DR. J.R.J. BENNETT, R25

RHEL/R 129

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Rutherford Laboratory Report

The Work of the Rutherford Laboratory from 1st October 1964 to 31st December 1965

Edited by
T R Walsh

Science Research Council

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THE WORK OF THE RUTHERFORD LABORATORY

1st OCTOBER 1964/31 DECEMBER 1965

Rutherford Laboratory
Chilton, Didcot, Berkshire.
January 1967

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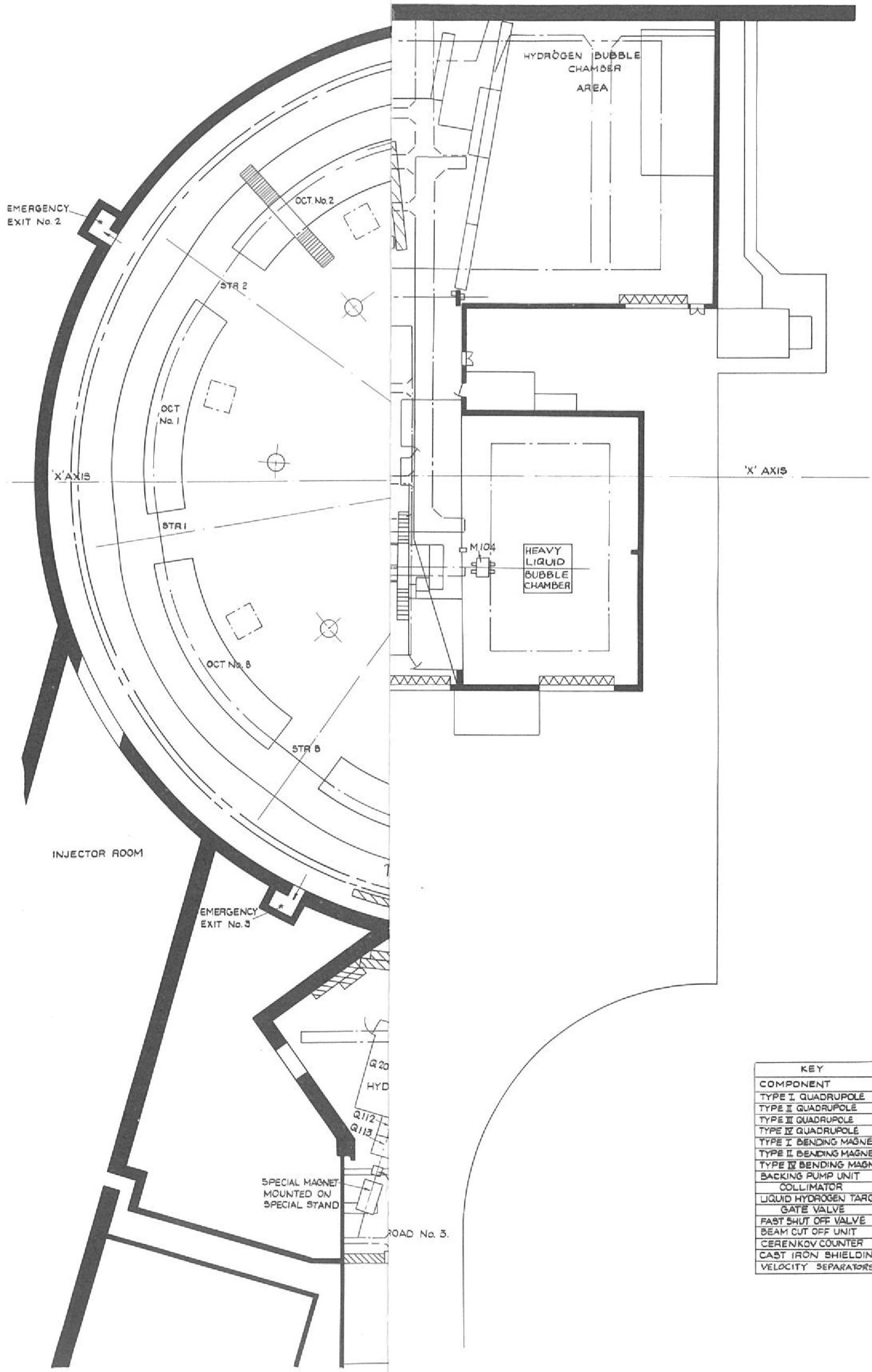
INTRODUCTION

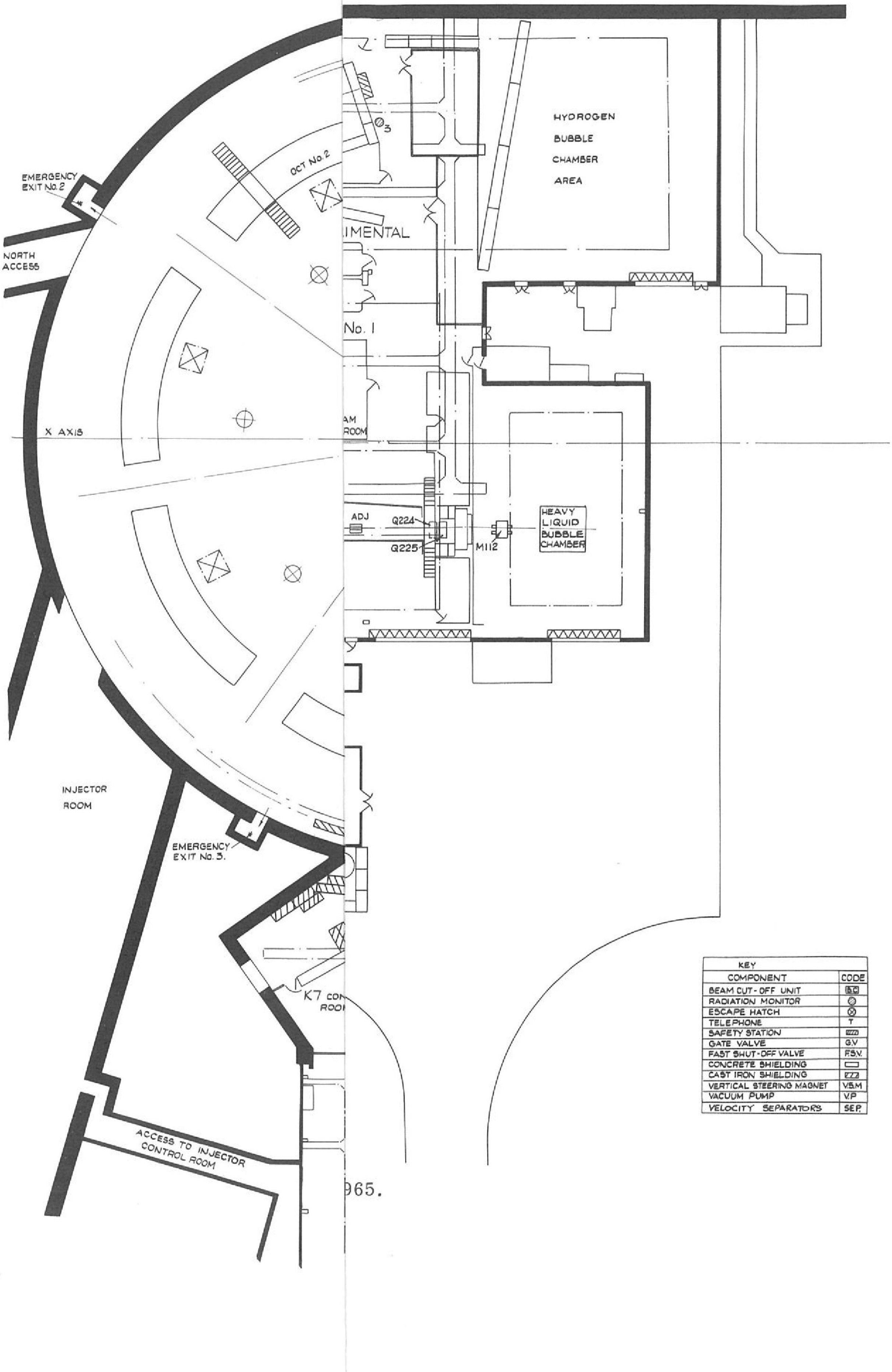
The work of the Rutherford Laboratory was formerly reported in the Annual Reports of the National Institute for Research in Nuclear Science, together with that of the Daresbury and Atlas Laboratories. These reports were written primarily to fulfill the Institute's obligation under its Charter to report on its work to the United Kingdom Atomic Energy Authority. The Seventh Annual Report of the Institute, covering the period 1 October 1963 to 30 September 1964, was the last before its responsibilities were taken over by the new Science Research Council on 1st April 1965.

The Science and Technology Act 1965 made the Science Research Council directly responsible for its own reports and accounts from 1st April 1965, and also for the accounts of the National Institute covering the period before the transfer. The first Annual Report of the Science Research Council for the financial year 1965/66 was published in October 1966 and includes a brief review of the work of the Rutherford Laboratory.

The present report presents an account in much greater detail of the work of the Laboratory following on from the last National Institute report as far as the end of 1965. It is more technical than both the SRC and the earlier NIRNS reports, being intended principally for physicists engineers and other specialists. It consists of a number of sections each devoted to the work of one of the Divisions of the Laboratory.



KEY	
COMPONENT	CODE
TYPE I QUADRUPOLE	Q1--
TYPE II QUADRUPOLE	Q2--
TYPE III QUADRUPOLE	Q3--
TYPE IV QUADRUPOLE	Q4--
TYPE I BENDING MAGNET	M1--
TYPE II BENDING MAGNET	M2--
TYPE IV BENDING MAGNET	M4--
BACKING PUMP UNIT	B.P.
COLLIMATOR	COL
LIQUID HYDROGEN TARGET	HYD
GATE VALVE	G.V.
FAST SHUT OFF VALVE	F.S.V.
BEAM CUT OFF UNIT	B.C.
CERENKOV COUNTER	C.C.
CAST IRON SHIELDING	(hatched)
VELOCITY SEPARATORS	SEP.


HYDROGEN
BUBBLE
CHAMBER
AREA
EMERGENCY
EXIT No.2
OCT No.2
IMENTAL
NORTH
ACCESS
No. 1
X AXIS
AM
ROOM
ADJ
Q224
Q225
M112
HEAVY
LIQUID
BUBBLE
CHAMBER
INJECTOR
ROOM
EMERGENCY
EXIT No.3.
K7 CON
ROO
ACCESS TO INJECTOR
CONTROL ROOM
KEY
COMPONENT CODE
BEAM CUT-OFF UNIT
RADIATION MONITOR
ESCAPE HATCH
TELEPHONE T
SAFETY STATION
GATE VALVE G.V
FAST SHUT-OFF VALVE F.S.V.
CONCRETE SHIELDING
CAST IRON SHIELDING
VERTICAL STEERING MAGNET V.S.M
VACUUM PUMP V.P
VELOCITY SEPARATORS SEP.

965.

HIGH ENERGY PHYSICS DIVISION

During the period from September 1964 until February 1965, NIMROD ran with an overall efficiency of about 70% and with a beam intensity of approximately 10^{12} protons per pulse. Four experiments on the programme were completed. The N2 beam line, used for the elastic n-p charge exchange experiment, was re-arranged and the existence of the CP violating decay $K_2^o \rightarrow \pi^+\pi^-$ was confirmed.

After the damage to the alternators in February, NIMROD was run at 2.0 GeV without alternators, directly from the national grid. This time was extremely valuable for studying the properties of the extracted proton beam and for setting up beam lines pending the return of the machine to 7 GeV and full repetition rate early in 1966. Some experiments collected data at the reduced energy, notably those on the P6 and Ø1 beams. The Saclay hydrogen bubble chamber took 300,000 pictures on the K1 line, and the heavy liquid chamber was commissioned.

In the emergency caused by the breakdown, CERN generously offered to mount one counter experiment - the search for the decay $K_2^o \rightarrow \pi^o \pi^o$ - and took 575,000 pictures for the heavy liquid chamber group's study of K_{e4} decays.

The majority of electronic experiments involved the use of spark chambers. Four experiments involved sonic spark chambers and one of them - a study of the decay modes of the f^o - successfully established and used an on-line link with the ORION computer. A polarized proton target was operated in the extensive study of π-p scattering, which led to definitive statements of the spins and parities of the N* (1688) and N* (1920) isobars.

Figures 1 and 2 show the layout of NIMROD beam lines in November 1964 and June 1965 respectively. Figure 3 is a photograph of some of the beam lines where they leave NIMROD.

In September 1965 the Laboratory organised the Oxford International Conference on Elementary Particles. Members of the Division played an active part in the Conference both as participants and in its organisation.

Composition of the H.E.P. Teams using NIMROD

	Physicists		Research Students		Support Staff*	
	Electronic Techniques	Bubble Chambers	Electronic Techniques	Bubble Chambers	Electronic Techniques	Bubble Chambers
Visitors+	57	32	39	21	17	25
Resident** RHEL Staff	17	6	0	0	17	11
TOTALS	74	38	39	21	34	36

* "Support Staff" listed include only technical assistance directly concerned with experiments on NIMROD and does not include general engineering support.

\+ "Visitors" includes staff from collaborating Universities, AERE Harwell, and Saclay bubble chamber group.

** Of the 23 RHEL physicists, 4 held permanent appointments, 3 had fixed term joint University-RHEL posts, and 16 were on short term contracts.

Experiments at Nimrod

Number	Experiment	Beam Line (figures 1 and 2)
1	π^--P Differential Elastic Cross Sections Near 2 GeV.	π 2
2	Charge Exchange Scattering of Pions at Momenta Near 2 GeV/c.	π 3
3	Elastic n-p Charge Exchange Scattering at 8 GeV/c.	N1
4	Measurement of Differential Cross-Sections and Asymmetries in Elastic Pion-Proton Scattering in the Range 875-1580 MeV/c.	π 1
5	The Decay of K^o_L Mesons into Two Charged Pions.	N2
6	Nucleon-Nucleon Total Cross Sections from 1-8 GeV/c.	P4

Number	Experiment	Beam Line (figures 1 and 2)
7	A Measurement of the Partial Width for the Decay $\omega^{o} \rightarrow e^{+} + e^{-}$	K2
8	An Investigation of the Production of Nucleon Isobars in p-p Collisions for Incident Protons in the Range 2.8-7.8 GeV/c.	P6
9	A Study of the Angular Distributions of the Charged Decay Modes of the f^{o} Meson.	P3
10	A Measurement of the Partial Width for the Decay $\phi^{o} \rightarrow e^{+} + e^{-}$	ϕ1
11	A Measurement of the Width of the 'η' and a Search for the s^{o} Meson.	ϕ1
12	A Study of the Leptonic Decay Modes of K^{+} Mesons.	K4
13	K^{-}-Nucleon Total Cross-Sections from 750-2500 MeV/c.	K6
14	A Study of the Decay of the K^{o}_{L} Meson into Two Neutral Pions.	CERN
15	A Study of Ke_4 Decays.	CERN
16	A Study of K^{-}-p Interactions at 3.5 and 6.0 GeV/c.	CERN
17	An Experiment to Study the Decay of the η Meson.	K1
18	A Study of K^{-}-p Interactions in the Range 1.5-2.0 GeV/c.	K1
19	A Study of K^{-}-d Interactions in the Range 1.5-2.0 GeV/c.	K1

Experiment 1

University College London,
Westfield College, London.

π^--p Differential Elastic Cross Sections Near 2 GeV

All the data for the $\pi^- + p \rightarrow \pi^- + p$ reaction was obtained, at 5 different pion momenta centred at 2.07 GeV/c.

The construction of the Westfield College vidicon system proceeded throughout 1965, with the intention of taking data on the π^+-p scattering using the vidicon system in parallel with the photographic system.

About 12,000 elastic events were analysed completely - more or less evenly distributed between the five momenta. A study of these five differential cross-sections is in progress and Legendre Polynomial coefficients have been obtained for the distributions. An attempt to provide a Breit-Wigner fit to the differential, as well as to the available total cross-section is being carried out, on the assumption that there are T = 3/2 and T = 1/2 resonances present at the invariant (πp) energies of 2360 and 2190 MeV respectively.

It is already clear that definitive answers will not be obtained for the spins and parities of the resonances from the $\pi^- + p$ data alone.

Experiment 2

Oxford University,
Rutherford Laboratory.

Charge Exchange Scattering of Pions by protons at Momenta Near 2.0 GeV/c.

The purpose of this experiment was primarily to obtain angular distributions for the reaction at five momenta, (1.71, 1.89, 2.07, 2.26, 2.46 GeV/c) aimed at obtaining information on the angular momentum of the excited nucleon state reported at a mass of 2190 MeV/c^2 (corresponding to a pion momentum of 2.07 GeV/c).

The experiment was performed by detecting the gamma-rays from the decay of the neutral pions. The incident pion beam bombarded a small liquid hydrogen target. Interactions in which no charged particles were produced triggered an array of spark chambers surrounding the target.(figure 4). The spark chambers had brass plates, approximately 0.1 radiation lengths thick in which the gamma-rays converted to produce electron showers. Events were observed in which up to ten gamma-rays were produced, so that information was also obtained about processes in which more than one neutral pion was produced.

In particular the following results were found to be of interest:

a. Angular distributions for $\pi^- + p \rightarrow \pi^o + n$

At high momenta (6-18 GeV/c) Reggeised ρ-exchange fits the measured cross-sections. The results (figure 5) indicate that this is still the dominant process,

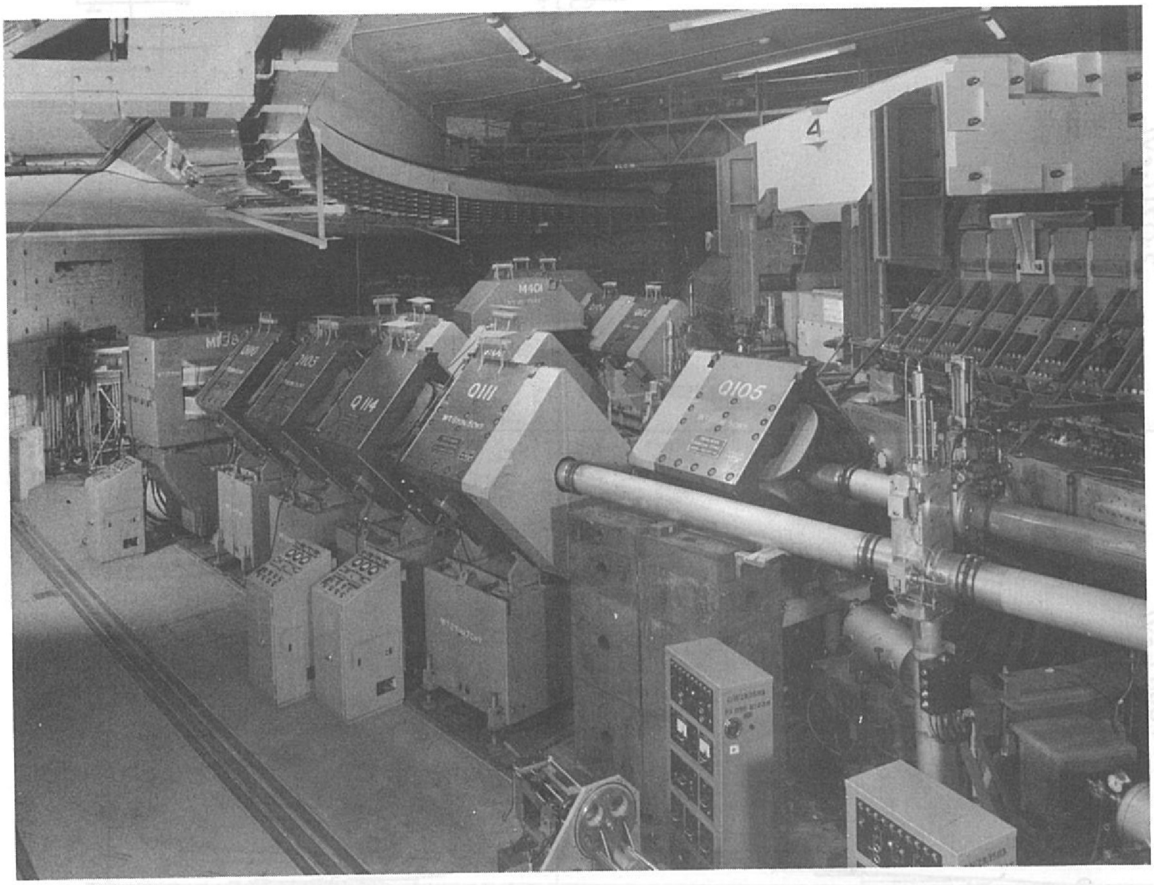


Figure 3.
Beam lines emerging from Octant 3. In the foreground is the P6 beam, immediately behind it is the main extracted beam P1 and in the background the beginning of the beam for P3 and $\pi 2$.

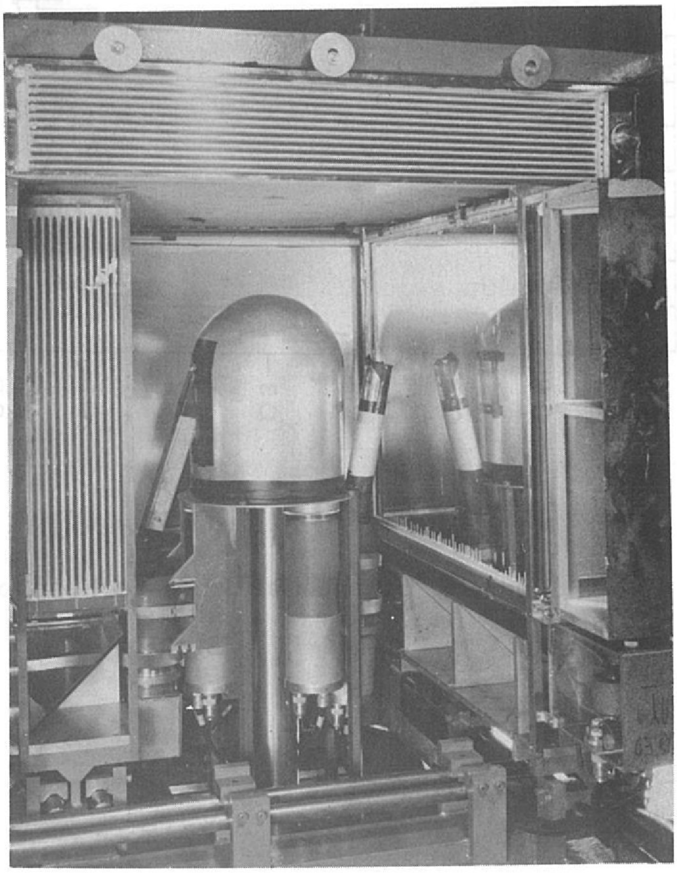


Figure 4.
Veto counter surrounding a liquid hydrogen target inside an array of spark chambers. One of the spark chambers has been removed.

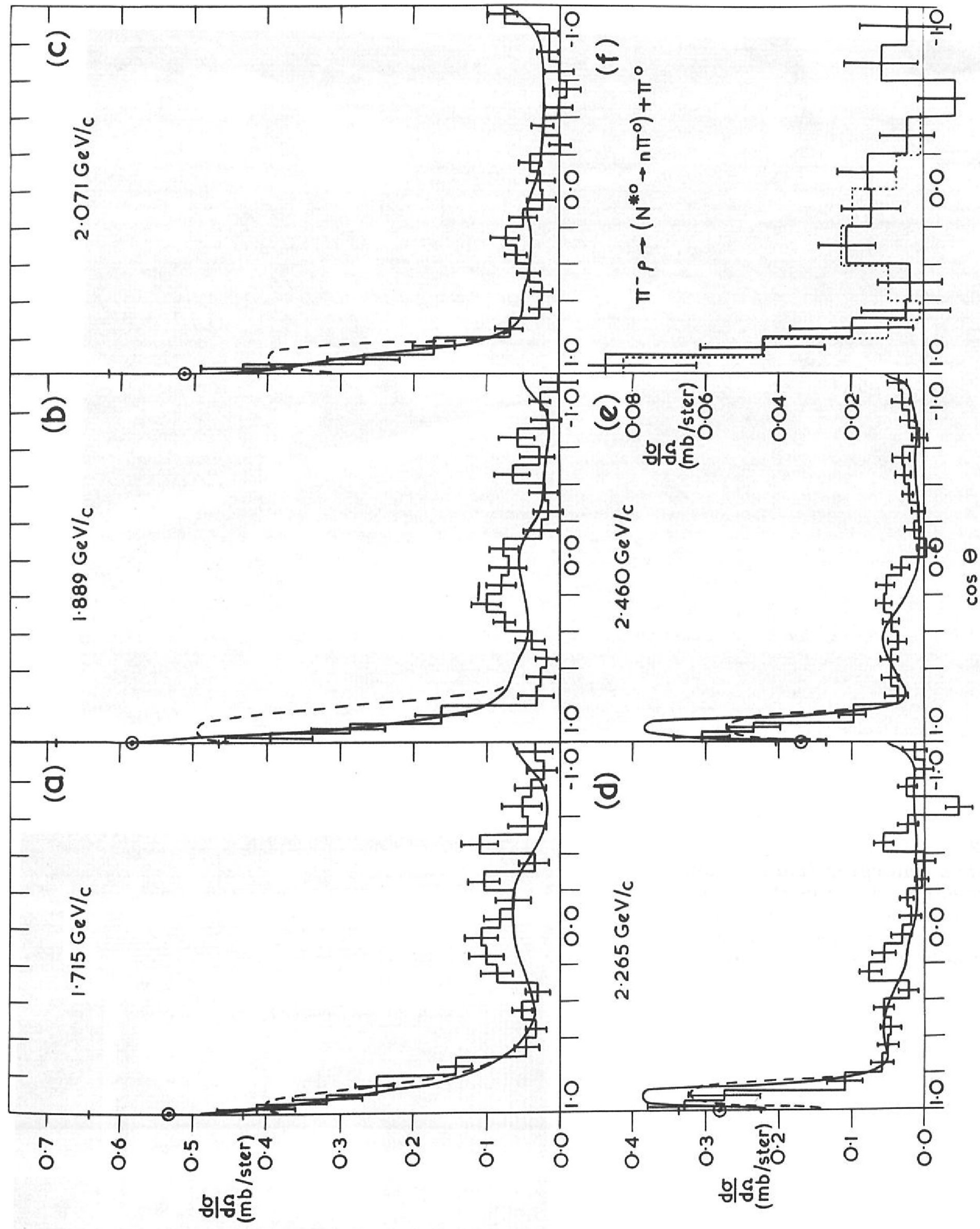


Figure 5. Differential Cross-Sections for $\pi^- p \rightarrow \pi^0 n$ and $\pi^- p \rightarrow N^{*0} \pi^0$

a result which is surprising at this low energy. A good fit is obtained when interference with N* (1920), N* (2190), N* (2360) is taken into account. This makes it difficult to draw firm conclusions about the spin and parity of the N* (2190), but $J = L-\frac{1}{2}$ is favoured.

b. Study of the process $\pi^- + p \rightarrow N^{*o}_{1238} + \pi^o$

The results indicate that this process can be explained by the same Regge-pole model as in (a).

c. Peripheral dipion production in the reaction $\pi^- + p \rightarrow \pi^o + \pi^o + n$

This provides information about the s-wave $\pi\pi$-interaction.

d. The reaction $\pi^- + p \rightarrow n + \eta (\eta^o \rightarrow 2\gamma)$

Angular distributions and total cross-sections are being studied.

Experiment 3

A. E. R. E., Birmingham University, Bristol University, Rutherford Laboratory.

Elastic n-p Charge Exchange Scattering at 8 GeV/c.

The experiment to study elastic n - p charge exchange scattering at 8 GeV/c was undertaken to investigate the basic interactions between nucleons and to yield information at higher energy to test specific theoretical models put forward to explain the unexpected sharp angular distribution observed in the reaction at 3 GeV/c.

A beam of neutrons was taken at 0^o from a target placed in the circulating beam of NIMROD. This beam, containing neutrons of all energies, was incident upon a hydrogen target in the experimental area. Detection equipment was arranged to detect events in which a neutron entered the hydrogen target and an energetic proton emerged in the forward direction. The trajectory of these protons through an accurately uniform magnetic field was traced using acoustic spark chambers placed before and after the analysing magnets (figure 6). Output information from these acoustic chambers was analysed by an on-line analogue computer; and those events of possible interest were then recorded in detail on punched paper tape for subsequent, more accurate analysis by a digital computer. The acoustic-chamber-analogue-computer system was able to analyse an event within 7 msec and hence was able to handle several events in one machine burst of 150 msec. A total of 2×10^6 events was analysed throughout the experiment resulting in 10^5 events to be analysed by the digital computer and 2000 final selected elastic charge exchange events.

These elastic events were characterized by the fact that the proton ejected from the hydrogen target by the entering neutron had the full energy of the protons circulating in the synchrotron, thus proving that no other particles were produced in the reactions in the internal target and in the external hydrogen target.

The angular distribution of elastically produced protons was obtained from their trajectory in the acoustic spark chambers placed before the analysing magnet. The angular distribution together with the cross-section for the process were then compared with other work at lower energies and with theoretical model predictions.

This comparison, together with other information, indicates that the basic interaction between neutron and proton cannot be described in terms of a simple pure imaginary spin independent amplitude and that the real part of this amplitude is different for the two possible isospin states. It also indicates that the exchange of pions play some part in the interaction and that the model for single pion exchange, including absorption effects, is able to describe at least the small-angle behaviour of the reaction. As yet, no model is able to explain the full angular dependence.

Experiment 4

Rutherford Laboratory,
Oxford University.

Measurements of Differential Cross-Sections and Asymmetries in Elastic Pion-Proton Scattering in the Range 875-1580 MeV/c.

The general aim of this work was to make a detailed study of the pion-nucleon interaction in the momentum range from 875 to 1580 MeV/c and in particular to give definite information about the spins and parities of the two resonant states, $N^*_{\frac{1}{2}}$ (1688) and $N^*_{3/2}$ (1924).

The experiment consisted of the measurement of differential cross-sections and polarisation effects. Pions and protons scattered from a 4" long liquid hydrogen target were detected by two scintillation counter arrays placed one on each side of the pion beam (figure 7). The number of counts detected in coincidence by any combination of two counters on opposite sides of the beam was stored in the magnetic core store of a 512-channel pulse height analyser. Regions of high counting rate, corresponding to elastic scatters, were clearly visible above the general background caused by inelastic events. After subtraction of this background, the differential cross-sections were calculated.

The second experiment used a polarised proton target in which the proton spin could be oriented normal to the π-p elastic scattering plane. The target was designed and constructed in conjunction with members of the NIMROD General Physics Group. The pion beam was scattered in a 1" crystal of Lanthanum Magnesium Nitrate ($La_2Mg_3(NO_3)_2 . 24H_2O$) enriched by the addition of a 1% admixture of Neodymium. This crystal was placed in a magnetic field of 18.2 Kgauss and cooled to 1.2^oK in a liquid helium cryostat. Microwaves of about 4mm. wavelength were used to polarise the free protons in the water of crystalization and polarisations in the region of 55% to 60% were obtained. The direction of proton polarisation can be reversed by making a small change in the microwave frequency so that the asymmetry in the scattering for opposite directions of the proton spin can be determined.

The counter arrays which detected the scattered particles were placed within the

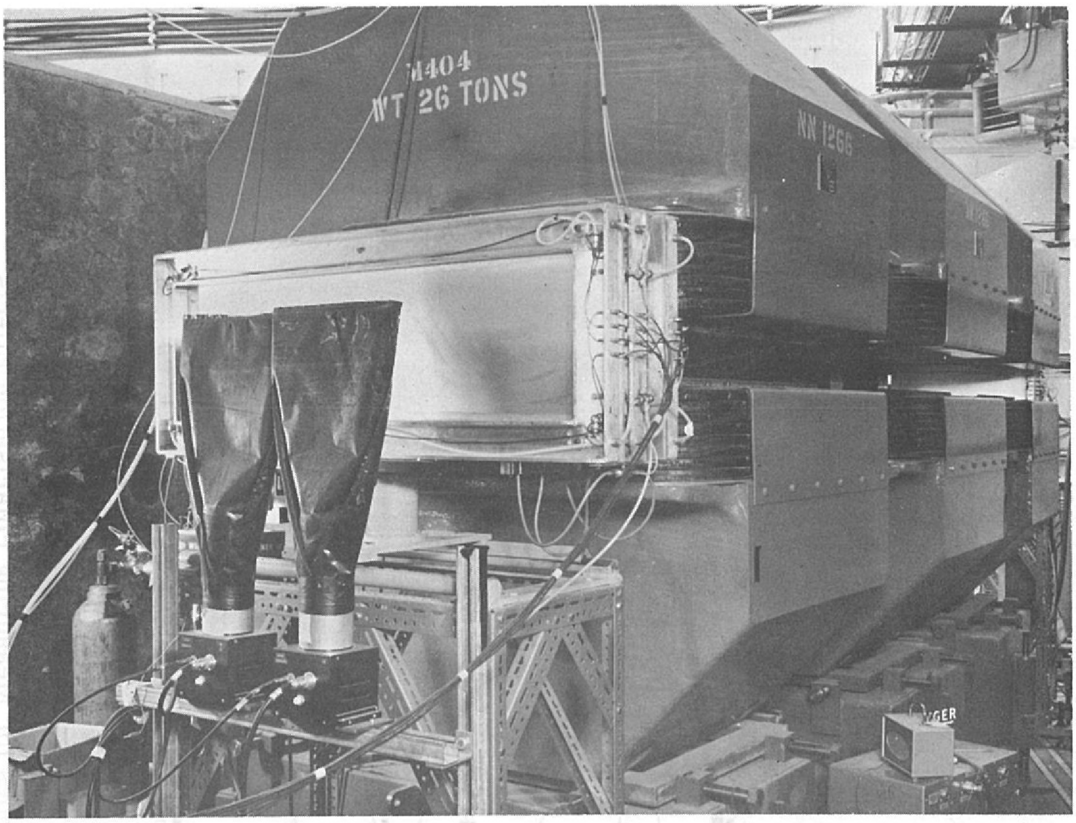


Figure 6. Acoustic spark chamber downstream from analysing magnets

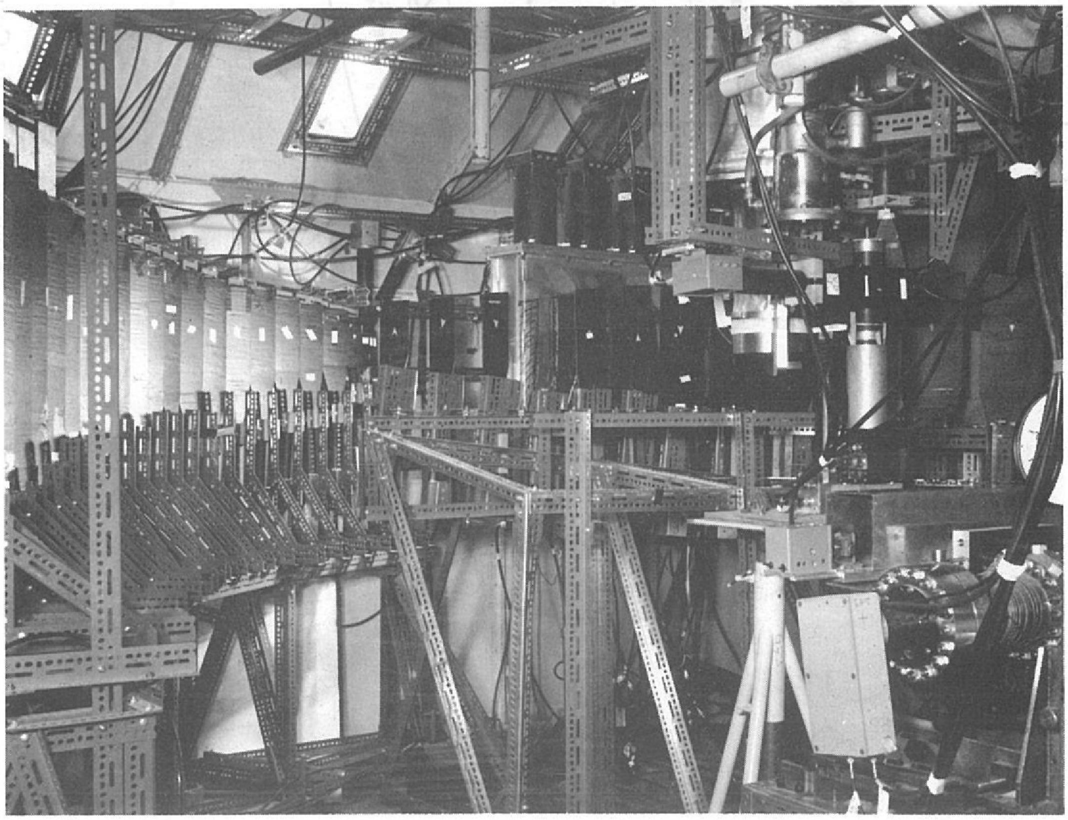


Figure 7. Array of scintillation counters for the study of pion/proton scattering

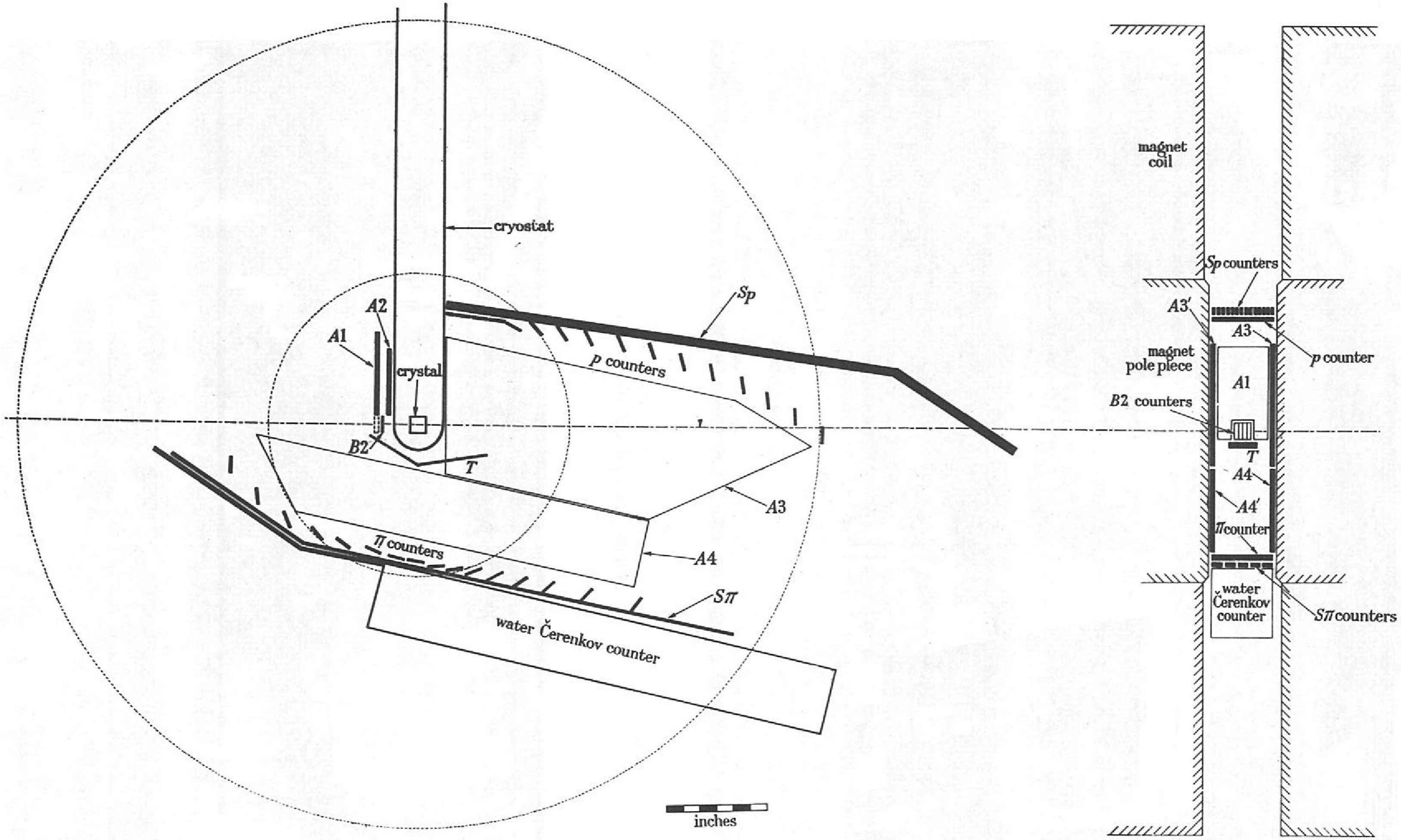


Figure 8. The Counter Hodoscopes for Measuring Polarisation Effects In π - p Elastic Scattering

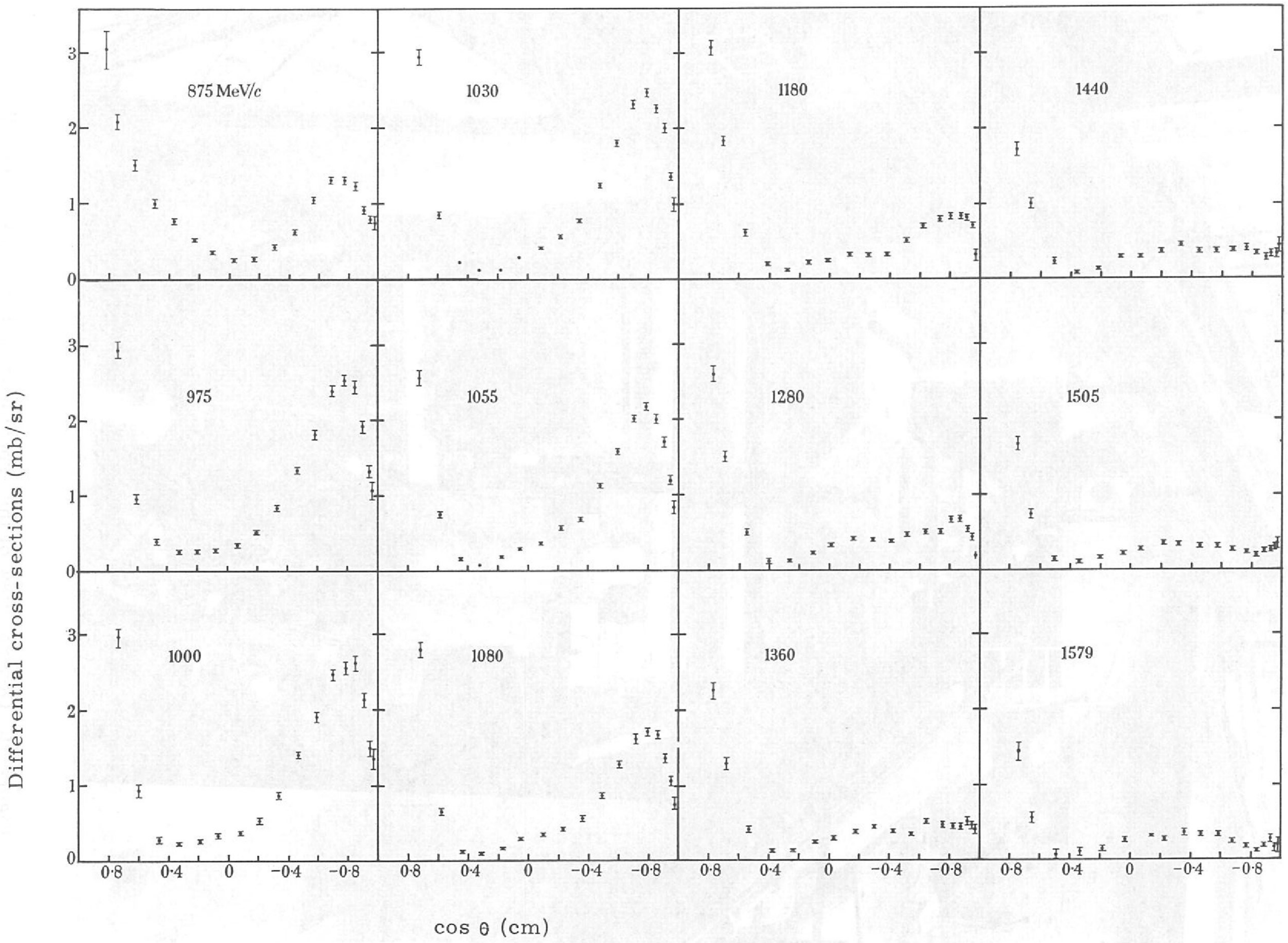


Figure 9. Differential Cross-Sections for π^--p Elastic Scattering

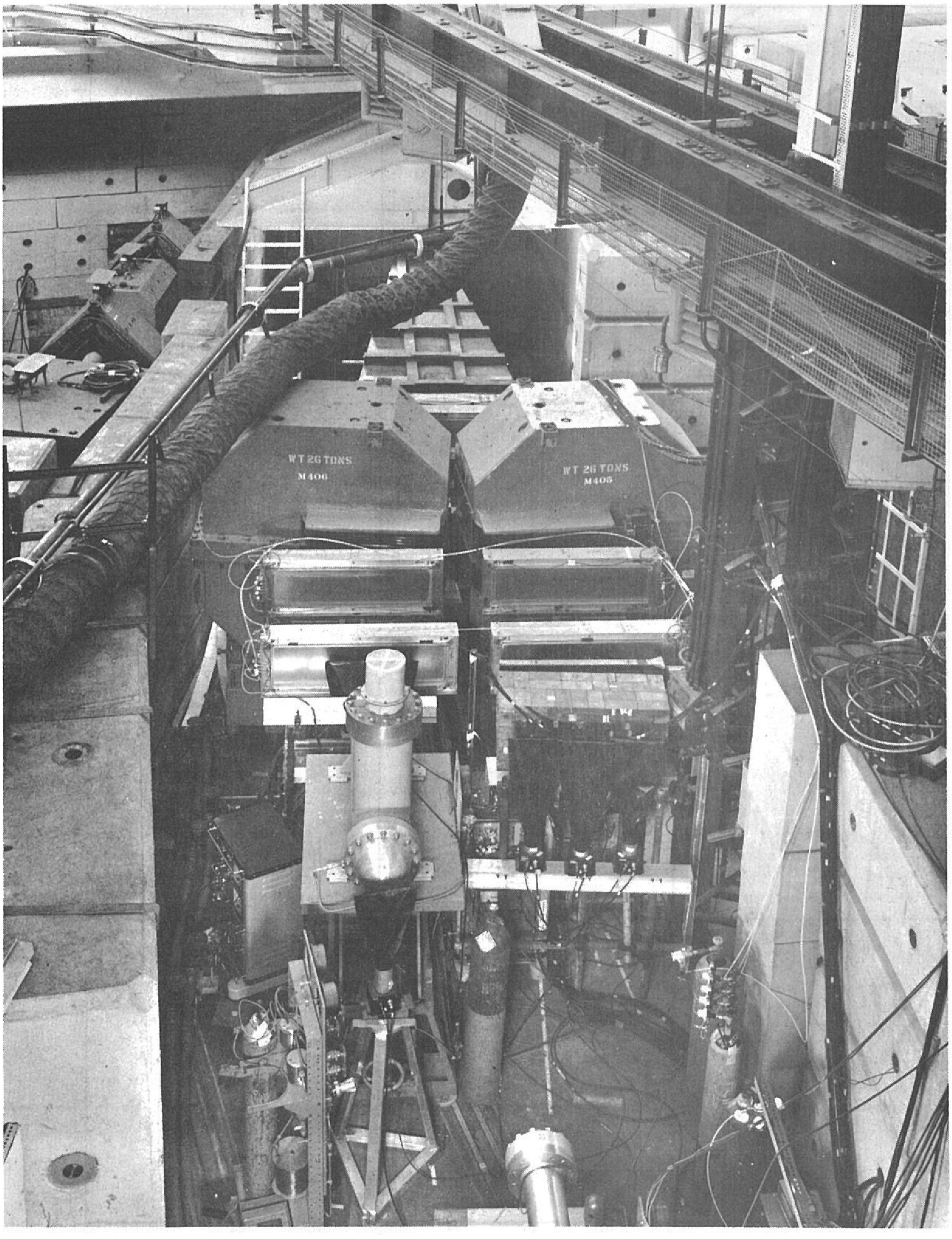


Figure 10. General view of the experiment on the decay of the K_L^o to two charged pions

4" gap of the polarised target magnet (figure 8). Several counter hodoscopes were used to reduce the detection probability for non-coplanar events produced by interactions with the heavy nuclei of the target crystal. This background was measured directly by replacing the crystal with a non-hydrogenous material having similar nuclear scattering properties.

Differential cross-sections for both π^+-p and π^--p elastic scattering were measured at 12 pion momenta and 18 angles of scatter at each momentum. Results for π^--p are shown in figure 9. The asymmetry measurements were made over a similar momentum and angular range but for π^--p only. The results show that the $N^*_{\frac{1}{2}}$ (1688) and $N^*_{3/2}$ (1924) resonances occur in the $F_{5/2}$ and $F_{7/2}$ partial waves. In addition, it was clear that there must exist a $D_{5/2}$ resonance, $N^*_{\frac{1}{2}}$ (1674). Phase shift analyses using the data from these experiments agree with these conclusions and also show that there are two S wave resonances namely $N^*_{3/2}$ (1690) and $N^*_{\frac{1}{2}}$ (1700) in this same energy region.

It is planned to extend the measurements of π^--p asymmetry to other momenta and to make a similar investigation for K^--p scattering. A new version of the polarised proton target is being constructed for this work. The experiment will use the new high speed circuitry being developed by the Electronics group. A PDP 5 processing unit, connected on line, will be used for the preliminary analysis and storage of data.

Experiment 5

A. E. R. E., Bristol University,
Oxford University, Rutherford Laboratory.

Decay of K^o_L Mesons into Two Charged Pions

Before 1964, one of the basic laws of elementary particle physics was believed to be the conservation of CP. (C - Charge conjugation, P - Parity conjugation). The best evidence of this conservation for the weak interaction was the absence of the decay $K^o_L \rightarrow \pi^+ + \pi^-$. In 1964, a Princeton group observed 50 examples of this forbidden decay. This discovery was followed by intense theoretical interest resulting in some possible explanations of the occurrence of the decay without rejecting the law of conservation of CP. The most pleasing of these explanations postulated that the decay was a manifestation of a hitherto unknown "fifth force." The object of the experiment was to repeat the earlier experiment over a range of K^o_L energies and hence to check their finding and also to test directly the prediction of the fifth force theory that the decay rate should depend upon the square of the energy of the K^o_L meson (γ^2).

The experiment consisted of detecting the two pions from the decay and measuring their energies. This was done by determining these particles' trajectories through a magnetic field, using a system of sonic spark chambers before and after large bending magnets. A general view is shown in figure 10.

The data was recorded automatically on magnetic tape and processed by computer. The analysis consisted of calculating the invariant mass of the neutral particle decays into the two detected charged particles, assuming these to be π mesons. Those events detected corresponding to the K^o_L gave a clearly defined peak in the region of the K^o meson mass. The angle θ_o between the incident K^o beam and the resultant momentum of the two detected charged particles was also determined. If the decay is $K^o_L \rightarrow \pi^+ + \pi^-$, there should be a peak at $\theta_o = 0$ for events in the K^o mass range (figure 11). Some 100 examples of the two-pion decay mode were obtained before the experiment was terminated.

The results confirmed the two-pion decay of K^o_L, the rate of charged 2π mode to all charged modes of K^o_L being $(2.0 \pm 0.3)10^{-3}$, averaged over the K^o_L momentum spectrum extending from 1.5-5.0 GeV/c. Furthermore, this rate, compared with that of the Princeton group at the lower K^o_L energy, and the CERN group at a higher energy, led to the exclusion of the fifth force postulate (figure 12), leaving open the explanation of the apparent CP violation.

Experiment 6

Cambridge University,
Rutherford Laboratory.

Nucleon-Nucleon Total Cross-Sections from 1 to 8 GeV/c.

There were two ideas behind the experiment. The first was simply to improve the existing data on total cross-sections. Before this experiment the proton-proton total cross-section was known to about $\pm$ 2%; the proton-neutron cross-section was known to only about $\pm$ 10% over most of the region. The aim in this experiment was an accuracy of $\pm$ .1%. The second idea was to look for structure in the total cross-section, that is to look for resonances or prominent inelastic thresholds. It has been well known for many years that the proton-proton cross-section rises from about 25 to 50 millibarns at the threshold for production of the N* (1238). It was anticipated that there might be similar structure, although perhaps only a few millibarns, at the threshold of the N* (1512) and N* (1688).

The technique used was the conventional one of measuring the attenuation of a proton beam in liquid hydrogen and deuterium targets. The way in which the experiment differed from earlier ones was in the care taken to achieve the maximum possible accuracy. In particular this involved careful design of the liquid hydrogen target. In order to know the density of the target to .1% it was so constructed (by means of an outer jacket cooled by liquid hydrogen) that the target liquid did not boil, and its temperature was determined from its vapour pressure. Fluctuations in temperature throughout the volume of the liquid were kept to less than .05°K. Likewise special precautions had to be taken with the electronics. The attenuation of the beam in the target was about 10%. Hence, to measure the total cross-section to .1% it was necessary to know the efficiency of the transmissions counters to $\pm$.01%. This was achieved by continuous monitoring throughout the data-taking.

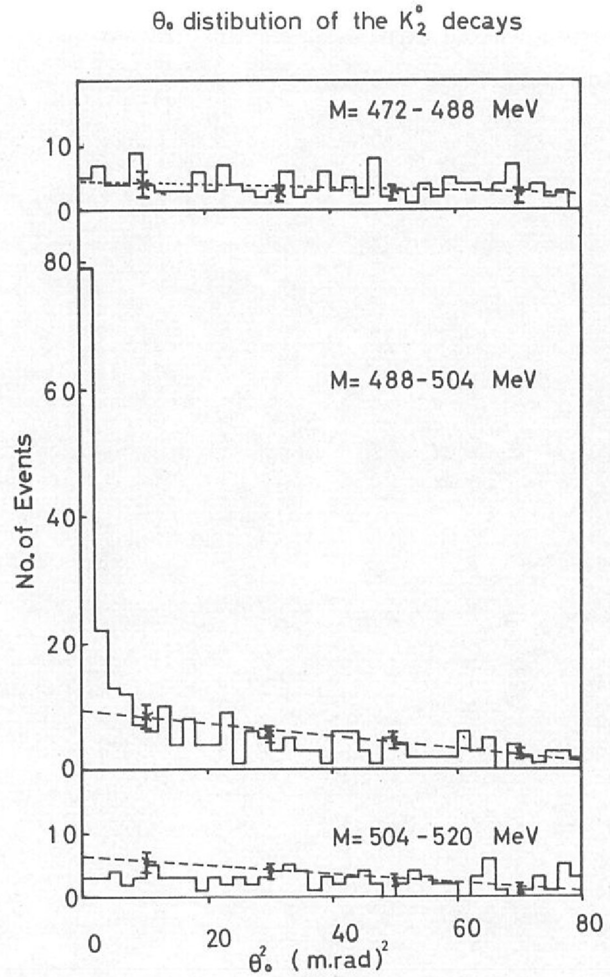


Figure 11. The Distribution of the Angle θ_O for Events with Missing Masses in the Ranges Below, Equal to, Above that of the K^O (498 MeV)

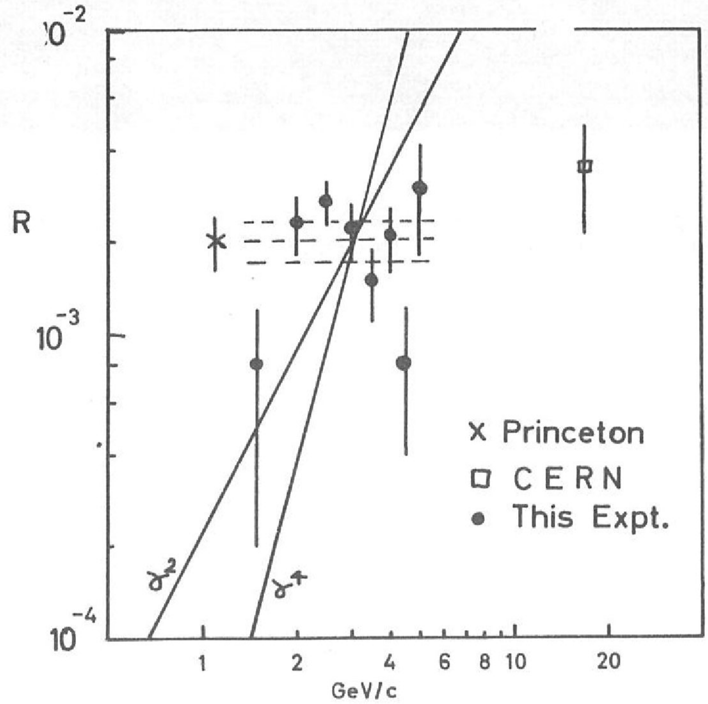


Figure 12. The Branching Ratio R = $K_L^O \to \pi^+ + \pi^-$ / All Charged Modes as a Function of K_L^O Momentum

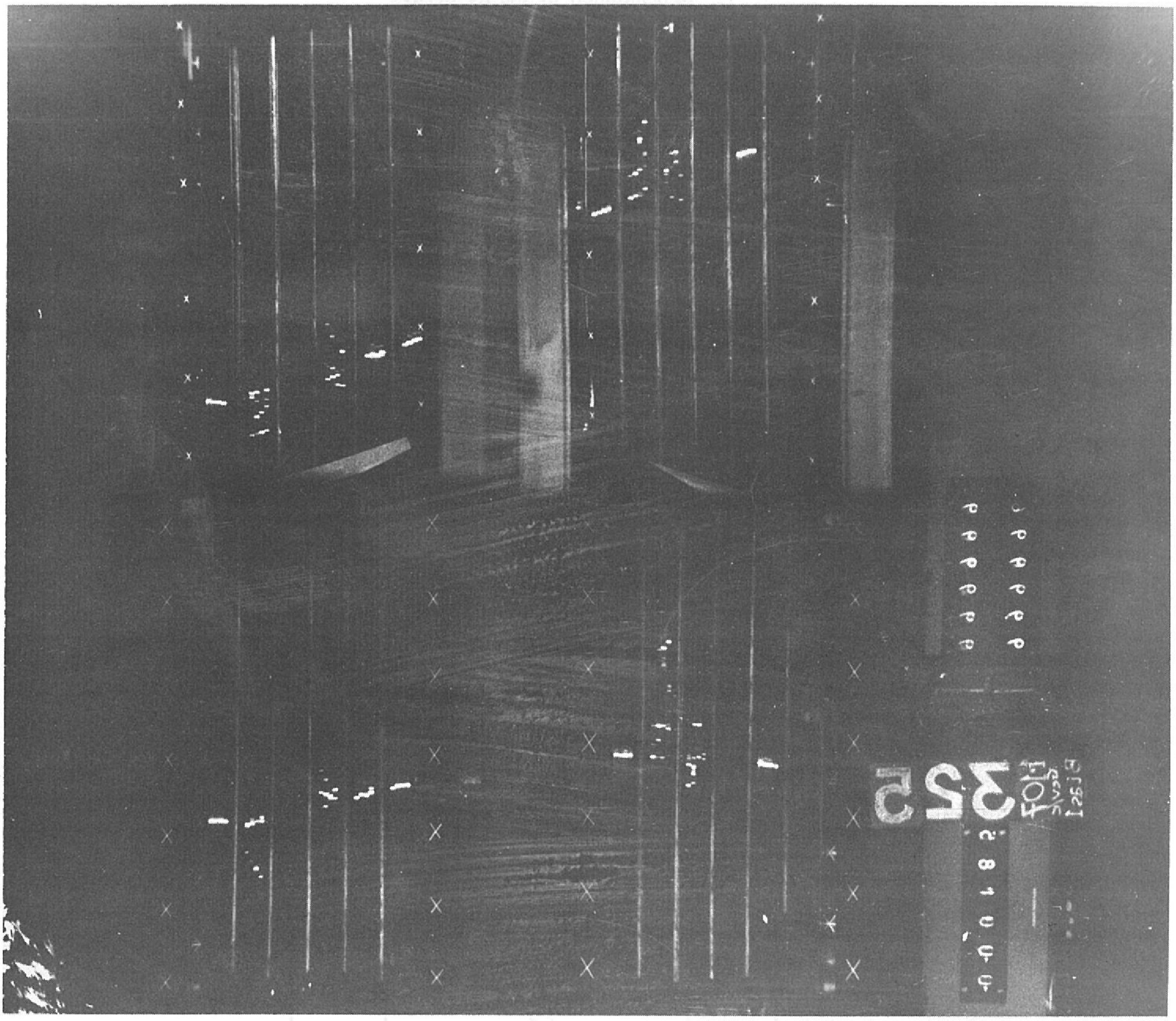


Figure 13. A Photograph of an $\omega^0 \rightarrow e^+ + e^-$ Decay in the Spark Chambers, Showing Two Views at Right Angles of the Shower Due to Each Electron

The beam was produced by scattering the NIMROD circulating beam out at a small angle. To cover the momentum range 1 to 8 GeV/c, it was necessary to run NIMROD over this range. This was achieved without any difficulty.

It was found that total cross-sections can indeed be measured with a consistency of ± .1%. Small structure was found in the proton-proton total cross-section at the threshold for N* (1688) production. However, this structure was rather smaller than anticipated, about half a millibarn. The deuterium data showed the proton-neutron cross-section to be rising rapidly but smoothly from 1.6 to 4 GeV/c; this cleared up uncertainties in this region where previous experiments were very inconsistent with one another.

Experiment 7

Imperial College,
Manchester University.

A Measurement of the Partial Width for the Decay $\omega^o \rightarrow e^+ + e^-$

The aim of the experiment was to measure the partial width for the decay $\omega^o \rightarrow e^+ + e^-$. The ω^o-mesons were produced in the reaction $\pi^- + p \rightarrow n + \omega^o$ using a pion momentum only slightly above the threshold. A ring of six large neutron counters was placed 3m. downstream of the hydrogen target and, by choosing a narrow band of neutron times of flight, events in which the ω^o-mesons were produced could be selected with high efficiency. Spark chambers containing lead plates were placed on either side of the hydrogen target to detect electrons from ω^o-decay.

During eight days of running on NIMROD for data-taking, a total of nearly 400,000 pictures of the spark chambers were taken. Of these, 240,000 were taken for an incoming pion momentum above ω^o-threshold, and the total number of "effective" ω^o-mesons for the determination of the branching ration was 14,000. For an event to be accepted as a possible example of the process $\omega^o \rightarrow e^+ + e^-$, it had to satisfy stringent conditions involving the "missing mass", and geometry, and detailed criteria involving the appearance of the cascade showers. Only three events which satisfied the criteria were found on the 240,000 pictures taken (figure 13).

For 140,000 photographs taken below the ω^o-threshold it was estimated that there were 2,000 "effective" ρ-mesons, and on these photographs no convincing event was found to fit all the criteria.

The result for the branching ratio of $\omega^o \rightarrow e^+ + e^-$ is thus quoted as 3/14,000, or, in terms of a partial width, $(1.8\,^{+1.5}_{-0.6})$ KeV. It should be emphasized that the events in this experiment were identified with much greater certainty than had hitherto been achieved.

Experiment 8

A. E. R. E., Rutherford Laboratory, Queen Mary College, London.

An Investigation of the Production of Nucleon Isobars in p-p Collisions for Incident Protons in the Range 2.8 to 7.8 GeV/c.

The reaction studied was $p+p \rightarrow p+X$ and measurements were made on the fast proton alone of the final state particles. Production of nucleon isobars, or the resonant behaviour of the group X, was demonstrated by bumps in the invariant mass spectrum of X, i.e., experimentally by bumps in the momentum spectrum of the fast proton. By making measurements at several incident proton momenta and various scattering angles, the production as a function of both s (c.m. energy squared) and t(four-momentum squared) could be studied systematically. Further, in the region of small t, comparison could be made with predictions of a model of peripheral interactions involving exchange of pseudo-scalar and vector mesons.

The experimental set up is shown schematically in Figure 14. An extracted beam, intensity 10^9 to 10^{10} protons per pulse, passed through two bending magnets M108 and M202 and was focussed on to an 11 cm. liquid hydrogen target. Counter telescopes and a spectrometer magnet momentum analysed the fast scattered protons. There were six counter telescopes spaced at 6 mrad. intervals. Large changes in scattering angle were made by adjusting the currents in M108 and M202 to give a total coverage of 22 to 144 mrad.

Figure 15 shows a momentum spectrum of scattered protons. The elastic peak and bumps associated with various nucleon isobars are clearly visible. Data was taken at 2.8, 4.5 and 7.8 GeV/c.

Experiment 9

A. E. R. E., Southampton University, University College London, Rutherford Laboratory.

A Study of the Angular Distributions of the Charged Decay Modes of the f^o Meson.

The purpose of the experiment was to study the angular distribution of the charged decay modes of the f^o meson resonance, in order to determine its spin and decay branching ratios - the expected accuracy of the $K^- K^+$ to $\pi^- \pi^+$ decay ratio being about 10% of its value - and to search for other neutral meson resonances produced in π^- -p interactions in the missing mass range from 700 MeV/c^2 to 1700 MeV/c^2.

The neutral meson resonance will be produced in the reaction $\pi^- + p \rightarrow n + X^o$. The mass of the resonance will be determined by measuring the time-of-flight of the neutron. The neutron is detected by an array of six large counters (figure 16), each consisting of a right cylinder of Ne 102A plastic scintillator, 12 inches diameter by 12 inches deep, and each viewed by a single 58 AVP photomultiplier. Their measured detection efficiency is greater than 30% over the range of neutron energy required by the experiment.

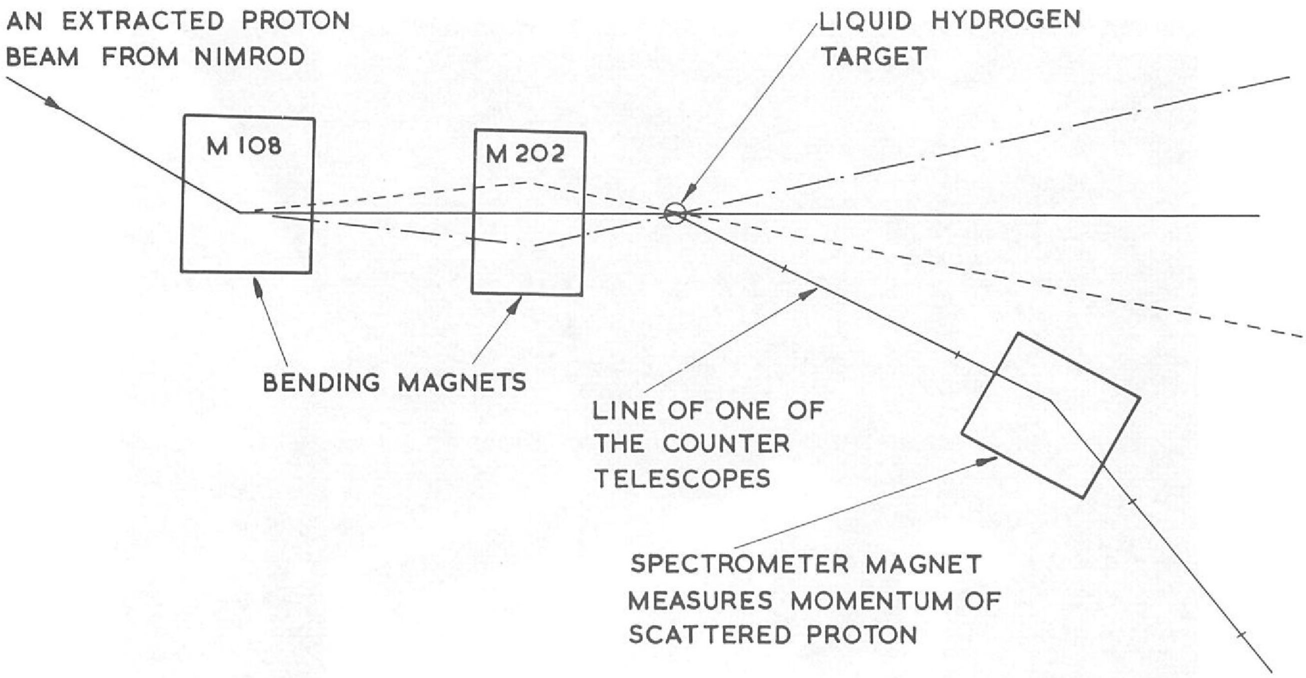


Figure 14. A schematic diagram of the Experimental Set Up for the Study of Nuclear Isobar Production in p/p collisions.

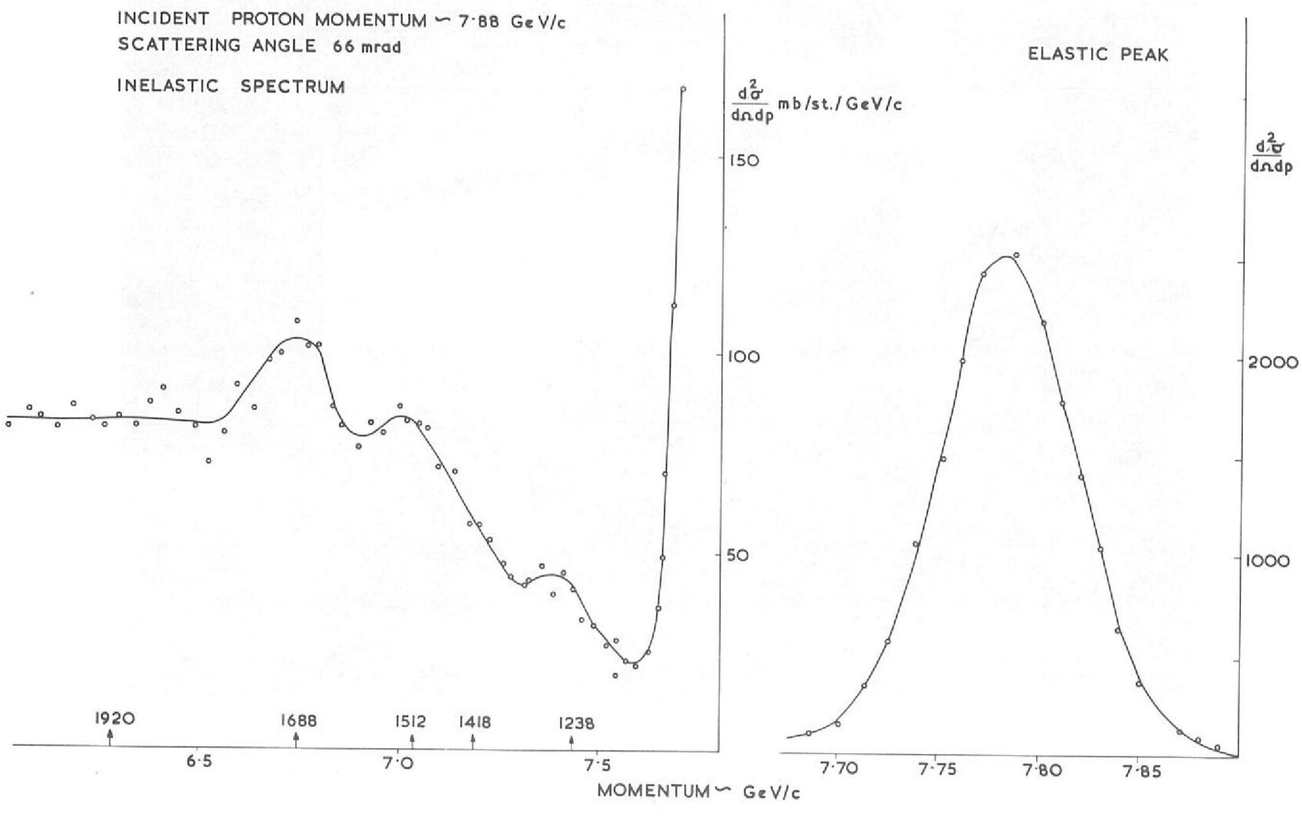


Figure 15. Momentum Spectrum of scattered protons.

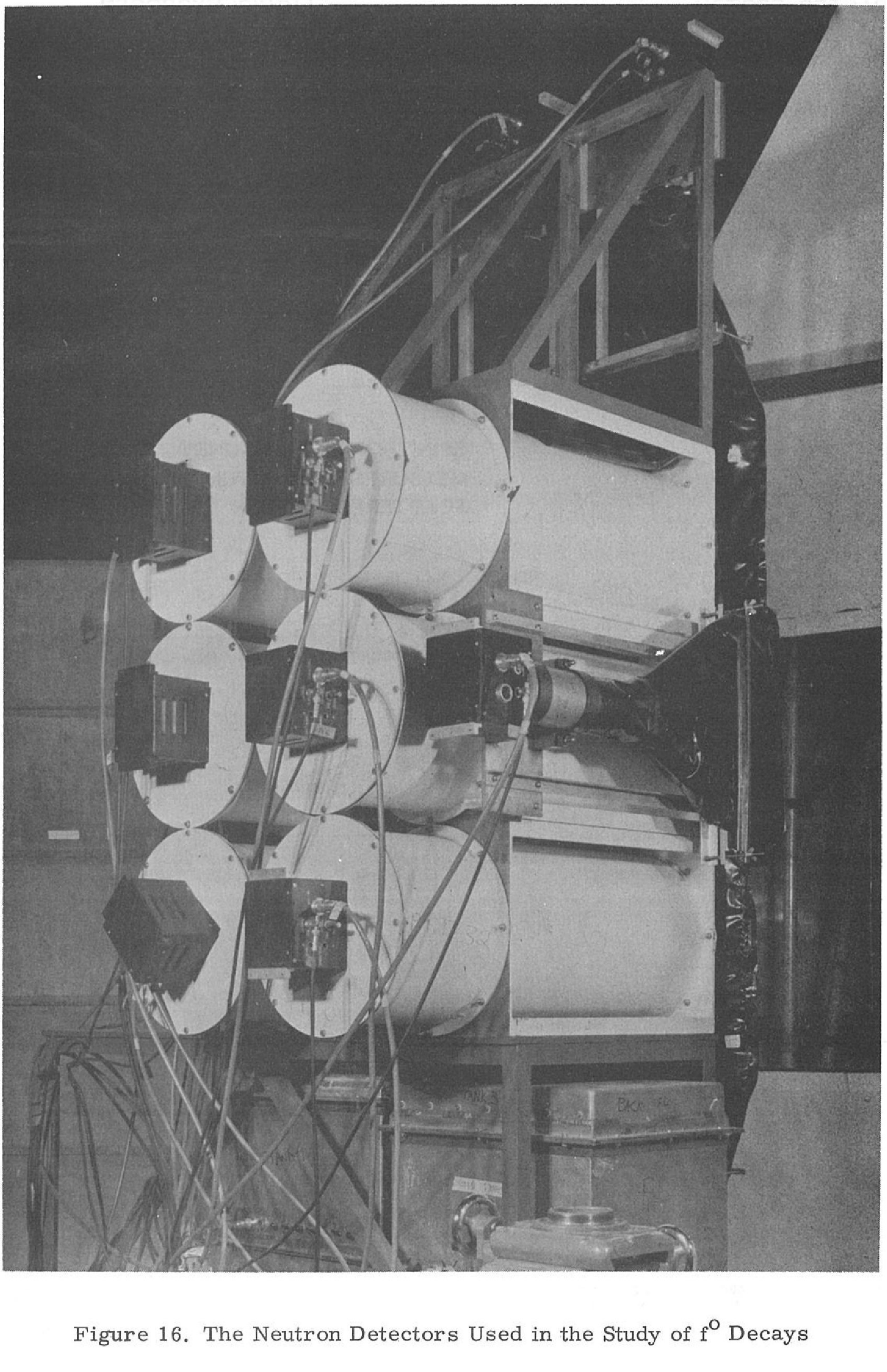


Figure 16. The Neutron Detectors Used in the Study of f^O Decays

The decay products of the resonance are detected in an array of 7 sonic spark chambers, the largest being 20 in. x 40 in. Each chamber consists of a 2 gap module with each gap monitored by 4 microphones. In order to ensure sufficient beam intensity at the higher momentum required for the missing mass survey, the beam optics accepts a momentum bite of 10%. A momentum analysis of each interacting beam pion is made using 4 sonic chambers and a type H bending magnet.

The data for every event, which includes the flight time for the spark sound to travel to the microphones (there were 104 microphones, and the flight-time might vary from 200 to 3000 microseconds), is transferred via a buffer store to a magnetic tape situated in a specially shielded room adjoining the P3 control room. The contents of this tape can be transferred on-line into the DDP 224 ORION computer system in Building R. 1.

The analysis of the data can be divided into three stages:-

1. On-line monitoring programme, NEDY. This programme assists the experimenters in detecting electronic failures in the experimental equipment. It scans each event for omissions and obvious inconsistencies in the data. When a serious fault is detected, a message will be transmitted via the DDP 224 to a typewriter in the P3 control room.

2. Partial Analysis, GRISLY. Events from a certain period of data taking will be analysed in ORION and selected histograms accumulated. This will assist the experimenters in assessing the results being obtained and so enable them to make suitable adjustments, i. e., to beam momentum, etc. Four of these histograms will be transmitted to the P3 control room via the DDP 224 and displayed on a memory oscilloscope.

3. Full data analysis. The Atlas computer will be used for the full data analysis.

The data will be collected when NIMROD commences 7 GeV operation.

Experiment 10

Imperial College,
Rutherford Laboratory.

A Measurement of the Partial Width for the Decay $\phi^o \rightarrow e^+ + e^-$

During the late Spring and Summer of 1965, the new ϕ1 beam line was set up and tested. This beam is to be used to look for ϕ^o-meson production in the reaction $\pi^- + p \rightarrow n + \phi^o$ and then to perform a branching ratio experiment on the reaction $\phi^o \rightarrow e^+ + e^-$ which will be similar to the completed experiment on $\omega \rightarrow e^+ + e^-$.

No data could be taken since the NIMROD operating energy was too low, but it is hoped to run the first part of this experiment (ϕ^o-cross-section measurement) early in 1966. The cross-section for this process is known to be small and the group will initially be looking for the $\phi^o \to K^+ + K^-$ decay. In outline, the method is as follows: $\pi^- + p \to n + \phi^o$ interactions will be selected where the neutron is accompanied by a "missing mass" close to that of the ϕ^o-meson, by means of a time of flight technique. The K^+K^- particles will be detected and measured in spark chambers behind the hydrogen target. Measurement of their ranges in lead plates and their angles of emission should enable the ϕ^o-meson to be identified with great certainty.

Experiment 11

Imperial College,
Rutherford Laboratory.

A Measurement of the Width of the η and a Search for the S^o Meson

During the 2 GeV and 3.7 GeV running, the ϕ1 beam was used for two measurements. First, the reaction $\pi^- + p \to n + \eta$ was investigated and a measurement of the 'η' width, which is expected to establish an upper limit about a factor of two better than the current limit, is being analysed. Second, the apparatus was used to look for the S^o-meson recently reported. By surrounding the hydrogen target with veto-counters and looking at neutron time of flight spectra, it was hoped that the presence of S^o would be detected. Analysis of a 4-day run to look for the S^o-meson is in progress.

Experiment 12

Oxford University.

A Study of the Leptonic Decay Modes of K^+ Mesons.

The decay modes of the K^+ meson with which the experiment is concerned are:

$$K^+ \to e^+ + \pi^o + \nu$$
$$\mu^+ + \pi^o + \nu$$
$$e^+ + \nu$$

The first two modes are relatively common, and account for roughly 8% of all K^+ decays. The purpose of the experiment is to measure the μ^+ polarisation and the distribution of the energies of the e^+ or μ^+ and the π^o. Such measurements will make possible an investigation of the structure of the interaction in relation to unitary symmetry models of the weak decay processes. They should also provide information on two further problems:

1. Are the μ^+ and the e^+ coupled in identical ways to systems containing strange particles?

2. Is the decay interaction time-reversal invariant?

If the process is time-reversal invariant, the electron resulting from the decay of the μ^+ should be symmetrically distributed with respect to the plane defined by the μ^+ and π^o in the K^+ rest frame.

The third decay mode is rare, and is predicted to account for 1.6 x 10^{-5} of all K^+ decays. It is proposed to attempt a measurement of this rate which is important in relation to the structure of the weak decay process and to problem (1).

The K^+ mesons are produced in a target placed in the extracted proton beam. They are defined in momentum and separated from π^+ and protons by a system of quadrupole and bending magnets and a region of transverse electric field. The K^+ are brought to rest in a small spark chamber constructed from beryllium plates, and the momentum of the e^+ or μ^+ is measured by a bending magnet and a system of sonic spark chambers, and recorded on magnetic tape. The $\mu^+ \rightarrow e^+$ decay and the gamma-rays from the π^0 are detected by visual spark chambers.

In 1965, it was possible to set up the beam and the counter electronics by virtue of the 2 GeV protons in the extracted proton beam. The backgrounds caused by residual π^+ in the secondary beam have been extensively studied.

Experiment 13

Birmingham University,
Oxford University,
Rutherford Laboratory.

K^- Nucleon Total Cross-Section from 750 to 2500 MeV/c.

The motivation for this experiment was to look for structure in K^- nucleon total cross-sections. A peak is known to exist at about 1 GeV/c, and it is proposed to investigate this more fully, since there are some indications that there might be two or more peaks as yet unresolved. Structure is to be expected at higher energies, if one believed the predictions of the SU(3) symmetry group Cross-sections will be measured to 1% accuracy. Pion cross-sections will be measured simultaneously to higher accuracies.

The experimental details are similar to experiment 6, except that various combinations of five Cerenkov counters are to be used for identifying K^- particles.

Experiment 14

A. E. R. E., Bristol University,
CERN, Oxford University,
Rutherford Laboratory.

A Study of the Decay of the K^0_L Meson into Two Neutral Pions

This experiment was supplementary to experiment 5, and was set up at the CERN PS machine. The rate of decay $K^0_L \rightarrow 2\pi^0$, compared to that of $K^0_L \rightarrow \pi^+ + \pi^-$, depends upon possible theoretical explanations of CP violation in the interaction. It is important therefore to establish that this decay mode does in fact, occur and to measure its absolute rate. The two neutral pions into which the K^0_L may decay each gave rise to two gammas and the experiment consisted in detecting these individual gammas and measuring their energies. This was done by a large system of scintillation counters, and visual spark chambers (figure 17). The gammas materialised in

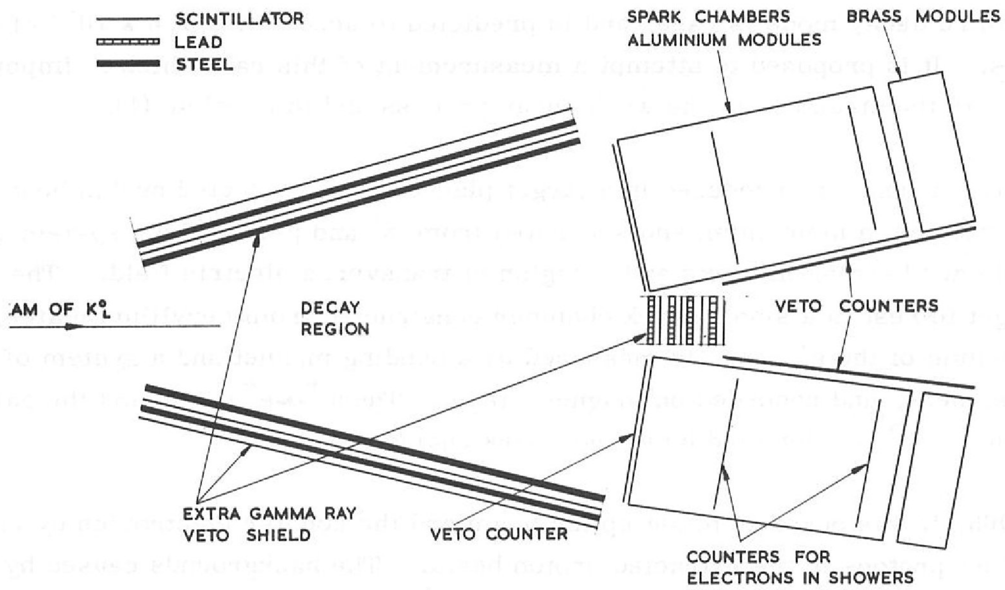


Figure 17. A schematic diagram of the apparatus used to detect the π^o π^o of the K^o_L

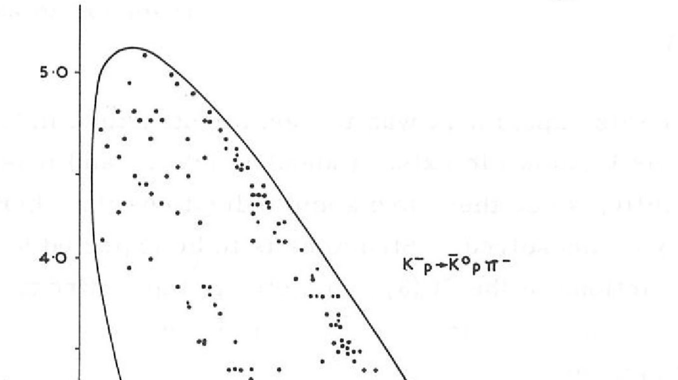


Figure 19. A Dalitz Plot Showing the Diagonal Band for the K*(1408)

the chambers and their directions in space were determined by photographing two orthogonal views. The gamma energies were determined by counting the individual sparks in the chambers. The problems lay in resolving the four gammas arising from the $2\pi^o$ mode from the much larger background of four gamma events from the normal $3\pi^o$ decay of K^o_L, where two out of the six possible gammas had escaped detection in the system. An important part of the apparatus comprised a large number of anti-coincidence counters (figure 18), which were disposed to detect as efficiently as possible the spare gammas from the $3\pi^o$, thereby reducing the trigger rate of the spark chambers to a usable level.

Some 200,000 pictures are required. About one third of these consist of events containing four gammas, and of these only about 1 in 1000 might be $K^o_L \rightarrow 2\pi^o$. An absolute calibration of the apparatus was made by measuring the rate of regeneration of $K^o_S(K^o_1)$ by K^o_L mesons in graphite and detecting the four gammas from the normal decay $K^o_S \rightarrow \pi^o + \pi^o$. Events of this type have been resolved satisfactorily (by hand analysis) and indicate that the equipment was functioning according to expectations.

Experiment 15

University College London,
University of Wisconsin,
L. R. L. Berkeley.

A Study of Ke_4 Decays

The aim was to collect 300 examples of the Ke_4 decay mode of the K^+- meson: $K^+ \rightarrow e^+ + \pi^+ + \pi^- + \nu$. This sample will represent four times the current world statistics and because of the small branching ratio involved stopping 12 million K^+-mesons. The interest in this decay scheme centres on the fact that it is unique in providing the only known situation where the interaction between two pions may be studied without interference from other strongly interacting particles. An analysis of angular correlations among the four decay products leads to an estimate of the difference between the S and P wave phase shifts in low energy $\pi\pi$ scattering; a parameter of great importance for testing various model-dependent theories.

The heavy liquid bubble chamber is ideally suited for performing this experiment as its short radiation length induce the electron to radiate and curl up in characteristic fashion. It thus allows one to instantly distinguish the Ke_4 from the π-decay which occurs with over 1000 times the frequency.

Because of the NIMROD breakdown, CERN generously offered to have the experiment transferred to their laboratory. The run was entirely successful. 575,000 pictures were taken containing the desired number of stopping K^+-mesons, and analysis of the film has started.

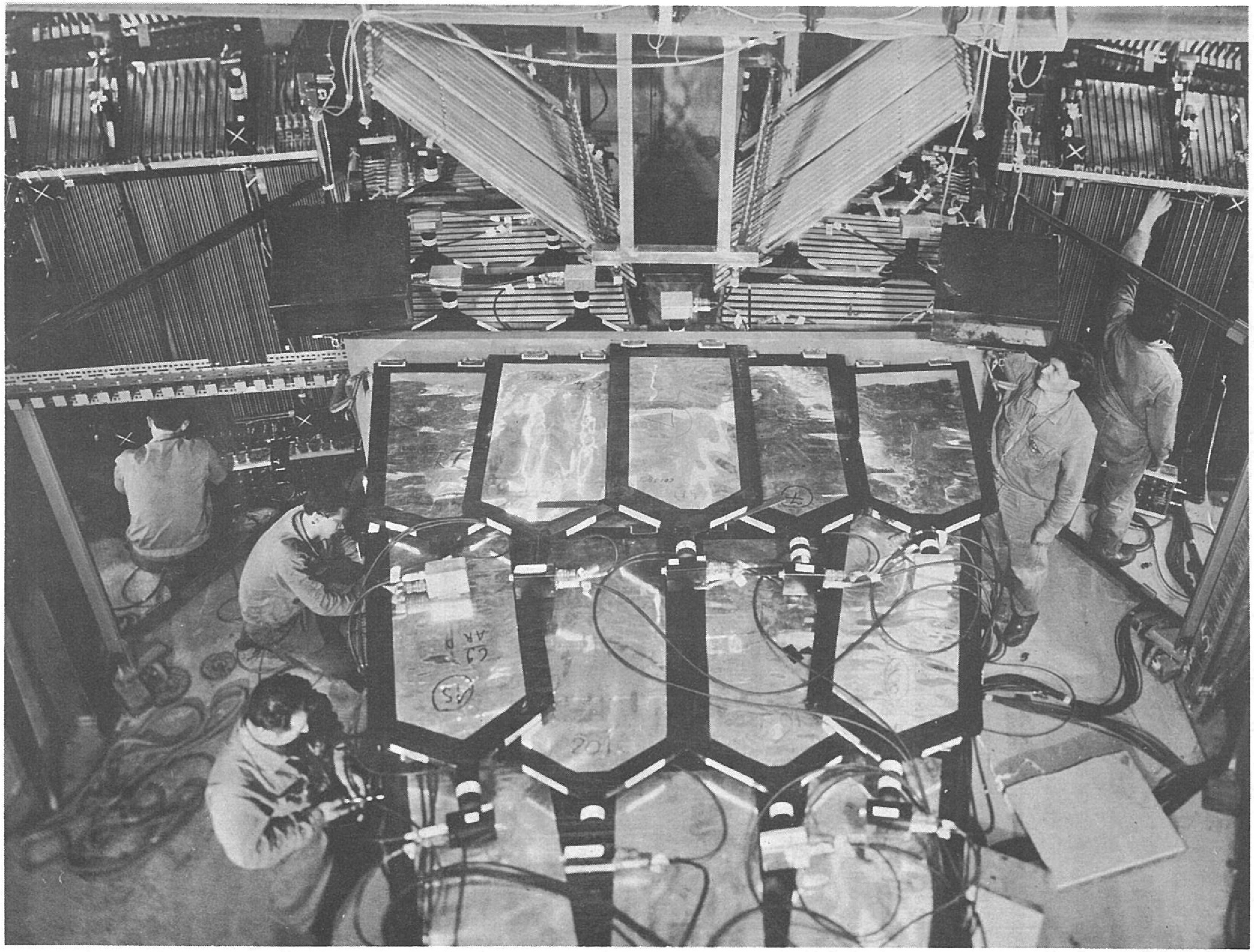


Figure 18. Part of the Anti-coincidence Shield and Spark Chambers from the $K_L^o \to \pi^o \pi^o$ Experiment. N. B. There are three real and two reflected men in the photograph

Experiment 16

Birmingham University,
Glasgow University, Rutherford Laboratory,
Oxford University, Imperial College,
Max Planck Institute Munich.

A Study of K^--p Interactions at 3.5 and 6.0 GeV/c.

The outstanding achievement of these experiments was the discovery of a new K* resonance of mass 1408 MeV, and a determination of its spin, I-spin and decay branching ratios. The K* (1408) can be shown to belong to a nonet of mesons with spin and parity assignment 2^+, in accordance with an SU3 classifications of particles. Figure 19 shows the new resonance as a diagonal band of points on a Dalitz plot of $Mass^2(p\pi)$ versus $Mass^2(K^op)$.

Other results of interest concerned a possible new hyperon resonance $Y^*_o(1645)$, but the result for the parity of a nearby resonance Y*(1660), in conflict with other experiments, as well as the branching ratios for the decay of the latter resonance, suggest that indeed there is more than one resonance in this mass region and detailed experiments will be needed to analyse the situation fully. Analyses of the production mechanisms of many two body final states were made, and in particular the production of both the K*(890) and K*(1408) were shown to occur via π and ω exchange. Preliminary results obtained at 6 GeV/c similarly show peripheral exchange processes to be completely dominating resonance production at this energy.

Also in the 6 GeV/c run, a good example of a Ω^- particle was found.

The film for both exposures was obtained at CERN, using the Saclay 80 cm and the British National 150 cm Bubble Chambers.

Experiment 17

Ecole Polytechnique,
Saclay, Rutherford Laboratory.

An Experiment to Study the Decay of the η Meson.

300,000 pictures have been obtained so far with the Saclay chamber at NIMROD, the aim being to look for violation of charge conjugation, C, in both the decays:

$$\eta^o \rightarrow \pi^+ + \pi^- + \gamma \quad (1)$$

$$\eta^o \rightarrow \pi^+ + \pi^- + \pi^o \quad (2)$$

It has been suggested that C violation of strongly interacting particles in electromagnetic decays may explain the CP violation observed in K^o decay, and at the same time indicate that our definitions of charge conjugation, parity and time reversal invariance must be reconsidered. This is then, an experiment of fundamental importance to physics, and it is intended to analyse several thousand decays of types (1) and (2) to obtain a definite answer as to whether or not these decays satisfy C.

Experiment 18

Rutherford Laboratory, Saclay.

A Study of K^--p Interactions in the Range 1.5 - 2.0 GeV/c.

Pictures will be taken when NIMROD returns to 7 GeV operation.

Experiment 19

Birmingham University,
Glasgow University,
Imperial College.

A Study of K^--d Interactions in the Range 1.5 - 2.0 GeV/c.

Both of these experiments are being performed in the K1 beam at NIMROD using the Saclay chamber. Their aim is to investigate the several Y* resonance states which are believed to occur in this momentum range, corresponding to Y* mass 2.0 - 2.2 GeV/c^2. Measurements of masses, widths, decay modes and deduction of the spins and parities of these states will allow one to perform a detailed test of the current classification of the fundamental particles.

Electronics Group

Standard Equipment

The first phase of the programme to provide the standard electronic equipment has been completed. The amount of equipment available, some bought commercially, some developed and supplied by A. E. R. E. and some developed and manufactured through the Laboratory is shown in the following table.

UNITS	QUANTITY	REMARKS
High voltage supplies for photomultiplier	50	3.5 KV, total current 1.5 A
High voltage distribution units for photomultiplier	100	To supply 500 photomultipliers
2000 series shelf units	700	A. E. R. E.
2000 series power supplies	750	A. E. R. E.
2000 series scalers	450	A. E. R. E.
Scaler read out machines	8	A. E. R. E.
Various 2000 series units	200	A. E. R. E.
Dual Discriminators	230	Rutherford Laboratory
Fan-out Units	200	Rutherford Laboratory
Coincidence Units	190	Rutherford Laboratory
Delay boxes	350	Rutherford Laboratory
Various RL units	300	Rutherford Laboratory

Development of Standard Equipment

The second round of counter experiments on NIMROD showed the need for a new approach to instrumentation. A new system of electronic units was designed to meet the needs of much larger counter experiments and to utilise efficiently the higher beam current of the accelerator.

These units can process the signals from photomultipliers at peak rates of 200 megapulses per second with unit delays of one nanosecond. These units, really better described as elements, are based on the ideas of computer logic circuits rather than on the ideas of discriminators, coincidence units and so on. They are particularly suitable for use in counter hodoscope arrays which usually use a large amount of electronic equipment.

The high rate capability of the elements make it possible to use electronic means for separating minority components from intense mixed beams. The small logic delay simplifies the processing of hodoscope information in which several depths of logic may be necessary before arriving at a decision as to whether an event is good or bad.

Over five hundred of these elements are assembled in an experimental system (K 7) and much operational experience will be obtained in the following few months. Other systems are being designed and constructed and should be in operation in the autumn of 1966.

Wire Spark Chambers

Electronic circuits have been developed for use in a large wire spark chamber experiment (π 4). This will use 30, 000 wires arranged in 120 planes. Associated with each wire is a ferrite storage core. These are pulsed in groups of 32 to read out the information relating to the position of the particle. As it is difficult to distribute the high current (1 Amp.) pulses required for this operation 960 pulse drivers are used, mounted adjacent to the storage cores. An electronic scanning system is used to search for any information stored in the cores and convert this to a digital representation for final computer processing.

All the circuits for this work are manufactured and tested. A small system of 10 planes has been assembled and is undergoing laboratory tests.

Special Developments

Many special units have been developed to keep pace with the increasing use of high speed data acquisition equipment. These usually involve circuits for handling digital data at rates of around one megacycle per second. Integrated circuits are used almost entirely for this application. These are as cheap as discreet element circuits and their performance exceeds all but the most elaborate special circuit.

Units that we have made in this way include a magnetic tape deck control unit, a binary coded decimal to binary converter and a digital buffer for a display system. Such units may contain up to two hundred integrated circuit elements, a total of three hundred gates. Construction of such units in previously conventional ways would have taken much more design, development and manufacturing time.

The use of these circuits is backed by a standard range of printed circuits, power supplies and chassis units. In the field of special digital instrumentation this results in significantly more output per man.

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Imperial College.

NIMROD DIVISION

At the beginning of the period of this report, NIMROD had just reached its design intensity of 10^{12} protons per pulse at 7 GeV. In February 1965, with the machine normally operating at 1.3×10^{12} p.p.p., there was a catastrophic failure of one of the alternators of the main magnet power supply which prevented further running using the alternators until November. During this period the machine was run direct from the public supply grid up to energies of 2 GeV with a pulse repetition rate of 10 pulses per minute which is about half the normal pulse rate using the alternators. The running at 2 GeV proved useful not only for synchrotron development but also for setting up and taking data on particle physics experiments. Following the repair of one of the alternators, running at high energies became possible late in November.

The effectiveness of using NIMROD for particle physics research was increased by improving the reliability of operation of the many components of the accelerator, by increasing the accelerated proton beam intensity and also by developing new and more efficient techniques for the utilisation of the accelerated protons.

New components were developed for transporting and analysing particles into beams for use by high energy physicists. The first electrostatic velocity separators to be used at NIMROD were installed and used in a beam line. The first polarised proton target to be developed at this Laboratory was used successfully in a particle physics experiment.

As experiments were completed, the beam lines providing particles for them were removed and replaced by new beam lines and experimental equipment. The arrangements of beam lines were now more complicated and congestion in the main experimental hall gave cause for concern.

Synchrotron Operation

From September 1964 to February 1965, the method of operation was to work on a 3 - week cycle giving $10\frac{1}{2}$ days for high energy physics, $3\frac{1}{2}$ days for machine development and 7 days shutdown for maintenance and modifications.

Operation at 7 GeV for high energy physics was achieved for 1330 hours of the scheduled 1770 hours, an efficiency of 75%. During the period of running at 2 GeV while the alternators were being repaired, more time was given to machine development, especially of the extraction system. About 1040 hours of 2 GeV operation were obtained from 1170 hours scheduled for high energy physics, an efficiency of 89%. One alternator was ready for use in November, and the machine was operated for high energy physics in December. During the 2 GeV operation, accelerated proton intensities of 1.4×10^{12} p.p.p. were achieved readily; intensities up to 1.8×10^{12} p.p.p. were seen occasionally.

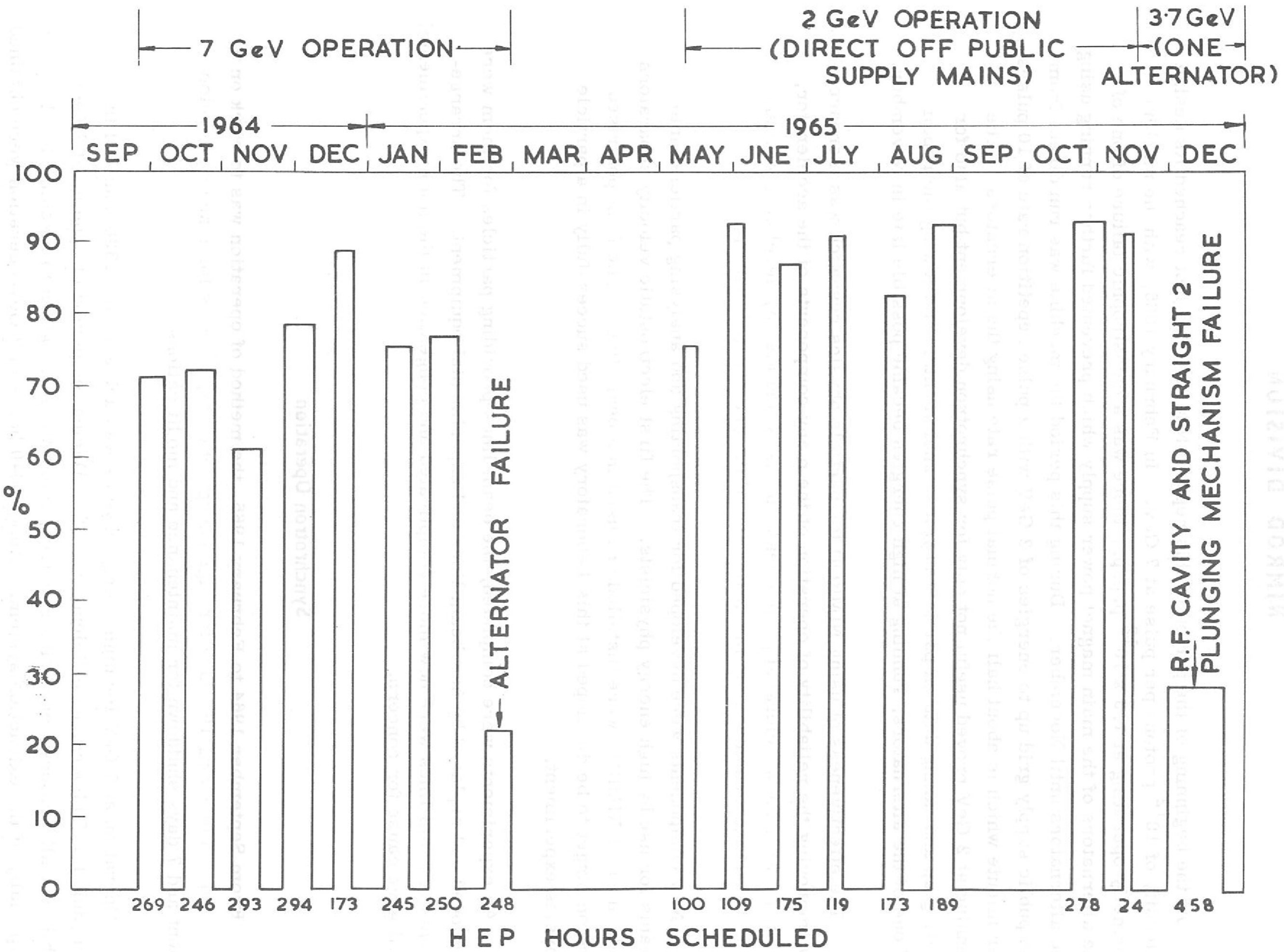


Figure 20. NIMROD operating hours for high energy physics
Efficiency = (time available/time scheduled) x 100

Injector

The standard operating current of the 15 MeV linac injector remained at 18 m A with a pulse length of 400 μ s. Higher currents up to 25 mA had been available from the injector for machine physics studies but at this level conditions in the linac became critical. Only one ion source, of the modified Thoneman r. f. type, was used throughout this period.

Magnet Power Supply

During this period the power supply plant operated for about 2700 hours and produced about 4×10^6 pulses at high current level. During the 2 GeV running the converter plant only was operated and produced about 1.5×10^6 pulses.

Equipment Reliability

The worst failure was, of course, that of one of the magnet power supply alternators. The primary cause was failure of a rotor pole end plate caused by fretting fatigue. The broken pole then damaged the stator of the alternator. Further cracks were found in pole end plates of both alternators and both had to be removed from service. The damaged stator was returned to the manufacturer's works for rewinding. In conjunction with the manufacturer, the Laboratory investigated the failure of the pole end plates and used the results of stress analysis and tests on full sized models to redesign the end plates. The rotors were then rebuilt at the makers' works.

The problem of breakdown in the electrostatic inflector was gradually overcome, mainly by redesigning the insulators for the high voltage plate.

Much effort was put into the commissioning of the mechanisms for plunging the magnets of the extraction system. In December, the first high energy run after return of the alternator was terminated by the failure of a component which attaches the kicker magnet to the plunging mechanism; there was a consequent leak which let the main machine vacuum vessel up to air. After the magnet had been removed, a large vacuum leak was found in the insulator across the main r. f. cavity gap. The r. f. cavity was removed; the leaking insulator was found to be severely damaged presumably due to breakdown during the time when the machine vacuum failed. Interlocks would prevent this type of breakdown in future.

The table on page 49 shows the beam time lost due to faults in the various components of the machine.

Figure 21. The Nimrod main magnet power supply alternator set.

Causes of Lost Beam Time

System	Beam time lost as percentage of total scheduled running time. %
Injector system	3.45
Inflector system including magnets and electrostatic element	3.4
Magnet system including pole face windings and peaking strips	0.35
Vacuum system. Main machine and linac	1.35
Synchrotron r.f. system	5.55 (1.35 if major failure of cavity subtracted.)
Targets and target mechanisms	1.20
Extraction plunging mechanisms and power supplies	4.8 (0.65 if major failure of magnet subtracted)
Main magnet power supply	0.15 (neglecting the major failure)
Cooling water systems	0.5

Note: The major failures of the r.f. cavity and plunging mechanism were concurrent.

Synchrotron Development

Ion Sources and D.C. Accelerators

The emittance of the R.F. ion source, which is capable of delivering 150mA at 40 kV, was carefully studied using a pin-hole plate with two methods of beam detection, photographic and electrical. Results showed that the emittance of a 40mA beam at 10 kV was typically 39 cm mradians, the beam usually having a complicated structure in phase space. Magnetic analysis indicated that different parts of this space contained the same proportion of the three hydrogen ion species (as well as some heavy ions and a substantial neutral component). The variation of emittance with time during a pulse was found to be small. As a result of all these measurements, it was thought that the emittance of the beam was mostly determined by the shape of the plasma boundary in the source. In this work, use was made of

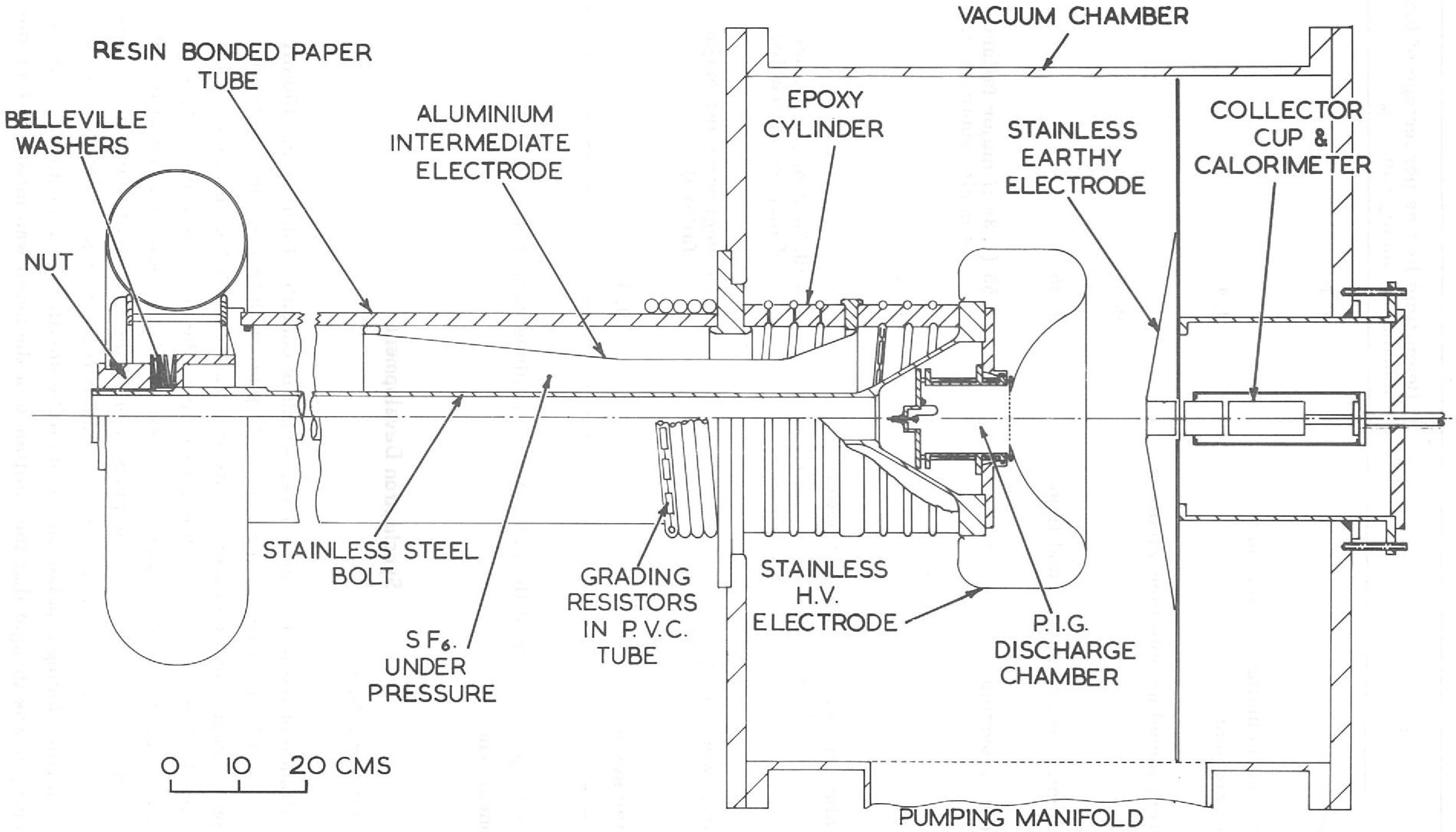


Figure 22. Cross-section of experimental single gap ion gun.

a combined calorimeter and collector cup which had been developed for reliable measurement of beam currents.

High current ion sources of the duoplasmatron and P. I. G. types were also under study. In these sources, ions were drawn from a large area of comparatively low density plasma. It was hoped to produce pulsed beam currents of about one ampere.

A novel design of 600 KeV D. C. accelerator was also under development. This incorporated a P. I. G. (or alternatively a duoplasmatron) source. The ion beam was accelerated to its final energy across a single gap which was specially shaped to focus the ion beam. The conventional focussing electrodes and long accelerating column were thus eliminated and it was hoped that the aberrations they introduced into the beam would be avoided. In preliminary experiments, a pulsed beam of 200mA had been accelerated to 300 kV.

Injector

The main development work was still directed towards improving reliability. A major improvement was the installation of a standby 600 kV generator for the pre-injector. The normal unscreened cable outlet from the SAMES generator was adapted to give an open termination so that changing over from one to the other of the two installed generators was simply a matter of moving the link between the generator and storage capacitor. The open termination system was provided by means of a potential grading resistor coiled around a length of the cable. This eliminated earlier trouble from cable discharges.

A new linac field level stabilizer, employing an RS1041 triode as a shunt control valve, was built to enable the linac to operate at higher beam currents. This equipment would be installed early in 1967.

A proton beam position measuring system was being developed for the 15 MeV beam. It consisted of pairs of loops, mounted in the flight-tube, which coupled with the r. f. component of the beam magnetic field. The system should greatly simplify the adjustment of beam alignment and it was hoped eventually to provide closed loop control of the beam steering magnets.

An interesting behaviour of the ion-source was observed, which might have an application in increasing the injector output current should this be required. A particular combination of source gas pressure and r. f. excitation was found at which there was a sudden increase in extracted current. This beam current was also found to have a smaller emittance, so that the percentage of it accepted by the linac also increased. With such a beam, short current pulses of 46mA were obtained at 15 MeV. Unfortunately it is not always possible to produce this mode of operation of the ion source.

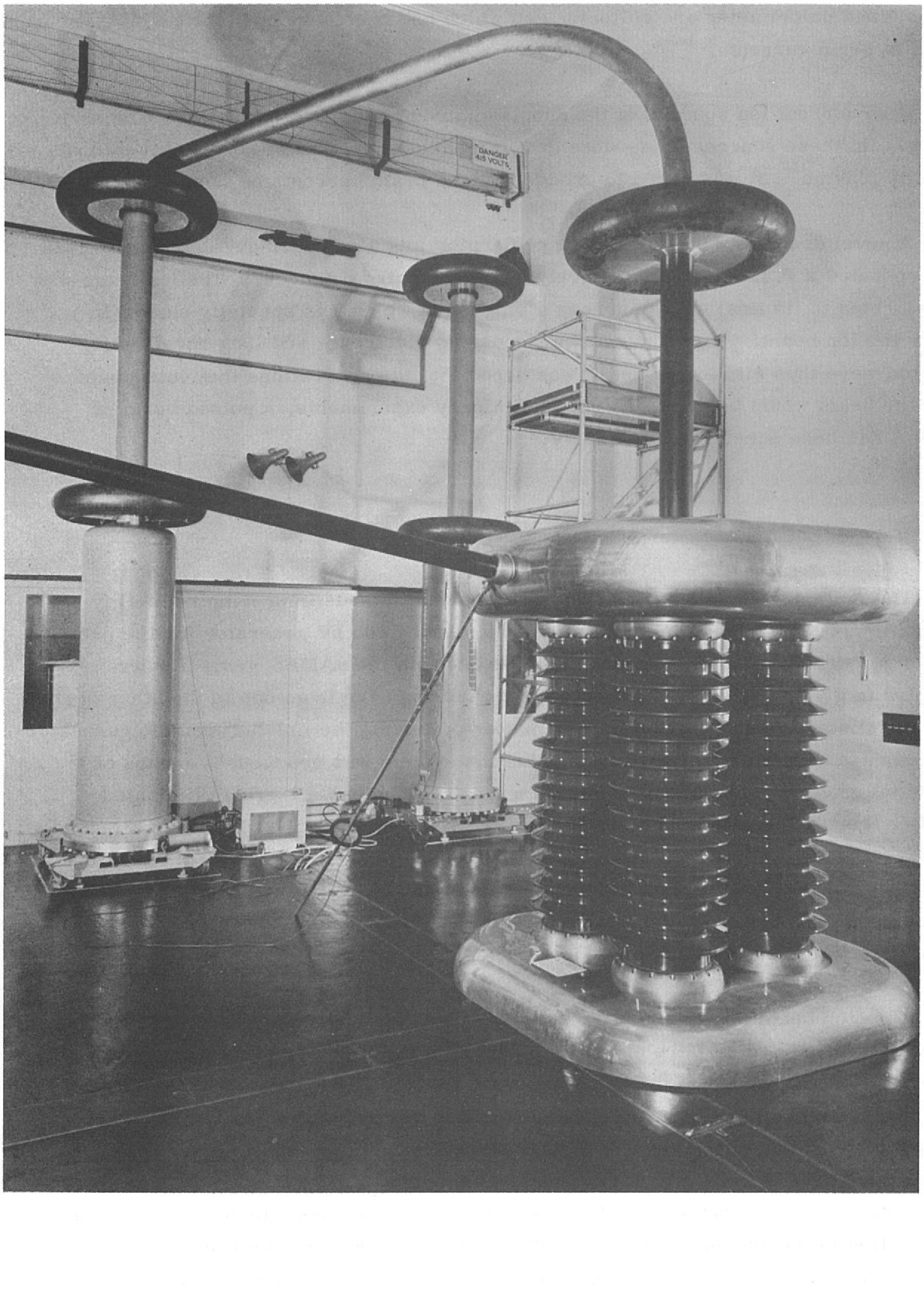


Figure 23. The two 600 kV generators for the preinjector are shown in the background with the new type of termination. Rapid changeover of generators is achieved by swinging the top arm from one to the other.

Injection Studies

Beam injection into the synchrotron was investigated in some detail. Although the range of control of the beam focussing system should be capable of producing the desired match into the synchrotron, there was some evidence that the circulating beam in the synchrotron was vertically mismatched. Beam emittance measurements, made within the synchrotron at the output end of the inflector, confirmed that there was a bad match and also showed that adjustment of the focussing controls had little effect. It was thought that there must be a significant amount of vertical focussing by the inflector magnets, whereas it had been assumed they were afocal in the vertical plane. Some additional emittance measuring equipment was to be installed to investiage this effect further.

A beam 'diluter', installed in the 15 MeV beam flight-tube, was used to investigate space charge effects in the injected beam. The beam diluter was simply a plate with a large number of holes in it, which allowed the injected beam current to be changed without affecting the beam emittance. This showed that with normal injection conditions there was a significant loss of beam due to space charge effects during the r.f. trapping of the beam in the synchrotron. The effect was most pronounced when the debuncher was on, which probably explains why there was little advantage to be gained in using the debuncher. The longitudinal space charge effect, which manifests itself in the form of bunching of the protons before the r.f. is switched on, was much more pronounced with the debuncher working.

The optimum trapped beam in NIMROD is obtained with a rate of change of magnetic field (dB/dt) at injection of 8 kG/s. Studies of the acceptance of the machine at lower dB/dt using a short injected pulse of protons indicated that increased injected charge should be available. Equipment was installed to enable a measurement to be made of the total circulating charge at the time when the accelerating voltage was switched on.

Acceleration Studies

Investigations of space-charge effects during the first 5 ms of acceleration, when a considerable amount of beam was lost, took the form of a study of bunch shape, and of the measurement of the coherent vertical betatron wavelengths for different beam intensities. These showed that the magnitude of space-charge effects was such that one would not expect them to limit the amount of beam accelerated.

The phenomenon of coherent vertical beam instability was observed and studied. The mechanism of the instability was well understood, and a damping device was under construction. At current beam intensities (1.5×10^{12} p.p.p.) slight steering adjustments are enough to remove the instability. Coherent radial oscillations were also observed, their frequency suggesting association with a $Q_R = 2/3$ resonance; but why the oscillations should be coherent was not understood.

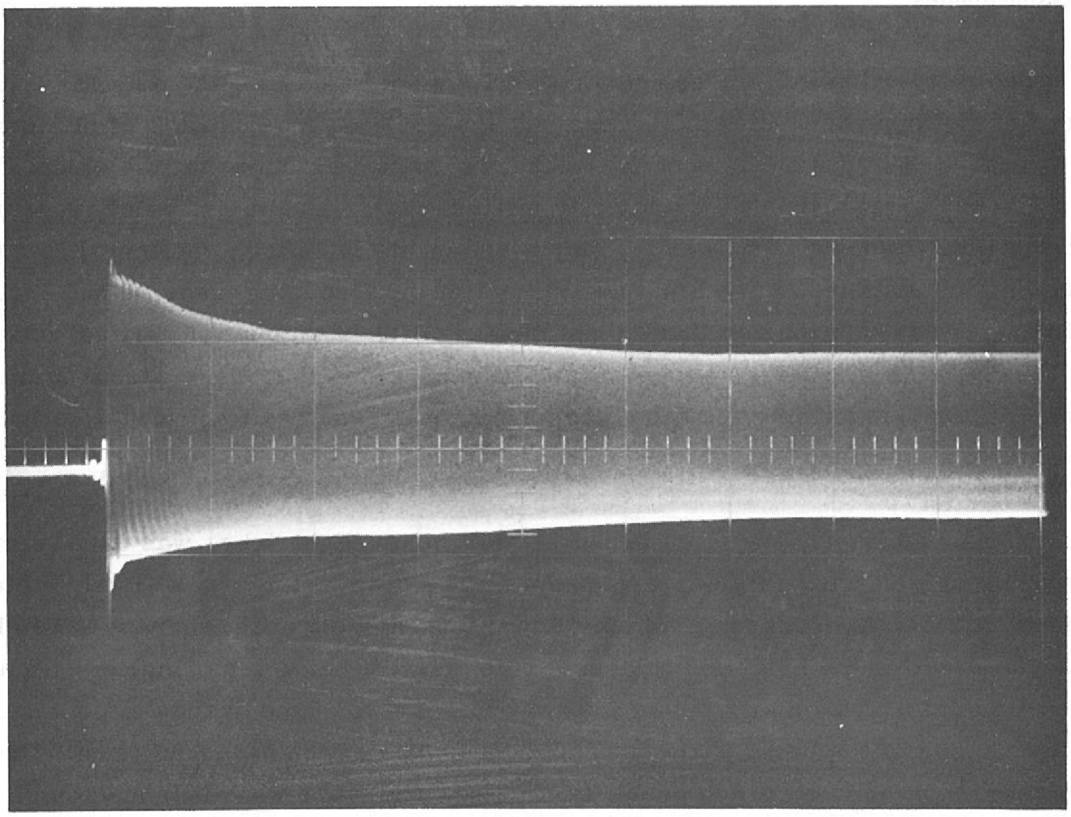


Figure 24. Signal from beam induction electrodes showing beam intensity loss at the beginning of the accelerating cycle. There is normally no loss of beam after the 18 ms. part of the cycle shown. The beam intensity at 18 ms. is about 1.5 x 10^{12} protons.

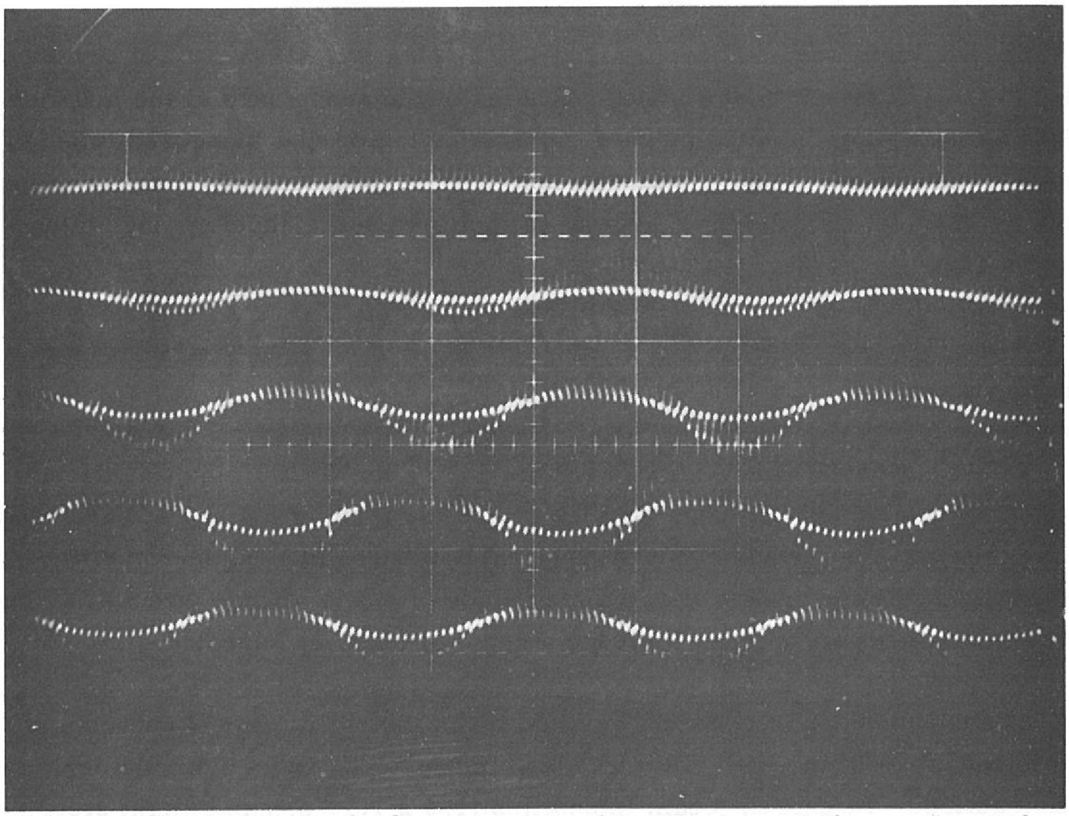


Figure 25. Build up of coherent vertical oscillations of the accelerated beam caused by the resistive wall instability. The successive traces are taken at 2 ms. intervals. Each small spike is the signal from one Nimrod bunch.

The radial betratron frequencies Q_R of the accelerated beam were measured at magnet gap fields up to 6 kG; Q_R was also measured as a function of radius at 5 kG as a prerequisite to extraction at 2 GeV. The results implied values of field gradient very close to those measured during the magnet field survey in 1962.

New pole face winding power supplies were installed to enable the magnetic median surface in the magnet gap to be varied at injection. An increase in accelerated beam of about 10% was achieved by raising the median plane, protons with large vertical betatron oscillation having been raised clear of the target mechanisms in the bottom of the vacuum vessel.

Magnet Power Supply

Twenty-five of the mercury arc convertors were fitted with redesigned anode and grid assemblies to reduce the number of arc-backs. The grid control units of the convertor plant were provided with means of controlling the magnet voltage to counteract the large transient depression of the magnet field caused by eddy current changes during flat-top. A prototype was also made of a redesigned grid control unit which would be at earth potential, unlike the present arrangement, and should thus facilitate plant investigation and modification.

Radiation Dosimetry

A comprehensive radiation dosimetry programme was continued to determine the expected useful life of the main vacuum vessels. The degradation in physical properties of samples of vessel materials irradiated with electrons and γ-rays were investigated. The measured doses of radiation received by the vessels led to an estimated life of the vessels of 7 to 12 years assuming NIMROD intensities of 2×10^{12} p.p.p. and existing methods of using the machine.

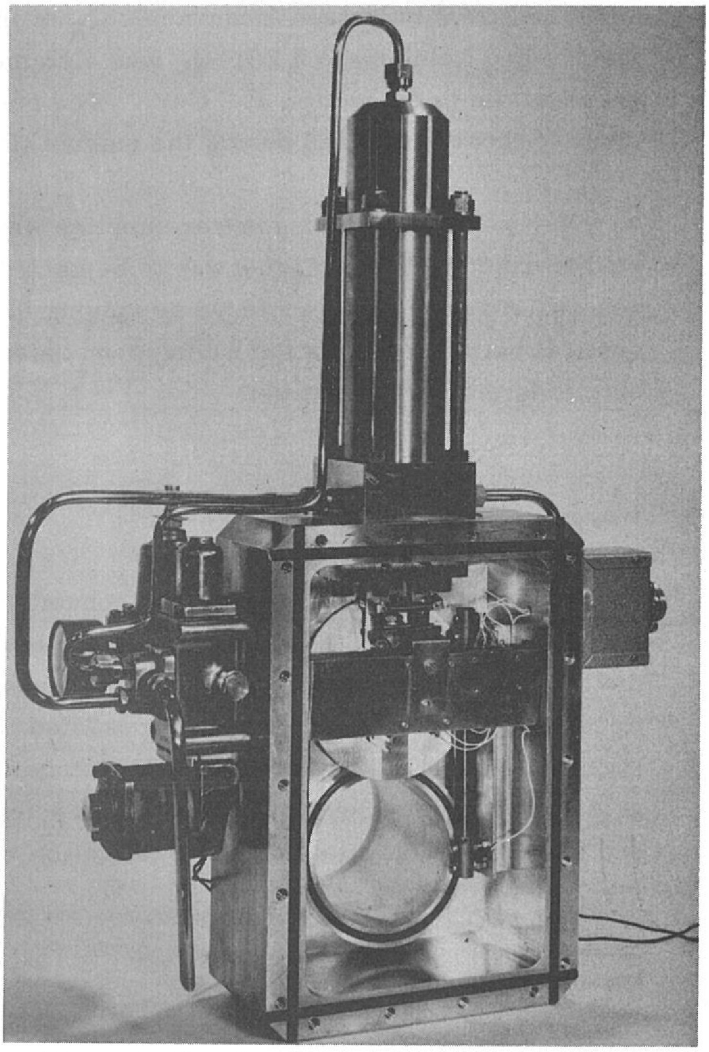
Vacuum Components

Methods of protecting the machine vacuum system against failure of attached systems, e.g. beam lines, were being continuously developed. The investigation of the properties of materials for use as thin windows in beam lines led to improved reliability. Fast shut-off valves were developed for use in conjunction with these windows.

Buildings

It had become obvious that it would be impossible to retain access for larger equipment through the main shield wall between the machine and the main experimental

Figure 26. Fast shut-off valve for 4 inch diameter pipe. This valve is pneumatically operated and clamped and may be reset remotely. The closure time is about 20 ms.



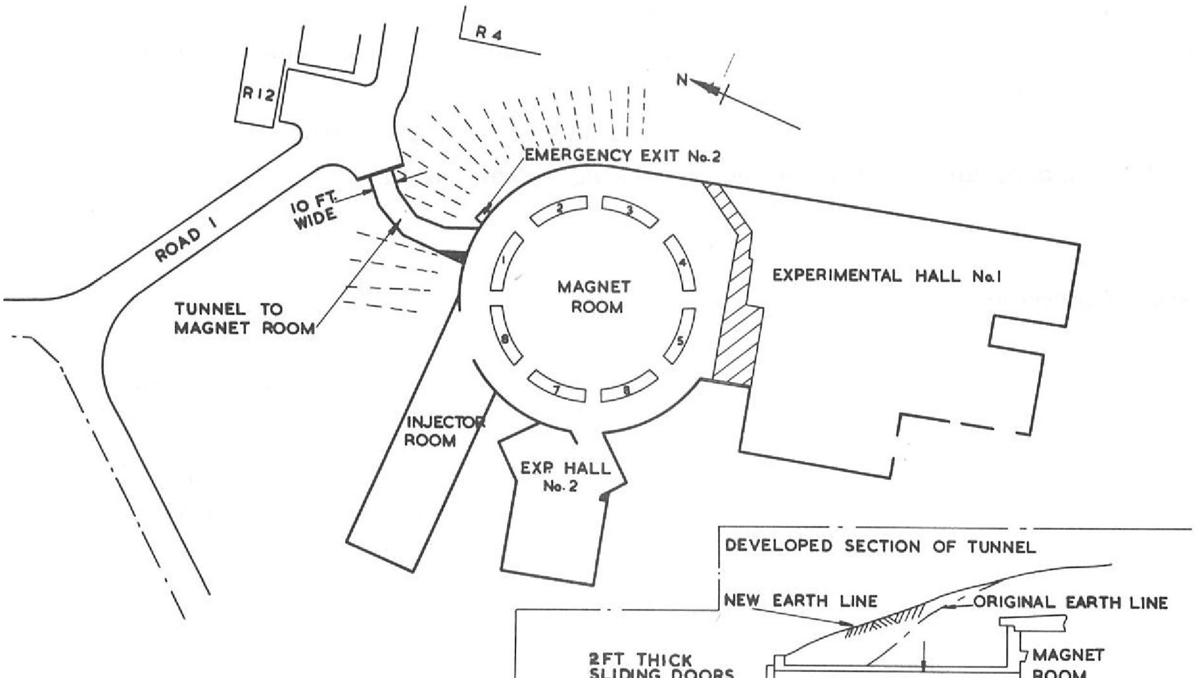


Figure 27. Layout of Nimrod and Experimental Areas showing new North Tunnel Access to magnet room

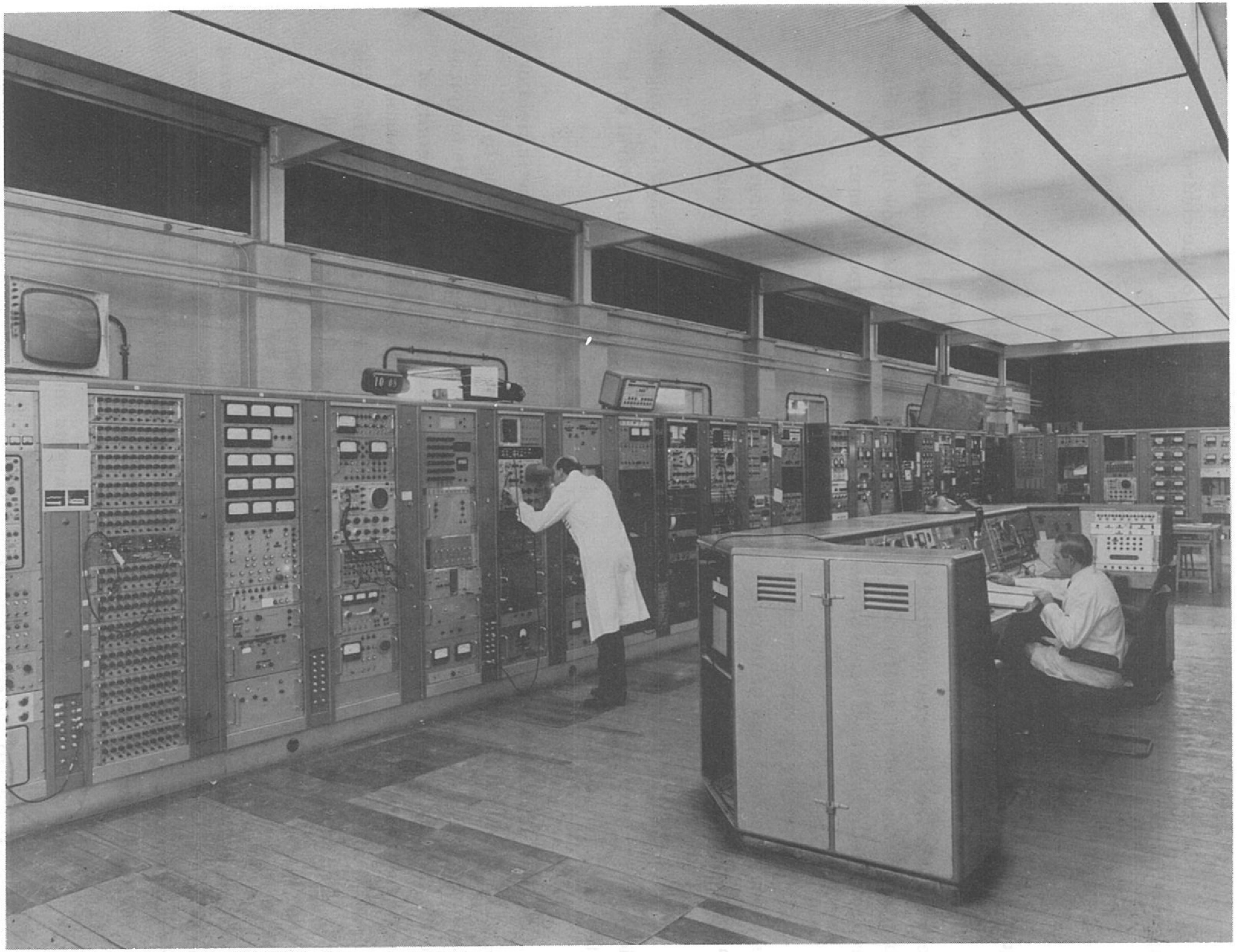


Figure 28. Part of the Nimrod main control room showing the new control equipment in the background on the right hand side of the photograph.

area. A new access tunnel, the 'North Tunnel', with a cross-section of roughly 10 feet square was therefore built and used as the main access for equipment into the magnet room.

The main control room was extended to allow installation of the control equipment for targetting and for the extracted proton beam.

Accelerated Beam Utilisation

Targetting

There are two main types of 'spill' on to targets in the machine. For 'counter' experiments a long (several hundred milliseconds) uniform spill is required; for bubble chambers a short spill (about 0.5 ms) is used. Techniques now in use enable sharing of the accelerated beam between several targets and experiments:

(1) For setting up experiments noise is fed into the r.f. system during the rising magnetic field part of the cycle to lose protons from r.f. trapping. These then move on to the target under the influence of the rising magnetic field.

(2) For bubble chambers, the phase of the accelerating r.f. voltage is changed rapidly during current rise; protons are lost rapidly from the r.f. and spiral on to the target to give a short spill.

(3) For counter experiments taking data, an almost constant magnetic field or flat-top is produced in the main magnet. Protons lost from r.f. trapping by switching off the r.f. or by changing the phase of the r.f. voltage are made to spiral on to the target over a period of several hundred milliseconds. The uniformity of the spill is determined mainly by the amount of ripple voltage on the main magnet supply. Work had continued on methods of reducing this ripple. The effective spill time is about half the total spill time of 300 ms. The protons could be shared between two targets during flat-top by varying their relative radial positions.

(4) A second bubble chamber spill is produced at the end of flat-top by steering some retained protons rapidly on to a target by manipulating the phase and frequency of the r.f. voltage. This had been especially useful in allowing the Saclay Bubble Chamber to take two pictures during each NIMROD pulse.

The mechanism for raising the internal targets into position was redesigned to give better reliability. A prototype of the new design was subjected to several million operations without failure and there was every indication that this experience would be repeated in mechanisms installed in the machine.

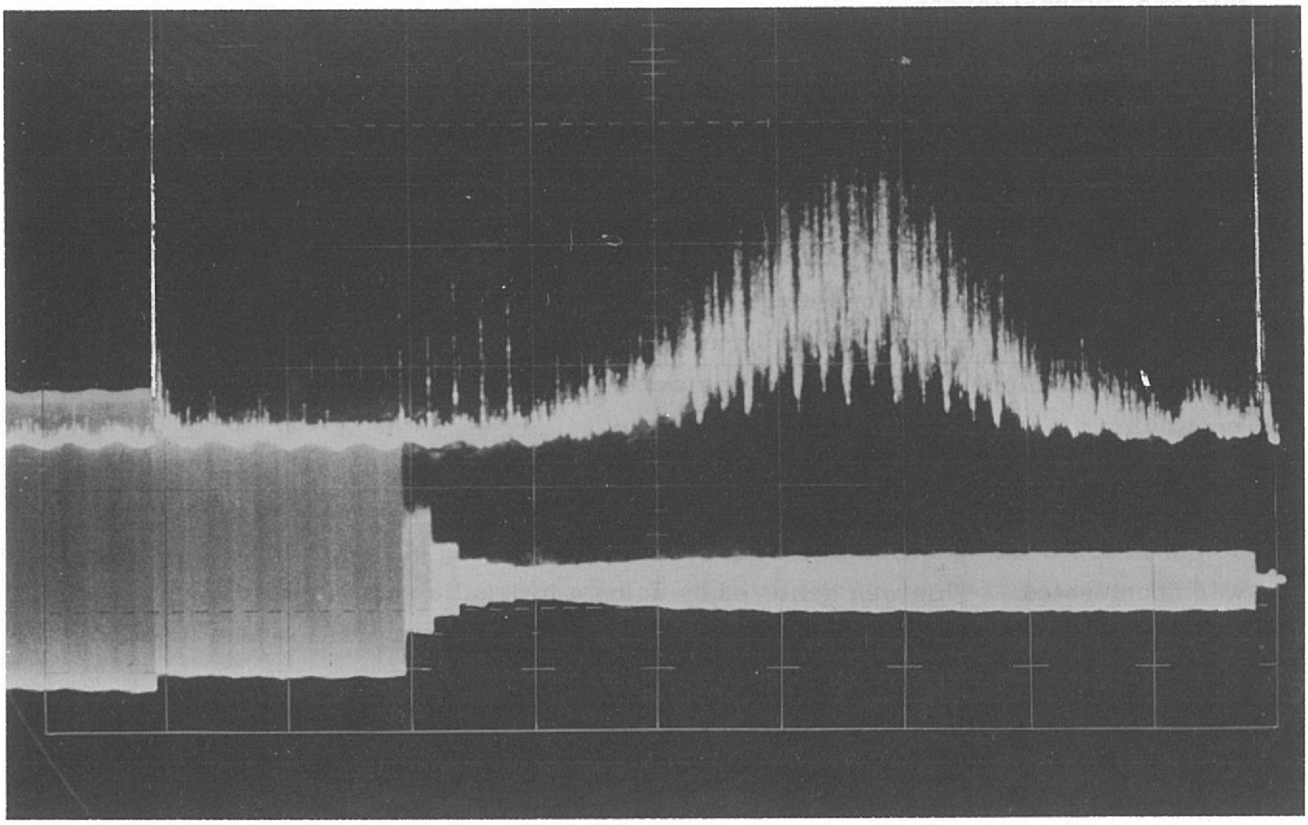


Figure 29. Sharing of accelerated beam. The upper trace shows a fast spill for a bubble chamber followed by a slow spill for one or two counter experiments followed by a second spill for the bubble chamber. The lower trace is the induction electrode signal showing beam intensity.

Extraction of the Accelerated Protons

The NIMROD extraction system uses an energy-loss target to direct the accelerated protons through a quadrupole focussing magnet to a deflector magnet. The latter kicks the protons into an external focussing channel and thence to a target in the experimental area. The current arrangement feeds two experiments (K4 and K6) from this one external target.

The system was tuned at 2 GeV and an extraction efficiency of 12% was obtained. Multiple scattering of the protons as they passed through the energy-loss target was one limit to the efficiency. Scattering is reduced with increasing energy so that an improvement might be expected at 7 GeV.

The orbits of the protons within the machine during the extraction process were studied using a computer programme (NIMDYM). Experimental studies of the paths of the protons in the machine were also made. These studies were continuing.

The extractor quadrupole and the kicker magnet (weight 1 ton) had to be moved 50 cm in 0.7 s into position following the radial shrinking of the proton beam as it was accelerated. This was achieved by using a hydraulic ram supplied by a variable delivery pump controlled electronically to obtain the correct position as a function of time.

Measurements of Particle Production

An experiment was completed which measured the differential production cross section of pions, kaons, and protons from a target in an external proton beam.

This was the first systematic study of particle yields at 7 GeV and provided accurate data which would be invaluable in design of secondary beams. Every precaution was taken to avoid uncertainties in the absolute value of the cross-section from which data at neighbouring energies were thought to suffer.

The measurements suggested the use of copper targets which could yield up to 80% more secondary particles than the lead and heavy metal targets previously used. In addition they confirmed that production at small angles is predominantly via N^* isobars.

Beam Transport Components

Magnets

By the end of 1965, there were 70 quadrupoles and 45 bending magnets available for beam lines at NIMROD.

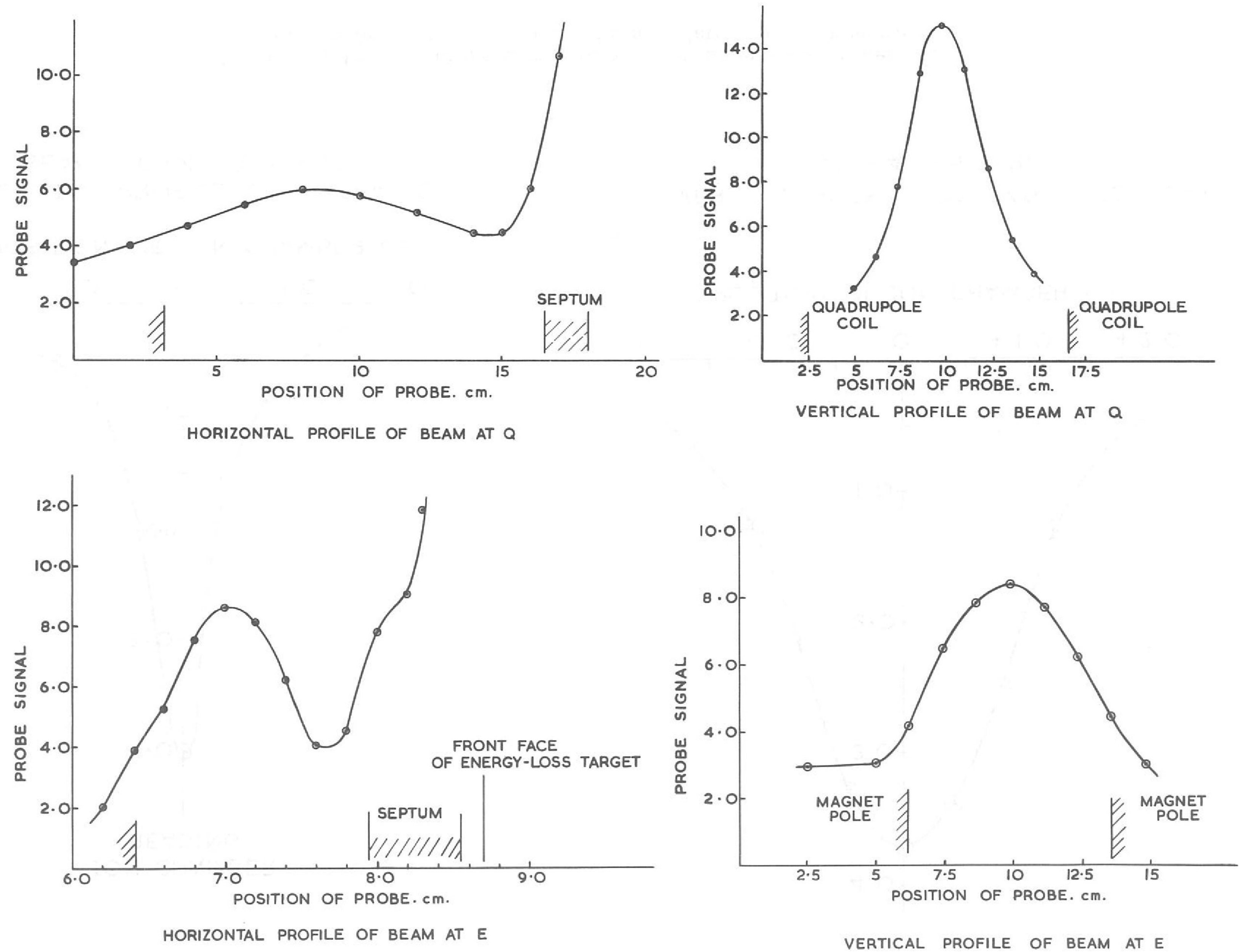


Figure 30. Profiles of proton beam in the synchrotron at entrance to the quadrupole, Q, and extractor magnet, E, during the extraction process. The probe used was a thin 'finger' of scintillator, the light from which was fed to a photomultiplier via a flexible light guide.

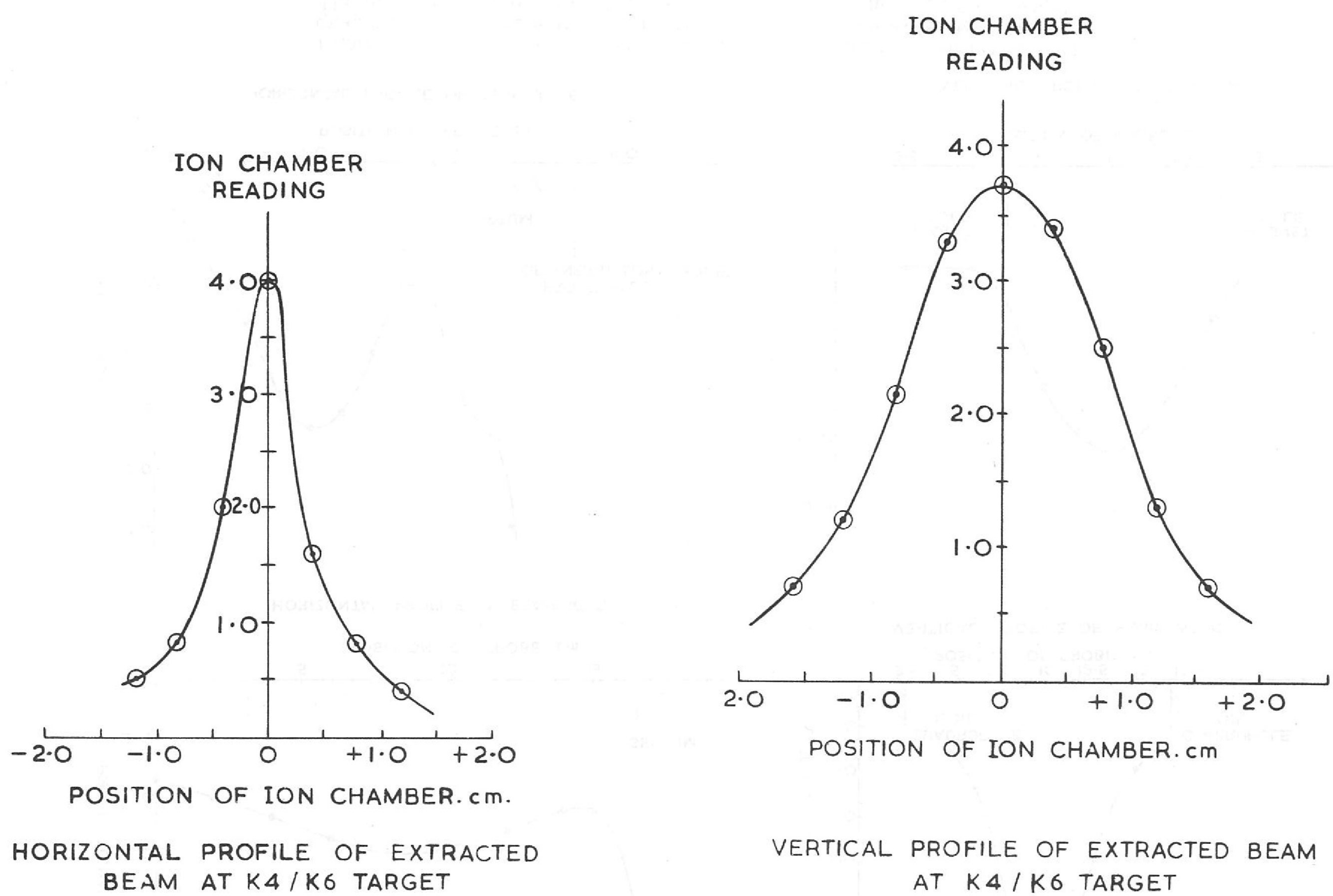


Figure 31. Profiles of the extracted beam at the external target. A strip ion chamber was used to obtain the relative beam intensities.

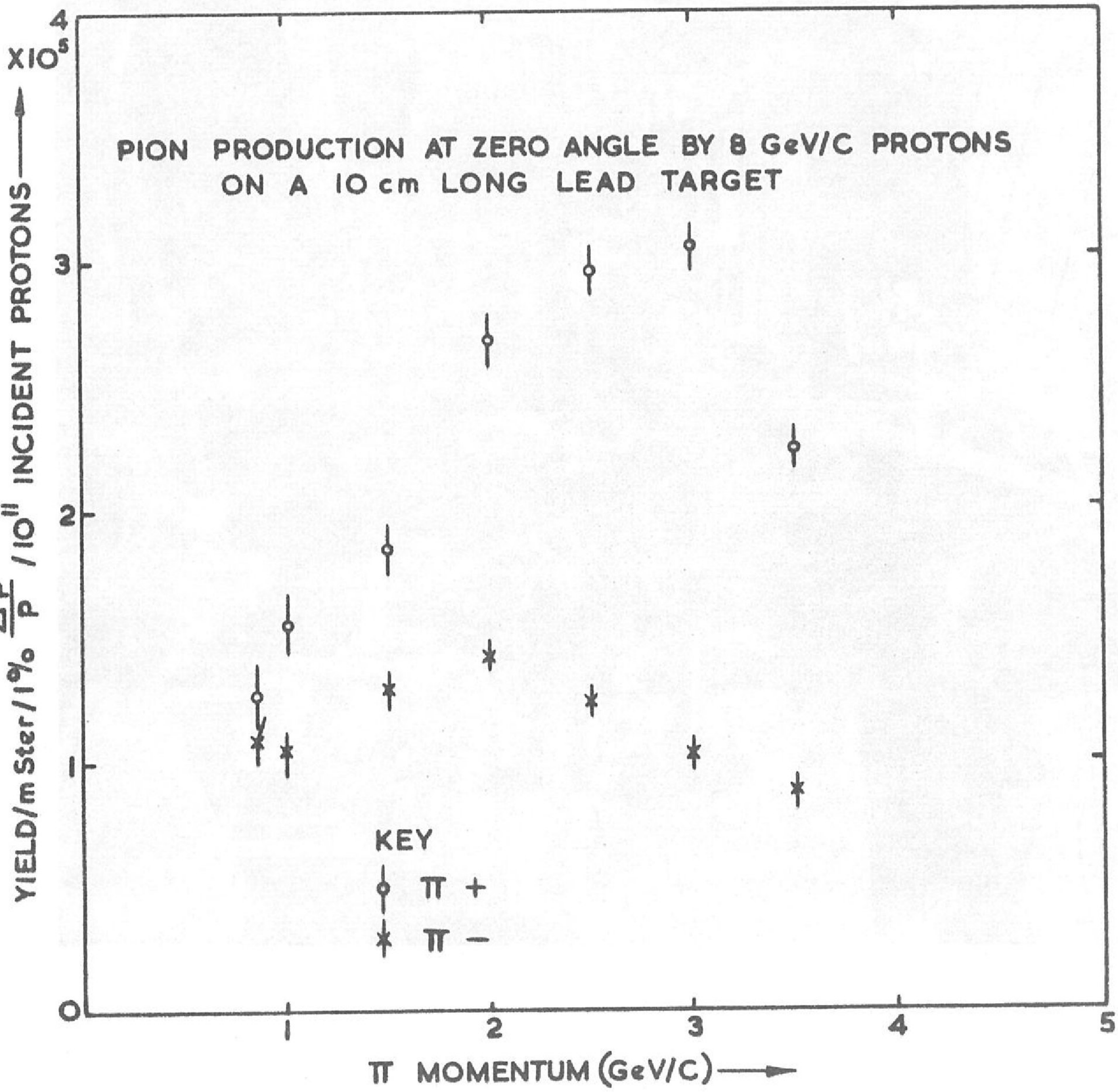


Figure 32. Some results of the yields experiment.

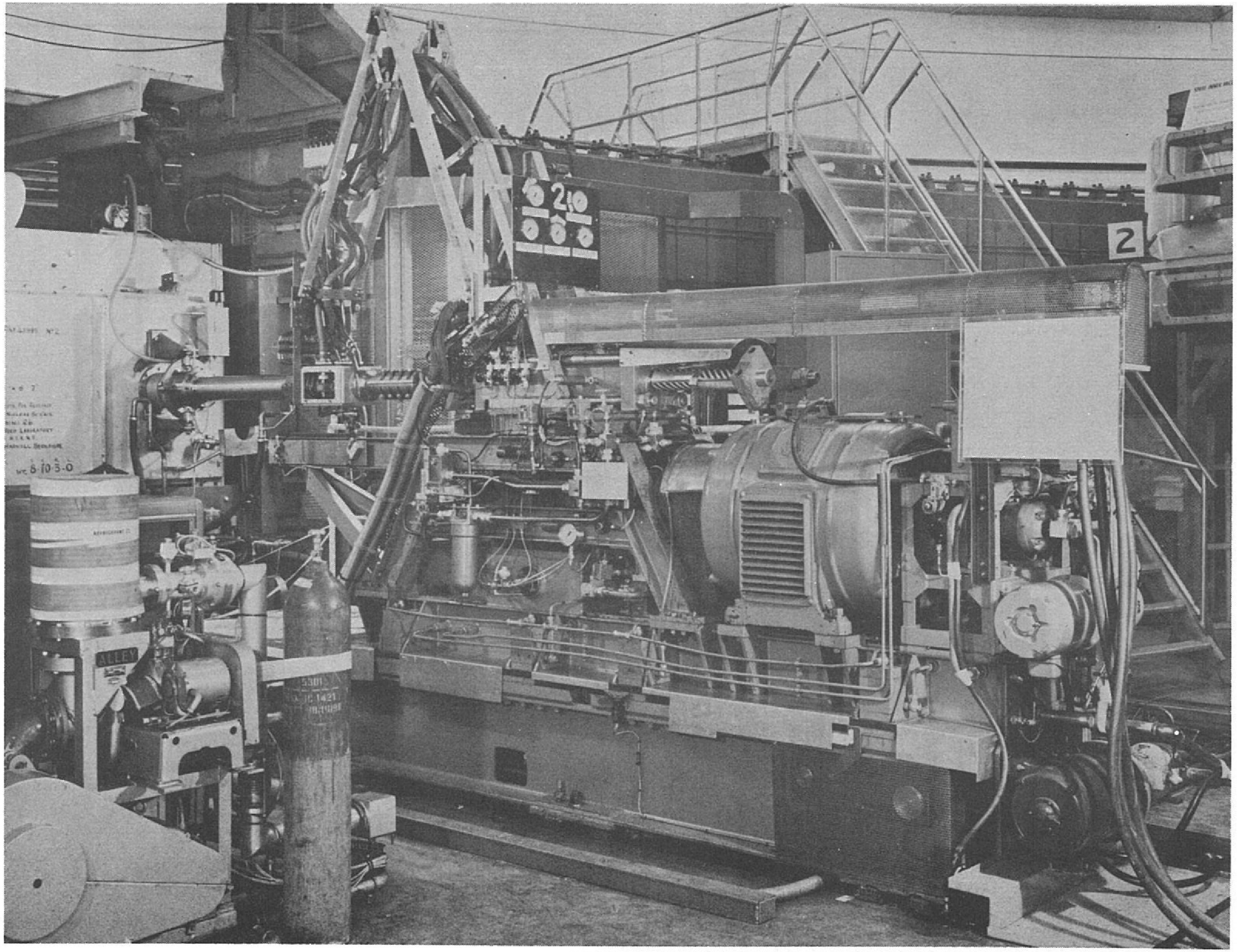


Figure 33. Mechanism for plunging extraction magnets.

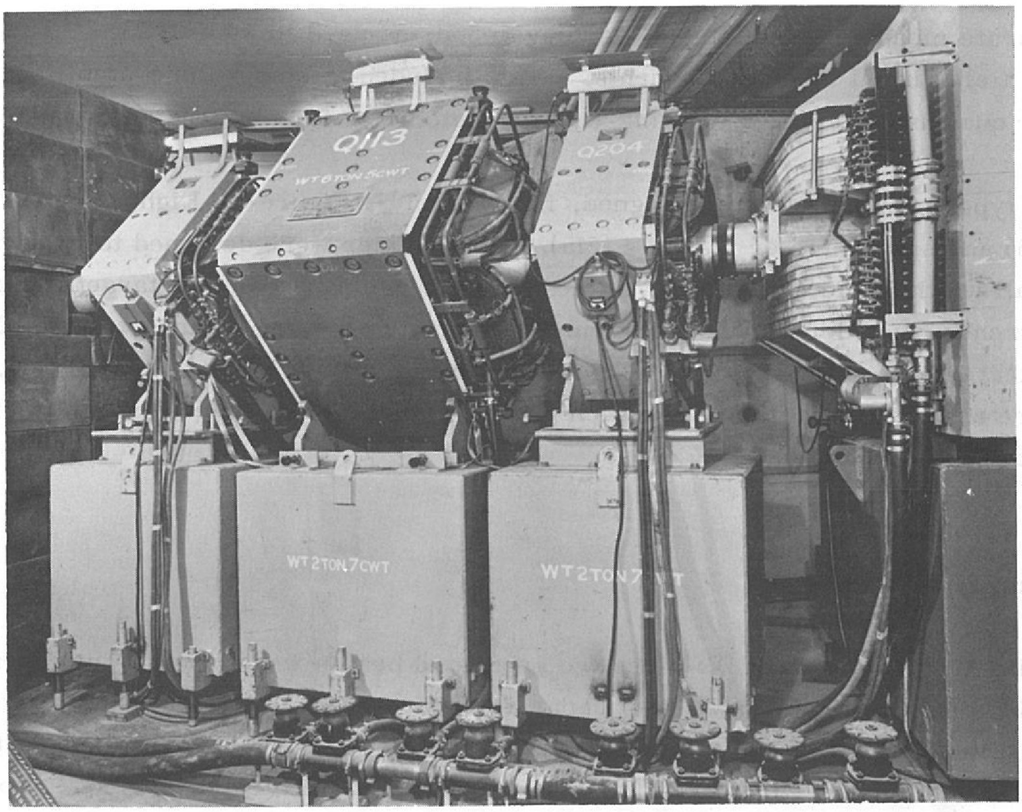


Figure 34. A section of beam line showing standard quadrupoles and part of a bending magnet

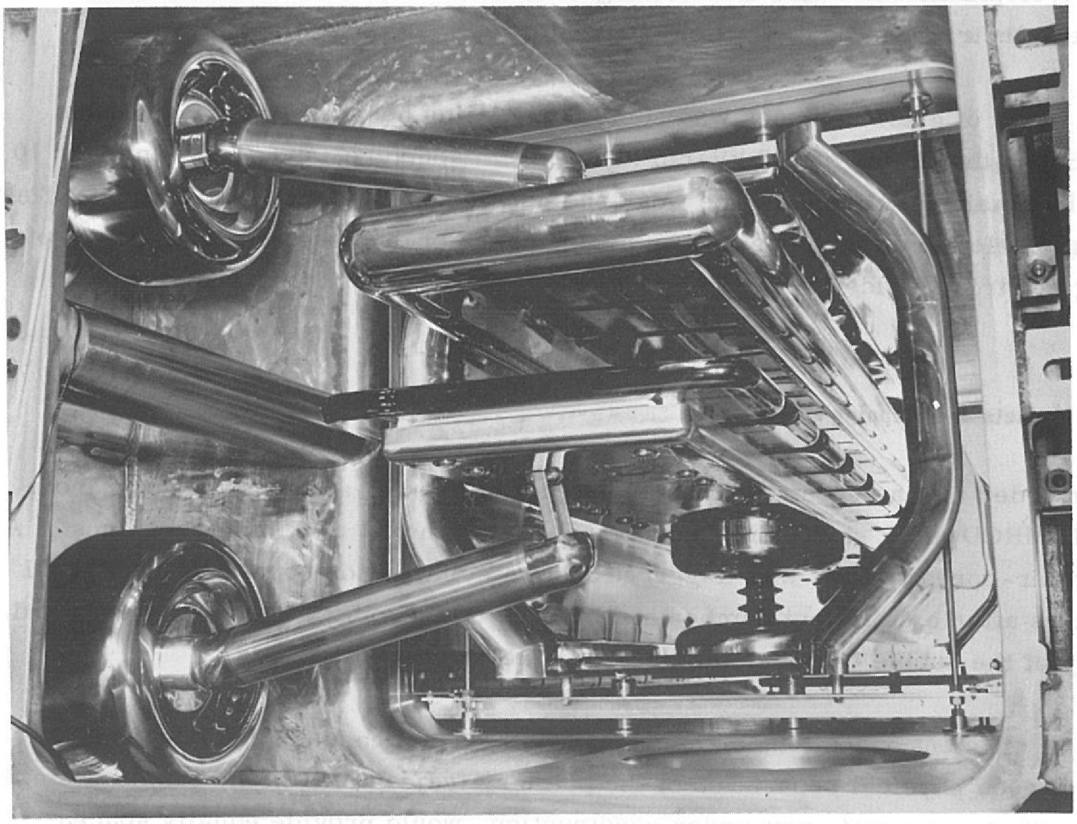


Figure 35. Internal view of electrostatic particle separator. A potential of 700 kilovolts is applied across the 10 cm gap between the stainless steel anode (top) and the heated glass cathode (bottom).

Accurate measuring equipment was developed and used to measure the magnetic fields in all these components. This included a temperature-stabilised Hall probe for quadrupoles, and a rotating-coil magnetometer for the bending magnets.

New types of magnet were designed, for example, 'Figure-of-Eight' quadrupoles (Q5) and spectrometer magnets (M5). The former were designed to minimise the overall width of the quadrupole, allowing closer packing near to a target. Six were currently on order. The spectrometer magnets provides a large volume of field so that larger solid angles are available for analysis of secondary particles. They were designed in 50 ton units which could be combined in several ways; four such units had been ordered.

D.C. Velocity Separators

During the year, NIMROD'S first two separated beams were brought into operation, K1 and K4. In K1, a total of 50 ft of separator operated at 50 kV/cm over a 10 cm aperture; in K4, 12 ft of separator operated at a voltage of 800 kV over gaps up to 20 cm. In both beams, the separators used stainless steel electrodes and 'lumped' magnetic fields at each end of a separation stage.

Development work included investigation of new electrode materials, and of crossed electric and magnetic field separators.

A study of glass cathodes was completed; using heated soda-glass, it was established that fields of 100 kV/cm over a 5 cm aperture, and 70 kV/cm over 10 cm could be obtained reliably. The work on superimposed electric and magnetic field separators led to an improvement in performance of these devices as a result of fitting electric shields to remove low electric field regions.

Shutter Magnets and Stepping Magnets

In order that a repeatable number of particles enter a bubble chamber from each NIMROD pulse, shutter magnets were used in the K1 and P3X beam lines. A pulsed air-cored magnet was triggered from a scintillation counter to deflect all particles after a sufficient number had entered the chamber. The efficiency and quality of the bubble chamber pictures was thereby improved.

For efficient operation, automatic scanning and measuring devices would require good physical separation of the primary trajectories in the bubble chamber. A 14-unit step-magnet, now under construction, would provide equally spaced trajectories, provided the intervals between particles always exceeded 12-13 μs, the resolution time of the device.

Superconducting Magnets

Superconductors offer the possibility of producing components with high magnetic fields more economically than in the past and the application of stabilization techniques should enable large superconducting magnets to be constructed and to work reliably.

In collaboration with the Applied Physics Division a thorough study was made of the stabilization of superconductors with particular attention to the improvement of overall current density which plays a crucial role in the design of beam transport magnets. A small solenoid was made as part of this programme. This was wound from stabilized tape made in the laboratory and produced a field of 40 kG in a two inch bore, working at a fully stable current density of 10^4 Amps/cm.^{2}

Work started on the design of the first operational magnet which will be a bending magnet, producing a transverse field of 50 kG over an aperture of 20 cm and a length 1.5 m. The magnet would be capable of deflecting the 7 GeV external proton beam through an angle of 15°.

Gas Cerenkov Counter

A differential gas Cerenkov counter was constructed based upon a design used at Brookhaven. It was intended for detection of Kaons of momentum greater than 1.5 GeV/c.

A ring of six photomultipliers grouped in coincidence detected Kaons, and pion counts were rejected by a further ring of photomultipliers which collected light from pions.

The rejection of the device could be as high as $1{:}10^5$ and additional pion detectors in the beam were therefore unnecessary.

Polarized Proton Targets

In a polarized proton 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.

Work on the first target to be built at the laboratory started in the middle of 1963. The target worked for the first time a year later and completed its first experiment (π 1), the determination of the parities of certain π p resonances early in 1965. This target was in the form of a cube, side 2.5 cm, of lanthanum magnesium nitrate ($La_2Mg_3(NO_3)_{12}24H_2O$) crystals in which one in 600 of the La^{3+} ions are

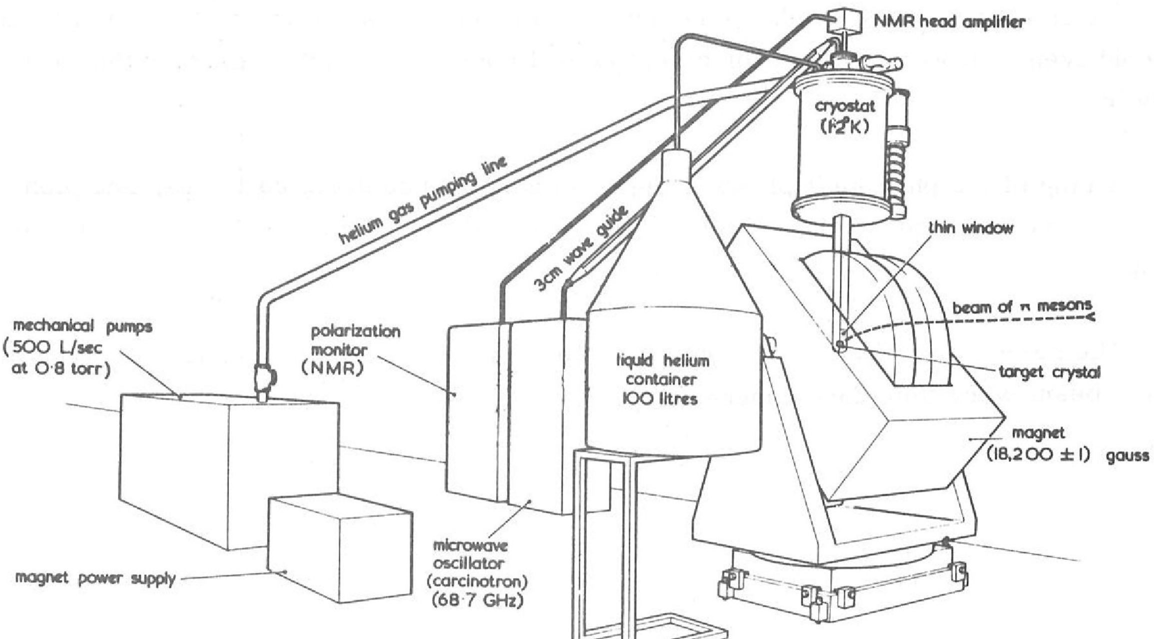


Figure 36. Schematic view of the first polarized target built at the Rutherford Laboratory in which the magnetic field was horizontal.

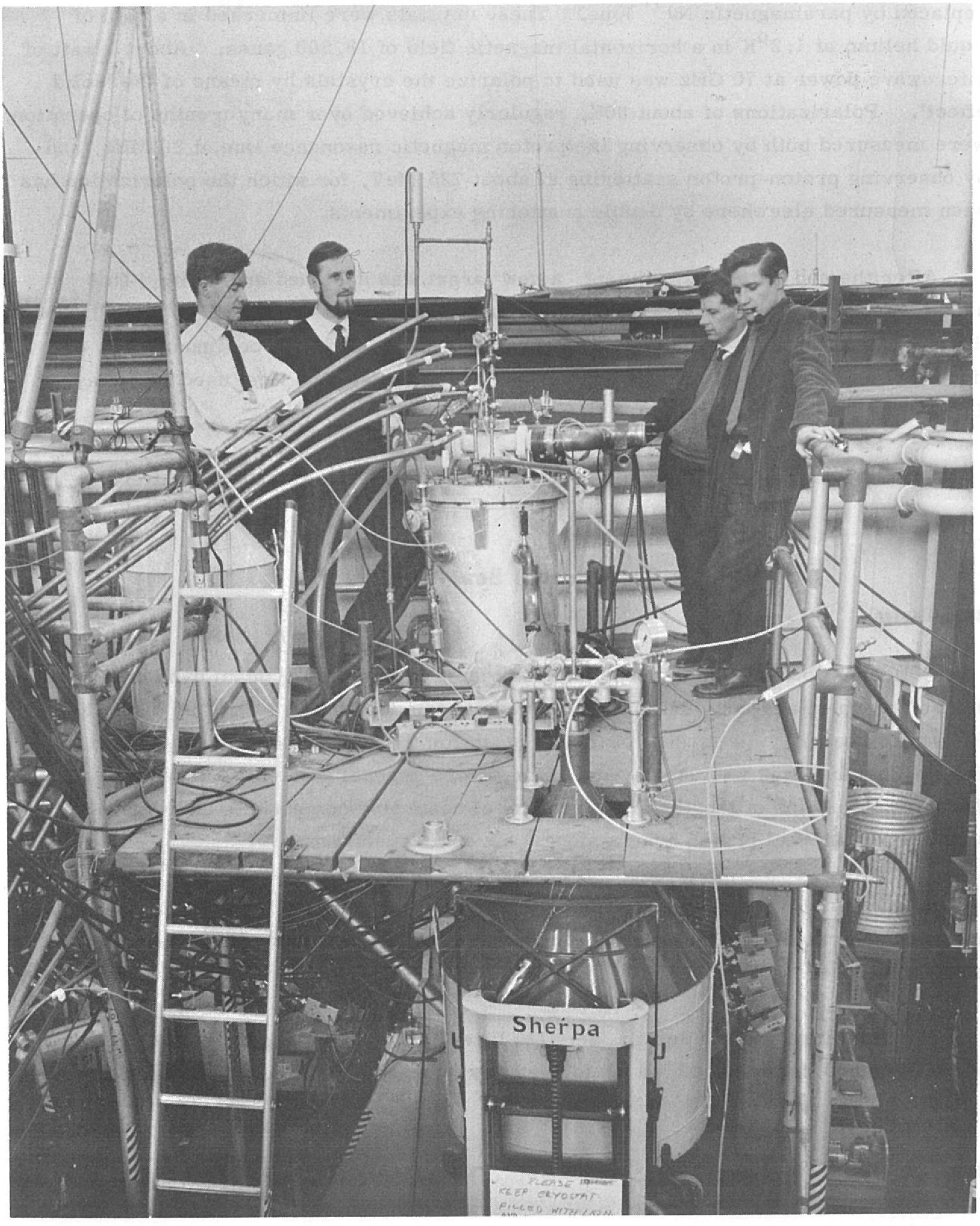


Figure 37. The First Rutherford Laboratory Polarised Proton Target

replaced by paramagnetic Nd^{3+} ions. These crystals were immersed in a bath of liquid helium at 1.2°K in a horizontal magnetic field of 18,500 gauss. About 1 watt of microwave power at 70 GHz was used to polarize the crystals by means of the 'solid effect'. Polarizations of about 60%, regularly achieved over many months of operation, were measured both by observing the proton magnetic resonance line at 80 MHz, and by observing proton-proton scattering at about 725 MeV, for which the polarization has been measured elsewhere by double scattering experiments.

After the end of this experiment, a new target was designed and built. This used target crystals of total length 7.5 cm and diameter 2.5 cm placed in a 'pod' at the end of a horizontal cryostat. The crystals were cooled by a continuous flow of liquid helium from a 100 litre reservoir, following the method first used at Saclay. The magnetic field was vertical.

This new target would be used in future experiments on πp and Kp scattering.

Experimental Beam Lines

Beam Design

Collaboration with high energy physics teams in the field of beam dynamics design continued and contributions were made to the design and setting up of the K1, P1 and K6 beams. The design of the K9 beam for the British National Hydrogen Bubble Chamber was well advanced. Also, more general studies were pursued of the optimum choice of lengths and strengths of beam line components and ways of sharing the external proton beam amongst several experiments.

A technique of trajectory plotting with scintillation counters was developed into a simple and rapid method of tuning single stage beams to obtain a minimum momentum bite.

After the fundamental design, detailed layout and engineering design of the beam lines and their associated equipment was necessary.

Beam Line Installation

The layout of beams at the beginning of the period is shown. (K1 was at an early stage of construction.) The main shield wall modifications for K1 were made during a machine shut-down period; the new arrangement of shielding was complicated by the inclusion of a 20 feet long electrostatic separator within the shielding. This separator and the 30 ft one in the same beam were the first to be used at NIMROD. During this time the Saclay 82 cm hydrogen bubble chamber was being commissioned by the French group. A large hydrogen-retention igloo was constructed around the chamber and the capacity of the hydrogen ventilation system was increased. Particles from NIMROD were used for setting up the beam, starting in

September 1964, and the chamber was operational in December.

The second large block of construction work was the removal of the P4 and P1* beams and the installation of the P6, P1, K4 and K6 complex for extracted beams. K4 and K6 took secondary particles from the same external target. These beams were heavily shielded to reduce the radiation levels expected from 2×10^{11} extracted protons at 7 GeV; about 5,000 tons of cast iron and concrete shielding were required. P6 was also an extracted beam but of lower intensity; a liquid hydrogen target was installed within its shielding and great care was taken with the safety precautions.

Commissioning of the Heavy Liquid Bubble Chamber continued until October 1965 and the P3 line was extended (P3X) to provide particles for this chamber.

In Experimental Hall 2 the beam lines K2 and $\pi 1$ were removed and replaced by $\phi 1$ with its liquid hydrogen target and K7 which uses a polarized proton target.

The increased number of components in the new arrangements required more power supplies. These could not be accommodated in the power supply building and had to be installed in or under the experimental area.

Figure 38. The magnet room end of the K1 beam line. Pions, kaons or protons are scattered from the target in the magnet at the right hand side of the photograph. After focussing and bending they pass through the steel shielding on the left hand side of the photograph to the first electrostatic separator buried in the shielding and thence to the experimental area.

Table. Characteristics of Beam Lines

Beam	Particle	Momentum GeV/c	$\frac{\Delta p}{p}$%	Intensity per 10^{12} protons	Experiments
K2	π^-	1.07 - 1.15	1	2.10^5	Two body decays of the ω^o meson
π 1	π^-	0.5 - 1.6	~9	$\leqslant 4.10^5$	Pion - proton differential cross-section and polarization measurements in the momentum region from 875 to 1579 MeV/c
P4	p	1.1 - 7.8	0.5	$\leqslant 4.10^4$	Proton - proton and proton-neutron total cross-section measurements
P1*	p(extracted)	2 - 7.8		5.10^{10}	Measurement of secondary particle yields
N2	K^o_2	1.5 - 5	-	4.10^4	A check on CP violation in K^o_2 decay
P3	π^-	1 - 4.5	$\leqslant 6$	1.2×10^5 at 2.5 GeV/c	A study of multipion resonances in $\pi^{\mp} + p \rightarrow \begin{cases} n + x \\ p + x \end{cases}$
π 2	π^-	1.6 - 2.8	1.5	8×10^3	Pion - proton differential elastic cross-section measurements near 2 GeV/c
K1	K^-(separated) also π^+, π^-, p	1.5 - 2.2	0.5	$15K^-$	Beam for Saclay B. C.
ϕ1	π^-	1.3 - 1.8	2	5×10^5 at central momentum	A measurement of the partial width of $\phi \rightarrow e^+ + e^-$

Beam	Particle	Momentum	$\frac{\Delta p}{p}$ %	Intensity per 10^{12} protons	Experiments
K7	π^-, K^-	0.6 - 2.5	±5	10^7 π^- } calculated yields 3×10^4 K^-) at 1 GeV/c.	K^- proton polarization measurements in the momentum range 700-1300 MeV/c
	π^+, K^+	uncertain yet.			
P6	p(extracted)	2 - 7.8	0.2	2×10^{10}	Proton - proton inelastic scattering measurements at various energies
P1	p(extracted)	2 - 7.8	0.2	$\leq 2 \times 10^{11}$	Main extracted proton beam on to external target for K4 and K6
K4	K^+	Stopping 0.7	±2	10^3 stopped per 2×10^{11} ext. target	A study of the leptonic decay modes of positive kaons
K6	π^-, K^- π^+, K^+	0.6 - 2.75	±0.5	π^- 1.5×10^5 at H_2 target per 2×10^{11} at ext. target K^- ~200 at H_2 target per 2×10^{11} at ext. target yields uncertain yet.	$K^\pm$ - nucleon total cross-section measurements in the range 0.6 - 2.5 GeV/c
P3X	π^+ (separated by degrader)	0.5 - 1.1	±0.25	~500 at 1 GeV/c	Beam for Heavy Liquid B. C.

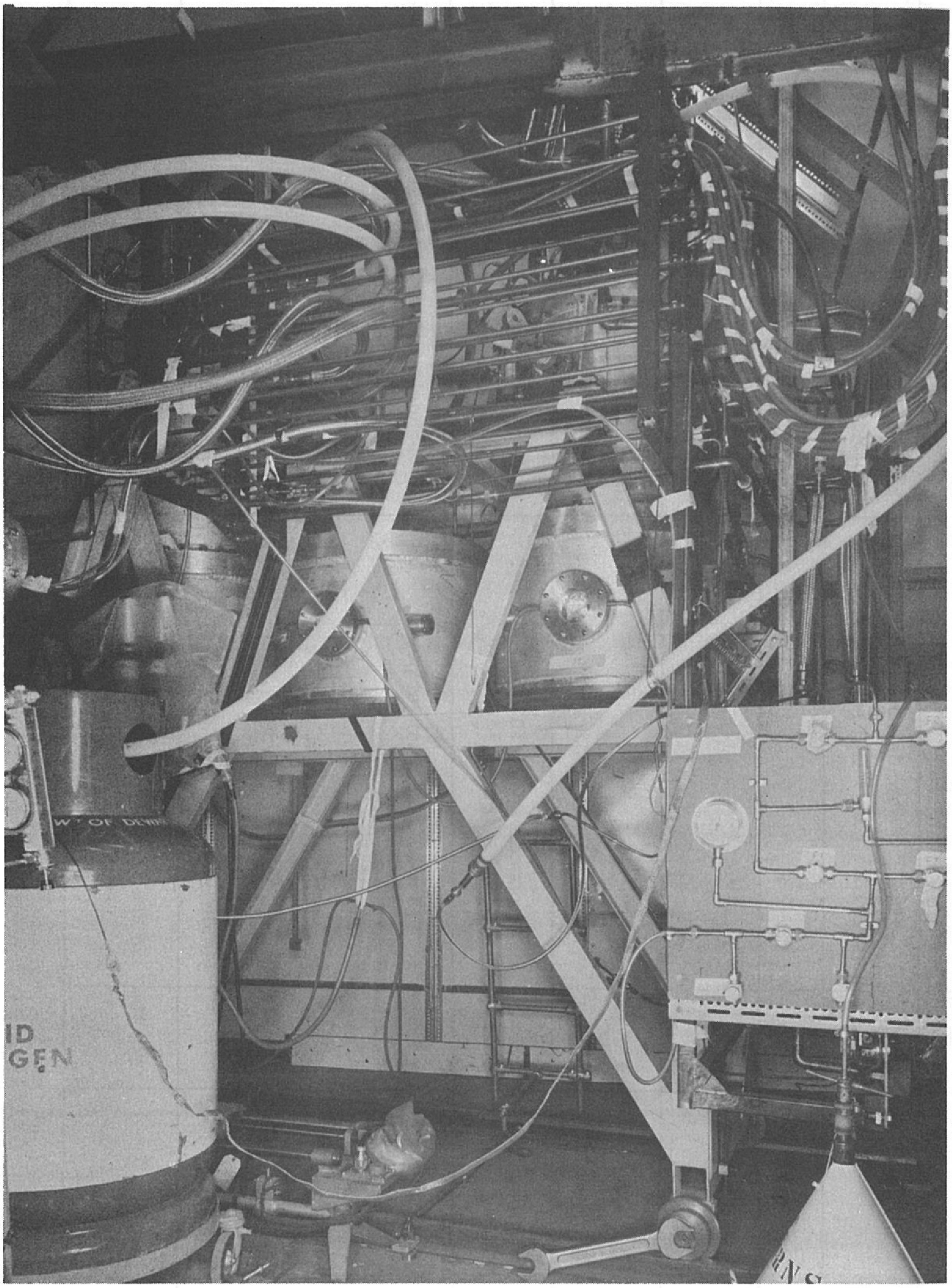


Figure 39. Target assembly for the P4 experiment. The left hand cylinder contains the liquid deuterium target, the centre cylinder is used for target empty runs and the right hand cylinder contains the liquid hydrogen target.

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APPLIED PHYSICS DIVISION

The major responsibilities of the Applied Physics Division are Bubble Chamber operation and development, track analysis measuring machines, computer facilities, the Variable Energy Cyclotron for AERE, Superconducting magnets and the Electrostatic Generator for Oxford University.

During the period of the report the 1.5 metre Hydrogen Chamber returned to the Laboratory from CERN. The Heavy Liquid Chamber operated and started its first experimental run. The Liquid Helium Chamber was in its final stages of commissioning. The Saclay 80 cm Hydrogen Chamber continued operating throughout the period.

The main point of interest in the computing field was the commissioning of the ORION/DDP coupled computer system which was used for on-line experiments. The system was fully time sharing and could accommodate the HPD flying spot digitiser, a CRT flying spot digitizer for spark chamber film, and three counter experiments. Details of the equipment are given below.

Off-line computing was carried out mainly on the CHILTON ATLAS although the Imperial College IBM 7050 and the Glasgow IBM 7044 were also used. The ORION computer would be replaced in late 1966 by an IBM 360/75 for both on-line and batch processing.

The Variable Energy Cyclotron which was designed by Rutherford Laboratory staff for the Atomic Energy Authority operated with an internal beam. Work was proceeding on beam extraction and ion source development.

The Electrostatic Generator at Oxford successfully reached its design specification.

Future projects included the construction of several superconducting coils to study high field production, a design study of a high field Bubble Chamber using superconducting coils, the implementation of the IBM 360/75 computer with on-line facilities and continued development of automatic measuring machines, including the construction of a second HPD flying spot digitizer.

Towards the end of 1966, when the ORION computer would be replaced by an IBM 360/75 computer, on-line users would be attached through the DDP 224.

Bubble Chambers

The 1.5m Hydrogen Bubble Chamber

This chamber was continuously in use at CERN on scheduled experiments on the 25 GeV Proton Synchrotron until it was returned to the Rutherford Laboratory in autumn 1965. During operation at CERN one and a half million pictures were taken for Bubble Chamber Teams from the U.K. and from other European countries.

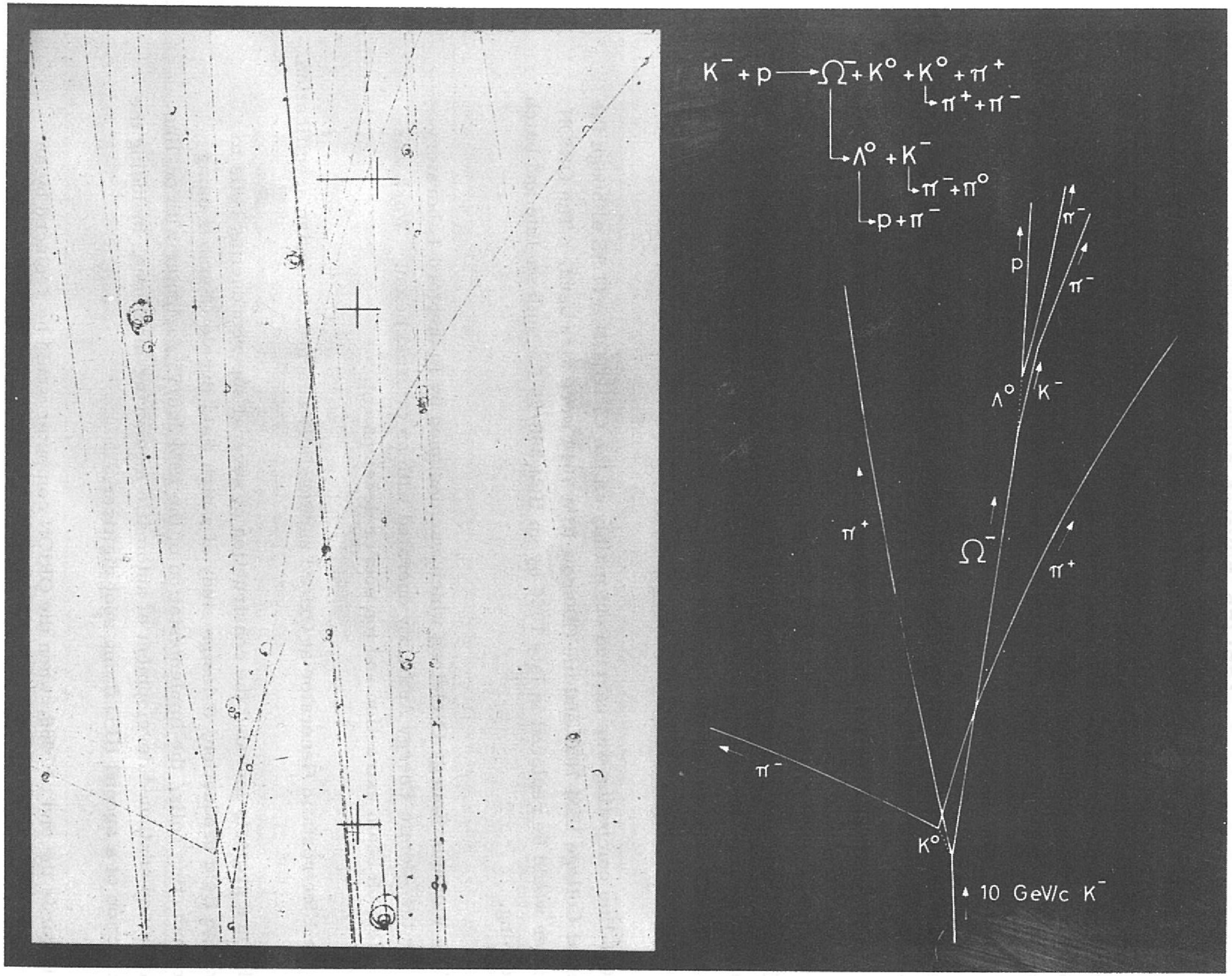

Figure 40. Production of an Ω^- particle.

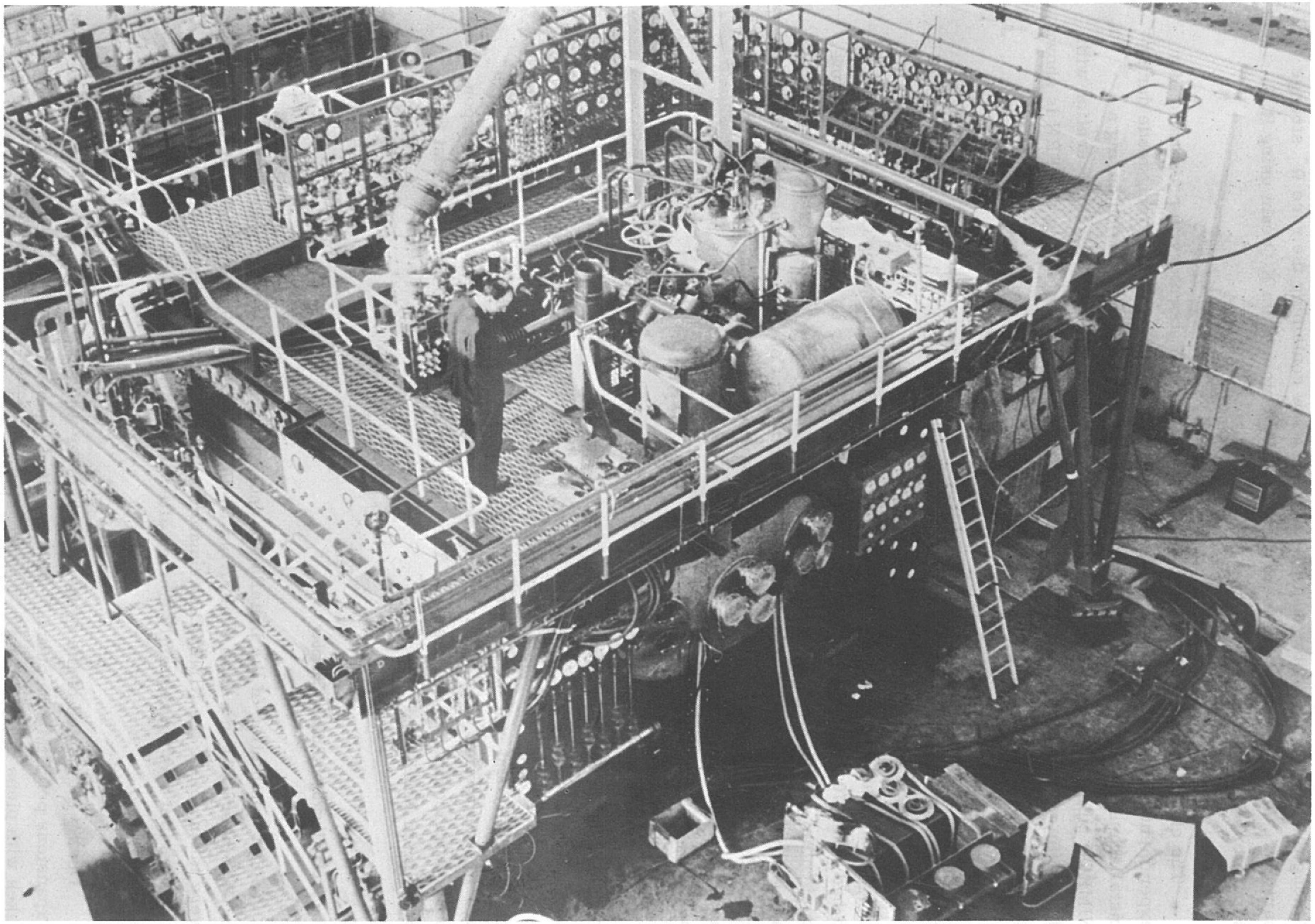

Figure 41. The 1.5m Liquid Hydrogen Bubble Chamber operating at CERN

Among the interesting photographs taken were a few containing the rare Ω^- strange particle. One such event produced by a 10 GeV/c momentum K^- beam using R. F. separators is shown in figure 40.

The chamber was being installed at the Rutherford Laboratory in preparation for experiments on NIMROD. A number of minor improvements were being made during installation and others under investigation, such as multiple expansion during a NIMROD pulse, would be introduced later. Additional plant needed for operation with deuterium would also be installed. A view of the chamber operating at CERN is shown in figure 41.

The Heavy Liquid Bubble Chamber

This chamber was completed and operated successfully during October 1965. It had taken 70, 000 pictures towards a total of 200, 000 for an experiment using a low momentum pion beam. It was filled with the freon CF_3Br but later experiments using other liquids including propane were planned. Considerable safety problems arose from the use of propane and these were under investigation. A view of the assembled chamber is shown in fig. 42 and a typical picture with a NIMROD pion beam is shown in figure 43.

The Liquid Helium Bubble Chamber

Both the magnet and refrigerator installations seen in figs. 44 and 45 operated satisfactorily and met the required specifications. The chamber assembly was nearing completion when the first cool-down would be made. Most of the component parts were completed and tested. The chamber was set up to receive a test pion beam from NIMROD.

The Saclay Hydrogen Bubble Chamber

After completion of the installation and assembly the chamber was operated in December 1964 in a kaon beam from NIMROD. Only 200, 000 pictures in hydrogen were taken before the NIMROD alternator failure. A low momentum pion experiment in deuterium was subsequently started after the additional deuterium equipment had been installed.

During the period of the report the chamber was developed to operate with two expansions per NIMROD pulse. This resulted in an output of 10^6 pictures mostly taken with pions in deuterium.

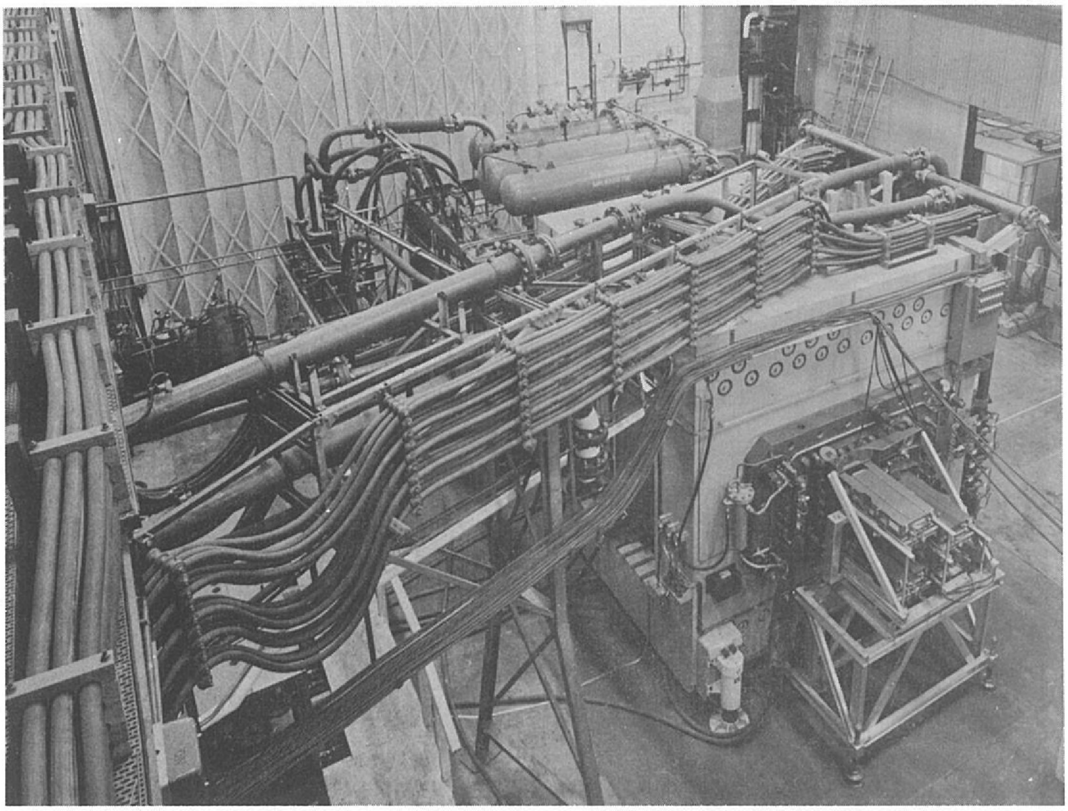

Figure 42. General View of the Heavy Liquid Bubble Chamber

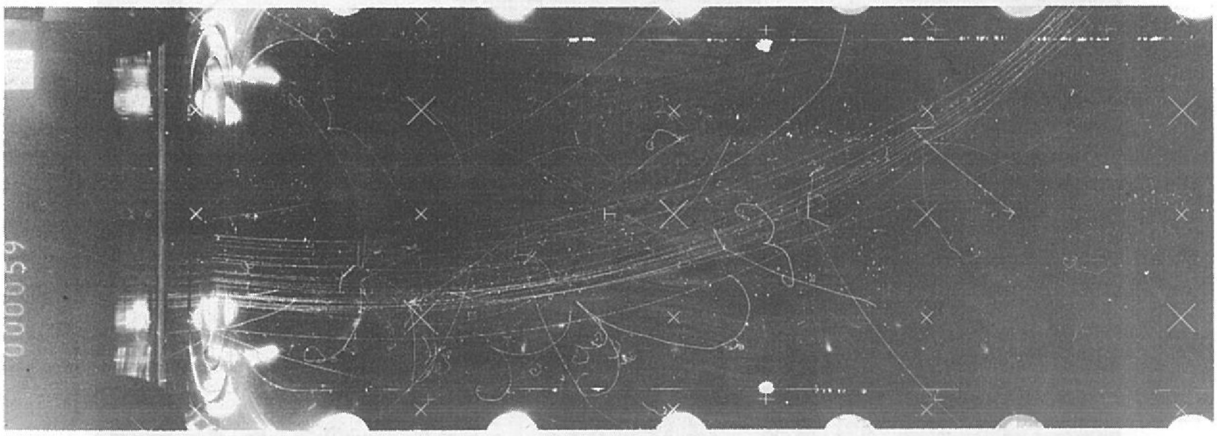

Figure 43. Typical picture in the Heavy Liquid Bubble Chamber.

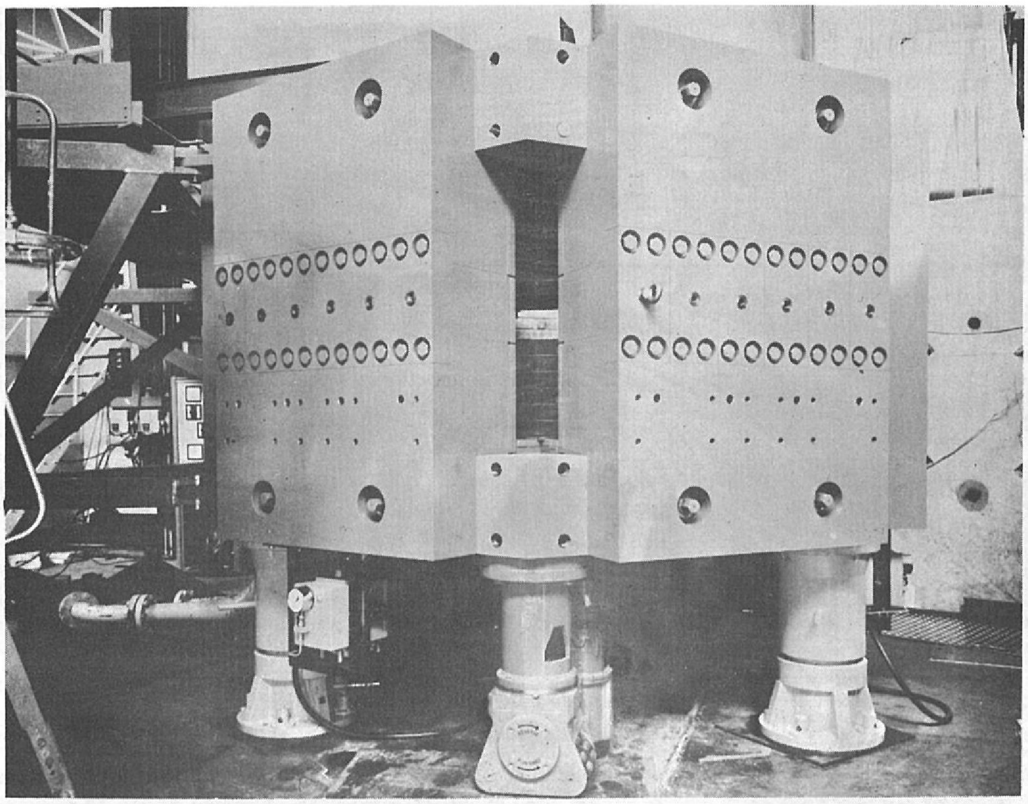

Figure 44. Magnet of the Liquid Helium Bubble Chamber

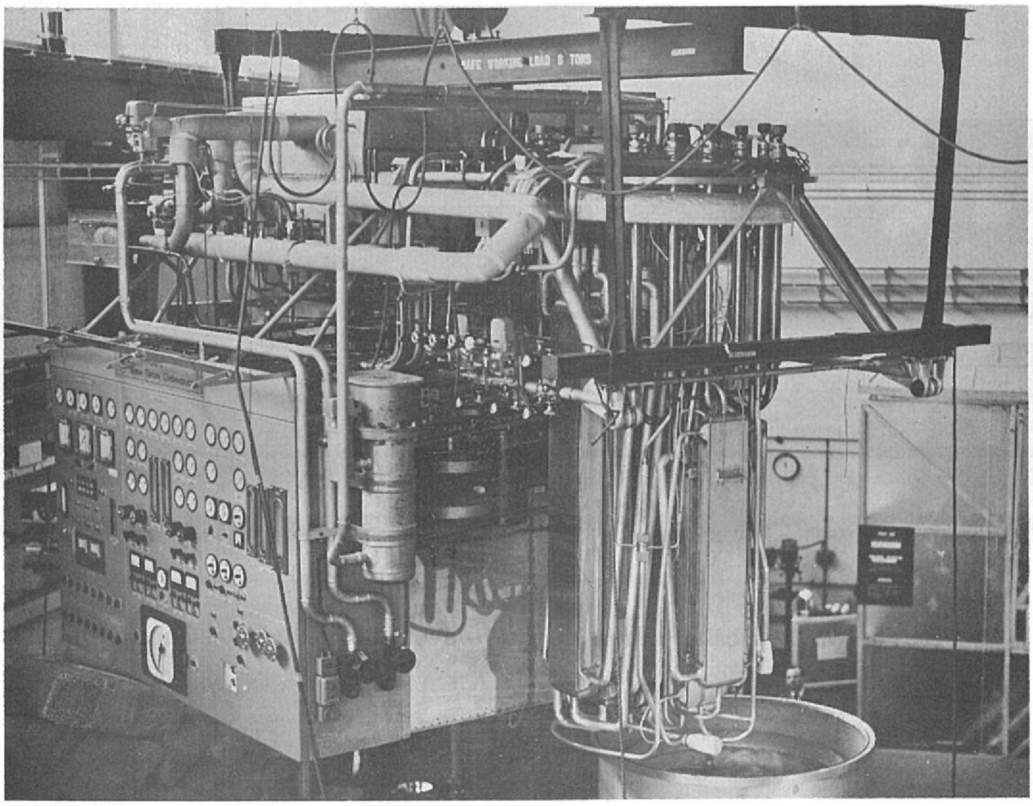

Figure 45. Refrigerator installation of the Liquid Helium Bubble Chamber

High Field Bubble Chambers

In order to extend the range of physics possible in hydrogen bubble chamber experiments on NIMROD it was necessary to increase the accuracy of measurement and the rate of data taking. By using the high fields obtainable with superconducting magnets it would be possible to obtain much greater accuracy than those achieved in the 1.5m hydrogen chamber. The size of chamber needed was approximately 1.5m diameter and 1m deep with a field of 70 Kilogauss.

The problems associated with such a chamber were being studied. In particular the optical and thermal distortions were being assessed and ways of minimising them investigated. In addition the cryogenic problems of the chamber and superconducting magnet were being studied.

Track Analysis

Conventional Measuring Equipment

The maintenance of all of the "projection-microscope" type of bubble chamber measuring machines along with six scanning tables was handed over to Central Engineering. Several of the measuring machines were extensively modified to improve their reliability. All of the teleprinters on these machines were being replaced by typewriters and paper tape punches.

Four of the scanning desks had their optics etc., improved so that they were accurate enough to be operated with rough digitizers. All four of these desks had rough digitizers fitted - three were made by Dobbie McInnes and one was a Laboratory design using a light pen and rotating mirror (known as IPD). These machines digitized over an area of 100 x 50 cm. Two further Dobbie MacInnes machines capable of measuring over an area of 150 x 75 cms had been delivered. Two further IPD's were nearing completion.

Hough Powell Device (HPD)

The HPD is a high speed, accuracy machine employing a mechanically generated flying spot for measuring bubble chamber pictures. Installation and commissioning of this machine continued through 1965. From February it had been operating on 50 cm film from the Saclay Bubble Chamber, and had started measuring film from the η experiment. Considerable work had been done on calibrating the HPD and operating it "on-line" with the necessary "track-following and filtering" programs. A major part of the development of the system was the writing of a filter program which could distinguish track measurements from background with very high reliability. A program using a track following method had been written and was operating with considerable success. Tests showed that measurements made with the

HPD were more accurate than those made by hand operated machines. Overall measuring accuracy of 2-3 microns on film had been achieved as compared with 6-7 microns for hand measurements.

Equipment has been ordered and designs started to increase the speed and resolution of the HPD, both by a factor of three.

CRT Film Scanner

During 1965 a flying spot measuring machine was built up around a high precision CRT. The machine was designed to measure 70 mm spark chamber film from the $K_o \rightarrow 2\pi_o$ experiment at 250 events/hour. It was shown that the accuracy of the machine was $\pm$ 3 microns and that the machine and spark finding programs found 80% of the sparks in a picture. A preliminary batch of 1,000 events had been satisfactorily measured ready to be tested with the "shower finding" programs.

Computing activities

ORION

ORION functioned throughout 1965 with acceptable reliability. Some changes were made to the Fortran operating system which made it easier to use and more economical of magnetic tapes. As the computing load continued to increase, use of ORION was restricted to programs dealing with on-line devices or experiments, other computation being done on the Chilton Atlas.

The largest program in the ORION system was that which controlled and read data from the Hough-Powell device via the direct data link to the DDP-224 computer. Other programs converted measurements punched on paper tape to a form acceptable by the Benson-Lehner graph plotter, or to magnetic tape for later use.

The DDP-224

This computer was installed in May 1965, and later augmented with the addition of 8K of core store, 2 magnetic tape decks, a Calcomp graph-plotter, and a visual display with light pen. A typewriter was situated in the Experimental Area (P3 experiment). On the whole the DDP behaved reliably, although latent hardware faults emerged as users of the system grew more ambitious. It was connected to ORION via a direct data link, to the P3 experiment, the HPD, the CRT scanner, and to a teleprinter set associated with the K6 experiment.

A control program was written which allowed more than one of these users to operate simultaneously, subject to the limitation of total core store requirements. Users wrote their subroutines in machine code (assembly language) but the control program managed most data input/output, message reception and dispatch, magnetic tape operations, and communication with ORION. The HPD data were sent on to ORION; other users wrote their results to paper tape or magnetic tape for later off-line analysis by ORION or ATLAS. Messages originating at the console or remote typewriters could command programs to enter defined courses of action or to change numerical program parameters. Messages originated by program could go to either typewriter to report on data received.

When the HPD program was not in ORION, or was temporarily suspended, the P3 experiment program in ORION could analyse data received, print the output on the ORION printer, and send summary information as requested, both graphical and literal, to a display tube in the P3 experimental area.

An alternative control program was written for ORION DDP which handled the transmission of all on-line information on behalf of several data-processing programs which could be simultaneously resident in ORION, the DDP acting solely as a data gathering and disseminating device. The ORION user programs could be written in Fortran and tested independently, a great advantage. The great size of the HPD program in relation to ORION core store unfortunately prevented use of this system.

On ATLAS, programs for the reduction and analysis of bubble-chamber data continue to be developed, and programs for processing data obtained via the DDP from the CRT scanner were written.

Practically all the above computing activity was carried out by teams of programmers, in particular the multi-use DDP program involved a great deal of cooperation on the part of users.

Variable Energy Cyclotron

During 1965 the magnetic field of the cyclotron was measured, the radio frequency system commissioned, and those components required to produce an internal beam assembled. A beam to full radius was obtained in December.

The magnetic field survey occupied three months; during this period nearly half a million points were measured, recording the behaviour of the main magnetic field at five field levels, and also the performance of each of the individual sets of trim coils which are used for shaping the field for the different ion and energy settings.

Full tests of the radio frequency system were made with the dee in a dummy vacuum box outside the magnet. Reliable operation of the transmitter and resonator over the working frequency range of 7-21 Mc/s at the required dee voltage was established.

Towards the end of the year the diagnostic probes were commissioned and calibrated, and the final assembly of components needed to produce an internal beam was completed by mid December. The machine was set up first to produce 23 MeV H_2+ ions, and a beam was obtained to full radius within a day of switching on.

Electrostatic Generator for Oxford University

The period of this Report saw the conclusion of the Electrostatic Generator Project at Oxford, for the Department of Nuclear Physics. In the field of nuclear structure physics, much accurate work has been carried out using electrostatic generators, which by virtue of their precision and flexibility are well suited to the experimental requirements. Originally the maximum available energy from such machines was 6 million electron volts for protons: this limit was doubled with the advent of the tandem. The range of energy was extended to 20 million volts at Oxford by injecting, into the tandem, ions from a vertical electrostatic injector operating up to 10 million volts (figure 46): the tandem was purchased from the H. V. E. C., while the injector was designed and commissioned by the Rutherford Laboratory team. Since such a machine had many uses operating independently, and since negative ions can be produced only in relatively small quantities, the machine was designed also to run positive, and to provide positive ions of the isotopes of helium and hydrogen. In figure 47 is shown the general arrangement: the injector on the left accelerates ions downwards into a magnet, which deflects the beam either into the injector target room, or, by rotation around a vertical axis, injects the beam into the tandem. The beam from the tandem, originating either from its own ion source or from the injector, is deflected by the tandem magnet into one or other of the experimental rooms.

Work by the Rutherford Laboratory team

Inside the injector the two access platforms were powered by hydraulic rams: one of these gave development problems, but these were cleared, and the final result had been satisfactory. Stabilization of positive and negative voltages was effected by varying the voltage on a liner to the pressure vessel: if the machine potential tended to rise with respect to earth the liner was reduced in voltage to compensate. A physically prominent feature was the intershield (figure 48) a cylindrical shell 21' high by 8' in diameter, which aided in smoothing the field variation between terminal and vessel: the expected improvement in performance (from 8 million volts maximum without intershield to 10 million volts maximum with intershield) was confirmed. On the test bench, and to a slightly less extent in the machine, analysed currents of 10 - 30 microamperes of negative hydrogen, oxygen and sulphur ions were delivered: the available currents of positive ions were considerably greater. Life tests were terminated after several hundred hours, because attempts to determine the limiting factor after an indefinitely long time seemed unjustified. Reliability in the machine was good. Properties of the external magnet systems were explored by alpha particles, so that the beam optics were fully established independent of the machine.

The beam optic elements - lenses and deflectors, of each machine were powered from the supply of the main beam bending magnet, an arrangement which kept the whole system in focus as the particle energy varied.

At the time of hand-over to Oxford, negative ions of hydrogen had been accelerated up to 10 million volts, and of oxygen to 9.5: while ions of He^+ had been accelerated up to 15.6 MeV, corresponding to 9.7 million volts positive on the terminal. Operation coupled with the tandem gave no trouble, and hydrogen ions were accelerated up to 20 MeV. Tests with oxygen at comparatively low energies (46 MeV total) showed that no difficulty was encountered in obtaining currents of 0^{6+} up to 0.9 microamperes. It should perhaps be added that the highest voltage previously attained by any electrostatic generator outside America was 7.5 M.V.: and that voltages above 10 million volts had been attained only by the Emperor tandem of the High Voltage Engineering Corporation, in which the effective diameter of the pressure vessel was 18' as compared with 12'6" in the Oxford injector.

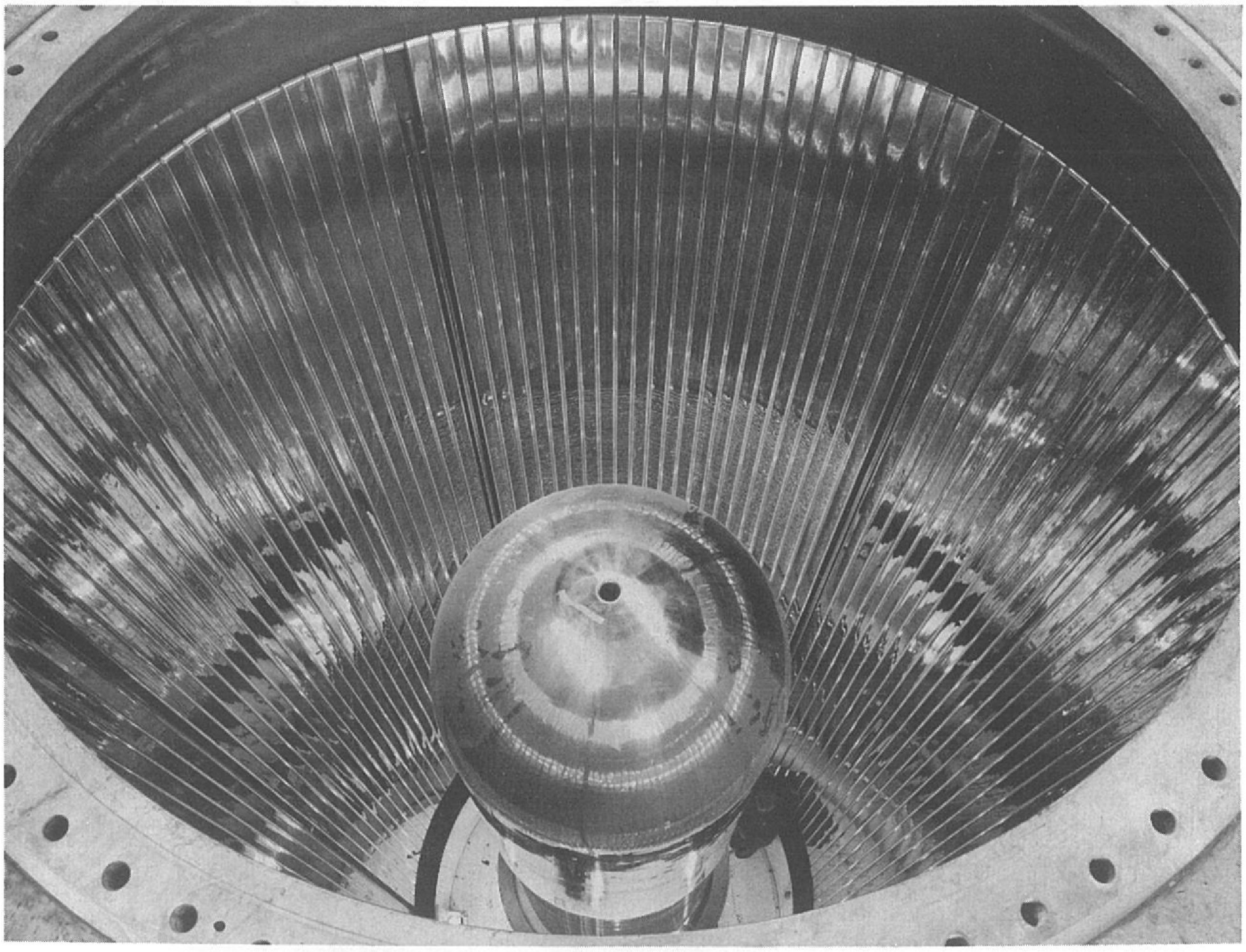

Figure 46. Top view of the Injector of the Oxford Electrostatic Generator

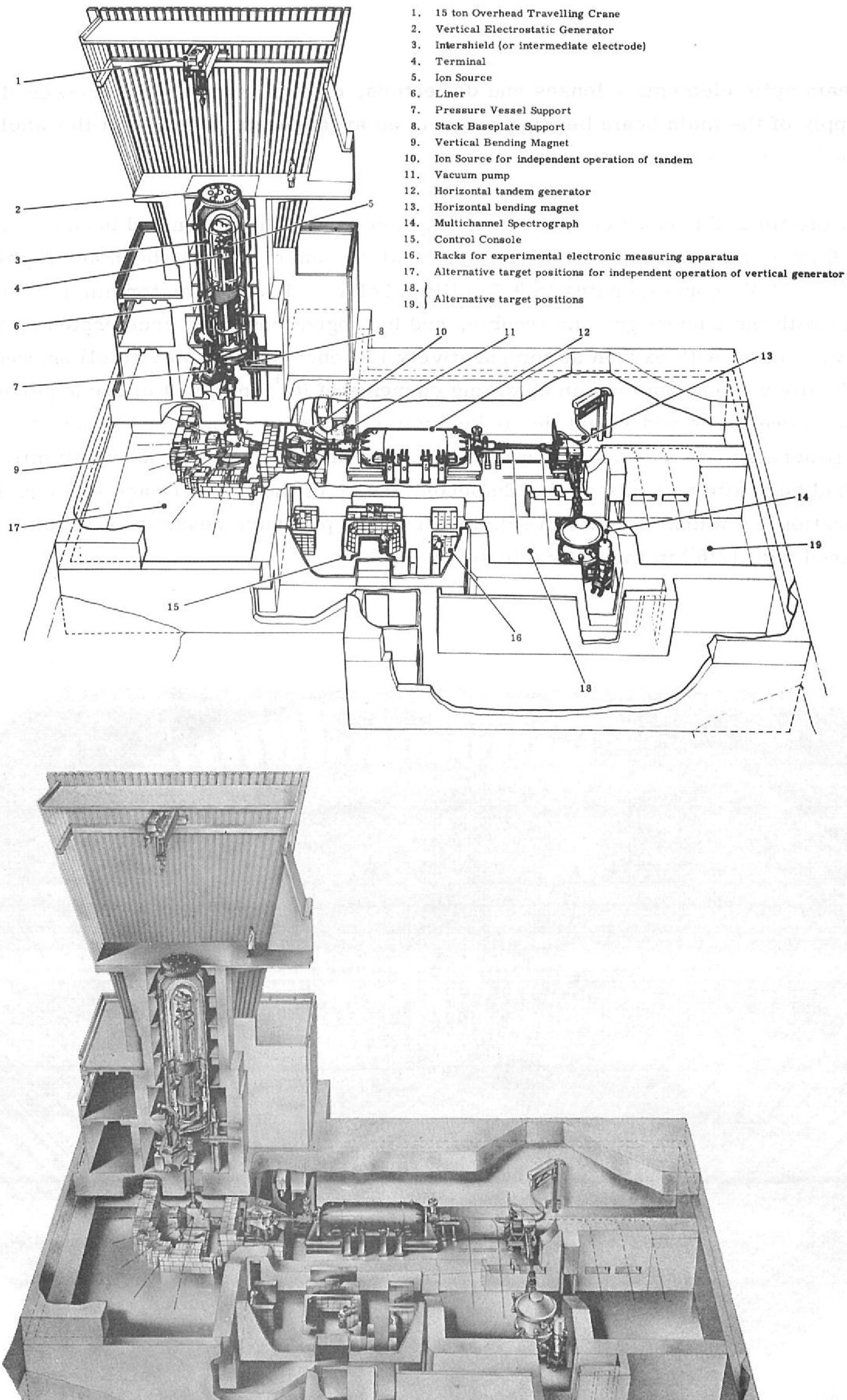

Figure 47. General arrangement of electrostatic generators at Oxford

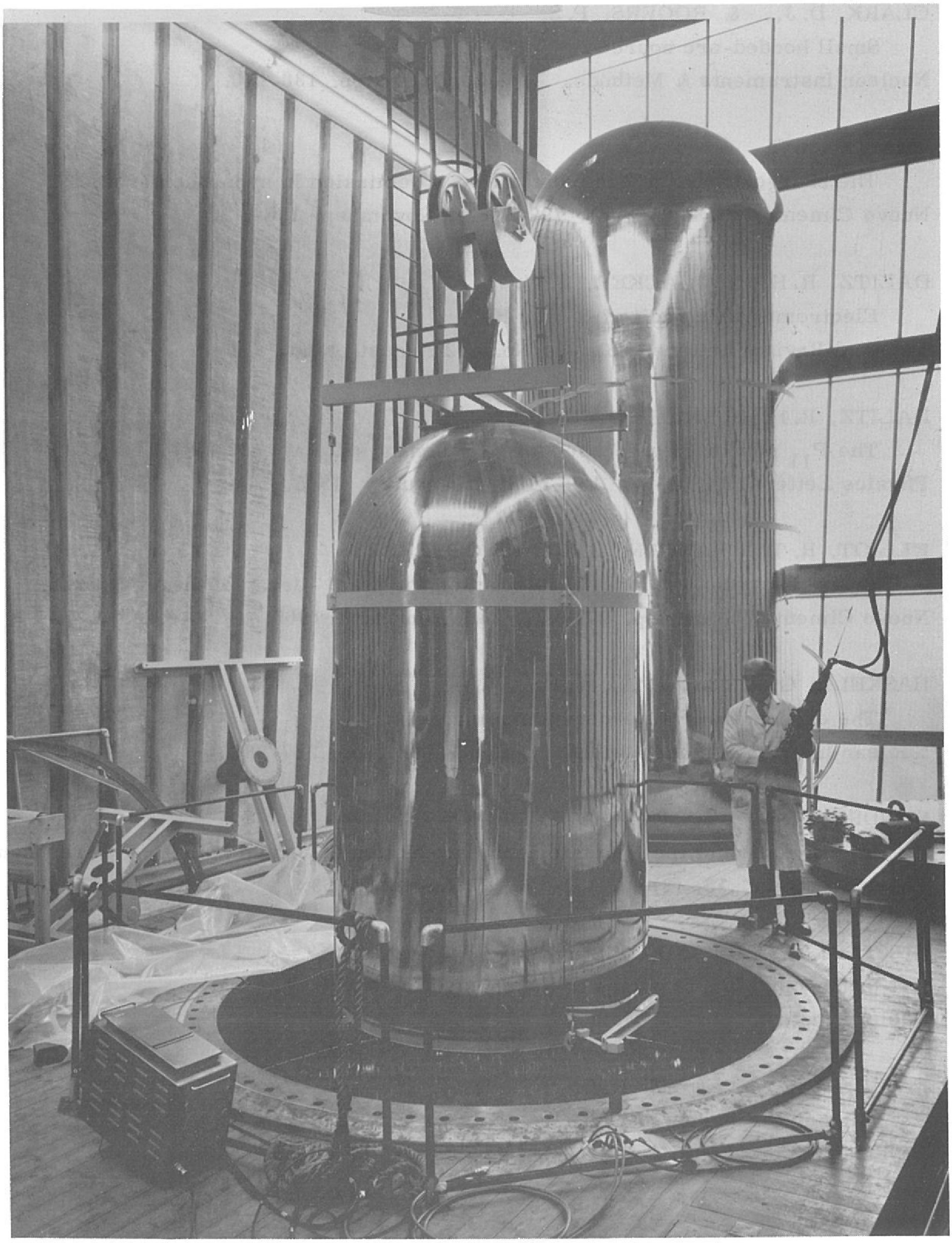

Figure 48. Terminal and Intershield of the Injector

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PROTON LINEAR ACCELERATOR DIVISION

Nuclear Physics on the P.L.A.

Many experiments were carried out on the Proton Linear Accelerator during the period covered in this Report, and the accelerator continued to be one of the principal centres for nuclear physics research in the 30 to 50 MeV energy region. Nine experimental teams used the P. L. A. during the past year and the demand for experimental time remained in excess of that available. Two of the principal features of the P. L. A., its polarized proton source and neutron time of flight facility were considerably improved in performance. The increase in polarization and intensity of protons from the polarized proton source currently allowed the double focussing spectrometer to be used for some experiments with the polarized beam and also enabled nuclear reactions induced by polarized protons to be studied. The neutron time of flight facility, which was unique in this energy region, was working very reliably and together with its improved resolution enabled neutron spectra to be measured over a very wide range of angles and energies. There was a marked increase in the use of the double focusing magnetic spectrometer. This instrument was found by the experimentalists to be very simple and convenient to use and suitable for a very wide range of experiments. This increasing use of the spectrometer occurred at a time when the emphasis of the work on the P. L. A. was moving away from the study of the nucleon-nucleon and nucleon-few nucleon interactions to the study of the more complicated nucleon-nucleus interactions and the level schemes of nuclei.

Studies with protons interacting with light nuclei, i.e. few-nucleon systems

The spectrometer has proved invaluable in the only experiment performed on the proton-proton interaction during this period, namely a measurement of the differential scattering cross-section at 50 MeV to an accuracy of approximately 0.5%. A preliminary theoretical analysis of this data suggested that the scattering phase shifts were known very accurately and no further experiments on this interaction were planned. The shift in emphasis in the study of the nucleon-nucleon interaction should now be towards neutron-proton scattering. One of the principal difficulties in these experiments was the production of a suitable "mono-kinetic" neutron source and measurements of energy spectra using the neutron time of flight facility suggested that the p + d or p + Li^7 reactions might be the most suitable. For many experiments polarized neutrons would be required and measurements of the transfer of polarization in (p, n) reactions at forward angles using polarized incident protons have been made. Using a deuterium target a polarization transfer approaching - 0.4 was observed for the high energy neutron group, in good agreement with theoretical predictions, but as the lower energy neutrons were found to be polarized in the opposite direction this reaction did not seem suitable as a source of polarized neutrons. Further measurements of neutron polarization were in progress and energy spectra for other reactions which might be suitable as neutron sources would be investigated.

Work continued on the measurement of the polarization and differential cross-section for the elastic scattering of 30 and 50 MeV protons by deuterium over a wide angular range. These measurements were almost complete and the polarization results showed a wide disagreement with theoretical calculations. Attempts to improve the calculations tended to increase the disagreement and it seemed that a major improvement in the theory was required.

The theoretical analysis of proton-alpha particle scattering data obtained at the P. L. A. and elsewhere had continued and suggested the need for possible additional experiments. These were being planned.

Reactions with heavier nuclei

The measurement by several experimental teams of the elastic scattering cross-section, polarization and reaction cross-section for a selected range of nuclei to be used in a study of the optical model for nucelon-nucleus scattering continued. The data at 30 MeV was complete and this work together with a theoretical analysis of the data had been published. Subsequently reaction cross-sections for these nuclei were measured for 30 and 50 MeV protons using an extension of a new technique recently used very successfully at lower energies.

Polarization data for most of this range of nuclei were measured using 50 MeV protons and experiments to measure the differential scattering cross-section were in progress. When these data become available it would be possible to make an optical model analysis of the results for 50 MeV protons and a comparison with the earlier analysis at 30 MeV would give information on the variation with energy of the parameters of the model.

The nuclei used for this study were chosen to have as near spherical symmetry as possible since this was one of the basic assumptions of the Optical model. Theorists had recently included the effects of nuclear deformation which gave coupling between elastic scattering and states of the nucleus easily excited by inelastic scattering. This coupled channels method was used in a comparison with elastic and inelastic polarization and differential cross-section data obtained using the P. L. A. for Carbon and Silicon at 30 and 50 MeV. The results indicated that it would probably be necessary to include spin dependent effects in the coupling potential to obtain satisfactory fits to the inelastic scattering polarization data.

Measurements of differential cross-sections for elastic and inelastic scattering of 50 MeV protons by deformed nuclei in the mass 50 and 64 region were in progress using the spectrometer magnet. The results, together with polarization data which it might be possible to measure for some of the elements, would also be compared with calculations using the coupled channels method.

Measurements of the polarization angular distribution in elastic scattering for

Carbon in the energy range from 20 to 30 MeV had shown that large fluctuations in the polarization could occur for relatively small changes in the incident energy. These measurements were extended and compared with an analysis in which compound elastic scattering from three excited states in N^{13} was considered. The agreement between theoretical calculations and experiment was rather poor but further work was in progress.

The polarized proton beam was used in a study of the asymmetry in (p, d) reactions for C^{12} and O^{16} using polarized protons. The results showed satisfactory agreement with DWBA calculations and the experimental and theoretical work was being extended to other nuclei.

A very large amount of data was also obtained in a study of (p, d) reactions for 50 MeV protons on the seven even isotopes of tin. This work used the spectrometer magnet with an acoustic spark chamber to detect the position of the particles in the magnet focal plane. Whilst the results were not yet completely analysed the angular distributions indicated not only the well known dependence on the angular momentum (L) of the picked up neutron but also a possible weaker dependence on its total angular momentum (J).

Measurement of the angular distribution of inelastic protons from the reaction C^{12} $(\vec{p}, p^1)$ C^{12*} exciting the 15.11 MeV level were measured for incident proton energies from 20 to 30 MeV. Excitation functions measured previously for this reaction had shown several unexpected features and the current measurements assisted considerably in understanding the reaction mechanisms involved.

The neutron time of flight facility was used in a study of (p, n) reactions on Li^6 and Li^7 targets. The experiment gave useful information on the possibility of using these reactions as neutron sources as mentioned earlier and also on the level schemes of the residual nuclei Be^6 and Be^7. Measurements of the angular distributions for excitation of isobaric analogue states have confirmed the striking variation with proton energy and atomic weight of the target which had been observed previously. These experiments also showed that "double analogue" $(T=T_Z+2)$ states could be excited in a (p, n) reaction. It had previously been thought that excitation of these states, which had recently been observed in other reactions, was unlikely in a (p, n) reaction.

Similar excited states could also be observed in experiments on (p, t) and (p, He^3) reactions and work had started on a range of nuclei to measure angular distributions for these reactions using mass discrimination techniques with semi-conductor counters to identify the tritons and He^3 particles. The Q values for the reactions which are also measured would enable tests to be made of formulae which had recently been proposed relating the masses of isobaric nuclei having the same total isotopic spin. The (p, He^3) and (p, α) reactions on light nuclei were also being studied using somewhat similar techniques to give information on the mechanisms for these reactions and on the structure of the nuclear surface.

Experiments at the Proton Linear Accelerator

Number	Experiment	Group
1.	Measurement of the proton-proton differential cross-section at 50 MeV.	University College London & Rutherford Laboratory.
2.	Polarization in the elastic and inelastic scattering of 30 and 50 MeV protons from nuclei.	Birmingham University.
3.	Studies of elastic and inelastic proton scattering.	Kings College, London.
4.	Elastic scattering of protons by deuterons.	Queen's University, Belfast, & Westfield College, London.
5.	Study of pick-up reactions with polarized and unpolarized protons.	Oxford University.
6.	Investigation of (p, He^3) and (p, He^4) reactions in light nuclei.	Westfield College, London and Queen's University, Belfast.
7.	Measurement of neutron energy spectra by the time of flight technique.	Rutherford Laboratory, & Queen Mary College, London.
8.	Polarization of neutrons from (p, n) reactions for incident polarized protons.	Rutherford Laboratory, & Queen Mary College, London.
9.	A study of (p, d) reactions on the even isotopes of tin.	A. E. R. E.
10.	Measurement of total reaction cross-sections.	Oxford University.
11.	Inelastic scattering of protons from C^{12}.	Oxford University.
12.	Study of (p, t) and (p, He^3) reactions.	Oxford University.
13.	Measurement of elastic and inelastic proton differential scattering cross-sections.	A. E. R. E.

Operation and Development

The use of the proton linear accelerator by nine teams on a 24 hour schedule testified to the continued demand for the facilities offered. During the period of this Report, there were two major shut-downs. The first, involving realignment and measurements on drift tubes and cavities, resulted in improved beam quality, improved performance of the polarized proton source, and greater independence of beam energy from machine parameters. The second was concerned primarily with improvements in the experimental areas, notably in the double focusing magnetic spectrometer. Apart from these shut-downs, the machine was scheduled continuously for 76 per cent of the possible time: of the remaining 24 per cent, there was a continued tendency for more time to be spent in installation and testing of new equipment (experimental and machine) and less in routine maintenance. Actual hours of operation are shown in the following table:

		1964 Nov. & Dec.	1965 Jan. to Dec.
Total hours scheduled		780	6127
Hours of satisfactory operation for nuclear physics	Total	458	5260
	Polarized beam	97	1470

From this table it may be seen that the time available for experiment was 83 per cent of the scheduled time. These satisfactorily high figures show the continued reliability of the machine, and particularly of the grounded grid triodes. Of these valves - once a major source of lost time - only one replacement in 1965 was required after 30,000 hours of valve operating time. Apart from two cavity faults in tank 3 which required access to a vacuum tank, all faults were cleared in a few hours. The improvement in beam quality referred to above is illustrated by the fact that the mean beam energy remained constant to within ± 50 kev throughout the year and to about ± 10 kev from day to day.

Machine Developments

Development of the polarized source continued, with the main emphasis on the design of a high field ionizer and its associated radio frequency transition unit. The ionizer, which was in the form of a modified Penning gauge, posed several difficult technical problems including the production of a very uniform field of several kilogauss and the injection of electrons into the axis of this field. The transition unit used the principle of adiabatic transition of atomic hydrogen in a low magnetic field and it was shown that the efficiency of the unit built here was at least 90 per cent. First tests of this ionizer on the P. L. A. were unsatisfactory due to minor electrical faults. The beam currently obtained had an intensity of 4 x 10^8 protons per second and 56 per cent polarization after acceleration through the P. L. A.; the beam at the source was at least 2 x 10^{12} protons per second (1/3 μ A). During 1965 the best beam obtained was 1.3 x 10^8 at 51 per cent polarization.

The design work on a quadrupole tank 1 was halted because there was no money allocated to its construction. Work on alternative proposals for increasing the beam current of the P. L. A. was started. Since the duty cycle of the P. L. A. was 1 per cent the counting rate on some experiments was limited by peak counting rate difficulties, but all experiments could use a higher duty cycle. Two modifications were proposed. As a first step the radio frequency pulses would be modified to 800 μsec at 25 c/s (from 400 μsec at 50 c/s) thus increasing the beam pulses to 600 μsec and the duty factor ot 1.5%. This inexpensive modification, which did not require any increase in mean power in any of the machine components, has been put in hand. A more ambitious aim was to increase the radio frequency pulses to 1200 μ sec at 50 c/s to give 5 per cent beam duty cycle. This required three times the mean power, and careful investigation of the capabilities of the radio frequency amplifiers and the accelerating cavities, in particular, was in progress.

Miscellaneous items of design development included improvements to the low energy drift space aimed at improving beam matching and control at 500 kV, a new buncher, and a modified unpolarized source of greater reliability and intensity. Collaboration with the 300 GeV design group continued on the investigation of the properties of accelerating structures.

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ENGINEERING DIVISION

The chief functions of the Engineering Division are to provide and maintain the buildings and services of the Laboratory and to provide comprehensive services to the scientific research divisions. Its activities cover civil, mechanical, electrical, electronic engineering, industrial chemistry and safety. Design, development and manufacturing services are available for each branch of the Division's work.

Each research division has some engineering support whose activities are dealt with under their own heading; but in addition the Engineering Division exists to cover the more general needs of the Laboratory and to permit the more comprehensive staffing of the larger projects.

On the civil engineering and buildings side, schemes completed or in progress were:- alterations to hostels; office blocks; drainage; temporary plant room for the Saclay Bubble Chamber; Plant Room for the Hydrogen Bubble Chamber. During the period a stores building and hazardous test buildings were completed and handed over by the U. K. A. E. A.

The mechanical engineering services for the above buildings were carried out principally by the Laboratory's own staff and contractors working under the Laboratory's engineering direction, but numerous alterations were necessary to existing space heating, air conditioning, ventilation, cooling water and trade waste pumping installations. A special feature of the work of the Division is the frequent movement of heavy loads, particularly shielding components, and specialist lifting equipment and staff are available as a central service.

Manufacturing Services

A well equipped engineering workshop is established capable of producing a wide variety of operations to a high degree of precision and skill. This shop specialises in "one-off" items of scientific and engineering equipment where close liaison with the scientific staff or design engineer is essential. The following items, produced during the period, are worthy or note: Polarised Targets, Helium Bubble Chamber Internal Assembly and Transfer Line, the 30 ins. Scatterchamber, Slit Boxes, Traversing Slits, a r. f. Oscillator and Amplifier.

Where close liaison was not so essential our own workshop capacity was supplemented by nearby industrial companies operating as a result of tender action. Inspection and progress services where required were provided by the Inspection and Progress branch of the U. K. A. E. A.

Many chemical problems arise from the high radiation levels and the use of unusual materials. Accordingly, a small industrial chemical Laboratory continued to deal with radiation dosimetry, materials testing (principally in the field of normal and reinforced plastic) the manufacture of plastic targets, and the continual surveillance of purifiers, water softeners and trade effluents.

Electrical Engineering

The major activity of the electrical design office was the design and construction of magnets together with their highly stabilised D. C. Power Supplies and associated control circuits. The Plunging Magnet described in the Mechanical Design Section of the report had a complex control circuit. Initially this employed moving contacts of limited reliability. Development work showed that transducers could be used, so that with the advances made in component design, the speed of response, precision and reliability were greatly improved.

The 4 MW Helium Bubble Chamber Magnet, was commissioned. The coils for the Variable Energy Cyclotron quadrupoles required development. The Nimrod extractor magnet, and the 4 MW Hydrogen Bubble Chamber Magnets made by industry failed prematurely during commissioning. The coils as redesigned at the Laboratory were now satisfactory. A 20 Kilovolt 10 Kilojoule earthing stick for the safe discharge of large capacitors was designed for use in S. R. C. establishments. The design work by the team working at Oxford University on the Electrostatic Generator was completed and commissioning was well advanced on the installed parts.

The electronic development section concentrated its efforts on instrumentation for the Nimrod polarised target and for the K7 beam line. Work was also in progress on D. C. stable power supplies (1 in 10^4) for magnets including one for a superconducting magnet. During the period NIMROD operated directly from the "Grid" and technical assistance was given to the A. E. R. E. to assist in minimising the effect of NIMROD pulses on sensitive apparatus.

The work of the service sections continued to expand. The electrical services section completed the initial design work for a new high voltage substation to feed 3. 3 KV services to the proposed new Experimental Hall No. 3 for NIMROD. Four medium voltage dry type packaged substations would be fed from the high voltage station.

The electronic and instrument repair section formed a separate section to deal with the maintenance and repair of the track analysis machines and bubble chamber data processing plant. This already showed that it was possible to reduce time lost on stoppages and to increase throughput in order to keep pace with the growing demands.

The electronics production unit was expanded to provide single items and batch production of electronic equipment totalling £100, 000 per annum. The average production time of a unit was about four weeks for conventional equipment, but might

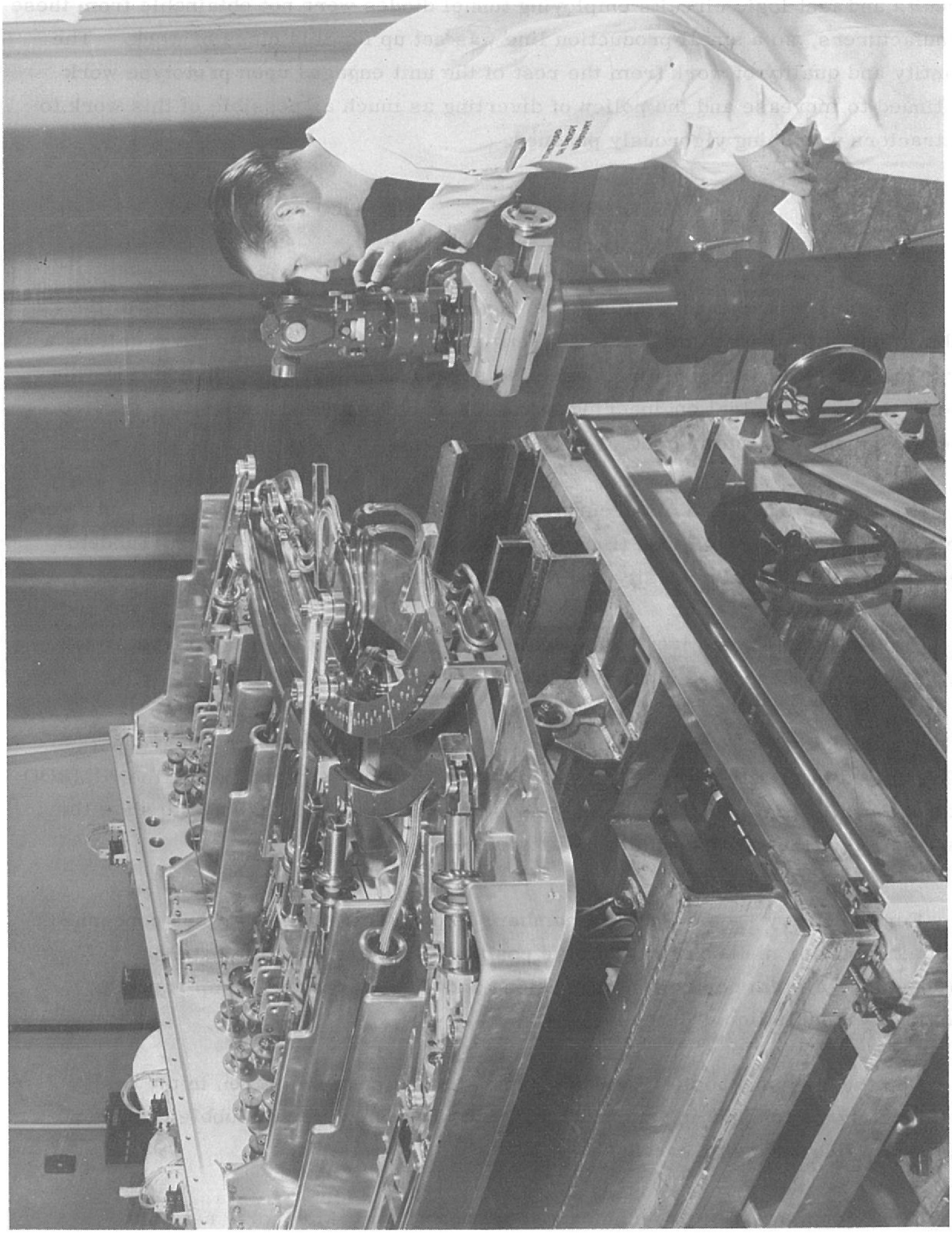

Figure 49. Precise alignment of components of the Variable Energy Cyclotron

be doubled where printed circuits were involved. A small design section was attached to this unit to re-arrange the circuits and draw up the printed circuit masters, and the manufacture was sub-let to six industrial firms. New techniques using integrated circuits and fast logic circuits employing tunnel diodes were not obtainable from these manufacturers, so a small production line was set up for this class of work. The quantity and quality of work from the rest of the unit engaged upon prototype work continued to increase and the policy of diverting as much as possible of this work to contractors was being vigorously pursued.

Mechanical Engineering

The group provides project engineering and design support to sections of the Laboratory which have limited attached engineering support. Projects requiring a large amount of engineering effort are also served by this group. In addition, the Group maintains central engineering statistics and provides an estimating service to ensure proper financial control of capital projects.

Projects which called for accurate positioning and alignment of components were the Variable Energy Cyclotron (figure 49) Heavy Liquid Bubble Chamber, Tandem Generator for Oxford University and Data Analysis equipment.

Close attention was given to the engineering problems of the Polarised Proton Target which is described elsewhere in this report.

A wide variety of stress problems were solved. In particular the group collaborated in the stress analysis associated with polar construction of the NIMROD alternators. This included adapting photo-stress analysis techniques to show the distribution of the stresses in the rotational parts.

For the Heavy Liquid Bubble Chamber, Laboratory engineers were concerned with air flotation methods to adjust the position of the magnet, the external nitrogen gas system controlling expansion, and the emergency "dump" system for the flammable liquid in the interest of safety.

For the Helium Bubble Chamber, general assistance was given in the design of the refrigeration system, support and handling gear, and the Bubble Chamber moving "wall" expansion arrangement.

The Group provided the engineering section of a working party set up to prepare a feasibility study on the proposal to use a separated orbit cyclotron as a NIMROD Injector.

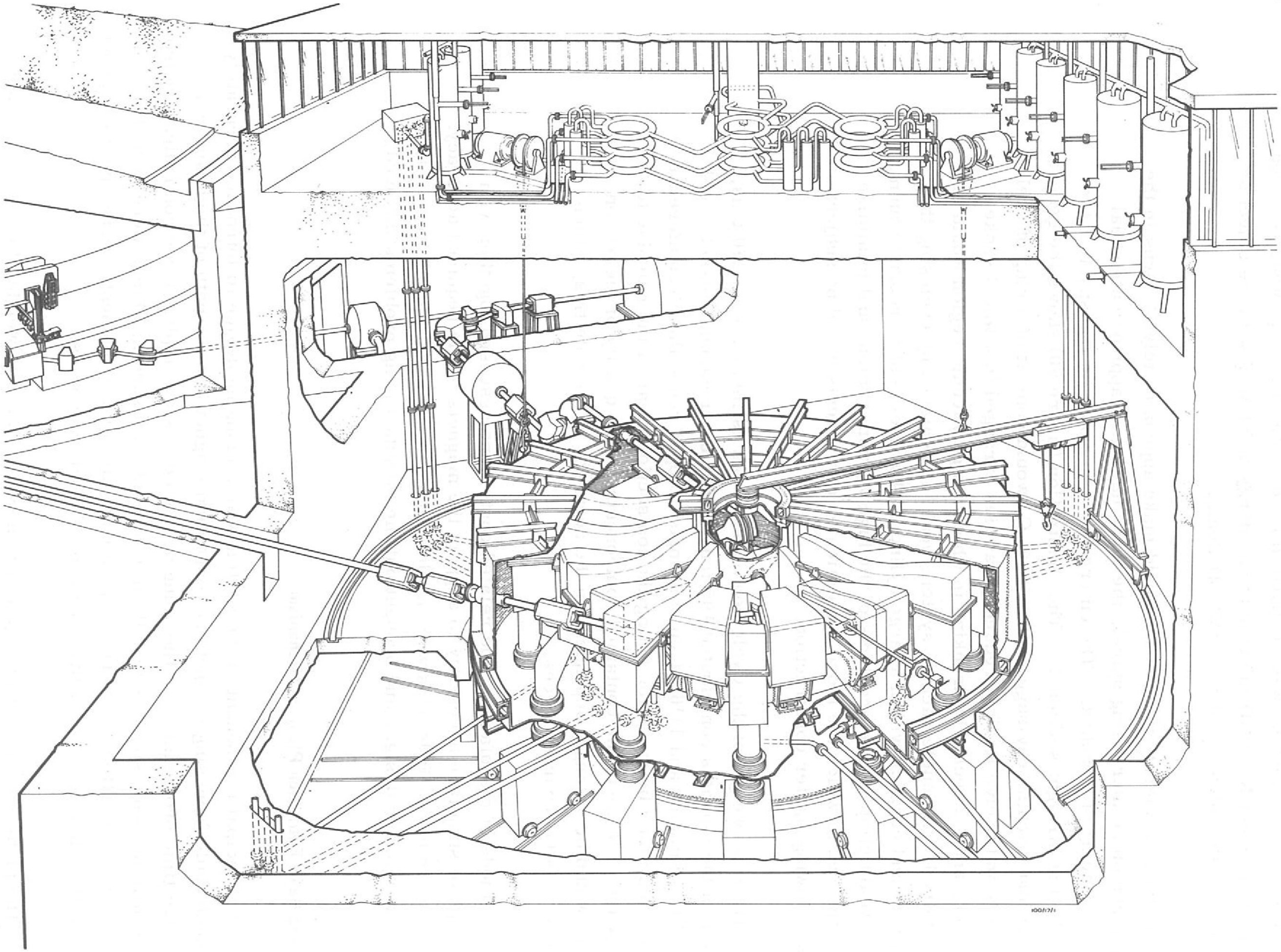

Figure 50. Proposed layout of the Separated Orbit Cyclotron

The S. O. C. machine was intended to accelerate 15 MeV protons received from the present NIMROD Injector to an energy of 70 MeV with the object of increasing the intensity of the NIMROD Beam.

During acceleration the beam would make approximately 17 turns in the cyclotron on an increasing spiral, the turns having an approximate equal radial spacing of 4 inches. The emergent beam would be transported into NIMROD at straight section 2. The illustration (figure 50) shows the general layout and machine envisaged. The S. O. C. would consist of a ring of twelve magnets and twelve Radio-Frequency cavities arranged in a wheel spoke manner, and connected by trunking in which a high vacuum region would be maintained. A double vacuum system would be achieved by enclosing the magnets and cavities within a large cylindrical vessel held at rough vacuum. This would simplify the problems of the high vacuum region, and minimise the stresses to which the more sophisticated components would be subject, thus allowing lighter construction.

The total weight of the Cyclotron booster was estimated to be 270 tons, of which the magnets contributed 195 tons. The outer vacuum vessel would be 37'6" diameter and 11'6" deep, arranged to open round the circumference. Provision would be made for lifting the top section clear of the machine to allow free access to the contained components. The quality of the proton beam would be strongly dependent on the accuracy of the pole tips, which numbered 400 separate pieces.

Methods of manufacture and related costs were assessed together with the type of structure necessary to support the magnets to the required accuracy. Test specimens of Pole Tips were made which demonstrated the practicability of the particular design, and brought out the manufacturing problems involved.

Nimrod Beam Extraction Plunging Mechanism

A principal component of the system was a plunging device to introduce accurately a quadrupole focussing magnet and extraction magnet into the path of the beam to a precise time programme. The plunging device was a complex servo controlled electro-hydraulic machine shown generally in figure 33. Two such machines were provided for operation in NIMROD, and a third for an intense development programme to improve reliability, long term stability, and control characteristics.

The plunging device was required to move a combined weight of one ton a distance of 20 ins. in 0.5 secs. The cycle was required to be accurately repeatable 30 times per minute, and be capable of continuous operation over long periods.

During 1965 two runs were carried out; one of 21 days duration at a repetition rate of 2,150 cycles/hr. and stroke time of 0.7 secs; and a second of 15 days duration at a repetition rate of 3,000 cycles/hr and stroke time of 0.4 secs. These runs involved a total of approximately 1 million cycles on each run, all of which were carried out at the full stroke of 20 inches. In all, some 3 million cycles were completed with stroke times down to 0.3 secs. and repetition rates as high as 3,600 cycles/hr.

The machine involved the development of a new type of pumped labyrinth vacuum seal, to seal the $5\frac{1}{2}$ ins. diameter shaft against high vacuum under these arduous operating conditions. The Plunging Mechanism is shown in figure 33.

Data Processing Equipment

During the latter part of 1965 members of the Group undertook design and commissioning of the mechanical parts of a cathode ray tube scanning device for spark chamber films in very close collaboration with Manufacturing Group. The machine required precise hydraulic positioning of the tables carrying the optical equipment used for locating and recording the position of tracks on photographs produced from spark chamber experiments. The work was successfully completed to meet urgent data processing needs.

Engineering Research

Research included tests on thin film windows. This work is related to the need for low density windows of good strength necessary for the containment of flammable liquids and gases under pressure. Tests on the various methods of mounting windows were carried out, and the failure stresses measured. Further work was continuing concerned with Cerenkov counters.

Thermal radiation and absorption studies were carried out on layered insulations at $80^{o}K$, the results being of particular value to assist design of various Cryostats, transfer lines for liquefied gases, and similar low temperature requirements.

Safety Section

The main function of the Section is to promote consciousness of the need for safety and accident prevention and to keep safety arrangements in the Laboratory under constant review.

The Section produced Codes of Practice which are regulations for certain equipment, procedures, and areas of the Laboratory, and also Safety Codes which contained recommendations and guidance. These documents covered various aspects of safety including mechanical, electrical, chemical, toxic, explosion and fire hazards.

The Laboratory's accident record had a lost time frequency rate for all staff of 0.24*. All accidents and dangerous occurrences are fully investigated to prevent their repetition and reduce any losses incurred by accidents.

Training

In conjunction with A. E. R. E. the Laboratory accepts 6 craft apprentices and 2 student apprentices each year, and at September 1965 the totals were 26 craft and 8 students. We are indebted to A. E. R. E. for their first year training and for the organisation of their later year's work. A high standard of intake has been maintained.

During the year 62 of the staff were allowed up to one day per week to continue their engineering training at local colleges of technology and a further 28 at evening classes were given assistance.

The Laboratory makes use of the various technical and managemental short courses run by A. E. R. E. and during the year 105 of the staff attended about 20 courses of varying duration between 1 and 10 days.

* Frequency rate = (No. of lost time accidents x 100, 000)/(No. of hours worked).

Publications by members of Engineering Division

Journal articles etc.

BOWLES, P.
Some engineering problems of the proton synchrotron Nimrod.
Electronics and Power, May 1965, pp. 155/159.

HADLEY, H.
Cables for Nimrod.
Electrical Distribution, January 1965, pp. 195/198.

SHELDON, R.
The automatic determination of heat deflection temperature.
Reinforced Plastics, February 1965, pp. 164/165.

Rutherford Laboratory Reports

COLYER, B.
Thermal radiation absorption of metals and layered insulations at $80^{O}K$.
NIRL/R/83.

HIGGINS, E. G.
The accurate alignment of the particle accelerator Nimrod.
NIRL/R/94.

MAJOR, J. H., SWAIN, J. H.
The plunging magnet system for the 'Nimrod'.extracted proton beam.
RHEL/R/117.

MIDDLETON, A. J.
Some pressure tests on circular and rectangular diaphragms of polyethylene terephthalate film.
NIRL/R/93.

PRICE, M. J., SHELDON, R.
The influence of structure on the post irradiation physical properties of epoxy resins.
RHEL/R/105.

SHELDON, R., CHAPMAN, C. E.
The measurement of radiation absorbed by particle accelerator structural components.
RHEL/R/106.

SHELDON, R., TINSLEY, D. M.
Studies in the use of amphipathic molecules as adhesion promoters between polar and non polar materials.
NIRL/R/77.

Rutherford Laboratory Safety Codes and Codes of Practice

RLSC3	"Fire Committee Recommendations for Buildings" Issue 2 August 1965.
RLSC4	"Secondary Cells". Issue 2 August 1965.
RLSC5	"Safety in the use of High Voltage Experimental Apparatus" Issue 2 August 1965.
RLSC7	"The repair of Drums or Tanks-Explosion and Fire Risks" Issue 2 August 1965.
RLSC8	"Instruction in the use of Self-Contained Compressed Air Breathing Apparatus". Issue 2 August 1965.
RLSC9	"Ladders, Steps and Trestles". Issue 2 October 1965.
RLSC10	"Safety in the use of Cryogenic Liquids".
RLCP3	"Prevention of Electrical Accidents". Issue 2 March 1965.
RLCP6	"Marking and Registration of Liquid Gas Dewars". Issue 2, August 1965.
RLCP7	"Safety in the use of Scaffolding and Staging". Issue 2 August 1965.
RLCP10	"Pressurised Equipment". Issue 1 May 1965.
RLCP12	"Custody of Poisons". Issue 1 January 1965.

Radiation Protection Group

The greater exploitation of NIMROD and the P. L. A. during the year has necessitated an expansion of existing radiation facilities and the development of new techniques.

The issue of film badges was extended to 800 $\beta\gamma$ films and 300 neutron films per month and a library of radioactive sources has been set up for the use of experimental teams. The calibration of radiation detectors used in the Laboratory is now carried out by means of a special calibration facility consisting of a variety of neutron and γ-ray sources and a 50 kev X-ray set mounted in a large scatter-free building. Portable β, γ monitors, ionisation chambers, quartz-fibre electroscopes and personal track film are among the many detectors calibrated regularly. In addition radiation monitors have been intercompared in the radiation fields found around the P. L. A. and NIMROD.

Many radiation measuring techniques and instruments were used and intercompared. In particular the personal track film calibration was found to be satisfactory, the neutron energy spectrum was investigated with the aid of threshold detectors, and lithium iodide scintillators were brought into use for routine surveys. The usefulness of the installed twin ionisation chamber instruments was increased by converting a number of them into self-contained transportable units with chart recorders for use in local control rooms and other critical and interesting points.

Radiation surveys on NIMROD showed the shielding around experiments and between the accelerator and the experimental halls to be satisfactory under all normal operating conditions. Shielding for the external proton beam was designed on the basis of existing data and tested by a shielding experiment.

Induced radioactivity was found to be primarily an external radiation hazard. Loose contamination was never a serious problem but precautions were required for the prevention and control of low level contamination arising from numerous engineering operations. The activity in concrete, iron and other materials was studied by gamma spectrometry. Survey measurements taken throughout the period showed that the build-up of long-lived isotopes was causing only a very slow increase in general radiation levels in the Magnet Hall.

The lack of an overall roof shield over the P. L. A. and its experimental areas has often meant that the machine's full available beam intensity has not been utilised for certain experiments without exceeding the statutory radiation levels at nearby uncontrolled areas and interfering with certain low level counting facilities at adjacent establishments. A system of permanently mounted radiation monitors was installed at various positions around the machine, reading out in the Control Room, to enable the operating staff to adjust the machine's output to a "safe" level.

The leakage radiation from the machine during operating periods was shown experimentally to consist mainly of fast neutrons, and that the "skyshine" component predominated for most locations outside the side shielding. The adequacy of available monitoring instruments and personal dosimeters to measure the leakage radiation was demonstrated and the basic data needed for shielding calculations was determined experimentally.

A systematic study has been started of the other major health physics hazard associated with accelerator operation - the induced radioactivity in machine components and experimental apparatus.

The radiation doses received during the period by staff within the Laboratory have been gratifyingly low - in most cases less than a tenth of the maximum permitted levels.

ADMINISTRATION DIVISION

The Administration Division is divided into four groups. The following statistical information gives an indication of the range of work undertaken. For the General Administration, Personnel and Scientific Administration groups the information refers to the calendar year 1965 but the financial statistics are given for the financial year 1st April 1965 to 31st March, 1966.

General Administration Group

In addition to the usual administrative services the group is responsible for the requirements other than scientific of the visiting experimental teams who carry out their research often at considerable distances from their home bases. During the year about 240 university and other visitors were actively associated with the Laboratory. Other information indicating the scale of operations of the group is given below.

Stores

Number of items stocked at Rutherford Laboratory	6,400
Number of issues from Rutherford Laboratory and A. E. R. E. (each issue covers an average of 2.5 different items)	28,000
Number of external receipts other than from A. E. R. E.	14,000
Value of Rutherford Laboratory stock	£40,000
Value of Rutherford Laboratory stock turnover	£100,000

Housing and Hostels

Rutherford Laboratory houses	100 unfurnished 5 furnished
AEA and Local Authority Houses (The extra 15 were to meet the peak caused by 50 staff returning from CERN)	120 + 15, all unfurnished
Number of placings during the year:	
Lodgings	41
The Coseners House Hostel	1050
AEA Hostels	90
Rutherford Laboratory furnished houses	22
AEA furnished houses	3
Privately owned houses or flats	25
Hotels	600

Restaurant

Total number of main meals served	186,615
Main meals served at weekends and evenings	20,215

Table 1. Details of staff in post

	Opening Strength 1965	New Entries	Resignations etc.	Promotions		Closing Strength 1965	Increase
				Into Classes	Out of Classes		
PROFESSIONAL							
Senior Staff	17		2	1		16	
Scientific Officer Class	65	1	8	4	1	61	
Fixed Term	28	14	7		3	32	
Experimental Officer Class	122	12	13	5	3	123	
Engineers I, II, III	73	3	5	6	1	76	
Assistant Design Engineers	26	1		1	2	26	
Total professional	331	31	35	17	10	334	1%
ANCILLARY							
Scientific Assistant Class	70	15	9	1	4	73	
Drawing Office Grades	16	11	3	1	1	24	
Technical Class	156	18	14	14	2	172	
Non-Technical Class	27		2	5	4	26	
Executive Class	25	2	1	1		27	
Clerical Class	44	8	5		1	46	
Secretarial and Typing Grades	32	6	10			28	
Stores Class	5	1		1		7	
Photographers	1	3				4	
Photoprinters	5		1			4	
Machine Operator Class	1	2				3	
Asst. Hostel Manageress	1					1	
Scanners	21	9	5			25	
Total Ancillary	404	75	50	23	12	440	9%
INDUSTRIAL							
Skilled	151	51	35		12	155	
General Workers	109	62	30		6	135	
Apprentices	28	7	3			32	
Total Industrial	288	120	68		18	322	11%
GRAND TOTALS	1023	226	153	40	40	1096	7%

Personnel Group

The staff in post at the beginning and end of the year and the movement of staff are shown in Table 1.

The closing strength of Divisions at 31st December, 1965 is shown in table 2.

Table 2. Closing strength at 31st December, 1965 by divisions

	Professional	Ancillary	Industrial	Totals
Nimrod	102	126	92	320
High Energy Physics	48	44	7	99
Applied Physics	60	36	7	103
Proton Linear Accelerator	45	39	23	107
Engineering	52	61	103	216
Administration	6	119	58	183
Electrostatic Generator Group	9	3	3	12
Radiation Protection	6	5		11
Training	3	7		10
Apprentices			32	32
Non Group	3			3
	334	440	322	1096

Staff Relations:

During the period covered by the report, the Science Research Council Whitley Council and the Rutherford Laboratory Whitley Committee were set up. The first meeting of the latter was held on 4th December 1964, and there were three meetings in 1965. On the Trade Union side the Rutherford Laboratory Consultative Committee met six times. In both committees a wide range of topics was discussed to the general advantage of both employees and management.

Finance and Accounts Group

Rutherford Laboratory expenditure for the financial year 1965/66 in £M.

Staff Expenditure			1.67
Divisional Budgets -	Nimrod	.66	
	High Energy Physics	.66	
	Applied Physics	.48	
	Proton Linear Accelerator	.22	
	Engineering: see Note 1	.73	
	Administration: see Note 2	.64	3.39
University Agreements			.20
Plant Budgets			.34
Plant Schemes			.21
Building Works			.11
Total: see Note 3			5.92
Total recurrent expenditure			4.85
Total capital expenditure			1.07
			5.92

Notes:

1.	Includes	Electricity	.31
		Site Services	.11
		A.E.A. Inspection etc.	.03
2.	Includes	Rates	.05
		Misc. A.E.A. charges	.12
		Travel & Subsistence	.10
		Advertising	.03
		Telephones etc.	.04
		Housing, Restaurant etc.	.07

3. With the exception of 1.67M for staff, this expenditure resulted from 20,500 invoices etc. and during the year 18,500 commitments were recorded.

Scientific Administration Group

University Research Agreements

During the year under review the Laboratory managed research agreements with the Universities of Birmingham; Bristol; Cambridge; Durham; Glasgow; London:- Imperial College, King's College, Queen Mary College, University College and Westfield College; Manchester; Oxford; The Queen's University of Belfast; Southampton; Battersea College of Technology (the proposed University of Surrey).

The following list shows the numbers of agreements in force at the beginning and end of 1965, classified according to the type of research.

Classification	1 January 1965	31 December 1965
Experiments with NIMROD	22	28
Experiments with the P. L. A.	7	8
Extra-mural-research	15	13
Capital Projects	4	1
Major Film Analysis Projects	1	3
Totals	49	53

Conferences

The main task was the organisation of the International Conference on Elementary Particles held at Oxford from 19th-25th September, 1965. This was the third in the European biennial series; the previous ones being at Aix-en-Provence in 1961 and Sienna in 1963. The Conference was sponsored by the Foreign Office, the Department of Education and Science, and the Science Research Council. A total of 552 participants from 31 countries attended, together with 71 observers and about 100 associates.

Visitors

During the year 714 visitors were shown around the Laboratory. The tours were usually preceded by an introductory talk and the showing of a film about the work of the Laboratory.

In addition a special "open day" was arranged for about 200 participants from the Oxford International Conference on Elementary Particles.

A press reception for about 80 visitors was also arranged in collaboration with the manufacturers of the refrigeration plant for the Helium Bubble Chamber.

Mobile Exhibitions

During the year arrangements were made with 11 firms to visit the Laboratory and exhibit specialised equipment of interest to our technical staff. These visits were usually of one day duration.

Library

Loan Transactions:	Internal:	Books	1869
		Periodicals	1874
		Reports	973
			4716
	External		893
	Total		5609

Reciprocal arrangements exist with 89 institutions in 15 countries for the exchange of report and preprint literature.

The Library Stock at the end of 1965 was:

4500 Books (vols)
400 Pamphlets
5000 Reports & Preprints
2700 Photographs
900 Slides
700 Press Cuttings
350 Periodicals (currently taken)

Approximately 400 books and 2100 reports and preprints were added during the year.

The P. L. A. Library had 550 books and took 33 periodicals.

The Atlas Library had 400 books and took 20 periodicals.

Documentation

Number of Rutherford Laboratory Reports issued	30
Number of Rutherford Laboratory Preprints issued	32

available from
Her Majesty's Stationery Office
49 High Holborn London WC1
423 Oxford Street London W1
13a Castle Street Edinburgh 2
109 St Mary Street Cardiff
Brazennose Street Manchester 2
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