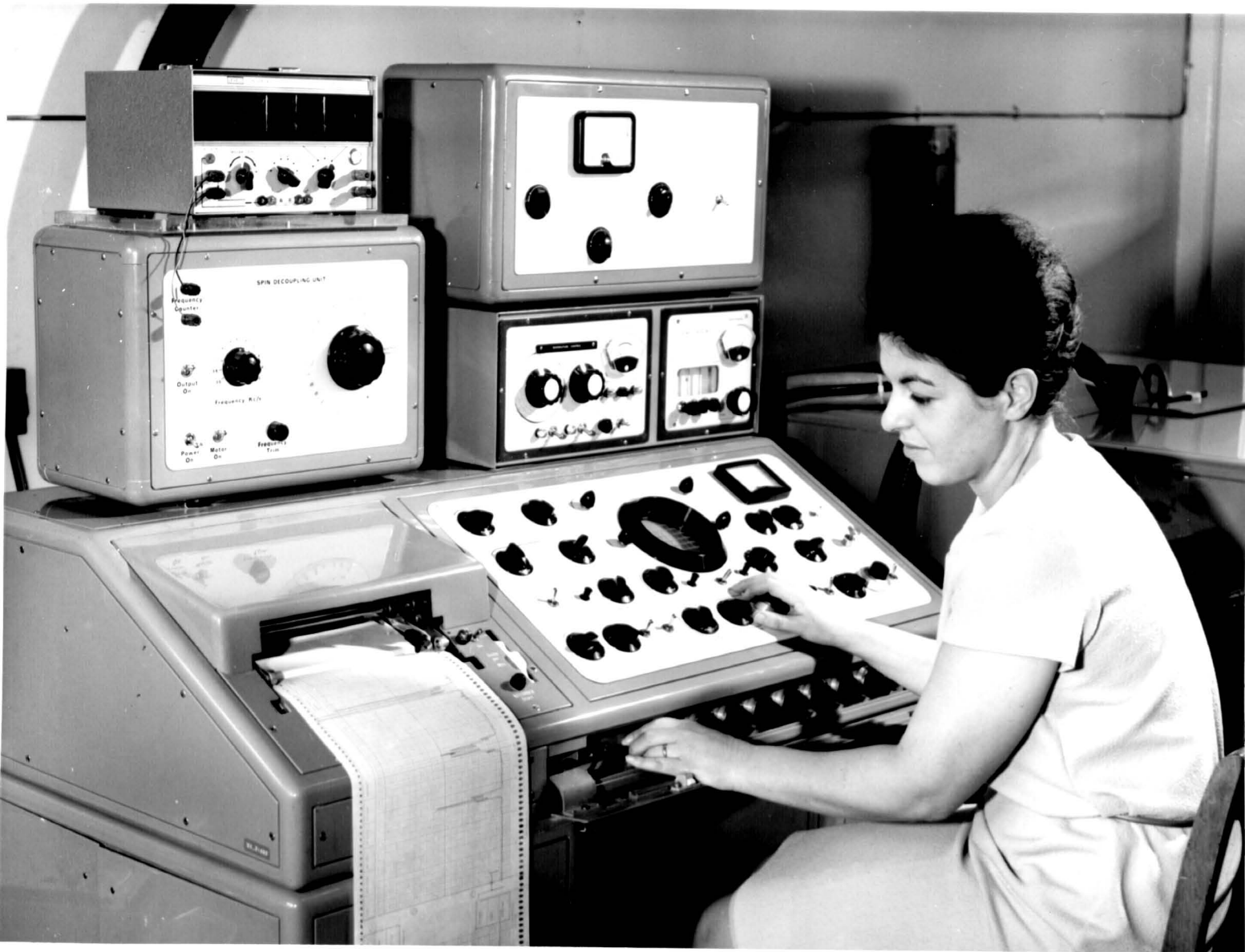












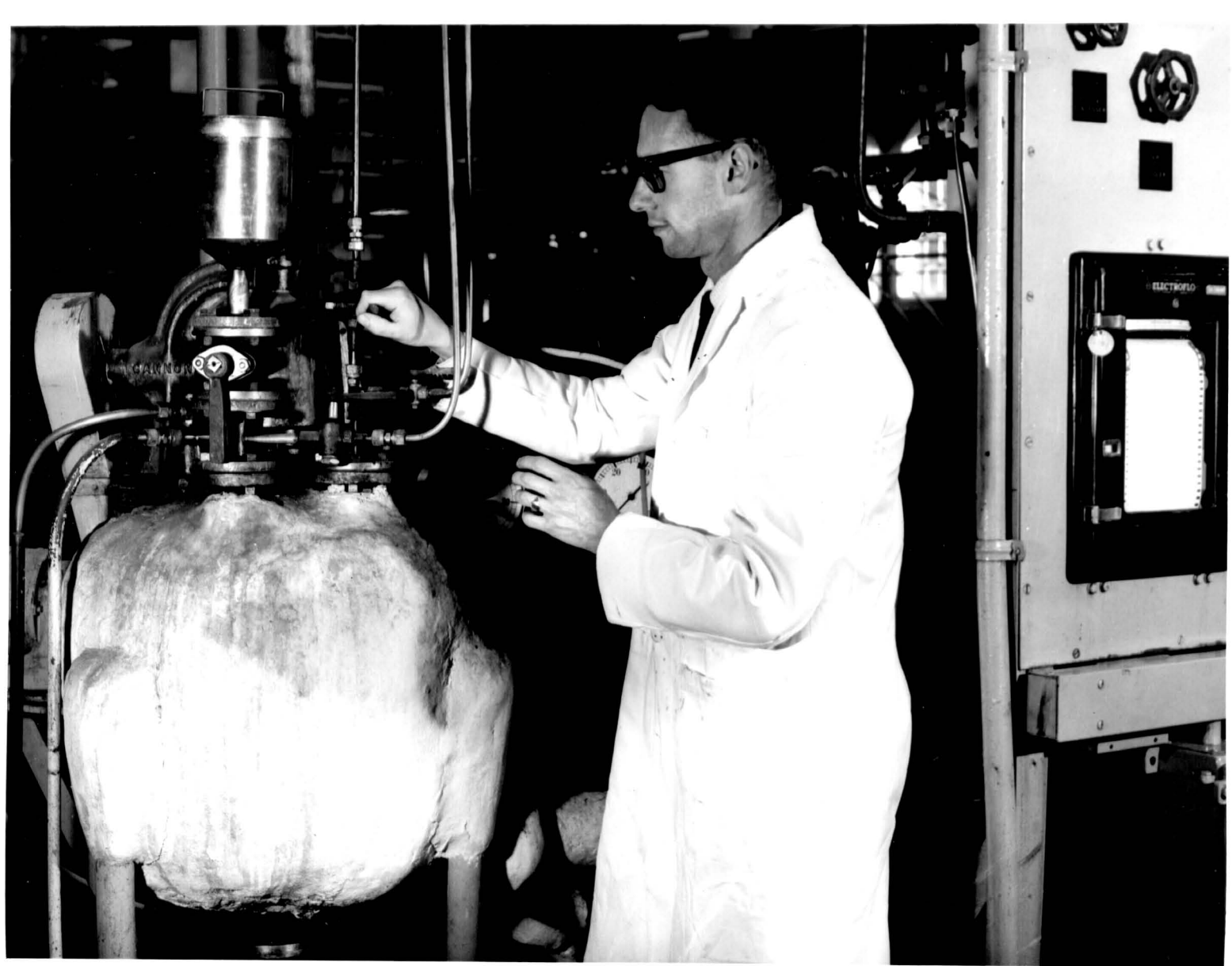




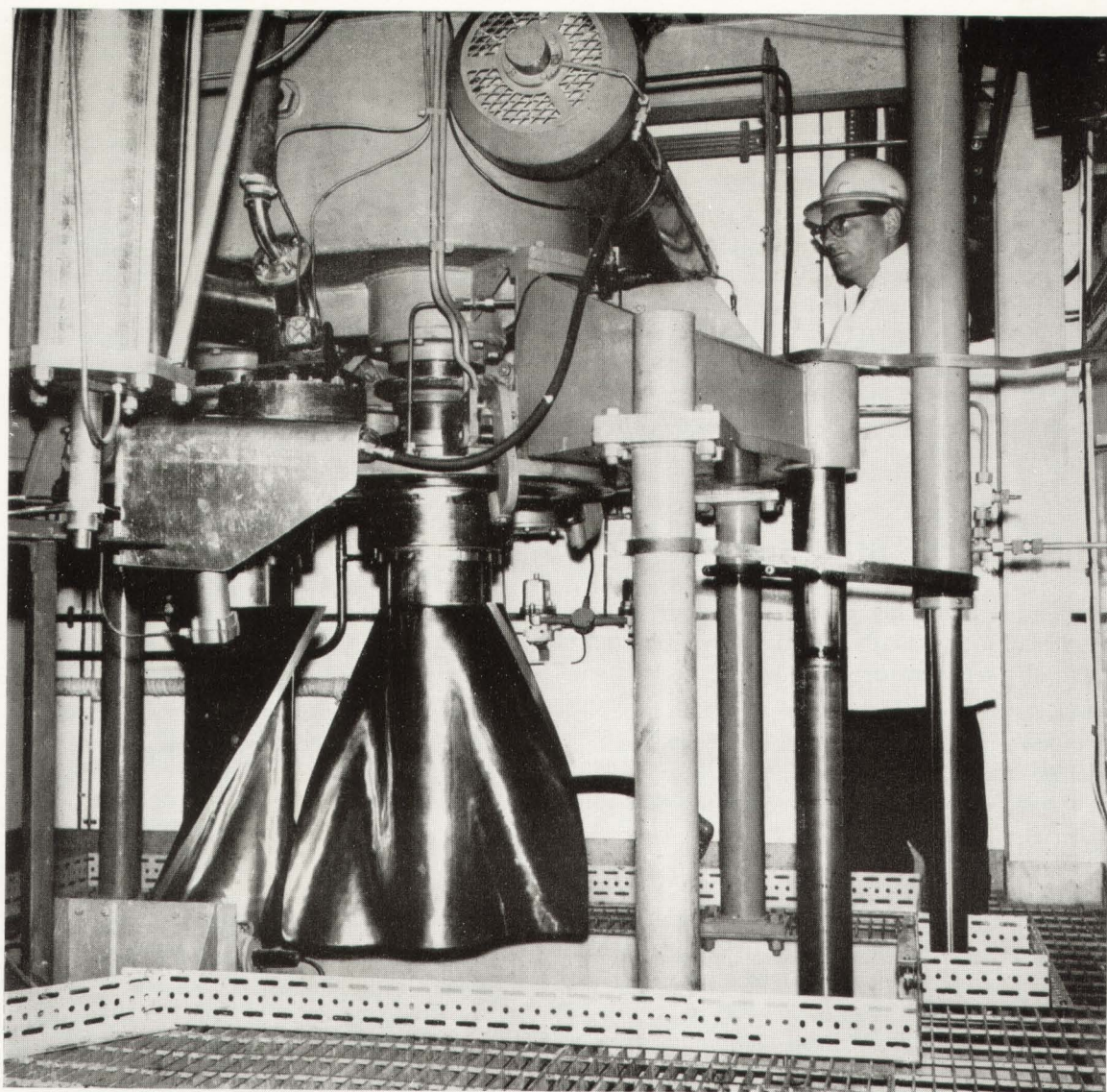












VERTICAL MIXER FOR RUBBERY-TYPE SOLID PROPELLANTS

The mixing pot has been lowered for removal of the propellant mix.

## Convective Heat Transfer to Cryogenic Fluids

Convective heat transfer to fluid hydrogen in the vicinity of the critical point and at supercritical pressures; fluid dynamics of cryogenic fluids.

*Remotely-operated test rig in which cryogenic fluids flow through asymmetrically heated rectangular ducts (maximum energy dissipation, 40 kW; maximum pressure, 5 MN/m<sup>2</sup>).*

## Convective Heat Transfer to Liquids

Convective heat transfer from electrically heated surfaces to aviation kerosene under subcooled, boiling, and supercritical conditions.