# THE RUTHERFORD LABORATORY

Press Visit – 22nd April 1964

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

RUTHERFORD HIGH ENERGY
LABORATORY

Chilton, Didcot, Berks.

# PRESS VISIT
# 22 April, 1964

*A Guide to the Laboratory and the Exhibits*

Not for publication until noon on 22 April, 1964.

A map of the Laboratory site is displayed on the centre pages.

## THE DAY'S PROGRAMME

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|---|---|
| 10.44 a.m. | Main party arrives Didcot Station. Travel by coach to Rutherford Laboratory. |
| 11.15 a.m. | Coffee in the Restaurant Lounge. |
| 11.30 a.m. | Introductory talk by Dr. T. G. Pickavance, Director of the Laboratory, in the Lecture Theatre. |
| 12.00 noon | Tour of the Laboratory. |
| 1.30 p.m. | Lunch in the Restaurant. |
| 2.30 p.m. | Continue tour of the Laboratory. |
| 4.00 p.m. | Press Conference in the Lecture Theatre. |
| 4.30 p.m. | Tea in the Restaurant Lounge. |
| 4.55 p.m. | Coaches leave for Didcot Station to catch the 5.29 p.m. train to Paddington. |
| 5.40 p.m. | Coaches leave for Didcot Station to catch the 6.16 p.m. train to Paddington. |

*NOTES:* A copy of the text of Dr. Pickavance's introductory talk is supplied with this Handbook. It will be appreciated if correspondents refrain from asking questions during or after this introductory talk. A panel of Senior Staff will answer questions at the Press Conference at 4.00 p.m.

Telephones will be available for Press use near the Lecture theatre at 12.00 noon and at 4.30 p.m.

The arrangements for the tours of the Laboratory will be detailed after the introductory talk. A list of the Technical Leaflets (more specialised literature available at exhibits) is given at the back of this handbook.

We hope your visit to the Laboratory proves interesting, worthwhile and enjoyable. Any future enquiries or applications to visit the Laboratory may be directed to Mr. T. R. Walsh, Abingdon 1900, extension 438.

# NUCLEAR SCIENCE

## HISTORICAL SURVEY

One of the oldest fields of research in science is concerned with the fundamental structure of matter. In the 19th Century, the Chemists assembled the Periodic Table of the elements, but this orderly situation was shortlived for Thomson, investigating the nature of the cathode ray in 1897, discovered that electrons are constituent parts of atoms.

The next advance was the result of Rutherford's experiment in 1911. The electrons in the atom were assumed to be dotted about in a sphere of positive charge to give a neutral atom. Rutherford fired a beam of quite energetic positively charged particles emitted by radioactive radium at the atoms in a gold foil. They were expected to plough through the spheres of positive charge with little deviation from their original paths but a small number were actually reflected in the direction of their source. (Rutherford's surprise at this observation can be judged from his remark "It was as incredible as if you had fired a 15 inch shell at a piece of tissue paper and it had bounced back and hit you.") To explain the results of his experiment, he suggested that the atom consisted of a tiny concentrated core of positive charge, about a millionth of a millionth of a centimetre in diameter, which reflected the alphas, and a cloud of electrons around it. This core was termed the nucleus and 'nuclear science' had begun.

## PROTONS, NEUTRONS AND MESONS

The nature of the electron cloud surrounding the positive core was clarified early in this century and the focus of attention moved to the charged nucleus. The positive particle in the nucleus was separately identified and called the proton.

In 1932 Chadwick demonstrated experimentally the existence of an uncharged particle, postulated by Rutherford some twelve years earlier, called the neutron. Protons and neutrons were found to share the nucleus in approximately equal numbers and both were given the name 'nucleons'.

It was obvious that some force must exist within the nucleus to overcome the Coulomb force tending to push the positive charges apart. In 1934, Yukawa, a Japanese theoretical physicist, ~~used Einstein's $E = mc^2$ relationship to~~ explain the nuclear binding force in terms of a particle which is exchanged between the nucleons. It was later given the name 'meson' and for a year after Yukawa's theory was published, scientists searched for experimental evidence of its existence. Then in 1936 Anderson and Neddermeyer recognised a particle from tracks on cloud chamber photographs of cosmic rays which was thought to be the Yukawa particle.

## ANTIPARTICLES AND DECAY

The concept of antiparticles originated in Dirac's theory of the electron in 1928. Dirac developed an equation to represent the motion of a free electron or proton and noted that both a positive and a negative solution existed. The negative solution implied particles of negative energy—'antiparticles'. For every particle there exists an antiparticle. Anderson and Blackett ~~had actually already~~ detected an electron—antielectron (called a positron) pair in 1932. The anti-proton had to wait until 1955 to be identified on the Bevatron accelerator in the U.S.A.

Electrons were observed to be emitted from a radioactive nucleus with a range of energies and their origin was explained as the breakdown or 'decay' of a neutron into a proton and an electron. (Almost all particles are now known to decay.) Pauli and Fermi suggested that a new particle, the neutrino, could carry off some of the energy so that the energy of the electron plus that of the neutrino is always the same. The neutrino has no mass and no charge which made detection difficult and it was 1956 before a conclusive experiment to demonstrate its existence was carried out by Cowan and Reines.

This was the state of affairs just before the second world war. The separate parts of the atom—electron, proton and neutron—had been identified and the existence of the meson apparently experimentally verified. Antiparticles were known to exist and the neutrino was postulated. If we add to these the photon, which carries the energy of the electro-magnetic field, we had a small group of fundamental units and we seemed to be in a much more satisfying position than even the Chemists with their many types of atom.

## COSMIC RAYS

Until the 1950's cosmic rays provided the major source of high energy particles. Primary cosmic rays are known to consist mainly of protons with small percentages of alpha particles and other heavier nuclei, sometimes with fantastically high energies (greater than a million GeV*), showering into our atmosphere. The 'creation' of new particles can only occur when the necessary energy is available for conversion into mass in accordance with Einstein's relationship, which explains the concentration of interest on cosmic rays. They were investigated using cloud chambers

*The electron volt (eV) is a measure of energy, being the energy gained by an electron falling through a potential difference of one volt. GeV is one thousand million electron volts (from 'giga'—one thousand million). The American equivalent is BeV since their name for one thousand million is 'billion'.

and later photographic emulsions in both of which they leave tracks which can be interpreted to provide a great deal of information.

Around 1947 it was realised that the meson detected by Anderson was not the one which fitted with Yukawa theory. Powell working at Bristol on cosmic rays identified the true Yukawa meson and called it the pi meson and the Anderson meson became known as the mu meson. Further unexpected particles followed the work of Rochester and Butler at Manchester who found two neutral particles, (later called the K meson, and the hyperon), in cloud chamber photographs of cosmic rays. This discovery of the hyperon was the first indication of a complex pattern of new particles heavier than the proton, which have now been identified.

## HIGH ENERGY ACCELERATORS

Cosmic rays are not a controllable source of high energy particles and the incidence of the heavier particles in particular is very rare. Many thousands of photographs may reveal the interesting particles only once, thus the possibility of producing the particles virtually to order to be investigated in the laboratory is invaluable. The development of the techniques to build high energy machines was a great breakthrough for the nuclear physicist. Cyclotrons with energy ranges below 1 GeV were first developed and used chiefly for pi meson physics. The proton synchrotrons followed from 1953 onwards and have provided a great mass of data on elementary particles and their interactions. The spearhead of the attack on the fundamental structure of matter has moved to the accelerator laboratories.

## PRESENT SITUATION

By the late 1950's a table containing some thirty particles had been assembled with additional particle names like xi, sigma and lambda. Then in 1960 another, even bigger, population explosion in the fundamental particle family began when it was found that the thirty particles represent only the 'unexcited states' of matter and that a great spectrum of particles with higher masses exists. These new particles are known as resonances and they 'live' for very short times (less than a millionth of a millionth of a millionth of a second) before decaying into other particles. The list of particles has been extended to about a hundred.

But at last some order is becoming apparent in the observations. The experimental data is beginning to fall into striking and partly predictable patterns.

The particle interactions have been classified into two types, strong and weak (in addition to the electromagnetic interaction). The strong interaction, such as that occurring between the nucleons, is some million million times more powerful than the weak interaction, such as operates in the decay of particles. From empirical and theoretical work it is known that the various interactions are ordered by certain conservation laws and a group of quantum numbers identifies each particle and defines its behaviour.

When the particles are assembled in tables, just as with the Periodic Table of the elements, according to their masses and their quantum numbers, the striking patterns emerge. The most successful recent theoretical work has evolved from a theory put forward by Ohnuki in 1960 and developed by Salam and Ward at Imperial College, London. It is called the Unitary Symmetry theory and Gell-Mann and Ne'eman have used it to draw up patterns of particles in groups of eight or ten. The recently discovered omega minus particle, which received considerable publicity, was the most successful prediction of this theory which is serving to co-ordinate and clarify a previously confused mass of experimental data.

It is this field of research, at the forefront of modern science, at the most fundamental level, which will be pursued at the Rutherford High Energy Laboratory.

## THE NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

In 1957 the Government set up the National Institute for Research in Nuclear Science to provide for common use by Universities and others, facilities which are beyond the scope of individual Universities and Institutions carrying out research in the nuclear field. This field includes high energy physics and nuclear physics, which require large particle accelerators, and also research in a wide range of subjects requiring nuclear reactors as radiation sources.

The objects for which the Institute are established and incorporated are set out in the Royal Charter as follows:

(a) To carry out research of any nature in connection with nuclear science or any matter related thereto.

(b) To provide, equip and operate facilities of any description which may, in the opinion of the Institute, be required for the purposes of any such research as aforesaid.

(c) Without prejudice to the generality of the foregoing, to provide, equip and operate, for common use by Universities and by other Institutions and persons engaged in research in nuclear and related matters, facilities which by reason of their size or cost or otherwise howsoever are beyond the scope of individual Universities, Institutions or persons as aforesaid.

(d) To permit and encourage scientists of Universities, Colleges and the United Kingdom Atomic Energy Authority and other Institutions, as well as scientists of industrial laboratories, to make such use of facilities provided as aforesaid as the Institute may determine to be appropriate.

(e) To co-operate with the United Kingdom Atomic Energy Authority in the solution of specific problems in the field of nuclear or related research.

(f) To train scientists and engineers in matters relating to nuclear science.

(g) To disseminate scientific and technical knowledge in the field of nuclear or related research.

(h) To acquire from the United Kingdom Atomic Energy Authority or from any other body or person whatsoever any property, equipment or other assets of any kind which in the opinion of the Institute are requisite for or conducive to the carrying out of research in connection with nuclear science or any matter related thereto and to enter into any contracts or agreements in furtherance of any such research.

(i) Generally to do all things necessary or expedient for the proper and effective carrying out of any of the objects aforesaid.

The Governing Body of the National Institute is made up as follows:

*Chairman:* THE RT. HON. THE LORD BRIDGES, G.C.B., G.C.V.O., M.C., F.R.S.

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## THE RUTHERFORD LABORATORY

The first Laboratory of the National Institute is the Rutherford High Energy Laboratory at Chilton, near Didcot, Berkshire. The site covers an area of about 75 acres adjacent to the Atomic Energy Research Establishment, Harwell and was transferred to the Institute from the Atomic Energy Authority in 1959. The bulk of what was the Accelerator Division at A.E.R.E. transferred to the Institute at the beginning of 1961 to staff the new Laboratory.

The total staff of the Laboratory (excluding visiting experimental teams) will reach about 1,000 and this complement is now almost entirely filled. The Parliamentary Grant to the National Institute for 1963–64 was £8,445,000 which was increased by a supplementary estimate to £8,998,000; of this about £7,000,000 was allocated to the Rutherford Laboratory.

The Laboratory will be officially opened and the 7 GeV proton synchrotron, NIMROD, inaugurated by the Rt. Hon. Quintin Hogg, Q.C., M.P., Secretary of State for Education and Science, on Friday 24th April 1964.

### Directorate and Division Heads

| | |
|---|---|
| *Director* | Dr. T. G. Pickavance (Directorate Member) |
| *Assistant Director* | Mr. L. B. Mullett (Directorate Member) |
| *Division Heads :* | |
| *Nimrod Division* | Dr. L. C. W. Hobbis |
| *High Energy Physics Division*<br>*P.L.A. Division (Temporary)* | Dr. G. H. Stafford (Directorate Member) |
| *Applied Physics Division* | Mr. W. Walkinshaw |
| *Engineering Division* | Mr. P. Bowles (Directorate Member and Chief Engineer) |
| *Administration Division* | Dr. J. M. Valentine (Directorate Member and Secretary of the Laboratory) |
| *Electrostatic Generator Group* | Dr. W. D. Allen |

# THE WORK OF THE LABORATORY

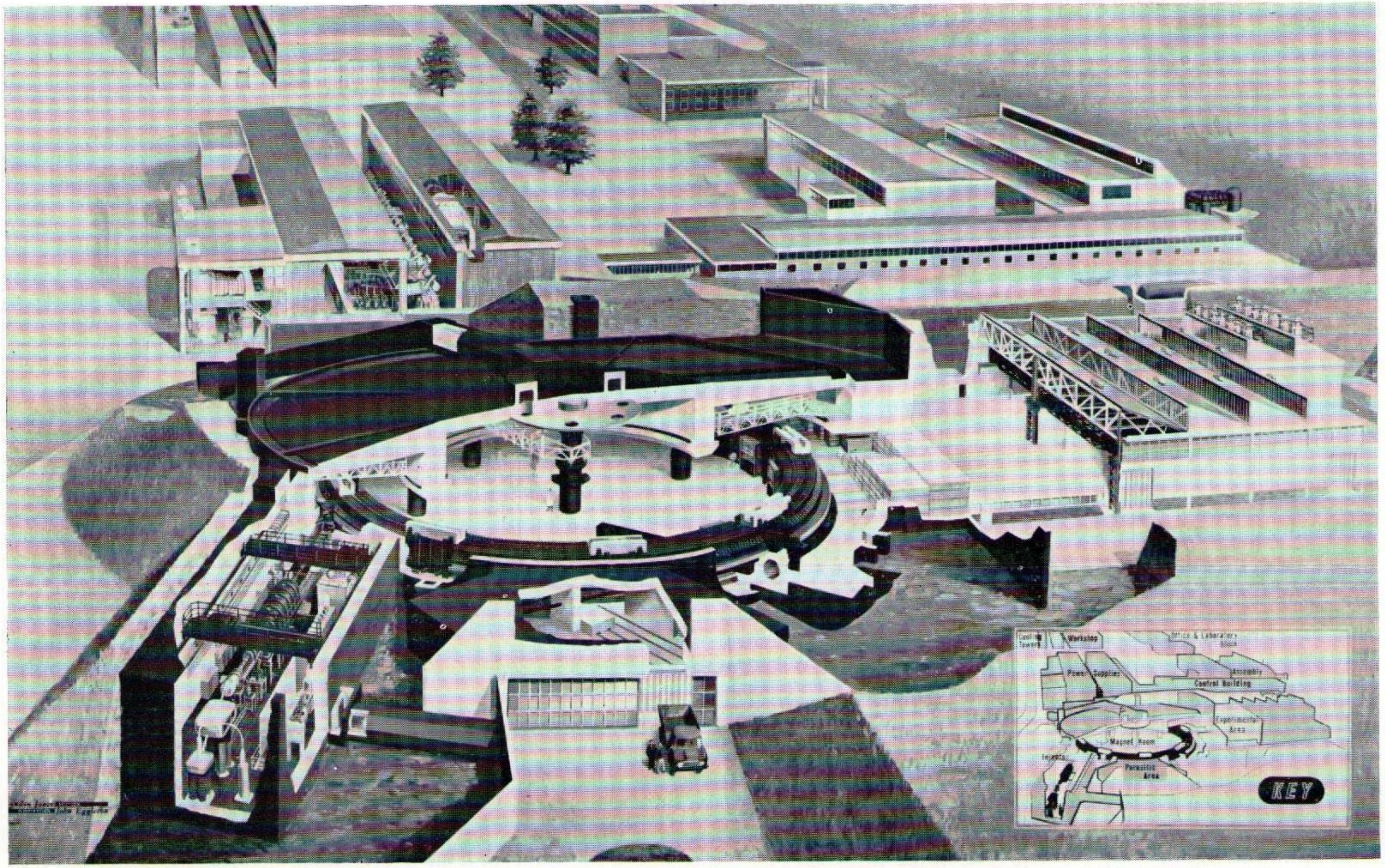
## NIMROD DIVISION

The minimum energy required for the production of antiprotons and antineutrons is about 6 GeV. This was a starting point when the first attempts were being made to choose a national accelerator for High Energy Physics. However, there are other factors which influenced the final choice. The yield of secondary particles per accelerated particle, generally increases with energy. At the time when the choice had to be made, it was generally considered that accelerated beam intensity would fall with increasing design energy, although the spectacular success of alternating gradient synchrotrons subsequently showed this idea to be wrong.

Also accelerators may be designed to produce beams of electrons or protons, but not both, and therefore the relative merits of these particles had to be considered. Protons are more effective in producing the mesons and other particles, because they are themselves closely connected with nuclear forces. On the other hand, electrons can usually be accelerated in greater numbers, which partially offsets their disadvantage and they can also be used in research into electromagnetic phenomena, which cannot be tackled with protons. On the whole, proton accelerators have been more productive in high energy research and, after careful consideration, a proton machine was chosen. The relationship with other existing and planned machines, at home and abroad was taken into account.

To be certain of achieving the required intensity a constant gradient or weak focusing machine was adopted. Six GeV was taken as the minimum energy, but the upper limit was not simply a question of economics. A 25 GeV proton machine was under construction at CERN in Geneva and since the United Kingdom participates in the work of CERN, this machine would be accessible to British physicists. Therefore the decision was made to carry out high energy work at CERN and to construct in England a high intensity machine at a lower energy, 7 GeV; the two machines are thus complementary. The machine was given the name NIMROD (A mighty one in the earth—*Genesis* 10, 8-2).

Work began on Nimrod in August, 1957 following extensive design studies and the machine first operated at full energy on 27th August, 1963. The total capital cost, including the buildings was just under £11 million.




*7 GeV Proton Synchrotron, NIMROD.*

THE MACHINE

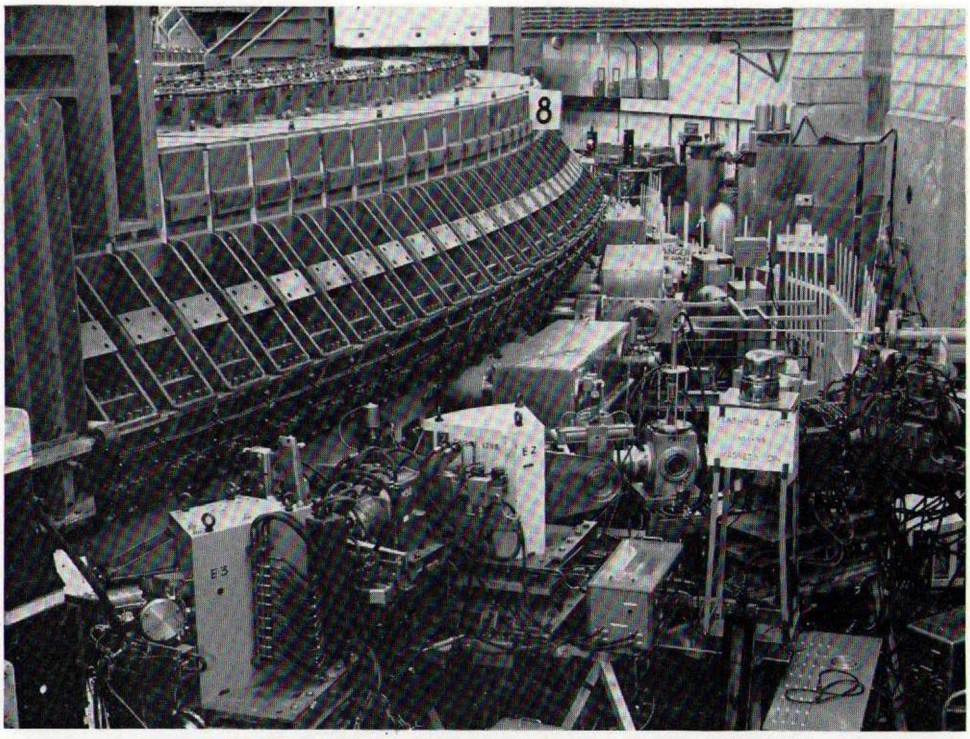
The main physical feature of Nimrod is a large ring-shaped electromagnet, 155 ft. in diameter, which weighs 7000 tons. The magnet comprises eight octants separated by straight sections which accommodate the radio-frequency (r.f.) accelerating cavity and various machine components. Each octant has its own 42 turn winding, fabricated from 50 ft. lengths of extruded copper, the total weight of the coils being about 350 tons. The conductors are cooled by demineralised water pumped through a 0·2 sq. in. hole in the centre. The total power dissipation is 3 MW at the normal pulse repetition rate of the machine.

A toroidal shaped vacuum chamber made from glass-fibre reinforced epoxy resin is situated between the poles of the magnet. This chamber comprises eight double walled vessels each the whole length of an octant. An outer vessel with thin walls is sandwiched between the poles and yoke of each magnet octant. An inner vessel of similar length is placed within the octant gap and evacuated to $10^{-6}$ torr* while the space between the two vessels is evacuated to about $10^{-2}$ torr. Thus the magnet structure supports practically all the atmospheric load and the inner high vacuum vessel has only a small differential pressure to withstand.

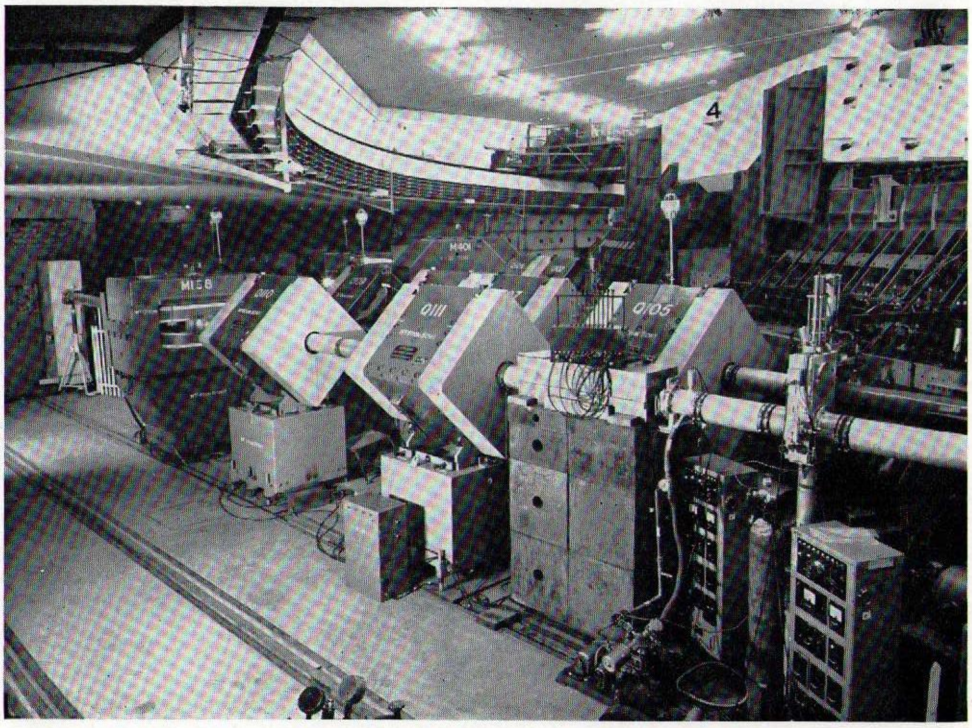
The origin of the proton beam is the proton source, where hydrogen gas at low pressure is ionised in a discharge induced by a radio-frequency field. Pulses of protons are then extracted and accelerated to an energy of 0·6 MeV in the pre-injector. The beam next enters the linear accelerator or 'linac' which is essentially a highly evacuated, cylindrical copper cavity, 44 ft. long by 5 ft. 6 in. dia. This cavity is resonated by 115 Mc/s r.f. power, producing an alternating electrical field along its axis. The protons passing along the axis are shielded from the decelerating parts of this field by a series of drift tubes and each drift tube contains a quadrupole focusing magnet to prevent loss of proton beam by excessive expansion during acceleration. Since pulses of up to 0·002 seconds long, at intervals of about two seconds, are required by the synchrotron, the power to the accelerating cavity (about 1 MW) is pulsed. The protons emerge from the linac with an energy of 15 MeV.

They are introduced into the main magnet ring by means of a 25° deflection system, consisting of four bending magnets followed by an electrostatic deflector which guides the beam into the vacuum chamber. There the protons are constrained by the magnetic field into a circular orbit in which they receive an acceleration from the r.f. field once in each revolution. During the acceleration period, lasting about three-quarters

*'*torr*' *after Torricelli, is becoming established as the standard abbreviation for pressure measurement. 1 torr is equivalent to 1 millimetre of mercury.*




*Octant 8 of the Nimrod magnet ring. The magnets of the Inflector system (E2 etc.) bringing the 15 MeV beam to the ring can also be seen.*




*Beam lines from the magnet ring into the experimental hall, showing quadrupole focusing magnets (Q111 etc.) and bending magnets (M198 etc.).*

of a second, the magnetic field strength and the frequency of the r.f. accelerating field have both to be increased steadily to confine the proton orbits to the magnet ring, and in such a manner as to maintain the delicately balanced stability in the motion of the protons.

The r.f. accelerator unit is excited by a variable frequency oscillator whose frequency rises from 1·4 to 8 Mc/s while the injected beam is accelerated to full energy. The peak accelerating voltage is 7 kV. Frequency control of the cavity is obtained by magnetically biasing ferrite cavity cores by a direct current which changes the inductance of the circuit.

Heavy currents up to 10,000 A with an applied voltage up to 15 kV are needed to energise the magnet during the short acceleration time. The power supply consists of a motor-alternator set, incorporating flywheels, connected to the magnet through a bank of rectifiers. This equipment supplies direct current of gradually increasing strength during the $\frac{3}{4}$ sec. acceleration period, and the current decays again to zero in a further 0·8 sec. ready for the next pulse. Energy is thus stored in the magnet during the current-rise period and is subsequently returned to the flywheels and rotors as the current is reduced again to zero. The amount of energy being shuttled to and fro amounts to some 40 megajoules. In this way, the motor-alternator set acts as a buffer between the load (the magnet windings) and the electrical supply grid.

The machine is designed to produce a beam intensity of at least $10^{12}$ protons per pulse at a repetition rate of 28 pulses a minute. After approximately a million revolutions the protons reach their maximum energy and are then either extracted from the vacuum chamber as an external proton beam for use with external targets or allowed to bombard targets in the magnet ring. The resulting secondary particles from the internal targets are channelled into experimental areas.

Two experimental halls have been built to house the high energy physics experiments and it is intended to provide a further large hall sometime in the future. The extracted proton beam or secondary particle beams are conveyed to the experimental equipment along beam lines where particle separators, quadrupole focusing magnets and bending magnets focus the beam and select the required particles at the required energy.

## PRESENT STATUS

Nimrod is currently being run for $3\frac{1}{2}$ days per week, a useful high energy beam being available for 50–60% of the scheduled time. Although this degree of reliability is quite good at the present stage of development a substantial improvement is expected during the remainder of 1964. It is also intended to increase the running time to 5 or 6 days/week over this period. Beam intensities around $5 \times 10^{11}$ protons per pulse are normally obtained; further improvements in intensity are expected and this is one of the subjects of machine studies which currently share available running time with High Energy Physics on a roughly equal basis. Major effort is also directed to the development of the external proton beam; the primary beam was extracted for the first time on March 24, 1964.

### Principal Parameters of Nimrod

| | |
|---|---|
| Maximum proton energy | 7 GeV |
| Proton beam intensity | $10^{12}$ protons/pulse |
| Duration of acceleration | 0·7 seconds |
| Number of orbits per pulse | $10^6$ approx. |
| Maximum pulse repetition rate | 28 per minute |
| Mean orbit radius | 77·5 ft. |
| Maximum magnetic field | 14,000 gauss |
| Maximum field at injection | 300 gauss |
| Weight of magnet steel yoke | 7,000 tons |
| Weight of magnetic coils | 350 tons |
| Magnet aperture, width | 36 inches |
| Magnet aperture, height | 9 inches |
| Proton energy at injection | 15 MeV |
| Acceleration system frequency | 1·4–8·2 Mc/s |
| Energy gain per revolution | 7 KeV approx. |
| Nominal rating of motor-alternators in magnet power supply | 120 MVA approx. |

### Exhibits

The whole of Nimrod—control room, power supply house, magnet room, injector hall and the two experimental halls—is open for the Press Visit and exhibits display various aspects of machine operation and special features of machine components. Technical Leaflets are available to give more detailed information.

## ORGANISATION OF DIVISION

The Division is divided into five groups. As with other Divisions, there are some Ph.D. students with the groups and Dip.Tech. students on sandwich courses spend six month periods at the Laboratory. Vacation work is also done by university students.

## NIMROD MACHINE ENGINEERING GROUP

Group Leader Mr. J. C. Louth

The group is made up of professional engineers, technicians, skilled craftsmen and semiskilled workers totalling around 150. It is concerned with the engineering aspects of the operation, maintenance and development of all aspects of the accelerator and its auxiliary plant. The work is divided into mechanical, electrical and power supply sections.

## NIMROD HIGH ENERGY PHYSICS ENGINEERING GROUP

Group Leader Mr. G. N. Venn

The group, about 50 strong, provides engineering support for the high energy physics work on Nimrod. It is responsible for the organisation and management of the two experimental halls which involves laying out, installing and surveying beam transport equipment and implementing safety measures against hydrogen incidents, radiation and general accident hazards. A design team works on high energy physics apparatus and the layout of beam lines; a planning team programmes design, manufacture and installation and an installation team manages the experimental halls and installs shielding and equipment.

## NIMROD MACHINE PHYSICS GROUP

Group Leader Mr. D. A. Gray

The group consists of about fifty scientists and technologists. It is responsible for the accelerator development work on Nimrod. This is directed towards providing whatever accelerated beam conditions are required by the high energy physicists for their experiments and in particular, is concerned with producing the highest possible beam intensity.

## NIMROD BEAMS PHYSICS GROUP

Group Leader Mr. A. J. Egginton

A group of twenty-five scientific staff is responsible for co-ordinating beam line developments on Nimrod. This work covers the development of an extracted proton beam and participation in the design of other major beams of secondary particles. In addition, the group is responsible for the physics design of all kinds of beam equipment and for the development of targeting techniques on Nimrod.

## NIMROD GENERAL PHYSICS GROUP

Group Leader Dr. H. H. Atkinson

The work of the group covers some special developments immediately connected with Nimrod and high energy physics experiments, and other research in subjects related to the work of the Laboratory. The group contains 13 scientists and technologists.

The production and initial acceleration of ion beams: New types of ion source and d.c. gun to give beams of much higher intensity and low aberration are under investigation. A source based on the 'duoplasmatron' discharge is being investigated and work is beginning on a new electrostatic discharge. Computer programmes and a resistor network have been developed for calculations on the beam optics of ions and electrons.

A single gap high voltage ion gun: This incorporates a scaled up r.f. ion source to produce intense proton beams. The ions are drawn from a large area of comparatively low density plasma and accelerated to 600 keV across a single gap. Thus the conventional focusing electrodes and long accelerating tube are eliminated and the aberrations they introduce into the beam are avoided. Beam currents of about one ampere are aimed at and, in a preliminary experiment, a pulsed beam of about 40 mA has been accelerated to 200 kV across a 3 inch gap.

Polarized proton target: When an elementary particle collides with a proton, the interaction depends, amongst other things, on the direction of spin of the proton. In conventional experiments (e.g. using a liquid hydrogen target) the proton spins are randomly orientated so that only the average effect of the spin direction can be observed. Much more information could be obtained if all the spins were lined up in the same direction. Such a 'polarized' target is being constructed and will be used in high energy physics experiments on Nimrod.

Electron physics: This work is not directly associated with Nimrod, but deals with some fundamental problems of charged particle beams of very high current (effectively many orders of magnitude higher than those occurring in present day accelerators). Investigations have so far been concerned only with beams of electrons, which are much easier to create and handle than ions, and have sought to establish the maximum stable current of electrons that can be conveyed through a vacuum from one place to another. Experimental results have confirmed, for the first time, predictions of space charged limited flow for magnetically confined flow in cylindrical drift tubes. It might be expected that by neutralizing the electron charge with stationary positive ions, almost unlimited currents could flow. However, the experiments show that a new limit is reached, when the beam suddenly becomes catastrophically unstable at only a few times the limiting value in the absence of ions. New vacuum guage: As a direct, but unanticipated, result of this study an entirely new type of high vacuum gauge has suggested itself. The gauge uses the space charge depression of an electron beam to trap positive ions for long periods of time so that, because one ion can influence millions of electrons, the device effectively has a very high amplication. Its simplicity and speed of response give it an advantage over conventional high vacuum gauges.

**Exhibits**

Ion source work is displayed in Lab. 6, R.1; the polarised proton target can be seen in R.25; electron physics work and the new type of high vacuum gauge are displayed in Lab. 3, R.1. Technical Leaflets are available at each exhibit.

## HIGH ENERGY PHYSICS DIVISION

The main aim of research with Nimrod is to investigate the properties of the so-called elementary particles in order to further our knowledge of the nature of the forces which occur in nuclear matter and thus to understand more clearly the basic facts upon which ultimately rests all science and technology. Nimrod is the first accelerator in this country capable of producing K-mesons, hyperons and the so-called anti-particles. It represents Britain's entry into a highly competitive field in which some of the world's finest laboratories have had many years of experience.

### EXHIBITS

The experimental techniques that are employed in this research work are very varied but fall broadly into three categories, viz: counters and spark chambers, bubble chambers and emulsions.

### COUNTERS AND SPARK CHAMBERS

This technique employs a great deal of electronic equipment. All the initial experiments on Nimrod fall into this category. The experiments are carried out using beams of particles generated in a target within

Nimrod. The particles are transported along beam lines to the experiment. Four such beam lines and experiments will be exhibited. The experiments have for convenience been designated by the name of the elementary particle mainly of interest in the experiment followed by a serial number; thus the four experiments to be exhibited, $\pi 1$, $\pi 2$, $\pi 3$ and N1 are three $\pi$ meson beams and a neutron beam. $\pi 2$ and $\pi 3$ use the same beam line and the two experiments can be run simultaneously. In the $\pi 1$ experiment $\pi$ mesons are scattered by the protons in a liquid hydrogen target. Both the scattered pions and the recoil protons are detected by an array of about 50 scintillation counters placed in an arc around the target. Elaborate electronic techniques correlate each scattered pion with the appropriate recoil proton knocked out of the hydrogen target and record the numbers scattered into each detector.

In the $\pi 2$ and $\pi 3$ experiments visual spark chambers are used to reveal by means of a series of sparks the path of the scattered particles. Stereo-photographs of these tracks which are later analysed on measuring machines enable each scattering event to be reconstructed. Two working arrays of spark chambers showing cosmic ray events will be on display in R.2.

In the N1 experiment sonic spark chambers are used to track the path of the particles. These chambers work on the same principle as the visual chambers but instead of photographing the sparks the position of the spark in the chamber is determined by an accurate measurement of the time taken for the sound from the spark to reach microphones placed at the edge of the chamber. These time intervals are measured electronically and recorded on a system of 50 scalers which incorporate a facility to enable the data to be printed out automatically and recorded on paper tape. The tape can then be fed into a computer. Sonic spark chambers are able to determine the position of a particle to an accuracy of $\pm$ 1/100 inch. A working sonic spark chamber array is on display in R.2. It will show how the movement of a small radioactive source over the chamber can be reproduced electronically on an oscilloscope.

## BUBBLE CHAMBERS

In a bubble chamber the track of the particle is revealed by a series of bubbles in a liquid such as hydrogen or helium. A magnetic field superimposed on the sensitive volume of the chamber produces curvature in these tracks and thus enables the momentum of the particle to be determined. Stereo-photographs are taken of the tracks. The analysis of the stereo-photographs is later carried out in two stages. The first stage on a scanning machine involves picking out photographs containing events of the required type. The selected events are then analysed on a measuring machine. Scanning machines and measuring machines will be on view and will be seen analysing film taken in an earlier experiment. A fuller account of this work will be found in the account of the bubble chamber group in the Applied Physics Division.

The Rutherford Laboratory will have three large bubble chambers. The British National Bubble Chamber, sponsored by N.I.R.N.S. and built by a consortium of Universities is about the size of a bath and is filled with liquid hydrogen. This chamber is at present the largest in Europe and is doing duty at CERN. Two other bubble chambers are in the course of construction. In one the active liquid will be helium and in the other a variety of denser liquids will be used. Once again the construction of these bubble chambers is a collaborative effort between the Rutherford Laboratory and the Universities. Each bubble chamber will have its own particular application in our research programme.

A small freon chamber will be exhibited working with a radioactive source.

## EMULSIONS

Nuclear emulsions like bubble chambers have the target and the detector contained in the same volume of material. Beams of energetic particles are fired into stacks of emulsion where some of them interact with emulsion nuclei. The charged particles passing through the emulsion have the same action on the grains of silver bromide as light so that subsequent development and fixing of the emulsion gives a permanent record of the scattering events.

Some typical emulsions are to be shown under the microscopes used for analysis. One of the microscopes exhibited has been developed to enable the physicist automatically to record on paper tape the co-ordinates of the track being studied.

## ORGANISATION OF DIVISION

The High Energy Physics Division is responsible for the organization and the co-ordination of the high energy physics research programme on Nimrod. The Division aims at close collaboration with visiting teams from Universities and other research establishments and approximately half of the research physicists and supporting staff in the Division are attached directly to visiting teams. The extent to which this collaboration has already been developed between Universities and the Rutherford Laboratory will be evident from the list of teams participating in the experimental programme. Some 80–90 physicists are involved.

| | Beam | Experimental Team | Team Leaders |
|---|---|---|---|
| 1 | P2 | A.E.R.E.<br>Queen Mary College, London<br>R.H.E.L. | Mr. A. E. Taylor<br>Dr. A. Ashmore<br>Dr. T. G. Walker |
| 2 | N1 | A.E.R.E.<br>Birmingham University<br>Bristol University<br>R.H.E.L. | Dr. G. Manning<br>Dr. H. B. van der Raay<br>Dr. J. Malos<br>Dr. N. Lipman |
| 3 | $\pi 1$ | R.H.E.L. | Dr. P. G. Murphy<br>Dr. J. J. Thresher |
| 4 | $\pi 2$ | University College, London<br>Westfield College, London | Dr. F. F. Heymann<br>Professor E. H. Bellamy |
| 5 | $\pi 3$ | Oxford University<br>R.H.E.L. | Dr. A. B. Clegg<br>Dr. A. Carroll |
| 6 | K2 | Imperial College<br>Manchester University | Mr. J. A. Newth<br>Dr. R. J. Ellison |

Three other experiments are being actively prepared for inclusion into the programme on Nimrod later this year, namely:

(a) A collaboration between groups from
A.E.R.E. (Mr. B. Rose)
Southampton University (Professor G. W. Hutchinson)
University College, London (Dr. R. E. Jennings) and
R.H.E.L. (Dr. E. G. Auld)

(b) A collaboration between Cambridge University (Dr. K. F. Riley) and R.H.E.L. (Dr. D. Bugg) and finally

(c) Hydrogen bubble chamber experiments to be done as a collaboration between Centre d'Etude Nucleaire de Saclay (Professor Berthelot), French Universities, British Universities and R.H.E.L. (Dr. E. Pickup).

Within the Division there is also an Electronics Group (Mr. P. Wilde) which is responsible for the design, construction and maintenance of much of the highly specialised electronic equipment that is required in high energy physics research. A fast electronics exhibit can be seen in Experimental Hall 1.

# APPLIED PHYSICS DIVISION

## HIGH MAGNETIC FIELDS GROUP

Group Leader Mr. J. D. Lawson

This small group of six scientific staff has been set up principally to investigate the possibilities of superconducting magnets. New alloys, developed in the U.S.A. during the last three years, enable high magnetic fields to be produced with negligible power consumption. If successfully developed on a larger scale, this technique may make possible a considerable reduction in the size and cost of the many types of experimental magnet required in high energy physics and may enable certain new types of apparatus to be constructed which have hitherto been too costly.

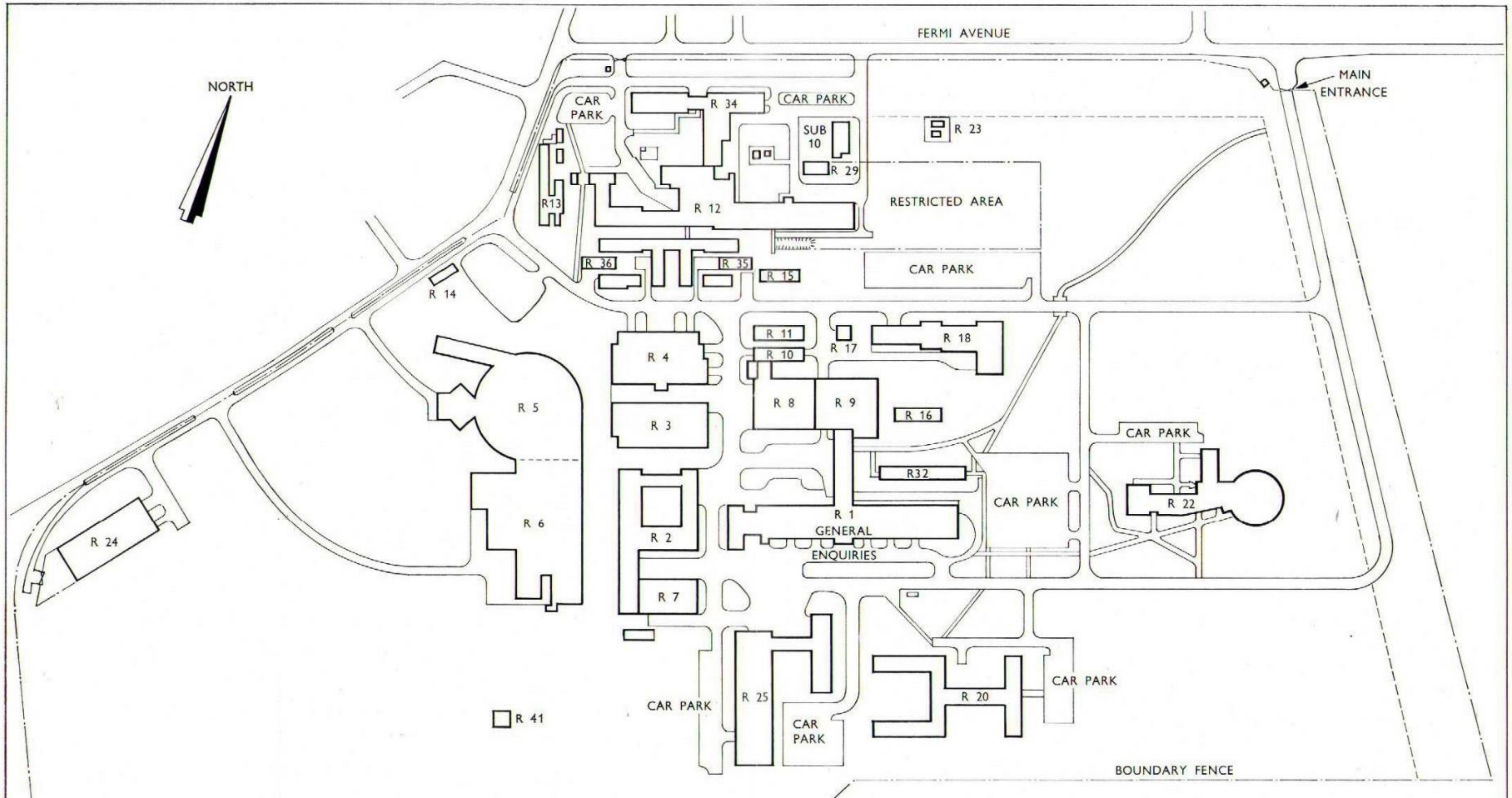
An extensive programme of experimental work is being carried out, both to investigate the problems of magnet construction and low temperature operation and to clarify the performance and reliability of the materials themselves. In addition, a detailed theoretical study is being undertaken of the economic and practical aspects of high magnetic fields in high energy physics, covering all applications from simple focusing devices to large storage ring magnets. This survey is providing Ph.D. material for the first postgraduate student at the Rutherford Laboratory.

## VARIABLE ENERGY CYCLOTRON GROUP

Group Leader Mr. J. D. Lawson

A 70 inch Variable Energy Cyclotron is being built for the Atomic Energy Research Establishment. A team from the Rutherford Laboratory (about 20 scientific staff and 15 engineers) are responsible for supervising its construction, installation and commissioning. Treasury approval for £1,600,000, which includes the building and the cost of design was obtained in 1962. The building is nearly complete and some of the cyclotron is installed; the first useable beams are expected in 1965.

The cyclotron will be used for a wide variety of basic studies relevant to the design of nuclear reactors. Among these will be the study of radiation effects on materials and on chemical processes, the production of special heavy elements (notably "transuranics") for chemical studies, and measurements designed to further the understanding of the fission process. Every effort is being made to make the machine as versatile as possible, so that many different types of ions can be accelerated, from protons to the nuclei of heavier elements such as neon and argon. Furthermore, the energy to which the ions can be accelerated will also be variable over a wide range. The information on radiation effects




NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

# RUTHERFORD HIGH ENERGY LABORATORY

SITE PLAN

Buildings to be visited during the Tour

R.1 SCANNING LAB. AND ORION COMPUTER
VARIABLE ENERGY CYCLOTRON
OXFORD ELECTROSTATIC GENERATOR } EXHIBITS
NIMROD GENERAL PHYSICS
R.2 NIMROD CONTROL ROOM
SPARK CHAMBER EXHIBITS

R.3 NIMROD POWER SUPPLY HOUSE
R.5 NIMROD MAGNET ROOM AND INJECTOR HALL
R.6 NIMROD EXPERIMENTAL HALL 1.
R.8 } ENGINEERING EXHIBITS
R.9

R.12 P.L.A.
R.22 RESTAURANT AND LECTURE THEATRE
R.25 PARTICLE SEPARATOR
TARGET MECHANISM } EXHIBITS
CYCLOTRON ION SOURCE
R.34 NUCLEAR AND RADIOCHEMISTRY LABORATORY

obtainable from beams of well defined energy and direction will be complementary to that obtained from omnidirectional neutron fluxes obtainable in a reactor and should enable comparable effects to be studied much more quickly.

The efforts to achieve versatility pose a number of problems. Parameters that are normally fixed, such as the accelerating frequency, the magnetic field distribution in the gap or the position of the ion source and beam extractor, all have to be made variable. This leads to great complexity with a large number of "knobs", all of which have to be correctly set (rather like a combination lock).

The maximum proton energy will be 50 MeV, with an extracted beam current of some 100 microamps. The energies of heavy ions will be of the order of 100 MeV, depending on the ratio of charge-to-mass which can be achieved (the more electrons that can be 'stripped' off an ion in the source, the higher will be its nett charge).

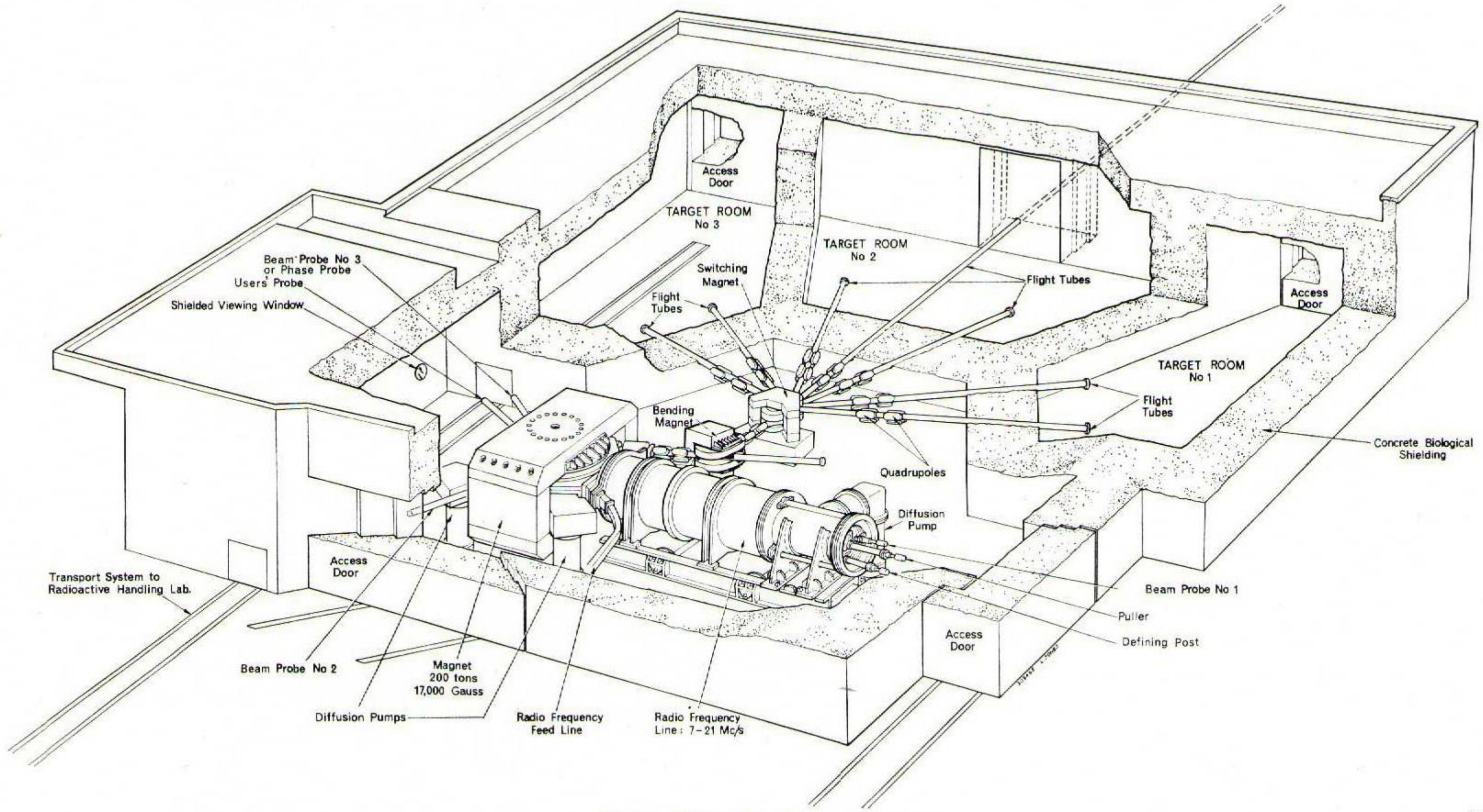
The main components of the machine are a 200-ton magnet (with gap and "ridges" aligned to a few thousandths of an inch), a radio frequency resonator and dee system some 20 ft. long, fed by a commercial radio transmitter with up to 250 kW of r.f. power and an electrostatic 'extractor' which will bring the circulating ion beam out of the machine, down a pipe through magnetic switches and lenses into one of three shielded target rooms.

Although some of the design can proceed according to well established principles, a considerable amount of subsidiary experimentation on magnets, radio frequency systems and ion sources is needed, each of these items being covered by one of the sections of the cyclotron group. In addition, there is a 'toy' working cyclotron, in which beam optics near the centre of the machine is studied under scaled conditions.

Even after the cyclotron is running, it is expected that there will be, for many years, scope for further development to increase the range of beam available and to improve properties such as their stability and uniformity.

**Exhibits**

The small cyclotron and a model of the Variable Energy Cyclotron are displayed in Lab. 2, R.1. Ion source work for the cyclotron is exhibited in R.25. Technical Leaflets are available at each of these exhibits.



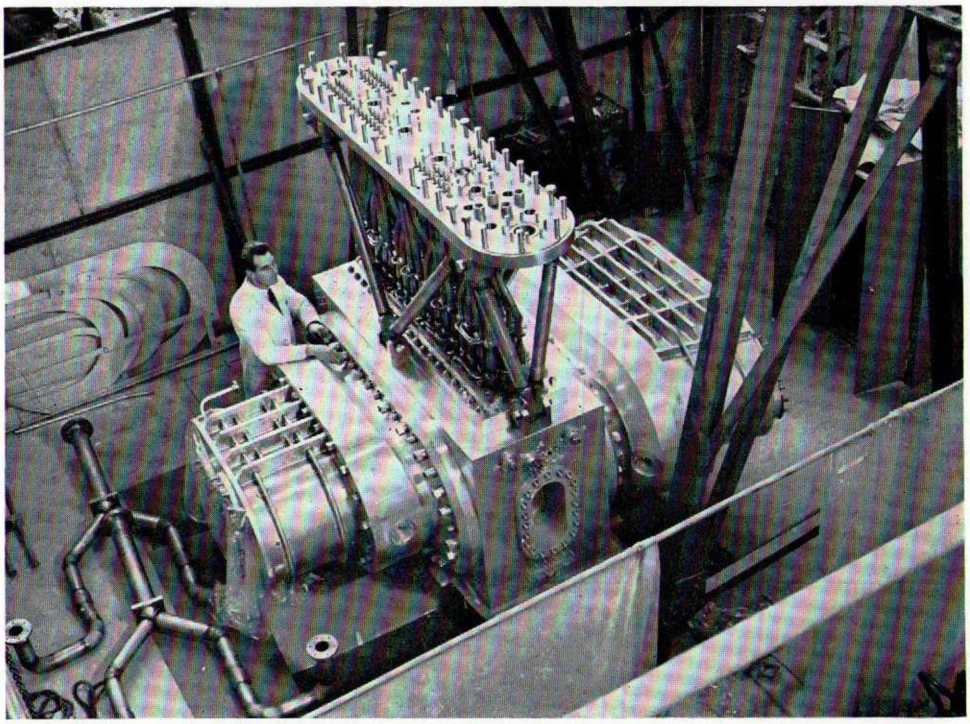

HARWELL VARIABLE ENERGY CYCLOTRON

## BUBBLE CHAMBERS GROUP

Group Leader Mr. M. Snowden

One of the most important developments in high energy physics in the last decade has been the invention of the bubble chamber. A bubble chamber allows individual interactions between particles to be observed, operating on the principle that the passage of an electrically charged particle through a superheated liquid leaves a trail of tiny vapour bubbles. In the presence of a magnetic field these tracks have a curvature depending on the charge and momentum of the particle. The tracks are photographed, using three cameras so that their path can be reconstructed in three dimensions, and by interpreting the tracks, a great deal of information about the properties of the particles can be obtained. Three large bubble chambers will be used with Nimrod.

The British National Hydrogen Bubble Chamber is a joint venture by the Rutherford Laboratory and several Universities financed by the Department of Scientific and Industrial Research. It was assembled at



*The British National Hydrogen Bubble Chamber.*

the Rutherford Laboratory by February 1963 and is at present in use with the 25 GeV proton synchrotron at CERN. Later the bubble chamber will return to the Laboratory for experiments on Nimrod. It is a 1·5 metre hydrogen chamber (hydrogen has the advantage that the target nuclei are single protons which greatly simplifies the interactions), but it can also be operated with liquid deuterium when each target nuclei would be a proton and a neutron.

A 1·4 metre Heavy Liquid Bubble Chamber (proposed by University College, London) has been financed by the National Institute and the chamber is under construction at the Rutherford Laboratory. A wide variety of liquids may be used, ranging from relatively light liquids such as propane to heavier ones such as freon. The liquids have complex nuclei consisting of many neutrons and protons and this type of chamber is used mainly for studying the decays of very short-lived particles produced in particle interactions. Chambers of this type are efficient detectors of high energy gamma rays and bring fast charged particles to rest so that they can be identified by the characteristic way in which they decay.

An 80 centimetre Liquid Helium Bubble Chamber (proposed by the Clarendon Laboratory, Oxford) was financed by the National Institute and construction is under way at the Laboratory. The helium nuclei are interesting targets because their stable configuration of protons and neutrons reduces the number of possible combinations of particles resulting from the interactions.

A small 8 inch freon chamber is used for beam monitoring and background measurements.

Exposed film from bubble chamber experiments is developed, scanned and interesting tracks are measured. A continuous developing machine is used and when the three lengths of film of the same events have been processed they are scanned to select the interesting interactions. The scanning machines project the three views onto a desk to be studied; the frame numbers of the interesting photographs are recorded and those photographs are passed on for measuring. All three views are measured and the measuring machines punch the data on tape to be fed to a computer. The computer reconstructs the topology of the event and applies various physical hypotheses to calculate the probabilities that the event corresponds to the hypotheses. This information is passed to the nuclear physicist for interpretation.

Work is underway on automatic measuring machines which would be controlled directly by a computer.

The group has a staff of forty-five, comprising physicists, engineers, technologists and experimentalists. The work covers the design, building, development and operation of the bubble chambers and the equipment for analysing the data recorded during the bubble chamber experiments. Collaboration with the University teams occurs at all stages in their work.

**Exhibits**

The heavy liquid bubble chamber and the freon bubble chamber are on display in Experimental Hall 1. The work of a scanning laboratory is shown in conjunction with the visit to the Orion computer. Technical Leaflets are available at each exhibit.

## THEORETICAL STUDIES GROUP

Group Leader Mr. W. Walkinshaw

During the past ten years emphasis has moved slowly from studies of the dynamics of particle accelerators towards a more active participation in the analysis of nuclear physics data and current work in the group, which has 26 scientific staff, is largely based on the application of computing techniques to the high energy physics programme.

Design studies of accelerators have been directed either towards increasing the beam intensity or to extending the energy of present machines. Laboratory staff have collaborated with a group at the European accelerator centre, CERN, in detailed studies of a proposed new European accelerator of 300 GeV energy. Theoretical studies of particle dynamics for Nimrod, the P.L.A. and the Variable Energy Cyclotron, including the optics of secondary particle beams are also actively pursued.

In recent years the advance of technology in detection and analysis of data from accelerators has been as impressive and about as costly as the machines themselves. Large bubble chambers are capable of producing millions of pictures of high energy events per year. Fast measuring devices have been designed to process these events and high speed computers are used extensively to analyse the data. Counter techniques indicate a similar trend with the development of spark chambers, sonic spark counters and hodoscopes.

During the past few years members of the group, in collaboration with University physicists, have been engaged in developing elaborate and sophisticated computer programmes for the analysis of this data. Work is also at an advanced stage to feed measured data from a flying-spot automatic measuring machine directly into the computer. This is an exciting new application of automation which is likely to develop rapidly over the next few years. The time sharing facilities on the Orion computer, which is operated by the group, will be used to analyse data coming directly from Nimrod while an experiment is actually running. Orion unfortunately, is rather slow and small to cope with all the data to be analysed and at present extensive use has to be made of computers outside the Laboratory until the N.I.R.N.S. Atlas computer comes into operation later this year.

## The Orion Computer

In January 1960 treasury approval was given for an Orion computer at a cost of £400,000. Orion is fully transistorised and has a fast general purpose central computer, facility for attaching up to 125 peripheral devices (paper tape recorders, tele-type punches, magnetic tape units, a line printer and an on-line direct data link to an automatic film reader) and a time-sharing system which allows several programmes to run concurrently. The computer will accept programmes written in both Autocode and Fortran language.

The central computer has a large two level store; an immediate access working store and a relatively slow backing store. The working store is made up of 16,384 'words' in magnetic cores with a cycle time of 12 microseconds. The backing store consists of two magnetic drums each holding a total of 16,384 words (128 tracks each containing 128 words) which revolve at 2500 r.p.m.

**Exhibits**

The Orion computer is on display for the Press Visit and its work is described in association with that of a scanning laboratory. A Technical Leaflet is available.

## P.L.A. DIVISION

The 50 MeV Proton Linear Accelerator (P.L.A.) was built by A.E.R.E. and transferred to the National Institute. It produced its first 50 MeV beam on 12th July, 1959. The machine works in a very interesting energy region from the point of view of nuclear physics for until quite recently this energy range was covered only by the 68 MeV P.L.A. at Minnesota, U.S.A. The Laboratory machine has about 100 times greater beam intensity, a very successful source of 'polarised' protons and a sophisticated 'time of flight' device—exceptional facilities which make possible many experiments which any other Laboratory would find very difficult.

### THE MACHINE

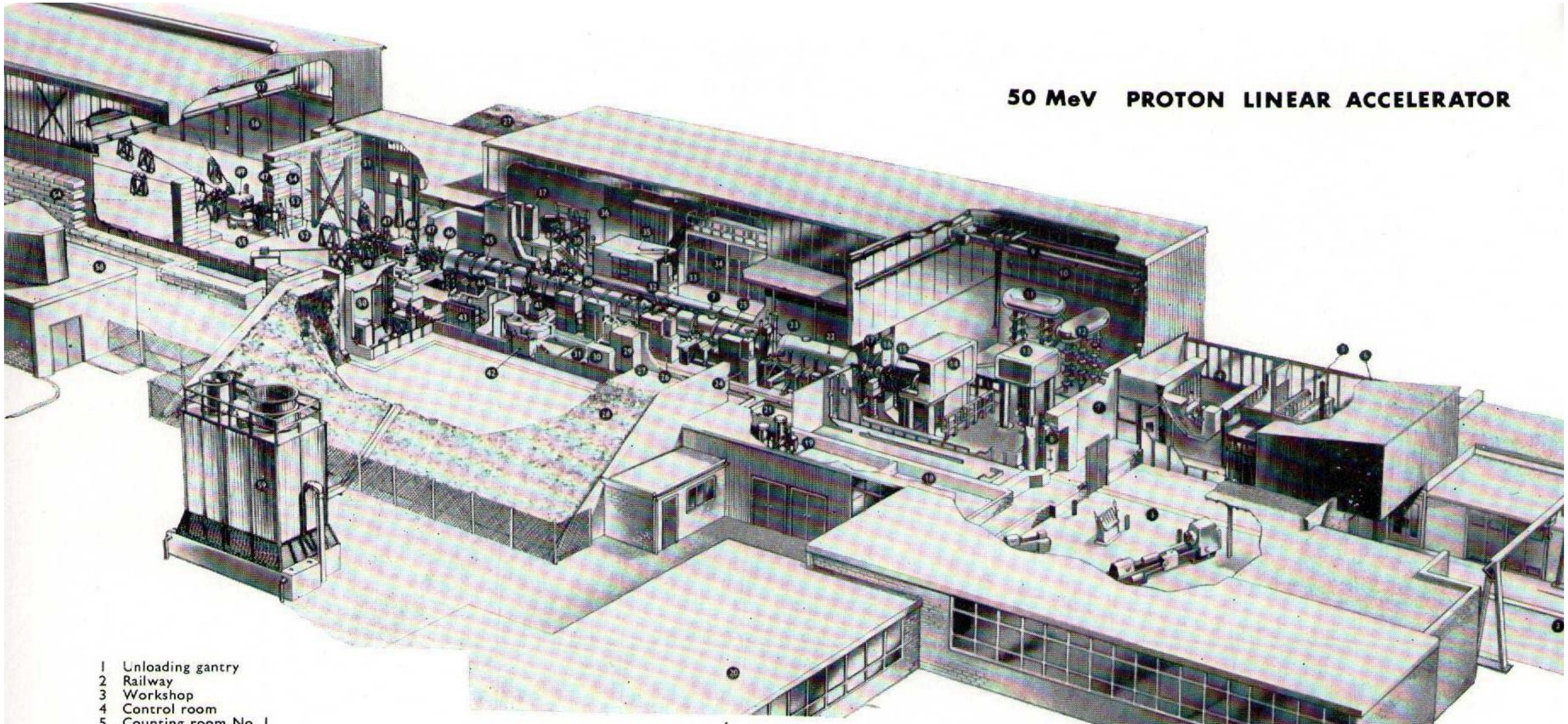
The P.L.A. is about 100 ft. long and has three main copper resonator sections or "liners" fed with r.f. power. Each is enclosed in an outer cylindrical steel vacuum envelope which is connected to a number of large 20 inch oil diffusion pumps to maintain a pressure below $10^{-5}$ torr in order to prevent scattering of the proton beam and avoid voltage breakdown in the resonator.

The first tank is about 18 ft. long and accelerates protons from 0·5 MeV to 10 MeV energy; the second and third tanks are each about 40 ft. long and take the protons successively to energies of 30 and 50 MeV. Drift tubes which shield the protons when the r.f. field is in the decelerating direction, are made of copper and supported on the axis of each resonator by two radial "stems". There are 42 in tank 1, 41 in tank 2 and 27 in tank 3. The proton beam receives about 110 separate "kicks" as it crosses between drift tubes to accelerate it up to 50 MeV.

600 kW of r.f. power is fed to tank 1 and about 1·25 to 1·5 MW to tanks 2 and 3. It is only practicable to produce such high powers in very short pulses, using radar type modulator techniques. (Even then, approximately 0·5 MW of mains power is required to run the whole machine.) 50 pulses per second are used, each 400 microsecs. long and the proton beam is accelerated for about 200 microsecs. during each pulse. The power is produced by a series of grounded grid triode amplifier valves, each capable of producing 1 MW of pulsed power. These valves were designed and developed by the A.E.R.E. valve group and are unusual in their "inside out" construction—having an external, directly heated, cathode and a central anode.

Two focusing methods are used on the P.L.A. to prevent the beam spreading out and colliding with the drift tubes. Grids are fitted in the entrance aperture of every drift tube in tank 1 and cause a distortion

# 50 MeV PROTON LINEAR ACCELERATOR



1 Unloading gantry
2 Railway
3 Workshop
4 Control room
5 Counting room No. 1
6 Counting room No. 2
7 Concrete shielding wall
8 Concrete doors
9 1½ ton crane
10 Injector room
11 Cockcroft-Walton high voltage generator
12 Filter stack
13 Ion source power supply platform
14 Polarised proton source bun
15 Injector column
16 Beam deflecting electrodes
17 Buncher
18 Laboratory workshop
19 Water softening plant room
20 Crew room
21 Modulator cubicles
22 Tank 1
23 Tank R.F. feed line
24 Valve A cubicle (Tank 1 main R.F. amplifier)
25 Tank 2
26 Valve C cubicle (Tank 2 main R.F. amplifier)
27 R.F. drive
28 Earth bank shielding
29 Valve B cubicle (High power R.F. drive amplifier)
30 Foster regulator
31 R.F. power dividing network
32 R.F. power combining bridge
33 Valve E (Tank 3 main R.F. amplifier)
34 Power supplies for beam transport system
35 Tank 3 R.F. amplifier cubicle for valves E and F
36 Auxiliary plant room
37 Bending magnet supply stabiliser
38 Valve F (Tank 3 main R.F. amplifier)
39 Generator supplying bending magnet
40 Local control racks
41 Vacuum pumping unit
42 Modulator cooling refrigerator
43 Pulse forming network
44 Valve D cubicle (Tank 2 main R.F. amplifier)
45 Tank 3
46 Beam monitor
47 Beam focusing quadrupoles
48 High speed shut-off valve and vacuum pump
49 Beam bending magnet
50 Modulator E.H.T. supply transformer
51 Experimental area No. 1
52 Beam transport pipes
53 Beam stop
54 Concrete block wall
55 Vacuum pumping unit
56 Experimental area No. 2
57 10 ton crane
58 Pump house
59 Cooling towers

of the r.f. field pattern which results in a focusing effect. In tanks 2 and 3, quadrupole magnets are placed inside every drift tube.

The proton beam is accelerated to 0·5 MeV in an 'injector column' before entering tank 1. This column has an r.f. type of proton source and a Cockcroft-Walton generator produces the 0·5 MV potential.

The 50 MeV beam leaving the end of Tank 3 is transported along evacuated flight tubes to either of two experimental areas. Further quadrupole magnet lenses are used to keep the beam focused and in each area a large bending magnet (weighing about 30 tons) is used to deflect the beam along a number of different beam lines, on each of which a different nuclear physics experimental apparatus can be set up.

Two special facilities of the P.L.A. are the 'polarised proton source' and the 'time of flight' device. The polarised proton source enables beams to be fed into Tank I for acceleration, containing protons whose axis of spin points in any specially selected direction. This means that one parameter (the spin) of the protons in the beam which hits the target is preselected and this enables experimental results to be interpreted which would otherwise have been impossible or very difficult.

Due to the use of very high frequency fields in accelerating the beam, protons arrive at the targets in bursts less than $10^{-9}$ secs. long and by suitable pre-selection, these bursts can be spaced up to 0·2 microsecs. apart. All the secondary particles produced from one burst will have passed a detector before the next burst arrives. Similar timing precision is possible at the detector so that velocities of secondary particles can be measured very accurately and without confusion by this 'time of flight' method.

**Principal Parameters of the P.L.A.**

| | Tank 1 | Tank 2 | Tank 3 |
|---|---|---|---|
| Dimensions of liners | | | |
| Length | 18 ft. | 39 ft. | 37 ft. |
| Diameter | 42 in. | 36 in. | 32 in. |
| Number of Drift Tubes | 42 | 40 | 28 |
| Energy of proton beam | 10 MeV | 30 MeV | 50 MeV |
| Velocity of protons (expressed as a fraction of the velocity of light) | 0·14 | 0·25 | 0·3 |
| Mean current at 50 MeV | $12{\cdot}5 \times 10^{10}$ protons/sec. | | |

## NUCLEAR PHYSICS ON THE P.L.A.

Associated with the P.L.A. are some fifty experimental nuclear physicists, the majority from Universities with two teams largely made up from Laboratory staff, and one from A.E.R.E. The University teams include physicists from Birmingham, London (King's College, Queen Mary College, University College and Westfield College) Oxford and Queen's University, Belfast. Experiments are often carried out by joint teams of Laboratory staff and University visitors and from time to time visitors from Canada, the U.S.A. and Poland have participated. The growing number of successful experiments is evident from the many published papers and the more than a dozen higher degrees which have now been awarded to members of the various teams.

With the special techniques available (polarised proton source and time of flight device), many different types of experiment are possible. One major activity is the study of the forces between isolated protons; here the interacting entities are simple and the 50 MeV energy is too low to introduce the complication of meson production. But the nature of the force is so complex that many different experiments, each of high precision are needed. The absolute scattering cross section (which represents the area a target proton presents to a proton in the beam) has been measured to 1%. The asymmetry in scattering has also been investigated: the tendency of a proton to be scattered to the left rather than the right, depends on whether its spin is pointing upwards or downwards relative to the plane of scattering. For proton-proton scattering the tendency is very feeble (only 3% more of the protons in a completely polarized beam will choose to go left rather than right at 50 MeV) but exact magnitude is very important, and has been determined as $0{\cdot}0316 \pm 0{\cdot}0017$, an accuracy unattainable without the polarized source. The next generation of experiments on the proton-proton system is to show how the spin direction changes in the scattering process and three of these measurements have been carried out successfully. Already much of the proton-proton interaction can be explained in terms of the clouds of $\pi$ mesons tied to the protons; other features may be due to $\omega$ and $\rho$ mesons. Studies are also under way on the proton-$\alpha$ particle collisions, where the asymmetry effects can be enormous (90% of spin up protons go left for one angle of scattering; but a change in the scattering angle of 20° gives 75% going to the right). Similar oscillations in the effect happen with heavier elements. There is a large programme to study these 'polarization angular distributions', as well as the 'differential cross sections' and the total probability of the proton reacting with the nucleus and to interpret all the results together on the 'optical model'. This 'model' attempts to correlate elastic scattering of protons from a variety of nuclei over a range of energies, in terms of a few numbers describing the size of the nucleus, the 'fuzziness' of its boundary and so on.

Apart from elastic scattering, there is an enormous variety of 'reactions' that can occur at 50 MeV. One of the simplest is radiative capture. The proton is absorbed and only $\gamma$-rays are emitted. Experiments show this particular reaction to be relatively rare, but not so rare as present theories predict.

Neutron emission can be studied very precisely by the time of flight method. When a proton strikes a deuterium nucleus and knocks the neutron out in a forward direction, the neutron has a very well defined energy in most cases. This is a particularly good source for neutron experiments. Interesting things happen with the more complex nuclei in which neutrons outnumber protons. It seems that a proton can eject one of the 'excess' neutrons and occupy the hole left by the neutron. The energy of the neutron does not then depend on which 'hole' the neutron came from but differs from the proton's by an amount fixed by the Coulomb repulsion felt by the proton. The effect changes in importance with energy and the size of the nucleus and more work is needed to understand it properly.

Time of flight is also a useful technique when charged particles are ejected. Their energy can be measured from the intensity of the light flash they produce in a scintillation counter, and with their velocity from the time of flight apparatus, electronic circuits can work out the particle's mass ($E = \frac{1}{2}mv^2$, or very nearly). With additional counters to measure rate of loss of energy, the charge can be found too. By this method protons, deuterons, $H^3$, $He^3$ and $\alpha$-particles have all been identified as reaction products and the angular distributions relative to the incident protons shown to agree with calculation in some cases. The (p, $He^3$) and (p, $H^3$) reactions are particularly interesting. They can be pictured as resulting from the incident proton plucking a proton-neutron pair, or a pair of neutrons, out of a nucleus. To be effective, the 'pair' must be preformed in the nucleus. It seems that whereas in light nuclei the existence of the two sorts of pairs, and so the probabilities of the two sorts of reactions, is equally likely, in heavy nuclei neutron pairs predominate because the Coulomb force due to all the other protons acts on protons but not on neutrons, and breaks up the neutron proton pairs.

It is evident that many years of interesting work lie ahead; improvements to the machine and new experimental techniques constantly helping the investigation of more and more complicated behaviour in the nucleus.

*Tank 3 of the P.L.A. showing the drift tubes; the vacuum cover and the liner lid are removed.*

*Part of the new P.L.A. Experimental Area showing the alternative beam pipes radiating from the bending magnet.*

**Exhibits**

The P.L.A. control room, the machine itself and the experimental areas are open for the Press Visit and Technical Leaflets are available to give more detailed information on the machine and the nuclear physics experiments.

## ORGANISATION OF DIVISION

### P.L.A. NUCLEAR PHYSICS GROUP

Group Leader Dr. R. C. Hanna

This group has about 18 scientific staff who use the P.L.A. for nuclear physics experiments and collaborate on experiments with visiting teams, as described above.

### P.L.A. MACHINE PHYSICS GROUP

Group Leader Mr. J. M. Dickson

26 scientists are concerned with accelerator physics. Their work covers development of the P.L.A., which includes improvements to the polarised proton source and redesign of the focusing system in Tank 1, and also studies on future linear accelerators.

A small team is engaged on a design study for a 200 to 250 MeV Proton Linac as an Injector for a 300 GeV Proton Synchrotron which is proposed as the next European accelerator. Another team is studying the possibility of applying superconductivity techniques to proton linear accelerators. The r.f. power requirements using superconducting resonators would be drastically reduced and the machine could have the great advantage of continuous running instead of pulsed operation as used at present. A further study of a machine to give continuous running and high intensity beams is concerned with a 'beehive' accelerator where particles would follow a path resembling a spiral helix.

### P.L.A. ENGINEERING GROUP

Group Leader Mr. J. B. Marsh

Some 14 professional electrical and mechanical engineers, 20 technicians and 27 instruments makers make up the engineering group. It is responsible for the operation and maintenance of the P.L.A. and for engineering support for the other two P.L.A. groups.

## NUCLEAR AND RADIOCHEMISTRY LABORATORY

Group Leader Mr. J. C. Cuninghame

To extend the National Institute facilities to chemists also, the A.E.R.E. Chemistry Division was asked to help in the design of a nuclear and radiochemistry laboratory and to provide a resident team to organise the work and manage the laboratory. The laboratory building, attached to the P.L.A. laboratories, was first occupied in December 1962 and is designed to house 12 to 16 chemists.

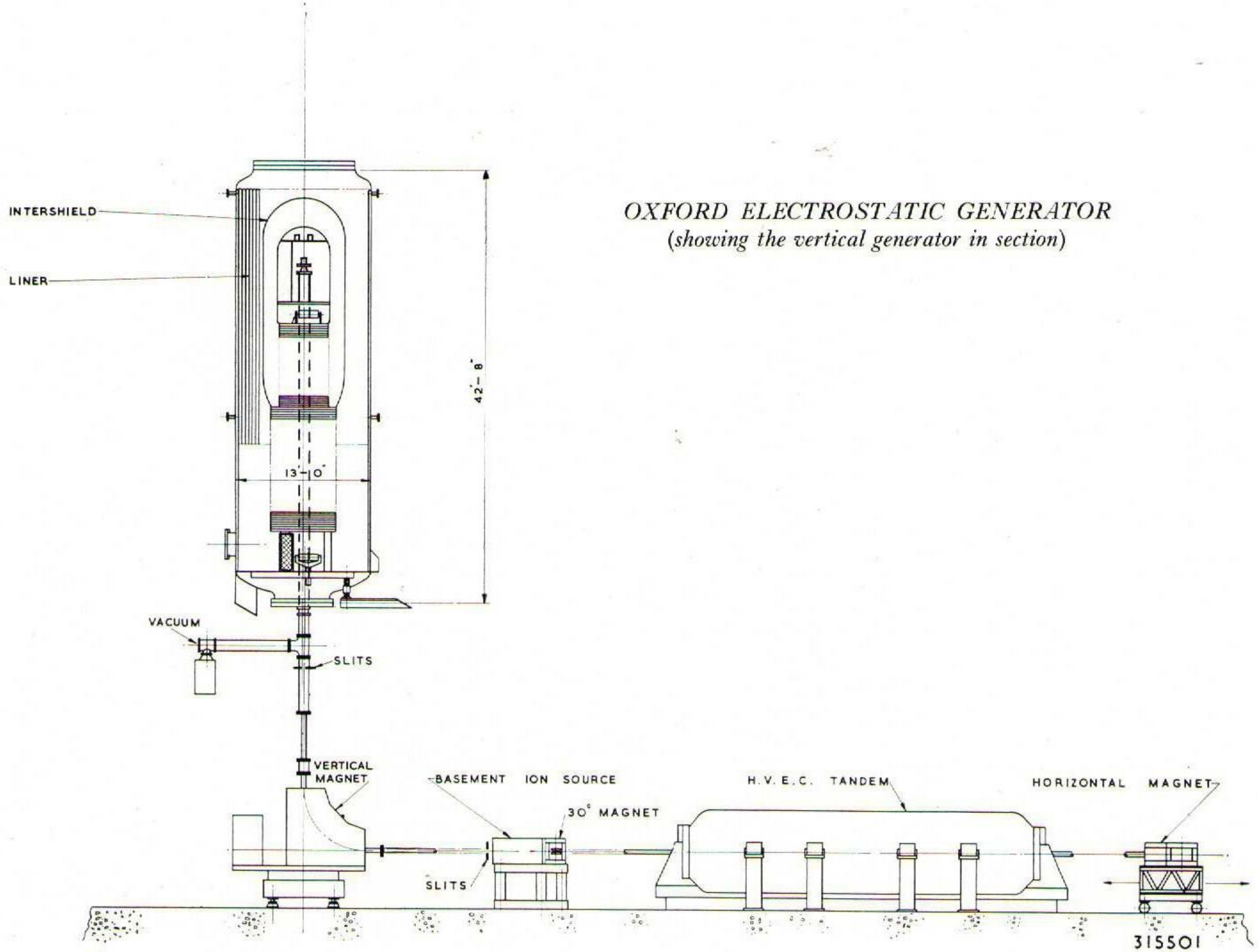
Nuclear and radiochemistry covers experiments involving both chemical and physical techniques in research with radioactive materials, with the object of exploring the properties of the nucleus and of tackling purely chemical problems.

Particle accelerators are used to irradiate materials which are then processed and measured using the special laboratory facilities. These include fume hoods with glove box equipment, to cope with a maximum of 50 grammes of plutonium at any one time, and a cave equipped with manipulators to handle up to 10 MeV/curies of gamma activity with full alpha protection. There is also excellent electronic counting equipment with an automatic data handling system. Although the laboratory is small it is well equipped to take advantage of the exceptional range of irradiation facilities in the immediate vicinity, a range perhaps unequalled anywhere else in the world.

An A.E.R.E. team, together with two visiting American professors from the Universities of Washington and Los Alamos are working on aspects of the fission process. A team from the Geology Department of Oxford University is using radiochemical techniques to study the distribution of trace elements in rocks. A team from the Nuclear Physics Department of Oxford University is concerned with Hot Atom Chemistry (which deals with the breaking of chemical bonds by energy derived from nuclear reactions). Other visitors have asked for space to work on spallation reactions, crystallography and on medical problems using tracer techniques.

**Exhibits**

The Laboratory is open for the Press Visit and some of the equipment is specially displayed. A Technical Leaflet is available to give more detailed information on the laboratory and its facilities.




*OXFORD ELECTROSTATIC GENERATOR*
*(showing the vertical generator in section)*

# THE OXFORD ELECTROSTATIC GENERATOR GROUP

The Department of Scientific and Industrial Research is contributing over £$\frac{3}{4}$ million towards establishing a research centre, the Nuclear Structure Laboratory, for Oxford University. The central feature of this Laboratory is an electrostatic generator, the first stage of which is an 8 to 10 MeV Van de Graff vertical machine. This first stage has been designed by a team from the Rutherford Laboratory who are also supervising the construction which is due for completion in 1964. The second stage is a commercially available horizontal tandem generator (from High Voltage Engineering Co., U.S.A.) and the Rutherford Laboratory team is responsible for integrating the whole system.

The electrostatic generator has the virtue of high precision in energy (of the order of one part in ten thousand) and also of flexibility, both in energy and in type of particle accelerated. Its limitation has always been the energy range through which the particles can be accelerated. Seven years ago, with 'single ended' machines, this limit was 6–7 million volts: a positive ion source was housed in the high voltage terminal and the ions were repelled from 6 million volts positive to earth. Since 1958–9 this limit has been doubled, in the so-called 'tandem' machines, through the principle of charge exchange. In these machines, negative ions (i.e neutral atoms which have an electron attached) are generated at earth potential, and injected into a machine in which the accelerating tube is continuous from end to end, and a centre terminal is held at 6 million volts positive. The ions are attracted to this terminal, which they reach with an energy of 6 million electron volts, and pass through a small quantity of matter (a thin foil, on a tube containing gas). Passage of ions through this material "strips" electrons off, leaving the particles positively charged. They are then repelled to earth, and emerge (if they are protons) with a total energy of 12 million electron volts.

Even 12 million electron volts is not sufficient to enable the physicist to study nuclear reactions in heavy atoms such as uranium, for which protons of at least 17 million electron volts are required. In the Oxford project, therefore, the negative ions are injected into the tandem, not at approximately earth potential, but with energies of 8–10 million electron volts gained from a separate single-ended machine. The final energy should be in the range 20–22 million electron volts.

In the Oxford project the chief responsibility of the group is the large vertical single-ended machine which constitutes the 'injector'. The pressure vessel, housed in a tower 84 ft. high, is 40 ft. long and 13 ft. in diameter and contains gas weighing 4 tons.

The insulating column is 20 ft. long and is made accessible for servicing by a lift hoisted by three hydraulic rams. The accelerating tube incorporates a series of electrodes tilted at a small angle to the horizontal. This development has been tried in three other machines, and shows great promise, since accelerating tubes with electrodes normal to the axis have hitherto been a major limitation in the performance of electrostatic generators, due to electron loading. On emerging from the injector, the beam is deflected into the horizontal by a 6 ft. radius bending magnet. At the output of the tandem, it is deflected by another 90° magnet into the target rooms.

As well as 'coupled' operation, the machines operate as separate units: the injector can fire positive or negative particles up to 8–10 million volts into a separate target room: a separate ion source, built by a combined Rutherford Laboratory and Oxford team, enables the tandem to operate as a separate machine.

The group is comprised of 15 scientific staff and 5 engineers. They have operated so far mainly in a hangar in A.E.R.E., where a 21 ft. deep pit has been an ideal home for a test machine. This test machine, with a 6 ft. long stack, has been a very valuable source of information on negative running machines, particularly as regards their stabilization. An electron beam has been accelerated to 4·2 million volts, 700 kV per foot, which is an exceptionally high value for electrostatic acceleration.

**Exhibits**

A display covering the Electrostatic Generator is exhibited in Lab. 7, R1. A Technical Leaflet, giving more detailed information on the project is available.

## ENGINEERING DIVISION

The work of the Laboratory demands a wide range of engineering experience in civil, chemical, electrical, electronic and mechanical disciplines. This work varies from the design, manufacture and maintenance of standard equipment, such as general power supplies and lifting gear, to challenging and unusual problems, such as the design and provision of plunging mechanisms and particle velocity separators.

After providing engineering support in the design and construction of Nimrod, the Engineering Division now supplies and maintains site and building services for the Laboratory, provides a comprehensive design and supply service for engineering equipment, and has design teams engaged on the Oxford Electrostatic Generator and the Variable Energy Cyclotron projects. The Division has about 100 professional engineers and technicians together with skilled craftsmen and unskilled workers.

Detail design assistance is often provided by private design and drawing office firms and assistance for plant installation, wiring and similar work is obtained on outside contracts. Manufacture is in the main obtained through the usual competitive tendering procedure and this was also used while Nimrod was under construction. The A.E.A. provides a service for major building works and also an inspection and progress service for the larger contracts.

Various workshop facilities are provided on the site. Their main function is to supply the smaller, specialised or more urgently required equipment and also to implement modifications made necessary by development or changed requirements, revealed by experimental and operational experience.

The Central Engineering Group of the Division (Group Leader Mr. G. E. Simmonds) has sections covering mechanical services and buildings, electrical design and services, and mechanical design and estimates. A group responsible for safety within the Laboratory reports directly to the Chief Engineer.

### Exhibits

Engineering exhibits, including exhibits from engineering sections of other Divisions, are on display in R.8, R.9. R.16 and R.18. Technical Leaflets are available which detail the work of the Division more thoroughly.

# ADMINISTRATION DIVISION

## GENERAL ADMINISTRATION GROUP

Group Leader Mr. W. W. Woodall

The group, with about 70 personnel, provides certain administrative services for the whole Laboratory; these include the stores organisation, transport, secretarial and typing services, accommodation, the restaurant and many others. In addition, certain specific administrative support is provided to other Divisions through Local Administrative Officers.

## PERSONNEL GROUP

Group Leader Mr. R. M. Jenkins

The group, numbering 13 staff, has two main functions. It recruits new employees, of all grades, to the Laboratory. It also interprets and implements the management's staffing policy in such matters as salaries and wages, conditions of employment, superannuation, promotions and so on.

## FINANCE AND ACCOUNTS

Group Leader Mr. A. Miller

The Finance and Accounts group has 22 staff and looks after the Laboratory grant from the Treasury. It is concerned with Divisional budgets and capital schemes, and also with assembling information for annual estimates, financial forecasts and other forward planning exercises.

## SCIENTIFIC ADMINISTRATION

Group Leader Mr. T. R. Walsh

The group, although numerically small with seven staff, covers a wide range of work. It is responsible for the library and information services, university liaison, public relations, technical writing, documentation and the secretarial work of many scientific or technical committees.

## RADIATION PROTECTION GROUP

Group Leader Mr. M. Snowden

Experiments in nuclear physics and nuclear chemistry involve ionising radiations of many kinds and energies. Different radiations have different effects on the human body and materials used in apparatus and, as much of this is a specialist study, the group has the function of advising as to the safety of operations, shielding requirements, permissible exposures to radiation and the suitability of radiation detecting instruments. The group also has a programme of research into new methods of radiation detection particularly in the field of neutron dosimetry at various energies, and the effect of proton and heavy particle radiation on the body.

Film dosimeters, both for ordinary radiations and for measuring fast neutron dose, are issued to experimenters. The 'badges' are distributed, processed and analysed at regular intervals, and a record is kept of each person's exposure. The maintenance and calibration of health instruments on the site is also a responsibility of the group and they are checked every few months or on request by the user. A daily check of instruments installed near the accelerators is logged.

The Radiation Protection Duty Officer surveys any experiments on request and advises upon safety and shielding requirements and gives advice on chemical methods so far as they affect safety. With the increasing energies of accelerators, shielding studies become more complex and a shield of the wrong material, or of the wrong thickness could make the radiation hazard worse. To study induced activities associated with this work a specialized low radiation background counting apparatus has been built.

A two-frequency radio network enables control points to be set up anywhere within several miles of the site. This has been used to study the effect known as sky-shine from targets in accelerators. The Laboratory has made major contributions to the study of this phenomenon and is planning more elaborate work.

The group consists of eight scientific staff and is outside the Divisional organisation being responsible directly to the Director of the Laboratory.

# OTHER NATIONAL INSTITUTE ACTIVITIES

## THE DARESBURY NUCLEAR PHYSICS LABORATORY

In July 1962 the Government approved the Institute's proposal to establish a second high energy physics laboratory in the North of England. The Laboratory will contain a 4 GeV electron synchrotron (NINA—National Institute Northern Accelerator) and will serve in particular the Universities of Liverpool, Manchester and Glasgow. Professor A. W. Merrison has been appointed Director on secondment from the University of Liverpool.

Construction work began on the Daresbury site in Cheshire in 1963 and the machine is scheduled for completion at the end of 1966 at a cost of £3½ million.

## THE ATLAS COMPUTER LABORATORY

At the request of the Government, the Institute agreed to manage a very fast electronic digital computer, ATLAS, to be installed adjacent to the Rutherford Laboratory site.

The machine, together with its necessary buildings, will cost about £3½ million. It was ordered in August 1961 and installation is now almost complete. The computing facilities will be available to the National Institute, the Atomic Energy Authority, the Universities and others. Dr. J. Howlett was appointed Director of the Laboratory in 1962.

## RESEARCH REACTORS

The National Institute, through their Research Reactor Committee under the Chairmanship of Sir John Cockcroft, review the requirements of Universities for nuclear reactors for teaching and research purposes. The Institute do not themselves own or operate a reactor and to meet the University needs they have arranged access to reactors owned by other organisations (principally the Atomic Energy Authority). For example, three major research programmes proposed by groups at the Universities of Birmingham, Cambridge and Reading are accommodated on the Herald reactor at the Atomic Weapons Research Establishment, Aldermaston.

## LIST OF TECHNICAL LEAFLETS

The following leaflets are available at the various exhibits.

| | |
|---|---|
| A 1 | Nimrod Proton Source and Pre-injector |
| A 2 | Nimrod Injector: Beam Monitoring System |
| A 3 | Nimrod Injector: Linac, Buncher and De-buncher |
| A 4 | Nimrod Injector: High Energy Drift Space and Inflector System |
| A 5 | Nimrod Magnet |
| A 5.1 | Peaking Strips for the Nimrod Magnet |
| A 5.2 | Nimrod Ripple Filter System |
| A 5.3 | Nimrod Vacuum System |
| A 5.4 | Nimrod Vacuum Vessel |
| A 5.5 | Nimrod Injector: Vacuum System |
| A 7 | Nimrod R.F. System and Beam Diagnostics |
| A 8 | Nimrod Target Mechanisms and Proton Extraction System |
| A 9 | Nimrod Control Room |
| A 10 | Nimrod Synchronising System |
| A 11 | Particle Separators |
| A 13 | Liquid Hydrogen Target Systems |
| A 18 | Maximum Current in an Electron Beam |
| A 19 | A Vacuum Gauge using ion trapping. |
| A 20 | Liquid Helium Level Indicator |
| A 26 | Nimrod Magnet Power Supply |
| A 26.1 | Nimrod Power Supply |
| A 29 | Polarised Proton Target |
| B 1 | $\pi 1$ Beam Line and Experiment |
| B 2 | $\pi 2$ Beam Line and Experiment |
| B 3 | $\pi 3$ Beam Line and Experiment |
| B 4 | N1 Beam Line and Experiment |
| B 9 | The Work of the Scanning and Measuring Laboratories |
| B 11 | Electronics Group |
| C 1 | Film Processing Laboratory |
| C 2 | The 1·4 M Heavy Liquid Bubble Chamber |
| C 3 | The Small Portable Freon Chamber |
| C 4 | Bubble Chamber Data Reduction |
| C 5.1 | Model Centre for the V.E.C. |
| C 5.2 | The Evolution of the Cyclotron |
| C 6 | The Variable Energy Cyclotron |
| C 7 | Ion Source Development for the V.E.C. |

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|---|---|
| D 3 | The Nuclear and Radiochemistry Laboratory |
| D 9 | The Polarised Proton Source |
| D 15 | P.L.A. Nuclear Physics |
| E 1 | Design and Manufacture |
| E 2 | Plunging Mechanisms |
| E 3 | Electronics and Instruments Section |
| E 4 | Electrical Services Section |
| E 5 | Industrial Chemistry Section |
| E 6 | Safety Section |
| E 7 | The Oxford Electrostatic Generator |
| E 8 | Mechanical Services Section |
| E 9 | Building Section |
| E 10 | Principal Contractors for Nimrod and P.L.A. |
| G 1 | Electrostatic Generators |

Leaflets from all exhibit areas will be available after the Press Conference if required.

*Lamport Gilbert & Co. Ltd., Gun Street, Reading*