RHEL/R 160

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Rutherford Laboratory Report

The Work of the Rutherford Laboratory in 1967

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Science Research Council

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Rutherford High Energy Laboratory
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May 1968

The Rutherford Laboratory from the south-west

Nimrod is located under the grassed mound to the left of centre, with the site of the new Experimental Hall 3 extending towards the foreground. The centre is occupied by general office, laboratory and workshop accommodation. The Proton Linear Accelerator is housed in the cluster of buildings on the extreme left, and at the top of the picture can be seen the SRC's Atlas Computer Laboratory.

Contents

Summary

This is the third in the series of Reports on the work of the Rutherford High Energy Laboratory; it covers the calendar year 1967.

The high energy physics research programme has again been a full one, with 7 experiments completed during the year, 7 continuing and 8 new experiments being started. Among the results obtained was supporting evidence, from Ke_2 decays, for the (V - A) weak interaction theory, and branching ratios for η decay that suggest no significant C violation in this process. The elastic scattering programme continues to provide better cross-section data.

The 80 cm Hydrogen Bubble Chamber has now returned to Saclay after three years at the Laboratory, during which time nearly 5 million pictures were taken for seven experiments. The 150 cm British National Hydrogen Bubble Chamber completed a re-commissioning run, following extensive modifications after its return from CERN, and the 80 cm Helium Chamber completed its first experiment. Film processing facilities have been expanded and improved. Experiments using electronic techniques have made increased use of the Miniature Logic ("Tunnel") System and also of small local computers for monitoring and data acquisition.

Beams were available from Nimrod for 3723 hours, with an average beam intensity of $1{\cdot}2 \times 10^{12}$ protons per pulse. The fracture of an alternator rotor support bolt (not a recurrence of the 1965 breakdown) affected operations during the last quarter of the year. A new beam line layout with several lines fed from one target in the X2 extracted proton beam has improved the utilisation of the floor space in Experimental Hall 1. The construction of Hall 3 is proceeding well and, when commissioned in early 1969, will double the area available for experiments.

The PLA has once again achieved a record operational year with over 5800 hours of beam-on time (90% availability). Modifications to allow operation with 600 μs beam bursts at 25 pulses per second have enhanced the duty cycle, and the energy spread has been reduced to less than 0·1% FWHH. 14 experiments were run during the year, with the polarized beam and the magnetic spectrometer both in frequent use. The PLA is to be closed down in October 1969 (it may then be used as an injector for Nimrod), following a Nuclear Physics Board survey of the U.K. contribution to nuclear structure physics.

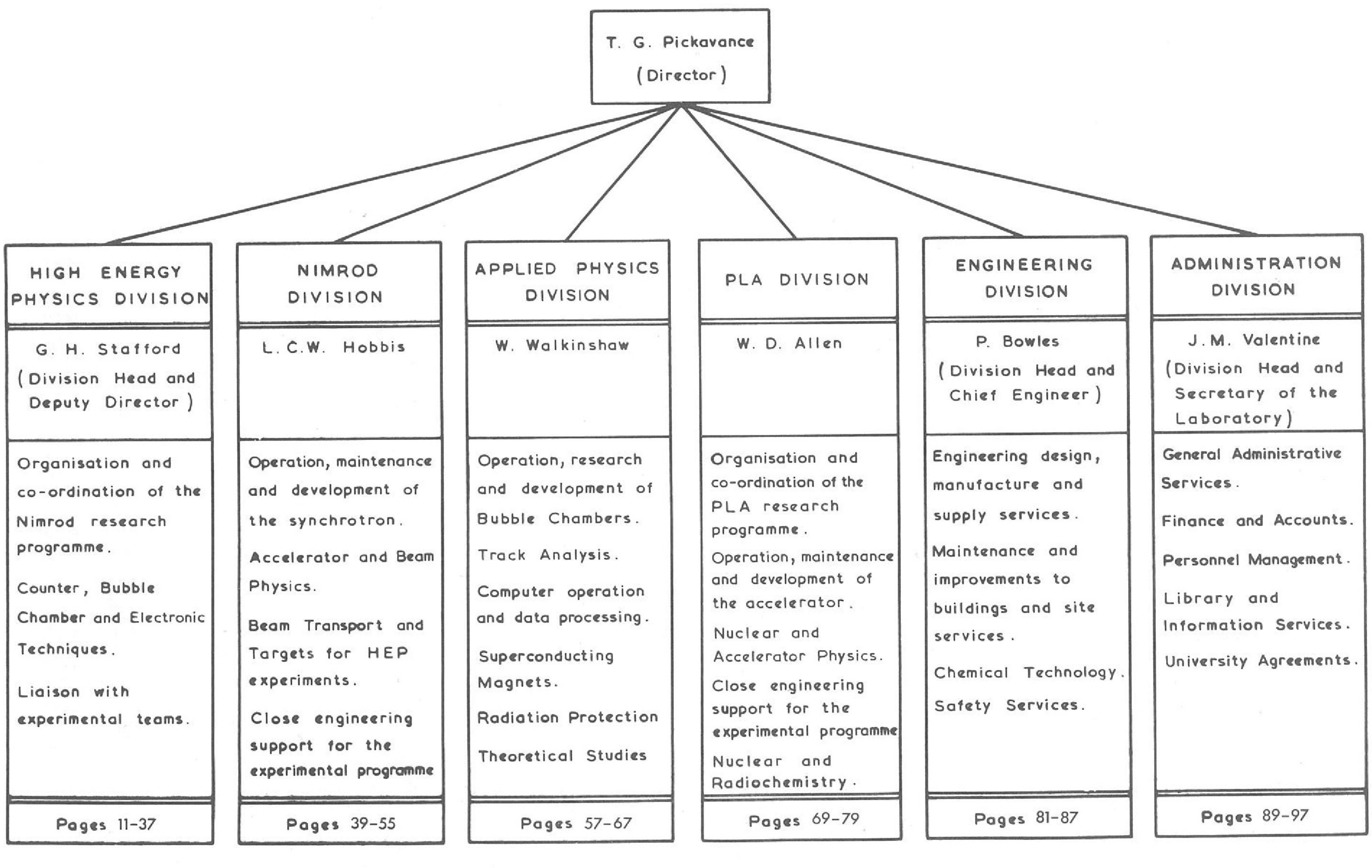
The Laboratory's new central computer (an IBM 360 Model 75) became fully operational and now provides a fast and efficient batch job service. Film measuring machines are also connected to it, on-line via a DDP 224, and plans are well advanced for real-time data processing for certain experiments on Nimrod.

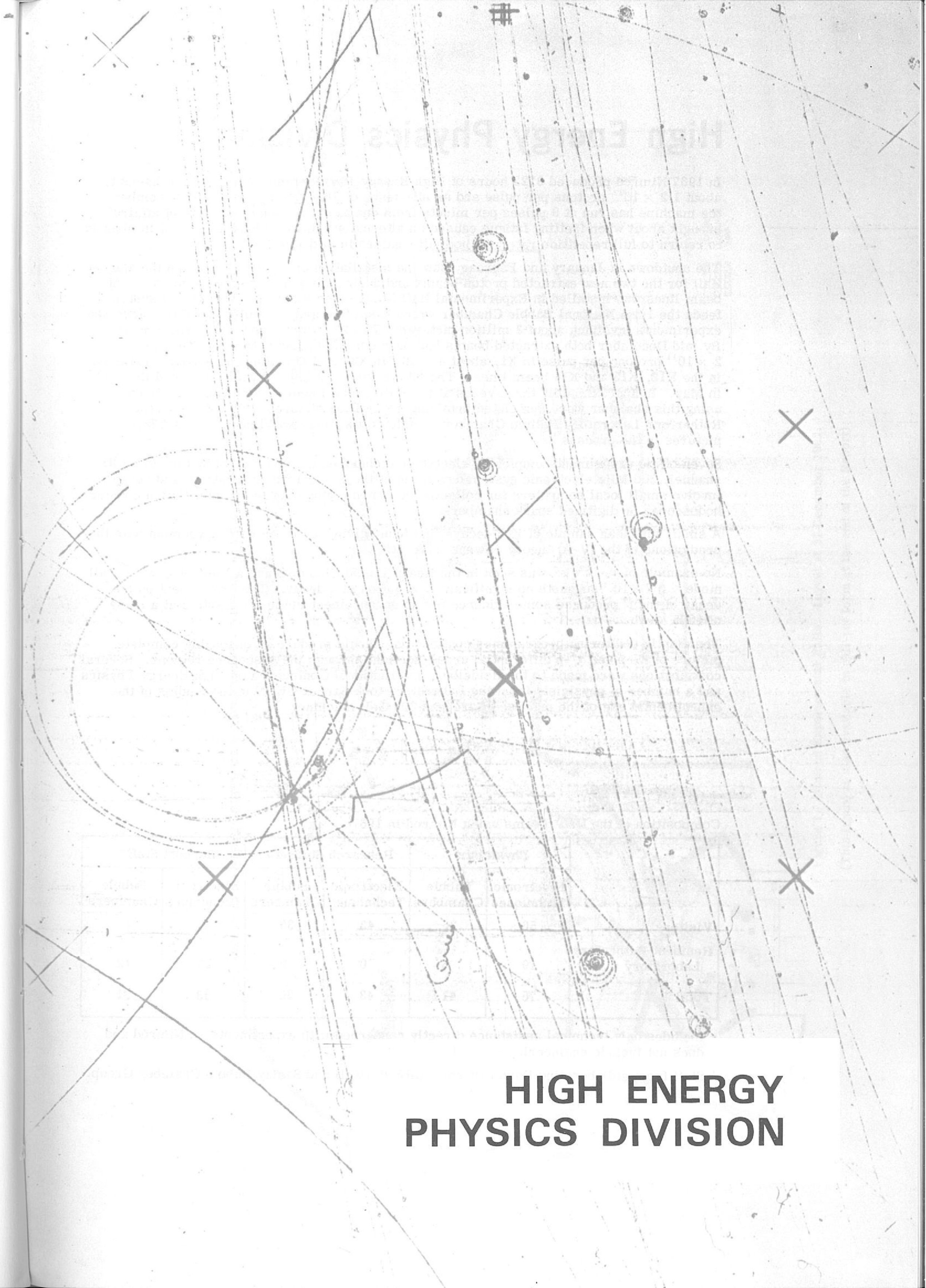
A superconducting beam bending magnet has been designed. Superconductors are also proposed for the High Field Bubble Chamber, for which design and utilisation studies have been carried out.

Engineering support services have been provided, as hitherto, for the whole of the Laboratory's activities, a major task being the development of extraction system components for Nimrod. The Laboratory organised, and published the proceedings of, the 2nd International Magnet Technology Conference at Oxford in July.

This summary highlights only a few of the years events, which are described in greater detail in the sections of this Report devoted to the work of the various Divisions. An organisational chart will be found overleaf, and a list of publications is included at the end of the Report.

RUTHERFORD LABORATORY ORGANISATION CHART





HIGH ENERGY PHYSICS DIVISION

High Energy Physics Division

In 1967 Nimrod produced 3723 hours of High Energy Physics time at an average intensity about $1{\cdot}2 \times 10^{12}$ protons per pulse and an efficiency of 78%. Since the end of November the machine has run at 9 pulses per minute from one alternator only – a state of affairs brought about when fretting fatigue caused an alternator failure in September. It is planned to return to full repetition rate with both alternators in mid 1968.

The shutdown in January and February saw the installation of the components in the Magnet Hall for the two new extracted proton beams and during the year a completely new set of beam lines was installed in Experimental Hall No. 1 – see figure 1. The X1/K9 system feeds the 1·5m National Bubble Chamber which has a forward committment of five accepted experiments involving about 3 million pictures. The X2 system feeds five experiments. By mid December both extracted beams had been commissioned with intensities about 2×10^{11} protons per pulse in X1, about 4×10^{11} in X2, and simultaneous setting up started in the K12, K13 and K14 beam lines. The 80 cm Saclay Bubble Chamber finished its run in May. In approximately three years at the Rutherford Laboratory seven experiments using this chamber were completed involving 4·9 million pictures. The 80 cm Oxford-Rutherford Laboratory Helium Chamber completed its first experiment, taking 772,000 pictures in the process.

Seven of the experiments employing electronic techniques use the Tunnel System (a multi-channel, 200 MHz electronic system developed at the Rutherford Laboratory) and seven involve small local computers for collecting and monitoring data from scintillation counter hodoscopes or digitized spark chambers.

A small but clean sample of Ke2 decays was found giving a rate in good agreement with the predictions of the (V-A) theory of weak interactions.

No example of $\eta \rightarrow \pi^0 e^+ e^-$ was seen in the Heavy Liquid Chamber and a limit of $\eta \rightarrow \pi^0 e^+ e^-$/all mode $< 3{\cdot}7 \times 10^{-4}$ suggests no significant C violation in η decay. The experiment on the decay of the f^0 produced some evidence for an enhancement in the $\pi^+\pi^-$ system at a mass of 1085 MeV.

The elastic scattering programmes continue and should produce a reasonably complete picture of K^+-p and π^+-p differential cross-sections through the resonance regions. Several contributions were made to the Heidelberg International Conference on High Energy Physics and a number of physicists from the Laboratory took part at CERN in the studies of the experimental use of the proposed European 300 GeV machine.

TABLE 1

Composition of the HEP Teams using Nimrod in 1967

	Physicists		Research Students		Support Staff*	
	Electronic Techniques	Bubble Chambers	Electronic Techniques	Bubble Chambers	Electronic Techniques	Bubble Chambers
Visitors⁺	56	36	43	36	10	19
Resident Rutherford Laboratory staff	19	5	0	0	23	12
Total	75	41	43	36	33	31

* Includes only technical assistance directly concerned with experiments on Nimrod and does not include engineering support.

⁺ Staff from collaborating Universities, AERE Harwell and Saclay Bubble Chamber Group.

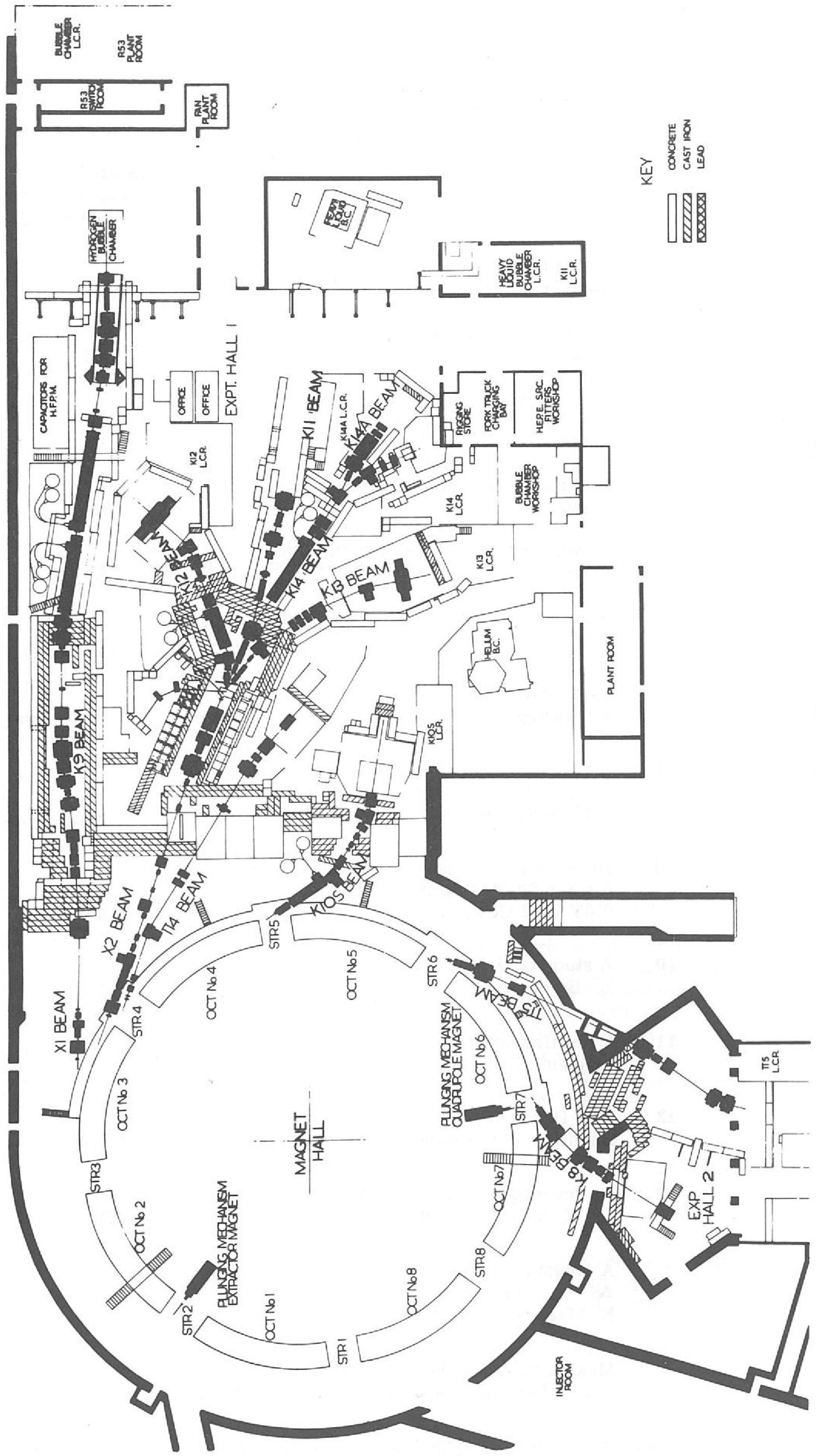


Figure 1. Nimrod Experimental Halls. Layout at 31 December 1967.
(This figure is also available in pull-out form at the end of the Report).

Experiments at Nimrod

ELECTRONIC TECHNIQUES

Number	Experiment	Beam Line (see Fig. 1 where applicable)	Status of Expt. December 1967
1	π^+p Differential Cross Section Measurements.	π2	Completed
2	$K^\pm$ and $\pi^\pm$ Nucleon Total Cross-sections from 600 to 2650 MeV/c.	K6	Completed
3	A Study of the Angular Distributions of the Charged Decay Modes of the f^0 Meson.	P3	Completed
4	A Study of the Leptonic Decays of K^+ Mesons.	K4	Data taken
5	A Measurement of the Ke2 Branching Ratio.	K4	Completed
6	A Measurement of the Partial Width for the Decay of $\phi^0 - e^+ + e^-$.	ϕ1	Data taken
7	Polarization Effects in π^-p and K^-p Scattering.	K7	Completed
8	A Measurement of the Polarization of the Σ^- Produced in π^-p Collisions at 1·13 GeV/c using a Polarized Target.	K7	Completed
9	Differential Cross-section Measurements for K^-p Scattering in the Range 0·85 - 2·2 GeV/c.	K8	Setting up
10	A study of the β-decay of the Σ^--Hyperon.	π4	Setting up
11	π^-p Differential Cross-sections for Momenta 1·5 - 3·5 GeV/c.	π5	Setting up
12	$K^\pm$p Differential Cross-sections for Momenta in the Range 0·45-0·85 GeV/c.	K12	Setting up
13	An Investigation of K^-p - Neutral States for K^- Momenta of 0·6 - 1·8 GeV/c.	K10S	Setting up
*	A Measurement of the Amplitude for $\Delta S = -\Delta Q$ Interactions in the Decay of K^0 Mesons.	K13	Setting up
*	Measurement of the Non-Leptonic Decay Parameters for the Σ^+.	K14	Setting up

* These experiments began setting up very late in 1967 and no progress report has been submitted.

BUBBLE CHAMBERS

Number	Experiment	Beam Line (see Fig. 1 where applicable)	Status of Expt. December 1967
14	A Study of the Decays of η Mesons Produced in the Heavy Liquid Bubble Chamber.	P3X	Completed
15	Single and Double Pion Production in pd Collisions at 2 GeV/c.	K1	Analysis
16	A Survey of π^+p Interactions in the range 0·6 - 1·05 GeV/c.	K1	Analysis
17	A Study of K^-p Interactions in the range 1·25 - 1·85 GeV/c.	K1	Analysis
18	A Study of K^-d Interactions in the region of 1·5 GeV/c.	K1	Analysis
19	A Survey of π^-p Interactions in the region of 0·5 GeV/c.	K1	Analysis
20	A Study of Coherent Scattering Processes in the Helium Bubble Chamber.	K15	Analysis
*	A Study of the Hyperon-Nucleon Interaction in the 1·5m Hydrogen Bubble Chamber.	K9	Setting up

* These experiments began setting up very late in 1967 and no progress report has been submitted.

Experiment 1

$\pi^\pm$p Differential Cross-Section Measurements

UNIVERSITY COLLEGE, LONDON
WESTFIELD COLLEGE, LONDON

The analysis of this visual spark chamber experiment which was described in detail in the 1966 Annual Report (Experiment 3) has now been completed. Out of some half-million photographs taken, about 120,000 were selected for measurement and detailed analysis, yielding over 50,000 elastic events. These events were due to both positive and negative pions at 10 different momenta in the range 1·72 to 2·80 GeV/c. A consideration of the π^- differential cross-sections showed that $G_{7/2}$ or $H_{9/2}$ waves (or both) were probably resonating in the region of the resonance $N^*_{1/2}$ (2190). The π^+ data suggests a tentative assignment of $H_{11/2}$ to the resonance $N^*_{3/2}$ (2420), corresponding to the second recurrence of the Δ_δ Regge trajectory.

Experiment 2

$K^\pm$ and $\pi^\pm$ Nucleon Total Cross-Sections

UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF CAMBRIDGE
RUTHERFORD LABORATORY

The aims and techniques of this experiment were described in the 1966 Annual Report (Experiment 4). The analysis of the data is now complete, and results have been submitted for publication.

Measurements have been made on K^- at 58 momenta at intervals of 25 - 50 MeV/c in the range 600 - 2650 MeV/c. The experimental accuracy is better than 1% above 700 MeV/c, and the momentum resolution of the beam is ±0·6%. The K^-p total cross-section and those for isotopic spin states I = 1 and 0 are shown in figures 2 and 3 and nine resonances are clearly in evidence, Y_1^* (1660; 1765; 2020; 2290; 2455) and Y_0^* (1695; 1815; 2100; 2340), and a detailed fitting of the data suggests the possible presence of two more, Y_1^* (1905) and Y_0^* (1865). These resonances promise to be a rich field for study in the next few years. The Y_0^* (1695) was first observed in this experiment.

The results of measurements with K^+ and $\pi^\pm$ are less dramatic, but equally useful for detailed analysis. The K^+ measurements have an accuracy of about 1% and confirm the existence of small peaks in the hydrogen and deuterium cross-sections at about 1·2 GeV/c. The π measurements (0·46 - 2·67 GeV/c) have a relative accuracy between neighbouring points of ±0·1% in cross-section and ±2 MeV/c in momentum; the overall systematic errors are about ± 0·5% in cross-section and ± 0·5% in momentum scale over most of the range. No new structure is observed but the measurements clear up some major discrepancies between earlier sets of data over the momentum range 0·5 to 1·3 GeV/c. Measurements of $\pi^\pm$ cross-sections on deuterium reveal two interesting points: (1) the π^- cross-section is systematically about 1% larger than the π^+, probably because of Coulomb effects[1], (2) the Glauber theory which has been used for a decade to calculate the shadowing of one nucleon by the other in the deuteron, does not appear to be adequate in the resonance region.

As a by product of the experiment a detailed study has been made of K^- and π^- yields at low momenta from copper and uranium targets of different lengths, over the angular range 0° to 15°. The maximum yield for long targets occurs at about 7° and it has been shown that this may be understood in terms of reabsorption of secondaries in the target. Appreciable yields of antiprotons, about 1 per 10^4 pions, were found around 2 GeV/c.

[1] Bugg D.V., Cottingham N. The effects of the Coulomb barrier on nuclear interactions at high energies. RPP/H 30.

Experiment 3

The Angular Distributions of the Charged Decay Modes of the f^0 Meson

AERE, UNIVERSITY OF SOUTHAMPTON
UNIVERSITY COLLEGE, LONDON
RUTHERFORD LABORATORY

This experiment was briefly outlined in the 1966 Annual Report (Experiment 6). The analysis of data collected in 1966 has continued during 1967. Figure 4 shows the missing mass distribution obtained in the reaction $\pi^- + p \rightarrow n + MM$ for incident momenta between 3·1 and 3·7 GeV/c. The solid line is a least squares fit to the data using a Breit-Wigner resonance form plus a polynomial background shown dotted. The mass and width of the f^0 resonance given by this analysis are 1270 ± 15 MeV and 160 ± 20 MeV respectively.

The angular distribution of events between 1200 and 1300 MeV decaying into $\pi^+ + \pi^-$ is given in figure 5, where θ^* is the angle between the π^- in the f^0 rest frame and the incident direction. Attention is drawn to the flat central region contrasting markedly with the enhancement to be expected in this region for a pure J-spin = 2 state. Analysis in terms of the Adair constraint where the angular distribution function contains only spin-flip and spin non-flip terms yields confidence levels ≪ 0·1% and indicates that a simple spin description is not sufficient. An analysis in terms of spin density matrix elements[1] gives the results shown in column two of Table 2.

TABLE 2 Spin density matrix elements for the decay of the f^0 into $\pi^+\pi^-$

	Present Expt. $\pi^-p \rightarrow n f^0$ 3·1 - 3·6 Gev/c	$\pi^+p \rightarrow N^{*++} f^0$ 8 Gev/c	$\pi^-p \rightarrow n f^0$ 4 Gev/c	$\pi^-p \rightarrow n f^0$ 3·7 Gev/c	$\pi^+d \rightarrow pp f^0$ 6 Gev/c
ρ_{00}	0·93 ± 0·07	0·85 ± 0·10	1·01 ± 0·20	0·64 ± 0·07	0·92 ± 0·10
ρ_{11}	0·27 ± 0·02	0·19 ± 0·04	0·21 ± 0·09	0·29 ± 0·06	0·27 ± 0·03
ρ_{22}	-0·24 ± 0·02	-0·12 ± 0·06	-0·22 ± 0·09	-0·11 ± 0·06	-0·23 ± 0·04

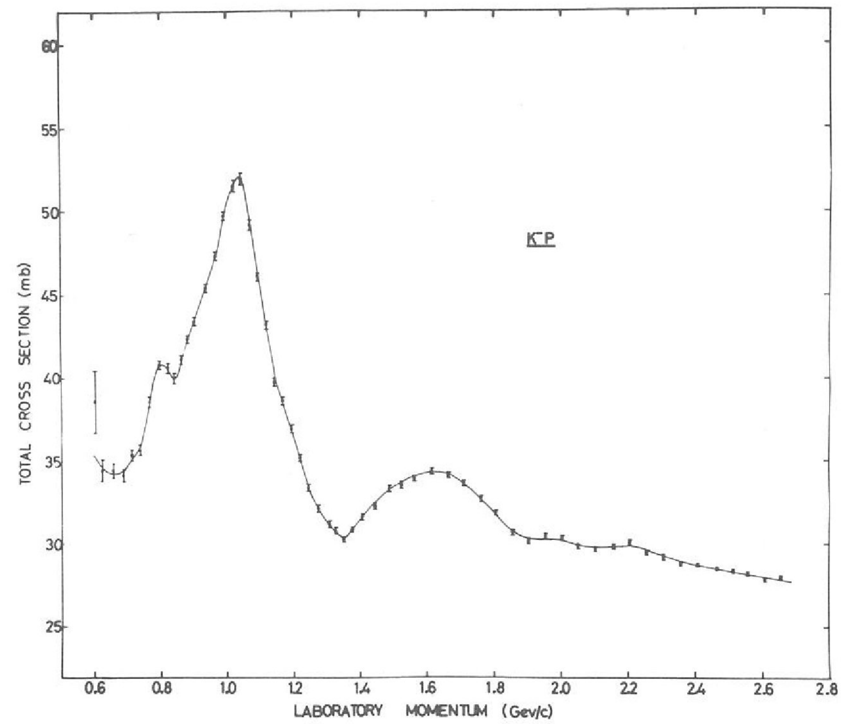


Figure 2. Total cross-sections of K^- on protons. The continuous curve is fitted by eye to the data and is used in extracting K^-n and I = 0 cross-sections.

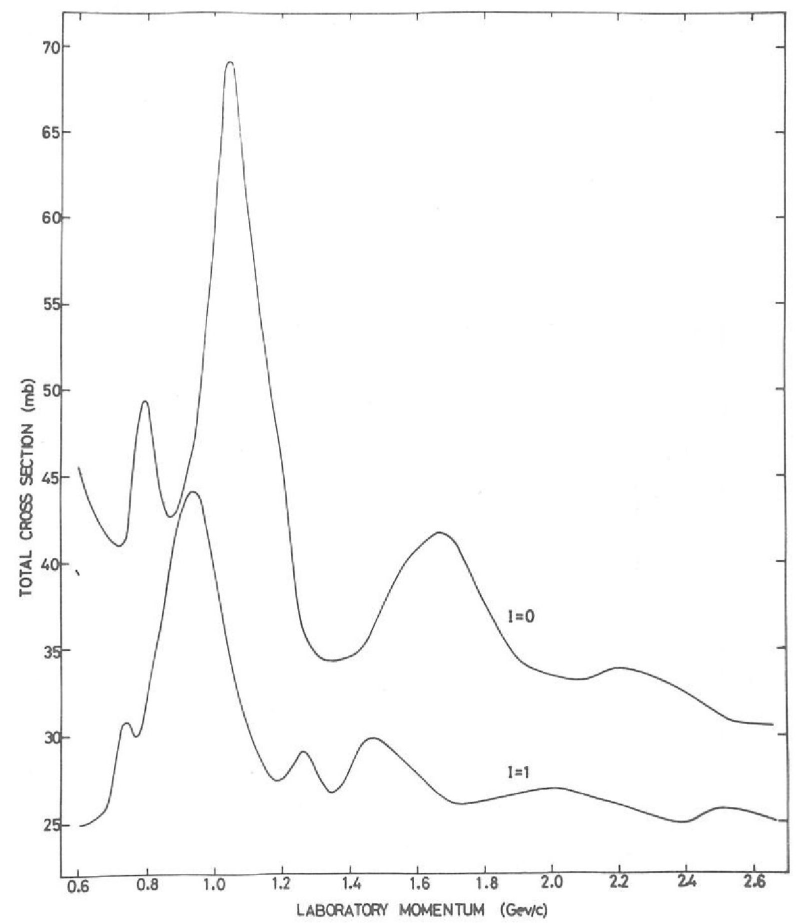


Figure 3. Total cross-sections for K^-N interactions in I = 1 and I = 0 states. The effects of Fermi motion have been unfolded.

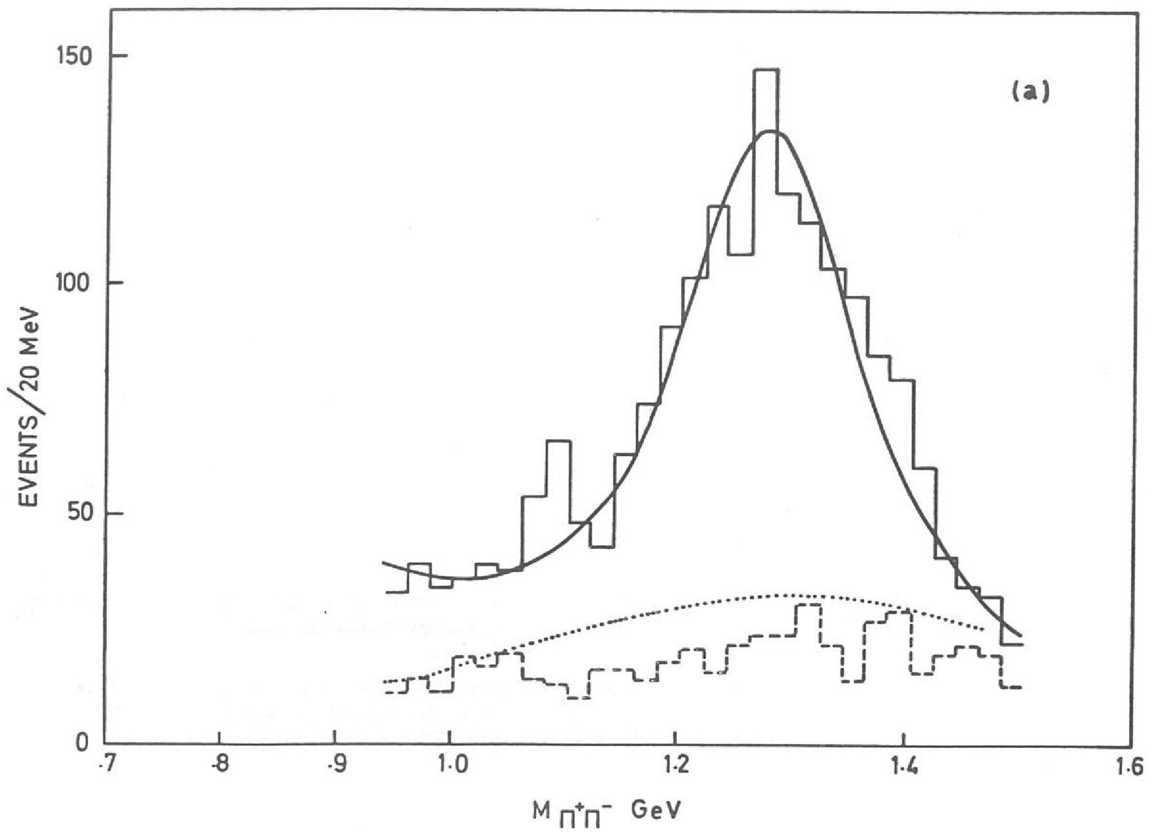


Figure 4. Distribution of $M_{\pi\pi}$ for the reaction $\pi^- + p \rightarrow n + \pi^+ + \pi^-$. The solid line is a least squares fit to the data using a Breit-Wigner resonance form plus a polynomial background term.

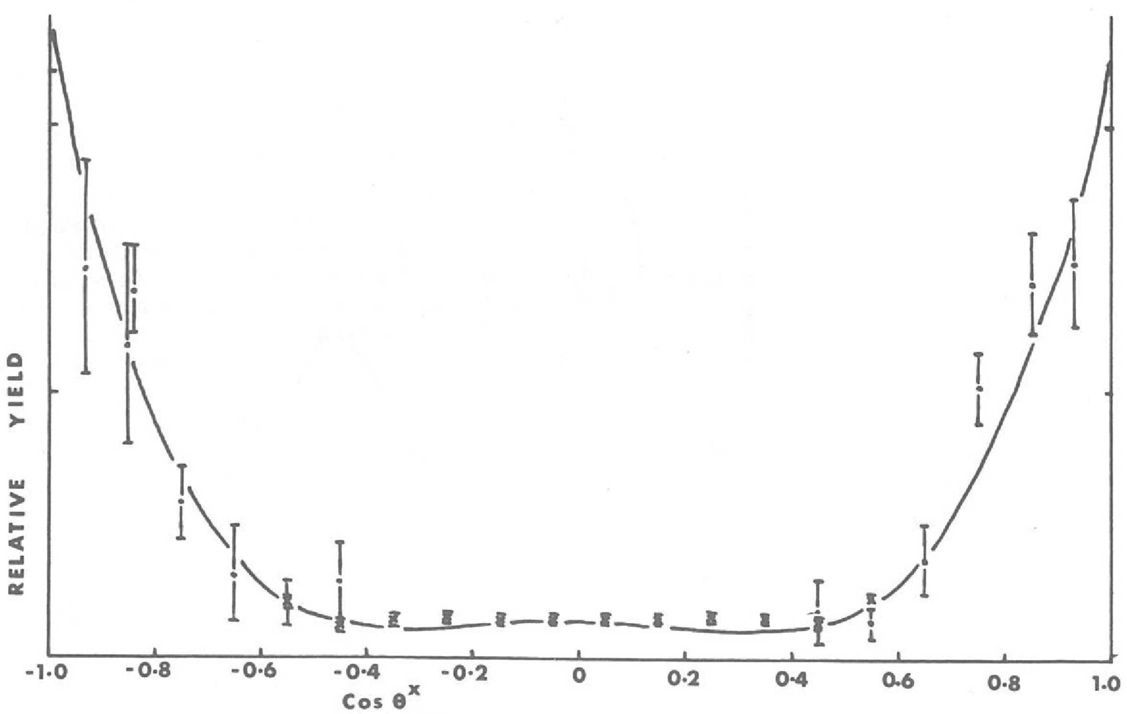


Figure 5. Angular distribution of events $\pi^- + p \rightarrow n + \pi^+ + \pi^-$ for events with missing mass between 1200 and 1300 MeV.

Columns three to six give the results from references 1, 2, 3 and 4 respectively. The negative value of ρ_{22} corresponds to the observations of far fewer events at values near cos $\theta^* = 0$ than expected from a pure J-spin = 2 state. This anomaly is ascribed to interference with a non-resonant S-wave background[1,2].

Attention is drawn to the enhancement at 1085 MeV shown in figure 4. This enhancement forms a 3·5 standard deviation effect above a smooth background with the best fit value for the peak of 1085 ± 10 MeV and the width ≤ 25 MeV with 70% confidence. A detailed analysis of our data and comparisons with previous experiments indicate an I = 0 assignment for this resonance. Detailed cross-section arguments based on the present data although not favouring J-spin zero do not strongly conflict with this assignment unless the width is appreciably less than the upper limit of 25 MeV. In summary the favoured description of this resonance is: Mass 1085 ± 10 MeV, $\Gamma \leq 25$ MeV, I = 0, J probably 0.

[1] Aachen-Berlin-Cern Collaboration. Phys. Lett., **22** (4) 533 (September 1966)

[2] Aachen-Birmingham-Bonn-Hamburg-London (I.C.)-Munich Collaboration. Phys. Lett., **5** (2) 153 (June 1963)

[3] Lee Y.Y., Roe B.P., Sinclair D., Vander Velde J.C. Phys. Rev. Lett., **12**, (12) 342 (March 1964)

[4] De Rosny G., Fleury P. Nuovo Cim., **48A** (4) 1137 (April 1967)

Experiment 4

The Leptonic Decay Modes and a Radiative Decay Mode of the K^+ Meson

UNIVERSITY OF OXFORD

This experimental study of the decay modes $K^+ \rightarrow e^+\pi^0\nu$, $\mu^+\pi^0\nu$, and $\pi^+\pi^0\gamma$ was described in the 1966 Annual Report (Experiment 7). The analysis of the data has continued during 1967, and is concerned with the following experimental measurements:

(1) the electron momentum spectrum in the Ke3 mode;

(2) the branching ratio for the Ke3 mode;

(3) the relative branching ratio of the Kμ3 and Ke3 modes;

(4) the branching ratio for the $\pi^+\pi^0\gamma$ mode, and the γ - π^+ angular correlation;

(5) the π^0 energy spectra in the Kμ3 and Ke3 modes;

(6) the three components of the μ^+ polarization in the Kμ3 mode.

The first two sections of the analysis have been completed. The electron momentum spectrum for 17,000 events is shown in figure 6c. It is in good agreement with the prediction for pure vector coupling at a 90% confidence level, the allowed relative intensities for scalar and tensor coupling are 0·10 and 0·02 respectively. In this experiment, the Ke3 branching ratio is found to be 0·0492 ± 0·0021, a result which leads to substantial improvement and clarification in the world average value. The measurement of this branching ratio is an essential link in the testing of the $\Delta I = \frac{1}{2}$ rule in semileptonic weak interactions.

If it is assumed that in addition to the $\Delta I = \frac{1}{2}$ amplitude $a_{1/2}$ there exists an amplitude $a_{3/2}$ associated with a CP invariant $\Delta I = 3/2$ quartet of currents, comparison of the absolute rate for Ke3 decay with the world average value, of the absolute rate for $K^0_L \rightarrow e^{\pm}\pi^{\mp}\nu$ (at the time of the 1967 Heidelberg Conference) strongly supports the hypothesis $a_{3/2} \neq 0$.

Parts 3 and 4 of the analysis are nearing completion and parts 5 and 6 will also be completed in 1968.

Experiment 5

The Ke2 Branching Ratio

UNIVERSITY OF OXFORD

The branching ratio for the Ke2 decay, $K^+ \rightarrow e^+ + \nu_e$, has been measured relative to the branching ratio for the Kμ2 decay, $K^+ \rightarrow \mu^+ + \nu_\mu$.

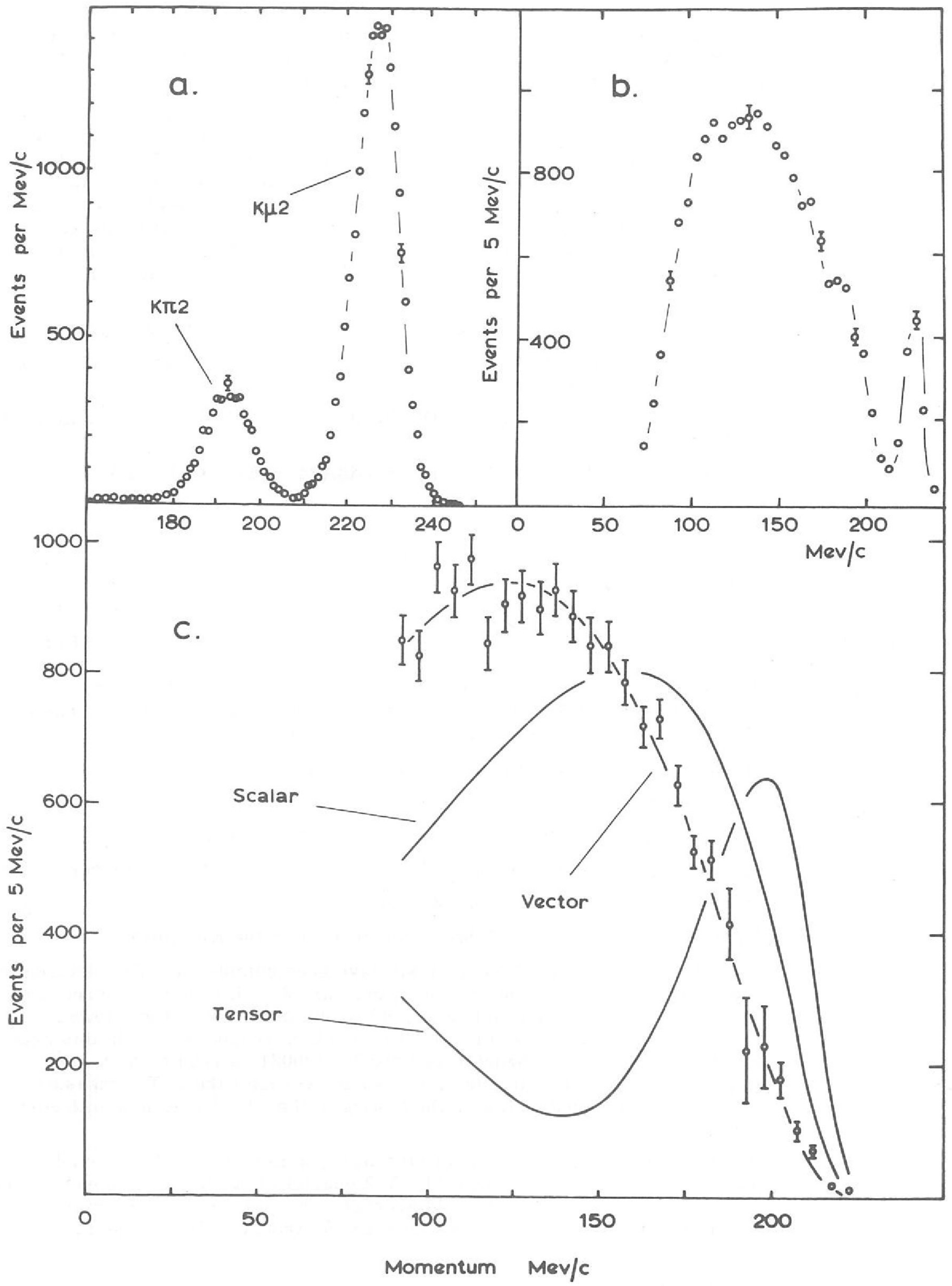


Figure 6. (a) The measured momentum spectra of $K\pi 2$ and $K\mu 2$ events used for calibration in this experiment.
(b) Ke3 electron momentum spectrum without corrections for momentum variation of the solid angle of the magnetic spectrometer and for random count induced breakthrough of $K\pi 2$ and $K\mu 2$ events.
(c) The corrected Ke3 electron momentum spectrum is compared with the predictions for pure scalar, vector and tensor couplings.

Positive kaons from a 700 MeV/c separated beam stopped and decayed in the beryllium plates of a small spark chamber. Charged decay products were momentum analysed with a spectrometer system consisting of a bending magnet and four sonic spark chambers. Electrons were identified by a threshold gas Cerenkov counter and a lead/aluminium range spark chamber.

Ten events were obtained in the Ke2 region of the electron momentum spectrum. The background in this region due to the $K\mu 2$ decay mode was estimated as 0·35 events. The analysis yielded a value for the ratio

$$R = \frac{\text{Ke2 branching ratio}}{K\mu 2 \text{ branching ratio}} = (1{\cdot}9 \begin{smallmatrix} +0{\cdot}7 \\ -0{\cdot}5 \end{smallmatrix}) \times 10^{-5}$$

This is in good agreement with the prediction of (V-A) weak interaction theory and the assumption of muon-electron universality, namely

$$R_{predicted} = 2{\cdot}095 \times 10^{-5}$$

The predicted value includes a radiative correction of -18·5% due to virtual photon processes.

From these measurements of R an upper limit on the amount of pseudoscalar coupling contributing to the Ke2 decay was determined. It was found that

$$|f^P| < 2{\cdot}2 \times 10^{-3} \, |f^A|$$

where f^P and f^A are the pseudoscalar and axial vector form factors describing the matrix element of the hadronic weak current.

Experiment 6

The Partial Width of the Decay $\phi^0 \rightarrow e^+ + e^-$

IMPERIAL COLLEGE, LONDON
RUTHERFORD LABORATORY

(1) A measurement of the cross-section of $\pi^- + p \rightarrow \phi + n$ near threshold.

Our analysis of the spark chamber and counter data for the reaction $\pi^- + p \rightarrow K^+ + K^- + n$ near threshold, where the K^+K^- system has a mass in the ϕ meson region, has been essentially completed. The secondary particles were detected using a neutron time-of-flight technique in conjunction with an arrangement of scintillation counters and a threshold Cerenkov counter sensitive to low mass K pairs (figure 7). Optical spark chambers were introduced so that for a sample of the data complete reconstructions of the events could be made.

Figure 8 shows the time-of-flight spectrum for the particles detected by the neutron counters when the beam momentum was set near the optimum for detecting ϕ meson production. The spectrum shows a peak in the ϕ region, i.e. a region centred around a time-of-flight corresponding to the centre-of-mass velocity of the $\pi^- p$ system. Figure 9 shows the variation in the total number of counts in the ϕ region as a function of beam momentum. Most of the sharp rise around 1560 MeV/c can be attributed to ϕ meson production. A detailed analysis, both of the time-of-flight spectra alone, and of the fully reconstructed events, shows that 80% of the K^+K^- n events in the K^+K^- mass range resulted from ϕ meson decay.

Angular distributions for the ϕ were obtained from the 185 reconstructed events in the mass range 1010 - 1030 MeV, the centre-of-mass final state momentum (p*) being between 30 and 200 MeV/c. The production cosine distribution for events with $p^* < 120$ MeV/c showed little deviation from isotropy; limited information at higher p*, up to 200 MeV/c, was also consistent with pure S wave production. In the decay system, the Treiman-Yang distribution was isotropic within the statistics and an examination of the decay distribution in the ϕ centre of mass with respect to the incident π, for the 29 events produced with small momentum transfer, showed no departure from isotropy. In particular, this was incompatible with the $\sin^2\theta$ form which would be expected on a simple ρ exchange model.

The total cross-section could be described in the simple form $\sigma = Ap^*$ μb. Inclusion of a p^{*2} term made little improvement in the fit. Including normalisation errors, the corrected value of A was 0·28 ± 0·07 μb/MeV/c.

The mass plot and angular distributions of events with K^+K^- effective masses outside the ϕ mass range indicated that the K^+K^-n background could be adequately described by a three-body phase space model over the total mass range covered (986 - 1050 MeV/c^2). Because

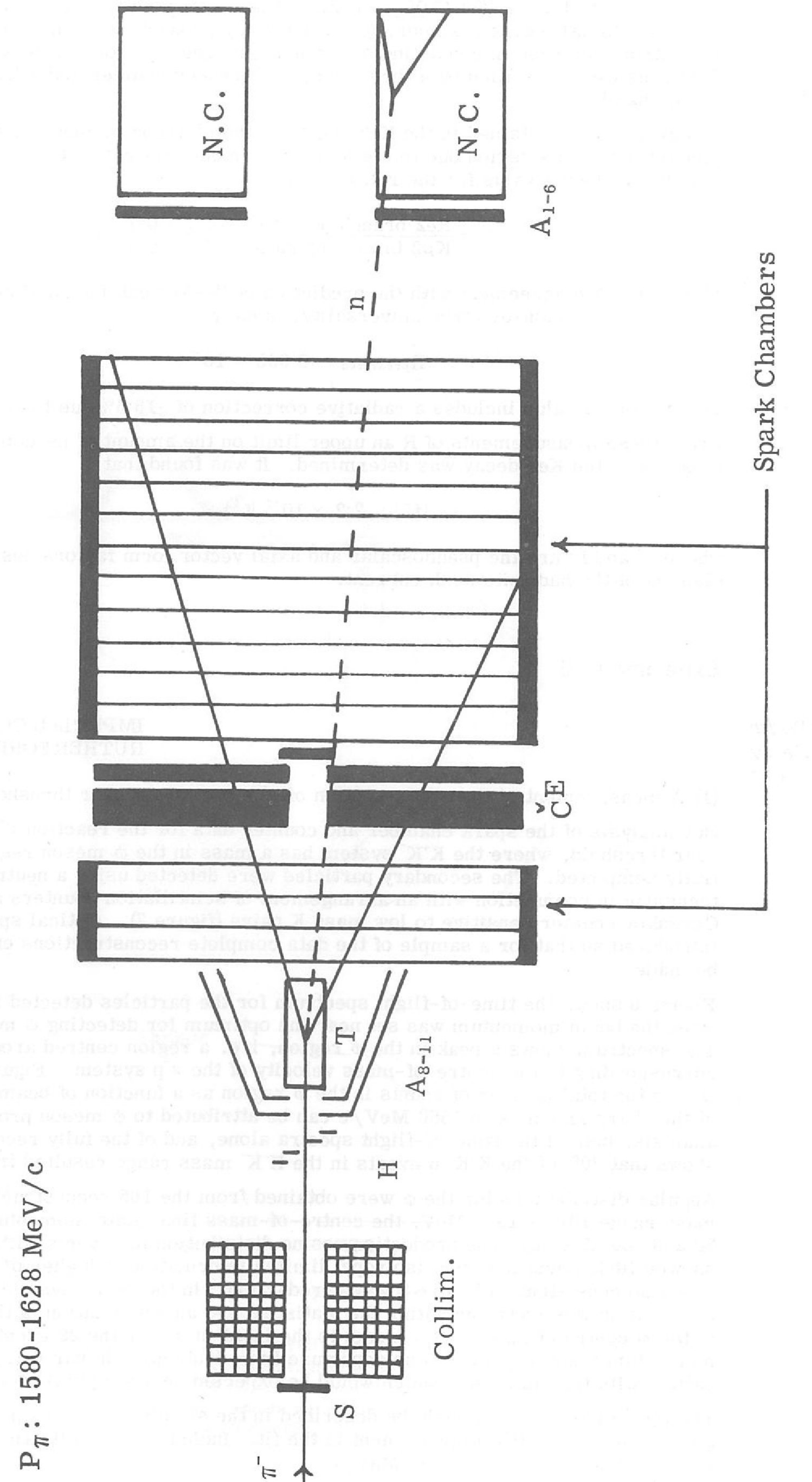


Figure 7. Apparatus used for detecting the reaction $\pi^- + p \rightarrow n + \phi$, $\phi \rightarrow K^+ + K^-$.

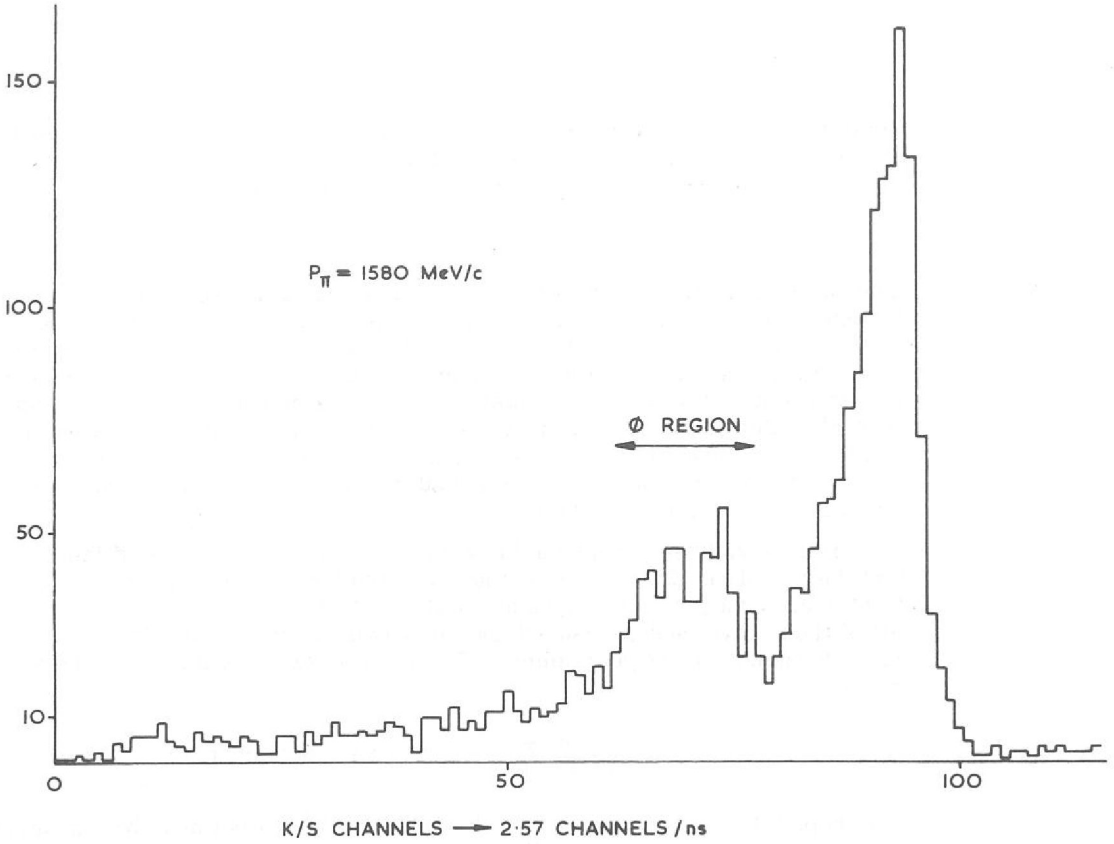


Figure 8. Neutron time of flight spectrum $\pi^- p \rightarrow K^+ K^- n$. Flight path 4m.

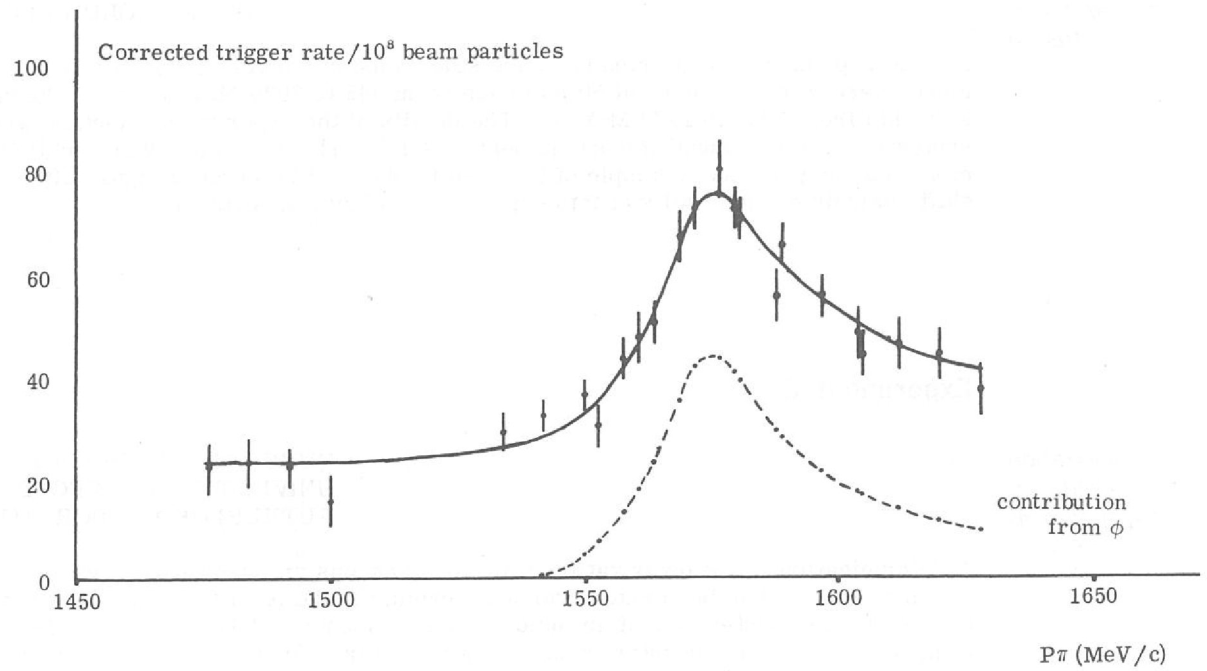


Figure 9. Yield v pion momentum for the reaction $\pi^- + p \rightarrow n + K^+ + K^-$. Continuous line shows best fit for a ϕ meson cross section rising linearly with c.m.s. momentum, + a phase space $K^+ + K^-$ background, + a constant η meson background.

of the narrowness of this mass range and the statistical uncertainties involved, significant contribution to this background from an S-wave enhancement in the I = 0 $K\bar{K}$ system near threshold (either the manifestation of a large $K\bar{K}$ scattering length, or a wide resonance at about 1050 MeV/c^2) could not however be ruled out.

(2) The $\phi \to e^+ + e^-$ decay

The equipment used to measure the ϕ production cross-section in $\pi^- + p \to \phi + n$ near threshold through the selection of the $K^+ + K^-$ decay mode was rearranged to be sensitive to an $e^+ + e^-$ mode. On each side of the hydrogen target 5 sheets of lead (each of thickness one radiation length) were mounted, and visual spark chambers were used to follow the development of any cascade shower and to give a measure of the direction of the incident particle. Scintillation counters were incorporated so that events were selected only when charged particles entered both sides, and when there was some evidence of a shower in at least one of the sides. Some 100,000 photographs were taken just above threshold, and a similar number just below.

The films have been scanned using very loose criteria (estimated loss of events < 5%), and the resulting 10% of frames thus selected have been scanned and rescanned using much tighter criteria (estimated loss about 10%), the total yield being about 500 events. Almost all of these have been measured and remeasured, and about three-quarters of them have been through a fitting programme. From the resulting data, it can be said that the branching ratio

$$\frac{\phi \to e^+ + e^-}{\phi \to \text{all}} < 2 \times 10^{-3} \text{ (95\% C.L.)}$$

It is hoped that a more accurate value will finally be obtained, but background processes are significant and it appears that the technique used is near its limit.

Experiment 7

Polarization Effects in π^- p and K^-p Scattering

UNIVERSITY OF OXFORD
RUTHERFORD LABORATORY

Elastic π^-p and K^-p scattering has been studied using a polarized proton target. Measurements were made for pions at 50 momenta from 643 to 2090 MeV/c and for kaons at 8 momenta from 1085 to 1370 MeV/c. The details of the experimental method were presented in the 1966 Annual Report (Experiment 10). The data which were obtained have now been analysed and a sample of the results obtained is shown in figure 10. A phase shift analysis of the results of this experiment is being undertaken.

Experiment 8

Polarization of the Σ^- Produced in π^- p Collisions

QUEEN MARY COLLEGE, LONDON
UNIVERSITY OF OXFORD
RUTHERFORD LABORATORY

A determination of the polarization of the Σ^- hyperons produced in the reaction $\pi^- + p \to \Sigma^- + K^+$ has been made over a Σ^- angular range of $-1{\cdot}0 < \cos\theta < +0{\cdot}3$ in the centre of mass system and at an incident pion momentum of 1130 MeV/c. This information, as well as being of interest in itself, is required for the interpretation of a current Nimrod experiment (No. 10) studying the β-decay process, $\Sigma^- \to n + e^- + \nu$. The pions were incident on a polarized proton target which consisted of a 1 inch cube crystal assembly of lanthanum magnesium nitrate (LMN) cooled to 1·2°K in a magnetic field arranged to be perpendicular to the Σ^-K^+ production plane, i.e. in a direction defined by the vector product, $k_\pi \times k_\Sigma$, of the momenta of the incoming π and outgoing Σ. The spin direction of the free

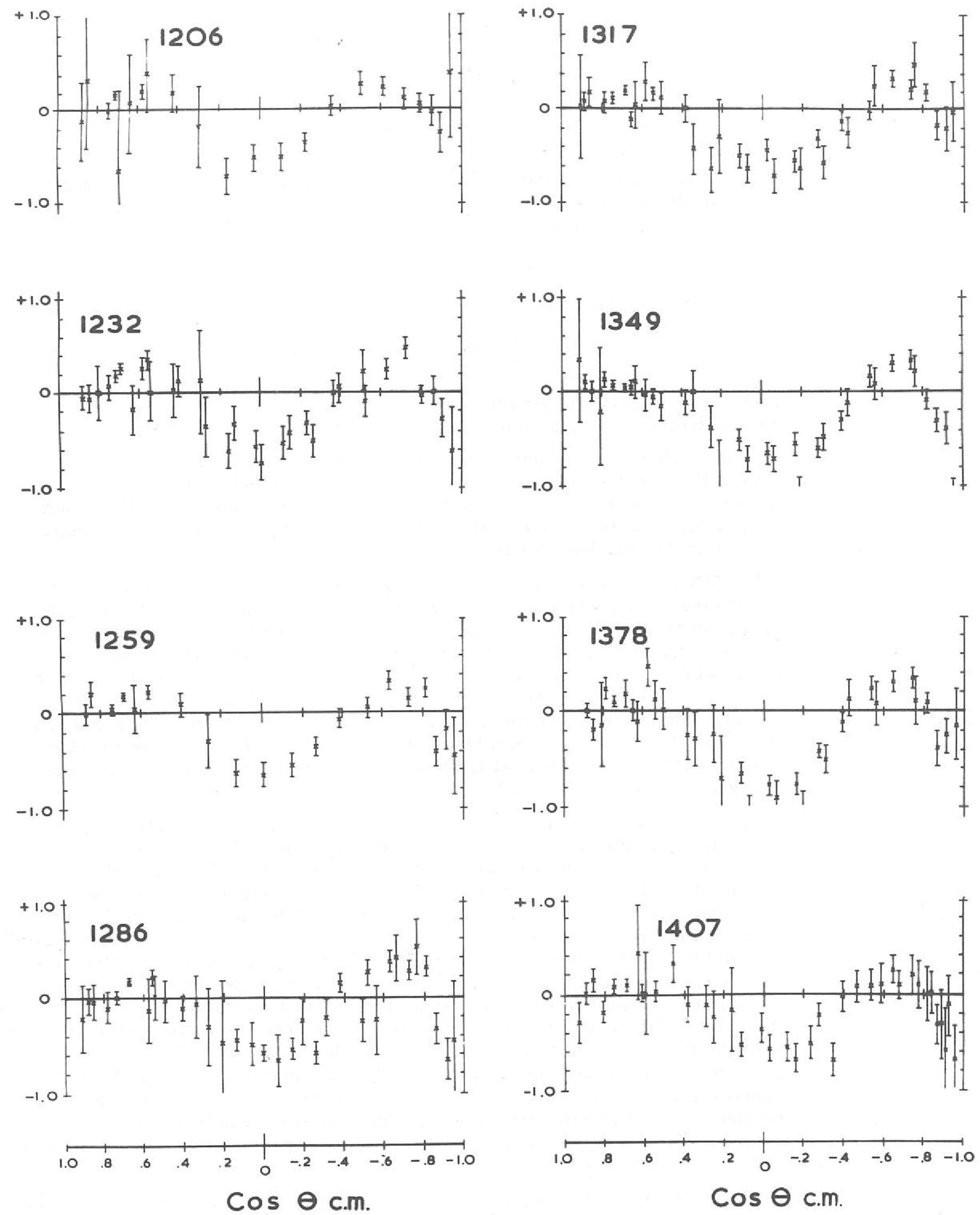


Figure 10. Asymmetries in π^-p scattering from 1206 to 1407 MeV/c. The incident pion momentum is shown in the top left-hand corner of each graph. At each momentum the asymmetry is plotted as a function of cosθ, where θ is the angle of scatter in the centre-of-mass system.

protons in the water of crystalization of the LMN could be oriented parallel or anti-parallel to the field direction. The experiment consisted of a measurement of the K^+ asymmetry ϵ, given by

$$\epsilon(\theta) = \frac{N^+(\theta) - N^-(\theta)}{N^+(\theta) + N^-(\theta)}$$

and the angular distribution I, given by

$$I(\theta) = \tfrac{1}{2}\,(N^+(\theta) + N^-(\theta))$$

In these formulae, N^+ and N^- are the K^+ counting rates from free protons in each of the two opposite polarization states of the target. The polarization of the Σ^- assuming a $KN\Sigma$ parity of -1, is given by

$$P_\Sigma(\theta) = \epsilon(\theta)/P_t\,,$$

and the differential cross-section is given by

$$\frac{d\sigma}{d\Omega}(\theta) = CI(\theta)/\Delta\Omega(\theta)$$

where P_t is the target polarization, C is a normalization constant and $\Delta\Omega(\theta)$ are the solid angles determined by a Monte Carlo calculation.

Because of energy conservation an 1130 MeV/c π^- in collision with a **free** proton can produce a K^+ only via the reaction $\pi^- + p \rightarrow \Sigma^- + K^+$. Identification of a K^+ therefore guaranteed selection of this desired final state from among the many competing channels. The decay properties and, to a lesser extent, the mass (range-momentum correlation) of the K^+ were used to make this identification.

The LMN target however, contains only 3% by weight of free protons. It was therefore necessary to distinguish the desired free proton events from a background of K^+ mesons produced on protons bound in the heavier nuclei of the target crystal. The usual constraints imposed by coplanarity and the angular correlation between the incoming and outgoing particles were not used to make this distinction because almost all the Σ^- hyperons decayed before emerging from the target. Instead, the K^+ production angle was determined and a rough measurement of its range and momentum was made. These measurements reduced the ratio of Σ^-K^+ events from bound protons to those from the free protons to 3·5:1. A dummy target that simulated LMN but contained no free protons was used to determine the bound proton background.

The arrangement of scintillation counters is shown in figure 11. The production angle of the K^+ was determined by two counter hodoscopes, F and R, each of which contained 25 counters. A water Cerenkov counter was placed behind F and R to veto events with an outgoing particle of velocity > 0·75c (c is the velocity of light). Varying thicknesses of copper absorber were placed between F and R to slow down the K^+ mesons so that those produced on free protons stopped in the centre of a 4·5 inch thick aluminium block placed behind the water counter. Counters behind the aluminium block vetoed events in which the particles did not stop. The decay products of the K^+ mesons were detected in large scintillation counters placed in pairs above and below the aluminium. The pulses from the scintillation counters were fed into a fast electronic logic system and the time delay between the occurrence of an event and the detection of the K^+ decay products was measured using a time-to-amplitude converter. This information, in digital form, together with encoded information from the counter hodoscopes, was stored in the memory of a PDP5 computer on-line to the experiment. The computer was programmed to select those events having a decay time in an appropriate range and passing through an allowed combination of F and R counters.

The experimental results, collected into 8 angular groups, are shown in figure 12. The solid lines show a fit to the data of the form:

$$\frac{d\sigma}{d\Omega}(\cos\theta_\Sigma) = \sum_{m=0}^{4} a_m P_m(\cos\theta_\Sigma)$$

$$P_\Sigma(\cos\theta_\Sigma)\,\frac{d\sigma}{d\Omega}(\cos\theta_\Sigma) = \sum_{m=1}^{4} b_m P_m^1(\cos\theta_\Sigma)$$

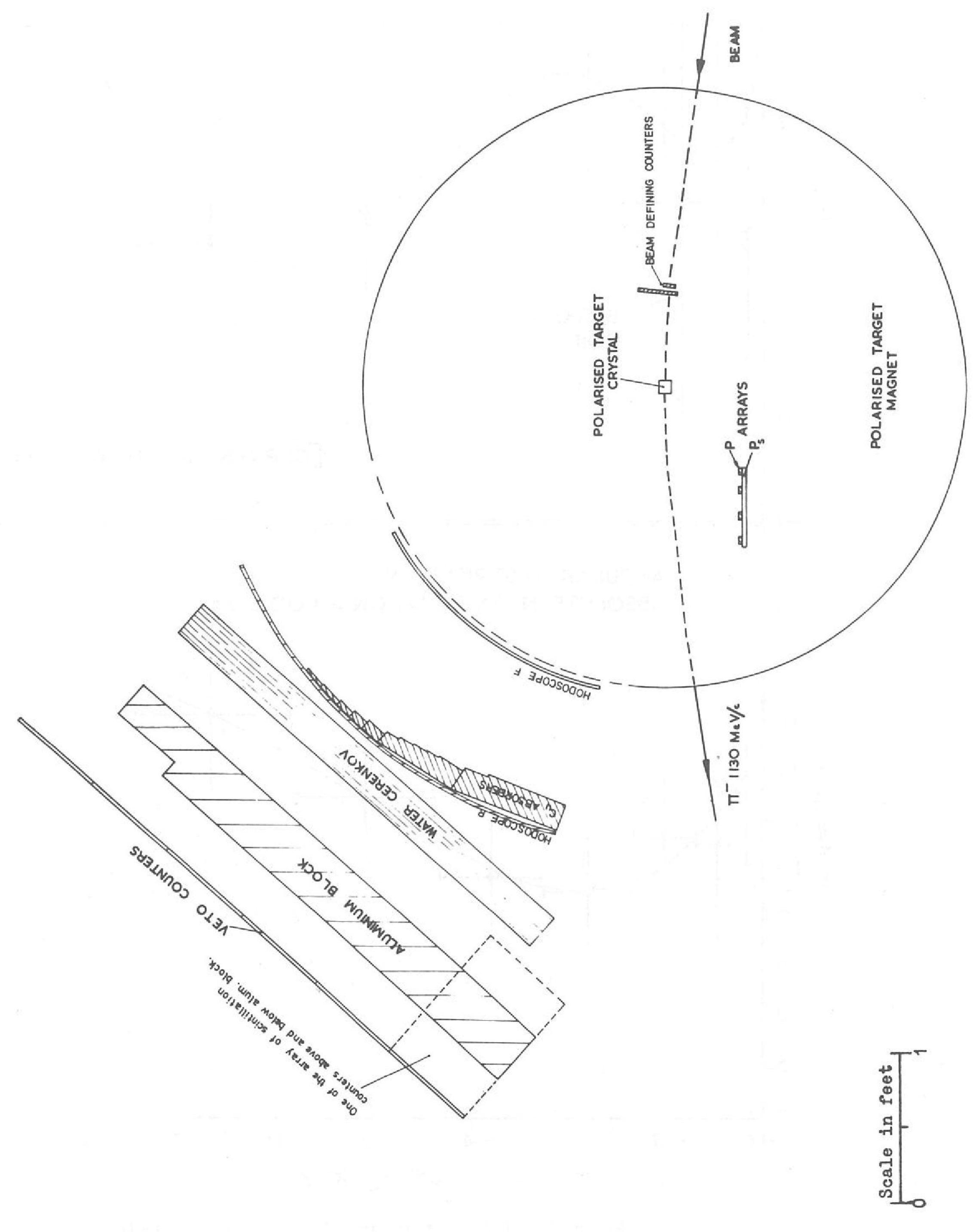


Figure 11. Disposition of counters and target for studying polarization of the Σ^- from the reaction $\pi^- + p \rightarrow \Sigma^- + K^+$ (Expt 8).

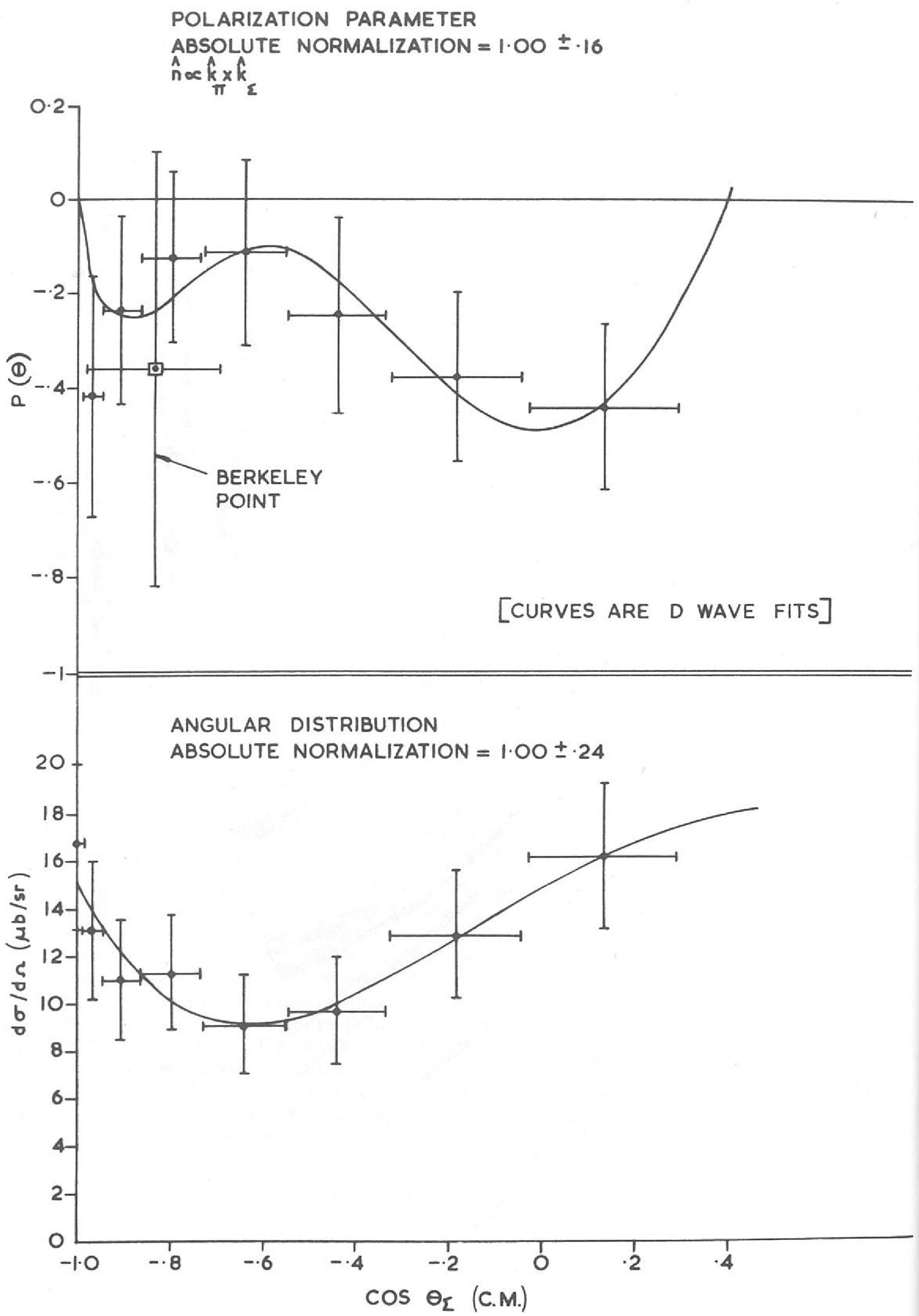


Figure 12. Polarizations and differential cross-sections for Σ^- production in $\pi^- + p \rightarrow \Sigma^- + K^+$ (Expt 8).

where P_m and P_m^1 are Legendre and first associated Legendre polynomials. The fit to $P\frac{d\sigma}{d\Omega}$ suggests the presence of at least D waves at this energy. Figure 12 also shows the P_Σ measurement from Berkeley[1] which is in good agreement with the present results.

[1] Weldon M.D. (thesis) Measurement of the Σ^- Polarization in the Process π^-p - $\Sigma^- K^+$. UCRL 17152.

Experiment 9

K^-p Differential Cross-Section Measurements

UNIVERSITY COLLEGE, LONDON

Work has continued in setting up an automatic wire spark chamber system, on-line to a small computer, for the study of K^-p elastic scattering in the momentum region 1·0 to 2·5 GeV/c. This region is rich in structure and a number of resonances appear in this range which still have no clearly assigned spins and parities.

The equipment required for this experiment has been completely constructed and is currently being tested in a K-beam on Nimrod. A DISC focussing Cerenkov counter has been built and is used to separate electronically the K's from π's in the beam. Scintillation counter hodoscopes define the incoming directions of the particles and large wire spark chambers (with core read-out) are used to observe the scattered particles. The data is fed into a PDP-8 computer system via a pre-processor where the events are analysed and the experiment is monitored. The results are accumulated on magnetic tape which will be processed by the IBM 360-75 computer.

The equipment is nearly operational and already a large number of test programs have been run in setting-up the experiment. These have shown the value of an on-line system of this type. Data taking should commence in March-April 1968.

Experiment 10

The β Decay of the Σ^- Hyperon

QUEEN MARY COLLEGE, LONDON
AERE, RUTHERFORD LABORATORY

The experiment concerns the decay $\Sigma^- \rightarrow n + e^- + \nu$ and entails a measurement of the angular distribution of the electrons about the direction of the spin of the Σ^-, from which the form of the weak interaction responsible for the decay may be determined. It is predicted to be V+.4A by an SU(3) analysis of hyperon leptonic decays.

The Σ^- hyperons are produced in the reaction $\pi^- + p \rightarrow K^+ + \Sigma^-$ at an incident pion energy of 1·13 GeV/c. The K^+ is identified by bringing it to rest and detecting its relativistic decay products. A one atmosphere gas Cerenkov counter discriminates between the π^- from the normal decay, ($\Sigma^- \rightarrow n + \pi^-$) and the electron from the β-decay. The production and decay are detected in a set of wire spark chambers with core readout. The experiment is described in detail in the 1966 Annual Report (Experiment 11).

The full electronic trigger has been set up and tested and appears adequate. A scintillation counter hodoscope has been installed in the incident beam in an attempt to detect the spatial position of the pion responsible for the trigger and so help the software to find the correct pion track. Using the additional hodoscope information, it may prove possible to raise the incident flux that can be tolerated in the beam spark chambers. This is currently $\sim 3 \times 10^5$ particles/burst, which with the usual machine spill gives an instantaneous rate of about 1 MHz.

Some data has been taken on the normal decay mode which has the same pattern in the spark chambers as the β-decay – the electron track being replaced by a pion. This data is being used to refine the existing software which has the task of finding and fitting decay events. The process involves selecting sparks to form vectors in the pion, kaon and decay particle subspaces, associating one of the incident pions with a kaon and performing a (π-K) vertex fit, then predicting a Σ^- direction and associating with it a decay track, and finally performing a geometrical fit to the full event. It is intended to have this programme operational before taking a large amount of data on the β-decay.

In order to achieve the aim of the experiment the Σ^- hyperons must be polarised on production. A preliminary result of experiment 8 suggests the mean polarization of the Σ^- used in this experiment is -0·24±0·09.

Experiment 11

Differential Cross-section for π^-p Elastic Scattering

UNIVERSITY OF BRISTOL
RUTHERFORD LABORATORY

In the last few years important advances have been made in the study of the pion-nucleon system. The existence of resonance-like structure in the π-N total cross-sections has been established for many years and further structure has recently been found. The spin and parity quantum numbers of these resonances, or short lived particles, can be found from measurements of the differential cross-sections and polarization effects. The aim of the present work was to provide values of the differential cross-sections at closely spaced momenta from 1·2 to 2·5 GeV/c, a region known to contain several resonances.

Negative pions were produced from an internal target in Nimrod and focussed onto a liquid hydrogen target 5 cm long. Scattered protons and pions were detected in coincidence by Counter Arrays I and II (figure 13). The arrays were designed to accept events in which incident and final particles were coplanar to within 15°. This reduced the background from inelastic processes such as

$$\pi^- + p \rightarrow \pi^- + p + \pi^0 \qquad (1)$$

The angular correlation between π^- and p from elastic scattering

$$\pi^- + p \rightarrow \pi^- + p$$

allowed a statistical separation from processes such as (1).

Particles which went through Counter Array II (figure 13) also passed between the poles of the spectrometer magnet and into the Back Magnet Array, which is illustrated in figure 14. This further reduced the inelastic background and resolved the ambiguity in angular correlation for the case of pion and proton emerging at the same angle.

Information from the counter arrays was processed by a tunnel-diode logic system and encoded in binary form. The data was fed directly to the core store of an Argus 400 computer which performed further on-line processing and monitoring of the experiment. Data for a particular momentum was accumulated in the computer and punched out onto paper tape for final processing by the Laboratory's central computer.

Data obtained at about thirty momenta is at present being analysed.

Experiment 12

$K^{\pm}p$ differential cross-sections

UNIVERSITY OF BIRMINGHAM

Arrays of scintillation counters and sonic spark chambers in a separated K-meson beam, (derived from X2), are being used to study firstly K^+p and secondly K^-p elastic differential cross-sections from 5° to 180° at about 10 momenta between 0·45 and 0·9 GeV/c. The aim of the former experiment is to investigate the possibility of structure near 0·6 GeV/c and to improve the data, at present statistically poor, in this momentum interval. The K^- study is concerned with attempting to improve our knowledge of the several resonances in this region, in particular the Y_1^* (1660) and Y_0^* (1700).

The flux of K^--mesons ranges from a few tens to a few hundreds per 2 $\times 10^{11}$ extracted protons. K^+ fluxes are approximately six times larger. The detectors subtend large solid angles at a 50 cm long hydrogen target. Forward and backward scattering are studied by measuring the momentum and angle of either the K-meson or the proton, using a large aperture spectrometer magnet. For the remainder of the angular range the scattered K-meson and the recoil proton are detected in coincidence. About 10^4 events per momentum

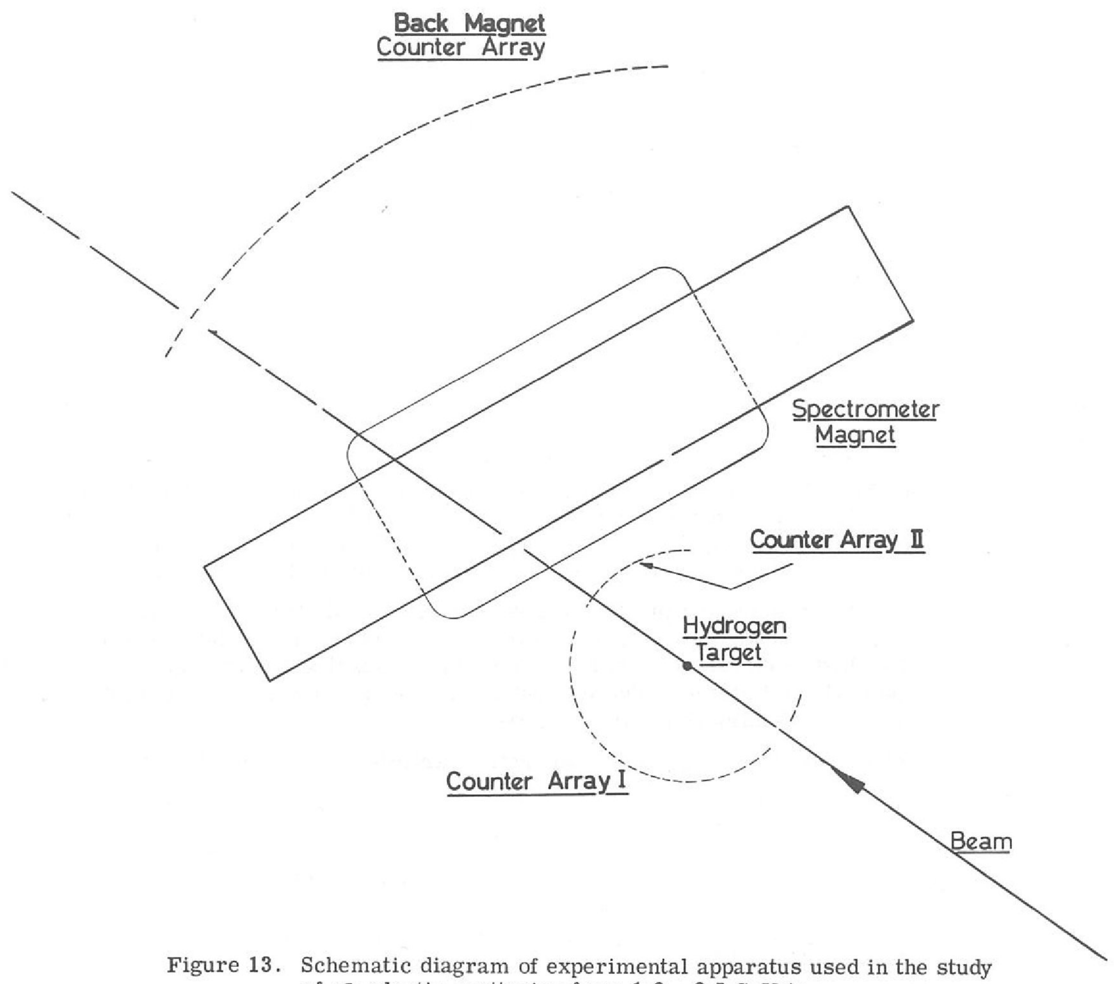
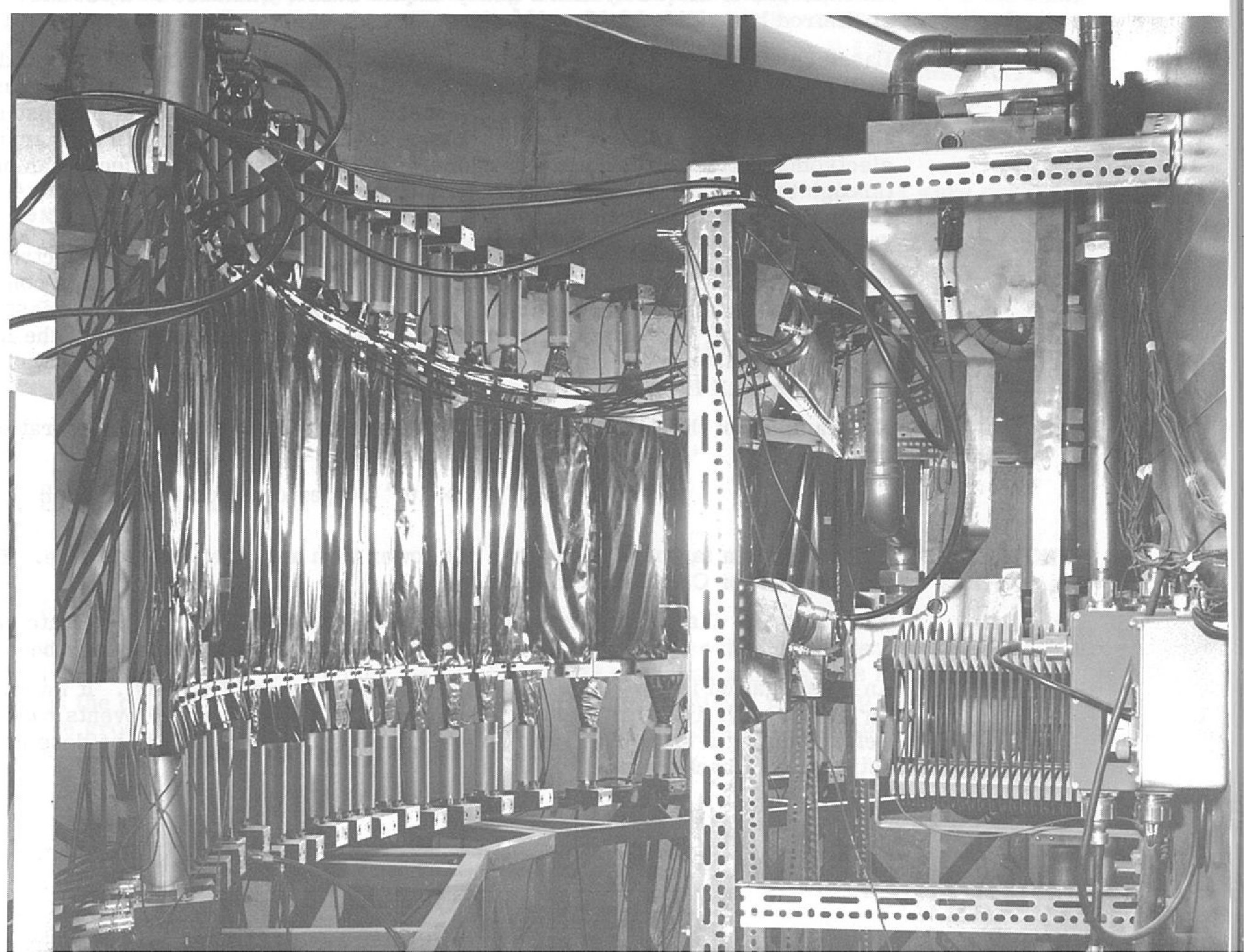


Figure 13. Schematic diagram of experimental apparatus used in the study of π^-p elastic scattering from 1·2 - 2·5 GeV/c.

Figure 14. "Back Magnet" counter hodoscope array (Expt 11).



will be obtained; the data will be fed on-line to a DDP-116 computer and thence on to a magnetic tape for eventual processing by the IBM 360-75. The on-line computer monitors the performance of the equipment and provides a CRT display of interesting quantities.

Experiment 13

Neutral States produced in K^-p Interactions

UNIVERSITY OF OXFORD

It is planned to measure the hyperon polarization and differential cross-sections for the final states $\Lambda^0\pi^0$, $\Lambda^0\eta^0$, $\Sigma^0\pi^0$, and $\Sigma^0\eta^0$, and the excitation functions for $\Lambda^0\pi^0\pi^0$ and $\Sigma^0\pi^0\pi^0$ resulting from K^-p interactions in the range 650-1150 MeV/c. These neutral final states have unique isospin, and the purpose of studying them is to achieve an understanding of the many closely spaced resonances in this momentum interval.

The K^- mesons are produced from a target inside the Nimrod vacuum box and transported to a small hydrogen target by a beam-line containing a single stage of mass separation. The hydrogen target is surrounded by a compact anticoincidence counter which selects neutral final states. The photons and Λ^0 decay products are detected by a system of optical and magnetostrictive wire chambers.

The work of setting up the separated particle beam started in December 1967.

Experiment 14

Decays of η^0 mesons

UNIVERSITY COLLEGE, LONDON
UNIVERSITY OF OXFORD

An exposure of the UCL/RHEL Heavy Liquid Bubble Chamber to a 930 MeV/c π^+ beam at Nimrod has yielded $2{\cdot}23 \times 10^6$ π^+-nucleus interactions in the heavy freon CF_3Br.

Based on a scan for the decay mode $\eta^0 \rightarrow \pi^0 e^+e^-$, the total number of η^0's produced in the experiment is 32,600 ± 3,000. The main reason for obtaining so large a number of η^0's was to search for the existence of the decay mode $\eta^0 \rightarrow \pi^0 e^+e^-$. The interest in this process stems from the fact that it provides a good test of charge conjugation invariance in the electromagnetic interactions of hadrons. If C is conserved, the decay can only proceed through two virtual gammas and the branching ratio is estimated to be $\approx 0{\cdot}4 \times 10^{-8}$. Observation of a branching ratio much in excess of this would be evidence of C violation.

The film was scanned, and half was rescanned, for events having an electron and a positron at the interaction vertex, together with two or more associated gammas converting to electron-positron pairs in the liquid. If the two pairs had an invariant mass consistent with that of a π^0, the invariant mass of the electron-positron system at the interaction vertex was determined. If this exceeded a value of 150 MeV an attempt was made to perform an overall fit to the scheme $\eta^0 \rightarrow \pi^0 e^+e^-$.

No examples of the decay were found. This result leads to a branching ratio upper limit of

$$\frac{\eta^0 \rightarrow \pi^0 e^+e^-}{\text{all } \eta^0} < 3{\cdot}7 \times 10^{-4} \text{ (90 per cent confidence level)}$$

This value is a factor of more than two lower than any other quoted value. Thus no evidence is observed for C violation in η^0 decay.

The discovery last year of inverse electropion production via intermediate vector mesons, i.e. $\pi^+ + n \rightarrow p + \rho^0$; $\rho^0 \rightarrow e^+e^-$, made with this same exposure, has now been published.

An investigation is now being made into the decay mode of $\eta \rightarrow 3\pi^0$. It involves scanning for events with five or six converted gammas. To date about 70 events have been seen. Before quoting a branching ratio however, much work has still to be done concerning the estimation of background.

Experiment 15

Single and Double Pion Production in pd Collisions

UNIVERSITY OF CAMBRIDGE

Work has continued on the analysis of 65,000 pictures taken in the 80 cm Saclay chamber filled with deuterium. The K1 beam was used at proton momenta of 1·825 and 2·110 GeV/c, the latter being the maximum momentum available with that beam line. The film was completely scanned for three and four-prong events corresponding to the reactions

$$pd \rightarrow p_s pp\pi^- \quad (1)$$

and

$$pd \rightarrow p_s pn\pi^+\pi^- \text{ or } p_s pp\pi^-\pi^0 \quad (2)$$

where p_s is a 'spectator' proton. The scanning produced some 6,000 events which have all been measured on conventional machines and processed by the CRAB system of programs on the Cambridge Titan computer. The analysis of the results is now in progress.

Numbers of events and cross-sections for events of types (1) and (2) are as follows:-

	1·825 GeV/c		2·110 GeV/c	
Channel	Events	σ(mb)	Events	σ(mb)
$p_s pp\pi^-$	1379	2·67 ± 0·10	1362	2·76 ± 0·10
$p_s pn\pi^+\pi^-$	340	0·66 ± 0·05	684	1·39 ± 0·07
$p_s pp\pi^-\pi^0$	48	0·09 ± 0·02	97	0·20 ± 0·03

Analysis has revealed that about half the events of type (1) contain a N*(1236) isobar and good agreement is found with calculations based on one-pion exchange models.[1] There is no clear evidence for a T = 0 amplitude in this channel, so that the rapid rise in the T = 0 cross-section in this energy region, which was observed in the nucleon-nucleon cross-section measurements made by a counter group from the University of Cambridge and Rutherford Laboratory, cannot be ascribed to single pion production. Work is still in progress on the events of type (2) which involve double pion production, but they seem considerably less peripheral.

The laboratory angle distribution of the spectator protons shows strong departure from the expected isotropy, with an increasing tendency to peak along the direction of the beam at higher spectator momenta. This is in agreement with results obtained previously at Cambridge in an antiproton-deuterium bubble chamber experiment at 1·67 GeV/c, and casts doubt on the validity of the impulse model in this energy region. To study this, some 650 four-prong events, similar to those of type (2) but without a spectator proton, have been measured and will be used to compare the reaction $pd \rightarrow n_s pp\pi^+\pi^-$ with $pp \rightarrow pp\pi^+\pi^-$ on free protons.

In the course of the experiment 281 events with deuterons in the final state were observed. Most were examples of the reaction $pd \rightarrow pd\pi^+\pi^-$ and separated cleanly, on the basis of laboratory momentum, into 'fast proton' and 'fast deuteron' events, the latter proceeding by baryon exchange. In these events evidence has been found for a $d\pi$ resonance of mass 2130 and width 50 MeV.

[1] Brunt D.C. (Ph.D. Dissertation, University of Cambridge, 1967). High Energy Proton-Deuteron Interactions.

Experiment 16

π^+p Interactions in the range 0·6 – 1·05 GeV/c

UNIVERSITY OF OXFORD

(a) 0·6-0·8 GeV/c.

100,000 pictures were taken in the Saclay 80 cm chamber during September 1966. Measurement of the film at 0·7 and 0·8 GeV/c is now far advanced and analysis has been started on the data at 0·8 GeV/c. An isobar model for the reaction $\pi^+p \rightarrow \pi^+\pi^0 p$ is consistent with the gross features of the data if the reaction proceeds from at least two incident partial waves, of opposite parity and comparable magnitude.

IMPERIAL COLLEGE, LONDON
WESTFIELD COLLEGE, LONDON

0·9 - 1·05 GeV/c

Most of the film has been double scanned for all interactions (2-prong, 4-prong and strange particle events). The scanning should be completed by the end of March 1968.

Events have been measured at three of the four momenta 0·9, 0·95, 1·0 and 1·05 GeV/c. At present most of the measuring effort is being concentrated on the remeasurement of failed events on the 0·9 and 1·0 GeV/c film. This will enable the detailed analyses of these momenta to proceed while the remaining events at the other momenta are being processed. An incomplete data summary tape (D.S.T.) has been created for the 0·9 GeV/c events and it is hoped that the final D.S.T. can be made for this momentum before the end of January.

Computer programs are being prepared so that the preliminary analysis of the data may take place along the following lines.

1. Determination of the behaviour of the $N^{*++}\pi^0$, $N^{*+}\pi^0$, $N^{*+}\pi^+$ cross-sections as a function of momentum between 0·9 and 1·05 GeV/c.
2. Study of the N^{*++}, N^{*+} interference in the $p\pi^+\pi^0$ channel.
3. Partial wave analysis of the $N^{*++}\ \pi^0$ channel.
4. Comparison of the elastic scattering data with the corresponding counter data in the 0·9 - 1·05 GeV/c momentum interval.

It is expected that this work, which has as its main aim the unravelling of the inelastic decay modes of the N* resonances observed in the elastic channel, should be completed and prepared for publication by about October, 1968. Attempts will also be made to analyse the three-body final states using the model independent techniques recently suggested by several authors.

Experiment 17

K^-p Interactions

SACLAY LABORATORY
COLLEGE DE FRANCE
RUTHERFORD LABORATORY

Pictures have been taken of K^-p interactions at 13 momenta evenly spaced from 1·25 to 1·85 GeV/c. The final pictures in this experiment were obtained in May 1967, during the last days of operation of the Saclay Hydrogen Bubble Chamber at Nimrod.

TABLE 3

Preliminary values of cross-sections (millibarns)

Incident K^- Momentum (GeV/c)	Channel			
	$K^-p \rightarrow \Lambda\pi^0$	$K^-p \rightarrow \bar{K}^0n$	$K^-p \rightarrow \Sigma^-\pi^+$	$K^-p \rightarrow \Sigma^+\pi^-$
1·270	1·38 ± 0·17	2·61 ± 0·24	0·59 ± 0·09	1·34 ± 0·17
1·323	1·07 ± 0·14	1·58 ± 0·16	0·42 ± 0·06	1·27 ± 0·13
1·375	1·35 ± 0·14	1·88 ± 0·24	0·40 ± 0·06	1·19 ± 0·13
1·422	1·27 ± 0·15	2·16 ± 0·24	0·38 ± 0·07	1·06 ± 0·15
1·472	1·17 ± 0·10	1·93 ± 0·10	0·36 ± 0·03	1·11 ± 0·06
1·520	1·07 ± 0·10	1·78 ± 0·14	0·37 ± 0·04	1·10 ± 0·08
1·552	1·07 ± 0·11	2·41 ± 0·15	0·31 ± 0·03	1·23 ± 0·07
1·613	1·04 ± 0·10	1·70 ± 0·13	0·36 ± 0·03	1·22 ± 0·08
1·659	0·94 ± 0·10	1·91 ± 0·11	0·33 ± 0·03	1·05 ± 0·05
1·712	0·86 ± 0·08	1·53 ± 0·14	0·25 ± 0·04	0·83 ± 0·09
1·746	0·79 ± 0·09	1·48 ± 0·12	0·32 ± 0·03	0·93 ± 0·06

This is a "formation experiment" in which K^-p interactions can form baryon resonances of strangeness -1 and isotopic spin 0 or 1, which then decay into various final states. The resonance behaviour is studied systematically as a function of energy.

Initial study has been concentrated on two body final states $\Sigma^{\pm}\pi^{\mp}$, $\Lambda\pi^0$, K^0n. Preliminary values for the partial cross-sections (see Table 3) for these channels were presented at the Heidelberg Conference, in September 1967. The differential cross-sections are being analysed in terms of partial waves, although there appear to be complications due to the presence of peripheral-like effects.

Other channels to be investigated include $Y^*\pi$, $\Lambda\eta$, $\Lambda\omega$, K^*N. Measuring of all these topologies is about two-thirds completed.

Experiment 18

K^-d Interactions

UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF GLASGOW
IMPERIAL COLLEGE, LONDON

235,000 pictures at 1·65 GeV/c were obtained during 1966 and a further 120,000 pictures at the same momentum were taken in the Spring of 1967 using the Saclay chamber. Interactions with a neutron have been processed for the whole of the available film and the physical significance of the results is being evaluated.

Also during 1967 350,000 pictures were taken at 1·45 GeV/c and about two-thirds of these have been processed to date.

The aim of the experiment is to study the properties of the Y_1^* (2030) resonance using pure I=1 states such as

$$K^-+d \rightarrow p_s + \Lambda + \pi^-$$

in K^-n reactions, where p_s is a spectator proton. In addition there is copious production of Y* resonances at 1385, 1405, 1520 and 1660 MeV and information about the decay mechanisms and branching ratios for these states will be obtained.

Experiment 19

π^-p Interactions in the Region of 0·5 GeV/c

SACLAY LABORATORY
UNIVERSITY OF OXFORD

530,000 pictures have been taken in the Saclay Chamber at Nimrod and more will be taken next summer at Saturne. It is hoped that a study of the $\pi^+\pi^-$ interaction well below the ρ-threshold may lead to a partial resolution of the present confusion with π^+ - π^- enhancement, such as the σ meson. Measurement of these events is proceeding at Saclay and at Oxford; some film is also being measured at Berkeley in collaboration with the Oxford Group. First results should be available during 1968.

Experiment 20

herent Reactions π^+ and p on He^4

UNIVERSITY OF OXFORD

This experiment is designed to study the yield of A_1 (1080) and N* (1400) resonances produced in coherent interactions of pions and protons on helium at an incident momentum (about 2 GeV/c) such that these events should be easily recognised, if they occur.

Data were collected during the period June to September 1967 before the Nimrod shut-down. The exposure of about 300 kilometres of film yielded over 700,000 pictures on four cameras with an average of 8 m of track per frame. One third of the exposure was devoted to π^+, one third to p, and one third divided between background at low momenta and bubble chamber engineering.

Electronics Group

Counter Electronics

The tunnel system, now becoming known as M.L.S. (miniature logic system) is in full production and in general use by the Nimrod counter teams. It now comprises the following major cards:

Card Number	Function
101	AEC/AERE type 3 Level to Tunnel Pulse Change.
121	Tunnel Pulse to AEC/AERE type 3 Level Change.
131	Tunnel Pulse to Positive Level Converter.
150	4 Input OR Gate.
151	2 Input OR Gate.
161	R-S Flip-Flop.
180	2 Input AND Gate.
200	Fast Pulse Amplifier.
300	Amplitude Discriminator (Digitizer).
440	Strobe-controlled Transmission Gate.
152/S	Two Input OR Gate with Multiple Outputs.
154/S	4 Input OR Gate with special logic providing an output when one, and only one of the inputs is present.
181/S	4 Input AND Gate.
301/S	Amplitude Discriminator (Digitizer).
471/S	3 Input AND Gate and Binary Store (R-S Flip-Flop).
480/S	AEC/AERE type 3 Level to AERE type 2 Level Converter.
490/S	Divide-by-four and divide-by-eight scaler.

'S' cards contain largely transistors and integrated circuits. They have a minimum clock rate of about 70 Megapulses per second and are therefore slower than cards containing tunnel and back diodes only. Important features of the S cards are their output level which is fully compatible with the AEC/AERE type 3 standard and also their greater logic power.

It is anticipated that the majority of the production for the coming year will be for tunnel/ back diode cards with a significant proportion of S cards for applications where the slower speed is acceptable.

In addition to the 'A' crates holding 62 cards per crate, a frame containing six racks, each of which has the holding capacity of the A crate, has been developed. Known as 'Barn Door' the frame contains one power supply and is designed to make patching of cards easier. The first production models are now being tested in the laboratory.

Data Handling for π 5 Experiment

A data handling system for the University of Bristol π5 experiment has been completed and used during the year. This system processes the data from the 140 photomultiplier tubes, which are arranged in three arrays together with beam vetoing.

If the event satisfies certain given criteria, the address of the three photomultipliers fired is supplied as a single 24 bit word to a fired Ferranti Argus 400 computer operated in the direct store access mode.

Data Acquisition from Magnetostrictive Spark Chambers

The electronic system accepts digitized pulses from magnetostrictive lines mounted on wire spark chambers. The signals define the co-ordinates of sparks corresponding with events of interest.

The system is modular in concept and designed to cater for any number of chambers. The data is stored in 16 bit, 20 MHz scalers mounted on standard printed circuit boards carrying four scalers with readout logic. These are gated off in sequence according to the magnetostrictive signal input by six stage shift register blocks, four to a printed circuit.

A standard assembly of 128 timing channels has been designed capable of handling up to 36 inputs averaging three sparks each. Integrated circuits are used throughout.

…uter Interfacing

A system for use with the IBM1130 computer has been developed and built for the K14 experiment of Westfield College. Five input-output channels are provided, one of which is used for data transfer associated with two magnetic tape transports (Potter type MT36). Data transfers are made to and from the computer via the 'Storage Access' channels.

An interface has been constructed for the DDP-116 computer fed by a magnetic tape system using a single tape transport (Potter type MT120). The equipment is for an experiment to be carried out shortly by the University of Birmingham on the K12 beam line. Data is transferred by program control and an output channel is also provided. This channel enables data to be transmitted over the new data link being installed between the experimental areas and the IBM 360-75 computer.

An interface has been built to link the PDP8 computer to the scalers in the COMUS system. It is shortly to be used by Imperial College. Data is transferred in the single cycle data break mode.

Two manual tape systems have been constructed. These are used for storing data from an experiment. The tapes are later read back and processed on either the IBM 360-75 or Atlas.

COMUS/JANUS Data Handling

This system, which has been evolved by the Electronics and Applied Physics Division, AERE, will be the preferred packaging system in electronics outside the M.L.S. ('tunnel' system). The two units which have been developed and are in production are a 16 bit 50 MHz ripple through binary scaler, and a 16 bit parallel entry register with a minimum rate of 20 Megabits per second. Further units are being developed.

Film Processing

New continuous processing machines have been installed in a specially designed building which includes facilities for film storage and collation, and for the preparation and control of the processing solutions. Most of the film handled (totalling some 4 million feet per year) comes from bubble and spark chambers, the remainder being computer output. Film widths from 16 to 70 mm can be accommodated, the commonest sizes being 35, 50 and 70 mm.

There are two machines, as shown in figure 15. The machines, which are commercial products, are of a novel friction drive type, having separate controlled torque motors on each shaft. The film is processed, washed, dried and re-wound at speeds of 500 and 700 metres per hour when the development time is 7 minutes. By variation of film speed and immersed length the development time can be varied from 4 to 15 minutes.

Each machine is capable of producing either negative or positive images, the reversal technique being used in the latter case. Positive film (i.e. white tracks on a black background) is more suitable for automatic measuring devices such as the HPD and CRT. Uniformity of processing is ensured by strict control of all parameters; the temperature of the solution (of which there are five in the case of reversal) is controlled to within 0·5°C.

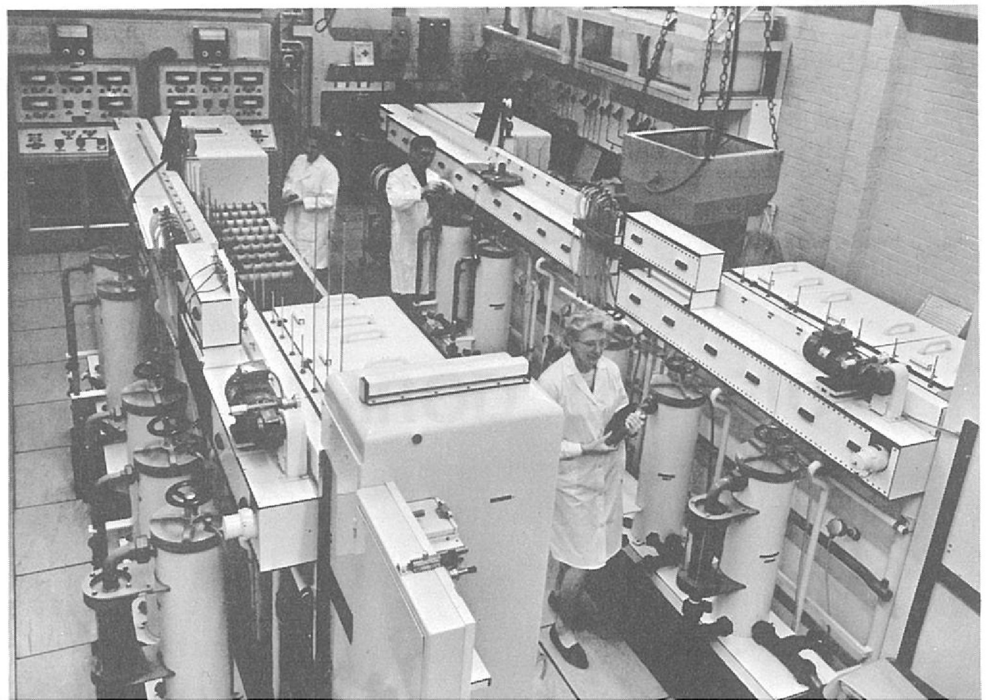


Figure 15.

The two continuous film processing machines. The input ends are in the foreground and the two processing tanks, in the centre of each machine, extend below floor level.

Number of pumps Mercury	4

agnet Power Supply

Number of Motor-alternator-flywheel sets	2
Alternator ratings nominal	60 MVA
Alternator ratings maximum	79 MVA
Alternator ratings thermal	46 MVA
Weight of rotors	60 tons
Weight of stators	72 tons
Motor rating	5100 h.p.
Motor speed	970 r.p.m.
Flywheel diameter	10 ft 6 in
Flywheel weight	24 tons
Stored energy in each flywheel at 1000 r.p.m.	250,000 h.p. sec
Speed reduction during pulse	4%

agnet

Beam radius mean	77·5 ft
Normal peak magnetic field at injection	300 gauss
Peak magnetic field	14,000 gauss
Useful magnetic aperture	9 in vertical 36 in horizontal
Number of magnet sectors	336
Weight of each magnet sector	19 tons
Number of turns in coil	42
Weight of magnet coil total	350 tons
Pulse rise time	0·72 sec
Pulse decay time	0·8 sec
Repitition rate of magnet pulse	28 pulses/min
Normal peak current in coil	9150 amps
Stored energy in magnet at peak field	40 megajoules
Number of protons accelerated	2×10^{12} per pulse

F. System

NIMROD DIVISION

R.F. frequency at injec[illegible]	Mc/s
R.F. frequency at peak	[illegible] Mc/s
Weight of ferrite	[illegible]00 lbs
Weight of cavity	[illegible]0 tons
Peak R.F. volts per gap	7 KV
R F power dissipation	14 KW
Ferrite working temperature	25°C
D.C bias winding ampere turns	7000

Nimrod Division

During 1967, Nimrod has been available for HEP for a total of 3,723 hours out of 4,758 hours scheduled representing an overall operational efficiency of 78·3% with an average beam intensity of $1{\cdot}16 \times 10^{12}$ protons per pulse. Although it will be mid-1968 before the consequences of the further alternator failure have been rectified, this fault did not seriously affect the programme in 1967, during which 7 experiments were completed and 8 new ones begun.

The new arrangement of beams in Hall 1 (figure 1) provides a much more effective use of the available space than hitherto. Together with the new Hall 3, by now well in evidence, the laboratory will soon have the basis of an extremely versatile and flexible set up of primary and secondary beams.

A great deal of effort has been devoted to improvement of component and systems reliability essential not only in its own right but also to free effort needed for operating the additional and more complex components continually being added to the facility. Beyond this, two main development projects for Nimrod are now under consideration; the replacement of the main alternator plant by a static system, and PLANIM, the scheme to adapt the 50 MeV PLA as an injector for Nimrod, to increase the beam intensity by a factor of about 3·5.

Synchrotron Operation

Overall Performance

Nimrod has continued to operate, with a crew of three, on a three week cycle of 404 hours for high energy physics experiments and 100 hours for accelerator physics and development out of which 12 hours is allocated for routine maintenance.

1,597 hours were scheduled for machine physics and development, and beam was available for 1,002 hours, an operating efficiency of 62·8%. The lower efficiency during machine physics operation is not very significant since some of the scheduled time is used for start-up, repairs and installation of special equipment. The extracted proton beam was scheduled to operate for 1,374 hours during the year (HEP plus machine physics) and 1,000 hours were realised, an operating efficiency of 73%.

As in previous years, the injector operated with a 20 mA, 350 μs beam pulse.

Equipment reliability

Nimrod efficiency during HEP scheduled operating time from 1 January to 31 December 1967 is shown in figure 16. There were two shut-downs during the year, from 17 January to 28 February and 3 October to 20 November.

Details of the performance and development of Nimrod are given in reports which are issued quarterly. (See List of Publications, page 104).

The causes of lost beam time are summarised in Table 1.

TABLE 1

System	Beam time lost as a percentage of total scheduled time
Synchrotron r.f.	4·63
Injector	4·47
Targets & target mechanisms	3·00
Nimrod magnet power supply	2·58
Vacuum systems	1·68
Plunging mechanisms	1·62 { represents 8·4% of EPB scheduled operating time
Inflector	0·90
Coolant systems	0·60
Pole face windings	0·37
Diagnostics	0·18
Radial & phase loops, induction electrode systems	0·08
Nimrod magnet	0·04

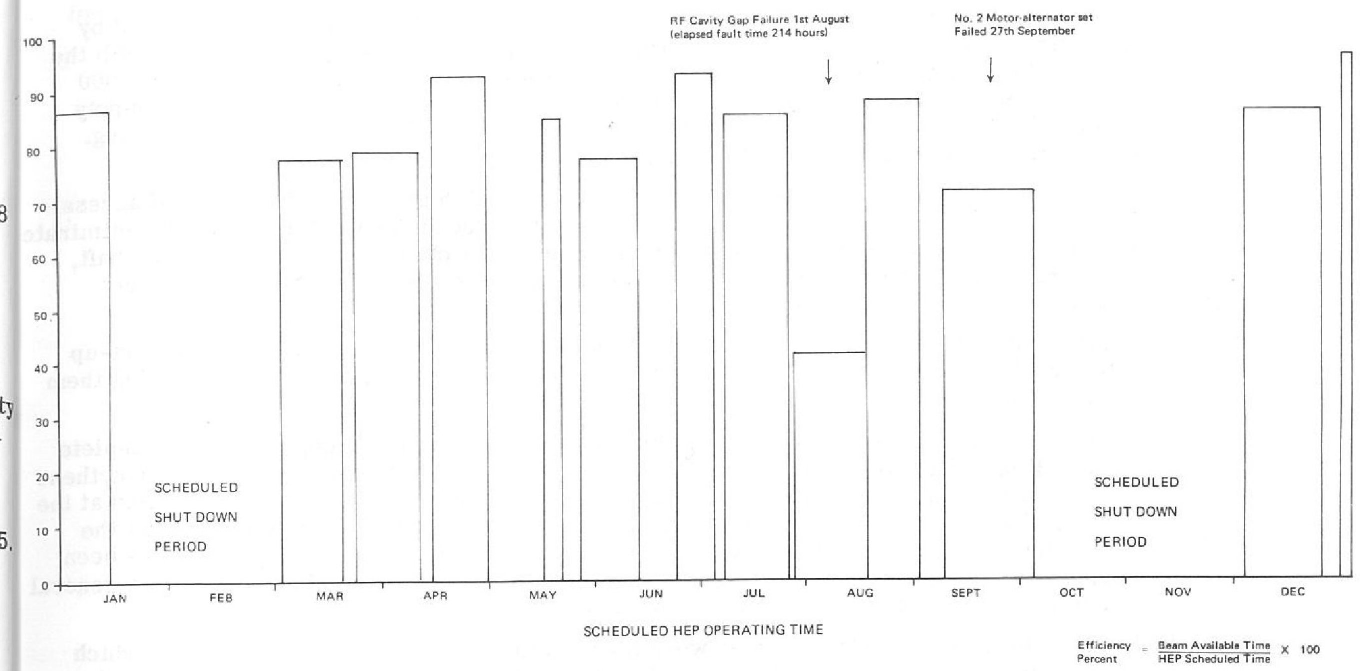


Figure 16. Nimrod efficiency during HEP scheduled operating time January to December 1967.

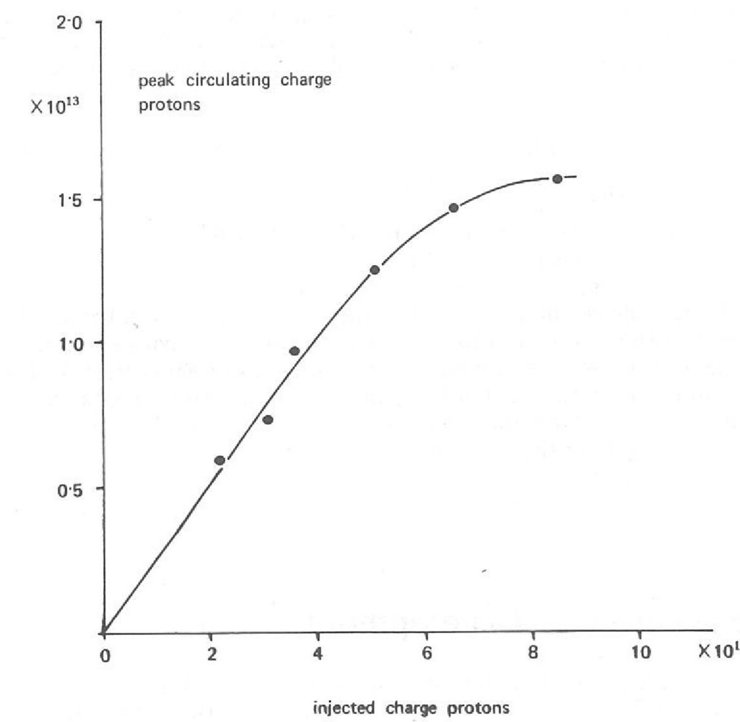


Figure 17. Plot of peak circulating charge in Nimrod against injected charge showing saturation effect due to space charge.

The reliability of the SAMES, 600 kV, preinjector supply has been greatly improved by operating throughout the year without pulse stabilisation of the output voltage and with the drive motors running at reduced speed. A generator failed in August after about 9,000 hours of operation. As an alternative to the SAMES generators, a 750 kV power supply has been obtained from Messrs. Haefely and is at present being assembled for testing. It is of the open, Cockcroft-Walton type.

An enlarged lid has been fitted to the EHT platform which gives greatly improved accessibility, and permits power supplies to be changed without the use of the crane. To eliminate the mechanical vibration which is caused by the present platform alternator drive shaft, a separate platform has been built to contain these components, though this is not yet installed.

Some trouble due to multipactor effects in the linac cavity were experienced on start-up after the October shutdown. This necessitated cleaning the drift tubes and recoating them with carbon black.

A failure of the Nimrod r.f. cavity occurred on 1 August which necissitated the complete dismantling and rebuilding of the cavity. The trouble was due to the melting of a polythene insulating section in an accelerating gap caused by r.f. arcing. The arcs originated at the contact blades of a switch, which was fitted originally to make it easy to disconnect the r.f. winding and remove the drift tube assembly for test purposes. The switch has been replaced by flexible connectors. The closed circuit TV system, which is used as a general monitoring facility has been greatly improved.

In the February shutdown, changes were made to the Type I plunging mechanisms which have resulted in improved reliability. A new labyrinth seal has been fitted and the lubricating oil changed from diffusion pump oil to a polyphenyl ester of very low vapour pressure. The hydraulic system has been simplified and the original slide wire position transducer replaced by a capacitive device with no mechanical sliding parts. This has improved position control.

Double acting gate valves of non-magnetic stainless steel were installed in the machine in October. These enable selected octants and straight sections to be isolated during fault conditions or for maintenance, without interrupting the operation of the magnet.

Magnet Power Supply

Both motor alternator sets and the complete convertor plant were in operation until 27 September the two alternators being electrically in parallel and mechanically separate. Following the failure of a Vee coil support bolt in No. 2 alternator rotor, a short period of pulsing direct from the 11 kV mains was carried out at 3 GeV to enable certain experiments to be completed before the beginning of the scheduled six-week shut-down on 3 October. Since the end of this shut-down the magnet has been pulsed using No. 1 alternator (with both flywheels) and the A1 convertor plant. Pulsing statistics are as follows:

	Pulsing hours	*Total Pulses*
(a) Prior to the failure of No. 2 alternator	4,211	5,615,706
(b) Pulsing from 11 kV mains	$88\frac{1}{2}$	38,248
(c) Pulsing from No. 1 alternator and A1 convertors	696	378,444

The failure of the support bolt was due to fretting fatigue. It caused severe damage to part of the stator and local damage to the pole edges and faces on the rotor. Both rotor and stator have been returned to the English Electric Co. Ltd., where the stator is being completely rewound and the damaged laminations replaced. The rotor will be rebuilt using the existing poles and field windings. The complete power supply will probably be back in operation by the middle of 1968.

Synchrotron Development

Ion Sources

A miniature duoplasmatron source has been successfully tested on a laboratory rig which is specially adapted to run automatically so that life tests on ion sources can be made. The present source has operated for 100 hours, with an output current of 150 mA, without difficulty. Special apparatus is being developed to make reliable measurements of beam emittance and to study the aspects of source design which affect it. One object of this work is to develop a source suitable for the PLANIM project (q.v.).

Injector and Injection

The new lens box (see 1966 Annual Report) was fitted to the pre-injector in February and its performance during the remainder of the year has been very satisfactory. A new r.f. source unit, modified to suit the new lens box, has given trouble free service. The original source unit had been in use for $2\frac{1}{2}$ years without faults or deterioration.

A new infra-red light guide signalling system for monitoring the platform power supplies has been developed in the laboratory and is at present being engineered. It will permit random access to any of 15 parameters which can be transmitted in either digital or analogue form.

A new RS 1041 circuit, designed to simplify maintenance of the linac radio frequency system, was tested during the October shut-down but found to be off tune. The new circuit replaces the existing anode-grid piston and cathode-grid input circuit. The modification necessary to correct the tuning is in hand.

A system for rapid measurement of beam emittance in the linac high energy drift space (HEDS) has been developed. A mechanism has been installed in the HEDS which moves a slit across the beam in steps of 1 mm. This slit defines the radial co-ordinate of the emittance diagram and at each radial position the divergence co-ordinate is measured by collecting the beam on a special multiwire target, the current distribution on the array of 30 wires being scanned electronically. Signals from these two devices are fed into the Nimrod data handling system and from there information on paper tape is used in a program on the IBM 360 to compute a detailed emittance diagram. The electronics is complete and the wire target has been made, but not yet fully tested. Progress has been made on the beam position servo. The position of the 15 MeV beam at two points in the HEDS can be monitored by signals from r.f. pick-up loops. These signals have been calibrated in terms of the beam position measured by 4 jaw boxes, but the feedback loop to the steering magnets has not yet been completed.

A system for programming the energy of the linac output beam during injection into the synchrotron has been constructed. By increasing the energy as injection proceeds a larger fraction of the beam is accepted than in the case of a mono-energetic beam. The change of energy is achieved by changing the phase of the debuncher gap voltage with respect to the linac r.f. The phase change is brought about by biasing the magnetic field in a ferrite loaded transmission line. A prototype system has been tested and shown to give the appropriate debuncher phase shift which gave an increase in intensity of about 20% in the Nimrod beam. A fully engineered system is now being made.

Anodised stress shields on the support insulators of the electrostatic inflector were in service for about 6 months. The performance was satisfactory but there was heavy spark damage towards the end of the period and the shields could not be restored to their original condition by polishing. Plain metal shields are to be used in future. Ceramic support insulators with swaged end caps have proved to be satisfactory in electrical performance.

Some studies of the injection process have continued. A special probe (the 'inside probe') has been commissioned which collects all the injected charge as it spirals towards the inside wall of the vacuum vessel. The charge is integrated and a signal displayed on a digital voltmeter, giving a quick method of measuring the circulating beam intensity before the radiofrequency accelerating field is switched on. Evidence has been obtained of a space charge limit to the circulating beam, at an intensity of about $1{\cdot}6 \times 10^{13}$ protons, for a value of $\dot{B}$ at injection of 5 kG/s. Figure 17 shows a plot of peak circulating charge against injected charge. In these experiments the linac produced a 30 mA, 600 μs pulse and variations in injected charge were achieved without changing any other beam parameter (such as emittance or alignment) by the use of diluters or 'sieves' to vary beam current. The figure of $1{\cdot}6 \times 10^{13}$ protons is in reasonable agreement with the theoretical transverse space charge limit. Work is continuing in an attempt to discover the actual mechanism of beam loss.

Magnet Power Supply

The dynamic braking installation was commissioned in February. Both motor-alternator sets can now be brought to a standstill from full speed in about $6\frac{1}{2}$ minutes instead of the 15-20 minutes taken previously.

A limited inspection on one half shaft of No. 1 flywheel, carried out in May 1966, showed that fretting of the joint faces between the half shaft and the flywheel had occurred. The surfaces were cleaned and coated with molybdenum disulphide, the coupling bolts modified, and on reassembly the bolt torques were increased. The same job was done on the remaining three half shaft-flywheel couplings during the January shut-down. On inspecting the original coupling, the degree of fretting was much less than that found in 1966.

Redesigned anode and grid assemblies have been fitted to certain convertor vessels to improve their arc-back performance. This modification is now complete on both A1 and A2 groups and the arc-back rate has improved from 1 in 87 hours in January to about 1 in

200 hours at the end of the year. The plant now has a higher performance than the specification. Five sets of grid control gear, made to the new design, have been installed on the A2 convertor plant, bringing the total of sets fitted to six. The new design enables all the grid control equipment to operate at earth potential rather than at the rectifier cathode potential, so that fault finding can be carried out under operating conditions.

Permanent equipment has been installed in the master timer to enable intermediate flat tops of various lengths to be produced during the magnet current rise. A series of tests has been carried out in conjunction with English Electric Company and Lloyds Register of Shipping to investigate the stresses set up in the shaft system of the rotating plant when pulsing under these conditions. The measurements of stress and the effects of fretting are being assessed.

During the October shutdown, the core and windings of the rectifier transformer in position A1½ were removed for inspection. This transformer was chosen because it had suffered the highest number of arc-backs. Its condition was found to be excellent, only minor adjustments being necessary. The two 300/600 c.p.s. interphase reactor units were also removed for inspection. Shrinkage of the windings had taken place and the necessary adjustments were made to compensate for this.

In mid-November a short period of pulsing was carried out from the mains, in collaboration with the C.E.G.B. to discover the nature and extent of the disturbances to the grid system caused by this mode of operation. A series of tests consisting of pulses of various magnitudes up to 7 GeV level at different repetition rates was carried out around mid-day on 14 November and repeated at mid-night on the same day, the two periods being chosen because of the different generating capacity available on the grid at these times. The object of this work was to find out whether the supply authority can tolerate a pulsing load of 'Nimrod' magnitude direct on the system. If so, rotating plant would not be required for main magnet power supplies, although additional static plant would be necessary. The results of the tests were most encouraging. Static power supplies are discussed in the Engineering Division contribution to this Report.

Controls

Further progress has been made in automatic digital measurement and control.

In collaboration with the Power Supply Group, the high speed data acquisition system in the Main Control Room was used to obtain a detailed plot of the complicated phase variations of load current in the alternator. This information was needed in connection with the problems of operating the two power supply alternators in parallel electrically while separated mechanically. The data logging system will be particularly useful when assessing the problems which might arise in operating the new spare (solid pole) rotor machine in parallel electrically with one of the present keyed laminated rotor machines. Individual measurements were made on each cycle of the alternator output over the duration of a complete magnet cycle. The period and the time delay between voltage and current were determined to a resolution of 1 μs. Using a paper tape punched by the system, a computer program converted the results into a table of phase angles and related functions, and a graph of phase against time. The technique proved successful and the system was then used to obtain detailed harmonic analyses of selected cycles of the alternator output at certain critical points in the magnet cycle. To do this, the waveform was sampled and digitised to a resolution of 0·1% every 200 μs during the selected cycle. As before, the readings were punched out on tape for analysis by a computer which gave a table of the relative amplitudes of all harmonics up to the 27th. The same system was also tried out as a data logger acting as a monitor on focussing magnet currents in the injector.

On Nimrod itself, new equipment has been installed for measuring and indicating the field in the magnet. Associated equipment stabilises the peak field by feeding back voltage adjustments to the power supply. Digital read-out devices have been installed to display peak magnetic field, rate of rise of field at injection and rate of rise of field on "flat top".

Radiation Dosimetry

Radiation dosimetry in the region of the vacuum vessel has continued and the data generated is given a clearer picture of the radiation environment of the vacuum vessel and other components in close proximity to the proton beam. This information is particularly important in estimating the life of the Nimrod vacuum vessel, which is now considered to be about 30 years at the present beam intensity. Even with a substantial increase in beam intensity, (resulting, for example, from the PLANIM project) the lifetime should be at least 10 to 12 years.

All dosimeters now installed are based on the hydrogen evolution technique. In 26 of the total 48 circumferential positions which are normally monitored in the inner vessel, the dosimeters are designed to be read immediately by means of pressure gauges. The dosimeters in all the other positions must be removed from the vessel for collection of data.

The radial dose pattern shows a maximum at approximately 10 cm from the back wall of the inner vessel. The circumferential pattern of total dose received by the vessel up to October, 1967 is shown in figure 18. Table 2 lists the average and peak doses for each octant up to October, 1967.

TABLE 2

Average and Maximum Dose per Octant up to October, 1967

($17{\cdot}8 \times 10^{18}$ protons accelerated)

Octant	Maximum Dose (Mrad)	Average Dose (Mrad)
1	160	135
2	110	83
3	68	57
4	75	64
5	125	92
6	110	92
7	142	112
8	172	142

These data are further illustrated in figure 19 which gives isodose contours corresponding to the total doses recorded from machine start-up.

In addition to the inner vessel data, results have been obtained for doses on the outer vessel, above the peak radial position recorded for the inner vessel. These values are one to two orders of magnitude smaller than the dose measured in the inner vacuum vessel. The highest regions of dose on the outer vessel occur immediately following straight sections due to the absence of the shielding action of the pole tips.

Accelerated Beam Utilisation

Targetting

The main methods of using internal targets in Nimrod are the same as those described in the 1966 report, though development work has continued. Considerable work has been done in an effort to reduce the structure appearing on the slow spill which is caused by the magnet power supply. The origin of certain undesirable commutation transients in the convertor plant has been traced and the firing angles of the excitrons have been corrected. Some progress has been made in improving the reliability of the primary ripple filter. A servo system has been installed to control the slow spill by control of some of the pole-face winding currents. As yet, however, the loop gain of the system is not high enough for this to be a useful device. The noise servo technique, which was described in the 1966 Annual Report, has been successfully used to spill the circulating beam onto the target for the X2 extracted beam. This is an important advance, one of the consequences being that magnet current ripple effects are much less serious.

A prototype system for producing a fast beam spill to bubble chamber experiments was installed during the January shutdown. This is the radiofrequency knockout system in which protons are made to strike a target by exciting radial betatron oscillations with a vertical radiofrequency magnetic field. An advantage of this method of spill is that the energy spread in the beam is no more than that due to the process of acceleration itself. Experiments at 7 GeV showed that most of the beam could be made to strike an internal target with relatively a low power r.f. magnetic field. The fact that some of the beam was not spilled is thought to be due to the variation of betatron oscillation frequency with amplitude i.e. the 'n' value varies across the machine aperture and particles oscillating with large amplitudes see a different mean 'n' to those with small amplitudes and so oscillate at a different frequency. It is intended to overcome this effect by sweeping the frequency of the magnetic field through the range covered by the beam, by means of a swept frequency, low power oscillator driving a broad band power amplifier. Work on the oscillator is nearing completion and it is hoped to commission a suitable power amplifier in the near future.

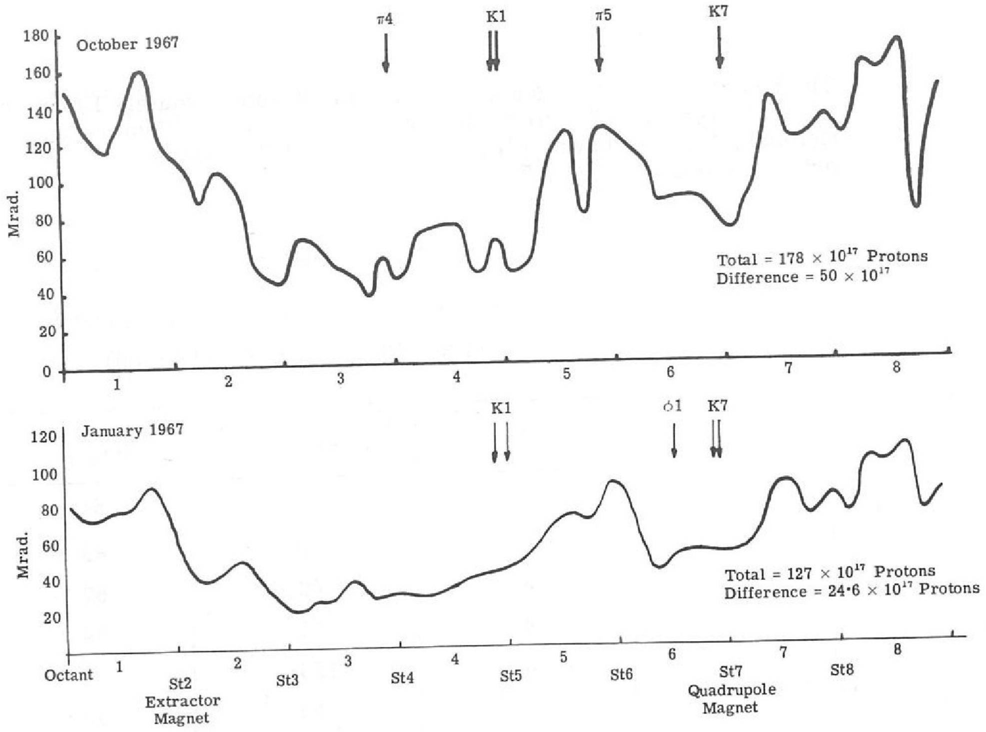


Figure 18. Absorbed radiation dose profiles for the inner vacuum chamber of Nimrod.

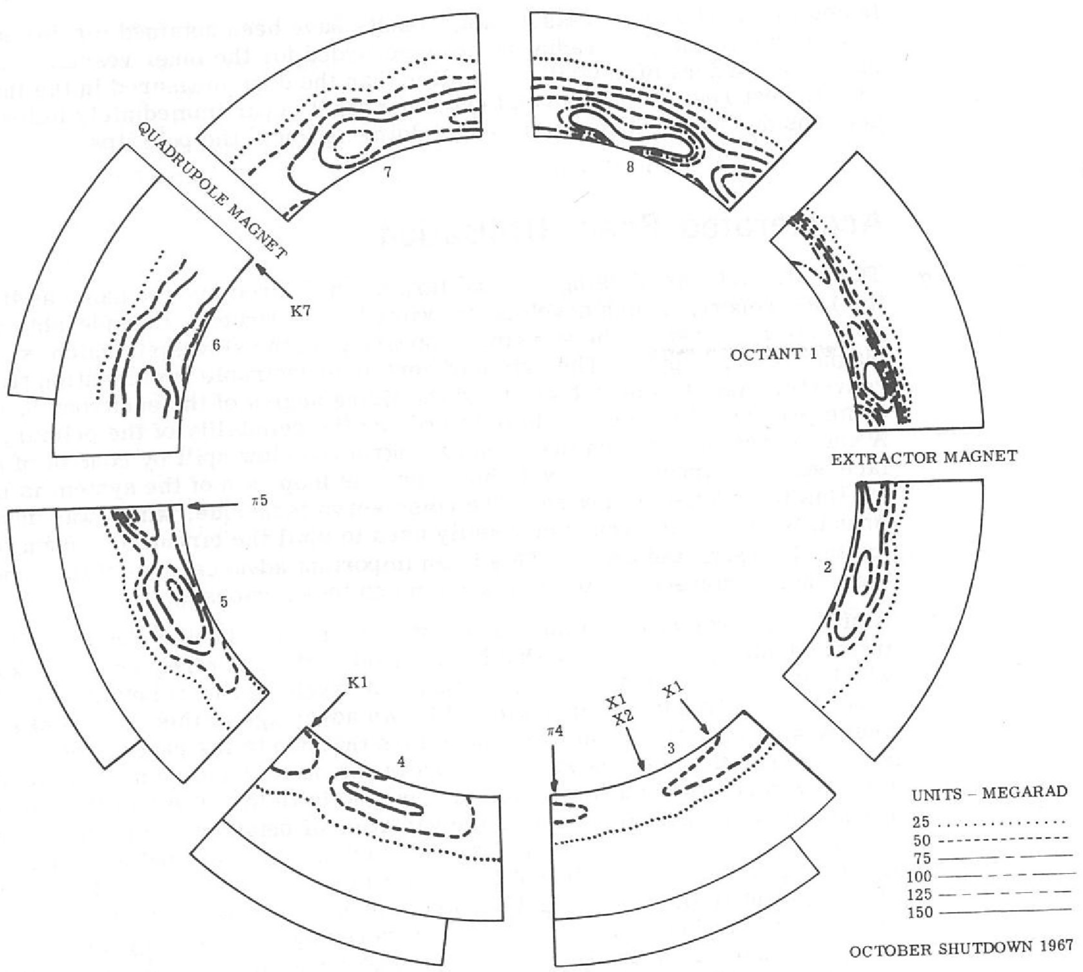


Figure 19. Integrated isodose contours for the inner vacuum chamber of Nimrod.

A target monitoring scheme is being developed which distinguishes between individual targets. Such a system will help in setting up the beam sharing programme, which is at present mostly done by consulting the monitoring facility on each beam line. Preliminary studies with directional Cerenkov systems showed that these require too much shielding to be practical. An electrometer system, which works by measuring the charge lost (due to the ejection of electrons by the beam) by an insulated target, has been successfully tested.

The Mk 1B internal target mechanism, which has to be withdrawn from the vacuum vessel when a change of target is required, has been replaced by an improved device. In this range of mechanisms (the Mk 1C range, see figure 20), the target can be changed through an air lock without disturbing the vacuum in the machine (figure 21). The mechanisms are designed to have high reliability, with interchangeable components and they occupy the minimum space external to the header vessel. The construction is mainly aluminium the reaction products from which have short half lives, thus minimising the handling problems caused by induced radioactivity. The operational life is limited to about 2×10^6 operations when the composite bearings need replacement. This is done as part of the routine maintenance. Alternative bearing materials are under development.

External Proton Beams

Two new external proton beams, X1 and X2, based on the Piccioni "energy-loss" system, were brought into operation during 1967. A significant part of the Nimrod experimental programme will depend on them in 1968. X1 (figure 1) replaces the earlier P1 beam and has an extraction efficiency of about 20% though the beam at the external target is focussed to a much smaller spot (about 2·5 mm diameter). There is evidence that X1 does not emerge from Octant 3 precisely along its calculated axis and further studies of this effect may be made. In X2, proton fluxes of about $2{\cdot}8 \times 10^{11}$ per pulse have been measured, corresponding to an extraction efficiency of about 35%. The spot size is about 2·5 mm diameter. Both X1 and X2 use the same extraction magnets in octants 2 and 7. At present they may share a given Nimrod pulse only by accepting a lower proton energy of about 5 GeV in X1. An alternative technique is to send a full energy scattered beam down X1 (from an outside radius target in octant 2) followed by normal extraction down X2.

Prototype external target mechanisms have been successfully commissioned in both X1 and X2 and allow rapid changes of target by remote control. Work has begun on an improved version to work in vacuum.

Several developments have been made in extractor magnets and quadrupoles. An existing quadrupole has been modified to provide a thinner septum and the latest extractor magnet pole pieces have been shaped to give a higher basic gradient (see figure 22). New magnets have been designed which incorporate these improvements as well as higher current ratings and better vacuum systems. A new control system for the pole face windings of the extractor magnet has been commissioned on X1 and X2.

A special switched power supply is almost completed, which will control the current in the extractor magnet and allow the beam to be switched from X1 to X2 during a single machine pulse.

Various improvements have been made to beam control and diagnostic procedures:

(a) A current transformer, or toroid, has been used to give a direct estimate of the proton flux in fast spill conditions.

(b) Preliminary work has been done with charge loss devices, in which the loss of charge from an insulated target, caused by the passage of the beam through it, is used as a measure of beam intensity.

(c) The electronics has been improved on the secondary emission chambers, which are used to measure beam intensity, leading to greater reliability.

(d) New, 0·1 mm diameter wire scanners have been used to measure beam profiles at foci.

An immediate check on spot size and stability of the external beam at the target is given by the use of scintillating screens viewed by closed circuit television. Scintillator telescope target monitors have been installed and provide a reliable signal to the secondary beam users under slow spill conditions. For fast spill, double Cerenkov target monitors are being developed.

Variable vertical and horizontal collimators have proved valuable in measuring beam alignment and optical behaviour in X2 and will be incorporated in future extracted proton beams.

The design of a third extracted beam, X3, to serve the new Experimental Hall 3 is well advanced. Theoretical studies of resonant extraction have continued and X3 has been planned to use either an energy loss or a resonant scheme. Initial operation may be in the

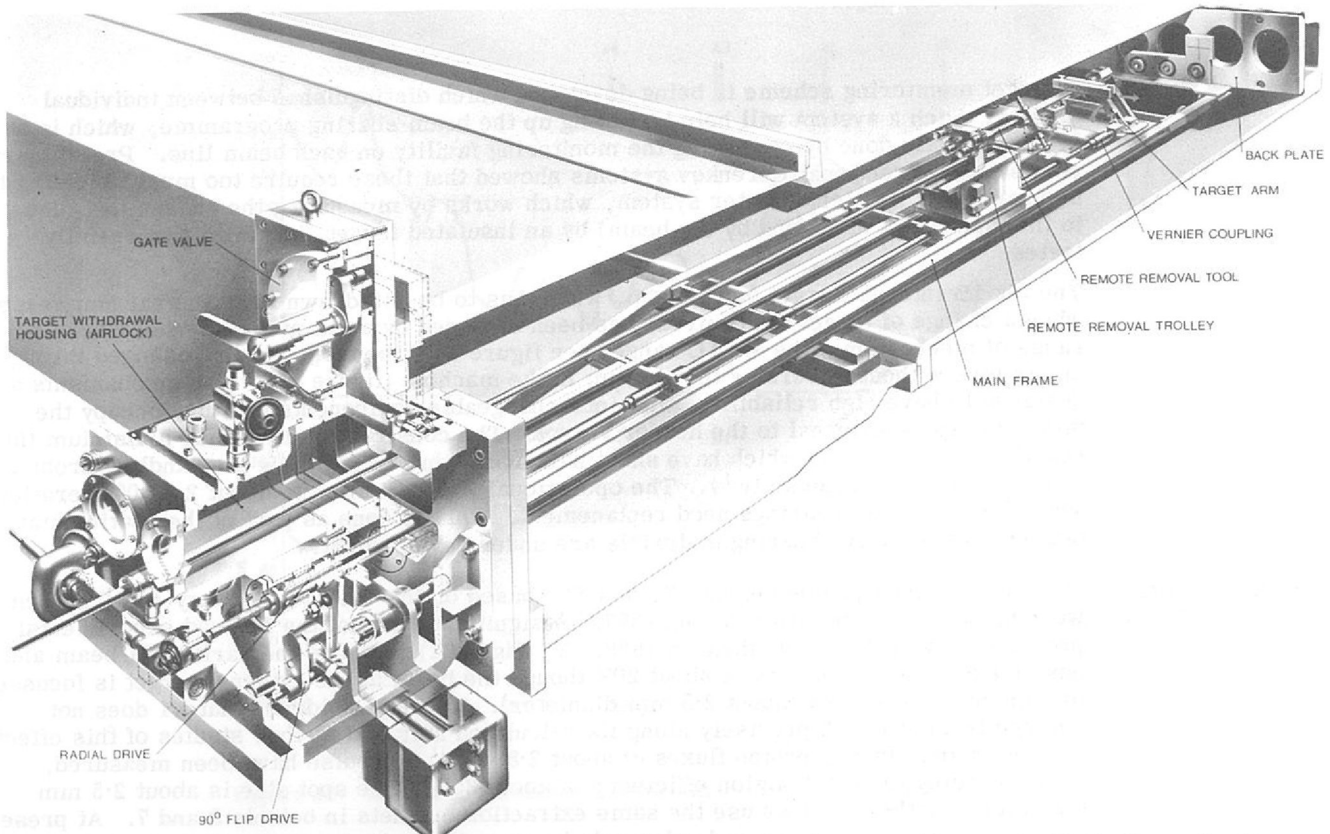


Figure 20. Mk Ic target mechanisms showing air lock and means of remote removal of targets.

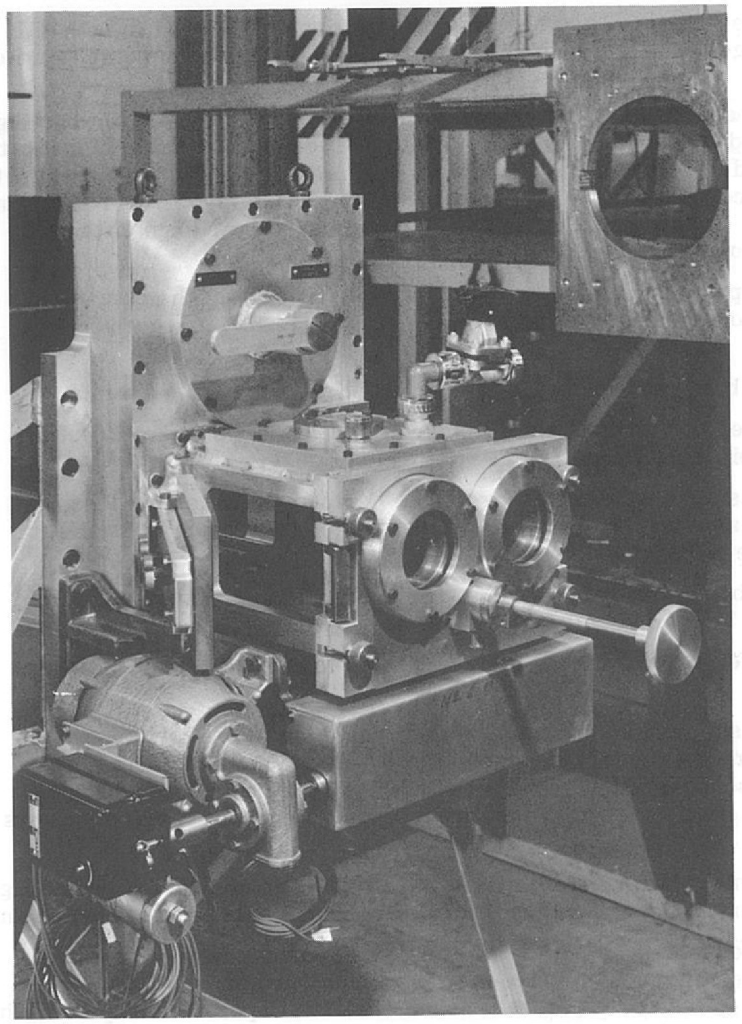


Figure 21. Mk Ic target mechanism air lock.

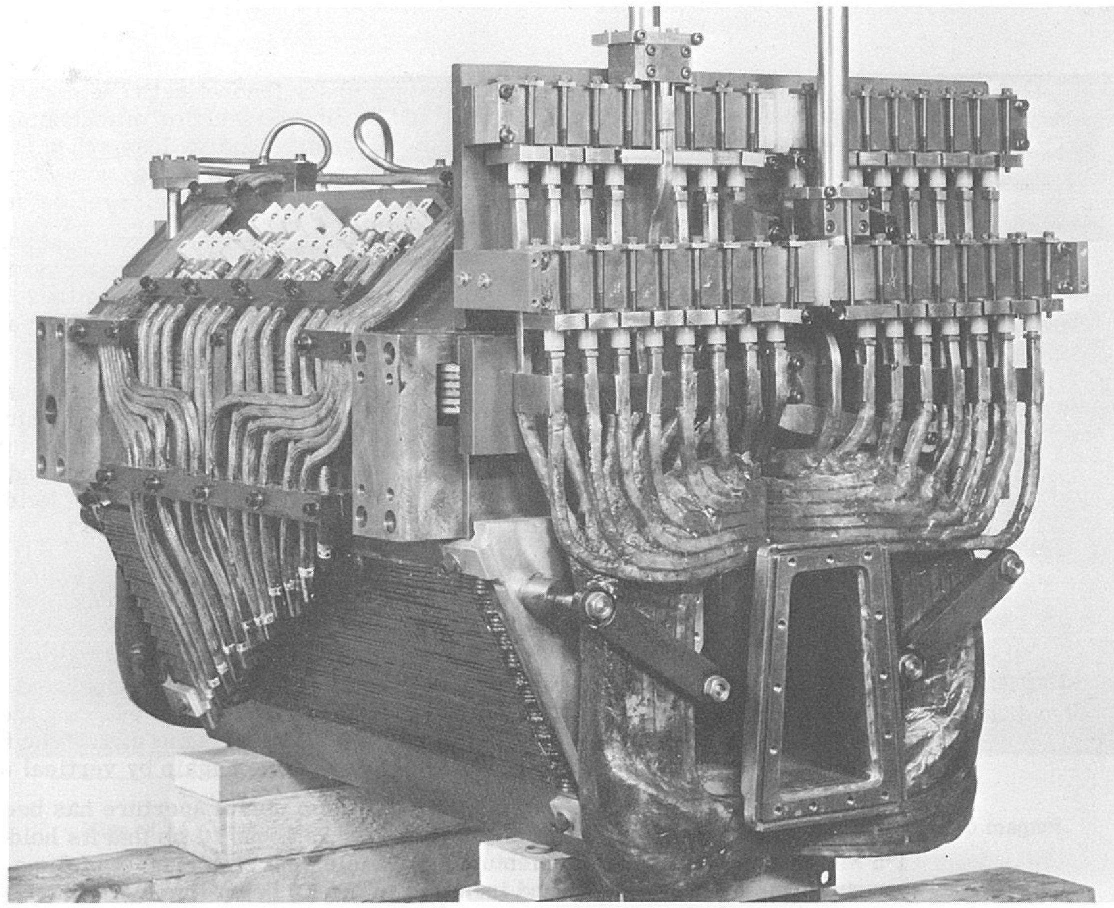


Figure 22. Redesigned extractor magnet. The vacuum can has been removed to show the improved water and electrical connections.

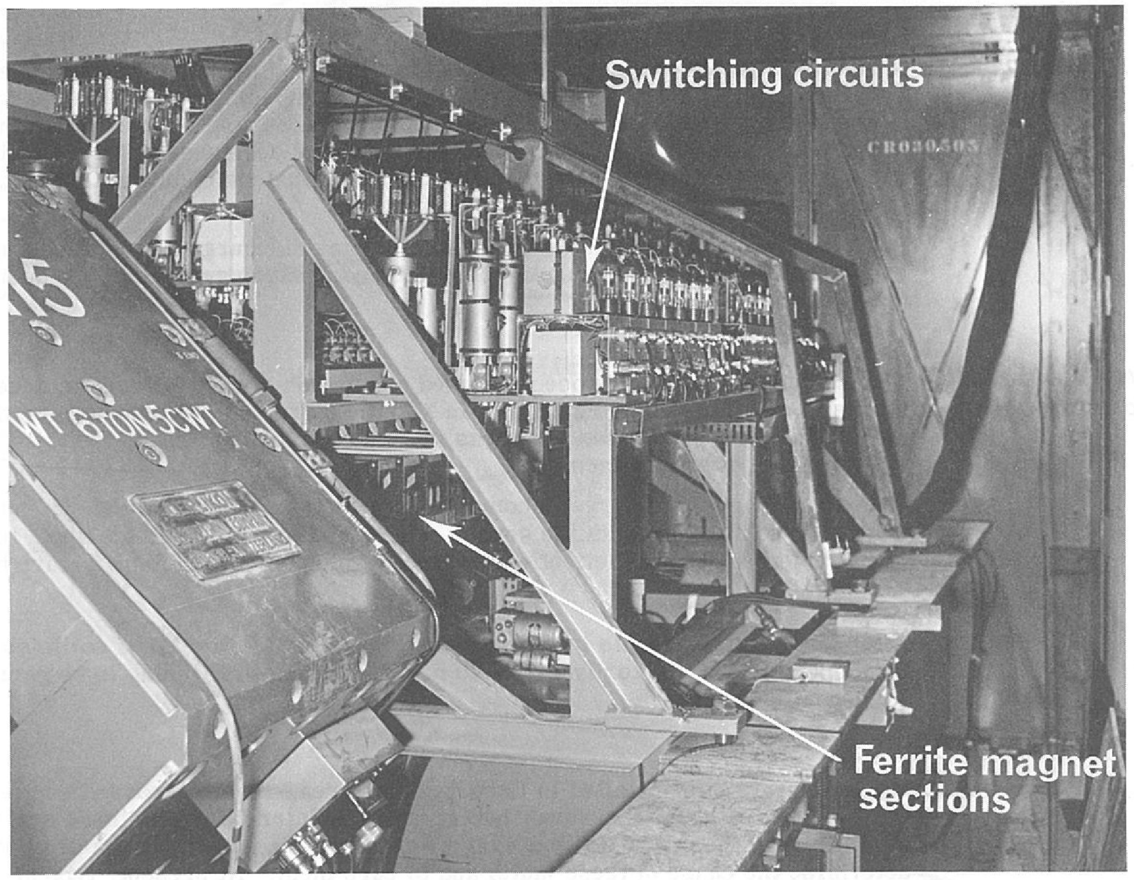


Figure 23. A 15 element step magnet installed in K9 beam line.

energy loss mode. The energy loss designs under theoretical consideration include new plunged magnets in straight sections 1 and 4 and the insertion of focussing quadrupoles in the header tank region of octant 5. In an alternative energy loss scheme, the extractor magnet septum thickness would be reduced to about 1 cm, allowing a very short target to be used, so that the quadrupole in straight section 1 would no longer be necessary.

For the resonant extraction system, prototypes of the first septum magnet and its power supply have been constructed for 20 kA pulsed operation. A compact vertical plunging mechanism has been built for this magnet. Opportunities of testing these devices on Nimrod are awaited. The 1 cm septum XE design mentioned above is appropriate to the second magnet of the resonant scheme.

Detailed theoretical studies are well advanced and have embraced different methods of initiating the $Q_r = 2/3$ resonance. In the distributed perturbation technique, Nimrod pole-face windings are energised to provide the perturbing field. The lumped perturbation technique involves discrete multipole and dipole perturbing elements, and the poleface windings are used to control the spatial and temporal distributions of field gradient in the machine during extraction.

Beam Transport Components

Shutter and Step Magnets

Two kinds of fast pulsed magnet have been developed for use in separated beams to bubble chambers. The step magnet deflects each successive particle entering the chamber by a finite vertical step across the aperture. The shutter magnet limits the total number of particles entering the aperture to a pre-selected value, again by vertical deflection.

A Mk II air-cored shutter magnet of 16 cm × 8 cm useful aperture has been constructed and installed in the K9 beam line. Its risetime is about 10 μs and its hold-off time about 1·5 ms at maximum beam momentum. A 15-element step magnet of 6 cm × 11 cm useful aperture has been developed and installed in the K9 beam line (see figure 23). The cores are constructed of permanent magnet ferrite, and rise times are less than 10 μs, (as shown in figure 24). Both elements are designed to accommodate double pulsing of the chamber and their parameters have been chosen with a view to creating prototypes of future standard elements.

High Field Pulsed Magnets

A high field pulsed magnet system has been designed to produce an enriched beam of Λ° hyperons into the 1·5 m hydrogen chamber. The design field is 70 kG over a length of 40 cm. Copper coils have been constructed and are being potted: the stainless steel support structure is ready. The 0·02 F capacitor bank has been assembled alongside K9, and the firing circuit has been constructed and tested. Final assembly and testing of the system awaits delivery of depleted uranium collimation.

Basic research has been initiated on a coiled gas discharge tube to take the place of heavy copper coil. This may result in a simpler and cheaper system for producing high pulsed magnetic fields.

Septum Magnets and Focussing Magnets

New septum magnets have been designed and are on order, tailored to accept secondary beams at small angles from targets in X3, the extracted proton beam for the new Experimental Hall 3. The septum thickness increases from the first to the third magnet, so as to minimise power requirements.

Focussing magnets to serve in comparable situations have been the subject of a design study. In comparison with the septum magnets, their fringe fields seem to present a more formidable problem in their effect on the on-going EPB, and manufacture has been deferred.

Collimators

After some initial trouble in commissioning, six of the new Mk II collimators (25 cm long) have operated satisfactorily in the K9 beam line, allowing tuning to be carried out by the "ray-tracing" technique.

D.C. Separators

All separators now installed in Experimental Area I involve crossed magnetic fields and heated glass cathodes. Several instances of insulator failure in these systems have necessitated limiting the operating temperature and voltage: investigations are under way to determine the cause of these faults and to cure them. At present, typical performance is 60 kV/cm across an 8 cm gap at 60°C.

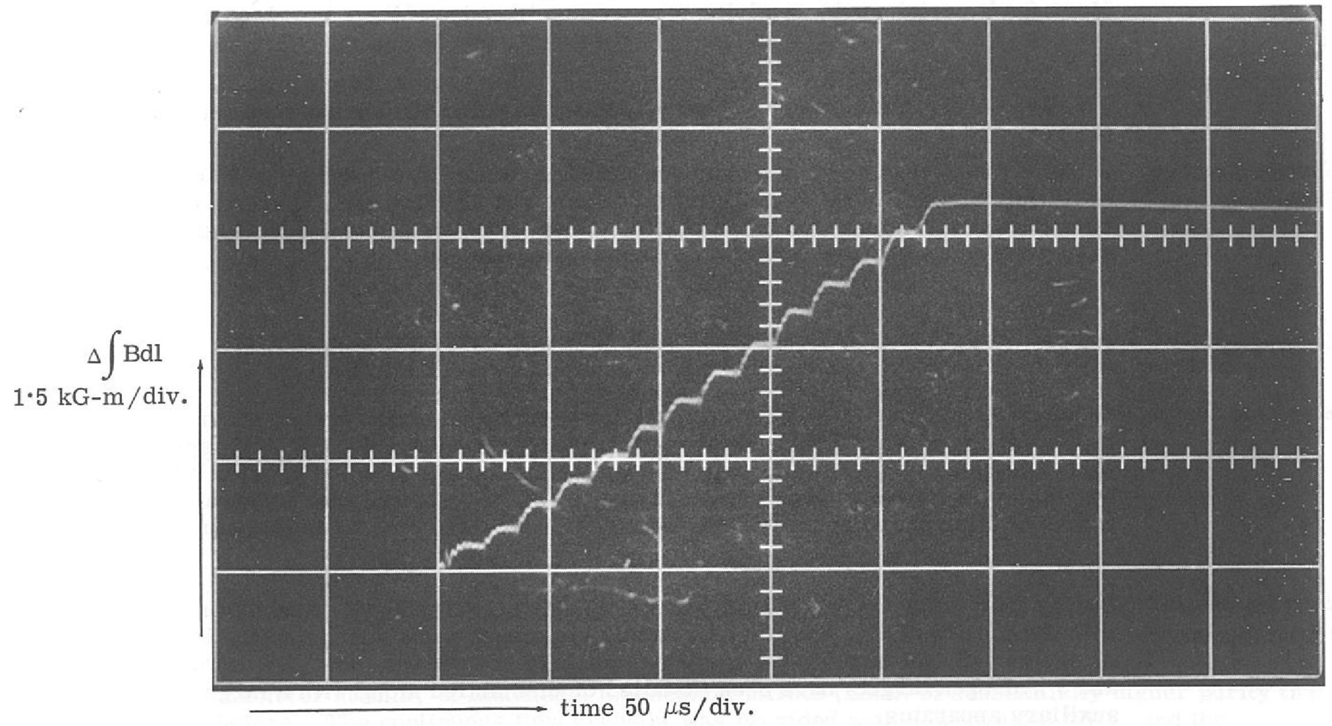


Figure 24. Integrated search coil waveform obtained during tests of the K9 step magnet.

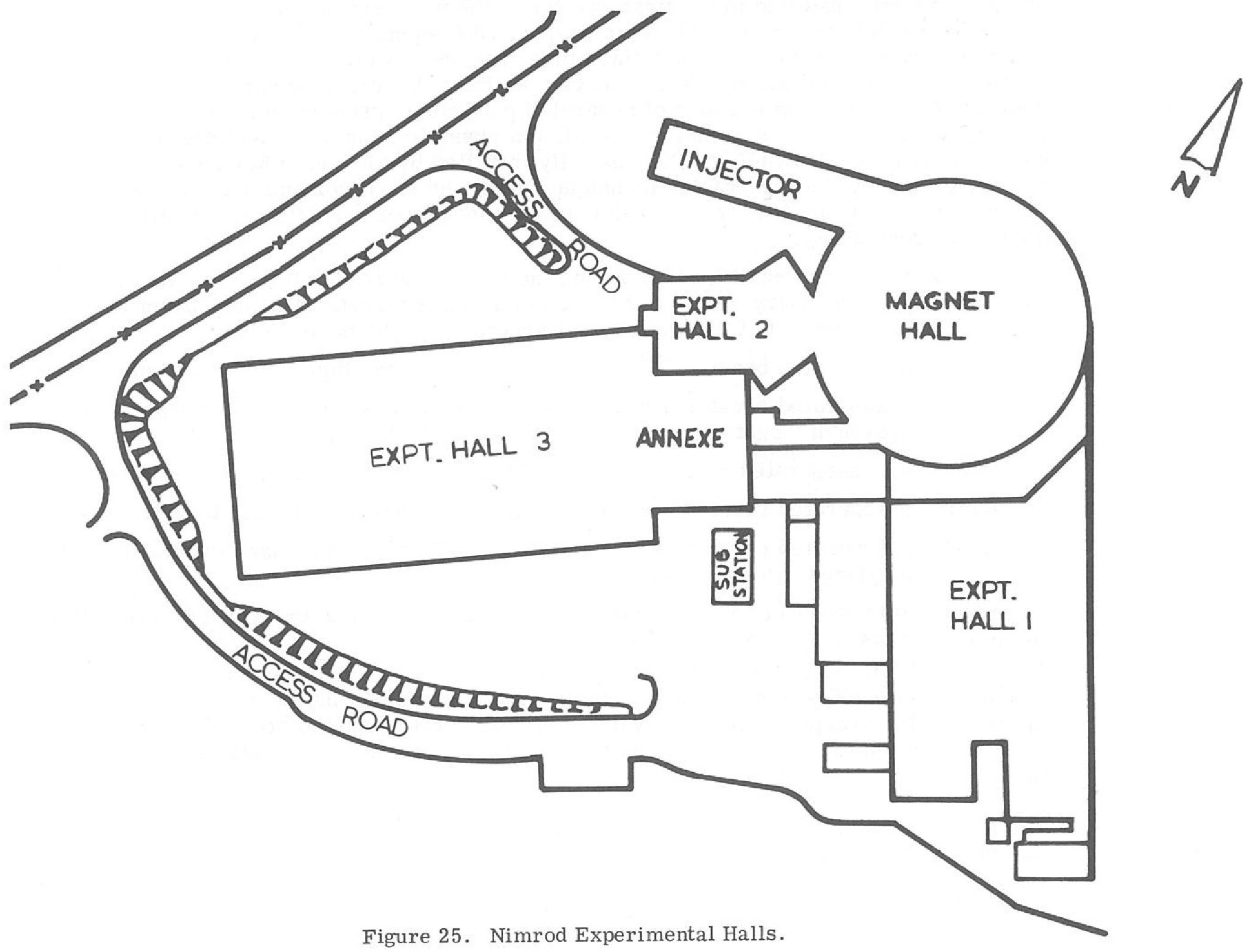


Figure 25. Nimrod Experimental Halls.

More fundamental work, involving measurements under voltage impulse conditions, is leading to a better understanding of the breakdown mechanism at electrode spacings typical of D.C. separators.

Finally, construction of a very high precision potential divider has been pursued throughout the year and is now nearing completion.

Superconducting Radio Frequency Separators

A basic research programme has been initiated, aimed at the design of 1300 MHz cavities to operate at 1·85°K, the most likely surface material being lead. Several test cavities have been constructed, and basic studies are in progress in the fields of structure geometry, r.f. system design, plating techniques and beam design.

Beam Lines

Beam Line Design

Standard Rutherford Laboratory computer programs for beam design, such as TRAMP, IPSO, LIMP and NIMDYN, have been converted to the IBM 360 FORTRAN system. At the same time, many improvements have been incorporated, aimed at greater efficiency, breadth of application, and more sophisticated output presentation. Several new programs of different complexity have been written for resonant extraction studies.

Beam Line Installation and Commissioning

During the year every beam line, except $\pi 4$, has been replaced. Apart from the difficulties with the electrostatic separators the whole programme was completed to schedule. Altogether 12,000 tons of shielding, 100 magnets and quadrupoles, 7 electrostatic separators and 5 hydrogen targets have been installed or dismantled along with a large quantity of auxiliary apparatus.

The layout of beam lines at the end of the year is shown in figure 1 (see page 13) for an indication of the nomenclature).

Most of the experiments in Hall 1 are now served by the two extracted proton beams X1 and X2. X1 was installed in the first quarter of the year and involved the rearrangement of the main shield wall to provide a block about 10 ft square, along the beam line, which can be easily removed to facilitate any future changes. A target in X1 provides secondary particles for the K9 beam line which serves the 1·5 m hydrogen bubble chamber, and is designed to provide a wide range of separated particles – protons up to about 8 GeV/c, positive or negative pions up to their maximum possible momentum and positive or negative kaons in the range 2-3 GeV/c. K9 was fully installed by the end of March and the beam has been tuned by the ray-tracing technique, using the Mk II collimators. Measurements indicate that the beam behaves according to the theoretical predictions. Detailed measurements are continuing.

The second EPB, X2, was installed during the second quarter of the year. X2 serves a complex of five secondary beams derived from a single target. All these beam lines had been installed by the end of the year, the characteristics being as follows.

K11: A separated beam of 2·3 GeV/c K^- for the heavy liquid bubble chamber.

K12: A separated counter beam of 0·45-0·85 GeV/c K^+ or K^-. It incorporates a hydrogen target and a 100 ton spectrometer magnet.

K13: An unseparated counter beam for 1·03 GeV/c π^- with a spectrometer magnet.

K14: A separated counter beam for 1·1 GeV/c π^+ with a hydrogen target.

K14A: A separated counter beam for 0·6-2·7 GeV/c π^+, to be used eventually with a polarized proton target.

Up to three of these beams may be run simultaneously i.e. K12 and K13 may run with any one of the beams K11, K14 and K14A.

The original K1S beam was dismantled during the last quarter of the year and replaced by a beam called K10S which uses a separator inside the magnet hall and a liquid hydrogen target with the exceptionally small volume of 0·02 litres. Special steps have been taken to counteract thermal contraction and to maintain the position of the target to within $\pm$0·01 inch.

The only beam line surviving from the previous year is $\pi 4$ though its local control room was repositioned, in itself a major operation.

The Saclay bubble chamber ceased operating in May and was shipped back to France in June.

In Experimental Hall 2, the $\phi 1$ beam line was removed in the first quarter of 1967 and replaced by a new beam called $\pi 5$. This beam uses a 100 ton spectrometer magnet and a liquid hydrogen target. The inner part of Hall 2 has a low roof and a special hydraulically operated mechanism was successfully used to manoeuvre the magnet into position.

Targets for High Energy Physics Experiments

Liquid Hydrogen Targets

A new type of liquid hydrogen target operational system, based on the use of a commercially available helium condensing refrigerator working on the Stirling cycle, is being manufactured. The system, which requires no external supplies of liquid hydrogen, is designed to make targets for counter experiments safer by reducing the amount of hydrogen to a minimum, placing the controls and helium purification system outside the target igloo and providing some automatic and remote control. The hydrogen from an accidentally burst target would be vented into a closed vacuum system to prevent possible ignition by static electricity.

Polarized Proton Targets

The target used for the K7' experiment was based on the K7 target (see 1966 Annual Report) with important changes in the crystals, cryostat and nuclear magnetic resonance (NMR) system. The target itself was in the form approximately of a cylinder, length 25 mm and diameter 25 mm, of lanthanum magnesium nitrate (LMN) of substantially higher purity than before. The continuous flow cryostat was provided with new straight tails, and the helium gas pumping speed doubled to 1200 litres per second.

In the fast sweep NMR and data handling system, which is entirely new and which has important advantages over conventional systems, the admittance of the tuned circuit which includes the target crystals is measured by observing the current (I) flowing when an r.f. voltage is applied across it from a "constant voltage" source. The polarization is then proportional to $\int(I-I_o)d\nu$ (I_o is the current when the sample is unpolarized and ν is the frequency); this can be rapidly computed 'on line' using a standard voltage-to-frequency converter, plus a scaler, instead of the more complicated analogue computer previously required. The system has the advantage that at low values of polarization the measurement is independent of the Q of the tuned circuit; hence the Q can be increased to achieve a better signal-to-noise ratio for the fast sweep thermal equilibrium proton line used for absolute calibration.

The target has operated for about 1300 hours during the K7' experiment. The maximum polarization, about 63%, was greater than in previous Rutherford Laboratory targets, largely due to the better crystals and higher pumping speed.

Progress has been made in research work aimed at improving present and future targets. Measurements have been made of the proton relaxation time in samples of target material ("1%" LMN). At $\sim$ 1°K in the magnetic field range 2 kG to 15 kG, the field dependence of the relaxation time is a sensitive test of the purity of the material as it affects the polarization. Each of the crystals used in the K7' target has been studied; the measurements indicate that at the field used on the target (18·5 kG) proton relaxation via unwanted impurities is negligible and that the concentration of unwanted impurities is considerably lower than in the K7 crystals. LMN crystals grown from $\frac{1}{2}$% Nd solution have also been studied.

Preliminary results have been obtained in the study of materials of higher hydrogen content. Measurements have been made at 3 kG on the electron and proton relaxation rates, and polarization in a material in which promising results at 25 kG have been recently reported: an ethanol-water mixture doped with the free radical porphyrexide. This work indicates the presence of large numbers of unwanted relaxation centres, which may limit the polarization obtainable.

A helium-3 refrigerator is being designed by the Central Engineering Group for use in measurements of relaxation times at temperatures down to 0·3°K. The device will also allow operation at power levels of $\gtrsim$ 0·1 watt at higher temperatures ($\gtrsim$ 0·8°K) for fast polarization.

In addition, hydrogen deuteride, a possible high proton material for future targets, has been prepared but not examined. An NMR system has been designed for use at fields up to 50 kG.

New Experimental Hall for Nimrod

Approval was obtained in December 1966 for the construction of a large new experimental hall, known as Hall 3 (see figure 25).

Clearance of the site began early in 1967 and excavation for the foundations, involving the removal from site of over 53,000 cubic yards of earth, was completed by June.

The large retaining wall which forms the east end of the annexe to the main hall and through which the extracted beam from Nimrod passes was completed by the end of the year. A good start was made on the main tunnels under the floor, the over-site concreting and the steelwork erection.

Orders have been placed for the equipment to extract the beam from Nimrod and transport it to the first target station in the new hall, and to construct a block-house with two emergent secondary beams.

The hall is scheduled to be available for experiments by early 1969.

The Planim Project

The decision to stop running the 50 MeV PLA for nuclear physics in October 1969 has opened the possibility of using the PLA as an injector for Nimrod. Experiments at injection and during trapping of the protons in Nimrod with its present 15 MeV injector indicate that the accelerated beam obtainable in Nimrod is limited by space charge effects. If this is so, then injection at 50 MeV should lead to an increase in accelerated beam of a factor of 3·5, i.e. to $4 - 5 \times 10^{12}$ protons per pulse. Continued measurements of the radiation dose to which the Nimrod vacuum vessels are subjected have indicated that with proton beams of this intensity, even without increased extraction efficiency, the useful life of the vessels will be 10 to 12 years. A major item in the cost and complication of converting Nimrod to a higher intensity machine is therefore removed.

A design study has been started to investigate the feasibility of using the PLA as a Nimrod injector. Injection would be into straight 2, by one of two possible schemes. Either the PLA would be moved to a new building alongside the existing injector, or it would be left in its present position with the 50 MeV beam being transported to Nimrod. More diagnostic equipment has been put into Nimrod to check whether the present upper limit to the beam intensity is due to space charge forces acting as predicted theoretically. A 50 MeV injector would have to deliver a more intense beam (possibly up to 75 mA) than the present 15 MeV injector, and major changes to the PLA will be needed. The present grid-focussed Tank 1 will be replaced by a quadrupole focussed section, and extra r.f. power will be provided for all three tanks. A new pre-injector will also be required, but the changes to Nimrod itself will be of a minor nature. Considerable thought has been given to ways of providing a computer-centred control system for PLANIM. The design study and cost estimates are expected to be complete by mid-1968.

The Proposed European 300 GeV Proton Synchrotron

Throughout the year detailed geotechnical and civil engineering studies have been made of the U.K. site offered at Mundford in Norfolk; the Rutherford Laboratory has collaborated where appropriate in this work as well as participating in the general activities of the Science Research Council relating to the site.

Members of the Laboratory continued in the work of the European Committee for Future Accelerators (ECFA). The Utilization Studies, begun in 1966, culminated in a two week Winter Study at CERN in January 1967. A strong body of physicists from the Rutherford Laboratory and U.K. universities joined with their colleagues from other European institutions and ECFA to study the utilization requirements and so ensure:

(i) that they are adequately provided for in the design and construction phase of the project,

(ii) that the funds and manpower forecasts would permit a balanced experimental programme during the first years of exploitation.

To this end possible experiments were considered along with the necessary beams. Their implications were studied for beam handling components and detection equipment, especially large track chamber systems. Feasible experimental area layouts were evolved which could be developed to their full potential over a period of, say, four years from start-up of the accelerator. The cost of this programme was found to be consistent with the fore-casts made previously by the CERN Design Study Group.

In its report, published in May, 1967, ECFA recommended the building of a large proton accelerator in Europe with the least possible delay and stated that the project as proposed by CERN provided a good basis for taking such a decision.

The proposal is still being considered by the prospective participating nations.

```
      SUBROUTINE WRITE(NC)
      COMMON /CAED/MESIN(20),MESOUT(64),KDOUT(20),N
      COMMON /CONS/NTAP,NABAN,NDIS,IFROLL,IPEVEN,KF
     1DY1(3),KFIDY2(3),KBRENX(2),KPICX(2),KFBINS,KW
     2TOL,N2,KTES1,KTES2,KYMAX,KTOLY,ITYM,NATTP,MAX
     3INY,KPMAXY,NATT1,NATT2,KTDAX
      COMMON/CRTLCS/KTCTY,MLCS,ILCS,KYDIG(1)
      INTEGER*2 KBIN
      COMMON/ARRAY/NAME(20),KSUM(200),KBIN(200),KBU
     1 ,KYBIN(100)
      COMMON /SCAL/IF,IFIRST,ISTOP,NEXT,IABAN,NTR,I
     1LD,NEVENT,IPIC,NAT1,NAT2,NATP,IY,IENDTR,KFCT,
     2ICCT,IBN,KWORKX,IPITCH,IABT,LONGSC,ICRT,IE
      N=NC
      IF((N.LT.1).OR.(N.GT.19))GO TO 500
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
    1 CALL MESS(39,2)
      WRITE(6,1001)
 1001 FORMAT('ERROR IN GO TO INDEX IN ROUTINE CYCLO
      GO TO 30
    2 CALL MESS(36,2)
      WRITE(6,1002)IE
 1002 FORMAT('EVENT CANNOT BE FOUND ON MAG TAPE.' I
      GO TO 30
    3 CALL MESS(37,2)
      WRITE(6,1003)
 1003 FORMAT('FILM REWOUND. PLEASE TYPE NEW COMMAND
      GO TO 30
    4 CALL MESS (35,2)
      WRITE(6,1004)
 1004 FORMAT('THE LAST COMMAND WAS NOT UNDERSTOOD')
      GO TO 30
    5 CALL MESS(26,2)
      WRITE(6,1005)IROLL
 1005 FORMAT('  IS ROLL' I8,'     READY')
      GO TO 30
    6 K=KLOCK(KSUM)
      CALL MESS(52,2)
      WRITE(6,1006)NEVENT,NAME(1),(KSUM(K),K=1,3)
 1006 FORMAT(I5,' EVENTS PROCESSED. LAST='I8,'  TIM
      GO TO 30
    7 CALL MESS(38,2)
      WRITE(6.1007)
 1007 FORMAT(                                  MISSE
      GO TO 3
    8 CALL ME
      WRITE(6
 1008 FORMAT(
      GO TO 3
    9 CALL MESS(38,2)
      WRITE(6,1009)
 1009 FORMAT('DATA BUFFER IN IBM 360 IS FULL.TYPE G
      ISTOP=1
```

APPLIED PHYSICS DIVISION

Applied Physics Division

The work of this Division covers the fields of computing, film analysis, theoretical high energy physics, bubble chambers, superconducting magnets, cyclotron ion sources and radiation protection. Details of the year's activities on each of these topics is given below.

Central Computer

Operations

The IBM 360 Model 75 computer was handed over to the Laboratory at the beginning of 1967. During the year an efficient computer service has been built up and is now running well on a two-shift basis. The work load has grown progressively and a third shift will be required by early March. The major change to the installation during the year has been the addition of the large capacity IBM 2314 disk store, which has relieved the pressure on space required by our growing libraries of users' programs. It has been necessary to retain the smaller IBM 2311 disks at present but these may be eventually replaced by a drum.

A special feature of the installation has been the growth of on-line usage. Two automatic film measuring devices – HPD and CRT flying spot machines – are now in operation and are attached to the Central Computer through a DDP 224. Several counter groups are now planning on-line connection of a variety of small computers and it is expected that four such users will be operational during the next six months.

During the year the number of jobs processed per week has risen from 1200 to 1900 and the availability of the machine from just above 80% to 92%. The content of the jobs has also changed; a year ago 40% of the time was spent in compiling, 20% in link editing, and 40% in execution. Corresponding figures today are 10%, 10%, 80%.

System Software

For the sake of the multiple on-line data acquisition system, the MFT1 operating supervisor – Multiprogramming Fixed number of Tasks – was used from the beginning. Possible successors to this, MFT version 2 and MVT – Multiprogramming Variable number of Tasks – are currently under study. Additions to the standard system were incorporated to exploit the Large Core Store, to facilitate transfer of control between the main on-line program and on-line users, and to re-order priorities so that long computing jobs such as Monte Carlo simulation studies can proceed concurrently with batch processing of short jobs.

MFT1 makes no attempt to overlap printing and card-reading with computing. To remedy this, HASP-Houston Automatic Spooling Program – was added to MFT1 and has been found very powerful and easy to use. It runs in the Large Core Store.

Since the most popular programming language in the Laboratory is Fortran, both the G and H compilers have been heavily used. Recently Cobol and PL/1 compilers have been made available but so far not greatly used. A number of standard procedures have been designed to simplify as far as possible the use of the computer by Fortran programmers. Three of the eight 2314 disks are reserved for libraries of user programs. For simple jobs the WATFOR system – a Fortran compile-and-go monitor designed by the University of Waterloo, Ontario – offers even simpler access and faster turn-round.

The Scientific Subroutine Package supplied by IBM has been extended by routines written at RHEL, and current work will bring in items from the Atlas and AERE Fortran libraries which perform functions not otherwise available.

On-Line Data Acquisition System (Daedalus)

The IBM 360/75 and the DDP-224 are connected via an 8-bit interrupt line and fast data channels through an IBM 2701 data adaptor and a hardware interface built at RHEL. Control programs have been developed which enable data, commands, and reports to be transferred between programs in the 360 and a maximum of 24 devices (including 8 typewriters) attached to the DDP-224. At present the HPD1 Flying Spot Digitiser and the Cathode Ray Tube film scanner are attached, with associated typewriters; the $\pi 4$ experiment has been attached, for a time, via its PDP8 computer and will later be re-attached. The data channel to the Nimrod Experimental Area is being rebuilt so that the K8, K12, and K14A experiments may be attached, all via local computers. The Calcomp Graph-Plotter and a large visual display are also available under Daedalus, but so far have not been heavily used although a comprehensive set of routines has been developed for the generation of straight line-elements, arcs of circles, and characters, and for automatic scale-transformations.

Information for Users

In order that all users of the 360 can be kept up to date with available facilities, Bulletins are issued on operational developments such as program libraries, standard procedures, and private tape and disk allocation, while Circulars describe utility subroutines or packages which perform generally useful programming sequences. In addition there is a great deal of informal day-to-day contact between members of the Computer Operations and Systems Group and all users of the machine. A Computer Users Advisory Committee, consisting of representatives of all main users of the system, meets approximately quarterly.

Film Measuring Systems

Conventional Measuring Machines

Over the last year an average of 600 events (of simple topology) have been measured per 60 hour-week on the four manual measuring machines.

Three of the six combined scanning and pre-digitizing machines are now fully operational as the preliminary "road-making" section of the HPD factory. On pre-scanned film, up to 15 events per machine per hour (with a maximum of 4 tracks per event) have been measured. In the near future, the pre-digitizers will be connected on-line to an IBM 1130 computer. The four Shiva scanning tables have given good service throughout the year.

H.P.D.

During the year the HPD1 measuring machine has been brought into operation connected on-line to the System 360/75. During the first half of the year a new digitizing system for the machine was commissioned. This enables the machine to operate with a scan-line period of $2\frac{1}{2}$ milliseconds, an improvement of a factor 3. During this period a new control program for operation with the System 360 computer was written and tested. During the second half of the year commissioning of the complete system, rough digitizing system, HPD measuring machine and programmes was undertaken. Limited production on K^- film from the Saclay bubble chamber using the system was started in January 1968.

Work on HPD2 has concentrated on the development of a new hydraulic drive system for the stages. A servo-controlled system has been produced which both eliminates the mechanical shocks associated with the current design and which also has improved performance.

C.R.T. Film Scanner

The CRT film scanner Cyclops is now controlled from the IBM 360/75 computer via the DDP-224 computer. Part of 1967 was spent in developing control and diagnostic programs for the scanner and studying the characteristics of the system to obtain high operational reliability. Work also continued in measuring more film from the K°_L - $2\pi^0$ experiment and previously measured film was remeasured to checkout the complete system.

The scanner is now being modified to measure a further two spark chamber experiments, on 35mm film, one being the leptonic decay of K° which is being carried out at the Rutherford Laboratory, and the other an e-p scattering experiment which is being run at the Daresbury Laboratory.

It is anticipated that some 300, 000 spark chamber pictures will be taken during the Rutherford Laboratory experiment and more than 50, 000 at Daresbury. All of the pictures require measurement and preparations are being made to measure both experiments concurrently.

Programs

The programs of both the bubble chamber and the spark chamber analysis system have been brought into operation on the System 360 computer. This has involved not only the fairly straightforward transfer of programs but the development of new operating procedures to exploit the disk storage of the System 360.

(i) Bubble Chamber programs

The geometrical reconstruction program has been converted to use a general input format which has been agreed as a standard with the CERN group. Two new post-kinematics processing programs JUDGE and JESTER have been brought into operation.

(ii) Spark Chamber programs

The program for the K°_L - $2\pi^0$ spark chamber experiment for finding 4γ rays on two views was further developed on the IBM 360/75 until a production version was obtained that had an 80% efficiency. With this program approximately 25,000 events were analysed. This above system is now undergoing small changes to deal with a new but similar experiment of about 100, 000 events. A more general program is under development for dealing with two new experiments on 35 mm film which consist mainly of charged particle tracks. This program will need no prescanning information.

Theoretical High Energy Physics

The interests of the group working in this field cover a wide range in particle physics, as may be seen from the publications list. Some of the investigations are summarized briefly below.

K^+p analysis

A detailed analysis of K^+p elastic scattering data has been made in order to obtain phase shifts from threshold to 2·0 GeV (centre of mass energy).

The current interest arises because the simple quark model of hadrons cannot accommodate any resonance in this channel, i.e. with strangeness +1 and hypercharge +2. Recent accurate total cross section data from RHEL and Brookhaven show a strong enhancement at 1·8 GeV. It is important to determine whether this is a resonance or some other effect (e.g. a strong inelastic channel opening up).

Further interest comes from the general study of kaon-nucleon dispersion relations and sum rules (e.g. superconvergence relations). The K^+p contribution to such relations is required in some detail in order to predict various coupling constants, Regge pole parameters, etc.

With currently available data (which is sparse and often of poor quality) and, using simple energy dependences for the phase shifts, four solutions have been found which fit the data equally well. Two solutions show resonance behaviour (in the $P_J = \frac{1}{2}$ phase shift), the other two do not.

Using these solutions it has been possible to indicate which measurements of elastic scattering would be most helpful in future analyses. Much interest has been shown by experimentalists and it is hoped that the data situation will be greatly improved over the next year or two.

P.C.A.C.

The concept of the partial conservation of the axial current (PCAC) allows one to connect weak leptonic decay processes with the strong pion coupling constants. This is understood because the divergence of the strangeness conserving weak axial current has the same quantum numbers as the π meson; indeed another abbreviation for the approximation is PDDAC which stands for 'pion dominance of the divergence of the axial current'. The relation obtained for neutron β decay is equivalent to the Goldberger-Treiman relation and is valid to about 15%. The sign of the discrepancy may be understood by considering other states π' which may contribute. Similarly, the strangeness changing weak axial current may be related to the K meson although in this case bigger corrections might be expected. The evidence from Λ β-decay and the strong coupling $g^2_{\Lambda NK}$ is not sufficiently precise at present to give any definite conclusions, beyond allowing the possibility that K-meson PCAC could be valid.

Single Pion Production

A programme of work was undertaken on the phenomenological analysis of single pion production in πN collisions between 500 and 700 MeV. Production data were perused in order to learn something about the inelastic decay modes of the P_{11}(1400), D_{13} (1525) and S_{11} (1570) resonances which have been detected in elastic scattering. Certain preliminary conclusions were reached, the most striking being that there are indications of a second P_{11} resonance, as has been subsequently confirmed by the elastic phase shift analysts. Conclusions were tentative, largely because present data is meagre and undetailed. A more comprehensive method of presenting future data was advocated.

Nuclear Bremsstrahlung

The emission of photons in the interactions of electrons is well-known. The analogous process involving a nuclear particle rather than an electron has only recently become a subject of experimental study.

The process $\alpha + b \rightarrow \alpha + p + \gamma$ with 20 MeV incident α-particles and a polythene target is being studied by a group from Bell Telephone Laboratories and Rutgers University. A calculation is being made, in collaboration with Professor L. Castillejo of University College, London, of the differential cross-section for this process, in order to compare with this experiment. Known α-p phase shifts are used and careful account is taken of Coulomb effects.

The computer program could possibly be used, with small modifications, to calculate other nuclear bremsstrahlung processes.

Internal Symmetries of the Electromagnetic Current: Experimental Tests

Although the electromagnetic (e.m.) current (j_μ (x)) is not invariant under the strong interaction symmetry groups SU(2) and SU(3), it is none the less believed to possess the following simple transformation properties; under SU(2)

I. j_μ (x) transforms as an iso-scalar, plus the third component of an iso-vector ($\Delta I = 0$, 1 rule);

and under SU(3)

II. (a) it is a U-spin scalar

(b) it has solely an octet component.

These properties are based on the assumption that the current j_μ (x) transforms in the same way as the electric charge. This would follow from the conventional form of the e.m. interaction if there were no particles (or fields) with spin ≥ 1. However, in general it is not necessarily so.

In the published paper describing this work, the (lack of) experimental evidence for these statements is reviewed, and possible tests discussed. In fact, as has been stressed by Grishin et al., and by Dombey and Kabir, there is no evidence whatsoever in support of the $\Delta I = 0$, 1 rule (I). To remedy this, a study of the reaction

$$\pi^- + p \rightarrow \gamma + n$$

in the region of the Δ(1236) resonance is proposed. The object of this is to determine the radiative decay width of the Δ^0 resonance. If the rule is valid, this should equal that for the Δ^+ resonance, which is well-known from the study of photo-pion production on protons.

For II(a) and II(b), the situation is a little better in that there is one approximate test of each, from the mass splittings of the $\frac{1}{2}^+$ baryons, and the Δ magnetic moment measurement respectively. It is suggested that this knowledge could be usefully augmented by a study of the radiative decay widths of the Y_1^* (1385) resonance, which is copiously produced in low energy K^-p interactions.

Bubble Chamber Operations

Helium Bubble Chamber

This chamber was successfully operated for a technical run in March and satisfactory track quality obtained. It was then stripped down and prepared for the first data taking run on Nimrod scheduled for June. During July and August 750, 000 pictures were taken, some of which were for investigating the operational characteristics of the chamber. A high standard of reliability was achieved during the experiment and no major changes are planned for the future.

In the course of the technical running, the chamber was operated with two or three expansions during one beam pulse from Nimrod. Track quality could be judged only on the first and third expansions during which beam particles were injected. The tracks were good and the chamber conditions quite reproducible, indicating that this mode of operation could be exploited in future experiments. Following this success, work on the camera mechanism has been started in order to allow a shorter cycling period to be used.

Heavy Liquid Bubble Chamber

Use of this chamber with propane has involved considerable installation and building modifications to comply with the Laboratory's safety standards. Two walls are now reinforced to withstand blast pressures of 1 psi and a separate control room has been built to the same pressure standard. The roof and the two other walls are mainly clad with expanded polystyrene panels designed to blow off at 0·14 psi.

Air enters at the roof, is extracted from the base of the chamber installation and is then conducted to a chimney stack. A separate exhaust system is provided for the dump tank area.

Some modifications to the chamber temperature control equipment have been made and the resiting of the electrical control equipment has afforded an opportunity to incorporate a number of improvements. Expansion and recompression valve life tests have been carried out to select the most satisfactory valve and boot design.

Hydrogen Bubble Chamber

The installation of the bubble chamber was completed in March and operation for technical runs started. Tracks were seen but no pictures were taken until the second run in May. The picture quality was then unsatisfactory due to condensed deposits on the optical system. At the third cool down in September very good pictures were obtained and the chamber was then scheduled for operation on Nimrod. However, for a variety of reasons connected with Nimrod, the X1/K9 beam and the bubble chamber, no significant amount of data taking was possible during the remainder of the year.

Failures of the Corblin compressor diaphragms have occurred twice and have necessitated the fitting of a more sensitive oil level indicator to give a warning of diaphragm cracks. The equipment for deuterium operation has been manufactured and commissioned and facilities for liquid dumping have been installed. An extensive programme on Nimrod is planned for 1968, and 35, 000 pictures for the Cambridge neutral beam experiment have now been taken.

High Field Bubble Chamber

The design study report published in January 1967 contained a complete technical appraisal for a chamber with the following basic specification:

Chamber Dimensions

Overall Size:	Diameter (Internal)	150 cm
	Depth (Internal)	180 cm
	Volume	3300 l
Fiducial Size:	Diameter	150 cm
	Depth	100 cm
	Volume	1750 l

Superconducting Magnet

Magnet Field 70 Kg

Refrigeration

Capacity at 25°K 5·0 kW
Capacity at 4·2°K 0·5 kW

Expansion System

Single shot expansion mode.
Multiple expansions at intervals of 50 - 100 ms.

Optics

Bright field retrodirective system
4 cameras with 70 mm film
Film advance speed 10 frames per second

Positional Accuracy

$<$ 100 microns throughout the fiducial volume

Throughout the year work proceeded on the development of the design and in September a study week was organised to discuss Optics and Beam Entry and Exit problems with potential users from university bubble chamber teams. For this study a considerable number of typical track events were reconstructed to represent views of the fiducial volume for various optical and beam entry conditions. This involved developing suitable computer programs for the transformations required. The report published in November records the papers presented together with the ensuing discussions and recommendations.

In March a series of Technical Committee meetings was started at which the progress on the various parts of the chamber are reported. A comprehensive report on the year's work is now being prepared.

On the experimental side an expansion test rig has been assembled and used for some preliminary measurements on braking systems. Tests on model fibre glass epoxy bellows have not yet started but one satisfactory pressure moulded model has been produced in the Laboratory. Stress calculations on various shapes have been performed by computer.

Specifications for the vacuum system and the refrigeration scheme have been prepared and discussions with possible suppliers have been initiated. Two separate refrigerators are preferred for operational flexibility during commissioning of the chamber and magnet.

Stainless steel strip wound on with the copper superconductor composite is thought to be the most promising solution to the stress problem in the magnet coils. Trial windings are now being started in collaboration with H9 workshop, AERE. Samples of conductor produced by IMI will be tested in low temperature apparatus at the Rutherford Laboratory.

Measurements on Scotchlite properties in air at room temperature have been made and will be compared with results in liquid hydrogen in the 10 inch bubble chamber. Glass to metal seals for the fish eye windows are being investigated at room temperature and will then be tested at low temperatures. A fibre optics system for flash illumination of the chamber is being assembled.

Various schemes for housing the chamber and ancilliary equipment for experiments on Nimrod are being investigated. The most satisfactory arrangement uses beams emerging at the back of Hall 3.

Superconducting Magnets

The problems of using superconducting alloys to produce high magnetic fields are being studied. There are many potential applications in high energy physics for magnetic fields higher or more economically produced than those provided by conventional magnets; among the more important are beam transport elements (bending magnets and quadrupoles) and large volume magnets for bubble chambers and spark chambers. Longer term possible applications include particle accelerators and storage rings.

The work may be conveniently divided into two parts; first, the design and construction of specific superconducting magnets using present techniques, and second, more basic studies aimed at the development of better techniques for the design and construction of future magnets.

In the first category, a large 80 kG solenoid with 14 cm bore is now nearing completion after progress had been delayed by a number of unforeseen difficulties (including the burn-out of one of the pancakes caused by a short circuited turn).

Superconducting Bending Magnet

A bending magnet for use with Nimrod was authorized in May, and by the end of the year construction was well under way. This is a fully stabilized design, and the copper and niobium-titanium composite conductor has been ordered from IMI (Imperial Metal Industries Ltd.). The uniform field is provided by two elliptical current distributions of opposite sign; these overlap giving a region of zero current density, in which it may be shown that the field is uniform. The winding is of open construction to allow free helium flow, the 0·15 inch diameter circular conductors being held in place by slotted mouldings made of glass loaded nylon. The magnet, which is shown in figure 26, has the following parameters:

Magnetic field	40 kG
Useful aperture	17 cm diameter
Effective length	140 cm
Current	1700 A
Current density ..	7300 A/cm^2
Expected helium boil off	2-4 l/h

Special features of the design are the provision of a persistent current switch and flux pump. The persistent current switch is a superconducting short circuit across the winding which can be made effectively open by heating it slightly. After the current is established in the magnet from the external power supply the switch is closed and the external leads, which would otherwise constitute a severe heat leak, are removed. The slow decay of current arising from the non-superconducting joints in the conductor will be corrected by means of a flux pump.

Though this magnet is unlikely to represent the ultimate design for a bending magnet, it should provide valuable operational experience. It is already evident that the control and protection problems are not trivial.

The group has also participated in the design of the coil for the High Field Bubble Chamber described elsewhere in this Report. In addition, preliminary studies have been made of a magnet for use with spark chambers, aimed at producing a field of 20 kG in a volume 2 metres diameter × 1 metre high, with good access.

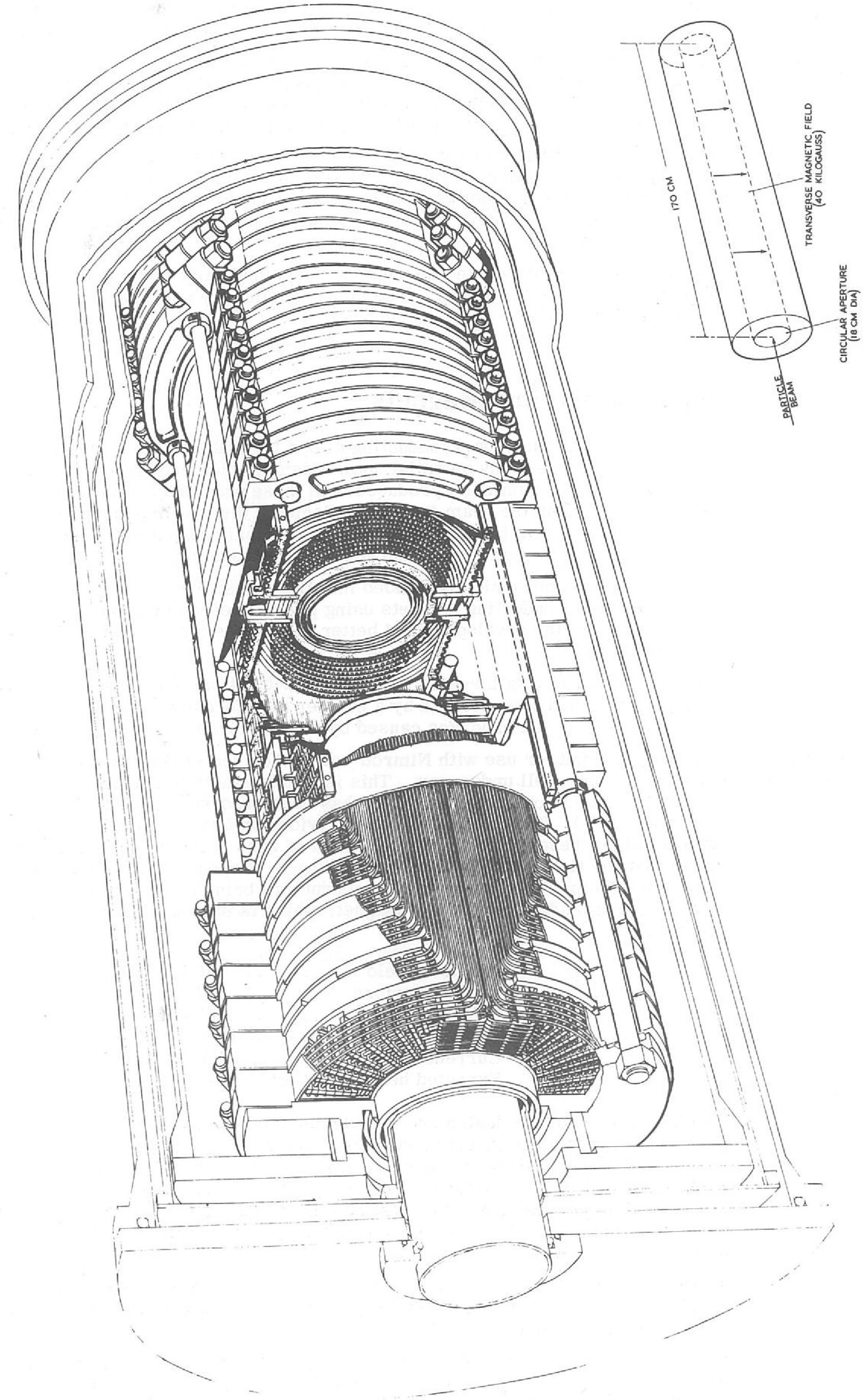


Figure 26. Superconducting Bending Magnet.

New Materials

Much of the more general effort of the group is directed towards finding an inherently stable conductor, and reliable criteria for partial stabilization. If either of these aims can be achieved, the intricate open construction which poses so many awkward engineering problems on the larger magnets can be dispensed with; such a development would also allow much higher overall current densities, resulting in more compact and economic magnets. The most promising line of approach involves the use of composites containing very fine filaments of superconductor, since there are good theoretical grounds for believing that such a material should be more stable. The presence of the metal matrix in which the superconducting strands are embedded complicates the situation, and both theoretical and experimental studies carried out during the year are helping to unravel the rather complicated behaviour of these composites. Samples for this work have been provided by I.M.I.

An additional motive for studying filamentary materials is provided by the fact that they will be essential if pulsed high field magnets with acceptably low loss are ever to be produced. The idea of a superconducting synchrotron is an attractive one, and earlier studies have been augmented in 1967 by computer calculations to establish parameters which might be typical of an 180 GeV machine with separated function lattice. This is primarily an exercise to see what the problems are, and what such a machine might look like, assuming that a stable low loss conductor is available. Some preliminary thought has also been given to power supplies using superconducting energy storage.

Variable Energy Cyclotron

The cyclotron was handed over to AERE in April; it now supports a varied research programme, details of which may be found in AERE publications. Work is continuing however at the Rutherford Laboratory on sources for heavy ions, and an axial injection system is being designed and constructed.

Ion Source Development

During the year a new high power source of simple mechanical design was developed, and is now in use on the VEC. Although C^{5+}, N^{5+}, O^{6+} and A^{8+} ions have been produced in source tests, the highest charge state so far accelerated successfully in the cyclotron is N^{4+}.

Progress was made on the design of the axial injection system, and several major components ordered. It is expected that it will be installed and working by the end of 1968. This system is based on an idea developed at Birmingham University in 1961-2. Ions are produced in a source external to the cyclotron and focussed down a vertical axial hole in the magnet yoke; they pass next through a mirror which deflects them through a right angle into the median plane of the cyclotron where they are captured into the normal spiral orbits.

In order to achieve a suitably versatile system capable of dealing with ions having a wide range of charge to mass ratio, many studies of beam optics and electrode geometry in the central region of the machine have been made. Much of this work has been done on the small 4 MeV cyclotron model, supplemented by computer studies and electrolytic tank measurements.

Arising from these studies, an alternative method of injecting from a conventional source has been devised, and tested on the small cyclotron. The source is placed at the geometrical centre of the machine instead of at the usual offset position of a few centimetres, and it is biased positively so that the beam is injected into the first orbit at a finite energy of order 10 keV per charge. Apart from the promise of mechanical simplicity (especially when interchangeability with an axial injection source is required) such an arrangement can give good beam quality and improved harmonic mode operation. Carefully shaped electrodes are needed to make a versatile system, and further development remains to be done before its full potentialities can be assessed.

Radiation Protection

Operational Health Physics

Personal Dosimetry Service The issue of both β-γ and fast neutron films continued at approximately the same level as for 1966. For the first ten months of 1967 an average of 1,070 β-γ films and 285 fast neutron films were issued per month. During 1968 a TLD (thermoluminescent dosimeter) personal monitoring service will be introduced, the technique having been described in the 1966 Annual Report; it is intended as a convenient and cheap replacement for the β-γ film for those personnel who visit radiation areas infrequently.

Detailed personal exposures are not yet (Jan. 1968) available for 1967 but ~ 80% of people continue to receive insignificant doses. Small increases in the whole-body β-γ exposures received by Nimrod Division maintenance staff and some experimental workers are anticipated. Fast neutron exposures for the first ten months of 1967 indicate no significant change from 1966. All whole-body exposures for 1967 are expected to be considerably lower than the maximum permissible exposure of 5 Rem.

Nimrod Environmental Surveys General levels due to induced activity around Nimrod have not increased significantly in the past year.

Commissioning of the X1 extracted beam indicated an efficient shield design with general radiation levels well below those produced by the comparable P1 beam. Preliminary surveys of the X2 complex indicate some weaknesses in the shielding, in general where experimental requirements have demanded some compromise in shield design. The majority of occupied areas are nevertheless below 2·5 millirem per hour.

PLA.* The performance of the new shielding installed in the Experimental Halls during October 1966 has been assessed. Due to the limitations of skyshine the existing shielding geometry has not significantly changed the overall pattern, magnitude (when normalised to beam intensity) and dose equivalent composition outside the main building shell. However the primary goal of increased accessibility to the experimental floor during machine operation with no significant personnel exposure has been achieved. No significant changes in the residual activity pattern have occurred.

The neutron attenuation through beechwood for neutrons produced by 50Mev protons at 90° to a carbon target has been measured using several detectors.

Nuclear Chemistry Wing (R. 34) and Radioactive Workshop (R. 52) The Nuclear Chemistry Wing has been used, in general, only for low level work. The Radioactive work is now in use but has yet to handle significant loose contamination levels.

Training Lectures and demonstrations on radiation hazards have been given to over 300 staff during the year.

Research and Development

Future High Energy Accelerators Collaboration with CERN and the Lawrence Radiation Laboratory, Berkeley, has continued. The extensive data obtained in the experiment completed in July 1967 has now been analysed and will shortly be published. Measurements of beam loss, radiation dose close to the accelerator, attenuation of the nuclear cascade in thick shielding, neutron spectra and tunnel transmissions have been obtained. An empirical model has been developed which is capable of predicting flux densities within the shielding to an accuracy of ± 30%.

In collaboration with the Industrial Chemistry Group studies have been made of the activities induced in chalk and water by high energy neutrons. The absorption of Be^7 and other nuclides produced in water by chalk has been investigated.

Neutron Spectrometry

Bonner Spheres The use of Bonner spheres in the evaluation of neutron spectra has been increased by the development of the computer programme ENDIM. An iterative unfolding method for response matrices developed elsewhere has been extended so that the iteration is terminated when an acceptable neutron spectrum is predicted from detector data. Analytic test spectra have been used to study the influence of experimental errors on the predicted spectra. These tests indicate that neutron spectra around shielded accelerators may be measured with some confidence provided that at least five spheres are used. Field tests have been carried out at the PLA and the neutron spectrum obtained is not inconsistent with previous estimates using other detectors.

Threshold Detectors The range of threshold detectors used in the evaluation of neutron spectra has been extended to include F^{18} produced in teflon (P. T. F. E) samples. This reaction has a threshold of 12 Mev and lies conveniently between the 6 Mev threshold of the (n, α) reaction in aluminium and the 20 MeV threshold of the (n, 2n) reaction in carbon. Preliminary work has confirmed the work at Berkeley on the production of Tb^{149} in mercury (600 Mev threshold), extraction efficiencies of ~ 70% having been obtained. Evaluation of neutron spectra from threshold detector measurement is now possible using the computer programme TELLY largely developed at Berkeley as part of the BCR shielding experiment.

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* *See also PLA Progress Report for 1967 (RHEL/R 156)*

Induced Activity

Induced Activity in Air A technique for the study of short-lived radioactive nuclides produced in air has been developed. Decay analysis and γ-spectrometry is used to identify the radionuclides produced. Preliminary measurements made close to the Nimrod X1/K9 beam target have shown that only O^{15}, N^{13} and C^{11} were produced in measurable quantities. At beam intensities of $\sim 2 \times 10^{11}$ p sec^{-1} upon the target the initial specific concentration of these nuclides amounted to $\sim 10^{-1}$ μCi $litre^{-1}$ (~50 m. p. c.) in regions close to the target. Initially the radiation hazard from such specific concentrations of radioactive air is comparable with that from radiation from nearby solid material. The rapid decay of the air activity, however, makes it a second-order hazard.

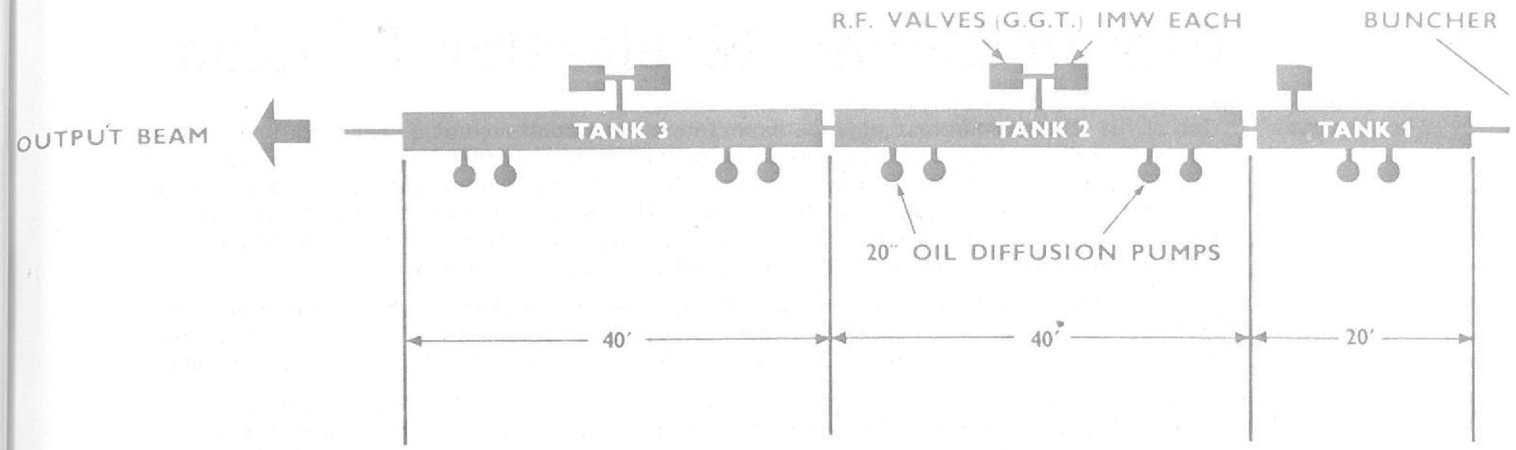
Induced Activity in Water Studies of radionuclides produced in the closed primary circuit pipes of the Nimrod water system have indicated dose rates approaching 1 millirem per hour during continuous operation of Nimrod. As in the case of air the only significant nuclides produced are short lived. The specific activity of nuclides producing this dose rate is nevertheless only a fraction of the maximum permissible concentration for radionuclides in drinking water. No contamination hazards exist from small spills of this water.

Dosimetry

Body Reflection Personal Neutron Dosimeter Preliminary studies have been made of a technique utilising the measurement of thermal neutrons escaping from the body when irradiated by fast and intermediate energy neutrons. Thermal neutrons are measured using Li^6F powder and field trials using a phantom situated in wide variety of positions at the PLA and under different accelerator operating conditions give encouraging results. Further work will continue in radiation fields around Nimrod.

Proton Dosimetry The dose response of KRM film and Li^7F powder to 50Mev protons has been measured in the range 5 - 8 × 10^4 rads.

Half Life of P^{32} Measurements have been made of the half life of P^{32}. Published values of this half life, which is of importance in determining neutron fluxes, range between 14·0 and 14·6 days. Samples of P^{32} produced by (n, γ) and (n, p) reactions have been used and their decay followed for about 120 days. The values obtained are in agreement with the generally accepted value of 14·3 days.



	Tank 3	Tank 2	Tank 1
PROTON ENERGY *(approx)* *(Accelerating rate 1.7MeV metre)*	50 MeV	30 MeV	10 MeV
Speed of proton / Speed of light	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{7}$
NO. OF DRIFT TUBES	26 2($\frac{1}{2}$)	40 2($\frac{1}{2}$)	41 2($\frac{1}{2}$)
BEAM APERTURE	1$\frac{1}{2}$"	1$\frac{1}{2}$"	$\frac{3}{4}$" $\frac{1}{2}$"
FOCUSING	A.G. MAGNETIC QUADRUPOLES	A.G. MAGNETIC QUADRUPOLES	GRIDS
R.F. PULSED POWER *(Peak)*	1400 kW	1200 kW	600 kW
(Mean)	28 kW	24 kW	12 kW

[*50 p.p.s. each $\frac{1}{2500}$ sec. long; 2% duty cycle for r.f. (400 μsec. pulses), 1% duty cycle for beam (200 μsec. pulses)*]

BEAM CURRENT *(Peak)* As % of injector output current			
WITHOUT BUNCHER	1·3 to 2·0	1·3 to 2·0	1·3 to 2·0 Loss factor: 50–60
WITH BUNCHER	2·6 to 5·0	2·6 to 5·0	2·6 to 5·0
Typical values			
WITHOUT BUNCHER	145		
WITH BUNCHER	300		

PROTON LINEAR ACCELERATOR DIVISION

without loss (after resetting of quadrupole focusing magnet total currents).

TIME OF FLIGHT	0·13 μsec.	0·20 μsec.	0·21 μsec.	0·1

Proton Linear Accelerator Division

Use of the PLA for nuclear physics experiments has continued at a very high level. The re-arrangement of the radiation shielding described in the 1966 Annual Report has considerably improved access to experiments whilst the machine is in operation. As a result, the time for which the machine is switched off to allow setting up of experiments has been reduced and this year the machine was scheduled for over 6,500 hours of operation. Machine availability continued at the very satisfactory level of 90%.

In March 1967 modifications were made to the machine to allow working with either 200 μs beam bursts at 50 pps (1% duty cycle) or 600 μs beam bursts at 25 pps (1½% duty cycle). This gives an increase of 50% in duty cycle which is most useful for many experiments.

In October 1967 modifications were made to the low energy drift space before the first accelerating tank; the field law along the length of tank I was altered and a debuncher installed at the entrance to the second experimental area. The aim of this work was to decrease the beam energy spread. With this equipment in use, energy spreads of 27 keV FWHH at 30 MeV and 45 keV at 50 MeV have been obtained.

In May of this year, the Nuclear Physics Board decided to recommend to the Science Research Council the closure of the PLA by October 1969; the recommendation was accepted by the Council in June. The chief reason for the recommendation was the concern of the Board that nuclear structure physics in the United Kingdom should be served by front-line machines, which were difficult to finance while the present full programme was maintained. As the PLA was prominent in the table of rate of expenditure per machine, major savings from current expenditure could be made effective only by the closure of the PLA. The machine will continue to operate round the clock until September 1968, when it will operate round the clock for five days a week until June 1969. The usage of the machine for the final three months is, as yet, undecided.

Nuclear Physics

In the section which follows, brief descriptions are given of the experiments carried out on the PLA in 1967. More detailed accounts of this work are given in the PLA Progress Reports which are published annually.

Experiments at the Proton Linear Accelerator

Number	Experiment	Group
1†	Measurement of polarization in elastic and inelastic scattering	University of Birmingham
2†*	Proton-deuteron elastic scattering	Queen Mary College, London, Queen's University, Belfast, and Westfield College, London
3†*	Cross-sections and polarization for elastic and inelastic scattering	King's College, London and West Ham College of Technology
4†*	Elastic and inelastic scattering of protons	University of Manchester
5*	Elastic scattering of 30 MeV protons	Atomic Energy Research Establishment
6†	Polarization effects in p-α scattering	Queen Mary College, London and Rutherford Laboratory
7†	Measurement of the R parameter for p-Ca scattering	Rutherford Laboratory
8†	Elastic and inelastic scattering of protons from He^3	Westfield College, London and Queen's University, Belfast
9*	Study of (p, d) and (p, t) reactions on even samarium isotopes	Rutherford Laboratory
10	Neutron spectra measured by time-of-flight methods	Rutherford Laboratory and Queen Mary College, London
11*	Studies of pick-up reactions	Atomic Energy Research Establishment
12	Investigation of pick-up reactions	Westfield College, London and Queen's University, Belfast
13†	Study of asymmetries in pick-up reactions using polarized protons	University of Oxford
14*	Pick-up reactions on Si^{28}, S^{32} and Ca^{40}	University of Oxford and Rutherford Laboratory

† Experiments using polarized proton beam.

* Experiments using double focussing magnetic spectrometer.

Experiment 1

Polarization in Elastic and Inelastic Scattering

UNIVERSITY OF BIRMINGHAM

Some work to study the formation of compound nucleus resonances in the scattering of protons from carbon in the energy region between 25 and 30 MeV was described in last year's report. In particular it has been shown that polarization data are most helpful in making an analysis of the results. This work has now been extended to a study of the scattering of protons by O^{16} in the energy region between 20 and 30 MeV. Cross-section measurements which have been made indicate that resonant effects may be present, particularly at the lower energies. Polarization measurements have been started and work is continuing. An experiment to measure the integrated cross-section for backward scattering as a function of incident proton energy is being planned.

Measurements of the cross-sections and asymmetry for the inelastic scattering of protons from Fe^{54} have been made previously by this group. An analysis in terms of the DWBA method has shown that there are considerable difficulties in explaining the polarization data. The measurements have therefore recently been extended to Fe^{56}, Ni^{58} and Ni^{60}. Analysis of these data is in progress.

The measurements on the elastic and ineleastic scattering by p-shell nuclei, notably Be^9, have been continued and extended to B^{10} and B^{11}. Again analysis of the data is in progress.

Experiment 2

Proton-Deuteron Elastic Scattering

QUEEN MARY COLLEGE, LONDON
QUEEN'S UNIVERSITY, BELFAST
AND WESTFIELD COLLEGE, LONDON

Measurements have been made of the polarization in the elastic scattering of 10 MeV and 22 MeV protons by deuterons. The low energy experiment is somewhat unusual in that it is the first one to be performed using the PLA at 10 MeV. The purpose was to attempt to resolve an apparent discrepancy between experiments performed at two other laboratories, and the availability of the polarized proton beam made the PLA a particularly suitable machine for such an experiment. The information from these experiments is of considerable value to theorists studying the three-body problem, and it is important to have an agreed set of experimental data. If the new 10 MeV and 22 MeV results are plotted on a contour diagram of polarization as a function of proton energy, they yield rather smoother contours than some of the previous work.

Whilst polarization measurements will assist in determining the scattering phase shifts, it is likely that triple scattering parameters will be necessary to obtain a unique set. Apparatus has been designed and constructed to make a measurement of the depolarization parameter at 50 MeV. Polarized protons scattered from a liquid deuterium target enter a helium polarization analyser. Inside this analyser, containing high pressure helium gas, protons scattered in the horizontal plane to the left and to the right are detected by scintillation counters. Coincidences are then recorded between these scattered protons and the recoil deuterons from the first scattering. The apparatus has been calibrated and preliminary measurements at 40°, 45° and 50° indicate that D is large and positive over this angular region. It is hoped to complete these measurements and to extend the work to study the A and R parameters.

Experiment 3

Cross-Sections and Polarization for Elastic and Inelastic Scattering

KING'S COLLEGE, LONDON AND
WEST HAM COLLEGE OF TECHNOLOGY

Cross-section data for the elastic and inelastic scattering of 50 MeV protons from $Zn^{64,66,68,70}$ have now been analysed and published. Information on the level schemes of these nuclei including the observation of previously unreported levels, particularly in Zn^{70}, has also been published. Measurements of the scattering of 30 MeV protons by these nuclei are in progress.

Measurements have also been made for the polarization and asymmetry for 50 MeV protons scattered elastically and inelastically by Zn^{68} and Cd^{114}. Similar measurements have been made at 30 MeV for $Zn^{64,68}$ and $Cu^{63,65}$. One of the principal aims of this work is to study the energy and isotopic dependence of optical model parameters. A technique for studying pairs of isotopes by fitting the differences in the cross-sections and polarization has been studied. Such a technique has been used with considerable success in electron scattering experiments and has the advantage that normalization errors are removed. Suitable computer programs have been modified and an analysis of the 50 MeV $Zn^{64,68}$ data has been started.

Optical model analyses by this group have indicated the importance of data at backward angles. Measurements using the double-focussing spectrometer are restricted to angles of less than 150°. Apparatus to detect particles over the angular range 124° to 176° has been constructed. It consists of a single large NaI counter covering the whole angular range and preceded by a sonic spark chamber to give an indication of the angular position of the scattered particles. The NaI counter is used to measure the energy of the particles. A 4096 channel analyser is used in the 32 × 128 mode to record and display the data. Measurements on p-C^{12} scattering at 50 MeV have shown promising results and further development of the apparatus is in progress.

Experiment 4

Elastic and Inelastic Scattering of Protons

UNIVERSITY OF MANCHESTER

Measurements of the cross-sections and polarization for the elastic and inelastic scattering of 50 MeV protons by Li^6 and Li^7 have been completed. Optical model and DWBA fitting of the angular distribution data is in progress. Data on the excited states of Li^6 and Li^7 have been fully analysed and a paper written for publication.

Cross-section and polarization measurements have also been made for 50 MeV protons scattered by Be^9, Sc^{45}, Ca^{44} and Zr^{90}. Further measurements over a wider angular range and their extension to other nuclei are in progress.

All these measurements were made using the double-focussing magnetic spectrometer.

Experiment 5

Elastic Scattering of 30 MeV Protons

ATOMIC ENERGY RESEARCH ESTABLISHMENT
(PROTON PHYSICS GROUP)

Elastic scattering measurements have now been made for a wide range of even and odd mass tin isotopes between Sn^{112} and Sn^{124}. The data are being analysed to obtain further information about the symmetry dependence of the optical model potential.

Experiment 6

Polarization Effects in p-α Scattering

QUEEN MARY COLLEGE, LONDON
AND RUTHERFORD LABORATORY

Polarization and differential cross-section measurements of protons elastically scattered from helium have been investigated for incident proton energies in the range 25 to 29 MeV in approximately 1 MeV steps. The purpose of this work is to determine the phase shifts in this energy region accurately and to investigate the effects on the phase shifts of the 20 MeV resonance seen in the mass 5 system.

Measurements were made using a liquid helium target with eight pairs of scintillation counters to detect the scattered protons. Some difficulties were experienced in making measurements at forward angles due to the large background observed from the nylon cylinder which contained the helium. The analysis of the experimental results is complete.

A very extensive phase-shift analysis is in progress using these results and other measurements available in the energy region between 10 and 50 MeV. The computer programmes have been modified so that the starting values for a phase-shift search are generated from random numbers. Using this programme a very complete analysis has been made of data in the region of 10 MeV. Whilst two solutions are found which fit the data at 10 MeV it has been shown that only one of these is consistent with analyses of lower energy data. This analysis is now being extended to higher energies.

Experiment 7

R Parameters for p-Ca Scattering

RUTHERFORD LABORATORY

Although triple-scattering measurements of the R parameter for nucleon-nucleon scattering are quite common, they are relatively rare for scattering by nuclei and have not been performed on nuclei heavier than carbon. The reason for this is that polarized proton beams are usually weak and good energy resolution is required. Recent improvements to the PLA polarized proton source have made such an experiment for Ca^{40} possible.

50 MeV polarized protons were scattered by a 10 MeV thick calcium target. The polarization of the scattered protons was measured using scattering at 57° from an 8 MeV thick carbon target, the doubly scattered particles being detected in a scintillation counter telescope.

The analysis of the experimental data is now complete and the results are in good agreement with some preliminary optical model calculations.

Experiment 8

Elastic and Inelastic Scattering of Protons from He^3

WESTFIELD COLLEGE, LONDON AND
QUEEN'S UNIVERSITY, BELFAST

The original motivation of this experiment was to investigate further three possible excited states of He^3 observed by other workers using the He^3 (p, p') reaction. It was decided to repeat as closely as possible the original experiment.

A He^3 gas target was used together with lithium-drifted silicon counters to detect the scattered protons. A mass discrimination system was used to ensure that only protons were detected.

No evidence was obtained for any of the previously observed excited states and this null result is in good agreement with other investigations made since the original experiment and using different reactions.

As an extension of this experiment and using similar apparatus the polarization in p-He^3 scattering at 30 MeV has been measured, the preliminary results being shown in figure 27. This information, together with differential cross-section measurements already made elsewhere, will be used for a phase-shift analysis.

Experiment 9

p-d and p-t Reactions on Even Samarium Isotopes

RUTHERFORD LABORATORY

The (p, d) and (p, t) reactions have been investigated on five samarium isotopes, Sm^{144}, Sm^{148}, Sm^{150}, Sm^{152} and Sm^{154}. The neutron numbers for these isotopes extend from N = 82 to N = 92. In their ground state those nuclei with $N \leqslant 88$ behave like spherical nuclei and for $N > 90$ as spheroidal nuclei. This investigation was undertaken to provide a systematic study of the low-lying levels of the nuclei which could be reached by (p, d) and (p, t) reactions starting from the above five nuclei. The magnetic spectrometer was used to momentum analyse the outgoing deuterons and tritons.

Only a preliminary analysis of the results has so far been made. The angular distributions for (p, t) reactions leading to the ground state of the residual nuclei show significant differences which can be associated with the change from rotational to vibrational nuclei. Four previously undetected levels in Sm^{142} have also been observed.

Experiment 10

Neutron Spectra Measured by Time-of-Flight Methods

RUTHERFORD LABORATORY AND
QUEEN MARY COLLEGE, LONDON

The studies of the excitation of isobaric analogue states in residual nuclei mentioned in last year's report have been continued. The measurements have been extended to Nb^{93} and Ho^{165} and the analysis of all the experimental data has been completed. The data have been analysed using the DWBA method in terms of a T-dependent potential. In order to obtain satisfactory fits to the data it is necessary for the potential to be complex. The results indicate that the real part must be of surface form but little can be said about the form of the imaginary part.

Studies of (p, n) reactions on Li^6 and Li^7 have been completed. Good evidence has been obtained for a second excited state of Be^6 and there is some evidence for a third state. The angular distributions for transitions to the ground states of Be^6 and Be^7 have been compared with DWBA calculations using a microscopic interaction potential. The transitions to the ground state of Be^7 have also been compared with a calculation using a macroscopic isobaric spin-dependent potential.

The energy spectra of neutrons from the D(p, n)2p reactions have been measured over a range of angles for both 30 and 50 MeV incident protons. The shape of the high energy peak in the spectrum due to the final state interaction between the two remaining protons is in satisfactory agreement with first order impluse approximation calculations. At wider angles the agreement is rather poor and attempts are being made to improve the fits by taking multiple scattering corrections into account.

Figure 28 shows some preliminary measurements which have been made of the neutron spectra from the He^4(p, n) reaction. In agreement with other recent work no evidence is found for a narrow state in Li^4 near 10·6 MeV above the p-He^3 threshold previously inferred from hyperfragment results.

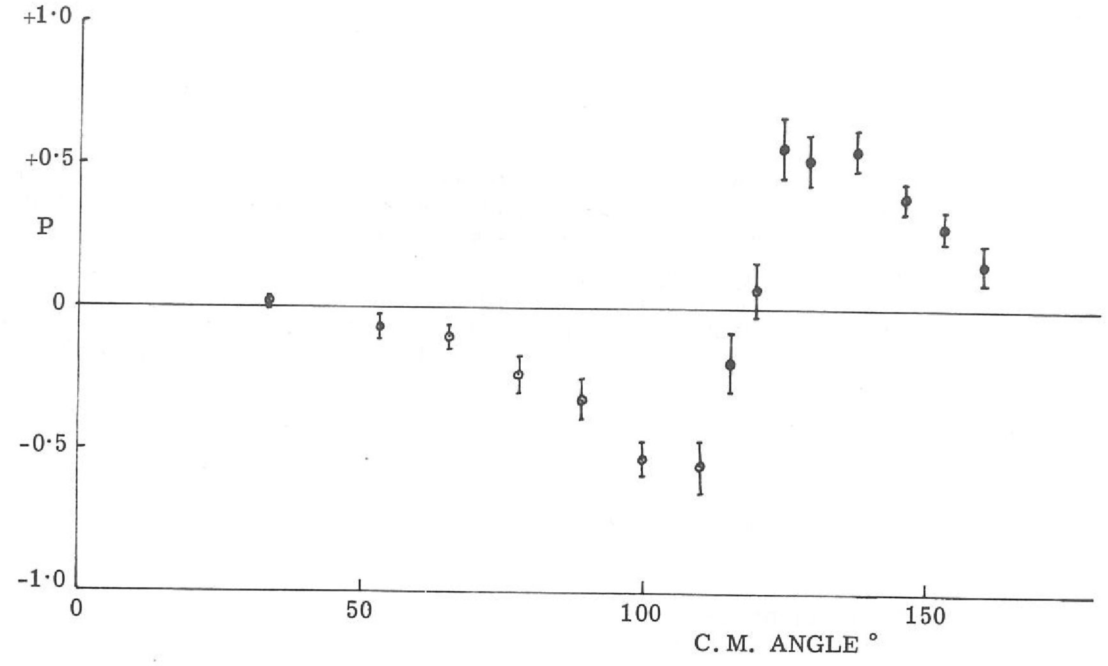


Figure 27. Preliminary polarization results for proton elastic scattering from He^3 at 30 MeV.

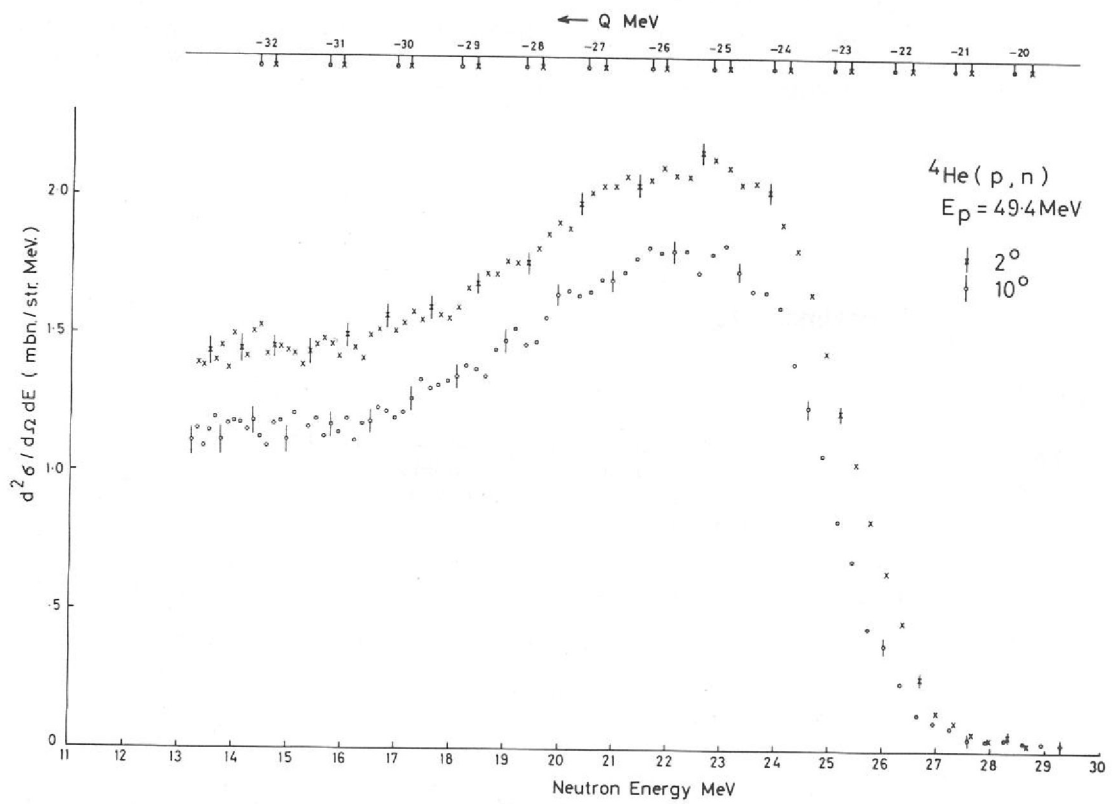


Figure 28. Neutron energy spectra at 2° and 10° from the He^4(p, n) reaction at 49·4 MeV.

Experiment 11

Pick-Up Reactions

ATOMIC ENERGY RESEARCH ESTABLISHMENT
(PROTON PHYSICS GROUP)

The measurements of angular distributions for (p, d) and (p, t) reactions on a range of tin isotopes have been extended to other isotopes. A considerable amount of information about the level schemes for the even mass tin isotopes has been obtained.

The results for (p, d) reactions have also been compared with the predictions obtained from a new theory of (d, p) reactions. One of the predictions of this theory is that the (p, d) angular distribution should be similar to that for elastic scattering and this is found in the present experiment. Some further detailed tests of the model have been made with generally satisfactory results.

Experiment 12

Pick-Up Reactions

WESTFIELD COLLEGE, LONDON AND
QUEEN'S UNIVERSITY, BELFAST

The experiment to study the Mg^{26}(p, t)Mg^{24} and Mg^{26}(p, He^3)Na^{24} reactions in order to locate the T = 2 levels in Mg^{24} and Na^{24} which are analogues of the ground state of Ne^{24} has been repeated and the results considerably improved.

Pick-up reactions on B^{10} have also been studied. The B^{10}(p, d)B^9 reaction has been used to look for states in B^9 previously observed in the C^{12}(p, α)B^9 reaction. The asymmetries of the outgoing deuterons using incident polarized protons have also been measured and the results will be compared with DWBA calculations. The B^{10}(p, α)Be^7 reaction has been used to investigate some previously reported states in Be^7. No evidence was found for a state at 14·6 MeV.

The deuteron spectra from the He^3(p, d)2p reaction has been measured. The majority of the spectra show a peak due to the final state interaction between the two protons. Theoretical analysis of the data is in progress.

Experiment 13

Asymmetries in Pick-Up Reactions Using Polarized Protons

UNIVERSITY OF OXFORD

Two nucleon transfer reactions are being increasingly used in studies of nuclear spectroscopy. The purpose of the present experiments, in which the asymmetry of the outgoing particles is measured using incident polarized protons, is to investigate the importance of spin dependent effects.

The reaction C^{12}(p, t)C^{10} was investigated first, as this reaction has several simplifying features. So far, theoretical analysis of these results has not produced satisfactory fits to the data but further work is in progress. The O^{16}(p, He^3)N^{14} reaction has also been investigated and again no satisfactory fit to the data has so far been obtained.

The asymmetries produced in the reaction O^{16}(p, t)O^{14} and O^{16}(p, He^3)N^{14*} (2·311 MeV) leading to isobaric analogue states have also been measured. These results should provide a critical test of the reaction mechanism theory and a detailed analysis is in progress.

Work has also continued on the use of (p, He^3) and (p, t) reactions to investigate isobaric analogue states. Targets of Na^{23} and Si^{30} have been used to investigate the T = 3/2 analogue levels in Na^{21} and Ne^{21} and the T = 2 levels in Si^{28} and Al^{28}.

Experiment 14

Pick-Up Reactions on Si^{28}, S^{32} and Ca^{40}

UNIVERSITY OF OXFORD AND
RUTHERFORD LABORATORY

The shell model in its simplest form predicts that certain sub-shells are filled for the nuclei Si^{28}, S^{32} and Ca^{40}. In practice the ground states of these nuclei may include considerable mixing of other shell model configurations. The present experiments were undertaken to investigate the extent of such possible admixtures and also to obtain information about the level schemes of the proton-rich nuclei Si^{26}, S^{30} and Ca^{38}.

Deuteron and triton spectra from (p, d) and (p, t) reactions were measured using the double-focussing spectrometer. The results indicate that there is considerable mixing of shell model configurations in the ground state of these nuclei. Further and more detailed analysis of the data is at present in progress.

Machine Development

The programme of accelerator physics summarized here and reported in greater detail in the PLA Progress Report for 1967 was initiated during 1966 and was well advanced before the decision to close down the PLA in 1969 was taken. It was, however, modified to exclude some longer term developments, such as the 1200 μs project and a scheme for increasing the number of available energies (by sub-dividing the tanks). More emphasis was put on completing a set of projects designed to be complementary, and collectively to reduce the energy spread of the beam, while retaining a maximum current capability of at least 300 μA (peak).

To attain the results desired from this programme careful planning was necessary, since it was essential that the installation of new apparatus should be completed in about three weeks; it was also necessary that the testing of individual items should be completed in the fourth week of the shutdown, so that the recommissioning of the machine could be achieved in the eight days allocated immediately after the shutdown. The difficulties were further aggravated by the fact that the staff of the Accelerator Physics Group were being redeployed on other projects in the Laboratory outside the PLA Division, and that soon after the shutdown the only staff remaining would be a small group engaged on the testing of GGT valves. In this work the Accelerator Physics Group enjoyed the competent support of the PLA Engineering Group, which was responsible for the design, manufacture and installation of the equipment.

With a PLA one cannot hope to achieve an energy resolution comparable to that of a Tandem Van de Graaff, nor could one achieve an unresolved energy spread equal to the energy resolution of a detector system such as a spectrometer magnet with a spark chamber detector (about 20 keV). However, the energy resolution at 50 MeV before the shutdown was 134 keV (FWHH) or 500 keV (at the base) and at 30 MeV it was 110 keV (FWHH) or 400 keV (at the base). There was, therefore, ample scope for improvement. The two lines of attack were firstly, to restrict the motion of protons in Tank I by reshaping of the r.f. field so that the energy acceptance along the tank remained constant, and secondly, to reduce further the width of the output spectrum by using a debuncher. Since the new field law in Tank I produced a relatively small phase acceptance it was necessary to utilise the injected beam more efficiently by,

(i) bunching the beam more effectively by means of the double buncher system;

(ii) improving the radial focussing of the 500 keV beam with two quadrupole triplets, and

(iii) increasing the ion source current.

These latter three requirements entailed a complete redesign of the low energy drift space, the design of a phase stabiliser for the bunchers, and an investigation of the stability of the energy of the injector beam.

The installation and commissioning of all these modifications to the machine were completed within the scheduled time, but the optimisation of some of the operating parameters was not. Subsequent tests during operation, maintenance and a short scheduled run have completed the programme. There has been a few teething troubles particularly with the power supply to the triplets, the tuning of buncher 1, and the multipactoring of the debuncher at low power levels. All these have been successfully overcome with the exception of the debuncher trouble. This only affects operation at 30 MeV however, and the difficulty can be overcome by running the debuncher at a power level slightly higher than optimum.

The best energy spectra so far obtained have full width at half height energy spreads of 27 keV and 45 keV at 30 and 50 MeV respectively. The maximum beam current so far obtained is 400 μA (peak).

Operation

During 1967 the PLA was scheduled for more hours, and the percentage of lost time was less than in any previous year of operation. The scheduled time, 6521 hours, was 85% of the total year, after subtracting the shutdown periods (2 weeks in March and 4 weeks in October) and the Christmas recess. The running time of the machine during the past 8 years is summarized in Table I. The operating cycle has changed slightly since last year and there are now, on average, about 13 operational days between maintenance periods. The maintenance periods are correspondingly fewer and now amount to about $2\frac{1}{4}$ days per fortnight instead of 3 days as previously. The frequency of minor faults on the machine was higher than in the previous year, but caused very little loss of operating time (approximately 10% of the total lost time). About 2·5% of the scheduled time was used for changing over from one experiment to another. The 5847·5 hours (67% of 365 days) was fault-free time during which beam was being accelerated and was available to the experimenters.

In March 1967, modifications were made to the machine to allow operation with either 200 μs beam bursts at 50 p.p.s. (1% duty cycle) or 600 μs beam bursts at 25 p.p.s. (1·5% duty cycle). This 50% increase in duty cycle was very useful for many experiments and was used for 44% of the scheduled time, thus giving a 22% increase in available time. This increased duty cycle could not, however, be utilised by experiments using spark chamber detectors. The $n = \frac{1}{2}$ spectrometer magnet was used for 49% of the total scheduled time and the polarized beam for 46%. Table II shows the distribution of hours between the nuclear physics teams using the machine.

During the year about 8% of the scheduled time was lost due to machine faults, half of this time being due to minor faults (less than 3 hours each). This is the same percentage and proportion as last year. The r.f. distribution system caused the greatest loss of time, the largest fraction of which was due to the drive chain. This equipment was responsible for nearly 60 hours fault time during the year, much of which was due to failures caused during testing of the system at 1200 μs (6% duty cycle). Since work on the 1200 μs project has now been terminated faults due to this cause will not recur. The overall performance of the r.f. system was, however, very satisfactory for a system of such complexity. There were four faults in the main amplifier valves (GGTs) which necessitated the removal of valves for overhaul. The performance of the GGTs remained satisfactory; three valves have operated for over 20,000 hours (filament-on time) and one for over 30,000 hours.

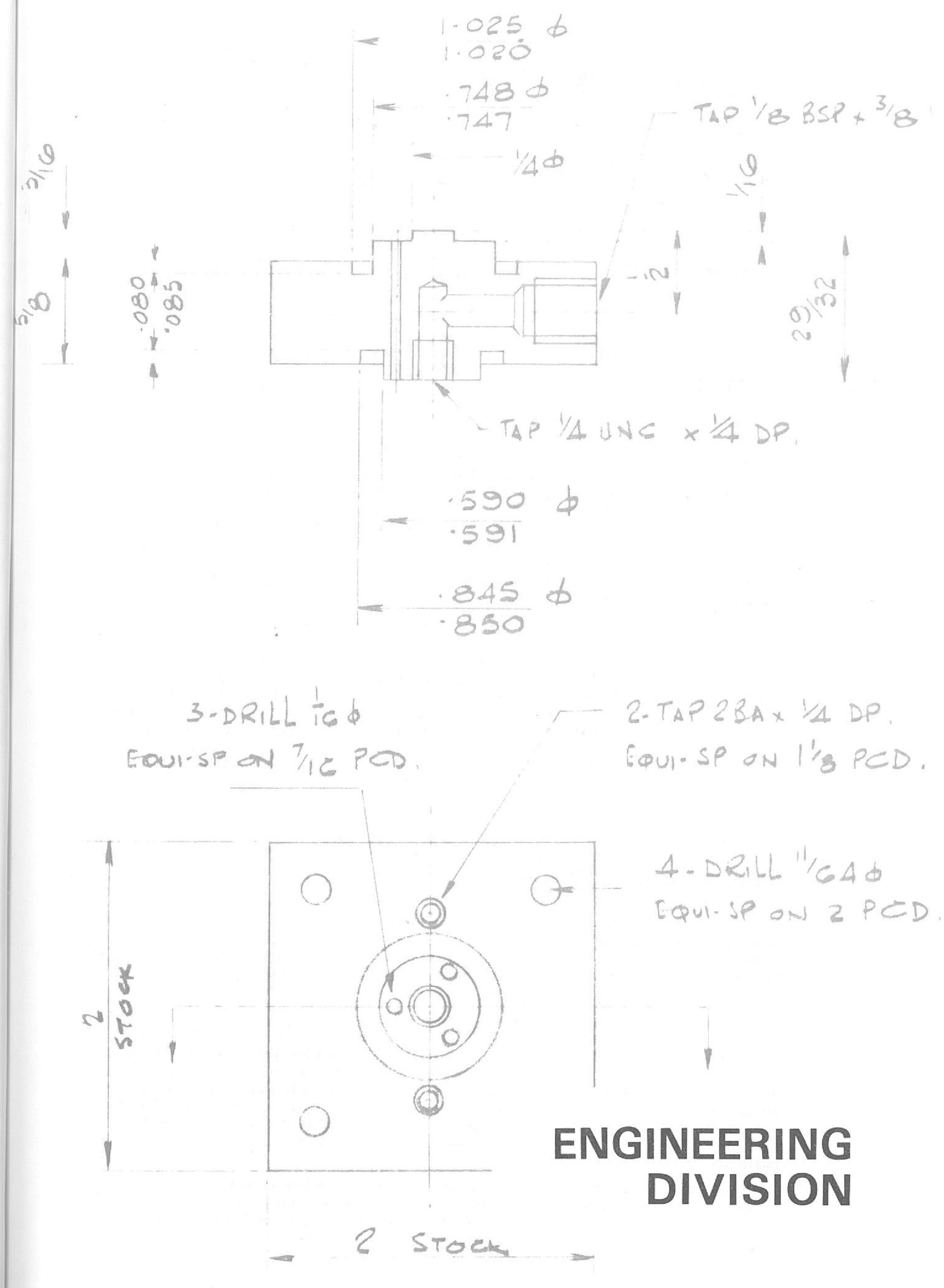
The deuterium thyratron switch tubes, VX3336 in the modulators have been trouble free during this year; the filament-on times now exceed 20,000 hours each. The experimental thyratrons VX3359 and VX3369 have run throughout the year and have each exceeded 10,000 hours. The two remaining machine faults worth mentioning are repeated faults in the peaking transformers in the modulator rectifier sets and in the DC gun resistors in the injector. Both these sources of trouble have been eliminated by the redesign of components.

Table I - Running Time 1960-67

	Hours scheduled	Hours available for use	Availability (%)
1960	1,420	980	69
1961	3,660	2,149	59
1962	5,544	3,971	72
1963	5,453	4,405	81
1964	5,573	4,664	84
1965	6,128	5,260	86
1966	6,303	5,605	89
1967	6,521	$5,847\frac{1}{2}$	90
	40,602	$32,881\frac{1}{2}$	

Table II - Running Time 1967

Experimental Teams	Hours scheduled	Hours available for use
Atomic Energy Research Establishment (Proton Physics)	696	$610\frac{1}{2}$
University of Birmingham	624	$548\frac{3}{4}$
King's College, London	813	$744\frac{1}{4}$
University of Manchester	648	$541\frac{1}{2}$
University of Oxford (Nuclear Physics)	$885\frac{1}{4}$	$814\frac{3}{4}$
Queen's University, Belfast, Westfield College, London, and Queen Mary College, London	1,078	$997\frac{1}{2}$
Rutherford Laboratory and Queen Mary College, London (I)	537	$504\frac{1}{2}$
Rutherford Laboratory and Queen Mary College, London (II)	480	$442\frac{3}{4}$
Rutherford Laboratory (Radiochemistry)	72	$58\frac{3}{4}$
Rutherford Laboratory (Nuclear Physics Tests)	$445\frac{1}{2}$	$390\frac{3}{4}$
Rutherford Laboratory (Accelerator Physics)	$167\frac{3}{4}$	126
Others	$74\frac{1}{2}$	$67\frac{1}{2}$
	6,521	$5,847\frac{1}{2}$



ENGINEERING DIVISION

Engineering Division

As in previous years, the Engineering Division had made major contributions to projects in the Laboratory's research programme. In addition, a wide range of services has been provided – some of a specialised nature, the remainder involving the more conventional aspects of mechanical, electrical and civil engineering.

Magnets for Beam Extraction and Beam Transport

The proton beam is extracted from Nimrod by means of an achromatic Piccioni system; this embodies a kicker magnet and a quadrupole, both of which are plunged into position after the start of the acceleration cycle. Both kicker and quadrupole have been redesigned, incorporating changes designed to improve both ease of servicing and efficiency of operation. The new kicker magnet has water-cooled pole pieces and additional circuits and is enclosed in a can that will withstand atmospheric pressure internally. Attention has also been given to features which will make it easier to dismantle the magnet for servicing and repair. Simplified maintenance procedures are important for items which become radioactive in use. A similar redesign on the plunging quadrupole has provided a thinner septum and an offset zero field point which should reduce beam loss and hence improve the extraction efficiency. At the end of 1967, acceptance tests were at an advanced stage, and the new components should be installed on Nimrod during 1968. Improvements have also been made to the extraction system power supplies; a 1500 amp 150 kW series transistor regulator (stability 1 in 10^4) has been built and is undergoing tests. Design work is in progress on septum magnets for the X3 extracted proton beam which will serve the new Experimental Hall 3. These new magnets will be short and strong; the thin septums and high power dissipations demand a special design of coil.

A number of new components have been designed, built and installed on external Nimrod beam lines. K9 (one of the bubble chamber beam lines) has been provided with a stepping magnet, complete with power supply and all instrumentation. This device enables the incident beam to be displaced rapidly across the chamber, resulting in a more rapid acquisition of data. A similar device, the shutter magnet, has also been constructed; it enables the duration of the beam pulse reaching an experiment to be accurately controlled. Components required for the redesigned K11 beam are under manufacture. Improvements have been made to general purpose beam line power supplies. A 10,000 amp series transistor regulator has been constructed. Its motor-generator set (250 kW) has been installed, together with a further 160 kW set.

Superconducting Magnets

Work on the High Field Solenoid has continued. Development and commissioning of the special rolling mill and soldering equipment for the copper/superconductor composite conductor was successfully completed. A brief description of this machine was given in the 1966 Annual Report. 8,000 ft of composite tape was produced in lengths of up to 350 ft. Winding of the coils is nearing completion.

In May 1967, the decision was taken to design and build a superconducting beam bending magnet. This device, illustrated and more fully described in the Applied Physics section of this Report, will provide a 40 kilogauss field over a path length of 140 cm. There are formidable engineering problems in the fabrication and insulation of the windings and in supporting them against the very high electromagnetic forces to which they are subject. Progress has been such that it is hoped to commence winding in March 1968. With a device of this size, sophisticated cryogenic design is necessary to reduce liquid helium consumption to a tolerable level. This aspect of the design is well advanced and some parts are already being made.

Development work on the electrical side has included protective circuits to forestall the undesireable consequences of part of the superconducting circuit going normal. Continuous monitoring of the resistance of sections of the winding enables circuit breakers or thyristor switches of up to 500 amp capacity to initiate appropriate remedial action.

Polarized Targets

Technological improvements have been made to the polarized proton target, the scientific developments of which are described in the Nimrod section of this Report. An improved cryostat has been produced, incorporating a thin formed stainless steel window. The forming technique, collaboratively evolved by an engineer and a skilled craftsman, will be described in a forthcoming report. The electromagnet has been modified to give better access for particle detectors without adversely affecting the field uniformity. Improvements have also been made to the target data acquisition system. A Helium-3 refrigerator has been designed and is due to be commissioned during the first half of 1968. It will be used for proton polarization research at temperatures down to 0·3°K.

Film Analysis Machines

The Engineering Division has been closely concerned with the development of this equipment. Extensive circuit changes have been made to HPD 1 (the first Hough-Powell Device) following the speed up of the disc. New logic and a rearrangement of the control panel have been introduced, the latter being based on operator experience with the original system. The film transport and computer control circuits are also being redesigned. It is planned to apply these improvements to HPD 2 and to the Birmingham University HPD; major pieces of the hardware needed (e.g. film transport and lamp supplies, and the controller for the disc motor) have been ordered. Mechanical changes to improve reliability and smoothness of operation are under trial on HPD 2; if these tests are successful, the other machines will be similarly improved. Two Hudson scanning machines were rebuilt to give greater magnification within the same space, and to enable three films to be scanned at the same loading.

The Track Analysis Maintenance Section's responsibilities have been extended to encompass the National machine, 3 Duff Machines, 3 Image Plane Digitisers, 3 D-Mac Digitisers and 2 new Shiva double scanning tables. These machines are in use for 75 hours per week and the routine maintenance is resulting in increased reliability.

High Field Bubble Chamber

An engineering support team of six has been co-operating with the Applied Physics Division on the design study for this chamber. Topics studied include the superconducting magnet, the expansion system, the optics, the buildings and the preparation of construction programmes. The work has been both theoretical and practical, the latter including the design and procurement of test equipment and specimens, and the execution and evaluation of the tests. Specialist assistance (e.g. on advanced stressing problems) has also been provided as and when required.

Experimental Hall 3

The Project Engineer has been provided with direct support from the Division throughout the year. This new experimental area for Nimrod is described briefly in the Nimrod section of this Report.

Electronics

The Electronics and Instrument Repair Section maintains the high speed printers and punches used on the Track Analysis machines and on the data acquisition equipment used in experiments on Nimrod and the PLA. The Flight-Research cameras used to record spark chamber events are also serviced. The repair and calibration of a wide range of commercial electronic equipment is also undertaken. The ever-increasing use of electronic techniques in the work of the Laboratory is reflected in the growing work load on this Section. As a result, much of the work on the more conventional instruments is put out to industrial firms. A silent-hours call-out service is provided in view of the 24 hour operation of the accelerators.

The work load of the Electronic Manufacturing Section has also continued to grow, the annual cost now exceeding £100, 000. The jobs range from single items to small batch production, mostly produced by industry to very short time scales. Since the bulk of this work involves printed circuits, a small design unit has been formed to design printed circuit cards from conventional circuit diagrams. Since short time scales and difficult techniques are often associated with prototype manufacture, the model shop continues to be under heavy pressure. Typical jobs undertaken during the past year include multiple access scalers and power supplies for magneto-strictive spark chamber readout systems, interfaces between experiments and PDP 8 computers and 'B' rack systems for tunnel diode and integrated circuit logic. The last mentioned job needed over 200 printed circuit cards, necessitating a temporary expansion of the production line. Various power supplies have been made, ranging up to 500 amps and up to 30 kV, and an automatic ageing device for electrostatic particle separators has been built. Development work was required on an r.f. e.h.t. unit and on over-voltage and over-temperature protection devices. Functional tests are performed on all production line units and, where possible, on prototype units before they leave the shop.

Other Development and Design Work

An improved camera film transport system has been designed and built for recording spark chamber events. The design incorporates a recently marketed electrostatic clutch. An exposure rate of 10 per second is anticipated; this would significantly increase the number of pictures taken per Nimrod pulse.

A small rig was designed and built for materials testing at liquid helium temperatures. It has been used to determine stress/strain and strain/resistance characteristics of stabilising materials for superconductors and to investigate the thermal contraction of loaded plastic insulating materials. More sophisticated equipment has been designed and purchased, in order to cope with the large amount of testing forseen in future years. An extensive programme of tests has been formulated and measurements will commence early in 1968. Results will be reported at appropriate stages.

Computer programs have been written for calculating stresses in magnet conductors, flexible expansion bellows and glass fisheye windows used in bubble chambers, and engineering support has been provided for the development of superconducting r.f. particle separators.

The PACE analog computer has been used for a variety of tasks including the simulation of the stabilisation system of the 4 × 1 MW generators feeding the bubble chamber coils. This study will permit the improvement and optimisation of the system, in which the 5 kW amplidynes will be replaced by a solid state system at present under design. The standards and calibration room facilities are fully utilised in this type of work and also by the Laboratory as a whole.

Electrical Installation and Maintenance

The electrical distribution network within the Laboratory has continued to grow, and the installed transformer capacity within the substations has increased to 24·5 MVA with the addition of one substation and the growth of another. The major substation for Hall 3 is being built and all the associated equipment is on order including the four packaged substations with a total capacity of 10 MVA which will be installed inside Hall 3.

The growth of installed plant has necessitated the contracting-out of an increasing amount of planned maintenance. Wherever possible, as in the case of lifts, this is done by the manufacturer. The electrical services workshop has been primarily engaged on the manufacture of the magnets and power supplies described earlier, but another major job undertaken during 1967 was the design, manufacture, installation and commissioning of the control system for the 1 MW airblast coolers.

The majority of electrical installations in the Laboratory are performed by contractors, the annual value of this work being £75, 000. The work is co-ordinated and supervised by Laboratory staff, who also do any design work needed for building services or plant installation. Installations completed during 1967 included the R58 film processing laboratory , the R2 electrical workshop and a wide variety of equipment associated with bubble chamber plant and Nimrod.

Buildings

Major new works completed during the year under report include the following. The film processing laboratory (R58) is a purpose-designed building to house two continuous film processing machines and all the requisite ancillary equipment. A special effluent delay and drainage system is provided, in addition to all normal site services. Extensive modifications were made to the cells in the concrete shield wall on the main control room side of Hall 1. Additional floors were needed to house rectifier units and a small substation, and an external access road was provided.

More conventional building work included extensions to building R2 to house the H. E. P. Engineering Group's electrical workshop and to the basement of the R1 link building to house the Reproduction Section. Normal maintenance and minor alterations formed a large fraction of the total work load. In addition, considerable effort was used in modifications to offices and laboratories to permit accommodation adjustments.

One major job not yet complete is the modifications to the Heavy Liquid Bubble Chamber annexe to building R6 to enable the chamber to be operated with a propane filling which presents an explosion hazard. An appropriate combination of strong and weak structures has been chosen to protect adjacent areas and to give preferred relief to an explosion. The latter feature has been achieved by a unique and experimentally proven form of wall construction using expanded polystyrene slabs; this will be described in a forthcoming report. An adjacent control room has been built.

Mechanical Services

Installations of mechanical services (i.e. water, heating, compressed air, gas and drainage) were carried out in the building works mentioned in the previous section. More specialised work was done in connection with the film processing equipment, the bubble chamber ventilation plant, the 1 MW airblast cooler for bubble chamber magnet water and a compressor installation for helium recovery. A major programme of planned maintenance was carried out on the site steam and condensate systems and on calorifier room plant.

Mechanical Manufacturing Services

The main workshop of Central Engineering Group continued to provide a manufacturing service to all scientific Divisions of the Laboratory. In addition to many of the items already mentioned, this workshop has produced a wide variety of equipment, including a variable height drive mechanism for the remote adjustment of targets in Nimrod beam lines, and several magnets and scattering chambers.

The Outside Manufacturing Section has again arranged the execution, by industrial firms, of a substantial fraction of the jobs placed on the Engineering Division. These averaged 95 per month, the value of work in hand at any one time being approximately £27, 000.

Chemical Technology

Work has continued on the effect of radiation on the mechanical properties of materials. The main effort has been devoted to the degradation of plastics and plastic composites, and to the temperature dependence of the strengths of irradiated materials. In the latter field, equipment for measuring strength characteristics at liquid helium temperatures has enhanced the testing capabilities.

A hydrogen pressure dosimeter has been developed to measure integrated radiation dosages in the hundred megarad range, such as are experienced by the Nimrod vacuum vessels. The dosimeter is based on the fact that the major gaseous product from irradiated aliphatic hydrocarbons is hydrogen (97-98% for polyethylene). One type of hydrogen pressure dosimeter at present in service embodies a direct reading pressure gauge previously calibrated in terms of radiation dose absorbed. These instruments are protected by patents, and a licence to manufacture is being negotiated.

Services such as the analysis and control of site water, the pickling of metals and the production of high purity crystals have been continued.

Static Power Supplies for Pulsed Magnet Loads

During the past year a comprehensive study programme has been pursued to examine the possibility of powering large accelerator-type pulsed loads directly from the public electricity network.

The original motivation for this work was partly the proposed European 300 GeV accelerator and partly the history of accelerator MG set failures at many large accelerator laboratories in Europe and the U.S.A.

The study programme had two principal requirements: firstly, to investigate methods whereby the associated pulse-induced voltage fluctuation on the public network could be minimised, and secondly, to investigate the dynamic behaviour of a large interconnected transmission/generation system when subjected to cyclic pulse loads of ± 150 MW having energy gradients of up to 170 MW/second.

The voltage fluctuation problem can be overcome by a number of methods. Of these, two appear to be completely practicable in that they impose no real restrictions on either accelerator or public network operational flexibility; these two methods are based on the use of either:

(i) Shunt capacitors and multi-core multi-winding saturable reactors, or

(ii) Shunt capacitors and switched linear inductors.

The latter method has the additional advantage of sub-division into small units without cost increase. However, both methods employ apparatus of proven reliability in pulsed applications, and both enjoy capital costs that are 50% less than the equivalent MG set installation that they would supplant.

The theoretical study of public network behaviour characteristics is a highly complex problem involving consideration of all dynamically-significant generation sources and loads. This "advanced representation" has been the subject of a joint CEGB/SRC study contract.

During November a reduced scale (90 MVA) practical pulse test was carried out on the U.K. super-grid in collaboration with CEGB, AERE Harwell and other SRC laboratories in order to obtain confirmation of the theoretical dynamic behaviour studies. The results were most encouraging – disturbance amplitudes were less than expected and no dynamic magnification occurred.

Investigations similar to the above have been made for Nimrod itself, with a view to the possible future replacement of the MG set by a static system, and (in conjunction with CERN and the Geneva electricity authorities) into the possibility of a static power supply for the new CERN Booster. Where appropriate, the computations have been supported by experimental investigations on scaled apparatus, in order to study problems such as resonance, switching and control.

Safety Group

The Safety Group continued to take special interest in the use of flammable gases at the Laboratory and fresh consideration was given to the possible effects of an explosion within a building. Information from outside sources on the design of buildings to accomodate apparatus using large quantities of flammable gases was studied and standards were suggested for inclusion in the design of Laboratory buildings. Liaison on safety matters continued with Saclay where during the year there was an explosion involving a large quantity of liquid hydrogen, and also with CERN.

A major function of the Group is to keep all matters of safety under review, and surveillance of the potentially most hazardous activities (i.e. those employing flammable gases, high voltages, mechanical handling equipment, and components under pressure) continued to be carried out by the three senior Safety Inspectors of the Group.

The Group provided technical secretaries for working parties investigating accidents and drafting or revising safety codes. The Chief Safety Officer is Secretary of the Safety Committee and is a member of the Fire Committee, the Special Hazards Committee, the Safety and Productivity Awards Committee and the Site Emergency Working Party.

Safety tours were made regularly, the entire Laboratory being covered three times during the year. The parties consisted of a member of the Safety Committee, a Radiation Protection Officer, a senior Safety Inspector, a Fire Officer and a Nursing Sister. The tours were arranged by an officer of the Safety Group who acted as Secretary and progressed action on the recommendations made.

Publicity on hazards continued by means of "Safety News" sheets and displays in the safety showcases. A "Safety Yearbook" which is an aide-memoire of safety regulations and information was issued to each member of the staff and to visitors.

By the very nature of its research programme, electricity is very widely used in the Laboratory, and, of all possible accidents, those of an electrical nature are the most likely. In order to minimise the effects of electric shock, training in artificial resuscitation and emergency first aid continued to be available for all staff. A total of 41 classes were held to give training in these techniques.

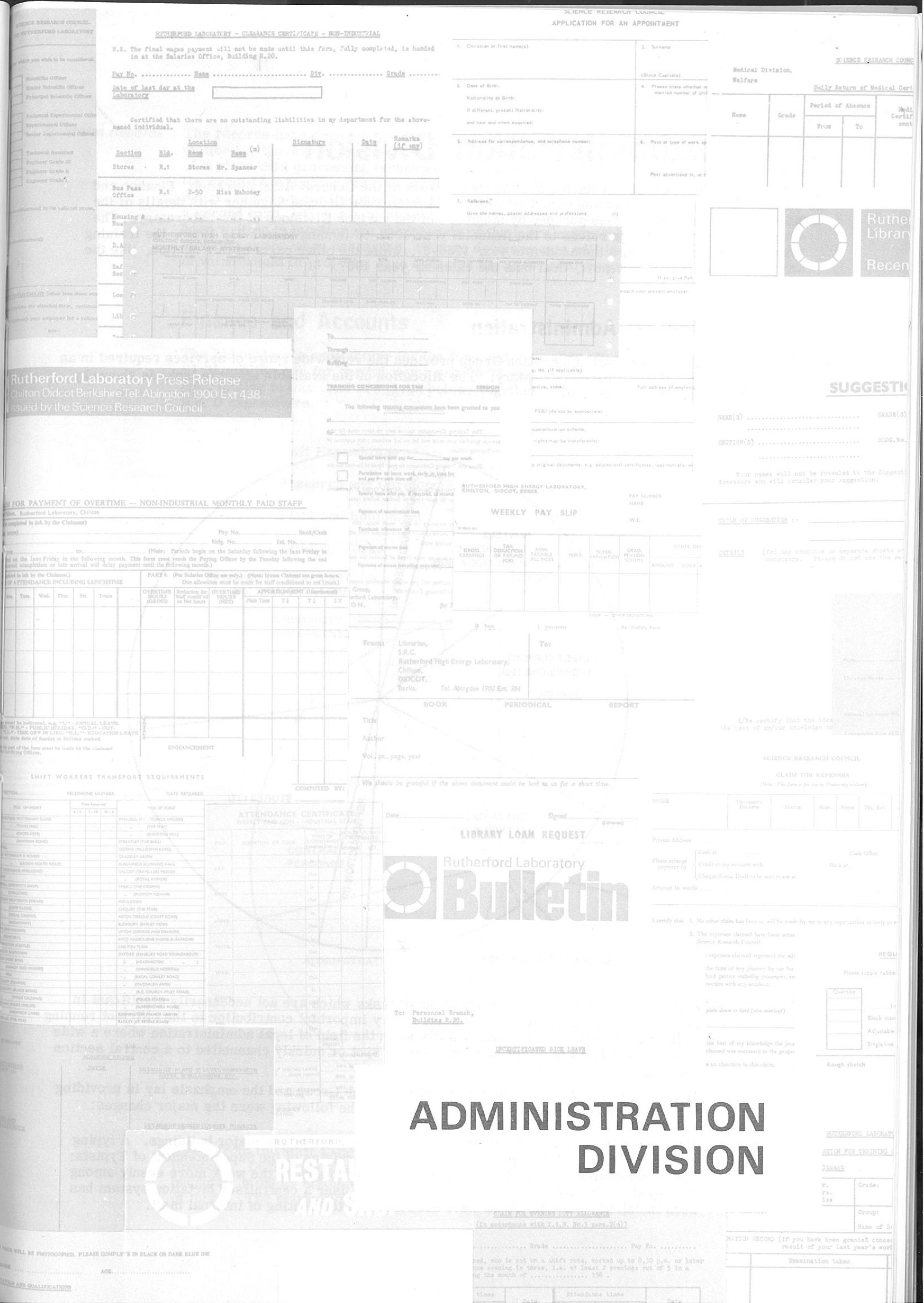
Accident statistics throughout the world indicate that incorrect manual handling methods (at home as well as at work) are responsible for a considerable loss of manpower. Approximately 300 persons attended lectures given by a member of the Group who had been trained as an Instructor during the previous year. Training was also given to a limited number of specialist staff in the use of compressed air breathing apparatus. Safety talks were also given on a variety of topics to staff and also to school leavers in local educational establishments.

A wide range of safety equipment was demonstrated and issued for use during the year; certain items required periodic inspection and maintenance which was given by the Safety Group staff.

The number of items of plant registered with the Group for safety inspection was 3263, an increase of 8% over the 1966 total. The number was made up as follows:- lifting tackle - 2014 items; lifting machines - 287; pressure vessels - 637; experimental high voltage apparatus - 201; safety equipment - 93; fire prevention - 31. The total number of inspections carried out by Laboratory and Contract staff was 6259.

During the year a total of 139 injuries were reported which involved Rutherford Laboratory staff, 16 of which resulted in lost time. The mean duration of absence due to the lost time accidents was 14·6 days. The "all-injury" frequency rate increased from 4·88 to 5·06 and the "lost-time" frequency rate increased from 0·57 to 0·58. These figures relate to all employees; for industrial staff, the "lost-time" frequency rate dropped from 1·74 to 1·30.

It is hoped that increased safety training will result in a reduction of these rates, which are calculated by multiplying the number of accidents by 100,000 and dividing by the total number of man-hours worked during the year.



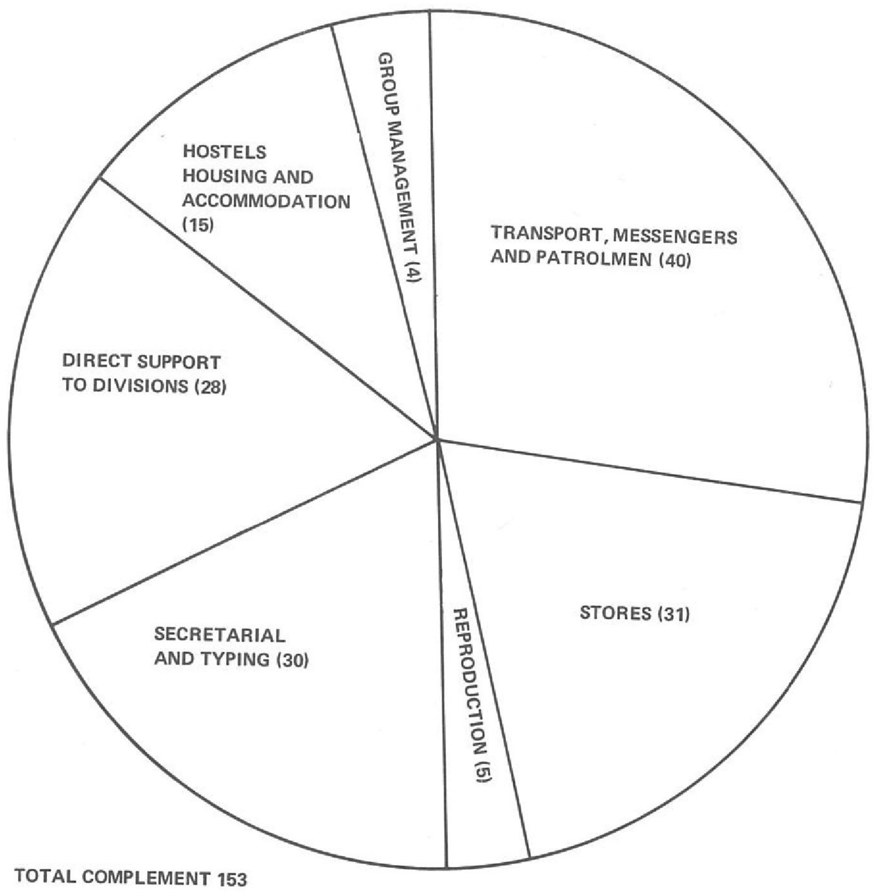
ADMINISTRATION DIVISION

Administration Division

This section of the Report covers the work of the General Administration, Finance and Accounts, Personnel and Scientific Administration Groups, together with details of the training courses pursued by members of the various Divisions of the Laboratory. The financial data refers to the financial year 1967-68 (ending March 31, 1968), the training report covers the academic year 1966-67, while the other parts of this section, like the rest of the Report, deal with the calendar year 1967.

General Administration

The General Administration Group provides the very wide range of services required in an advanced research laboratory. The allocation of the available effort to tasks is shown by the following diagram:



TOTAL COMPLEMENT 153

The majority of the work consists of small tasks which are not necessarily significant in themselves but which collectively make a very important contribution to the efficient running of the Laboratory. This is particularly so in the field of local administration where a wide range of problems is either dealt with on the spot or quickly channelled to a central section with the expertise or effort to cope.

1967 was primarily a year of consolidation for the Group and the emphasis lay in providing existing services in a more efficient manner. The following were the major changes:

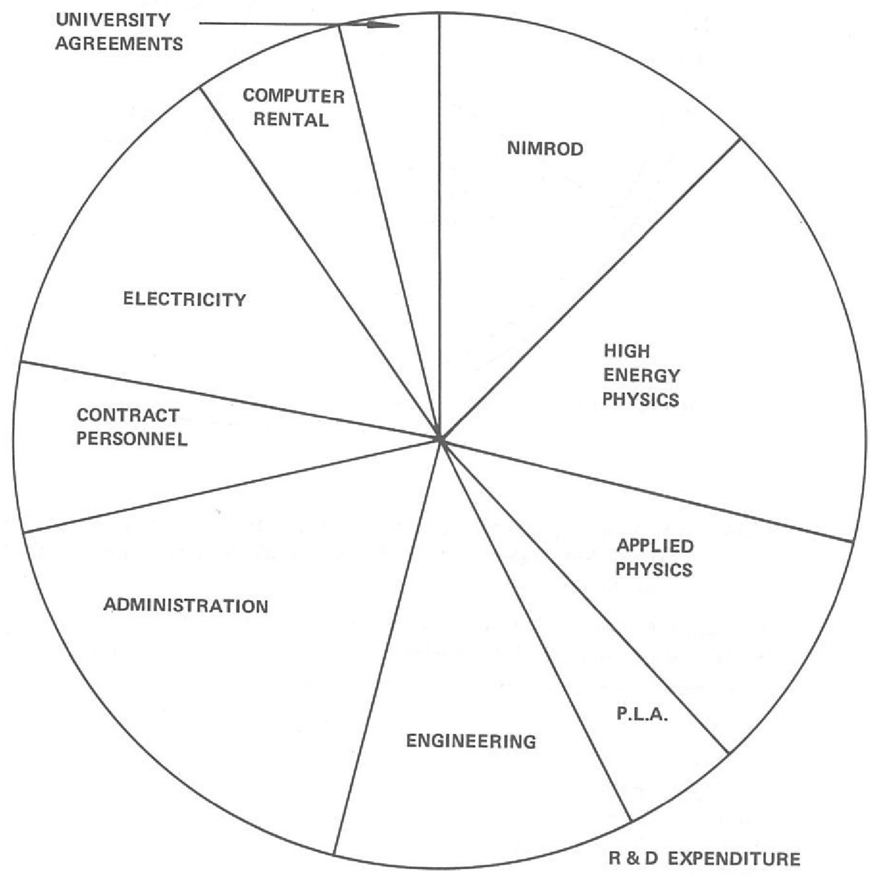
Typing Previously the general typing effort was dispersed among the major buildings. A typing centre has now been set up under the direct supervision of the Superintendent of Typists; this concentrates the effort and makes it possible to spread the work more evenly among the typists. To improve communication with the user a centralised dictation system has been installed, and alterations have been made in the routing of internal mail.

Stores Records The records have been analysed and effort is now directed towards providing better information for the Stores management, eliminating unnecessary clerical work and making use of modern data processing techniques. Considerable progress has been made in reducing the record keeping for the cheaper items; the re-order point is physically indicated at the bin at the time when the stock reaches a certain level rather than relying on the figures on a record card, which can be at variance with the true position. Computer programs have been written to monitor the stock levels of the more expensive items, and to initiate re-stocking action when necessary. Future developments will include the analysis of costs of withdrawals to projects, thus reducing the associated manual accounting procedures.

Finance and Accounts

The Laboratory's expenditure for the financial year 1967/68 totalled £7·05 million, of which £1·31 million was for capital items and £5·73 million was recurrent. The itemised sums contributing to this total are given below, together with a diagrammatic breakdown of the R & D expenditure.

	£M
Staff Expenditure	2·22
Research and Development	3·72
Plant and Equipment	0·51
Building Works	0·60
Total	7·05

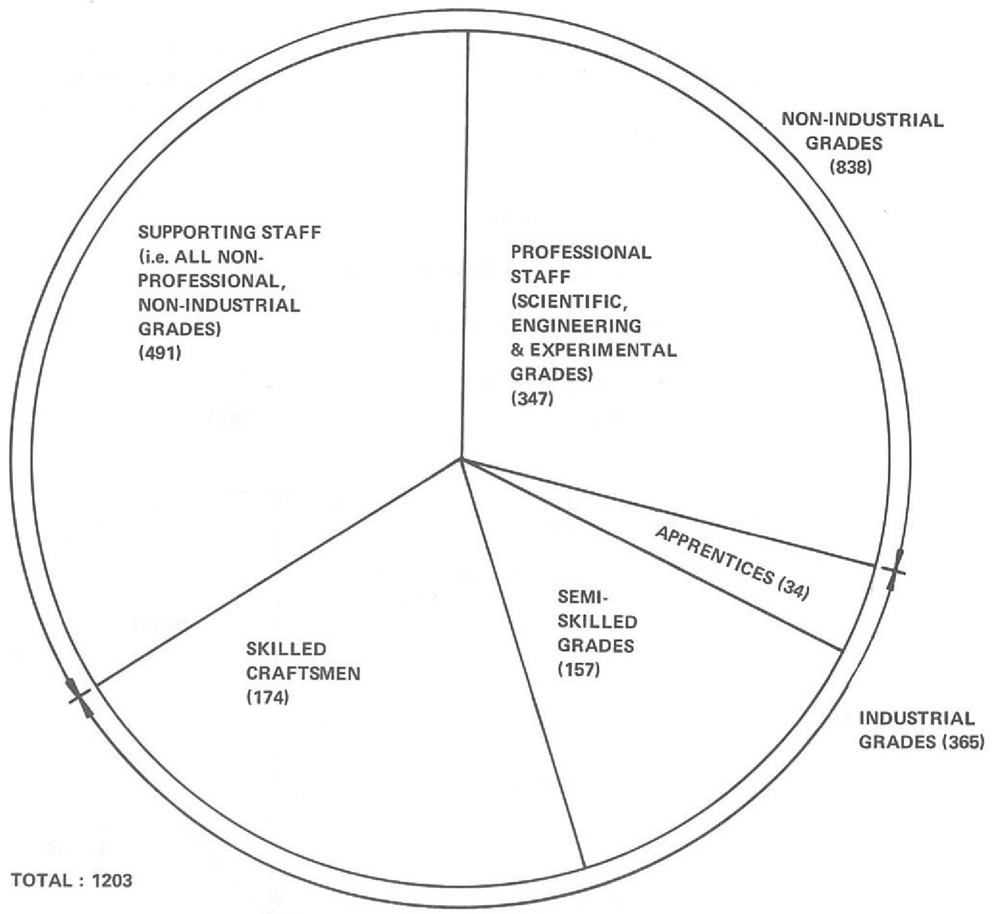


R & D EXPENDITURE

Apart from the Staff Expenditure, the remaining sum of £4·83 M. resulted from 22,500 invoices. During the year, 22,000 commitments were recorded against some 250 group budgets. Monthly statements are issued to budget holders as an aid to effective control of funds. The production of these and other financial summaries will in future be done by computer, the necessary programs being in an advanced state of development. A small unit is being set up with the responsibility of developing and co-ordinating the application of computer techniques to the handling of administrative records of all kinds.

Personnel

The total numbers of staff in post at the end of 1967 is shown in the following diagram, and in greater detail in the table opposite.



During the year the professional staff numbers increased by 3·1%, the supporting staff by 0·7%, while industrial staff numbers remained unchanged. This gives an overall growth for the year of 1·2%.

The disposition of the staff among the Laboratory's six Divisions at the end of the year is tabulated below, the totals also being shown diagrammatically on page 94.

	Professional	*Supporting*	*Industrial*	*Total*
Nimrod	103	142	107	352
High Energy Physics	53	49	19	121
Applied Physics	91	63	6	160
Proton Linear Accelerator	39	38	25	102
Engineering	50	72	102	224
Administration	6	127	72	205
Miscellaneous	5	0	34	39
	347	491	365	1,203

STAFF NUMBERS FOR 1967

	Opening Strength 1.1.67	Changes during 1967		Closing Strength 31.12.67
		Gains	Losses	
PROFESSIONAL				
Senior and Banded Staff	17	2	1	18
SO class	58	13	8	63
Fixed Term	39	14	14	39
Exp. O class	123	19	18·5	123·5
Engineers I, II, III	89	8	2	95
ADE	11	0	2	9
Total Professional	337	56	45·5	347·5
ANCILLARY				
SA and SSA	79	14	26	67
Draughtsmen	31	4·5	2	33·5
Technical class	190	23	9·5	203·5
Non-Techs. and Stores	35	3	2	36
Executive	28	6	4	30
Clerical	49	9	12	46
Secretarial and Typing	27	13	12	28
Photographers	4	1	0	5
Photoprinters	5	0	0	5
Machine Operators	7	7	5	9
Asst. Hostel Manageress	1	0	0	1
Scanners	31·5	5	9·5	27
Total Ancillary	487·5	85·5	82	491
INDUSTRIAL				
Craft	169	44	39	174
Non-craft	159	37·5	39·5	157
Apprentices	37	9	12	34
Total Industrial	365	90·5	90·5	365
GRAND TOTALS	1,189·5	232	218	1,203·5

The figures listed under "changes" include new entrants, resignations and promotions. Staff on sandwich courses, and those working part-time are counted as half.

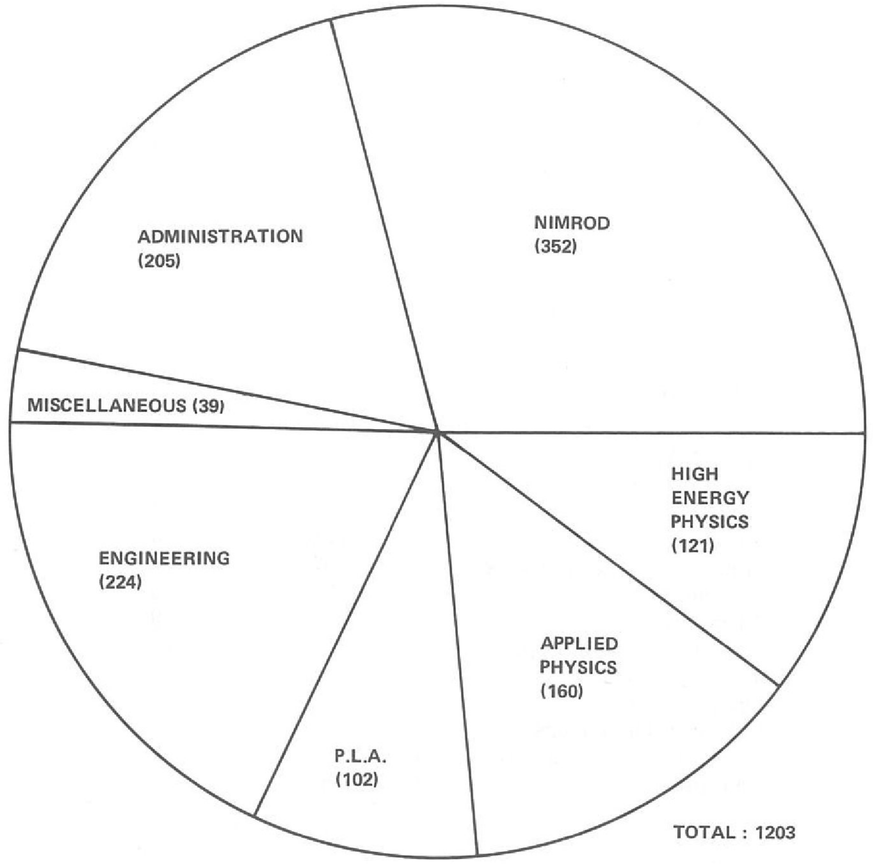
The above figures relate to the staff of the Laboratory; in addition some 85 students have spent periods of up to 6 months at the Laboratory during university vacations or as part of their industrial training.

Travel Arrangements

The number of foreign visits arranged in 1967 was 223, including 32 to the U.S.A. Arrangements were also made for 3 long-term visitors coming with their families from the U.S.A. and for 3 members of the Laboratory and their families going on overseas postings. 57 journeys were booked for the French Bubble Chamber team, and visitors holding open return tickets accounted for a further 50 bookings. Arrangements were also made for 150 U.K. air journeys.

The claims section paid 7,608 travel and subsistence claims (including 2,432 from university visitors) during the year; these totalled £89,000.

DIVISIONAL ALLOCATION OF STAFF AT 31.12.67



Staff Relations

During the year under report the Rutherford Laboratory Whitley Committee was renamed the Atlas & Rutherford Laboratories Whitley Committee. Its membership was enlarged to include Atlas Laboratory representation and also to allow greater staff side representation. The Committee met three times during the year; the wide range of topics discussed can be seen in the Minutes, which are published as Rutherford Laboratory Circulars. Representatives of the Trade Unions and Management also met on numerous occasions, and one of the most important topics discussed was the possibility of applying to Industrial Employees Civil Service type conditions of service in place of those of the U. K. A. E. A.

Staff Training

The Laboratory encourages its staff to pursue courses of further education, most of which lead to improved academic qualifications. There are three Training Officers (one each for scientific, engineering and administrative staff) who devote an appreciable fraction of their time to advising intending students as to the most appropriate courses of study, and to providing guidance throughout the academic year. Most of the training is on a part-time basis, supported by concessions of up to 1 day per week release and by the payment of fees and travelling expenses. Courses pursued on this basis ranged from O-level subjects, through a variety of National Certificates to L. Inst. P. and Part III I. E. E. Five students attended part-time M. Sc. courses in physics and electronics. A wide variety of short courses has been attended, on both managerial and technical topics. These courses are run by local technical colleges, specialist bodies and by the A. E. R. E. Education and Training Centre, to which the Laboratory has supplied a number of lecturers.

Twelve students have been engaged upon full-time courses during the academic year 1966-67, one on a one-year Part III I. E. E. course, two on three-year degree courses, the remainder on four-year sandwich courses. One of these students held an S. R. C. award while the others were granted unpaid leave while financed by L. E. A. awards. The qualifications gained as a result of full-time study this year were an Upper Second class degree in Applied Chemistry and a Lower Second class degree in Applied Physics. Statistics on the numbers of courses attended are tabulated thus:

	Short Courses	Evening Classes	Day Classes	Full-time Courses	Examinations Entrants	Examinations Passes
Scientific staff	47	11	51	10	56	42
Engineering staff	190	26	131	2	142	108
Administrative staff	26	3	3	0	4	4
Totals	263	40	185	12	202	154

In addition to arranging this training for its own employees, the Laboratory provided industrial training for 37 college-based sandwich course students reading Applied Physics, Applied Chemistry, Applied Mathematics and Electronic Engineering. The Laboratory has continued to enjoy the use of the training facilities provided by A. E. R. E. for Scientific Assistants and for apprentices. 5 S. A. 's on laboratory duties were trained under these arrangements during the year under report, as were the 2 student apprentices and 5 craft apprentices recruited during this period.

Scientific Administration

University Research Agreements

During the year agreements were arranged with the Universities of Birmingham; Bristol; Cambridge; Exeter; Glasgow; Liverpool; London (Imperial College, Kings' College, Queen Mary College, University College, Westfield College); Manchester; Oxford; the Queen's University of Belfast; Southampton; Surrey.

The following list shows the number of agreements in force at the beginning and end of 1967, classified according to type of research. At the beginning of August a total of 16 experimental agreements were taken over by the University Grants Committee.

Classification	*1. 1. 67*	*31. 12. 67*
Experiments with Nimrod	24	18
Experiments with PLA	8	7
Extra-Mural Research	3	3
University use of A. E. A. Accelerators	1	1
Major Film Analysis Projects	3	4
	39	33

Conferences and Exhibitions

The Laboratory organised the Second International Conference on Magnet Technology held at Oxford from 11th-13th July, attended by 285 participants from 19 countries, including representatives from industry. The primary aim of the Conference was the communication of technological information on magnets for research in physics, particularly elementary particle physics. The Conference was sponsored by the Science Research Council, the Institute of Physics and the Physical Society, the Institution of Electrical Engineers and the International Union of Pure and Applied Physics. The proceedings were edited and published by the Rutherford Laboratory.

At the Annual Physics Exhibition the Laboratory displayed some high speed data processing equipment utilising tunnel devices. This electronic apparatus was developed at the Laboratory to detect and process signals from fast particle counters, with a time resolution of 5 nanoseconds.

During the year 16 industrial firms held one-day exhibitions of their specialised equipment at the Laboratory.

Public Relations

Parties totalling 1,560 visitors were taken on conducted tours of the Laboratory during the year. On 19th September the Secretary of State for Education and Science the Rt. Hon. Patrick Gordon Walker M.P. toured the Laboratory and met members of the staff, and representatives of the Staff Associations and Trades Unions.

A film dealing with the design and construction of Nimrod and its use in the Laboratory's high energy physics programme was made in association with Granada Television. This film formed part of a series of schools television programmes for science sixth forms.

The film "The Rutherford Laboratory", in addition to being loaned on numerous occasions to various organisations, was also shown at the Canadian Expo. 67 exhibition.

Liaison continued with the local and national press on feature articles and news items concerning the Laboratory, and several press releases were issued. A large number of enquiries for photographs and information for journal articles were dealt with from industry.

The production of the Laboratory Bulletin continued and 800 copies per week are now distributed.

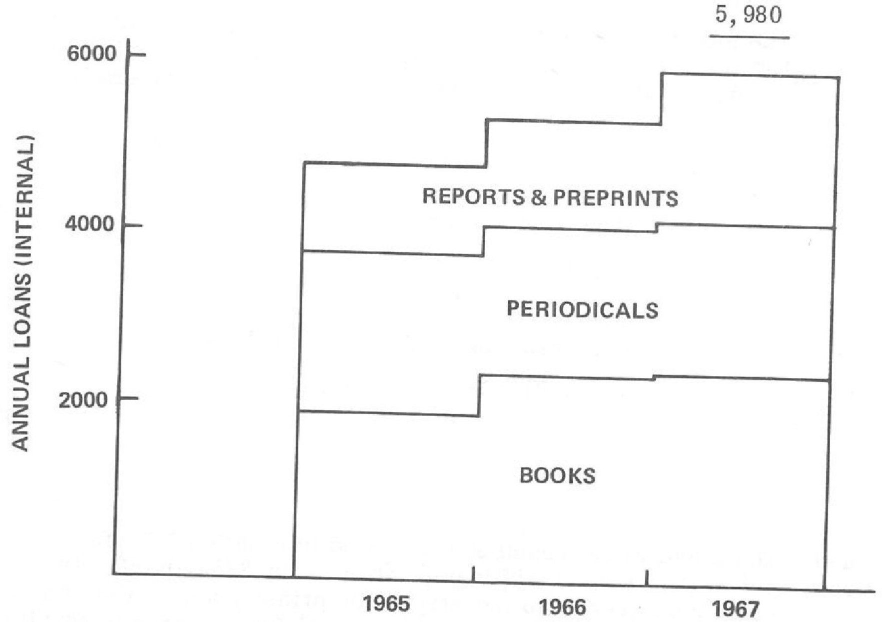
Documentation

The preparation and production of 20 reports was arranged in collaboration with their authors. These reports are in the RHEL/R series, on sale through H.M.S.O. 38 preprints in the RPP series and 15 memoranda in the RHEL/M series were issued directly by their authors.

Library and Information Services

The figures summarising the Library's activities during the year reflect the continuing increase in the utilisation of the facilities available. Internal loan statistics are given below, together with a diagram showing the growth in recent years. These figures do not include loans from 'self-service' branches such as that in the PLA Division.

Internal loans, 1967	Books	2,369
	Periodicals	1,847
	Reports	1,765
		5,980



A significant portion of the material loaned is specially borrowed from external sources such as the National Lending Library. Such requests, currently averaging 12-15 per week, are now dealt with directly instead of through the agency of the A.E.R.E. Library.

The Library's holdings were increased by 900 books (approximately 550 different titles) and 3,500 reports and preprints. These and other new acquisitions were notified to Library users by the weekly additions list, of which 300 copies are circulated. The year under report has also seen the completion of the process whereby the ordering, accessioning and cataloguing of books has been taken over from A.E.R.E. The stock at the end of 1967 is represented by the following data:

Books (volumes)	5,900
Pamphlets	680
Reports and preprints	11,500
Photographs	3,000
Slides	900
Press cuttings	870
Periodicals (currently taken)	403

Back numbers of some journals have been acquired, as part of a continual attempt to improve the length and continuity of the runs of the most important journals. There has been a large increase in the number of institutions with whom arrangements exist for the exchange of report and preprint literature. At the end of the year there were 210 institutions in 40 countries on the list, both figures being roughly double those of a year ago.

During the year, it has become possible to provide an information service, whereby technical enquiries can be answered. The service includes finding scientific data and conducting literature searches. Utilisation of this new facility has increased rapidly, and appears to be of value to Laboratory staff and visitors in exploiting the published literature.

LIST OF PUBLICATIONS

List of Publications

High Energy Physics Division

Journal Articles

ALLISON W.W.M., CRUZ A., SCHRANKEL W., HAQUE M.M., TULI S.K., FINNEY P.J., FISHER C.M., GORDON J.D., TURNBULL R.M., ERSKINE R., SISTERSON K., PALER K., CHAUDHURI P., ESKREYS A., GOLDSACK S.J. (University of Oxford, M.P.I., Munich, University of Birmingham, Rutherford Laboratory, University of Glasgow and Imperial College, University of London)
The production of strangeness zero mesons in multibody final states in 6 GeV/c K^-p interactions.
Phys. Lett., **25B** (10) 619 (November 1967)

BELLAMY E.H., BUCKLEY T.F., DOBINSON R.W., MARCH P.V., STRONG J.A., WALKER R.N.F., BUSZA W., DUFF B.G., GARBUTT D.A., HEYMANN F.F., NIMMON C.C., POTTER K.M., SWETMAN T.P. (University and Westfield Colleges, University of London)
Spin and parity of the $N^*_{3/2}$ (2420).
Phys. Rev. Lett., **19** (8) 476 (August 1967).

BILLING K.D., BULLOCK F.W., ESTEN M.J., GOVAN M., HENDERSON C., KNIGHT W.L., MILLER D.J., OWEN A.A., STANNARD F.R., TOMPA E., TOVEY S., WALDRON O.C. (University College, London and University of Oxford)
Search for the decay mode $\eta^0 \rightarrow \pi^0 e^+ e^-$.
Phys. Lett., **25B** (6) 435 (October 1967), preprinted as RPP/H 26.

BOTTERILL D.R., BROWN R.M., CORBETT I.F., CULLIGAN G., EMMERSON J. McL., FIELD R.C., GARVEY J., JONES P.B., MIDDLEMAS N., NEWTON D., QUIRK T.W., SALMON G.L., STEINBERG P., WILLIAMS W.S.C. (University of Oxford)
Measurement of the branching ration for the decay $K^+ \rightarrow e^+ + \nu$.
Phys. Rev. Lett., **19** (17) 982 (October 1967), preprinted as RPP/H 27.

BRUNT D.C., CLAYTON M.J., WESTWOOD B.A. (University of Cambridge)
The final state $pd\pi^+\pi^-$ in pd interactions at about 2 GeV/c.
Phys. Lett., **26B** (5) 317 (February 1968).

BUSZA W., DAVIS D.G., DUFF B.G., HEYMANN F.F., NIMMON C.C., WALTON D.T., BELLAMY E.H., BUCKLEY T.F., MARCH P.V., STEFANINI A., STRONG J.A., WALKER R.N.F. (University and Westfield Colleges, University of London)
π^-p elastic scattering in the neighbourhood of $N^*_{1/2}$ (2190)
Nuovo Cim., **52A** (2) 331 (November 1967), preprinted as RPP/H 21.

CARTER A.A. (University of Cambridge)
Evidence for an S = +1, I = O resonance in the K^+- nucleon system.
Phys. Rev. Lett., **18** (19) 801 (May 1967), preprinted as HEP 67-2 (Cambridge).

CARTER A.A. (University of Cambridge)
Meson-nucleon coupling constants from nucleon-nucleon forward dispersion relations.
Nuovo Cim., **48A** (1) 15 (March 1967), preprinted as RPP/H 14.

COLLEY D.C., MACDONALD F., MUSGRAVE B., BLAIR W.M.R., HUGHES I.S., TURNBULL R.M., GOLDSACK S.J., PALER K., SISTERSON L.K., BLUM W., ALLISON W.W.M., LOCKE D.H., LYONS L., FINNEY P.J., FISHER C.M., SEGAR A.M. (University of Birmingham, University of Glasgow, Imperial College, University of London, M.P.I., Munich and Rutherford Laboratory)
Production of Y_1^* (1700) in K^-p collisions at 6 GeV/c.
Phys. Lett., **24B** (9) 489 (May 1967), preprinted as RPP/H 24.

CULLIGAN G., QUIRK T.W. (University of Oxford)
A compact Cerenkov counter for detecting electrons.
Nucl. Instrum. Meth., **53** (2) 261 (August 1967), preprinted as RHEL/M 120.

DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W., CARTER A.A., RILEY K.F., TAPPER R.J., BUGG D.V., GILMORE R.S., KNIGHT K.M., SALTER D.C., STAFFORD G.H., WILSON E.J.N. (University of Birmingham, University of Cambridge and Rutherford Laboratory)
Structure in the K^-- nucleon total cross section between 600 and 1400 MeV/c.
Phys. Rev. Lett., **18** (2) 62 (January 1967), preprinted as RPP/H 16.

DUFF B.G., GARBUTT D.A., ROSNER R.A., WALKER R.N.F. (University and Westfield Colleges, University of London)
The selection of spark chamber tracks by computer methods.
Nucl. Instrum. Meth., **54** (1) 132 (September 1967).

ESTEN M.J., GOVAN M., KNIGHT W.L., MILLER D.J., TOVEY S., BOWLER M.G., CASHMORE R.J., PERKINS D.H., WALDRON O.C. (University College, London and University of Oxford)
The production of electron pairs of high invariant mass in 830 MeV/c (π^+- nucleus) interactions.
Phys. Lett., **24B** (2) 115 (January 1967).

GAILLARD J.M., KRIENEN F., GALBRAITH W., HUSSRI A., JANE M.R., LIPMAN N.H., MANNING G., RATCLIFFE T., DAY P., PARHAM A.G., PAYNE B.T., SHERWOOD A.C., FAISSNER H., REITHLER H., (CERN, A.E.R.E. Harwell, University of Aachen and Rutherford Laboratory)
Measurements of the decay of long lived neutral K mesons into two neutral pions.
Phys. Rev. Lett., **18** (1) 20 (January 1967), preprinted as RPP/H 20.

LITCHFIELD P.J., RANGAN L.K., SEGAR A.M., SMITH J.R., LARRIBE A., LEVEQUE A., MULLER A., PAULI E., REVEL D., TALLINI B. (Saclay and Rutherford Laboratories)
A study of the decay mode $\eta \rightarrow \pi^+\pi^-\gamma$.
Phys. Lett., **24B** (9) 486 (May 1967), preprinted as RPP/H 23.

Conference Papers

BINNIE D.M., DUANE A., HORSEY J., JONES W.G., MASON D., UR-RAMMAN I., WALTERS J., HORWITZ N., PALIT P. (Imperial College, University of London and Rutherford Laboratory)
The reaction $\pi^- + p \rightarrow \phi + \eta$ near threshold and preliminary results on the search for $\phi \rightarrow e^+ + e^-$.
International Conference on Elementary Particles, Heidelberg, September 1967.
[Proceedings (Filthuth H. (ed.), North-Holland (1968) includes title only of this, and the following 9 contributed papers]

BIRD L., WHITEHEAD C., AULD E.G., CRABB D.G., OTT R.J., McEWEN J., AITKEN D.K., BENNETT G., MAGUE J.F., JENNINGS R.E., PARSONS A.S.L. (A.E.R.E., Harwell, Rutherford Laboratory, University of Southampton and University College, University of London)
Inelastic π^-p interactions in the region of 3·2 GeV/c.
Ibid.

BOTTERILL D.R., BROWN R.M., CORBETT I.F., CULLIGAN G., EMMERSON J. McL., FIELD R.C., GARVEY J., JONES P.B., MIDDLEMAS N., NORTON P.R., QUIRK T.W., SALMON G.L., STEINBERG P., WILLIAMS W.S.C. (University of Oxford)
K^+ leptonic decays.
Ibid.

COX C.R., HEARD K.S., SLEEMAN J., DUKE P.J., HILL R.E., HOLLEY W.R., JONES D.P., THRESHER J.J., SHOEMAKER F., WARREN J.B. (University of Oxford, Rutherford Laboratory, University of Princeton and University of British Columbia)
Measurement of polarization effects in elastic K^-p scattering.
Ibid.

DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W., CARTER A.A., RILEY K.F., TAPPER R.J., BUGG D.V., GILMORE R.S., KNIGHT K.M., SALTER D.C., STAFFORD G.H., WILSON E.J.N. (University of Birmingham, University of Cambridge and Rutherford Laboratory)
Total cross sections of K^+ and K^- mesons on protons and deuterons from 0·6 to 2·7 GeV/c.
Ibid.

HEARD K.S., COX C.R., SLEEMAN J., DUKE P.J., HILL R.E., HOLLEY W.R., JONES D.P., THRESHER J.J., SHOEMAKER F., WARREN J.B. (University of Oxford, Rutherford Laboratory, University of Princeton and University of British Columbia)
Polarization effects in π^-p scattering from 0·65 to 2·14 GeV/c.
Ibid.

RILEY K.F., CARTER A.A., TAPPER R.J., BUGG D.V., GILMORE R.S., KNIGHT K.M., SALTER D.C., STAFFORD G.H., WILSON E.J.N., DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W. (University of Cambridge, Rutherford Laboratory and University of Birmingham)
Pion-nucleon total cross section.
Ibid.

SACLAY, COLLEGE de FRANCE and RUTHERFORD LABORATORY
K^-p interactions in the K^- momentum range 1·5 - 1·8 GeV/c.
Ibid.

UNIVERSITY OF BIRMINGHAM, IMPERIAL COLLEGE, UNIVERSITY OF LONDON, RUTHERFORD LABORATORY, M.P.I. MUNICH, UNIVERSITY OF GLASGOW AND UNIVERSITY OF OXFORD
The production of strangeness zero mesons in multibody final states in 6 GeV/c K^-p interactions.
Ibid.

UNIVERSITY AND WESTFIELD COLLEGES, UNIVERSITY OF LONDON
π^+p elastic scattering between 1·72 and 2·80 GeV/c.
Ibid.

Unpublished Preprints

BUGG D.V., COTTINGHAM N. (Rutherford Laboratory and University of Birmingham)
The effect of the Coulomb barrier on nuclear interactions.
RPP/H 30.

BUGG D.V., GILMORE R.S., KNIGHT K.M., SALTER D.C., STAFFORD G.H., WILSON E.J.N., DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W., CARTER A.A., TAPPER R.J., RILEY K.F. (University of Birmingham, University of Cambridge and Rutherford Laboratory)
Kaon-nucleon total cross sections from 0·6 to 2·65 GeV/c.
RPP/H 31.

CARTER A.A., RILEY K.F., TAPPER R.J., BUGG D.V., GILMORE R.S., KNIGHT K.M., SALTER D.C., STAFFORD G.H., WILSON E.J.N., DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W. (University of Birmingham, University of Cambridge and Rutherford Laboratory)
Pion-nucleon total cross sections from 0·5 to 2·65 GeV/c.
RPP/H 32.

COLLEY D.C., DODD W.P., MACDONALD F., MUSGRAVE B., TULI S.K., BLAIR W., ERSKINE R., GORDAN J., HUGHES I., TURNBULL R., CHAUDHURI P., ESKREYS A., GOLDSACK S.J., PALER K., SISTERSON K., BLUM W., DEHM G., SCHMITZ N., SCHRANKEL W., ALLISON J., ALLISON W.W.M., BRODY A.D., LOCKE D.H., LYONS L., FINNEY P., FISHER C., RANGAN L.K., SEGAR A.M. (University of Birmingham, University of Glasgow, Imperial College, University of London, M.P.I. Munich, University of Oxford and Rutherford Laboratory)
Two body processes in K^-p scattering at 6 GeV/c.
RPP/H 25.

DAVIES J.D., DOWELL J.D., HATTERSLEY P.M., HOMER R.J., O'DELL A.W., SPROUL M.E., CARTER A.A., RILEY K.F., TAPPER R.J., BUGG D.V., SALTER D.C., WILSON E.J.N. (University of Birmingham, University of Cambridge and Rutherford Laboratory)
Particle production from copper and uranium targets by 8 GeV/c protons.
RPP/H 28.

MUSGRAVE B., SCOTTER D.G., WHITTAKER J.B., BLAIR W.M.R., GRANT A.L., GORDON J.D., ERSKINE R., HUGHES I.S., NEGUS P.J., TURNBULL R.M., AHMAD A.A.Z., BAKER S., CELNIKIER L., MISBAHUDDIN S., SKILLICORN I.O., DAVIES W.T., FIELD J.H., GRAY P.M.D., LAWRENCE D.E., LOKEN J.G., LYONS L., MEADOWS B.T., MULVEY J.H., OXLEY A.J., WILKINSON C.A., FISHER C.M., PICKUP E., RANGAN L.K., SCARR J.M., SEGAR A.M. (University of Birmingham, University of Glasgow, Imperial College, University of London, University of Oxford and Rutherford Laboratory)
The reaction $K^-p \rightarrow$ mesons + nucleon at 3·5 GeV/c.
RPP/H 29.

PALER K., CHAUDHURI P., SISTERSON L.K., ESKREY A.W., ALLISON W.W.M., LOCKE D.H., LYONS L., FINNEY P.J., TURNBULL B., GORDON J., ERSKINE R. (Imperial College, University of London, University of Oxford, University of Glasgow and Rutherford Laboratory)
A double peripheral interpretation of some 6 GeV/c K^-p interactions.
RPP/H 22.

WHITEHEAD C., McEWEN J.G., OTT R.J., AITKEN D.K., BENNETT G., JENNINGS R.E. (A.E.R.E., Harwell, University College, University of London and University of Southampton)
Observation of an enhancement in the I = O $\pi^+\pi^-$ system at 1085 MeV.
RPP/H 33.

Reports and Memoranda

DUKE P.J., JONES D.P., KEMP M.A.R., MURPHY P.G., PRENTICE J.D., THRESHER J.J., COX G.R., HEARD K.S. (Rutherford Laboratory and University of Oxford)
The results of differential cross section and polarization measurements in πp elastic scattering in the momentum range from 875 to 1579 MeV/c.
RHEL/M 128.

MANNING G., SALTER D.C.
Information on the Nimrod experimental programme.
HEP/MISC/2.

STAFFORD G.H.
Review of the Nimrod experimental programme from February 1964 to July 1967.

STAFFORD G.H., BUTTERWORTH I., THOMAS D.B., FISHER C.M., PERKINS D.H.
Symposium on the results of the design study of the High Field Bubble Chamber.
HEP/MISC/3.

Doctoral Theses

BROWN R.M. (University of Oxford)
Measurement of the decay rate of the K^+ meson into an electron and a neutrino.

BRUNT D.C. (University of Cambridge)
High energy proton-deuteron interactions.

CARTER A.A. (University of Cambridge)
Total cross sections and forward dispersion relations.

CRABB D.G. (University of Southampton)
An 'on-line' sonic spark chamber experiment to measure the reaction $\pi^- + p \rightarrow n + \pi + \pi$.

HUSSRI A. (University of Bristol)
The two neutral pion decay of the long lived K meson.

OTT R.J. (University of Southampton)
Investigation of resonance production in $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ at 3·2 and 3·5 GeV/c using a sonic spark chamber/scintillation counter on line computing system.

POTTER K.M. (University of London (University College))
The use of visual spark chambers in the detection of neutrino interactions and the study of pion-proton elastic scattering.

QUIRK T.W. (University of Oxford)
Energy spectrum of electrons produced in Ke_3 decay and related topics.

TAPPER R.J. (University of Cambridge)
High energy total cross section measurements.

Nimrod Division

Journal Articles

CHANDLER H.A.
A mains-operated cold trap filler.
Engg. Rev. (A.E.R.E.), **6** (12) 15 (December 1967)

SUTHERLAND J.C.
A novel method of making thin slits in metal.
J. Sci. Instrum., **44** (12) 1043 (December 1967).

WROE H.
Some emittance measurements with a duoplasmatron ion source.
Nucl. Instrum. Meth., **52** (1) 67 (June 1967).

WROE H., FOWLER R.G.
A simple feed through plug and socket connector.
J. Sci. Instrum., **44** (12) 1056 (December 1967).

Conference Papers

BROOKS H.C., REED A.B.D.
The failure of the alternators of the Nimrod main magnet power supply.
U.S. National Particle Accelerator Conference, Washington D.C., 1-3 March 1967. Proceedings (IEEE Trans. Nucl. Sci., **NS-14** (3) 517 (June 1967)), preprinted as RPP/N 10.

GARDINER I.S.K., HAROLD M.R., REES G.H.
The resistive wall instability and damping in Nimrod.
Ibid., p.653, preprinted as RPP/N 12.

GRAY D.A.
Operational experience with Nimrod.
Ibid., p.743, preprinted as RPP/N 11.

BENDALL R.G., NEWMAN M.J., SHEEHAN M.J., WILSON E.J.N.
Beam handling magnets for Nimrod.
Second International Conference on Magnet Technology, Oxford. 11-13 July 1967. Proceedings (Hadley H. (ed.), Rutherford High Energy Laboratory (1967)) p.122.

BROOKS H.C., BAKER R.J.
Parallel operation of machines used to pulse Nimrod 7 GeV proton synchrotron magnet.
Ibid., p.421.

ELLIOTT R.T.
A fast stepping magnet.
Ibid., p.281.

GILBERT F.S.
A high stability step programmed power supply for Nimrod extraction magnets.
Ibid., p.451.

KING N.M., WILSON E.J.N.
Focussing properties and choice of parameters for beam transport magnets.
Ibid., p.106.

McPHERSON G., WILSON E.J.N.
A study of the design of alternating gradient beam transport magnets.
Ibid., p.114.

MORGAN R.H.C., GRESHAM A.T., DAWSON J.M.
Extractor magnets for Nimrod.
Ibid., p.291.

ELLIOTT C.T., CHATTERTON P.A., SMITH W.A.
A study of spark formation phenomena between short vacuum gaps, using a Kerr cell camera system.
IPPS Conference on Spark Discharges, Liverpool, April 1967.

MASON T.R., SMITH W.A.
Impulse breakdown measurements at high voltages in vacuum.
IPPS Conference on High Voltage Insulation in Vacuum, London, September 1967.

WROE H., FOWLER R.G.
The high voltage performance of a 500 kV feed through bushing in the pressure range 2×10^{-6} torr to 1×10^{-3} torr.
Ibid.

ATKINSON H.H.
The technology of present high energy polarized targets.
International Conference on Polarized Targets and Ion Sources, Saclay, 5-9 December 1966. Proceedings (La Direction de la Physique (ed.), C.E.N. Saclay (1967)) p.41, preprinted as RPP/N 9.

KING N.M., WILSON E.J.N.
Target stations in high energy extracted proton beams.
Sixth International Accelerator Conference, Cambridge (U.S.A.), 11-15 September 1967, preprinted as RPP/N 13.

Reports and Memoranda

CONTE M.
Resonant extraction from an ideal circular weak focussing synchrotron.
RHEL/M 126.

CONTE M.
Resonant extraction from an ideal circular weak focussing synchrotron (slowly varying conditions).
RHEL/M 134.

EDWARDS V.W., ELLIOTT R.T., MATHEWS W.A.
Fast shutter magnets for separated particle beams.
RHEL/R 147.

GRAY D.E.
Nimrod operation and development – quarterly report September 30 to December 31, 1966.
RHEL/R 142.

GRAY D.E.
Nimrod operation and development – quarterly report January 1 to March 31, 1967.
RHEL/R 148.

GRAY D.E.
Nimrod operation and development – quarterly report, April 1 to June 30, 1967.
RHEL/R 151.

GRAY D.E.
Nimrod operation and development – quarterly report, July 1 to September 30, 1967.
RHEL/R 155.

HOBBIS L.C.W., WROE H.
Ion sources.
RHEL/M 125.

PLANNER C.W.
A study of the feasibility of transporting the beam from the 50 MeV PLA for injection into Nimrod.
RHEL/R 141.

Applied Physics Division

Journal Articles

BARNES K.J., KAZES E., PATON J.E., WILLIAMS R.M.
Properties of the colinearised algebra of vector densities in the infinite momentum representation.
Nuovo Cim., **50A** (4) 935 (June 1967), preprinted as ICTP/67/8.

BERENDS F.A., DONNACHIE A., OADES G.C.
A note on the Ke4 and Kμ4 decay rates.
Phys. Lett., **26B** (2) 109 (December 1967).

CHAU Y.C., DOMBEY N., MOORHOUSE R.G.
Analysis of pion photoproduction in the second resonance region.
Phys. Rev., **163** (5) 1632 (November 1967), preprinted as RPP/A 16 (Rev.).

COSTA G., KABIR P.K.
Possible CP-Noninvariant effects in $\pi\pi\gamma$ decay of neutral kaons.
Nuovo Cim., **51A** (2) 564 (September 1967), preprinted as RL/K/8.

COSTA G., KABIR P.K.
Possible CP-Noninvariant effects in $\pi\pi\gamma$ decay of charged K-mesons.
Phys. Rev. Lett., **18** (11) 429 (March 1967), preprinted as RL/K/6.

DASS G.V., MICHAEL C.
Superconvergence relations for pion-baryon scattering.
Phys. Rev., **162** (5) 1403 (October 1967), preprinted as RPP/A 22.

DELOFF A.
Meson-baryon scattering in a quark model.
Nucl. Phys., **B2** (5) 597 (August 1967), preprinted as RPP/A 21.

DONNACHIE A., SHAW G.
Low energy photopion production, SU(6) and the Panofsky ratio.
Nucl. Phys., **87** (6) 556 (February 1967), preprinted as CERN/TH 673.

FIELD G., KABIR P.K.
The parameters of $K^0 \rightarrow 2\pi$ decay and the magnitude of $Re(A_2/A_0)$.
Z.Phys., **208** (1) 60 (January 1968), preprinted as RL/K/10.

HENDRY A.W., MOORHOUSE R.G., PATON J.E.
Strangeness + 1 baryons in $U(6) \otimes U(6)$.
Phys. Rev., **159** (5) 1340 (July 1967), preprinted as RPP/A 19.

KABIR P.K.
The symmetries of the weak interactions. (Review Lectures)
Particle Interactions at High Energies (Scottish Universities Summer School, 1966), pp.248-93, Preist T.W. and Vick L.L.J. (eds), Oliver & Boyd, 1967.

KABIR P.K.
Two-body decay of the neutron.
Phys. Lett., **24B** (12) 601 (June 1967), preprinted as RL/K/9.

KABIR P.K.
A possible restriction on CP Noninvariance in K^0 decay.
Nature, **213** (5079) 898 (March 1967), preprinted as RL/K/5m.

KENNY B.G.
Phenomenological model of T-violation in non-leptonic decays.
Ann. Phys. (N.Y.), **45** (1) 25 (October 1967), preprinted as EFINS 66-99.

LAWSON J.D.
The build-up of radial oscillations induced by first harmonic field errors in a cyclotron.
Nucl. Instrum. Meth., **49** (1) 114 (March 1967).

LEA A.T., MARTIN B.R., OADES G.C.
K^+p phase shift analysis below 1500 MeV/c.
Phys. Rev., **165** (5) 1770 (January 1968), preprinted as BNL 11699.

MICHAEL C.
Shape of the N* (1236) resonance.
Phys. Rev., **156** (5) 1677 (April 1967), preprinted as RPP/A 11.

MICHAEL C.
Spin flip in high energy elastic πN scattering.
Phys. Lett., **26B** (6) 392 (February 1968), preprinted as RPP/A 35.

MICHAEL C.
Corrections to ρ dominance and PDDAC.
Phys. Rev., **166** (5) 1826 (February 1968), preprinted as RPP/A 28.

MORGAN D.
A phenomenological analysis of $I = \frac{1}{2}$ single pion processes in the energy range 500 to 700 MeV.
Phys. Rev., **166** (5) 1731 (February 1968), preprinted as RPP/A 27.

NICHOLAS D.J., TROWBRIDGE C.W., ALLEN W.D.
On the lifetime of the negative helium ion.
Phys. Rev., **167** (1) 38 (March 1968), preprinted as RPP/A 25.

PATNAIK B.K., KABIR P.K.
TCP-Invariance in K^0 decay.
Z. Phys., **209** (2) 157 (February 1968).

RUSSELL F.M.
Tracks due to electron showers observed in mica.
Nature, **216** (5118) 907 (December 1967), preprinted as RPP/A 30.

RUSSELL F.M.
The observation of tracks of charged particles in mica from neutrino interactions.
Phys. Lett., **25B** (4) 298 (September 1967).

SARKER A.Q.
Current algebra and the decay modes $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$ and $\eta \rightarrow \pi^0\gamma\gamma$.
Phys. Rev. Lett., **19** (21) 1261 (November 1967), preprinted as RPP/A 26.

SHAW G.
Sum rules for pion-hyperon scattering.
Phys. Rev. Lett., **18** (23) 1025 (June 1967).

SHAW G.
Model of the N* (1236).
Phys. Rev., **158** (5) 1479 (June 1967), preprinted as RPP/A 15.

SHAW G.
Internal symmetries of the electro-magnetic current: experimental tests.
Nuclear Phys., **B3** (3) 338 (October 1967), preprinted as RPP/A 24.

SHAW K.B., THOMAS R.H.
Radiation problems associated with a high energy extracted proton beam.
Health Phys., **13** (10) 1127 (October 1967).

SMITH P.F., LEWIN J.D.
Superconducting proton synchrotrons.
Nucl. Instrum. Meth., **52** (2) 298 (July 1967).

SMITH P.F., THOMAS D.B.
Superconducting magnets in high energy physics.
Nature, **216** (5119) 964 (December 1967).

WEIS A., KABIR P.K.
Electroproduction of intermediate bosons.
Nucl. Phys., **B4** (7) 643 (March 1968), preprinted as RL/K/7.

Conference Papers

McEWAN J.F., SHARP P.H.
CYCLOPS: a flying spot digitizer for spark chamber film analysis.
International Conference on Programming for Flying Spot Devices, Munich, 18-20 January 1967. Proceedings (Powell B.W. and Seyboth P., (eds.), Max-Planck Institut, Munich (1967)) p.5.

REDMAN A.J., SPARROW J., WAGON D.J.
Software for the F.S.D. CYCLOPS in operation at the Rutherford High Energy Laboratory.
Ibid., p.12.

FERRAN M., GERARD J., MOORHEAD G., SAMBLES A., SEARLE J., BURREN J.
Progress with a minimum guidance program at CERN and RHEL.
Ibid., p.346.

SHAW K.B.
Neutron studies in shields and tunnels of the 7 GeV proton synchrotron Nimrod.
Conference on Radiation Measurements in Nuclear Power, Berkeley (U.K.) September 1966. Proceedings (Inst. of Phys. and Phys. Soc. Conf. Series No. 2 (1967)) p.201.

LAWSON J.D.
Beam measurements in the Harwell Variable Energy Cyclotron.
U.S. National Particle Accelerator Conference, Washington D.C., 1-3 March 1967. Proceedings (IEEE Trans. Nucl. Sci., **NS-14** (3) 635 (June 1967)).

BUBBLE CHAMBER GROUP
Status report on the RHEL 1·5 m × 70 kG hydrogen bubble chamber.
International Colloquium on Bubble Chambers, Heidelberg, April 1967. Proceedings (Leutz H. (ed.), CERN 67-26) Vol.I, p.147.

THOMAS D.B.
Optical distortion in bubble chambers arising from turbulent convective motions.
Ibid., p.215.

THOMAS D.B.
A proposal for a mammoth hydrogen bubble chamber for use with the 300 GeV European accelerator.
Ibid., p.191.

COUPLAND J.H.
Magnetic measurements of the Harwell Variable Energy Cyclotron.
Second International Conference on Magnet Technology, Oxford, 11-13 July, 1967. Proceedings (Hadley H. (ed.), Rutherford High Energy Laboratory (1967)) p.669.

MIDDLETON A.J., TROWBRIDGE C.W.
Mechanical stresses in large high field magnet coils.
Ibid., p.140.

MORRIS W.R.
An experimental analysis of 90° uniform field beam bending magnets.
Ibid., p.727.

SMITH P.F.
The superconducting magnet programme at the Rutherford Laboratory.
Ibid., p.543.

SMITH P.F.
Synchrotron power supplies using superconductive energy storage.
Ibid., p.589.

SMITH P.F.
Pulsed superconductive magnets for proton synchrotrons.
Ibid., p.594.

WILSON M.N.
The performance of stabilised conductors.
Ibid., p.482.

Unpublished Preprints

COSTA G., SHAW G.
Dispersion relations and consistency conditions.
RPP/A 29.

DELOFF A.
Lambda-nucleon scattering.
PAN/IBJ 848/VII/PL (Inst. of Nucl. Res., Warsaw), submitted to Nucl. Phys.

HENDRY A.W., SHAW G.
Form factors and vector meson nonets.
RPP/A 20.

LO S.Y.
The path approximation in strong interactions.
RPP/A 18.

LO S.Y.
Some statistical considerations of hadron spectroscopy.
RPP/A 23.

LO S.Y.
Current-field identity and universality.
RPP/A 32.

RUSSELL F.M.
Duration of the sensitive period of track recording in mica.
RPP/A 31.

RUSSELL F.M.
Rutherford scattering in muon tracks in mica.
RPP/A 34.

Reports and Memoranda

BUBBLE CHAMBER GROUP
Proceedings of the Study Week on Optics, and Beam Entry and Exit Problems for the High Field Bubble Chamber, 11-15 September 1967.
AP/DS/HFC/9.

BUBBLE CHAMBER GROUP
Design study for a high magnetic field hydrogen bubble chamber for use on Nimrod.
RHEL/S/101.

BURREN J.W., SEDMAN E.C.
Modifications to the RHEL geometrical reconstruction program.
RHEL/R 150.

DENNY P.A.
GRAPHPAD – Notes on the program in the IBM System/360 computer for graphics – on-plotter-and-display using the DDP-224 computer.
RHEL/M 127.

NOLAND T.
A user's guide to the "JUDGE" program.
RHEL/M 130.

RUSSELL F.M.
An heuristic examination of holes in cavities.
RHEL/M 121.

RUSSELL F.M. (ed.).
Proceedings of the Symposium on Separated Orbit Cyclotrons and Beam-Cavity Interactions, Oxford, July 1966.
RHEL/M 124.

SEDMAN E.C.
Job control language for the Rutherford Laboratory System/360.
RHEL/M 131.

SPARROW J.
The CYCLOPS on-line program for the $K_2^0 \to 2\pi^0$ experiment.
RHEL/M 133.

STEVENSON G.R.
A user guide to the ENDIM program.
RHEL/M 135.

STEVENSON G.R.
Neutron spectroscopy from 0·025 eV to 25 GeV.
RHEL/R 154.

WAGON D.J., BRYDEN A.D.
The general statistics program "JESTER".
RHEL/R 143.

Proton Linear Accelerator Division

Journal Articles

BAKER C.A., BATTY C.J., WILLIAMS L.E.
Calibration of Time-to-Amplitude converters.
Nucl. Instrum. Meth., **59** (1) 125 (February 1967).

BATTY C.J., GRIFFITH T.C., IMRIE D.C., LUSH G.J., ROBBINS L.A.
Measurement of the differential cross-section in proton – proton scattering at 49·41 MeV.
Nucl. Phys., **A98** (3) 489 (June 1967), preprinted as RPP/P 11.

BAUGH D.J., KENNY M.J., LOWE J., WATSON D.L., WOJCIECHOWSKI H.
The elastic and inelastic scattering of 30·4 MeV protons by Fe^{54}.
Nucl. Phys., **A99** (2) 203 (June 1967).

BURGE E.J., EDWARDS V.R.W., LEWIS V.E., GANGULY N.K.
The optimum design of student experiments on Rutherford scattering.
Amer. J. Phys., (in the press).

CALDERBANK M., BURGE E.J., LEWIS V.E., SMITH D.A., GANGULY N.K.
The elastic and inelastic scattering of 50 MeV protons by Zn^{64}, Zn^{66}, Zn^{68} and Zn^{70}.
Nucl. Phys., **A105** (2) 601 (December 1967).

CALDERBANK M., BURGE E.J., SMITH D.A.
New energy levels in Zn^{64}, Zn^{66}, Zn^{68}, and Zn^{70}.
Phys. Lett., **25B** (3) 201 (August 1967).

CHANT N.S., FISHER P.S., SCOTT D.K.
Asymmetries and differential cross-sections for the $C^{12}(p, d)C^{11}$ and $O^{16}(p, d)O^{15}$ reactions induced by polarized protons.
Nucl. Phys., **A99** (4) 669 (July 1967).

DAVIES B.W., CRADDOCK M.K., HANNA R.C., MOROZ Z.J., ROBERTSON L.P.
A measurement of the p-He^4 differential elastic scattering cross section at 49 MeV and phase shift analysis of p-He^4 scattering.
Nucl. Phys., **A97** (2) 241 (April 1967).

ELTON L.R.B.
A-dependence of nuclear charge and mass distributions.
Phys., Rev., **158** (4) 970 (June 1967).

ELTON L.R.B.
A note on re-arrangement energy.
Phys. Lett., **25B** (1) 60 (July 1967).

ELTON L.R.B.
Nuclear charge distributions (derived from sources other than electron scattering).
Landolt – Börnstein "Numerical data and functional relationships in science and technology (New Series)". Group I – Nuclear Physics and Technology. Vol. II "Nuclear Radii" (Schopper H. ed.) Springer, Berlin 1967.

ELTON L.R.B., JACKSON D.F.
Quasi-elastic scattering near zero recoil momentum.
Phys. Rev., **155** (4) 1070 (March 1967).

ELTON L.R.B., SWIFT A.
Single particle potentials and wavefunctions in the 1p and 2s-1d shells.
Nucl. Phys., **A94** (1) 52 (March 1967).

FANNON J.A., BURGE E.J., SMITH D.A., GANGULY N.K.
Elastic and inelastic scattering of 50 MeV protons by C^{12} and O^{16}.
Nucl. Phys., **A97** (2) 263 (April 1967).

FISHER P.S., SCOTT D.K.
A fast computing circuit for particle identification using signals from a $\Delta E, E$ counter telescope.
Nucl. Instrum. Meth., **49** (2) 301 (April 1967).

GANGULY N.K., RUSH A.A., BURGE E.J., SMITH D.A.
The $Mg^{24}(p,t)$ reaction at 50 MeV.
Z. Phys., **208** (1) 73 (January 1968).

GRUNBAUM L., GANGULY N.K.
The low-lying levels of O^{18}.
Nucl. Phys., **A100** (3) 645 (August 1967), preprinted as RPP/P 12.

GRUNBAUM L., GANGULY N.K.
Electromagnetic properties of low-lying states of Ca^{42}.
Z. Phys., **205** (4) 387 (September 1967).

HARBISON S.A., KINGSTON F.G., JOHNSTON A.R., McCLATCHIE E.A.
A search for excited states in He^3 by the $He^3(p,p')He^3$ reaction.
Nucl. Phys., **A108** (2) 478 (February 1968).

HARDY J.C., SKYRME D.J.
T = 3/2 analogue levels in mass 25 and 29.
Nucl. Phys., (in the press).

HARDY J.C., TOWNER I.S.
Determination of the signs of shell model matrix elements from two nucleon stripping data.
Phys. Lett., **25B** (10) 577 (November 1967).

JACKSON D.F.
Information obtainable from the non-coplanar (p, 2p) reaction.
Phys. Rev., **155** (4) 1065 (March 1967).

JACKSON D.F.
The investigation of two-hole states in light nuclei.
Nuovo Cim., **51B** (1) 49 (September 1967).

JAIN B.K., JACKSON D.F.
Spectroscopic factors for the (p, 2p) reaction.
Nucl. Phys., **A99** (1) 113 (June 1967).

JOHNSON R.C., SANTOS F.D.
The effects of the deuteron D-state and J-dependence in (d, p) and (p, d).
Phys. Rev. Lett., **19** (7) 364 (August 1967).

LEWIS V.E., BURGE E.J., RUSH A.A., SMITH D.A., GANGULY N.K.
Polarization and asymmetry in the elastic and inelastic scattering of 50 MeV protons by Mg^{24}, Zn^{64} and Zn^{68}.
Nucl. Phys., **A101** (3) 589 (September 1967).

RIMMER E.M., FISHER P.S.
Resonances in the (p, n) reaction on C^{12}.
Nucl. Phys., **A108** (3) 561 (February 1968).

RIMMER E.M., FISHER P.S.
Resonances in the (n, p) reaction on C^{12}.
Nucl. Phys., **A108** (3) 567 (February 1968).

RUSH A.A., BURGE E.J., LEWIS V.E., SMITH D.A., GANGULY N.K.
Elastic and inelastic scattering of 49·5 MeV protons by Mg^{24}.
Nucl. Phys., **A104** (2) 340 (November 1967).

SCOTT D.K., FISHER P.S., CHANT N.S.
Intermediate structure in N^{13}.
Nucl. Phys., **A99** (2) 177 (June 1967).

SKYRME D.J.
The passage of charged particles through silicon.
Nucl. Instrum. Meth., **57** (1) 61 (December 1967).

TSCHALÄR C.
Straggling distributions of large energy losses.
Nucl. Instrum. Meth., **61** (2) 141 (May 1968).

WROATH P.D.
Methods in astrophotography for the amateur.
J. Brit. Astron. Ass., **77** (6) 408 (June 1967).

Conference Papers

GANGULY N.K., RUSH A.A., BURGE E.J., SMITH D.A.
Reaction studies on Mg^{24}.
American Physical Society Meeting, Toronto, 21-23 June, 1967. Abstract in Bull. Amer. Phys. Soc., **12** (5) 664 (May 1967).

ELTON L.R.B.
A note on re-arrangement energy.
Conference on High Energy Physics and Nuclear Structure, Rehovoth, February 1967. Abstract in Proceedings (Alexander G. (ed.), North Holland (1967)) p.199.

ELTON L.R.B.
Nuclear charge densities and wavefunctions from electron scattering and μ - mesic X-rays.
International Conference on Electromagnetic Sizes of Nuclei, Ottawa, May 1967.

REEVE P.A., SWALES F.J., WROATH P.D.
A Hall-effect magnetic field probe system of high stability.
Second International Conference on Magnet Technology, Oxford, 11-13 July, 1967. Proceedings (Hadley H. (ed.), Rutherford High Energy Laboratory (1967)) p.693.

SWALES J.F., REEVE P.A.
Comparison of the predicted and achieved performance of a large spectrometer magnet.
Ibid., p.699.

JAIN B.K., JACKSON D.F.
Spectroscopic factors from the (p, 2p) reaction on light nuclei.
Symposium on Nuclear Forces, Few-Nucleon Problem and Light Nuclei, Brela, Yugoslavia, July 1967.

JACKSON D.F.
Information obtainable from nuclear reactions in the energy region 100-600 MeV.
American Physical Society Meeting, Seattle, 31 August-2 September 1967 (Invited paper – title only appears in Bull. Amer. Phys. Soc., **12** (6) 900 (August 1967)).

BURGE E.J., CALDERBANK M., RUSH A.A., THOMAS G.L.
The symmetry term in the proton optical model potential at 50 MeV.
International Conference on Nuclear Structure, Tokyo, September 1967.

CALDERBANK M., BURGE E.J., LEWIS V.E., SMITH D.A., GANGULY N.K.
Differential cross-sections (p, p), (p, p') of Zn^{64}, Zn^{66}, Zn^{68}, Zn^{70} for 49·08 MeV protons.
Ibid.

GANGULY N.K., RUSH A.A., BURGE E.J., SMITH D.A.
The reactions $Mg^{24}(p,t)$ and (p, d) at 49·6 MeV.
Ibid.

JACKSON D.F.
Proton hole states in light nuclei.
Ibid.

JOHNSON R.C., SANTOS F.D.
J - dependence in (p, d) reactions and the effects of the deuteron D - state.
Ibid.

BATTY C.J., BONNER B.E., TSCHALÄR C., WILLIAMS L.E.
Excitation of isobaric analogue states in (p, n) reactions at 30 and 50 MeV.
IPPS Conference on Nuclear Physics, Manchester, September 1967.

BATTY C.J., BONNER B.E., TSCHALÄR C., WILLIAMS L.E., CLOUGH A.S.
Excited states in Be^6 and Be^7.
Ibid.

CALDERBANK M., RUSH A.A., GANGULY N.K.
Coupled-channels analysis of elastic and inelastic scattering of 50 MeV protons.
Ibid.

CALDERBANK M., BURGE E.J., LEWIS V.E., SMITH D.A., GANGULY N.K.
Elastic and inelastic scattering of 50 MeV protons from Zinc nuclei.
Ibid.

CLOUGH A.S., BATTY C.J., BONNER B.E., TSCHALÄR C., WILLIAMS L.E.
Angular distribution for the d(p, n)2p reaction at 30 and 50 MeV.
Ibid.

DAVIES W.G., HARDY J.C., SKYRME D.J., MONTAGUE D.G., RAMAVATARAM K., HODGES T.A.
Pick-up reactions on "closed shell" nuclei in the (2s, 1d) shell.
Ibid.

GANGULY N.K., MONTAGUE D.G., RAMAVATARAM K., ZUCKER A., PLUMMER D.J.
The (p, t) and (p, d) reactions on the even isotopes of Samarium.
Ibid.

GANGULY N.K., RUSH A.A., BURGE E.J., SMITH D.A.
DWBA analysis of the Mg^{24} (p, d) and (p, t) reactions at 49·6 MeV.
Ibid.

GRUNBAUM L., GANGULY N.K.
Electromagnetic properties of the low-lying levels of Ca^{42}.
Ibid.

MANI G.S., DIX A.D.B.
Excited states in Li^6 and Li^7.
Ibid.

MANI G.S., DIX A.D.B., JONES D.T.
Elastic and inelastic scattering of 50 MeV polarized and unpolarized protons by light nuclei.
Ibid.

JACKSON D.F.
Nuclear physics at moderately high energies.
Ibid.

JOHNSON R.C., SANTOS F.D.
J-dependence in (p, d) reactions and the effects of the deuteron D-state.
Ibid.

THOMAS G.L., BURGE E.J.
Relative differences in differential cross-sections and polarizations for the elastic scattering of protons of energy up to 50 MeV from pairs of isotopes.
Ibid.

Reports and Memoranda

BATCHELOR K., DICKSON J.M., NORCLIFFE S.
Some calibration measurements on the PLA.
RHEL/R 110.

HERBST L.J.
An introduction to transistor circuit techniques.
RHEL/R 133.

JACKSON D.F., JAIN B.K.
A DWIA program for the (p, 2p) reaction.
S.R.C. Atlas Nuclear Physics Program Library Report No.4.

REEVE P.A.
The design of beam lines with high resolving power.
RHEL/R 149.

SWIFT A.
Phase shift analysis of high energy elastic electron scattering.
S.R.C. Atlas Nuclear Physics Program Library Report No.5.

TSCHALÄR C.
Energy loss distributions of heavy particles in thick absorbers.
RHEL/R 146.

TSCHALÄR C., BICHSEL H.
Multiple scattering correction to the average energy loss of heavy particles.
RHEL/R 153.

Doctoral Theses

CALDERBANK M. (University of London (King's College))
The elastic and inelastic scattering of 50 MeV protons from $Zn^{64, 66, 68, 70}$ using a wedge-shaped scintillation detector with a magnetic spectrometer.

HUNT J.B. (University of London (Queen Mary College))
Measurement of neutron spectra from (p, n) reactions.

McCLATCHIE E.A. (University of London (Westfield College))
A study of direct interactions in the nuclear surface.

PLUMMER D.J. (University of London (Queen Mary College))
Proton - Helium 4 interactions in the energy region 25 to 30 MeV.

SKYRME D.J. (University of Oxford)
Two-nucleon pick-up processes in proton-induced nuclear reactions.

SWIFT A. (University of London (Battersea College of Advanced Technology, now the University of Surrey))
Nuclear form factors from high energy electron scattering.

TOWNER I.S. (University of London (Battersea College of Advanced Technology, now the University of Surrey))
Radial wavefunction in p-shell nuclei and the (p, d) reaction.

Engineering Division

Conference Proceedings

HADLEY H. (ed.)
Second International Conference on Magnet Technology, Oxford, 11-13 July 1967, Proceedings (Rutherford High Energy Laboratory (1967)).

Conference Papers

COLYER B.
Cryogenic problems of superconducting magnet systems.
Second International Conference on Magnet Technology, Oxford, 11-13 July 1967. Proceedings (Hadley H. (ed.), Rutherford High Energy Laboratory (1967)) p.624.

FOX J.A.
Static power supplies for large pulsed magnets.
Ibid., p.373.

HEWITT A.G.
Field trimming coils for the Harwell Variable Energy Cyclotron: Practical problems involved.
Ibid., p.757.

HOPES R.B., FALLON G.R.
Technique developed to produce strip conductor for superconducting magnets.
Ibid., p.524.

MIDDLETON A.J., TROWBRIDGE C.W.
Mechanical stresses in large high field magnet coils.
Ibid., p.140.

MORGAN R.H.C., GRESHAM A.T., DAWSON J.M.
Extractor magnets for Nimrod.
Ibid., p.291.

PEEL T.D., ROAF D., SHAW D.F., TURNER W., WEEKS G.C., HADLEY H., SEAGER P.
Performance of the magnet for the Oxford-Rutherford Laboratory 80 cm helium bubble chamber.
Ibid., p.722.

SHELDON R., STAPLETON G.B.
Resin encapsulation of magnet coils.
Ibid., p.352.

Reports and Memoranda

FOX J.A.
A preliminary study of a static power supply for the CERN-PS Booster.
E/PS-DS/PSB/1.

FOX J.A.
A review of static power supply alternatives for the 300 GeV accelerator magnet system.
E/PS-DS/300 GeV/JAF-2.

FOX J.A., KENT P.
Frequency Variation of the United Kingdom Electricity Grid System during the 90 MVA cyclic pulse loading tests, 14-15 November 1967.
E/PS-DS/300 GeV/JAF-3.

MIDDLETON A.J.
Fatigue tests on pressurised membranes of polyethylene terephthalate.
RHEL/R 140.

MORGAN J.T., SHELDON R., STAPLETON G.B.
Stress relaxation and ageing of natural rubber by radiation.
RPP/E 9.

PICKLES D.C., COLYER B.
Heat transfer through low pressure helium gas at temperatures below 4·2°K.
RHEL/R 145.

Administration Division

TELLING F.M. (ed.)
The work of the Rutherford Laboratory in 1966.
RHEL/R 144.

LIBRARY
List of reports issued by the Rutherford High Energy Laboratory, 1960-66.
RHEL/M 118.

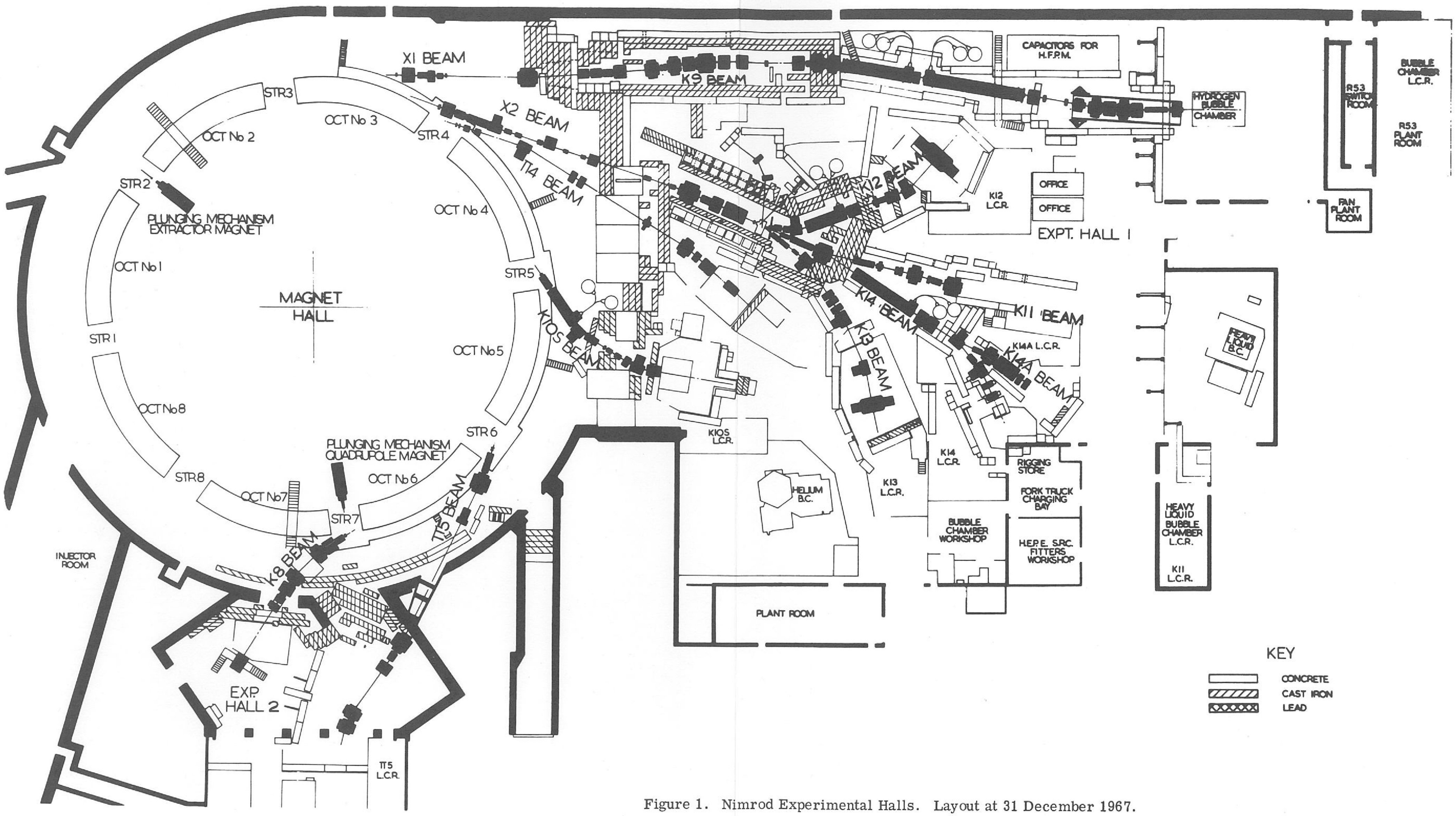


Figure 1. Nimrod Experimental Halls. Layout at 31 December 1967.