The Rutherford Appleton Laboratory

1957 - 1982.

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INTRODUCTION

As 1982 sees the 25th anniversary of the establishment of the National Institute for Research in Nuclear Science (NIRNS) - which was set up to provide facilities for research in the nuclear field - it seemed appropriate to look at the work of its first laboratory, namely the Rutherford Appleton Laboratory.

This dissertation has by no means covered all the work which has been carried out by the Laboratory. Due to the sheer volume of information available it has been necessary to select a very small proportion of the research in order to show the wide range of subjects covered by the Laboratory. The projects which have been excluded are not necessarily less important than those which have been included, and my apologies are extended to those people whose work has not been mentioned, but it was almost impossible for my untrained eye to decide on the relative merits of each highly complex subject area. Very little attention has been paid to the general resources of the Laboratory, eg. the Council Works Unit, which provides a consulting engineering service to the various SERC establishments; the Health and Safety Group, which gives assistance and advice on all aspects of general safety, radiation protection and occupational hygiene; and the library, which provides an excellent information service to the permanent Laboratory staff as well as to visiting researchers, and once again this was due to lack of space : I hope this brief mention will pacify any people I have inadvertently antagonised.

The SERC is divided into four main subject Boards : Nuclear Physics, Science, Engineering and Astronomy, Space and Radio; and for the purpose of clarity this report is subdivided in the same way.

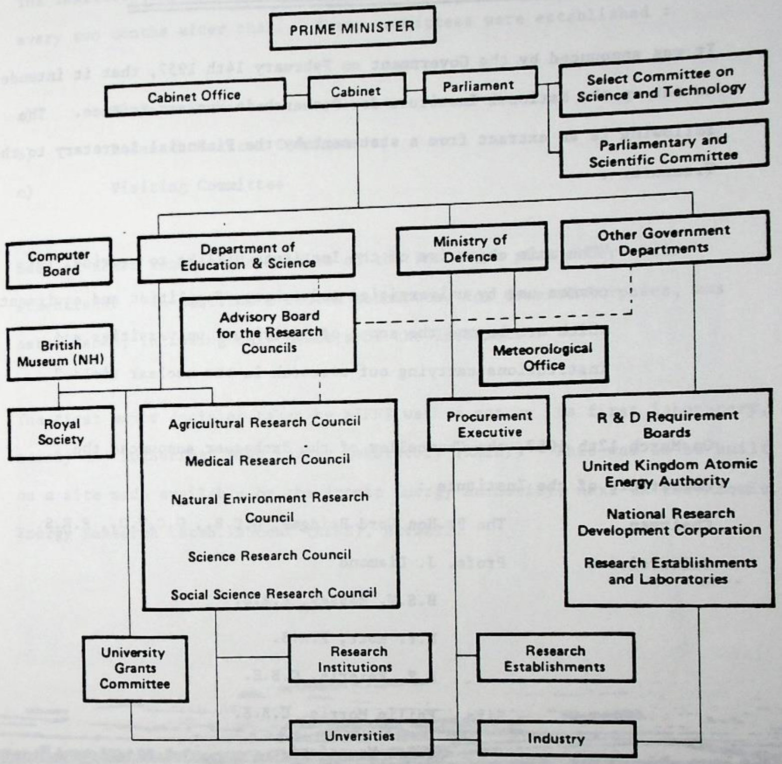


Fig. 1
Organisation of Science in Britain

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE (NIRNS)

It was announced by the Government on February 14th 1957, that it intended to set up the National Institute for Research in Nuclear Science. The following is an extract from a statement by the Financial Secretary to the Treasurer :

> "The main objective of the Institute will be to provide, for common use by universities and others, facilities and equipment which are beyond the scope of individual universities and institutions carrying out research in the nuclear field."

On March 12th 1957, the Chancellor of the Exchequer announced the membership of the Institute :

Chairman		The Rt.Hon.Lord Bridges, G.C.B., G.C.V.O., F.R.S.
Universities	Profs.	J. Diamond
		H.S.W. Massey, F.R.S.
		N.F. Mott, F.R.S.
		R.E. Peierls, C.B.E.
	Sirs	Philip Morris, C.B.E.
		James Mountford
	Dr.	D.H. Wilkinson, F.R.S. (now Professor)
U.G.C.	Mr.	J.C. Gridley, C.B.E.
	Sir	George Thomson, F.R.S.
Royal Society	Sir	David Brunt, F.R.S. (retired January 1958; replaced by Prof. W.V.D. Hodge, F.R.S.)
U.K.A.E.A.	Sirs	John Cockcroft, O.M., K.C.B., C.B.E. F.R.S.
		Donald Perrott, K.B.E.
	Dr.	B.F.J. Schonland, C.B.E. F.R.S.
D.S.I.R.	Prof.	P.M.S. Blackett, F.R.S.
	Dr.	H.W. Melville, F.R.S. (now Sir ...)

The Institute held their first meeting on the same day and approximately every two months after that. Three committees were established :

a) Physics Committee
b) Research Reactor Committee
c) Visiting Committee

Each of these constituted members of the Institute plus other senior scientists. In addition a fourth committee, for General Purposes, was established, including only members of the Institute.

The first major decision taken by NIRNS was to set up its first laboratory, namely the Rutherford High Energy Laboratory (RHEL). This was to be built on a site made available by the Atomic Energy Authority, next to the Atomic Energy Research Establishment (AERE), Harwell.

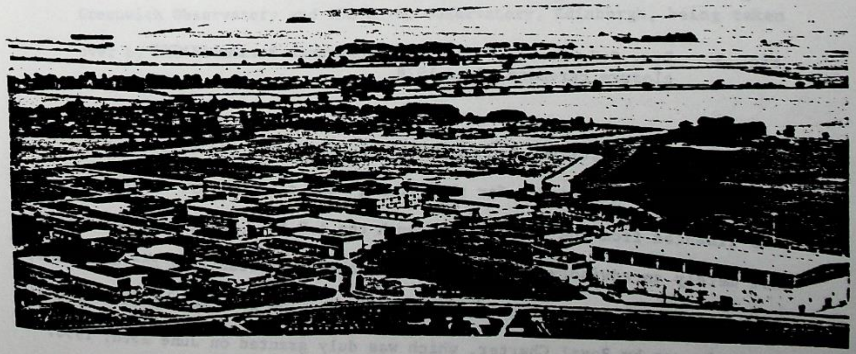


Fig. 2. The RHEL, about 1974

The main feature of the Laboratory was to be a 7 GeV proton synchro tron, but it would also contain a 50 MeV proton linear accelerator (P.L.A.), donated by the A.E.A. in April 1959. The Institute named Dr. T.G. Pickavance as the Director of the R.H.E.L., a position he held until he was appointed Director of the Nuclear Physics Division in London office in 1969. He was succeeded by Dr. G.H. Stafford.

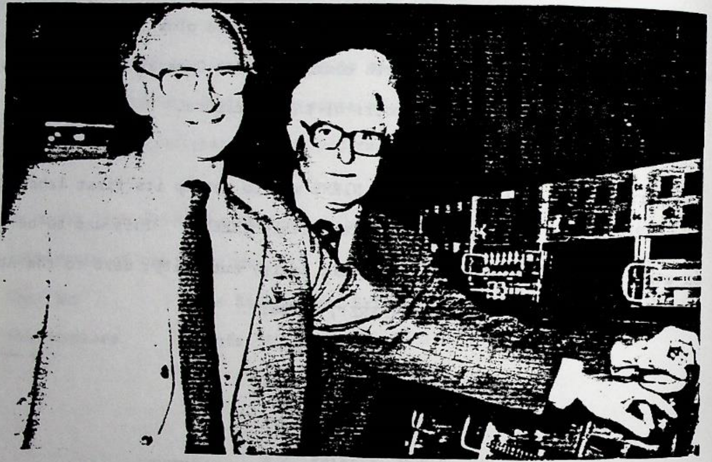


Fig. 3. Drs. G.H. Stafford and T.G. Pickavance at the NIMROD closure ceremony, June 1978.

Initially, the Institute had only a small staff, ie. the Director of R.H.E.L.; a Group Leader for the P.L.A.; and a Secretary. The Institute was financed from the Treasury, through the A.E.A. Since the Institute was not merely an advisory body, but had to take legal liability for decisions, they had to seek some kind of incorporation. The most appropriate method for this was by Royal Charter, which was duly granted on June 23rd, 1958.

Progress was made fairly quickly in 1958 : the 50 MeV P.L.A. was handed over by the U.K.A.E.A.; construction of the 7 GeV proton synchrotron, named NIMROD (Like Nimrod a mighty hunter" - Gen. 10 v.9), was proceeding steadily; the first university visitors arrived at the end of the year, to work on the preparation of experiments to be done on the P.L.A. In order to quickly build up an experienced team of scientists to work on NIMROD, physicists from R.H.E.L. were sent to work for short periods on the accelerators at Berkeley and Brookhaven in the U.S.A.

Originally the Institute was to provide a small staff concerned with general direction and nuclear physics research, while the A.E.A. would provide construction and maintenance staff. However, it was decided that a larger staff would be needed when NIMROD came into operation, and the A.E.A. could not cover this.

Following the Science and Technology Act 1965, the Government's reorganisation of its civil scientific research programme led to the responsibilities of NIRNS, the Radio and Space Research Station, the Royal Greenwich Observatory and the Royal Observatory, Edinburgh, being taken over by the Science Research Council (S.R.C.).

SCIENCE AND ENGINEERING RESEARCH COUNCIL (SERC)

The primary purpose of the Science and Engineering Research Council (SERC) is to encourage and support research and advanced training in science and engineering. Its fields of interest are, broadly, astronomy, nuclear physics, the biological sciences, chemistry, mathematics, physics, the engineering disciplines and applied sciences.

The Council was set up in 1965 as the Science Research Council (Engineering was added to the title in 1981). It is funded by the Department of Education and Science and devotes its resources to :

a) helping university and polytechnic staff to carry out basic research at the forefront of their subjects, either in their institution, in one of the Council's research establishments, or elsewhere;

b) encouraging active collaboration in research between the higher education institutions and industry;

c) identifying and supporting areas of special importance;

and

d) enabling suitable graduates to receive further training in methods of research or a specialised branch of science or engineering of importance to British industry.

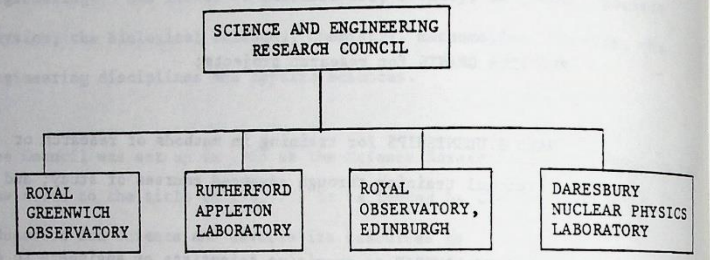
To this end, the SERC:

- CONSTRUCTS AND OPERATES major facilities for use by university workers;
- PROVIDES GRANTS for research projects;
- AWARD STUDENTSHIPS for training in methods of research or vocational training through advanced courses of study; and
- AWARDS FELLOWSHIP to promising scientists or engineers to enable them to carry out independent research programmes.

Developments in engineering research and training geared to the needs of industry are a major priority of the SERC. Special programmes are being supported in three areas - polymer engineering, marine technology and production engineering; other subjects receiving special support include microelectronics and computer applications (eg. industrial robotics), biomaterials and coal technology.

The SERC maintain four research establishments : the Royal Greenwich Observatory at Herstmonceux (Sussex) and the Royal Observatory, Edinburgh; the Daresbury Laboratory, Warrington; and the Rutherford Appleton Laboratory, Chilton (Oxon). Each establishment is a centre of specialised research and is also used for the development and operation of research equipment beyond the resources of a university providing, for example, facilities for research in nuclear physics and interactive computing.

The SERC provides national contributions to international organisations such as CERN, the civil science programme of NATO, the Anglo-Australian Telescope, part of the ESA contribution and the Institut Laue-Langevin at Grenoble.



Structure of the SERC

RAL ORGANISATION

Director: Dr G Manning Deputy Director: Professor J T Houghton, FRS

Associate Directors:
Astronomy, Space and Radio : Professor J T Houghton, FRS
Engineering : Dr D B Thomas
Nuclear Physics : Dr J J Thresher
Science : Dr G Manning
Technical Services : Dr G Manning

Laboratory Secretary: Dr JM Valentine

The Laboratory is organised on a divisional basis. Although the functions of each division are shown separately, there is a large amount of liaison and shared work on common projects.

ADMINISTRATION DIVISION

General and administrative services for the Laboratory, for visiting scientists and for the UK participation at research facilities overseas. Division Head: Dr J M Valentine

COMPUTING DIVISION

Provision of a service on the SERC batch and interactive computing facilities. Support for the Engineering Board Information Engineering Committee's specially promoted programmes. Development activities in Wide and Local Area Networks. Support for specific Board projects in Applications areas. Division Head: Professor F R A Hopgood

ENGINEERING AND BUILDING WORKS DIVISION

Provision of electrical, mechanical, building and environmental services. The Division includes the Council Works Unit which caters for SERC establishments. Division Head: Mr R Tolcher

GEOPHYSICS AND RADIO DIVISION

Experimental and theoretical research into atmospheric, ionospheric and magnetospheric science, including remote sounding of the atmosphere from space. Planning, procurement, co-ordination and support for UK scientific research using rockets and balloons. Division Head: Mr J T Delury.

HIGH ENERGY PHYSICS DIVISION

Experiments in particle physics and nuclear physics in collaboration with university groups. Support for teams of scientists from the UK and abroad, and supervision of UK involvement in the CERN and DESY programmes. Division Head: Dr J J Thresher

INSTRUMENTATION DIVISION

Design, manufacture and commissioning of special physics apparatus and electronics for use by experimental teams. Control of support workshops and outside manufacture. Support for energy research. Division Head: Dr T G Walker

LASER DIVISION

Experimental and theoretical research in laser-plasma interactions and laser compression in collaboration with university groups. Development of high power laser systems. Division Head: Dr A F Gibson, FRS

NEUTRON DIVISION

Support of and collaboration with university groups using neutron scattering techniques and facilities at Harwell and at the Institut Laue-Langevin, Grenoble; theoretical condensed matter studies; instrument and techniques development. Preparation for the exploitation of the Spallation Neutron Source. Acting Division Head: Mr H Wroe.

SPACE AND ASTROPHYSICS DIVISION

Study of solar and stellar ultra-violet and X-rays. Planning, co-ordination and support of scientific satellite projects. Satellite ground control and data processing. Division Head: Dr A H Gabriel

SPALLATION NEUTRON SOURCE DIVISION

Development, construction and installation of the Spallation Neutron Source. Division Head: Mr D A Gray

TECHNOLOGY DIVISION

Design, development and construction of experimental apparatus, particularly electronics. Exploitation and application of new techniques especially in microelectronics, electron beam lithography, computer-aided design, radio propagation and satellite communication systems. Division Head: Dr D B Thomas

THEORY DIVISION

Research in the theory of elementary particles. Division Head: Dr R J N Phillips

NUCLEAR PHYSICS BOARD

INTRODUCTION

Investigations into the basic structure of matter have occupied many physicists, both experimental and theoretical, for most of the present century. The rapid progress, which has taken place in this field, has been made possible by conceptual innovations and major advances in particle accelerators and allied technologies. When the charged nucleus became the centre of attention 50 years ago, it became clear that in order to understand the forces holding the nucleus together, the structure and interactions of the neutrons and protons themselves had to be further explored.

There are three types of interaction which are of prime concern in high energy physics : the strong force, which operates between nuclear particles and is responsible for the binding together of protons and neutrons to form atomic nuclei; the weak force, which governs the decay processes; and the electromagnetic force. Most of the nuclear particles have very short lifetimes (typically, around 10^{-8} - 10^{-10} seconds) and can only be created by bombarding atomic nuclei with protons which have been accelerated to very high energies, eg. as with NIMROD.

NIMROD

NIMROD ("Like Nimrod a mighty hunter" - Gen. 10 v. 9) was used as a source for fundamental research into the physics of elementary particles. Its main physical feature was a large ring-shaped electromagnet, 160 ft. in diameter; which weighed 7,000 tons. A toroidal shaped, evacuated chamber, made from glass-fibre reinforced epoxy resin was situated between the poles

of the magnet. A pulse of protons, given an initial acceleration to 15 MeV in a linear accelerator, was injected into this chamber and the protons forced by the magnetic field into a circular orbit, in which they received an acceleration from a radio-frequency electric field once in each revolution. After approximately one million revolutions the protons would have reached their maximum energy and would then be either extracted from the vacuum chamber or allowed to bombard internal targets; the resulting secondary particles being channelled into an adjoining area, where they were used for experiments. During the acceleration period, lasting about three-quarters of a second, the magnetic field strength and frequency of the accelerating field were both increased steadily, to confine the proton orbits to the magnetic ring and in such a manner as to maintain the delicately balanced stability in the motion of the protons. The whole machine was housed in a semi-underground circular building of reinforced concrete 200 ft. in diameter, with a 6 ft. concrete roof, on which a 20 ft. layer of earth was placed as additional radiation sheilding.

Table 1 Timetable for NIMROD

1957	work began on NIMROD. Contracts were placed for the magnet yoke and buildings.
1958	the injector room and experimental hall were virtually complete and the magnet room was well advanced.
1961	the first 15 MeV beam achieved on 1st August. Injector performance and reliability improved before being needed for commissioning NIMROD.

1962	detailed investigations of health and safety aspects of the project.
1963	August 27th : 3 GeV achieved - NIMROD became the highest energy accelerator in Britain.
1964-5	NIMROD was inaugurated by the Rt. Hon. Quintin Hogg on April 24th at the official opening ceremony of the Laboratory. NIMROD reached its design intensity of 10^{12} protons per pulse at 7 GeV. Efficiency of 75% was achieved. An alternator breakdown meant that the machine had to be run direct from the public supply grid.
1966	accelerated protons for high energy physics were available for 4850 hours - 82% of scheduled time. Approval was given for a new experimental hall.
1968	realisation of switching between two extracted beam channels within the same machine pulse.
1969	the highest ever use was made of NIMROD by experimental teams. The new experimental hall was commissioned. Designs were started for a superconducting synchrotron to replace NIMROD.
1970	20% more accelerated protons. Beam intensity was the highest ever - 3 x 10^{12} protons per pulse. Increased involvement with CERN.
1971	proposal put forward for the injector energy to be increased from 15 MeV to 70 MeV.

1972	the energy crisis meant that NIMROD had to close down during February. Approval was given for the new injector.
1973	record accelerated beam intensities were obtained due to an additional RF system (twice the frequency of the basic system)
1974	feasibility studies for EPIC, a colliding beam storage ring aimed at replacing NIMROD and NINA
1975	installation of the new X1 extracted proton beam line in the magnet room. Work continued on 70 MeV injector. Plans for EPIC were shelved due to financial uncertainties.
1977	the last full year of NIMROD.
1978	closed on June 6th by G.H. Stafford and T.G. Pickavance. NIMROD operated for 14 years; it achieved 60,000 hours of beam time; 80 major experiments were completed; 125 theses were submitted for work performed on NIMROD.

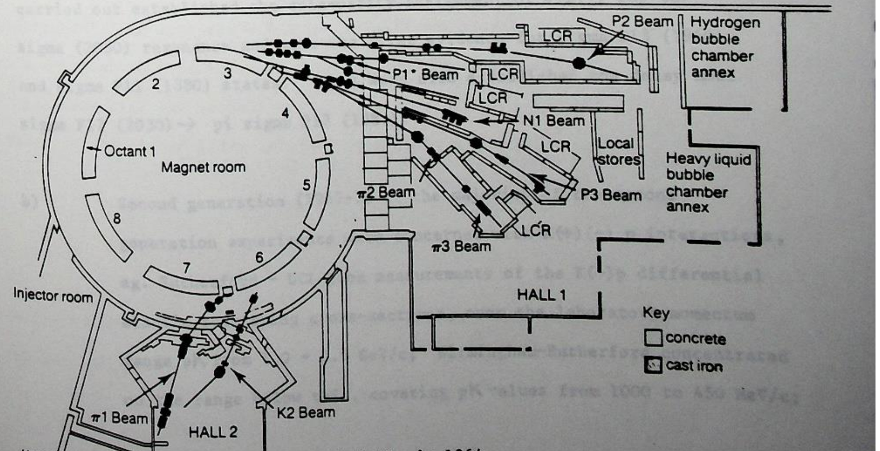


Fig. 4. Layout of the experimental halls in 1964.

EXPERIMENTAL PARTICLE PHYSICS

Particle physics experiments performed on NIMROD can be divided quite distinctly into three "generations".

a) **First generation (1964-67);** the majority of these were concerned with the study of pion-nucleon scattering, the measurement of differential cross-sections and polarisation differential cross-sections. Work by an Oxford-Rutherford collaboration during this time proved the existence of several new resonance states, eg. NF15 (1688) - this was formulated from studying the "bump" in σ (tot) (pi(-)p) at 1688 MeV, which was found to be F wave, but with spin 5/2. Measurements of the differential cross-sections for pion-nucleon charge-exchange were also carried out, and later proved to be relevant to the analysis of the N(*) (2190) bump.

Accurate measurements were also made of the total cross-sections for positively and negatively charged pion and kaon beams incident on proton and deuterium targets

Experiment	Details	Collaboration
$\left.\begin{matrix}\pi^+p\\ \pi^-p\end{matrix}\right\}$ $d\sigma(\theta)/d\Omega$ and $P(\theta)$	P_π = 650-2140 MeV/c (12 momentum values)	Oxford-Rutherford
$\left.\begin{matrix}\pi^+p\\ \pi^-p\end{matrix}\right\}$ $d\sigma(\theta)/d\Omega$	P_π = 1700-2800 MeV/c (10 momentum values)	University College-Westfield
$\left.\begin{matrix}\pi^-p\rightarrow\pi^0n\\ \rightarrow\eta n\end{matrix}\right\}$ $d\sigma(\theta)/d\Omega$	P_π = 1710-2460 MeV/c	Oxford-Rutherford
$\left.\begin{matrix}\pi^\pm p \text{ and } \pi^\pm d\\ K^\pm p \text{ and } K^\pm d\end{matrix}\right\}$ σ_{tot}	Incident momentum 600-2700 MeV/c	Birmingham-Cambridge-Rutherford
$pp\rightarrow pp$	Nuclear-Coulomb interference at 8 GeV/c	AERE–Queen Mary College–Rutherford
$pp\rightarrow pX^+$	P_p = 2.8 - 8 GeV/c	
pp and pd σ_{tot}	Lab. momentum 1-8 GeV/c	Cambridge-Rutherford
$np\rightarrow pn$ $d\sigma(\theta)/d\Omega$	at 8 GeV/c	AERE-Birmingham-Bristo Rutherford

Table 2. Some first generation experiments on NIMROD

After their initial successes, NIMROD's users turned to the study of the corresponding hyperonic resonances, the lambda (*) and sigma (*) states, using K(-) beams incident on proton and deuteron targets. K(-)p work carried out established the spin-parity assignment of 7/2(+) for the sigma (2030) resonance and gave the first evidence for sigma D13 (1940) and sigma P11 (1880) states. This work also established the decay mode sigma F17 (2030) → pi sigma P13 (1385).

b) **Second generation (1967-70 :** the majority of the second generation experiments were concerned with K(+)(-) p interactions, eg. Rutherford - UCL took measurements of the K(-)p differential elastic scattering cross-sections, over the laboratory momentum range pK from 1.0 - 2.5 GeV/c; Birmingham-Rutherford concentrated on the range below this, covering pK values from 1000 to 450 MeV/c;

and the Oxford group looked at the inelastic K(-)p reactions leading to neutral final states, such as (lambda)(pi(o)) and (lambda)(pi (o)) (pi (o)). Groups without previous NIMROD experience tackled work in less demanding, but no less important, areas of the dσ/o(omega) measurements for the pion-nucleon system.

Experiment		Details	Collaboration
K^+p K^-p	$d\sigma(\theta)/d\Omega$	$p_K = 1000\text{-}2500$ MeV/c	Rutherford-Univer College
K^+p K^-p	$d\sigma(\theta)/d\Omega$	$p_K = 450\text{-}1000$ MeV/c (including Coulomb- nuclear interference effects)	Birmingham-Ruthe
$K^-p \rightarrow \Lambda\pi^0, \Sigma^0\pi^0, \Lambda\eta, \Lambda\pi^0\pi^0$		$p_K = 865\text{-}990$ MeV/c .	Oxford
π^-p	$d\sigma(\theta)/d\Omega$	$p_\pi = 1200\text{-}2500$ MeV/c	Bristol-Rutherford

Table 3. Some second generation experiments on NIMROD

Considerable attention was focused onto the K(+) - proton interaction at this time, due to the observations of small "bumps" in σ (tot) (E) for K(+)p and K(+)d, which happened to be close to the threshold for K(delta) or K(*)N excitation. The outcome of the work gave no indication of the existence of an I = 1 state Z(1)(*); although this negative finding was less exciting than a positive one would have been, it still helped in the understanding of baryonic states.

c) Third generation (1970 -); this group of experiments is characteristic for its increased sophistication as improvements were made in statistical and measurement accuracy and the equipment became more complex. A particularly important experiment for baryonic resonance physics was the study of the polarisation differential cross-section for the exchange reaction pi(-)p → pi(o)n over the laboratory momentum range 600 - 2700 MeV/c, which gave higher statistical accuracy than any previous experiments. In 1974 it was reported that 55% of relevant data contributions in pion-nucleon scattering had come from experimental work with NIMROD.

Experiment	Details	Collaboration
K^+p $d\sigma(\theta)/d\Omega$ $\pi^\pm p$ $d\sigma(\theta)/d\Omega$ K^-p $d\sigma(\theta)/d\Omega$	$p_K = 900\text{-}2000$ MeV/c $p_\pi = 400\text{-}2150$ MeV/c $p_K = 950\text{-}2000$ MeV/c (high statistics)	Bristol-Rutherford- Southampton
$K^-p \rightarrow K^-p$ $P(\theta)d\sigma(\theta)/d\Omega$	$p_K = 965\text{-}1285$ MeV/c	Queen Mary College- Rutherford
$K^+n \rightarrow K^+n$ and K^0p $P(\theta)d\sigma(\theta)/d\Omega$	$p_K = 860\text{-}1365$ MeV/c	
$K^+n \rightarrow K^0p$ $d\sigma(\theta)/d\Omega$	$p_K = 450\text{-}950$ MeV/c	Birmingham-Rutherfor
$\pi^-p \rightarrow \pi^0n$ and ηn $d\sigma(\theta)/d\Omega$ and $P(\theta)$	$p_\pi = 600\text{-}4000$ MeV/c	Rutherford-Warwick

Table 4. Some third generation experiments on NIMROD

NIMROD played a less dominant role in lambda (*) and sigma (*) resonance physics because of the higher energy accelerators available at CERN and Brookhaven.

A fourth generation of experiments was cancelled with the order for the closure of NIMROD.

The experimental examples given above cover only elastic scattering, some two body reaction processes and baryonic resonance physics, but NIMROD was used for experimental work in several other areas of elementary particle physics. A NIMROD "speciality" was the study of such reactions as pi(-)p→ X(o)n and pi(-)p→ X(-)p in the neighbourhood of the threshold energy. This involves accurate measurement of the nucleon recoil momentum, which determines the "missing mass", m(x). The technique proved particularly useful in the area of the measurement of meson production cross-sections near threshold, especially with eta-meson production where the threshold cross-section is unusually large. Some of the earliest experiments with NIMROD were concerned with the nucleon-nucleon system, especially inelastic processes. When the cross sections of inelastically-scattered protons were plotted against "missing mass", m(x(+)) for the process pp → pX(+), peaks were clearly seen corresponding to production of the nucleonic resonance states N(*)(1470) and N(*)(1688).

Using the British hydrogen bubble chamber much information was obtained concerning the K(pi)(pi) and K(pi) systems in the final states. The heavy liquid chamber was used more for hadronic experiments, eg. the UCL group measured the mass value of the xi(o) hyperon as 1315.15(+)(-) 0.9 MeV.

A lot of experimentation was performed looking for charge conjugation (C) invariance, especially in electro-magnetic interactions. Early bubble chamber experiments were superseded by the spark chamber work of the Rutherford-Westfield College collaboration, which looked at eta-decay processes (see Fig. 5).

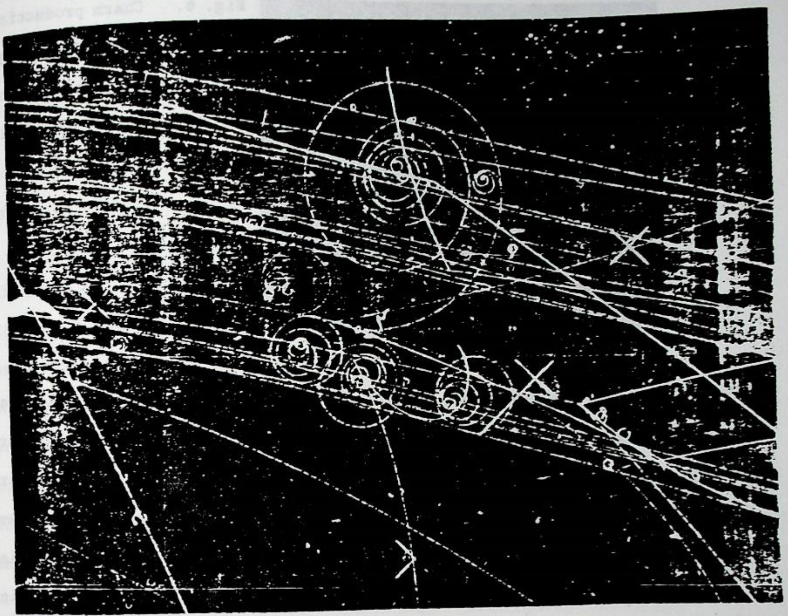


Fig. 5. An eta→ (gamma)(gamma) event photographed in a bubble chamber.

In recent years the particle physics world has seen several major events, eg. the discovery of the heavy upsilon particle (nine times more massive than the proton) and confirmation of the existence of a new massive lepton. Since the beginning of the 1970s physicists have been working even harder towards formulating a unified theory for elementary particle interactions. This work has often been hindered by theoretical and practical difficulties, but two events helped to clear the view a little, ie. the discovery of neutral currents at CERN and a new property of matter called "charm" (see Fig. 6.)

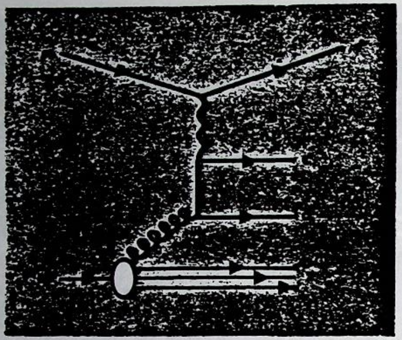
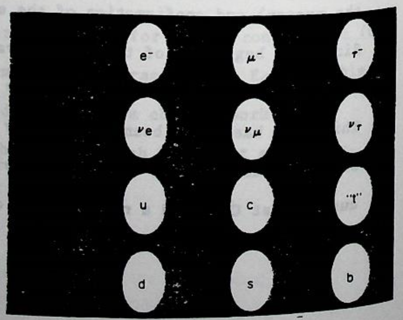


Fig. 6. Charm production by muons, via photon-gluon fusion

It also became clear that particles are composed of sub-units called quarks, which have mass, electric charge and two special properties : flavours - properties of isospin, strangeness and charm; and colours - it appears that each flavour state can exist in three different colour states. However, all the currently observed particles are neutral in colour (white), ie. the three quarks in a proton have each to be of a different colour, leaving no net colour change. A new theory called quantum chromodynamics (QCD) is attempting to explain these phenomena. Probes into the validity of quantum electrodynamics (QED) led to the unexpected discovery of a sequence of high mass, semi-stable lepton and meson states ; psi, upsilon and tau (see Fig.7).

Fig. 7. The two families of leptons and quarks are believed to make up subnuclear matter



Baryons are made up of 3 quarks, of which the proton with two "up" quarks (u) and one "down" quark (d) is the least massive. The replacement of any one of these quarks by a strange quark (s) converts the nucleonic matter into a so-called "strange' particle of which the hyperons and K mesons are the best known.

1979 was significant for British particle physics as one of its leading figures, Professor Abdus Salam, shared the Nobel prize for physics for his pioneering work in formulating a viable theory of the weak force and its relationship with the electromagnetic force. The Rutherford Laboratory has been closely involved in the experimental work confirming the Weinberg-Salam model. The same year provided possible evidence for "gluons" - the quanta which QCD predicted would carry the force between the quarks (analogous to the way QED requires photons to transmit the electro-magnetic force).

INTERNATIONAL LINKS

With the closure of NIMROD in 1978 all particle physics research is now carried out abroad, mainly at CERN (European Centre for Nuclear Research, Geneva) and DESY (Deutsches Elektronensynchro tron, Hamburg). These international collaborations provide the highly powerful and sophisticated machinery that the individual member countries cannot afford to provide separately. Research at CERN is financed by contributions from 12 European countries, including the U.K. At CERN there is a complex of several accelerators : the 600 MeV synchro cyclotron (SC); the 28 GeV proton synchrotron (PS); the 450 GeV super proton synchrotron (SPS); the intersecting storage rings (ISR), which allow the investigation of collisions between protons at energies up to 31 + 31 GeV; and the pp(bar) collider, which was inaugurated in 1981 and allows the study of proton-antiproton collisions at 270 + 270 GeV. Approval has also been obtained for a Large Electron Positron colliding ring (LEP).

DESY provides major facilities for U.K. physicists with its electron-positron colliding beam machine, PETRA (19 + 19 Gev).

Other centres which also welcome U.K. groups are the Stanford Linear Accelerator Center (SLAC), the Tri-University Meson Factory (TRIUMF, Canada) and the Institut Laue-Langevin (I.L.L. France).

THEORETICAL PARTICLE PHYSICS

The Theory Division pursues a range of research programmes. Much of this work is phenomenological, concerned with analysing the theoretical implications of new data from the world's accelerators, and the experimental consequence of new ideas.

Much of the Theory Division's early work involved studying the Regge-absorption model, which expands the idea that interparticle forces come from exchanging virtual particles. However, Regge poles alone cannot explain all the high-energy scattering data and the model had to be modified. Other areas for research around this time (1971) covered many subjects. Further work was carried out on the unanswered questions about medium energy hadron physics, leading to experiments which could be performed on NIMROD. A major area of discussion was that of duality, which suggests that there is a connection between the interactions of the strongly interacting particles (hadrons) in the low-energy "resonance" region and in the high-energy "Regge-pole exchange" region.

One region of intense activity has been multiparticle production and inclusive reactions. From results at the Batavia accelerator and the ISR at CERN it was shown that particles are profusely produced. The average charged multiplicity is about 10, while events with as many as 25 charged particles, in the final state, are commonly observed. The "inclusive approach" measures and studies the production cross-section and momentum distributions of only some of the final particles, without specifying in general how many particles are actually produced. There are two main reasons for this shift of emphasis :

a) inclusive cross-sections are easier to measure; and

b) it is seen as more natural for a system with many particles, as in describing a liquid - it is more appropriate to consider qualities such as density without specifying the exact number of liquid molecules involved.

During 1975 the Theory Division's main research revolved round the discovery of the upsilon particle in experimental particle physics. If the new quantum number "charm" existed, then there should be new charmed particles produced in strong interactions at high enough energies. Working around Regge-pole exchange, duality and generalising $SU(3)$ to $SU(4)$ symmetry, predictions give very small charm production cross-sections. An approach within the quark-parton model gives larger cross section estimates. Several candidates for charm production have been looked at, eg. neutrino scattering and di-muon events.

Theory work tends to reflect the state of events in the area of experimental particle physics; so the dominant theme of 1977 was deep inelastic interactions. The quark substructure of hadrons was apparent, as were new quarks and leptons and the new family of upsilon particles. In recent years many experimental results have been nicely explained by partons; a high-energy hadron is regarded as a swarm of point-like constituents (partons), moving in the same direction, each carrying some fraction x of the hadron's momentum. These partons are assumed to be quarks and gluons and, although a theory has been put forward, it needs to be generalised to accommodate the extra transverse degrees of freedom displayed by partons.

While it has not been possible to cover any more than a handful of the major areas of research, others include, trimuon production by neutrinos; QCD and multiquark spectroscopy; charm production by muons; antiproton annihilation; and glueballs.

SCIENCE BOARD

NEUTRON BEAM RESEARCH UNIT (NBRU)

In 1971 the SRC took a step forward in providing for an expanding neutron beam programme, when it decided to establish a Neutron Beam Research Unit (NBRU) at the Rutherford Laboratory. The purpose of the unit was, and still is, to provide SRC laboratory support for university scientists in current research, as well as the long term developments of instruments, techniques and sources for neutron beam research. Areas of special interest to the NBRU included: development studies in the use of neutron guide tubes; feasibility studies in the field of polorisation analysis; development of position-sensitive neutron detectors; and the provision of improved monochromating crystals.

During 1972 the direct strength of the NBRU increased to a total of 20, and one of its major activities was the preparatory work for the proposed U.K. High Flux Beam Reactor (HFBR), which was cancelled when discussions opened for SRC to become a full partner in the Institut Laue-Langevin (ILL) at Grenoble. Meanwhile the NBRU was responsible for the support of U.K. university scientists actually at I.L.L. Much work was carried out on position sensitive detectors (PSD), the main effort being directed towards a new system using a scintillator, as a neutron convertor, optically coupled to a photocathode with a channel plate as a PSD. (See Fig. 8)

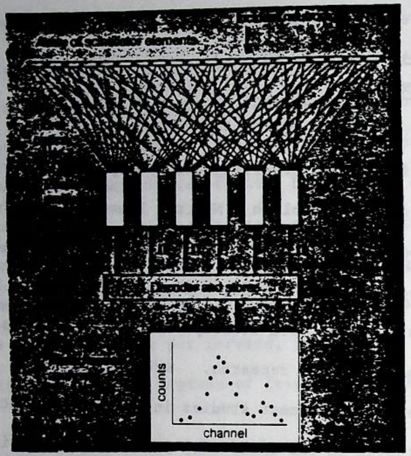


Fig. 8. The position sensitive detector system using scintillator elements and cooled photo-multipliers.

Other major areas of study were polarising monochromators and filters. The potential of a new type of thermal neutron spin flipper, described by F. Mezei (Budapest) was investigated in collaboration with the AERE. When the neutron energy becomes very low, the critical angle for total reflection at a surface can become greater than 90°. This condition occurs at the highest neutron energy for a beryllium surface (25×10^{-8} eV, wavelength approx. 60 Angstroms). The ultra cold neutrons (UCN) can thus be contained in a closed beryllium vessel and behave as a very low pressure, low temperature, ideal gas. The Neutron Gas Facility was a proposal by Sussex University to study and exploit the unique properties of UCN at the DIDO reactor. The ability to store UCN increases the time available for measurements on each neutron. Project definition was carried out during 1972 in order to confirm the final design and cost estimate and the clean vacuum system and in-pile assembly for the UCN facility was delivered to I.L.L. in 1977. (see Fig. 9).

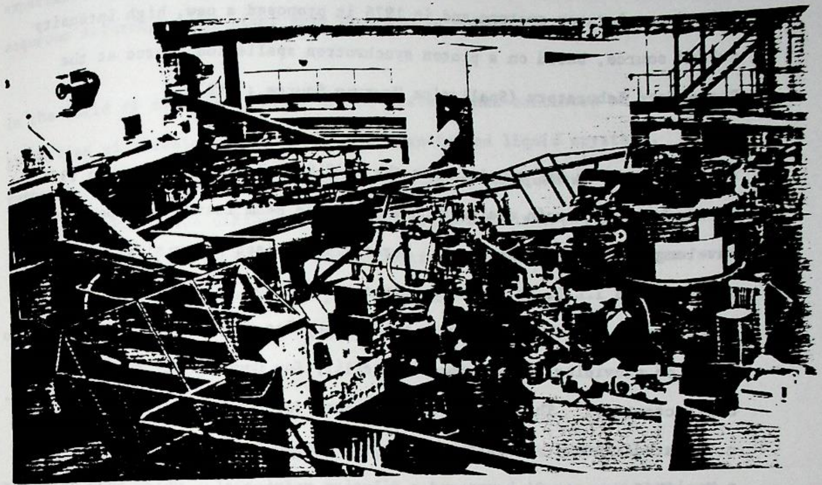


Fig. 9. The Ultra Cold Neutron facility at I.L.L.

In 1973 the SRC became a full partner in I.L.L. and the NBRU continued to support neutron beam experiments in the U.K. and abroad. The Laboratory increased its involvement with I.L.L. in 1974 when the polarised beam diffractometer, D3, was installed.

In the area of instrumentation development the Laboratory successfully adapted foil-stretching techniques for neutron beam purposes. The efficiency of neutron collimators was successfully increased by 10% and these are now being produced as standard at the Laboratory (see Fig. 10.)

Fig. 10. A neutron collimator

The NBRU became aware that the future pointed towards more sophisticated pulsed accelerator systems and in 1976 it proposed a new, high intensity pulsed source, based on a proton synchrotron spallation source at the Rutherford Laboratory (Spallation Neutron Source : SNS).

Development work was completed on the (149)Sm polarising filter in 1977 and it was used as a spin analyser on a polarised beam instrument operating at wavelengths around 1 Angstrom. Three miniaturised polarising guides were delivered to I.L.L. in the same year : two for the IN11 spin-echo spectrometer and the third for a nuclear physics experiment. Work was also begun on providing a new gamma-ray facility for Compton scattering and diffractometry. The NBRU acted as liaison for the provision of a (3)He cryostat designed to maintain scattering sample temperatures in the range 0.3 - 3K for up to 24 hours and a dilution refrigerator which will initially be used for experiments on the properties of (3)He and (3)He-(4)He mixtures.

From 1978 onwards special attention has been given to work on detectors, polarised neutrons, choppers and neutron guides; much of the work being carried out in relation to the SNS facility. For use with the SNS, collimator applications will have to be adapted slightly: collimators are normally utilised in scattered beams, where the neutron fluxes are comparatively low, however, for the SNS, it will often be necessary to place the collimators in the direct beam. To cope with this the development of a radiation-hard collimator, using grids of neutron absorbing wires, has had to be undertaken.

During 1981, the Harwell linac was brought into operation and beam tests into the condensed matter target were carried out at half beam power. Laboratory support for U.K. university teams has gradually increased since the inception of the NBRU and at present 95 groups, comprising 365 university staff and students, are involved in the programme. 300 proposals for

experiments at SERC and ILL were approved, eg. inelastic scattering from acqueous solutions, and giant spin clusters in AuFe.

In the field of condensed matter theory research has continued on the properties of classical one-dimensional magnets and liquid crystals. New research topics include the dynamic properties of the quantum Ising-Heisenberg chain, the diffusion of cross-link points in a polymer gel or rubber, and the contribution of non-adiabatic processes to the nuclear scattering of energetic neutrons from atoms and molecules.

SPALLATION NEUTRON SOURCE (SNS)

With the closure of NIMROD, there was an opportunity for building a new research facility at a much reduced cost. In 1977 approval was obtained for the conversion of NIMROD into a new, high intensity pulsed neutron source.

The Spallation Neutron Source (SNS), which will be the world's most powerful source of pulsed neutrons, is based on a high intensity 800 MeV proton synchrotron, the beam from which is directed onto an external heavy metal target; as 70 MeV H(-) linear accelerator as injector; a target station; and neutron beam lines to supply the experiments mounted in and around the main experimental area. The resulting fast neutrons are slowed down by an assembly of moderating (hydrogenous) materials and reflectors. The main design parameters of the SNS are :

Proton energy	800 MeV
Pulse repetition rate	50 Hz (nominal)
Injection energy	70 MeV
Proton intensity	2.5×10^3 per pulse
Proton burst length	0.4 microsecond
Fast neutron average rate	4×10^{16} per second

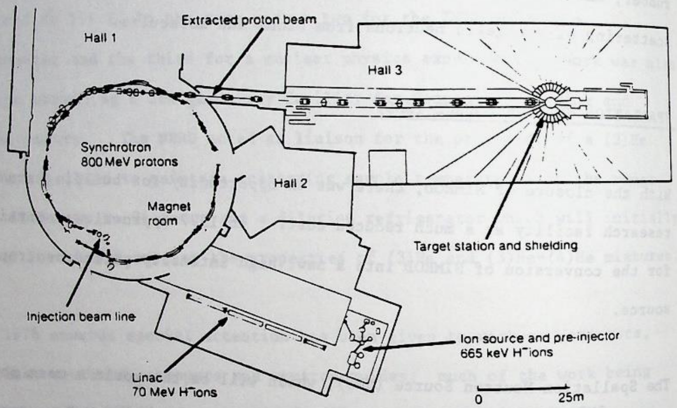


Fig. 11. Layout of the SNS.

Two important properties of slow neutrons for condensed matter research are that their wavelengths are comparable with interatomic distances and their energies are of the same magnitude as the vibrations and excitations of molecular systems. Thus, both elastic and inelastic experiments are possible and, in the case of pulsed neutron sources, time-of-flight techniques are used to determine the neutron velocity and, hence, its energy or wavelength.

Decisions by the SRC, in 1980, on the availability of funds in future years, enabled firm plans to be made for the SNS programme. A detailed projection chart could be laid down:

Early 1982	Injector complete. 70 MeV H(-) beam.
Early 1983	Magnet ring and vacuum system complete. Injection line and injection system complete. Some machine diagnostics installed. Injection tests.
Mid-1983	2 RF stations installed (out of 6). Main magnet power supply working. Acceleration studies at low intensity.
Late 1983	4 RF stations installed. Extraction system installed. Extraction studies at low intensity.
Early 1984	With 4 RF stations, extracted proton beam installed, target station installed : 600 MeV protons (low intensity) producing neutrons in the target.
Late 1984	6 RF stations installed. 800 MeV proton (low intensity) (see Fig. 12)
1986	Full intensity operation with 800 MeV protons.

The use of the SNS in fields outside neutron scattering can be very varied, eg. elementary particle research using the intense fluxes of pions, muons, neutrinos etc, produced at the target and at another proposed target; research with ultra-cold neutrons.

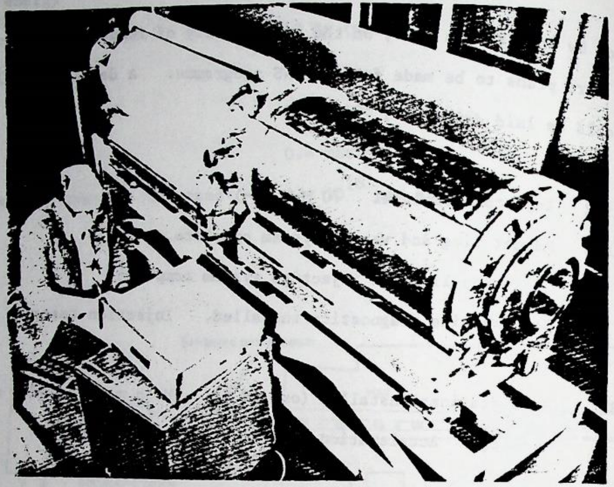


Fig. 12. Prototype RF accelerating cavity on test

A comprehensive system for data acquisition and reduction is linked to the SNS project, eg. graphics terminals, line printers, hard-copy graph plotters etc. The final control system will be based on four active GEC 4070 computers. A fifth machine will be used for software development during the setting up and commissioning phase of the SNS; during full operation it will become the off-line program development computer. The final system will be as follows :

Central computer	for the main control consoles, alarm enunciation and as a centre for the computer network.
Satellite 1	for the H(-) injector and the injection beam line
Satellite 2	for the synchrotron main ring
Satellite 3	for the extraction beam line and the target station

The Laboratory has collaborated with GEC in the writing of the compiler/interpreter, GRACES, which will be used as the system real-time control language.

The SERC is hoping to see the SNS being used by scientists from outside the U.K., as well as by U.K.-based researchers.

CENTRAL LASER FACILITY

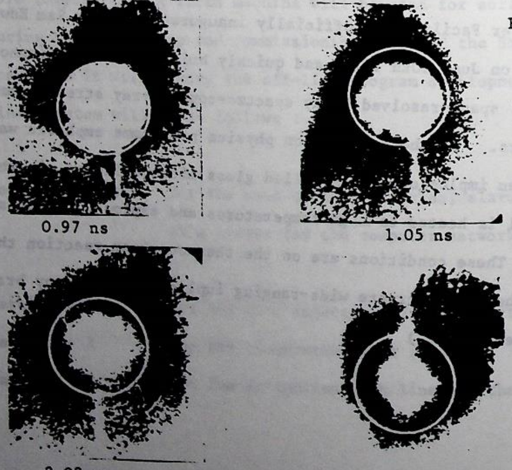
In 1975 plans were made to establish a Central Laser Facility at the Rutherford Laboratory. The facility was initially provided with a high power neodymium : glass laser capable of delivering a peak power of 800 Gigawatts in two beams, together with a range of diagnostic and experimental equipment for monitoring the laser and supporting the experimental programme. Proposed experiments were to include the study of the interaction of single beams from the laser with plane targets at powers up to 100 GW, and a range of topics in plasma physics and non-linear optics.

The Central Laser Facility was officially inaugurated by Sir Sam Edwards (SRC Chairman) on June 20th 1977, and quickly built up plasma diagnostic techniques, eg. space-resolved X-ray spectroscopy, X-ray streak cameras and neutron counters. In the compression physics programme emphasis was put on the laser-driven implosion of gas filled glass micro-balloons, in which the thin glass wall is heated to high temperatures and explodes, compressing the gas filling. These conditions are on the thermonuclear reaction threshold and study of them could create wide-ranging implications in many branches of physics (see Fig. 13.)

Fig. 13. Two micro-balloons viewed by an interference microscope to select for uniformit and to measure accuratel the wall thickness.

The Laser Division also initiated a programme of gas laser development, aimed at investigating the characteristics of novel laser systems. The main experiments in this programme utilise a high power, pulsed electron-beam source (ELF) as a means of pumping the gas laser.

Results were achieved quickly by the Division and some important developments were the reliable measurements of magnetic fields in laser generated plasma, the development of backlighting techniques for the study of ablative compression and time-resolved harmonic spectroscopy. (see Fig. 14).



0.97 ns

1.05 ns

2.02 ns

2.45 ns

Fig.14. A sequence of radiographs of spherical implosions using the short duratio X-ray back lighting pulse t obtain the time resolution.

Work on the ELF reached a successful conclusion, in 1978, with the production of the first electron-beam pulse taking place in November.

One of the most significant developments of 1979 was the experimental confirmation of the advantages of using wavelengths shorter than 1 micrometre. By halving the wavelength of the glass laser the ablation pressure and hydrodynamic efficiency were increased significantly, the hot electron preheat of the core was reduced and there appeared to be no penalty in increased Brillouin backscatter. Major improvements made to the glass laser in the same year were ; the laser glass was changed from silicate to phosphate type, and the commissioning of a six beam target area for laser compression of spherical targets. (see Figs. 15 and 16).

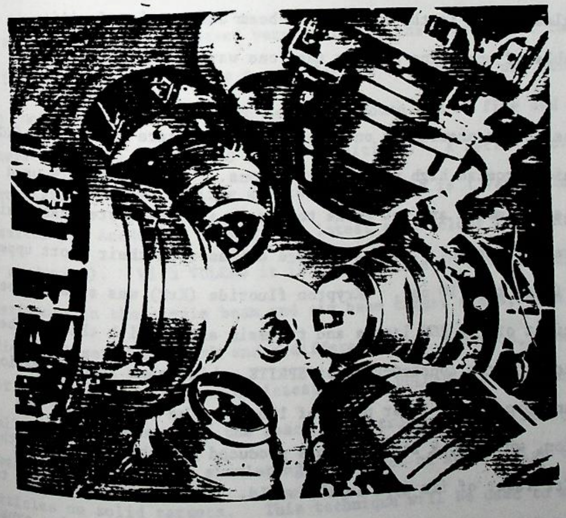


Fig. 15. View inside the 6 beam target chamber

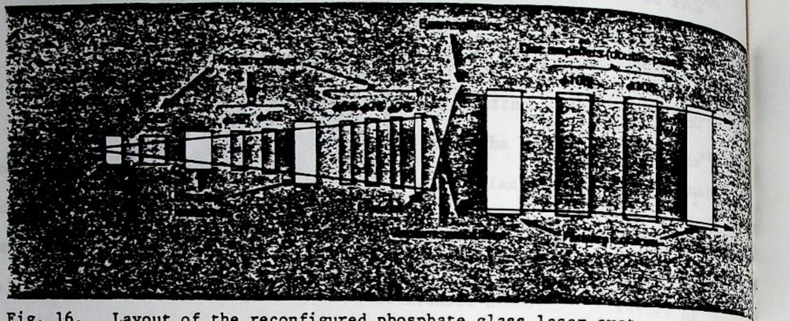


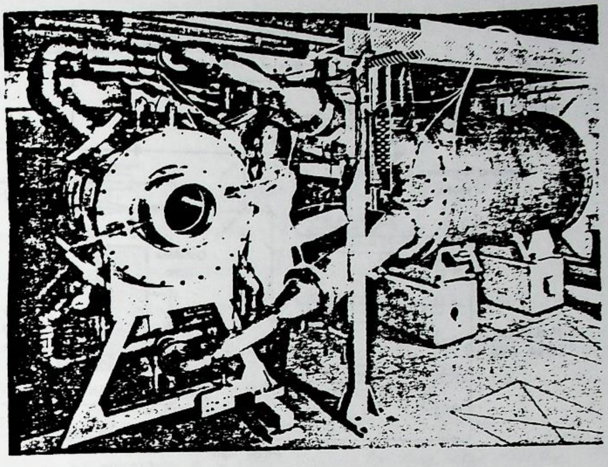
Fig. 16. Layout of the reconfigured phosphate glass laser system

Each of the six high power beams is capable of powers up to 1 TW (in a 100 ps pulse) and energies up to 200 J in a 1 ns pulse, when operated at a wavelength of 1.054 micrometres. As a result of this work the six beam RAL glass laser is the first multi-beam compression facility in the world capable of operating at more than one wavelength.

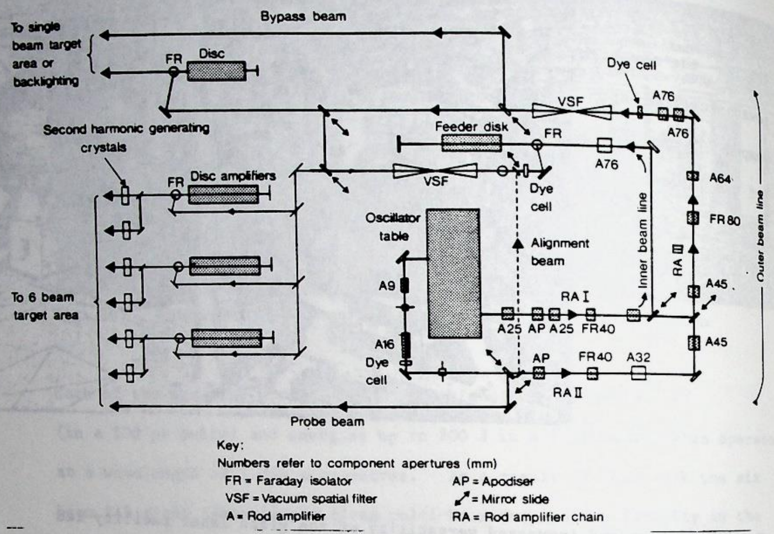
Much of the work concentrates on experiments with rare gas halide (RGH) lasers, which promise high power applications. Gas lasers are used so that the lasing media are not prone to damage and the system can easily be cooled by recirculation. A disadvantage arises from their short upper-state lifetimes (less than 10 ns). Krypton fluoride (KrF) was shown to be the most efficient of the RGH lasers and the main effort with this has been directed towards the construction of SPRITE, which came into operation in May 1982 and produced a laser pulse of 160 J. The development and construction, which took 2½ years, has produced a machine which is the most powerful KrF laser of its type in the world. There are also plans to build a 12-beam KrF laser facility for use in laser-driven compression experiments. (see Fig. 17.)

Fig. 17.

SPRITE - the new high power electron-beam-pumped 249 nm Krf gas laser



The enhancement and increased versatility of the glass laser facility led the Laser Division to devise a name for the essentially new structure. The name chosen was VULCAN, Vulcan being the Roman God of fire and patron of workers with fire, including plasma physicists. A Latin acronym seemed appropriate for the facility and the one derived is : Versicolor Ultima Lux Cohaerens pro Academica Nostra (the latest multicolour coherent light for our academics). With VULCAN it is now possible to have concurrent experiments in the single beam and six beam target areas, each receiving a different laser wavelength and a different pulse duration, from the same shot of the main laser. The latest use of VULCAN, in conjunction with a smaller laser operated by the Space and Astrophysics Division, has been to develop a technique for simulating the impact of small, high velocity particles on solid targets. This technique will be used to mimic the impacts expected when a space-probe (GIOTTO) collides with the dust particles of Halley's Comet. (see Fig. 18.)



Fog. 18. A schematic layout of the VULCAN laser system.

ASTRONOMY, SPACE AND RADIO BOARD

COSMIC RESEARCH

From 1978 onwards work continued, in collaboration with the Appleton Laboratory, on the design of the Millimetre Wave Radio Telescope. This is a 15m radio telescope designed for astronomical observations at frequencies up to 400 Ghz. Its main use will be in studying cool clouds of molecules and dust that are found in many parts of the Universe, which emit radiation most strongly at millimetre wavelengths. Such clouds are believed to be the birthplace of new stars and the Millimetre Telescope will enable information to be obtained on how the clouds condense into stars, the rate at which this happens and the size and arrangement of the newly formed star groups, all of which is essential to our understanding of the evolution of galaxies.

SERC's Dutch counterparts, ZWO, have signed an agreement with SERC, which means they will contribute 20% of manpower and financial resources. Originally it was intended to build the telescope at 8,000 ft. on La Palma, but tests suggested that the site may not be suitable for studying wave-lengths of less than 1mm. The most obvious alternative is the 14,000 ft. observatory on Mauna Kea, Hawaii, which already houses the U.K.I.R.T. (U.K. Infra-red telescope) facility.

The surface of the telescope is made up of 264 panels, which will be supported on a backing structure of sophisticated design that will maintain the correct shape despite gravitational distorting.

If Mauna Kea is agreed upon as the site, it is anticipated that the Millimetre Telescope facility will be completed for commissioning in 1986 (see Fig. 19.)

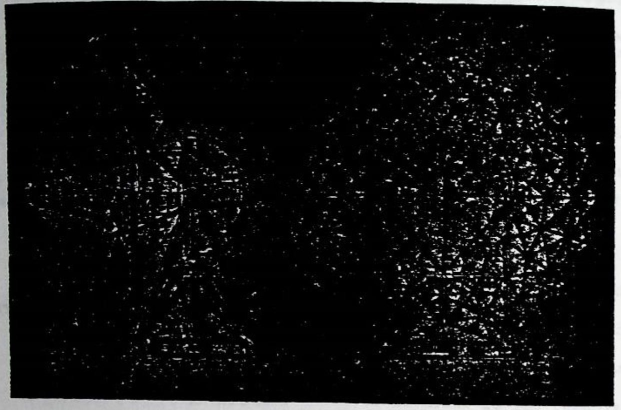


Fig. 19. An artist's sketch of the Millimetre Wavelength Radio Telescope

The Infra-Red Astronomical Satellite (IRAS) is a collaborative project, involving the United States, the Netherlands and the United Kingdom, and aims at a complete infra-red mapping of the sky. The ground operations include the provision of the tracking station, the control centre, the associated software to drive the total system and the post-launch operations and data processing activities. The tracking station is planned around a 12m portable antenna, which has has an electrical control and drive system installed. The centre will also house NASA communications equipment providing a data link to the Jet Propulsion Laboratory (JPL) and Ames Research Center. The satellite is scheduled for launching in December 1982, however it was learned early in 1981 that the IRAS lifetime will be 300 days at best, as opposed to the 400 days, which had previously been expected. During testing of the tracking system the centre was able to track the Landsat-3 satellite under programmable control (see Fig. 20.)

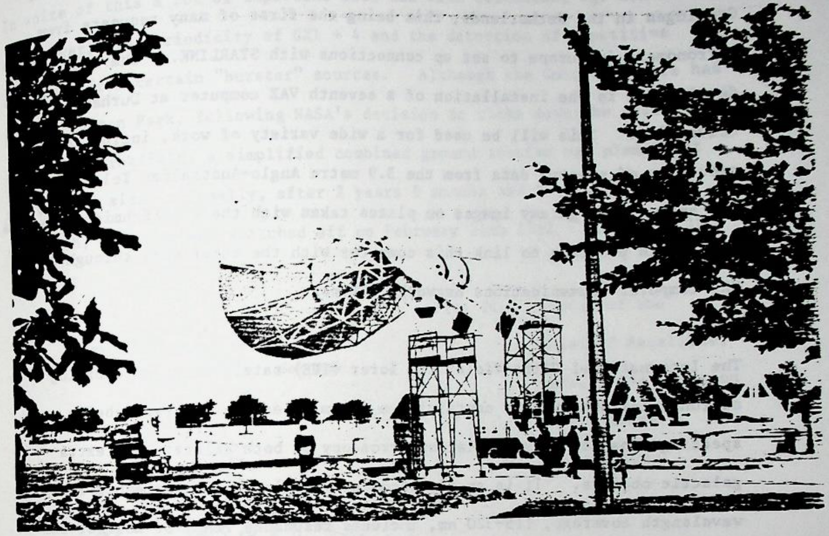


Fig. 20. View of the 12m antenna of the IRAS project installed on the Chilton site.

In July 1979 the SRC approved the STARLINK project to establish an interactive image processing facility for the U.K. astronomical community. STARLINK was to involve six VAX 11/780 computers ; one at the Laboratory, one each at the Royal Observatories and the other three at Cambridge, UCL and Manchester. A further VAX computer is to be purchased for the IPIPS (Interactive Planetary Image Processing System) project at UCL, which will continue to be associated with STARLINK. The STARLINK project was officially inaugurated in October 1980. STARLINK offers a powerful interactive service using both conventional graphics and alpha-numeric terminals and also high-speed image display systems, using the Advanced Raster Graphics System (ARGS).

During 1981, an experimental link was made with the PDP 11/70 computer at Groningen in the Netherlands, this being the first of many requests from astronomers in Europe to set up connections with STARLINK. The most recent development is the installation of a seventh VAX computer at Durham University. This will be used for a wide variety of work, including the reduction of spectra data from the 3.9 metre Anglo-Australian Telescope and the analysis of galaxy images on plates taken with the U.K. Schmidt Telescope. Work is in progress to link this computer with the other six, through SERC's X25 computer communications network, SERCnet.

The International Ultra-Violet Explorer (IUE) satellite is an orbiting astronomical observatory containing a 45 cm telescope and two echelle spectrographs for ultra-violet spectroscopy of both galactic and extra-galactic objects. It is an important astronomical facility since its wavelength coverage, 115-320 nm, includes resonance lines of most of the common atoms and ions of astrophysical interest and enables composition, temperature and line-of-sight velocity to be determined. It was built and operated as a collaborative venture between ESA, NASA and SRC, and was launched into a geosynchronous orbit in January 1978. During 1980 IUE made observations of the twin quasars Q0956 + 561 A,B; of variations on timescales of a few days in the composite spectrum of the Seyfert galaxy NGC4151; and of very young, massive H 11 regions in irregular galaxies. One of the most far-reaching successes of the IUE has been the identification of a "hot" highly-ionised halo to our own galaxy.

Ariel VI was launched in June 1979 and carried three experiments; a cosmic ray experiment and two X-ray experiments. It was spin stabilised and was orientated such that the solar array, at the base of the satellite, faced the Sun. Many operational difficulties were encountered during the satellite's flight, mainly radio interference from the ground and defects in the painted surface causing the spacecraft battery and tape recorders to overheat. In spite of this a lot of important data has been collected, eg. monitoring of the variable periodicity of GX1 + 4 and the detection of repetitive outbursts from certain "burster" sources. Although the Control Centre had been at Ditton Park, following NASA's decision to close down the ground station at Winkfield, a simplified combined ground station was planned at the Chilton site. Finally, after 2 years 8 months and 14,800 orbits of the Earth, Ariel VI was switched off on February 24th 1982. (see Fig.21.)

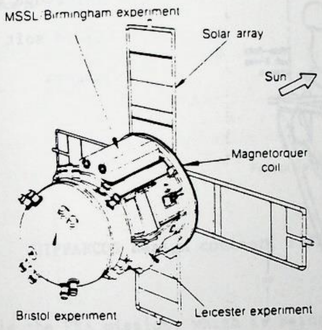


Fig. 21. Sketch of the Ariel VI Satellite, showing the location of the three experiments.

In February 1980, the German Ministry for Science and Technology (BMFT) invited foreign participation in their plans for the ROSAT (Roentgensatellit) X-ray astronomy satellite. The German instrument alone is intended to provide the first deep, all-sky surveys of X-ray sources between 0.15 and 2 keV energy (6 to 80 Angstroms). By including a Wide Field Soft X-ray Camera (WFX), which is a complementary instrument proposed by the University of Leicester, the spectral range would be extended to the extreme ultra-violet (EUV), covering energies between 0.04 to 0.2 keV (60 to 300 Angstroms), with a sensitivity two orders of magnitude lower than any earlier XUV surveys.

The current programme requires a detailed project definition, which started in 1982, leading to a launch on the space shuttle in 1987. The ROSAT spacecraft will be released from the Shuttle and will then transfer to an operational orbit at around 450 km altitute, 56° inclination and be controlled from the German Space Operations Centre (GSOC) (see Fig. 22.)

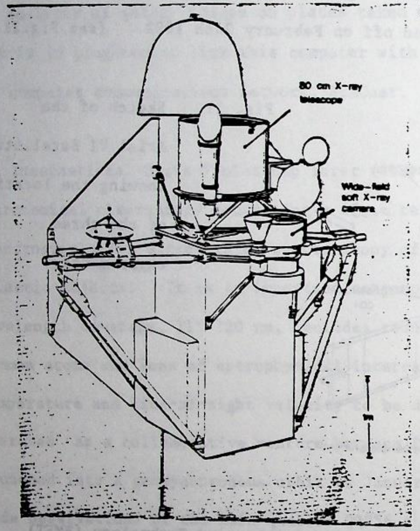


Fig. 22. Sketch of the ROSAT, showing the location of the 80cm X-ray telescope and wide field soft X-ray camera

A second planned satellite project is HIPPARCOS. The aim of this space astrometry mission is to make accurate measurements of the trigonometric parallaxes, proper motions and positions of some 100,000 selected stars. HIPPARCOS should produce data 1000 times more accurate than those which are available now. If successful, HIPPARCOS will lead to the derivation of a more precise distance scale for the Universe; a self-consistent reference frame for the study of stellar and planetary motions; stellar mass and orbital parameters of a large number of binary systems; a more precise intrinsic luminosity for hot stars, and hence their evolutionary models;

and the rotation of the galaxy in the local region (see Fig. 23.)

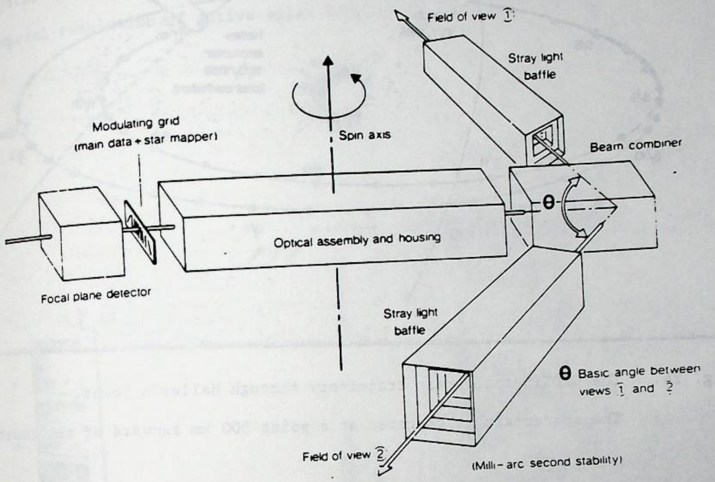


Fig. 23. HIPPARCOS design concept, 1981.

GIOTTO is the ESA mission, which is being sent to rendezvous with Halley's Comet when it returns to our solar system in 1986. RAL is supporting the University of Kent in the building of a Dust Impact Detector System (DIDSY) for inclusion on the spacecraft. DIDSY will measure the dust particle number spectrum in the cometary atmosphere as GIOTTO passes within 100 km of the comet's nucleus, and so determine the comet dust to gas ratio, the extent and nature of the dust envelope, and the structure of the dust particles (see Fig. 24)

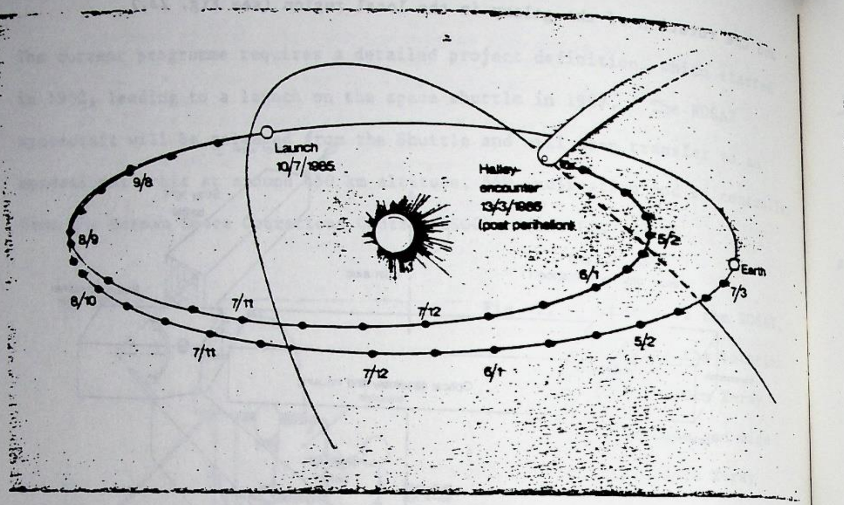


Fig. 24. The GIOTTO spacecraft trajectory through Halley's Comet.

The spacecraft is targeted at a point 500 km sunward of the comet.

SOLAR RESEARCH

RAL has played a major role in observations of the Sun from space, most recently in contributing to the highly sophisticated Solar Maximum Mission (SMM) and in the development of solar experiments to be carried out on the Spacelab facility.

The NASA SMM spacecraft was launched in February 1980, to coincide with the peak in the 11-year cycle of solar activity. One of the seven experiments on board was the X-ray polychromator (XRP), built jointly by the Mullard Space Science Laboratory, Lockheed Missile and Space Company and RAL. Important spectral lines of seven abundant elements on the Sun are present in the X-ray band from 1.4 to 22.4 Angstroms and the XRP uses this spectral interval to investigate the production of solar flare plasma in the 1.5 to 50 million degree temperature range. It employs two X-ray spectrometer systems, one using large flat crystals and the other a novel curved crystal configuration. Together they provide for high spatial, spectral and temporal resolution of active solar features. (see Fig. 25.)

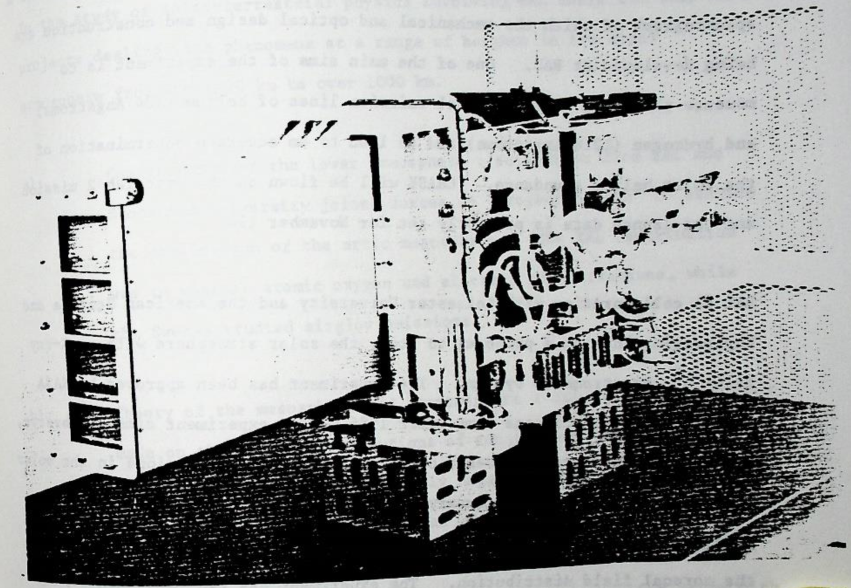


Fig. 25. The flat crystal spectrometer of the XRP, prior to integration into the SMM Satellite.

Normal operations on SMM stopped in November 1980, when the attitude control system on the spacecraft failed. In the intervening months, however, the XRP had accumulated large quantities of new data on solar flare phenomena. These data have been used to cover a wide range of topics, eg. one project used the XRP observations to derive new ionisation balance data for highly ionised calcium and iron. At present NASA is giving high priority to plans to use the space shuttle in March 1984 to visit and repair the SMM spacecraft.

The two experiments planned for flight on Spacelab are designed to study the outer solar atmosphere (the corona).

The Coronal Helium Abundance Spacelab Experiment (CHASE) is to be used to look at the solar spectrum between the wavelengths 1335 and 150 Angstroms. It consists of a 1 cm^2 aperture grazing incidence telescope attached to a 1 m spectrograph of which the mechanical and optical design and construction are being developed at RAL. One of the main aims of the experiment is to measure the ratio of the coronal emission lines of helium (304 Angstroms) and hydrogen (1216 Angstroms) and so lead to an accurate determination of the solar helium abundance. CHASE will be flown on the Spacelab 2 mission and the launch date is presently set for November 1984.

RAL is collaborating with Leicester University and the American Science and Engineering Inc. on a proposal to study the solar atmosphere with an X-ray telescope spectrometer system. The experiment has been approved by NASA for a shuttle launch some time after 1986. The experiment aims to observe, measure and interpret the behaviour of high temperature regions in the solar atmosphere and to study time-varying magnetic structures by observing the plasma dynamic processes that produce or accompany topological changes in the coronal field distribution. The experiment has two complementary modules :

a) an imaging X-ray telescope fitted with a video camera plus a pair of film cameras; and

b) a three-channel, high spectral resolution X-ray spectrometer.

RAL's immediate tasks are the detailed designs and the procurement of the very large crystals required for the spectrometer.

TERRESTRIAL RESEARCH

This area of research can be divided into three major categories : solar - terrestrial physics; remote sounding; and rockets and balloons.

In the study of solar-terrestrial physics involving RAL there are four main projects dealing with phenomena at a range of heights in the upper atmosphere from about 10 km to over 1000 km.

a) Constituents of the lower atmosphere : scientists from RAL and Stockholm University joined forces in "Project Oxygen" to examine the composition of the artic mesosphere. The RAL contribution was to measure atomic oxygen and electron concentrations, while the Swedes studied airglow emissions.

b) Theory of the mesosphere and stratosphere : calculations have been made on the height distributions of constituents in the height range 60 to 140 km; particularly negative ions, electrons and neutral sodium atom distributions have been considered. A new method of calculating the transmission of gravity waves, through regions of wind shear, has been investigated in a joint study with the Open University.

c) Magnetospheric plasmas : charged particles in the plasmas surrounding the Earth are measured, including those that enter the atmosphere at high latitudes and produce aurora. Instrumentation is being developed for the AMPTE mission (see later section) to measure the electron distributions of the plasmas of the Earth's magnetosphere, when the plasmas are in a quiescent state and when they are disturbed. The instrumentation for the VIKING satellite is part of an experiment to determine the composition of energetic ions in the Earth's magnetosphere. During the GIOTTO mission, the natural plasmas in the vicinity of Halley's Comet will be studied. Studies have also been carried out using Petrel rockets and the geostationary satellite Geos-2.

d) **Theoretical magnetospheric physics** : the multipole method of expanding planetary main magnetic fields has been used to calculate the true quadrupole and octupole parameters for six different models of Jupiter's main magnetic field, which are based on measurements made by the Pioneer 10 and 11 spacecraft.

AMPTE (Active Magnetospheric Particle Tracer Explorers) is a project aimed at investigating how solar energy is intercepted and stored in the magnetic fields and charged particles that form the comet-shaped magnetosphere surrounding the Earth, out to distances of more than 100,000 km. A German satellite will release lithium ions (acting as tracers) into the solar wind 10,000 km upstream from the magnetosphere and an American satellite, orbiting closer to the Earth, will detect the arrival of the ions and note the extent of their expected increase in energy. The German spacecraft will also record the distrubances expected to be triggered by the sudden deposition of lithium ions in the natural plasma of the solar wind. The U.K. spacecraft will be a sub-satellite of the German one, aiding it in the measurement of the disturbances. The three AMPTE spacecraft are to be launched on a single Thor Delta vehicle from Cape Canaveral in August 1984. The UKS is 1m in diameter and weighs 69 kg. It has two pairs of deployable booms carrying the magnetometer and wave-experiment search coil and the electric field experiment pre-amplifiers. Transmission of data will be via an S-band link to the 25m dish at Chilbolton. (see Fig. 26.)

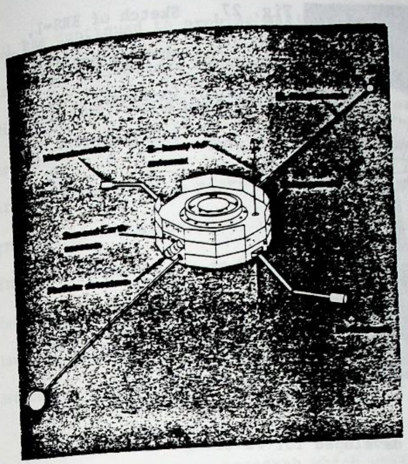


Fig. 26. AMPTE UKS spacecraft

The EISCAT (European Incoherent Scatter) radar system was officially opened by the King of Sweden in August 1981. EISCAT will compromise two radar systems, UHF (933 MHz) and VHF (224 MHz), which will study the atmosphere, ionosphere and magnetosphere. Most of the data received are "raw", eg. radar spectra, and have to be processed. U.K. observers have access to an EISCAT database, based at RAL. Staff are also working on research topics related to possible EISCAT observations.

Several projects have been established in the area of remote sounding, centring on the development of advanced microwave and infra-red measurement techniques for use in atmospheric and climate research from spacecraft and other platforms. Much of this work has revolved around the planning of the first European Remote Sensing satellite, ERS-1, due to be launched by ESA in 1987. (see Fig. 27.)

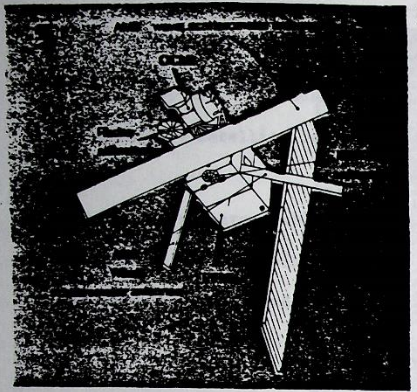


Fig. 27, Sketch of ERS-1, showing possible in-flight configuration

Millimetre wave devices are being developed for wavelengths between 3 and 0.6 mm., for application in superheterodyne radiometers. Many space - or balloon-borne radiometers require all solid-state radiometers, which are now feasible up to about 250 GHz, using devices developed at RAL. Current work has concentrated at 230 GHz to support various astronomy programmes (at U.K.I.R.T.) and site testing for the Millimeter Telescope. RAL, in collaboration with Heriot-Watt University, have proposed the inclusion of a Microwave Pressure Sounder on ERS-1, which will measure atmospheric transmission at frequencies near the 60 GHz O(2) band. Precision radar altimetry from satellites offers promising new studies in oceanography, glaciology and climatology, with the radar altimeter proposed for ERS-1 providing the most comprehensive set of high resolution data so far. In another collaborative project, a programme of microwave altimeter, scatterometer and ranging measurements, is planned : these measurements to be made from an aircraft over artic regions. A new infra-red technique, for measuring sea surface temperature from space, has been developed and a proposal has been sent to ESA for its mounting on ERS-1.

RAL has continued to provide assistance to Oxford University in its work on infra-red radiometers mounted on NASA spacecraft. The two experiments, Nimbus 5 (SCR) and Nimbus 6 (PMR), were closed down with regards to data collection, in 1981. The Stratospheric and Mesospheric Sounders (SAMS) is still working well, 4 years after its launch. It provides temperature profiles of the atmosphere, up to a height of 120 km, by measuring radiation from carbon dioxide. An improved SAMS instrument (ISAMS) has been accepted for inclusion on NASA's upper atmosphere research satellite due to be launched in 1988. The improvement lies in the enhanced sensitivity of the detectors, achieved by cooling to about 70K with closed cycle refrigerators.

RAL supports university research which utilises both sounding rockets and scientific balloons as a means of placing experimental apparatus outside the majority of the Earth's atmosphere, to collect data over periods of minutes (for rockets) or hours (for balloons). At this time, rockets are used mainly for geophysical and balloons for astrophysical studies. The rockets used are Petrel sounding rockets and they have been used for a variety of projects, eg. a proving trial for the Pulse Code Modulation (PCM) telemetry system and for chemical release experiments. Six Petrels launched in rapid succession (within 75 minutes), early in 1982, collected data related to nightglow.

Between 1980-81 ten balloon flights took place, all for astrophysics experiments. Also in 1981 the redesign and reconstruction of the stabilised balloon platform were completed, providing arc-second pointing accuracy in three axes (see Figs. 28 and Appendix B).

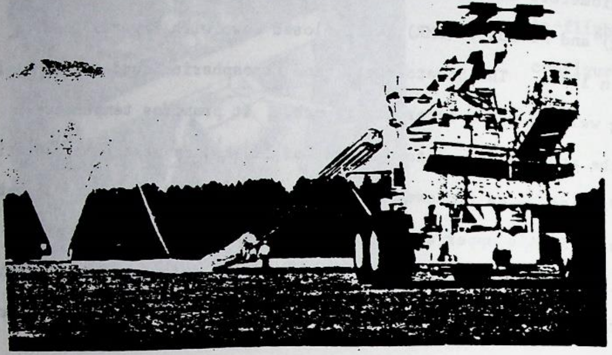


Fig. 28. The Stabilised Balloon Platform. The payload is suspended on the "Tiny Tim" launch vehicle in the foreground, with the balloon in the background.

ENGINEERING BOARD

RADIO RESEARCH

Since the merger of the Rutherford and Appleton Laboratories work has continued on the development of radio techniques for terrestrial and space communications. This involves the study of the properties of both the lower and upper atmosphere and of propagation phenomena affecting a wide range of radio frequencies.

The work at RAL is aimed at improving the efficiency of existing methods for predicting the performance of high-frequency (HF) sky-wave telecommunications systems, and also developing new methods for specific applications. Collaboration with the University of Concepcion, Chile, has enabled RAL to develop a method for predicting attenuation of signals propagating through the auroral zones. Another contract, with Exeter University, will study sporadic - E ionisation, with a view to the improved prediction of its effect on radio propagation. Studies of ionospheric variations on different time-scales have been carried out in order to identify the causes of ionospheric variability and to improve the accuracy of ionospheric predictions made for communications purposes.

The sea-state radar project, which is being carried out jointly with the University of Birmingham, aims to develop and demonstrate the use of shore-based radar systems for the study of the sea surface and the related winds and sea currents. Two separate types of HF radar systems are currently under investigation : the first irradiates the sea area by means of radio waves reflected from the ionosphere; and the second system operates in a surface wave mode. For sky-wave work, an existing radar system with a 300 m linear array, located in southern England, is being used to obtain a series of daily observations covering a large part of the North Atlantic Ocean.

This system was used during the international MARSEN (Maritime Remote Sensing) experiment, which recorded the ionospheric Doppler shift of the transmitted pulse signals.

The closure of the Ditton Park site necessitated the transfer of the Millimetre Experimental Range to Chilbolton. This 500 m. range is designed to provide the necessary data to model atmospheric effects on radio links at millimetric, infra-red and optical wavelengths. By adding meteorological sensors, eg. raingauges, the facility has been planned to meet a wide-ranging research requirement in a part of the spectrum where little experimental information is available. Transmitters and receivers operating at 37, 57, 97, 137 and 210 GHz have been installed.

The dual polarisation radar mounted on the Chilbolton antenna has been used during the last 3 years for probing the structure of rain cells. The technique, which was pioneered at RAL, is superior to that of conventional radar, in that it measures the differential reflectivity of back-scattered power between horizontal and vertical polarisations. This measurement is directly related to the statistical distribution of rain drop size and can also be used to distinguish between the water and ice phase in rain cells.

UNIVERSE

For several years the Laboratory has been developing new technologies for high-speed computer networking, ie, networking with megabit per second data transmission rates rather than the current kilobit rates. Building on previous experience, eg. the STELLA project which links CERN, DESY, Pisa and RAL by a 1 Mbit s^{-1} satellite link, the Laboratory joined with Cambridge University, Loughborough University and UCL to propose to SERC an experiment in high-speed computer networking UNIVERSE (Universities Expanding Ring and Satellite Experiment). The proposed experiment investigated the use of a series of Cambridge rings and a small dish satellite network to provide a wide-area computer network. The general configuration is the use of interlinked rings within a site for local distribution, with the satellite joining the sites together (see Fig. 29.)

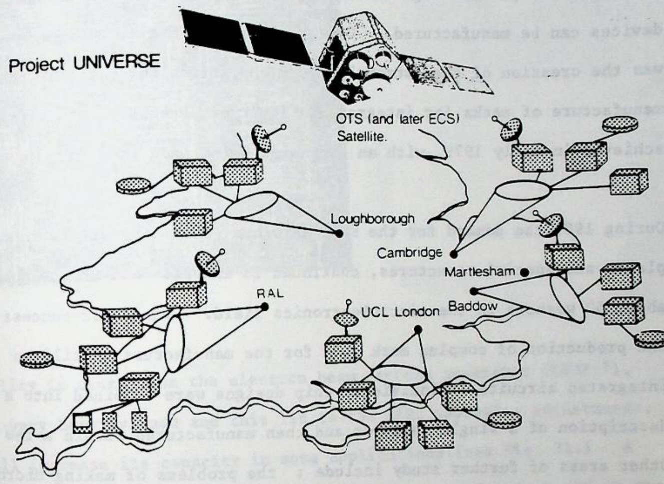


Fig. 29. The general configuration of the UNIVERSE project in which 7 sites are linked via a satellite network.

The seven sites are : the four SERC sites, GEC/Marconi Research Centre at Great Baddow, British Telecom research at Martlesham and the Logica offices in London. Due to the limited life of the OTS satellite, work schedules have been tight. When the system was brought into operation in early 1982, RAL and Martlesham used existing earth stations and four new Marconi stations are planned for the other sites (Logica is to be linked to the UCL site by a high-speed ground link).

ELECTRON BEAM LITHOGRAPHY

The Electron Beam Lithography facility (EBLF) was officially inaugurated by Mrs. Shirley Williams in July 1979. The EBLF was set up to provide universities and polytechnics with better facilities for the preparation of prototype integrated circuits and other microelectronic structures. The aim is to produce high definition mask sets from which microelectronic devices can be manufactured. One of the major initial equipment problems was the creation of the extremely clean conditions required for the manufacture of masks for integrated circuit construction, but this was achieved in early 1979, with an extension being made in 1980.

During 1981 the demand for the EBLF services, producing precision mask plates and special structures, continued to increase and it now supports about 50 workers in the microelectronics field. One major success has been the production of complex mask sets for the manufacture of silicon integrated circuits : individual chip designs were combined into a description of a single mask set and then manufactured within a few weeks. Other areas of further study include : the problems of making micron and sub-micron features; construction of an advanced electron beam lithography machine; and investigations into X-ray lithography. (see Fig. 30.)

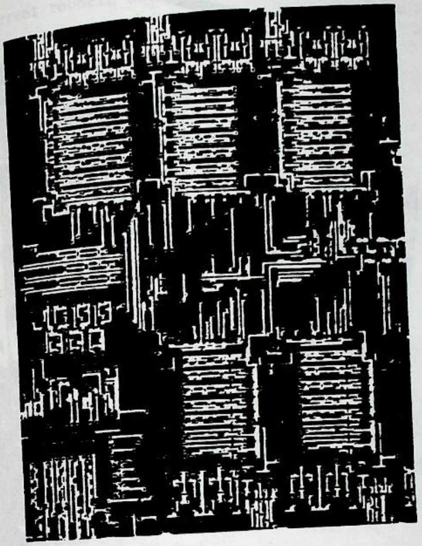


Fig. 30. Part of an integrated circuit design produced using the computer-aided-design system GAELIC

The facility is centred on the electron beam pattern generator (EBMF-2), which is very heavily used and this led to the SERC approving adjustments, which will increase its capacity in some applications.(see Fig. 31.) A complete software system for pattern layout has been designed, based on the computer-aided-design system, GAELIC. After a period of familiarisation with GAELIC using a DEC 10 computer, work was instigated to provide versions of GAELIC on the PRIME 400 machine at RAL, which will mean that pattern files from users of the EBLF can be more easily transferred by direct connection to the EBL control computer.

Fig. 31. The EBMF-2 electron beam pattern generator installed in a clean room at the EBLF.

INDUSTRIAL ROBOTICS

In July 1980 the SRC officially announced a major new initiative in Industrial Robotics, involving partnerships between academic groups and industrial firms. Funds approaching £800,000 p.a., for the next five years, have been set aside. The programme aims to "leapfrog" the present generation of robotic devices and help provide the research and training needed to ensure that U.K. industry can take full advantage of the intelligent robot when it emerges in the mid-1980s.

Current robotic devices are capable of being used for simple tasks, eg. spray painting, spot welding, but the next generation will tackle more advanced tasks, eg. arc welding, automatic inspection.

The project has been divided into five major areas of research; sensory devices; fine mechanical; control; safety; diagnostic and error recovery function; and standards and grants to these have been allocated accordingly.

The overall direction of the research and the implementation of individual projects have been actively guided by the programme co-ordination team based at RAL. They have centrally purchased £400,000 worth of robotics equipment as part of a loan pool for use in individual projects.

INTERACTIVE COMPUTING FACILITY

An intimate dialogue between a computer and a reseacher or designer can effectively increase man's creativity and extend his memory. This kind of dialogue is called interactive computing - in which the designer himself becomes part of the computation, taking decisions and guiding the step-by-step progress towards solving the problem.

The Interactive Computing Facility (ICF) was set up in 1977 to fill the demand for interactive computing in universities and polytechnics. A main trunk network was established between Edinburgh, Manchester (UMIST) and Chilton and there are secondary links which reach individual terminals or clusters of terminals at many other sites. From many types of Multi-user Minicomputers (MUM), two were investigated in depth (the GEC 4070 and the PRIME 400 series computer) and are now defined as the standard for the ICF.

Originally the major interactive computing power was provided by Digital Equipment Corporation's DEC 10 K1 configurations at UMIST and the Edinburgh Regional Computing Centre (ERCC). Both of these configurations were upgraded in 1978. About 500 users kept both the DEC10s well used at their peak, but by 1979 discussions were taking place to decide on more modern replacements for these. By 1980 there were 1700 registered users on the 21 ICF machines (two DEC 10, twelve GEC 4000 series and nine PRIME 550 or 750). The interactive power supplied by the DEC 10s has now been replaced by the more modern MUMs. In line with ICF policy of concentrating DEC 10 hardware and support at one site, the KI-10 processor at ERCC was upgraded to a KL-10 and the UMIST DEC was replaced by a PRIME 750. (see Fig. 32.)

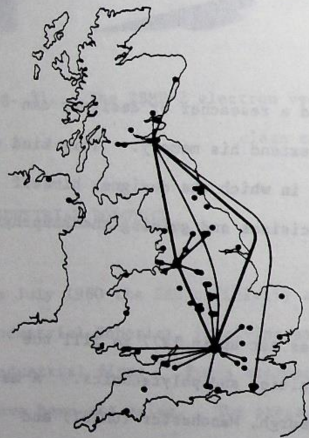


Fig. 32. The main trunk network of the ICF linking Edinburgh, Manchester and Chilton. Secondary links reach other individual terminals at many other sites.

Some experience has also been gained on single-user mini-computers (SUM) and 1980 saw the delivery of a new, powerful SUM - the PERQ. This machine provides, to one user, the computing power, memory and disc space comparable to a small MUM coupled to a high-quality raster graphics display and input devices.

The GEC computers have been fully networked for some time, forming the SERCnet and offering :

a) ITP protocols for interactive use, so that users at one machine can run interactive programs on another;

b) FTP protocols for file transmission between machines;

c) HASP protocol providing a remote job entry link to the central batch facilities.

All these protocols use the SERC version of the standard X25 protocol. The DEC computers are linked via DECnet (which does not use X25). The restrictive PRIMEnet link between the PRIME computers has been transferred to the SERCnet.

The most recent development has been the installation of the GEC 4090, which is aimed at competing with the PRIME 750 or VAX 11/780. Gradually these are replacing the smaller GECs at the main sites involved.

APPLIED SUPERCONDUCTIVITY

Superconducting magnets provide high magnetic fields with negligible power consumption. They offer both economic and practical advantages over conventional magnets and proved to be very useful in HEP experimentation, eg. bubble chambers and beam handling systems.

A major advance in 1968 was the development of a new intrinsically stable composite superconductor. This consisted of a twisted array of five superconducting filaments embedded in a matrix of supporting metal, usually copper. (see Fig. 33.)

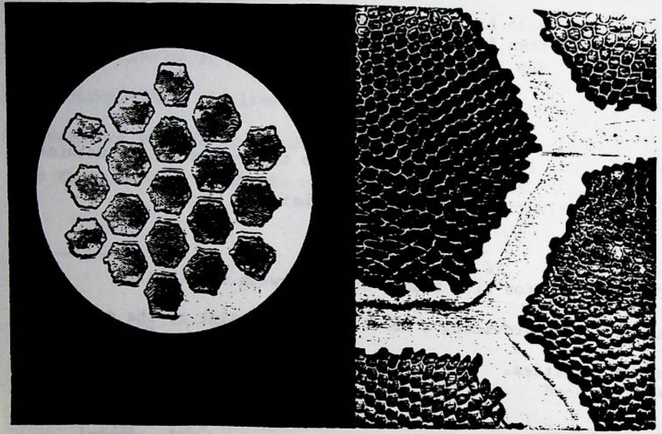


Fig. 33. Cross section (enlarged) of a composite superconducting cable.

Such a conductor could be made in which as much as 50% of the cross section was superconductor, allowing much higher over current densities to be achieved than with conventionally established composites. Although much work still had to be done on conductor and cable manufacture, effort was still devoted to the construction of a series of pulsed dipole prototype magnets ie. AC3, AC4 and AC5. The AC3 was successfully completed in 1971, using a 0.4 mm diameter composite and containing 1045 filaments of 8 micrometre diameter. Both AC4 and AC5 had iron shields, since at the required magnetic level of 4.5 T the iron itself contributes about one-third of the total field and, in doing so, significantly reduces the amount of superconductor required and the stored energy in the magnetic field. (see Fig. 34).

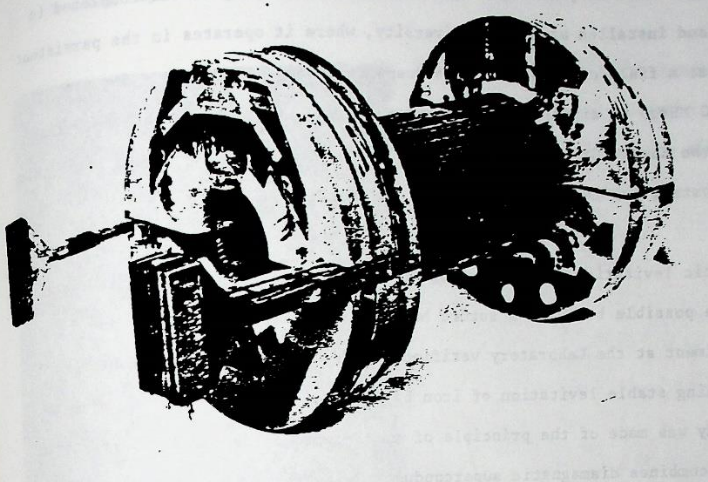


Fig. 34. The AC3 pulsed dipole magnet.

A new type of cable was developed in 1972 for use in high current pulsed magnets. The cable consisted of a hallow tube of helically twisted wires, which had been flattened into a tape by rolling. It proved possible to compact this cable until the wires filled more than 90% of the cable cross-section, without significantly damaging the superconducting properties of the wire.

At the request of the SRC Science Board, the Laboratory undertook the supervision of the development of a high field niobium-tin insert magnet, which forms part of the 460 MHz high resolution NMR (nuclear magnetic resonance) system being used by a biochemistry group at Oxford University. A technique was developed for making a persistent current joint to the niobium-tin conductor. The joint was tested on a 2/3 model and sufficient field homogeneity and stability were obtained to observe the NMR spectrum of deuterium in a sample of deuterated pyridine at a field of 9.2 T. Eventually the Laboratory's involvement in this project increased to include the manufacture and design of some of the electronic equipment used in pulsed NMR spectrometers. The project was completed in 1978 and installed at Oxford University, where it operates in the persistent mode at a field of 11 T, which corresponds to an NMR frequency for protons of 470 MHz. A significant development in the Laboratory's collaboration with the Enzyme Group at Oxford has been the commissioning of the high-field NMR system, for the routine study of biochemical molecules.

Magnetic levitation began arousing interest around 1975, when it was seen as the possible basis of a future high speed transport system. An experiment at the Laboratory verified an idea from the Culham Laboratory for obtaining stable levitation of iron by means of a superconducting magnet. A study was made of the principle of mixed-permeability magnetic levitation, which combines diamagnetic superconductor with ferromagnetic iron. The mixed-permeability system requires bulk superconductors and the most successful approach so far has been to use a stack of niobium titanium foils which are laminated between sheets of pure copper. Emphasis has recently been placed on shaping the iron rails : the experimental work has shown that the geometry of the rail can have a dramatic effect on the force/displacement characteristics of the system. A small AC coil has been designed, for University College of North Wales, which will be used to investigate the dynamic effects on the behaviour of the superconducting screen, due to vehicle bounce.

During 1977, funding was approved for a Science Board special project : a superconducting three-pole wiggler magnet to be installed at the Daresbury Laboratory Synchrontron Radiation Source (SRS) to enhance the spectrum of hard X-ray radiation. The 5 T magnet was successfully tested with its refrigerator at Daresbury towards the end of 1981. The magnet assembly comprises an aluminium alloy support structure, 8 modular pairs of race track superconducting coils and a rectangular laminated yoke, all mounted

in a vertical cryostat. (see Fig. 35).

Fig. 35. Sketch of the superconducting wiggler magnet built for the SRS at Daresbury Laboratory.

While these major projects have been emphasised, other equally important work has been taking place, eg. testing of superconducting materials; hexapole magnets for neutron beam research; and participation in the Euratom thermonuclear programme.

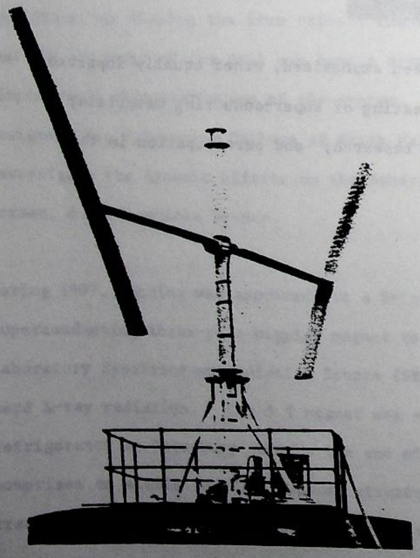
CENTRALLY FUNDED ACTIVITIES

ENERGY RESEARCH SUPPORT UNIT (ERSU)

ERSU was formally started in 1977, providing the Secretariat of the SRC Energy Proposals Committee (EPC), which receives grant applications for energy systems research projects and for inter-disciplinary energy-motivated research. The EPC is concerned with three main areas : heat pumps, heavy ion fusion and fusion technology. At any one time ERSU has several projects running in collaboration with university groups, examples of which are given below.

A windmill and generator system has been designed and built for the Cambridge Autarkic House project. It will be capable of giving about 7.5 kW peak. (see Fig. 36.)

Fig. 36. The 6m. diameter windmill which has been built for the Cambridge Autarkic House project.



ERSU is involved with instrumentation and data collection in three major projects :

a) monitoring 40 houses at Abertridwr - 20 with current standards or insulation and 20 with higher standards;

b) investigating the variation of u-values of building materials in service; and

c) assisting Oxford Polytechnic in research on modifications to windows in existing school buildings.

In collaboration with the Open University, work has been initiated on an experimental H_2SO_4 heat pump with a design heat output of several kilowatts. In vacuum, concentrated sulphuric acid at 80°C will continue to pump water vapour from water at 10°C. Heat deposited in the sulphuric acid from both the latent heat of the vapour and from the heat of the chemical combination. A heat pump/boiler has been successfully tested to give outputs up to 8 kW at 80°C. (see Fig. 37.)

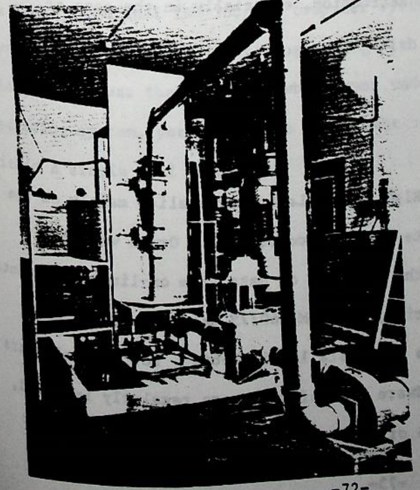


Fig. 37. A test rig for an experimental chemical heat pump and energy storage system which uses water on sulphuric acid.

The concept of heavy ion fusion involves accelerating intense, short pulses of heavy ions to high energies and focussing them on to a small pellet containing a mixture of deuterium and tritium. The resulting thermonuclear burn produces a gain in energy of about two orders of magnitude. Studies in fluidised bed combustion have started to show promise for increasing the efficiency of coal combustion processes and for converting coal in a gaseous fuel. Large-scale energy storage for the electricity supply is an attractive idea but there is a lack of suitable geographic areas for extending pumped storage capacity. An alternative scheme stores energy in kinetic form. A massive ring, free to rotate about its axis of symmetry, is accelerated to high speeds by motors coupled to the ring through wheels or gears. Power is extracted by decelerating the ring using the same motors as generators.

Until now fusion technology has concentrated on the materials aspects of reactors, eg. radiation damage in structural materials. Recently, however, ERSU has been trying to broaden the scope of the programme and emphasis is being shifted to the areas of heavy electrical and mechanical engineering. This shift will be mainly in the areas of design and systems modelling, rather than actual construction, especially in the case of university groups.

GENERAL COMPUTING FACILITIES

Between 1966-70 the Rutherford High Energy Laboratory relied mainly on the Chilton Atlas for the bulk of its off-line computing. Orion was used mainly for the reception (via the DDP-224) of data from on-line experiments and measuring devices. Like Orion, the IBM 360/75 used the DDP as an on-line data collector, and thus was installed in 1966. For several years after this installation the hardware and software were regularly improved, eg. in 1969 an extra 500 K bytes of main store was added. To house the

the additional central computer installation building R1 was extended in the same year.

In 1970, approval was given for the purchase of a new central computer, an IBM 360/195, at a total cost of £3.6 million. During that year the ELECTRIC job submission and file-handling system also came into full use. Another facility available on ELECTRIC is the retrieval of graphics files. New versions of ELECTRIC appeared at regular intervals.

The GEC 4080 (bought in 1974 to replace the old DDP 224 computer) is a powerful minicomputer with the processing power of approximately one "Atlas unit".

When the Atlas Computer Laboratory became part of the Rutherford Laboratory in 1976, it gave an added dimension and expertise to the existing facilities (See Appendix A).

A second IBM 360/195 was installed in 1977 and the 195/1 was switched off. At the same time, use of the Atlas ICL 1906A was reduced pending its closure in 1978. The dual IBM 360/195 computer system continued under the operating system OS/360 with MVT (Multiprogramming with a Variable number of Tasks) and alongside it was the IBM 3032, which runs under the Virtual Machine (VM/370) operating system, permitting the concurrent running of many virtual machines within a single real computer.

The Conversational Monitor System (CMS) is an interactive time-sharing system, which runs in a virtual machine under the VM/370 operating system on the IBM 3032. It gives users the ability to create and update files, to run jobs in a CMSBATCH virtual machine and to run jobs interactively in their own virtual machines. CMS is intended to replace ELECTRIC, which was frozen towards the end of 1980 and all development on user facilities ceased. There was a need to compensate within ELECTRIC for the reduced CPU power of the 3032 compared with the 195 in order to maintain the same performance. (see Fig. 38.)

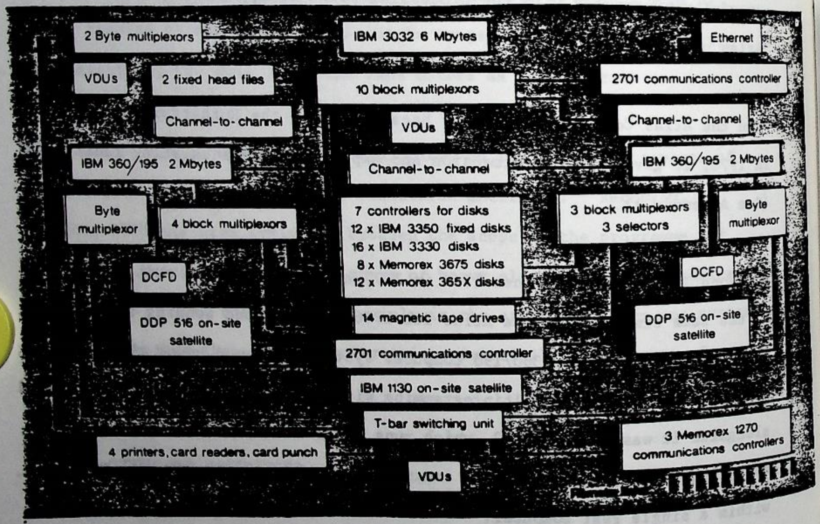


Fig. 38. The layout of the three machine complex which forms the Central Computing Facility.

It is almost impossible to mention all the facilities and research in progress in the computing division, but a few can be listed briefly : the FR80 microfilm recorder has worked successfully for several years producing high quality graphical output on colour or black and white film, hardcopy or on 105 mm. microfiche; a new Graphics Section was set up in 1980 to bring together all the individual graphics research projects; in 1981 a Database Section was formed to be involved with data and procedural analysis, sizing, design, development, implementation and maintenance of databases. Two major projects in this section are the engineering drawings database and the library catalogue.

In 1981 the Laboratory took a large step towards helping school pupils, studying computer science, to gain experience by providing time on the PRIME computers. A-level students in the Chilton area have available the PRIMOS operating system, as well as FORTRAN and PASCAL and a graphics package. RAL is able to provide a PRIME 400, with 512 kbytes of store and an 80 Mbyte disk. Leased lines have already been installed between RAL and three local schools. Besides equipment, RAL has also been able to offer computing work experience at the Laboratory during the Summer holidays.

APPENDIX A

THE ATLAS COMPUTER LABORATORY

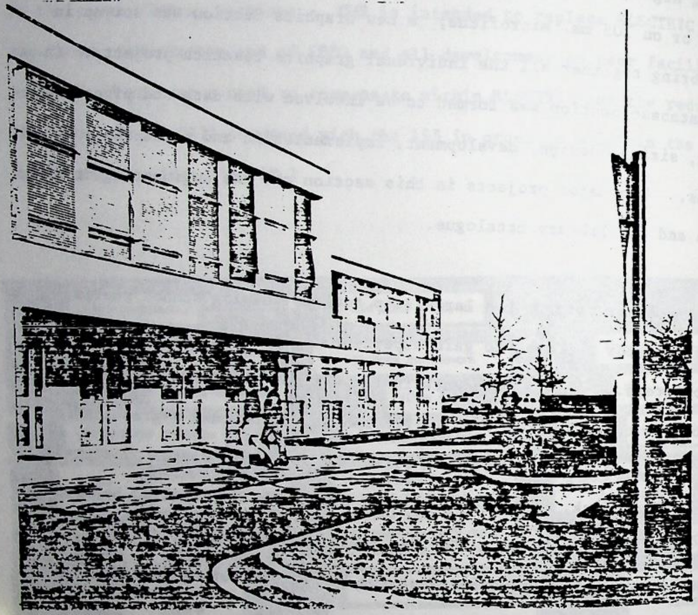


Fig. 39. The Atlas Computer Laboratory.

The Atlas Computer Laboratory was set up by the British Government in 1961, originally under the administration of NIRNS, although it was not exclusively concerned with nuclear research. The intention was to establish a very broad based computing laboratory around the large "Atlas" computer, providing facilities on a large-scale to research workers in universities and other Government laboratories.

The building, equipping and staffing of the laboratory took most of 1962-64, and the new Atlas building became available in early 1964; the machine being delivered (in 20 lorries) in May 1964. The computer was the Ferranti-ICL Atlas model, and a regular service was opened around it. A very short time after its opening, the Laboratory was giving computational support to research workers in all fields of science.

The Atlas computer was developed 1957-61 by the computer scientists and engineers at the University of Manchester, headed by Dr. Tom Kilburn. The aim was to produce a large-scale computer, which had a high basic speed and a very powerful, flexible and largely automatic means of organising and controlling the flow of work through it. Many of its features are standard on today's generation of computers, but in 1960 they were exceptionally advanced, eg. the paged store, which is a means of organising the computer store so that the operating system can allocate storage to programs and data, and can move these around in the store, in a free and flexible way. Atlas was a very fast machine for its time, eg. the simplest mathematical or logical operations, such as addition, took between 1.6 and 2.2 microseconds, while multiplication took 5.9 microseconds. This meant that a set of 5000 numbers could be sorted into numerical order in 1 second.

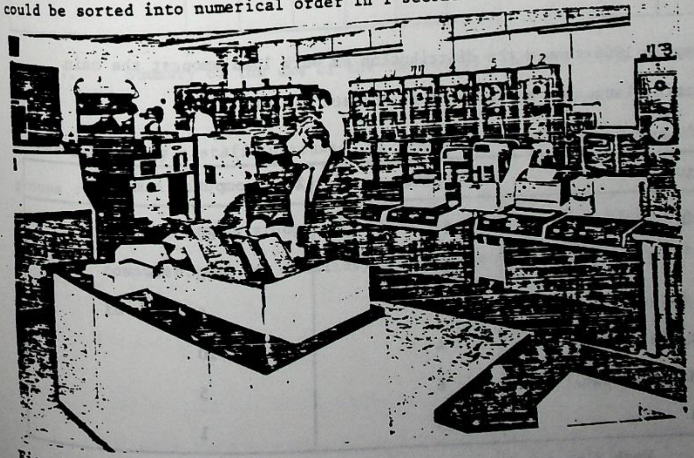


Fig. 40. Part of the Atlas machine room.

HARDWARE

Apart from the Atlas mainframe computer and an ICL 1906A, the Laboratory has always maintained other pieces of standard hardware, eg. disc files, magnetic tape equipment. A computer graphics system was built up over the years 1967-72, including a DEC PDP-15 computer, keyboards, light pens and a microfilm recorder (FR80). The Laboratory also had a 20% share of the Rutherford Laboratory IBM 360/195.

SOFTWARE

The laboratory has available the full range of manufacturers' compilers, but most of the work is done in FORTRAN or ALGOL. Libraries of standard programmes and routines are held, together with the NAG library of numerical-analysis procedures. The Laboratory has also designed and produced its own comprehensive software, and will acquire, commission or develop software packages for which there is an obvious need; examples of packages in operation are POLYATOM and ALCHEMY in quantum chemistry, ASCOP in statistics and COCOA in text processing.

A survey in 1966 showed the distribution of work load amongst the main programming languages and also broad subject fields.

Table 5

Language	% of jobs	% of computer time
FORTRAN	64	68
ALGOL	10	10
Atlas Autocode	6	6
Mercury Autocode	4	10
ABL (Machine code)	6	5
Others	10	1

Work distribution of main programming languages.

Subject	% of jobs
Mathematics	23
Physical sciences	29
Biology and medicine	5
Engineering	31
Social services	5
Others	7

Table 6

Number of jobs

according to subject

	Jan-Mar			Apr-June			July-Sept			Oct-Dec		
	Hr.	Min.	Sec.	Hr.	Min.	Sec.	Hr.	Min.	Sec.	Hr.	Min.	Sec.
Science Board	656	05	57	644	11	07	595	14	23	569	49	48
ASR Board	112	09	48	134	08	17	91	47	25	89	34	58
Engineering Board	135	56	18	163	17	48	236	54	15	234	42	23
NERC	33	34	52	57	14	13	53	34	31	29	46	52
Atlas	269	20	50	316	29	25	299	03	59	335	16	57
Total	1206	27	40	1315	20	50	1276	34	33	1259	10	58

Table 7. Summary of the use of the IBM 360/195 and ICL 1906A in 1975

As the Laboratory's staff increased, if logically divided into three technical groups :

a) the operations group receives work, processes it through the main computer, and any auxiliary machines, and despatches the results to users.

b) the programming group is concerned mainly with basic software - compilers and library programs. It also offers help and advice to users.

c) there are also posts for individual research, usually for people with some academic connections, eg. university or college fellowships.

Other groups include; User Services - for the provision and control of the computing services; Basic Software Group deals with general problems of software, eg. compilers; Applications Software Group deals with software concerned with particular problems and fields of science.

The Laboratory buildings were planned totally to meet the needs of a computing service. Since then the building has been extended three times. The whole building was cabled for data communications, so that every office could have a keyboard and VDU connected to a communications centre in the machine area.

The users of a large proportion of the computer time came from the four fields of chemistry, physics (non-nuclear), mathematics and engineering. About 80% of computer time is used by the universities; 15% by Government; and 5% by the Laboratory for its own research and development. The services to the universities are free, but Government users are charged at cost. The greater part of the Laboratory's resources are intended for users with large-scale projects, whose work requires that they have regular and large allowances of machine-time over extended periods.

At the end of August 1975, with the retirement of the Atlas Director, Dr. J. Howlett, the responsibility for the Laboratory was transferred to the Director of the Rutherford Laboratory. The Atlas Computer Laboratory then became known as the Atlas Computing Division of the Rutherford Laboratory.

APPENDIX B

THE APPLETON LABORATORY

After the formation of the Radio Research Board in 1920, four sub-committees were established to deal with propagation, atmospherics, direction finding and thermionic valves. Several eminent people involved in this early work included Lord Rutherford, Sir Henry Jackson, E.V. Appleton, R.L. Smith-Rose and R.A. Watson Watt. The first Chairman of the R.R.B. was Admiral Sir Henry Jackson, who held this position for nine years.

In 1921, radio direction finding work began at the Ditton Park site, dealing largely with studying field strength measurements and methods of screening units and groups of apparatus from electromagnetic fields. The first published works on these experiments began to appear in 1922, and they also told that :

> "Experiments, which are likely to lead to valuable results, have been made with a coil, rotatable about a horizontal axis."

This was work on the angle of arrival of radio frequency (RF) energy, which would shortly become vitally important.

By this time the Board had five sub-committees, the fifth being to study the problems of wireless telephony. That year's International Conference on Scientific Wireless Telegraphy voted to adopt the Committee's programme as suitable for international research.

Geophysical science came to the fore about 1925, as Appleton and his colleagues proved the existence of an ionised layer at a height of about 80 km, which was followed by the discovery of a further layer at a height of 250 km.

On December 1st 1927, two events, of a very different nature, occurred which had a great effect on Ditton Park. The first was the merging of three areas of study; direction finding, field strength and atmospheric research, to form the Radio Research Station (R.R.S.), with Watson Watt as Superintendent. The second event was a fire, which destroyed the 210 ft. wooden lattice tower and many surrounding buildings. Nobody was hurt, but damage stood at about £3,000. New, more suitable, buildings were completed by 1928 and research resumed.

Meanwhile, during observations of the ionosphere, it had been noticed that reflections were obtainable at nearly vertical incidence : arrangements were made for a transmitter and receiver to be placed a short distance apart, ie. one at Ditton Park, the other at Windsor Great Park (4 miles away), to study this. After a series of experimental measurements of heights and densities of ionised layers had been performed, an observational routine was established.

When a method of investigating the ionosphere, using radio wave pulses, was started in America, scientists at Ditton Park compared it with the continuous wave method used by Appleton. The first transmitter was based on a simple, self-pulsing valve oscillator from a time base circuit, which was a forerunner of present ionospheric sounding equipment. Shortly after, an improved pulse transmitter (developed by Ratcliffe and White) was installed and the Ionospheric Laboratory was properly established.

During an analysis of data obtained from an R.R.S. expedition to Norway, in the Second International Polar Year, it was suggested that solar and ultra-violet light accounted for the normal ionisation of the two main regions of the ionosphere and for the daily and seasonal variations. Abnormalities at lower levels were attributed to the action of the Earth's magnetic field on charged particles as they entered the atmosphere. A relationship was also observed between thunderstorm activity and increased ionisation in the lower layer.

In January 1935, the Air Ministry approached the R.R.S. with a suggestion of investigating the possibility of radiating energy sufficient to cause damage to an aircraft or its occupants (the SciFi "Death Ray"). The impracticality of this was demonstrated, but Watson Watt, in his report, included the very understated paragraph :

> "Meanwhile, attention is being turned to the still difficult, but less unpromising, problem of radio detection ... and numerical considerations on the method of detection by reflected radio waves will be submitted when required."

Of course, the Air Ministry was highly interested in this research and the R.R.S. provided figures, even though they were of a lesser magnitude than had previously been expected. Watson Watt's paper of 1935, "Detection and location of aircraft by radio methods", has been called one of the most vital scientific documents ever produced. It explained detection by reflected energy; and proposed the use of rotating beams to provide a system showing range and direction on a cathode ray oscilloscope display at a single station.

A demonstration of the apparatus for the Air Ministry took place at Daventry on February 26th 1935. When the aircraft eventually came into view its distance was correctly estimated to be eight miles, by reflecting detectable energy into the receiver. Obviously, further work into this had to be done in secrecy and the relevant staff left Ditton Park for Orfordness, where radar investigations escalated. Photographs of the radar demonstration are extremely rare, but Fig. 41 shows the van in which it was carried out.

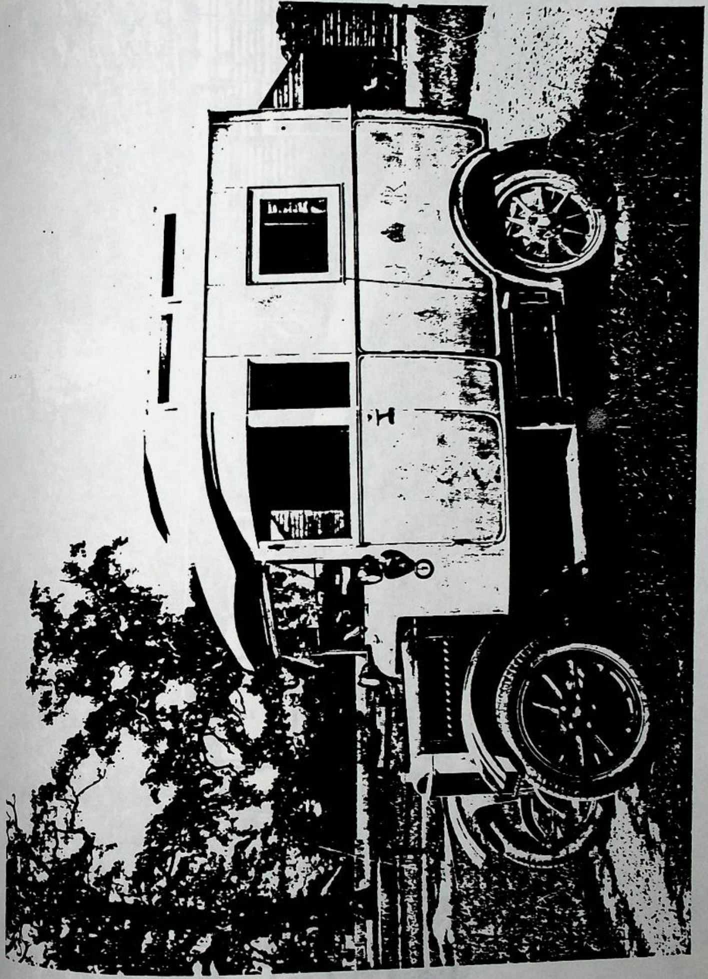


Fig. 41. The van in which the radar demonstration, at Daventry in 1935, was carried out.

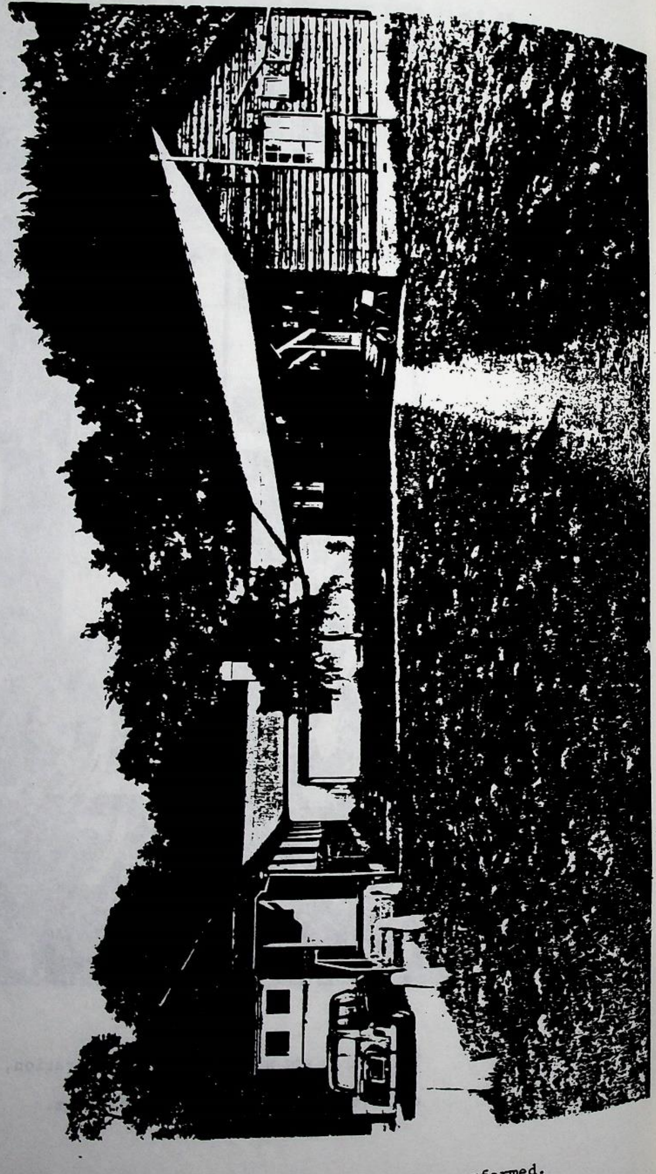


Fig. 42. The building where Watson Watt's radar work was performed.

With the outbreak of war in 1939, the ionospheric forecasting services grew, as long distance communications needed to be improved, mainly for aiding the Services. After the war, a revised programme of research, to suit predictions for the future, was needed. In a report submitted to the Council for Scientific and Industrial Research, it was suggested that the connections between the R.R.S. and the National Physical Laboratory (NPL) should be severed. This was agreed and the Radio Research Organisation was established, with Dr. R.L. Smith-Rose as its first Director. The same report listed fifteen major items of scientific activity, which covered fields of work summed up under seven headings :

a) Detailed ionospheric studies, and the provision of a service about ionospheric conditions.

b) Propagation studies of radio waves having frequencies from 10 kc/s to 3×10^6 Mc/s.

c) The improvement and development of radio measurement techniques, particularly power and impedance measurements above 600 Mc/s.

d) The study of all types of random disturbance giving rise to radio frequency noise.

e) The study of the fundamental aspects of the generation and detection of electromagnetic oscillations at the highest available frequencies.

f) The study of the properties and structure, both physical and chemical, of materials used in communcations.

g) provision of means for the "fullest useful dissemination of information on all aspects of radio".

These guidelines formed the basis of research at the newly-formed Radio Research Organisation, and continued to do so for many years.

Several outstations were set up at this time, in a variety of places world wide : Port Stanley in the Falkland Islands (the station suffered bomb damage during the recent campaign there), Singapore, Port Lockray, Sunnymeads and Winkfield.

As the work at Ditton Park became more diversified, facilities such as those at the N.P.L. became essential, and a new laboratory building to provide these was started in the West Park of Ditton Park in 1954. The inauguration was performed by Sir Edward Appleton, a man who had long been associated with the R.R.S.

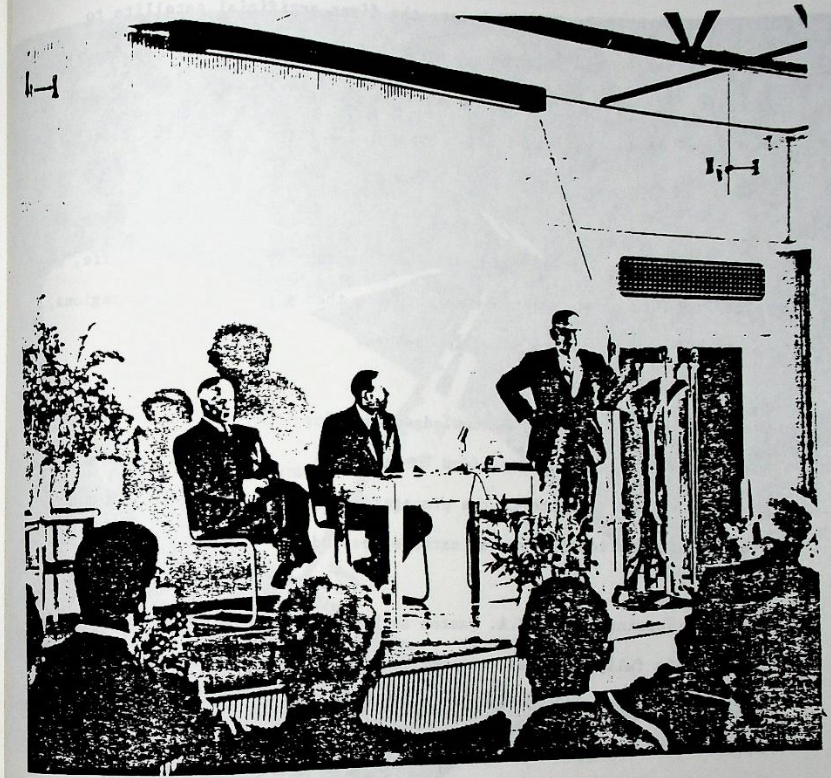


Fig. 43. The inauguration of the new laboratory in 1957, showing R.L. Smith-Rose, H. Melville and E.V. Appleton.

1958 saw the opening of an International Geophysical Year, for which preparations had started in 1956, and in which Ditton Park was to play a significant role. Slough became one of the four World Data Centres for the collection and exchange of ionespheric information; a task which it still performs today (at the Chilton site).

On October 4th 1957, SPUTNIK became the first artificial satellite to orbit the Earth, and it was tracked by the R.R.S. using the cathode ray direction finder, a device which had been developed at Ditton Park. From this time onwards space science constituted a large part of the Station's work.

From 1960-66 the Station was under the Directorship of J.A. Ratcliffe, who guided it through some notable work on the theory of ionospheric regions, eg. the chemistry of the lower ionosphere.

Space science was finally acknowledged as being important in the Station's work in 1965 when SPACE was added to its title. This was appropriate because the interest in research on the propagation of radio waves through the troposphere and ionosphere had extended beyond the ionosphere, into space.

With the appointment of J.A. Saxton as Director in 1966, a new instrument, ie. the 25m fully steerable parabolic radio telescope, was commissioned at the Chilbolton Observatory. This was capable of serving tropospheric research, as well as ionospheric science and astronomy. (see Fig. 44.)

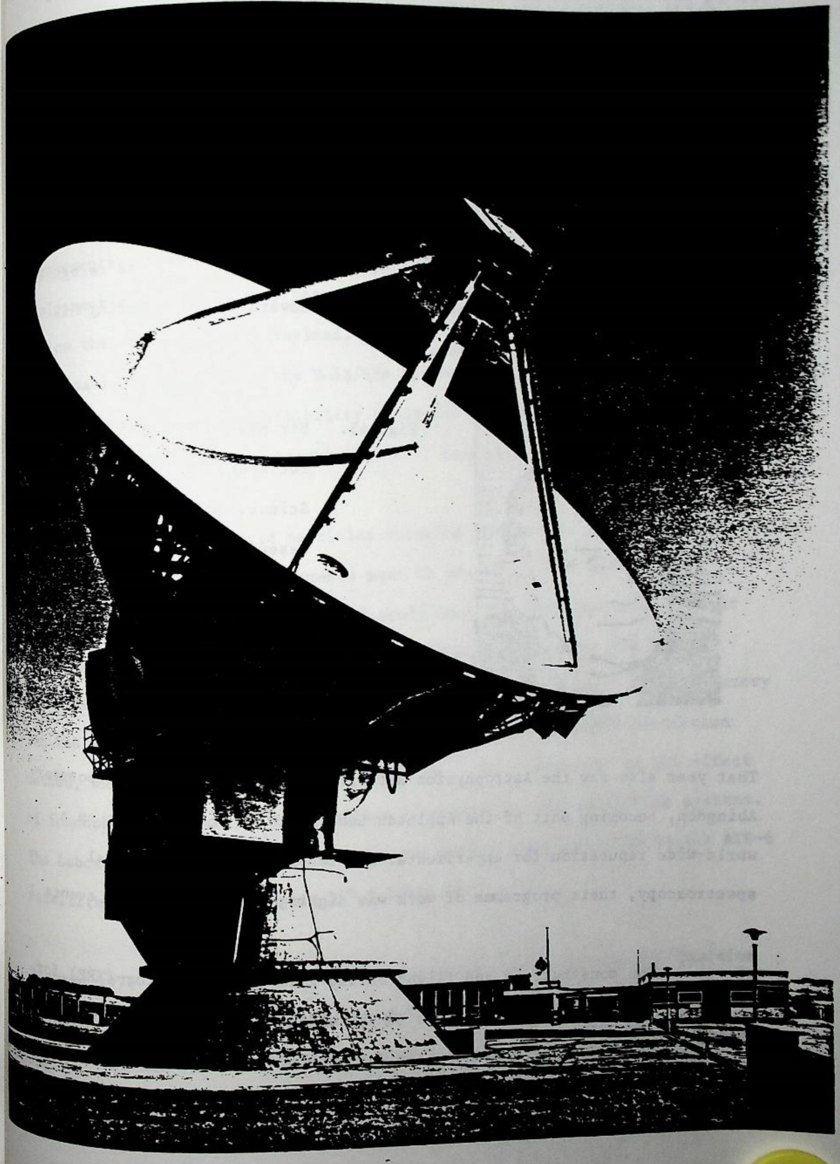


Fig. 44. The 25m steerable parabolic radio telescope at the Chilbolton Observatory.

During his time as Director, Dr. Saxton carried out the important task of steering the Station's prime function towards the support of university projects, particularly in the space field. By 1968, approximately half the Station's work was concerned with space research, even to having its experiments flying in rockets and satellites. The total number of staff had grown from the original two to almost 300.

The establishment was renamed the Appleton Laboratory in 1973, as recognition of the advances made in radio research by Sir Edward Appleton during his long association with the Station.

Fig. 45. Sir Edward Appleton, F.R.S. Secretary of Department of Scientific and Industrial Research 1939-49, Nobel Laureate 1953.

That year also saw the Astrophysics Research Unit, at the Culham Laboratory, Abingdon, becoming part of the Appleton Laboratory. Having built up a world-wide reputation for experimental and theoretical astrophysical spectroscopy, their programme of work was highlighted by two major events :

a) The construction and flight of the X-ray polychromator (XRP) for the Solar Maximum Mission (SMM), which is carrying experiments to study solar flares over a wide range of regions of the spectrum.

b) The Coronal Helium Abundance Spacelab Experiment (CHASE), which is to be an experiment on the Spacelab 2 mission, its aim being to determine the ratio of helium to hydrogen in the solar corona.

During 1975-76, the stellar spectroscopy programme involved direct support of the International Ultraviolet Explorer (IUE) project, through laboratory measurements of specific properties of components for the payload, and the development and provision of test equipment. Progress was also made in the work on the Skylark rocket payload, which is linked to the IUE programme. Participation continued in the NASA/ESA Space Telescope project, particularly in instrumentation and a feasibility study for an astronomical survey experiment in the extreme ultraviolet (EUV) region.

The acceleration of charged particles entering the Earth's atmosphere was studied further, using measurements made in previous years from Skylark and Petrel rockets. Other areas of study included ionospheric incoherent scatter, the influence of solar activity and geomagnetism in the lower atmosphere, and the improvement of HF prediction techniques. The Laboratory led the way in the production of a new sky-wave field-strength prediction method, which was developed for the C.C.I.R. Work continued on the effect of ionospheric properties on satellite communication and navigation systems. The Laboratory also took part in wave propagation experiments while the ATS-6 satellite was geostationary at 35° E longitude.

Between 1978-79 several major events took place, not least the SRC decision to merge the Rutherford and Appleton Laboratories, closing the Ditton Park site. The man who had the difficult task of steering the Appleton Laboratory through this pre-merger period was F. Horner, who was the Director from 1977-79.

Meanwhile, the Laboratory had assumed the management of the Central Balloon Programme, organising the provision of balloons and gas and payment of range charges for approved scientific balloon flights, which are largely launched from Palestine, Texas and Alice Springs, Australia. The Stabilised Balloon Platform, partially developed by the Appleton Laboratory, provided 3-axis stabilisation for experiments weighing up to 400 kg, with arc-minute pointing accuracy. The maiden flight of the modified platform took place in September 1978. During 1979 further improvements were made to the platform, eg. refinement of the servo-systems and lightweight crash protection equipment.

The final Skylark rockets were launched in 1978; two examples of the experiments on board are :

a) observing the Sun's corona; and
b) investigating the auroral phenomena.

Other rocket launchings included six Fulmar rockets and the continuation of the Petrel rocket programme (see Figs. 46 and 47).

One of the major events of this period was the launch of the IUE, a collaboration between ESA, NASA and the SRC; its purpose being to provide a UV astronomy facility in geosynchronous orbit. IUE contains a telescope and spectrographs covering the wavelengths 1150 - 3200 Angstroms. The Appleton Laboratory's responsibility was to monitor the three spectrograph TV cameras. During this time (1978-79) 53 observers used IUE in U.K.-allocated time.

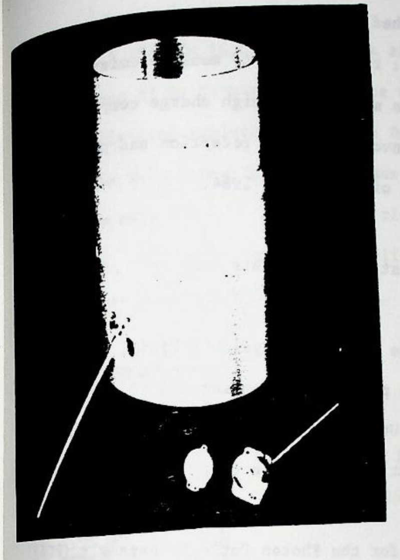
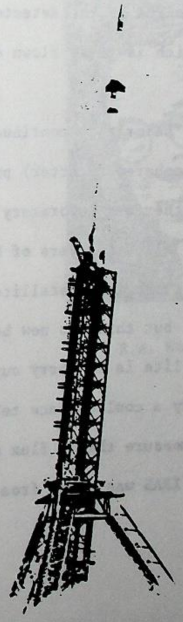


Fig. 46. Detail of a 7½ inch diameter Petrel rocket, showing the newly-designed telemetry and battery bay complete with improved aerials.

Fig. 47. A Skylark rocket firing at Woomera, South Australia



On June 2nd 1979, Ariel VI was launched from Virginia, U.S.A. The satellite carried three experiments : two designed to measure emissions from cosmic X-ray sources and the third to measure the high charge components of cosmic rays. The R.R.S. had been involved in the reception and processing of telemetered data since the launch of Ariel 2 in 1964.

Two major image processing projects stand out at this time :

a) Interactive Planetary Image Processing System (IPIPS), which is aimed at meeting the image processing requirements of the planetary meteorological studies at UCL, especially for the Voyager images of Jupiter and the Meteosat images of the Earth.

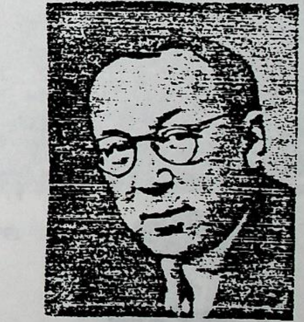
b) Image processing software for the Photon Detector Assembly (PDA). The PDA is the detector element of the Faint Object Camera (FOC), which is to be flown on the Space Telescope in 1983.

The Appleton Laboratory continued to support the U.K. participation in EISCAT (European Incoherent Scatter) project and also set up an EISCAT databank using the Rutherford Laboratory IBM 360/195 computer, which will be a major facility for all U.K. users of EISCAT. Work has developed further on the Infra-Red Astronomical Satellite (IRAS) - its original launch date was August 1981, but this has now been put back to December 1982. The objective of the satellite is to carry out a complete sky survey at infra-red wavelengths. It will carry a cooled space telescope equipped with 64 detectors, which will be used to measure the IR flux at 10, 20, 50 and 100 microns. The ground station for IRAS was moved from Ditton Part to Chilton in September 1979.

The merger of the two laboratories took effect on September 1st 1979, upon the retirement of F. Horner. His place was taken by Professor J.T.Houghton, who became Director Appleton, under the Director General Dr. G.H. Stafford. Following his appointment plans were made to enter the field of remote sensing from satellites. At the same time other projects were coming to maturity, eg. the control of IRAS; applications of hf radar techniques; and participation in the EISCAT project.

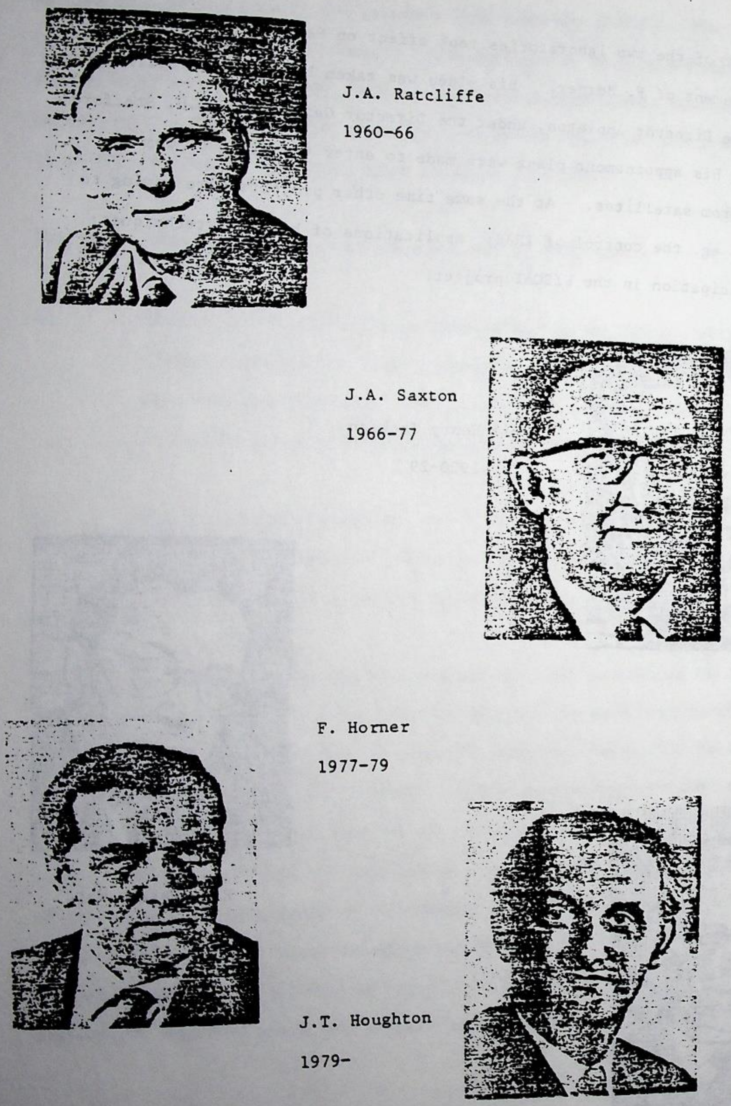
Sir Henry Jackson

1920-29



R.A. Watson Watt

R.L. Smith-Rose



J.A. Ratcliffe

1960-66

J.A. Saxton

1966-77

F. Horner

1977-79

J.T. Houghton

1979-

Fig. 48.

Directors of the Appleton

Laboratory.

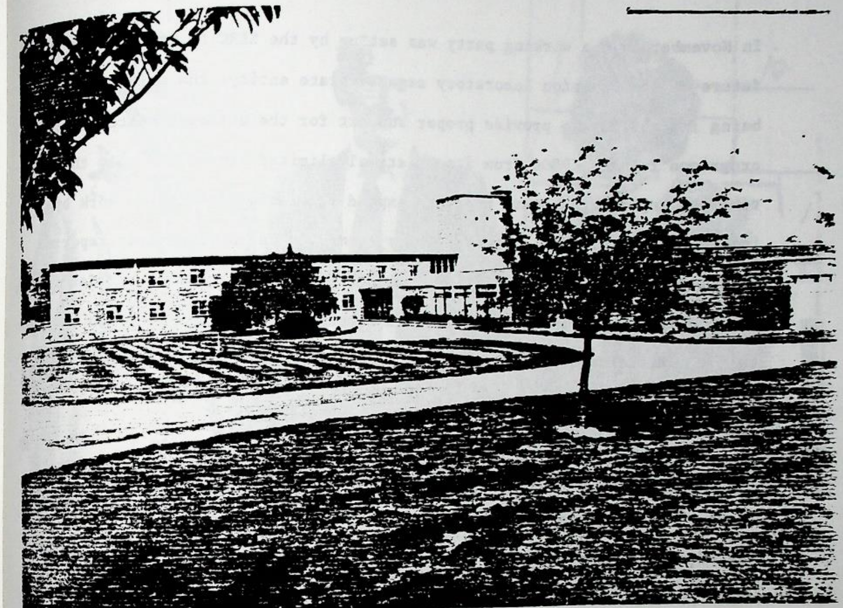


Fig. 49. A view of the Appleton Laboratory at Ditton Park.

APPENDIX C

RUTHERFORD APPLETON MERGER

In November 1976 a working party was set up by the SERC to investigate the future of the Appleton Laboratory as a separate entity, the main concern being its ability to provide proper support for the national space science programme for the 1980s from its relatively limited resources. At the same time the Engineering Board hoped to expand its radio propagation work by introducing studies on communication systems. The working party reported in July 1978 and, after receiving comments from various Boards and Committees, the Council took its final decision in October 1978. This decision stated that the Rutherford and Appleton Laboratories should be merged, under a common management on one site, ie. Chilton.

The future of our space research programmes was under review, but it was clear that the demand for experiments conducted from space would grow. It was hoped that by combining the expertise of the two laboratories, a team could be created which would be the focus for support of space research in the U.K. It was also decided that the Astrophysics Research Unit at the Culham Laboratory (part of the Appleton Laboratory since 1973) should be moved to the Chilton site.

Dr. G.H. Stafford became Director General of the combined Laboratories, with Dr. G. Manning as Director Rutherford and Professor J.T. Houghton as Director Appleton. On Dr. Stafford's retirement in 1981 Dr. Manning became Director, with Professor Houghton as his Deputy. (see Fig. 50.).

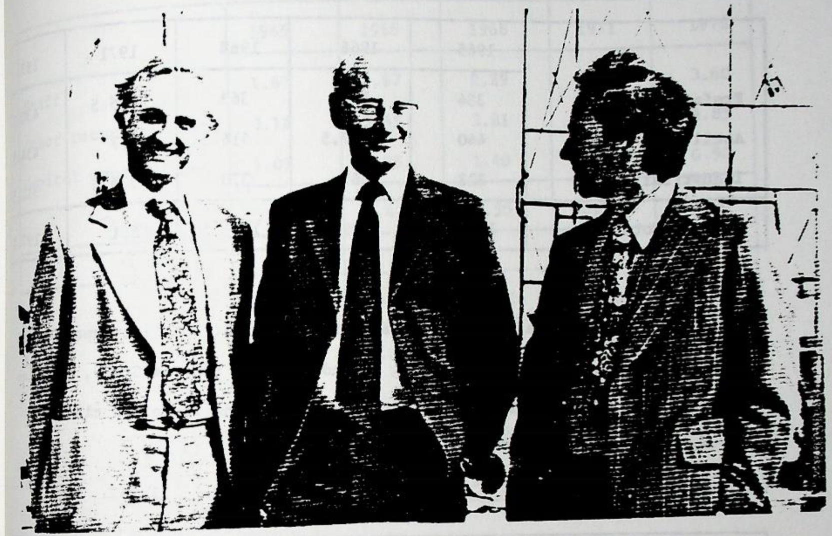


Fig. 50. Professor J.T. Houghton; Dr. G.H. Stafford; and Dr. G. Manning

APPENDIX D

STAFFING

	1965	1966	1968	1971	1972
Professional	334	337	363	385.5	430.5
Ancillary	440	487.5	516.5	497	454.5
Industrial	322	365	370	338.5	312.5
Total	1096	1189.5	1249.5	1221	1197.5

Table 8.

In the early 1970s these figures were affected by the Scientific, Experimental and Scientific Assistant classes being merged into the Science Group, and also by the merging of the Engineer, Chemist, Draughtsman and Technical classes into the Professional and Technology Group.

	1975	1977	1978	1980	1981
Non-industrial	997	898.5	919	1266.5	1220
Industrial	326	278	273	346.5	353
Total	1320	1176.5	1192	1613	1573

Table 9

The staffing levels around 1975 and 1980 show marked increases due to the mergers with the Atlas Computing Laboratory and the Appleton Laboratory, respectively.

APPENDIX E

FINANCE

	1965	1966	1968	1971	1972
Staff	1.67	1.87	2.29	3.26	3.60
Other recurrent costs	3.18	3.65	3.81	3.54	3.85
Capital expenditure	1.07	0.95	1.40	3.70	0.90
Total	5.92	6.47	7.50	10.50	8.35
	1975	1977	1978	1980	1981
	6.84	7.0	7.2	14.7	16.2
	6.54	6.6	9.3	20.7	22.5
	1.45	2.7	4.0	7.4	6.0
Total	14.83	16.3	20.5	42.8	44.7

Table 10. RAL finance £ million

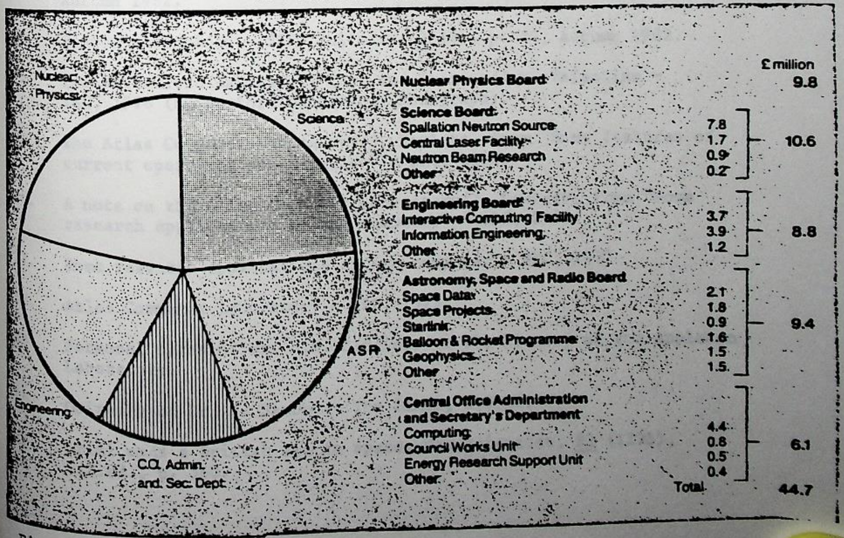


Fig. 51. Division of funding in 1981

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