Dr Hobbis

11th November, 1963 PSPC/P107

NIMROD PROJECT COMMITTEE

FINAL REPORT

1. Terms of reference and constitution

On 17th May, 1957 the Governing Board of the National Institute for Research in Nuclear Science approved the construction of a 7 GeV Proton Synchrotron (NIMROD) to be located on a site adjacent to the Atomic Energy Research Establishment at Harwell.

On 30th May, 1957 the U.K.A.E.A. undertook responsibility for building this machine on behalf of the National Institute, and the NIMROD Project Committee was set up by the Authority Member for Research (Sir John Cockcroft) to see that the Authority's responsibility for design, construction and commissioning through to the working stage was carried out satisfactorily.

The specification for the accelerator had previously been approved by the N.I.R.N.S. Physics Committee, and it was therefore the Project Committee's responsibility to ensure that this specification was met within the approved estimates.

The Project Committee consisted of representatives of the Authority, the National Institute and the Universities. The first meeting took place on 9th July, 1957, the Chairman being Mr. D.W. Fry; on 8th April, 1960 I took over from him. A list of members of the Committee is at Appendix I.

2. Construction programme

The original target date for completion of the construction of the machine was 1st January, 1962; after a further year for commissioning the machine was to be available to experimentalists on 1st January, 1963.

Early in 1960 it became apparent that this tight time-scale was unrealistic, and the machine construction completion date was therefore deferred to October, 1962.

In the summer of 1961 it was again found necessary to carry out a critical review of the construction schedule, due mainly to the uncertainties of the vacuum vessel production programme, and a machine completion date of 1st October, 1963 was accepted. With strict site testing and proving of vacuum components prior to erection it was hoped to reduce the commissioning period considerably, and 1st January, 1964 was set as the revised date on which the machine should be available to experimentalists.

Machine construction was completed by late July, 1963, and commissioning operations began on 6th August, 1963; a beam of 8 GeV was produced on 27th August, 1963. The machine has now been handed over to the machine physicists, and it is expected that the machine will be available for the first experiments to be started on 1st January, 1964.

A brief report on the progress of NIMROD construction work under the headings of the major components is at Appendix II.

3. Commissioning

Commissioning operations started on 6th August, and four machine runs per week were planned. At the end of the first week a proton beam had survived 20 turns, but at 10 kilogauss/sec. only a very weak beam for 3 turns was observed; during the second week 40 surviving turns were observed. Radio frequency was tried without any appreciable success, and towards the end of this week it became evident that further adjustments were required to the field correction devices. At the beginning of the third week the number of surviving turns had increased to 57, and there were signs of particles with small amplitude betatron oscillations. Towards the end of this week the radio frequency was brought on, and acceleration for 40 ms. was observed. On the Tuesday morning of the fourth week, August 27th, further work with the radio frequency law curve-corrector took the beam to 6.5 GeV, corresponding to the peak field being used. The peak field was then increased and a small number of pulses was tried at 15.9 kilogauss; by 18.30 hours a beam of 8 GeV had been achieved with about 10^9 protons per pulse and by 1900 hours 7 GeV with 10^{10} protons per pulse.

This first full performance of the machine was better than could have been hoped for at such an early stage in the commissioning period. Much remains to be done, but the way is now clear for achieving an output of up to 10^{12} protons per pulse.

Apart from known minor deficiencies, there seemed to be no major design or construction fault. The vacuum system behaved well; the average pressure was about 10^{-6} mm of mercury, and the speed of pumpdown was high.

A full report of the commissioning period is given in Appendix III.

4. Financial control

Treasury approval for the construction of NIMROD and its associated buildings was granted in 1957 at an estimated cost of £6.9M excluding an allowance for contingencies. This estimate was divided into two main categories - machine and building works.

An Estimates and Sanction Section was set up within the NIMROD Project Group to ensure close control of the machine budget. This section was responsible for estimating prior to commitment, technical assessment of contractors' claims, collaborations with contracts departments, the preparation of forward estimates and cost statements and general advice to Group Leaders on financial requirements.

Control of the building estimate was originally undertaken by the A.E.R.E. New Works Group and later by the Southern Works Organisation. To ensure complete conformity with machine requirements, regular meetings were held with the Project Group at which the building programme and estimate were critically assessed.

Quarterly financial statements were prepared for discussion at and approval by the Project Committee before submission to the N.I.R.N.S. General Purposes Committee.

During NIMROD's six-year construction period modifications and additions were introduced which made it necessary to seek further funds from the Treasury. The rates of commitment and expenditure in relation to the approved estimates and the approved increases in the estimates are shown in graph form in Appendix IV. The present Treasury approved estimate for NIMROD is £11.2M, and, taking outstanding commitments into account, it will be possible to complete NIMROD within this sum.

5. Disbandment of Project Committee

At the Project Committee meeting held on 25th September, 1963 it was clear from progress reports submitted by the respective Group Leaders and from the report on commissioning to date that the Project Committee had completed its task. It was therefore formally proposed and accepted that the financial powers of the Project Committee should be handed over to the Director of the Rutherford High Energy Laboratory, who will then be responsible to the N.I.R.N.S. General Purposes Committee for outstanding capital commitments on the NIMROD Project.

F.A. Vick
Chairman, Project Committee

Appendix I

List of Members of Nimrod Project Committee

Mr. E.L. Ashley	UKAEA, Risley	From 22. 5.58.	To 24. 9.63.
Mr. P. Bowles	N.I.R.N.S.	9. 7.57.	24. 9.63.
Mr. J.P. Clark	UKAEA, Harwell	22. 1.59.	19. 3.59.
Mr. J.R.V. Dolphin	UKAEA, Harwell	9. 7.57.	3. 9.57.
Mr. W. Davies	UKAEA, Risley	9. 7.57.	27. 3.58.
Mr. F.A. Entwistle	UKAEA, London Office	16.11.61.	11.12.62.
Mr. D.W. Fry (Chairman)	UKAEA, Harwell	9. 7.57.	8. 4.60.
Mr. J.D. Glanville	UKAEA, Risley	14. 8.57.	11. 2.58.
Mr. L.B. Mullett	N.I.R.N.S.	9. 7.57.	24. 9.63.
Mr. M.J. Moore	Liverpool University	9. 7.57.	24. 9.63.
Dr. T.G. Pickavance	N.I.R.N.S.	9. 7.57.	24. 9.63.
Mr. R.F. Payne	UKAEA, London Office	24. 9.58.	11. 4.61.
Mr. R.E. Reynolds	UKAEA, Harwell	28.11.57.	3. 6.59.
Mr. M. Smith	UKAEA, Harwell	9. 7.57.	8. 4.60.
Professor H.W.B. Skinner	Liverpool University	9. 7.57.	22.12.59.
Mr. F.A. Tatford	UKAEA, London Office	14. 8.57.	24. 9.63.
Mr. B.L. Tozer (Secretary)	UKAEA, Harwell	9. 7.57.	28.11.57.
Mr. F.M. Telling (Secretary)	N.I.R.N.S.	28.11.57.	24. 9.63.
Dr. F.A. Vick (Chairman)	UKAEA, Harwell	24. 9.59.	24. 9.63.
Mr. K.P. Varney	UKAEA, Harwell	24. 9.58.	24. 9.63.
Professor D.H. Wilkinson	Oxford University	14. 8.57.	24. 9.63.
Dr. J.A.V. Willis	N.I.R.N.S.	27. 3.58.	24. 9.63.

Appendix II

NIMROD Construction Work

1. Buildings

The site was opened up in August 1957, and construction work started in the following December. The control and preparation buildings were completed during the spring and summer of 1958 respectively. The construction of the main magnet buildings made steady progress; the western end of the injector section was completed by October 1958 and the eastern end by early 1959. The construction of the foundations for the electromagnet and the main magnet room, 200 ft. in diameter, presented many novel problems, but by the early summer of 1959 the magnet room was weathertight and by the autumn was ready for the storage of magnet sectors. The experimental area was completed during early 1960. The alternator building was weathertight by October 1960, and the converter building was available for plant access by the early summer of 1960. Problems were encountered in the design of the sprung foundation for the 100 ft. long rotary plant, but this was eventually ready for plant erection by January 1961.

By the summer of 1961 all building work associated with the NIMROD Project, including the majority of the earth shielding, was virtually complete. In spite of setbacks, the building work had generally kept abreast of machine installation requirements.

2. Injector

The first major contract, for the 650 KV equipment, was placed in September 1957; installation of the pre-injector stage began in the autumn of 1958. The 650 KV equipment was received during March 1959, and the construction of the pre-injector was completed during the late summer of that year. The first accelerated beams from the D.C. gun were produced in December 1959.

The 50 ft. long vacuum tank for the linear accelerator arrived on site in early December 1959, and the r.f. cavity followed in July 1960. The main r.f. valve was received in January 1960 and the modulator for the r.f. drive chain in February. The drift tube assemblies arrived during a period of nine months, the last one being finally installed by May 1961. By early July, r.f. power was fed into the linear accelerator, and successful acceleration of a proton beam to 15 MeV was achieved on 1st August, 1961. This proton beam was later used to study the effect of the spilled beam on the vacuum vessel and to develop diagnostic equipment for commissioning NIMROD.

During 1962 the commissioning of the linear accelerator continued together with the manufacture and installation of the high energy drift-space, debuncher, and the inflector system. By mid-July 1963, 15 MeV beams were passed through the inflector system into the synchrotron under pulsed load conditions.

Beam currents from the pre-injector have been as high as 60 mA with a 600 μs pulse length. This stage of injection is usually operated to provide 600 KV beams of about 35 mA, and its performance is very reliable. Without the buncher the transmission factor of the linear accelerator is around 0.25; with the buncher in use this increases to around 0.55. This means that with 35 mA from the pre-injector, about 19 mA are accelerated to 15 MeV. The highest 15 MeV beam current achieved from the linear accelerator is 24 mA, the r.f. drive chain providing power in excess of 1.2 MW. The highest beam current passed through the injector into the synchrotron is 22 mA with a 600 μs pulse length.

The commissioning of the injector is continuing, and its performance during the NIMROD operational period was very satisfactory.

3. Magnet

The contract for the supply of the 336 magnet sectors was placed in October 1957. The early stages of manufacture produced problems associated with plate distortion during heat treatment, but in November 1958 the first experimental sector was delivered. By March 1959 sectors were arriving on site daily and were being tested in a rig developed specifically to determine their magnetic properties. By July 1960 all sector measurements had been completed, and the alignment of sectors in their final position on the magnet ring had begun. The alignment and survey work called for exacting standards, and special equipment and survey methods had to be developed. By early 1961 all sectors had been aligned, the erection of the octant end structures was progressing and the coil installation was under way. The development and manufacture of the pole-pieces raised many problems, but in July 1961 the first alignment of the pole pieces in the machine (without the outer vacuum vessel sections in situ) commenced. By the summer of 1962 a magnetic survey, during which the magnet octants were measured under pulsed load conditions, had been concluded with satisfactory results. By late 1962 the outer vacuum vessel sections and pole-pieces were finally installed. During early 1963 the magnet was pulsed for further periods with all the vacuum vessel sections installed. The magnet was finally completed in July 1963. During the commissioning period a small number of pulses was tried at 15.9 kilogauss, and throughout the operational stages the magnet functioned according to specification.

4. Power supply

The contract for the magnet power supply was divided between two contractors, one providing the converter equipment, the other the main rotary plant, and was placed in March 1958. This split contract required the formation of a special committee to ensure complete co-ordination between the two firms.

The converter equipment began to arrive on site during July 1960; erection of this equipment continued, and testing commenced in July 1961. In the early summer of 1962 the converter equipment was successfully used for the magnetic survey. Commissioning continued and by April 1963 was substantially complete and generally acceptable, apart from an excessive backfire rate. In order to minimise the effects of this problem, the mercury arc converter plant was subjected to a special high voltage ageing process to enable the converters to withstand the very high inverse voltage at which they operate. Some reduction in backfire frequency did result. Several weeks of investigation by the contractor's engineers have, however failed to identify the causes positively, and in addition assymetry, arc-through and over-current trips have been frequent. The contractor is at present building special test equipment to assist in the determination of the causes of these difficulties, and this should be available by late 1963.

In July 1961 the motors and flywheels of the rotary plant were delivered and by the late summer of 1961 one motor-alternator-flywheel set had been erected on site. (This machine was later successfully used for the magnetic surveys carried out in 1962). In November 1961, after extended tests at the maker's works, it was decided to rebuild the rotor of the second alternator set. This caused a serious delay in the power supply programme, but fortunately the site alternator set was able to meet the load requirements for the magnetic surveys. In August 1962 the second alternator set was delivered to site and by late October 1962 had been run up to speed. On 21st November 1962 the complete rotary plant on its common 100 ft. long shaft system ran up to speed for the first time. During 1963 extensive tests were carried out, and the rotary plant was finally accepted from the manufacturers in August, 1963.

To enable the alternator shafts and flywheels to be checked for any possible defects in the material, it was necessary to develop and construct unique ultrasonic survey equipment. It is believed that this is the first equipment to be developed to scan large machine forgings from the bore. Surveys, which are automatically recorded by the equipment, have recently been completed on both alternator rotors and corresponding flywheel half-shafts, and the results are at present being analysed.

5. Vacuum system

Design and development work during the early days was concentrated on a single-walled vacuum vessel, but by July 1958 it was accepted that this highly-stressed vessel could receive severe damage from radiation effects under certain operating conditions. Consequently a double-walled vessel with an inner skin of stainless steel was specified; the design of this vessel proceeded during late 1958, and early in 1959 instructions to proceed with the development and manufacture of these vessels was given to the contractor. The subsequent production of the glass reinforced epoxy resin vessel sections, each 50 ft. in length, proved to be a most difficult problem, and it was this factor which eventually delayed the machine completion date. After repeated set-backs an acceptable prototype outer vessel section was delivered during February 1961 and achieved satisfactory vacuum test results. Further intensive work was carried out, and by mid-1961 the manufacturing processes could be defined and strict quality control laid down. By early 1962 production sections were arriving on site, and by late 1962 all outer and several inner sections had been installed in the machine after vacuum testing on site. The installation of inner and header sections and closure plates continued during 1963 together with successful vacuum testing under pulsed load conditions.

Steady progress was made with the other component parts of the vacuum system. The contract for the main vacuum pumps was placed in May 1958, and delivery and proof testing were completed by late 1962. Erection in the machine was phased to enable the various octants to be pumped down and tested under pulsed load conditions. The tenders for the straight section boxes were placed during the summer of 1961, and were delivered during mid-1962; after extensive site testing the boxes were installed in their final position during early 1963.

The vacuum system was ready for operation on 1st August, 1963 and during the operational period the system performed satisfactorily with an average pressure of about 10^{-6} mm of mercury. The speed of pump-down was high.

6. Radio frequency system

The major part of the development and prototype work was carried out at the Rutherford Laboratory, but assistance was sought from outside manufacturers in providing an engineered version of the prototypes. The r.f. programme was phased in with the machine construction programme and was ready for the first operation of NIMROD. Some main points of interest of the system are:

R.F. cavity. This consists of two highly re-entrant E_o10 resonators loaded symmetrically by a total of 4 ferrite cores to provide a large and variable inductance. The ferrite is biased by a d.c. winding. Considerable difficulty was experienced with arcs from the r.f. turns, but this was overcome by fitting ceramic insulators to the r.f. windings and ensuring sufficient clearance between the windings and the fibreglass oil jackets around the ferrite. Some of the long limbs of ferrite failed initially at the glued joints, and after unsuccessful attempts by the manufacturers to provide a joint of acceptable strength, it was decided to fit stainless steel clamps to support the sectioned portions. These proved satisfactory.

High power r.f. amplifier. This amplifier has to accept a signal from the primary frequency generator and deliver the necessary voltage and power to the accelerator cavity. A complete prototype was produced in the laboratory, and an engineered version was produced by an outside manufacturer. This unit is now installed and working satisfactorily.

Bias supply. A thermionic version is fully operational, but the frequency response is limited to a value below that necessary to control phase oscillations; also the switch-on transient was large enough to affect slightly the proton capture. Because of these disadvantages and to ensure long term stability, a transistored version was also designed in the laboratory and engineered by outside manufacture and is now working satisfactorily.

Primary frequency generator. The development took place in three stages; first a system using thermionic valves throughout, second a system using thermionic valves in the r.f. and d.c. circuits with transistors in the ancillary control circuits, and finally a system using transistors throughout. The first system has been stored, and the second is used as the present prototype system for operating with NIMROD until the third system has been engineered and installed.

Ancillary equipment. The oil coolant plant for the ferrite cooling in the cavity is working satisfactorily. A demineralised water cooling system for valves in the drive chain and bias supplies has also proved satisfactory.

7. Control system

Early in 1958 an appraisal of the control system was compiled. During 1959 and 1960 the controls progressed generally to programme, and during this period the installation of control equipment for the liner accelerator was completed; work on the requirements for the main control room progressed, and controls for the power supply were determined. During 1961 the design of all control items for the injector was completed together with those for the magnet room. During 1962 the control work was phased in with the injector and magnet commissioning programmes, and work continued on the interconnection of the various controls to operate as a complete entity. During early 1963 the vacuum system controls were being commissioned octant by octant, and the main control room was progressively commissioned. At this stage only essential control modifications were being carried out. The control system was available at the end of July 1963 for the NIMROD commissioning period. Work is continuing on refinements, fault indications and the integration of individual items into a working system.

THE FIRST OPERATION OF NIMROD TO FULL ENERGY

For some time it had been planned that as soon as a reasonable vacuum had been achieved around the whole of the machine, an attempt would be made to accelerate to full energy. This impatience was natural after six years of construction, and it seemed wise to check for major faults as soon as possible. By August 5th the average pressure was a few times 10^{-6} mm of mercury and still falling.

At this stage the following work had not been done:-

Commissioning of poleface winding corrections to the magnetic field (particularly gradient or n value and radial aperture).

Commissioning of the de-buncher to reduce the energy spread from the injector, installation of the low frequency ripple filter on the magnet power supply, and installation of the full set of diagnostic equipment required for detailed study of injection and acceleration.

Operations started on August 6th, and four machine runs per week were planned. The run-up of various parts of the machine started during the afternoon, whilst installation and other work continued. In the late afternoon the areas were locked and searched, and operations began from the Injector Control Room. When the duty officer was satisfied as to the security of the area and the state of readiness of the equipment, particularly the injector, he transferred himself and control to the Main Control Room. There he inserted an interlock key known as the "7 Gev key". Up to this point it is not possible to have in operation more than any two of the following: magnet power supply, injector, synchrotron, R.F.

The following diagnostic equipment was available:-

a retractable scintillator with T.V. camera to view the beam in Octant 1 immediately after the inflector,

retractable fluorescent grids with T.V. cameras. The grids cover the full aperture and have a transmission factor of 97 to 98%. One grid per Octant,

a directive scintillator probe on the inside of the aperture at Octant 6. Viewed by a photomultiplier through a flexible light guide. Oscilloscope presentation,

induction electrodes in Straight 6 with oscilloscope presentation of sum signal (beam current) and difference signal (radial position),

various counter set-ups looking at "spill" from the machine.

The following diary of events is abstracted from the Log Book.

First Week

August 6 Tuesday First Turn	First injection into the complete machine. Peak field 9120 gauss with the correspondingly reduced rate of rise of field ($\dot{B}$) without using the "injection platform" to reduce initial rate of rise. Injected pulse length 50 μs. Beam seen immediately on grids 5 and 6 (Octants 5 and 6) and improved by steering. Dubious evidence of second turn on grid 5. Induction electrodes with D.C. connection showing mainly charge collection.

August 7th
Wednesday

Peak field 14,000 gauss. Injection platform would not work. Changed to 90% volts, 14.6 kilogauss, 18 kg/sec. Definite signal at Octant 6 photomultiplier showing circulation for 100 μs with 50 μs pulse going in. Acceleration tried with no success.

August 8th
Thursday

100% magnet volts; no injection platform; 20 kg/sec. Alignment on grids as before. Grid pictures gave an idea that Q vertical was near to 1, hence Q* radial near to ½. Chopper used to give 0.25 μs pulse. Second turn seen after A.C. connection of induction electrodes. Power supply trouble.

August 9th
Friday

Magnet volts 100%. 1.1 μs chopped beam. Survival for 20 turns seen on induction electrodes. Difference electrodes showed Q radial near to ½. At 10 kg/sec only 3 very weak turns observed.

Second Week

August 10th
Tuesday

Decided to try for 7 GeV with 20 kg/sec. With several turns survival R.F. was tried without any sign of acceleration. Discovered at end of run that grids 2 and 4 were still in.

August 14th
Wednesday

* First acceleration

40 turns. Grids 2 and 4 probably stayed in on all previous runs. Difference electrodes indicated Q radial about 0.53. The inside probe showed something like the energy spread of the injector on alternate pulses. This also indicated Q radial about 0.5.

R.F. tried with signs of R.F. trapping. After critical setting of initial conditions, survival was seen to 7 ms. on the induction electrodes. Spill seemed to be observable on counter to 12-15 ms with a vague indication of the occasional pulse to 50 ms.

August 15th
Thursday

n shift of .07 was available, also some aperture correction windings, all for low fields. None of the corrections did any obvious good, and generally things got worse. R.F. was tried, but the acceleration time was no better. A power supply on the poleface windings was burnt out.

August 16th
Friday

The field corrections all self-powered. The evidence from survival of a short pulse was that the corrections were the wrong way round.

Third Week

August 20th
Tuesday

Poleface windings now connected correctly. No survival could be obtained with n shift on all octants, but with correction on Octants 6 and 7 only there was a marked improvement. This was consistent with the higher average n in these two octants from field survey. After the usual loss in the first turn the amplitude hardly changed until signal began on the inside probe. The aperture winding increased the injection period from 225 μs to 260 μs. In all, the number of surviving turns went up from 40 to 57, and there were at last signs of particles with small amplitude betatron oscillations.

August 21st
Wednesday

Good amplitude and survival of short pulses was obtained. Q radial now in the range 0.58 to 0.6 instead of 0.53 to

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* Q is the number of betatron oscillations per revolution.

0.56 as without poleface windings. Many faults closed down the run.

August 22nd Thursday	Good starting conditions. R.F. on and acceleratin to 16 ms. Sum and difference induction electrode signals showed beam to be going inwards at 5 ms.
August 23rd Friday	Inflector moved in 1". Better injection but pulse to pulse reproduceability very bad. R.F. survival to 40 ms with strange "resonances" and a sudden cut-off.

Fourth Week

August 26th Monday	Injection improved markedly with a very critical adjustment of the inflector voltage. Acceleration to 65 ms after working with R.F. frequency law curve-corrector. "Resonances" on induction electrodes are obviously not beam blow-up. They are either resonances of the electrodes and/or beam spill on to the electrodes. Things looking more hopeful.
August 27th Tuesday Morning start up *6.5 GeV to 8 GeV	Amplitude and survival of short pulse the best so far. After R.F. curve correction acceleration was obtained to 230 ms. Beam would not survive beyond this point which is on the knee of the frequency curve, and loss occurred to the outside of the aperture. The shaper coil in the tank circuit of the P.F.G. was changed from 1.17 μH to 1.72 μH to give a shallower knee. Further work with the curve corrector took the beam all the way to 6.5 GeV corresponding to the peak field being used. The intensity was about 4×10^9 protons/pulse.

The peak field was increased in small steps and rough optimisation was carried out by varying initial $\dot{B}$. A small number of pulses was tried at 15.9 kilogauss and 8 GeV was observed with about 10^9 protons/pulse. There did not appear to be any appreciable loss from 6.5 to 8 GeV. The run continued at 7 GeV and the highest intensity achieved was 10^{10} protons/pulse.

17.20 hours	6.5 GeV
18.30 hours	8.0 GeV
19.00 hours	7 GeV, 10^{10} protons/pulse

The "corrected" frequency law was substantially below that which we started with until beyond the knee of the curve, and there were considerable bumps. The deviation corresponded to something like an error in stable orbit of one metre. The bumps were later ironed out.

The drama was intense for those who were actively engaged and for the many others who visited us and encouraged us until the early hours of the morning. It must be admitted that the high energy physicists "got there first". The operator of the frequency-curve corrector was so concentrating on pushing the beam further and further along his oscilloscope trace that he didn't have his zero set and didn't realise immediately that he had got to the end. It must also be admitted that three key experimenters misjudged the time to take their evening meal and the news had to be brought to the restaurant by runner. That night we closed down some three to four hours earlier than usual for a minor celebration, but not before we had telephoned the good news to Lord Bridges, the Director and others. The following day saw the Laboratory full of smiling faces. We had the proud and happy task of sending telegrams around the world and the pleasure of receiving a tremendous number of most complimentary replies.

This first full performance of the machine was better than we could have hoped for at so early a time and with so many things still to be done. To have 10^{10} protons/pulse at 7 GeV was extremely pleasing since we knew that without the magnetic field corrections injection was poor, and in any case with the full rate of rise of magnetic field the injection time was short. The measurement of current is a tricky business, but we believe our figures to be conservative. The way seems to clear for achieving an output between 10^{11} and 10^{12} protons/pulse. To go on to 8 GeV without any high field correction and with no appreciable loss of beam was quite a surprise. With a bigger and better beam at injection, the beam is likely to be bigger at full energy, so that correction may then be necessary to obtain a sufficient "good field" region.

Apart from the known deficiencies, there did not appear to be any major design or construction fault. The vacuum system behaved well and the average pressure was about 10^{-6} mm of mercury with one of the gauges reading just below 10^{-7}, and the speed of pump-down was high. The first pump-down of the whole vacuum vessel started on August 1st and the pressure was down to 6×10^{-6} on August 3rd. Later pump-downs were much faster and after a complete power failure which resulted in the pressure being equalised between the inner and outer vessels at about 0.1 mm of mercury, the pressure was sufficiently low for operation some two hours later. This leads us to believe that we have a reasonable factor in hand to deal with outgassing and leaks resulting from the introduction of targets and other experimental apparatus. The reliability of the major parts of the machine was at least as good as could be expected. Most of the faults, although admittedly time consuming and annoying, were minor things such as interlock and cable faults and failures of water cooling.

A 7 GeV beam has been run on several occasions since, in particular for a radiation survey. Some work was done on slower rate of rise of field at injection and an output of 2×10^{10} was recorded. We were about to suspend acceleration to 7 GeV for a period of some three or four weeks to "commission" the poleface windings and work on injection conditions whilst having little other disturbance of the machine. Unfortunately some suspected breakdown occurred in one of the eight transformers between the alternators and the rectifier groups. Whilst this trouble was being investigated the programme was switched to carrying out essential installation, including some beam ports and target mechanisms. No conclusive information could be obtained from a wide range of tests on the transformer so that, by elimination, the fault appeared to be inter-turn breakdown in the primary or secondary. The transformer had to be put back into service to check this theory, and within a very short time the evidence of an inter-turn short on the primary developing to include a short to the core was quite obvious. The transformer started on its way back to the manufacturers in Scotland to be rewound on 16th September. Despite the best efforts of all concerned we are most unlikely to have it back in service in less than a month, and six weeks would not be unexpected. At the same time the transformer will be checked for design or constructional faults which might result in further breakdown in this transformer and the others. We are fortunate in having a power supply in symmetrical halves. The commissioning of poleface windings is being carried out with half the power supply feeding halves of the magnet in succession. Further work with the poleface windings and injection studies with reduced rate of rise of field can be done with half the power supply feeding the whole of the magnet. Trapping and acceleration studies can also go on in this fashion. The time will not be wasted, and indeed the delay to programme will not be as serious as it might appear.

20th September, 1963 L. B. MULLETT
Rutherford High Energy Laboratory,
Chilton, Didcot, Berkshire.

All N.I.R.N.S. Committees' Members
Nimrod Project Committee Members

Appendix IV

NIMROD
PLANT AND BUILDINGS