THE FULMER RESEARCH INSTITUTE

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1946
1966

OWNED BY:

THE INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

SHEP.

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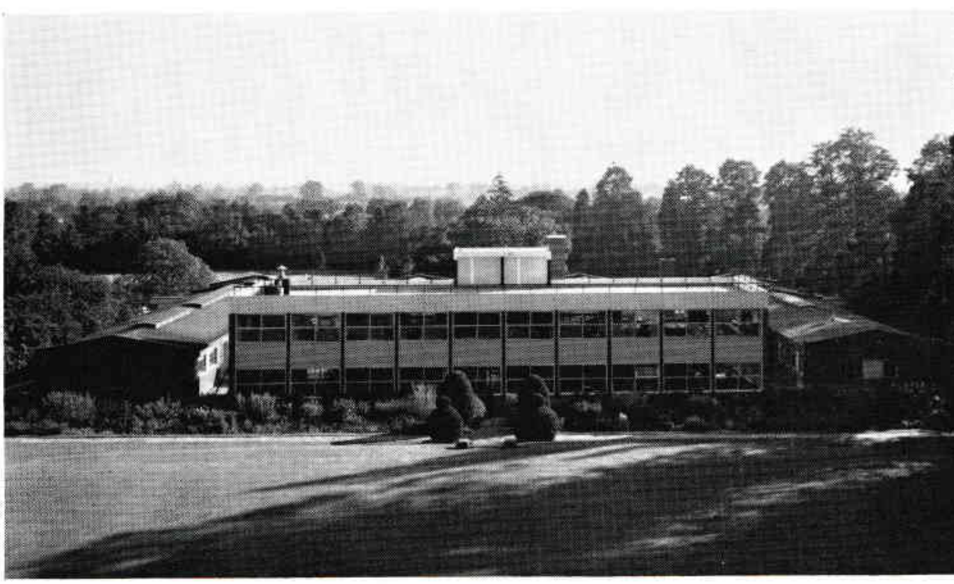
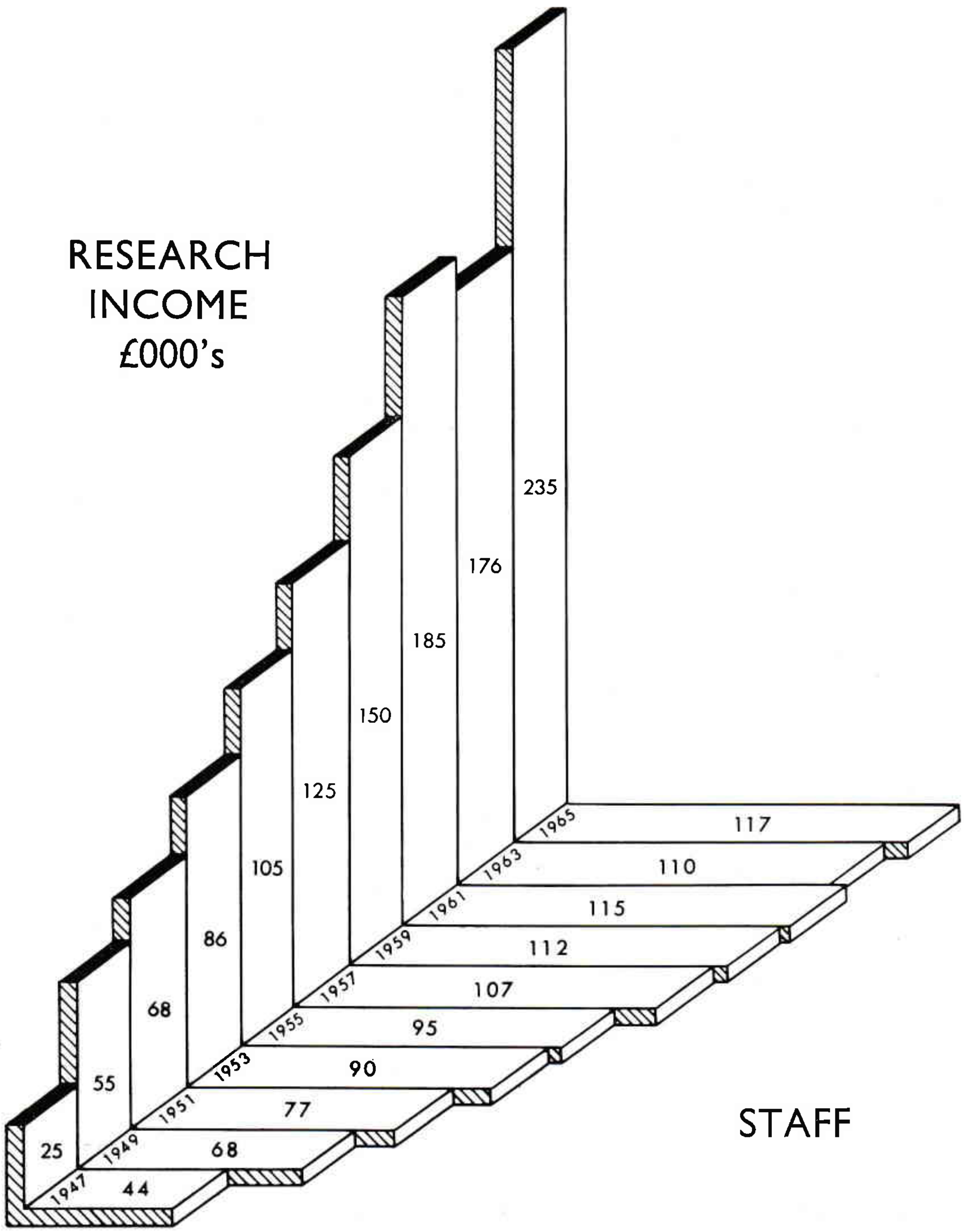
THE FULMER RESEARCH INSTITUTE



New Laboratories

THE FULMER RESEARCH INSTITUTE LIMITED

STOKE POGES, BUCKINGHAMSHIRE



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DIRECTION

As the owner of the Fulmer Research Institute, the Institute of Physics and The Physical Society is responsible for the appointment of directors.

The present board of directors consists of:

W. R. Merton, M.A., F.Inst.P. (*Chairman*)
*P. Gross, D.Phil.
*E. A. G. Liddiard, M.A., F.Inst.P., F.I.M.
Sir Gordon B. B. M. Sutherland, Sc.D., LL.D., F.Inst.P., F.R.S.
Sir James Taylor, M.B.E., D.Sc., F.Inst.P.

**Executive directors.*

SCOPE AND FUNCTIONS OF THE INSTITUTE

THE Fulmer Research Institute is wholly owned by the Institute of Physics and the Physical Society. It was founded in 1946 to carry out contract research and was originally associated with Almin Ltd. and passed to Imperial Aluminium Company Ltd. when Almin was acquired by them. It was acquired by the Institute of Physics and the Physical Society in 1965 and it is the first sponsored research organisation to be owned by a professional scientific institution.

The Fulmer Research Institute is run on strictly commercial lines and has received no endowment, subsidy or grant from any outside source or from the parent organisation since it first opened. Its income derives solely from payment for work done. The growth of the organisation (shown opposite) has been achieved by ploughing back profit and the present value of the capital assets is estimated at about £250,000 which has built up from an original capital of £40,000.

The main fields of activity are metallurgy, physical, inorganic and analytical chemistry, and solid state physics, but there are no prescribed limits to the type of work undertaken. Patents arising from major investigations which are the subject of the Institute's standard contract belong to the sponsor, and all results are confidential and are divulged or published only with the sponsor's permission.

A large part of the research work is for Government departments and the U.K.A.E.A., and a substantial proportion of the Institute's income is from overseas. Nevertheless, there is increasing use of the Institute by industry. Larger firms, with their own laboratories, find it economical to sponsor work in fields where the Institute has specialised experience and equipment. Smaller firms can call upon the Institute for far more extensive research facilities than they have available internally, without being involved in capital outlay on expensive items of equipment and the employment of specialised staff.

Both large and small firms make extensive use of the facilities for mechanical testing, chemical analysis and consulting services, and short term investigations are undertaken to solve specific production difficulties. This short-term work represents about 20% of the Institute's total income.

STRUCTURE

The principal divisions within the Institute are:

(1) **Physical Metallurgy.**
(2) **Foundry, Metal Working and Ceramics.**
(3) **Physical Chemistry, Thermodynamics and Extraction Metallurgy.**
(4) **Physics (including Electron Microscopy).**
(5) **Engineering and Mechanical Testing.**
(6) **Corrosion and Electrodeposition.**
(7) **Chemical Analysis.**
(8) **Spectrography.**
(9) **Chemical Engineering.**

Ancillary services at the Institute include well equipped workshops (in which much of the Institute's specialised apparatus has been made) and an extensive library which receives more than 250 scientific and technical periodicals. Information and advice based on published work can be supplied quickly to sponsors, and a translation service is available.

The internal organisation of the Institute is flexible. Most researches are done by team work employing all appropriate available man power and equipment from different departments, but work of a highly specialised nature may be the responsibility of one man working virtually alone. Where possible, contacts are made direct between the investigator and the sponsor's technical staff.

CONDITIONS OF SPONSORSHIP

Services provided and costs

(i) Certain work, generally of a routine nature, such as mechanical testing or chemical analysis, can be undertaken for a fixed agreed fee.

(ii) Investigational work of short duration dealing with service failures, etc., is charged on the basis of the time devoted to the solution of the problem.

(iii) Other work is carried out on a contractual basis, a standard research contract being drawn up between the Institute and the sponsor after the terms of reference and the experimental programme have been agreed, and the costs of the programme estimated.

(iv) If the experimental work is carried out under contract the results and patents arising therefrom belong to the sponsor, and are treated as confidential, together with any information given to the Institute by the sponsor.

(v) Contract research is not carried out on the same subject for more than one sponsor, except by agreement, but routine or consulting work is not subject to this limitation.

(vi) Nominees of sponsors may work in the Institute's laboratories, thus facilitating the development and application of research results in industry.

(vii) Publication of contract research results is only made with the sponsor's permission.

(viii) The sponsor makes acknowledgement to the Institute and its staff, in any publication which contains results of work carried out by the Institute.

Process metallurgy and chemical engineering laboratories

Main building

EQUIPMENT AND SPECIALISED TECHNIQUES

X-ray Crystallography

Phase transformations in metals, and atomic and molecular structures generally are studied by X-rays in the Physics Laboratory where there are seven generators. An X-ray diffraction camera has been designed for studying reactive metals such as titanium and zirconium at temperatures up to 1000°C. in a vacuum of better than 10^{-6} mm Hg. A Geiger counter spectrometer has been developed for studying the structures of liquids including metals liquid at elevated temperatures. Facilities for examining crystal structures at sub-zero temperatures are also available. The structure of superconducting metals and intermetallic compounds have been studied.

Particular attention has been paid to the development of high sensitivity single crystal techniques using monochromatic radiation. These have proved most useful for studying precipitation in alloys. X-ray diffraction is used extensively for identification and analytical purposes.

Electron Microscopy

The latest 125 kV version of the Siemens Elmiskop IA high resolution electron microscope has recently been installed together with important new equipment which allows an X-ray spectrometric analysis with simultaneous electron microscopic observation in transmission. Using this equipment, quantitative chemical analysis of particles, down to 100Å diameter, on carbon extraction replicas and in metal foils is possible. A.E.I. EM3A and EM6 electron microscopes are also in use for reflection and transmission electron microscopy and electron diffraction.

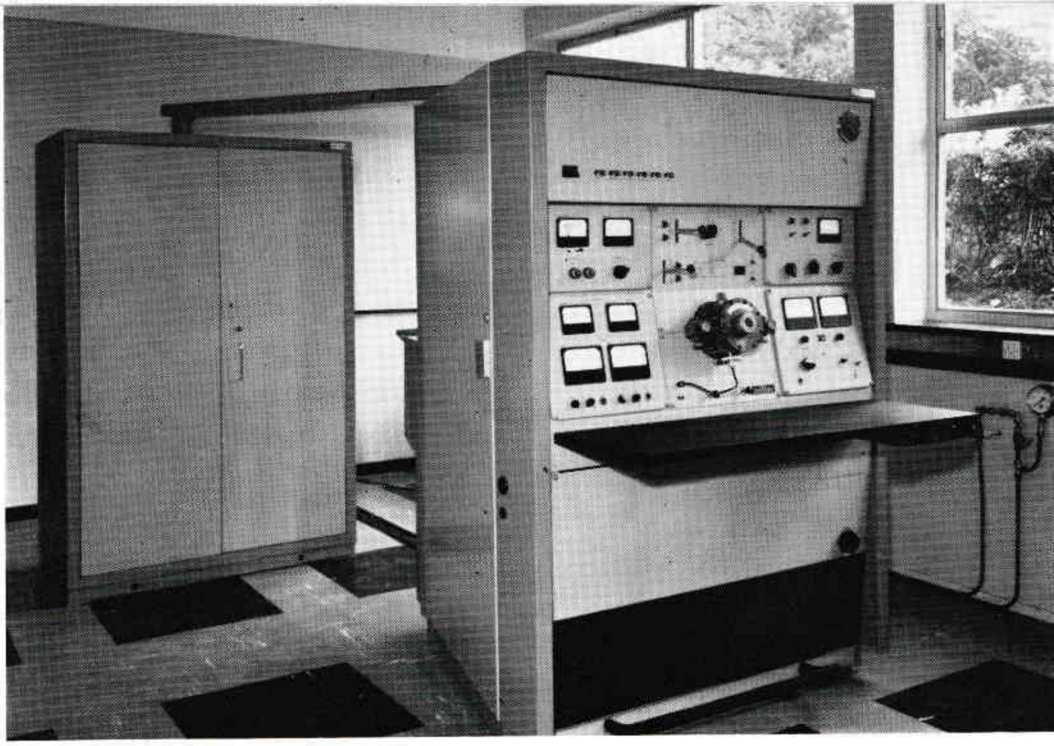
The application of high resolution electron microscopy to long term research has continued to expand and recent or current investiga ions include the determination of carbon solubility in stainless steels, the examination of metastable structures in uranium alloys, the study of brittle fracture in special steels and the development of new aluminium alloys. In addition, the instrument continues to be used in a variety of short term investigations including the examination of welding failures, "hot tearing" in low alloy steels, hydrogen embrittlement of steels and particle size determinations.

In special cases the electron microscopes have also been made available to investigators from other organisations for the examination of their own specimens.

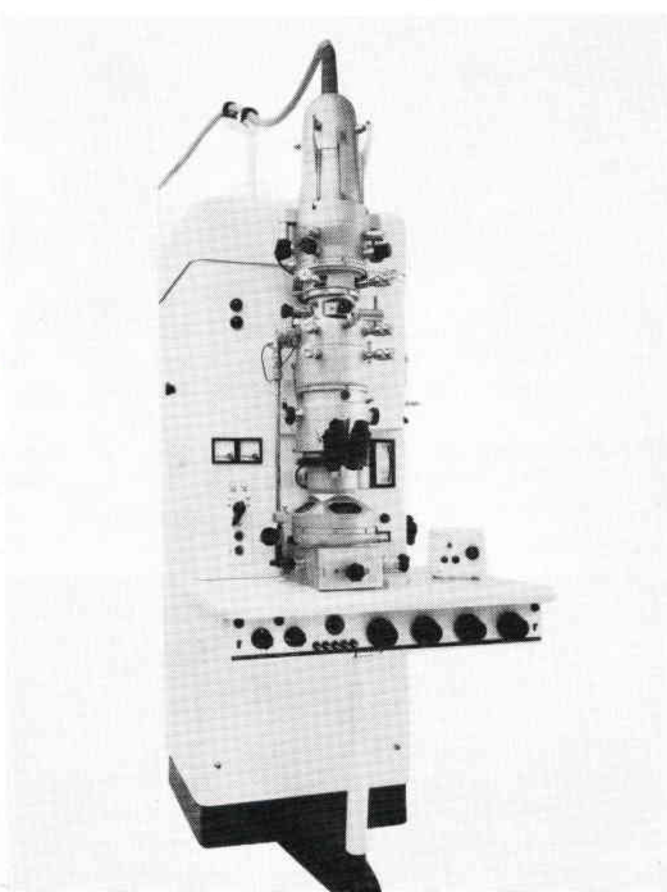
Mass Spectrometry

An A.E.I. MS 702 mass spectrometer has recently been acquired and is available as an inorganic analytical service or for contract research. The instrument is able to make a complete survey of all elements in the range ^{7}Li to ^{238}U in one analysis and to detect impurities down to one part in 10^{9}.

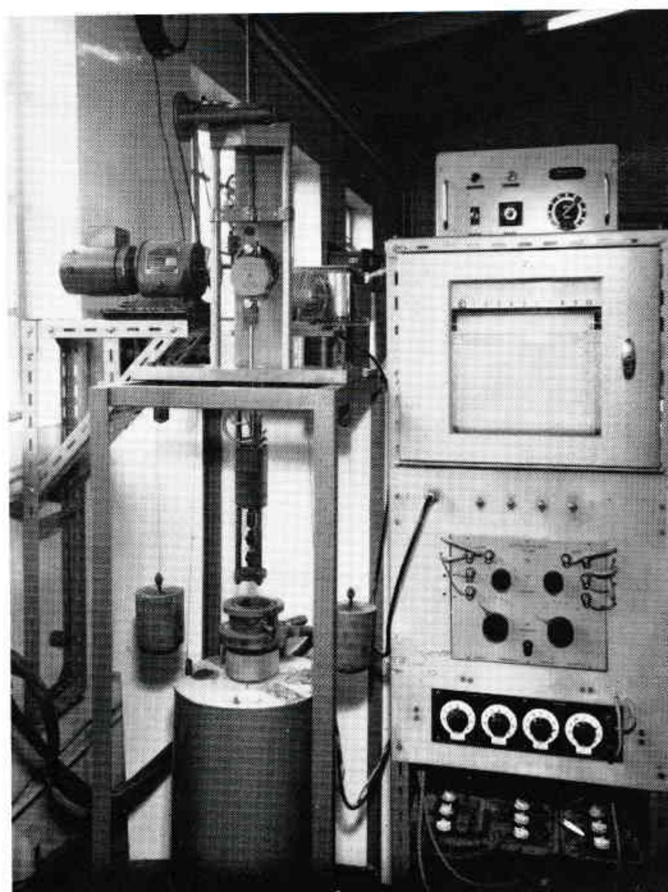
New A.E.I. MS702
Mass Spectrometer

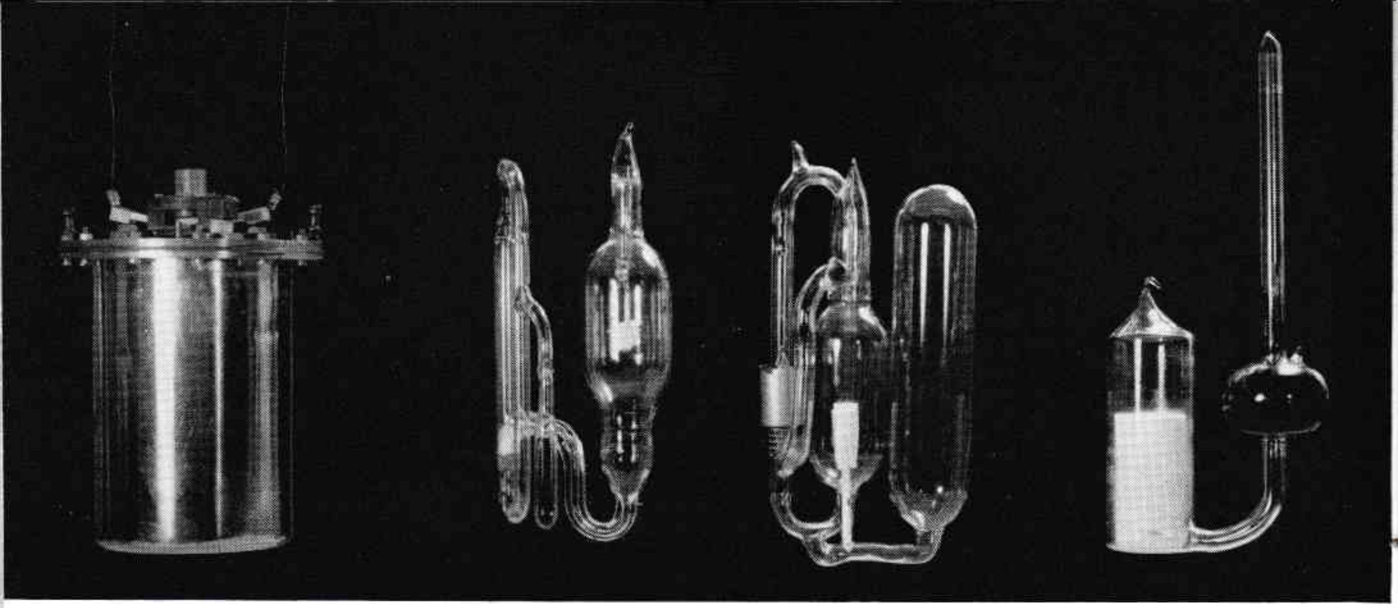


New Siemens 125 kV Elmiskop IA
Electron Microscope



High Accuracy Polanyi Tensile Testing Machine used for Deformation Studies.





CALORIMETRIC REACTION VESSELS

Heats of combustion of elements and compounds in the gaseous halogens (F_2, Cl_2, Br_2) at pressures up to 8 atmospheres have been measured using glass vessels consisting of one bulb for the combustion of the substance (in a refractory crucible) and one bulb containing the halogen. Reaction occurs when a membrane separating the two is broken. Heats of formation have also been obtained by dissolution measurements in hot hydrofluoric acid contained in a platinum vessel, and in liquid bromine contained in a glass vessel.

The photo shows from left to right: the platinum vessel, a glass vessel for reaction with chlorine or bromine gas under pressure, a glass fluorination vessel, and a vessel for reaction with liquid bromine.

Metallography and Physical Metallurgy

A Bausch & Lomb metallograph, a Reichert MeF metallurgical microscope, a Watson stereoscopic zoom microscope and several bench microscopes (one of which is equipped for phase contrast microscopy and micro-hardness testing) are available for metallography. Various specialised pieces of equipment have been developed for studying phase changes, particularly in reactive alloys. These include a hot hardness tester that will operate at temperatures up to 1000°C. in a vacuum of 10^{-5} mm. Hg, and a dilatometer. This utilizes a transducer capable of detecting displacements of 0.1 in. to 2.5×10^{-6} in., and is used for studying isothermal and martensitic transformations in alloys as well as for the accurate determination of coefficients of thermal expansion of materials. There is also a sensitive stress-strain machine of Polanyi type for studying yield point phenomena and machines for examining the effect of strain rate changes during slow creep. A simple torsional pendulum has been constructed for investigations of the diffusion and precipitation of interstitial elements such as nitrogen in the b.c.c. metals iron and chromium by measurements of internal friction.

Physical Chemistry

Special techniques are available for physical chemical studies up to 2300°C. Gas equilibria and thermodynamic activities have been determined at high temperatures. Thermochemical measurements of high precision and on reactions which proceed only at elevated temperatures (up to 800°C) have been made. Equilibrium measurements have been applied to determine the stability of various compounds (Al_4C_3, $TiCl_2$ (gas), $TiCl_3$ (gas)), of normally non-existing radicals (AlCl, AlBr, AlF, BF) and the activities of various constituents of many alloys. The gas transference method has been used at total pressures of about 1 atmosphere, and the effusion method for pressures below about .01 mm mercury; for the latter a vacuum micro-balance and a torsion cell are available. The "capillary vessel" method has been developed in the Institute for measurements in the intermediate pressure range.

For thermochemical determinations, calorimeters of various design, resistance thermometers for different temperature ranges and ancillary equipment for calibration of calorimeters and thermometers are available.

Halogen bomb calorimetry in which substances are combusted in fluorine, chlorine and also bromine in glass vessels at pressures up to 8 atmospheres has been developed in the Institute. Flow type calorimeter vessels made from various materials for reaction with the halogens and other gases, in instances at 700°C, and equipment for determining the heat of the interaction between solids (including metals) at temperatures below 800°C, are also available. Reaction with the halogens constitutes a new development in the determination of the heats of formation of a wide range of inorganic compounds (oxides, nitrides, phosphides, borides, etc.). Measurements of the kinetics of chemical reactions have been made. The radiation of gases at high temperature has been measured. Equipment constructed for these and more conventional investigations is available.

Chemical and Spectrographic Analysis

In addition to the mass spectrometer described earlier, the Institute is equipped for inorganic and metallurgical analysis and the analytical staff have extensive experience of working with alloys and compounds. The equipment includes large and medium quartz emission spectrographs, a Wild-Barfield vacuum fusion apparatus, a cathode ray polarograph and U.V. spectrometer.

Ceramics

The laboratories are equipped for the fabrication of ceramics by processes such as pressing and sintering, slip casting, and hot pressing, as well as reaction sintering in inert atmosphere.

A process for making crucibles and ceramic shapes by reaction bonding has been developed in this laboratory.

Ceramic vessels are being prepared from the melt by an electron beam technique and pilot experiments on the production of oxide single crystals by floating-zone melting are in progress. An important new technique being developed is the purification of alumina by electron beam zone refining. This promises to yield the purest alumina available.

Ceramic coatings can be made by rod or powder flame spraying or by enamelling.

Melting and Casting

The experimental foundry is equipped with conventional oil, gas and electric furnaces for melting. More specialised equipment includes induction furnaces for melting and casting, with or without special atmospheres, or in vacuo. Reactive alloys are prepared in small argon arc furnaces. A consumable electrode argon arc furnace, capable of melting ingots 4 in. or less in diameter is available. Apparatus is available for electron bombardment melting and is also used for zone refining and growing single crystals of both metallic and ceramic materials.

Metal Working

Metal working equipment includes a forging hammer, a rolling mill with plain and grooved rolls for hot and cold work, and small jewellers' rolls. Metals and alloys can be fabricated into sheet, rod and large diameter wire forms. There is also a 60-ton press, used for hot pressing metal powders, and a small laboratory extrusion press. A salt bath heated by means of the electrical resistance of the molten salt is available for pre-heating and heat treatments up to a temperature of 1350°C.

Electrodeposition

Laboratory facilities are available for small scale experimental plating, anodising, etc. On a larger scale, there are two rectifiers with an output of up to 250 amps which may be used for electro-winning chromium of very high purity using a fluoride bath and are capable of producing in the region of 8 lb. per week.

Techniques are at present in use for electro-machining and high speed electro-forming involving high rates of circulation of electrolytes.

Corrosion

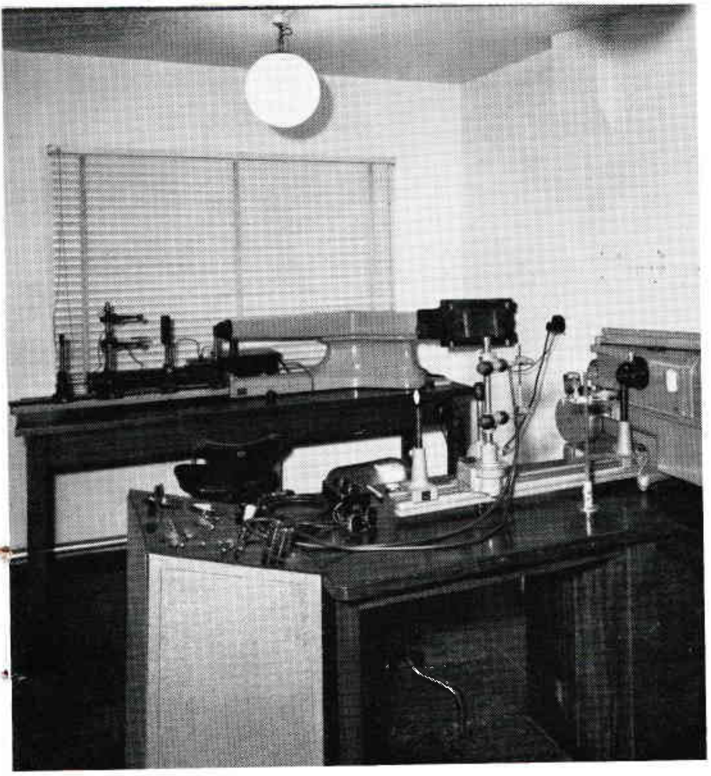
The corrosion section is able to undertake short term investigations to solve corrosion problems and also has facilities for long term fundamental investigations. Equipment available to allow rapid laboratory investigations of corrosion susceptibility includes salt spray, sulphur dioxide and humidity cabinets and a number of types of stress corrosion rigs. The Institute has atmospheric exposure sites in industrial marine and rural environments. Electronic equipment such as electrometers, potentiostats and constant current devices are used for studying the effect of applied potentials and currents on corrosion reactions, particularly during stress corrosion and corrosion fatigue.

Chemical Engineering

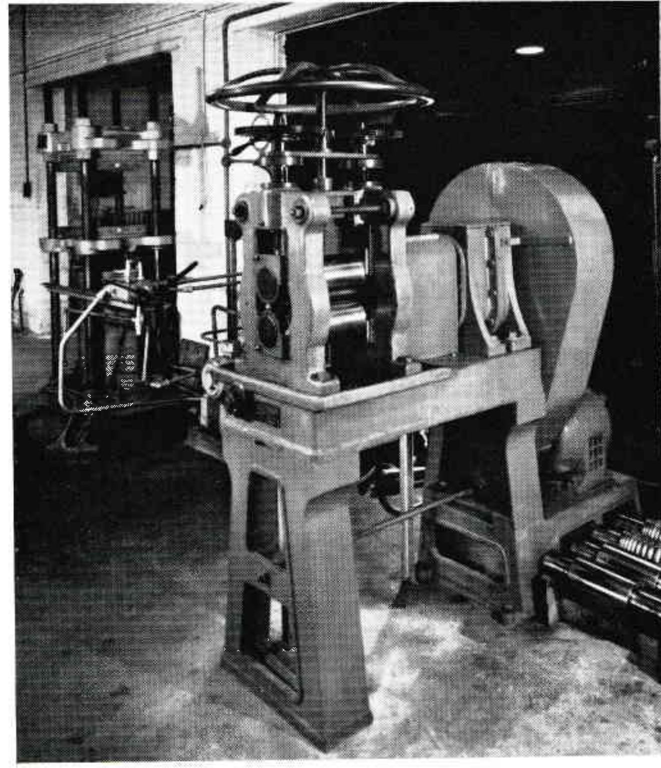
A recently formed section concerned with process and equipment design and development, and operation of pilot plant to obtain additional design data. Fields of interest and work undertaken include:

(1) Heat transfer including unsteady state conduction, infra red heating, evaluation of performance of heat exchangers.
(2) Mass transfer including solvent extraction, ion exchange and economic evaluation of continuous reactor systems.
(3) Fluid mechanics including mixing, liquid-solid separation, and hydraulic transport of solids including economic evaluation of slurry pumping systems.

The process interests are essentially inorganic chemistry, extraction metallurgy and hydrometallurgy. Some work has been done on treatment of effluents, including metal recovery and removal of emulsified oils.

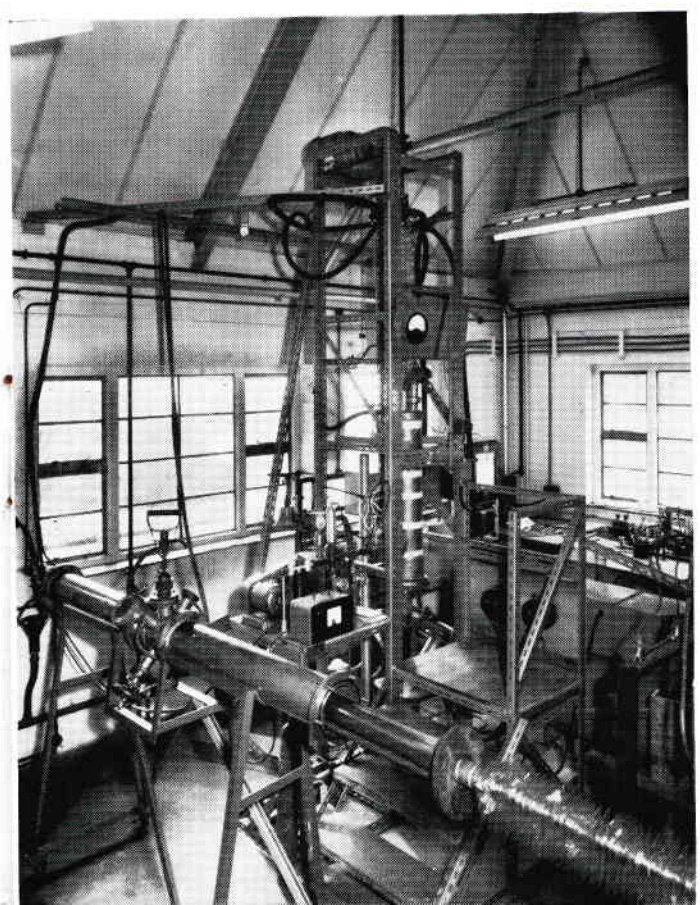


Large and Medium Quartz Spectrographs

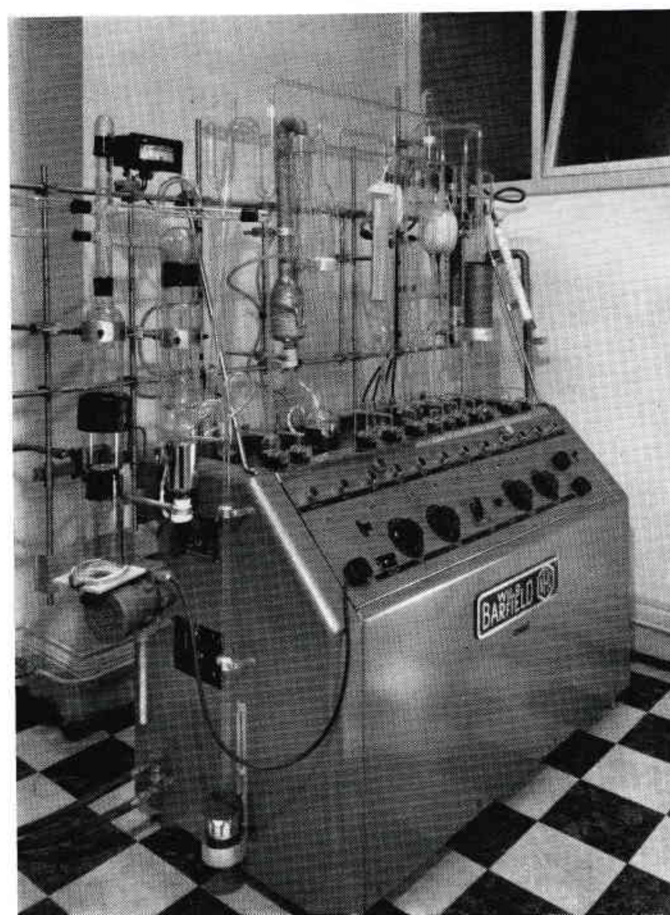


Rolling Mill

Consumable Electrode Argon Arc Furnace



Apparatus for Vacuum Fusion Analysis



FIELDS OF INVESTIGATION

The following notes contain brief descriptions of some of the work completed or in progress. Work is confidential to the sponsor and the account given is confined to those investigations which have been published or otherwise made available with the permission of the sponsor.

Chemical Thermodynamics

A knowledge of chemical thermodynamic data (heats of formation, free energies of formation and thermodynamic activities) of compounds is necessary for calculating the equilibria of chemical reactions in which they participate. These equilibria comprise those occurring in metallurgical extraction and refining processes, including the precipitation of metals by gas phase reactions for coating purposes and the preparation of thin layers of intermetallic compounds, for instance those needed for superconductors. The preparation and purification of elements and compounds, particularly semiconductor compounds, by "chemical transport" also involves reversible chemical equilibria, a knowledge of which is essential for the understanding of the processes and for selecting optimum conditions of operation. Chemical equilibria, very often involving species which are unstable at lower temperature, occur also in high temperature flames and thermodynamic data are necessary to predict reaction of flame products with solid high temperature materials with which they are in contact. Thermodynamic data relating to alloy constituents are of interest in physical metallurgy because they determine the stability of the various phases. Similarly, a thermochemical study of the compounds in the system sodium—oxygen—iron in the presence of liquid sodium has been made with a view to elucidating the mechanism of the attack on iron by liquid sodium containing oxygen; an analogous study in the system sodium—oxygen—chromium is in progress.

For the evaluation of "sophisticated" rocket propellants which involve the combustion of light elements in fluorine or oxygen, the heats of formation of the oxides, fluorides and other compounds of the light elements are of primary importance. The heats of formation constitute a very essential part of thermodynamic data and can, at present, be only determined experimentally with sufficient accuracy. The heats of formation of the following compounds have been determined calorimetrically:

By combustion in fluorine: BF_3, BN, GeF_4, GeO_2(hex), GeO_2(tetr), PF_5, SF_6, TiF_4, UF_3, UF_4, UF_6.

By combustion in chlorine: $BeCl_2$, α- and β-Be_3N_2, $HfCl_4$, $NbCl_5$, $TaCl_5$, $TiCl_4$, VCl_4, $ZrCl_4$.

By combustion in bromine: $NbBr_5$, $TaBr_5$.

By reaction of solids with gases other than halogens: α-Be_3N_2, $LiBF_4$, $NaBF_4$, UN, $UN_{1.5}$.

By solution calorimetry, in bromine: $TiBr_4$; in hydrochloric acid: $FeO.2Na_2O$; in hot hydrofluoric acid: $B_2O_3.2Al_2O_3$, $2B_2O_3.9Al_2O_3$, $Li_2O.Al_2O_3$, $B_2O_3.3BeO$, $Li_2O.2BeO$.

By reacting the components of powder mixtures with each other: AlF_3, BeF_2, Li_3AlF_6, Na_3AlF_6, $LiBeF_3$, Li_2BeF_4, USi_3, USi_2, USi, U_3Si_2.

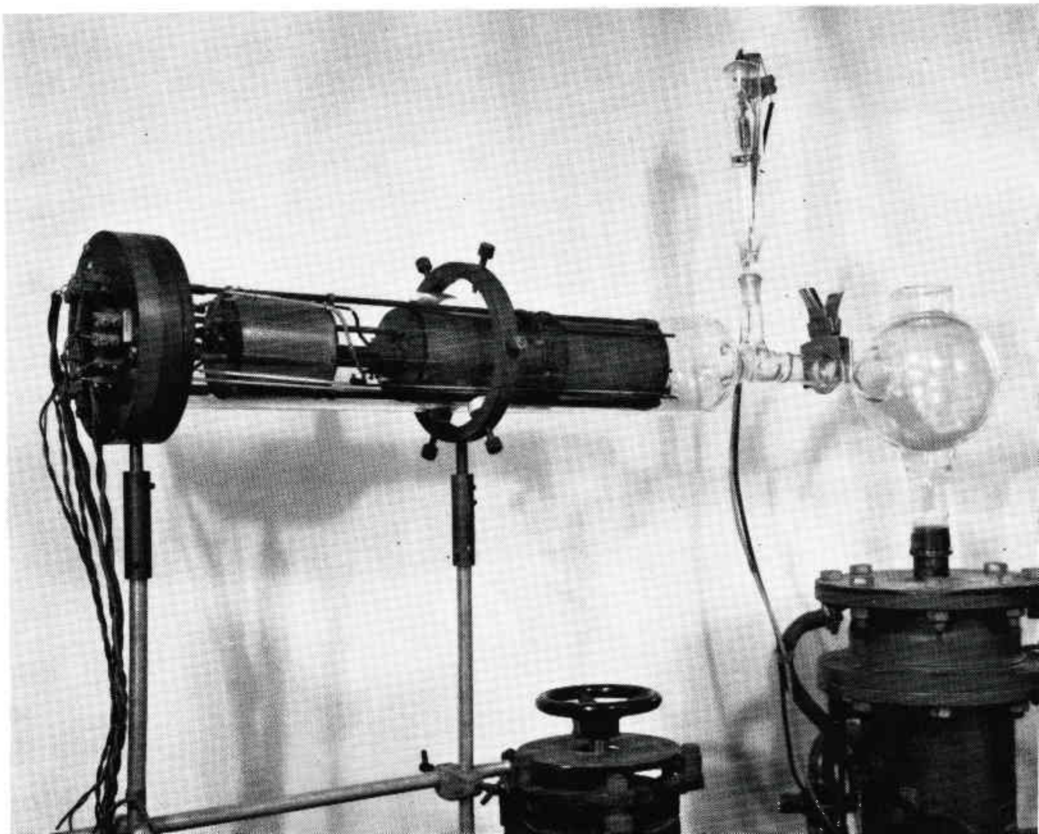
The free energies of formation of the compounds Al_4C_3 (solid), $TiCl_2$ (gas), $TiCl_3$ (gas), and of the unstable radicals AlF (gas), AlCl (gas), AlBr (gas) and BF (gas) have been determined.

The activities of various constituents in the following alloy systems have been measured: aluminium-manganese, aluminium-iron, aluminium-iron-silicon arc furnace alloys, bismuth-uranium, bismuth-thorium, chromium-iron-carbon. For all these determinations each system requires a special approach and novel techniques have been developed, for example, in the preparation and handling of highly reactive materials or in overcoming problems arising from the difficult experimental conditions frequently encountered.

High Temperature Equilibrium Apparatus

At high temperatures elements form compounds in which they have a lower than their normal valency; for instance, the halide vapour MeX_2 of the divalent element Me will, particularly at low pressure, react with further Me (solid) to form the "radical" MeX [according to the equation: $MeX_2(vapour)+Me(condensed)=2MeX(Vapour)$].

The photograph shows the apparatus for the study of an equilibrium of this kind. In the evacuated glass envelope can be seen (from left to right): furnaces for the MeX_2 evaporator, for the reaction cell (containing Me), and for the condenser on which the reaction is reversed by absorption of Me.



Deposition from the Vapour Phase

The deposition of metals and of intermetallic compounds from the vapour phase is of increasing technological importance. The Institute has facilities for these processes.

Tungsten, molybdenum and rhenium have been deposited by reduction of their fluorides by hydrogen, tantalum and niobium by reduction of the chlorides.

The conditions necessary for the preparation of sound coatings of tungsten, and their physical behaviour, have been studied extensively; deposits varying in thickness from less than one thousandth to more than one eighth of an inch have been produced. Graphite rocket nozzles have been coated with tungsten and have shown good performances in actual firing tests. Tungsten vessels have been made by coating formers.

Coatings of oxidation resistant molybdenum disilicide on molybdenum have been made by forming the compounds on the surface of molybdenum by keeping it at elevated temperatures in an atmosphere containing the normally non-stable silicon dichloride. Boron has been incorporated into such coatings in a similar way. The coatings obtained have excellent high temperature oxidation resistance under both static and cycling conditions.

The co-deposition of metals from their halide vapours by hydrogen reduction can be accomplished under conditions which can be estimated from the thermodynamics of the chemical processes involved. Thin layers of a super-conducting intermetallic compound have been deposited on various substrates (metals and inert oxides) by this method.

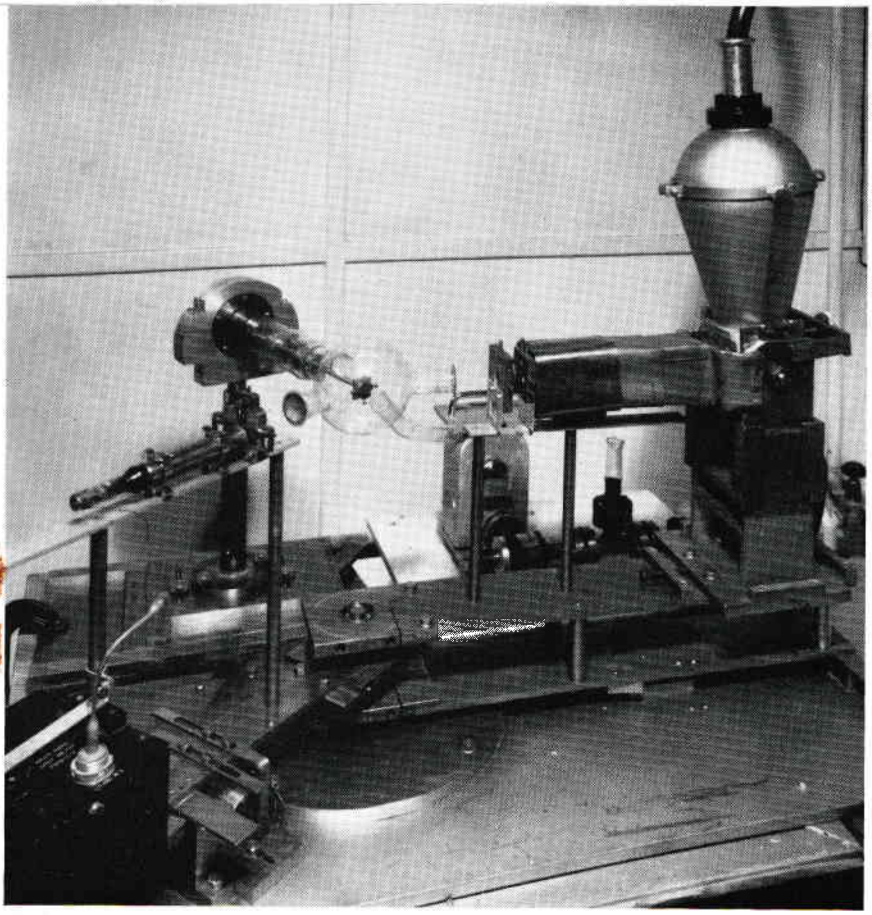
Extraction Metallurgy

The "catalytic" aluminium distillation process (invented by Dr. P. Gross) is thought likely to be competitive with the conventional extraction process. Aluminium trichloride is passed over an aluminium alloy obtained by arc smelting of bauxite. Aluminium monochloride is thereby formed and subsequently converted into pure aluminium and aluminium trichloride which is recirculated. The process can also be used for aluminium refining. Extensive laboratory and development work was carried out at the Institute.

A somewhat similar process involving titanium tetrachloride and its lower chlorides has also been developed for the extraction of pure titanium from commercial ferro-titanium alloy and has been developed on a laboratory scale and could be extended to the pilot plant stage.

A related method has been applied to the purification of beryllium with good results.

A study of the thermal reduction of alumina by carbon to the various intermediate products—aluminium oxy-carbides and aluminium carbide—and finally aluminium at temperatures up to 2300°C has been made.



HIGH VACUUM HIGH TEMPERATURE X-RAY CAMERA

This camera enables specimens of reactive materials to be examined at high temperature under conditions of high vacuum.

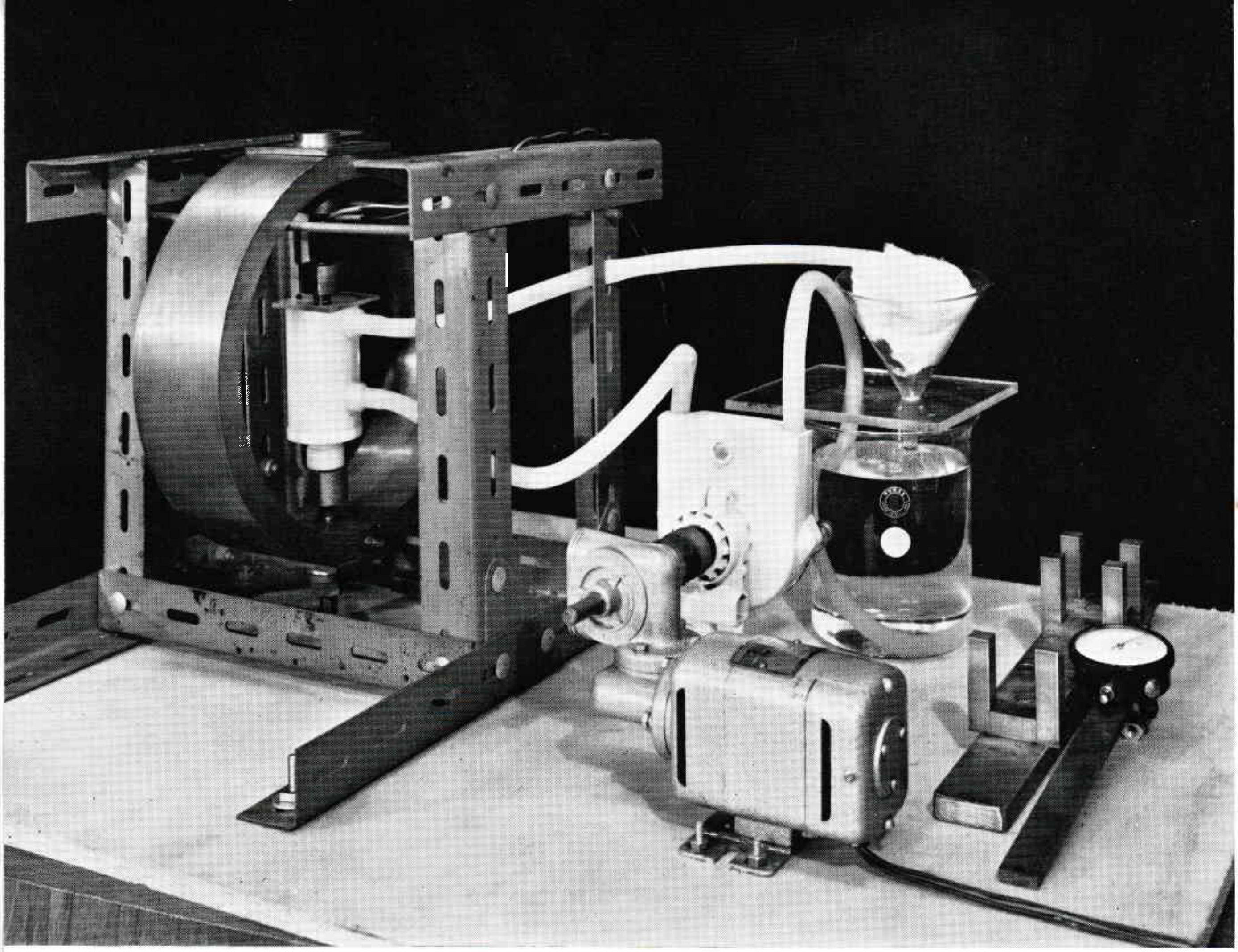
A vacuum of better than 1×10^{-8} mm Hg is possible so avoiding the contamination found in more conventional equipment. The external heater element consists of an ellipsoidal reflector with a 1000 watt bulb at one focus, the specimen being at the second focus. In this way specimen temperatures up to 1000°C. are readily achieved.

This type of apparatus has been used for studying phase transformation in alloys of Zr and Ti, and is now being used to measure changes in grain size in β uranium.

Aluminium and its Alloys

The Institute's work on the effect of trace elements on precipitation hardening has been reviewed in F.R.I. Special Report No. 3. More recent work has been concerned with the stability of precipitates on prolonged ageing at elevated temperatures, and it has been shown that in aluminium-copper alloys, trace elements such as cadmium, indium and tin, can inhibit precipitate coarsening and so can influence creep behaviour. The effect of trace elements in alloys of the Concorde type DTD.5070A composition are being studied; for example, silver additions improve the creep resistance of these alloys which is associated initially with finer precipitation and later the nucleation of a more stable phase.

A large investigation on the influence of metal spraying and grit blasting on the corrosion fatigue of high strength aluminium alloys has been completed. Investigations have shown that an Al-Cu-Cd alloy developed by the F.R.I. has very much superior resistance to exfoliation corrosion and stress corrosion than conventional Al-Cu base alloys such as HE.15, particularly in the welded condition. Extensive work has been carried out on anodised aluminium and aluminium alloys and exposure tests in marine, rural and severe industrial environments to study the effect of anodised film thickness on corrosion resistance are continuing. An aluminium-tin bearing alloy containing up to 30% tin, developed in conjunction with the Tin Research Institute, is being widely used in industry, both in the U.K. and overseas, in for example motor car engine bearings.



STRESS CORROSION APPARATUS

The photograph shows a single unit from one of a batch of 12 for sustained axial load testing on ultra high tensile in corrosive environments. The stress is applied by means of a pre-set proving ring and the corrosive media is continuously pumped through a small cell surrounding the specimen.

This single unit is used for potentiostatic work to try to differentiate between stress corrosion and hydrogen embrittlement.

Copper-base Alloys

The nucleation and propagation of cracks in complex aluminium bronzes are being studied. Cracks are nucleated after very small amounts of deformation at coarse K particles or in regions of retained β but these do not propagate in wrought materials where these structural features are usually isolated.

Chromium and its Alloys

Work on chromium and chromium alloys has concentrated on the room temperature brittleness of these materials and has shown what ductilities can be obtained in combination with good high temperature strength and oxidation resistance.

A process for making high purity electrolytic chromium has been developed as well as a method for making tubes and parts in pure chromium by electroforming.

Ferrous Metallurgy

Recent work has included the determination of the solubility of carbon and the nature of the carbide first precipitated in two steels containing 20% Cr, 25% Ni, 0.6% Nb and 17% Cr, 14% Ni, 2.7% Mo respectively. In each case, the logarithm of carbon content varied linearly with the reciprocal of absolute temperature and the slope of this line could be related to the heat of formation of the carbide precipitated.

Advice on the selection and routine quality control of high speed steels has been given and a specification has been devised.

A study is in progress on the stress corrosion and hydrogen embrittlement characteristics of several ultra high tensile steels; the relative merits of various protective schemes are also being investigated.

Another project is the examination of the structure of oxide films produced on stainless steels by high strength hydrogen peroxide. The structure and composition of the oxide is being determined by X-ray diffraction and spectroscopic measurements and an infra-red absorption, technique is being used to measure film thickness.

Phase Diagrams

The Institute is equipped to determine phase diagrams of alloys using techniques such as differential thermal analysis, dilatometric analysis, optical, electron and X-ray metallography including electron probe X-ray microanalysis.

Recent examples of work in this field include the U-Al and U-Al-Fe phase sections, the solubility of carbon in two stainless steels and equilibria in tin-base alloys. Accurate thermal analyses of Magnox alloys and chromium cast irons have also been achieved.

Tarnish Resistance

Work is being carried out on making improvements to metal polishes, with a view to developing tarnish resistant finishes. Organic additives have been investigated and a number of promising compounds found; for one of these patent cover has been obtained. Improved resistance to atmospheric corrosion has also been obtained by incorporation of certain vapour phase inhibitors in oils, grease, lacquers and similar corrosion barriers.

Liquid Metals

Structure

Previous work at the Institute has shown that the structures over a range of temperatures of many liquid metals including Ga and Sn and the alloys Au-In and Au-Sn, are different from those of simple liquids such as Na, K and Au. Recent work shows that liquid mercury, too, does not have a simple structure. The X-ray pattern of liquid mercury indicates a departure from simple mixing and radial distribution analysis of the patterns shows that two distances of close approach of the atoms occur. These distances can be correlated with the two shortest distances present in the solid allotropes of mercury, suggesting that the cohesive forces in the solid exist, to some extent at least, in the liquid. Current work includes studies of Au-Al alloys and mercury based alloys.

Surface Compounds

Recent work at the U.K. Atomic Energy Establishment, Risley, has shown that materials containing Cr or Mo are lubricated by liquid sodium. This effect may be attributed to the formation of a surface compound of the form $NaCrO_2$ or Na_2MoO_4. An X-ray camera has been constructed which allows specimens to be heated in liquid sodium or its vapour and then examined in the camera without exposure to the atmosphere, for evidence of formation of these compounds.

Surface Tension

To provide data on liquid metals, which may be of use in applications involving wetting and joining, equipment has been built for determining the surface tension of these liquids up to 1700°C by the maximum bubble pressure method. Liquids under examination include tin, copper and uranium alloys.

Electrical Resistors

Thin film potentiometers

Evaporated nickel-chromium films on glass and alumina substrates have been examined to ascertain their suitability for use as the resistance element of a variable resistor. Films on glass were found to have a life of only some 10,000 cycles when worn by a light sliding contact; any current through the moving contact reduced the life further. Films on recrystallised alumina however, withstood one million traverses with little damage. The wear resistant properties of these films are attributed to the relatively high values of elastic modulus and thermal conductivity of the alumina substrate and the adhesion of the film to the substrate.

A number of potentiometer units have been made and their properties evaluated. Satisfactory results have been obtained for values of noise, temperature coefficient, wear and endurance in dry and damp heat. The dependence of these properties on substrate condition and design of moving contact has been studied.

Resistance Alloys with high stability

The structural effects occurring in certain high resistance alloys, which may be associated with their low temperature coefficient and electrical stability, are being studied. The influence of heat-treatment on these properties is being examined. The techniques used include precision measurement of resistance, thermal e.m.f.'s against copper and X-ray diffraction of single and polycrystalline specimens.

ANCILLARY SERVICES

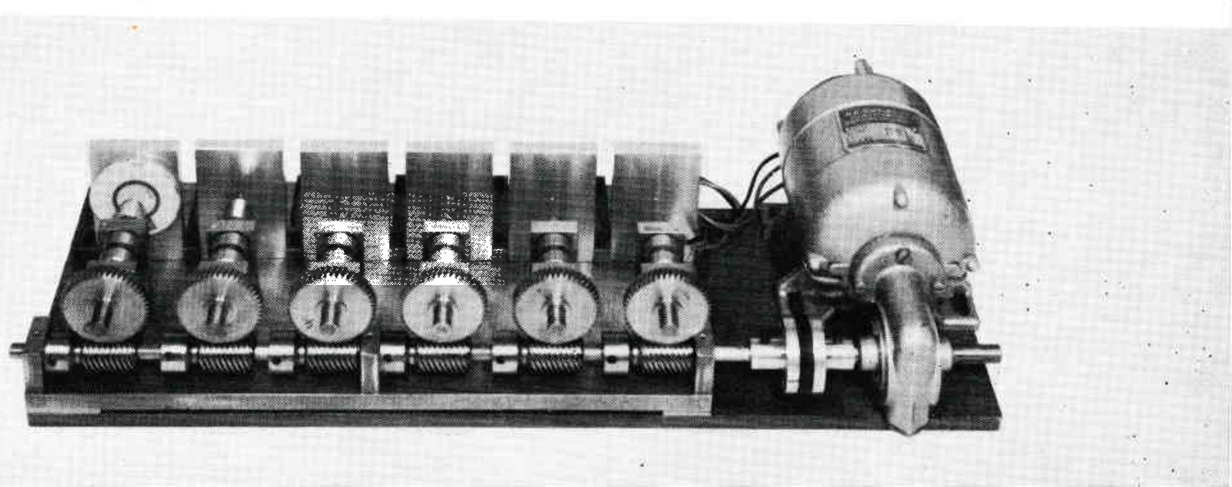
Testing and Consulting Work

The Institute's main function is to carry out research of a relatively long-term nature, but there is a steadily growing demand from industrial firms for testing and consulting work. Many firms regularly send samples for spectrographic analysis together with chemical analysis, mechanical testing and weld examination for which the Institute is A.I.D. approved. Facilities for metallography, crack detection, radiography, X-ray and electron diffraction, and electron microscopy are also available. In this routine work, X-ray diffraction techniques find their principal application in the identification of corrosion products and surface films. Electron microscopy is employed for particle size and shape studies and in the examination of a variety of different samples, including razor blade edges, fractured surfaces, fibres, magnetic tapes used in computers and cement samples. A photographic service is also available including cine-photography with a 16 mm. Bolex camera.

Special tests are devised to meet individual requirements where there is no established testing procedure. For example, procedures have been devised for assessing the efficiencies of a special repair system for fractured castings and other massive parts, and on anti-freeze and anti-corrosive preparations. Fabrication techniques have also been worked out and applied to the manufacture of light machinery, e.g. shavers.

The Institute undertakes the examination of service failures and recommendations are made for improvements in design and the choice of material. Gear cutters, electric motor windings, electric contact arms, bearings, shafts and studs are among components received for examination. Members of the staff act in a consulting capacity in connection with production difficulties; the occurrence of excessive porosity in castings, the uneven solution of plating anodes, cracking in brass nuts and analysing methods of producing components by spinning and drawing, are examples of problems investigated. Members of the corrosion section investigate corrosion and plating problems and give advice on the selection of materials and protective finishes for particular environment.

Apparatus for studying wear resistance of thin metal films. Six lightly loaded slides are driven backwards and forwards in arcs along circular vacuum deposited metal tracks on ceramic substrates. Wear of the film can be followed by electrical measurements.



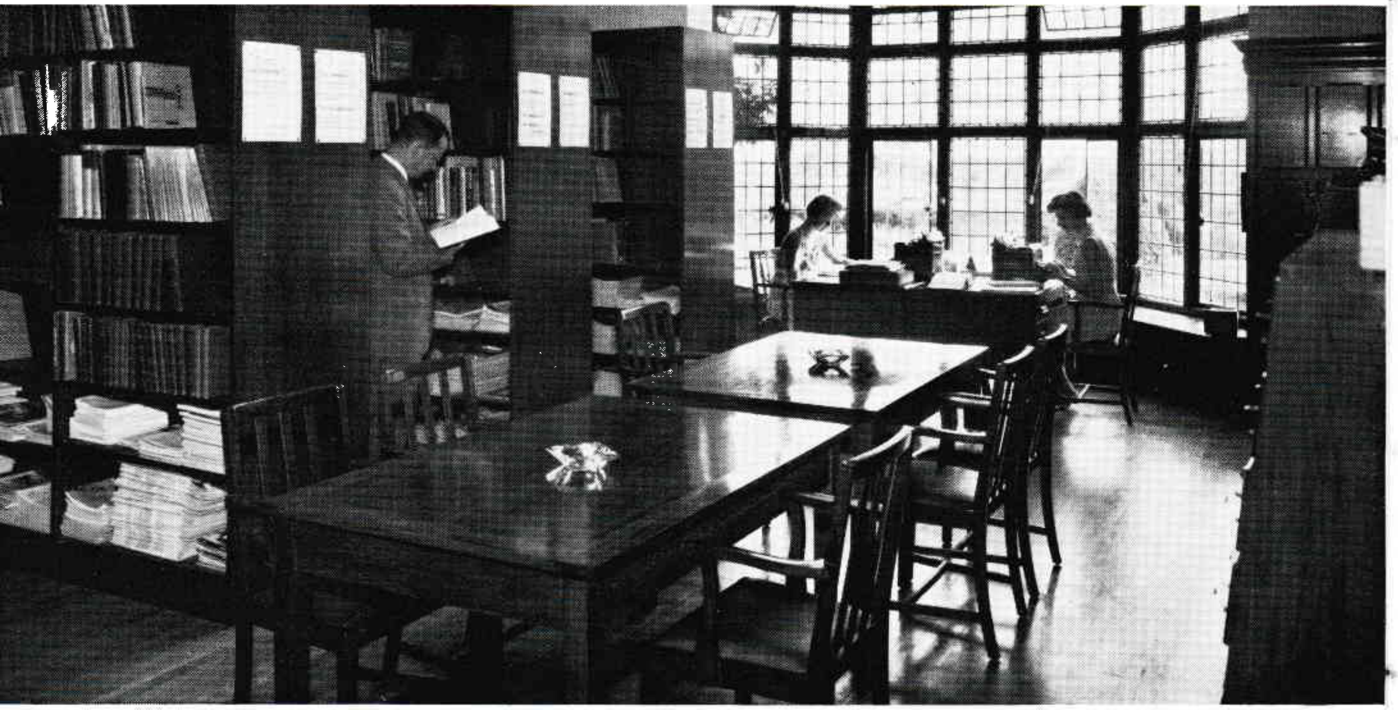
Litigation

Where expert opinion has been required in connection with legal disputes and litigation, the Institute has on many occasions provided this and has carried out experimental programmes designed to settle points in dispute.

Supply of Special Materials and Equipment

The Institute provides special materials, melting and fabricating facilities, and items of equipment for outside and laboratories. Materials supplied include high purity chromium and iron, small quantities of experimental steels for research purposes, and reactive alloys, in both the as-melted and rolled conditions. Fabrication techniques are being developed for manufacturing superconducting alloys such as Nb_3Sn, Nb/Zr and V_3Ga.

The design and manufacture of equipment to meet individual requirements is also undertaken.



The Library

Library and Information

The information requirements of the Institute staff are provided by the library which contains some 4,500 volumes and approximately 250 scientific and technical periodicals are currently received. It maintains close contact with other libraries and the staff prepare reviews and bibliographies of particular subjects for sponsors, as well as for investigators. Translations of foreign language articles of wide interest are available for loan or sale. Reprints of most of the published papers are available.

Scale of Charges

The Institute's charges are based on time of staff, plus materials at cost, with overheads at 110 per cent of salaries and wages. Major researches are the subject of separate contract agreements which normally specify the rate of expenditure. The total cost per graduate with appropriate assistants and services is roughly £6,300 per annum. Small investigations and consulting work are charged on the same basis and amounts to about 25 guineas per day. Rates for analytical and test work can be quoted on application but will vary with the nature and number of samples. Typical charges are:

	£ s. d.	
Chemical analysis of steels and common industrial alloys	1 10 0	per element
Other materials, e.g. minerals and ceramics, by quotation		
Vacuum fusion analysis of O_2, N_2 and H_2 in metals—		
1st Sample	10 10 0	
Subsequent similar samples... ...	8 8 0	
Spectrographic analysis (Qualitative) ...	5 5 0	per average sample
Mass spectroscopy (Quantitative) ...	40 0 0	per average sample
Optical metallography	3 3 0	per specimen (or £3 15 0 with photograph)
Electron Microscopy—		
Preparation and examination only of plastic/carbon or carbon extraction replica	12 0 0—15 0 0	
Preparation and examination of carbon extraction replica using electron diffraction techniques	40 0 0—50 0 0	
Preparation and examination only of thin metal foil	20 0 0	
Complete examination of specimen using carbon extraction replica and metal foil together with appropriate electron diffraction analysis in replica, or foil, or both	60 0 0—70 0 0	
Mechanical Testing—		
Tensile test, room temperature ...	1 1 0*	
Tensile test, sub or super normal temp.	4 10 0*	
Fatigue S/N curves (8 tests)	55 0 0	(10^7 cycles)*
Creep—exclusive use of one high accuracy machine	500 0 0	per annum*
Medium accuracy machine	350 0 0	per annum*

**Excluding machining.*

STAFF

(*as at* 31*st August*, 1966)

Director of Research	E. A. G. Liddiard, M.A., F.I.M., F.Inst.P.
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Assistant Development Officer	M. W. H. Gillham, L.I.M.
Secretary	E. Sugars, A.M.C.I.A.
Librarian	R. F. Flint, A.L.A.
Workshop Superintendent	F. S. Palmer
Director's Secretary and Clerical Supervisor	Elizabeth S. Duckett
Cashier	R. Butler
Assistant Cashier	V. C. Edwards
Photographer	W. Collis

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D. G. S. Davies, B.A.	Ceramist
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M. E. Giles, B.Sc., Ph.D., A.I.M.	*Corrosion**
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B. A. Hatt, M.Sc.	Physicist
C. Hayman, M.A.	*Physical Chemistry**
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K. W. Mitchell, B.Sc.(Eng.), Wh.Sch., C.Eng., M.I.Mech.E.	*Engineering**
D. Nicholas	*Spectroscopy**
J. K. R. Page, B.A.	Physicist
J. R. Payne, Dip.Tech.	Metallurgist
A. G. Provan, B.Sc., A.R.T.C., A.R.I.C.	Metallurgist
V. G. Rivlin, M.A., D.Phil.	Physicist
I. G. Rose, B.Sc.	Metallurgist

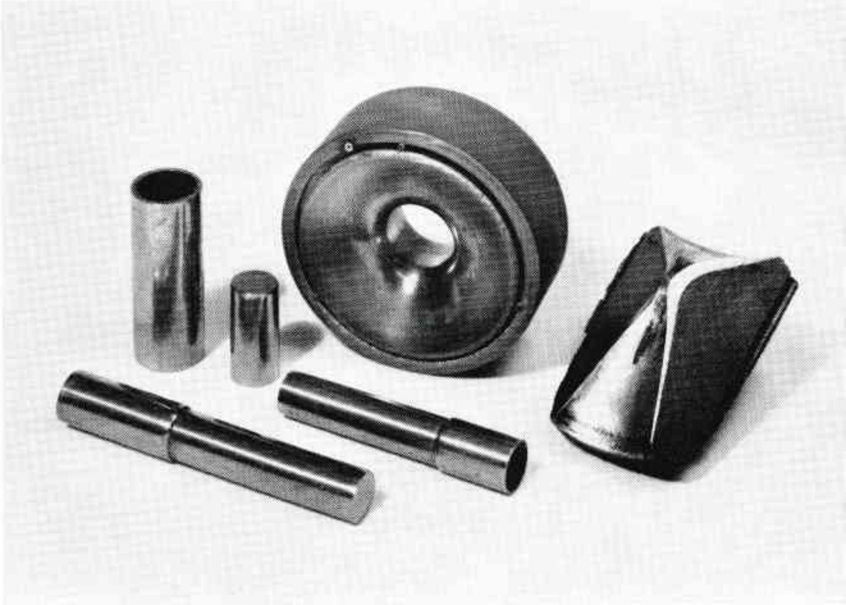
G. W. Russell, G.I.Mech.E.	Engineer
I. C. Schomburgk, Dip.Chem.Eng.(U.C.L.) B.Tech., C.Eng., A.M.I.Chem.E.	*Chemical Engineering**
H. H. Smith, A.R.I.C.	*Analytical Chemistry**
J. Smith, B.Sc.	Physicist
P. J. Stevens†	Engineer
R. M. Waghorne, B.Sc., D.I.C.	Mathematician
G. I. Williams, B.Sc., Ph.D., F.Inst.P.	*Physics**
G. L. Wilson, M.A.	Physical Chemist

* In charge of Department or Section
† Higher National Certificate

RESEARCH ASSISTANTS

R. E. Ayling	J. A. McBain	D. Stewart
A. H. Bowry	B. A. Parsons	M. C. Stuart
F. A. Collins	G. P. Ray, B.Sc.(Calcutta), L.I.M.	W. Warr
M. J. Flynn	B. Smith, B.Sc.	K. D. Weller
N. D. Levin, L.R.I.C.		

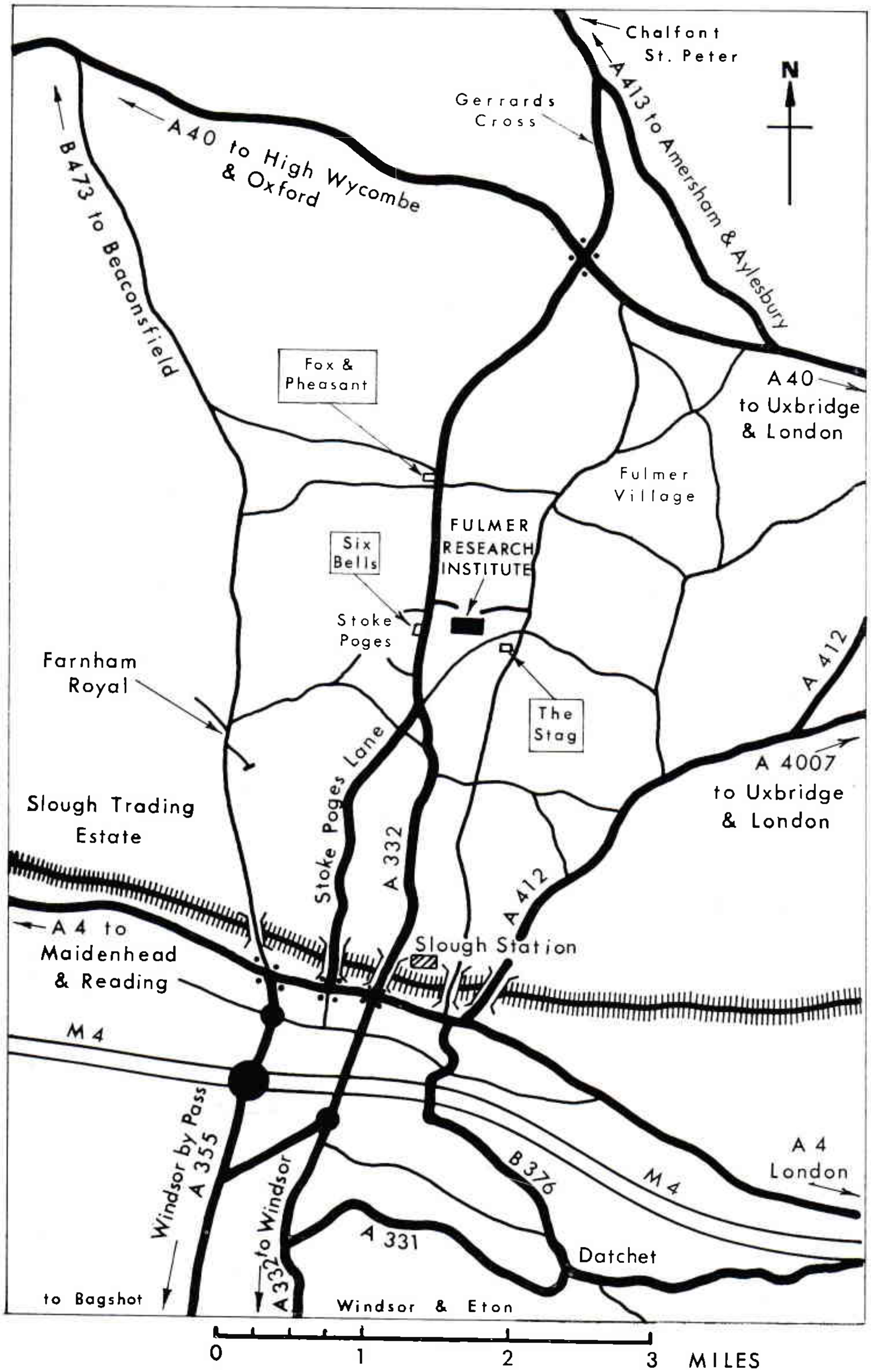
In addition to the above there are 60 laboratory assistants and other staff.



VAPOUR DEPOSITION OF REFRACTORY METALS

Coatings consisting of refractory metals (e.g. Ta, Mo, W, Re) from less than 0.001 *to* 0.125 *inch thickness are made on a variety of substrates by hydrogen reduction of the gaseous halides. By removal of the substrate after deposition, articles of varying shapes can be made.*

The photograph shows tungsten coated graphite rocket nozzles and various crucibles.



Chalfont
St. Peter
N
Gerrards
Cross
A413 to Amersham & Aylesbury
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& Oxford
B473 to Beaconsfield
A40
to Uxbridge
& London
Fox &
Pheasant
Fulmer
Village
FULMER
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INSTITUTE
Six
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Maidenhead
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should be addressed
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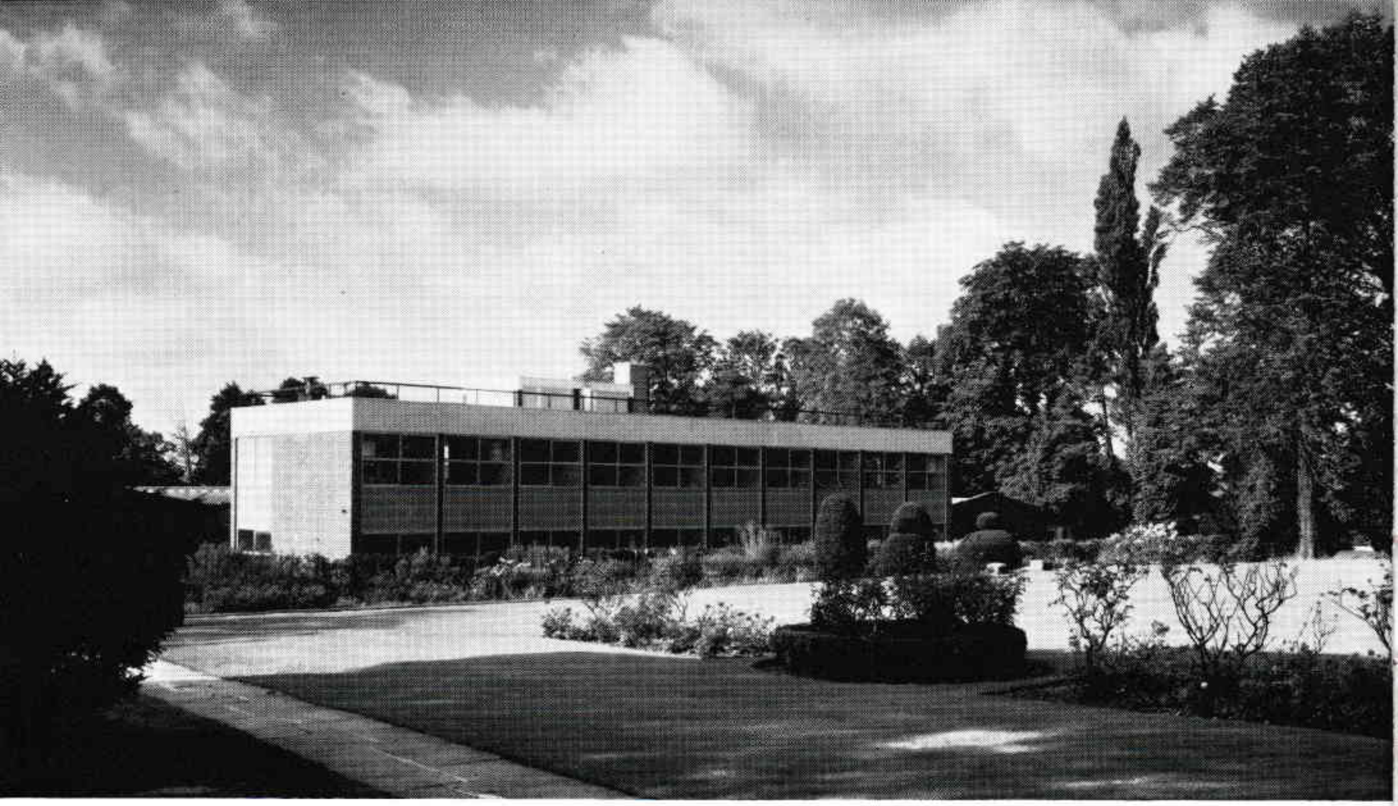
DIRECTOR OF
RESEARCH

FULMER RESEARCH INSTITUTE
STOKE POGES, BUCKINGHAMSHIRE
Telephone: Fulmer 180-4 Grams: Research Slough



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