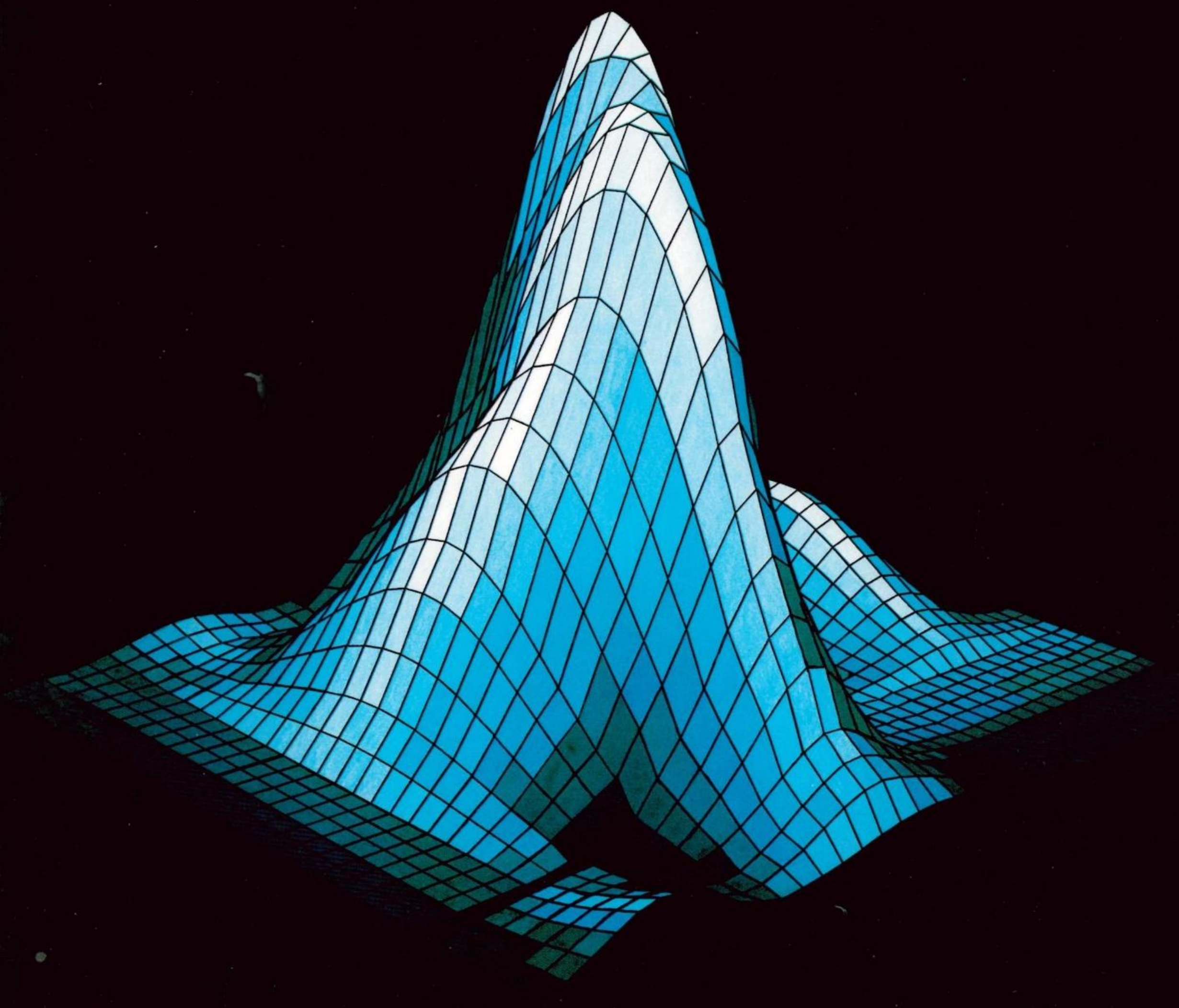
RUTHERFORD

THE RUTHERFORD LABORATORY



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The cover design is based on a computer drawn representation of a very high energy proton-proton collision in which a "jet" of particles is produced. Such "jets" may be the result of quarks, inside the protons, scattering individually.

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THE ROLE OF THE RUTHERFORD LABORATORY

The Rutherford Laboratory promotes university research and development work by providing facilities which are beyond the means of individual universities.

As well as offering its own extensive resources, the Laboratory also provides access to important facilities at other research centres in the UK and overseas. This results in a significant level of co-operation and collaboration in a wide range of projects at both national and international levels.

Set up in 1957 as the first establishment of the National Institute for Research in Nuclear Science, the Laboratory became part of the Science Research Council in 1965.

The Laboratory has from its early days played an important part in co-ordinating the UK particle physics research effort in the use of high energy particle accelerators both nationally and internationally.

This activity over the years has been extended in other areas of science and engineering where the experience of the Rutherford Laboratory in designing, constructing and running large central facilities such as the 8 GeV proton synchrotron Nimrod, bubble chambers and other complex experimental equipment has provided the basis for establishing similar services to university research communities in many other disciplines.

The Rutherford Laboratory is at present actively involved in directly supporting or providing facilities for research in particle physics and particle accelerators, neutron beam scattering, high power lasers, computing and advanced engineering.

LABORATORY ORGANISATION

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.

Director:
G. H. Stafford CBE

Deputy Director:
G. Manning

ADMINISTRATION DIVISION

General and administrative services for the Laboratory as a whole, for visiting scientists and for the UK participation in the CERN research programme. Division Head and Laboratory Secretary: J. M. Valentine

ATLAS COMPUTING DIVISION

Computer applications and interactive computing. Division Head: G. Manning.

COMPUTING AND AUTOMATION DIVISION

Operation of the Laboratory's central computers together with all the services and peripheral equipment involved in the processing of experimental data, including the provision and maintenance of telecommunications links between universities and other research centres and the Laboratory. Research and development work in computing and related techniques.
Division Head: W. Walkinshaw OBE.

ENGINEERING DIVISION

Provision of electrical, mechanical, manufacturing, safety, building and environmental services. The Division includes the Council Works Unit which caters for other SRC establishments as well as the Laboratory.
Division Head and Chief Engineer: P. J. Bowles OBE.

HIGH ENERGY PHYSICS DIVISION

Experiments in particle physics and nuclear physics in collaboration with university groups. Co-ordination of work on the Laboratory's Nimrod accelerator. Support for teams of scientists from the UK and abroad, and supervision of U.K. involvement in the CERN research programme. Division Head: J. J. Thresher.

INSTRUMENTATION DIVISION

Investigation and design of new particle accelerator systems. Design and manufacture of special physics apparatus and electronics for use by experimental teams. Support of energy research.
Division Head: D. A. Gray.

LASER DIVISION

Provision of beams and instrumentation for scientists using laser radiation in experiments. Development of high-power lasers. Division Head: A. F. Gibson.

NEUTRON BEAM RESEARCH UNIT

Support for research by universities using U.K. reactors and the reactor at the Institut Laue-Langevin, Grenoble. Development of new instruments and techniques, investigation and design of new neutron sources and participation in experiments. Head of Unit: L. C. W. Hobbis.

NIMROD DIVISION

Operation and development of Nimrod 8 GeV proton synchroton accelerator. Accelerator design; experimental area management; development of beam line components and cryogenic targets.
Division Head: R. G. Russell.

TECHNOLOGY DIVISION

Design, development and construction of major items of experimental apparatus. Exploitation and application of new techniques, especially superconductivity. Division Head: D. B. Thomas.

THEORY DIVISION

Research in the theory of elementary particles, their scattering, decay and reaction mechanisms, with special emphasis on phenomenological analysis of experimental data. Division Head: R. J. N. Phillips.

Further details of the work of the Laboratory are available in the Laboratory's Annual Reports, copies of which are available from the Library.

THE WORK OF THE RUTHERFORD LABORATORY

The rapid progress which has been made in recent years in understanding the basic structure and properties of matter is the result not only of conceptual innovations and a deeper understanding of Nature, but also of major advances in technology. The provision of these new resources has enabled physicists to probe deeper into the atomic nucleus and to study in detail the atomic and molecular structures of a wider variety of materials.

After the charged atomic nucleus was discovered, it gradually became clear that in order to understand the forces involved, the structure and interactions of the nuclear particles themselves must be further explored. Such exploration has been in the forefront of physics ever since and has revealed phenomena quite unsuspected when the theory of the nucleus as a whole began to take shape.

In particular, many new 'elementary particles' with short lifetimes have been discovered. These particles decay very rapidly and can only be produced in high-energy collisions using particle beams with energies of several thousand million electron-volts (GeV's). A careful study of their formation, interactions and decay is necessary to construct a satisfactory description of the nuclear forces.

In order to probe deeper into the structure of these particles higher energy particle beams and thus increasingly larger accelerators are needed.

The experimental high energy physics programme at the Rutherford Laboratory is based on its particle accelerator Nimrod, an 8 GeV proton synchrotron. UK particle physics research carried out at other international research centres, particularly at CERN in Geneva on accelerators of up to 400 GeV, is also supported by the Rutherford Laboratory.

The Laboratory is also a major centre for the study of theoretical high energy physics and the resulting close contact between the theoretical and experimental physicists yields well motivated experiments, better understood results and successful theoretical approaches to the subject.

In other areas of physics, the study of condensed matter (solids and liquids) by shining radiation of some sort on a sample and measuring the scattering and absorption effects has been a powerful research technique for a long time. When a new type of radiation is discovered it is almost always used in this way as its properties become well understood. The most spectacular case of a discovery, followed immediately by a practical application, must be that of X-rays which became front page news all over the world within days of Roentgen's discovery. The subsequent discovery of X-ray crystallography has allowed enormous advances to be made in the understanding of the structure of solids.

The advent of the nuclear reactor meant that beams of neutrons could be produced readily and neutron scattering is now widely used in the study of condensed matter in physics, chemistry, materials science and increasingly in biology. Thus a Neutron Beam Research Unit was established at the Laboratory in 1971 to support the community of UK university research scientists who use slow neutron scattering as a major research tool. For the most part these neutrons are provided by the research reactors at AERE Harwell and the Institut Laue-Langevin (ILL) Grenoble, where there is a high-flux reactor. The UK became a third equal partner in the ILL, with France and Germany in 1973.

Increasing attention is being given to the use of particle accelerators for neutron production. The Unit supports a research programme at the AERE Harwell electron linear accelerator, and is investigating new neutron sources.

The invention of the laser has provided scientists with yet another powerful tool, and a programme is under way at the Laboratory which provides central high-power laser facilities for a range of university research interests.

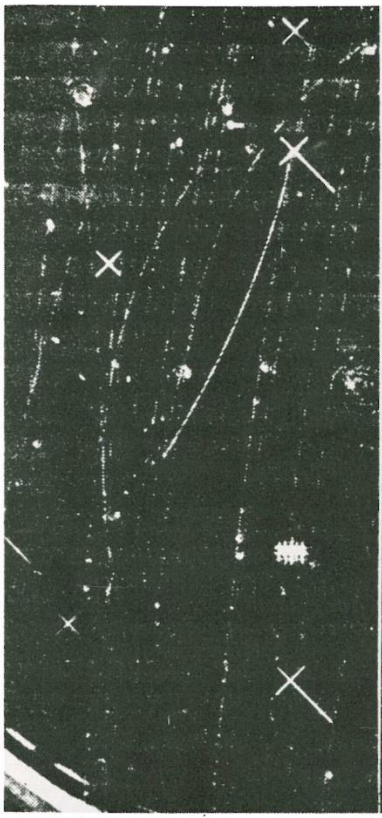
All this scientific research requires a supply of new and sophisticated apparatus in order to carry out the necessary experiments. An important part of the Laboratory's activities is therefore concerned with the design and manufacture of instrumentation and equipment for all kinds of experiments carried out at the Laboratory and at other research centres.

Applications of superconductivity – the dramatic decrease in electrical resistivity seen at very low temperatures – is proving especially valuable in many areas of science and engineering, and the Laboratory is intimately involved in the development and application of superconductor techniques.

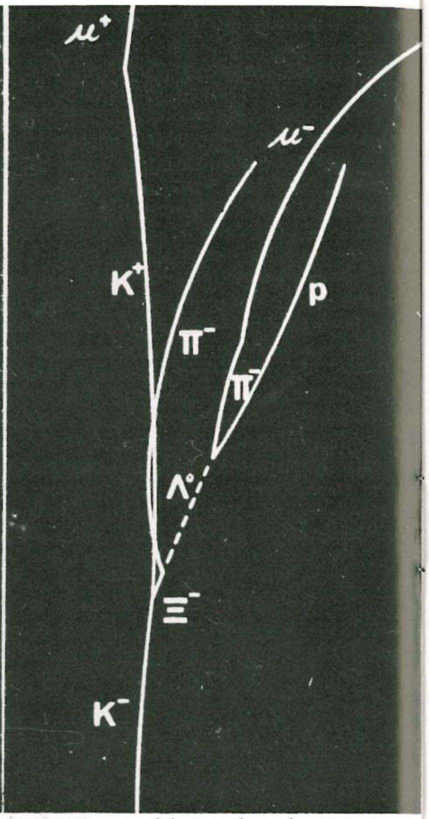
These research and development programmes are supported by an extensive computer system based on IBM 360/195 and ICL 1906A machines with special peripheral equipment and with communications links to workstations and to other computers. This system also provides data processing power for university users in general and enables the Laboratory to carry out its own research and development work in computing.

The Laboratory employs some 1200 industrial and non-industrial staff. In addition, about 1000 university scientists work in close collaboration with the Laboratory on its range of research and development projects.

PARTICLE PHYSICS



(*a*) *A hydrogen bubble chamber photograph of the collision of a K^- meson with a proton.*



(*b*) *Identification of the particle tracks shown in* (*a*)

Particle Physics is the search for and study of the underlying structure of matter, the goal being to discover the basic constituents of matter and relate their existence to the various forces, or interactions, found in Nature. The idea that matter is not infinitely divisible and is instead composed of elementary constituents was first put forward by the Ancient Greeks, and we still use their word – 'atom' – to describe the smallest units of bulk matter which take part in ordinary physical and chemical changes.

The Greeks postulated that atoms were indivisible, but in modern physics each step forward has opened a new world in which the particles of matter proposed as the basic building blocks of Nature have become progressively smaller. The postulated limit of divisibility has now progressed from the atomic world to the nuclear world of Lord Rutherford, and on to the realm of subnuclear particles of the post war era.

After the discovery of the proton and the neutron in nuclear matter, further investigations revealed the existence of many more types of subnuclear particles. It is the business of the particle physicist to uncover, measure and explain all the characteristics of these particles. Because so many different subnuclear particles have now been discovered, a central theme in this work is to find patterns and rules which enable these particles to be classified into sets and which go on to relate these sets of particles to each other. It is found that these sets have clear underlying patterns and this suggests strongly that there could be an even more basic set of particles, yet to be observed, from which all the different sets and patterns can be built. These postulated basic particles are called 'quarks'.

As well as particles, Nature also contains forces, and the particles and the forces acting upon them are closely related. The particles are the source of the forces of Nature, while the carriers of the forces are themselves particles. The forces are the means by which the particles interact and communicate their presence to each other – a kind of particle 'language'.

Only four basic forces have been discovered – the weak nuclear force giving rise to radioactivity, the strong nuclear force binding nuclear particles together, the electromagnetic force controlling chemical reactions and atomic and molecular behaviour, and the gravitational force which guides the movement of celestial bodies. The inter-relation and possible unification of these very different forces is one of the underlying goals of particle physics.

How does one study this particle world? The first problem is to break the 'glue' binding the larger particles together and allow the smaller particles to appear. The next problem is actually to observe all this happening.

The first task is performed by a particle accelerator which accelerates particles, usually protons or electrons, to high energy and fires them at a target. The energy of the particle beam breaks up the nuclei in the target and produces subnuclear particles. The stronger the glue binding together the constituents of a particle, the higher the energy of the accelerated particle beam must be to probe it and finally break it apart – hence the continual requirement for larger and more powerful particle accelerators.

The detection and observation of particles is achieved through their electromagnetic interaction with the atoms of the detecting equipment. This interaction can take various forms according to the type of detector used. Sparks between electrically-charged plates are used in spark chambers, flashes of light in special transparent material are used in scintillation detectors, bubbles of gas in a superheated liquid are used in bubble chambers and light radiation is used in Cerenkov counters.

From the signals received in these detectors, the nature of the particles can be determined, their paths followed and their momentum measured. From such results, particle physicists can deduce the existence of particles which decay so quickly as to be undetectable by direct means.

View of Experimental Hall looking toward the Nimrod shield wall.

Each new particle discovered and each new measurement made goes towards building a total picture which will ultimately contribute to the understanding of the underlying structure of matter and to discover what are the real basic building blocks of Nature.

Another aspect of particle physics actively pursued is concerned with the interactions of elementary particles with complex nuclei and the low energy properties and behaviour of these particles. This nuclear physics work, as well as being carried out at the Nimrod and CERN accelerators also makes use of the intense neutron beams available from nuclear reactors at the Institut Laue-Langevin in Grenoble, France, and other sites.

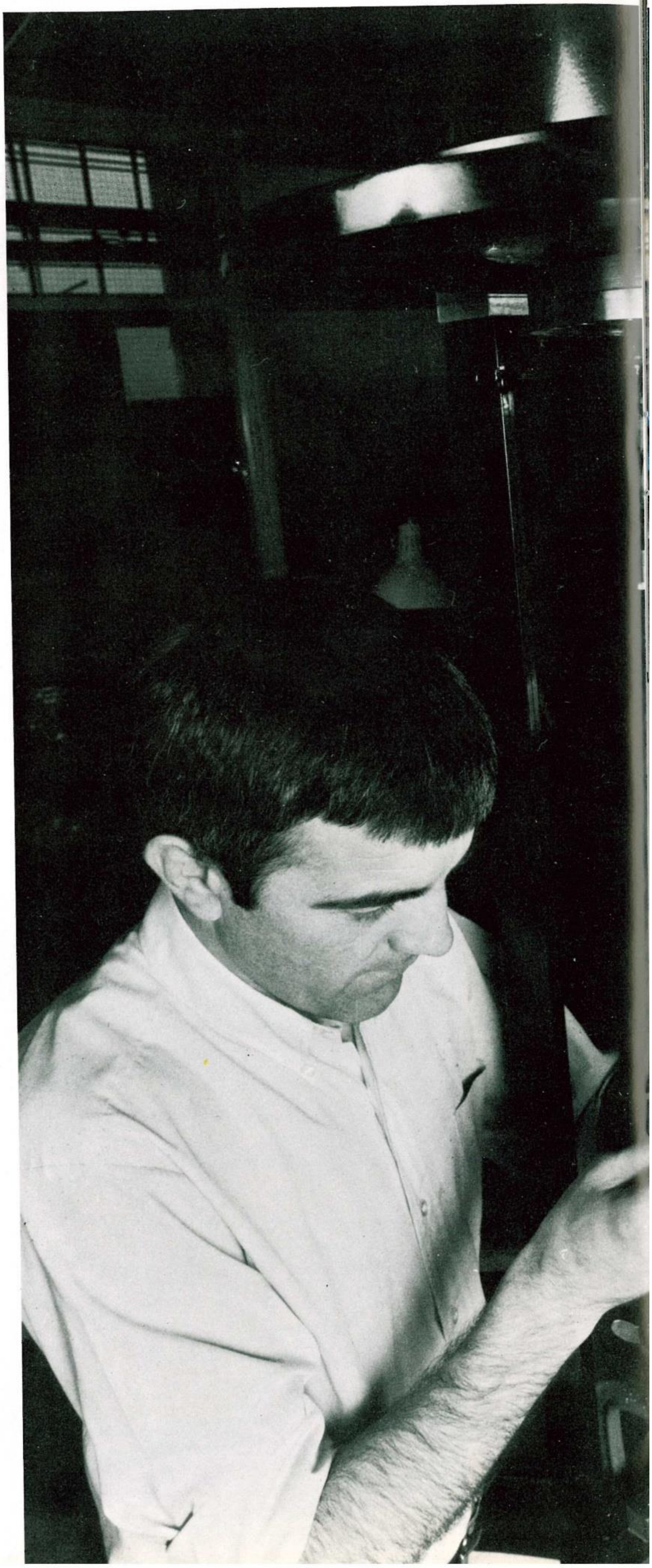
In addition to the research into the fundamental aspects of particle physics, the effect of high energy particle beams on biological systems is also being studied, with a view to assessing the effectiveness of these beams for medical applications.

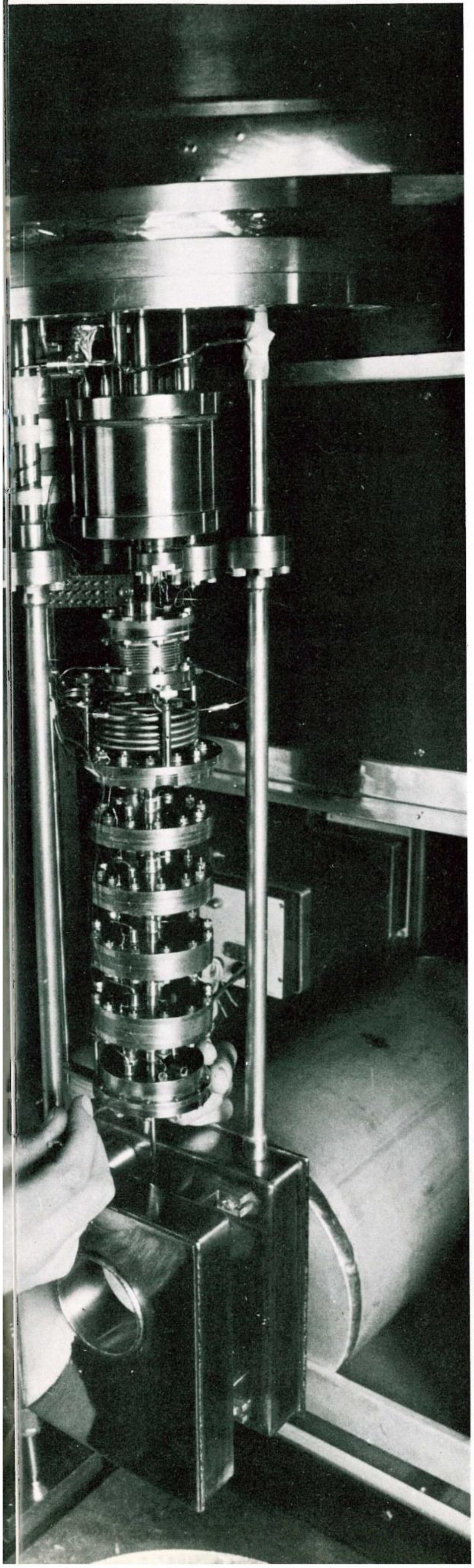
The European Centre for Nuclear Research CERN in Geneva, Switzerland where much of the UK particle physics research is performed. Photo CERN

NEUTRON BEAM RESEARCH

Neutron beams provide a powerful tool for physicists, chemists and biologists to study the structure and properties of matter under a variety of conditions. The Neutron Beam Research Unit supports this work by university scientists which is part of the programme of the SRC's Neutron Beam Research Committee. The activities of the Unit cover a wide range, including the development of new instruments and techniques, the study of new neutron sources, scientific collaboration with university scientists and provision of technical support for their research, and liaison with relevant research establishments, especially the Institut Laue-Langevin (ILL), in Grenoble, France.

The Unit development programme has led to a number of important advances in the design of neutron beam equipment. A polarized samarium filter operating at a temperature of 16 mK for providing polarized thermal neutron beams has been built and operated successfully. Thin film mirror techniques have been developed for manipulating neutron beams in various ways, for example for bending, polarizing or collimating beams; already over three dozen thin film collimators have been provided for various laboratories around the world. There is a continuing programme of neutron detector development, with emphasis on position sensitive devices. The Unit collaborates with the ILL in the design and manufacture of neutron scattering instruments. As examples, two instruments can be cited. The first is the polarized neutron diffractometer, called D3, which was supplied to ILL complete with a dedicated PDP 11 computer for control and data collection. The second is the major modification to the existing small angle scattering instrument at ILL to allow simultaneous measurements of diffuse scattering at both small





and large angles. For this project the Unit supplied among other things, a new vacuum vessel, cryostat and sample changer.

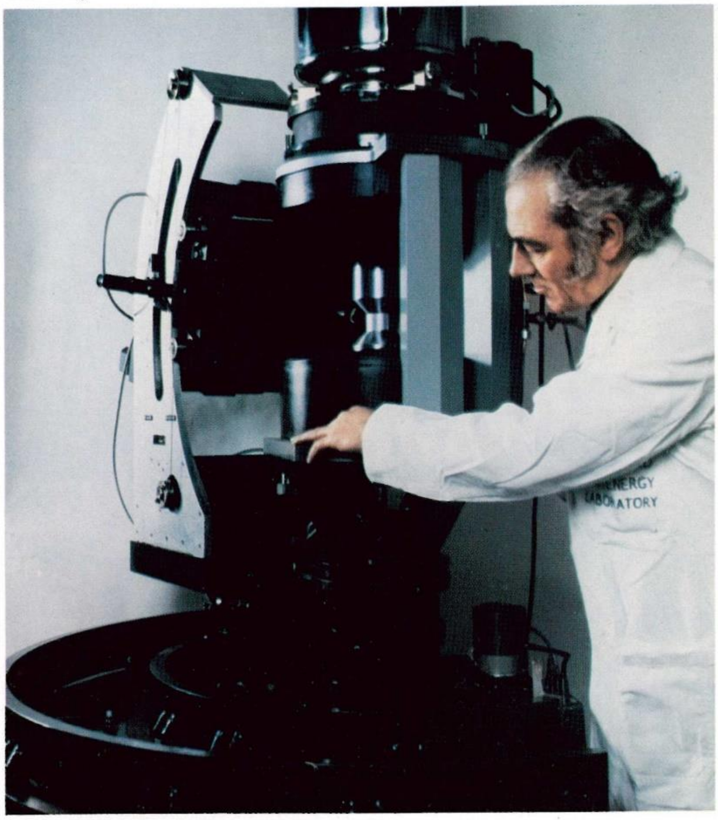
A long term activity of the Unit is the study of neutron sources which could form the next generation of major facilities for neutron scattering research. Special attention has been given to the technical feasibility and scientific potential of pulsed sources. Unit staff collaborate with AERE (Atomic Energy Research Establishment) Harwell in work using the Harwell electron linac for the development and use of pulsed source instruments. Plans have been prepared by the Rutherford Laboratory in collaboration with university users to provide a major pulsed source at the Laboratory based on the use of a proton synchrotron to generate intense neutron pulses from a spallation target.

Considerable effort is deployed in supporting university users, especially in helping them to use the ILL facilities effectively. Over 250 university scientists can be identified with the SRC supported neutron scattering programme both in the UK and abroad. All applications by these university scientists for experimental time on UK and foreign reactors are processed by the Unit. In any year over 100 applications can be expected for time on UK reactors and more than 200 for time on the High Flux Reactor at ILL. All funding for travel, subsistence, equipment and materials for approved experiments is done through the Unit. Close technical liaison is maintained with all establishments in which SRC supported work is carried out.

Unit staff are encouraged to spend part of their time on neutron scattering research. Some of the fields in which contributions have been made include magnetic structures, studies of alloys and defects, molecular spectroscopy and liquid crystals.

Left.
Dilution refrigerator for the ^{149}Sm polarising filter under test at the Rutherford Laboratory.

Below.
The polarized neutron diffractometer, D3, for the Institut Laue-Langevin during commissioning at the Rutherford Laboratory.



LASER RESEARCH

The Science Research Council has established a Central Laser Facility at the Rutherford Laboratory to serve as a central facility for university research in plasma physics and laser technology. The main equipment is a high-power Neodymium: Glass laser system generating a peak power of 800GW (8 x 10^{11} Watts) in pulses of 30 to 300 picoseconds. This laser is installed in a specially-designed air-conditioned laboratory where the air cleanliness, temperature and humidity are closely controlled. It is linked to a data acquisition and control system based on a GEC 4080 computer.

The principal scientific objectives are to create and study in the laboratory dense plasmas generated by laser compression of matter, non-linear interactions of intense laser radiation with matter and to develop more efficient and new high power lasers for future experiments in these and other fields. University scientists take an active role in all this work.

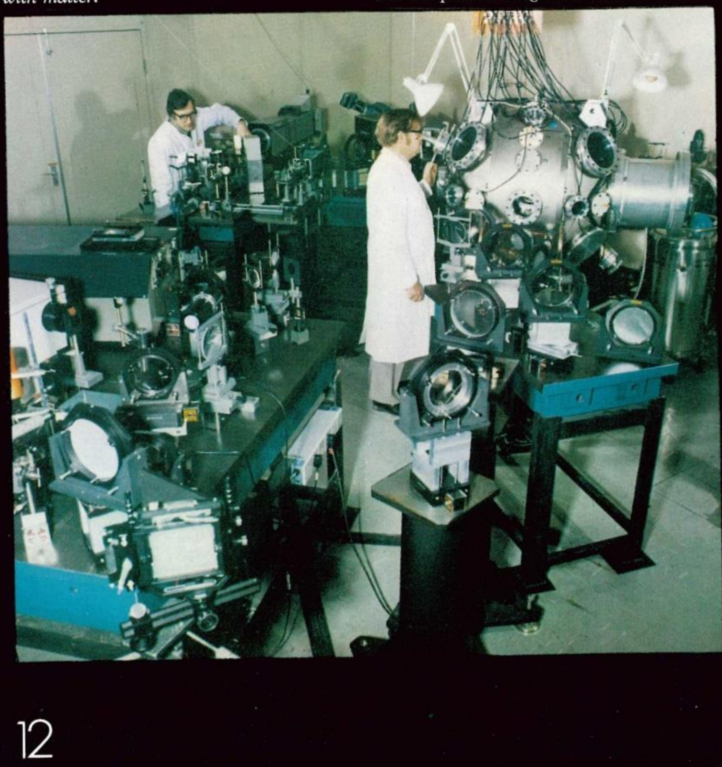
Particular interest is in the study of the mechanisms of absorption, energy transport and the generation of intense magnetic fields in plasmas. Other experiments may use neutrons, generated in thermonuclear fusion reactions occuring in the target, to study the compression process.

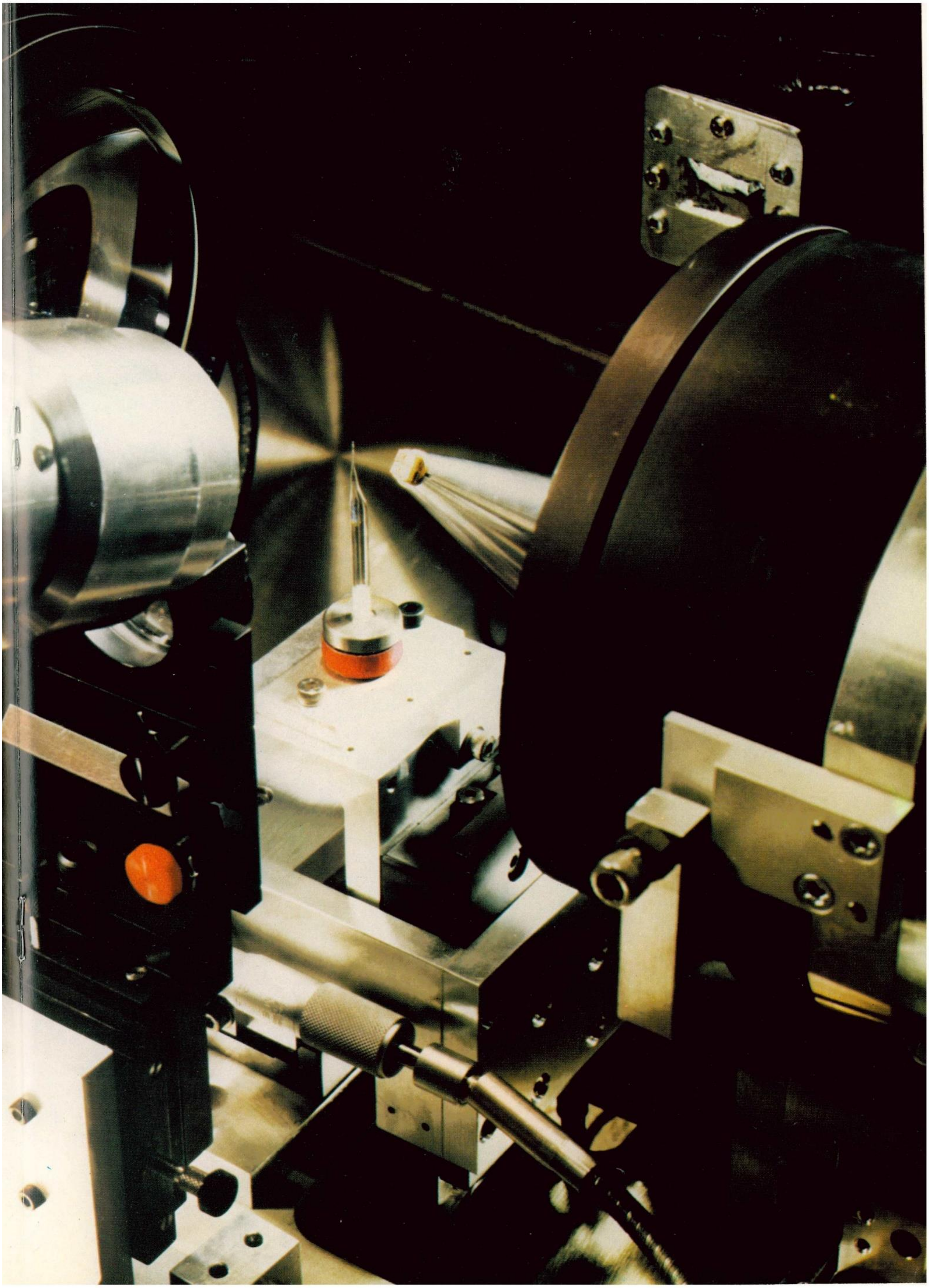
Approval to proceed was obtained in October 1975. Laser beams of adequate power were produced about one year later.

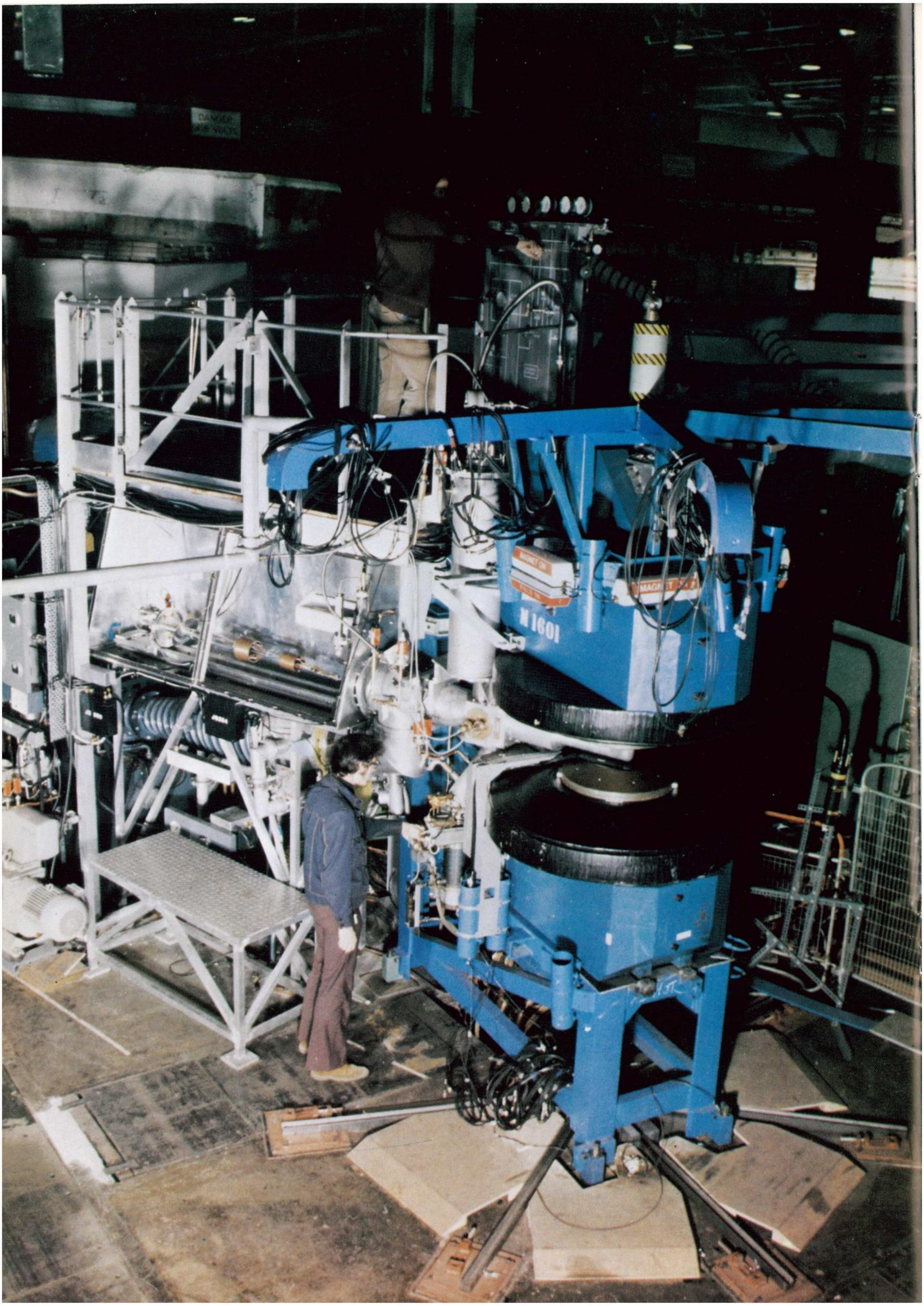
The first experiment – a determination of the X-ray emission spectrum of highly ionised iron and which is of astrophysical interest – was performed in December 1976. Compression of matters by laser beams was first observed in April 1977. The two illustrations feature the target chamber and target used for the compression studies.

General view of target area showing target vessel in which plasmas are generated by interaction of laser beams with matter.

Close up of double beam arrangement inside the target vessel showing the glass microballoon target (85 microns in diameter and 0.5 microns wall thickness) mounted on a a stem in the centre. The target is surrounded by the two F1 focussing lenses and the plasma diagnostic instruments.



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TECHNOLOGY

The technological work of the Laboratory covers a wide field of research and development ranging from specific advanced apparatus for particle physics experiments to longer term research studies of technical importance in science and engineering. The technological complexity of these activities requires support personnel in such areas as physics, mechanical and electrical engineering, computing, metallurgy, electronics and cryogenics.

The Laboratory has played a leading role in research and development work for applied superconductivity. Superconducting magnets allow devices to be considered which would either be technically impossible or prohibitively expensive using conventional techniques. Following the discovery of high field superconductors in the early 1960s, the initial impetus for development came from an increasing demand for high magnetic fields in elementary particle detection and guidance systems. The range of potential applications has since been extended to include power generation, levitated transport, plasma containment in nuclear fusion, energy storage and nuclear magnetic resonance.

In collaboration with Imperial Metal Industries Ltd., the Laboratory was responsible for the development of stable filamentary conductors of niobium titanium alloy. These conductors have been adopted throughout the world in a wide range of applications generating magnetic fields up to 10 Tesla. Considerable emphasis has been placed on the development of pulsed magnets suitable for a future high energy particle accelerator. A programme of work with prototype magnets has been completed and feasibility established.

In the quest for still higher magnetic fields (10–20 Tesla) the superconducting properties of niobium-tin are particularly attractive. However it is a brittle compound which does not lend itself to conductor fabrication. The Laboratory, in collaboration with the Atomic Energy Research Establishment Harwell and Imperial Metal Industries, has evolved a technique for producing multi-filamentary niobium-tin conductors. The technology of making magnets with niobium-tin conductors is relatively complex, but solenoid fields in excess of 12 Tesla have already been achieved and stable conductor operation in a straight sided coil demonstrated. At present the emphasis is on extending the work to higher field levels and the development of standard reproducible conductors.

One region where superconductivity promises to play an important role in the future is plasma containment for thermonuclear fusion. The requirement here is for very high magnetic fields, in excess of 8 Tesla, over large volumes. A research programme is under way to develop a suitable conductor for the enormous magnet system envisaged by fusion reactor designers.

Another important aspect of the Laboratory's technological work is in the construction of polarised targets for particle physics research. A number of targets have been constructed at the Laboratory and operated successfully in experimental areas. In these targets, the spin axes of the free protons (or deuterons) are aligned, and such dynamic polarisation is achieved when the material is subjected to microwave power in a high magnetic field. In order to prevent thermal depolarisation, the target material must be held at a temperature near to absolute zero using a helium-3 refrigeration cycle. New and more sophisticated targets are under construction while basic research into target materials continues.

The Laboratory has developed a new particle detection system which will facilitate high statistic studies of certain particle interactions. The system embodies a small bubble chamber for information retrieval at the interaction vertex surrounded by wire spark chambers for analysis of the reaction products. The bubble chamber section is designed to operate at a frequency of 60 Hz compared with standard speeds of just a few Hz, hence the name rapid cycling vertex detector.

The design of high accuracy magnet systems requires advanced computational techniques. A 3-dimensional interactive graphics computer program (GFUN) has been written with magnetic field calculation and optimisation routines. The system is augmented by other routines, covering important design features, such as coil stress, magnetism, eddy currents and quench behaviour. The programme is in use throughout the world in laboratories involved in high energy physics, fusion research and other branches of advanced technology.

Left.
The polarised deuteron target showing the cryostat between the poles of the electromagnet.

Below.
Superconductor test area.

INSTRUMENT--ATION AND APPARATUS DEVELOPMENT

An important part of the Rutherford Laboratory's work involves the provision of specialist skills and services to answer the needs of experimental groups working at the Laboratory and at other research centres.

These needs range from detection equipment and individual electronic components to major new experimental facilities. As well as taking care of specific requirements as they emerge, substantial effort is devoted therefore to examining and anticipating requirements for such major new developments.

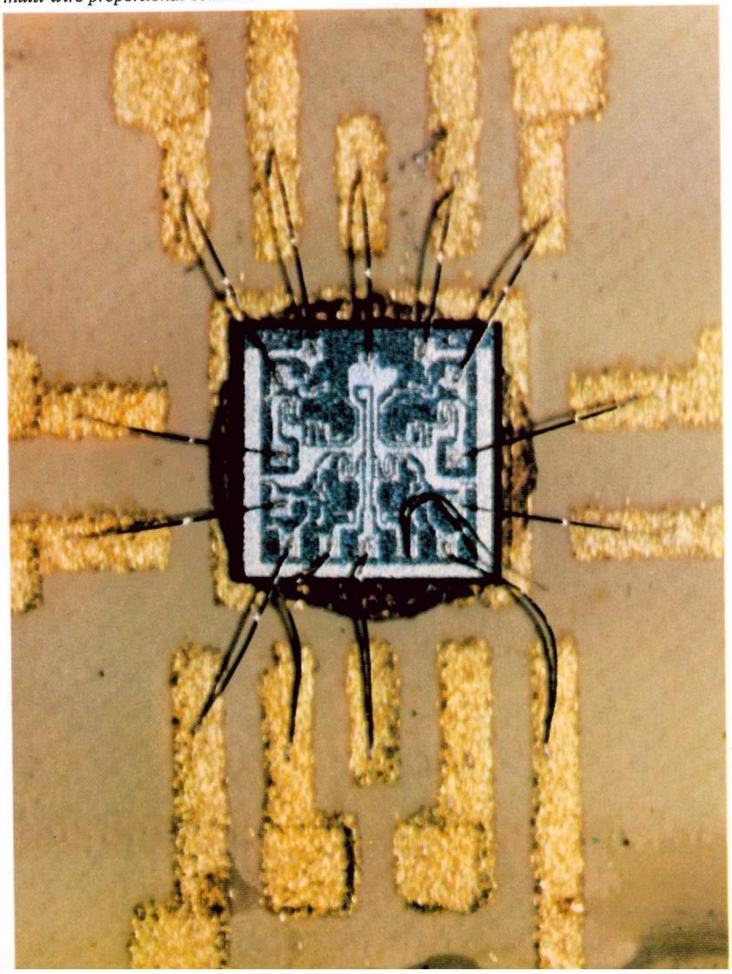
Design and manufacture of detector equipment for elementary particle physics experiments in the UK and abroad cover scintillation counters, spark chambers, proportional counters and drift chambers, each type of equipment having its own particular design criteria.

Special techniques have been developed to facilitate the manufacture of this equipment; in particular the 'film-wire' method, in which large parallel arrays of wires are bonded to thin plastic films, has enabled lightweight spark chambers to be produced for use in complex detection systems.

Most of the electronics work which goes on in the Laboratory is connected with data acquisition and control applied to laboratory instrumentation. Much experience has been accumulated in the design of large CAMAC systems, computer to CAMAC interfaces, controllers and CAMAC modules. In addition it has often been necessary to develop precision low level analogue circuits to transform transducer signals to a form more suited to the CAMAC specifications. These designs have included the multiplexing of thousands of channels with short duration low level signals from proportional chambers and the multiplexing of very

Computer display of bone density based on the transmission of X-rays through part of a human femur, each colour is set to represent a given density range.

A magnified view of a section of a hybrid amplifier/discriminator circuit for use with multi-wire proportional counters.



high impedance circuits associated with ionisation chambers.

In the more general field of digital system design several computer peripheral controllers have been designed and detailed knowledge of several mini-computers has been acquired.

A special development has been the design of television camera electronics which have been used for precision distance measurement. Resolution of 1 part in 8000 has been obtained with full scale measurement ranging from 2 meters to 2 millimeters. These systems are particularly suited for dynamic position measurement, a frequency response of 1 kHz being possible.

Also being studied is the design of high-speed digital data processing units to increase the computing power of mini-computers. This development is aimed at rapid on-line processing of experimental data.

A significant project involves the provision of special instrumentation for use in atmospheric research and in spacecraft.

Other current developments include the electronics and computer interface circuits for an X-ray detector which will be used for bone-mineral estimation. The techniques used in this instrument draw heavily on the experience gained in the development of instrumentation for high-energy physics experiments.

Printed circuit layout designers as well as skilled craftsmen and assembly workers are available for manufacture of electronics. High quality production skills are available both for wire-wrap assembly and printed circuit work, and computer aided techniques are used for the production of wiring schedules for the wire wrap work.

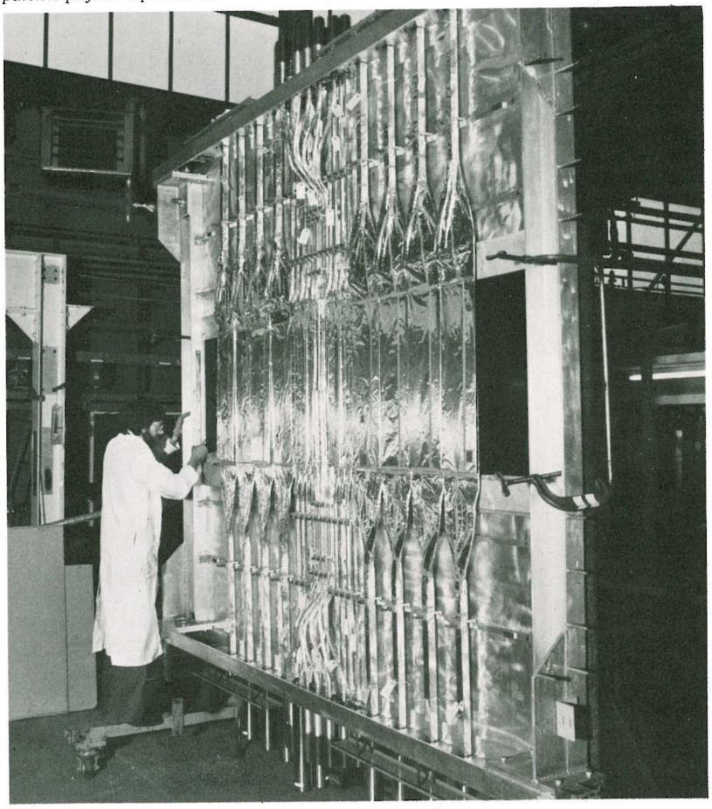
It is now clear that much of the design and development work for new large particle accelerators has to be carried out at an international level, and the Rutherford Laboratory collaborates actively with other research centres in this work.

All aspects of the design of charged particle accelerators are covered, including theoretical work on the dynamics of charged particles in electromagnetic fields and the design and development of components and systems for accelerators. These include ion sources, magnets and their power supplies, radiofrequency cavities and power supplies, vacuum systems, target stations and sophisticated control systems, both digital and analogue. Specific studies in hand include an 800 MeV high intensity proton synchrotron for producing low energy neutrons (about 1 eV) for studies of condensed matter. Contributions are also being made to considerations of very high energy accelerators and storage rings as possible European or intercontinental facilities.

Instruments developed for high energy physics frequently find application in other fields of research. Arising from its development of a mass spectrometer for searching for a fundamental heavy particle, the Laboratory has designed a mass spectrometer using a novel technique for the measurement of carbon isotopes for carbon dating work.

A small unit at the Laboratory gives technical help to universities involved in energy research topics. This includes a secretariat for the SRC committees (Energy Round Table and Energy Proposals Committee) dealing with energy research. The unit has as one aim the initiation of discussion between industry and universities on industry's needs for research and how the universities can participate to maximum effect. Technical help is given on research projects for total energy systems, more efficient engines and energy conservation in buildings.

Array of foil covered scintillators and light guides prior to installation in a particle physics experiment.



COMPUTING

The Rutherford Laboratory, which now includes the former Atlas Computer Laboratory, provides computing services for university scientists and engineers supported by specialist Science Research Council committees and for other Government-funded organisations. These services are intended mainly for those users with large-scale projects needing access to powerful computing facilities over extended periods, so that projects of high scientific quality can be assured of a continual supply of computing power.

Extensive computer facilities are also necessary for the large amount of data analysis involved in high energy physics, space research and other scientific activities both at the Laboratory and at other research centres.

This computing power is provided from a complex containing two IBM 360/195 machines and an ICL 1906A, extensive secondary storage capacity, special peripheral units and communications equipment.

Most of the users of the computer facilities numbering approximately 1000 are from UK universities and other research establishments. Thus an extensive network has been built up of remote stations sited at about 40 university and laboratory locations, connected to the main computers via Post Office lines. Typically a remote station consists of a group of terminals (typewriters, visual display units and graphics devices), a card reader and a line printer, all connected via a small computer. Some 200 terminals are connected to the Laboratory, both locally and through remote stations, and over 70 per cent of jobs averaging 13000 per week, are submitted from terminals by means of the on-line file handling and job submission systems developed at the Laboratory.

The development of remote stations based on GEC 2050 computers was carried out by the Rutherford Laboratory and some 17 of these GEC 2050 systems now connect with the central computers, the remaining stations using IBM 1130s and 370/145s, various PDP machines, Satellites 1s, etc. Software has been developed on a GEC 4080 computer to permit remote stations access to more than one SRC computer.

A further development is in the area of networks which link computers, allowing access from one machine to another for a variety of purposes. The Laboratory is linked on an experimental basis into the American ARPA network, which covers some 70 sites in the USA, mainly university and government research laboratories. This allows physicists in the UK and the USA to access each other's computers for common data analysis and research. The Laboratory is extending its network concept within the UK mainly through the Post Office Experimental Packet Switched Service (EPSS). In this way a remote station at a university will be able to access several SRC computers.

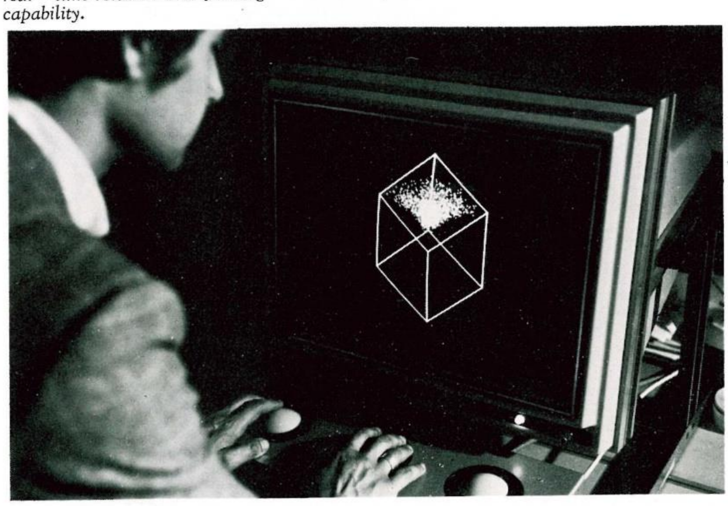
Some on-line devices are also linked to the IBM 360/195 through various smaller satellite computers. The major uses are automatic film measuring machines and rough digitisers, both used for the analysis of bubble chamber and spark chamber film to pick out those frames which show 'events' — interactions of elementary particles — which are of interest to physicists.

The automatic film measuring machines are two HPDs (Hough-Powell Devices) connected to the IBM 360/195 through one common satellite computer. The machines automatically digitise a variety of film types, e.g. 35mm from the CERN 2m chamber or the 1.5m British National chamber, and 70mm from the CERN BEBC chamber. A digitised image of each film frame is produced by an HPD, and parts of the image of interest to the physicist are then sent to the IBM 360/195 for future processing. A single HPD can measure up to 20,000 frames per week.

A special programme of development work has enabled an interactive graphics facility to be built up around a GEC 4080 system. Initial applications involve the correction of HPD digitising of bubble chamber film, and the interactive design of magnets.

The IBM 360/195 computers are linked together and run under IBM multi-programming software enabling the computers to handle many activities simultaneously. The ICL 1906A computer is run under the ICL GEORGE 4 operating system.

Exploring multidimensional data for structure using computer graphics with real – time rotation and zooming capability.



General view of interactive computing facilities.

Rutherford Laboratory staff have considerably enhanced the capabilities of both systems by providing additional capabilities such as automatic control of job submission and on-line job submission and output retrieval for the IBM machine, and job scheduling software for the ICL machine.

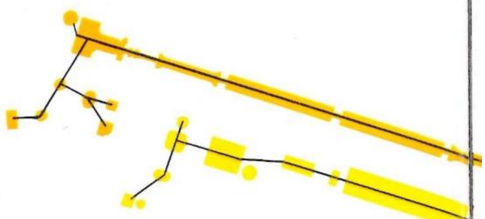
Engineers and technologists in the UK universities are being provided with specialised interactive computing facilities based at Edinburgh and Manchester but managed under contract with Rutherford Laboratory for use in design and other studies where interactive rather than batch computing facilities are needed. An interactive computing network is being set up with links to the central batch facilities at the Rutherford Laboratory.

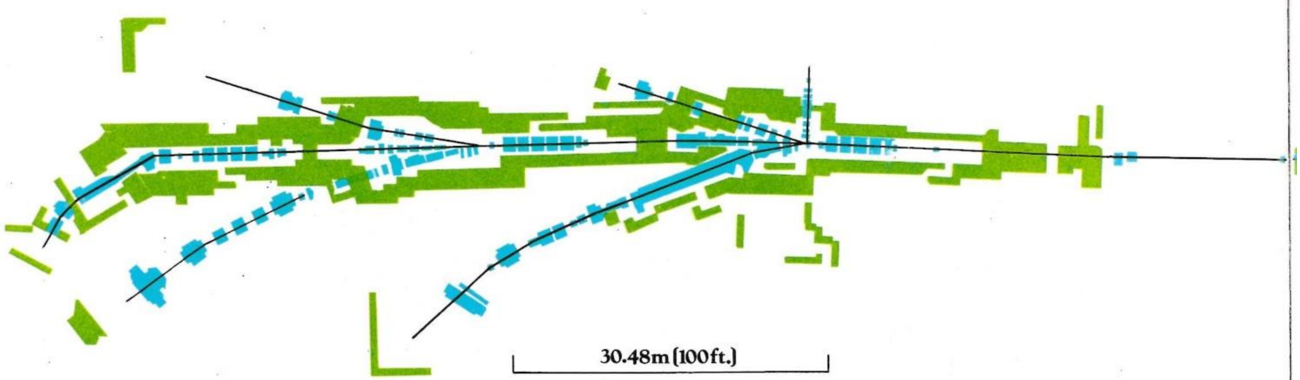
A sophisticated FR80 microfilm recorder from Information International Inc enables computer output to be directed to photosensitive paper, microfilm and microfiche, and is also used for research in film animation and character generation. The device may be used to prepare graphical output on paper or film and to study time dependent features of mathematical models of physical phenomena by means of cinefilm.

The powerful computing facilities are supported by an extensive programme of applications software development reflecting both the experimental apparatus in use and the need to develop efficient methods for the solution of problems in engineering physics, chemistry and many other branches of science.

NIMROD

Nimrod, a proton synchrotron, is a machine providing research teams with protons at high energies for fundamental research into the physics of elementary particles. Its main physical feature is a large ring-shaped electromagnet, 47.6 metres in diameter, and 7000 tonnes in weight. A toroidal shaped high vacuum chamber made from glass-fibre reinforced epoxy resin is situated between the poles of this magnet. A burst of protons, given an initial acceleration to an energy of 15 MeV (15 million electron volts) in a linear accelerator, is injected into this vacuum chamber and the protons are guided by the magnetic field into a circular orbit in which they receive an acceleration from a radio-frequency field once in each revolution. After approximately a million revolutions the protons reach their maximum energy of 8 GeV (8 thousand million electron volts). They are then extracted from the vacuum chamber and focussed on to external targets in adjoining Experimental Areas. The resulting secondary particles are then used for experiments. This sequence is repeated 20 times a minute. During the acceleration period, lasting about three-quarters of a





Original 15 MeV injector
This unit gives an initial acceleration to the protons

New 70 MeV injector
A higher energy replacement for the 15 MeV injector

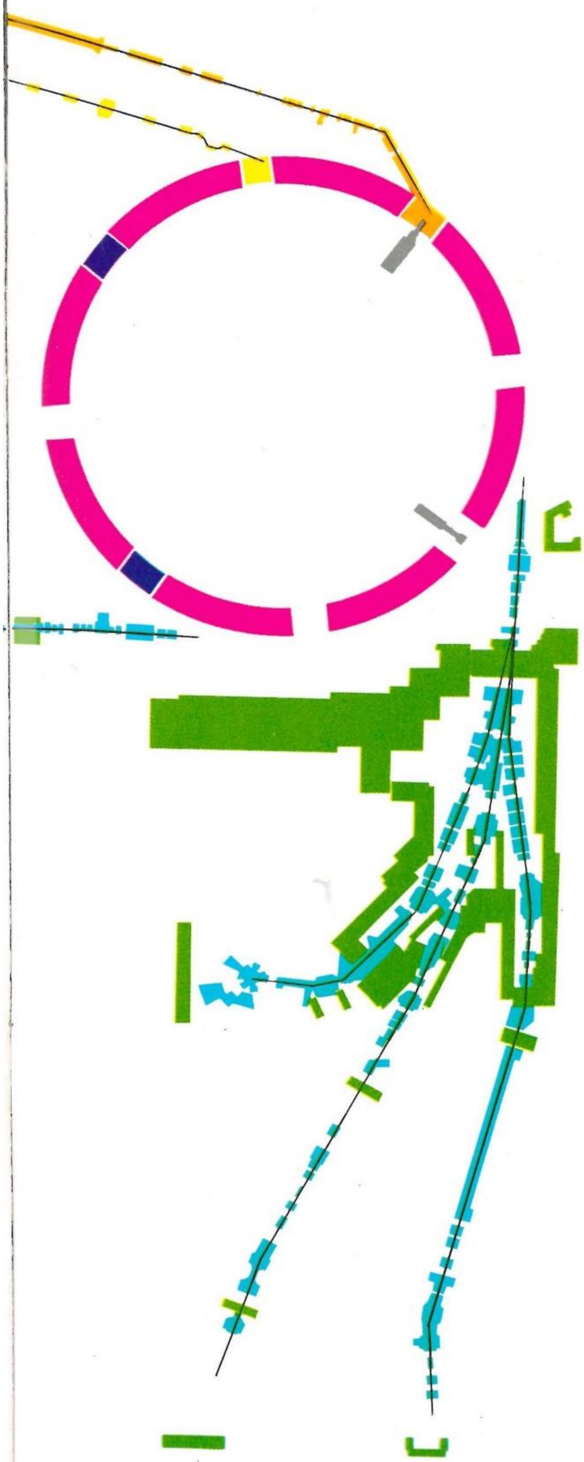
Electro-Magnet
The large magnet guides and focusses the protons in an orbit of constant radius.

R.F. Systems
The radio-frequency accelerating system gives the protons a peak 7kV kick on each turn.

Plunging mechanism
Apparatus for extracting the 8GeV proton beam from NIMROD

Beam line components
For transporting particle beams to the experiments.

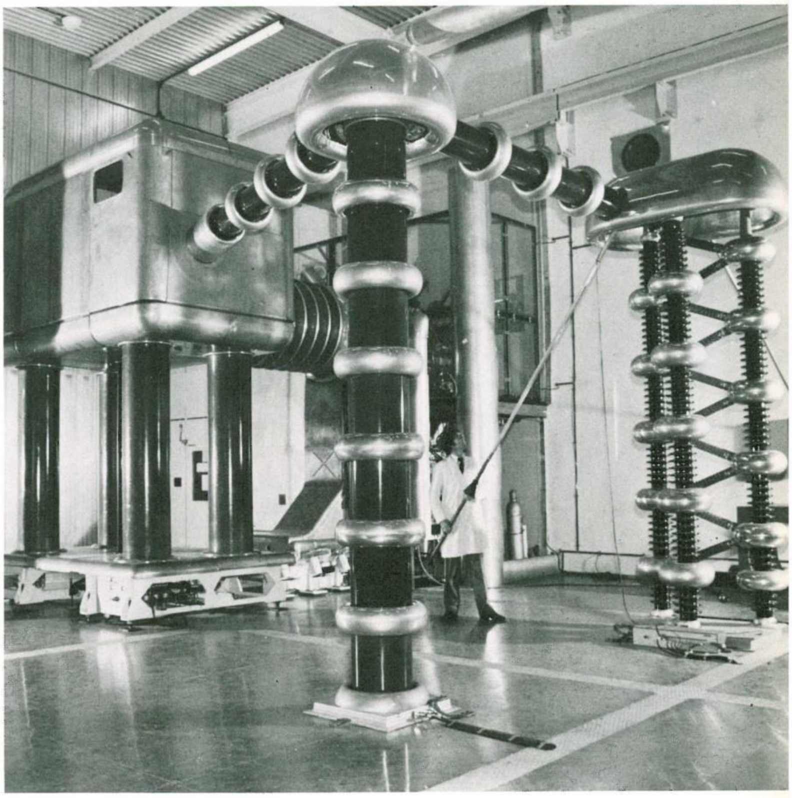
Shield walls
Steel and concrete to give protection from radiation.



second, the magnetic field strength and the frequency of the electric accelerating field have both to be increased steadily to confine the proton orbits to the magnet ring, and in such a manner as to retain the delicately balanced stability in the motion of the protons. In order to protect personnel against the hazards of nuclear radiation the whole machine is housed in a semi-underground circular building of reinforced concrete 61 metres in diameter with a 1.8 metre thick concrete roof on which a 6 metre layer of earth is placed. The machine is remotely controlled.

There are two large Experimental Halls, where physicists conduct their experiments, served by protons from Nimrod. The larger of the experimental areas has floor dimensions 91 metres in length by 45 metres in width (as long as a football field but not quite as wide). The main spinal beam-line consists of some 40 focussing and bending magnets which guide the extracted proton beam from Nimrod to 3 primary target stations spaced at intervals in series along the hall. Secondary particles derived from these targets are similarly guided by magnets to each experiment where behaviour of the particles is studied. Typically an experiment takes about a year to carry out involving several months each of construction, set-up and test, and data-taking. This is "floor" time and excludes planning beforehand and analysis of the results afterwards.

Where the protons start: Very high voltage equipment to give the protons their initial acceleration.



TECHNICAL AND ADMINISTRATIVE SERVICES

The work of the Rutherford Laboratory is backed up by a comprehensive support service, principally from members of the Engineering and Administration Divisions.

Building, electrical, and mechanical services form a considerable part of the Laboratory's activities. Apart from the provision and maintenance of normal services such as electricity, steam, water, compressed air, gas etc., the complex nature of equipment and apparatus have resulted in the formation of skilled maintenance and development sections staffed by engineers, design draughtsmen, skilled craftsmen and experimental workers.

The Council Works Unit, based at the Rutherford Laboratory provides a consulting engineering service to SRC Establishments and other nominated participants. The Unit undertakes new works of specified magnitude and also provides advice as required by Operating Divisions on construction work financed from research grants.

Safety, including radiation protection, is of prime importance in the Laboratory since the operation of particle accelerators and lasers produce several hazards as does the use of high voltage equipment and liquified gases.

Administration Division provides personnel, finance and accounts and general administration services such as transport, stores, housing and similar requirements. The Laboratory has a comprehensive library service.

Photographic and reprographic units are also available for Laboratory users.

Library reading room

RUTHERFORD

Science Research Council

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