TRIUMF

ANNUAL REPORT
1975

MESON FACILITY OF:

UNIVERSITY OF ALBERTA
SIMON FRASER UNIVERSITY
UNIVERSITY OF VICTORIA
UNIVERSITY OF BRITISH COLUMBIA

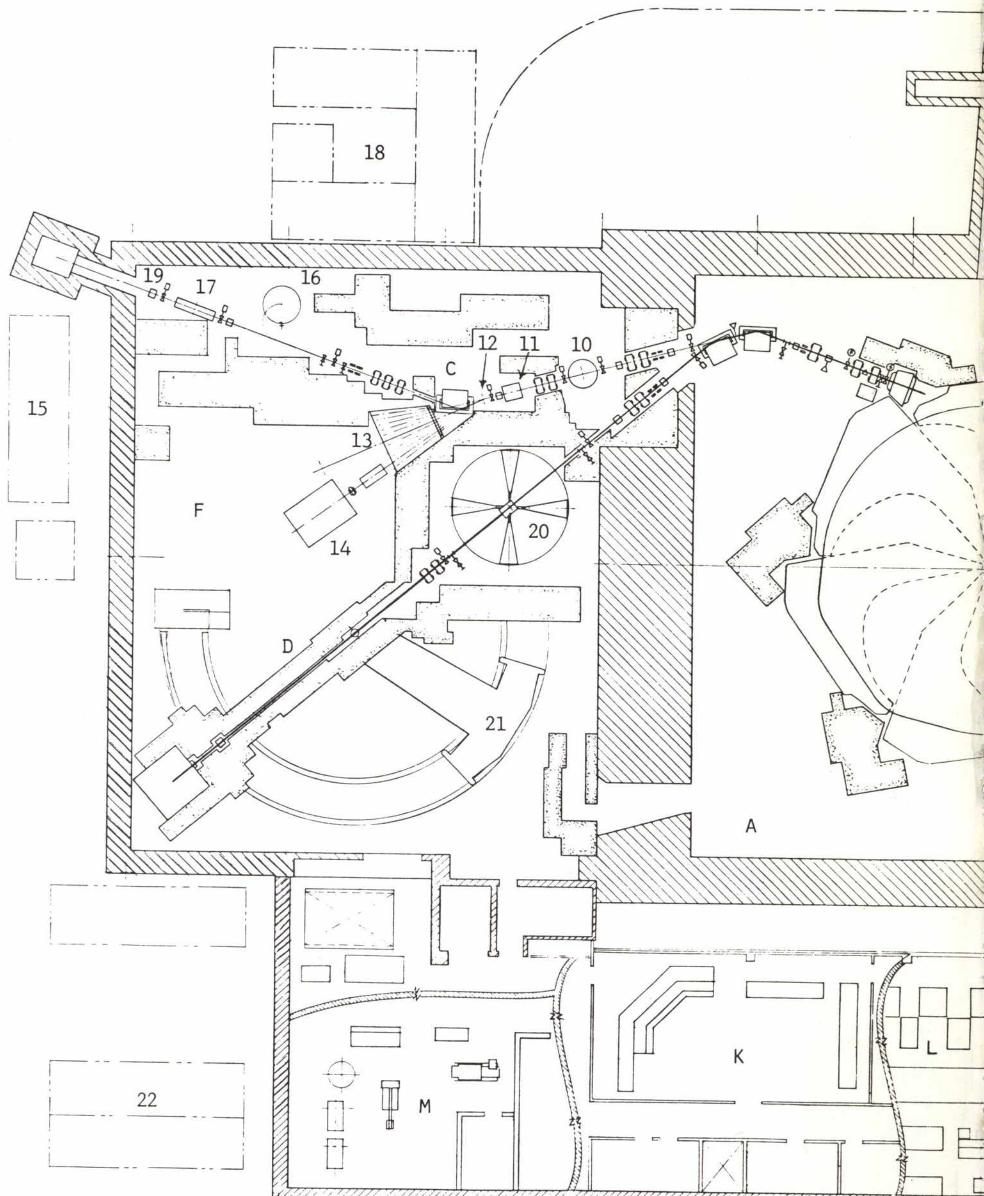
MAY 1976

TRIUMF

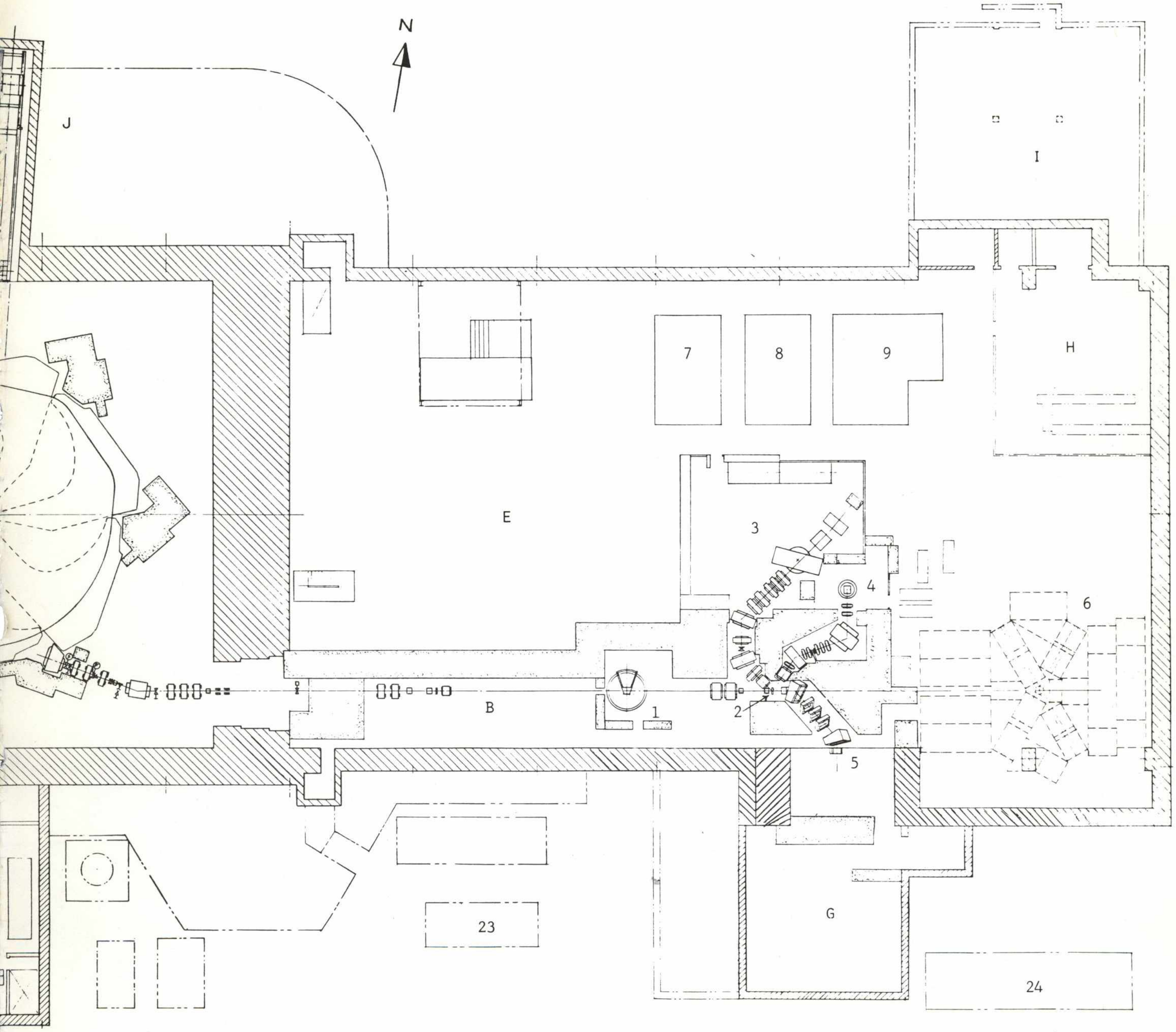
ANNUAL REPORT 1975

TRIUMF
UNIVERSITY OF BRITISH COLUMBIA
VANCOUVER, B.C. .
CANADA V6T 1W5

A Cyclotron vault
B Beam line 1
C Beam line 4A
D Beam line 4B
E Meson hall
F Proton hall
G Biomedical annex
H Remote handling laboratory and hot cell
I 'Chemistry' annex: design office and probes laboratory
J Cyclotron service bridge (retracted)
Service annex:
K Control room 289 ft level
L RF generator 276 ft level
M Cooling & electrical services 276 ft level



1 Pion spectrometer (Exp. 10)
2 Meson production target 1T2
3 Meson beam line M9 (Exps. 9,23,41,42,52,53,57)
4 Muon beam line M20 (Exps. 35,73)
5 Biomedical pion beam line M8 (Exps. 1,54,61)
6 Future location thermal neutron facility
7,8,9 Meson experimental local control rooms
10 60-in. (152-cm) scattering chamber (Exps. 3,6)
11 Superconducting solenoid (Exp. 40)
12 Liquid deuterium neutron production target (Exp. 40)



13 Neutron collimator (Exp. 40)
14 Neutron (proton) detector (Exp. 40)
15 Experiment 40 trailer
16 Moderator tank (Exp. 48)
17 Gas-jet system (Exp. 11)
18 Trailers for Experiments 3,6,11,48
19 Cs target assembly for ^{123}I production (Exp. 77)
20 Elastic and quasi-elastic proton scattering and pion production measurements (Exps. 12,14,15,16,24,58, 59,66,79)
21 Medium resolution proton spectrometer
22 Trailers for experiments on beam line 4B
23 Trailer for Experiments 1,10,54
24 Trailer for biomedical experiments

FOREWORD

A fully operating meson factory is much more than an extracted beam from an accelerator—even when the accelerator is the large, complex cyclotron of TRIUMF which reached its major milestone of a first extracted beam in late 1974. In addition one needs beam lines, targets, major experimental facilities, shielding, remote handling and still much more—above all a cyclotron whose efficiency and reliability allows high intensity beams to be extracted into a complete system of beam lines plus shielding and remote handling. In 1975 TRIUMF made many of the major steps toward becoming a fully operating meson factory.

Visitors during 1975 will have noticed the massive shielding enveloping the various beam lines and experiments. They may have detected the excitement about initial experiments or appreciated the satisfaction emanating from the achievement of many of TRIUMF's unique capabilities—such as variable energy and simultaneous beams. Perhaps less manifest was the steady progress in cyclotron performance after some initial teething problems with vacuum and RF systems. Overall, it was a year of very satisfactory achievement.

This report records, in some detail, much of the splendid effort of TRIUMF's Director, J.R. Richardson, and his team of scientists and engineers during 1975, and of the experimentalists embarking on the initial research program. The most important scientific rewards should lie just ahead.

Emil Vogt

E.W. Vogt
Chairman of the Board of Management

HISTORY

TRIUMF was established in 1968 as a laboratory operated and to be used jointly by the University of Alberta, Simon Fraser University, the University of Victoria and the University of British Columbia. The facility is also open to other Canadian as well as foreign users.

The experimental program is based on a cyclotron capable of accelerating two simultaneous beams of protons, individually variable in energy, from 180-520 MeV. The potential for high beam currents—100 μA at 500 MeV to 300 μA at 400 MeV—qualified this machine as a 'meson factory'.

Fields of research include basic science, such as medium-energy nuclear physics and chemistry, as well as applied research, such as nuclear fuel research and isotope research and production. There is also a biomedical research facility which will use mesons in cancer research and treatment.

The ground for the main facility, located on the UBC campus, was broken in 1970. Assembly of the cyclotron started in 1971. The machine produced its first full-energy beam in 1974.

The laboratory employs approximately 135 staff on the main site. The number of university scientists associated with the initial scientific program is about 100.

CONTENTS

INTRODUCTION

As reported last year, the first acceleration of H^- beam to the design energy of 500 MeV was accomplished on December 15, 1974. The first few months of 1975, therefore, were an exciting time as several of the remaining goals were realized quite quickly. After installation of the stripper foil mechanism in early January, a unique advantage of the TRIUMF cyclotron—the extraction of a variable energy proton beam—was demonstrated and beams of energies from 183 to 520 MeV were transported to the beam line 4B dump in the proton hall. In February, as soon as the beam line 1 components in the meson hall became operational, a second beam was extracted down this line from a fixed foil. Simultaneous extraction of beams of differing energies was then achieved, with a portion of the circulating beam extracted at several different energies along beam line 4 and the remaining beam extracted at a fixed energy along beam line 1. Subsequently, energy variation in both lines was achieved routinely.

The remainder of the year 1975 at TRIUMF has been devoted to three main objectives:

1) Investigating and improving the properties of the cyclotron beam in the energy range 180-525 MeV and the performance of the three external beam lines

2) Improving the reliability of the major components of the facility

3) Starting some research programs in intermediate-energy nuclear science

Because of lack of shielding, the proton beam intensities have been held down to 0.5 μA with 100% duty factor, although 50 μA at 1% duty factor has been accelerated as a test. This is to be compared with the design current for the proton beam of 100 μA. The energy resolution of the proton beams, FWHM, is less than 1 MeV in the energy range from 200 to 525 MeV. This will be improved further by improving the radial emittance of the cyclotron.

A polarized H^- beam of 250 nA intensity has been passed through the injection system of the cyclotron. In accordance with the previous experience with our unpolarized source, we will expect at least 20 nA of 80% polarized H^- ions to be accelerated to 500 MeV. Here also the energy will be variable from 180-525 MeV. (This milestone was actually achieved in March 1976.)

The following facilities are in operating condition:

1) Variable energy neutron beam from p + d (200-500 MeV)

2) Gas jet system for spectroscopy studies of short-lived spallation product nuclei

3) Scattering chamber for study of heavy fragments from fission and spallation reactions

4) Large scattering stand for study of light nucleus reaction products

5) Stopping π and μ channel

6) Special channel for studies with muon spin precession in chemistry and solid-state physics

7) Two large NaI crystals for study of rare processes involving the emission of high-energy gamma rays or electrons or neutral pions

8) Biomedical channel for development of radiotherapy with negative pions

Thus we see that during 1975 the main features of TRIUMF which make it a meson factory of outstanding flexibility have been proven. It remains now to complete the development and make use of these features.

During 1975 some 16 experiments were started (nine on beam line 1, four on beam line 4A and three on beam line 4B). However, because of the heavy emphasis on facility development and improvement of reliability, only two of these experiments were completed in 1975.

I would like to express the thanks of TRIUMF to several members of the TRIUMF Board of Management who left the Board during 1975 after a number of years of valuable service. They are Dr. J.T. Sample of the University of Alberta and Dr. H.W. Dosso and Dr. S.A. Jennings of the University of Victoria.

J. Reginald Richardson
Director

A. OPERATION AND DEVELOPMENT OF FACILITIES

During most of 1975 the available cyclotron beam time was divided between beam dynamics studies inside the cyclotron, commissioning the external beam lines, and delivering first beam to experimenters' targets. Formal scheduling of beam time started on April 9, in meetings of experiment representatives presided over by the Director.

The highlights of the operation of the facility are indicated in Fig. 1. More detail of the achievements will be found in the reports on beam development and on the beam lines and experimental facilities. Details of the problems encountered during the year will also be found in various group reports, notably the RF system which was responsible for most of the downtime throughout the year.

1. CYCLOTRON

Operation

The operation of the cyclotron during the commissioning period was on the basis of two 8-hour shifts per day, 14 shifts per week, with three operators and a safety officer on each shift assisted by one or more machine physicists. As many new systems were being brought into operation during this period and the working systems were continuously being improved, the assistance of many of the support groups was also required for successful machine operation. For this reason, round-the-clock operation was not possible until May when system reliability reached a level where the operators could handle most problems and support group intervention could be on an on-call basis.

The control system proved to be extremely flexible and was responsible for much of the improved machine performance and reliability. Initially, considerable downtime was caused by problems with the many magnet trim coil power supplies. The implementation of software to scan the many machine parameters, and indicate when faults occurred, eliminated most of the delays caused by this and similar problems. Considerable machine set-up time has been saved by the capability of storing the values of most of the machine parameters on request and re-establishing these values when required. This is especially useful for setting up the beam lines, as tapes of the required settings of beam line components exist for most of the desired energies. These tapes are updated as improved beam line tunes are found.

In May the machine operating cycle was changed to 24-hour operation starting on Tuesdays at 0700 and terminating on Saturdays at 1100. Maintenance is carried out by the support groups on Mondays. Beam time is presently scheduled in 12-hour shifts.

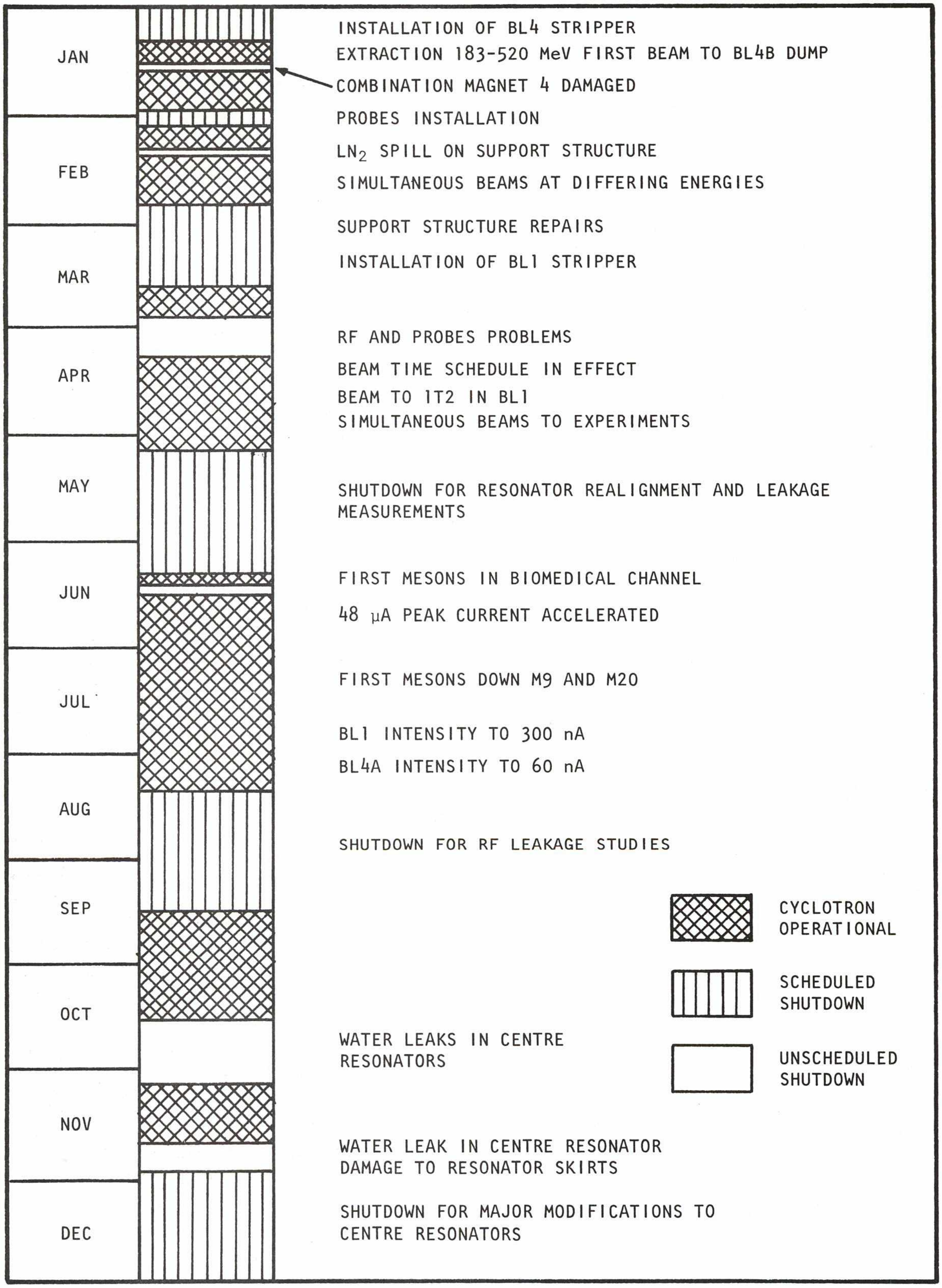


Fig. 1. Cyclotron performance 1975.

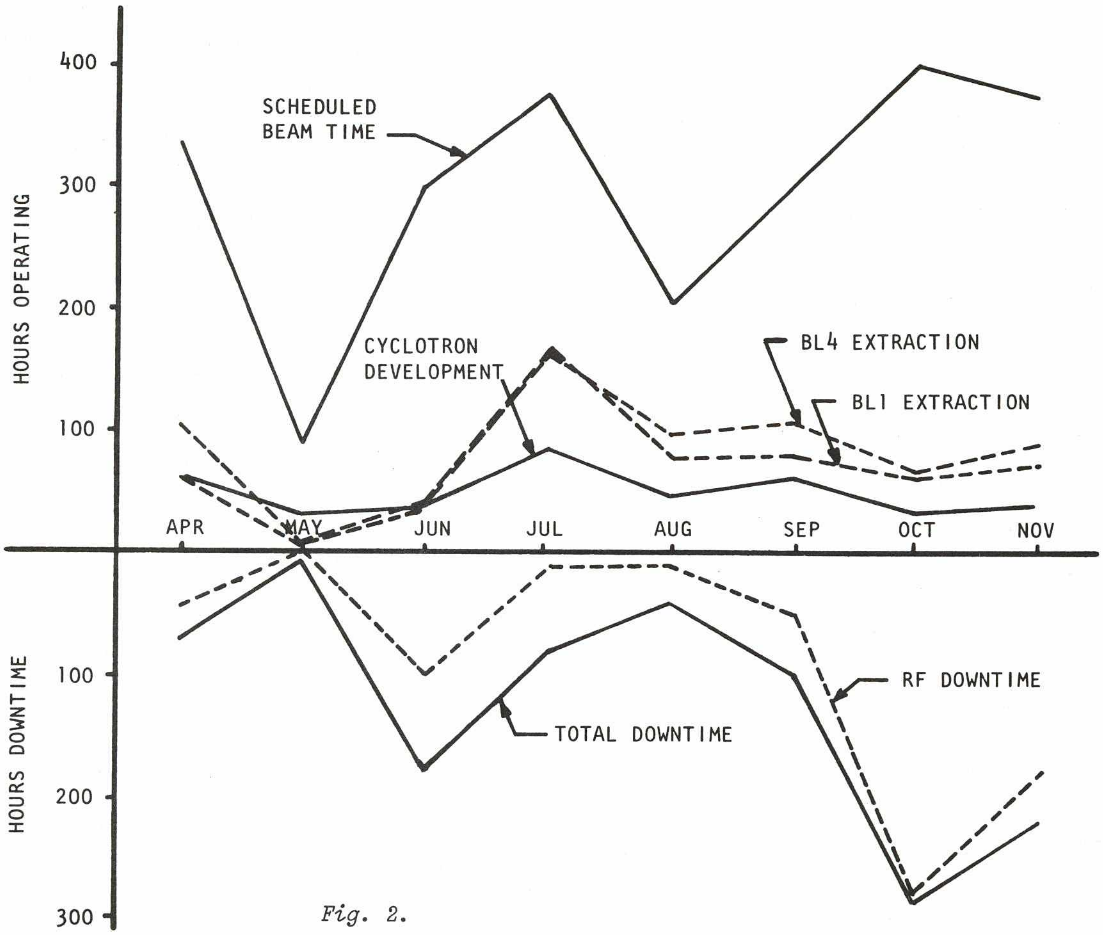


Fig. 2.

Performance

The performance of the cyclotron is summarized in Fig. 2 and Table I. In spite of the many problems encountered during the first year of operation, machine availability, as defined by the ratio of hours of cyclotron operation to scheduled operating time, is quite creditable. What was not as successful, from the experimentalists' viewpoint, was the number of hours delivering a beam on target which satisfied their particular requirements. Although there were long periods of very stable operation with good quality beams extracted along both beam lines, indicating the capability of the machine, there were also periods of unstable operation, or operation with beams of poor quality. The solutions to the problems of beam quality, ease of simultaneous extraction and beam intensity splitting (from the beam dynamics point of view) are well in hand. Indeed the understanding of the beam dynamics inside the cyclotron was one of the successes of operation during the year. The achievements are listed in Table II (p.8), and are described in detail in the section on beam development.

The proton beam intensity has been intentionally kept low during normal operation to minimize machine activation. Intensity limits have been set on the beam loss inside the cyclotron and on the spill along the beam lines as measured on spill monitors connected to the safety system. As the transmission through the cyclotron improved by better tuning and a better vacuum, the spill along the beam lines became the limiting factor in determining the beam intensity on target. However, increased effort by the Beam Development group in understanding the beam line transport and improvements in the extracted beam emittance have resulted in 300-nA operation along beam line 1 and 50-nA operation along beam line 4A with greatly reduced spills.

Early in 1976, the current along beam line 1 will be increased to 1 μA, the limit determined by the present beam line shielding. A task force on 100-μA operation is scheduling the necessary beam measurements and hardware improvements to achieve this goal, with 10 μA operation an intermediate objective for later in the year.

Table I. Summary of Machine Performance April-December 1975

Scheduled operating time (hours)		2368
Cyclotron	Start-up and shutdown	155
	Tune-up and development	392
Beam line 1	Extracted beam	578
Beam line 4	Extracted beam	676
Total hours of operation		1226
Downtime - System failures		987
RF system		306
Resonator water leaks		367
ISIS		130
Vacuum		62
Magnet		23
Diagnostics		17
Beam lines		36
Controls		28
Safety system		9
Services		9
Machine availability (average)		51.8%

Downtime

The problems of downtime or unstable operation due to hardware faults are still with us and will require considerable effort to solve in the coming year. The distribution of downtime by subsystem indicates that the major source of problems has been in the RF system, and in particular with the resonators inside the vacuum tank. As might be expected, the task of containing 1.4 MW of RF power in a large cavity is not trivial. Initially, problems showed up as burnt contacts between resonator sections, RF leakage outside the resonator cavity which damaged and restricted the use of the diagnostic probes, and unexplained frequency shifts of the resonators. Just when it appeared that some understanding of the problems was being gained, a series of water leaks occurred in the centre resonators due to RF damage. During conditioning after one of these water leaks was repaired, some melting of the resonator tip skirts occurred in the central region.

As most of the difficulties were associated with the centre resonators, it was decided to eliminate a possible source of the problems, the special root elements installed to improve the third harmonic quality factor. This removal may delay implementation of third harmonic operation but will, it is hoped, improve reliability at present for fundamental operation.

The ion source and injection system performed well. The major reason for downtime here was the filament power supply inside the ion source. The vacuum pressure inside the cyclotron is typically 5×10^{-8} Torr with the RF off and 1.5×10^{-7} Torr with the RF on. The major component of the residual gas with the RF on is hydrogen. An improvement in the speed of hydrogen pumping is planned using cryogenic pumping at 3.5°K.

Other sources of downtime were the many power supplies for the magnet trim and harmonic coils and the beam line components. As the settings of these power supplies stabilized, these delays have substantially reduced.

2. BEAM DEVELOPMENT

The first year of cyclotron operation has seen a considerable diversification in the activities of the group concerned with beam behaviour in the cyclotron, reflected in the change in title from 'Beam Dynamics' to 'Beam Development'. In the first place, beam behaviour can now be studied by experiment, as well as by calculation. [Here it is a pleasure to acknowledge the work of the Probes and Controls groups which has made possible the measurements described below.] Secondly, the group's members have provided the core of 'beam physicists' on duty during day and evening shifts, responsible for tuning up and maintaining the beam properties. Thirdly, as the beam lines have become commissioned, responsibility for beam studies and diagnostic equipment has devolved onto the group. In addition, individual members have assumed responsibility for the coordination of activities on the primary beam lines and for the newly set-up 100-μA and Separated Turn task forces.

In the twelve months since ions were first accelerated to 500 MeV, considerable progress has been made towards meeting the beam design specifications. Table II gives a description of the best beam performance achieved—though not yet always available on a regular basis—and a comparison with the original specifications.

Table II. Beam Performance

Property	Achieved		Design Aim	
	Initial	Best to 31/12/75	1972	1966
Energy range		183-520 MeV	165-500 MeV	200-500 MeV
Current	0.1 μA	0.3 μA 48 μA pulsed	100 μA (500 MeV) 300 μA (450 MeV)	100 μA (500 MeV) 350 μA (450 MeV)
Microscopic duty factor maximum minimum	11%	11% (5 nsec) 4% (chopped)	20% (3rd harm[c]) 1% (slits)	25%
Transmission (5 → 520 MeV)		70%	86%	80%
Split ratio (Line 4/Line 1)		$5 \pm 1 \times 10^{-4}$	$5 \pm 5 \times 10^{-4}$	
Isochronism (sin ϕ)	±0.9	±0.6	±0.1	
Vertical centring	±1 in. (25 mm)	±0.15 in. (4 mm)	±0.25 in. (7 mm)	
Energy spread (10% peak) restricted phase spread (10% peak)	3 MeV	2.0 MeV 1.5 MeV	<1.8 MeV 0.5 (slits) 0.1 (3rd harm[c])	1.5 MeV
Radial emittance external (90%)	20 π mm-mrad	5 π mm-mrad	3 π mm-mrad	2 π mm-mrad
Vertical emittance external (90%) internal	20 π mm-mrad	3 π mm-mrad 1 π mm-mrad	2.4 π mm-mrad 1.2 π mm-mrad	1.6 π mm-mrad
Beam spot size at 1T2	40 × 40 mm	3 × 14 mm	2 × 10 mm	

Transmission

Following successful acceleration of the first ions to 500 MeV in December 1974, the first task in the new year was to improve the beam transmission through the cyclotron. Under optimum conditions 8% of the dc beam from ISIS has now been accelerated to 500 MeV—the injection efficiency being 11% and the transmission through the cyclotron 70%. These figures are close to the theoretical maxima for the present RF voltage and residual vacuum, in the absence of third harmonic RF.

The beam loss at injection is entirely attributable to the 40° limitation to the phase acceptance. With a dee voltage of 85 kV, only those ions within ±45° of the RF voltage peak-phase gain enough energy to clear the centre post on their first turn, and only those within ±40° are expected to have good enough radial centring to remain in the beam. Furthermore, ions with negative (leading) phases suffer vertical defocusing on their first few crossings of the dee gap and are also lost. This process can be followed in Fig. 3, where the total current measured on probe LE1 at various radii has been plotted against injection phase for a beam restricted to 15° width by means of the ISIS chopper. This figure also illustrates the importance of the electrostatic vertical steering plates in retaining ions with phases close to zero over the central region; these ions are potentially the most valuable since they can yield the finest beam quality and energy resolution.

The transmission of beam through the cyclotron is illustrated in Figs. 4a (LE1 probe, 1-60 MeV) and Fig. 5 (HE1 probe, 80-500 MeV). It is clear that after selection of the phase acceptance on the first few turns, the beam continues to the full energy of 500 MeV with no significant localized losses. (The small irregular current variations in Fig. 4a are caused by part of the probe head being inoperative, and in Fig. 5 by variations in distribution of the beam across the probe fingers, which have different detection efficiencies.) Confirmation that there are no significant phase losses due to beam dynamic effects is provided by observations that the time spectrum of the external beam consists of 5-nsec pulses every RF period of 44 nsec—i.e. a microstructure duty factor of 11%, consistent with the 40° phase acceptance at injection.

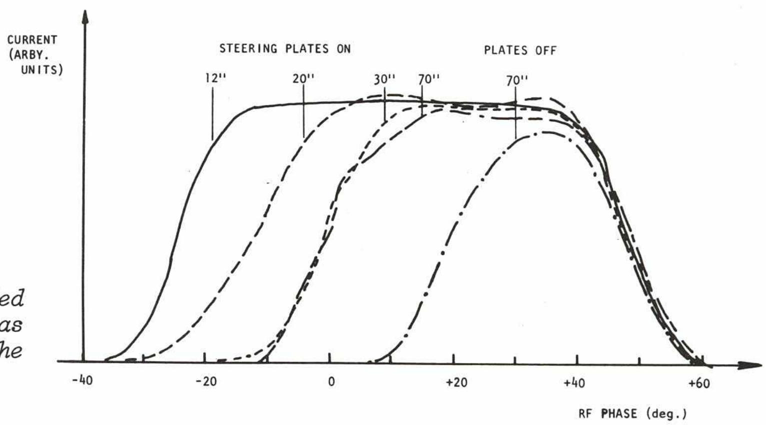


Fig. 3. Total current recorded on probe LE1 at various radii as a function of the RF phase of the chopped beam.

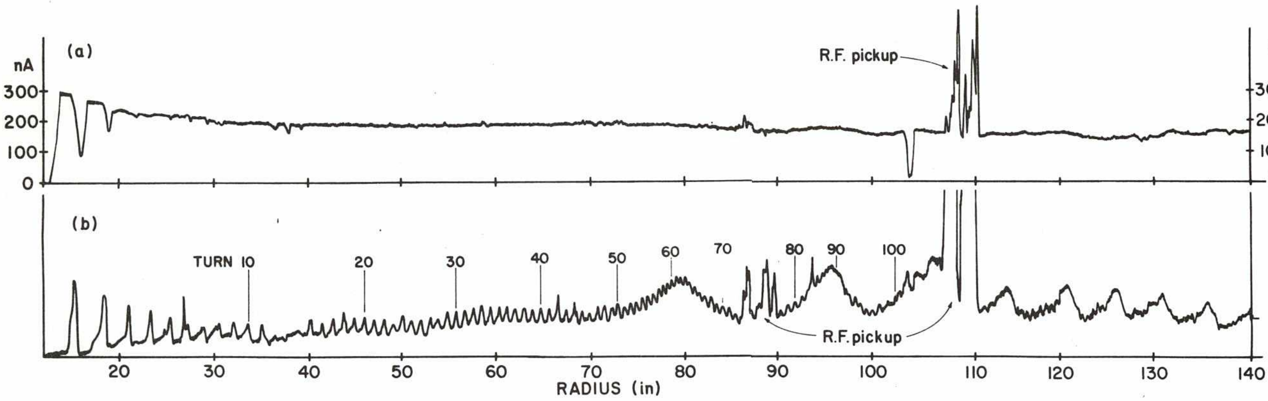


Fig. 4. (a) Total current on the 2.0-in.-wide × 2.2-in.-high probe LE1 as a function of radius; (b) current on the 0.2-in.-wide differential section of probe LE1, with the beam steered off centre to display radial precession patterns and turn structure at large radii. Both traces were taken with unrestricted phase acceptance.

Fig. 5 shows a gradual loss of beam with radius consistent with that expected for stripping of the H^- ions by the residual gas molecules in the vacuum tank (as shown by the smooth curve). Direct measurements of the loss of beam caused by the deliberate injection of hydrogen and air into the tank are shown in Fig. 6. The loss observed for air is in good agreement with that predicted from a relativistic extrapolation of B.T. Wright's formula[1] for the air stripping cross-section. For hydrogen, allowing for the reduced sensitivity of the ion gauge, the stripping cross-section appears to be a factor 4 or 5 smaller. For the present residual vacuum of 10^{-7} Torr of air and 2×10^{-7} Torr of hydrogen, the total loss of beam is about 20%; however, because most of the loss occurs at low energies the 'power-equivalent' loss of 500-MeV protons is only 4%.

H^- ions can also be torn apart by the oppositely directed forces experienced by the proton and two electrons as the ion orbits in the magnetic field of the cyclotron. The total loss due to this electromagnetic stripping is predicted to be 1% at 450 MeV, 7% at 500 MeV and 17% at 530 MeV. Measurements of beam transmission near 500 MeV are consistent with a loss

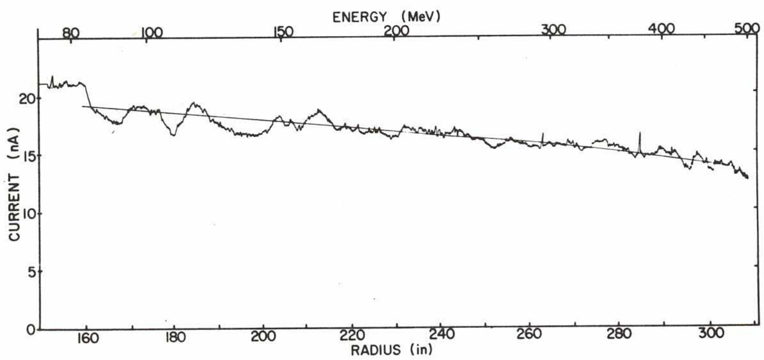


Fig. 5. Total current on probe HE1 as a function of radius. The smooth curve illustrates the theoretical fall-off due to gas stripping. No electric stripping is discernible.

[1]B.T. Wright, Arch. Math. Naturvidenskab 54(2), 9 (1957)

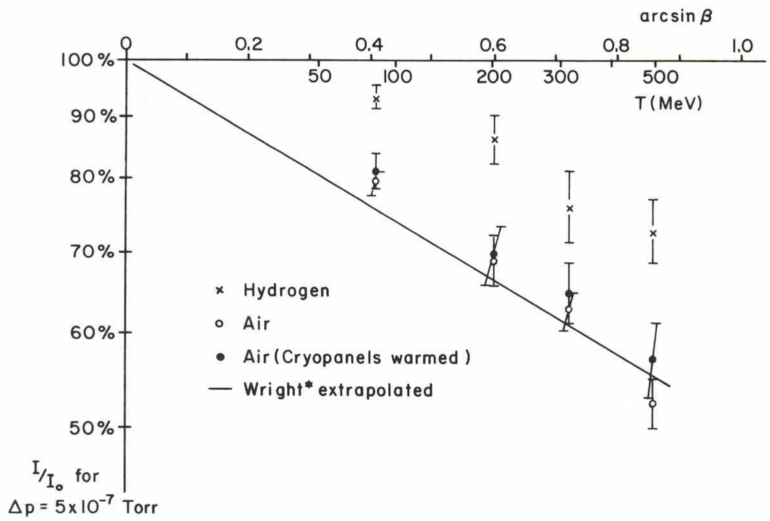


Fig. 6. Beam survival as a function of radius for pressure increase of 5×10⁻⁷ Torr. Note log scale of ordinate.

of this magnitude (Fig. 7); however, variations in probe efficiency of the same order of magnitude make it impossible to say that the effect has been identified unequivocally so far.

Intensity

In view of the installation work still to be completed in the vacuum tank it has been necessary to restrict the beam intensity in the cyclotron; with the present beam transmission of 70%, the limit set permits acceleration of 300 nA on average to 500 MeV. 300 nA beams have in fact been delivered to the pion production target 1T2 in beam line 1 for extended periods. Beam line 4A, with less shielding, has been limited to 50 nA. The independence of the two beams is such that it has been possible to raise their intensity ratio to 2000:1 without the fluctuations in the less intense beam exceeding 25%.

To investigate whether higher currents could cause beam dynamic problems, a beam of 48 μA was accelerated to 500 MeV during one 10-μsec pulse every

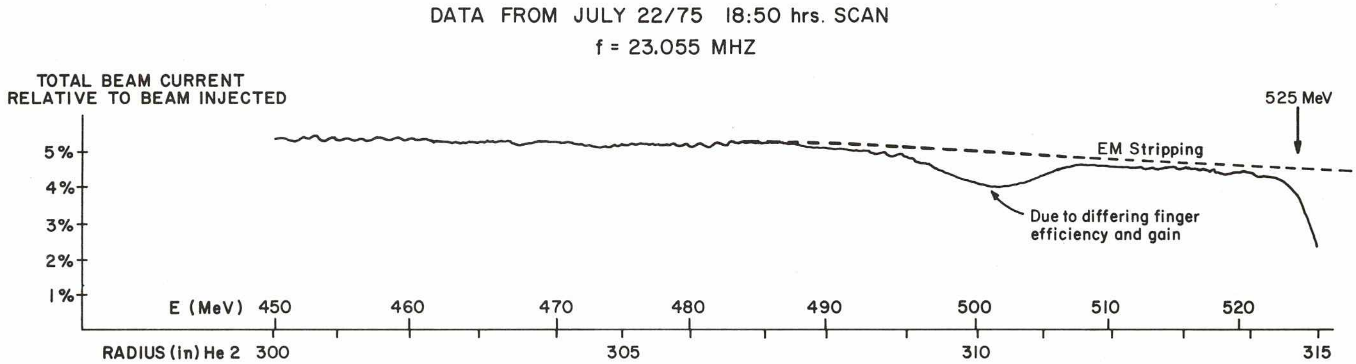


Fig. 7. Beam vs. radius at high energy. Predicted EM stripping normalized at 450 MeV.

millisecond. These pulses are long enough to fill 46 consecutive turns in the cyclotron and reveal any inter-turn effects on the beam. No change in behaviour was observed, as expected, since a beam of 100 μA (time average intensity—not pulsed) has previously been accelerated in the central region cyclotron through the region where any intensity effects should be most significant. Further work towards increasing the beam intensity is described in the report of the 100-μA task force.

Steering

The absence of transmission losses due to beam dynamic effects indicates that the beam is being steered at least within the transmission window defined by the 3-in. (7.6-cm) vertical gap between the upper and lower resonators and the 180°-wide accelerating half of the RF cycle. In order to obtain good beam quality and reduce the sensitivity of the tune to drifts or changes in field, finer steering is necessary to bring the beam as close as possible to the ideal orbit, centred radially, vertically and in phase. Good vertical centring has in practice also proved vital in extracting simultaneous beams at different energies; vertical excursions combined with extraction probe travel limitations can make it impossible to strip only part of the beam on an inner stripping foil (with the rest continuing on to an outer one), and can also complicate stripped beam trajectories. As will be described below, considerable success has been achieved in bringing the beam level close to the median plane, and a start has been made in reducing the radial and phase excursions.

Phase history

The phase history has been investigated by two methods. Over the range of extraction energies (183-520 MeV) the time of arrival of protons scattered from an external beam monitor (4VM2) can be measured relative to an RF signal. Correction must be made for differences in flight path at different energies, but these do not exceed one RF period (43 nsec). With a chopped beam the timing peak had a 2.5-nsec FWHM, making possible a time resolution of 0.25 nsec or 2° in phase. The ease of varying the extraction energy enables the phase history to be measured relatively quickly—a measurement at every 10 MeV from 183 to 520 MeV can be completed in just over an hour.

At energies below 183 MeV [R < 220 in. (559 cm)] the phase history $\phi(r)$ was also probed by means of the trim coils, using a special control mode in which any two or three coils could be run together, the ratio of their currents being chosen to give a localized phase change. Fig. 8 shows the changes in sin ϕ which were sufficient to remove 50% of the beam, as observed at 500 MeV, for various trim coil pairs and triplets. The phase history curve for the median phase should touch each of these curves at the radius of loss. The value of sin ϕ at the loss radius can also be inferred from the rate of beam loss with change in trim coil current (diamonds). Though this method offers far less precision than timing the external beam, the figure shows that it is capable of determining the broad outlines of the phase history; indeed there is good agreement

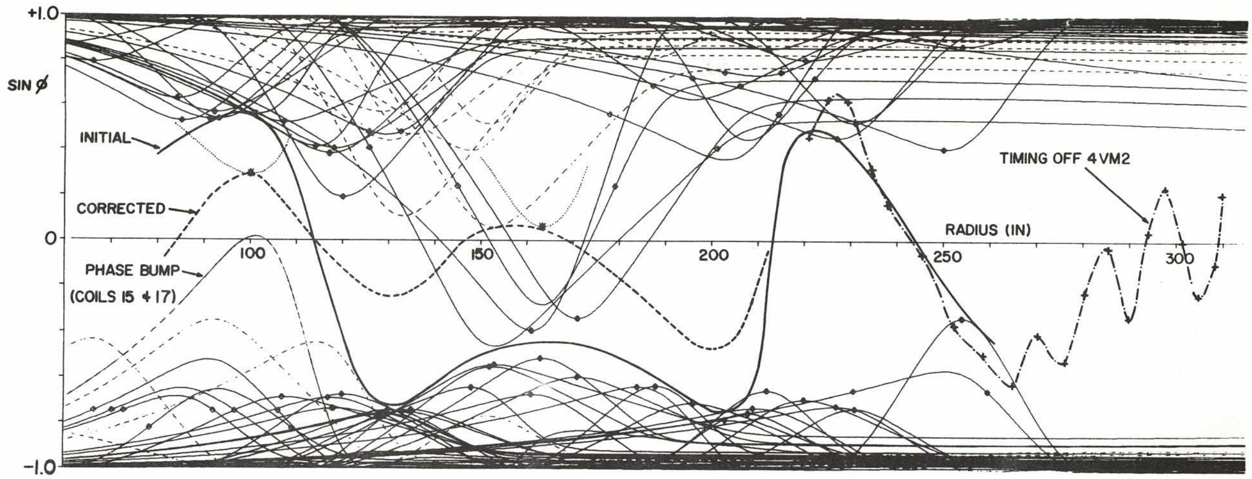


Fig. 8. Phase history sin ϕ as a function of radius (heavy curves). The light curves show the local changes in sin ϕ needed to remove 50% of the beam at 500 MeV.

between the two methods in the region of overlap from 220- to 260-in. (559- to 660-cm) radius. From 260 in. (660 cm) outwards, the oscillations in phase agree in position with those predicted from the magnetic field survey, although their amplitude is somewhat larger. The large oscillations at smaller radii may be attributed to installation of equipment including steel parts (e.g. probe drive motors) after the end of the field survey. The trim coil current changes needed to reduce the oscillations between 90 and 210 in. (229 and 533 cm) have been computed and implemented (dashed curve). Spot checks with two triplets (dotted curve) confirmed the improvement. The oscillation between 200 and 260 in. (508 and 660 cm) remains to be corrected.

Time of flight

The flight time of the ions between the ion source and an external target has been measured for a 480-MeV extracted beam. 10-μsec-long beam pulses 1 msec apart were produced by means of a square wave pulse generator. The signal produced in a scintillator by protons scattered from the target were compared on an oscilloscope with the trailing edge of the square wave, delayed by a known amount. The flight time in the cyclotron was found to be 310 μsec, indicating that 1430 turns were taken in reaching 480 MeV, and that the average value $\overline{V_{RF} \cos\phi} = 84$ kV. If the dee voltage V_{RF} is assumed to be 90 kV, as indicated by the most recent central region orbit measurements, and uniform with radius (see below), then $\overline{\cos\phi} = \cos 21°$.

In a separate experiment, the time of flight between the ion source and one of the high-energy probes was measured between 150 and 500 MeV. The time was found to increase linearly with energy, within 2 or 3 μsec, indicating that the dee voltage does not vary significantly along the dee gap. However, small oscillations were observed around linearity and these showed interesting correlations with the oscillations in phase illustrated in Fig. 8. It is hoped to improve the resolution and accuracy of measurement (at present 1-2 μsec) by an order of magnitude in order to explore the possibilities of using the method for tuning and measuring the phase history.

Vertical steering

Vertical displacements of the beam outside the central region are the results of vertical asymmetries in the magnetic field. A mean radial field component $\overline{B}_r$ will displace the equilibrium orbit of mean radius R vertically by

$$z = \frac{R\overline{B}_r}{\nu_z^2 \overline{B}_z},$$

where $\overline{B}_z$ is the average vertical component of the magnetic field and ν_z is the vertical tune (number of betatron oscillations per turn). Thus the TRIUMF cyclotron, which is designed with relatively large R and low $\overline{B}_z$ (to avoid electromagnetic stripping of the H^- ions) and also low ν_z^2, is particularly sensitive to B_r components. Because of the scalloping of the orbits, harmonic components of B_r and B_θ can also contribute to the vertical displacement, effectively altering $\overline{B}_r$. At the radius of greatest sensitivity to this effect, where ν_z^2 has its minimum value of 0.02, an effective $\overline{B}_r$ of only 0.3 G causes an excursion of 1 in. (2.5 cm). In spite of this sensitivity, it has been possible to reduce the vertical excursions to within ±0.15 in. (4 mm) everywhere from 65 to 520 MeV. Fig. 9 illustrates three successive stages in the adjustment of the 44 asymmetrically powered trim coils. These results were achieved with the aid of an interactive computer code which predicts the adjustments in current needed to correct the beam level; the mean beam level is itself computed on-line from the currents on the five fingers of the HE probe. Beam level measurements have also provided the clearest evidence yet of the stability level of the undisturbed magnetic field: over a

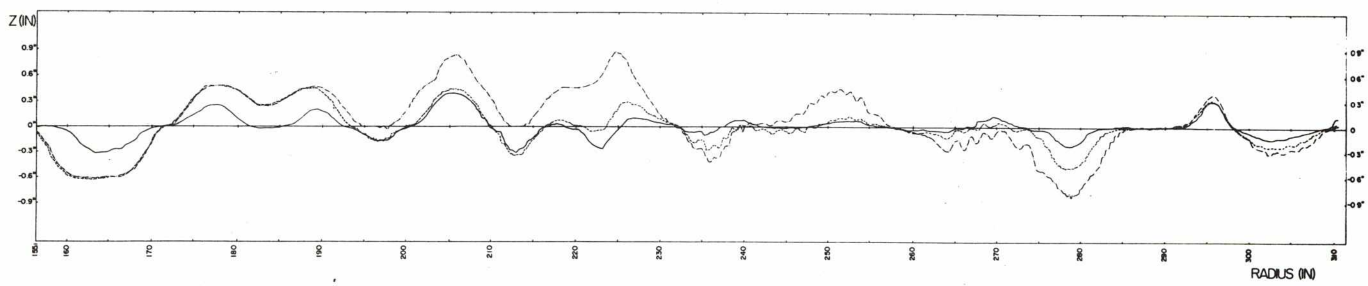


Fig. 9. Mean vertical displacement of the beam from the median plane between 150 in. (381 cm - 70 MeV) and 310 in. (787 cm - 500 MeV) radius for three successive stages of computer tuning the 44 asymmetrically powered trim coils.

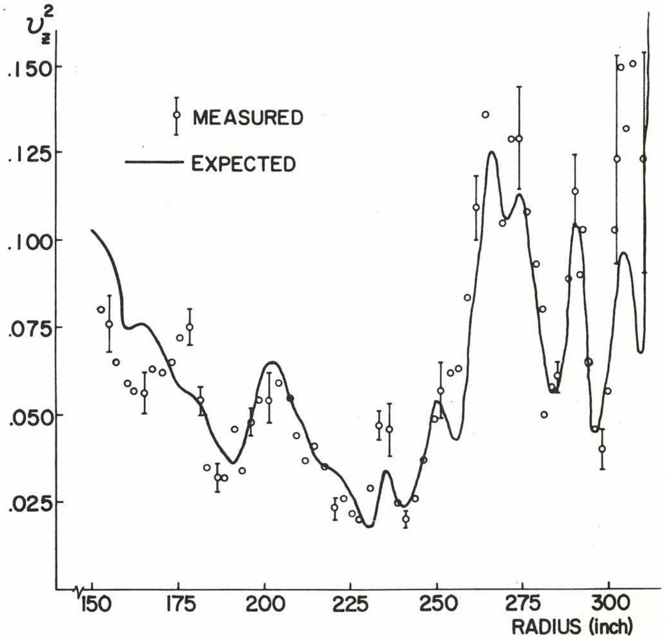


Fig. 10. ν_z^2 *as a function of radius. The points were obtained from measurements with the beam, the curve from calculations based on a magnetic field survey.*

period of three weeks running without the upper magnet being raised, the beam level was observed to be reproducible to within ±0.1 in. (2.5 mm).

The equation above suggests a direct method of measuring the axial tune ν_z by observing the change in mean height of the beam for a given change in $\overline{B}_r$, obtained by adjusting the trim coil currents. In practice, the currents were adjusted in a group of neighbouring coils so as to give a uniform change in $\overline{B}_r$ over a range of radii. The observed change in mean height at the probe azimuth was corrected for the sector-modulation of the envelope, to give the true change in the azimuthally averaged height. Fig. 10 illustrates the results of the measurement, compared with a curve derived from orbit calculations based on the magnetic field survey. The agreement appears to be reasonably good. The accuracy of the measurements was chiefly limited by the requirement that no beam should be driven off the probe head; as a result the permissible displacements were only of the order of the finger width, and sometimes smaller.

Radial steering

The radial centring of the beam at high energies is an essential factor in determining the precise energy of a beam extracted from a particular radius. The radial deviations from the ideal centred orbit are a consequence of the imperfection (non 6-fold) harmonics of the magnetic field. The radial centring was investigated experimentally above 70 MeV by means of shadow measurements of the beam radii on the two HE probes, 180° apart. The difference between these two radii exhibited radial variations of ±0.3 in. (8 mm) amplitude, in reasonable agreement [<0.05 in. (1.3 mm)] with the variations predicted from the odd harmonics of the magnetic field.

In order to check the energy calibration of an extracted beam, the Experiment 10 group determined the energy of an extracted beam to be 348.3 ± 1.7 MeV by momentum analysis of pions from the ($pp \rightarrow d\pi$) reaction. The energy expected from the stripping foil location, corrected for errors in radial centring, was 348.6 ± 0.8 MeV.

Radial beam quality

The energy resolution and radial emittance of the external beams are determined by the radial quality of the internal beam. This depends on a number of factors, firstly beam emittance at the ion source, secondly steering and emittance-matching at injection, thirdly radial-longitudinal coupling, and finally resonances between the beam and magnetic field imperfections, principally the first harmonic imperfection. The emittance of the collimated beam leaving the ion source at 12 keV is 30 π mm-mrad, corresponding to 0.13 π mm-mrad at 500 MeV, or an incoherent radial betatron amplitude A_r = 0.03 in. (0.8 mm).

At injection the beam must be steered into the cyclotron with the correct direction, radius and energy. If it is not, the ions will develop oscillations about the ideal orbit which are coherent for individual phases, but which effectively increase the incoherent amplitude of the whole beam. The resulting radial precession patterns are illustrated in Fig. 4b where the beam was deliberately steered off-centre to enable the radial betatron oscillation frequency ν_r to be estimated from the number of turns between peaks $\left(= (\nu_r-1)^{-1}\right)$.

To determine the quality of centring immediately after injection requires measurements at several azimuths. Unfortunately damage by RF currents has severely curtailed use of the low-energy (LE) probes and completely prevented operation of the centring probes. Consequently our experimental knowledge of the beam behaviour from injection to 70 MeV is very limited. On one occasion, however, observations were made on the first few turns using both LE probes, 180° apart. The orbit centres appeared to be displaced 0.4 in. (10 mm) southwards, while the average radii were larger than expected, indicating too high an injection energy. The energy was lowered by 10 keV, resulting in the radial emittance of the external beam being halved, the energy resolution improved, and the tune of the magnetic field becoming less sensitive. In the absence of further direct measurements on the central orbits, the initial steering and focusing provided by ISIS and the inflector and deflector have been adjusted empirically to optimize the overall transmission and the beam energy resolution after extraction.

On the final two factors affecting radial beam quality, (radial-longitudinal (r-ϕ) coupling and imperfection harmonics in the magnetic field), no direct measurements from the orbits are available. The effect of coupling between the radial and phase motions over the initial orbits is to increase the effective oscillation amplitude A_r, but this increase can be minimized by a suitable choice of phase history. A first harmonic component of magnetic field produces a resonance near the centre, where ν_r = 1, and drives the orbits off-centre, again increasing the effective A_r. In the absence of orbit measurements, the phase history and first harmonic near the centre have been adjusted empirically by means of the circular and harmonic trim coils to optimize the transmission and energy resolution.

The amplitude A_r of the radial betatron oscillations can be estimated from measurements of the width of the shadow cast by one HE probe on the other, diametrically opposite. Such measurements have been made at 80-MeV [160-in. (406-cm) radius], a sufficiently large radius that the chief factors responsible for worsening the radial beam quality, as described above, should have completed their work. At higher energies, as ν_r deviates from unity and the radius gain per turn falls relative to A_r, the measurement becomes less sensitive and more difficult to interpret. The shadow width found at 80 MeV indicated $A_r = 0.25 \pm 0.05$ in. (7 mm ± 1.3 mm). Such an oscillation amplitude would be expected to yield a 500-MeV external beam with radial emittance 6 ± 1 π mm-mrad (twice the design aim) and total energy spread 1.6 ± 0.2 MeV.

Energy resolution

The energy spread of the external beam has been obtained from measurement of the beam profile at a dispersed focus on beam line 4B. Since this method depends on separating the contribution of energy spread and emittance to the profile width, an experimental technique has been developed to check the beam line transfer matrix elements. This uses a combination of stripper foil movement with harmonic and trim coil changes to alter any one of the energy, position and direction of the extracted beam independently of the others. By this means, the dispersed focus in beam line 4B has been checked at 400 MeV, and the magnification and dispersion found to be 0.86 ± 0.16 and -11.0 ± 1.5 cm/% $\Delta p/p$, respectively, compared to calculated values of 0.75 and -12.6 cm/% $\Delta p/p$.

Fig. 11 shows the horizontal profiles measured at three energies about 1 MeV apart near 500 MeV, using a gas-filled multi-wire proportional chamber. The wire spacing was 2 mm, so that the dispersion amounted to about 0.2 MeV/wire. The full curves, taken with the unrestricted phase acceptance at 40°, show a FWHM of 0.9 MeV and a width at 10% of the peak height of 2 ± 0.2 MeV, after correction for the finite image size. The dashed profile (normalized to the same

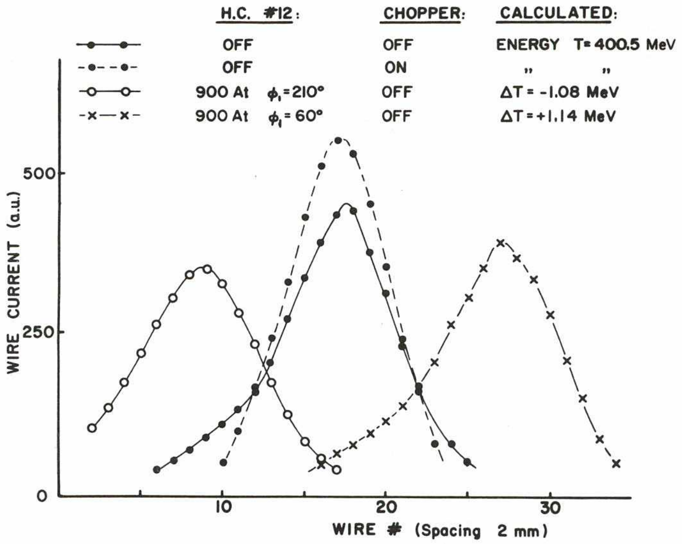


Fig. 11. Beam profiles at a momentum dispersed focus.

area) was measured for a chopped beam of 15° phase width; the FWHM is little changed but the width at 10% peak height is reduced to 1.5 ± 0.2 MeV.

External beam emittance

The emittance of the external beam has been estimated using three methods. In the first, the beam width is measured at a waist and at the exit of the preceding quadrupole. In the second method, beam profiles are measured at three locations separated by drift spaces; the emittance is taken to be the largest ellipse in phase space consistent with these profiles. In the third method, profiles are measured downstream of a quadrupole for a number of different quadrupole current levels. Theoretically the beam width should vary hyperbolically with quadrupole strength for an elliptical emittance; a least-squares fit to the data gives the shape and area of the emittance. For optimum results, the line upstream is tuned to bring the beam close to a waist at the entrance to the quadrupole used.

The radial emittance for 90% of the beam, immediately downstream of the stripping foil, was found to be 5 ± 2 π mm-mrad. This is consistent with the measurement of radial oscillation amplitude at 80 MeV, and indicates that the radial beam quality is not significantly worsened by resonances at higher energies in the cyclotron.

The vertical emittance for 90% of the external beam immediately downstream of the stripping foil was found to be 3 ± 1 π mm-mrad. After passing through the 4VM1 monitor [0.005-in. (0.13 mm) Al] the emittance increased to 6 ± 2 π mm-mrad, in good agreement with the expected effect of multiple Coulomb scattering. The aluminum stripping foil is itself expected to have contributed 2 π mm-mrad to the external beam emittance, which is thus consistent with the internal beam value of 0.9 π mm-mrad, obtained from measurements of the vertical beam width on the HE probe.

The internal beam vertical emittance is thus seven times larger than that of the beam leaving the ion source. The HE probe measurements indicate that the emittance rises from 0.45 π mm-mrad to 0.9 π mm-mrad between 180- and 210-in. (457- and 533-cm) radius. A possible explanation for this doubling may lie in the $\nu_r - \nu_z = 1$ resonance, which is crossed at 194 and 212 in. (493 and 538 cm).

Tasks remaining

The outstanding problem remaining in meeting the beam design specifications is the tuning of the low-energy region (up to 60 MeV) where the beam quality is chiefly determined. When more extensive measurements can be made on the beam in this region, it will become possible to reduce the radial emittance by fine control of the central orbits and careful compensation of the first harmonic component of the magnetic field. A reduced radial emittance will not only lead to reduced spot sizes for the external beams—a particularly important factor in meeting the intensity specifications for the pion and muon beams—but should also bring the energy spread down to the design aim of ±0.6 MeV. It will also become possible to set up the internal slits to select a beam of better quality. In addition it should become possible to identify and remove the cause of a loss of beam, which occurs somewhere in the inner region and reduces the optimum observed transmission of 8% between ISIS and 500 MeV to a more usual 5%.

3. BEAM LINE DEVELOPMENT

Detailed descriptions of the proton beam lines have been given in the two previous annual reports. The layout is reproduced in the frontispiece. In December 1974 beam had been run only in the vault section of beam line 4; by February 1975 it had been delivered along lines 4A and 4B to serve five experimental areas, and it was brought along beam line 1 to serve four more experimental areas by July. This was achieved with a great deal of assistance from experimenters from many groups. During the rest of the year, effort has been expended in improving the reliability of components and the general level of engineering on the lines, and in improving the beam quality and in reducing spill to enable larger beam currents to be run.

In the last eight months the beam lines caused 36 h of downtime, compared with about 1000 h of extracted beam time; the total scheduled operating time was 2368 h. The maximum current delivered to the meson production target, 1T2 on beam line 1, on a regular basis was about 300 nA. During operation, the radiation levels in the experimental shacks on the meson floor were less than 0.25 mR/h and the maximum radiation level inside the tunnel close to the beam line shortly after shutdown was 20 mR/h, the average along the line being 6 mR/h. These levels provide an acceptable working environment for the work still to be done on the lines and should permit operation at 1 μA, the limit of our present licence, during the coming year.

The spill levels have been reduced by improving the steering in the beam lines, plus improving the beam emittance emerging from the cyclotron and maintaining it during transmission down the lines. The cyclotron emittance was initially two or three times larger than the value adopted for beam line design; the emittance is now within the design limits, but not as good as had been hoped at this stage of development. As noted above, at 400 MeV the vertical emittance inside the cyclotron has been measured as 1 π mm-mrad. Multiple scattering in the 0.001-in. (0.025-mm) aluminum stripping foil is calculated to increase this to 2 π mm-mrad for 90% of the beam, and a value of (3 ± 1) π mm-mrad has been measured in the beam line. Fig. 12 shows the calculated effect on the vertical emittance (for 90% of the beam) of scattering introduced by the foil; it is planned to use lighter foils in the near future. Fig. 13 shows a comparison of the expected and measured vertical emittance in the vault section of line 4B. The horizontal emittance after the extraction foil

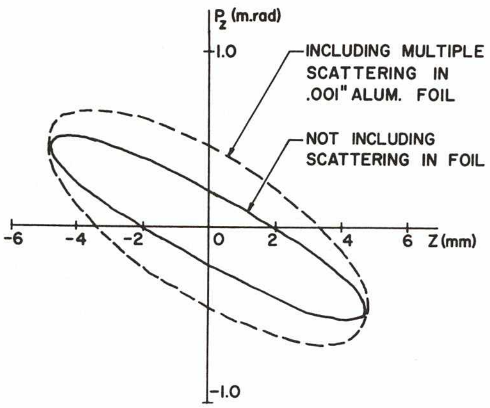


Fig. 12. Calculated vertical emittance of extracted beam at the stripping foil for 90% of the beam showing the effect of multiple scattering.

is about 5 π mm-mrad and the energy spread has been measured as ±1 MeV for 90% of the beam.

The emittances in the lines were further worsened by more than a factor of two due to multiple scattering in 0.001-in. (0.025-mm) havar vacuum foils or windows. Some of these were installed in the urgency to get the first beam to experimental targets, in order to separate regions of good (10^{-6} Torr) vacuum from regions of poor vacuum; others are necessary to protect the cyclotron from possible rupture of gas or liquid targets. It was not always possible to put these windows at double waists in the beam envelope, and it is estimated that one window in beam line 1 caused 2% of the beam to strike the beam pipe downstream. The combination of initially poor emittance and windows required running beam line 1 in two different modes, one to deliver high current to 1T2 with little spill, and a second to produce a small waist at the (p,π) experiment, rather than

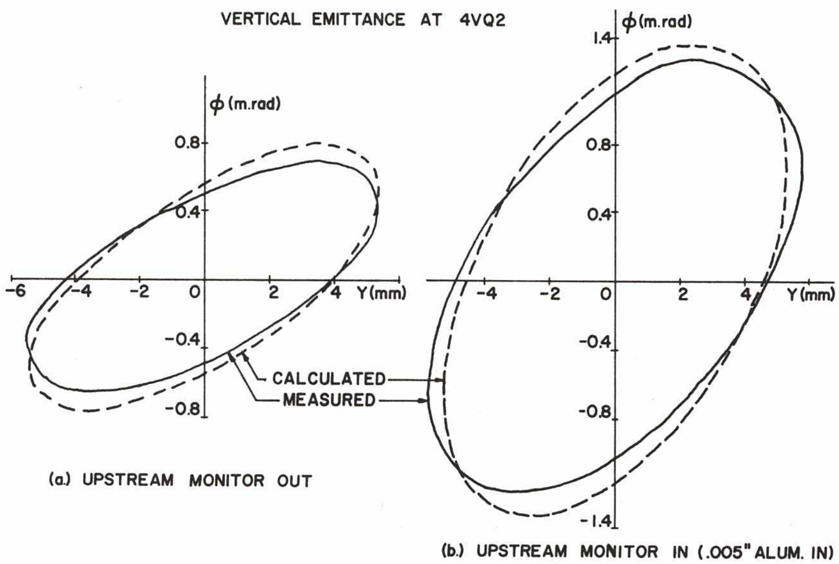


Fig. 13. Vertical emittance measured at the entrance to quadrupole 4VQ2 with and without a monitor inserted upstream.

running it in the original universal mode. A program is being implemented to improve the vacuum and remove some windows, to reduce the thickness of others, and to insert thick windows only when needed for machine protection in the case of certain experiments.

With the present extraction foils, the smallest fraction of the cyclotron beam that can be delivered in a stable fashion to a given area is 1/2000. At this level, the fluctuations in real beam current, measured by counting scattering protons over one-second intervals, were about ±25% after discounting statistical variations. This corresponds to a relative stability of cyclotron beam height vs extraction foil height of a few thousandths of an inch.

Initially it was difficult to extract certain energies; radial and azimuthal variations in the height of the beam 'plane' at the corresponding radii did not permit the extracted beam to be centred in the geometric mid-plane at the foil position, without the loss of some of the circulating beam elsewhere on the resonators or other obstructions. This was especially true in cases where the foil was dipped into the beam from above to provide partial extraction. This situation has been alleviated by cyclotron tuning, which reduced the size of the beam plane excursions and reduced the vertical width of the beam, by including a choice of smaller foils in the stripping foil cartridge, and by asymmetrically exciting the first quadrupole, by up to 5%, to provide vertical steering at the entrance to the beam line.

The vertical component of the cyclotron fringe field, which is of the order of 100 G, affects the horizontal steering in the vault section of the beam line. If the stripping foil and combination magnet are adjusted to centre the beam at one particular location, it may be displaced by 1-2 cm elsewhere; the quadrupoles then steer the beam and at lower energies the edge of the beam comes to within 1 cm of the beam pipe. This makes set-up tedious, and efforts are under way to shield and/or compensate for this fringe field.

A fast valve system has been installed that is triggered by a spark plug firing when the local pressure rises above 100 μ; the valve closes in 17 msec and protects the cyclotron from ruptures further away than 6 m.

The beam line diagnostic system consists of ZnS and Al_2O_3 scintillating screens, secondary emission centroid monitors, and gas-filled multi-wire ion chambers for profile monitoring. The individual wire currents in the ion chambers are integrated for a time variable from 1 to 500 msec, and the resulting voltages transmitted sequentially to the control room. There they can be displayed in analog fashion, or converted to digital form for computer processing. This system has worked well, giving useful signals for beam currents as low as 1 nA. The gas-filled chamber signals begin to saturate at beam currents above 100 nA; multi-wire secondary emission devices have been tested at currents above this level, and should be adequate for the next stage of development to currents of a few microamperes. At the moment all monitors intercept the beam.

The Controls group have assisted the beam line commissioning by providing convenient multiplexing of monitor signals, together with computer analysis of the signals to display position and width of the beam. The beam line focusing and steering elements are controlled from two sub-consoles, one for each line. Because of scattering-induced spill from the gas-filled monitors, the beam lines are usually tuned with currents of about 5 nA; the monitors are then withdrawn and, if necessary, minor corrections are made at higher currents while observing spill monitors. The multi-wire secondary emission devices to be used in future at higher currents will produce less spill and simplify the procedure. A beam of an energy that has previously been well tuned can presently be re-established in about 30 min. Sources of irreproducibility of beam element settings are being investigated, as an aid in speeding up this process.

4. 100-μA TASK FORCE

In June a task force was set up to plan, oversee and implement the achievement of the design goal of 100 μA of protons in the cyclotron and beam line 1. The goal for beam line 4A is 10 μA. The task force includes representatives from ISIS, Beam Development, Beam Lines, Beam Diagnostics, Vacuum, RF, Remote Handling, Safety, Controls and Users groups. The approach toward 100 μA will be a step-by-step one in two main phases. During phase 1 the residual activation in the cyclotron vacuum tank and along most of beam line 1 will be kept at a level which will allow major modifications or improvements to be made without the need for sophisticated remote-handling equipment. The current will gradually be raised, while the beam spills in the cyclotron or along the beam line will be reduced or localized and taken care of by adequate shielding structures. It is expected that the beam level corresponding to this situation will be somewhere between 2 μA and 10 μA.

Phase 2 will start when the resonators, the probes and the vacuum systems inside the vacuum tank operate reliably and when all improvements planned for these systems and beam line 1 have been completed. The emphasis then will be on remote handling. For currents higher than 10 μA the present 1T2 target will no longer be adequate, and the beam line 1 extension and the thermal neutron facility will have to be ready to accept the beam.

The first step in this program occurred shortly after the August shutdown, the maximum current normally delivered to the users being increased from 100 nA to 300 nA in beam line 1 and from a few nanoamperes to ∿50 nA in beam line 4A. This was possible since the Vacuum and Beam Development groups had improved the transmission of the beam in the cyclotron in the region between 130 and 500 MeV. Along beam line 1 the spill was substantially reduced by the Beam Lines and Beam Development groups by adjusting the beam line tune and reducing the cyclotron emittance. As a result of these improvements, residual activities were found to be decreasing on average, even though the beam current had been raised.

Before the end of 1975 a vacuum protection window in beam line 1 was removed from its original location and brought substantially closer to the 1T2 target. The spill reduction which resulted, together with the completion of the commissioning of the 1T2 target and other progress by the Remote Handling group, has made the beam line compatible with 1 μA. It is expected to deliver this current normally to the experimenters during the first months of 1976.

In an advanced stage of design are special liquid helium cryopumps which should furnish an additional 50,000-ℓ/sec pumping speed for hydrogen and a special system of graphite blocks and graphite-containing cans which will be used to protect the surfaces of the magnet yokes and of the vacuum tank from the primary protons or hydrogen atoms produced by electric stripping of the H^- beam during acceleration. These devices will allow further important steps towards the completion of phase 1.

A special transmission sensor is being designed for ISIS to avoid damage to the electrostatic 300-keV injection line, which could result from uncontrolled beam losses. Transmission sensors in the low-energy region and spill sensors for higher energies will be interlocked to the ion source beam stop to avoid thermal problems or excessive activation.

5. ION SOURCE AND INJECTION SYSTEM (ISIS)

The construction of the polarized ion source injection line and completion and commissioning of the polarized source have absorbed a major part of the Ion Source group's efforts during 1975. By January 1976 55 nA of polarized beam had been transmitted to the 'fast' target. (This is the last target at 300 keV before injection into the cyclotron.) Also 2 nA of unpolarized beam from the polarized ion source had been observed at 500 MeV within the cyclotron.

The unpolarized source has operated satisfactorily as the cyclotron injector with transmissions of typically 60-90% to the fast target for currents of 5-100 μA. Chopped and bunched beams were injected into the cyclotron for the first time during this year, and a 500-μA pulsed beam was injected to yield an instantaneous peak extracted current of 48 μA.

Unpolarized source and injection system

Due to the workload represented by the polarized source little was done to improve the hardware of the existing source and injection system. However, some effort was dedicated to the improvement of the safety interlock system.

The unpolarized source with emittance-reducing slits in the 12-keV region has produced beams between 50 nA and 5 μA routinely, with 60-90% transmission through the 0.050-in. (1.3-mm) chopper slits located immediately above the fast target and about 3 m above the median plane of the cyclotron. At these low currents and with some slight filament modifications, the filament lifetime has increased dramatically to an average of 280 h. The source and injection system is stable and reproducible in day-to-day operation but requires extensive optimization after a long shutdown period. This could be attributed to alignment changes in the injection line, minor changes in the stray magnetic field or its compensation, or changes in the initial alignment within the source.

Beams of intensities greater than 5 μA have been transmitted through the injection system but usually in pulsed mode to prevent the accidental loss of large average currents. In the 1% pulsed mode 500 μA of a 1-mA source beam was transmitted to the fast target. This beam, when accelerated, gave 48 μA (peak) of extracted beam at 500 MeV with a 10% duty factor. The low (50%) transmission of this beam to the fast target was attributed to plasma oscillations within the source which gave rise to 50% current oscillations in the 100—200-kHz region. Such current oscillations are incompatible with the space charge dependent injection line optics encountered at these current levels.

Chopped and bunched beams were injected into the cyclotron for the first time this year. The 23-MHz double gap sinusoidal buncher is very effective in increasing transmission from the ion source to the machine, as is seen in Fig. 14, where the bunching factor is shown as a function of buncher voltage and phase acceptance. It can be seen that for beams of small phase width the transmission can be increased by as much as a factor 10. More normally, when the cyclotron phase acceptance is optimized (∿45°), bunching factors of about 3 are observed.

The 11.5-MHz sinusoidal chopper has been used successfully to inject beams of 10-15° of phase into the cyclotron for diagnostic and experimental purposes. For long-term operation of the chopper a means of continuous monitoring of the beam phase width is required to maintain

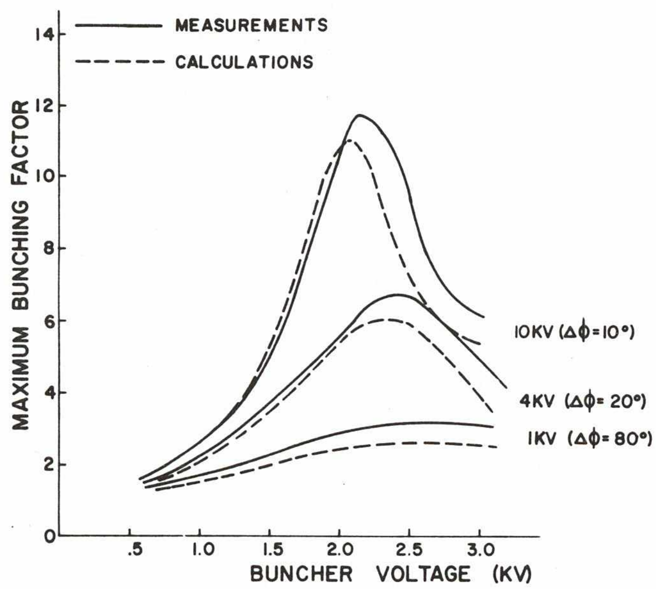


Fig. 14. Effects of bunching on beam transmitted through chopper slits, with phase acceptance and chopper peak voltage as parameter.

necessary beam centring on the chopper slits. The non-intercepting probe is expected to give this information at high current levels; however, since chopped beams may be required from the polarized source, and for other low-intensity beams, alternative means of maintaining beam centring are being investigated.

A 100-μA dc beam has been transported to the fast target with a transmission of 90%. This is sufficient to produce 10 μA of extracted beam, provided transmission through the cyclotron is good and the buncher is operating. The transportation of such a beam in a routine operational sense is not yet feasible. A satisfactory method of detecting beam losses within the injection system, and the interlocking of the source to this detection system to protect the injection line against damage due to accidental beam loss, will be required before this is possible.

To proceed to currents above 100 μA, work will have to be done on both the ion source and injection line. The major source problems will be the reduction of plasma oscillations, source conditioning at high currents, and filament lifetime. To transport high beam currents from the source with a reasonable transmission the beam must be more closely aligned to the optical elements in the injection line than is presently the case. This alignment will require not only time but better beam diagnostic devices than those available and may also require further fringe field shielding.

Polarized source and injection system

Intensive work on the construction of the section of injection line connecting the polarized source to the existing injection system and on the completion of the source itself began in late January. Construction proceeded relatively smoothly, with the result that by late July the injection line was complete and the source room ready to receive the 300-kV power supply. The 300-kV power supply was late in delivery from Delta Ray Corporation due to a materials availability problem. A further delay was incurred by damage to the supply in transit. The supply finally became operational in late August and the first 300-keV beam was produced by the source at this time.

The first months of commissioning the source and injection line were made extremely difficult by frequent 300-kV sparks. These unfortunately were transferred to the primary of the 300-kV isolation transformer, with disastrous effects on the fuses and circuit breakers in the 480-V power line. In spite of these difficulties 2 nA of unpolarized direct H^- beam was accelerated to 500 MeV in October. At this point the transmission to the fast target was only 10%, although transmission through the polarized source section of injection beam line was ∿80%. The problem of matching the two sections of injection line could have been caused by the two-component nature of the direct H^- beam formed in the cesium region, i.e.

1) $p \rightarrow H^-$ 500 eV
2) $H_2^+ \rightarrow 2H^-$ 250 eV

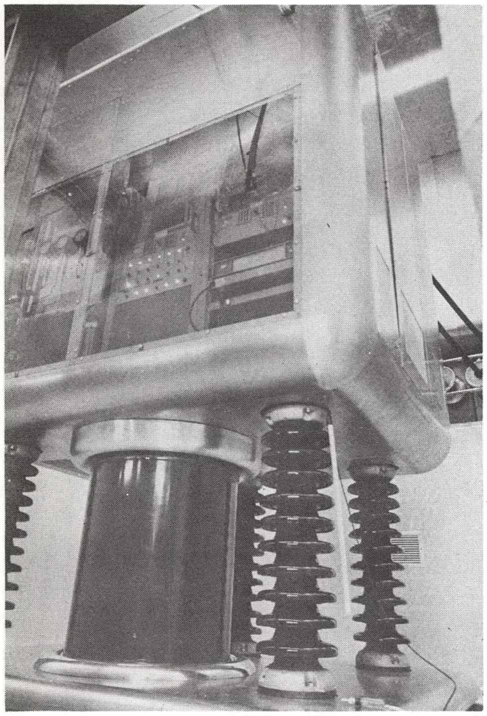


Fig. 15. High voltage generator and the Faraday cage housing the Lamb shift polarized ion source.

For this reason further beam studies were always conducted with polarized and unpolarized H^- beams from charge exchange in argon. By late October a small, well-centred beam was obtained in the Wien filter region, and a non-dispersive solution very close to the theoretical solution was found through the first 90° electrostatic bend. Transmission through the POLISIS injection line was 80-90%; however, problems were still encountered in matching to the existing injection line, and a transmission of only 40% to the fast target was the best achieved.

In November and December problems were encountered with the duoplasmatron magnet coil, one of the solenoid coils, and with all of the magnet power supplies within the source. Minor modifications were made to these elements to enable the source to operate; however, a more serious effort at redesign and reconstruction will be necessary at a future date. In this period the 300-kV isolation transformer was dismantled. No defects were found except for an obvious arcing in the connector to the primary winding of the transformer. This was repaired and spark arresters installed in the primary supply line. The 300-kV supply has operated well since this time and sparks have not caused the interruption of the 480-V power experienced previously.

It is hoped in the first few months of the new year that emittance measurements will be carried out in the Wien filter region and that, subject to satisfactory results, the Wien filter will be installed in preparation for the injection of polarized beam into the cyclotron early in 1976.

6. RF SYSTEM

Since the cyclotron became operational, in December 1974, the RF system has had its share of problems and has undergone major changes.

RF amplifiers

In order to improve the reliability of the amplifiers the following major modifications were made:

1) Water cooling was added to the PA cathode drive dc blocking capacitors and air cooling was added to the PA output vacuum capacitors.

2) The crowbar circuit was modified to prevent false triggering caused by the self-inductance spikes of the sensing resistors.

Some downtime was caused by failure of surge-limiting resistors in the main 20-kV 130-A dc power supply and failure of SCRs in the PA filament power supplies. However, the major downtime caused by the amplifiers was due to the failure of three cathode metering shunts followed by the failure of three 4CW250000A tetrode tubes.

RF resonators

Extensive tests were carried out to determine the source of RF leakage in the beam gap which caused serious RF pick-up on the beam probes and damage to the probe tracks and cabling.

The greatest reduction in RF leakage was obtained by adjusting the ground arm trips in such a manner as to change the relative voltage on the north resonators with respect to the south resonators and the voltage on the upper resonators with respect to that on the lower resonators. Unfortunately, ground arm tip adjustments are required to maintain the proper frequency, and so some other means (not yet established) will have to be used to adjust relative voltages on the resonators.

The failure rate of the fine-tuning foils and their associated driving bellows necessitated operation without the fine-tuning system. This was surprisingly stable, depending only on the control of the cooling water temperature and pressure to maintain the proper frequency.

The RF system was plagued with three major water leaks. The first leak was in the hot arm extrusion cooling lines and beam stop of the north-east segment #1. The other two leaks were in the same segment but on the RF surface of the resonator, due to arcing from the water channels on the panel to the third harmonic non-contacting shorts at the root of the segments. Attempts were made to reduce the voltage at the non-contacting short but meanwhile another major failure was experienced in the resonator tip of the #1 segments in the west side. Although the cause was not established immediately, the effect was to melt large holes in the aluminum resonator tip extrusion and part of the vertical wall facing the centre post. In order to repair the damage, a major shutdown was inevitable; thus it was decided to include the replacement of the non-contacting shorts with standard root shorting pieces and the replacement of the movable tuning foils in all segments with fixed copper foils. The above modifications were completed just prior to the Christmas holidays ready for tests in the new year.

7. CYCLOTRON MAGNET ELEVATING SYSTEM

A liquid nitrogen spill onto the top of the primary beams in the cyclotron support structure caused extensive brittle fracture cracking early in February. The cracks radiated out from the ISIS vertical access hole; the top flange and part of the web of beam #10 was cracked right through. The cracking occurred during the night, and the cyclotron tank was still under vacuum when the spill was discovered.

The tank was vented, strain gauges were applied at the end of each crack and the vacuum chamber re-evacuated. The gauges established that the cracks were not propagating over a twenty-four hour period. Also, switching the magnet on and off had no effect, as was expected.

The cyclotron was operated and one gauge was monitored for a two-week period. The machine was then shut down and the accessible cracks were gouged out and repaired by Ebco Industries, working two and three shifts a day. The welds were inspected ultrasonically before, during and after the repair.

Following the repair, new gauges were installed to measure the beam operating stresses and as crack propagation monitors on an unrepaired portion of the vertical central tube where access made welding impractical without removing the ISIS vertical line. These gauges revealed that measured primary beam bending stresses were less than those calculated in the original design when the chamber was under vacuum, and 94% of the calculated value when the lid raised. The central tube crack was stable during elevation and vacuum loading. Subsequent monitoring of the gauges on the central tube crack revealed no change throughout the year. The welding of the cracks caused a slight upward distortion of beam #10. The difference of 0.11 in. (2.8 mm) at the elevating column was shimmed out, and the reference of the elevating jack was readjusted so that the support structure is free of differential stresses, both under vacuum load and during elevation.

During the repair of the damage, the elevating system was thoroughly inspected. Two elevating jacks with problems in their operating history were taken apart. The examination showed a negligible wear of friction surfaces. All moving parts were re-lubricated; the main elevating screws were lubricated with molybdenum disulfide compound.

The cyclotron 2200-ton upper half has been lifted 49 times during 1975, bringing the total to 360 lifting cycles. The only significant problem encountered with the elevating system has been excessive grease leakage from the elevating jacks.

8. MAGNET POWER SUPPLIES

Cyclotron magnet

The main magnet power supply performed successfully for 2691 h, bringing the total to 5630 h of operation.

Breakdown of the reference unit in the summer caused one shift of accelerator downtime. The reference unit has been replaced after approximately 20,000 h of reliable service at 37°C ambient temperature. Stability tests with the new reference unit showed that the main magnet power supply performs within specifications: 5 parts in 10^6 over 15 min, 1 part in 10^5 over 8 h.

Numerous minor failures, mostly of power transistors, during July and August were due to high ambient temperature; these caused very little if any delay and were repaired during the next maintenance period.

Trim and harmonic coils

Power supplies for the trim and harmonic coil system were rearranged several times to match coils ranging from 0.16 Ω to 1.6 Ω in resistance and from 40 A to 90 A in current rating. Power supply diagnostics have been developed so that the potential failures are identified during weekly maintenance periods, and the power supplies concerned replaced with standbys. Approximately 1% of the power supplies develop minor problems per week. 17% of the power supplies had a major failure by year-end, caused in most cases by a thermal deterioration of components.

In the second half of 1975 the trim coil system has not caused any downtime. Trim coil zero (which provides B_r correction for the effects of the upper centre support structure) ran without any breakdowns throughout the year.

Combination magnets

A failure of water flow interlocks when temperature interlocks were temporarily shorted caused extensive damage to the combination magnet on beam line 4. The coils were removed and repaired. The power supply was also damaged by the short-circuit to which it was subjected, and power fuses, transistors and degaussing transistors needed to be replaced. The power transistors originally specified are now no longer available

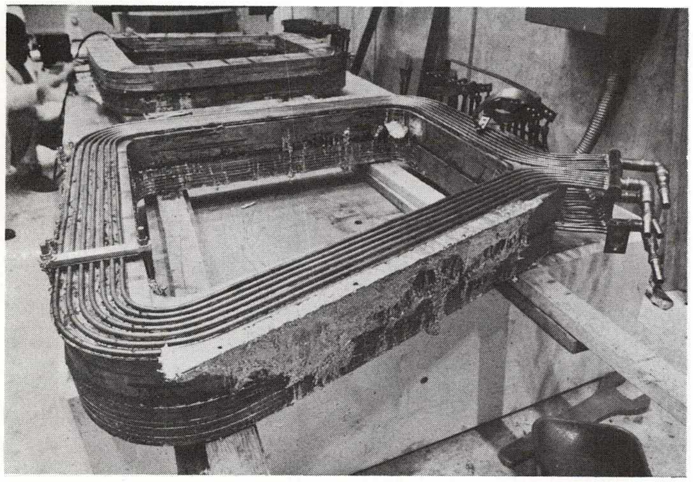


Fig. 16. Combination magnet coils being repaired following damage by overheating.

and, without spares, it was necessary to reduce the output current rating to 75% of its design value. The pass bank has been redesigned and the new unit is ready for installation.

Beam line magnets

The beginning of the year was spent in installation and commissioning. Many of the 36 quadrupole power supplies were damaged by vibration prior to arrival. A problem with inefficiency of heat sinks was also encountered and is being rectified. 10% of the bending magnet power supplies exhibited initial transient-response problems, but now give reliable service.

9. VACUUM SYSTEM

The cyclotron chamber vacuum system has operated satisfactorily during the past year, apart from the problem of a high H_2 partial pressure ($\sim 2 \times 10^{-7}$ Torr) when the RF is on.

The indicated vacuum chamber pressure, read on a Bayard-Alpert ionization gauge located behind the resonators, has reached minimum pressures of 2×10^{-8} Torr with the RF off and 1.5×10^{-7} Torr with the RF on. The gas composition with RF off is about 90% mass 18. When the RF is on, it is about 95% mass 2. (This latter measurement was taken before the RF was conditioned. Due to interference by the cyclotron's magnetic field, no measurements have been taken following RF conditioning.) A liquid helium cryopump, to run at 3.5°K, is being designed to pump hydrogen with a speed of 5×10^4 ℓ/sec.

The 20°K and 80°K cryopanels are normally defrosted once a week but on one occasion they were run two weeks with no difficulty. Following defrosting, the RF has been brought back on and conditioned down to an indicated pressure of 3×10^{-7} Torr in as short a time as 2-3/4 h. Following a tank opening period, the RF conditioning takes about two days. A dry air venting system for the vacuum chamber has been installed to reduce the RF conditioning time on those occasions when the tank is vented but the lid is not raised.

10. BEAM PROBES

The initial operating experience with the diagnostic probes in the cyclotron median plane is described in the 1974 annual report. In spite of some problems which have limited their use, the diagnostic probes have been successful in providing the necessary beam information (vertical height, position and intensity) to enable the cyclotron to be tuned to near optimum, and simultaneous extraction of two good-quality beams to be achieved.

Most of the problems associated with the use of the probes have been due to the RF leakage fields, which cause serious pick-up on the probe heads and in some cases damage to the probe cables or mechanisms as a result of RF arcing. These problems have been tackled in two ways, with some success. Modifications have been made to the probe mechanisms to provide good RF contacts between sliding surfaces to minimize damage due to arcing, and better shielding has been installed around the heads to minimize pick-up. On a longer time scale it is hoped that a better understanding of the mechanisms causing the RF leakage fields will result in their suppression.

At present the two high-energy probes, which cover the radial range from 142 to 315 in. (361 to 800 cm), 65 to 520 MeV, provide most of the beam information for tuning. Use of the low-energy probes, which cover the region inside 144 in. (366 cm) between the upper and lower resonator arrays, has been restricted by excessive sparking, and a proper optimization of the central region has therefore not been possible.

After some operating experience in setting up and maintaining the desired conditions for simultaneous extraction of two external beams, it was felt that a quick method of checking the beam transmission at several points in the cyclotron would be useful. Four pneumatically actuated pop-in probes have been designed and installed at radii between 180 and 300 in. (457 and 762 cm) to provide this information. They have pick-up heads similar to those for the high-energy probes. One head consists of five fingers, each 0.25 in. (7 mm) in vertical height, and enables the vertical size of the beam to be measured and minimized.

Both extraction probe mechanisms have operated reliably since they were installed. Some changes have been made to the stripper foil cartridge to enable a variety of foil shapes to be deployed. For simultaneous extraction of two beams, the technique used at present inserts the stripper foil extracting the lower-energy beam from above to pick up the desired portion of the circulating beam. The remaining beam spirals out to the second extraction foil which is positioned on the median plane. To improve the radial emittance of the lower-energy beam, and to improve the intensity stability when a small fraction of the beam is extracted, the inner foil width has been reduced to less than 0.100 in. (2.5 mm). In the next period of cyclotron operation, pyrolytic graphite foils will be used to permit higher intensity operation down beam line 1 and reduced emittance due to reduced multiple scattering in the foil.

The vertical flag, which is installed at a radius corresponding to 4 MeV, is used diagnostically to improve the vertical beam emittance, while the movable radial slits have not been used during normal operation. The centring probes have also not been used successfully. A new design has been made for a centring probe covering a limited radial range of 60 in. (152 cm), and this will be installed during 1976.

Several techniques have been developed to provide information about the beam phase as a function of radius. By timing the arrival of protons scattered from a monitor in the external beam relative to the RF signal, the phase history can be measured over the range of extraction energies relatively quickly to an accuracy of about 2° in phase. Using a beam pulser in the ion source, beam pulses 10 μsec long and 1 msec apart can be produced. Such pulses can be detected on a high-energy probe and the time of flight from the ion source to the high-energy probe measured to an accuracy of 1 μsec. This measurement provides information about the combination of the accelerating voltage and the average phase of the beam as a function of radius. At lower energies the phase history of the beam has been determined by a third technique in which a magnetic field bump is produced by a combination of several trim coils and the beam transmission measured as a function of the magnitude of the field bump. Further details of these techniques are described in the section on beam development.

11. CONTROL SYSTEM

In late 1974 the TRIUMF control system was ready to participate in cyclotron commissioning, providing accessibility to all essential parameters from the central control room. The full potential of the computer-based system was largely unused, however, and the emphasis in 1975 has been to exploit it to assist in routine operation as well as in internal and external beam development.

Operational aids

The major operational improvement since commissioning has been the implementation of automatic save and restore operations which allow cyclotron parameters to be reset to previously determined values in a few minutes. One year of experience has allowed 'master' magnet and injection line parameter value sets to be determined, and deviations from the master sets may be logged on request.

A scan has been implemented to detect and annunciate spontaneous changes in over 250 power supplies. This is occasionally helpful in determining the source of an operational problem, but its usefulness has been impaired by the large number of spurious messages which still occur. These should be reduced by improvements planned in the measuring system.

Several CRT displays of the status of machine parameters have been made available. In particular, graphic displays of the external beam lines indicating the status of beam monitors and tabular displays of probe position and interlock status have proved convenient. Several operations previously not available on the cyclotron console, such as video multiplexing and changing of amplifier gain ranges, have been implemented using the console CRT and keyboard.

Beam development aids

In 1975 a substantial effort was made to assist beam physicists in their studies of internal beam properties. The patch panels originally used to route probe output signals to the chart recorder and moving coil meters were replaced by a CAMAC-addressable multiplexer. This change not only eliminated a major source of human error; it also expanded the input capability to include a number of computer-generated signals, among which an analogue signal proportional to the vertical centroid of the beam was provided. Other analogue signals proportional to calculated machine parameters have been used to produce hard copy x-y plots. Histogram displays of the vertical beam profile, as seen by the four current probes, are provided on a storage display and are helpful in beam optimization.

A series of algorithms have been implemented which allow trim coils to be run together as pairs or triplets, changes in their currents being kept at a constant ratio. Magnetic effects are thereby localized, and this technique has proved most useful in practical beam optimization as well as in studies of beam phase history and vertical excursions. Programming support for a time-of-flight phase history study was also provided.

A link between the TRIUMF control system and the UBC Computing Centre, using an intermediate computer, has been established. This permits data on machine parameters—generally the magnet or beam line power supply settings—to be transmitted to the UBC Computing Centre for analysis. Most recently the ability has been added to transmit to the Computing Centre the digitized results of a radial scan of beam characteristics as it takes place.

System reconfiguration

A major development in 1975 has been the consolidation of the three control system computers and a back-up computer, which is used when

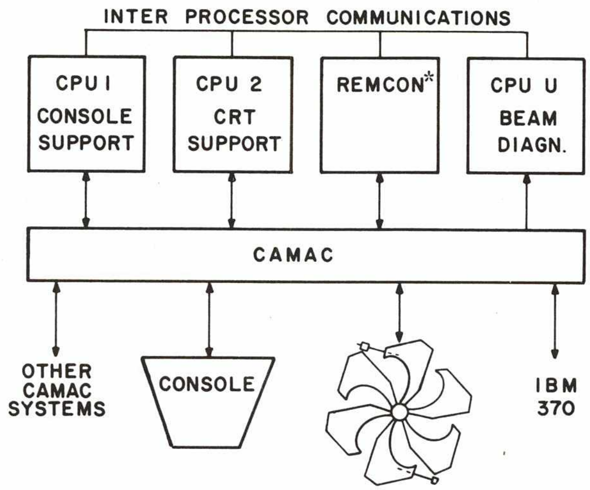


Fig. 17. Fully multisourced system configuration.

available for beam diagnostics, into one large CAMAC system (see Fig. 17). This configuration is extremely versatile, and results in a degree of redundancy which has on occasion permitted cyclotron operation to continue in spite of the failure of one or more computers. Our experience with a large (35-crate) multi-sourced parallel CAMAC system is unique in the world, and has enabled TRIUMF to make useful suggestions to the international CAMAC committee formulating specifications for similar systems.

Reliability

Cyclotron performance records indicate that, since October 1974, failure of control system components has accounted for about 30 h, or <2%, of cyclotron downtime. There have been three computer failures in this time. Two occurred during operation, but only one of these resulted in a (two-hour) machine shutdown. CAMAC system failures, primarily power supplies, account for most of the downtime. Program failures, which occur on an average of once daily and typically require 1-5 min to diagnose and remedy, account for the remainder.

12. SAFETY

The TRIUMF Safety Group has been extensively involved in cyclotron operation as well as having the responsibility for continuing the installation of the safety interlock system, development of radiation monitoring systems, and assay of radioactivity levels in cooling water, air filters and soil samples.

The TRIUMF Safety Executive Committee met every two weeks and reviewed submissions for 37 experimental proposals. Major effort was put into

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*remote console computer

finalizing the liquid hydrogen target safety regulations, with considerable help from the hydrogen target designers. Routine items of business included a review of shielding installations and radiation levels, the safety interlock system commissioning, and industrial safety.

Safety interlock system

The interlock system for personnel safety and machine protection was operating for the cyclotron vault in January. By August the system was commissioned to include three proton beam lines and three meson beam lines. The system functions such that access is allowed in one beam line area, essentially independent of operation of other beam line areas. The system is now about 90% complete and can be readily expanded to include one more meson beam line. The only major subsystem that remains to be commissioned is the beam line vacuum interlock system, which will be completed by the Beam Lines group and interfaced to the central machine protection system.

Radiation protection

For most of the year there were 12 beam-spill monitors and 4 neutron monitors, some of which were used to assist operators in optimizing beam line tunes. Others were set to trip the cyclotron when radiation levels exceeded 50 mR/h in experimental areas that were not locked. By the end of the year there were 10 additional beam-spill monitors installed and operating.

Limits were placed on extracted beam currents in order to restrict activation of components; the radiation levels in accessed experimental areas must be less than 0.25 mR/h and the radiation at the site boundary must not exceed 3 × background. The limited inventory of shielding blocks and the need for improved tuning have been the primary impediments to operation at higher current levels.

The residual activity has not yet approached a level where remote handling techniques are required. For example, the typical dose rates in the beam line 1 tunnel, one hour after shutdown, were only 2 to 10 mR/h at 1 m from the beam line. The maximum permitted current levels were gradually raised during the year following reduced beam losses. Further increases in current may still be possible without a need for further shielding through improved tuning. The maximum currents permitted at the end of the year were 300 nA in beam line 1, 50 nA in beam line 4A and 20 nA in beam line 4B.

Of the approximately 300 persons on the film badge service at TRIUMF there were 17 individuals who received 20 mrem and all other readings were zero, according to the Radiation Protection Bureau. Individuals who enter the cyclotron vault wear pencil chambers, and a few of these were returned with readings of 5 to 10 mrem, which are consistent with null readings on film badges since the latter are not as sensitive as the pencil chambers.

Accident record

There were about 5 man-weeks lost due to accidents at TRIUMF in 1975. The majority of the accidents were minor in nature, but a rash of mishaps during a shutdown in August resulted in the formation of the TRIUMF Accident Prevention Committee (TAPC). This committee of professional and technical staff meets biweekly to discuss and resolve site deficiencies and general industrial safety matters. Site inspections are carried out routinely by members of TAPC and safety deficiencies found have been corrected.

13. BEAM LINES AND EXPERIMENTAL FACILITIES

General

During this year, the primary and secondary beam lines, described in detail in previous annual reports, were completed and commissioned in co-ordination with cyclotron operation, and generally with considerable volunteer assistance from visiting experimentalists and TRIUMF scientists. For much of the year, two proton beams were delivered simultaneously; one was directed down beam line 1, to serve the p,π experiment and the 1T2 target which fed mesons to M9, M20 and M8 (the biomedical channel); the second ran down either beam line 4A, serving the 60-in. scattering chamber, the BASQUE experiment, the FERFICON apparatus, the gas-jet target chamber, and ^{123}I production, or beam line 4B, for the elastic and quasi-elastic scattering experiments, the pion production experiment, and the cyclotron beam development program.

The year's stepping stones were:

January	Beam line 4B commissioned from 183-500 MeV
February 20	Simultaneous extraction into both beam lines 1 and 4
April 10	Beam transmitted to target 1T2 on beam line 1
June 14	First meson beam in M8 biomedical channel
July	First pions, muons and electrons in M9 and M20

Also this year, the BASQUE liquid hydrogen/deuterium target system was installed and commissioned on beam line 4A, while the liquid hydrogen target originally intended for the BASQUE group has been installed on the M9 channel and will be commissioned early in 1976. The MRS spectrometer dipole has been surveyed and prepared for installation; its support structure and superstructure were installed in the proton hall.

Early in the year, the coils for combination magnet 4 were repaired and extra cooling arrays were added, following damage caused when an interlock system failed. The beam blockers were redesigned and rebuilt to

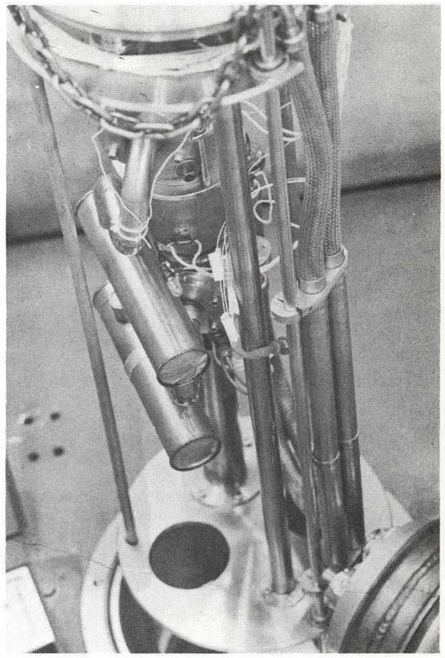


Fig. 18. The liquid deuterium flask, and dummy flask (for background measurements), used to produce the neutron beam for the BASQUE experiment. The targets are 20 cm long and 2.5 cm diam. They can be used vertically by remote control.

overcome mechanical problems. The fast vacuum valve system was commissioned to protect the cyclotron from damage due to beam line window breakage. A continuing program is under way to upgrade the diagnostic system and its readout. The beam line vacuum system is also being upgraded, but its interlock system is still in the design stage. The service connections for vault magnets are being modified for quick disconnection, to facilitate remote handling and servicing in the future when the radiation levels rise, following increased beam currents.

1T2 meson production target

The 1T2 meson production target was placed in position in beam line 1 early in 1975. By May the target assembly was connected to the beam line pipe, leak checked and ready to produce the first mesons for the three secondary channels. The local control system was installed on the south mezzanine of the meson hall, from which position any one of six targets can be inserted into the proton beam. The water-cooling package was installed during the summer months, and by the end of the November-December shutdown the commissioning of the target was essentially complete, with remote operation of the target possible from the main control room.

The monitoring system for the target and cooling package was also completed by the end of the year. Twenty-one parameters are monitored and available in the main control room, including target ladder position, cooling water inlet and outlet temperatures, water flow rate, purity and pressure.

Targets available on the 1T2 ladder during 1975 were (sequentially): no target, 14-cm beryllium, 1-cm polyethylene, 3-cm beryllium, 1-cm copper, and 10-cm beryllium. For checking the location and shape of the proton beam on the target, a ZnS scintillator was located in front of the 3-cm beryllium target for checks at low proton currents, and an Al_2O_3 scintillator in front of the 1-cm copper target for higher proton currents.

All of the metal targets present an area 5 mm wide by 15 mm high to the proton beam, which was designed to be 2 mm wide by 8 mm high at the position of 1T2. However, the yield of pions down the secondary channels is a factor of three lower than anticipated, thought to be due to a larger beam spot than expected. Consequently, in December it was decided at a meeting of 1T2 users to replace the 3-cm beryllium target by a fat 15-mm-wide by 20-mm-high aluminum target, 10 cm long. Such a target is presumed to be large enough to intercept all of the proton beam. In addition, the 14-cm beryllium and 1-cm polyethylene targets are to be replaced by 1-cm tungsten and 1-cm water, respectively, early in 1976.

Liquid hydrogen targets

Development has continued this year on two similar liquid hydrogen targets for use by experimental groups, to a design initiated by Mr. R. Wimblett (Rutherford Laboratory). Both targets use a CTI 'Cryodyne' refrigeration system with a capacity of 10 W at 20°K.

The first target system, developed mainly for neutron scattering experiments, has a refrigeration system loaned by the nuclear physics group at AERE Harwell, and an eight-litre condensing vessel. Special low-temperature couplings have been developed to facilitate the quick change of the three mylar target flasks, which have been made for this target: an 11-cm-diameter by 50-cm-long flask for the neutron scattering experiments, a second 5-cm-diameter by 12.5-cm-long for the proton-proton scattering experiments, and a third 11-cm-diameter by 12.5-cm-long for pion capture experiments. This target is first being set up in the meson hall and will be used to produce monoenergetic gamma rays from stopped negative pions via the $\pi^- p \rightarrow n\gamma$ reaction, in order to measure the line shape of a large sodium iodide crystal. The target will then be moved to the proton hall, for the neutron scattering experiments.

The second target, which is being assembled with a five-litre condensing vessel and a stainless steel flask 3 cm diameter by 8 cm high, will be ready early in 1976. This target will be installed in the meson hall and used on a time-shared basis for pion capture and pion production experiments.

The cool-down time from room temperature plus liquefaction has been found for the first target to be of the order of 18 h. Approximately 8 h is required to change the target flasks when the assembly is at room temperature.

Fig. 19. View of 1T2 meson production target and the three meson channels, showing beam line 1 entering from the left and (clockwise) M9, M20 and M8.

Meson hall

M9 channel

In July 1975 the first π's and μ's were observed in the M9 channel (see Fig. 20), which is now capable of producing pion and muon beams in the momentum range 80 to 150 MeV/c. Table III gives characteristics of some beams obtained so far at the primary π focus compared with the design values (in parentheses). Figs. 21 and 22 show a range curve at pion energy T_π = 27 MeV and an RF-referenced time-of-flight spectrum at pion energy T_π = 21 MeV. Experiments using π^+, π^- and μ^- beams have begun.

Table III. M9 Beam Characteristics

Quantity	Value	π Energy (MeV)	Production Target
Maximum flux π^+	1.5×10^3/sec/nA (4.5×10^3)	30	10 cm Be
π^-	0.3×10^3/sec/nA	30	10 cm Be
μ^-	0.3×10^2/sec/nA	30	10 cm Be
Momentum resolution	4% (FWHM) (1%)	30	1 cm Cu
Momentum acceptance	24% (FWHM) (28%)	30	1 cm Cu
π Spot size (2nd focus)	4 cm diam (FWHM) midplane (2.5 cm) slits < 10 cm		1 cm Cu
π Beam contamination e	50%	30	1 cm Cu
e	10%	30	10 cm Be
μ	10%	30	all targets

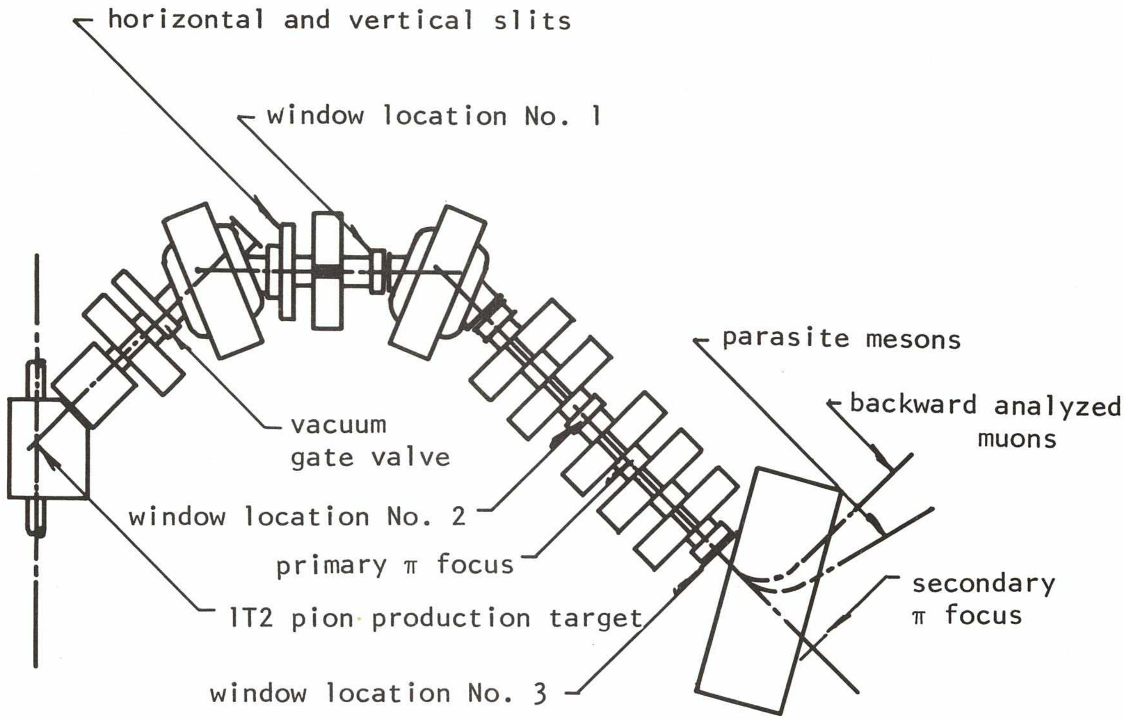


Fig. 20. Layout of M9 channel. The B3 dipole is a 12-in. gap cyclotron magnet obtained from Oregon State University.

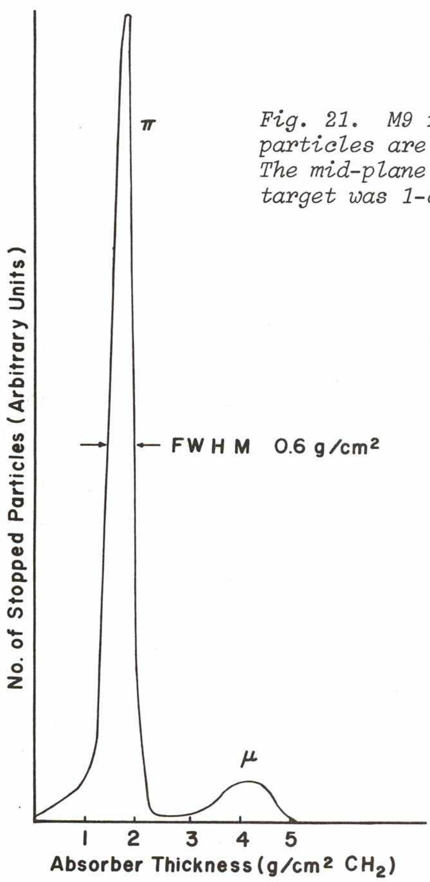
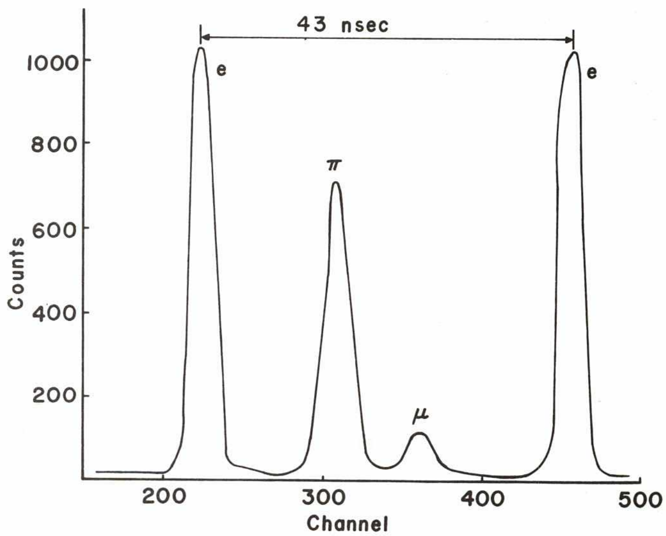


Fig. 21. M9 range curve for $T_\pi = 27 \pm 1.5$ MeV. The particles are stopped in a 0.3-g/cm^2-thick scintillator. The mid-plane slits were closed to 1 cm and the production target was 1-cm Cu.

Fig. 22. RF-referenced time-of-flight spectrum for $T_\pi = 21$ MeV in M9. The production target was 1-cm Cu and the mid-plane slits were open.



M20 channel

The 'muon spin research' (μSR) beam line accepts pions emitted at 55° from the 1T2 production target, and can provide both 'conventional' and 'Arizona' muons. For details see the 1974 annual report and TRIUMF report TRI-75-2 (Experimental Facilities at TRIUMF).

The final assembly of the beam line (including power supply hook-ups for operation as a conventional muon line) and installation of indium seals in the radiation-hard flanges adjacent to 1T2, was completed by June 1. A beam development program was begun shortly thereafter, for a range of pion momenta from ∿100 MeV/c to ∿170 MeV/c. There are presently no slits in the beam line, and the pion momentum bite, measured by a range curve, was found to be about 5%. From time-of-flight spectra, the π^+-to-e^+ ratio was found to be ∿30/1 with a 1T2 target of 10-cm Be but only ∿3/1 with 1-cm Cu; moreover, the total π^+ yield from a Cu target is only about 1/5 that from the Be target.

Operating in a conventional mode, the channel was tuned for forward μ^+ and the first μ^+SR spectrum was obtained from a carbon target in mid-July; this was repeated in August and is shown in Fig. 23. The channel is now capable of producing ∿10·μ^+ stops/nA/sec in a thick 25-cm^2 target. Presently, there is a large 'cloud muon' flux coming directly from the 1T2 target, and this results in a low measured polarization of the stopped μ^+—about 50%!

In the very near future, it is planned to tune the channel for negative muons and measure the flux and polarization so that μ^-SR experiments can begin. It is hoped also to improve the polarization of the muon beam by a more careful tuning and range selection for high momentum muons. The power supplies for operation of the μSR channel in the Arizona mode (∿20-MeV/c stopping μ^+) are now installed, and tuning the channel in this mode should begin early in 1976. The big advantage for μ^+SR studies of these very low momentum muons, which come directly from π^+ decay in the skin of the production target, is that they are monochromatic and very nearly 100% polarized. Much of the μ^+SR and associated muonium chemistry studies at TRIUMF will be accomplished with Arizona muons.

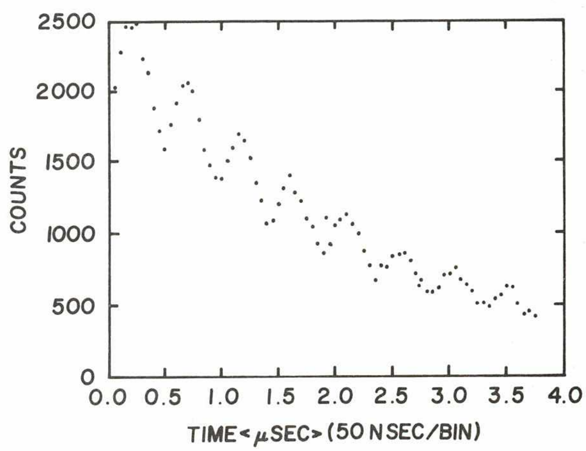


Fig. 23. Time spectrum showing positive muon precession in carbon in transverse applied field of 157 G. Data from a run of ∿1 h with 100-nA proton beam on 10-cm Be target. Fitted asymmetry = 15.8 ± 0.4%.

The M8 channel and the biomedical facility, funded jointly by the British Columbia Cancer Foundation and the Health Resources Fund of Health and Welfare Canada, has been constructed to investigate the potentially favourable properties of pions in treatment of cancer. The design of the M8 channel was discussed in last year's report and is shown in Fig. 24.

The last of the magnets for this channel was received early in 1975. All magnets were assembled, tested, surveyed and installed, with the vacuum system and shielding, by the scientific staff of the biomedical group, including biologist volunteers. The dipole magnets were surveyed and shimmed to bring them close to the shape of true sector magnets, a complete field survey of the final shimming being recorded via flip coils. The central five magnets were prealigned in a horizontal position and moved to the 30° slope as a single unit. The magnets were positioned to within 0.025 in. (7 mm) in spite of the difficult surveying in the 30° plane. The complete vacuum system with its peripheral equipment was installed by June 1. In spite of its late start, the biomedical channel was the first secondary channel to deliver pions—on June 14.

The biomedical laboratory facilities were also completed during the year, and the physics group has taken occupancy of the lower two floors. The biology laboratories are ready for occupancy as soon as the cyclotron gives sufficient beam to begin biological studies. The medical building

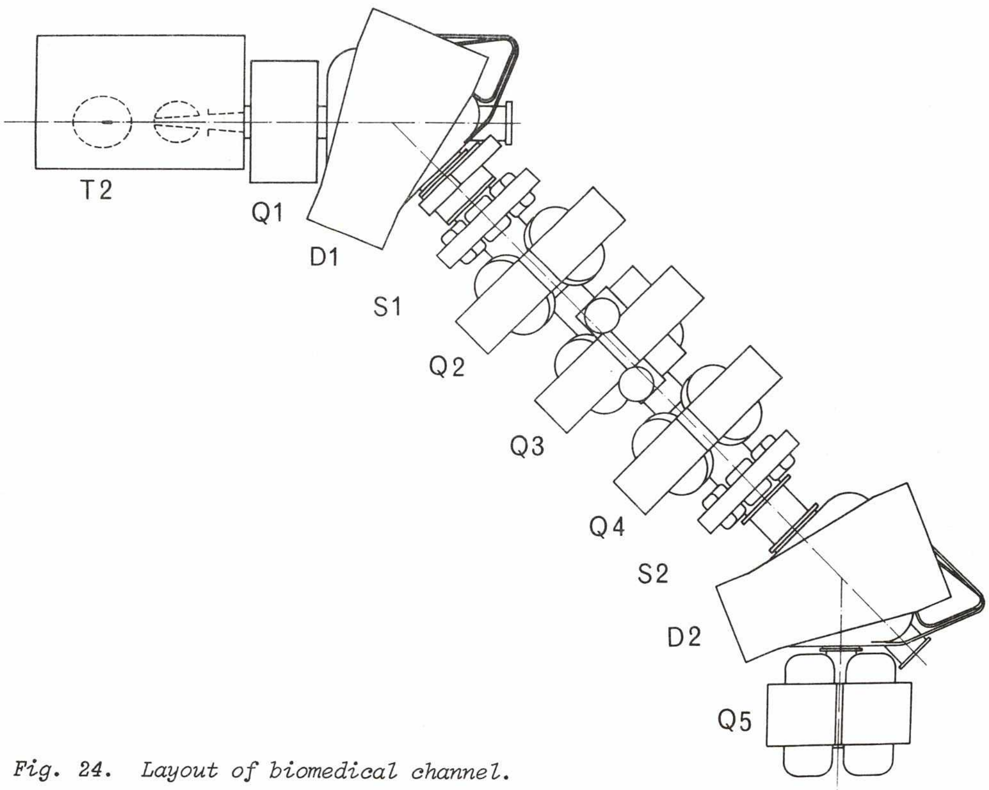


Fig. 24. Layout of biomedical channel.

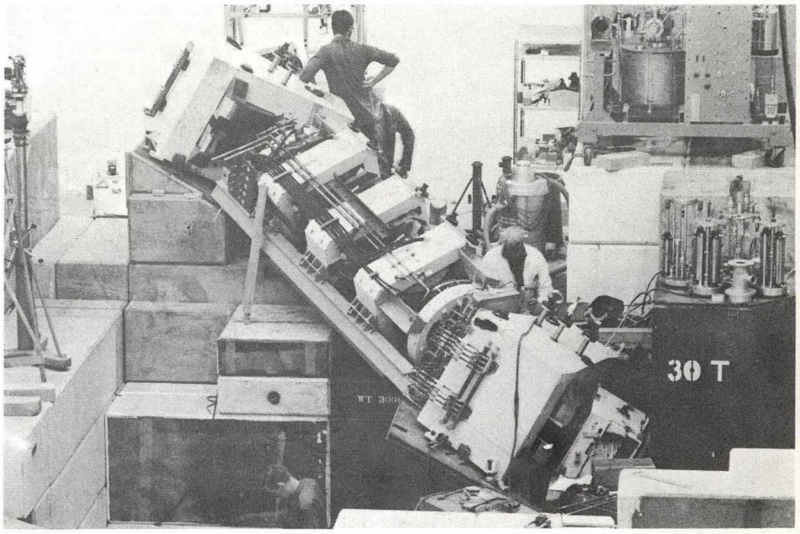


Fig. 25. View of biomedical channel.

has been named the Batho Biomedical Facility in memory of Dr. H.F. Batho without whose initial enthusiasm and planning the facility would never have been started.

Thermal neutron facility

The conceptual design of the final beam target to be used as a thermal neutron facility has been modified from the original conceptual design study reported in TRI-71-3 with emphasis on simplicity. Use was made of two-dimensional reactor code calculations to optimize flux while minimizing volume. The decrease in volume results in a saving in shielding costs and in D_2O inventory. Heat transfer studies have demonstrated the feasibility of a natural convection system of water in contact with Pb or Pb-Bi.

A TNF task force was formed this year to complete conceptual design of, and develop budgets for, the TNF, the associated extension to beam line 1, radioisotope production facilities, and related installations at the east end of the accelerator building. Various schemes for beam optics of the BL1 extension were considered, and the spill resulting from scattering in the 1T2 target upstream studied via several calculation approaches. A preliminary schedule was developed for detailed design and construction of the TNF and its environs.

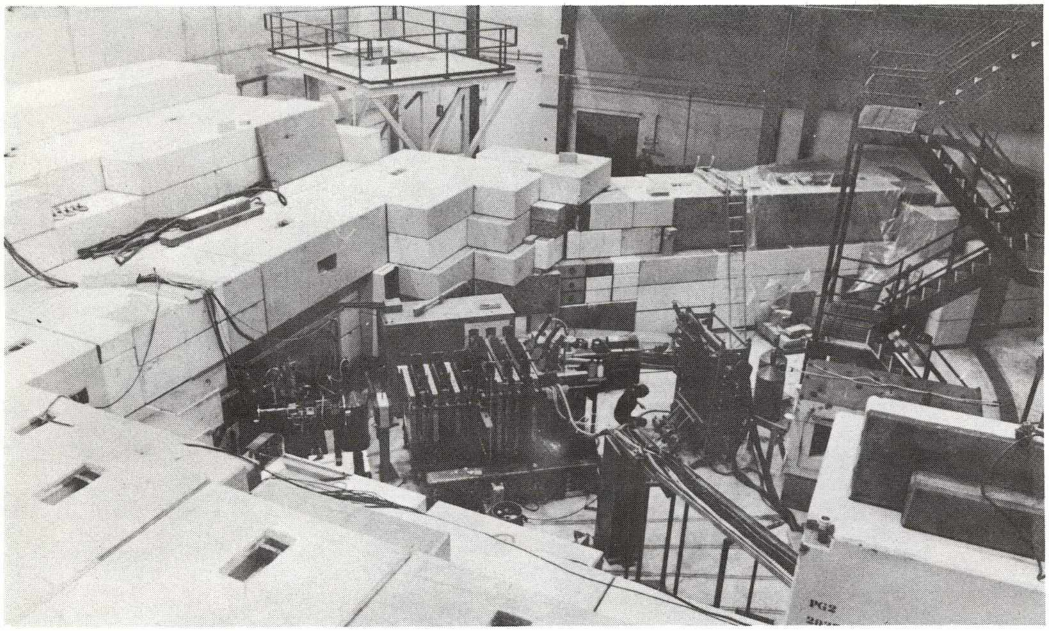


Fig. 26. View of proton hall, showing beam line 4A shielding in foreground, the BASQUE polarimeter, beam line 4B shielding, and the MRS superstructure in background.

Proton hall

Scattering chamber

During 1975 the 60-in.-diam (152-cm) scattering chamber in beam line 4A was fully operational and used by Experiment 3. Work on the chamber system accomplished early in the year included upgrading and modifying the control systems. All six remotely positionable elements (four detector arms, target ladder elevation, and target angle) are now interfaced via CAMAC to the computer system used for data collection by the experimental groups using the chamber, allowing computer interrogation and control of these elements.

Time-of-flight mass identification facility

The time-of-flight mass spectrometer (for measurements on nuclei recoiling from beta decay at the end of the radionuclide gas-jet transport system on beam line 4A) was described in the 1974 annual report.

In 1975 the last of the system components were delivered, and assembly of the apparatus was completed. A number of frustrating delays were experienced with vacuum problems (necessitating refabrication of some components) and insulating feed-through failures in the 20-kV system. In addition the chevron detector, employed in detection of heavy ions at the end of the flight path, proved to have characteristics not described properly in the manufacturer's literature; these included sensitivity to ionization from various sources, including vacuum gauges.

By year's end, however, all such problems were overcome, and the detector properties better understood, to the point that the first time-of-flight spectra could be recorded.

FERFICON facility

In July 1974, a contract was concluded with the concurrence of TRIUMF between SFU and Atomic Energy of Canada Ltd. for a series of experiments to study fertile-to-fissile conversion of nuclear fuel material by proton bombardment. The experiments are described on p. 65.

In 1975, the necessary apparatus was installed in beam line 4A. This consists of a 6-ft-diam (1.8-m) stainless-steel tank to hold water moderator, surrounding a target can (in which are mounted arrays of Pb, Th or U rods) and neutron-detection systems. The proton beam is carried to the targets by an evacuated beam pipe section.

For irradiations in this program, a section of the normal BL4A pipe is removed, and the tank assembly is motor-driven into the irradiation position.

Irradiation of 10 μA • h have been normal; 'retraction' of the tank, recovery of neutron-detection foils, and re-establishing the normal beam-line 4A pipe configuration is achieved in 20 min.

In 1975, the FERFICON target was also used as a localized radiation source in measurements of the radiation fluxes penetrating the BL4A shielding. Such tests of the TRIUMF shielding calculations will continue as shielding configurations and beam spill distributions stabilize.

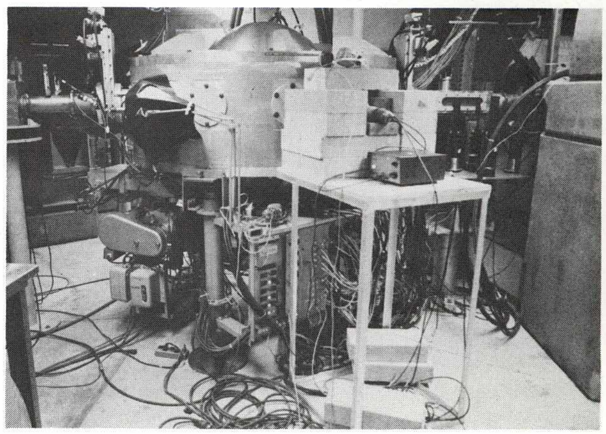


Fig. 27. 60-in. (152-cm) scattering chamber for measurement of fragments from spallation and fission reactions.

Experimental facilities on beam line 4B

The 1974 annual report described installation at 4BT1 of four detector telescope supports, remotely controlled and with digital encoding of angular position. This year, two target chambers, one rectangular and one cylindrical, have been provided.

The rectangular chamber measures 31 in. × 23 in. × 17 in. (79 × 58 × 43 cm) and couples to 4-in. (10-cm) beam pipe on its entrance and exit sides. Kapton foil windows cover angles from 37° to 102° and 146° to 170°. A 6-ft- (1.8-m) long extension piece (the 'horn') can be attached to the downstream side of the box, enabling detection of charged particles at angles between 3° and 14°.

The cylindrical chamber couples to 4-in. (1.8-m) beam pipe but reduced to 1.5 in. (3.8 cm) i.d. at its entrance and exit ports. Kapton windows permit detection of charged particles on both left and right sides over the range 10° to 170°. Support posts are set in ball-bearing-mounted rings and may be repositioned while the chamber is under vacuum. A ladder with positions for four solid targets permits remote selection of the target.

These facilities have been used in experiments to measure pion production cross-sections, proton elastic scattering at small angles, and quasi-elastic processes such as (p,2p) and (p,pd). In addition, beam development work has been carried out using a beam profile monitor which can be mounted in the rectangular chamber.

MRS proton spectrometer

Nearing completion at TRIUMF is a proton medium resolution magnetic spectrometer (MRS). This instrument, capable of a resolution of the order of 500 keV FWHM at 500 MeV, is the initial step in the construction of a high resolution proton spectrometer (HRS), the design of which calls for a quadrupole and two 60° dipoles; the MRS consists of the quadrupole and first dipole of the HRS system.

The dipole arrived on site in early April, six months late due to cutting errors by the steel supplier. The magnet was disassembled, and trim windings and the main coils installed, followed by water and power connections. First field maps were obtained in August, which indicated that a change in the geometry of the pole ends should be made. Modified pole ends were received in December.

In August also, the superstructure of the spectrometer support arm was received and installed, to await installation of the dipole. The quadrupole arrived in mid-summer and field measurements were made during the fall. A power supply for the quadrupole is under construction. The vacuum box for the dipole arrived in the last quarter of the year. This item is fabricated from 310 stainless steel and is the second such

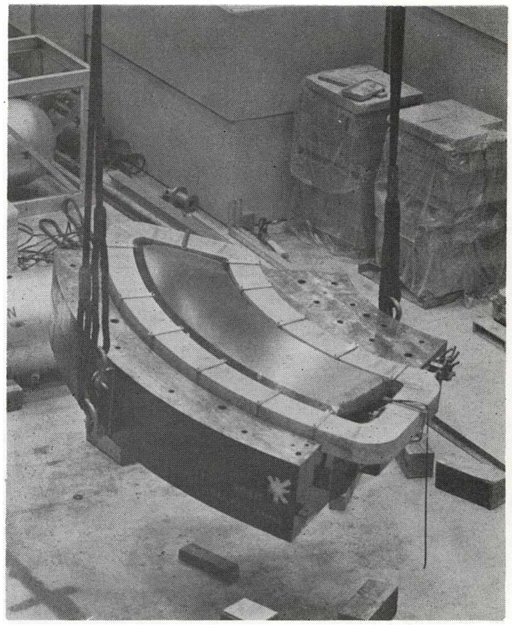


Fig. 28. Assembled dipole for the MRS proton spectrometer.

vessel to be manufactured. The original item was made from 316 stainless steel and was found to be magnetic after fabrication.

At the present time the dipole has been taken apart to allow installation of both the new pole ends and the vacuum box prior to installation of the dipole in the support structure.

14. REMOTE HANDLING

During 1975, final plans for remote handling during full-power operation were formalized. The major developments in the three areas of activity are:

Cyclotron service

A fully powered trolley for the cyclotron service bridge was commissioned. It was designed as a personnel carrier for manual surveillance, and as a work platform in the tank. It is considered as an interim or prototype trolley for evaluating electric and pneumatic power distribution, personnel communication, and electro-mechanical remote-positioning concepts. The specifications called for minimizing personnel time in the tank, giving personnel better access and services at discrete tank locations.

In addition to 'local' (on-trolley) controls, a fully remote control mode was established. The remote mode has been successfully used for radiation surveys (usually conducted when the lid first goes up after a period of cyclotron operation) and for a variety of closed circuit TV lighting tests that have led to the development of a remote-handling system utilizing TV alignment. This latter allows us to pick up or place any object (radiation monitor, pick-up tool, nut-runner, resonator, etc.) at any predetermined location to ±0.010 in. (0.25 mm). Consequently the 1° peripheral indexing (now supplemented by 0.5 in. (13 mm) radial indexing) need not be developed further.

As the resonator removal trolley is considered the most complicated of TRIUMF's remote handling tasks, a design has been completed that will remotely give all the motions/movements required and utilizes the TV locating system for final positioning and alignment.

The arrangement of bridge-trolley services has been modified to allow a 360° bridge sweep for radiation surveys that are in turn strip-chart recorded. Such surveys can be run at any desired tank radius. Remote TV surveys have also successfully been run for such tasks as checking the tank seal insertion prior to lowering the lid.

Beam line service

The radiation-hard indium seals have proved successful under both the expected thermal cycling and the unexpected gross misalignments. Temporary rubber seals were left in M9 and the LD_2 target and will have to be replaced next year.

The target-handling flask and locating bridge were completed (without all the Pb shielding) and commissioned over all five stations where targets and beam blockers must be handled (see below). Design modifications were made and installation started for remote handling all components in the shielded sections of the vault beam lines.

Hot cell service

A temporary hot cell installation (with three water windows and two manipulators) was completed, and the procedures were commissioned for loading into the hot cell of target 1T2, monitor 9 and the M9, M20 and biomedical blockers. Experience so obtained has been used in developing the design for second generation cells.

15. SHIELDING

The fabrication of the regular and special shaped iron and concrete shielding blocks currently intended for the experimental areas was completed during the year, and essentially all have been installed. The inventory of concrete blocks should, according to preliminary measurements of the operating external dose-equivalent rates, allow operating currents approaching 1 μA in beam lines 1 and 4A. Each decade increase in the beam current requires the addition of approximately 4 ft (1.2 m) of concrete around the experimental beam lines.

The fixed cyclotron vault shielding was essentially completed during the year, by pouring the outside 8 ft (2.4 m) of the wall between the cyclotron vault and the service annex. The concrete vault wall thickness now is 16 ft (5 m) everywhere.

16. SITE, BUILDINGS AND SERVICES

Budgetary restraints did not allow any major new construction or expansion of buildings during 1975.

The largest construction work during the year was the completion of the cyclotron vault south shielding wall mentioned above. The work involved the placing of 680 cubic yards (517 cubic metres) of concrete [1360 tons (1234 metric tons)] between the service annex and the cyclotron vault. The entire operation took six weeks to complete, and construction work was carefully engineered so as not to interrupt or hinder operation of the cyclotron. An access opening was broken through the exterior building wall to pump the concrete into the confined space between the control room, RF room and cyclotron vault. Despite difficult conditions, the work was completed by Mutual Construction on schedule.

1975 was also the year when the area around the TRIUMF buildings and part of the parking lot was finally paved, reducing dust and mud, and facilitating the operation of fork lifts and other vehicles around the site.

A 30 × 40-ft (9 × 12-m) extension to the existing stores building was erected to provide urgently needed fabrication and storage space for the TRIUMF machine shop. Prefabricated metal construction on a reinforced concrete slab was again chosen for economy and speed of erection.

Other minor building improvements in 1975 included:

- A portable steel stair tower to provide access from the meson hall to the power supply gallery and the top of the vault shielding
- An access gallery on top of the east vault shielding wall
- One flight of stairs on the east side and two flights of steel stairs on the west side of the vault to provide access to the vault roof
- Completion of the mezzanine in the proton hall

Electrical services

The electrical systems operated well throughout the year. The highest demand was recorded in August at 5896 kW. On two occasions it was necessary to shut down the site for repairs to the Hydro 64 kV line. There were three unscheduled power failures during the year without any serious problems. B.C. Hydro has increased TRIUMF's power costs by about 35%

and their demand charge is now made on a kVA demand rather than a kW demand. This necessitated the purchase and installation of an additional capacitor bank to increase the power factor from 0.93 to unity.

Electrical work was completed along beam line 1 and experimental channels 4B, M8, M9 and M20.

Mechanical services

All cooling systems functioned well over the year, with some cooling capacity adjustments to individual units, and improved heat transfer from heat sinks to cooling water in many power supplies. However, most systems are operating well beyond design capacity, and major additions will require new cooling systems.

The heating, ventilating and air-conditioning systems also operated well throughout the year. The duct work on the power supply floor was revised to re-distribute the air, and the air flow increased generally by 20%. This all helped to relieve high-temperature problems in this area, but it seems the only real solution will be future installation of air-conditioning.

The active cooling system was extended to cool the power supplies on the secondary lines along beam line 1 on a temporary basis. Work has begun on a more permanent installation using the cooling system from the central region cyclotron.

Two hydrogen gas exhaust systems were installed, one in the meson hall and one in the proton hall.

Cranes

Again this year many tons of shielding blocks and magnets have been moved. There have been no equipment failures; however, due to the constant use of the overhead cranes, continued maintenance is required. A thorough mechanical inspection was performed on the cranes by the manufacturer. This was the first such inspection on the cranes since they were installed, and no deficiencies were found.

17. NEW FACILITIES

The New Facilities group was formed in August 1975, and is somewhat unusal in that it is not oriented toward accomplishing a particular mission; rather the members of the group are involved in a number of diverse projects. The function of the group is to assist in the planning and development of new facilities which are of general importance to TRIUMF, and to work closely with task forces engaged in execution of large projects, especially in the planning stages of such projects.

Beam Line Faraday Cup. A Faraday cup has been designed to directly measure the proton beam current with an accuracy of 1%. Fabrication is under way in the TRIUMF machine shop.

New Beam Line Proposal. A cost estimate and technical critique was performed on a proposal for a new beam line in the proton hall. An alternative means of performing the proposed experiments was suggested.

M9 Commissioning. The group is assisting with the tuning and optimization of the backward scattered pion channel at 1T2 on beam line 1.

Beam Spill Monitors. An inexpensive gas-filled ionization chamber has been designed and tested. A large number of the chambers will be used to measure beam spill as a function of position along beam line 1 and around the cyclotron. The chambers are in the final stages of fabrication in the TRIUMF machine shop.

Beam Spill for the Thermal Neutron Facility. A calculation has been performed on the beam spill to be expected downstream of 1T2. The calculation is important in designing the shielding and beam line between 1T2 and the TNF. Details of the calculation are in TRIUMF design note TRI-DN-75-10.

Production of Radiopharmaceuticals by Proton Bombardment. A collaboration between TRIUMF and Vancouver General Hospital (VGH) has been formed to study the feasibility of large-scale production of iodine-123 through its xenon precursor. VGH has applied for and received licence to manufacture labelled radiopharmaceuticals for distribution in Canada. The reactions $^{127}I(p,5n)^{123}Xe$ and $^{133}Cs(p,2p9n)^{123}Xe$ are being studied by activation, to permit choice of the most promising target material and beam energy. The dynamics of a generator-type target for continuous rather than batch production have been examined, and the thermodynamics of a molten cesium system have been studied. A model target has been fabricated for testing near the beam dump on beam line 4A.

18. INSTRUMENTATION

The TRIUMF Instrumentation Advisory Committee continued to hold monthly meetings during 1975.

The TRIUMF Instrumentation Pool was able to provide a new service in 1975, the rental of instrumentation to experimental groups working on approved experiments. In addition, the Pool has continued to evaluate new instrumentation and update its list of TRIUMF standard instrumentation. Facilities for evaluating and testing CAMAC instrumentation were greatly improved with the acquisition of a small NOVA computer. The full listing of TRIUMF nucleonic instrumentation was committed to computer storage (on the UBC IBM 370/168). By this means, day-to-day editing, including recording of the fault history of individual items, is greatly facilitated.

The present list of TRIUMF standard instrumentation is shown in Table IV.

Table IV. TRIUMF Standard Instrumentation

1. RACKS	Type 000003070
Premier Metal Housings (Montreal)	
2. POWER SUPPLIES, BINS AND CRATES	
NIM bins	
Bin and power supply: B.L. Packer	Bin NB10
	200W power supply 1001-3
CAMAC crate	
Crate: GEC Elliott	VC0011/CP1
Power supply: B.L. Packer	1031 BC (300W)
Photomultiplier high voltage:	Power Designs 1570
High voltage distribution:	TRIUMF THV100
3. PHOTOMULTIPLIERS AND HOUSINGS	
2 in. 12-stage, bi-alkali photomultipliers:	RCA 8575R or RCA 8850R
Housings:	N.P.W. England Ltd.
4. NIM MODULES	
Fast NIM	
Discriminators, quad updating:	LRS 621 L
bridged input version:	LRS 621L/4
quad zero-cross:	EGG T140 NL
constant fraction:	ORTEC 473 (requested for evaluation)
AND (coincidence) gates:	
Triple 4-fold logic:	LRS 465
[Dual 4-fold majority logic LRS 364 and 365 accepted but not recommended for new purchases]	
Dual 4-fold overlap:	TRIUMF B024
Quad 2-fold overlap:	TRIUMF B042
Quad 2-fold AND/or (updating):	LRS 622
[LRS 322A accepted but not recommended]	
OR gates and logic fan-out:	
Logic 8-fold fan-out	TRIUMF 14X2951 } LRS 429
OR gate: Dual 4-fold	TRIUMF 14X3001 } LRS 429
Linear Fan-in/Fan-out	LRS 428
[LRS 127 and 128 accepted but not recommended for new purchases]	
Linear gate:	Borer 330
Linear gate and stretcher (integrator):	EGG LG 105/N
Legal converter (NIM Fast ←→ TTL):	LRS 688 AL and EGG L1380/NL
Gate pulse and delay generator:	EGG GG202
Scaler (visual display): 100 MHz, 6 digit:	
Dual unit:	Joerger VS
[accepted but not recommended]	ORTEC 772
Variable delay units (cable-switched):	
Passive '64 nsec':	TRIUMF BO 07

4. NIM MODULES (cont'd)	
Variable attenuators (50Ω)	LRS A101 L
Fast pulse generator: (Berkeley)	BNC 8010
High resolution ADC:	
10-bit amplitude encoder (requires scaler for read-out)	EGG EA 101/N
High resolution TDC:	
10-bit time encoder (requires scaler for read-out):	EGG EA 102/N
Spark chamber TDC (routing unit):	
Clock generator (up to 200 MHz) and scaler required. Dual unit:	TRIUMF BO 0100
Slow NIM	
Gate biased amplifier	ORTEC 444
Research amplifier	450
Timing filter amplifier	454
Delay line amplifier	460
Delay amplifier	427A
Linear gate	426
Linear gate and stretcher	442
Fast coincidence	414A
Universal coincidence	418A
Time-to-pulse-height converter	467
Gate and delay generator	416A
Precision pulse generator	419
5 kV power supply	459
Constant fraction timing SCA	455
Digital current integrator	439
Biased amplifier	408A
5. CAMAC MODULES	
Coincidence buffer (pattern unit): Dual 12-fold	EGG C212
Multi-ADC: Octal 8-bit units	LRS 2248
or	NE 9040
Multi-TDC: Quad 9-bit	LRS 2226A
Octal 10-bit	LRS 2228
Scalers: Hex 24-bit, 100 MHz:	Kinetics 3615 *
Crate A controller:	Kinetics 3900
[GEC Elliott accepted but not recommended for new purchases]	
TTY output:	NE 7061-1
16-bit (relay-type) output register:	GEC OD 1606
24-bit (TTL) output register:	SEC PR 612
24-bit in/out (TTL) register:	NE 9017
24-bit input gate	SEC PG 604
16-fold fast NIM out:	SEN
256-bit input gate (for MWPC)	GEC

*[LRS - 2550 quad units accepted but not recommended for new purchases

B. EXPERIMENTAL AND THEORETICAL PROGRAM

1. INTRODUCTION

This year has been an exhilarating experience for the experimental groups, as they have had the first opportunities to attempt research with the TRIUMF facilities. At times the beam has been quite spasmodic, and significant advances in reliability will be required before the more difficult experiments can be contemplated. Nevertheless, a lot has been accomplished; several experiments are now set up and taking data, and Experiment 79 on pion production and Experiment 14 on small-angle proton scattering from ^{4}He have been completed.

The proton area was operating soon after the first full-energy beam was extracted. In beam line 4B the Experiment 79 group has completed their survey of π^+ production, and the energy of the beam being stable but adjustable proved very useful in showing beyond doubt that pion production increases monotonically with proton energy. In proton scattering experiments, the polarized beam is eagerly awaited. The quasi-scattering experiments are under way and preliminary data have shown that the equipment works well. In beam line 4A the BASQUE group has tested the deuterium target with liquid hydrogen, has commissioned their complete array of wire chambers, and is now ready to take data on the triple scattering parameters in proton-proton scattering (Experiment 74). The scattering chamber is working and preliminary data on Experiment 3 have been taken; similarly, the gas-jet facility has been commissioned and γ-ray spectra have been obtained for the radioactive products from reactions produced by high-energy protons.

Progress in the meson area was delayed because of the time needed to complete the meson production target 1T2 and the meson channels. The initial tests were started in June, and within a month all three meson channels were operational. There followed several months of commissioning in which the characteristics of the three meson channels were studied, and extensive data now exist (for beams at various energies) on μ-e contamination, momentum resolution, etc. In the last few months of the year, preliminary work started on various experiments, but problems with the cyclotron seriously delayed the experimental program. However, the μSR group has taken spin precession data and there are indications that Experiment 73 has observed interesting effects. The other groups (TINA and University of Victoria) have tested their equipment and are ready to take data.

A full list of the experimental proposals is given in Appendix 5. Proposal summaries may be obtained from the Secretary of the Experiments Evaluation Committee (J.E.D. Pearson, Physics Department, University of British Columbia).

2. BEAM LINE 1 EXPERIMENTS

Experiments 1, 54
Pi scattering and total cross-section measurements

A continuing collaborative beam development program by all M8 users has resulted in a well-understood channel. Fig. 29 gives a preliminary 30-MeV π^+ time-of-flight spectrum. The pion production target at 1T2 was copper, and the channel tune agrees well with optics calculations via the TRACTUS program.[1] These indicate that the dispersion plane slit axes intercept some beam and account for most of the discrepancy between design specification and performance. With 300-nA proton beam on 1T2, the channel delivers 3.2×10^5 π^+/sec to the experimental area.

Three M8 channel shifts have been devoted to experimental development. Plastic stopping counters are used with the π^+ beam, since their resolution is adequate for initial experiments, and Fig. 30 shows a pulse height spectrum from 30-MeV π^+ in the stopping counter. The FWHM resolution (about 1 MeV) was obtained with a 1-in. (2.5-mm) slit and a π^+ flux of about 7×10^4 π^+/sec, while the target beam spot was constrained to a 1-cm by 1-cm area. After installation of electronics for rejection of muons produced by decay in flight, data-taking will begin. A slow CAMAC data link between the biomedical area and the pion scattering trailer has been installed, allowing static scaler readout but no interrupt handling.

A CAMAC-FORTRAN interface program was developed as a summer student project. The computer is presently shared with the pion production group (Experiment 10). A series of subroutines are available to allow CAMAC

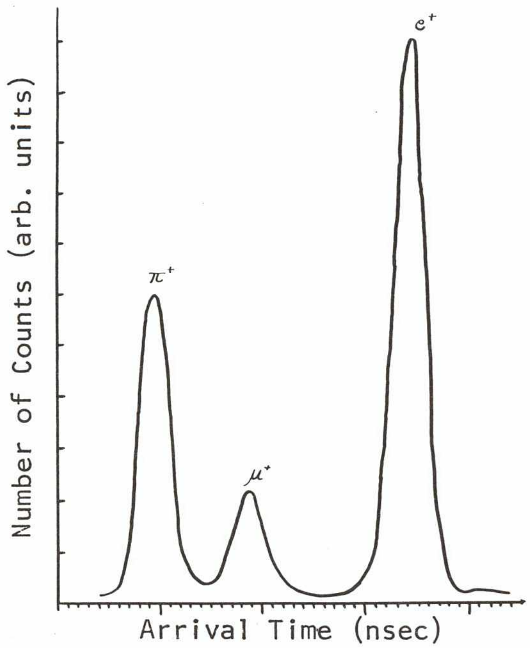


Fig. 29. Time-of-flight spectrum with biomedical channel set to accept 30-MeV pions.

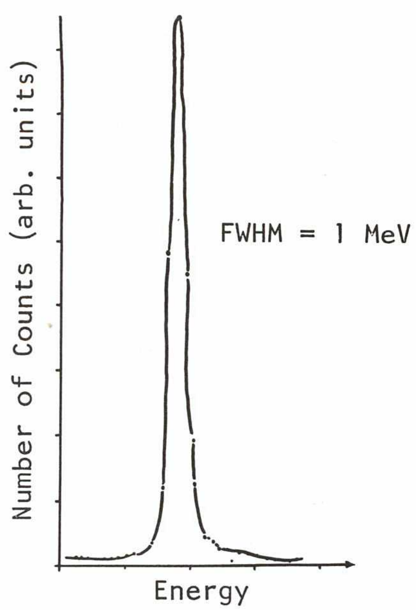


Fig. 30. Pion energy distribution with the channel set for a nominal 30 MeV.

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[1] K.R. Kendall, B.C. Cancer Foundation

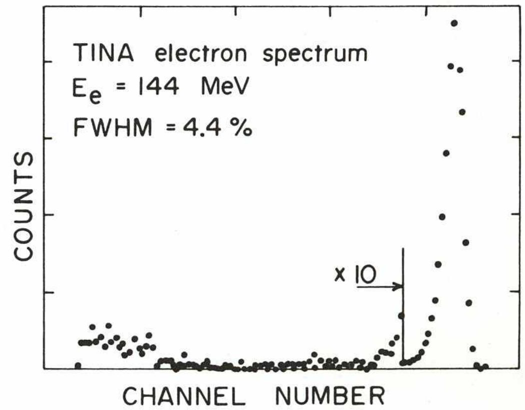

Fig. 31. The pulse height spectrum of the large NaI scintillator from a 144-MeV beam of positrons in the M9 channel. The spread of 4.4% in pulse height is primarily due to the energy spread of the positrons.

sequences to be defined while writing a FORTRAN program. Interrupts from CAMAC may be serviced and data channel transfers performed. The programming technique is moderately fast, allowing a nuclear event rate of about 10^3 per second, and makes available all real-time FORTRAN programming options. The pion production experiment uses the CAMAC-FORTRAN interface extensively. The pi scattering experiment uses the computer for small angle event-by-event analysis and data reduction.

Experiment 9
$\pi^- + p \to \gamma + n$ at pion kinetic energies from 20-200 MeV (TINA)

The past year has seen the installation and commissioning of a lot of complex experimental equipment. The counting room has been fitted out and is now a satisfactory centre for the control of the experiment. The PDP-11/40 from the Université de Montréal has been working for several months now, and has been successfully used during several experimental runs. In the M9 area, a hydrogen target has been installed downstream of the Corvallis magnet, and should be operational in January 1976. It will be used with a stopping π^- beam to make a new determination of the Panofsky ratio in hydrogen and to search for the allowed reaction ($\pi^- + d \to \pi^0 + n + n$) which has never been observed.

The RF structure of the beam from the TRIUMF cyclotron has proved ideal for time-of-flight studies with the pion beam. It has been possible to determine both the energy and composition of the beam by measuring the time difference between the RF and the pulses in a single counter. The best results have been obtained with a chopped beam, for which the timing resolution is about 1.5 nsec.

The TINA crystal [a NaI detector measuring 18 in. (46 cm) in diameter and 20 in. (51 cm) long] has been tested using the electron component of the M9 beam; the timing resolution is about 2 nsec, and the energy resolution was about 5% at 100 MeV and 4.4% at 144 MeV (see Fig. 31). This was dominated, however, by the energy spread in the electron beam. In the spectral response of the crystal, it has been confirmed that the low-energy tail is very small, and that almost all the pulses are in the full-energy peak. To obtain better spectra, it will be necessary to stop a π-beam in the liquid hydrogen target, but our tests to date indicate that the characteristics of the NaI detector are as good as, and maybe even better than, we had anticipated.

Experiments 23, 57
Search for decay modes $\pi^0 \rightarrow 3\gamma$ and $\mu^+ \rightarrow e^+ + \gamma$; and investigation of the decay mode $\pi^+ \rightarrow e^+ + \nu_e + \gamma$ (MINA)

In 1975, a PDP-11/40 computer was transferred from Montreal (where it had been used for program development) to the TRIUMF site, together with CAMAC crates and various modules. The second large NaI (MINA) was received in April from Bicron Corporation (Newbury, Ohio) and was subjected to a series of acceptance tests. It is a 14-in. diam by 14-in. long (36 × 36 cm) crystal, equipped with 4 RCA 4522 tubes.

Preliminary tests in the M20 channel at TRIUMF, using electrons produced at the 1T2 target, indicated upper limits on the resolution consistent with those expected from such detectors, (the momentum acceptance of the channel, ∿6%, being of the same order as the resolution measured).

Timing resolution was determined with cosmic rays as being 3.2 nsec FWHM for a dynamic range 1:20 using constant fraction discriminators, and 2.8 nsec for a restricted range of 1:4 (50 to 200 MeV). These numbers compare very well with those obtained for TINA, although better energy resolution was obtained with the latter (4.4% at 144 MeV).

Computer simulation of the group's first experiment (23a, measurement of branching ratio $\pi^+ \rightarrow e\nu\gamma$) showed that, using realistic (measured) response functions from the two NaI detectors and approximate stopping distributions for the π^+, and by calculating energy-dependent efficiencies, it should be possible to get an accurate prediction of the axial form factor for π^+ with 1000 events. This experiment requires $\sim 10^6$ stopped π^+ and a good beam spot, conditions which will be met by the M9 channel as soon as 1 μA of protons are available onto 1T2.

Experiment 41a, b
Radiative pion capture

This experiment will study the radiative capture and charge exchange of pions in nuclei using the two large NaI detectors at TRIUMF (TINA and MINA).

Most of the group's efforts during the past year have been on channel development and measurement of detector properties, although preliminary gamma-ray spectra were obtained during one 6-hour period, by stopping π^- mesons in CH_2 and LiH targets. In this way an energy resolution of 5% FWHM was obtained for the 129-MeV γ-ray from $\pi^- + p \rightarrow \gamma + n$, but unfortunately the statistics were rather poor. A study of a pulse-shape discrimination system to reject neutron events is currently under way as an alternative to the time-of-flight method.

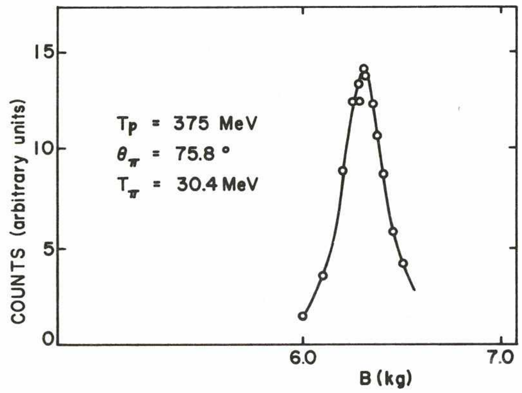

Fig. 32. The coincidence rate of pions from $pp \rightarrow d\pi$ as a function of the magnetic field in the Browne-Buechner spectrograph. The energy of the pions gives a good check on the proton energy.

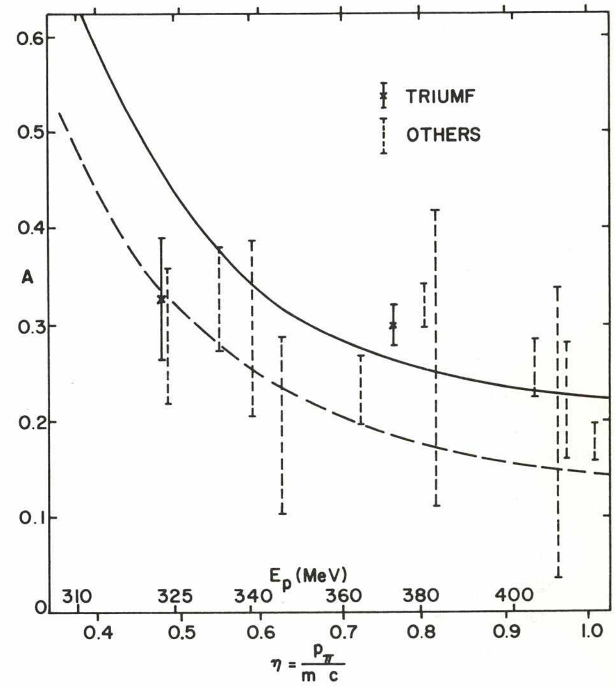

Fig. 33. The parameter A in $d\sigma/d\Omega \propto A + \cos^2\theta$ for the reaction $pp \rightarrow d\pi$. The curves are the results of phenomenological calculations due to Measday (solid curve) and Crawford and Stevenson (broken curve).

Experiment 10
Pion production

Instrumentation associated with the 50-cm Browne-Buechner magnetic spectrograph, including its 24-element scintillation counter hodoscope and additional coincidence counters, was completed prior to receiving first beam in April 1975. Pions produced by the $pp \rightarrow d\pi$ reaction in a thin CH_2 target were readily detected. Following the addition of local shielding to improve the background level, the $pp \rightarrow d\pi$ reaction was observed at proton energies of 395, 375, 350 and 325 MeV.

The spectrograph, which subtends a solid angle of 2 msr at the target, can be rotated over the angular range 35-145° with respect to the beam direction. The energy resolution of the spectrograph, determined by the size of the hodoscope counters, is 2% of the central energy (e.g. 1 MeV for 50-MeV pions), a value comparable with the energy spread of the proton beam and the spot size at the target. As the spectrograph is intended for measurements of low-energy pions (15-100 MeV kinetic energy), a momentum calibration of the system was readily accomplished with an ^{241}Am alpha-particle source (equivalent to 32.7-MeV pions).

To date, measurements of the $pp \rightarrow d\pi$ reaction have employed a CH_2 target of 1/16-in. (1.7-mm) thickness. A typical measurement of the $pp \rightarrow d\pi$ pion line is shown in Fig. 32, where the coincidence event rate (involving hodoscope 10) is plotted as a function of magnetic field. The position of the line affords a convenient determination of the incident proton energy, which can be obtained by this means to an accuracy of ±0.5 MeV.

Preliminary angular distribution measurements have now been made at proton energies of 375 and 325 MeV, by recording such pion lines at a number of angular positions. The results are normalized to the counting rate obtained in a scintillation counter telescope fixed at 90° to the beam. The results were fitted to a distribution of the form: $d\sigma/d\Omega \propto A + \cos^2\theta$ (in the centre-of-mass system). The value of A obtained from these measurements is shown in Fig. 33. The curves shown illustrate the expected dependence according to the phenomenological theory of Gell-Mann and Watson, fitted to total $pp \to d\pi$ cross-section data. The two curves refer to different assumptions regarding the momentum dependence of the total cross-sections. More measurements are planned in the 310-MeV region, as well as measurements of the azimuthal asymmetry of pion production, when the TRIUMF polarized proton beam becomes available.

Experiments 35, 60, 71, 73, 78
The muon spin research (μSR) experimental program

From the group's preliminary experiments at the 184-inch synchrocyclotron in Berkeley in the past few years, as well as experiments by others at the SREL machine in Virginia and at the JINR synchrocyclotron at Dubna in the USSR, it has become abundantly evident that the muon is an exciting new tool for a whole range of interdisciplinary research in chemistry and solid-state physics. The unique utility of the muon probe is evidenced by the extensive research programs now (or soon to be) under way at SIN and at TRIUMF; five separate proposals for muon experiments have been approved by TRIUMF's Experiments Evaluation Committee.

The μSR channel (M20) was originally expected to produce experimentally useful muon fluxes when TRIUMF reached intensities of ≳1 μA. Fortunately, there is a large flux of 'cloud muons' (see p.41) which, though poorly polarized, make experimental work feasible at present intensities (300 nA on 1T2). Results should accumulate quickly, as soon as the beam current on the 1T2 target begins to improve.

In the meantime, a great deal of tuning and development of experimental hardware has taken place; preliminary experiments have demonstrated the power and flexibility of the μSR data acquisition and analysis system, which is based on a PDP-11/40 computer with a Bi-Ra MBD-11 pre-processor interface between CAMAC and the PDP-11. The MBD is a fast minicomputer (3 nsec) which handles all CAMAC operations and transmits 'partially digested' data directly into the memory of the PDP-11. The entire system is supported by the versatile RSX 11-D software. An effective experimental control program, based on a graphical display with light-pen commands, is now in use. *Simultaneous* access to the entire system, including CAMAC, can be made available to 'parasitic' experiments and other users; a data link from the Université de Montréal computer has recently been implemented in a preliminary configuration.

Three separate arrangements of μSR apparatus have been completed and tested under data-taking conditions: A Varian magnet from the University of Tokyo, with associated counters, provides a very uniform field up to

10 kG; it was used to obtain the carbon μ^+SR spectrum shown in Fig. 23 (p.41). A Helmholtz coil, obtained from the University of Arizona, provides fields up to 150 G with complete freedom of access to the target; in October it was used in the successful observation of MSR (muonium spin rotation) in quartz at a field of 3 G. An air-cooled magnet from AECL Chalk River (the 'Chalk River magnet') has been modified for use in Experiment 73, where it provides fields up to 7 kG in an inter-pole spacing of 5.5 in. (14 cm), large enough to accommodate the counters and a sophisticated cryostat containing the target. Preliminary results are highly encouraging and suggest, as hoped, that the large hyperfine field in an erbium target will re-polarize a μ^- in its 1s orbit. More beam time is, however, needed to definitely establish the effect. In addition, a superconducting magnet (recently shipped from Tokyo) will be used to produce magnetizing fields up to 50 kG for use in Experiment 73 and in various longitudinal-field studies.

The Tokyo contingent has made available to the μSR group an impressive array of high- and low-temperature apparatus for solid-state μSR studies. This includes a 20°K mechanical refrigerator, and a helium dilution refrigerator which can routinely operate at 0.1°K and is capable of reaching 0.02°K. A target oven has also been prepared, such that controlled temperatures from 0.1°K to several hundred degrees centigrade are available. These will be used initially to study internal hyperfine fields in a variety of precious ferromagnetic targets which are now on hand. They include large single crystals of pure Fe, Ni and various Ni alloys, as well as other ferromagnetic materials, such as Co, Gd and various Hensler alloys.

A complete apparatus for gas-phase muonium chemistry studies is ready for use as soon as the μSR channel has been tuned for selection of Arizona muons, for which it is now equipped. An apparatus for investigating muonium diffusion in powdered insulators (Experiment 60) is also being readied for use with such muons.

In summary, a large collection of experimental apparatus has been prepared for μSR research, and waits only for a consistent and substantial beam to begin producing results.

Experiment 61
Biomedical experimental program

As noted above, under Experiments 1 and 54, much initial effort has gone into optimizing the beam flux from the channel. The flux now agrees with that theoretically predicted, to within the uncertainty of the π^- production cross-section from 500-MeV protons. The upstream half of the beam line was tuned to give a good dispersion and a focus at the beam-line mid-plane. This was established by placing a narrow aperture at the mid-plane and investigating the variance of the pion range in water as a function of various magnet settings. The minimum variance was found and the resulting range curve is shown (Fig. 34). This range curve corresponds to $\Delta p/p$ of approx 2%, after the width due to the counter

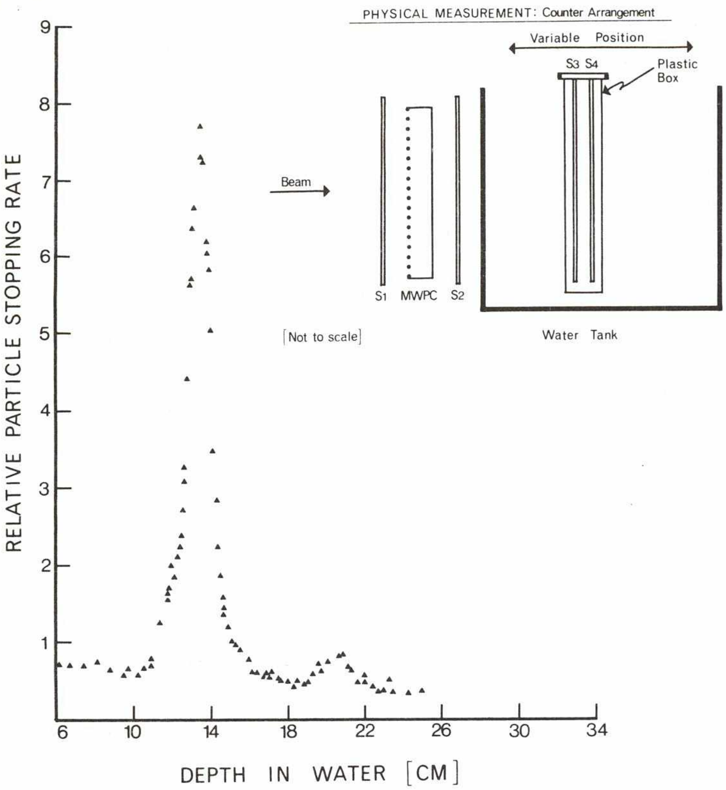

Fig. 34. Differential range curve.

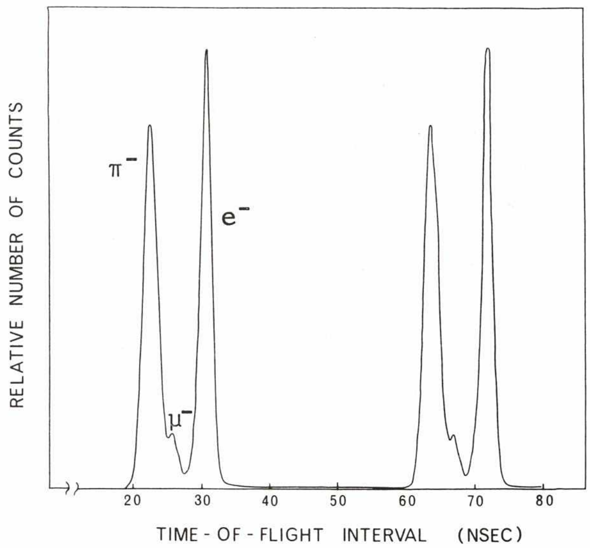

Fig. 35. Time-of-flight spectrum at 148 MeV/c from a Be target.

thickness and range straggling have been corrected for. The dispersion was measured to be 0.6 cm/$\Delta p/p$ %.

The particle composition of the beam was found to be best determined by time of flight. Typical results from a Be target at 1T2 show an electron contamination of approx 46% (Fig. 35). Whether this can be improved with other targets has not yet been determined. Only preliminary studies of the beam size and shape at the end of the beam line have been made. It is, however, possible to vary the size of the irradiation field over a large range. Detailed calculations of the beam characteristics have been carried out during the shutdown of the cyclotron at the end of 1975.

During the year no biological irradiations were made at TRIUMF, as the flux of pions remains too low. However, control studies using cobalt-60 γ-rays were carried out at the B.C. Cancer Foundation to establish baselines for the effects of radiation on mouse skin, spinal cord and lens of the eye and on the lower abdominal region of pigs. Such studies are sufficiently advanced to allow comparison with pion irradiation as soon as a sufficiently intense beam becomes available.

3. BEAM LINE 4A EXPERIMENTS

Experiment 3
The production of light nuclear fragments

During 1975, the fragment measurement equipment has grown to a configuration with a 3-detector 'monitor telescope' at a fixed position and a movable 5-detector 'fragment telescope'. The monitor telescope collects data in a ΔE-E-E_{reject} mode; it also monitors the product of the beam intensity and effective target thickness by measurement of helium isotopes in a fixed-energy range, determined by single-channel analysers on the E and E_{reject} detectors. The fragment telescope is a set of silicon detectors of increasing thicknesses, designed to collect information over a wide range of fragment energies, that allows optimum identification of fragment type.

Initial studies demonstrated isotopic resolution for fragments up to Be or B, and elemental resolution through oxygen or fluorine, both from a Ag target. The first collection of experimental data stimulated work on improved algorithms for fragment identification, which now yield good fragment identification over larger ranges of fragment type and energy than in previous studies.[1,2] Fig. 36 shows a histogram of the particle

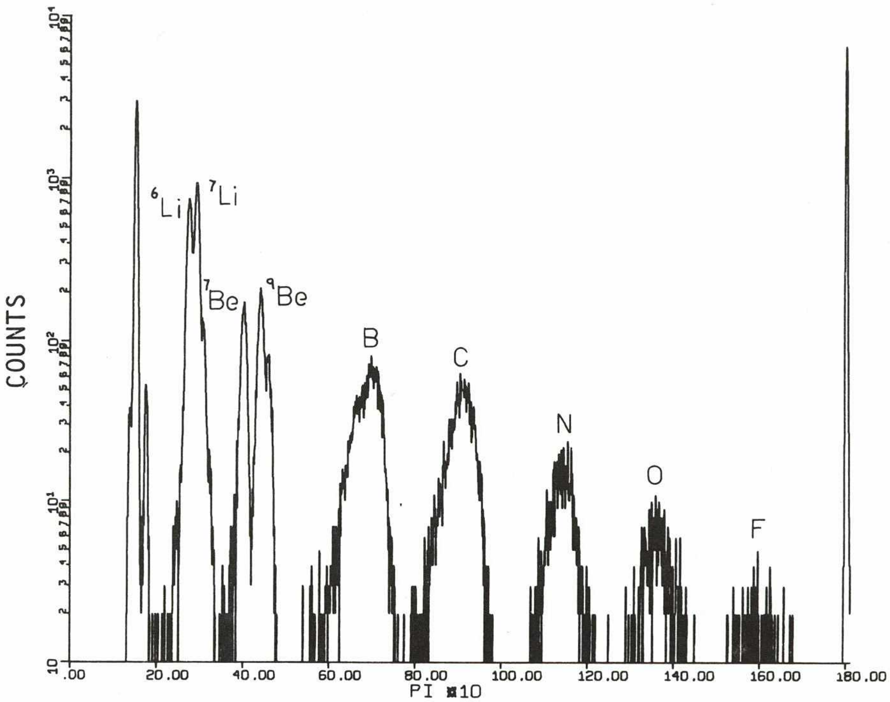

Fig. 36. Fragment spectrum from Ag at 90° with incident 480-MeV protons.

[1] E. Volnin, A. Vorobejov, V. Grachow, D. Sleverstor and E. Spiridenkov, Publication #101, June 1974, Leningrad Institute of Nuclear Physics.
[2] A. Poskanzer, G. Butler, E. Hyde, Phys. Rev. C3, 882 (1971); E. Hyde, G. Butler, A. Poskanzer, Phys. Rev. C4, 1759 (1971); R. Korteling, C. Toren, E. Hyde, Phys. Rev. C7, 1611 (1973).

identification values (PI) generated by the analysis program for events of all energies observed in one experiment. Signals from all hydrogen isotopes and from most of the energy range of the helium isotopes were eliminated in the electronics to conserve analysis time. The identification is quite good considering that a 16.6-μ-thick ΔE detector was used, in order that low-energy fragments could be observed.

Fig. 37 shows differential cross-section data for ^{7}Be emission from Ag, which display the general qualitative features expected from higher-energy work and from cascade-evaporation calculations; they also indicate an unexpected excess cross-section on the low-energy side of the cross-section. Possible instrumental or analysis difficulties which might be responsible are being checked, but so far none has been found.

Close examination of the energy loss distribution of ^{4}He and ^{7}Be in 16- and 34-μ totally depleted silicon surface barrier detectors, used in ΔE-E measurements, has shown that the FWHM in energy does not decrease smoothly with increasing particle energy, as would be expected from previous results.[3] The variation in width, as illustrated in Fig. 38, is beyond statistical deviation, and is reproducible. A closer inspection of the data suggests correlation with the velocity of the K-shell electrons in the silicon, as large variations in the resolution are found consistently at those particle velocities that coincide with that of the silicon K-shell electrons. A similar effect might be expected to occur at particle velocities equivalent to that of the silicon L-shell electrons. These observed variations are similar to those found in x-ray absorption fine structure.[4]

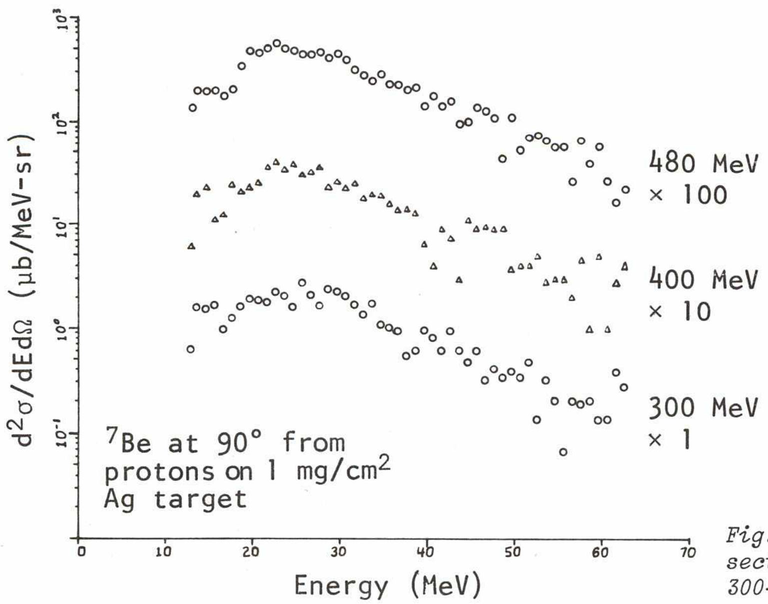

Fig. 37. Double differential cross-sections at 90° for ^{7}Be from Ag with 300-, 400- and 480-MeV protons.

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[3]V. Avdeichikov, E. Ganz and O. Lozhkin, Nucl. Instr. & Meth. 118, 274 (1974).
E. Stern, Phys. Rev. B10, 3027 (1974);
F. Lytle, D. Sayers and E. Stern, Phys. Rev. B11, 4825 (1975);
E. Stern, D. Sayers and F. Lytle, Phys. Rev. B11, 4836 (1975).

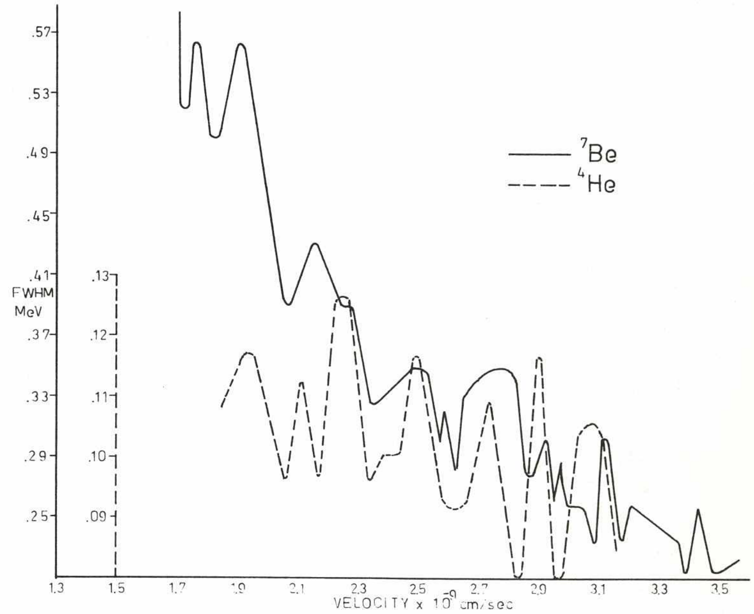

Fig. 38. FWHM distributions for energy loss by ^{4}He and ^{7}Be as a function of particle velocity incident on 16-μ silicon surface barrier detectors.

Experiment 11
Gas jet

Experimental work was begun in 1975, initially with beam line 4A currents of a few nanoamperes, rising to 50 nA near the end of the year. First efforts have been directed towards evaluating performance of the gas-jet radioactivity transport system, and taking the first nuclear spectroscopic data on short-lived nuclides.

The transport efficiency of the gas-jet system for fission fragments from a uranium foil target has been investigated, with 500-MeV protons as projectiles. With the first large-volume target chamber employed, yields were good with ethylene gas, nitrogen plus ethylene, and also nitrogen plus methanol or benzene injected as an aerosol, although average transport times (due to gas residence in the chamber) were found to be uncomfortably long at a few seconds.

Transport efficiency in the same chamber for products of spallation of Ag at 500 MeV was close to zero. This was thought due to the short range of such products, and the existence of a dead layer near the target surface not effectively flushed by the gas stream. A redesigned chamber, with this feature corrected and with a smaller total volume to reduce gas residence time, is installed ready for testing. It should provide access to nuclides of half-life of less than one second.

Transport efficiency was found to be good for spallation products from an argon gaseous target (mixed with ethylene for transport), and from iodine bombarded as an aerosol of methyl iodide dissolved in methanol injected into nitrogen carrier gas. Identification of the spallation product nuclides collected at the end of the transport system was effected by gamma-spectrum analysis. Tests are planned of other aerosol systems, as this seems to be a useful general technique.

The time-of-flight mass spectrometer for nuclei recoiling from beta-decay processes (which was described in last year's annual report) has been assembled and leak checked. Problems with the chevron ion-detector and ion-acceleration high voltage system have been overcome and the first ion time-of-flight spectra obtained. In addition, a beta-scintillation spectrometer system has been built for application in beta-gamma coincidence measurements on short-lived nuclei. The objective is decay energy measurement, and hence mass measurement, on nuclei remote from stability.

Measurement of x-gamma and gamma-gamma coincidence spectra plus spectrum peak decay half-lives has permitted identification of a large number of fission products of U + 500-MeV protons (in comparison with products from U + 14-MeV neutrons) and acquisition of nuclear spectroscopic data. Data analysis is proceeding.

Experiment 40
BASQUE

The objective of this group is a precise determination of the pp and np elastic scattering amplitudes in the energy range 200-520 MeV, by means of measurements of Wolfenstein parameters, polarization, and $d\sigma/d\Omega$. The first two will be measured by scattering of polarized beams of protons or neutrons from liquid hydrogen, and analysis of the polarization of scattered protons in a polarimeter.

The unpolarized extracted proton beam, electronics and polarimeter were set up between February and June, and test data were taken in August with a hydrogen gas target. The first liquid hydrogen target was commissioned during September and October.

The polarimeter consists of a carbon plate (3 or 6 cm thick, according to proton energy) sandwiched centrally in an array of 12 multi-wire proportional chambers. The front 6 chambers, defining the proton incident on the polarimeter, have active areas of 50 cm^2; the back 6, defining the scattered proton, have active areas of 100 cm^2. The measurement efficiency for a useful scattering event in 6 cm of carbon is 5%, with an analyzing power which varies with energy and scattering angle, but is typically 35%. The array has an overall efficiency better than 99%, and is capable of recording 250 events/sec.

The first stage of the experiment consists of calibrating this polarimeter using protons of known polarization from pp elastic scattering. The spin of the proton is precessed alternately ±90° using a superconducting solenoid, as a check against instrumental asymmetries. The calibration has been completed at two energies with statistics of 5×10^5 scatters

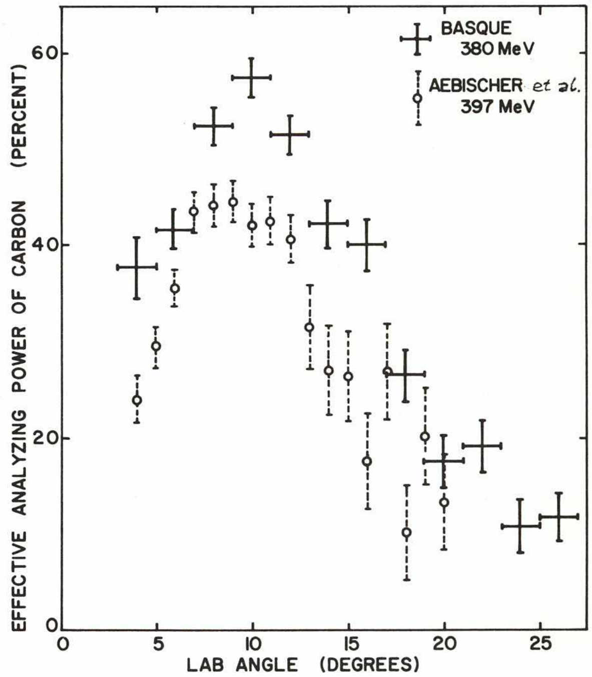

Fig. 39. Preliminary results on the analyzing power of carbon at a proton energy of 380 MeV. The values given in Ref. 1 are shown for comparison.

at each energy. The preliminary result, shown on Fig. 39, at 380 MeV gives an analyzing power somewhat higher than that observed by Aebischer *et al.*,[1] but in close agreement with the older results of Birge and Fowler.[2] This calibration will be repeated at 40-MeV steps.

Experiment 48
FERFICON

An experimental program has been undertaken by Simon Fraser University under a contract from Atomic Energy of Canada Ltd. to measure the neutron yield and consequent fertile-to-fissile conversion reaction rates in high mass, thick targets bombarded by high-energy protons. The particular conversion reactions of interest are radiative neutron capture in ^{238}U and ^{232}Th leading through two β-decay steps to the production of ^{239}Pu and ^{233}U, respectively.

The apparatus and equipment have been commissioned for measuring the neutron yield from proton stopping targets, via the thermal neutron flux in a 6-ft-diam (1.8-m) water tank surrounding the targets. Two methods have been used to measure the neutron flux: one is gold foil activation and the other is measurement of the β current through a thin MgO insulation layer surrounding a thin vanadium wire. Data have been obtained by both methods for a 10-cm-diam, 30-cm-long lead target with 500-MeV protons incident. Future measurements will be made on natural uranium and thorium targets, of various sizes and at two proton energies.

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[1] D. Aebischer, B. Favier, G. Greeniaus, R. Hess, H. Junod, C. Lechanoine, J.C. Nicklès, D. Rapin and D. Werren, Nucl. Instr. & Meth. 124, 49 (1975)
[2] R.W. Birge and W.B. Fowler, Phys. Rev. Letters 5, 254 (1960)

4. BEAM LINE 4B EXPERIMENTS

Experiment 14
Elastic scattering of protons from ⁴He

During the past year, calibration has proceeded of the range telescopes which are used in most current investigations at the 4BT1 target position at TRIUMF. The results have been analyzed and are shown in Fig. 40 for protons undergoing reactions in both copper and NaI. As the energy increases, corrections for scattering of particles out of the detectors become progressively more important, and at about 450 MeV there is no plateau in the efficiency-versus-position curve for this geometry. This can be seen by comparing data for 252 MeV and 466 MeV, shown in Fig. 41. A detailed account of these calibrations, which may be very useful to others working in this energy range, is being prepared.

Extensive data have been taken on small angle scattering of protons from ^{4}He through the TRIUMF energy range using a new technique. Low-energy recoiling ^{4}He nuclei are detected in coincidence with forward-going protons in a low-pressure gas target. Corrections for energy loss of the ^{4}He particles is made via data taken at the University of Alberta Van de Graaff (NRC Progress Report 1974), while an alpha-energy window together

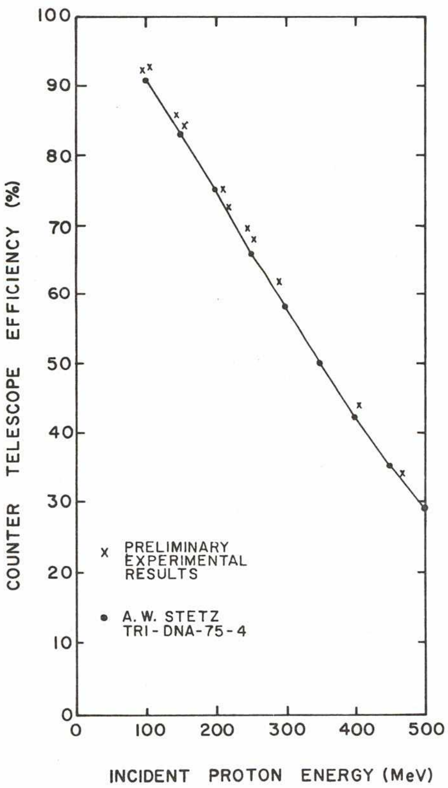


Fig. 40. Detector efficiency vs. proton energy.

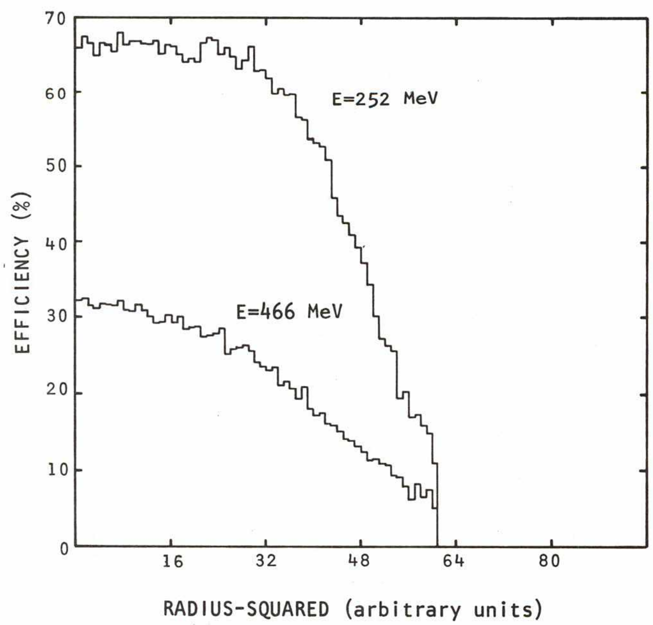


Fig. 41. Detector efficiency vs. square of distance from centre of crystal.

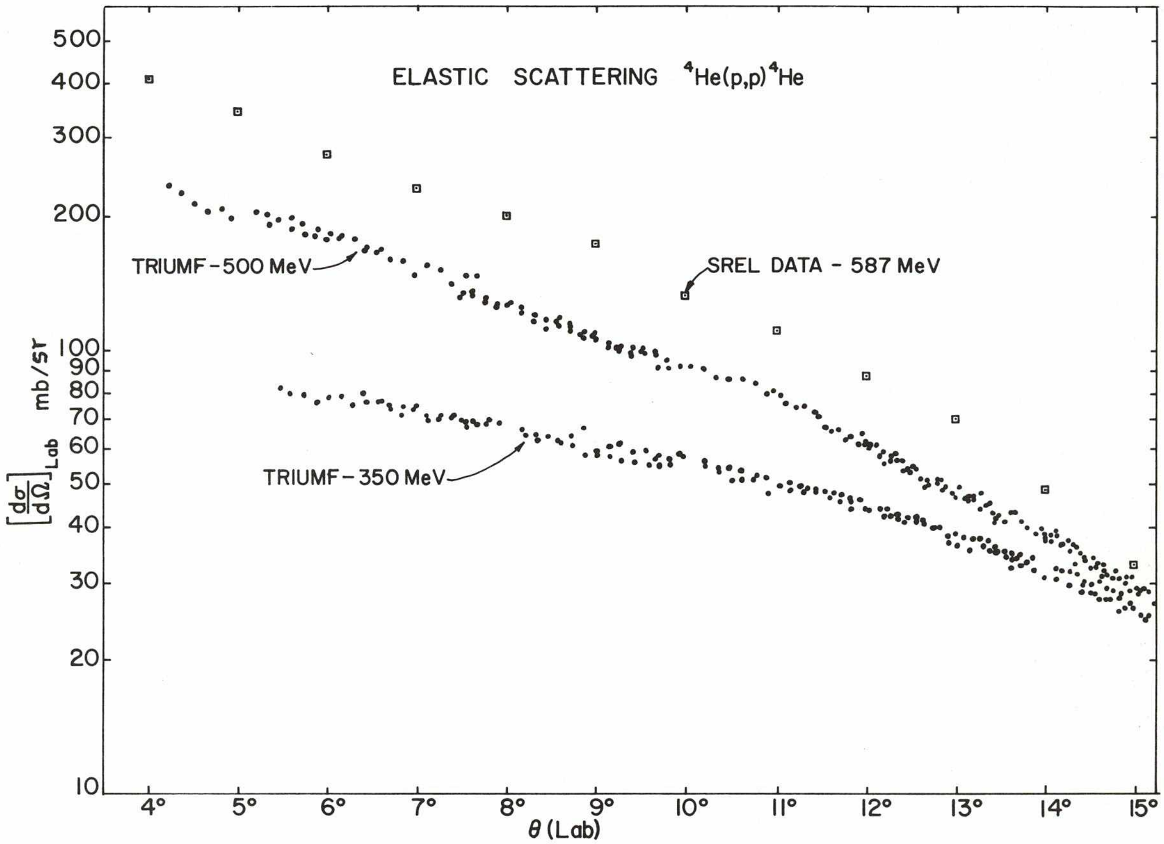


Fig. 42. Preliminary results on the angular distribution of the elastic scattering cross-section for p - ^4He in the laboratory system. Recent normalization requires the values in the graphs to be divided by the factor 1.03 at 500 MeV and 0.875 at 350 MeV.

with the alpha detector geometry is used to define the target volume and detection solid angle. The proton-coincidence requirement allows easy separation of elastic scattering events.

Analysis of the data at 200 MeV is not yet complete. The data at 350 and 500 MeV are shown in Fig. 42 and compared to measurements at nearby energies. Some uncertainty still exists as to absolute normalization and it is planned to check this with the Faraday cup being installed by the New Facilities group, as soon as equipment can be installed again for this experiment.

Experiment 15
Nucleon-nuclear quasi-free scattering

The medium resolution spectrometer facility (MRS) will detect protons up to 500 MeV with a resolution of 500 keV (FWHM) at laboratory angles of 10° or greater. Experiments will also use a neutron time-of-flight counter array in the case of (p,pn) measurements and a multi-wire NaI detecting system for (p,2p). For such apparatus, the maximum energy of the detected particle is limited to about 150 MeV in order to achieve reasonable resolution. Thus most measurements will use a nonsymmetric geometry, with the MRS at a forward angle detecting a relatively high energy proton. A number of interesting cases can be studied, with the MRS fixed at a laboratory angle of 21° while the low-energy detector is moved both in and out of the reaction plane. The object in these first measurements will be to test understanding of the quasi-free scattering process and to observe neutron hole states in nuclei.

Among the equipment developed, a prototype phototube housing for 5-in.-diam (12.7-cm) RCA 4522 tubes has been constructed and tested. It is a dc-coupled device similar to the RL/Daresbury standard base for 2-in. (5-cm) tubes. Enough 5-in. and 2-in. tubes have been obtained to make up two modules of eight detectors each. In addition, 16 constant fraction triggers have been constructed and tested. The low-energy arm for (p,2p) experiments is essentially the same as has been used at 4BT1, so that the equipment is already available.

The main task remaining is to complete the MRS. Results of the preliminary field survey are encouraging. Squared-off pole tips have been ordered and the vacuum tank has been delivered. Detector wire plane construction is well advanced, and it is expected that a usable MRS facility will be set up at a fixed angle and ready for initial experimental runs in the spring of 1976.

Experiment 16
Proton-deuteron quasi-elastic scattering

The first stage of this experiment was set up during the past year (Fig. 43). Sodium iodide detectors measure the energies, plastic scintillation counters measure the dE/dx values and times of flight, while multiwire proportional chambers measure the angles of both outgoing particles. An ionization chamber monitors the number of incident protons. All of the equipment is working satisfactorily, and this experiment is now taking data.

The mass of a detected particle is calculated by means of an empirical formula from dE/dx and total energy, and protons and deuterons are clearly separated. The mass can also be calculated from the particle time of flight and energy; in this way, events in which the outgoing particles are protons in coincidence with deuterons can be unambiguously identified.

From conservation of energy

$$E_o = E_1 + E_2 + E_{miss}$$

where E_o = kinetic energy of incident proton
E_1 = kinetic energy of outgoing proton
E_2 = kinetic energy of outgoing deuteron
E_{miss} = separation energy required to remove a deuteron from the target plus excitation energy of residual recoil nucleus.

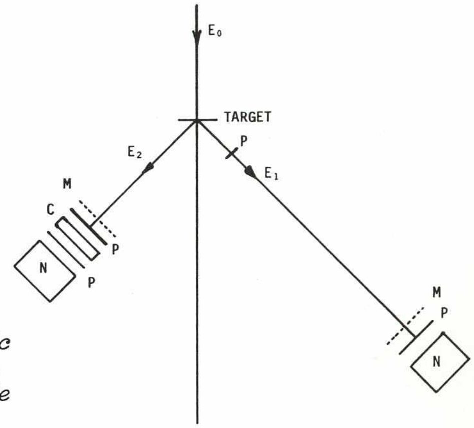


Fig. 43. Experimental arrangement, with P ≡ plastic scintillation counter, M ≡ multi-wire proportional chamber, C = copper absorber, and N = sodium iodide crystal (12.5 × 7.5 cm).

Since E_0 is known and E_1 and E_2 are measured in the sodium iodide detector, E_{miss} can be calculated for each event. For elastic scattering, E_{miss} should clearly be zero. The distribution of events as a function of E_{miss} for a CD_2 target, with the detectors at angles appropriate for elastic p-d scattering, is shown in Fig. 44. The distribution is centred around zero, with a FWHM of 8 MeV, which indicates an overall energy resolution of $\sim$2%. The measured energy resolution of the sodium iodide detectors and straggling in the copper absorber satisfactorily account for this.

A typical missing energy spectrum with a carbon target is shown in Fig. 45. The prominent peak corresponds to population of the ground state and

Fig. 44. Missing energy spectrum for p-d scattering.

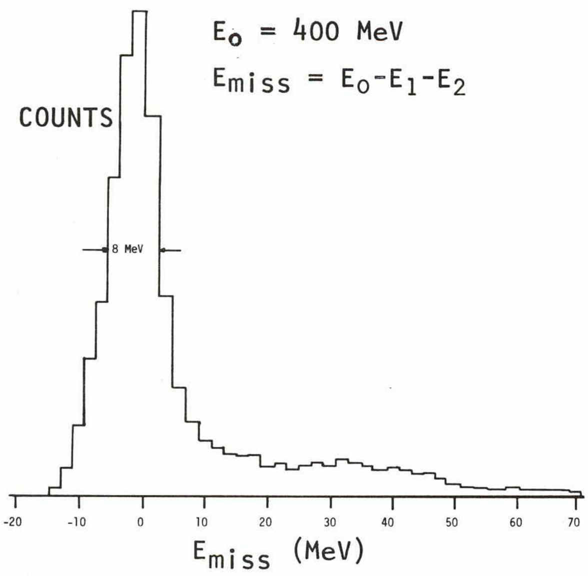
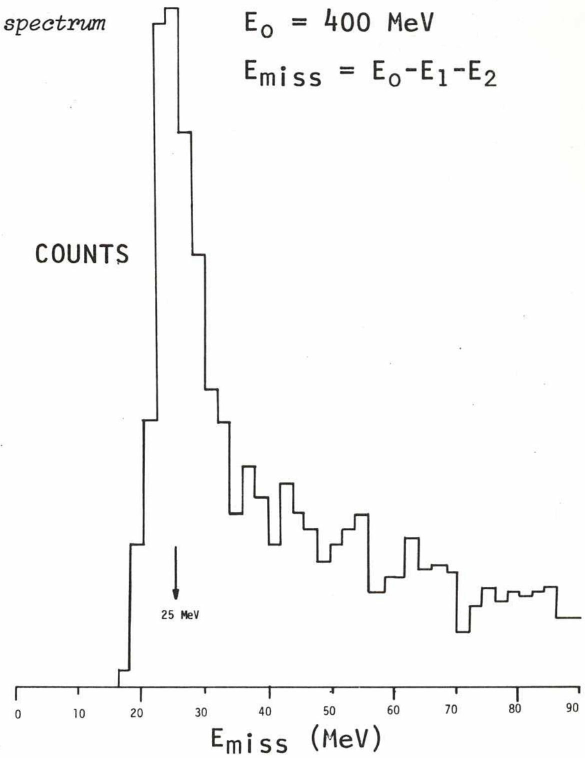


Fig. 45. Missing energy spectrum for $^{12}C(p,pd)^{10}B$.



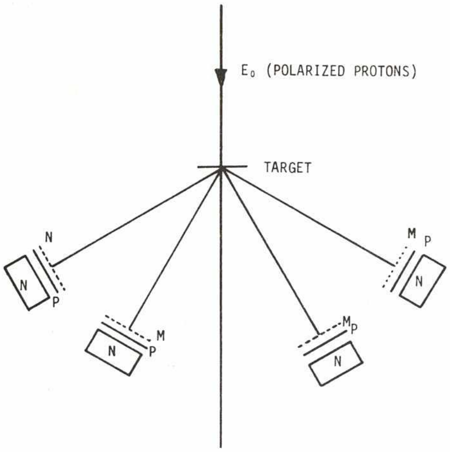


Fig. 46. Experimental arrangement, with P ≡ plastic scintillation counter, M ≡ multi-wire proportional chamber, and N = sodium iodide crystal (12.5 × 7.5 cm).

low-lying levels of ^{10}B, and its position at $E_{miss} \approx$ 25 MeV is in agreement with the known separation energy of deuterons from carbon of 25.01 MeV.

Several thousand events have been accumulated for the reaction $^{12}C(p,pd)^{10}B$, and these are currently being analyzed. A few more shifts of data taking would serve to complete this experiment and to obtain some data on the reaction $^{16}O(p,p\alpha)^{12}C$.

Experiment 58
Polarization effects of the spin-orbit coupling of nuclear protons

The experimental layout is shown in Fig. 46. All the equipment has been tested and performs as expected, but no data have been taken. As soon as polarized beam is available this experiment will be the highest priority for the quasi-elastic scattering group. If the initial experiment on ^{16}O is successful, the MRS will be employed to make similar measurements on other nuclei, where this technique should prove a powerful method of investigating spin-orbit splitting.

Experiment 66
A survey of p-p bremsstrahlung

A survey of proton-proton bremsstrahlung ($p + p \rightarrow p + p + \gamma$) is being undertaken, to investigate the sensitivity of the ppγ cross-section to off-shell features of the nucleon-nucleon force. Previous ppγ experiments revealed no new features of the NN interaction; however, these experiments were performed at energies well below 200 MeV and for proton angles greater than 15°. Off-shell effects are generally expected to influence the cross-section more at smaller angles and high bombarding energies. For these reasons, it is proposed to begin by measuring the ppγ cross-section at symmetric proton angles of 10°, and over a range of bombarding energies above 200 MeV.

The apparatus necessary to do the proposed small-angle experiment has been constructed, including two large solid-angle proton telescopes, a gas-handling system for the hydrogen target, and a special thin wire chamber which will allow measurements at very small angles.

A prototype of the proton telescope was successfully tested with 50-MeV protons at the University of Manitoba. The final version of one of the telescopes has been assembled and successfully tested at the University of Alberta. Installation of the telescopes at TRIUMF is now well under way.

The design of the hydrogen gas-handling system has been approved by the TRIUMF Safety Executive Committee. The control system to ensure safe filling and emptying of the target has been built and tested. A hydrogen vent line has been installed from the target area to the roof of the proton hall.

The TRIUMF Theory group has developed a computer program to calculate approximate ppγ cross-sections, as the first two terms in the Low expansion. These terms contain all the information on the pp interaction which is unambiguously determined from elastic scattering (see p.36 for further details of the calculation). To improve the measurements' sensitivity to the desired off-shell parts of the amplitude, attention will be concentrated on kinematic regions where the calculation shows that the contributions from the on-shell parts are small.

Work on a complete relativistic model calculation has also been progressing. The first phase of the calculation (the computation of cross-sections from boson exchanges with nucleons radiating) is complete.

Work is also well under way on a Monte Carlo computer program to simulate the experiment, to determine the effects of kinematics and experimental resolutions in distorting the measured bremsstrahlung spectra. The program is being written in such a way that it should be useful for any scattering experiment involving the coincidence detection of two charged particles.

Experiment 79
Low-energy π production

Summary

The data acquisition runs on this experiment were completed during the owl shift of October 2, 1975. Data analysis is almost complete. Preliminary results are presented here.

The cross-sections for production of low-energy positive pions from targets of C and Cu were measured at three angles, 60°, 100° and 150°, for pion energies of 23, 32, 53, 76 and 102 MeV, for proton-bombarding energies of 400, 450 and 500 MeV. At an angle of 100°, an excitation function for production of 32- and 53-MeV positive pions from carbon was measured at six proton energies between 400 and 500 MeV.

Experimental Procedure

Positive pions produced in targets located at the 4BT1 target position were detected in a pion range telescope. The procedure was similar to that used in a measurement of a proton energy of 590 MeV by members of the group at the Space Radiation Effects Laboratory, Newport News, Virginia. Particles stopping in the fourth counter of the five-counter telescope shown in Fig. 47 are indicated by the five-fold coincidence $1234\bar{5}$. The stopping pions were separated from muons by requiring the detection of a subsequent pulse from the decay μ in counter 4, during a period between 20 and 100 nsec after the stop signal. Background from protons and electrons was reduced by recording time of flight between counter 1 and 2 and dE/dx from counter 3 in a two-dimensional pulse height analyzer for each 'pion' event signal. The initial energy of pions accepted by the telescope was changed by placing various thicknesses of copper degrader between counters 2 and 3. Five pion energies were measured, 23, 32, 53, 76 and 102 MeV, using this telescope.

The relative proton beam intensity was monitored using a three-element scintillation counter telescope to detect particles scattered from the aluminum windows of the beam line monitor 4BM6, located 3 m downstream of the target location. This was calibrated absolutely in terms of the activation of a carbon foil using the known $^{12}C(p,pn)^{11}C$ reaction cross-section, by measuring the β^+ activity from ^{11}C normalized to a calibrated ^{22}Na source.

Measurements were also made of the $pp \rightarrow \pi^+ D$ cross-sections using a CH_2 target, for three proton bombarding energies, 400, 450 and 500, at pion

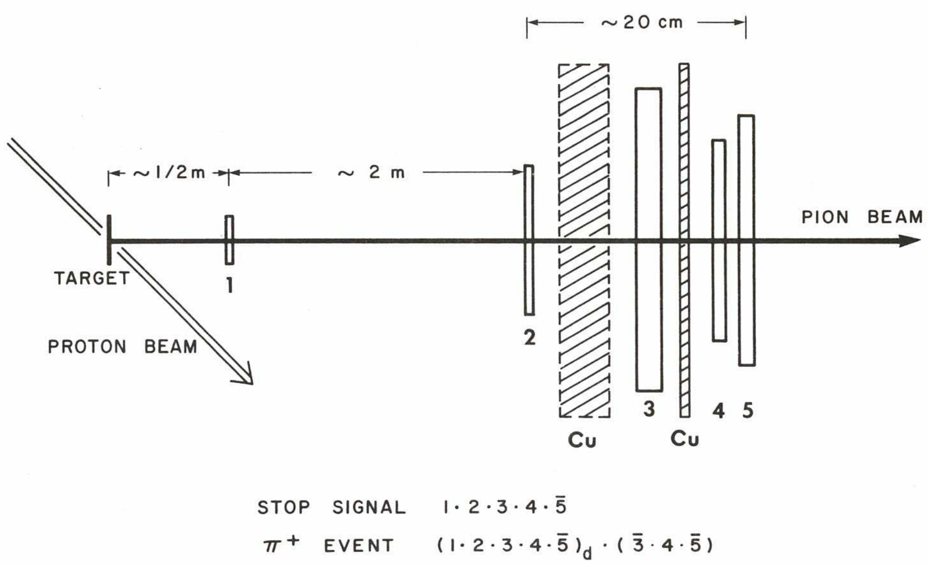


Fig. 47. π^+ *telescope.*

energies available within the restricted angular ranges permitted by the scattering chamber. This provided a check on the beam normalization and telescope efficiency calculations, by enabling a comparison to be made between the measured yields and the known cross-section for this reaction. The results confirm the calculations of the telescope efficiencies for 53-, 76- and 102-MeV pions and beam monitor calibrations at 400, 450 and 500 MeV.

Results

The differential cross-sections measured at production angles of 60°, 100° and 150° for carbon at 400-, 450- and 500-MeV proton bombardment energy are shown in Fig. 48, and those for copper at 450 and 500 MeV are shown in Fig. 49.

An excitation function for the production of 32- and 53-MeV pions at 100° was measured at six proton energies between 400 and 500 MeV. The results are shown in Fig. 50. This excitation function varies monotonically with energy, and extrapolates smoothly to the SREL results at 590.

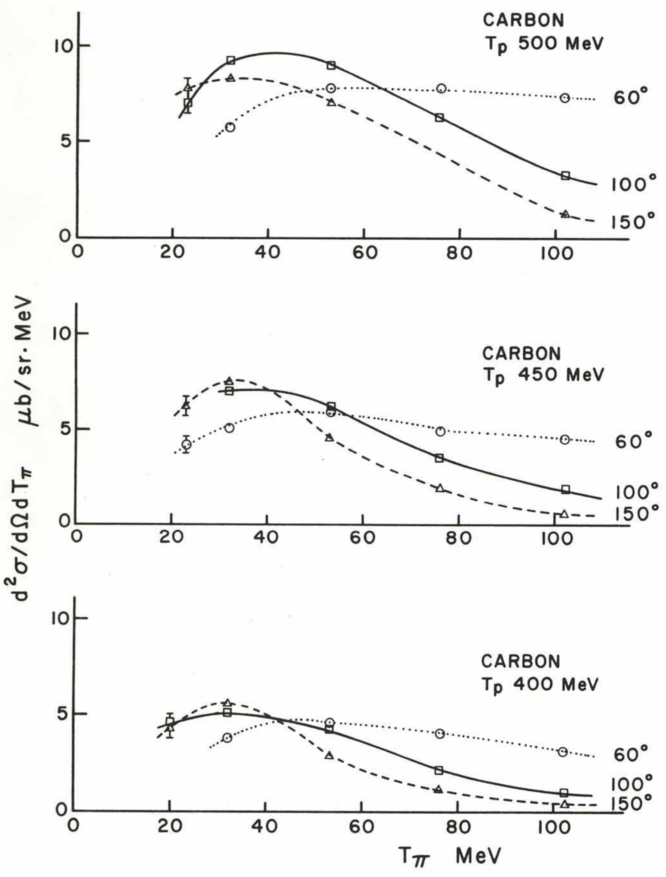


Fig. 48. π^+ production cross-sections for carbon. Curves drawn through the experimental points are only to guide the eye.

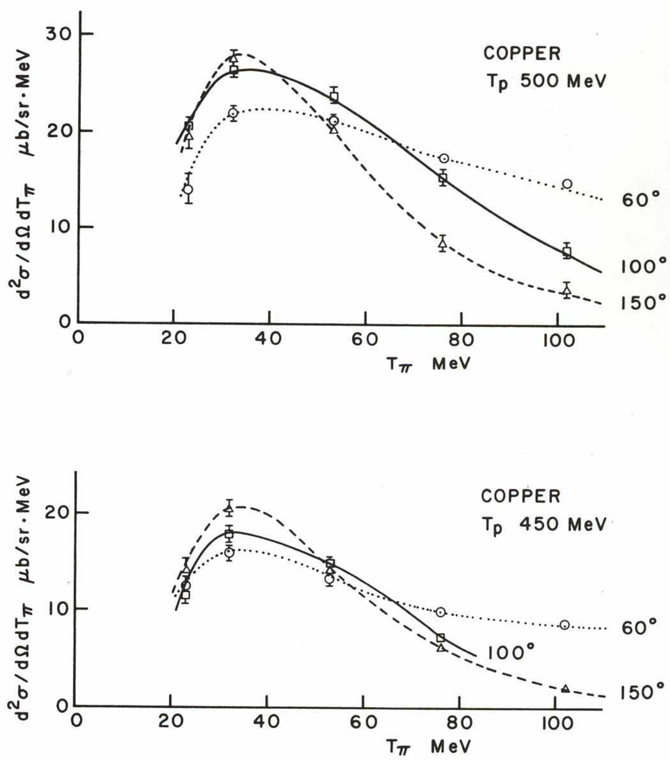


Fig. 49. π^+ production cross-sections for copper. Curves drawn through the experimental points are only to guide the eye.

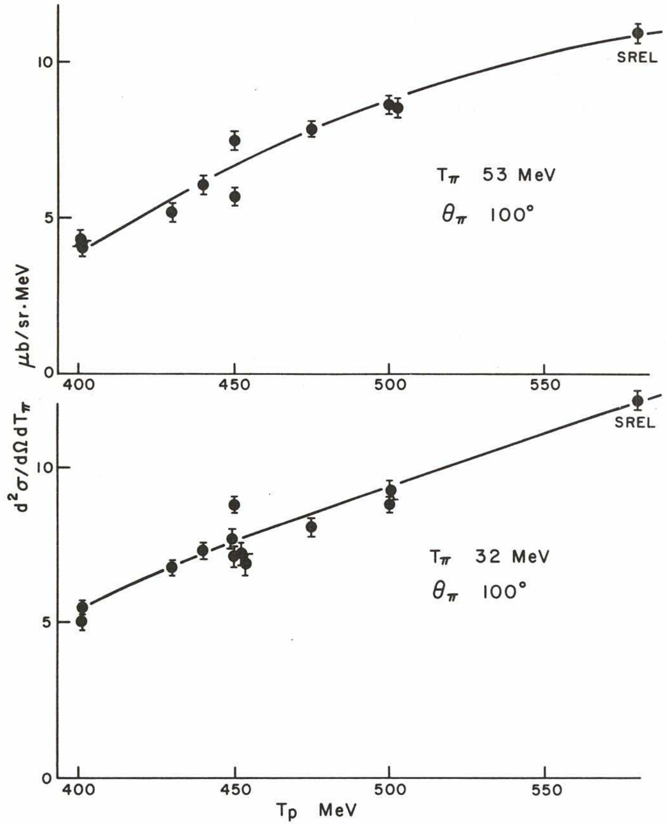


Fig. 50. Excitation function between 400 and 500 MeV for 32- and 53-MeV π^+ production from carbon at 100°.

The 450-MeV, 60° production cross-sections from carbon reported here do not show the large values previously reported by Lillethun.[1] The 60° yields from carbon measured at 450,[1] at 590,[2] and at 740 MeV,[3] together with the TRIUMF results reported here, are shown in Fig. 51.

Conclusions

The results from this experiment indicate that, unfortunately, a magic energy for low-energy positive-pion production does not appear to exist in the region of 450 MeV, as previously reported work would indicate. The yields vary monotonically with energy, but at a slow enough rate that for TRIUMF it will be advantageous to operate with primary beams of 400 μA at 450 MeV, as against 100 μA at 500 MeV. Comparison of these measurements with the theoretical predictions of Beder and Bendix[4] show general agreement, except that the theoretical results predict too large production cross-sections for the higher-energy pions at 60° and 100°.

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[1]E. Lillethun, Phys. Rev. 125, 665 (1962)
[2]P.W. James, Ph.D. thesis, University of Victoria (1975)
[3]D.R.F. Cochran, P.N. Dean, P.A.M. Gram, E.A. Knapp, E.R. Martin, D.E. Nagle, R.B. Perkins, W.J. Schlaer, H.A. Thiessen and E.D. Theriot, Phys. Rev. D6, 3085 (1972)
[4]D.S. Beder and P. Bendix, private communication (1975)

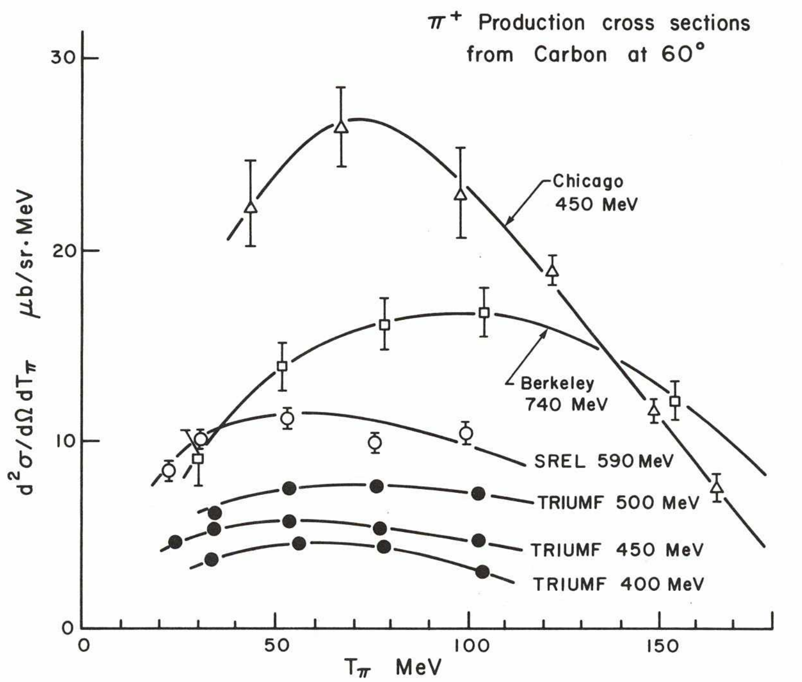

Fig. 51. 60° π production cross-section from carbon at various energies. Chicago: Lillethun (1962); Berkeley: Cochran et al. (1972); SREL: James (1975); TRIUMF: present experiment.

5. THEORETICAL PROGRAM

During the past year the first step was taken toward the formation of a medium-energy theory group at the main site. One staff member was hired in July, a second is expected in the fall of 1976, and there are currently two associated graduate students. It is hoped eventually to have enough theorists to make a viable theoretical group, possessing some expertise in each of the major areas of interest at TRIUMF. It is intended that the theoretical group will both a) be a service group to provide consultation and theoretical support for experimental groups working at TRIUMF, and b) carry out an independent research program in medium-energy physics. which may generate new ideas for experiments which might utilize the capabilities of TRIUMF.

Specific research areas which have been of interest in the past year include the following:

1) Nucleon-nucleon bremsstrahlung

In principle, nucleon-nucleon bremsstrahlung provides a way of obtaining information about off-mass-shell aspects of the nucleon-nucleon force. Most previous calculations of the process have been based on low-energy potential approaches, which are of limited applicability at TRIUMF energies. In anticipation of TRIUMF bremsstrahlung experiments, a program of relativistic calculations based on a soft-photon model has been started. Such an approach does not give a specific prediction for the off-mass-shell terms. It is, however, completely relativistic and gauge invariant, and allows one to easily explore the kinematic region, to find those areas where on-mass-shell terms are small and thus where a search for off-mass-shell information might be most fruitful. Similar techniques will also be used to see what additional information might be obtained using polarized protons.

2) (p,π) reactions

One of the areas of recent excitement in medium-energy physics, an area under active experimental investigation at TRIUMF, is that of (p,π) reactions in nuclei. Such processes should give information about high momentum components of nuclear wave functions and about basic aspects of the πNN interaction. Several calculations have been made using a distorted wave impulse approximation model in which the nuclear (p,π) reaction is assumed to be dominated by $pp \to \pi d$. So far $pd \to t\pi$, $pd \to {}^3He\pi$, and $p{}^3He \to {}^4He\pi$ have been investigated, but the formalism is available for reactions on an arbitrary nucleus. Similar techniques have been applied with some success to the analogous (p,γ) reactions. Again, investigation of possible new information obtainable using polarized protons will be the next step.

3) Photon asymmetry in radiative muon capture

The asymmetry of photons emitted following capture by polarized muons in a nucleus is very sensitive to certain of the weak interaction couplings, particularly the induced pseudoscalar. The single currently available experiment disagrees drastically with theory, and a second experiment is planned for TRIUMF. Calculations have been made, which indicate that certain previously neglected terms may affect the theoretical result, and a calculation of these terms is in progress.

Other general areas of interest for the present staff member and students include muon capture and reactions, general weak interactions, radiative processes, and particle decays. The staff member coming in the fall has done extensive calculations on πd elastic scattering using a Faddeev approach, and will thus add expertise in that and related areas to the group.

C. ORGANIZATION

Board of Management

The Board of Management of TRIUMF manages the business of the project and has equal representation from each of the four universities. It reports to the Board of Governors of the University of British Columbia which has legal and financial responsibility for TRIUMF. At the end of 1975 the Board comprised:

University of Alberta	President H.E. Gunning Dean Kenneth B. Newbound Mr. W.A.B. Saunders (Jan. 9, 1976)
Simon Fraser University	Dean S. Aronoff Mr. G. Suart Dr. B.G. Wilson
University of Victoria	Dr. J.M. Dewey Dr. R.M. Pearce President H.E. Petch
University of British Columbia	Dr. R.R. Haering Dr. E.W. Vogt (Chairman) Dean G.M. Volkoff (Secretary)

Ex-officio Dr. J.R. Richardson, Director, TRIUMF

Until mid-year Dr. H.W. Dosso and Dr. S.A. Jennings of the University of Victoria served on the Board in places now occupied by President Petch and Dr. Pearce. The vacancy in University of Alberta Board membership, following the resignation of Dr. J.T. Sample, was filled just after the year-end when Mr. Saunders joined the Board. The Board met three times in 1975.

Operating Committee

The Operating Committee of TRIUMF is responsible for the operation of the project. It reports to the Board of Management through its chairman, Dr. J.R. Richardson. It has four voting members, one from each of the four universities. The members of the committee (alternate members in parentheses) at the end of 1975 were:

Dr. J.R. Richardson	Director	(Chairman)	
Dr. B.D. Pate	Associate Director	(Secretary)	
Dr. W.K. Dawson	University of Alberta		(Dr. W.C. Olsen)
Dr. R.G. Korteling	Simon Fraser University		(Dr. A.S. Arrott)
Dr. L.P. Robertson	University of Victoria		(Dr. G.R. Mason)
Dr. J.B. Warren	University of B.C.		(Dr. D.A. Axen)

In July R.M. Pearce returned to University of Victoria after serving as Associate Director during a year on leave at main site and was succeeded by B.D. Pate, on leave from Simon Fraser University for the 1975/76 academic year. The Committee met nine times during the year.

TRIUMF Safety Executive Committee

Dr. B.D. Pate (Chairman)
Dr. E.W. Blackmore
Mr. J.W. Carey
Mr. A.J. Otter
Mr. P.C. Taylor
Mr. I.M. Thorson
Dr. J.R. Richardson
Mr. M. Zach
Dr. G.D. Wait (Secretary)

Dr. M.W. Greene, B.C. Dept. of Health Services and Hospital Insurance
Dr. W. Rachuk, Radiation Protection and Pollution Control Officer, UBC
Dr. L.D. Skarsgard, B.C. Cancer Foundation

Mr. S.C. Frazer of the Workers Compensation Board attends meetings as an observer.

Experiments Evaluation Committee

Dr. G.T. Ewan	(Chairman)	Queens University
Dr. D.G. Fleming		University of British Columbia
Dr. E.M. Henley		University of Washington
Dr. E.P. Hincks		Carleton University
Dr. W.J. McDonald	(until Dec 31)	University of Alberta
Dr. B. Margolis		McGill University
Dr. D.F. Measday	(Scientific Secretary)	University of British Columbia
Dr. B.D. Pate		Simon Fraser University
Mr. J.E.D. Pearson	(Secretary)	University of British Columbia
Dr. H. Primakoff		University of Pennsylvania
Dr. J.R. Richardson		TRIUMF
Dr. J.T. Sample		University of Alberta
Dr. L.D. Skarsgard		B.C. Cancer Foundation
Dr. E.W. Vogt		University of British Columbia
Prof. Sir Denys Wilkinson		Oxford University

Until July E.W. Vogt served as Chairman of the Committee.

Biomedical Experiments Evaluation Committee

Dr. L.D. Skarsgard (Chairman)	B.C. Cancer Foundation
Dean S. Aronoff	Simon Fraser University
Dr. M.J. Ashwood-Smith	University of Victoria
Dr. J.M.W. Gibson	B.C. Cancer Foundation
Dr. H.C. Johns	Ontario Cancer Institute
Dr. R.R. Johnson	University of British Columbia
Dr. T.R. Overton	University of Alberta
Dr. J.T. Sample	University of Alberta
Dr. D.C. Walker	University of British Columbia
Dr. G.F. Whitmore	University of Toronto

D. FINANCIAL STATEMENT

Statement of revenue and expenditures, April 1, 1974-March 31, 1975:

Revenue		
Atomic Energy Control Board		$7,650,000
Interest and cash receipts		193,174
B.C. Cancer Institute reimbursement		463,962
Total		8,307,136
Subtract:	Balance carried forward from previous year	(1,472,683)
		$6,834,453
Expenditures		
Capital		$3,761,187
Operating		2,591,898
Experiments		947,611
B.C. Cancer Institute		480,507
Total		7,781,203
Subtract:	Overexpended funds at March 31, 1975	(946,750)
		$6,834,453

Expenditures for nine-month period to December 31, 1975:

Major grouping:

Administration	$ 93,284
General payroll	1,791,314
Power & operations	190,652
Cost centres and holding accounts	284,001
Commissioned facilities	388,187
Major facilities	995,875
Experimental programs	576,494
	$4,319,807

Summary:

Contribution funds (operating)	$2,166,761	
Grant funds	714,082	
Cost centres	138,006	
Total operating expenditures		$3,018,849
Contribution funds (capital)		1,154,963
Deferred income		145,995
		$4,319,807

CONFERENCES

Continuing the tradition started by the Banff Summer School in 1970, a NATO Summer School on Nuclear and Particle Physics at Intermediate Energies was held from June 23 to July 2 at Brentwood College School near Victoria. TRIUMF scientists at the University of Victoria and University of British Columbia organized the School, with financial support provided by Atomic Energy of Canada Limited and National Research Council as well as NATO. The School's aim—to explore several of the research avenues possible at meson factories—was well met, and many useful contacts were made by TRIUMF scientists with participants from eastern Canada, Europe and the United States.

During the year papers on TRIUMF were presented at the following conferences: [Details on those which have been, or are to be, published are given in Appendix 2.]

Western Regional Nuclear Conference, Winnipeg, February 20-22

1975 Particle Accelerator Conference, Washington, March 12-14

Fifth International Conference on Magnet Technology, Frascati, April 14-18

American Physical Society General Meeting, Washington, April 28-May 1

Canadian Association of Physicists Congress 1975, Toronto, June 9-12

VIth International Conference on High Energy Physics and Nuclear Structure, Santa Fe and Los Alamos, June 9-13

Seventh International Cyclotron Conference, Zurich, August 19-22

Fourth International Symposium on Polarization Phenomena in Nuclear Reactions, Zurich, August 25-29

VIIth International Conference on Few Body Problems in Nuclear and Particle Physics, Delhi, December 29-January 3

PUBLICATIONS

Conference proceedings:

J.R. Richardson, E.W. Blackmore, G. Dutto, C.J. Kost, G.H. Mackenzie and M.K. Craddock, Production of simultaneous, variable energy beams from the TRIUMF cyclotron, IEEE Trans. Nucl. Sci. NS-22 (3), 1402 (1975)

R.L. Poirier and M. Zach, TRIUMF RF system, *ibid.*, 1253

R.H.M. Gummer, Accelerating voltage control and stabilization in the TRIUMF cyclotron, *ibid.*, 1257

J. Beveridge, E.W. Blackmore, P.F. Bosman, G. Dutto, W. Joho, R. Riches, V. Rödel, L.W. Root and B.L. White, Initial operating experience with the TRIUMF 300 keV H^- injection system, *ibid.*, 1707

C.J. Kost and G.H. Mackenzie, COMA, a linear motion code for cyclotrons, *ibid.*, 1922

E.G. Auld, R.E. Marek and A.J. Otter, The commissioning of the TRIUMF cyclotron magnet, Proc. of 5th Int. Conference on Magnet Technology (CNEN, Frascati, 1975), p.93

J.R. Richardson, The status of TRIUMF, Proc. of 7th Int. Cyclotron Conference (Birkhäuser, Basel, 1975), p.41

R.H.M. Gummer, R.L. Poirier and M. Zach, TRIUMF RF system - Initial operating problems and their solutions, *ibid.*, 167

M.K. Craddock, E.W. Blackmore, G. Dutto, C.J. Kost, G.H. Mackenzie, J.R. Richardson, L.W. Root and P. Schmor, Properties of the TRIUMF cyclotron beam, *ibid.*, 240

G. Dutto and M.K. Craddock, Focusing in RF accelerating gaps with asymmetrically curved electric equipotentials, *ibid.*, 271

D.P. Gurd, D.R. Heywood and R.R. Johnson, The use of CAMAC with small computers in the TRIUMF control system, *ibid.*, 561

G. Roy, The TRIUMF polarized ion source, Proc. of 4th Int. Symposium on Polarization Phenomena in Nuclear Reactions, Zürich (to be published)

J.R. Richardson, Preliminary results of the research on few body problems at TRIUMF, Proc. of VIIth Int. Conference on Few Body Problems in Nuclear and Particle Physics, Delhi (to be published)

Reports:

TRI-75-1	Studies à propos $\mu^- p \to \nu n \gamma$ and $\pi \to e \bar{\nu} \gamma$ experiments D.S. Beder
TRI-75-2	Experimental facilities at TRIUMF R.M. Pearce, ed.

TRI-75-3 Measurements and calculations of reaction losses of medium-energy protons in NaI detectors
C.A. Goulding and J.G. Rogers

TRI-75-4 What pp parameters need measuring from 200 to 525 MeV?
D.V. Bugg and C. Oram

TRI-75-5 What np elastic scattering data are needed from 200 to 520 MeV?
D.V. Bugg

Journal publications:

H.W. Fearing, Theorem for the photon asymmetry in radiative muon capture, Phys. Rev. Letters 35, 79 (1975)

H.W. Fearing, General formalism for pion production in nuclei: application to $pd \to t\pi$, Phys. Rev. C11, 1210 (1975)

H.W. Fearing, Effect of the deuteron D state on distorted-wave impulse-approximation calculations of (p,π) reactions, *ibid.*, 1493

J. Spuller and D.F. Measday, On the s-wave production of pions in $p + p \to \pi^+ + d$, Phys. Rev. D12, 3550 (1975)

STAFF

BREAKDOWN OF TRIUMF STAFF TOTAL AS OF DECEMBER 31, 1975

	Main Site	UBC	UVic	SFU	UAlta	Total
Scientists	26	4	2[1]	5	2[1]	39
Faculty full-time main site 1975/76[2]	(4)		(1)	(1)	(2)	
Faculty part-time		13	6	3	11	33
Engineers	12				1	13
Operators	12					12
Programmers	5			3		8
Graduate students		14	7	5	2	28
Technicians	53	4	2	1	4[1]	64
Designer-draftsmen	5		1			6
Workshop staff	8		1		1	10
Plant	6					6
Administration	3					3
Office staff:						
Secretarial & clerical	10	1	1	0.6	1	13.6
Library/Information Office	1					1
Stores	3					3
	144[1]	36	20	17.6	22	239.6

[1]Main site total includes three additional scientists from University of Victoria and four from University of Alberta who are based at main site. Two technicians from University of Alberta also work full-time at main site.

[2]Faculty members spending the 1975/76 academic year at main site have been included in appropriate category; during such leave faculty members are paid by TRIUMF rather than the respective university.

TRIUMF Vancouver (listed in order of joining the project)

Name	Position	Area	% TRIUMF Payroll	Staff Changes During 1975 From	Until
J.R. Richardson	Director				
J.J. Burgerjon	on sabbatical at LAMPF			Aug 1	
G.H. Mackenzie	Research Associate	Beam Development			
L. Root	Research Associate	Beam Development			Sep 30
R.H.M. Gummer	Research Associate	RF			Nov 14
A.J. Otter	Magnet Engineer	Beam Lines			
M. Zach	Research Engineer	Operations			
R. Poirier	Research Engineer	RF			
E.W. Blackmore	Research Associate	Probes/Operations			
J.W. Carey	Plant Engineer				
O.K. Fredriksson	Cyclotron Engineer		100		
D.R. Heywood	Research Associate	Electronics			
G. Dutto	Research Associate	Beam Development			
R.G. Bendall	Critical Path Co-ordinator				Apr 30
C.J. Kost	Computer Analyst	Beam Development			
J.V. Cresswell	Research Engineer	Electronics			
P. Bosman	Research Engineer	ISIS			
D.C. Healey	Research Associate	Vacuum			
F. Choutka	Structural & Architectural Designer				
V.J. Verma	Electrical Engineer	Beam Lines/Cabling			
R.E. Marek	Research Engineer	Magnet & Power Supplies			
J.H. Brewer	Research Associate	μSR Facility	27		
R. Riches	Research Associate	ISIS/Electronics			
C.W. Bordeaux	Business Manager				
W. Cameron	Mechanical Engineer	Probes/Remote Handling			
L. Moritz	Research Associate	Safety			
D. Pearce	Research Associate	Alignment			
P. Schmor	Research Associate	Beam Development	100		
J. Beveridge	Research Associate	POLISIS/New Facilities			
D.R. Gill	Research Associate	Safety			
G.D. Wait	Research Associate	Safety		Jul 1	
J.S. Vincent	Research Associate	New Facilities		Jul 1	
J.G. Rogers	Research Associate	New Facilities		Jul 1	
H.W. Fearing	Research Associate	Theory		Jul 1	
M. Wilson	Visiting Scientist	on leave from LAMPF	0		
J. Yandon	Shift Supervisor Operations				
K. Lukas	Shift Supervisor Operations				
G. Roy	Operator				
J. McIlroy	Shift Supervisor Operations				
S. Langton					
F. Bach					
J. Kaminski					
M. McDonald	Operators				
G. Wight					
A. Hurst					
B. Stanton					
J. Drozdoff			100		Sep 1
L. Udy		Vacuum			
J. Fawley		RF			
B. Ozzard		Electronics			
H.H. Simmonds		RF			
D. Evans	Technicians	Magnet			
L. Voboril		Alignment			
B. Trevitt		ISIS			
A.M. Teteris		Safety/Remote Handling			
F. Humphrey		Electronics			

TRIUMF Vancouver (cont'd)

Name	Position	Area	% TRIUMF Payroll	Staff Changes During 1975 From	Until
P.C. Taylor		Probes			
N. England		Electronics			
K.R. Arbuthnot		ISIS			Mar 31
Y. Langley		Electronics			
S. Turke		Probes			
J. Lenz		ISIS/Safety			
L. Humphreys		Beam Lines			
W. Noelte		Beam Lines			
B.E. Evans		ISIS			
A.O. Lacusta		Electronics			
R. Hilton		Beam Lines			
W. Wu		ISIS			
L. Chua		Electronics			
R. Corman		ISIS			Nov 21
G. Takacs		ISIS/Vacuum			
T. Moskven		Safety			
R. Hansen		Electronics			
E. Klassen		Electronics			
C. Star		Vacuum			
D. Johnson		Remote Handling			
L.T. Wong		ISIS			
J. Case		Vacuum			Mar 31
C. Mark		Remote Handling			
C. Yee		Electronics			
J. Stewart		Probes			
D. Shorter	Technicians	Electronics			
N. Shiboaka		Electronics			
M. Smyth		Probes			
C. Fairey		Vacuum/Beam Lines			Jan 15
R. Skegg		Electronics	100		
D. Smith		Electronics			
C. Laforge		ISIS			
L. King		Safety			
P. Tautz		Electronics			
J. Gehlen		Electronics			
H. Shum		ISIS			Mar 31
R. Palmer		Night Watchman			
M. Lewis		Electronics			Jul 31
J. Hu		RF			
J. Lau		Electronics			
S. Storgeoff		Night Watchman			Oct 22
A. Bishop		Vacuum			
J. Tipton		Magnet			
R. Ginn		Magnet			
R. Moore		Cabling			
O. Thorkelson		RF			Jun 30
P. Harmer		Vacuum			
J. Love		RF		Aug 11	
D. Smith		Safety		Sep 1	
A. Johnson		Remote Handling		Sep 1	
P. van Rook	Design Office Supervisor				
H. Hansen					Mar 31
A.T. Bowyer					
J. Hallow	Designer-draftsmen				
H. Sprenger					
H. Mertes					

TRIUMF Vancouver (cont'd)

Name	Position	% TRIUMF Payroll	Staff Changes During 1975 From	Until
R. Brewer	Machine Shop Supervisor			
S. Olsen	Machinists			
W. Frey				
W. Koch				
L. Crozier	Welder			
P. Gormley	Machinists			
L.M. Nazar				
P. Sterritt				May 15
W. Carr				Dec 31
G. Fletcher	Woodworker			Feb 28
V. Duggal	Machinist			May 31
R. Roper	Late Shift Supervisor			
P. Inderbitzen	Machinist			May 31
F. Bousek	Machinist			Mar 27
G.J. Ratzburg	Electrician			
S.J. Smith	Maintenance Technicians			Jul 31
S.P. Lee				
P. Ram				
L. Clement	Crane Operator			Mar 31
A. Salter	Maintenance Technicians			Jun 30
H. Dougan				
W. Ford				
W. Thaller				
D. Marquardt	Programmers	100		
W. Fung				Apr 15
P. Brown				
P. Bennett				
R. Callon				
R. Berg			May 15	
W. Dawes	Stores Supervisor			
C. Bruce	Receiver/Storekeeper			
D. Sawyer	Storekeeper/Receiver			Jul 31
E. Wright	Storekeeper/Receiver		Sep 2	
A. Strathdee	Asst. Information Officer			
N. Palmer	Secretary to Director			
M. Williams	Secretary			
P. Sparkes	Buyer			
P. Moase	Purchasing Assistant			Jun 30
M. Tainsh	Secretary			Aug 15
V. Hannah	Clerk			
V. Turner	Accounting Assistant			
M. Stancer	Buyer			
I. Duelli	Clerk			Jun 4
H. McIlroy	Clerk			
D. Staples	Secretary			
D. Osaduik	Receptionist			

UBC

Faculty

Name	Position	Program	% TRIUMF Payroll	From	Until
E.G. Auld	Assoc. Professor	Experimental Program	0		
D.A. Axen	Assoc. Professor	Experimental Program	0		
M.K. Craddock	Assoc. Professor	Beam Development	0		
K.L. Erdman	Professor		0		
D.G. Fleming	Assoc. Professor	μSR Facility	0		
M. Hasinoff	Asst. Professor	Experimental Program	0		

UBC (cont'd)

Name	Position	Program	% TRIUMF Payroll	Staff Changes During 1975 From	Until
R.R. Johnson	Assoc. Professor	Experimental Program	0		
G. Jones	Professor		0		
P.W. Martin	Assoc. Professor		0		
D.F. Measday	Assoc. Professor		0		
E.W. Vogt	Professor		0		
J.B. Warren	Professor	Experimental Program	0		
B.L. White	Professor	on sabbatical at CERN	0		

Graduate Students

Name	Position	Program	% TRIUMF Payroll	From	Until
J. Alexander		Theory	0		
J-M Bangoura		Experimental Program	0		
D. Berghofer			0		
F. Corriveau			0		
M. Currie-Johnson			100		
R.A. Duncan			0		
L. Felawka			100		
D.M. Garner			100		
A.R. Johnston			0		
M. Kent			0		
C. Lee			30		Dec 31
R. MacDonald			100		
G. Marshall			100		
P.R.H. McConnell			0	Jun 1	Jul 31
J.E. Spuller			0		
T. Suzuki			30		

TRIUMF UBC

Name	Position	Program	% TRIUMF Payroll	From	Until
S. Jaccard	Visiting Fellow	Experimental Program	30		
T. Masterson	Research Associate		100		
A. Morgan	Technician		100		
K. Nagamine	Visiting Fellow		15		
J-M Poutissou	Visiting Fellow		0		
H. Prior	Secretary		100	Oct 27	
L. Ratcliffe	Secretary		100		Jul 31
M. Salomon	Research Associate		100		
R.C. Stevens	Technician		100		
A.K. Stevenson	Technician		100		
J. Va'vra	PDF		100		
L.C. Vaz	Research Associate		5		
P. Walden	Research Associate		100		
S. Wood	Technician		100		
T. Yamazaki	Visiting Fellow		15		Aug 31

TRIUMF Victoria

Name	Position	Program	% TRIUMF Payroll	From	Until
D.A. Bryman	Research Scientist		100		
T.R. Gathright	Technician				
H. Hodapp	Technician				Sep 30
T.A. Hodges	Research Associate	Targets			
J.R. Hunt	Secretary				
R.R. Langstaff	Designer-draftsman				
J.A. Macdonald	Research Associate	Experimental Program			
J.T. Nelson	Technician				
A. Olin	Research Associate	Experimental Program	77		
P.A. Reeve	Research Associate	Beam Optics	100		
J.D. Ridley	Technician				Feb 28
P.G. Verstraaten	Machinist				
J.S. Vincent	Research Fellow	to Main Site			Jun 30

UVic

Faculty

			% TRIUMF Payroll	Staff Changes During 1975 From	Until
G.A. Beer	Assoc. Professor	on sabbatical at CERN	0	Jul 1	
D.E. Lobb	Assoc. Professor		0		
G.R. Mason	Assoc. Professor	on leave to TRIUMF	50	Jul 1	
R.M. Pearce	Professor	on leave to TRIUMF	67		Jun 30
C.E. Picciotto	Assoc. Professor	on sabbatical at CERN	0		Jun 30
L.P. Robertson	Professor		17		
C.-S.Wu	Asst. Professor	on sabbatical	0	Jul 1	

Graduate Students

		% TRIUMF Payroll	From	Until
R.P. Fryer		100		
P.W. James		100		
S.K. Kim		100		
D.A. Lim		0		
D.E. Marriner	Experimental Program	0	Sep 1	
E.L. Mathie		77		
P.A. Poffenberger		0	Sep 1	
J.E. Reyes		100		Jun 30

TRIUMF SFU

			% TRIUMF Payroll	From	Until
W. Bishop	Programmer	Experimental Program	20		
V. Cowley	Technician	Thermal Neutron Fac.	100		
I. Duelli	Secretary		66	Jun 5	
J. Grabowski	Research Associate	Experimental Program	100		Aug 31
R. Green	Research Associate	Experimental Program	100		
S. Heap	Secretary		66		Jun 6
F.M. Kiely	Research Associate	FERFICON	0		
A. Kurn	Programmer	Experimental Program	33		
T. Templeton	Research Scientist	Thermal Neutron Fac.	75	Apr 1	
I.M. Thorson	Research Associate	Shielding & Activation	100		
R. Toren	Programmer	Experimental Program	33		
G.D. Wait	Research Associate	Safety	100		Jun 30
W.J. Wiesehahn	Research Associate	Experimental Program	100		

SFU

Faculty

			% TRIUMF Payroll	From	Until
A.S. Arrott	Professor	Thermal Neutron Fac.	0		
J.M. D'Auria	Assoc. Professor	on sabbatical at CERN	0	Aug 1	
R.G. Korteling	Assoc. Professor	Experimental Program	0		
B.D. Pate	Professor	on leave to TRIUMF	50	Jul 1	

Graduate Students

		% TRIUMF Payroll
G. Bischoff		
H. Blok		
D. Dautet	Experimental Program	0
H. Dautet		
A. Seamster		

Visiting Scientists

		% TRIUMF Payroll	From	Until
L. Church	from Reed College	0	Apr 1	
G. Coote	from Inst. of Nuclear Sciences, New Zealand	0	Mar 1	
J.K.P. Lee	from McGill University	0	Sep 1	

TRIUMF Edmonton

			% TRIUMF Payroll	Staff Changes During 1975 From	Until
R. Adolph	Technician				
A.N. Anderson	Research Associate				
R.M. Churchman	Technician				
H.G. Coombes	Technician				
H.W. Fearing	Visiting Scientist				Jun 30
M.A. Fisher	Secretary			Jun 17	
D.P. Gurd	Asst. Res. Professor				
D.A. Hutcheon	Research Scientist				
A.N. James	Visiting Scientist		100	Jul 25	
A. Lank	Machinist				
T. Lesoway	Technician				
J.A. Lidbury	Design Engineer				May 30
C.A. Miller	Research Associate				
M. Proverb	Secretary				Jun 13
J.G. Rogers	Research Associate	to Main Site			Jun 30
J. Soukup	Design Engineer			Aug 1	
G.M. Stinson	Asst. Res. Professor				
A.N. Thorn	Design Engineer				Jun 30

UAlberta

Faculty and Research Staff

			% TRIUMF Payroll
E.B. Cairns	Professional Officer		
J.M. Cameron	Assoc. Professor		
W.K. Dawson	Professor		0
J.B. Elliott	Professional Officer		
P.W. Green	Visit. Asst. Professor		
P. Kitching	Assoc. Professor	on leave at TRIUMF	100
W.J. McDonald	Professor	on leave at TRIUMF	100
G.A. Moss	Assoc. Professor	on sabbatical CEN-Saclay	
G.C. Neilson	Professor		
W.C. Olsen	Professor		
G. Roy	Assoc. Professor		0
J.T. Sample	Professor		
D.M. Sheppard	Assoc. Professor		
H.S. Sherif	Assoc. Professor		
A.W. Stetz	Visit. Asst. Professor		

Graduate Students

	% TRIUMF Payroll
R.H. McCamis	0
R.S. Sloboda	0

USERS GROUP

University of Alberta:

J.M. Cameron, Chairman 1976
E.B. Cairns
W.K. Dawson
J.B. Elliott
G.R. Freeman
H.E. Gunning
D.A. Hutcheon
P. Kitching
R.H. McCamis
W.J. McDonald
C.A. Miller
G.A. Moss
G.C. Neilson
A.A. Noujaim
W.C. Olsen
T.R. Overton
G. Roy
R.F. Ruth
J.T. Sample
M. Schacter
D.M. Sheppard
H. Sherif
L.G. Stephens-Newsham
A.W. Stetz
G.M. Stinson
R.C. Urtasun
J. Weijer

University of British Columbia:

D.G. Fleming, Chairman 1975
N. Auersperg
E.G. Auld
D.A. Axen
D.V. Bates
D.S. Beder
D.H. Copp
M.K. Craddock
K.L. Erdman
R.R. Haering
L.G. Harrison
M.D. Hasinoff
R.R. Johnson
G. Jones
P. Larkin
K.C. Mann
P.W. Martin
T. Masterson
C.A. McDowell
J.M. McMillan
D.F. Measday
R.L. Noble
J. Phillips
M. Salomon
H. Stich
J. Trotter
J. Va'vra
E.W. Vogt
G.M. Volkoff
P. Walden
D.C. Walker
I.H. Warren
J.B. Warren
W. Westlund
B.L. White

University of Victoria:

M.J. Ashwood-Smith
G.A. Beer
D.A. Bryman
G. Bushnell
T.W. Dingle
M. Dixit
G.B. Friedmann
J. Haywood
T.A. Hodges
A.D. Kirk
D.E. Lobb
J.A. Macdonald
G.O. Mackie
G.R. Mason
A. Olin
R.M. Pearce
C.E. Picciotto
P.A. Reeve
L.P. Robertson
C.S. Wu

Simon Fraser University:

A.S. Arrott
J.M. D'Auria
B.L. Funt
R. Green
C.H.W. Jones
M. Kiely
R.G. Korteling
B.D. Pate
I.M. Thorson
W. Wiesehahn

TRIUMF Vancouver:

J. Beveridge
E.W. Blackmore
J.H. Brewer
H. Fearing
D.P. Gurd
G.H. Mackenzie
J.R. Richardson
J.G. Rogers
A.W. Thomas
J.S. Vincent

B.C. Cancer Foundation:

B. Douglas
J.M.W. Gibson
C.J. Gregory
R.W. Harrison
R.M. Henkelman
K. Kendall
*R.O. Kornelsen
B. Palcic
J. Probert
K.R. Shortt
L.D. Skarsgard
D.M. Whitelaw
*M.E.J. Young

**B.C. Cancer Control Agency*

Visiting experimentalists:

R. Brown, D.V. Bugg, J.A. Edgington, C. Oram, K. Shakarchi, *Queen Mary College, University of London*
N. Stewart, G. Ludgate, *Bedford College, University of London*
A.S. Clough, *University of Surrey*
S. Jaccard, *Université de Neuchâtel*
G. Waters, *Rutherford Laboratory*
J-M Poutissou, R. Poutissou, *Université de Montréal*
T. Yamazaki, K. Nagamine, R. Hayano, N. Nishida, *University of Tokyo*
A.N. James, *University of Liverpool*
J.K.P. Lee, *McGill University*
C.A. Goulding, *University of Manitoba*
G.E. Coote, *INS, Dept. of Science & Industrial Research, New Zealand*
L. Church, *Reed College*

Other institutions:

T. Matthews, S. Rowlands, *University of Calgary*
R. Cobb, T. Walton, *Cariboo College*
R.L. Clarke, E.P. Hincks, *Carleton University*
G.A. Bartholomew, E.D. Earle, J.S. Fraser, O. Häusser, F.C. Khanna, P. Lee, A. McDonald, *Chalk River Nuclear Laboratories*
W.W. Scrimger, S.R. Usiskin, *Dr. W.W. Cross Cancer Institute*, *Edmonton*
B.S. Bhakar, N. Davidson, W. Falk, J. Jovanovich, B.T. Murdoch, K.G. Standing, W.T.H. van Oers, D.O. Wells, *University of Manitoba*
B. Margolis, K. Scott, *McGill University*
J. McAndrew, *Memorial University of Newfoundland*
P. Depommier, B. Goulard, J-P Martin, *Université de Montréal*
G.T. Ewan, H.B. Mak, A.T. Stewart, *Queens University*
H.S. Caplan, *University of Saskatchewan*
M. Krell, *Université de Sherbooke*
J.M. Daniels, T.E. Drake *University of Toronto*
A. Cone, *Vancouver City College Langara Campus*
R.T. Morrison, *Vancouver General Hospital*
L.W. Reeves, *University of Waterloo*
W.P. Alford, *University of Western Ontario*
R. Eisberg, *University of California, Los Angeles*
F.P. Brady, *University of California, Davis*
L. Wolfenstein, *Carnegie-Mellon University*
H. Plendl, *Florida State University*
M. Rickey, G.T. Emery, *Indiana University*
T.R. Witten, *Kent State University*
K.M. Crowe, F.S. Goulding, R.H. Pehl, *Lawrence Berkeley Laboratory*
L. Rosen, *Los Alamos Scientific Laboratory*
N.S. Wall, *University of Maryland*
C. Schultz, *University of Massachusetts*
M. Bardon, *National Science Foundation*
L.M. Lederman, *Nevis Laboratories*
J.K. Chen, *State University of N.Y. Geneseo*
D.K. McDaniels, *University of Oregon*
K.A. Krane, S. Richert, L.W. Swenson, A. Smith, *Oregon State University*
T.L. Houk, *Pacific Lutheran University*
H. Primakoff, *University of Pennsylvania*
R.F. Carlson, A. Cox, *University of Redlands*
V.G. Lind, R.E. McAdams, O.H. Otteson, *Utah State University*
K. Ziock, *University of Virginia*
M. Blecher, K. Gotow, *Virginia Polytechnic Institute and State University*
H. Bichsel, V. Cook, I. Halpern, E.M. Henley, J.E. Rothberg, K. Snover, P. Wooton, *University of Washington*
H.B. Knowles, *Washington State University*
W.C. Sperry, *Central Washington State College*
R.R. McLeod, *Western Washington State College*
C.F. Perdrisat, *College of William and Mary*

D. Wilkinson, N. Tanner, *Nuclear Physics Laboratory*, *Oxford University*
I.M. Blair, *Atomic Energy Research Establishment, Harwell*
Cl. Perrin, *Institut des Sciences Nucléaires, Université de Grenoble*
J.P. Blaser, *Schweizerisches Institut für Nuklearforschung*
M. Furic, *Institute R. Boskovic, Zagreb*
I.R. Afnan, *Flinders University of South Australia*
K. Sakamoto, S. Okada, N. Suzuki, T. Ono, *University of Tokyo*

EXPERIMENT PROPOSALS

The following lists experiment proposals received up to the end of 1975 (missing numbers cover proposals that have been withdrawn, replaced by later versions, or combined with another proposal). Page numbers are given for those experiments which are included in this annual report.

[Spokesman underlined] Page

1. Low-energy pi nuclear scattering, E.G. Auld, D.A. Axen, R.R. Johnson, G. Jones, (*Univ. of British Columbia*) 54
2. Investigation of the D(p,2p)n reaction, J.M. Cameron, P. Kitching, W.J. McDonald, G.A. Moss, W.C. Olsen (*Univ. of Alberta*)
3. The study of fragments emitted in nuclear reactions, J.M. D'Auria, R. Green, R.G. Korteling, B.D. Pate (*Simon Fraser University*) 61
4. A study of the reaction $p + p \to p + p + \pi^0$ near threshold, D.F. Measday, J.E. Spuller (*Univ. of British Columbia*)
6. Studies of the proton- and pion-induced fission of light to medium mass nuclides, D. Dautet, F.M. Kiely, B.D. Pate (*Simon Fraser University*)
9. A study of the reaction of $\pi^- + p \to \gamma + n$ at pion kinetic energies from 20-200 MeV, M.D. Hasinoff, D.F. Measday, M. Salomon (*Univ. of British Columbia*), J-M Poutissou (*Univ. de Montréal*) 55
10. Positive pion production in proton-proton and proton-nucleus reactions, D.A. Axen, R.R. Johnson, G. Jones, M. Salomon, J.B. Warren (*Univ. of British Columbia* L.P. Robertson (*Univ. of Victoria*), P. Kitching, W.C. Olsen (*Univ. of Alberta*) 57
11. A study of new, high neutron excess nuclides, G. Bischoff, J.M. D'Auria, H. Dautet, R.G. Korteling, B.D. Pate, W. Wiesehahn (*Simon Fraser University*), G.E. Coote (*INS, Dept. of Science & Industrial Research, New Zealand*) 63
12. An experiment to measure the mass of new elements with isospin T_z=-2 and T_z=-5/2 using (p,^{8}He) and (p,^{9}Li), J.M. Cameron, D.A. Hutcheon, G.C. Neilson (*Univ. of Alberta*), D.R. Gill (*TRIUMF*)
13. Measurement of the electromagnetic size of the nucleus with muonic x-rays, particularly the 2s-2p transition, G.A. Beer, G.R. Mason, R.M. Pearce, C.E. Picciotto, C.S. Wu (*Univ. of Victoria*), D.G. Fleming (*Univ. of British Columbia*), W.C. Sperry (*Central Washington State College*)
14. The interaction of protons with very light nuclei in the energy range 200-500 MeV, J.M. Cameron, R. McCamis, G.A. Moss, G. Roy, A.W. Stetz (*Univ. of Alberta*), B.S. Bhakar, C.A. Goulding, W.T.H. van Oers (*Univ. of Manitoba*), J.G. Rogers (*TRIUMF*) 66
15. A Proposal to study quasi-free scattering in nuclei, J.M. Cameron, P. Kitching, W.J. McDonald, C.A. Miller, G.C. Neilson, W.C. Olsen, J.T. Sample, A.W. Stetz, G.M. Stinson (*Univ. of Alberta*), A.N. James (*Univ. of Liverpool*) 67
16. Proton-deuteron quasi-elastic scattering, D.A. Hutcheon, P. Kitching, W.J. McDonald, C.A. Miller, G.A. Moss, W.C. Olsen, D.M. Sheppard, A.W. Stetz (*Univ. of Alberta*), A.N. James (*Univ. of Liverpool*), J.G. Rogers (*TRIUMF*) 68
18. Influence of chemical environment on atomic muon capture rates, G.A. Beer, T.W. Dingle, D.E. Lobb, G.R. Mason, R.M. Pearce (*Univ. of Victoria*), D.G. Fleming (*Univ. of British Columbia*), W.C. Sperry (*Central Washington State College*)

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61. Pre-clinical research on the π^- beam at TRIUMF (Biomedical), C.J. Gregory, R.W. Harrison, R.M. Henkelman, K.R. Kendall, B. Palcic, K.R. Shortt, L.D. Skarsgard (*B.C. Cancer Foundation*), R.O. Kornelsen, M.E.J. Young (*B.C. Cancer Control Agency*) 59

62. Measurement of the π^- atomic cascade time in light elements, G.A. Beer, D.A. Bryman, G.R. Mason, A. Olin, R.M. Pearce, L.P. Robertson (*Univ. of Victoria*)

63. Measurement of the π^- mass, G.A. Beer, D.A. Bryman, S.K. Kim, G.R. Mason, A. Olin, R.M. Pearce, C.E. Picciotto (*Univ. of Victoria*)

64. Total cross-section and total reaction cross-section measurements for the p-^{3}He systems and n-^{3}He systems, B.S. Bhakar, C.A. Goulding, M.S. de Jong, W.T.H. van Oers, A.M. Sourkes (*Univ. of Manitoba*), J.M. Cameron, G.A. Moss (*Univ. of Alberta*), R.F. Carlson and A.J. Cox (*Univ. of Redlands*)

65. Radiosensitivities of tumors in situ to π-meson irradiation, S. Okada, T. Ono, K. Sakamoto, N. Suzuki (*Univ. of Tokyo*)

66. Survey of p-p bremsstrahlung far off the energy shell, J.G. Rogers (*TRIUMF*), J.M. Cameron, A.N. Kamal, A.W. Stetz, A. Szyjewicz (*Univ. of Alberta*), J.V. Jovanovich (*Univ. of Manitoba*) 70

67. Two nucleon emission following reactions induced by stopped pions, J.M. Cameron, W.J. McDonald, G.C. Neilson (*Univ. of Alberta*), P.W. Martin (*Univ. of British Columbia*), G.A. Beer, G.R. Mason, A. Olin (*Univ. of Victoria*)

68. Feasibility study of use of high purity germanium detectors for detection of high-energy charged particles, J.M. Cameron (*Univ. of Alberta*), D.R. Gill (*TRIUMF*), F.S. Goulding, R.H. Pehl (*Lawrence Berkeley Laboratory*), P.W. Martin, M. Salomon (*Univ. of British Columbia*)

69. Pion double charge exchange on very light nuclei, J.M. Cameron, W.J. McDonald, A.W. Stetz (*Univ. of Alberta*), N.E. Davidson, B.T. Murdoch, W.T.H. van Oers (*Univ. of Manitoba*), V. Perez-Mendez (*Lawrence Berkeley Laboratory*)

70. Proton total cross-section and total reaction cross-section measurements for light nuclei, B.S. Bhakar, C.A. Goulding, B.T. Murdoch, A.M. Sourkes, W.T.H. van Oers (*Univ. of Manitoba*), R.F. Carlson, A.J. Cox (*Univ. of Redlands*), J.M. Cameron, G.A. Moss (*Univ. of Alberta*), H. Postma (*Univ. of Groningen*)

71. Muon spin rotation project, R. Hayano, S. Kobayashi, K. Nagamine, S. Nagamiya, N. Nishida, T. Yamazaki (*Univ. of Tokyo*), J.H. Brewer, A. Duncan, D.G. Fleming (*Univ. of British Columbia*) 58

72. Solid-state studies by muonic x-ray polarization, R. Hayano, K. Nagamine, N. Nishida, T. Yamazaki (*Univ. of Tokyo*), R.M. Pearce (*Univ. of Victoria*)

73. Artificial muon polarization, R. Hayano, K. Nagamine, N. Nishida, T. Yamazaki (*Univ. of Tokyo*), J.H. Brewer, D.G. Fleming, M.D. Hasinoff (*Univ. of British Columbia*) 58

74. Proposal to measure D, R and R′ in pp scattering, 200 to 520 MeV, D.V. Bugg, J.A. Edgington, K. Shakarchi, C. Oram (*Queen Mary College, London*), D.A. Axen, J. Va'vra (*Univ. of British Columbia*), S. Jaccard (*Univ. de Neuchâtel*), G. Ludgate, N.M. Stewart (*Bedford College, London*), A.S. Clough (*Univ. of Surrey*)

75. The d(p,π^+)t pion production reaction for high momentum transfer, P. Kitching, W.C. Olsen (*Univ. of Alberta*), H. Fearing (*TRIUMF*), C.F. Perdrisat (*College of William and Mary*), G. Jones, T. Masterson, P. Walden (*Univ. of British Columbia*)

76. A proposal to study elastic scattering on ^{16}O and ^{40}Ca, D.P. Gurd, D.A. Hutcheon, P. Kitching, W.J. McDonald, C.A. Miller, G.C. Neilson, W.C. Olsen, G. Roy, G.M. Stinson (*Univ. of Alberta*)

77. Evaporation-cooled metallic cesium target assembly for production of ^{123}I, J.W. Blue (*NASA Cleveland*), T.A. Hodges (*Univ. of Victoria*), J.S. Vincent (*TRIUMF*), R.T. Morrison (*Vancouver General Hospital*), J.B. Warren (*UBC*), W.J. Wiesehan (*SFU*)