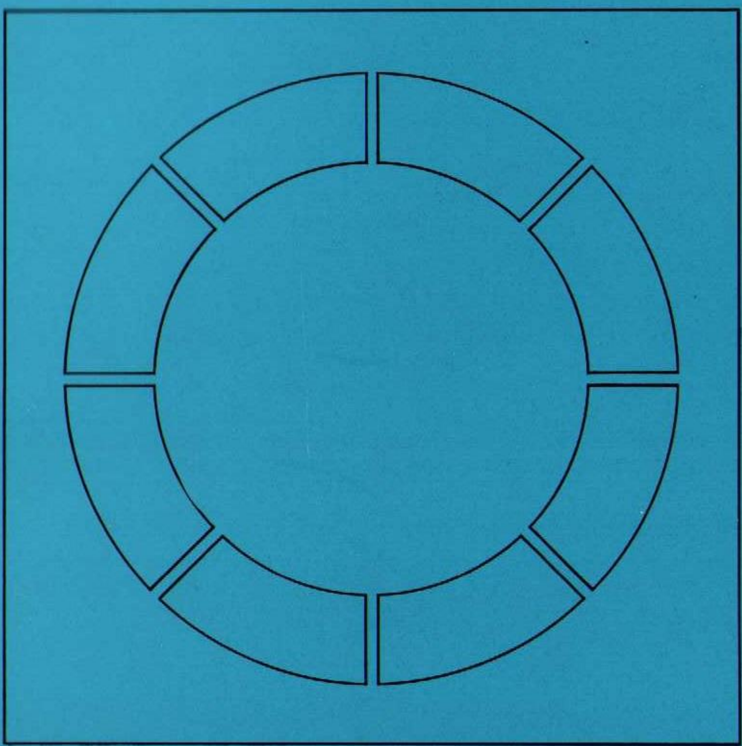
Science Research Council

Rutherford Laboratory
Open Day
19th May 1966



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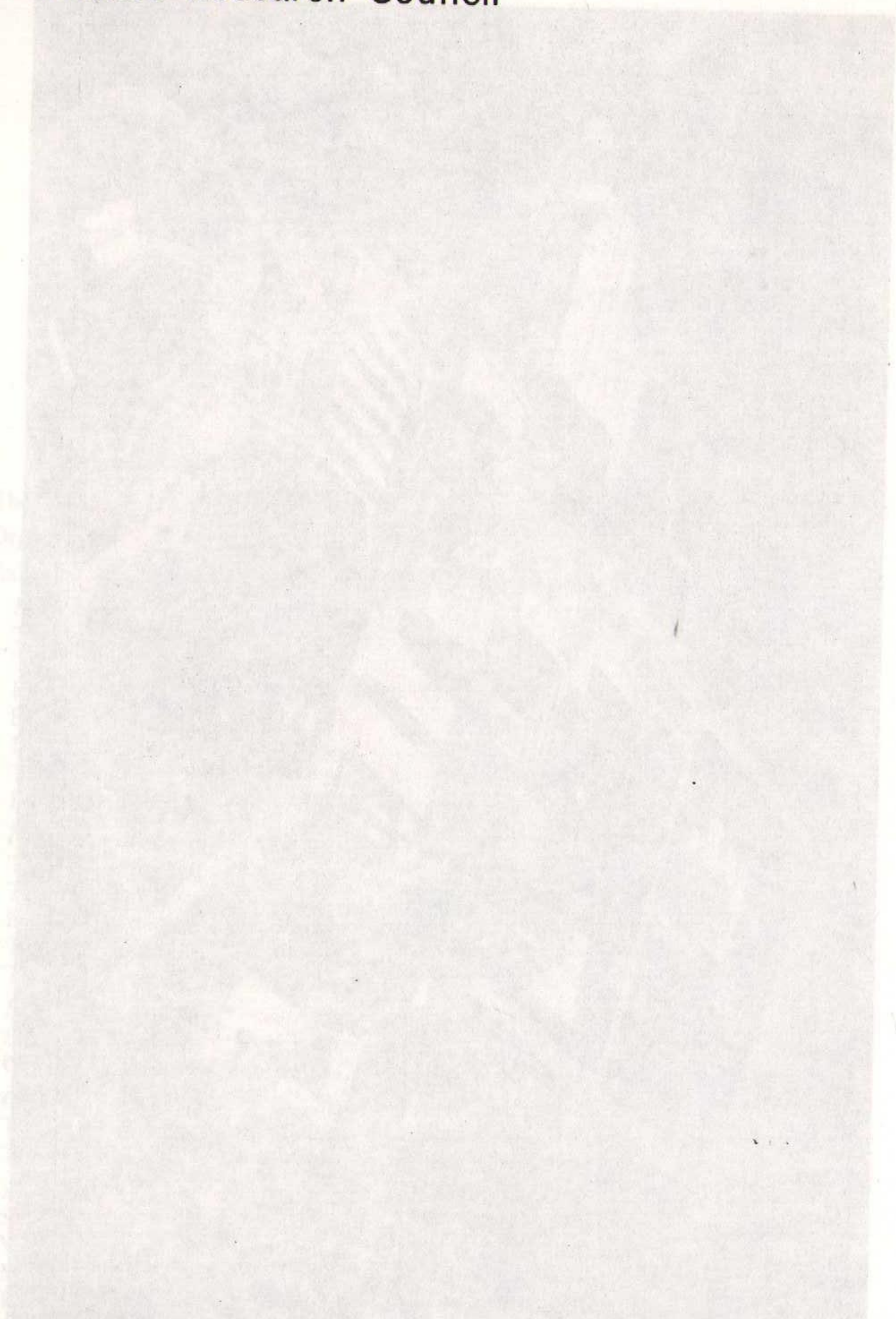

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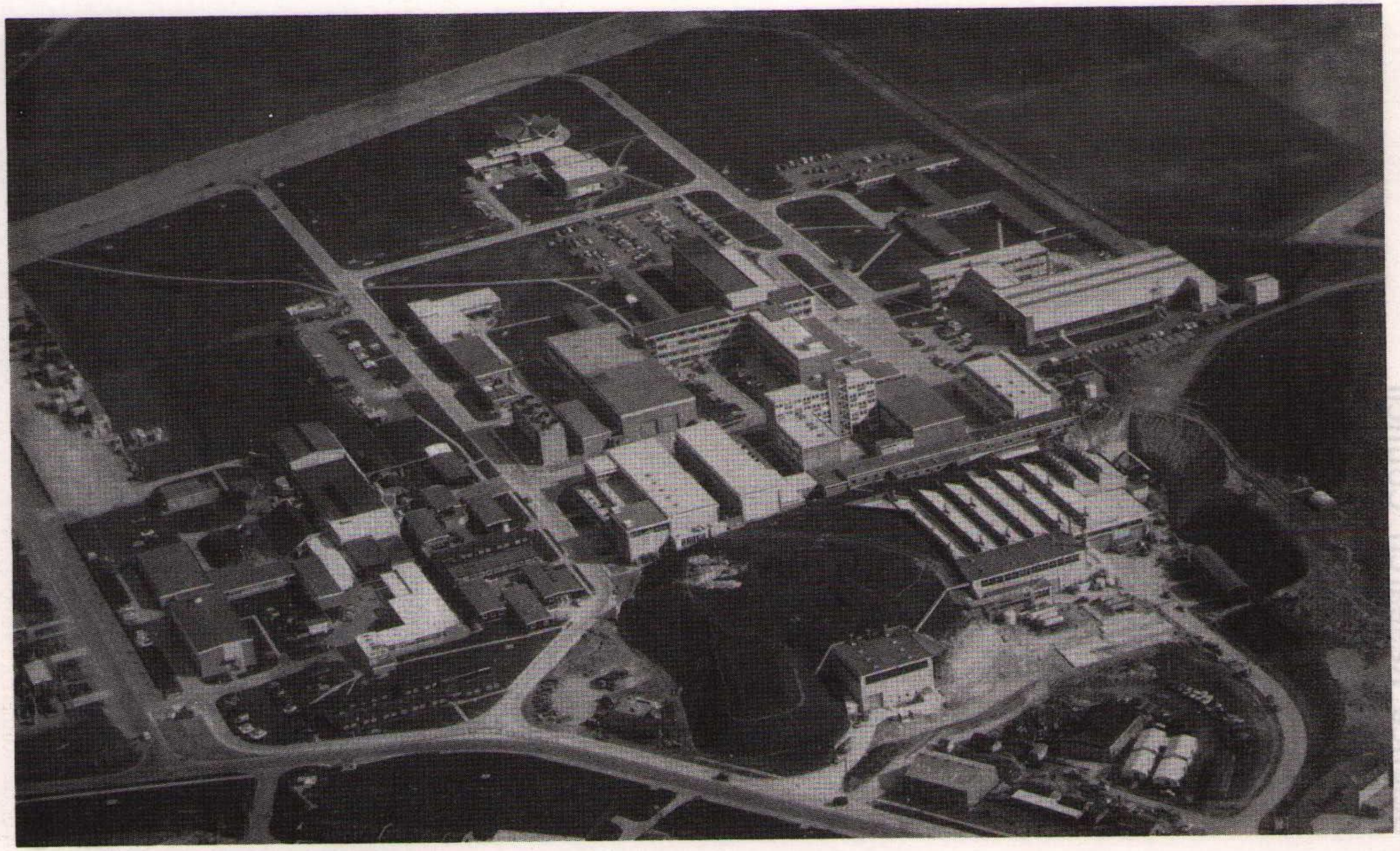


THE RUTHERFORD LABORATORY

Contents

General Notes

Travel

The Rutherford Laboratory is situated beside the A.34 nine miles south of Abingdon and fifteen miles north of Newbury. The approach to the Laboratory will be sign posted from the main road immediately south of A.E.R.E. Harwell.

The nearest railway station is Didcot (Western Region) which has regular services to Paddington, Reading, Oxford and Swindon. The journey from the station to the Laboratory takes under twenty minutes.

Information Desk

An information desk will be open in the main entrance hall of Building R.1. Besides general information staff will be available to assist visitors with scientific and technical questions.

Local Bus Services

A minibus service will operate between the Visitors' Car Park (see plan on page 39) and the main entrance Building R.1.

A coach service will be continuously operated on the following route:

Main Entrance, Building R1
Main Entrance, Building R2
Building R4
Experimental Hall No. 2, Building R5
Experimental Hall No. 1, Building R6
Building R4
The Restaurant, Building R22 (after 3.15 p.m.)
Main Entrance, Building R1

Afternoon tea will be served in the Restaurant from 3.15 p.m.

Visitors will be free to visit the exhibits in any order they may wish except that, due to the restricted space, it is necessary to conduct small parties through the exhibits listed under the heading "High Energy Physics and Nimrod".

The Rutherford Laboratory

The possibility that the physical world might be made up from vast numbers of similar small units or "atoms" has attracted the curiosity of man since the time of ancient Greece, but until the nineteenth century theories based upon this possibility had been purely speculative. At the beginning of the last century, however, Dalton provided the first scientific account of the atomic nature of matter. In the latter part of the century Mendeléef published his Periodic Table which classified the properties of the chemical elements and indicated that they could be related to some far-reaching scheme of unification. After the discovery of the electron at the turn of the century and the work of Rutherford and Bohr a decade or so later, it became clear that the regularities of the Periodic Table could be explained in terms of atoms consisting of very dense nuclei surrounded by orbiting electrons. By the nineteen thirties this atomic theory had been practically perfected and the most fundamental problems centred on the nucleus itself, its constituents the neutron and proton and the forces which bind them together. The subsequent investigation of these problems has led to the discovery of a hundred or so different elementary particles which today are as much in need of a theoretical scheme of classification as were the chemical elements in the earlier era. In the last few years there have been some very promising advances in this direction, and many physicists believe that we are on the point of discovering a far-reaching synthesis of the phenomena of elementary particles.

The traditional home for basic studies of this kind is the University, but as they have developed there has been a need for experimental facilities of such great complexity and on such a scale that they are beyond the resources of any single university. To meet this problem the Rutherford Laboratory was set up as a national centre for research in elementary particle physics and the physics of the nucleus. It is intended primarily for the use of physicists of British Universities but also caters for other institutions conducting basic research in these fields.

The heart of the Laboratory is the proton synchrotron Nimrod which is the central experimental facility for the teams of elementary particle physicists. The Nimrod complex consists of the machine itself with its beam injection and extraction equipment, its power supply, and two experimental halls. These two halls are protected against the intense radiation from Nimrod by a large steel and concrete shield wall through which pass "beam lines" carrying high energy particles to the experiments. Eight or nine experiments are usually set up on the experimental floors, and during periods when Nimrod is operating at high energy about four of these collect data. The experimental teams operate in turns whilst the machine works round the clock for weeks at a time.

There is a broad distinction between "counter" experiments and bubble chamber experiments. In the counter experiment the interesting events, that is particle collisions or disintegrations, are recorded only when they are "recognised" in the apparatus by producing a particular response in a system of particle counters. In the bubble chamber experiment hundreds of thousands of events occurring in the bubble chamber liquid are photographed and scrutinised later, so that the significant ones can be identified. At present there are two bubble chambers in operation, one a heavy liquid chamber and the other a liquid hydrogen chamber which is on loan from the CEN laboratory at Saclay in France. Two more bubble chambers are being assembled.

For the study of nuclear physics there is also a central experimental facility, the 50 MeV Proton Linear Accelerator or PLA. It is smaller than Nimrod and less complex but its method of catering for the experimental teams is similar. Here too are two experimental halls in which a number of experiments share beams of accelerated protons from the PLA. All these low energy experiments are counter experiments, the bubble chamber being very much a high energy facility. The PLA is one of the most reliable accelerators in the world and has some special features which make it one of the most versatile. These are a polarised proton source, a neutron time of flight facility and a double-focusing magnetic spectrometer. Attached to the PLA is a Nuclear and Radiochemistry Group which carries out research in these fields. The group works in a close reciprocal relation with both the PLA and Nimrod.

About 160 visiting scientists base their research on Nimrod and the PLA. The Laboratory itself has three elementary particle physics groups one of which attaches individual physicists to visiting teams in order to promote good liaison with the Laboratory. Another Laboratory group specialises in nuclear physics on the PLA. There are also a number of applied physics groups concerned with accelerator physics, bubble chambers, experimental data processing equipment, apparatus for experiments in elementary particles, and other applied research related to the main experimental programmes. Nimrod has two engineering groups one concerned with the accelerator and the other with the experiments. The PLA has its own engineering group whilst a central group provides engineering services throughout the Laboratory.

A special group is responsible for the radiological protection of the staff who work on the accelerators and in the experimental halls.

The Laboratory has a centralised double computer time sharing system which is used mainly to analyse the data from experiments on

Nimrod. The Computers are managed by a group in which programmers and theoretical physicists work closely together.

The Laboratory has a permanent staff of about 1,100 and the budget for 1966/67 is £6.2 million.

The Rutherford Laboratory has a sister establishment the Daresbury Nuclear Research Laboratory in Cheshire. This Laboratory is based on the 4 GeV electron synchrotron NINA which will, when it comes into operation later this year, provide to elementary particle physicists in the north of England facilities similar to that provided by Nimrod. Both Laboratories became establishments of the Science Research Council in April last year.

Organisation

The Rutherford Laboratory is organised into six divisions each responsible for a part of the Laboratory's work. To assist the Director (Dr. T. G. Pickavance) in managing the Laboratory there is a committee of Division Heads which meets fortnightly.

High Energy Physics Division organises and co-ordinates the research programme using Nimrod. It is primarily divided into counter groups and bubble chamber research group; these each contain one or more research teams made up from University visitors and Laboratory staff. An electronics group assists with the design and construction of specialised equipment for experiments. The Division Head is Dr. G. H. Stafford and Dr. R. C. Hanna who is a member of the Division Heads' Committee has a special responsibility for bubble chamber research.

Nimrod Division is responsible for the operation, maintenance and development of Nimrod, its auxiliaries, and its beam lines, together with the engineering support to meet the requirements of high energy physics. The Division Head is Dr. L. C. W. Hobbis.

Applied Physics Division operates and develops bubble chambers; is responsible for the construction of data processing apparatus; has a group devoted to theoretical physics, computer operation and data processing; and has been responsible for co-ordinating the building of accelerators for other laboratories. Mr. W. Walkinshaw is Division Head.

Proton Linear Accelerator Division is responsible for the research programme using the PLA including the operation, maintenance and development of the accelerator. A small nuclear and radiochemistry wing is attached to the Division. The Division Head is Dr. W. D. Allen.

Engineering Division is responsible for centralised services which are required for the general running of the Laboratory and to provide a comprehensive engineering design and supply service; it also co-ordinates safety. The Division Head is Mr. P. Bowles.

Administration Division is organised to provide the full range of administrative services required in an advanced laboratory. An important part of its role is to publish the reports on the scientific and engineering work of the Laboratory. The Division Head and Secretary of the Laboratory is Dr. J. M. Valentine.

The Radiation Protection Group is responsible to the Director for radiation safety.

Exhibits

High Energy Physics and Nimrod

(Buildings R.5 and R.6)

The various parts of the accelerator (injector, magnet ring, experimental halls, power supply, control room) are accessible and it is recommended that visitors follow the fold-out map. The Nimrod Magnet power supply is located in Buildings R.3 and R.4 and the Main Control Room in Building R.2.

NIMROD—EXPERIMENTAL HALL NO. 2

K7 Experiment: *Scattering of Pi-Mesons and K-Mesons on a Polarised Proton Target*
(RHEL Resident Group. Dr. J. J. Thresher)
The aim of this experiment is to investigate the interaction of both pi-mesons with protons and K-mesons with protons in a target in which the spin direction of the protons is known. The method of investigation is to use a beam of pi-mesons (or K-mesons) to bombard a target containing hydrogen and to detect the scattered meson and the recoiling proton from the hydrogen. When this scattering process takes place, various resonant states (elementary particles of very short life) may be produced, depending on the energy of the particles in the beam. The properties of some of these states were obtained from an earlier version of this experiment, which used only a pi-meson beam. In the present experiment more of these states will be investigated, including those produced by K-mesons as well as those from pi-mesons. This work is particularly useful at the present time because of the need to test an important theoretical scheme known as Unitary Symmetry. This scheme is able to correlate the pi-meson and K-meson scattering processes and to classify any resonant states that may be produced. It is important to check these predictions experimentally.

In many scattering experiments the direction of the proton spin is outside the control of the experimenter and oriented at random so that effects arising from this spin are averaged out. In this experiment a special "polarised" target is used in which a fraction of the protons in the target material are orientated parallel to an external magnetic field. (Details of the target are given below.) The use of such a target removes a major source of ambiguity in the interpretation of the results.

The polarisation of the protons in the target is only achieved at the expense of considerable complexity. In particular, the experiment must be designed to eliminate the interactions between the beam and all the elements in the target material except hydrogen because only the interactions with hydrogen carry useful information. In order to do this more than 70 scintillation counters are placed around the target to detect the scattered particles and another 30 counters are placed in the beam itself. The outputs from these counters are fed to a high speed electronic network that has recently been developed by the electronics group of this laboratory. The signals from this network go directly to a PDP 5 computer which has been programmed to take into account the position of each counter and to reject the unwanted interactions. The final analysis of the data is carried out on the Atlas computer.

Polarised Proton Target (General Physics Group)
In the polarised target, hydrogen nuclei are lined up so that their spin axes are mostly pointing in a specified direction. The results of scattering beams of elementary particles from such aligned protons provide considerably more information about the way in which many high energy interactions occur than do conventional experiments in which the target particles are randomly orientated.

In principle, such a target could be made by cooling protons to a very low temperature in a very strong magnetic field. However, the values required (1/100°K and 100kG) for high polarisation are quite impractical for a working target, so it is necessary to use a special method in which free electron spins are added to the target. The electrons, having a considerably larger magnetic moment than the protons, are almost completely aligned at the reasonable values of temperature (1°K) and field (19kG) used; by "pumping" with microwaves (4 mm.), the electron polarisation is communicated to the protons. By means of this dynamic process, proton polarisations of 60% are regularly obtained in the material at present used, single crystals of lanthanum magnesium nitrate. $(La_{99.85\%}, Nd_{0.15\%})_2Mg_3(NO_3)_{12}.24H_2O$. The target in the K7 experiment (the second to be built at the Laboratory) uses a number of these crystals mounted to form a cylinder of length 7.5 cm. and diameter 2.5 cm. This cylinder is mounted in a "pod" in the tail of a horizontal cryostat. The magnetic field is vertical. The crystals are cooled by a continuous flow of liquid helium from a 100 litre dewar. The microwaves are supplied from a carcinotron, and the polarisation is determined by integrating the observed magnetic resonance line of the protons using an analogue computer.

ϕ Experiment: *A Search for the ϕ° Meson.*
(Imperial College/RHEL Group. Dr. J. Walters, Dr. P. Palit)
A recent considerable advance in our fundamental understanding of the strongly interacting particles has been the success of a symmetry

scheme known as SU3 in classifying and grouping these particles. This theory in addition makes specific predictions about some of the properties of the particles classified and one of the essential steps in the further development of the theory is an experimental check of these predictions. One such case is a prediction of the rate at which two unstable particles the ω and ϕ meson decay into an electron positron pair. [$\omega \rightarrow e^- + e^+$ and $\phi \rightarrow e^- + e^+$]. It is the aim of this series of experiments to search for these rare decay modes (they happen only once in several thousand decays).

The first half of the experiment ($\omega \rightarrow e^+ + e^-$) decay has already been completed. The second half consists essentially of two parts—
(a) to measure the probability with which ϕ° mesons are produced by incoming negative pions colliding with protons in a liquid hydrogen target;
(b) to measure how many of them decay by the e^+e^- mode, an experiment which is feasible only if the ϕ's are produced sufficiently copiously in the first place.

Part (a) is currently in progress. The ϕ-mesons are identified by their relatively abundant decay products K^+ and K^- particles, whose ranges and angle with the incoming π^- beam are measured in spark-chambers with lead plates in between. The chambers are triggered and a picture taken only when there is also an accompanying neutron with the right velocity $\pi^- + p \rightarrow \phi^\circ + n$.

Part (b) will consist of taking spark chamber pictures of cascade showers developed by high energy electrons from the $\phi \rightarrow e^+ + e^-$ decay, in lead plates, and of identifying such events unambiguously.

NIMROD INJECTOR ROOM (Building R.5)

The injector consists of two main units, the ion gun and the linear accelerator proper. In the ion gun, protons are produced at low velocity in an ion source, which operates by maintaining an electrical discharge in hydrogen at low pressure. 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-feet long by 5-feet 6-inches diameter. 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 focussing 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.

A local control room enables the injector to be operated independently of the main accelerator.

NIMROD MAGNET ROOM (Building R.5)

Nimrod is a constant gradient proton synchrotron. The magnet is an electromagnet 155 feet in diameter and contains about 7,000 tons of special magnet steel mainly in ¼″ plate. It comprises eight octants separated by straight sections which accommodate the radio-frequency accelerating cavity, beam control, beam extraction and other facilities. Each octant has its own 42 turn winding and the total weight of the coils is about 350-tons.

The torodial shaped vacuum chamber made from glass fibre epoxy resin is situated between the poles of the magnet. 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.

On the pole piece surfaces, several conductors run the length of the octant. These are known as pole face windings and they can be powered during the acceleration cycle to correct any minor defects in the field.

The useful dimensions of the magnet gap are 36-inches radially and 9½-inches vertically and the maximum magnetic field, for full energy of 7 GeV, is 14 kilogauss. Other items of major interest in the Magnet Hall are the plunging quadrupole and extraction magnets, target mechanisms, vacuum chamber pumping systems, beam line outlets, closed circuit television cameras and radiation shielding.

NIMROD—EXPERIMENTAL HALL NO. 1

K6 Experiment: *A measurement of the K^-–nucleon total cross-sections in the range 0.7—2.4 GeV/c.*

(Cambridge University/Birmingham University/RHEL Group: Drs. K. F. Riley, J. D. Dowell and D. V. Bugg).

This experiment is a collaborative effort between members of Cambridge and Birmingham Universities and the Rutherford Laboratory. The experiment measures the total interaction rate (total cross-section) of K^-, K^+, π^+, and π^- mesons with protons and neutrons. It is well know that at certain energies the interaction rate exhibits large peaks, called "resonances", corresponding to the formation of excited states of the proton or neutron. Many of these resonances are known in the interaction of π mesons with nucleons. Theory predicts that they should also be present in the interactions of K^-, but probably not for K^+. In this experiment, a precision measurement is being made over the momentum region of greatest interest, 750 to 2600 MeV/c, in an attempt to find small peaks which have previously escaped detection. The precision will be approximately $\pm 0.5\%$ for K^+ and K^-, and $\pm 0.2\%$ for π^+ and π^-.

The particles originate from a target in the extracted proton beam. K and π mesons are separated electronically using 3 Cerenkov detectors. The beam intensity is approximately $2 \times 10^5 \pi$, $10^3 K^-$, and 5×10^3 K^+ per pulse. The interaction rate is determined from the attenuation of the beam in 55 cm. targets of liquid hydrogen and deuterium.

K4 Experiment: *A study of the Leptonic Decay Modes of positive K Mesons.*

(Oxford University/RHEL Group: Drs. P. B. Jones, A. B. Clegg and W. S. C. Williams).

This experiment has been designed to make simultaneous studies of the three-body decay modes of the K^+ meson: $K^+ \rightarrow \pi^o + \mu^+ + \nu$ and $K^+ \rightarrow \pi^o + e^+ + \nu$. For these particular decay modes, it is proposed to measure the π^o, μ^+ and e^+ energy distributions, and also in the former reaction, the spin polarisation of the μ^+. These measurements allow the investigation of the form of the coupling in the weak interaction which is responsible for the decay, of the form factors, or spatial distributions involved in the decay, and that the same weak interaction is responsible for both the electron and the μ–meson modes of decay. The polarisation of the μ–meson will also give a test of CP non-invariance which has been observed in K° decays. The branching ratio for the rare decay mode $K^+ \rightarrow e^+ + \nu$ will be measured.

The K^+ beam is produced from a target in the external proton beam which is shared with the K6 experiment. There is one 13-ft. stage of electrostatic separation to separate out the K^+ mesons from the π^+ and protons which are all produced in the target. The K^+ mesons stop in the small beryllium plate spark chamber; their decay products are studied by means of a magnet to measure the momentum of the charged particles, and four brass plate spark chambers to detect the γ–rays which come from the decay of the π° mesons. The charged particles are tracked through the magnet by means of four spark chambers whose spark positions are detected accoustically and recorded on magnetic tape for feeding directly into the ATLAS computer. The electrons which go through the momentum analysing magnet are indicated by the output of the Cerenkov counter filled with propane gas. Finally, the μ-mesons are stopped in a thick plate spark chamber where their decay into an electron is observed by delaying the firing of this spark chamber for 3 microseconds giving time for their decay.

π2 Experiment: *Differential Cross-Section Measurements in $\pi^+ = p$ elastic scattering near 2 GeV.*
(University College, London/Westfield College Group: Dr. F. F. Heymann and Professor E. H. Bellamy).
The present experiment forms the second half of a programme to investigate the fundamental interaction between π mesons and nucleons near 2 GeV. This energy region was chosen in order to investigate in detail the interaction in the neighbourhood of two small resonances that had been observed in the total cross-section. By measuring the angular distributions in detail for both π^-p and π^+p scattering, information on the angular momentum of these two resonant states, one in each of the two isotopic spin combinations of the meson-nucleon system, can be obtained.

The data on the π^-p scattering at 5 energies about the resonances was taken before the breakdown of Nimrod. The mesons were scattered at a hydrogen target and the scattered particles were detected in scintillation counters which triggered off a spark chamber system. Photographs were taken of the tracks made by the particles in these spark chambers enabling the scattering angles to be determined with high precision and inelastic events to be rejected. These photographs were subsequently measured and analysed and good angular distributions with 2,000 events at each of 5 energies have been obtained.

These results are already sufficient to show that the resonances have high spins. The present experiment will make measurements at 7 energies using π^+ mesons and two additional energies for (π^-–p). Taken in conjunction with polarisation measurements at these energies being made at the Argonne Laboratory definite assignments of spin and parity to these states may be possible.

For the present experiment, in addition to the normal photography, the "vidicon" system developed at Westfield College for use in subsequent experiments is also being tested and will be on show. This uses television cameras to record the positions of the sparks in the chambers, the information being dealt with electronically at once and stored on magnetic tape for input to a computer. This will dispense with the time consuming semi-manual measurement of the film and enable the analysis to be completed more quickly.

P3 Experiment: *A search for Multipion Resonances in the Process*$^{-} + p \begin{cases} (n+x \\ (p+x \end{cases}$

(AERE/Southampton University/University College, London/RHEL Group: Drs. C. Whitehead, R. E. Jennings, E. G. Auld).

The purpose of this experiment is to study the properties of the f° meson resonance. It is 1.4 times heavier than a proton, and has a lifetime of approximately 10^{-23} seconds. The experiment will investigate the decay modes of the f°. The results will help to identify which classification of particles it is related to in the symmetry theories that have evolved in the past two years.

The f° will be produced in the interaction of an energetic negative ion with a stationary hydrogen nucleus (proton). The interaction in question produces an f° and a neutron. The f° decays too quickly to be detected, but the neutron is detected in a large counter array. The decay products of the f° have long life-times. They are detected by an array of spark chambers situated near the hydrogen target. The spark chambers can measure the direction of these decay particles to a high accuracy. The event can then be reconstructed by analysis in a computer and the decay products of the f° can be identified.

All the spark chambers are of the Sonic type, that is the spark position is detected by a sound ranging technique. Four microphones are mounted in each chamber (one in each corner). The microphones are cylindrical in shape, $\frac{1}{4}$-inch diameter and $\frac{1}{4}$-inch long. The experiment requires 26 chambers of various sizes, hence a total of 104 microphones. All the microphone measurements are transferred automatically to a magnetic tape in the experimental control room. While the experiment is proceeding, the data on this tape can be transmitted directly (via a cable link) to the ORION-DDP224 computer system situated in Building R.1. The data is analysed and the results can be presented back in the control room either on a typewriter or on an oscilloscope display. This technique of "on-line" analysis of data assists the experimenter in detecting any faults that may occur in the equipment as well as analysing the physics of the experiment.

K1 Experiment: *Interactions in Hydrogen and Deuterium Bubble Chambers.*

(Universities of Birmingham/Cambridge/Glasgow/Imperial College, London/D Ph PE Saclay/R.H.E.L.)

The K1 beam is designed primarily to provide pure beams of K^- mesons of momenta up to 2.2 GeV/c, so that their interactions with the hydrogen or deuterium of the chamber can be studied free of any background from other particles in the beam. It can also provide pure beams of π^+, π^-, K^+ or protons, and a range of experiments involving all these particles is currently in progress.

There are 5 experiments in progress on K1, all directed toward further understanding of current problems in the classification of the fundamental particles, and in the properties of the forces which couple them together.

The recent discovery of a small CP violation (charge conjugation times parity) in K° decay has suggested that our knowledge of all the transformation properties of the nuclear forces should be reviewed. One property which has not been checked, is the charge conjugation in electromagnetic interactions, which states that for example particle and antiparticle (π^{+} and π^{-}) spectra should be identical in the decays of the η particle:

$$\eta \rightarrow \pi^{+}+\pi^{-}+\pi^{\circ}$$
$$\rightarrow \pi^{+}+\pi^{-}+\gamma$$

One experiment on K1 makes use of the reaction

$$\pi^{+}+d \rightarrow \eta+p+p$$

to produce a large sample of η events, on which the symmetry of the spectra of the decay can be tested. Analysis of the spectrum of the decay

$$\eta \rightarrow \pi^{+}+\pi^{-}+\pi^{\circ}$$

has led to the suggestion of a new particle, the σ meson, and this experiment should be able to show whether or not such a particle exists.

The discovery of new particles or resonances is the aim of three other experiments on K1. Fundamental particle physics is at a very exciting stage just now, in that the discovery of, and elucidation of the properties of many new particles has for the first time enabled theoretical physicists to classify them and to understand the ways they are coupled together. However, much more experimental information on the new particles is required before it is accepted that these theories are well established. From survey experiments in which we study ($K^{-}+p$) ($K^{-}+n$) and ($\pi^{-}+p$) reactions over a range of momenta we hope to discover and measure the decay properties of some of the new hyperon and nucleon resonances.

Engineering Support for High Energy Physics

The detailed co-ordination of the experimental programme involves the planning of new beam lines which are compatible with the existing layout of the experimental halls. At the same time the necessary beam line equipment must be obtained: magnets for focusing and bending beams; hydrogen targets which will interact with the particles contained in the beams; and separators to eliminate unwanted particles from beams. An installation team co-ordinates the work in the experimental halls to achieve the greatest efficiency.

The frequent movement of large items of experimental equipment and radiation shield blocks requires a considerable amount of mechanical handling support and subject to the requirements of the experimental programme at the time, demonstrations of the movement of some of the beam line components and radiation shield blocks may be seen in Experimental Hall No. 1.

BUBBLE CHAMBER ANNEXES

When the protons accelerated by NIMROD interact with matter the charged particles produced may be detected in a variety of ways. One particularly spectacular method of detection is employed in the bubble chamber. The principle used is very simple though, as will be seen, the apparatus used in the NIMROD experiments is extensive and complex.

Suppose we have a vessel containing a liquid at a temperature just below its boiling point. If we now increase the pressure in the vessel to greater than the atmospheric pressure we find that even when we increase the liquid temperature above its normal boiling point it still doesn't boil. However, should we suddenly reduce the pressure to atmospheric again spontaneous boiling will ensue.

It was found that by carefully controlling conditions in the liquid that this boiling occurred preferentially along the paths traversed by any charged particles entering the vessel. If we therefore take a very short exposure photograph immediately after the pressure has fallen we find that the particle tracks are defined as fine threads of tiny bubbles. By taking stereoscopic views with two or more cameras we can then identify the particle trajectories in three dimensions and therefore ascertain information about the kind of interaction that has taken place.

Different liquids can be used in bubble chambers, liquid hydrogen and helium being very interesting because of the simplicity and uniqueness of their nuclei. Denser liquids such as propane and freon have importance for observing any secondary reactions caused by the particles produced in the first interaction.

Hydrogen Bubble Chamber (1.5 metres)

The 1.5 metre liquid Hydrogen Bubble Chamber is now being re-assembled after its return from 2 years operation at C.E.R.N. It has a useful volume 150 cm along the beam direction, by 45 cm wide and 50 cm high.

The chamber body is machined from a single aluminium alloy forging and is closed on either side by glass windows 15 cm thick; the windows are protected by hydrogen shields. The top of the chamber is closed by an assembly of 48 pipes leading to the gas expansion system. The whole unit is hung inside a stainless steel vacuum tank, around which fit the two halves of an electromagnet. The magnetic field is 12 Kilogauss for an input power of 4 Megawatt.

Cooling of the chamber is by a 3 Kilowatt hydrogen refrigerator employing liquid nitrogen pre-cooling and Joule-Thompson expansion to three independent circuits.

Circular flash tubes are used to illuminate the chamber and are made to form ring images around the three camera lenses by means of a condenser lens system. Only light scattered by the bubbles can then enter the camera lenses. The tracks are photographed on 35 mm unperforated film.

The design and construction of the chamber and its ancillary equipment was the joint project of Birmingham and Liverpool Universities, Imperial College, and the Rutherford Laboratory.

Hydrogen Bubble Chamber (82 centimetres)

The 82 cm liquid Hydrogen Bubble Chamber from C.E.N., Saclay, France, is being used at Nimrod in a research collaboration between French and British physicists.

The stainless steel chamber body has a useful volume 82 cm long by 50 cm high and by 50 cm wide, closed on each side by a glass window 15 cm thick. The top of the chamber terminates with a cylinder in which moves the piston used to operate the chamber.

An electromagnet consuming up to 4 Megawatts of power produces a magnetic field in the chamber of approximately 20 Kilogauss.

Cooling of the chamber is by liquid hydrogen produced by a liquefier remote from the chamber; the liquid is transported in 1,000 litre mobile containers.

Dark field illumination of the chamber is by six linear flash tubes and a complex optical system.

Tracks are recorded on 50 mm single perforated film, using three cameras to enable stereoscopic reconstruction of each event.

K1 Experiment: *K^- Bubble Chamber Experiments*
(French and British Bubble Chamber Groups)
This project is a co-operative effort between the Rutherford Laboratory and C.E.N., Saclay, near Paris. The film taken is being analysed by collaborations of British and French bubble chamber groups in the Universities, the Rutherford Laboratory and Saclay.

The K1 beam is designed primarily to provide pure beams of K^- mesons of momenta up to 2.2 GeV/c, so that their interactions with the hydrogen or deuterium of the chamber can be studied free of any background from other particles in the beam. It can also provide pure beams of π^+, π^-, K^+ or protons, and a range of experiments involving all these particles is currently in progress.

There are five experiments in progress on K1, all directed toward further understanding of current problems in the classification of the fundamental particles, and in the properties of the forces which couple them together.

Heavy Liquid Bubble Chamber
The 1.4 metre Heavy Liquid Chamber has recently come into operation, and is currently employed on a physics experiment using the Freon CF_3Br as the liquid filling.

The chamber body of stainless steel has inside dimensions 55 inches long, 26 inches high, 18 inches wide, and is closed on one side by a glass window 9 inches thick and on the other side by a diaphragm which transmits the gas pressure cycle to the chamber. This assembly is held in position between the poles of the 4 Megawatt electromagnet in a magnetic field of 21 Kilogauss. The magnet pole behind the diaphragm contains the pressure cycling valves, and the other is hollow to enable photographs to be taken and is pressurised to reduce the force on the window.

Tracks are recorded by three cameras on 35 mm unperforated film with dark field 90 degrees illumination. The twelve flash tubes are fitted into recesses at the top and bottom of the chamber.

The design and construction of the chamber was a joint project of University College, London, and the Rutherford Laboratory.

P3X Experiment: *A study of the Decay Modes of the η° Meson*
(University College, London/Bristol University Group: Drs. C. Henderson and F. R. Stannard).

The Heavy Liquid Bubble Chamber at the Rutherford Laboratory was designed by physicists and engineers at U.C.L. It first came into operation in October 1965 and is now doing its first experiment.

It is so named to distinguish it from the other bubble chambers in which the sensitive liquid is of a light and simple atomic composition, such as hydrogen, deuterium, or helium.

A high energy particle in general produces several secondary particles on hitting a nucleus of the chamber liquid. If these are charged particles they can be seen in any bubble chamber. If they are gamma rays then the light liquids are unresponsive whereas the heavy liquids frequently convert them into pairs of oppositely charged electrons whose tracks are visible. The Heavy Liquid Bubble Chamber therefore obtains more completeness in revealing the secondary particles, but the collision that produced them is more complicated because the liquid contains complex nuclei. Hence the Heavy Liquid Bubble Chamber is used most effectively in the many experiments where the prime interest lies only in a study of the properties of secondary particles. The experiment at present in progress is a good example.

A π^+ beam of about 1000 million electron volts (MeV) can be seen leaving the south end of the experimental hall and dipping towards the ground. This dip is necessary to counteract the deviation of the beam as it enters the magnet that surrounds the bubble chamber, the total effect being to place the particles nicely in the visible region of the chamber.

The chamber is synchronised with Nimrod so that it is made sensitive at roughly two second intervals. To photograph the bubble tracks xenon lights in the chamber are flashed and the film moves on to await the next pulse. The tracks can readily be seen by eye through a telescope and viewing port.

The interest of the experiment lies in the measurement of certain decay modes of the eta meson. One mode is into 3 neutral π mesons that decay immediately into 6 gamma rays. To get 500 of these events some 200,000 photos will be taken.

A search will also be made for a decay mode ($\eta \rightarrow \pi^0 + e^+ + e^-$) that should not be permitted if conventional theories are correct. This decay mode would be very easily identified in the chamber, and the question of its existence is of great current interest.

Helium Bubble Chamber

The 80 cm Liquid Helium Bubble Chamber, which is now being commissioned, has an active volume 32 inches long by 16 inches wide and 17 inches deep. The stainless steel chamber body is closed at the bottom and top by glass windows 2 inches and 3 inches thick, and on one side by a moveable wall for expansion of the chamber.

The chamber in its vacuum tank, used for heat insulation, is lowered into the central hole of the hexagonal 4 Megawatt electromagnet which provides a vertical magnetic field of over 20 Kilogauss.

Refrigeration for both the chamber and radiation shield is provided by a helium refrigerator using gas bearing turbines running at speeds up to 300,000 rpm.

Four cameras will be used with dark field illumination from a single condenser lens system.

This chamber is a joint project of the Oxford University Nuclear Physics Department and the Rutherford Laboratory.

NIMROD MAIN CONTROL ROOM (Building R.2)
Entry into the Magnet or Injector Rooms whilst proton beams are running would be extremely dangerous. A very secure system is therefore provided to ensure that no one enters the area during full machine operation and to prevent switching on when entry to the area is made.

It follows that all apparatus situated in the Magnet and Injector Rooms must be operated remotely for long periods without requiring local attention or inspection. Entry into the area necessitates switching off the beam and an accelerator of this size is more prone to faults during start-up and shut-down than during operation. Adequate monitoring and control equipment must be provided.

The Nimrod Main Control Room therefore provides these facilities; it houses over 50 racks of electronic monitoring and control equipment with provision for expansion to permit accelerator development work, which is always in progress.

The following are the main functions dealt with:

(i) The switching and control of all equipment in the Magnet and Injector Room vital to the operation of the accelerator;
(ii) Measurement of the injected beam, final machine energy and accelerated beam intensity;
(iii) Setting up targetting conditions for supplying beam to experiments;
(iv) Controlling and diagnosing the extracted proton beam;
(v) Measurement of vacuum pressure at over 20 different points;
(vi) Three separate television systems;
(vii) Tannoy, G.P.O. and internal telephone and Centrum intercom. systems covering the machine and experimental areas;
(viii) Radiation level monitoring inside and outside the main shield walls;
(ix) Generating and monitoring of the master radio-frequency programme;
(x) Monitoring of R.F. waveforms and the timing system;
(xi) Monitoring of about 1,000 flow and 1,500 temperature points on the water cooling system;
(xii) Checks on machine interlocks and beam stops.

A model displaying the sequence of accelerator operation can be seen in the Main Control Room. Photographs of typical monitoring signals are also on display.

NIMROD—POWER SUPPLIES (Buildings R.3 and R.4)
Heavy currents of up to 10,500A with an applied voltage of up to 15 kV are need to energise the Nimrod magnet during the short acceleration period. The magnet power supply consists of two motor-alternator sets incorporating flywheels, connected to the magnet via phase splitting transformers and 96 single anode water-cooled mercury arc rectifiers. This equipment supplies direct current of gradually increasing strength during the 0.75 sec. acceleration period and the current decays again to zero in a further 0.8 sec. ready for the next pulse.

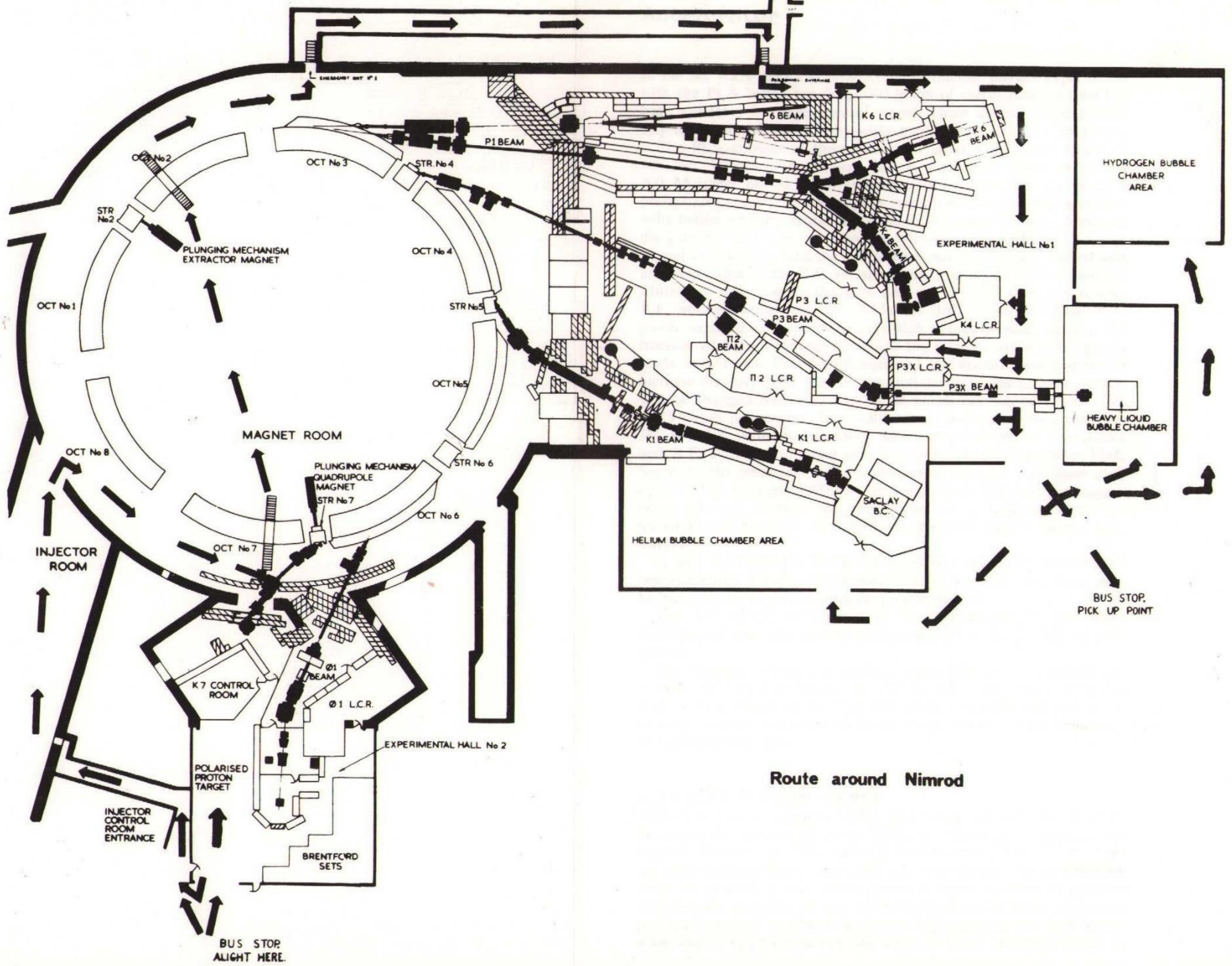
Energy is thus stored in the magnet during the current-rise period and is subsequently returned to the flywheels and rotors as the current is reduced again to zero. The amount of energy being shuttled to and fro is about 45 megajoules. In this way only the circuit losses have to be provided from the C.E.G.B. grid system, via two 5,100 h.p. slipring induction drive motors.

The alternators are 60 MVA, 12.8 kV machines, with 30 ton flywheels. The set weighs about 400 tons and is mounted on a reinforced, post-stressed concrete foundation block of about 1,200 tons, itself supported on 80 spring units and 12 viscous damper units. This was done to overcome the vibration problems arising out of the rapid change from generating to motoring conditions in the rotating plant, the speed of which falls typically from 970 rpm to 930 rpm and rises again to 970 rpm within the pulse cycle time.

The motor-alternator-flywheel sets have equipment to measure bearing vibration, bearing temperature, shaft eccentricity and shaft torsional stress. Ultrasonic flaw detection equipment is used to inspect the forgings of the rotors and flywheels from the central bore holes in the shafts.

The power plant is controlled from a separate control room which also houses two of the most important items of control equipment, the master timer unit and the automatic voltage regulator.

The exhibits include: flaw detection equipment; strain gauge measurements on the motor-alternator sets; rectifier grid control units (all in Building R.3); and ripple filter equipment (Building R.4).



Route around Nimrod

Nuclear Science and The Proton Linear Accelerator

In the six years since the programme of nuclear physics experiments with the PLA began nearly 23,000 hours of useful running time has been available for experimental teams. These teams comprise some fifty experimental nuclear physicists, mainly from British Universities.

The PLA consists of three evacuated tanks with a total length of 100 feet. Within each vacuum tank is a resonant cavity excited at 200 Mc/s by pulsed radio frequency power. Protons are given a preliminary acceleration through a potentional drop of half a million volts before arriving at the first tank. An increase in energy occurs in the gaps between a series of hollow cylindrical electrodes (drift tubes) spaced at intervals along the axis of each resonant cavity. The protons are accelerated by the R.F. voltage pointing in the direction of motion while they are crossing the gaps and are shielded from the reverse R.F. voltage while they are inside the drift tubes. Since the R.F. power supplied to the tanks is very high, the duty-cycle, which is the fraction of total time during which the protons are accelerated, is made low (1 %). Two modifications of the machine are planned to increase the duty cycle. Firstly, the modulation of the radio frequency will be changed from 400μ sec at 50 pulses per second to 800μ sec at 25 pulses per second. This will increase the beam duty cycle from 1% to 1.5%, without increasing the mean power in the modulators and R.F. system; the target date for completion is September 1966. Secondly, the possibility is being studied of increasing the beam duty cycle to 5% by using 1200μ sec modulation at 50 pulses per second. Since this will increase the mean power by a factor of three the technical and financial aspects of this proposal require careful consideration.

A new ion source is being developed to increase the unpolarised beam intensity. Under certain conditions of operation the beam may be increased by up to ten times the present intensity.

The low energy drift space is being redesigned to give more flexibility of operation and to provide space for the addition of new devices.

The emergent beam can contain many protons, (ten billion per second), or very few (about ten per second); their mean energy is fixed to better than 0.1%. This well defined beam is transported via bending magnets and magnetic lenses along any one of ten beam lines to experimental rigs.

POLARISED PROTON SOURCE

Protons possess a property called spin which can be thought of as similar to the spinning of a top. When the axis of spin is taken as the vertical direction, protons spinning clockwise are said to have spin up and those spinning anti-clockwise spin down. An unpolarised beam of protons is one which possesses equal numbers of protons with the two directions of spin. A vertically polarised beam of protons possesses unequal numbers of protons with spin up and spin down, when examined in the vertical direction. A beam can be polarised in any direction desired, and the polarisation in the vertical, transverse and longitudinal directions derived.

The short range force exerted on a proton by a nucleus depends, among other factors, on the direction of the proton's spin.

The purpose of the polarised proton source (PPS) is to provide a beam of polarised protons which can be accelerated in the linear accelerator and used in nuclear physics experiments, in particular in the investigation of the spin dependent force and its influence in nuclear scattering and nuclear reactions.

The figure of merit (or usefulness) of the source has been increased by a factor of 16 since it was first installed in 1961. The 50 MeV beam now has a mean intensity of 4 x 10^8 protons per second and a polarisation of 56%.

NUCLEAR PHYSICS EXPERIMENTS

One of the experiments exhibited is the measurement of Neutron Energy Spectra. The apparatus is used to measure the energies of neutrons emitted from a target bombarded by 30 or 50 MeV protons. The energy is determined by measuring the time of flight of the neutron from the target to a detector placed at a known distance from the target. By radio-frequency deflection of the proton beam before the first accelerating tank of the PLA bursts of protons less than 1 nanosecond (one thousand millionth of a second) wide and spaced by 180 or 360 nanoseconds are obtained. A magnet used to clear the proton beam away after passing through the target allows measurements to be made in the forward direction. After suitable collimation and shielding the neutrons are detected in a plastic scintillator mounted with its associated photomultiplier in a temperature controlled enclosure. Flight paths of 6 or 10 metres can be used and measurements made at angles between 0° and 85° in 5° steps. The overall time resolution is better than 1.5 nanoseconds.

The apparatus has been used to study the excited states of some light nuclei and the excitation of analogue states in medium weight and heavy nuclei.

THE $n=\frac{1}{2}$ DOUBLE FOCUSING SPECTROMETER

The double focussing spectrometer is used by approximately half the experimenters working on the PLA. A higher energy resolution is obtained in the beam incident upon the target, than that given by the PLA, by the use of a combination of slit-apertures and a bending magnet to select a range of momenta. This beam line is adjusted to give normally either 100 KeV or 60 KeV beam energy spread at 50 MeV and 30 MeV machine energy respectively, with negligible low energy tails in the distribution. This energy "bite" represents the biggest factor in the determination of the resolution of measurement, for the target and spectrometer effects may be made very small. The use of a sliding curtain for the vacuum seal on the scattering chamber enables the spectrometer to be operated with completely clear beam paths; consequently there are no fluctuations in energy loss on passing through materials other than the target as would be the case with a vacuum system using thin foil windows.

The mean particle radius in the spectrometer is 40 inches and it is possible to focus protons of about 140 MeV, deuterons of about 72 MeV, and tritons of 48 MeV.

The maximum usable solid angle is 2 milli-steradians and the energy range over the useful part of the focal plane is $\pm$ 5%. The beam incident upon the target is monitored, most usually, on a Faraday cup positioned downstream of the target in the scattering chamber and this allows scattering angles down to 5° to be observed. For low beam currents an ion chamber is substituted for the Faraday cup and when the polarised beam is in use and the spot position is critical then the spot position is monitored with split plate ion chambers. An additional monitor is sometimes used in the form of a very thin foil from which the coulomb scatter at a small angle is observed.

The detector arrangements on the spectrometer are not standardised and experiments have used a wide variety of systems. Solid-state counters, scintillators, wedge scintillators, and acoustic spark chambers have all been used at various times with some form of particle identification wherever possible.

THE NUCLEAR AND RADIOCHEMISTRY WING

The Nuclear and Radiochemistry Wing was built so that radiochemists from universities and other organisations would be able to enjoy the same kind of benefits which the Rutherford Laboratory confers on physicists.

The term "radiochemist" simply implies that the scientist concerned is a chemist who works with radioactive materials. Radiochemists use these materials in a variety of ways, but primarily two main ones. Firstly, where the object of the work is to investigate problems related to the **atomic nucleus,** chemical techniques are used to separate the different atomic species involved; this is "nuclear chemistry". Secondly, where the object is to investigate **chemical** or other problems which are not concerned with nuclear reactions, use is made of the radio-activity as a convenient label to help in the analysis; "tracer chemistry" and "radioactivation analysis" both come into this category.

The Nuclear and Radiochemistry Wing is designed for 12–16 radiochemists. It is a necessary condition that the work involves either :—

(1) The investigation of radioactivities which the scientist concerned has produced by irradiation of his target in one of the accelerators or reactors of the Rutherford Laboratory or of A.E.R.E. and which are too short-lived for him to transport to his own laboratory.

(2) Facilities which the scientist cannot reasonably be expected to have in his own laboratory.

Facilities available in the Nuclear and Radiochemistry Wing

The wing is divided into four laboratory suites, each consisting of a radiochemistry laboratory, an office, vestibule, and counting room. Each suite is designed for 3—4 chemists working full-time. In addition to these, there is a balance-room, cave-room, and changing and utility rooms.

Experimental Data Processing

SCANNING AND MEASURING EQUIPMENT

The data from a bubble chamber experiment is presented in the form of two or more stereoscopic pictures recorded on negative film. Interactions which have taken place in the chamber can be found and recognised by projecting the views on a scanning table for inspection by a physicist or trained operator. Events of interest are noted on a data sheet and the film may then be taken to the measuring machine. Here a trained operator will turn to the frame numbers noted on the data sheet and make accurate measurements of the positions of the tracks on the film relative to fiducial marks which are fixed on the bubble chamber windows and recorded on each photograph. The co-ordinates of a track in two or more views enables the position of the track in the chamber to be determined. Co-ordinates and other data are punched on paper tape at the measuring stage and the reconstruction of the tracks in space is carried out by a complex computer programme. A further programme can then work out the kinematics of the event measured and prepare the necessary statistics for the experiment.

Scanning Machines

The scanning machines were developed as part of the 1.5 metre British National Hydrogen Bubble Chamber project. A three channel projector system is used, enabling stereoscopic views of the bubble chamber to be projected simultaneously on to the scanning surface.

Measuring Machines

The National Machine

The film to be measured is accurately located in a gate mounted on a stage which can be precisely moved in two directions at right angles. Optical digitisers using the Moiré fringe principle record the "x" and "y" co-ordinates of this stage. A magnified view of the photograph is projected on to a screen to enable the operator to bring any point on the film into alignment with a fixed cross-wire.

The stage motion and film transport are fully motorised for ease of operation and the recorded data is punched on paper tape. Track co-ordinates on the film are obtained to an accuracy of 4.10^{-4} cm.

The Duff Machine

This is a simpler version of the National Machine with somewhat reduced accuracy and speed of operation. It uses mechanical digitisers geared to an accurate screw thread for measuring the co-ordinates of the stage.

Image Plane Digitiser, Mk I and II

The image plane digitiser is used to make rapid, low precision measurement of bubble chamber tracks. The measurements are stored on paper tape, and can subsequently be used to guide the H.P.D. (or any other automatic measuring device).

Point measurements are made by a triangulation method. The projection surface is "scanned" using a rotating mirror and a number of fixed mirrors. A small light source is placed at the point to be measured and the angular position of the rotating mirror is digitised when the light is seen by a photomultiplier tube through a lens and slit assembly. The angular position of the mirror is determined using a radial grating and a Moiré fringe reading head. The angular resolution is 15 secs of arc.

"D. Mac" Digitisers

These machines are used for the same work as the I.P.D.'s above. An electromagnetic link is established between the operator's probe and a slave is driven by Servomotors via five stainless steel wires. Rotary encoders driven by the same wires are used for digitising.

Flying Spot Digitiser (Hough Powell Device)

The Hough Powell device (H.P.D.) is a machine for automatically measuring bubble chamber film. As with the other measuring machines the film is accurately located in a gate while the measurements are being made. An intense spot of light is produced and after transmission through the film is detected by a photomultiplier. If the spot is now made to scan across the film dark tracks will be detected in the photomultiplier circuits. A television type of raster scan is used to cover the whole of the photograph and the detected signals pass, after processing, to a computer direct data input channel.

At the scanning stage, in addition to finding the events of interest the operator uses an Image Plane Digitiser to obtain rough co-ordinates of the tracks to be measured. These are then passed on paper tape to the computer to which the H.P.D. is in direct connection and enable the computer to ignore all the signals received from the H.P.D. except those associated with the tracks of interest. Effectively this is equivalent to putting over the photographs a masking plate out of which a rough pattern of the wanted tracks has been cut.

The machine operates entirely under computer control and will measure 30–50 events per hour giving co-ordinates to an accuracy of 2.10^{-4} cm. Subsequent processing in the computer is the same as for other measuring machines.

CRT Device

This device is used to measure information recorded on photographic film produced in spark or bubble chamber experiments. It employs a flying spot or line on a cathode ray tube which scans across the film. The spot or line traverses a fixed path on the CRT (y co-ordinate) and the film is moved in a direction perpendicular to the scan (x co-ordinate). At the start of a scan an x co-ordinate is produced and each time the spot or line crosses a spark or track a y co-ordinate is recorded. The co-ordinates are fed directly from a 24-bit register into the core store memory of the DDP-224 computer via a direct memory access channel. The CRT device is controlled by orders from the DDP-224.

ORION AND DDP-224 COMPUTER COMPLEX

The above two computers are fully integrated into a coupled time-sharing system which is arranged to allow simultaneous access to the computers by several users in either or both of the following modes:

Mode I: In Real-Time to monitor and process data generated by one or more experiments being run on the Nimrod accelerator. This is extremely valuable; not only to do consistency checking during the actual data-taking run but to act as a control during the setting-up of the experiments by verifying accuracy and quality of data.

Mode II: In an "On-Line" mode to analyse and process digital data from the two automatic measuring devices—Hough Powell Device and "C.R.T."

Both computers are also used conventionally for compiling and assembly of parent programmes and for a limited amount of data processing. (The bulk processing is done at the Atlas Laboratory.)

The DDP is a small fast computer and has extensive facilities for being interrupted by external signals.

Orion is a larger, slower, computer with fully protected time-sharing.

In Real-Time operation, the DDP will read experimental data into its main memory, making a note of which of several concurrent experiments originated the data. When enough data has been received, the DDP can signal to Orion that it has data from a particular experiment. A controlling programme in Orion will read these data via memory-to-memory link, and inform a corresponding programme also in Orion, that there are data to be processed. Thus the DDP acts as a time-smoothing data-gatherer for Orion.

The DDP can also do a limited amount of consistency-checking on the data.

Orion may keep a real-time watch on the experiment, or merely record the data on magnetic tape for later processing, say at hourly intervals. The DDP can also transmit messages between the two computers and electric typewriters situated in the Nimrod experimental halls.

The Laboratory is to take delivery in November 1966 of an IBM System 360 Model 75, the speed and power of which will greatly enhance the capacity to develop and expand both the real-time and on-line environment and also enable the increasing load of bulk processing to be done in the Laboratory.

Outside Projects

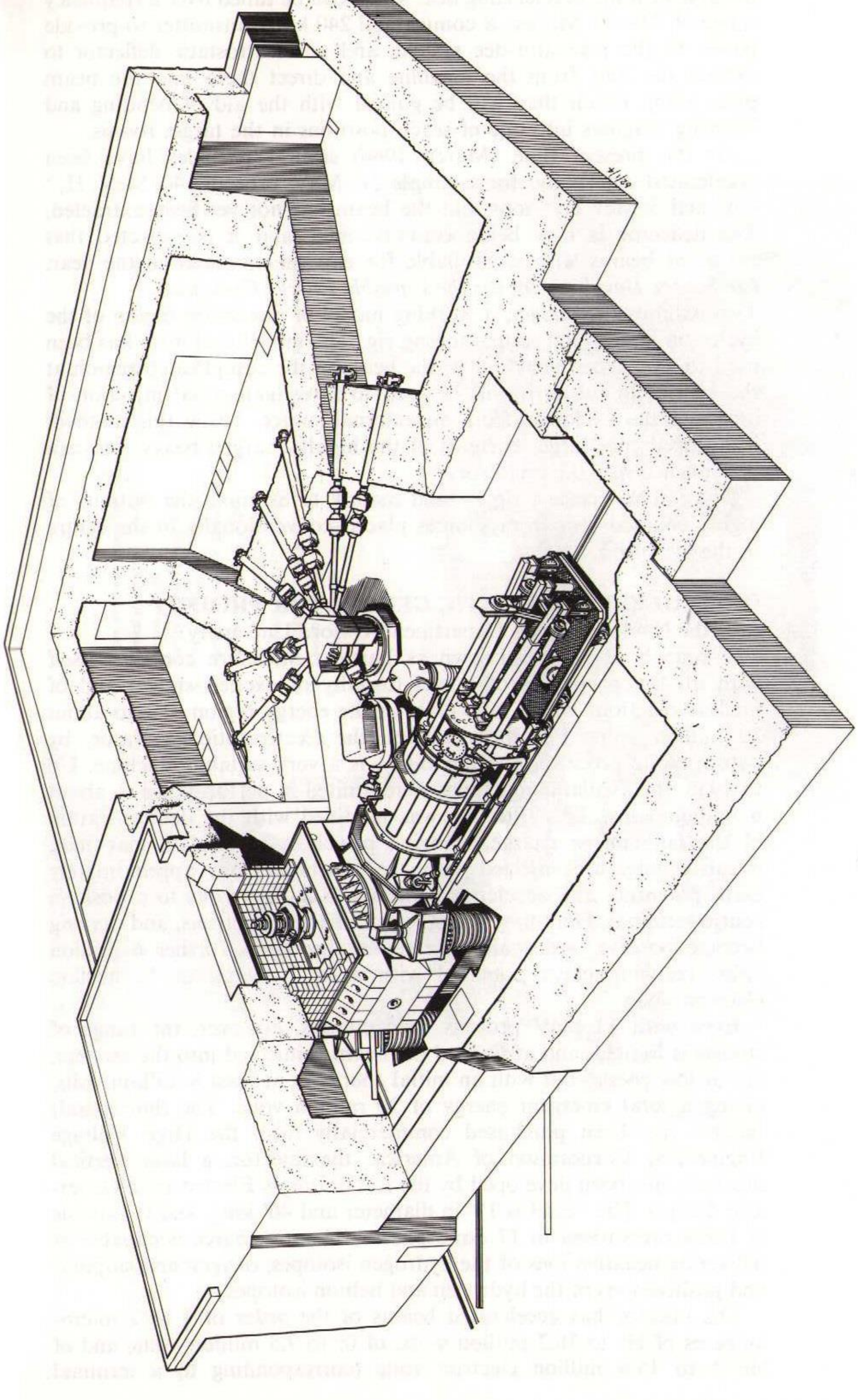
A display of models and photographs is in the
Main Entrance Hall, Building R.1

VARIABLE ENERGY CYCLOTRON

(For A.E.R.E. Harwell)

This accelerator (the "V.E.C."), has been designed by the staff of the Rutherford Laboratory and built under their direction, mainly for studies in radio chemistry, radiation chemistry, and radiation effects in solids. A beam was first obtained in the cyclotron in December 1965, but before experiments can be started it will need to be extracted. The cyclotron is located on the A.E.R.E. site, in its own building, the core of which is a vault with shielding walls 8 ft. thick, adjacent to which there are three shielded target rooms into which the beam will be steered for experiments.

The emphasis in the design has been on versatility; the ultimate aim is to be able to accelerate a number of different ions over a range of energies. The main features are as follows: a 200 ton magnet with 70" pole diameter fitted with a series of auxiliary "pole face windings"



CUT-AWAY VIEW OF VAULT, SHOWING CYCLOTRON & BEAM TRANSPORT SYSTEM to control the shape of the magnetic field; a high frequency resonator integral with the accelerating dee, which can be tuned over a frequency range of 7.6—23 Mc/sec; a commercial 240 kW transmitter to provide power to the resonator-dee system, and an electrostatic deflector to extract the ions from the machine and direct them into the beam pipe, along which they will be guided with the aid of bending and focusing magnets into one of seven positions in the target rooms.

At the present time (March 1966) several particles have been accelerated internally, for example 50 MeV protons, 40 MeV H_2^+ ions and 5 Mev H_2^+ ions, but the beam has not yet been extracted. The deflector is now being commissioned, and it is expected that extracted beams will be available for experiments later in the year.

Ion Source Development for the Variable Energy Cyclotron

Two exhibits are shown; a working model of the centre region of the cyclotron and an ion source testing rig. The model cyclotron has been used to study the behaviour of the beam in the complicated region at the centre. In future it will be used to investigate axial injection of ions into the cyclotron from an external source. Using this method, it is hoped that larger currents of the highly charged heavy ions can be launched into the cyclotron.

The ion source test rig is used mainly to examine the outputs of highly charged ions from sources placed conventionally in the centre of the cyclotron.

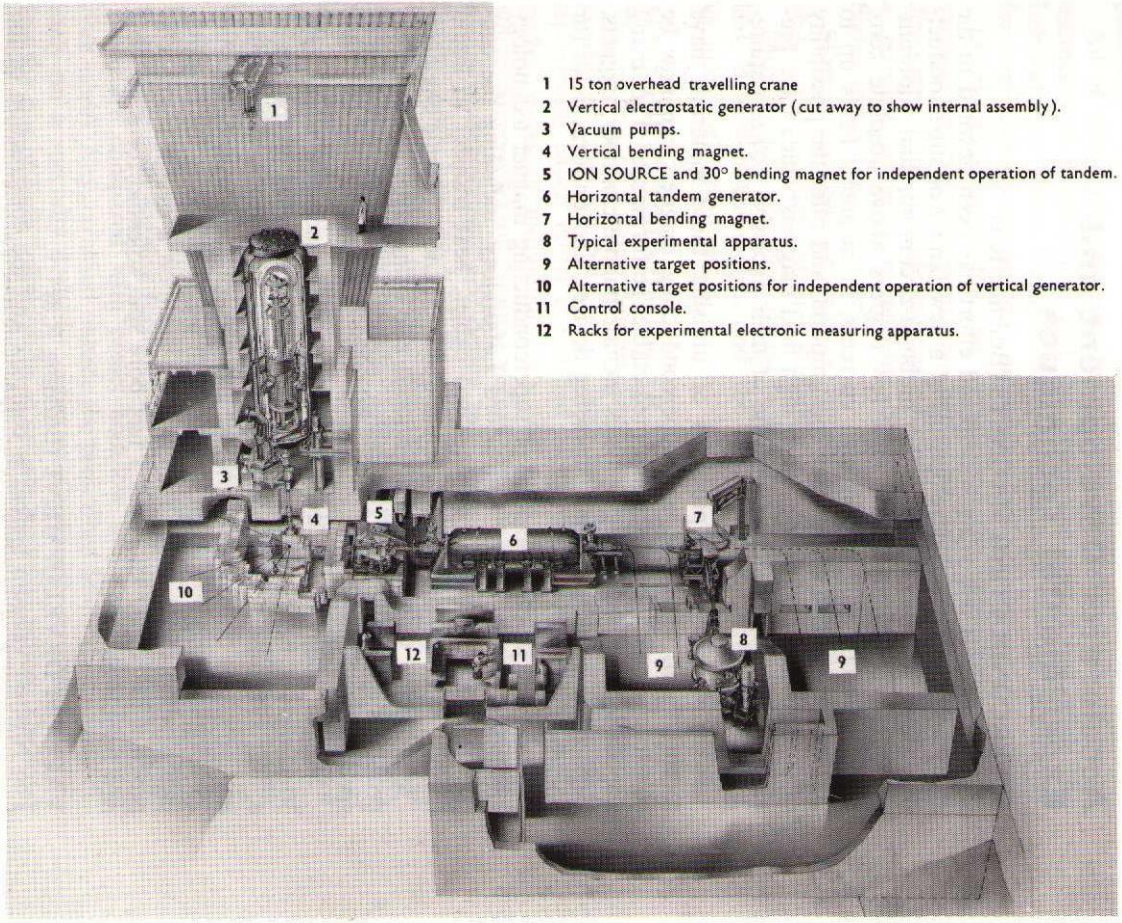
OXFORD ELECTROSTATIC GENERATOR PROJECT

(For the Nuclear Physics Department, Oxford University)

The branch of physics known as Nuclear Structure concerns itself with all the properties of nuclei (usually of excited states) and of nuclear reactions which take place in the energy region of 1 to about 20 million volts. For these studies, the electrostatic generator, by nature of its precision and flexibility, is a very suitable machine. Up to 1958, the available machines were limited in performance to about 6 million volts. This situation was modified with the demonstration of the tandem, or charge changing principle. In tandem machines, negative ions are injected into the machine from approximately earth potential, and accelerated through 6 million volts to a positive centre terminal. Here they are stripped of their electrons, and, having become positive, are again accelerated through a further 6 million volts, reaching earth potential with a total energy of 12 million electron volts.

Even with 12 MeV protons or deuterons, however, the range of studies is limited, and at Oxford the beam is injected into the tandem, not at low energy but with an initial energy of at least 8 million volts, giving a total emergent energy of 20 million volts. The (horizontal) tandem has been purchased commercially from the High Voltage Engineering Corporation of America: the injector, a large vertical machine, has been developed by the Laboratory's Electrostatic Generator Group. The vessel is 13′ in diameter and 40′ long, and is capable of being pressurised to 17 atmospheres. The ion source is capable of delivering negative ions of the hydrogen isotopes, oxygen and sulphur, and positive ions of the hydrogen and helium isotopes.

The injector has accelerated beams of the order of $\frac{1}{2}$ to 2 microamperes of H^- to 10.2 million volts, of 0^- to 9.5 million volts, and of He^{++} to 15.6 million electron volts (corresponding to a terminal



OXFORD ELECTROSTATIC GENERATOR

voltage of 9.7 million volts). Coupling the injection to the tandem has proved straightforward: the transmission efficiencies have been in the range 10—30%, and protons have been accelerated up to 20 million electron volts (of which 9.25 was from the injector) while 0.02 microamperes of oxygen have been accelerated up to 46 million electron volts. The machine has been handed over to the Department.

Accelerator Development and Experimental Techniques

SUPERCONDUCTING MAGNETS (Building R.1)

During the past five years widespread effort has been devoted to the study and commercial development of a new family of superconducting alloys, notably niobium-tin, niobium-zirconium, and niobium-titanium. At a temperature of a few degrees above absolute zero, these materials will sustain high currents, in magnetic fields up to 200 kilogauss, with zero power consumption, and offer the possibility of constructing a variety of large high field magnets which have previously been impracticable because of their excessive power requirements.

Many of the initial problems of utilising these materials have recently been overcome, and superconducting magnets can now be constructed with reliable and predictable performance. The many applications in high energy physics include bubble chamber magnets, large angle bending magnets, focusing devices, and uniform fields for polarised targets.

Nearly all practical aspects of superconducting magnet technology are being studied at the Rutherford Laboratory, including the construction and behaviour of stabilised cables, heat transfer to liquid helium, stabilisation of high current densities, and cryogenic engineering problems. Considerable attention is also being given to theoretical problems associated with coil design, economics, and the provision of specified field shapes.

Several magnets are under construction, including a 6 ft. long, 30 kilogauss, bending magnet for the Nimrod external proton beam, a 100 kilogauss 5″ bore research solenoid to study new materials and problems of magnet operation, and two corrected solenoids giving 25 kilogauss and 50 kilogauss fields with high uniformity for research into new polarised target materials. In addition a design study is in progress for an 80 kilogauss 5 feet bore split solenoid for a possible new bubble chamber.

VACUUM DEVELOPMENT (Building R.8)

The Nimrod vacuum system is complex and the construction of the vacuum vessels from epoxy resin/glass fibre laminate posed some extremely difficult problems in design and manufacture. A great deal of development work was involved before a satisfactory vessel could be produced. Some appreciation of the problems involved may be gained from the size and operating pressures of the vacuum system. Each vessel is approximately 50 ft. long, subtending 45° on a 60 ft. inner radius so that eight sections form a complete torus. The cross sectional measurements of each vessel are approximately 3′ 6″ x 1′. The system consists of $\frac{1}{4}$″ thick inner vessels, $\frac{1}{8}$″ thick outer vessels and 2″ thick header vessels; the inner and header vessels normally operate at a pressure of 10^{-6} torr (a torr is a unit of pressure approximately equal to 1 m.m. of mercury). Because of the fragility of the vessels, suitable protective devices incorporating pressure switches and equalising valves to prevent pressure differences on pump-down must be incorporated in the pumping system, which consists essentially of 40 24″ oil diffusion pumps together with 24 large rotary pumps.

All of this equipment requires a continuous programme of maintenance and development and the experience gained has made the Laboratory a centre for the development of high vacuum techniques for large high vacuum systems on accelerators.

Development work for new vessels and the improvement of the vacuum system is continuous; particular attention is paid to the development of suitable materials for vacuum vessels in the light of a possible increase in machine beam intensity and consequently higher irradiation dose rates.

More comprehensive technical information on the Nimrod vacuum vessels and vacuum system is available.

Displays and demonstrations include sections of vacuum vessels, leak detection techniques and the use of mass spectrometry; and vacuum coating processes.

MACHINE PHYSICS (Buildings R.2 and R.25)

The success of a large complex machine such as Nimrod, depends greatly on the reliability of a large amount of high performance equipment. Much effort is directed to improving the reliability and performances of individual units and parts of the accelerator as a whole. Since work on Nimrod began, there have been many improvements in components and design techniques. Much recent electronic design work has involved the use of pre-fabricated circuit blocks including integrated circuits. The use of these latter devices has resulted in considerable reductions in the size of units, together with improved performance and reliability, often at lower cost. Apart from those involving high voltages, most units now employ semiconductor devices exclusively.

A number of recently designed units (in one case contrasted with earlier versions) are on display in Building R.25.

As an aid to diagnosing fault conditions as early as possible, the Data Recording System in the Main Control Room is being extended to provide data logging facilities for up to 400 machine parameters. These are compared with preset high/low limits (held in the main core store). Any variation outside the prescribed limits shows immediately on a specially designed indicator. Eventually it is proposed to use the out of limit information to initiate remedial action. The total scanning time for the 400 variables is approximately 8 seconds.

The display indicator is exhibited in "bread-board" form in Building R.25.

Experience has shown that the stability of the accelerator is improved by continuity of operation. A comprehensive simulator has been built and installed in the Main Control Room, Building R.2, to provide this continuity and to act as a test facility during times when the Magnet Power Supply is off (e.g. during maintenance periods).

Other specialised equipment includes :—

(i) Electro-magnetic Monitor for the External Proton Beam

This is a toroidal current transformer used to measure the beam pulse current, the beam acting as a single-turn primary.

Particular advantages of this type of monitor are negligible beam disturbance and ease of calibration.

Current transformers are used to monitor the injector beam of Nimrod, but the extracted beam "spill" time may be as much as 0.5 secs., with a corresponding beam current of less than $1\mu A$. A high-gain low-noise d.c. amplifier is used to amplify the minute transformer secondary current and to obtain the necessary low frequency response the transformer is included in a feed-back loop.

The transformer core consists of 8 strip-wound cores of very high permeability mu-metal stacked together, the large core window being dictated by the beam aperture required.

The 5000-turn secondary winding uses 3 miles of copper wire.

(ii) A Signal Enhancing System for Retrieving a Repetitive Signal from Random Noise by a Process of Successive Averaging

This is intended for use in conjunction with the External Proton Beam monitor and also with the Polarised Proton Targets as part of the calibration system.

This equipment is on display in Building R.25.

BEAM PHYSICS

(Buildings R.25, R.2, R.1 and Nimrod Magnet Hall)

Transport, focussing, and separation of high energy particle beams demand large and complex equipment. Components such as quadrupole focussing magnets, bending magnets, electrostatic velocity separators and remotely controlled collimators undergo continuous design, development, and testing before installation on Nimrod experiments.

Explanations of beam techniques are set up in the Magnet Room and some of the devices used are displayed in Building R.1.

A demonstration of magnet testing, using the floating wire method to simulate particle behaviour, may be seen in the Preparation Hall (Building R.2).

Separated beams are the most demanding in terms of "optical" precision, particularly when the detecting device is a bubble chamber. Different types of particles must be physically separated by means of high voltage electric fields. Because the particles travel close to the velocity of light, many metres of field are needed to produce a few millimetres separation.

Separator assembly and testing are exhibited in the Heavy Duty Laboratory (Building R.25), together with a 1 megavolt impulse generator used to investigate high voltage breakdown phenomena. In some cases, the separators include a magnetic field at right angles to the electric field. The technique of magnetic field measurement may also be seen in Building R.25.

GENERAL PHYSICS

The work of the group covers some special developments immediately conected with Nimrod and high energy physics experiments, together with other research in subjects of the group lie in two general fields.

At present the main interests of the group lie in two general fields.

Firstly, in the production and acceleration of intense charged-particle beams, including studies of electron beams, of ion sources, and of an ion gun with a single accelerating gap at very high voltage. Secondly, in making a polarised proton target for use in high energy physics experiments; this target may be seen in Hall No. 2 and is described on page 10. Also, in collaboration with other groups an investigation is also being made, using photoelastic methods, into the dynamic stresses in the pole pieces of the Nimrod alternators.

Electron Beams (Laboratory 3, Building R.1)

A space charge high vacuum gauge is shown operating with a simple transistor control unit which presents the pressure on a meter with a linear scale. Electrostatic plasma oscillations are also demonstrated using this equipment.

Duoplasmatron Ion Source (Laboratory 6, Building R.1)

The exhibit shows a modified duoplasmatron ion source. An "expansion cup" has been added to improve the quality and intensity of the extracted ion beam. This ion source is intended for use on a 600 KeV single gap d.c. accelerator. (See below.)

Single Gap Ion Gun (Building R.25)

The exhibit shows a single gap d.c. accelerator. It is intended for operation at 600 KeV—the injection energy for the Nimrod linear accelerator. The electrodes have been shaped to produce a focused ion beam. The ion source currently in use is based on a hot cathode P.I.G. (Penning Ionisation Gauge) discharge. A modified duoplasmatron is also being developed for this accelerator. (See above.) The gun has been successfully operated to produce a 300 KeV 200 milliamp ion beam.

Dynamic Stress Analysis (Laboratory 3, Building R.1)

The dynamic stress in parts of the main Nimrod alternators is being studied while the machine is rotating in normal operation, by the combination of high speed flash photography with standard photoelastic techniques. A thin piece of transparent plastic is stuck to the (moving) part to be examined (e.g. the end plate of a pole piece) by reflecting cement. Light from a fast flash-tube passes through the plastic to the cement where it is reflected back through the plastic towards a stationary analyser. The difference in the principal strains at every point in the plastic, and therefore at corresponding points in the substrate being studied, can then be determined from photographs taken with a camera viewing through the analyser. The light flash is synchronised to the rotation of the machine using electronic equipment developed in the Laboratory, so that a selected region can be examined both by ciné and single frame photography.

The method will be demonstrated using a model, since the alternator will not be rotating during the Open Day.

Engineering

(Buildings R.9 and R.18)

The demands of a large laboratory engaged on research in nuclear and elementary particle physics presents a stimulating challenge to civil, chemical, electronic, electrical and mechanical engineers. Developments are rapid, and all staff are caught up in the excitement and urgency of the requirements. In advanced physics international collaboration is unique but competition is severe to be first in particular sectors of knowledge. Although the use of research apparatus is entirely the field of the physicist, its design, construction, installation and operation is predominently an exercise in engineering; highly sophisticated engineering, since research apparatus must be constructed so that the overall precision of an experiment is detrimentally affected to a minimum by the apparatus used. So far as mechanical engineering is concerned, limits usually associated with small precision measuring instruments have to be achieved in large scale apparatus, and in electrical engineering currents may require stabilisation to 1 part in 10^5.

Building large accelerators poses many unusual problems for engineers throughout the design stage, during construction and at the commissioning stages. The Variable Energy Cyclotron at Harwell and the Electrostatic Generator at Oxford University now nearing completion are no exceptions.

Engineering at the Laboratory has been principally directed to the building and operating of two large accelerators, Nimrod and PLA and the construction of the experimental apparatus for utilising these machines. These large accelerators and the major experimental equipment represent a major capital investment, and for greatest efficiency and best utility they operate around the clock. This requirement sets a high standard for the reliability of all engineering components and services. Some of the electrical components and devices operate in the micro-ampere range for measurement and control circuits, whilst megawatts of power are used for other purposes.

The installation and modification of beam lines requires the rapid and accurate positioning of large components, the provision of power, cooling water, and massive concrete and steel shield walls, the work being planned to minimise "down" time. It is necessary to keep at the fore-front of knowledge in developing cryogenic equipment and in techniques in steering, selection and detection of particle beams. The exacting environments in which materials are used calls for the examination of their behaviour under irradiation and very low temperatures.

Bubble chambers are in themselves complete engineering projects costing many thousands of pounds, whilst the automatic analysis of the vast number of photographs produced, 2 to 3 million a year are envisaged in the near future, is an example of the extremely intimate association demanded of engineers and physicists in linking the scanning of photographs direct to computers enabling an event to be assessed up to 100 times faster than the best visual scan can achieve.

Whenever possible private industry is used, not only in engineering manufacture, but extensively in assistance in detail design and mechanical and electrical installation on the site. Changes and modifications are inevitable and they have to be incorporated in a design and carried out with the least possible effect on parts already made or on delivery times. All equipment must be subjected to adequate trials and tests to prove performance and reliability before installation in the experimental beam lines or on the main machines.

Developments in experimental techniques call for adaptation of existing buildings and the provision of new whilst the electrical, steam, water, compressed air, towns gas, and other laboratory services must be extended and continuously maintained. The Rutherford Laboratory uses over 15 Mw of electrical power and over 10 million gallons of cooling water are circulated daily. The vast array of electronic instruments seen throughout the Laboratory must be kept constantly in working order whilst special units and adaptions are produced in large numbers. With so many potentially hazardous materials and pieces of equipment the safety of the individual and of the Laboratory must at all times be zealously guarded and it forms part of the engineers work in the Laboratory, in the first place by introducing safety in design, and secondly by well considered Codes of Practice to cover use.

Radiation Protection and Safety

RADIATION PROTECTION (Building R.20)
The Radiation Protection Group has as its primary task the protection of staff and visitors from harmful radiation. This is achieved by measuring both the general level of radiation in affected areas and the actual radiation received by an individual. A strict control is maintained on radio-active sources and contaminated materials. The measurement of radiation is a complex problem and continual development of techniques is necessary to meet the changing demands of high energy physics and its associated accelerators.

It is hoped to improve the understanding of the fundamental processes involved in the production of radiation fields and a programme is being prepared to further this work. The information produced will be used in the design of new facilities around Nimrod and other existing proton accelerators.

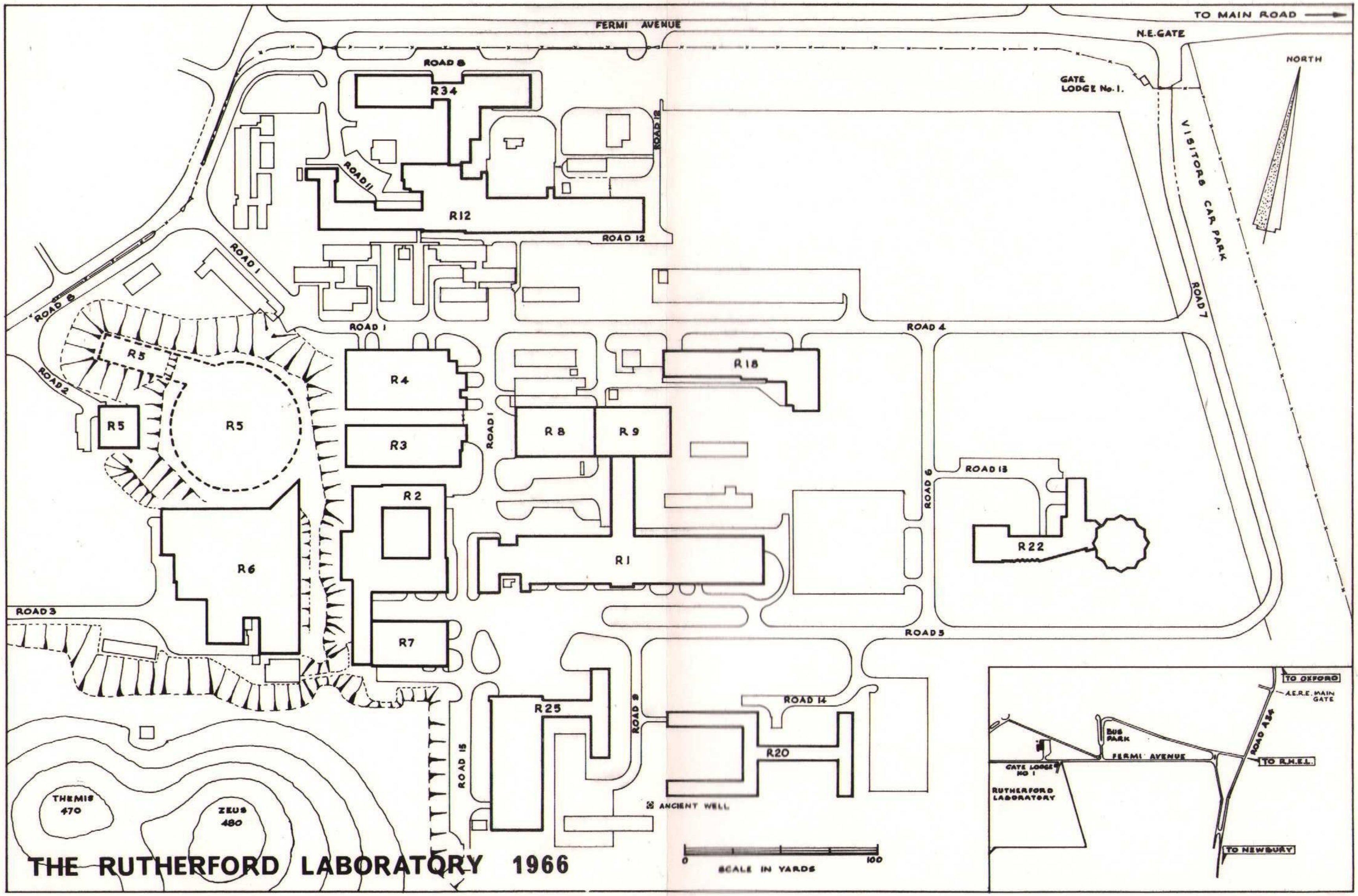
Displays will include the operation of the film badge service which provides data on the type and amount of radiation absorbed by individuals; and the scanning and counting techniques used to measure radiation.

SAFETY
The main function of the group is to promote a consciousness of the need for safety and accident prevention and to keep safety arrangements in the Laboratory constantly under review. The display cabinets in Buildings R.1, R.2, R.12 and R.20 feature some aspects of the work, other duties include advice on the statutory requirements for safety and fire prevention, routine inspection of pressure vessels, lifting equipment and high voltage equipment. Close liaison is maintained with other research laboratories and other bodies concerned with safety at a national level.

Notes

Key

Building Number	Function
R.1	*Laboratories and Offices*
R.2	*Nimrod Control Room, Offices and Workshops*
R.3 & R.4	*Nimrod—Power Supplies*
R.5	*Nimrod — Injector and Magnet Rooms; Experimental Hall No. 2*
R.6	*Nimrod — Experimental Hall No. 1 and Bubble Chamber Annexes*
R.7	*Bubble Chamber Plant*
R.8	*Assembly and Testing*
R.9	*Engineering Workshops*
R.12	*Proton Linear Accelerator*
R.18	*Engineering Workshops*
R.20	*Library, Radiation Protection and Offices*
R.22	*Restaurant and Lecture Theatre*
R.25	*Laboratories and Offices*
R.34	*Nuclear and Radio-Chemistry*


TO MAIN ROAD
FERMI AVENUE
N.E. GATE
NORTH
GATE LODGE No. 1.
VISITORS CAR PARK
ROAD 8
R34
ROAD 12
ROAD 11
R12
ROAD 1
ROAD 7
ROAD 4
R18
R5
ROAD 2
R4
R3
R8
R9
ROAD 13
ROAD 6
R2
R1
R22
R6
ROAD 3
R7
ROAD 5
TO OXFORD
A.E.R.E. MAIN GATE
ROAD 14
R25
ROAD 9
R20
BUS PARK
ROAD A34
FERMI AVENUE
TO R.H.E.L.
GATE LODGE No 1
RUTHERFORD LABORATORY
ROAD 15
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