THE NATIONAL INSTITUTE
FOR RESEARCH IN NUCLEAR SCIENCE

SECOND ANNUAL REPORT

1958-59

RUTHERFORD HIGH ENERGY LABORATORY
HARWELL, DIDCOT, BERKSHIRE

THE NATIONAL INSTITUTE
FOR RESEARCH IN NUCLEAR SCIENCE

Second Annual Report

for the period 1st April, 1958
to 31st March, 1959

Presented to the United Kingdom Atomic Energy Authority
in pursuance of Article 13 of the Institute's Royal Charter

RUTHERFORD HIGH ENERGY LABORATORY
HARWELL, DIDCOT, BERKSHIRE

Membership of the National Institute

March, 1959

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CONTENTS

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

SECOND ANNUAL REPORT

for the year ending 31st March 1959

PART I ORGANISATION AND ACTIVITIES

INTRODUCTION

1. The Institute were honoured by the grant of a Royal Charter on 23 June, 1958. A copy of the Royal Charter is included as an Appendix to this Report.

2. One change in membership of the Institute occurred during the year. Sir Philip Morris resigned on 31 July, 1958, on completing his term of office as Chairman of the Committee of Vice-Chancellors and Principals. His successor in that office, Dr. R. Aitken, the Vice-Chancellor of the University of Birmingham, was appointed to membership by the authorities named in the Royal Charter.

3. Good progress has been made during the year in the construction of the Rutherford High Energy Laboratory, Harwell, which is still the Institute's only laboratory. The 50 MeV proton linear accelerator, then nearing completion, was handed over to the Institute by the U.K. Atomic Energy Authority at the end of the year. The construction of the 7 GeV proton synchrotron, which has now been given the name Nimrod, proceeded steadily. These major activities are described in more detail later in this report.

ARRANGEMENTS FOR RESEARCH

4. Arrangements for research workers from universities were further developed. Detailed rules for the financing of research at the Laboratory by university visitors were agreed with the University Grants Committee and the Department of Scientific and Industrial Research, the broad principle being that the university is responsible for the salaries of its graduate research staff, but that the Institute is responsible for the other costs directly concerned with the experiment.

5. The first university visitors arrived at the end of the year, to work on the preparation of experiments to be done on the proton linear accelerator.

6. It has been decided to make a number of fixed-term research appointments to the resident nuclear physics research teams. The posts were advertised.

7. In order to build up experience to ensure that the most efficient use is made of Nimrod as soon as possible, it has been decided for the next few years to request permission to send physicists from the staff of the Rutherford Laboratory or of a university to work for short periods on the large accelerators at Berkeley, and Brookhaven, U.S.A. Requests were accordingly made to these Laboratories and have been accepted.

In the same way, in preparation for the completion of the proton linear accelerator, the Institute financed a visit for six weeks early in 1959 by a physicist from Birmingham University to study the experiments done with the proton linear accelerator at the University of Minnesota, U.S.A.

RESEARCH REACTORS

8. Although it has always been understood that in addition to supplying accelerators, the Institute might also be required to provide research reactors, no clear requirement has yet been established for the construction by the Institute of a new high powered research reactor on a central site for common use by universities. The Institute have however agreed to co-ordinate and support university requests for the use of reactors at the Atomic Energy Research Establishment and to appoint a liaison officer for this purpose. The facilities which can be made available are limited but the Director, A.E.R.E., has promised to help as far as possible. It is planned to erect a low-activity chemical laboratory at the Rutherford Laboratory for the use of university research workers using A.E.R.E. reactors.

9. In certain cases, it appears that requirements might be established for small low-powered research reactors at particular universities. The Institute's Research Reactor Committee have been co-ordinating the information on these requirements.

OPERATION OF THE RUTHERFORD HIGH ENERGY LABORATORY

10. The original intention was that the Institute's own staff would be a small one concerned mainly with general direction and with the nuclear physics research while the construction, operation, maintenance and development of the machines and equipment at the Rutherford Laboratory would be carried out as a service by the Atomic Energy Authority. Accordingly nearly all the staff engaged on designing, building and operating the Laboratory and its accelerators are at present Authority employees. This arrangement has resulted in very rapid progress. While a change in this policy was not definitely agreed during the year under review, it became clear that the Institute might have to take over the operation of the Laboratory progressively with their own staff; a start was made in preparing plans for this. The principal reason for such a change is that it is now foreseen that by 1962, when Nimrod is due to be coming into operation, a considerably larger staff will be required at the Laboratory than was originally anticipated. The Atomic Energy Authority have indicated that while they have undertaken to design and construct Nimrod they would have difficulty in providing such a large number permanently. The number will also be large enough to give a reasonable range of posts and career prospects, and this being so, there are obvious advantages in having the staff directly under the authority of the Institute. It is therefore probable that the Institute will take over the responsibility for staffing the Laboratory progressively during the next few years, and that they will also make their own arrangements for providing services except those which are clearly more economically provided by the Authority.

It is anticipated that many of the Institute staff will be obtained by transfer from the Authority. For this reason, and to reduce the number of administrative staff required, it is intended generally to follow the practice of the Authority on pay and conditions of service.

DEVELOPMENT OF THE RUTHERFORD HIGH ENERGY LABORATORY

11. A substantial addition to the laboratory, workshop and office accomodation at the Laboratory, was approved by the Treasury. When this is completed, there will be space at the Laboratory for a total of about 350 scientific, technical

and administrative staff. Partly owing to the change foreshadowed in the previous paragraph, which would increase the number of engineering and administrative staff required at the Laboratory, it may soon be necessary to ask approval for a further addition.

HOUSING AND HOTELS

12. The Authority have agreed to transfer to the Institute, Coseners House, Abingdon, a pleasant house with frontage to the Thames, which has been in use as a hostel by the A.E.R.E. After some modification, it will be opened later in the year as an Institute hostel, mainly for university visitors, with about ten single and six double rooms. The Director, A.E.R.E., has kindly agreed to provide a small number of houses for rent to university visitors with families who come to work at the Rutherford Laboratory before the Institute have had time to provide their own houses. The Institute have already discussed some plans for flats and houses, but no building scheme has yet been adopted.

ACCOUNTS

13. Financial business was transacted by the Atomic Energy Authority on behalf of the Institute during the period before their legal incorporation on 23 June, 1958, the date of the grant of the Royal Charter. It has been decided to include accounts for this pre-incorporation period with those for the year 1958/59 which it is expected to summarise in next year's Report. No accounts are, therefore included in this Report. A broad indication of the rate of expenditure may however be appropriate. In the period up to 31 March, 1959, capital expenditure was approximately £1·8 million mainly on the construction of the Rutherford Laboratory and Nimrod. Recurrent expenditure was approximately £0·7 million. This was almost wholly on the services of A.E.R.E.

PART II THE RUTHERFORD HIGH ENERGY LABORATORY ACCELERATORS

THE 7 GeV PROTON SYNCHROTRON ("NIMROD")

14. Nimrod is a machine for accelerating protons, (positively charged nuclear particles which form the nuclei of hydrogen atoms), to energies of approximately 7 GeV or 7 thousand million electron volts*. At these energies the protons are travelling at speeds very close to that of light, (3×10^{10} cm/sec). These high energy protons will be used in fundamental studies of nuclear and sub-nuclear phenomena, in particular the creation and properties of a number of nuclear particles which can only be produced at these high energies.

Principle of operation

15. It may be appropriate to describe briefly the principle on which proton synchrotrons such as Nimrod operate. Protons, after being initially accelerated in a subsidiary accelerator, are injected at low energy into a circular path enclosed by a ring shaped magnet. The magnetic field coerces the protons to move in a circular orbit rather than continue undeviated in straight lines, and they proceed to revolve in this manner for very many revolutions. It is arranged that the protons receive a small acceleration at a particular point in the orbit, and this is repeated with each revolution until the protons acquire their maximum energy. As the protons are accelerated, the magnetic field strength needed to keep them moving in the same circular path must be progressively increased, and simultaneously the frequency of the accelerating pulse which the protons experience on successive revolutions must be increased to keep in step with the increased frequency of rotation of the protons around the ring. This variation of frequency has to be carried out with great accuracy if serious loss of particles from the beam is to be avoided. After the protons have reached their maximum energy and been extracted from the machine, the magnetic field is reduced to its minimum value once more in readiness for the sequence of operations to be repeated.

*An electron volt is the unit of energy most frequently used in nuclear physics, and is the energy acquired by an electron, (a negatively charged sub-atomic particle), in falling through a potential difference of 1 volt.

The various proton synchrotrons which have been constructed in the world, (about six in all), differ considerably in details of design. The principal feature of Nimrod will be the intensity of the beam of protons which it is designed to produce, i.e. 10^{12} protons per pulse, at a repetition rate of 28 pulses per minute (about 1/16th of a microampere).

16. Work began on Nimrod in August 1957 following extensive design studies, and is due to be completed at the end of 1961. The various features of the machine and the progress made in the year under review are described in greater detail in the following sections. The main parameters are given in the following table.

PRINCIPAL PARAMETERS OF NIMROD

Maximum proton energy	7 GeV
Expected intensity of proton beam	10^{12} protons/pulse
Duration of pulse	0·72 seconds
Number of orbits per pulse	10^6 approx.
Pulse repetition rate	25–30 per minute
Mean orbit radius	77ft. 6·4 inches
Maximum magnetic field	14,000 gauss
Magnetic field at injection	300 gauss
Weight of magnet steel yoke	7,000 tons
Weight of copper used in magnetic coils	250 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.
Total peak rating of motor-alternators in magnet power supply	100 MVA approx.
Number of rectifiers in magnet power supply	96

Buildings

17. The buildings required to house Nimrod and associated plant comprise the following. A building to contain the accelerator proper, i.e. injector and magnet rooms; a large adjacent hall for containing experimental equipment into which the high energy proton beams will be directed; a control building which will be the nerve centre of the machine, permitting not only remote control of the machine itself but also allowing remote observation of the course of experiments being carried out in the adjacent experimental area; a preparation

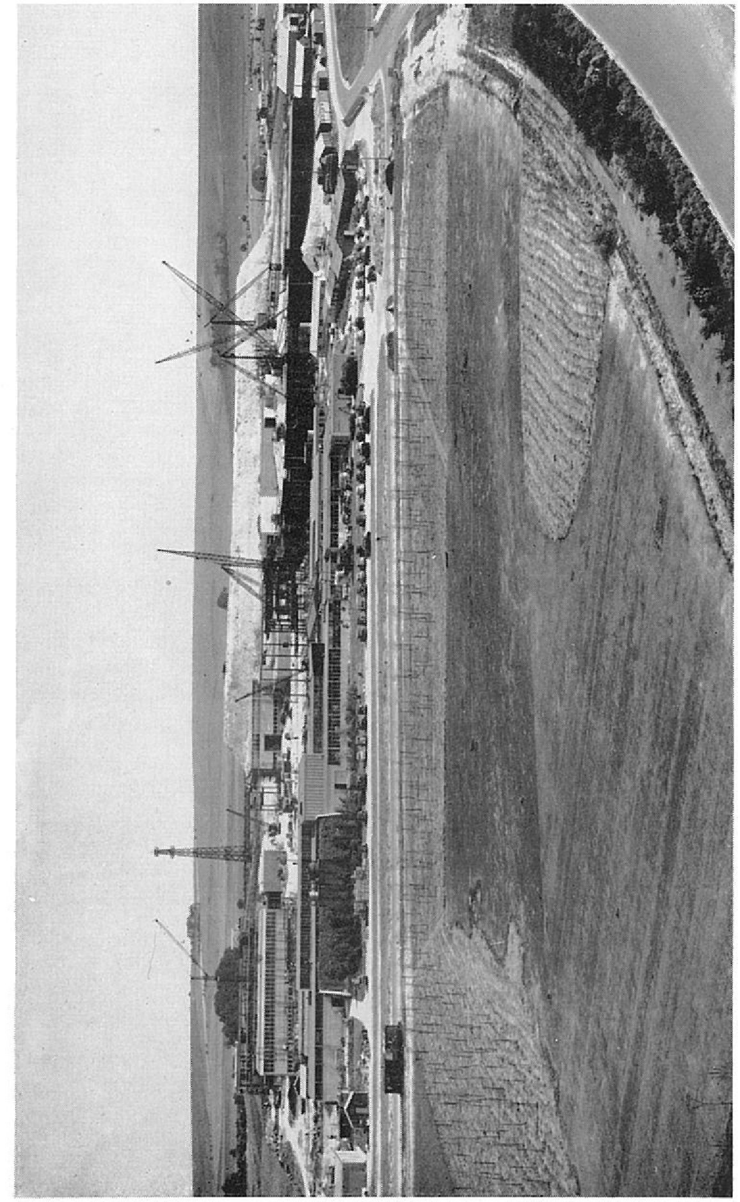
area in which heavy equipment required for experiments can be assembled, (this is initially being used for testing the magnet sectors, to be described later); buildings to house the power plant designed to supply the large amounts of electrical energy required by the 7,000 ton electromagnet; a large building to be used initially for preparatory assembly and testing work and ultimately as a workshop; and finally a three-storey laboratory and office block.

18. Principal interest centres on the injector and magnet rooms, not only because they will house the accelerator itself but because of their novel design and construction. Two principal requirements were dominant when the magnet and injector rooms were being designed. First, adequate shielding must be provided against the intense radiation which is produced when the machine is operating in order that the radiation level in all occupied areas is reduced well below the agreed health tolerance values. Secondly the 7,000 ton ring-shaped electromagnet, 150 ft. in diameter, has to be supported in such a way that it will not sink, tilt or distort by more than very small amounts. Both these requirements indicated that very strong foundations were essential.

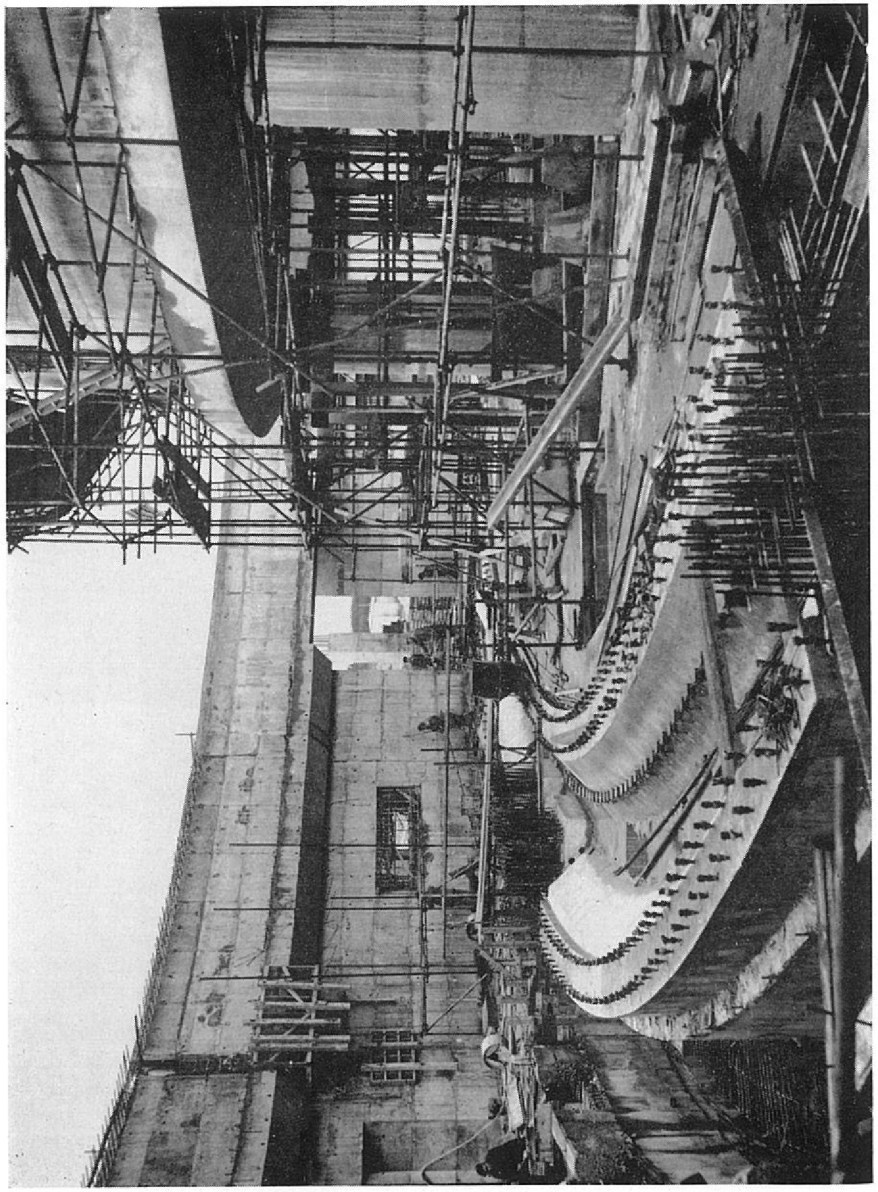
19. The magnet will be housed in a semi-underground circular building of reinforced concrete some 200 ft. in diameter, with walls and roof of sufficient thickness to support the necessary shielding, the bulk of which is provided by mounds of earth. The concrete roof for example has to be 6 ft. thick in order to support a 20 ft. thick layer of earth which will be placed on top. The foundation required to support this very heavy structure takes the form of a monolithic concrete raft of sufficient thickness and rigidity to support the additional weight of the magnet without undue distortion over long periods of time. Similar, but unconnected foundations are provided to support the injector room and shielding wall. The latter separates the magnet room from the experimental area and is 30 ft. thick and 140 ft. long. It is made up of large but transportable rectangular concrete slabs, the purpose of these being to cut off all radiation from the accelerator other than the high speed beams of particles required for experiments. Above this wall is a concrete beam 30 ft. wide and 18 ft. deep with a span of 140 ft. supported on abutments at each end and a central pier. This beam plays a major part in supporting the concrete roof. All the usual services (i.e. water, electricity) will be provided to the various parts of the machine in underground ducts and service trenches. Overhead cranes will be installed in the injector and magnet rooms and experimental area to handle the massive equipment, one of these being a 30 ton crane running on an annular track in the magnet room. Most of the power fed into the plant must ultimately be removed by various cooling services, and a battery of induced draft cooling towers and pumps is being installed which will cool and recirculate 420,000 gallons of water per hour.

20. During the year under review considerable progress had been made with the main buildings. The injector room and experimental area were virtually completed and the magnet room was in an advanced state of construction with only the roof still unfinished. The weight of concrete used so far is about 85,000 tons.

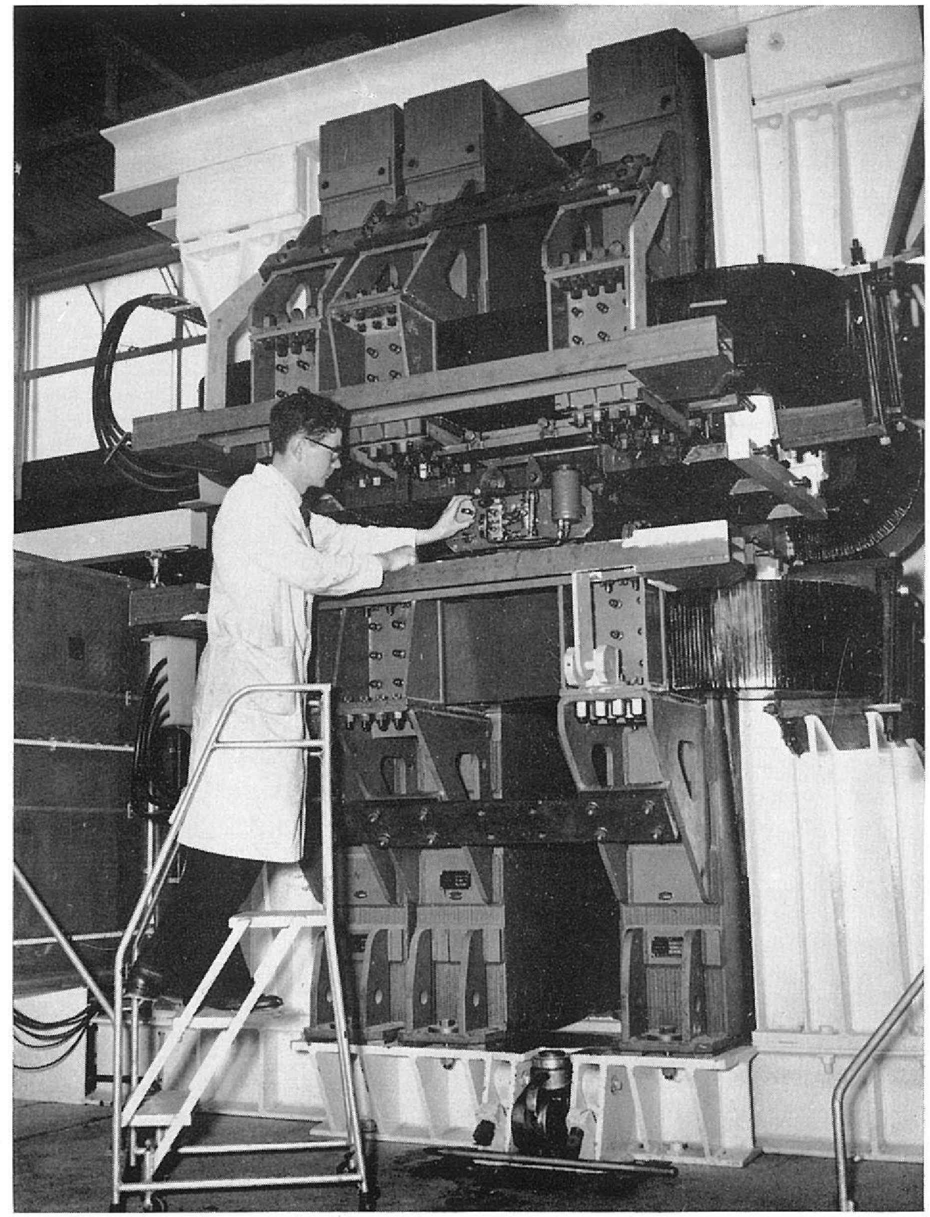
21. Of the remaining buildings, which are of conventional steel framed construction, several have been completed during the year. These include the control building, the preparation area and the workshop. Work on the laboratory and office block is in an advanced state and should be completed during 1959. A start had been made on the power plant buildings.



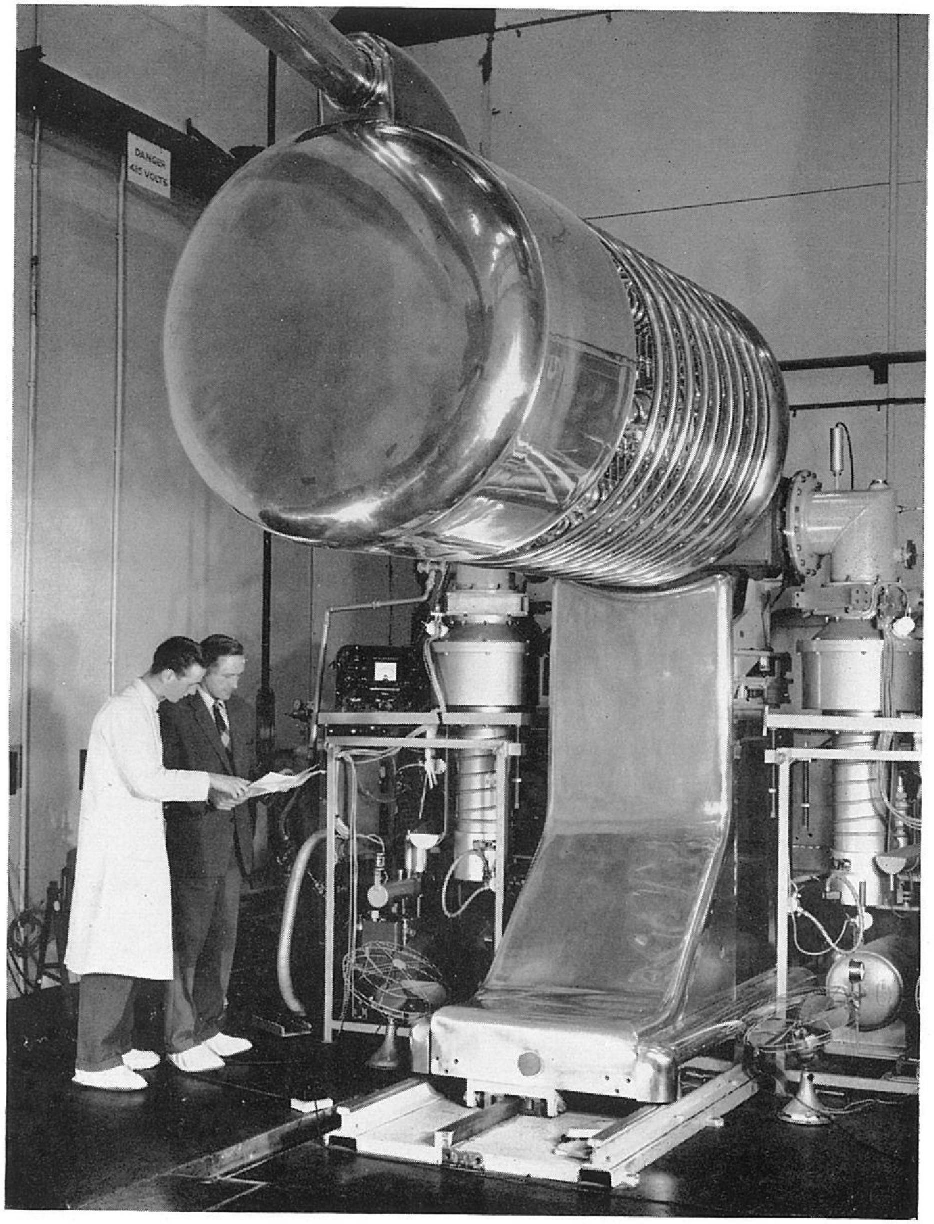
General view of the Rutherford High Energy Laboratory



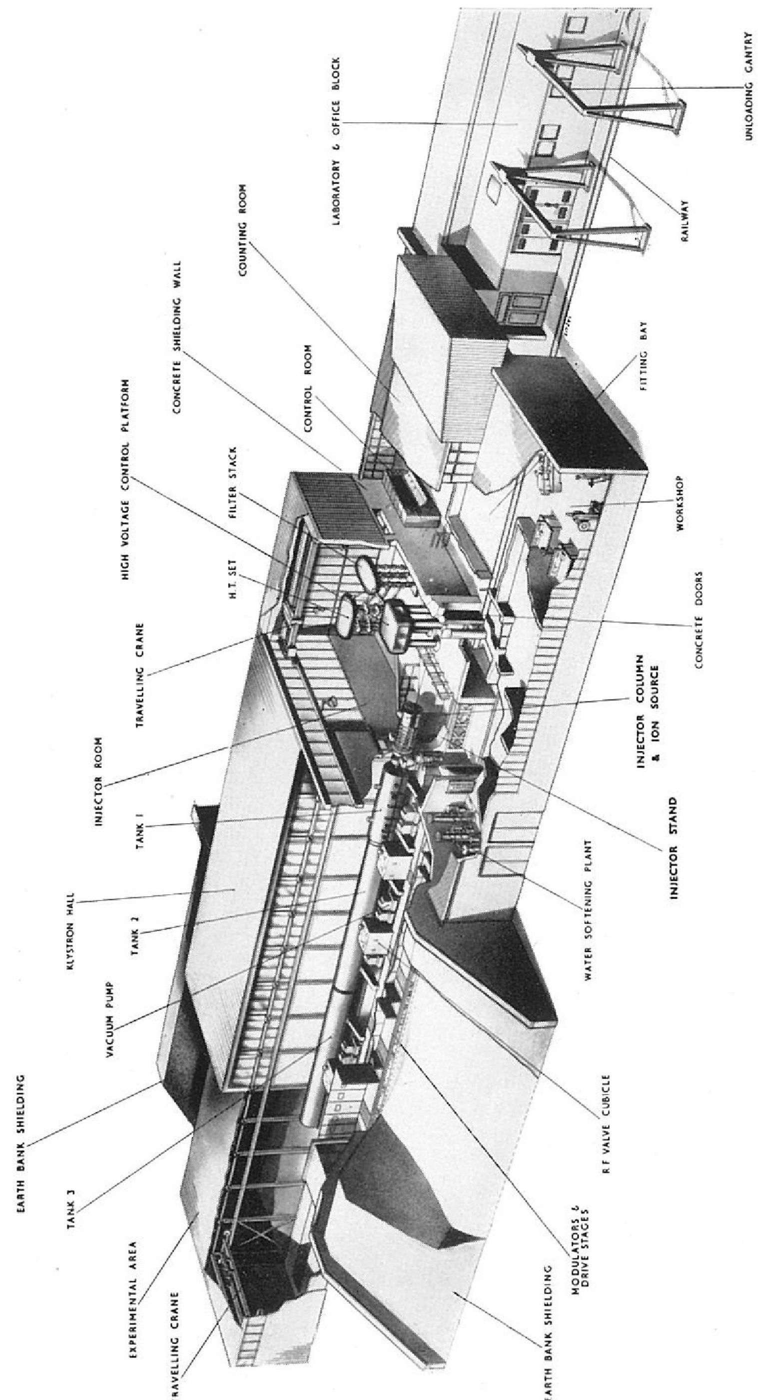
Nimrod magnet room under construction



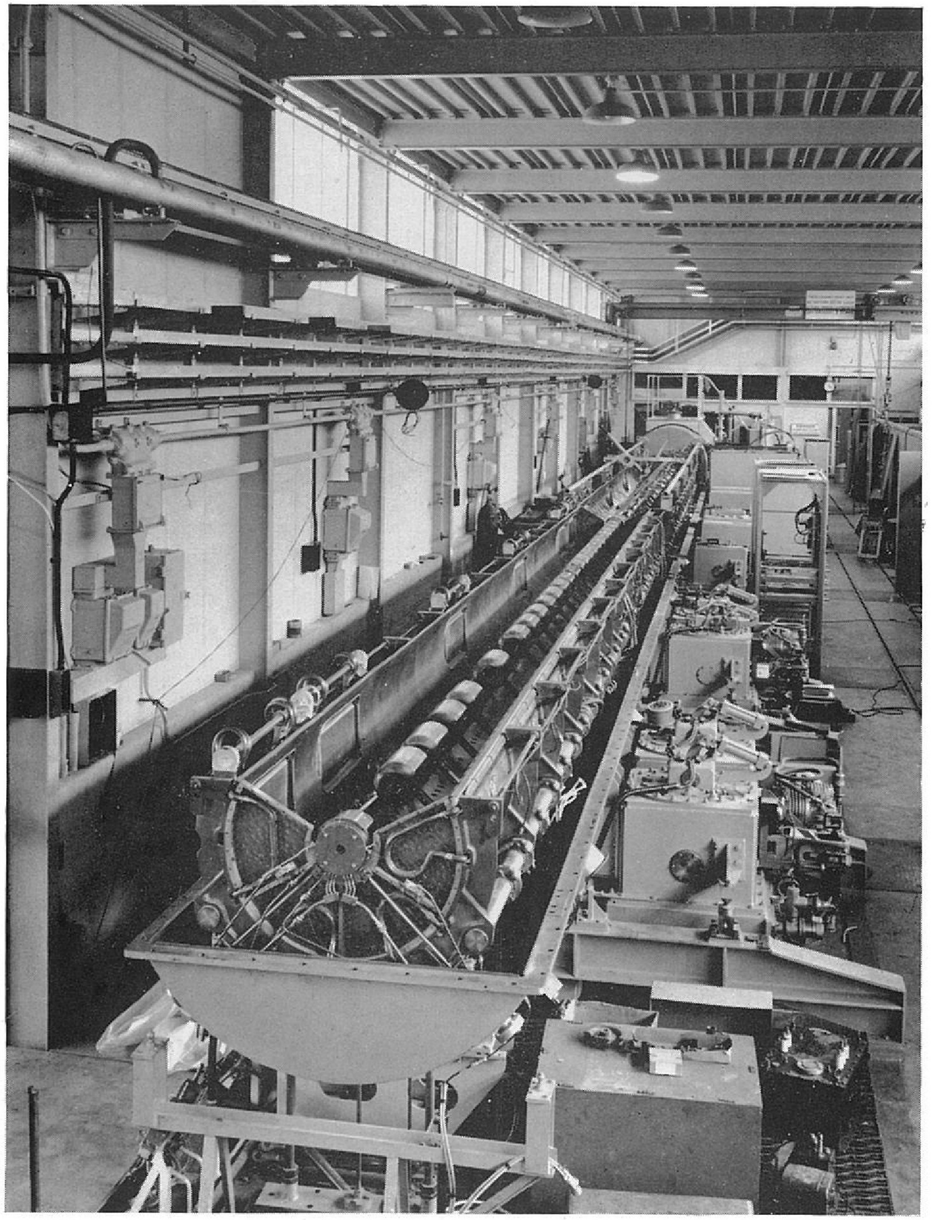
Testing rig for measuring magnetic properties of Nimrod magnet sectors



High-voltage ion gun in which protons are focused into a beam prior to entering the injector of Nimrod



50 MeV PROTON LINEAR ACCELERATOR



Exposed view of drift tubes in tank III of the 50 MeV Proton Linear Accelerator

Injector

22. The injector is that part of the machine in which the protons will be produced and given an initial acceleration before entering the magnet ring. It will consist of two main parts, an ion gun and a linear accelerator. In the ion gun, protons are produced by passing an electrical discharge through hydrogen gas at low pressure. A hydrogen atom consists of a negatively charged electron revolving round a positive proton, and the passage of the electrical discharge causes the electrons to be stripped off from many of the hydrogen atoms leaving behind protons. These are extracted from the discharge tube, focused into a beam and accelerated down an evacuated pipe to an energy of 600 keV.

23. The 600 keV beam is then admitted into the linear accelerator. This consists essentially of a cylindrical copper tank known as the liner contained in a steel vacuum tank 44 ft. long and 5½ ft. in diameter—which is excited by radio frequency electrical oscillations generated by an external high powered transmitting valve. The dimensions of the liner are such that it becomes resonant at a frequency of 115 Mc/s, and the amplitude of the electrical oscillations developed in the liner then reaches a maximum. The situation is analogous to that of any mechanical or accoustic system capable of free oscillation (e.g. a stretched string or column of air), which resonates or vibrates when excited by oscillations of the appropriate frequency. For half the time of each electrical oscillation the axial electric field drives the protons along the axis of the liner in the correct direction, but if no provision were made, the situation would be reversed in the negative half of the cycle when the field was in the opposite direction. To overcome this, a series of 48 tubular electrodes known as drift tubes are spaced along the axis in such a way that the protons pass through them during the negative half of each cycle, and in this way are screened from the reversed electric field. Focusing magnets are incorporated with each drift tube, their purpose being to prevent the proton beam from diverging excessively from the axial direction. About 1 MW of radio frequency power is required to drive the protons down the liner and since it would be quite impossible for the generating valves to deliver such power continuously, the injector is operated in pulses, each pulse lasting approximately 2 milliseconds, with a repetition rate to match the requirements of the synchrotron (up to 28 pulses per minute). After leaving the linear accelerator with an energy of 15 MeV the protons will be deflected through an angle of 25° so as to enter tangentially into the synchrotron magnet ring.

24. At the end of the period under review all the basic physics and engineering design work on the injector had been completed, and all major contracts for the manufacture of the components had been placed, with the exception of those for the drift tube assemblies, the inflector (producing the 25° deflection of the beam), and some ancillary equipment. Part of the injector hall was finished in October and since then installation of the ion gun and its associated apparatus has been nearly completed.

Magnet

25. The 7,000 ton magnet ring has a C-shaped cross section with the open end of the C facing radially outwards. The purpose of the magnet is to direct and focus the protons into an approximately circular path, 155 ft. in diameter. When the 15 MeV protons enter the ring the magnetic field will be 300 gauss. Subsequently, as the protons are being accelerated up to 7 GeV, the magnetic field will increase to a peak value of 14,000 gauss during a time interval of

0·72 sec. The magnet will be constructed from 336 separate sectors, each fitted with two detachable polepieces to give the correct magnetic field distribution. The sectors will be arranged in 8 octants of 42 sectors each, separated by 8 field-free 'straight-sections' alternately 11 ft. and 14 ft. in length; these will accommodate the RF accelerating cavity, connection with injector, beam extraction equipment, etc. Each octant will be 'wound' with copper coils capable of carrying a peak current of 9150 amperes for the purpose of energising the magnet.

26. The magnet sectors, each weighing approximately 20 tons are constructed from $\frac{1}{4}$ in. and $\frac{1}{2}$ in. plates of 1% silicon steel. After cutting and welding to general shape, the 125 in. × 111 in. plates are annealed, flattened, drilled and insulated. About 45 plates are bolted and welded together to form a sector. The gap of the 'C' is then machined out to 0·005 in. accuracy, and the flanks of the sector machined to a slightly tapered form to permit close stacking into the magnet ring. Despite many difficulties encountered in the manufacturing process, some 10 sectors had been delivered by the end of the year under review and the production rate had reached 3 per week.

27. The magnetising coils comprising 42 turns on each octant will be made from 1·375 × 2·625 in. section copper conductors with an 0·2 sq. in. central hole for water cooling. Each turn will consist of four separate lengths of conductor bolted together; two lengths of about 50 ft. will each span the complete arc of a magnet octant, and two shorter lengths will serve as cross-connections at the octant ends. Contracts for the manufacture of the coils have been placed.

28. Each polepiece will consist of a stack of about 450 thin steel laminations, bonded together into a rigid block weighing approximately 8 cwt. The laminations will be accurately profiled to give the required distribution of magnetic field in the magnet gap. This distribution is important since it controls the efficiency with which the magnet can focus the protons into a narrow beam. The detailed design of the polepieces is still proceeding, with the aid of small-scale magnet models.

Radio Frequency Accelerating System

29. The function of the radio frequency system is to raise the energy of the circulating proton beam from its initial value of 15 MeV to a final value of 7 GeV. This is achieved by passing the proton beam on each revolution through two adjacent accelerating gaps across which alternating voltages are applied at a radio frequency synchronised with the rotation frequency of the protons round the orbit. Each time the protons traverse the gaps they experience a force exerted by the electric field accelerating them to higher velocities. The corresponding increase in energy of the protons resulting from this acceleration is about 7 keV per revolution. After about a million revolutions the final energy is attained. The accelerator unit containing the gaps is basically part of the main vacuum system, the flanges of the vacuum vessel located within the unit actually acting as the electrodes across which acceleration of the proton beam occurs.

30. The problem is therefore to generate a signal whose frequency is synchronised to the rotation frequency of the protons and to amplify this signal to a sufficienctly high power level that it will give the required 7 kV/turn acceleration when applied to the accelerating gaps. At injection the proton revolution frequency is about 358 kc/s and increases to a value of 2·0 Mc/s as the protons speed

up to their final energy. The radio frequency signal has actually been chosen to be four times the revolution frequency i.e. 1·4 Mc/s to 8·0 Mc/s, causing the circulating proton beam to split into four separate bunches each of which is given the appropriate 7 kv/turn on traversing the accelerating gaps. The reason for applying a higher 'harmonic' frequency of the basic frequency of rotation is that focussing of the proton beam is much better under these conditions.

31. To avoid loss of protons caused by them getting progressively out of step with the accelerating field, it is necessary to achieve very accurate matching of the frequency of the accelerating system and the instantaneous magnetic field. Since the latter is much more difficult to control than the former, it has been arranged that the radiofrequency variation shall follow the magnetic field variation. This is done by inserting probes into the magnet and they deliver, through suitable electronic devices information to the master frequency generator of the radiofrequency system which determines the frequency of the accelerating voltage. This frequency must be correct to 0·1% over the whole accelerating cycle. Small errors in frequency cause the proton beam to move away from the centre of the vacuum chamber and be lost by striking the side walls. Such beam movements are detected by beam control electrodes which apply suitable correction signals to the oscillator.

32. The signal is then amplified and applied to the accelerating gaps. In order to reduce the amount of radio frequency power needed these gaps are continuously tuned by a variable inductance. This inductance is made up of a single copper turn on a core of ferrite. Ferrite is a ceramic-like magnetic material suitable for use at these high frequencies, since it has very low electrical conductivity resulting in negligible eddy current losses; about 6 tons are required. A peak power of 50 kW is dissipated in the ferrite and is removed by an oil circulating system.

33. During the course of the year prototypes for all the low power electronic circuits have been designed and some contracts were about to be placed for the manufacture of the components. The 'drive chain' for generating the appropriate frequencies was almost completed and a good proportion of the ferrite had been delivered.

Vacuum Chamber

34. The vacuum chamber is a toroidal-shaped vessel located between the pole pieces of the magnet, in which the protons are accelerated. A good vacuum is required to prevent serious scattering and loss of the protons by collision with air molecules. The design of the vacuum system raises problems peculiar to this type of machine. It must work in an intense and varying magnetic field and must therefore be of non-conducting material to eliminate eddy currents. For economical machine design the vertical aperture of the vessel must be as large as possible in order to make the best use of the magnet gap and so the horizontal walls must be thin. Also when the machine is operating the vessel will be subjected to intense radiation and its mechanical and vacuum properties should remain satisfactory under these conditions. The structural materials which most nearly meet these requirements are the glass fibre reinforced epoxy resins. These will be used to construct a double walled vessel, the thin outer skin of which is supported by the magnet pole tips. This enables the inner vessel to have thin walls also, since it has vacuum both inside and outside; the consequent low

stressing of this vessel makes it less susceptible to the effects of radiation degradation of its mechanical properties. The pressure in the outer cavity of the vessel will be less than 1 millimetre of mercury and the pressure in the inner vessel will be 10^{-6} millimetres of mercury. A very large pumping capacity is required to achieve and maintain these low pressures. In view of the large volume to be evacuated (approximately 3,000 cu. ft.), the pumps must be capable of high pumping speeds. Design of the vessel is well advanced and a manufacturer has been appointed.

Power Supplies

35. Heavy currents (up to 9,000 amperes) are needed to energise the magnet of the synchrotron and large amounts of electrical energy are therefore required to operate the machine. Furthermore the power requirements are intermittant since the magnetising currents are only required for the duration of the pulse (0·7 sec.) while the protons are being accelerated, the pulses being repeated at a rate of up to 28 per minute. It would be impractical to take such a heavily fluctuating load direct from the normal electricity supply as the surges of power would be of the order of 120 MVA; some form of energy storage is therefore required.

36. The power plant will consist of a motor-alternator set with fly-wheels for energy storage, converter equipment comprising mercury arc rectifiers and phase shifting transformers. This will supply direct current of gradually increasing strength during the pulse, followed by a period of current decay. Energy is thus stored in the inductive windings of the magnet coils during the current-rise period and is subsequently returned to the flywheels in the intervals when power is no longer required. The amount of energy being shuttled to and fro amounts to some 40 megajoules. In this way the flywheel acts as a buffer between the load (the magnet windings) and the electrical supply.

Contracts for the manufacture of the power supply equipment have been placed and building work was about to commence towards the end of the year.

THE 50 MeV PROTON LINEAR ACCELERATOR

37. The 50 MeV Proton Linear Accelerator as its name implies, is a machine for accelerating protons in a straight path as compared with the more usual types of accelerator, e.g. cyclotrons and synchrotrons which accelerate particles in circular paths. Linear accelerators have several advantages over other types of machine at these lower energies. No large and expensive magnet is needed, and the beam produced is confined to a narrow cross section with a well defined energy. It is possible to extend the machine if it is required to go to higher energies, and the extraction of the beam is comparatively simple compared with circular accelerators.

The Machine

38. The principle on which linear accelerators operate was described previously in paragraph 23 on the 15 MeV injector for Nimrod. Whereas the latter only has one cylindrical resonant structure down which the protons are accelerated, the 50 MeV machine has three such structures which successively accelerate the protons to energies of approximately 10, 30, and 50 MeV. Each of these structures is contained in an evacuated 'tank' and the three tanks placed end to end total some 100 ft. in length.

Some information about these tanks and the proton beams passing through them are summarised in the following table.

	TANK 1	TANK 2	TANK 3
Dimensions of liners contained in evacuated tanks.			
Length . .	18 ft.	39 ft.	37 ft.
Diameter . .	42 in.	36 in.	32 in.
Number of Drift Tubes . .	42	40	28
Energy of emergent proton beam	9·95 MeV	30·56 MeV	49·95 MeV
Speed of emergent protons expressed as fraction of the velocity of light (3×10 cm/sec.) . .	0·14	0·25	0·3

The resonant structures are excited at a frequency of 202·5 Mc/s., and since the radio frequency power required to accelerate the protons exceeds 4 MW, the machine has to be operated in a pulsed fashion, owing to the inability of the valve generators to supply this level of power continuously. Each pulse lasts 200 millionths of a second and the repetition rate is 50 pulses per second. It is expected that when in full operation the mean proton current will approach 5 microamperes (3×10^{13} protons/sec.) while during the pulses the current will rise to 0·5 milliamperes. This would be many times greater than that achieved with other accelerators of this kind.

Experimental Arrangements

39. There is a large area at the end of the accelerator where the nuclear physics experimental apparatus will be set up. In order to make the most efficient use of the machine a bending magnet will be installed which will deflect the proton beams in any of five or more directions. This will enable several sets of apparatus to be set up and left undisturbed. In addition to performing experiments with 50 MeV protons it will also be possible to obtain protons at energies of 30 and 10 MeV by switching off the power in the last one (or two) tanks and allowing the beam to "coast" through to the experimental area.

40. Extensive safety precautions are planned. The experimental area will be separated from the machine by a concrete shielding wall varying in thickness from 2 ft. to 3 ft. to cut off any harmful radiation. Earth banks outside the building provide protection where necessary and the area where a radiation hazard might exist is protected by a safety fence. An extensive warning and interlock system has been incorporated to protect personnel against possible accidental exposure to radiation and high voltages.

Research Programme

41. Protons were first accelerated through Tank 1 to an energy of 10 MeV in November and this section of the machine has been in satisfactory operation since then. Tank 2 was almost finished by the end of the year under review and the complete machine was expected to give a beam of 50 MeV protons by mid

1959*. The accelerator will be the first to come into operation at the Rutherford Laboratory. It was designed and built by the Atomic Energy Authority in collaboration with industry and was transferred to the ownership of the National Institute at the end of the year under review.

42. There are three broad fields of nuclear research which it is intended should be covered by the accelerator; namely, experiments aimed at studying the interaction between nucleons, experiments designed to extend the so-called "optical" model interpretation of the scattering of neutrons and protons by nuclei and finally experiments aimed at studying details of nuclear structure. Experiments are planned in all these broad fields by teams of physicists from the Universities of Oxford, Birmingham, Manchester, and Glasgow, King's College and University College London, the Atomic Energy Authority, together with the resident Proton Linear Accelerator nuclear physics Group of the National Institute.

Meetings between the groups from the various laboratories have been held to discuss collaboration on experiments of common interest, and the first resident university visitors arrived to prepare their experiments towards the end of the year. The National Institute is providing the support needed to assist them in conducting their research programme. Apart from the field of nuclear physics, interest has also been expressed in using the accelerator for neurological experiments and radio-chemical research.

*This has since occurred. Tank 2 first gave a 30 MeV beam on 23rd May and the first 50 MeV beam was produced on 12th July, 1959

APPENDIX

THE NATIONAL INSTITUTE

FOR RESEARCH IN NUCLEAR SCIENCE

Copy of the Order in Council dated the 7th May, 1958

and of the

Royal Charter

dated the 23rd June, 1958

AT THE COURT AT BUCKINGHAM PALACE

The 7th day of May, 1958.

PRESENT,

THE QUEEN'S MOST EXCELLENT MAJESTY IN COUNCIL

WHEREAS there was this day read at the Board the Draft of a Charter for constituting a body corporate under the style and title of "The National Institute for Research in Nuclear Science":

HER MAJESTY, having taken the said Draft into consideration was pleased, by and with the advice of Her Privy Council, to approve thereof, and to order, as it is hereby ordered, that the Right Honourable Richard Austen Butler, one of Her Majesty's Principal Secretaries of State, do cause a Warrant to be prepared for Her Majesty's Royal Signature, for passing under the Great Seal a Charter in conformity with the said Draft, which is hereunto annexed.

W. G. Agnew.

ELIZABETH THE SECOND

by the Grace of God of the United Kingdom of Great Britain and Northern Ireland and of Our other Realms and Territories Queen, Head of the Commonwealth, Defender of the Faith.

TO ALL TO WHOM THESE PRESENTS SHALL COME, GREETING!

WHEREAS the Lord President of Our Council and the Chancellor of Our Exchequer have appointed certain persons to be the Chairman and the other Members of an Institute for the furtherance of research in nuclear science and matters connected therewith to be known as The National Institute for Research in Nuclear Science:

AND WHEREAS it has been represented to Us that for the purpose of carrying out the objects of the said Institute in relation to nuclear research and with a view to facilitating the holding of and dealing with property both real and personal it is expedient that the said Institute should be incorporated:

NOW THEREFORE KNOW YE that We, by virtue of Our Royal Prerogative and of all other powers enabling Us in that behalf, of Our especial grace, certain knowledge and mere motion have granted, willed, directed, ordained, constituted and declared and do by these Presents for Us, Our Heirs and Successors, grant, will, direct, ordain, constitute and declare as follows:

1. THE persons now the Chairman and the other Members of the National Institute for Research in Nuclear Science as aforesaid (whose names are set out in the Schedule hereto), and all such persons as may hereafter become the Chairman and other Members of the body corporate hereby constituted, shall for ever hereafter be one body corporate under the name of "The National Institute for Research in Nuclear Science" (hereinafter referred to as "the Institute"), and by the same name shall have perpetual succession and a common seal, with power to break, alter and make anew the said seal from time to time at their will and pleasure, and by the same name shall and may sue and be sued in all courts and in all manner of actions and suits, and shall have power to do all other matters and things incidental or appertaining to a body corporate.

2. WE do for Us, Our Heirs and Successors, notwithstanding the Statutes of Mortmain, license, authorise and for ever hereafter enable the Institute to purchase, take on lease or otherwise acquire any lands, tenements or hereditaments within Our United Kingdom of Great Britain and Northern Ireland not exceeding in the whole the annual value of £250,000 to be determined according to the value thereof at the time when the same are respectively acquired and to hold all or any lands, tenements or hereditaments, or interest therein, in perpetuity or on lease or otherwise and from time to time to grant, demise, let, alienate, mortgage, charge or otherwise dispose of the same or any part thereof.

3. AND WE do hereby also for Us, Our Heirs and Successors, give and grant Our licence to any person or persons and any body politic or corporate to assure in perpetuity or otherwise, or to demise or let to or for the benefit of the Institute any lands, tenements or hereditaments whatsoever within Our United Kingdom of Great Britain and Northern Ireland within the limits of value aforesaid, hereby nevertheless declaring that it shall not be incumbent upon any such person or persons or body to inquire as to the annual value of the property which may have been previously acquired by the Institute.

4. THE objects for which the Institute are established and incorporated are 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 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.

5. ALL moneys and property howsoever received by the Institute, including any moneys voted by Parliament, shall be applied solely towards the promotion of the objects of the Institute and no portion thereof (except as otherwise provided in this Our Charter) shall be paid or transferred directly or indirectly to the Members thereof.

6. (1) The Institute shall consist of a Chairman and fifteen other Members.
(2) All the Members shall be appointed by, and the terms of their appointments shall be determined by, the Minister for the time being exercising the functions conferred on the Lord President of Our Council by the Atomic Energy Authority Act, 1954, the Lord President of Our Council and the Chancellor of Our Exchequer, acting jointly.
(3) Every Member of the Institute shall hold and vacate his office in accordance with the terms of his appointment, and shall, on ceasing to be a Member, be eligible for re-appointment, but any Member may at any time by notice in writing to the Minister for the time being exercising the said functions resign his office.
(4) No person who is a Member of the House of Commons shall be appointed to, or shall hold, the office of Chairman of the Institute.
(5) Except as provided in paragraph (6) of this Article, the Institute shall, in the case of such Member or Members of the Institute as the Lords Commissioners of Our Treasury may determine, pay such remuneration as the said Lords Commissioners shall approve.
(6) No person shall in any circumstances or at any time receive any remuneration whatsoever as a Member of the Institute for or in respect of any period when he is also a Member of the House of Commons but this shall not prevent the reimbursement to him of actual out of pocket expenses previously and necessarily incurred by him in the performance of his duties as such Member of the Institute.

7. (1) The Institute may act notwithstanding a vacancy among the Members thereof and the validity of any proceedings of the Institute shall not be affected by any defect in the appointment of a Member thereof.

(2) The quorum of the Institute shall be six Members personally present or such number, not being less than six, as the Institute may from time to time determine.

8. SUBJECT to the provisions of this Our Charter, the Institute may regulate their own procedure.

9. (1) The Institute may appoint such officers and take into their employment such other persons as the Institute may determine.
(2) The Institute shall—
(*a*) pay to their officers and other persons employed by them such remuneration as the Institute may determine; and
(*b*) as regards any officers or persons employed, in whose case it may be determined by the Institute, with the approval of the Lords Commissioners of Our Treasury, so to do, pay to or in respect of them such pensions (including gratuities), or provide and maintain for them such pension schemes (whether contributory or not), as may be so determined.

10. THE Institute shall expend such sums for administrative purposes, including travelling expenses and subsistence allowances for Members and staff, as the Institute may determine.

11. THE application of the Seal of the Institute shall be authenticated by the signatures of the Chairman or some other Member of the Institute authorised by the Institute to authenticate the application of the Seal thereof, and of one of such officers of the Institute as may be authorised by the Institute to authenticate the application of the said Seal.

12. THE Accounts of the Institute shall be made up for each financial year ending on the thirty-first day of March, and shall be prepared, audited and submitted to the United Kingdom Atomic Energy Authority in such manner and at such times as the Lords Commissioners of Our Treasury may direct.

13. THE Institute shall in every year prepare and submit a report of the work of the Institute to the United Kingdom Atomic Energy Authority.

14. IT shall be lawful for Us, Our Heirs and Successors by Supplemental Charter to add to, amend or repeal the provisions of this Our Charter or any of them.

15. WITHOUT prejudice to the provisions of Article 14 of this Our Charter, the Institute may by a resolution in that behalf passed at a meeting of the Institute by a majority of not less than three quarters of the Members present and voting (being an absolute majority of the whole number of the Members of the Institute) and confirmed at a further meeting of the Institute held not less than one month nor more than four months afterwards by a like majority, alter, amend or add to this Our Charter, and such alteration, amendment or addition, when allowed by Us, Our Heirs or Successors in Council, shall become effectual, so that this Our Charter shall thenceforward continue and operate as though it had been originally granted and made accordingly: and this provision shall apply to this Our Charter as altered, amended or added to in manner aforesaid.

IN WITNESS whereof We have caused these Our Letters to be made Patent.

WITNESS Ourself at Westminster the Twenty-third day of June in the Seventh year of Our Reign.

BY WARRANT UNDER THE QUEEN'S SIGN MANUAL

COLDSTREAM