TRIUMF

ANNUAL REPORT
SCIENTIFIC ACTIVITIES
1985

MESON FACILITY OF:

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

OPERATED UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

MAY 1986
FOREWORD

As shown in this report, 1985 marked another outstanding year in scientific productivity for TRIUMF. Although much of the credit for this productivity must be attributed to the scientists, the TRIUMF staff and technicians who made the facility operate in such an efficient manner, much of the credit for the smooth operation of the facility and the enthusiasm of the users of TRIUMF must be attributed to the current Director, Dr. Erich Vogt. In fact, the Board of Management was so pleased with TRIUMF's performance under Dr. Vogt's guidance that it unanimously voted to renew his Directorship for a further five years.

July 1985 marked ten years of scientific output for TRIUMF. To mark the occasion many long-time friends were invited for a celebration of the event. Although the occasion was primarily to celebrate the successes of the past ten years, the occasion was also used to mark the beginning of the KAON era. There was unanimous agreement that the future of TRIUMF lay in a high intensity KAON factory. If this new, exciting project is to come to fruition, it will demand the co-operation of all the parties that have made TRIUMF such a success—four founding universities, the Federal Government, the National Research Council, and all those individuals who have supported TRIUMF during the past years.

Croy Neilson
Chairman, Board of Management
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 programme is based on a cyclotron capable of producing three simultaneous beams of protons, two of which are individually variable in energy, from 180-520 MeV, and the third fixed at 70 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 isotope research and production and nuclear fuel research. There is also a biomedical research facility which uses mesons in cancer research and treatment.


The laboratory employs approximately 385 staff at the main site in Vancouver and 18 based at the four universities. The number of university scientists, graduate students and support staff associated with the present scientific programme is about 440.
# CONTENTS

## INTRODUCTION

1

## TEN YEARS OF SCIENTIFIC RESEARCH AT TRIUMF

3

## SCIENCE DIVISION

8

### Introduction

8

#### Particle Physics

10

- $\mu \rightarrow e$ conversion in titanium
- Measurement of the $\pi$-$p$ spin correlation parameter $A_{\pi n}$
- Measurement of the slope of the $\pi^0$ electromagnetic form factor
- A study of the decay $\pi \rightarrow e^+ e^-$
- Radiative muon capture with the TPC
- Test of charge symmetry by the comparison of $d\sigma(\pi^+d + pp)$ with $d\sigma(\pi^-d + nn)$
- Branching ratio of $\pi^0 \rightarrow e^+ e^-$
- Measurement of parity violation in $p$-$p$ scattering
- The reaction $pp\pi^0$ near threshold
- Measurement of $K^+ \rightarrow \pi^+\nu\bar{\nu}$
- The SLD group

#### Nuclear Physics and Chemistry

21

- Nonevaporative fragment emission
- Radiative capture of polarized neutrons
- Isospin dependence of pion absorption on $^3$He at 37 MeV
- $(\pi,\pi')$ scattering
- $t_{20}$ in $\pi d$ elastic scattering
- Proton-proton bremsstrahlung
- Search for evidence of $\Lambda$-nucleus intermediate state in proton elastic scattering
- Studies of the $A(p,\pi^-)A+1$ reaction
- Proton nucleus interaction
- Energy dependence of isovector effective interactions from the $^{14}$C$(p,n)^{14}$N reaction
- Initial studies of the $(n,p)$ reaction on light nuclei
- A measurement of the Gamow-Teller strength distribution in the $^{54}$Fe$(n,p)^{54}$Mn reaction at 298 MeV
- Transverse spin-flip probabilities in $^{24}$Mg$(\vec{p},\vec{p}')$
- Investigations of the pion absorption reaction $^{6}$Li,$^{12}$C$(\pi^\pm,X_1)X_2$
- Exchange effects in $0^+ \rightarrow 0^-$ inelastic scattering
- Proton scattering from $^{208}$pb at large momentum transfer
- Elastic scattering of pions on $^3$He for pion energies between 30 and 50 MeV
- Spin rotation parameter $Q$ for $p^{208}$Pb elastic scattering at 290 MeV
- Measurement of $X_{gs}$ in $pp + d\pi$
- Measurement of $\pi^\pm$-$p$ elastic differential cross sections
- P-A measurement for $^{12}$C$(p,p')$ at 400 MeV
- Isoscalar and isovector $1^+$ excitations in $^{28}$Si$(\vec{p},\vec{p}')$
- Measurement of tensor observables in the $\pi^d$ elastic scattering reaction
- Study of the energy dependence and the A dependence of the double charge exchange reaction at low energy
- Y scaling in inclusive proton scattering from $^9$Be and $^{12}$C at 300 MeV
- A search for the tetraneutron

### Research in Chemistry and Solid-State Physics

47

- Muonium in ice
- Muonium chemistry in condensed media
- A new muonium relaxation mechanism: Random hyperfine anisotropies
Research in Chemistry and Solid-State Physics (cont'd)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The chemistry of stopping ( \pi^- ) in hydrogenous materials</td>
<td>49</td>
</tr>
<tr>
<td>Temperature dependence of reaction rate constants for muonium</td>
<td>49</td>
</tr>
<tr>
<td>reactions in liquid phases</td>
<td></td>
</tr>
<tr>
<td>Muon spin rotation studies of supported metal catalysts</td>
<td>50</td>
</tr>
<tr>
<td>The reaction of muonium with hydrogen peroxide in water</td>
<td>51</td>
</tr>
<tr>
<td>Muon spin rotation of paramagnetic solutions</td>
<td>51</td>
</tr>
<tr>
<td>Muonium-radical formation mechanism</td>
<td>53</td>
</tr>
<tr>
<td>Muonium reaction rates on surfaces</td>
<td>53</td>
</tr>
<tr>
<td>Positive muon probing soliton in polyacetylene</td>
<td>54</td>
</tr>
<tr>
<td>Gas phase muonium addition reaction kinematics</td>
<td>55</td>
</tr>
<tr>
<td>The effects of large oscillating fields in low frequency double</td>
<td>57</td>
</tr>
<tr>
<td>electron muon resonance</td>
<td></td>
</tr>
<tr>
<td>Ultra-low energy muon production</td>
<td>58</td>
</tr>
<tr>
<td>Muon molecular ions and ion-molecule reactions</td>
<td>59</td>
</tr>
<tr>
<td>Heavy fermion conductors</td>
<td>62</td>
</tr>
<tr>
<td>Spin dynamics in crystalline and amorphous DyAg</td>
<td>63</td>
</tr>
<tr>
<td>Observation of muon-fluorine 'hydrogen' bonding in ionic crystals</td>
<td>64</td>
</tr>
<tr>
<td>Resolved nuclear hyperfine structure of muonated free radicals</td>
<td>65</td>
</tr>
<tr>
<td>using level crossing spectroscopy</td>
<td></td>
</tr>
</tbody>
</table>

Theoretical program

- Introduction
- Nuclear structure
- Scattering and reactions on nuclei
- N-nuclear physics and hypernuclei
- Hadron structure
- Hadron-hadron scattering
- Electroweak interactions
- Heavy ion collisions
- Muon spin rotation
- Numerical techniques

APPLIED PROGRAMS DIVISION

<table>
<thead>
<tr>
<th>Program</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>82</td>
</tr>
<tr>
<td>Biomedical program</td>
<td>82</td>
</tr>
<tr>
<td>42 MeV cyclotron</td>
<td>83</td>
</tr>
<tr>
<td>Radioisotope processing (AECL)</td>
<td>84</td>
</tr>
<tr>
<td>500 MeV radioisotope production</td>
<td>84</td>
</tr>
<tr>
<td>Positron emission tomography (PET)</td>
<td>85</td>
</tr>
<tr>
<td>TRIM program</td>
<td>89</td>
</tr>
</tbody>
</table>

CYCLOTRON DIVISION

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>90</td>
</tr>
<tr>
<td>Beam production</td>
<td>92</td>
</tr>
<tr>
<td>Projects</td>
<td>93</td>
</tr>
<tr>
<td>Alternative extraction system</td>
<td>93</td>
</tr>
<tr>
<td>Resonator improvement program</td>
<td>96</td>
</tr>
<tr>
<td>New projects</td>
<td>99</td>
</tr>
<tr>
<td>Cyclotron</td>
<td>100</td>
</tr>
<tr>
<td>Cyclotron development</td>
<td>100</td>
</tr>
<tr>
<td>RF operation</td>
<td>103</td>
</tr>
<tr>
<td>Vacuum upgrade</td>
<td>103</td>
</tr>
<tr>
<td>Probes and diagnostics</td>
<td>104</td>
</tr>
<tr>
<td>Engineering physics</td>
<td>104</td>
</tr>
<tr>
<td>Ion sources and injection system</td>
<td>105</td>
</tr>
<tr>
<td>Primary beam lines</td>
<td>107</td>
</tr>
<tr>
<td>Control system</td>
<td>109</td>
</tr>
<tr>
<td>Operational services</td>
<td>111</td>
</tr>
</tbody>
</table>
EXPERIMENTAL FACILITIES DIVISION

Introduction 113
Experimental support 114
Data acquisition systems 114
Computing facilities at TRIUMF (CFAT) 115
Nucleonics and IAC 116
Detectors facility 116
MWPC facility 117
Meson hall 117
M9 channel 117
M11 channel 118
M13 channel 118
M15 channel 119
QDD spectrometer 120
μSR facility 122
Proton hall 123
Charge exchange facility for (p,n) and (n,p) spectroscopy 123
Beam line 4A 125
Beam line 4B 126
Neutron facility 126
MRS 126
Focal plane polarimeter for the MRS 127
TISOL/ISOL 128
Dual arm spectrometer system/second arm spectrometer (DASS/SASP) 129
Targets 130
Experimental facilities engineering 131

ACCELERATOR RESEARCH DIVISION

Introduction 134
Beam Development 135
Cyclotron 135
ISIS Electrostatic quadrupole aberrations 135
ISIS Third buncher 135
Alternative extraction program 135
ISOL post-accelerator 137
Modelling synchrotron injection 138
Primary beam lines 139
Secondary channels 139
Beam line diagnostics 140
Computing services 142
KAON factory studies 143

TECHNOLOGY AND ADMINISTRATION DIVISION

Introduction 150
Site services 150
Safety program 150
Building program 152
Mechanical engineering 152
Planning 153
Controls, electronics and computing 154
Electronics 154
Data Analysis Centre 157
Administration 158
Business Office 158
1985 was a year of significant events for TRIUMF. In mid-year a major celebration marked the tenth anniversary of TRIUMF's first beam. In the fall TRIUMF published the KAON factory proposal. At the end of the year, in a burst of scientific activity, the charge exchange facility emerged full blown as a major new facility for new physics. Apart from these events it was a year of strong scientific output and again of record beam delivery.

Vibrant youth is a cause for celebration. The tenth anniversary of first beam was an occasion to assess TRIUMF's impact on the world of subatomic physics. From its beginnings as an idea in the middle 1960s and its birth as a funded project in 1968, TRIUMF progressed through a period of construction and development to achieve its first beam ten years ago and finally to bring into full flourish the present science programme. During the past ten years TRIUMF has put Canada on the world map in subatomic physics. In celebration of that accomplishment our friends from around the world assembled at the site in early July for a ceremony and a salmon barbecue, followed the next day by a major scientific symposium. The speech of Sir Denys Wilkinson at the ceremony, which is produced in full in this annual report, captures very eloquently the spirit of the event. Also at the ceremony the leaders of Canada's foremost science agencies made very gracious remarks about the development of TRIUMF.

The science symposium which followed the ceremony brought together world leaders of large new accelerator facilities to describe the present perspective in the science of quarks, leptons and unified forces. Alan Astbury of TRIUMF described the role that the new KAON factory will play in this perspective. He was followed by Dr. Volker Soergel, the Director of the DESY Laboratory of Hamburg, West Germany, who described the new HERA facility now under construction in Hamburg for high energy collisions of electrons and protons. Dr. Carlo Rubbia described the plans at CERN for high energy proton-antiproton collisions and the future plans for large hadronic colliders. Dr. D. Allan Bromley described the United States plans for relativistic heavy ion colliders and for the high energy cw electron machine in Virginia (CEBAF). Dr. J. David Jackson of Berkeley described the planning and development work for the superconducting super collider (SSC) in the United States. Finally Dr. K. Kikuchi from Japan described the plans for electron-positron collider work (TRISTAN) at the KEK Laboratory in Japan. The combination of the ceremony and the symposium will be regarded as an important event in the history of TRIUMF and of Canadian science.

The emergence of the KAON factory proposal heralds the next few decades of TRIUMF's history. The idea for such a proposal was germinated at TRIUMF six years ago with the world's first KAON Factory Workshop held in the summer of 1979. From that beginning the present proposal has emerged after a great deal of design and development work and the pursuit of the ideas in science which such a facility would address. It is significant that the same kind of facility is now being strongly pursued not only in Canada but also in the United States, Europe and in Japan. TRIUMF's KAON factory proposal describes the singular opportunity for Canada which this facility constitutes, it summarizes the many new ideas in science which would be addressed by it, and it gives details about the accelerators and experimental facilities which would be added to create this facility. The next few years should be very interesting for TRIUMF as it approaches and achieves the funding of the KAON factory and begins its construction.

Progress in science does not always flow smoothly. It often comes in quantum leaps. This is true for the year 1985 of TRIUMF. About sixty experiments received significant beam time and two-thirds of these were completed during the year. The section on science in this annual report describes the whole programme. Perhaps the single most important quantum leap occurred at the end of the year when the charge exchange facility in the proton hall emerged, quite suddenly, as a major new world focus for nuclear physics. It is a unique facility which some of TRIUMF's competing laboratories will emulate in the coming years. However, for the next two or three years dozens of major experiments with this facility will be accomplished at TRIUMF. For several years there has been great interest world-wide in the response of a nucleus to nucleons at intermediate energies. The response can be analysed in terms of interactions corresponding to different angular momentum, spin and isospin, etc. Of
special importance has been the recent reaction in which the spin and the isospin both flip. Pioneer work on (p,n) reactions, below 200 MeV, at Indiana have opened the field. What was needed was a facility to provide such (p,n) reactions in TRIUMF's realm of energies (200 MeV-520 MeV) and also, very importantly, to provide the complementary information obtainable with (n,p) reactions. The new facility achieves both. The details of how this was accomplished are given in this annual report.

What the new charge exchange facility means for TRIUMF is that important experiments will now flow out of the proton hall during beam production periods previously of comparatively low scientific priority in the proton hall, namely unpolarized beam periods. There are now very many approved experiments awaiting the use of this facility and they will be important in subsequent annual reports.

Many other significant events should be singled out from the year and from the many detailed parts of this annual report. This would certainly involve the successful completion of the polarized deuteron target and its use to resolve a longstanding controversy concerning reactions with pions and deuterons. This also occurred in the final weeks of the year. Certainly one should mention the very beautiful experiments continuing to emerge from the µSR beam lines. Also we should note the progress made on the new resonators and on the development of advanced ion sources. All facets of the applied programme showed important advances, in particular the pion cancer therapy programme, with the many patients treated providing very favourable, though still anecdotal, evidence for the effectiveness of pions in treating deep-seated tumours. A strong new thrust in 'technology transfer' from TRIUMF to local industry is under way. In sum it was a most satisfactory year of research and development at TRIUMF.

Throughout 1985 the TRIUMF Board of Management prospered under the very able chairmanship of Prof. G. Croydon Neilson, one of the founders of TRIUMF. The Board membership also had significant change through normal turnover. At Simon Fraser University Dr. George Ivany and Dr. Tom Calvert replaced Dr. John Webster and Dr. John Cochran, while at the University of Victoria Dr. Alan Astbury and Dr. A.T. Matheson replaced Dr. Charles Picciotto and Dr. R.R. Davidson. The Board continues to benefit from the strong interest of the very competent members appointed to it by the four universities constituting the TRIUMF Joint Venture.
I am happy to be here to help you celebrate the first ten years of work of one of the world's most successful nuclear accelerators. In terms of the range, intensity, quality and flexibility of its primary and secondary beams and in terms of the range, significance and quality of its academic output, this is the triumph of TRIUMF.

I am here not just because I have a forty-year-long affectionate relationship with this country dating from the time when I performed the first physics experiment on Canada's first nuclear reactor, nor because I hold two of Canada's universities in honorary filial piety, nor because I was for many years Chairman of the Committee in Europe charged with work in TRIUMF's field, nor even because, from its beginning, I supported and urged the construction of TRIUMF and was a member of its first Experiments Evaluation Committee, but rather because I have a passionate commitment to internationalism in science and TRIUMF is Canada's chief expression of that internationalism.

Effective internationalism must be based on excellence at home and the making of major contributions, at home, to the internationalism of which you form a part. This constitutes the necessary base for the taking of a significant place in the truly international commonality of science. That, through TRIUMF, Canada has provided. Canada possesses in TRIUMF an accelerator, itself of the highest international class, to which scientists of 20 or more countries flock to work, that has made many scientific advances that are at the top of the highest class, and that provides Canada with an unquestioned entrée into the club of great powers in the international scene of nuclear and particle physics.

Canada has shown excellent taste. Canada, 20 years ago, did not decide simply to build the largest and highest energy accelerator that she could afford. This would have given her an accelerator obsolete when completed and by now long outmoded: an embarrassment leading nowhere. Canada rather resolved, courageously, to build one of the finest accelerators technically possible in the then slightly problematical field intermediate between that of classical nuclear structure physics and that of the, differently targeted, high energy particle physics machines of the bigger battalions at CERN, Geneva and at Brookhaven in the United States. This intermediate energy field has, in the event, proved rich and fruitful; as well as having major importance in its own intellectual right it acts as an essential interface between the two worlds of nuclear structure and particle physics. Together with the linear accelerator LAMPF in Los Alamos and the fixed-energy cyclotron at SIN, Switzerland, TRIUMF takes its unquestioned place in the world triumverate - I almost said TRIUMFverate - of intermediate energy physics.

On such a day as this one might naturally expect somewhat extravagant and hyperbolic remarks to be made but I do not exaggerate in speaking as I have just done. Indeed, contributions to recent international conferences have spoken for themselves showing a productivity from TRIUMF that is second to none.

As we look back on TRIUMF's first ten years we must look forward to its future as Canada's prime expression of aspiration in the academic nuclear field. In my view the future should be the mixture as before. Just as, twenty years ago, Canada asked herself what she could do that would both be of world class in its own right and also provide the entrée to those activities that would be beyond her own scope, so now the same question must be posed with respect to the next phase. Canada must now define a world class facility in a field naturally linked to that of TRIUMF's current exploitation that will put her in the forefront of such endeavours and act as the natural logistic and intellectual springboard for participation in larger scale activities elsewhere. A KAON factory, to which TRIUMF would be the injector, is a natural and realistically possible proposal; this will be the new intermediate energy field and will be to the 90s and beyond as TRIUMF was to the 70s. This project would give Canada a pre-eminent position in that

*Delivered as the opening address at the Celebration of Ten Years of Scientific Research at TRIUMF, held at TRIUMF on July 7, 1985.
field, the new interface, of high importance in its own right and linking naturally into those activities, now themselves under serious consideration elsewhere, that involve accelerators whose dimensions are measured not in tens of metres but in tens of kilometres.

I shall now attempt to give you some sort of feeling for some of the highlights of TRIUMF's work of the last ten years, work that has so amply justified your investment of the past and that so clearly calls for your investment of the future. I shall mention nothing that is not incontestably at the forefront of international accomplishment. I shall not name names and I shall not attempt to distinguish between work carried out by members of TRIUMF's own academic faculty, members of the four participant universities, other Canadian universities or scientists from the more than 20 foreign countries who have looked to TRIUMF for the realisation of their own intellectual aspirations; I shall just refer to TRIUMF as if it itself were the prime active agent.

I am going to speak only of experimental work while recognising that TRIUMF has also built up a theoretical group which is itself of world class and that is important not only for its own academic accomplishment but for its stimulating effect upon the TRIUMF experimental programme.

It is our business to find out how Nature works, from the fundaments of the atom to beyond the stars. Man attempts to identify the basic units out of which the complex extended structures in which he interests himself are built up and then to understand how those basic units are assembled into those complex extended structures. If he is a chemist, interested in atoms and molecules, the basic units are the atomic nucleus and the electrons that circle it; he is not concerned with the fact that the nucleus is itself a complex extended structure. Such latter matters are for the nuclear physicist who tries to understand how the complex extended nucleus works on the basis of the forces that operate between the neutrons and protons, the basic units out of which it is made; forces whose own nature he must also find out. The nuclear physicist in his turn is not concerned with the fact that the neutrons and protons are themselves complex extended structures. Such matters are for the particle physicist for whom the complex neutron and proton are built out of their own basic units the quarks. Although we seem unable to prise quarks loose we can infer their properties through experiments on those collective enterprises the neutron and proton. As we read in Voltaire's Pensées Philosophiques:

"Les Philosophes qui font des systèmes sur la secrète construction de l'univers, sont comme nos voyageurs qui vont à Constantinople, et qui parlent du Sérail: Ils n'en ont vu que les dehors, et ils prétendent savoir ce que fait le Sultan avec ses Favorites."

The natural world is chiefly emptiness: the neutrons, protons and electrons occupy only a million millionth of the volume of the atom while the quarks occupy no more than a millionth of the volume of the neutron and proton, so that the matter out of which an atom is composed, ultimately as we now understand it, occupies less than a million million millionth part of its volume. So far as we can tell, electrons and quarks are points and themselves have no structure at all. But is this so? I have used the words 'ultimately as we now understand it' and 'so far as we can tell'. With yet deeper probing may the electron and quark not themselves reveal a substructure on a yet finer scale? Will there be any end to little fleas having lesser fleas upon their backs to bite them?

We must keep an open mind and not claim that because quarks and electrons today look to us like points tomorrow will not reveal them to be as lumbering and ungainly as those gigantic objects, atoms, appear to us today.

I have brought myself to the first of my TRIUMF experiments. If you are looking for possible structure in an object, such as an electron, you should not do so through its interaction with an object, such as a proton, that you know itself to be structured; the electron-proton interaction involves the structure of the proton, the effect of which must be calculated and subtracted out before you can assess the possible influence of a structure for the electron itself. Atomic experiments, in other laboratories, on the structure of the hydrogen atom are at the point where their interpretation in terms of a possible structure for the electron is inhibited by our limited knowledge of the structure of the proton. How can we advance? Only by replacing the proton by another particle that we have reason to believe must be structureless if the electron is structureless. Such a particle is the muon which in all respects behaves like an electron but is
about two hundred times heavier. If we could make a synthetic hydrogen atom, replacing the proton at its centre by a positively charged muon, and repeat the atomic experiments, our interpretation would be unclouded by the structure of the positive particle itself. But this is a desperate proposition because muons come as the decay products of the pions that have to be made at high energy accelerators - enter TRIUMF - and, once made, live for only a millionth of a second before themselves decaying. So in that millionth of a second you have to persuade an electron to attach itself appropriately to the muon and then do your experiment. But the desperate deed has been done and TRIUMF has measured the so-called muonium Lamb shift, a spectacular tour de force. But the electron remains a point.

I began with that jewel of an experiment because it attached itself naturally to the end of my story of deeper and deeper delving into the structure of matter. In the middle of that story I spoke of the nuclear physicist's attempts to understand the structure of the atomic nucleus on the basis of the forces between the neutrons and protons that it contains and of his concomitant need to find out what those forces are. Now the electric force that holds atoms together is very well known, so when we seek to understand the structure of the atom we at least know the law of force that operates between its constituents. But within the nucleus, the force between neutrons and protons, the situation is very different: there there are not one but many different laws of force, differing with the electrical charges of the two particles between which the interaction is taking place, with the states of relative motion of the two particles and with the relative orientations of the spins of the two particles. In some such combinations neutrons and protons attract each other, in others they repel; more usually they cannot make up their minds, finding each other attractive when far apart but repulsive at closer acquaintance: a phenomenon with which we are all familiar. The force between neutrons and protons is a dreadful complicated mess. Unlike for the electric force where theory gives us brilliant quantitative guidance, in the neutron-proton case theory is not so much silent as speaking in a babel of conflicting tongues that it would be generous to describe as totally useless. But we must know these nuclear forces if we seek to describe and understand the complex nuclei to which they give rise. And I should here lift my eyes to the stars for these same nuclear forces are critical for our understanding of those celestial radio beacons, the pulsars, and of supernovae, those fortunately rare cosmic stellar explosions in which a dying star blows itself to pieces in a terminal moment of galactic glory, often leaving behind a winking pulsar to remind the Milky Way of what once was.

TRIUMF with its superb particle beams, and with its capacity for providing those beams with the neutrons and protons spinning in chosen directions, was the natural venue for a major attack on the neutron-proton force. It took a large international collaboration, acronymed BASQUE, 8 years to do the job and we are the richer for it. It is often remarked that BASQUE doubled the world understanding of the neutron-proton force. But the value of the work was greater than that because it completed our knowledge of the neutron-proton force in its energy range, and it is in the completion of knowledge that virtue lies; there is not much use in half a motor car.

We believe that, in a deep sense, neutron and proton are not different things but only different manifestations of a single entity, the nucleon: the proton, electrically charged; the neutron electrically neutral. In fact, the masses of neutron and proton differ by only about one-tenth of one per cent and they interconvert radioactively: the free neutron emits an electron and becomes a proton, taking, on the average, about ten minutes, as was first incontrovertibly established here in Canada. But if a proton differs from a neutron only by a bit of electricity about with it, then the forces between two neutrons should be the same as those between two protons if we subtract out the purely electric forces in the latter case. The increasingly rigorous testing of this fundamental symmetry has occupied great efforts in many laboratories for many years. It is in the TRIUMF Annual Report of 1979 that we first read of preparations towards a sensitive test, involving polarized neutron beams, at which TRIUMF is pre-eminent, and polarized proton targets. Results recently achieved constitute the first unequivocal demonstration of the breakdown of this fundamental symmetry. This will be a key experiment for our attempts to understand the finer details of the origins of the nuclear force.

I have spoken about the importance of extended structure. If an object has such a
structure, finding out what that structure is

tells us what the more basic objects out of
which the structured object is made are doing
inside it. There is intense interest in the
arrangement and movements of the nucleons
within the nucleus and in the behaviour of
the quarks out of which the nucleon, in its
turn, is made. We understand the myriad ex-
cited states into which a nucleus can be
raised as being due to the alternative ar-
rangements of its constituent nucleons rela-
tive to each other. We similarly understand
the many excited states of the nucleon it-
self in terms of the rearrangement of its
constituent quarks. But in one extremely im-
portant case we have no such simple model.
It is the case, of all cases, surely of most
concern to TRIUMF: the M of its very name.
The M of TRIUMF stands for meson, namely the
pion, the lightest particle that interacts as
strongly with the nucleon as do nucleons with
each other. But the pion, TRIUMF's bread and
butter, is understood by nobody; it is,
indeed, schizophrenic if not hermaphroditic.
We can describe its composition in terms of
quarks. But its real-life mass, about one-
seventh of that of the nucleon, is then much
too small. From another, fundamental, point
of view the pion is forced into existence by
the fact that the nucleon itself has a finite
mass. But then this fundamentally important
pion, unlike the real-world pion, should
itself have zero mass. So the real-life pion,
the M of TRIUMF, is either too light or too
heavy depending on your point of view. What
can we do to enhance our understanding of
this, the most important of all accelerator-
produced particles? On the theoretical side
we can attempt a rapprochement that leads us
to describe the pion not as a simple quark-
based structure but as a complicated coherent
superposition of many such simple structures
combined into a collectivity from which
emerges something more like the fundamental
tity of the other viewpoint. Experimentally
we can go and see what the pion is like
inside. The primitive quark-based picture
gives us a definite prediction while the
other picture says that the pion is struc-
tureless. Looking at the structure of the
pion is a tricky business. A nucleus or a
nucleon will sit there indefinitely and let
you probe it, but a pion has to be made
artificially and then, in its electrically
neutral form of present concern, lives only
for about one ten thousand million millionth
of a second before it decays. Not much time
to do experiments there. But it will, in-
deed, reveal its structure to us if we look
in detail at the rare processes in which it
decays not, as it usually does, into two
gamma-rays but rather into one gamma-ray plus
a pair of electrons, positive and negative,
or into two such electron pairs, or into just
a single electron pair, so rarely that you
have to examine the decay of ten million
neutral pions to find a single such event.
Experiments at TRIUMF are bringing us such
structural information of an accuracy and
reliability in excess of that available any-
where else; when they are completed we should
know, for the first time, what the M of
TRIUMF looks like.

When we construct nuclei by putting together
neutrons and protons we naturally presume
that those nucleons themselves remain un-
changed in the process just as the electrons
inside an atom are the same as the electrons
in your TV tube. But an electron is a struc-
tureless object whereas nucleons are them-
selves structured and, furthermore, are not
very widely separated in the nucleus in re-
lationship to their own sizes, so that their
structures must there interpenetrate to some
degree, the quarks on one nucleon interacting
with the quarks in another; this mutual pro-
pinquity must somewhat modify the structure
of the nucleons. But this would also sensa-
tionally modify our traditional description
of the structure of a nucleus. A crisis is
being forced upon us by observations at CERN,
and other places, on the scattering of high
energy muons and electrons from nuclei, tell-
ing us directly and unambiguously that a
nucleus is not just a collection of ordinary
neutrons and protons. Either there is some-
thing else inside there or nucleons inside
the nucleus are different from nucleons out-
side, or, of course, both. If we explain this
by a modification of the structure of a nucl-
eleon on becoming incorporated into a nucleus
we must assume that it there swells by about
fifty per cent. This would play havoc with
our cherished images of the nucleus. But do
we, or do we not, know that nucleons inside
the nucleus are the same as those outside?
Work at TRIUMF, again leading the world,
seems to be coming to our rescue; polarized
protons are scattered off the nucleons inside
nuclei, the scattering being compared with
what is expected on the basis of the BASQUE
measurements on nucleons in the free state.
The scattering agrees with our traditional
ideas about nuclear structure; it would be
difficult to reconcile this work with the
swelling of a nucleon, inside the nucleus, by
fifty per cent. The work is one of the very
few fundamental linchpins for our traditional
description of nuclear structure.
Human affairs often appear to be extremely complex until we perceive some underlying pattern to them. The meaningless rushings and clashings of a football game are suddenly clarified when we know that they are governed by a few simple rules, although knowledge of those rules does not permit us to predict the outcome of the game. The living world also is governed by a few simple rules, a half-a-dozen or so at most, although as with football knowledge of those rules does not permit us to predict the incredible richness of the flora and fauna of Canada's prairies and forests, let alone the results of the next parliamentary election. These basic rules are, in the scientist's jargon, called symmetries; they are literally the rules of the game; finding them out is our deepest quest in natural science.

TRIUMF has made great contributions to our testing of fundamental subatomic symmetries. I will give one example. The muon seems to be identical to an ordinary electron apart from being about two hundred times heavier. If the muon and the electron are so nearly identical there seems to be nothing to prevent the muon transforming itself into an electron, releasing its extra energy as a gamma-ray, and we can easily calculate how long this process should take. But work at TRIUMF, the world leader in this game, has shown that this process takes more than a million million million million times longer than it should. This discrepancy between theory and experiment is a bit much to swallow. But when this sort of thing happens we are not disheartened; on the contrary, we are delighted; we announce triumphantly that we have discovered a new Law of Nature that says that is how it has to be and sit back contentedly awaiting the Nobel Prize. This, and related phenomena, also studied better at TRIUMF than anywhere else, are simply part of Nature's rules of the subatomic game, rules that must be tested ever more rigorously in the hope that violations will eventually be discovered because it is through the rare violation of rules that we can hope to understand where those rules themselves come from.

The recently established union between the electromagnetic interaction and the weak interaction of radioactivity demands the existence of the very heavy W and Z particles that were indeed put into evidence at CERN two years ago. But it is a well-known characteristic of the weak interaction that it is not ambidextrous; it is handed; it imposes a corkscrew pattern on the disintegrations that it provokes. Loosely speaking, the W particle is left-handed; but is this the whole story? May there not also be a right-handed W particle whose influence is smaller than that of the now-familiar left-handed particle because it is heavier? Extremely delicate studies at TRIUMF on the weak radioactivity of the muon have set by far the best limit yet to the mass of the possible right-handed W particle: it must be more than five times heavier than the left-handed W; that is to say more than 400 times heavier than the nucleon. This is of high importance for fundamental symmetries.

Several of these very delicate experiments have been performed using the time projection chamber, a kind of complex magnetic and electronic camera capable of snapping the motion of charged particles in a millionth of a second. In this field of nuclear diagnostics TRIUMF is again the world leader.

TRIUMF has also been pre-eminently successful in fields other than nuclear research. For example, her rich muon beams have permitted the powerful development of muon spin resonance, in which the muon lodges in various niches within a crystal lattice and there betrays the intimate secrets of its host environment in a manner accessible to no other physical or chemical technique.

But of this and of many other of TRIUMF's activities of absolutely first class I, unhappily, have no further time to speak. So, once more, I salute the triumph of TRIUMF, looking to a future as glorious as the past and, within that future, to those major developments that TRIUMF has shown herself capable of making to the credit of Canada and for the benefit not only of Canada but of the world's community of fundamental scholarship.
The year 1985 was again a very successful one for the Science Division. An essential condition for this success was the continued reliable operation of the cyclotron, which produced more than 300 mAh in 25 weeks of unpolarized running and currents of up to 800 nA in 13 weeks of polarized running. The number of weeks of polarized running was increased at the expense of unpolarized running, reflecting the high scientific priority accorded to MRS experiments in the proton hall, but because of increased average currents the total integrated current was greater than last year. A total of 63 experiments received beam, and of these 44 completed data-taking. The substantial increase over last year's totals of 51 and 20 reflects the coming into full operation of the M15 beam line and the MRS spectrometer, both of which were commissioned last year.

Experiment 104, the search for \(\mu^+e\) conversion with the time projection chamber (TPC) finally finished several years of data-taking in December, pushing the limit on the branching ratio below \(10^{-11}\). The completion of this experiment is the culmination of intense efforts by scientists from a number of institutions, particularly TRIUMF and NRC, in first building the TPC and then continually improving it during the course of the experiment.

The continuing controversy between LAMPF and SIN concerning the behaviour of \(t_{20}\) in \(\pi d\) elastic scattering should be resolved by the completion of two experiments on M11. Experiment 205 utilized a \(^3\)He polarimeter to measure the polarization of the outgoing deuteron. Experiment 337 was the first experiment to use the polarized deuteron target built for the Cryogenics group. This target, which had 10% tensor polarization, is another major technological achievement for the same group which built the frozen spin hydrogen target used in the \(n-p\) charge symmetry breaking experiment completed last year. Other important experiments finished on M11 were Expt. 322, measurements of the \(\pi^p\) elastic scattering cross section, and Expt. 270, a test of charge symmetry by comparing \(\pi^+d + pp\) with \(\pi^-d + nn\). On M13 pion scattering measurements were carried out on \(^3\)He and \(^4\)He (Expt. 285), \(^{12}\)C (Expt. 278) and \(^{20}\)Ne (Expt. 202) as well as pion absorption on \(^3\)He (Expt. 199). Pion double charge exchange experiments on \(^8\)O and \(^{26}\)Mg were also finished, and both the energy dependence and A dependence of this reaction are now being extensively investigated (Expts. 350/351). Among the \(\mu SR\) experiments completed on M15 and M20, the most noteworthy was Expt. 358, a study of nuclear hyperfine structure using level crossing spectroscopy (LCR), which produced some beautiful resonance spectra. This new technique originated and developed at TRIUMF should prove a powerful new tool for the investigation of solids by \(\mu SR\).

As part of the continuing nucleon-nucleon program at TRIUMF two important experiments were completed by the University of Alberta group. The first (Expt 208), a measurement of proton-proton bremsstrahlung with polarized protons, gives information on the off-shell behaviour of the nucleon-nucleon force, whilst the second (Expt 190), on radiative capture of polarized neutrons is sensitive to meson exchange and isobar effects. Polarized beam experiments on the MRS went into high gear with analysing power and cross-section measurements on Expts. 207 (\(^{48}\)Ca), 236 (\(^{40}\)Ca), 283 (\(^{208}\)Pb) and 335 (\(^{26}\)Si). The new focal plane polarimeter was successfully commissioned and utilized in Expts. 272 (\(^{24}\)Mg), 294 (\(^{208}\)Pb) and 324 (\(^{12}\)C). The polarimeter performance exceeded expectations and will enable complete spin transfer measurements to be made after longitudinal polarization becomes available in 1987.

In the proton hall we finished the year on a very strong note with the first experiments on the new \((p,n)(n,p)\) facility which uses the MRS as a recoil spectrometer. This facility, designed and built at a comparatively modest cost within two years of its first conception, gives TRIUMF unique capabilities in the most interesting energy range in a field which is almost unexplored. We expect that with this new addition the TRIUMF proton hall will play a central role in experimental nuclear physics over the next few years.

Finally, 1985 saw TRIUMF playing a major role in preparations for experiments at Brookhaven National Laboratory and at Stanford Linear Accelerator. In the Brookhaven experiment TRIUMF is collaborating with physicists from Brookhaven and Princeton in a search for the rare decay \(K^+ + \pi^+\nu\bar{\nu}\). Major portions of the...
apparatus are now being constructed and tested at TRIUMF, with the aim of installing the experiment at Brookhaven in the latter half of 1986. At SLAC TRIUMF is part of the SLD group building a state-of-the-art detector for the linear collider. It is planned that a major part of the calorimeter for this detector will be constructed at TRIUMF.

The contributions on individual experiments in this Report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission of the authors.
The search for the lepton-flavour-violating reaction $\mu^- + ^{46}_{\text{Ti}} \rightarrow e^- + ^{46}_{\text{Ti}}$ in the TRIUMF time projection chamber completed data-taking at the end of this year. In many models this reaction is very sensitive to the existence of hypothetical new neutral particles such as heavy neutrinos, particles and leptoquarks.

Analysis of one-third of the data (from $5 \times 10^{12}$ muons stopping in the target) produced no candidate event. An upper limit of $1.6 \times 10^{-11}$ (90% C.L.) for the branching ratio of this reaction relative to ordinary muon capture was deduced. The average net efficiency, including all cuts, was about 4%. Table I shows the correction factors for the total acceptance. Figure 1 shows the spectrum of high-energy electrons obtained from this set of data, together with Monte Carlo predictions of the bound muon decay spectrum and a hypothetical $\mu^- + e^- \rightarrow e^- e^- Ti$ conversion branch at a level of $10^{-10}$.

$\mu^- e^-$ conversion is primarily a coherent process in which the Ti nucleus remains in its ground state. Incoherent muon-electron conversion resulting in an excited nucleus is suppressed by Pauli blocking. The limit for the branching ratio for the incoherent process was estimated to be $<1.6 \times 10^{-9}$ from the difference between the Monte Carlo and experimental spectra, and with crude assumptions on the spectrum shape.

Table I. Correction factors for the total acceptance.

<table>
<thead>
<tr>
<th>Correction Factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^- + e^- \rightarrow e^- e^- Ti$ acceptance (includes following cuts)</td>
<td>0.12</td>
</tr>
<tr>
<td>cosmic ray</td>
<td>0.8</td>
</tr>
<tr>
<td>others</td>
<td>0.9</td>
</tr>
<tr>
<td>$\chi^2$ cut and visual inspection</td>
<td>0.9</td>
</tr>
<tr>
<td>Pion-background cut (beam)</td>
<td>0.9</td>
</tr>
<tr>
<td>Target-position cut</td>
<td>0.9</td>
</tr>
<tr>
<td>Time window</td>
<td>0.7</td>
</tr>
<tr>
<td>Energy window (97-105.5 MeV)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

This report gives the state of plans to measure the spin correlation parameter $A_{nn}$ for $n-p$ elastic scattering at 220, 325, 425 and 495 MeV incident neutron energy. As outlined in the Expt. 182 proposal, the measurement will be made in the neutron area using a modification of equipment prepared for Expt. 121 (test of charge symmetry). Scattered neutrons are detected in $1.05 \times 1.05 \times 0.30$ m scintillator arrays and recoil protons are detected in coincidence in delay-line wire chambers (DLCs) and range counter telescopes. The $A_{nn}$ measurement consists of scattering polarized neutrons from a polarized proton target and measuring the difference in yield for spins parallel and antiparallel. If we can determine $A_{nn}$ to an absolute accuracy of ±0.03, the state of the nucleon-nucleon phase-shift data base will be greatly improved. The errors of some partial waves will be reduced by up to a factor of two and some correlations between different phases will be eliminated, thus stabilizing the phase-shift solutions.

![Fig. 1. Solid-line histogram: experimentally observed events. Solid curve: Monte Carlo simulation for $\mu^- + e^- \nu \bar{\nu}$ decay in atomic orbit. Dashed-line histogram: Monte Carlo spectrum of $\mu^- + e^- Ti$ events for a branching ratio of $10^{-10}$.]
Unlike the charge symmetry experiment, the measurement of $A_{nn}$ requires accurate knowledge of both beam and target polarizations. Since our original proposal most of the effort has concentrated on methods of making an accurate measurement of the frozen spin target (FST) polarization. The present NMR system is accurate to no better than ±5% absolute and cannot be improved in time for the experiment. We have devised the following scheme which should yield an accuracy of ±2% (absolute). It involves scattering protons from the FST at an angle and energy for which the pp analysing power is precisely known.

1) Replace the liquid deuterium in the neutron production target (LD$_2$ in Fig. 2) with liquid hydrogen.

2) Turn off the proton clearing magnet (bender 4AB2) and stop the proton beam in a beam stop in the 0° port.

3) Take the protons scattered at 9° (which will have a polarization normal to the scattering plane) and turn their spins through 90° using the Manitoba superconducting solenoid.

4) Place the two MRS front-end wire chambers upstream of the FST to define the hit position.

5) Place a thin scintillator counter at the exit of the 9° collimator to determine the time of flight for the incident protons.

6) Detect coincident protons scattered from the FST at 24°-61° lab. At this angle and at an energy of 485 MeV the pp analysing power is accurately known [Greeniaus et al., Nucl. Phys. A322, 308 (1979)]. Because the spins of the incident protons are in the scattering plane the measured left-right asymmetry will be due to the target polarization only.

By use of this method one can determine not only the polarization but also the distribution of polarization throughout the target. The polarization of a 6 mm × 6 mm square of target normal to the beam can be determined to a statistical precision of ±0.01 with a 10 to 15 h run (assuming 500 nA primary proton beam).

Several modifications to the Expt. 121 apparatus have been introduced: the first 60 cm × 60 m DLC from each proton boom has been removed and replaced with a 25 cm × 25 cm chamber from Expt. 190. The 60 cm × 60 cm chambers removed from the proton booms are mounted on rails attached to the neutron arrays such that the chambers can slide into place in front of the neutron array during FST calibration and slide out during $A_{nn}$ measurements. A ring-type veto scintillator will be installed on each neutron arm. These present no obstruction during measurement of $A_{nn}$ yet can be used to define good events during FST calibration. The 0° beam stop is 1 m of graphite followed by steel shielding. The existing p-TOF and n-TOF scintillators have been redesigned to permit free movement of the booms when changing angles (something that was not necessary for Expt. 121).

Experiment 217

Measurement of the slope of the $\pi^0$ electromagnetic form factor (J.-M. Poutissou, TRIUMF; A.W. Stetz, Oregon State)

Experiment 217 has measured the slope of the $\pi^0$ electromagnetic form factor 'a' by a careful study of the invariant mass spectrum of the lepton pairs emitted in the $\pi^0 \rightarrow e^+e^-\gamma$...
decay. The differential decay rate $\frac{d\sigma}{dx}$ for reaction (b) can be calculated for a point-like pion using ordinary QED. The form factor $\Gamma(x)$ modifies this distribution as follows:

$$\frac{d\sigma}{dx} = \left(\frac{d\sigma}{dx}\right)_{\text{QED}} |\Gamma(x)|^2$$

where $x$ is the invariant mass square of the $e^+e^-$ pair. In the small range of momentum transfer considered here it is customary to parametrize $\Gamma(x)$ as $\Gamma(x) = 1 + 'a'x + d(x^2)$ where 'a' is the slope of the e.m. form factor and to neglect higher-order terms. The invariant mass square $x$ is determined from

$$x = \frac{1}{(m\gamma)^2} \left[ 2m^2_e + 2E_p E_\gamma - 2p_+ p_- \cos \theta \right]$$

by measuring $E_\gamma$, the energies of the positron and electron in two large NaI detectors and the opening angle of the pair in two telescope of three wire chambers each. To be sensitive to 'a' an experiment has to detect pairs $e^+e^-$ with large $x$, which in turn implies large opening angles.

The main data-taking runs for Expt. 217 occurred in May and June 1984. The experimental arrangement was described in last year's Annual Report. Data were taken at three different opening angles between TINA and MINA $\left(150^\circ, 135^\circ, 60^\circ\right)$. The relative normalization for these three runs was obtained from the third NaI detector (Sophie), which remained at the same location for the duration of the experiment to monitor the high-energy photons from $\pi^0 \to \gamma \gamma$. The effort this year has concentrated on the analysis of our data and on refining our Monte Carlo simulation of the experiment.

1) Energy calibration. For each data run we have established a calibration for the energy of single photons recorded in parallel with our electron-positron pairs. We have fitted the distribution for $\pi^0$ decay product as well as the monoenergetic 129 MeV line from radiative $\pi^0$ capture. We then have a table of the gain and pedestal for each run. For the energy calibration of charged particles a correction has to be applied because the energy deposited (and registered) by the NaI detector is not the incident particle energy due to energy losses in the defining counters, target and dead layer of the sodium iodide detectors.

2) Absolute normalization. We are attempting to extract a value for 'a' from the change in rate for the reaction $\pi^0 \to e^+e^+\gamma$ above a given threshold. To do so we need to know the number of $\pi^0$ produced for each run. We monitored the single photons via a third NaI crystal (Sophie) and can find the relative normalization quite accurately (<0.05%). The absolute normalization was deduced from separate runs where we exploited the kinematics of $\pi^0 \to \gamma \gamma$ (Fig. 3). One of the two photons was converted into an $e^+e^-$ pair on one side and registered into MINA. We then measured the fraction of accompanying $\gamma$ seen by Sophie at its standard position. The expected solid angle was compared to an accurate Monte Carlo prediction and agreed to within ±1%.

3) Tracking efficiency of the wire chambers. Using the internal conversion pairs from $\pi^-p \to e^-e^-\gamma$ we have established the absolute efficiency of our charged particle telescope for each run; an independent method using pairs produced in a small scintillator gave the same efficiency within 0.25%-1.0%.

4) Monte Carlo studies. Using a specialized version of EGS (photon shower program from SLAC) we have simulated our apparatus and are able to establish the background contributions in various domains of the $E_T$ versus $x$ plot. So far no difficulties are envisaged with our analysis. We have shown that multipion events (two pions stopping simultaneously in our target) cannot contribute a significant background. We have explained the large number of events seen in the low $E_T$ region, with both deposited energy very small as
originating from $\gamma$ conversion in the post of the large vacuum vessel. These events can be cut out without affecting our efficiency, but it was important to fully understand the behaviour of our apparatus to gain confidence in our simulation. We expect to fulfill our commitment and produce a value for $\alpha$ with a 0.02 error. Finally, we have established contact with J. Smith of Stony Brook who calculated the radiative corrections to the Dalitz decay originally. With the help of his student he has been reprogramming his calculation to adapt it for our geometry. We have received a copy of the new program and are starting to evaluate the effects of radiative corrections on our result.

Experiment 248
A study of the decay $\pi \to e\nu$ (T. Numao, TRIUMF)

Constraints on massive neutrinos in the $\pi + e\nu$ decay

Massive neutrinos appear naturally in many extensions of the standard electroweak model. If neutrinos have nonzero mass, the mass eigenstates $v_1^l$ may be related to the weak eigenstates $v_\nu^l$ by a unitary matrix $U_{e1} = \sum_{l=e,\mu,\tau,...} U_{e1}^l v_\nu^l$, where $l = e,\mu,\tau,...$. According to Shrock [Phys. Rev. D 24, 1232 (1981)] the contribution of a mixed state of a massive neutrino to $\pi e_2$ decay can be written as

$$R_{e1} = \frac{\Gamma(\pi + e\nu_1)}{\Gamma(\pi + e\nu)} = |U_{e1}|^2 \rho_e(\delta_1), \quad (1)$$

where the branch involving $v_1$ refers to the conventional massless neutrino and $\rho_e(\delta_1)$ is a kinematic factor with $\delta_1 = (m_{v_1}/m_\pi)^2$. The decay $\pi + e\nu$ is helicity suppressed by a factor of $10^4$. However, for a massive neutrino the suppression is reduced substantially, making a search for additional peaks in the $\pi + e\nu$ electron spectrum a sensitive test of mixing.

For the decay $\pi^+ + e^+\nu$ [Bryman et al., Phys. Rev. Lett. 50, 1546 (1983)], the dominant $\pi\mu\tau$ decay ($\pi^+ + \mu^+\nu$ followed by $\mu^+ + e^+\nu\nu$) limits the sensitivity obtainable in the $v_1$ mass region 60–140 MeV corresponding to the background of muon decay positrons ranging from 0 to 53 MeV. To improve the sensitivity we have developed a technique based on the measurement of the total energy deposited by the stopping pion and its subsequent decay products in the beam counters. For $\pi + e\nu$ decay events the total energy deposited in the beam stopping counters is the sum of the kinetic energy of the pion and a small part of the energy of the emitted positron ($\epsilon \sim 1$ MeV). For $\pi\mu\tau$ decay there is an additional muon kinetic energy of $T_\mu = 4.2$ MeV. Two peaks are observed in the spectrum of the total energy in the beam counters, one for the $\pi + \nu$ decay and the other, 4.2 MeV higher, for the $\pi\mu\tau$ chain. By selecting only those events in the lower energy peak the background due to the predominant decays involving muons is strongly suppressed.

The experiment was carried out at the TRIUMF M13 low energy pion channel. Positive pions were degraded and stopped in a plastic scintillator target. The decay positrons were analysed in a 46 cm diameter x 51 cm NaI(Tl) spectrometer (TINA) positioned 20 cm from the target and subtending a solid angle $\Omega \sim 5\%$ defined by 2 multi-wire proportional chambers and 4 plastic counters. The total energy in each of the target counters was measured using a charge-sensitive ADC gated by a 200 ns wide pulse. A second ADC was gated by a narrow pulse with 7 ns overlap in the rise time region of the analog pulse. Together these ADCs provided pileup information in the target counter enabling additional detection of $\pi\mu$ decay.

Figure 4(a) shows a positron energy spectrum with only a timing cut for the region 2 to 30 ns after a pion stop equivalent to the spectrum used in Bryman et al. to search for evidence of heavy neutrinos. The effect on the positron spectrum of the additional cuts on target energy and the pileup information described above is shown in Fig. 4(b). The $\pi\mu\tau$ background is reduced by a further factor of 160. This spectrum was used in the search for peaks in the $\pi + e\nu$ decay due to massive neutrinos.

The search for an additional small peak was carried out using two methods. In the first method the fitting included an additional peak whose shape was the same function used to fit the $\pi + e\nu_1$ peak but scaled to approximate the response function of TINA at any given energy. After a smooth background was included in the fit the distribution of these sample peak areas was consistent with random statistical fluctuations about a mean value of zero, the largest peak being $1.9 \sigma$ from zero corresponding to $m_\nu = 115$ MeV. We conclude that there is no evidence for massive neutrinos in the region investigated. Upper limits on the branching ratio at the
Fig. 4. (a) Typical positron total energy spectrum in TINA using 10% of the data accepted from 2 to 30 ns after a pion stop. (b) Same spectrum obtained from the total data after beam counter energy and pileup cuts were applied. For both spectra the energy dispersion is 45 keV/channel.

90% confidence level were deduced with the prior assumption that the peak area must be positive. The result is shown by the heavy solid curve in Fig. 5(a). In the second analysis the residuals spectrum was searched for peaks using the methods described in Bryman et al. The result is shown in Fig. 5 by the thin solid curve. The upper limits of the mixing coefficients $|U_{el}|^2$ for heavy neutrinos coupled to electrons were derived using Eq. (1). The results shown in Fig. 5(b) give limits on $|U_{el}|^2$ which are more than an order of magnitude lower than those obtained from the previous study [Bryman et al.] of $\pi^+ + e^-$ decay for the neutrino mass region 60–130 MeV.

Experiment 249
Radiative muon capture with the TPC
(G. Azuelos, TRIUMF)

Feasibility studies of a radiative muon capture experiment in liquid hydrogen on the TPC have been made. Such a measurement will yield an independent value for $g_\mu$, the induced pseudoscalar coupling constant in the weak hadronic current. The world average of previous measurements of ordinary muon capture in hydrogen yields a 22% error. The aim of this experiment is to reach a 10% error.

A converter-scintillator package was built and tested in the TPC. The tests were aimed at measuring the efficiency, resolution, background rejection capabilities and trigger rates as a function of magnetic field and trigger requirements. With the present TPC, multiplexed by 12, the efficiency was sufficient to attempt a measure of radiative muon capture on calcium at the end of the year. Analysis is in progress, but a preliminary acceptance function is shown in Fig. 6, where data from the reactions $\pi^+ + \text{CH}_2$ and $\pi^+ + \text{C}$ were subtracted. Figure 7 shows part of the data obtained from radiative muon capture on calcium.

For the experiment in hydrogen Monte Carlo studies were made to help in the design of the target and the beam counter geometry. Because of the extremely low branching ratio for this process ($6 \times 10^{-8}$) it is necessary to have as high an efficiency and as large a muon stopping rate as possible, without generating too many false triggers. Demultiplexing in time of the TPC, with a flash-ADC system similar to that of CDF at Fermilab, was envisaged. However, a more appealing solution would be to replace the TPC chamber.
Fig. 6. Acceptance function of photons in the range $55 < E_\gamma < 85$ MeV, obtained from the subtraction, properly normalized, of the photon spectra in the reactions $\pi^-+H_2$ and $\pi^-+C$ at 2.5 kG in the TPC.

by a drift chamber similar in design to that used for the Brookhaven Expt. 787 on rare K decays. One main advantage would be the shorter drift time, reducing the likelihood of spurious tracks from muon decay electrons in the chamber during that time.

Experiment 270
Test of charge symmetry by the comparison of $d\sigma(\pi^-d \to pp)$ with $d\sigma(\pi^-d \to nn)$
(B.M.K. Nefkens, UCLA)

Experiment 270 was installed in the M11 channel and ran during July and August. Four beam energies were studied: 142, 180, 217 and 254 MeV and four angles in the range $20^\circ < \theta_{c.m.} < 90^\circ$ were measured simultaneously. These energies were chosen to preferentially select the $\Delta$ intermediate state since a charge symmetry violation due to the mass difference between the $\Delta^-$ and $\Delta^{++}$ should be maximized here. High statistics runs were taken at the first three energies; the running at the highest energy was mainly exploratory in nature.

Three beam counters (B1, B2, B3) were used to define a $\pi^+_1$ (B1•B2) and a $\pi^+_\text{stop}$ (B1•B2•B3). In addition, a four counter beam hodoscope in the beam stop was used to monitor the position of the beam on the target. The target used was a 2 in. LD$_2$ target provided by the TRIUMF Cryogenics group. The recent addition of the recycling unit to it was especially helpful because it permitted a rapid emptying and filling of the target flask. This allowed us to take empty target (background) runs every few hours during the experiment. To reduce the background in the neutron runs we installed a target anti-box (T1, etc.) to veto the event if a charged particle was emitted from the target. The BPM was used only during the beam tuning and was removed for the data runs.

The simultaneous measurement of four angles required 8 identical counters (4 pairs). The scheme for measuring the efficiency of each detector entailed using one counter of the pair as the tagging counter and then varying the distance from the target of the other one to verify total containment of the shadow. The situation was then reversed to measure the efficiency of the first counter.

Each neutron detector (Fig. 8) consisted of 3 counters whose BC408 scintillator measured 10 in. × 10 in. × 3.5 in. giving a detector size of 10 in. high × 10.5 in. wide × 10 in. deep. With its six PM assemblies these detectors were rather substantial. To ensure the detection of only neutral particles in these counters a thin, charged particle veto counter measuring 12 in. high × 13 in. wide × 1/8 in. thick was mounted on the cart to cover the face of the detector. Additional veto counters were installed to shield L4 and R4 because of their proximities to the beam line. For the proton runs we used the veto
counters at the face of each cart as our proton detectors.

The data analysis is currently under way at UCLA. The initial phase of the analysis has concentrated on trying to understand the TOF spectra and the effect of the cuts on them for the proton runs at $T_p = 142$ MeV. We have calculated some preliminary relative cross sections here and find the following ratio for the left-side counters (right-side tagging)

$$1.00 : 1.59 \pm 0.05 : 2.83 \pm 0.09 : 3.84 \pm 0.10$$

and for the right-side counters (now left-side tagging)

$$1.00 : 1.60 \pm 0.04 : 2.98 \pm 0.08 : 3.72 \pm 0.10$$

where the ratio is for counters 1:2:3:4. This clearly demonstrates the internal consistency of our data. This can be compared with data on the inverse reaction [Hoftiezer et al., Nucl. Phys. A402, 429 (1983)]

$$1.00 : 1.65 : 2.99 : 4.03$$

where the authors quote an overall absolute precision better than 2%.

Since the last annual report appeared work has progressed in several directions: i) more precise Monte-Carlo studies, ii) stopping rate studies, and iii) understanding the kinematics.

Monte-Carlo calculations now include correct treatment of all processes with four or more final-state particles, including external conversions and double Dalitz events. Stopping rate measurements have been made on M9, indicating that $3 \times 10^5 \, \pi^- \, s^{-1}$ can be stopped in a 2 cm diameter liquid hydrogen target. At this rate it would take a year (elapsed time) to accumulate enough stops ($3 \times 10^{12}$) to be able to distinguish between the theoretical expectation for the branching ratio ($6 \times 10^{-8}$) and the current experimental value ($1.8 \times 10^{-7}$). Data-taking could not start until early 1987, after completion of the liquid hydrogen target and demultiplexing of the TPC. This would put the measurement at a disadvantage with respect to the competition: experiment 777 at Brookhaven (M. Zeller et al.) and a SINDRUM proposal at SIN (A. van der Schaaf et al.) which are both expected to run in 1986.

However, it was noticed from the kinematics of the major background $\pi^- p \rightarrow n e^+ e^-$ that a measurement of the $e^+ e^-$ invariant mass (in which the $\pi^0 \rightarrow e^+ e^-$ signal appears) could be made independent of the measured momenta, providing that the opening angle is measured precisely. Using this approach a much cleaner $\pi^0 \rightarrow e^+ e^-$ signal can be extracted than hitherto envisaged. Unfortunately, the TPC is not well suited to such a measurement due to scattering in the central structural member. Thus to test these ideas, a collaboration has been formed with the SIN group with the intention of taking data in late 1986. Their detector - SINDRUM - is well suited to this experiment, and it is hoped to make a better measurement than either of the two groups had planned separately.
energies a number of parity-forbidden mixings are possible and the angular distribution of $A_z$ is not isotropic. Measurement of an angular distribution of $A_z$ is therefore required to determine the mixing parameters. $A_x(\theta)$ will be measured in 6 angle bins from $7^\circ$ to $43^\circ$ lab to a precision of $3\times10^{-8}$.

Choice of beam energy

Simonius has made calculations [private communication] of the angular form of the $J=0$ ($^1S_0-^3P_0$), $J=2$ ($^3P_2-^1D_2$, $^1D_2$, $^2F_2$) and higher-order contributions to $A_x(\theta)$ between 200 and 500 MeV. These distributions have been used to estimate the statistical precision with which the $J=0$ and $J=2$ parity-violating mixing parameters can be determined. From these results it is found that the energy at which the measurement will best determine the mixing parameters at TRIUMF is in the region of 230 MeV. Measurement of $A_x(\theta)$ to $3\times10^{-8}$ will yield the S-P, P-D and D-F mixing parameters to approximately 10%, 15% and 60%, respectively, of their present values.

Beam line

Beam optics calculations for line IB [Stinson TRIUMF design note TRI-DNA-84-4] at 200, 300, 400 and 500 MeV have demonstrated the feasibility of producing a longitudinally polarized beam with required spot size and divergence at all energies in the above range by using the two-solenoid, two-dipole magnet arrangement also to be instituted on beam line 4B. These calculations have been repeated for proton energies of 230 and 450 MeV for slightly different beam line geometry and with inclusion of multiple scattering.

The present IB beam stop would be a source of background in the parity experiment and will be moved out of the meson hall. An extra quadrupole triplet will refocus the beam from the target location 1BT1 onto the LH$_2$ target at 1BT2. The parity apparatus will be followed by a quadrupole doublet.

Target and instrumentation

A 20 cm long LH$_2$ target is positioned at location 1BT2. In order to stabilize beam intensity, position and direction of the target and to ensure that transverse components of beam polarization are small and well known, feedback systems will be used. Servo loops on beam intensity, position and direction will have a bandwidth of 1-10 kHz, while the spin reversal rate will be a few hertz, ensuring that beam parameters are very well controlled during the measurement. The LH$_2$ target is located between two parallel plate ionization chambers which measure the beam intensity up and downstream of the target and provide feedback to the ion source to stabilize the beam intensity at the target. The LH$_2$ and parallel plate ionization chambers are preceded and followed by monitors of intensity profile (wire ionization chambers) and of transverse polarization profile (scanning polarimeters). A set of wire ionization chambers will also be placed upstream of the bending magnet 1BVB3 to monitor beam position and profile at that point. The intensity profile monitors allow corrections to the beam transport via sets of aircore steering magnets. Upstream there will also be a set of split-plate secondary electron emission monitors coupled to steering magnets using a slow ($\sim0.1$ MHz) feedback system. We intend to use a superconducting solenoid placed after the bending magnets to determine the sensitivity of the measurement apparatus to transverse polarization components in the horizontal and vertical directions.

Detector arrays

The detector array is located immediately downstream of the LH$_2$ target and consists of six arrays of plastic scintillator in the form of concentric rings spanning the angular range from $7^\circ$ to $43^\circ$, each ring being divided into 16 segments viewed by vacuum photodiodes. As an alternative a segmented ionization chamber is being considered.

Noise measurements

Measurements have been made of the Fourier spectrum of noise in the beam intensity and horizontal and vertical positions at 230 and 450 MeV. The beam intensity and position power spectra were determined using two split plate ionization chambers (SPICs) and placed in beam line 4A at the normal positions of the SEMs upstream of the LD$_2$ target. We intend to improve the precision and frequency range of these measurements and obtain the power spectrum of the proton beam direction and sensitivity of the power spectra to ion source and cyclotron parameters.

The most important feature of the results is that there is a minimum in the power spectra between 2.0 and 3.0 Hz at both 230 and 450 MeV. This range is close to the ideal for the spin reversal frequency in the parity experiment.
Polarized source

First tests have been made of the Lamb-shift polarized source operating in spin filter mode. The source operated well and, although not optimized, yielded about 500 nA of beam of 70-75% polarization in both spin states, of which about 200 nA was accelerated in the cyclotron. Future tests will implement rapid spin flipping, and investigations will be made of the stability of the transverse polarization of the beam extracted from the cyclotron.

Error analysis

Errors due to imperfections in the apparatus and the presence of transverse components of beam polarization have been estimated.

Consideration has been given to effects of:
1) beam possessing a nonzero first amount of polarization
2) nonuniformity of the scintillator material
3) unequal sizes of scintillator segments
4) unequal transverse components of polarization in the two helicity states of the beam

The detectors should approach cylindrical symmetry as closely as possible. Regarding the treatment of data, it is found that the effects of systematic errors are least, in general, when a parity-violating asymmetry is derived for each segment in a ring and then averaged over the segments (rather than summing the light outputs of the segments and then calculating an overall asymmetry).

Experiment 301
The reaction pp\pi^0 near threshold
(D.F. Measday, UBC)

Of all the pion production reactions in proton-proton collisions the least studied is \( pp \rightarrow pp\pi^0 \), because the \( \pi^0 \) is difficult to detect and the reaction cross section is relatively small in the TRIUMF energy range. The reaction is normally designated \( \sigma_{11} \) in the standard isospin convention. This cross section is not only interesting in its own right but is also an important ingredient for understanding pion production in neutron-proton collisions, for example the charged pion production is given by

\[
\sigma(np+\pi^+nn) = \sigma(np+p^-pp) = \frac{1}{2} \left( \sigma_{01} + \sigma_{11} \right).
\]

Now in many phase-shift analyses below 1 GeV \( \sigma_{01} \) has been equal to zero, in which case these reactions would be identical to \( pp \rightarrow pp\pi^0 \). However, the poor data that exist do not bear this out. For example the \( \pi \) angular distribution is normally described as

\[
\frac{d\sigma}{d\theta} = \frac{1}{3} + b \cos^2 \theta.
\]

Old Russian measurements on \( pp \rightarrow pp\pi^0 \) have found \( b = 0.06\pm0.06 \) between 400 and 700 MeV, whereas more recent SIN measurements on \( np + \pi^+nn \) have obtained \( b = 0.6\pm0.1 \) from 500 to 600 MeV. At present no polarization data exist, but there is indirect evidence from IUCF that the asymmetry might be quite significant, because they found values of \( \sim0.2 \) in studies of the reaction \(^{12}\text{C}(p,\pi^-)^{14}\text{O} \).

We have had a preliminary run in August on beam line 1B, using TINA as the principal detector. So far it has been found impossible to obtain singles data which are dependable. However, data taken in coincidence with a lead glass Čerenkov detector are quite reliable, as long as the proton beam is kept down to a few tens of picoamperes and the beam halo is under control.

An example of a coincidence spectrum is given in Fig. 9. This is the \( \gamma \)-ray energy spectrum in TINA in coincidence with a \( \gamma \)-ray which enters a lead glass Čerenkov detector located at about 180°. Pions heading towards TINA produce \( \gamma \) rays Doppler shifted up in energy \( (E_\gamma > 67.5 \text{ MeV}) \), whereas pions heading towards the lead glass Čerenkov detector produce \( \gamma \) rays in TINA which are Doppler shifted

![Fig. 9. The \( \gamma \)-ray energy distribution in TINA from the reaction \( pp \rightarrow pp\pi^0 \) at 500 MeV. The lines represent the \( \gamma \)-rays from a reasonable \( \pi^0 \) energy distribution, folded with the TINA response function.](image-url)
down in energy \( (E^\gamma < 67.5 \text{ MeV}) \). Thus two laboratory angles are measured simultaneously. The two lines represent \( \gamma \)-ray distributions resulting from a simple \( \pi^0 \) energy distribution. It is hoped to be able to obtain improved data under better beam conditions in the near future.

Measurement of \( K^+ \rightarrow \pi^+\nu\bar{\nu} \)
(D. Bryman, Victoria/TRIUMF)

The measurement of \( K^+ \rightarrow \pi^+\nu\bar{\nu} \), E787 at the AGS at Brookhaven National Laboratory, is being performed by a collaboration of BNL, Princeton University and TRIUMF. The aim is to reach a branching ratio sensitivity <2 \times 10^{-10}, comparable to the standard model prediction and three orders of magnitude lower than the present experimental limit. A signal appearing in the range >5 \times 10^{-10} could indicate the presence of new physics in the form of extra neutrino generations, axions, familons, SUSY, technicolor, Higgs particles, leptoquarks or compositeness. If the standard model prediction is confirmed, it would provide a unique, sensitive test of a calculation of a higher-order weak amplitude.

TRIUMF beams are being used to test detector prototypes and production models for E787. Several short measurements were done during 1985 to determine the performance of pion range stack scintillators and phototubes and to test developmental electronics which will be used for \( \pi/\mu \) discrimination. In addition, prototypes of the central drift chamber under construction at TRIUMF were exposed to a 200 MeV/c pion beam to test the performance of the jet type cell being used. Towards the latter part of the year a 100-wire prototype chamber was installed in the Sagané magnet located on the b leg of M11. Position resolution and rate dependence of performance are being measured in the presence of a uniform 10 kG magnetic field. A FASTBUS readout system has been developed for these tests.

The SLD group
(A. Astbury, TRIUMF/Victoria)

A TRIUMF/UBC/Victoria group has formed a sub-collaboration in the SLAC SLD group. The SLD group is building a state-of-the-art detector for the SLAC linear collider (SLC), an \( e^+e^- \) machine designed as a \( Z^0 \) factory. A clear difference between the \( e^+e^- \) detectors of the previous generation (e.g., MKII at SLAC) and the new detector being planned for the SLC and LEP is the presence of 4\( \pi \) hadron calorimetry, which played such an important role in the discovery of the W boson at the CERN p-p collider. Our subcollaboration has joined the calorimetry group on the SLD project. Figure 10 shows the SLD detector.

This year we have been investigating the properties of calorimeters with liquid argon (LA) as their active medium, as the SLD group has chosen LA as the most suitable for a 4\( \pi \) detector. Most calorimeters suffer from a defect, that is they give a different response to different particles of the same energy. In particular the response to electrons is about 40% higher than for hadrons. It was believed on the basis of previous measurements by Fabjan et al. [Nucl. Instrum. Methods 141, 61 (1977)] that a uranium calorimeter would correct for this imbalance by collecting energy fission products from fissions induced by the primary hadron and its secondaries.

The collaboration built and tested four prototype calorimeters, with the following structures:

- Pb radiator, G10 readout (Pb-G10)
- U-Fe radiator, G10 readout (U-Fe-G10)
- U radiator, Pb tile readout (U-Pb)
- U radiator, U tile readout (U-U)
These calorimeters were placed in a SLAC test beam of $\pi$, $\mu$ and $e$. Data were taken at 5.5 and 11 GeV. The results of these measurements on the relative response of $\pi$'s and $e$'s is shown in Table II. Given the practical problems involved in building a uranium structure the group on the basis of these results has decided to build a Pb/liquid argon device. At present we are planning to build a significant fraction of the calorimeter at TRIUMF.

<table>
<thead>
<tr>
<th>Device</th>
<th>$E_{\text{inc}}$ (GeV)</th>
<th>$e/\pi$</th>
<th>% interaction length of U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-G10</td>
<td>11</td>
<td>1.35</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>1.24</td>
<td>0</td>
</tr>
<tr>
<td>U-Fe-G10</td>
<td>11</td>
<td>1.23</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>1.23</td>
<td>35</td>
</tr>
<tr>
<td>U-Pb</td>
<td>11</td>
<td>1.29</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>1.22</td>
<td>65</td>
</tr>
<tr>
<td>U-U</td>
<td>11</td>
<td>1.16</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>1.10</td>
<td>90</td>
</tr>
</tbody>
</table>
NUCLEAR PHYSICS AND CHEMISTRY

Experiment 142
Nonevaporative fragment emission
(R.G. Korteling, Simon Fraser)

The major effort of the past year has been
the mounting and running of the final stage
of Expt. 142. An extensive set of data has
been collected where the emission of light
fragments has been studied in coincidence
with high energy protons, believed to be the
incident projectile, in an effort to determine
whether there are components of direct
interactions in these exclusive measurements
not observed in inclusive measurements. These
data are now being analysed, both at SFU and
at Argonne.

The preliminary results show the following
qualitative features:

1) The shape of the singles and coincident
fragment spectra are basically the same ex­
cept for a magnitude effect due to the coinci­
dence requirement and an energy shift which
can be understood as coming from the momentum
of the particular emitting source selected by
the coincidence requirement.

2) The shape of the fragment spectra are
essentially the same for the widely different
targets Be and Ag except for the low energy
Coulomb barrier cutoffs and the different
kinematics involved. This is true for both
the singles and coincidence spectra. The
magnitudes of the cross sections scale
linearly with the target mass.

3) The coincidence rates maximize at or near
the QTBS angles (the coincidence angle at
which there is the minimum momentum transfer
to the rest of the system). The magnitude of
the effect is a function of the target and
the fragment energy. Be shows about twice
the effect that Ag does. The effect for the
high energy He's (>40 MeV) from Be is about
twice that for the low energy evaporative
He's. The high energy He's also show the
effect but the effect is washed out for the
low energy He's.

These results seem to indicate some inconsis­
tencies in understanding the reaction in
terms of equilibrated sources, the mechanism
normally suggested to govern these reactions.
For example, although the fragment spectra
are reminiscent of emission from equilibrated
sources, it is difficult to reconcile such a
mechanism with the enhancement at the QTBS
angles for certain fragments and not others.
In general, the results illustrate the impor­
tance of obtaining as complete a kinematic
description as possible before drawing any
conclusions about these complex reactions.

Experiment 190
Radiative capture of polarized neutrons
(D. Hutcheon, TRIUMF)

We have completed data-taking in our study of
the np → pγ reaction, with production runs at
neutron beam energies of 370 and 480 MeV.
This, together with our earlier measurements
below pion production threshold, forms a data
set from 180 to 480 MeV.

For the runs above pion production threshold
we used position-sensitive, large-acceptance
photon detectors in coincidence with counter
telescopes for the measurement of deuteron
62, 1114 (1984)]. Opening angle and coplan­
arity tests made it possible to suppress
background from the prolific reaction np +
d^7\rightarrow dγγ. The detection system was left­
right symmetric, to reduce problems of in­
strumental asymmetry. Our target was liquid
hydrogen, 10 cm thick. The TRIUMF polarized
neutron beam facility provided up to 5×10^6
neutrons/cm^2-s with typical polarizations of
45 to 55%.

Preliminary results for analysing power are
presented in Fig. 11. Also shown are results
of a nucleon-delta coupled channels calcula­
tion, kindly supplied to us by H. Arenhövel
of Mainz. Our preliminary results differ
noticeably from the 'full' calculation in­
cluding meson-exchange currents and isobar
components.

Experiment 199
Isospin dependence of pion absorption on \( ^3\text{He} \) at
37 MeV (A. Altman, UBC)

The group received beam time during the
summer to study pion absorption on \( ^3\text{He} \) at low
energy (37 MeV). This should allow completion
of the data base of differential cross sec­
tions and angular distributions for the reac­
tions \( ^3\text{He}(π^+,2p)p \) (absorption on a \( T=0 \) pn
pair) and \( ^3\text{He}(π^-,pn)n \) (absorption on a \( T=1 \) pp
pair). These cross sections were measured
near the delta resonance energies at SIN, at resonance energies and above at LAMPF (up to 550 MeV) and at low energies at TRIUMF (65 and 85 MeV) by the present group [see Moinester et al., Phys. Rev. Lett. 52, 1203 (1984) and Aniol et al., TRIUMF preprint, submitted to Phys. Rev. C)]. However, the main motivation to study the same reaction at such a low energy (37 MeV) is raised by the behaviour of the angular distribution for the $^3$He$(\pi^- ,pn)n$ reaction at 65 and 85 MeV.

The angular distribution for the above reaction is asymmetric about 90° in c.m. This may be due to interference between the 2N amplitude and the 3N amplitude. On the other hand the asymmetry may be a signature of a mixture of even and odd partial waves. If we assume that in low energy we have only the $l_{\pi 2N} = 0,1$ waves in the initial state we can calculate independently the coefficients for a Legendre polynomial expansion of the angular distribution of the $^3$He$(\pi^- ,pn)n$ reaction. The conclusion from these calculations [Aniol et al.] is that at low incident energies the absorption on the proton pair is dominated by the $l_{\pi 2N} = 1$ transition ($\sim 70\%$). This transition has a total $J^\pi$ value of $1^+$, total isospin $T=0$, and therefore does not allow the formation of the delta resonance as an intermediate state. We note that if a delta resonance is formed in this reaction (e.g. through $\pi^- 2N = 0$), it cannot form together with the second nucleon a system with relative angular momentum $L_{AN} = 0$, which is the dominant transition in pion absorption on deuteron. It was noted by Silbar and Piasetzky [Phys. Rev. C 29, 1116 (1984)] that a $P_{11}$ isobar, if formed in the process of pion absorption on a $^1S_0$ T=1 nucleon pair, could form with the second nucleon a system with a relative angular momentum L=0. The dominance of the $l_{\pi 2N} = 1$ transition as discussed above may indicate that $P_{11}$ isobar plays a role in this absorption process, similar to that played by the delta for pion absorption on a pn pair. At low energy such as 35 MeV the assumption of taking in account only $l_{\pi 2N} = 0,1$ is much more justified. We also hope that the energy dependence of the angular distribution at the low energy region will give more information on the exact mechanism leading to the asymmetry in the angular distribution discussed above.

The experiment was accomplished last summer using the new Tel-Aviv neutron array which consists of vertical bars with a flexible geometry. The second arm, as in the past, consisted of three NaI detectors. Very preliminary analysis has been done. The results display a stronger contribution from final-state interaction than in 65 and 85 MeV. The final-state interaction peak is seen clearly even for the $\pi^+2p$ channel, indicating contribution from a $\pi^+3He + p+(pp)$ process.

In Fig. 12 we display an energy spectrum of protons from $^3$He$(\pi^+,2p)$ reaction detected at 120° in coincidence with protons centred around -48° which is the conjugate angle for the free $\pi^+d + 2p$ reaction at this energy. Figure 13 presents the angular correlation of the protons in the bars array detected in coincidence with protons in the NaI detector at 120°. Results from the $\pi^-3He$ reaction are shown in Figs. 14 and 15. Figure 14 presents a two-dimensional display of the time of flight of neutrons in the bars array versus the energy of the protons detected in coincidence. The three-body phase space is along the high density region. Figure 15 is the projection of Fig. 14 on the energy axis, namely, it is the energy spectrum of protons in the NaI detector at 120° in coincidence with neutrons in the bars centred around -48° (the conjugate angle for the $\pi^-d + 2p$ reaction). The final state interaction peak corresponds to the reaction $\pi^-3He + p+(nn)$ in which the two neutrons are emitted together as if they were a single particle.
In early October 1983 a cryogenic target left University of Toronto for TRIUMF where it was assembled and tested. This target presented to the pion beam a bubble-free circular slab of liquid deuterium of 6 mm thickness and 4 in. diameter. The pressure difference between inner liquid target windows and outer helium vacuum windows is held to <0.2 Torr. The target was mounted on a scattering chamber with sliding seals that allow one to change the target angle and to choose one of three vertical target positions in the pion beam. It was designed for use with the QQD spectrometer. In November 1983 the target was used with liquid deuterium for the

In *Experiments* 202, 263, 278

\((\pi,\pi')\) scattering (T.E. Drake, Toronto)
d(π,π')d(t_{20}) dibaryon resonance experiment on Mil (Expt. 205). Computer control of the target was added in the spring of 1984, and it was used again for Expt. 205 runs in 1984 and March/April 1985 (Expt. 205 results are described below).

This target is also designed to liquefy small quantities of isotopically enriched \(^{22}\text{Ne}\) and \(^{20}\text{Ne}\). Here the bubble-free target is 3 mm thick and 3 in. in diameter. Pion scattering experiments on \(^{20}\text{Ne}\) and \(^{22}\text{Ne}\) began in May 1985 (Expt. 202), and they will be completed in spring-summer 1986. The preliminary data are being analysed. A target head of smaller cross-sectional area but thicker was used with the pionic X-ray experiment on \(^{22}\text{Ne}\).

A paper describing the targets has been submitted to Nucl. Instrum. Methods.

The first results of the \(^{12}\text{C}(\pi,\pi'\gamma)\) coincidence experiment (Expt. 263) were published (Sobie et al., Phys. Lett. 143B, 338 (1984)). The second more thorough experiment was completed this year and the data are currently being analysed.

Our recent measurements of pion scattering to the \(^0^+\) (7.65 MeV) state in \(^{12}\text{C}\) (Expt. 278) have shown that the \(^0^+\) + \(^0^+\) monopole transition is indeed very sensitive to the EELL effect in pion-nucleus scattering. Such sensitivity was anticipated by Jennings and de Takacsy [Phys. Lett. 124B, 302 (1983)]. The data analysis is progressing.

\textbf{Experiment 205}

\(t_{20}\) in \(\pi d\) elastic scattering

(Y.M. Shin, Saskatchewan)

The final running period for this experiment in March/April saw the completion of the measurements proposed. The excitation function over the range 118-148 MeV at \(\theta=15^\circ\) (lab) was completed together with an angular distribution at 134 MeV (to reinforce the previously measured values at 141 MeV). Figure 16 [Shin et al., Phys. Rev. Lett. 55, 2672 (1985)] shows a comparison of our data with those of the SIN group [Konig et al., J. Phys. G9, L211 (1983)] and the measurements done at LAMPF [Ungricht et al., Phys. Rev. C 31, 934 (1985)]. These final data points consistently agree with our previous measurements and support the LAMPF-ANL values. As a check of the reproducibility we also re-examined the 134 MeV/15° configuration, previously measured in 1984, and found agreement to within the statistics.

The consistently negative \(t_{20}\) values and the lack of any oscillatory nature are, generally, in good agreement with the LAMPF-ANL measurements. Our data and the LAMPF-ANL results suggest that the measured tensor polarization can be explained with conventional three-body theory without introducing exotic effects such as dibaryon resonances. The best theoretical calculation that fit our data appears to be that of Garcilazo [Phys. Rev. Lett. 53, 652 (1984)] in which a relativistic three-body model is used. The pion-nucleon \(P_{11}\) partial wave in this model is different from that used by Blankleider and Afnan [Phys. Rev. C 24, 1572 (1981)] and by Avishai and Mizutani [Phys. Rev. C 27, 312 (1983)]. This model also gives fair agreement with measured \(I_{11}\). To obtain the fit Garcilazo claims...
that the pion absorption effects must be reduced significantly. The discrepancy with other models is thought to arise from the inadequate treatment of the $P_{11}$ interactions [Blankleider and Afnan; Avishai and Mizutani]. Whether the origin of the discrepancies between theory and experiment is the relativistic effect or is the inadequacy of the $P_{11}$ interaction remains to be investigated through observations of other quantities such as spin transfer coefficients, for example (see Expt. 360 proposal).

Although our data resolve the controversy between the various measurements of $t_{20}$, the discrepancy between the SIN values and the other world data, including the very recent preliminary results of Expt. 337 by Smith et al., still exists. In order to try to understand these discrepancies we have investigated several potential problems common to all three experiments. We find that great care must be taken to correctly measure, in particular, the incident deuteron energy spectrum as the effective polarimeter efficiency is critically dependent on the appropriate application of the calibration data (our polarimeter was calibrated using the polarized deuteron beam at the Texas A&M Cyclotron Institute in April 1984). Each measurement requires that a match of the polarimeter aperture with the beam spot both spatially and in angular spread be made (for example, a beam spot that is close to or larger than the polarimeter will cause 'edge effects' and over-counting of deuterons resulting in a more positive $t_{20}$ value).

Experiment 208
Proton-proton bremsstrahlung
(P. Kitching, Alberta/TRIUMF)

The objective of this experiment was to study the off-shell properties of the nucleon-nucleon force through bremsstrahlung production in proton-proton scattering. An earlier TRIUMF experiment measured cross sections at 200 MeV; the surprising result was that potential model calculations were in poorer agreement with the data than were the results of the soft photon approximation (SPA), which contains no off-shell input. The novel feature of the present experiment was that analysing powers for a polarized proton beam would be obtained with good statistics for proton angles down to 10°. Such data provide a good test of the SPA versus calculations using modern potentials.

Beginning in December 1984 and continuing through January 1985 we began collecting ppy data and completed data-taking in a long run in June. (These were preceded by several commissioning runs, which have been described in the 1984 Annual Report.) In total there were about 140,000 ppy events recorded on magnetic tape, amongst about 10,000,000 background events.

Bremsstrahlung events were produced by bombarding a thin target of liquid hydrogen with a 280 MeV beam of polarized protons. All three particles in the final state were detected in order to reduce background, detection being limited to the horizontal plane. The photon was detected in one of 16 lead-glass Čerenkov counters, covering the polar angle range 10° to 170°. The two protons were observed in identical polar angle ranges of 10°-30°, but on opposite sides of the beam: the proton emitted on the same side as the photon typically had low energy and was detected by one of five plastic scintillators, while the proton emitted on the opposite side (usually of higher energy) was momentum analysed in a spectrometer consisting of a 'C' magnet and four vertical drift chambers plus trigger scintillators.

Most of the triggers were not ppy events but triple accidental coincidences of elastically scattered protons in the proton detectors and beam-induced room background in the photon counters. Several measures were taken to reduce this accidental trigger rate: absorber and veto scintillator behind each proton counter to reject the energetic elastically scattered protons; direct shielding of the detectors from entrance and exit windows in the beam and from the beam dump; a permanent magnet to suppress delta rays; second scintillators in the spectrometer side of the trigger in order to suppress signals induced by neutral particles; rejection of events of low pulse height from the 'low energy' (LE) proton counters.

Data analysis began with tests that the high energy (HE) proton track originated in the liquid hydrogen target and that the Čerenkov detector fired at a suitable time with respect to the cyclotron rf. Figure 17 shows how cleanly the ppy locus appeared after application of these common tests. The data were then binned into 480 groups according to the detector number for the photon and LE proton, and the polar angle of the HE proton. For each bin the kinematical parameters of ppy events are tightly constrained and suitable...
cuts on (1) proton bend angle through the spectrometer, (2) pulse height in the LE proton counter, (3) LE proton time of flight, and (4) HE proton time of flight strongly suppressed the background events. The accidental background remaining after this analysis was only 0.7% to 1.6%, depending on proton angles.

Analysing powers versus photon angle are shown for several sets of proton angles in Fig. 18. They are compared with calculations for the Bonn and Paris potentials and also with the soft photon approximation. Calculations with modern potentials are in accord with our data, while the SPA is not, in contrast to the result for the cross sections at 200 MeV.

Extraction of 5-fold differential cross sections from measured ppy yields is in progress. This is more difficult than determining analysing powers, because factors such as acceptance, particle absorption and counter efficiency must be evaluated.

**Experiment 221**
Search for evidence of Δ-nucleus intermediate state in proton elastic scattering
(H.O. Meyer, IUCF)

Standard optical models have failed to reproduce the available data for large angle elastic scattering of protons with energies between 100 and 200 MeV from $^{12}$C [Meyer et al., Phys. Rev. C 27, 459 (1983)]. The discrepancy was tentatively attributed to the formation of Δ isobars. This explanation has been tested during the first runs of Expt. 221 where an angular distribution of the p-$^{12}$C cross section at $T_p = 300$ MeV was obtained. The results ruled out the Δ hypothesis and left us without explanation for the anomalous behaviour of large angle p-nucleus elastic scattering at incident energies between 100 and 200 MeV.

To fill the gap between 200 and 300 MeV we devoted the last part of the beam time allocated to Expt. 221 to the measurement of the differential cross section and vector

**Fig. 17.** Number of events as a function of photon detector number and (a) HE proton bend angle, (b) LE proton energy.

**Fig. 18.** Asymmetry vs lab photon angle for proton angles $\theta_{HE} = 12^\circ$, $\theta_{LE} = 10^\circ$--$18^\circ$. The curves are calculations with Bonn or Paris potentials, or the soft photon approximation.
analysing power angular distributions for $^{12}\text{C}(p, p)^{12}\text{C}$, and also for $^{12}\text{C}(p, p')^{12}\text{C}^*$ ($2^+$; 4.44 MeV) at $T_p = 250$ MeV. An angular range from 3° to 96° in the laboratory frame was covered. TRIUMF's medium energy spectrometer (MRS) was used to identify protons scattered from a natural carbon target. Two target thicknesses were used: 11 mg/cm² for the small scattering angles and 93.4 mg/cm² for larger angles. The beam current was monitored by means of a secondary electron emission detector which was calibrated against p-p elastic scattering from a polyethylene target. An in-beam polarimeter was used to monitor the polarization and to provide a further check on beam intensity.

The analysis is currently in progress. Data for the vector analysing power $A_y$ are shown in Fig. 19. The preliminary results for the elastic cross section indicate an oscillatory behaviour similar to the one at 200 MeV, with a first minimum occurring at about 86° c.m. angle.

Experiment 234
Studies of the $A(p, \pi^-)A+1$ reaction
(R. Bent, IUCF; G.J. Lolos, Regina)

The experiment received beam time in January and July of this year to investigate the energy dependence of specific transitions in the $^{13}\text{C}(p, \pi^\pm)^{14}\text{O},^{14}\text{O}$ reactions. As we had experienced earlier, high quality beam delivered to 4BT2 with the required dispersion is very difficult to achieve when running against high intensity beam in beam line 1A. Nevertheless, we managed to obtain an excitation function at constant momentum transfer values for 250, 354 and 489 MeV incident proton energies. The upgraded MRS coupled with the LISA off-line analysis program provides a powerful and versatile spectroscopic tool, albeit a complicated one. The results are being analysed at present and very early indications are for quite different excitation functions for $(p, \pi^+)$ and $(p, \pi^-)$ processes to mirror states, as can be seen in the preliminary yield plot shown in Fig. 20. The states that were seen to be preferably populated at $\omega = 572$ MeV/c.

Fig. 19. Vector analysing power distributions for (a) $^{12}\text{C}(p, p)^{12}\text{C}$ and (b) $^{12}\text{C}(p, p')^{12}\text{C}^*$ ($2^+$; 4.44 MeV) at $T_p = 250$ MeV.

Fig. 20. $(p, \pi^\pm)$ yields at q.c.m. $\sim 572$ MeV/c. $^{13}\text{C}(p, \pi^+)^{14}\text{C} (6.73, 3^\circ); ^{13}\text{C}(p, \pi^+)^{14}\text{C} (11.57, 4^\circ); ^{13}\text{C}(p, \pi^-)^{14}\text{O} (6.27, 3^\circ).$
IUCF energies were poorly selected at TRIUMF energies with their yields falling with increasing proton energies. We expect to have the analysis completed early in 1986.

Experiment 236
Proton nucleus interaction
(D. Frekers, R.E. Azuma, Toronto)

One of the most interesting problems in nuclear physics is to determine how the components of free nucleon-nucleon t-matrix are altered by immersing the struck nucleon inside the target nuclear medium. The medium-modified t-matrix can, for example, be calculated from the local density-dependent potential generated according to the recipe outlined by v. Geramb. Calculations along these lines have been shown to be quite successful in describing the elastic and inelastic scattering data at medium energies (see, for example, Expts. 283/295, p. 35). More recently these calculations have been challenged by relativistic approaches. Here it was shown that the effective optical model potential is a residue of the cancellation of much larger covariant potential terms. When medium and exchange effects are properly included, as has been done by Horowitz and Murdock [Horowitz, Phys. Rev. C 31, 1340 (1985); Horowitz and Murdock, Phys. Lett. (in press)], calculations are surprisingly close to experimental data and, for spin observables like Q, they seem to be even superior to nonrelativistic models.

Of course, a consistent study of the interaction must include inelastic transitions. The low-lying collective natural parity states in closed shell nuclei, like $^{40}$Ca, are ideal for this study, as they probe different density regions at the nuclear surface. These densities are well known from electron scattering experiments leaving little or no freedom in tuning nuclear structure parameters.

Experiment 236 focused on cross section and analysing power angular distribution for ground state and the low-lying natural parity states at 3.737 MeV (3$^{-}$), 3.902 MeV (2$^{+}$) and 4.492 MeV (5$^{-}$) in $^{40}$Ca. It was the first high resolution experiment after successful completion of the MRS upgrade and therefore served for a long time as a measure for the MRS performance. The choice of our energy at 362 MeV was partly dictated by the fact that extensive studies of beam line optics and MRS performance had been done at this energy. The target was a 50 mg/cm$^2$ metallic natural calcium foil. The resolution during this experiment was generally of the order of 140 keV, topping 100 keV for some runs.

Angular distribution data for the ground state and 3$^{-}$ state are shown in Figs. 21 and 22. The smoothness of the angular distribution shapes clearly underlines the high performance of the MRS. The solid lines in Figs. 21 and 22 are calculations based on a phenomenological relativistic optical model (elastic data) and a relativistic DW code (3$^{-}$ data). Although purely phenomenological at this stage, the agreement with the inelastic 3$^{-}$ data is impressive. Further analyses will go beyond phenomenological approaches. Microscopic calculations based on the Hamburg G-matrix approach, as well as microscopic relativistic calculations, are presently in progress.

Fig. 21. Cross section and analysing power data for the 3$^{-}$ (3.737 MeV) state in $^{40}$Ca, together with relativistic DW calculations.
Studies of the \((p,n)\) reaction at IUCF have shown a strong energy dependence of the strengths of the isovector central effective interactions at energies below 200 MeV [Taddeucci et al., Phys. Rev. C 25, 1094 (1981)]. Preliminary results [Zafiratos, private communication] of measurements at 318 and 800 MeV have also been reported. These experimental results have stimulated a number of efforts to relate these effective interactions to nucleon-nucleon scattering data [Franey and Love, Phys. Rev. C 31, 488 (1985)].

Experiment 265 measured the relative cross sections for the \(^{14}\text{C}(p,n)^{14}\text{N}\) reaction leading to the \(0^+\) state at 2.31 MeV (Fermi transition) and the \(1^+\) state at 3.95 MeV (Gamow-Teller transition). Measurements were carried out at \(0^\circ\) at energies of 200, 300, 400 and 450 MeV using the new charge exchange spectrometer described in the Experimental Facilities section of this report. Overall energy resolution of 1 MeV or better was achieved in all measurements. In addition, angular distributions were measured out to \(10^\circ\) with energy resolution of \(\sim 1.5\) MeV at 200 and 400 MeV. A typical spectrum at 200 MeV is shown in Fig. 23.

Relative cross sections for the F and GT transitions were obtained by using the program OPDATA to make a least squares fit to the spectrum at each energy. The cross-section ratio was then independent of uncertainties in target thickness, beam integration and counter efficiency, and had negligible dependence on spectrometer acceptance. The resulting uncertainty in the ratio was determined almost completely by the statistical uncertainty in the data with a small additional contribution due to uncertainty in the line shape as determined by the peak fitting program. The cross-section ratio versus beam energy is given in Table III.

An estimate of the effective interaction strengths for \(q=0\) was obtained using the factorized distorted wave impulse approximation [Petrovich et al., Phys. Rev. C 21, 1718 (1980)]. In this approach the cross section is given by

\[
\sigma_{\text{factorized}}(E) = \frac{1}{\sigma_{\text{GT}}(E)} + \frac{1}{\sigma_{\text{F}}(E)} + \frac{1}{\sigma_{\text{NN}}(E)}
\]

where \(\sigma_{\text{GT}}(E)\), \(\sigma_{\text{F}}(E)\), and \(\sigma_{\text{NN}}(E)\) are the Gamow-Teller, Fermi, and nucleon-nucleon cross sections, respectively.

![Fig. 22. Elastic \(^{40}\text{Ca}(p,p)^{40}\text{Ca}\) cross section and analysing power data, together with relativistic OM calculations.](image)

![Fig. 23. A portion of the spectrum at \(0^\circ\) for the \(^{14}\text{C}(p,n)^{14}\text{N}\) reaction at \(E_p = 200\) MeV.](image)
Table III. $\sigma_{GT}/\sigma_F$ for $^{14}\text{C}(p,n)^{14}\text{N}$

<table>
<thead>
<tr>
<th>$E_p$ (MeV)</th>
<th>$\sigma_{GT}/\sigma_F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>18.8 ± 1.0</td>
</tr>
<tr>
<td>300</td>
<td>23.0 ± 2.5</td>
</tr>
<tr>
<td>400</td>
<td>19.7 ± 2.5</td>
</tr>
<tr>
<td>450</td>
<td>16.0 ± 3.2</td>
</tr>
</tbody>
</table>

$$\frac{d\sigma}{d\Omega} = \left[ \frac{\mu}{\pi A^2} \right]^2 \frac{k_f}{k_i} \left[ J_{GT}^2 N_{GT} B_{GT} + J_{FJ}^2 N_{FJ} B_{FJ} \right]$$

where $J^2$ is the volume integral of the effective interaction for $q=0$, $N$ is a factor accounting for nuclear distortion and absorption and $B$ is the beta-decay strength between the states in question. The distortion factor is given by

$$N = \left. \frac{d\sigma/d\omega_{(DW)}}{d\sigma/d\omega_{(PW)}} \right|_{\theta=0^\circ}.$$ 

In calculating $N$ optical potentials were obtained by folding the Love-Franey interaction with a nuclear matter distribution deduced from electron scattering results. The Love-Franey interaction was also used as the two-body scattering interaction. Calculations were carried out using the code ALLWRLD [Petrovich, private communication].

The ratio of interaction strengths

$$\frac{J_{GT}^2}{J_F^2} = \left( \frac{\sigma_{GT}}{\sigma_F} \right)_{\text{expt}} \frac{N_F}{N_{GT}} \frac{B_F}{B_{GT}}$$

is shown in Fig. 24 along with data from other measurements. The curve in Fig. 24 is calculated in the impulse approximation using the Love-Franey interaction. The present measurements agree well with the IUCF results at 200 MeV and are in clear disagreement with the theoretical prediction at all energies above 200 MeV.

According to calculations by Bauhoff [preprint 1985] the disagreement between measurements and calculations could be plausibly attributed to density-dependent effects at 200 MeV. At 400 MeV, however, density-dependent effects should be small and would not explain the observed difference, which is at least as great as at 200 MeV.

Experiment 266

Initial studies of the $(n,p)$ reaction on light nuclei (K.P. Jackson, TRIUMF)

The successful commissioning of the charge exchange facility outlined on p. 123 provides an opportunity for nuclear spectroscopy which for the $(n,p)$ reaction at intermediate energies is absolutely unique. Of the initial proposals forming the basis for the development of this facility, Expt. 266 was specifically designed as a first experiment providing a significant benchmark by which the facility could be critically assessed. Included are measurements of the differential cross sections at forward angles for the $(n,p)$ reaction at 200 MeV on $^6\text{Li}$, $^7\text{Li}$, $^{12}\text{C}$ and $^{13}\text{C}$. The self-conjugate nuclei provide ideal comparisons with the corresponding $(p,n)$ spectra recorded both at TRIUMF and IUCF. The $(n,p)$ spectra on each of the four targets contain unique spectroscopic information on the four neutron-rich final nuclei. Of vital importance for subsequent experiments is the fact that all of the targets except $^7\text{Li}$ are cases for which the yield at $0^\circ$ of a strong ground-state transition can be used to calibrate the $(n,p)$ reaction as a probe of Gamow-Teller strength by comparison with a well-known $\beta$-decay matrix element.

During the five weeks from November 13 to December 18 used to commission the $(n,p)$
Fig. 25. A typical (n,p) spectrum recorded on line with 4 natural carbon targets (total 0.37 g/cm²) in the segmented target chamber.

facility 9 shifts were devoted to the specific goals of Expt. 266. An example of the data recorded on line is shown in Fig. 25, a spectrum of the 12C(n,p)12B reaction at 0° recorded in 8 h and exhibiting a resolution of 1.0 MeV. The segmented secondary target chamber developed primarily to increase the total thickness of the (n,p) target without loss of resolution also enabled the concurrent recording of the spectrum for CH₂ shown in Fig. 103, p. 125. These data indicate the capability of measuring cross sections with a precision of a few per cent by direct comparison with the known value for the (n,p) reaction on H. This reaction is also the source of the peak on the left in Fig. 25, which can be attributed primarily to the isobutane in the counter gas of the segmented target chamber. The background originating from all the material in this chamber is subtracted on the basis of spectra recorded with an empty target ladder.

The specific data recorded as part of Expt. 266 included the measurement of angular distributions at 5 angles from 0° to 15° for 12C and at 0°, 5° and 10° for 6Li and 13C. Although final analysis of all these data is still in progress, Fig. 25 is typical of the quality. They will provide the basis for a letter demonstrating the capability of the facility and presenting the simple results of greatest impact.

The completion of this experiment will involve the extension of the angular distributions on 6Li and 13C to 20° and limited data for 7Li. The combined data set should then provide ample material for one or more detailed publications.

Experiment 267
A measurement of the Gamow-Teller strength distribution in the 54Fe(p,n)54Mn reaction at 298 MeV
(O. Häusser, M. Vetterli, Simon Fraser/TRIUMF)

The selectivity of charge exchange reactions at TRIUMF energies makes them a highly useful tool for the study of Gamow-Teller strength distributions in nuclei, particularly at excitation energies that are inaccessible to 8 decay [Gaarde et al., in Spin excitations in nuclei, p. 65; Rapaport et al., Nucl. Phys. A410, 371 (1983)]. The (p,n) cross sections near 0° are a measure of B(GT⁻), the 8⁻ decay strength, while the (n,p) cross sections are related to B(GT⁰). The results can be compared to the model-independent sum rule of Ikeda [Prog. Theor. Phys. 31, 434 (1964)]:

\[ B(GT^-) - B(GT^0) = 3(N-Z) \]

It could, nevertheless, be concluded that at most 60% of the sum rule is identifiable in the (p,n) reaction in the low-energy region [Garde et al.]. The missing strength is attributed to coherent A-hole excitations and/or to tensor correlations which cause a mixing of lplh and 2p2h states, producing a long tail of GT strength to higher excitation energies.

We are using the recently commissioned CHARGEX facility at TRIUMF’s MRS to carry out a purely experimental test of Ikeda’s sum rule. Both the 54Fe(p,n) and (n,p) reactions are being investigated at 300 MeV. We report here on first results for the 54Fe(p,n)54Mn reaction at 0° and 5°. For the (p,n) reaction shell model calculations [Bloom and Fuller, Nucl. Phys. A440, 511 (1985)] predict a large value of B(GT⁻) = 9.1, which should be mainly concentrated between 0.5 and 4 MeV. Background from higher multipole transitions is expected to be large at higher excitations, and thus the (n,p) reaction is more favourable than (p,n) to detect a high-energy GT tail, should it exist.

The 298 MeV neutron beam was produced with a dispersed proton beam on a 7Li strip target, and the segmented secondary target stack (described elsewhere) consisted of two 54Fe foils, one carbon foil, one CH₂ foil, and two empty cells. The wire chambers, which indi-
cate from which part of the stack the proton originates, were originally operated with an argon-isobutane mixture. Since the hydrogen in the counter gas caused substantial background in the $^{54}$Fe(n,p) spectrum ($Q = 0.09$ MeV), we switched to an argon-CO$_2$ mixture after about one-third of the data had been taken.

The spectra from the different cells of the target stack were combined to yield the results shown in Fig. 26. All three spectra shown have the 'empty cell' contribution removed. The top spectrum corresponds to pure hydrogen and shows the distribution of incident neutrons. The two lower spectra have the contribution from the low-energy neutron tail subtracted using a simple deconvolution procedure; they correspond to a monoenergetic 298 MeV neutron beam. The middle spectrum, from carbon ($Q$ value = $-12.6$ MeV), shows negligible background between $Q = +10$ MeV and $Q = -10$ MeV. The $^{54}$Fe spectrum (bottom) shows a broad peak at $Q = 2$ MeV and a dip at $Q = -8$ MeV. The rise in yield at more negative $Q$ values probably arises from L=0 multipoles, as indicated by the $5^+$ data: at the larger momentum transfer the yield between $Q = 0$ and $Q = -8$ MeV is greatly reduced relative to the higher excitation region.

In a preliminary analysis we have assumed that in the region from $Q = -0.5$ MeV (there are no known $1^+$ states in $^{54}$Mn below 1.4 MeV) to $Q = -8$ MeV the observed yield is purely L=0. The cross sections in Table IV were relative to the hydrogen (53 mb/sr) in the CH$_2$ target. Experimental $B(GT^+)$ values were obtained using a ratio $\sigma/B(GT^+) = 2.53$ [Osterfeld, private communication]. They are substantially smaller than predicted by Bloom and Fuller.

Future more detailed angular distribution measurements should allow a multipole decomposition up to high excitation energies. Similar measurements will be carried out for the $^{54}$Fe(p,n)$^{54}$Co reaction, at the same energy (300 MeV), and using the same experimental set-up. It is hoped these data will clarify whether the sum rule is valid in the low-energy excitation region.

Experiment 272
Transverse spin-flip probabilities in $^{24}$Mg(pp)

The spin-isospin response of nuclei can be studied very effectively with intermediate energy nucleon beams at small momentum transfer. Because of the dominant $t_{0T}$ term in the
NN interaction spectra of protons inelastically scattered at extreme forward angles exhibit strong peaks from $\Delta S = 1$ excitations. Natural parity states which are weakly present in the spectra can be completely suppressed if the transverse spin-flip probability $S_{NN}$ is measured: $S_{NN}$ is approximately zero for $\Delta S = 0$ states, but large for $\Delta S = 1$ excitations (~0.6 for $1^+$ states near $\theta = 0^\circ$).

The first measurement of $S_{NN}$ at TRIUMF has been carried out in October following the commissioning of the focal plane polarimeter (FPP) for the medium resolution spectrometer (MRS). The major difficulty of the experiment consists in the fact that a large number of events from the target need to be accumulated although they constitute only a small fraction (~10^{-3}) of the protons passing through the MRS. Several experimental steps were taken to overcome this difficulty: i) elastic protons were either prescaled using a veto scintillator at the focal plane or eliminated using a Pb stopper between focal plane and FPP; ii) inelastic background was reduced by operating the wire planes of the front-end chamber to define an optimal solid angle for the MRS; iii) neutron-induced counting rates in the focal plane detectors were reduced by appropriate shielding of the beam stop near the target.

The resulting spectra for the $^{24}$Mg($p,p'$) reaction at $E_p = 250$ MeV and $\theta = 3^\circ$ exhibit adequate resolution (~150 keV FWHM) and low background. The transverse spin-flip probability $S_{NN}$ and the spin-flip strength $\sigma_{NN}$ are shown in Fig. 27 up to 40 MeV of excitation in $^{24}$Mg. The $S_{NN}$ values for the discrete states are as expected, i.e. about zero for ground state and low-lying states and ~0.6 for the very dominant $1^+, T=1$ state at 10.71 MeV. The considerable spin-flip strength between 10 MeV and 40 MeV is qualitatively similar to that observed in heavier nuclei [Nanda et al., Phys. Rev. Lett. 51, 1526 (1983)]. This gross feature can be explained as arising from quasielastic NN scattering. To achieve a decomposition of the spin-flip strength into Gamow-Teller strength and higher multipoles, detailed nuclear structure calculations and additional data at larger scattering angles are required.

Experiment 281
Investigations of the pion absorption reaction $^4$Li,$^6$C($\pi^\pm,X_i$)$X_2$ (G. Lolos, Regina)

This experiment received four 12 h shifts of parasitic test time in August. Some of the counters were tested and as a result significant modifications became necessary. The experiment, whose purpose is to investigate in-flight pion absorption on two, three or more nucleons, was also scheduled beam time in December and January of 1986.

The detection system, shown in Fig. 28, consists of two arms with scintillator counters and wire chambers. Particle identification is provided by $\Delta E$ and $E$ telescopes capable of stopping up to 250 MeV protons. A hodoscope grid of thin (0.1 cm) plastic scintillators with fibre-optic lightguides will provide the target-mounting frame and serve several other functions as well. It will define incident beam flux, time of flight based on the absorbed pion and a beam profile and position.
Time reversal invariance is, however, no longer applicable if exchange terms are included, which then leads to the more generalized relations:

\[ P = -A_y, \quad D_{N'N} = -1, \quad D_{S'LS} = D_{L'S} = D_{S'S} = -D_{L'L} \]

Thus we find the important result that non-zero analysing power values are entirely due to the exchange contributions in the interaction. This is a unique situation in p-nucleus interaction.

There are four known 0^- states in light nuclei (6.902 MeV in ^14C, 10.957 MeV (T=0) and 12.797 MeV (T=1) in ^16O, and 5.880 MeV in ^18O) which can be studied in high resolution experiments. Initially we have focused on the ^16O case, since the nuclear structure involved is particularly simple and only involves a \((1p_1^1/2, 2s_1^1/2)\) configuration. (Note that the nuclear structure cannot be elucidated by electron scattering.)

In a short unpolarized beam experiment on the MRS we did feasibility studies in order to assess background problems and the resolution requirements. We eventually measured a six-point angular distribution at 200 MeV in small-angle configuration (3.09, 6.01, 8.57, 10.27 and 13.5°) for the 10.957 MeV (T=0) state using a 70 mg/cm^2 BeO target. Despite a poor resolution (>200 keV) and the inherent background due to broad Be states, the 0^- transition could easily be discerned. Most of the background under the 0^- peak was in fact found to be due to the Be content of the target. A sample spectrum is shown in Fig. 29. With increasing scattering angle the resolution requirement gets more stringent, as higher spin states start to grow in the spectrum. At large angles at least 140 keV will be required to resolve the T=0 state, and a resolution of 60 keV is estimated for resolving the T=1 state. With the recent improvements on the MRS the first requirement can easily be met, making a detailed investigation of the T=0 state possible and leaving the T=1 state as the next goal not too far away.

In Fig. 30 we show the measured angular distribution together with two DWIA calculations using the Hamburg potential (curve labelled H), and the Love-Franey effective interaction (curve labelled LF). Both curves show radically different shapes. It is to be noted that similar differences show up in the analysing power predictions. Our present data do not favour one over the other. A clarify-
Fig. 29. 200 MeV proton spectrum at 6° from a BeO target.

An experiment providing cross section and analysing power data out to 30° is clearly needed. Such an experiment has been approved.

Experiments 283/295
Proton scattering from 208Pb at large momentum transfer (T.E. Drake, Toronto; C.A. Miller, TRIUMF; A. Scott, Georgia)

Our large-angle studies on elastic and inelastic scattering from 208Pb at 200 MeV using the MRS have now been completed. Cross section and analysing power data are now available from 3° to 90° lab angle for the elastic, the 3° and the 5° states in 208Pb. The elastic data (submitted to Phys. Lett.) show a pronounced saturation effect in the analysing power for angles greater than 60°. This behaviour is well accounted for by microscopic Schrödinger calculations (MSC) based on the Hamburg G-matrix approach. On the other hand the effect is in marked contrast to predictions made on the basis of the relativistic impulse approximation (RIA), which would indicate a serious deficiency of the RIA. However, C. Horowitz has done new relativistic calculations which for the first time include exchange effects and Pauli blocking. These calculations show a remarkable improvement and are in good qualitative agreement with the data (Fig. 31). Apparently the proper treatment of exchange effects seems to be more crucial than whether or not a relativistic approach is being used. However, both calculations, MSC and RIA, share a common deficiency. The oscillatory behaviour in the cross section at large angles is out of phase with the data (Fig. 32). This effect is presently not understood.

Complementary studies for the elastic and inelastic channels have begun at 400 MeV. The analyses for the 400 MeV data and the inelastic 200 MeV data are presently being performed at the University of Toronto.

Experiment 285
Elastic scattering of pions on 34He for pion energies between 30 and 50 MeV (K. Crowe, Berkeley)

Pion-helium elastic scattering data at low energy have in general been of mediocre quality. This is due to the difficulty of obtaining high π intensities at these energies, and the short lifetime of the pion. However, recent results by Fournier et al. [Nucl. Phys. A426, 542 (1984)] at Saclay have produced very good measurements for a few energies between 25 and 65 MeV. Their data consist of π⁺ and π⁻ elastic scattering on both 3He and 4He for angles between 43° and 150°. Unfortunately their measurements do not extend farther forward than 43°. At forward angles one obtains the real and imaginary parts of the forward scattering amplitude. This is the most important 'global' information about the elastic process. The real part comes from the Coulomb and nuclear interference and the imaginary part is approximately dσ/dΩ. Data from this region will also furnish us with more information on the
Fig. 31. Analysing power for $^\uparrow + ^{208}$Pb at 200 MeV. The triangles are the new data from Expt. 283/295. The calculations are: a) nonrelativistic microscopic Schrödinger calculation performed by von Geramb, b) new relativistic calculation performed by Horowitz.

Fig. 32. Same as in Fig. 31, but for cross sections.

partial wave composition of the scattering amplitude.

In the summer we ran the initial phase of this experiment. It was performed on the M13 channel using the QQD spectrometer and a newly built liquid helium target. The QQD spectrometer was upgraded by including a smaller forward wire chamber which allowed us to measure at $\sim 15^\circ$. This wire chamber proved capable of handling rates of $\sim 10^6$/s. Installation of a motorized drive and TV readout on the QQD allowed rapid change of angular setting.

Then going to small forward angles, muons from pions having decayed in the beam line will ultimately enter the spectrometer. At 50 MeV the muons are emitted in a forward cone of 18° relative to the beam axis. Figure 33(a,b) shows the elastic peak for 32° and 20° with minimal cuts applied. At 32° the results are very clean. Even at 20° the elastic peak is well separated from the background but we can see the effects of the beam halo. We have not had time to examine carefully the 15° data yet but the clean signal at 20° gives confidence that the 15° data can be resolved.

In Fig. 34 we present preliminary data for $\pi^+$ and $\pi^-$ at 50 MeV and $\pi^+$ at 45 MeV. The data for 45 MeV, $\pi^+$, have been normalized to the corresponding Saclay data. The 50 MeV $\pi^+$ and $\pi^-$ data have in turn been normalized to our 45 MeV data. The data are compared with the theoretical predictions of Landau for 45 MeV [Comput. Phys. Commun. 28, 109 (1982)].
Fig. 33. (a) Momentum spectrum for a scattering angle at 32°. The horizontal scale is Δp/10p where Δp is the reconstructed momentum less the central spectrometer momentum. (b) Momentum spectrum at a scattering angle of 20°. The elastic peak and beam halo are separated.

curves represent: i) 'complete' calculations (solid curves), ii) without spin-flip and Coulomb effects (dotted curves).

Experiment 294
Spin rotation parameter Q for p+208Pb elastic scattering at 290 MeV (O. Hlusser, Simon Fraser/ TRIUMF; C. Glover, ORNL)

Calculations based on the relativistic impulse approximation have been remarkably successful in explaining elastic proton scattering data near E = 500 MeV, but disagree with experiment at lower proton energies (E = 200 MeV). Recently, Tjon and Wallace, and independently, Horowitz, have overcome these difficulties by advocating the use of pseudovector rather than pseudoscalar π-N coupling and the inclusion of exchange terms. For heavier targets effects of Pauli blocking are also expected to be of some importance.

Fig. 34. π± scattering on 3He data are compared with Saclay data and Landau theory (see text). (a) π+ scattering at 45 and 50 MeV, (b) π− scattering at 50 MeV.
Fig. 35. Proton polarization in $^{208}\text{Pb}(\bar{p}p)$ at 290 MeV. The theoretical curves are explained in the main text.

Fig. 36. Spin rotation function for $^{208}\text{Pb}(\bar{p}p)$ at 290 MeV. The calculations are described in the main text.

To test the validity of the new relativistic approaches at the crucial lower energies we have measured spin observables for elastic proton scattering from $^{208}\text{Pb}$ at 290 MeV using the newly commissioned focal plane polarimeter of the MRS. The experiment was carried out with sideways polarized beam whose polarization was obtained by rotating the spin by $\pm 90^\circ$ using a solenoid in beam line 4B. Simultaneous measurements of the polarization components after scattering, $P_S$ and $P_L$, were used to obtain the spin rotation parameter $Q = D_{SS} \sin \theta - D_{SL} \cos \theta$. Because of spin precession in the MRS dipole (precession angle $\xi = 140^\circ$) about 63% of the longitudinal component is converted into the normal direction, i.e., $P_N = P_L \sin \xi + P_N \cos \xi$. Separation of the $P_L$ and $P_N$ components is achieved by flipping the spin of the incident beam: $P_L$ changes sign where $P_N$ does not. This method is vulnerable if unknown longitudinal components exist in the incident beam. For this reason the same sideways polarization $P_S$ but longitudinal polarizations of both signs, were obtained using different combinations of the spin of the incoming beam (up/down) and of the solenoid current (+/−). We found that at 290 MeV $P_L$ was negligible.

The angular dependence of the polarization $P$ and the spin rotation function $Q$ are shown in Figs. 35 and 36. These results together with TRIUMF data on cross sections at 300 MeV [Hutcheon et al., to be published], completely specify the scattering matrix for elastic scattering. The dashed curves were calculated nonrelativistically by W. Bauhoff who used von Geramb's density-dependent interaction derived from the Paris NN potential. The predictions are significantly at variance with the data, especially for $Q$ between $5^\circ$ and $20^\circ$. The two other curves represent relativistic calculations carried out by C. Horowitz. They use pseudovector $\pi$-$N$ coupling and include exchange in a fit to NN data [see Phys. Rev. C 31, 1340 (1985)]. The effects of Pauli blocking are either included (solid lines) or omitted (dot-dashed lines). The agreement of the full calculation with experiment is impressive considering the sensitive cancellations of effects of Pauli blocking and exchange. We intend to perform similar measurements at 200 MeV where medium modifications should play an even larger role.

Experiment 300
Measurement of $K_{\text{em}}$ in $pp \rightarrow d\pi$
(D.A. Hutcheon, TRIUMF)

During the past year steady progress has been achieved in the commissioning of a deuteron polarimeter. The focal plane polarimeter (FPP) of the medium resolution spectrometer (MRS) has been adapted to the measurement of polarization of deuterons produced in targets at line 4B. The aim is to construct a deuteron polarimeter sensitive to the $T_{21}$ and $I_{11}$ components of the polarization. Tests in early 1985 using unpolarized beams of protons on a CH$_3$ target were carried out to check the operation of the FPP for scattered deuterons, specifically to determine the ability to isolate deuterons from other background processes. At that time it was determined that the use of front-end wire chambers of the MRS was (a) not feasible because of the high counting rates encountered, but (b) not necessary for the $pp \rightarrow d\pi$ reaction. Deuterons of three different energies were studied and
the effects of the carbon scatterer and iron absorbers for proton background suppression were investigated. Very small angle scattering (less than about 5°) was eliminated using preprocessing by STARnCIRTS microprocessor.

The first use of the system for deuteron polarizations in the $^3\!\!P^0 + ^3\!\!D^1$ reaction took place in September. Deuterons were detected for pion centre-of-mass angles ranging from 120° to 160°. A superconducting magnet precessed the proton spins from the normal to the sideways direction. At each angle 1.4 to 2.6 nA h of data were collected. An in-beam polarimeter indicated the presence of a significant non-normal component of polarization of the protons exiting from the cyclotron. Consequently, the time was divided roughly equally between runs with protons precessed by +90° onto the scattering plane and with protons precessed by -90°. It appears it will be possible to operate the system without any front-end detectors on the MRS. Data analysis programs have been written, and replay of the September run has commenced.

**Experiment 322**

**Measurement of $\pi^-p$ elastic differential cross sections**

(D. Gill, TRIUMF; R. Ristinen, Colorado)

During the spring and summer precision measurements of $\pi^-p$ elastic differential cross sections were made at the M11 pion channel. These measurements were made at 17 pion scattering angles between 62.5° and 155° in the laboratory system and at nominal incident pion kinetic energies of 70, 90, 120, 130 and 143 MeV.

The motivation for the work arose out of the major discrepancies in this energy region between the recent measurements made by a group at Los Alamos [Frank et al., Phys. Rev. D 28, 1569 (1983)] and earlier measurements made by a number of investigators. In particular, the 90 MeV $\pi^+p$ cross sections of Frank et al. are about 30% lower than the 95 MeV cross sections reported by three groups [Bertin et al., Nucl. Phys. B106, 341 (1976), Bussey et al., Nucl. Phys. B50, 363 (1973), and Ritchie et al., Phys. Lett. 125B, 128 (1983)] and also about 30% lower than phase-shift predictions. The predicted energy-dependent downward shift in cross sections going from 95 MeV to 90 MeV is only about 13%, leaving a significant discrepancy. Similar discrepancies exist for the $\pi^+p$ elastic data at 70 and 30 MeV, and appreciable discrepancies also exist for the $\pi^-$ data relative to phase-shift predictions.

In order to resolve this problem our approach has been to use a scintillation counter system with a well-defined and understood efficiency. This was accomplished with an array of scintillators as depicted in Fig. 37. The scattering target is CH$_2$, typically 1 mm thick, and incident pion fluxes were about $10^6$/s for both $\pi^+$ and $\pi^-$. Sufficient statistical accuracy was attained at each angle, for both $\pi^+$ and $\pi^-$, to ensure statistical precision of better than ±3%.

Figure 38 shows a dot plot used for incident pion identification, with the pion group outlined by a software box. Within this box there are variable pulse amplitudes due to variable numbers of pions in a given rf bucket. This phenomenon is understood and does not present a problem in data analysis.

A typical spectrum, from which the event count is derived, of the time-of-flight difference for a $\pi^-p$ counter pair is shown in Fig. 39. The key feature here is the exquisite peak-to-background ratio, where the background includes both randoms and reaction products from the carbon component of the CH$_2$ target. Runs taken with a graphite target
Fig. 38. A plot of particle velocity versus pulse amplitude in S2 for $T_\pi = 70$ MeV. The box contains the pion component of the incident beam; above it are the muons, and above them the electrons.

confirmed that background in these spectra was indeed tiny.

Current efforts are directed toward data reduction with emphasis on Monte-Carlo computation of multiple scattering effects in the counter elements, the target and the air. The current analysis also considers pion decays, rate effects, beam contamination, incident pion kinetic energy, and several other factors. The data include extensive systematic checks such as effects due to variable target angle, target thickness, counter thickness and location, size of beam spot, primary proton beam current, channel jaw settings, etc. Our goal is to achieve a set of $\pi^-p$ elastic differential cross sections with an absolute accuracy of about $\pm 5\%$, and we expect to have the analysis completed within the next few months.

Experiment 324
P-A measurement for $^{12}$C(p,p') at 400 MeV
(K.H. Hicks, Simon Fraser; J.R. Shephard, Colorado)

A measurement of polarization-analysing power differences (P-A) is a good example to show that measurements of spin variables are most useful when used in combinations. The observable P-A is directly related to the nonlocal part of the nuclear force [Love and Comfort, Phys. Rev. C 29, 2135 (1984)] (from transition amplitude terms that contain nuclear convection currents). This information on nonlocalities is not available from a measurement of either P or A only.

Fig. 39. A plot of the time-of-flight difference for one $\pi^-p$ counter pair, for $T_\pi (\text{incident}) = 70$ MeV, $\theta_\pi (\text{lab}) = 142.5^\circ$, and for a 99 mg/cm$^2$ CH$_2$ target. This spectrum includes the continuum backgrounds due to both randoms and carbon. The FWHM width of the peak is about 400 ps.

In conventional (nonrelativistic) DWIA calculations a nonlocal force can only arise from knock-on exchange [Love and Comfort]. In the relativistic impulse approximation (RIA) approach one finds that nonlocalities arise naturally even without exchange and that adding exchange does not change the calculation significantly [Shepard et al., Colorado preprint; Sparrow et al., Phys. Rev. Lett. 54, 2207 (1985); Shepard, private communication].

Experiment 324 was performed in two parts for the P and A measurements, respectively. The P measurements were the first use of the focal plane polarimeter (FPP) which is described elsewhere in this Annual Report. A substantial fraction of the Expt. 324 beam time was used to optimize the operation of the FPP, and for this reason data were obtained at only three angles. Furthermore, the statistical accuracy was overestimated due to lack of experience with the FPP. The A measurements were fairly standard and gave good results for all three angles ($\theta_{\text{lab}} = 5^\circ$, 8° and 11°) in good agreement with LAMPF data [Jones, private communication (thesis)].

Preliminary results of the P-A measurement are given in Table V. The first four excited states are expected to have P-A = 0 due to their collective structure. The $1^+, T=0$ state at 12.7 MeV and the $1^+, T=1$ state at 15.1 MeV are expected to have nonzero (although small) P-A for these angles. The $2^+, T=1$ natural-parity state at 16.1 MeV is expected to have
Table V. P-A for $^{12}$C(p,p') at 400 MeV

<table>
<thead>
<tr>
<th>E°</th>
<th>5.58°</th>
<th>8.92°</th>
<th>12.27°</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>-0.05±0.05</td>
<td>-0.04±0.08</td>
<td>-0.03±0.04</td>
</tr>
<tr>
<td>4.44</td>
<td>-0.03±0.06</td>
<td>+0.10±0.07</td>
<td>0.00±0.03</td>
</tr>
<tr>
<td>7.65</td>
<td>0.001±0.15</td>
<td>-0.04±0.15</td>
<td>+0.07±0.06</td>
</tr>
<tr>
<td>9.64</td>
<td>-</td>
<td>-0.15±0.23</td>
<td>+0.03±0.06</td>
</tr>
<tr>
<td>12.71</td>
<td>0.05±0.14</td>
<td>+0.44±0.31</td>
<td>-0.24±0.24</td>
</tr>
<tr>
<td>15.11</td>
<td>-0.12±0.06</td>
<td>-0.15±0.21</td>
<td>-0.23±0.21</td>
</tr>
<tr>
<td>16.1</td>
<td>-</td>
<td>-</td>
<td>0.04±0.25</td>
</tr>
</tbody>
</table>

P-A = +0.2 for these angles. A comparison of the expected values with the measured P-A is difficult due to the large statistical error. A repeat of the 8° and 11° angles is scheduled to take place in early 1986.

Experiment 335
Isoscalar and isovector $1^+$ excitations in $^{28}$Si(p,p')
(O. Häusser, Simon Fraser/TRIUMF)

Small-angle inelastic proton scattering at TRIUMF energies can be used very effectively to excite spin-isospin modes in nuclei. This selectivity reflects the properties of the NN interaction at small momentum transfer. However, because of the complexity of the hadronic probe the quantitative relationship between observed differential cross sections and Gamow-Teller strength is not yet fully understood. With the intent to test current models of the (p,p') reaction we have used the medium resolution spectrometer (MRS) to study several $1^+$ states in $^{28}$Si at five different bombarding energies (200, 250, 290, 360 and 400 MeV). The target was chosen because $^{28}$Si is the heaviest nucleus which contains a strong and rather pure isoscalar excitation (the $1^+, T=0$ state at 9.50 MeV) in addition to several discrete $1^+, T=1$ states. The energy resolution was typically 115 keV FWHM. At all energies differential cross sections and analysing powers were obtained at four c.m. angles between 3.5° and 6.5°; at 250 MeV a more complete angular distribution was taken.

Differential cross sections for the strongest isoscalar and isovector excitations at 9.50 MeV and 11.45 MeV, respectively, at $\theta_{c.m.}=4^\circ$ are shown in Fig. 40. Theoretical cross sections depend on the nuclear structure assumptions (we used wave functions of Chung and Wildenthal), on the NN scattering input, on the reaction model, and on the optical potential which describes the wave distortions. Calculations using the density-dependent Hamburg interaction derived from the Paris potential and a microscopically derived optical potential are shown as solid lines. Comparison with the dashed lines calculated with a vanishing Fermi momentum $k_F=0$ shows the importance of medium modifications. We note that the cross sections for the $1^+, T=1$ state at 11.45 MeV can be described by a constant 'quenching factor' of ~0.35, whereas the same factor for the $1^+, T=0$ state at 9.50 MeV increases from ~0.3 at 200 MeV to ~0.5 at 400 MeV. This indicates a deficiency of the Hamburg interaction in describing isoscalar excitations. Also shown are calculations for 330 MeV obtained with the Love-Franey interaction (Phys. Rev. C 31, 488 (1985)) and an optical potential from the
literature (Hirtz et al., Phys. Rev. C 30, 1976 (1984)). Additional measurements of elastic scattering at several energies are planned to reduce the uncertainties associated with optical model parameters.

Experiment 337
Measurement of tensor observables in the $\pi^-d$ elastic scattering reaction
(G.R. Smith, TRIUMF)

For the past several years one of the most intriguing questions in intermediate energy pion physics has revolved around two sets of conflicting measurements of the tensor analysing power, $t_{20}$, in $\pi d$ elastic scattering. Previous measurements of this observable were made in double scattering experiments at LAMPF and SIN, and recently also at TRIUMF. Experiment 337 was proposed in order to resolve the controversy and extend our knowledge of the spin observables in $\pi d$ elastic scattering by performing the measurement in a single scattering with a tensor polarized deuteron target.

Considering the fact that, to our knowledge, a tensor polarized deuteron target has never before been used in a scattering experiment, the achievement of the TRIUMF polarized target group in 1985 was phenomenal. During the course of the year a polarized deuteron target with 2.5 T horizontal polarizing field and a dilution refrigerator capable of reaching temperatures of 80 mK was developed. Many tests were performed to study and optimize the target polarization and to improve the measurement of the tiny deuteron NMR signal. By the end of the year typical vector polarizations of 34% were achieved. The reliability of the target had been sufficiently well established by November that we were able to begin Expt. 337 at that time.

In parallel with the polarized deuteron target developments (with which certain key members of the experimental group were involved) a new detection facility was designed, built and tested by the summer. This facility, which we have dubbed the TOF spectrometer, consists of six identical arms which provide an extremely clean and accurate measurement of $\pi d$, $\pi p$ and $\pi d + 2p$ events. Each arm consists of a two-element pion scintillator telescope, in coincidence with a three-element deuteron scintillator telescope. The deuteron telescope has a thin AE scintillator followed by an adjustable thickness of absorber, then a thick E scintillator and a veto scintillator. With this setup six scattering angles may be measured simultaneously. The total solid angle of the device is 180 msr.

The final developments made were in the software regime. First, the relatively inflexible MULTI data acquisition package was replaced by the more versatile and user-friendly STAR system, developed by this group. Off-line analysis software was implemented on the VAX. Software to analyse the complex deuteron NMR signals was also developed.

In November the polarized deuteron target and the TOF spectrometer were installed in the M1 area. Extensive modifications had been made to this channel during the preceding shutdown: namely, a polarized deuteron target platform had been installed, and the second half of the channel had been moved approximately two feet downstream in order to accommodate an additional sextupole magnet. Insufficient tuning time was available to completely understand the behaviour of the newly modified M1 channel, but enough was learned to produce a pion focus with only slightly worse size, divergence and intensity than were available previously.

The first week of the four-week run was therefore spent tuning. The remaining three weeks were split between measurements of the $\pi d + 2p$ reaction at $\theta_{c.m.} = 90^\circ$, and measurements of the $\pi d$ elastic reaction at $T_\pi = 134, 151$ and 219 MeV. The former reaction was measured because the tensor analysing power is known there, and thus it provides a means to study and calibrate the target tensor polarization seen by the incident pion beam. The latter reaction is, of course, the focus of Expt. 337.

The preliminary analysis of the $\pi d$ elastic scattering data indicates that the measured data are consistent between several pairs of polarized and unpolarized runs. This check is made to look for possible systematic errors, and we therefore have confidence that the technique we have chosen is a sound one. The target vector polarization was 34-35% during the run, which corresponds to only 9-9.5% tensor polarization. The analysis of the data should be completed by February 1986. The preliminary analysis, however, indicates that the value of $T_{20}$ at $T_\pi = 134$ MeV is deeply negative between 135° and 170° (c.m.). Our results are therefore inconsistent with those measured in the double scattering experiment at SIN, which were positive and had strong
angular and energy-dependent variations. The SIN data had been the source of speculation that dibaryon resonances were needed to explain the behaviour of $T_{20}$. In light of the fact that our results in particular, as well as those of two other double scattering experiments at LAMPF and TRIUMF, all indicate negative values of $T_{20}$, it is safe to conclude at this point that the SIN measurements are wrong.

We plan to make further measurements of $T_{20}$, as well as first measurements of $T_{21}$ and $T_{22}$, during 1986.

Experiments 350/351

Study of the energy dependence and the $A$ dependence of the double charge exchange reaction at low energy (A. Altman, UBC)

The QQD spectrometer was used to measure differential cross sections of several double charge exchange (DCX) reactions at low energies during the last year. Early measurements of the DCX cross section to the double isobaric analog state (DIAS) at 50 MeV have already established the importance and the interesting features of this reaction. The forward peaking and the relatively high cross section have been reported for $^{18}$O($\pi^+, \pi^-)^{18}$Ne (DIAS) at 50 MeV by the present group [Altman et al., Phys. Rev. Lett. 55, 1273 (1985) and 1984 Annual Report]. The same features have been reported for the $^{14}$C($\pi^+, \pi^-)^{14}$O (DIAS) reaction at 50 MeV by the TRIUMF TPC group and by a group at LAMPF [Navon et al., Phys. Rev. Lett. 52, 105 (1984) and Leitch et al., Phys. Rev. Lett. 54, 1482 (1985)].

Several theoretical works attempted to explain the behaviour of the DCX cross section at low energy which cannot be described by a simple sequential model of two single charge exchange scattering to analog states. Calculations involving quark degrees of freedom using a six-quark bag model including absorption were able to reproduce reasonably well the forward part of the angular distributions of the above reactions [Miller, Phys. Rev. Lett. 53, 2008 (1984) and Proc. LAMPF Workshop on Pion Double Charge Exchange, January 1985]. More conventional calculations in the $\Delta$-hole model were able to reproduce, at least qualitatively, the angular distributions on $^{14}$C and $^{18}$O [Karapiperis, LAMPF Workshop on DCX; Karapiperis and Kobayashi, SIN preprint PR-85-08 (1985)]. Other calculations in optical model using short-range and long-range correlations were only partially successful [see, for example, Gibbs, LAMPF Workshop on DCX]. All the above calculations emphasize the important role of the two-valence neutrons in the reaction mechanism and indicate a correlation range of less than 1 fm.

The QQD spectrometer was used with the 50 MeV M13 pion beam in the same configuration as reported for the study of the $^{18}$O($\pi^+, \pi^-)^{18}$Ne at 50 MeV (see references above). The spectrometer polarity was reversed to accept charge opposite of the incident beam; the magnetic fields were adjusted to place the peak of the double isobaric analog transition (DIAT) in the centre of the exit wire chambers. The differential cross sections of the $^{26}$Mg($\pi^+, \pi^-)^{26}$Si (DIAS) were measured at six angles for 50 MeV incident pions. Electrons were rejected by using time-of-flight technique, as illustrated in Fig. 41, and the resulting spectrum after applying all the cuts is shown in Fig. 42. Figure 43 displays the angular distributions of the differential cross sections for the DIAT in $^{14}$C, $^{18}$O and $^{26}$Mg at 50 MeV. The similarity between the results on these nuclei is remarkable if we recall that the excitation functions of zero-degree cross sections of the DIAT for the above nuclei exhibit different behaviour.

The A dependence of the DIAT cross sections, as seen from the experimental data on $^{14}$C, $^{18}$O and $^{26}$Mg, seems to be different than that
Fig. 42. The momentum spectrum ($\Delta p/p$) of the particles as determined by the spectrometer at $\theta = 40^\circ$ after applying all the required cuts.

at 165 MeV and 292 MeV. At 292 MeV this dependence is dominated by $A^{-10/3}$ (for the same $n$-$z$ value) [see, for example Baer, Proc. LAMPF Workshop on DCX] while at 50 MeV the cross sections for the above nuclei are about the same.

Recently we studied the energy dependence of the $^{18}O(\pi^+,\pi^-)^{18}Ne$ (DIAS) cross sections. We measured the differential cross sections of this reaction at 21, 32 and 64 MeV incident pions at four angles between 20° and 90°. On-line analysis indicates that the forward angle cross section is about twice as large at 32 MeV as at 50 MeV, and it continues to rise even at 21 MeV. The angular distribution, however, tends to be more flat at 32 and 21 MeV than that at 50 MeV.

In Figs. 44 and 45 are energy distributions of $A_y$ from our measurements at 120°.

In the optimal impulse approximation [Gurvitz Phys. Rev. Lett. 47, 560 (1981)] the analysing power is strongly correlated with that evaluated for nucleon-nucleon scattering at the appropriate c.m. momentum and angle. For the $^9Be(\bar{p},p')X$ reaction at 300 MeV $A_y$ is predicted to be $\sim -0.4$ at $\theta_{1ab} = 120^\circ$ and $\sim -0.12$ at $\theta_{1ab} = 160^\circ$, practically constant for protons in the range $E_p = 50$-200 MeV. Since these predictions are characteristic of the nucleon-nucleon interaction and are independent of the target nuclear structure, they are expected to be the same for the $C(p,p')X$ reactions as well. The values of $A_y$ obtained in this work are on average small and depart significantly from the ones quoted above for a single scattering mechanism.

Nonetheless, the outgoing protons do have an analysing power of the predicted sign over the entire range of the detected proton. This is a new feature not observed in the 800 MeV data [Frankel et al., Phys. Rev. Lett. 41, 148 (1978)] where $A_y$ values range from small and negative values at low detected proton energies to large but positive values at high energies. Note that apart from kinematical shift the energy distributions of $A_y$ are identical for Be and C.
A natural interpretation of the energy dependence observed in Figs. 44 and 45 would be in terms of rescattering. As indicated in Gurvitz all rescattering in the pA scattering amplitudes are in terms of direct scattering amplitudes which are large only in the forward directions; the pA backward scattering is essentially the backward scattering on one nucleon with subsequent forward rescattering. Thus one expects that rescatterings would mainly affect the magnitude of the cross sections, an effect which is substantial in the high energy data but not at 300 MeV.

The similarity in the energy distributions of Figs. 44 and 45 suggests that $A_y$ values in pA scattering at backward angles should be correlated with those corresponding to pN scattering. Similar distributions of $A_y$ for Be and C which are smoothly decreasing, with energy, can be obtained for a 'quasi-free' knockout of $P_{3/2}$ nucleons. In that case the struck nucleon is effectively polarized and the analysing power becomes energy dependent through the spin-spin correlation function, a phenomenon well known from $(p,2p)$ measurements. With a crude estimate of the effective polarization for a $P_{3/2}$ nucleon the $A_y$ values appear to be in a better agreement with experiment.

Measurements of nonvanishing $A_y$ values are not sufficient to rule out contributions from other reaction mechanisms such as the $(A-1)$ nucleon exchange model or the scattering from nucleon clusters. However, the present measurements are performed in a kinematical region where electron and proton scattering cross sections have been shown to be consistent with the $y$ scaling and the hypotheses of a single scattering mechanism. Contributions from other mechanisms are not required but the single scattering mechanism model [Gurvitz, op. cit.] must be modified to allow for energy-dependent $A_y$ values that are smaller than anticipated for free NN scattering.

Experiment 365
A search for the tetraneutron
(T. Gorringe, UBC)

We aim to measure the $\pi^+$ energy spectrum in the pion double charge exchange (DCX) reaction $^4$He($\pi^-,\pi^+)$X. Production of tetraneutrons (4n) would appear as a peak in this energy spectrum. Depending on the tetraneutron binding energy it would lie either on or just above the $\pi^+$ continuum from inclusive double charge exchange.

Whilst the DCX reaction on $^4$He has been employed before in the search for tetraneutrons we will for the first time use low energy incident pions $T_{\pi^-} = 80$ MeV. This has several advantages. It reduces the momentum transfer to the protons directly involved in the DCX reaction, enhancing the probability of the resultant neutrons remaining together with the spectator neutrons. Secondly the continuum background from inclusive DCX on $^4$He, which has determined the sensitivity of previous experiments, is likely to be reduced by a factor of 1000 due to the reduced phase space, allowing a much more sensitive search.
The experiment will be carried out using the TRIUMF time projection chamber (TPC) and a high pressure $^4$He gas target. The large acceptance of the TPC (about 10%) is a major benefit in the search for low cross-section reactions. Its resolution is sufficiently good that the measured $\pi^+$ energy resolution is primarily determined by the $\pi^-$ beam momentum bite.

Important requirements for a successful experiment are a narrow parallel $\pi^-$ beam ($\sigma_x, \sigma_y < 2$ cm), with small momentum bite ($\Delta p/p$(FWHM) < 4%) and sufficient intensity $\sim 10^6 \pi^-$/s. A large beam spot would result in a major contribution to the $\pi^+$ continuum from DCX on the side walls of the aluminum target flask. A large momentum bite would yield a correspondingly poor $\pi^+$ energy resolution. Both of these factors would reduce the experimental sensitivity. Since the TRIUMF M9 channel had not previously been operated for 80 MeV (170 MeV/c) pions, in September/October we carried out tests to measure and optimize intensity, beam profile and momentum bite. The results showed a beam of the required characteristics was possible.

In November further tests were carried out to determine the feasibility of using the TPC for such an experiment. The cross section for pion DCX is many orders of magnitude below that for elastic and inelastic scattering. It is therefore important to have a trigger sufficiently restrictive to discriminate in favour of DCX events. The six-fold symmetry of the TPC allows a trigger based on the direction of curvature of tracks - enabling the selection of either positive or negatively charged particles. Figure 46 shows a DCX event selected by a positive charge trigger. Using this, the trigger rate from $\pi^-$ scatters was reduced to only twice that of triggers from positive particles. Those $\pi^-$ events observed originated from close to the TPC inner walls enabling them to fake a positive direction of curvature.

Another important requirement is the ability to discriminate $\pi^+$s from protons and positrons. This may be done by energy loss in the trigger counters and TPC, and also range in the layers of trigger counters outside the projection chamber. Analysis of our ability to make this discrimination is in progress.

Thirdly we measured elastic scattering data at several energies with an identical trigger but $\pi^+$ beam to determine the acceptance and energy resolution of the apparatus.

Finally inclusive DCX data on $^4$He, aluminum and carbon, which all contribute possible sources of background, were measured.

After completing the analysis of these data we aim to make a search for the tetraneutron early in 1986.
Data-taking in this experiment is now complete – both the muonium and diamagnetic signals have been fully characterized over the temperature range 8–270 K for single crystals of H$_2$O and D$_2$O. In contrast, free H atoms have not been successfully detected in pure ice in the temperature range 50–160 K, nor is there any report of a study of H in monocrystals of ice. Our work in previous years led to the discovery of a small axial anisotropy in the muonium hyperfine interaction [Percival et al., Chem. Phys. Lett. 93, 366 (1982)], and revealed a missing fraction of muonium polarization in ice at temperatures above 200 K [Percival et al., Chem. Phys. 95, 321 (1985)]. In the past year the emphasis has been on the diffusion of Mu in ice, as evidenced by its effect on the spin relaxation of muonium and the dependence on temperature, magnetic field, and crystal orientation. Apparent discrepancies in some of the earlier data have been resolved by confirmation of the dependence of the relaxation rate on crystal orientation. The most reliable and complete set of data was taken at 37 G applied field (Fig. 47). At this field the frequency splitting induced by the Zeeman interaction is exactly offset by that of the anisotropic hyperfine interaction if the c-axis of the crystal is parallel to the field. The relaxation mechanism is attributed to modulation of the muonium–proton (deuteron) dipolar interaction by translational diffusion of muonium along the ice lattice channels parallel to the c-axis. This magnetic interaction accounts for the difference between the H$_2$O and the D$_2$O results and is temperature dependent. Thus, the variation with temperature evident in Fig. 47 reflects the change in diffusion rate. The motional correlation function takes the form $\tau + \tau / (1 + \omega^2 \tau^2)$ where $\tau$ is the diffusional correlation time and $\omega$ is the precession frequency. The step apparent in the H$_2$O results about 75 K is interpreted as the point where $\omega \tau = 1$, thus providing an invaluable absolute determination of $\tau$ at this temperature.

Full experimental results and relevant theoretical calculations are contained in the M.Sc. thesis of Siu-keung Leung [Department of Chemistry, Simon Fraser University, August 1985].

---

Fig. 47. Transverse spin relaxation rate of muonium in single crystals of H$_2$O (•) and D$_2$O (○) as a function of temperature. The crystals were oriented with their c-axes parallel to the applied field of 37 G.
In Expt. 191 the adsorption, diffusion and trapping of muonium (Mu) atoms on the surfaces of fine silica powders have been studied extensively via the manifestation of such behaviour in the spin relaxation of polarized triplet Mu. Zero-field muonium spin relaxation (ZF-MSR) measurements showed rapid relaxation of Mu at low temperatures in the absence of strong dipolar or nuclear hyperfine relaxation mechanisms, leading to the hypothesis that the relaxation could be due to random distortions of the Mu electronic wave function. Such distortions are known to lead to anisotropies in the muon-electron hyperfine coupling, as vividly illustrated by previous observations in quartz crystals. Such anisotropies are to be expected for Mu atoms adsorbed on the surfaces of silica grains. To confirm this model ZF-MSR measurements were made in bulk fused silica, where all other relaxation mechanisms are absent and where the magnitudes and distributions of the random hyperfine anisotropies (RHFA) could be approximated from the crystalline quartz results. The theoretical ZF-MSR relaxation functions predicted for Lorentzian distributions of the magnitudes of the distortions are shown in Fig. 48.

Depending upon whether the distortions are axisymmetric or not, one obtains relaxation functions \( G(t) \) that approach asymptotes of 1/6 or 0. The \( G(t) \) curve with the fastest initial relaxation is for equal contributions from both types of distortion symmetry; this type of \( G(t) \) function was used to fit the ZF-MSR data for Mu in bulk fused silica at 7 K, shown in Fig. 49.

At higher temperatures the Mu atoms begin to hop between sites with different anisotropies and a complicated motional narrowing process sets in. These results support the proposed mechanism for Mu relaxation on powder surfaces and also introduce a new class of relaxation mechanisms (RHFA) to this and other branches of paramagnetic resonance.

Muonium formation at surfaces: Effect of helium coverage

Measurements of the amplitude or asymmetry of triplet Mu precession in weak transverse fields (TF-MSR) were made in fine silica powders at low temperature (6 K) as a function of the coverage of the surfaces by He films, as shown in Fig. 50. The horizontal axis is essentially the density of He atoms per unit area on the surface; one monolayer is approximately complete when the vapour pressure over the surface (circles) begins to rise rapidly. These data show that the Mu asymmetry decreases with increasing surface coverage, suggesting that the charge exchange cross section for Mu is significant at the helium-silica interface. It may be that the He atoms play a passive role, simply covering the surface and thereby impairing Mu formation, which would thus be a surface-related process. Alternatively, He atoms may actually dissociate newly formed Mu atoms as they emerge from the surface. We are unable as yet to distinguish between these two scenarios.
In another experiment we measured capture rates in plastic scintillators and found them to be very small, probably due to the aromatic monomers that are used in the fabrication. We found:

- NE110 (polyvinyltoluene) $(0.41\pm0.02)\%$ TINA
- SCSN38 (polystyrene) $(0.33\pm0.03)\%$ TINA
- C$_6$H$_5$ (benzene) $(0.39\pm0.03)\%$ Krumshtein
- C$_6$H$_{12}$ (cyclohexane) $(1.43\pm0.055)\%$ Krumshtein
- C$_6$H$_{14}$ (hexane) $(1.66\pm0.054)\%$ Krumshtein

It is interesting to note that in a recent experiment at KEK they stopped K$^-$ in a SCSN38 scintillator and found that $\sim1.3\%$ were captured on the hydrogen. There is other evidence to substantiate that for both K$^-$ and p the probability for capture at rest by the hydrogen is substantially greater than for $\pi^-$.

Experiment 241
Temperature dependence of reaction rate constants for muonium reactions in liquid phases
(Y.C. Jean, Missouri K.C.)

The muonium (Mu) kinetics in liquid environments have been studied in various solvents for addition reactions of ethene and benzene molecules. Important information of kinetics theory of light atoms in liquids has been obtained by using Mu as a light isotope of H atom.

The Mu and diamagnetic muons have been observed in pure methane, propane and isopentane in a wide range of temperatures. The fractions of Mu and diamagnetic muon yields in these liquids are found to be $0.2$ and $0.6$, respectively. The important results by using these liquids as solvents for Mu kinetics are: quantum tunnelling effect, non-Stoke’s diffusion and solvent effect.

Quantum tunnelling. Mu addition reaction rate constants to benzene have been measured as a function of temperature between 136 K and 295 K in isopentane. The Arrhenius plot shows a concave curve at low temperature due to a significant quantum tunnelling of Mu in liquid hydrocarbon environments. The results are shown in Fig. 51. The activation energies were found to be $3.7$ kJ/mole at high temperatures and to be about $0.4$ kJ/mole at low temperatures. The width of reaction barrier for this reaction is deduced.

Non-Stoke’s diffusion. Accurate Mu addition rate constants to ethene molecules have been determined in liquids of different polarities. The results are shown in Table 52. The deuterium addition reaction rate constants to ethene have been measured in liquid hydrocarbons and are given in Table 53. The results are shown in Fig. 52. The activation energies were found to be $9.5$ kJ/mole at low temperatures and to be about $3.7$ kJ/mole at high temperatures. The width of reaction barrier for this reaction is deduced.
Experiment 245
Muon spin rotation studies of supported metal catalysts (R.F. Marzke, Arizona State)

Five shifts of beam time were allotted to the subject of this experiment, namely transition-metal catalyst supported on the finely divided SiO₂ powder studied by Harshman et al. in Expt. 191. (Another five shifts, allocated to Expt. 245, were actually used instead for a related investigation that is part of Expt. 288, Keitel et al. This work involved gases physisorbed to the surface of the silica support alone, no transition metal being present.) During the five shifts of Expt. 245 proper transverse-field muonium spin rotation (MSR) studies were made of Pt/SiO₂ catalysts over a broad range of temperatures, from 5 to 300 K. These were performed on the new M15 channel, and the new Lakeshore temperature controller was used as well as the then-new MAX VAX 11/750. The latter's speed permitted data analysis almost on line for the first time in this experiment, so that all four MSR histograms from the temperature station preceding the one at which data were being taken could easily be fitted to theoretical expressions using MINUIT. The immediate availability of current values for the muonium relaxation rate proved invaluable to the conduct of the experiment over the broad temperature range required.

The goal of the study was in fact to measure this rate as a function of temperature, as muonium interacts with the surfaces of the platinum particles constituting the active elements of the catalysts. Two samples were used, one with a nominal platinum loading (1%) by weight, the other much more lightly loaded (0.1%). Results are shown in Fig. 52.

Solvent effects. Solvents have been found to play a significant role in Mu kinetics. Mu reaction rate constants for diffusion-controlled reactions have been obtained in various solvents, i.e. water, methanol, hydrocarbons and liquid N₂. We found that the rate constants not only depend on the physical properties of the solvent, temperature, but also on the Mu chemical reactivities with molecules. These rate constants are found significantly higher than gas rate constants and H reactions. More studies of solvent effects in Mu reactions are in progress.

measured as a function of temperature in methane and isopentane liquids. The Arrhenius plots give activation energies ~1.5 and 4 kJ/mole in liquid methane and isopentane, respectively. These energies are lower than the activation energies due to viscous flow of solvents. These results show that Mu atoms do not follow the classical Stoke-Einstein equations nor by means of Smoluchowski diffusion in liquid hydrocarbons. These new findings are very different from our previous kinetics results in aqueous solutions.

Solvent effects. Solvents have been found to play a significant role in Mu kinetics. Mu reaction rate constants for diffusion-controlled reactions have been obtained in various solvents, i.e. water, methanol, hydrocarbons and liquid N₂. We found that the rate constants not only depend on the physical properties of the solvent, temperature, but also on the Mu chemical reactivities with molecules. These rate constants are found significantly higher than gas rate constants and H reactions. More studies of solvent effects in Mu reactions are in progress.

Fig. 51. Arrhenius plot of Mu addition reaction rate constants to benzene in liquid isopentane. The concave curve shows the clearest evidence of quantum tunnelling for Mu reactions in liquids.

Fig. 52. Muonium relaxation rate as a function of temperature in 1% platinum supported on silica.
for the 1% sample, which had exhibited a strong relaxation above 30 K in preliminary studies conducted last year. This effect was attributed to the presence of Pt, both in our annual report contribution for 1984 and in an article written this year for Chemical Physics Letters. (For comparison, last year's M20 data are also included in the figure.) The following observations pertain to results for both samples: 1) despite systematically higher values of relaxation rates for the M15 data their dependences on temperature follow quite closely those of the M20 data, 2) the dependences show clear evidence that a temperature-dependent interaction with the surface occurs, most likely a chemical reaction, and 3) a new effect is seen in the gradual decrease of the relaxation rate at temperatures above 70 K. More studies of these catalysts are planned, involving treatments of the Pt surfaces with hydrogen, oxygen and other gases, in order to elucidate the nature of their interactions with muonium.

Experiment 260
The reaction of muonium with hydrogen peroxide in water (PW. Percival, Simon Fraser)

The reaction of Mu with hydrogen peroxide was originally studied to clarify the mechanism of the corresponding H atom reaction. Two pathways are known for the gas phase reaction:

\[ H + \text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \cdot\text{OH} \]  
(1)

and \( H + \text{H}_2\text{O}_2 \rightarrow \text{H} + \cdot\text{OOH} \),  
(2)

but there is ambiguity as to which one dominates in aqueous solution. Measurements of the muonium reaction rate led to a totally unexpected result, for which there is no equivalent data for the H atom: the effective rate constant varies with pH. First attempts to characterize the pH and temperature dependence were complicated by the poor stability of hydrogen peroxide at high pH. This difficulty has now been overcome by purification of the sodium hydroxide used to adjust pH. (The trace amounts of transition metals, which catalyze peroxide decomposition, can be removed by coprecipitation with magnesium hydroxide.) Analysis of the data was carried out under the assumption of competitive parallel reactions of Mu with \text{H}_2\text{O}_2 and \text{HO}_2\text{−} (and the deuterated equivalents in \text{D}_2\text{O}):

<table>
<thead>
<tr>
<th>Table VI. Rate constants for reactions of muonium</th>
</tr>
</thead>
<tbody>
<tr>
<td>reaction</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>\text{H}_2\text{O}_2</td>
</tr>
<tr>
<td>\text{HO}_2\text{−}</td>
</tr>
<tr>
<td>\text{OH}_−</td>
</tr>
</tbody>
</table>

\( a) \text{ at } -22 \, ^\circ\text{C}, \ b) \text{ at } 25 \, ^\circ\text{C}. \)

The temperature dependence of each rate constant was also investigated, but the analysis is not yet complete. Some of the data is displayed in Fig. 53.

In addition to the measurements of muonium decay rates, a study was made of residual polarization in the diamagnetic products of the \text{H}_2\text{O}_2 and \text{HO}_2\text{−} reactions at both natural pH and pH12. The characteristic field dependence of the polarization \( P_d \) allows determination of the muonium reaction rate, the polarized muonium fraction, and the initial diamagnetic fraction. With the exception of the lowest concentration at each pH, the values extracted from the fits (Fig. 54) are completely consistent with a simple model in which diamagnetic products are formed from muonium at the rate predicted from direct decay measurements in dilute solutions. The deviations at low concentration are believed to be due to a hitherto unknown field dependence in the pure solvent, and will be further explored in a new proposal (Expt. 361 Muonium in water).

A preliminary report on this experiment will appear in the Proceedings of the XVIIth International Symposium on Free Radicals, to be published by the National Bureau of Standards, U.S.A.

Experiment 261
Muon spin rotation of paramagnetic solutions (PW. Percival, Simon Fraser)

Despite the recent success of this experiment in utilizing relaxation rates in the presence of paramagnetic ions to characterize two separate diamagnetic signals in organic liquids (Newman et al., Chem. Phys. Lett. 113, 347, 1985), there remain some unresolved questions concerning the relaxation rates themselves. Therefore, aqueous solutions of manganous nitrate have again been studied,
Fig. 53. The temperature dependence of muonium reaction rates in aqueous solutions of (a) \( \text{H}_2\text{O}_2 \) at pH 3, (b) \( \text{H}_2\text{O}_2 \) at pH 12.4, (c) \( \text{D}_2\text{O}_2 \) at pH 2.6, (d) \( \text{D}_2\text{O}_2 \) at pH 12.5.

Fig. 54. Muon polarization in aqueous solutions of hydrogen peroxide at (a) natural pH, (b) pH 12.
but this time at a concentration just above 1 M. This is close to the low concentration limit for μSR, but orders of magnitude above that which can be studied by NMR. Longitudinal spin relaxation rates were measured as a function of magnetic field at three temperatures (see Fig. 55). Such variable field measurements are very difficult in NMR, but of great value since they allow ready extraction of the motional correlation times of significance to the relaxation mechanisms. The lower field 'step' in the relaxation rates occurs for the condition \( \omega \tau_\text{e} = 1 \), where \( \omega \) is the electron Larmor frequency (proportional to field strength) and \( \tau_\text{e} \) is the spin-lattice relaxation time of the Mn^{2+} ion, the correlation time for modulation of the electron-muon scalar interaction. The second step occurs at \( \omega \tau_\text{C} = 1 \), where \( \tau_\text{C} \) is the rotational correlation time of the \( \text{Mn(H}_2\text{O)}_\text{6}^{2+} \) complex, the characteristic time for modulation of the dipolar interaction. Fits of the theoretical expressions to the experimental results give values of the scalar hyperfine coupling constant and muon-Mn distance in the complex in excellent agreement with literature values obtained by NMR methods for solutions a thousandfold more dilute. [Newman et al., 'Variable-field muon spin-lattice relaxation studies of aqueous solutions of manganese(II) nitrate: Separation of scalar and dipolar relaxation', Chem. Phys. Lett., in press, TRI-PP-85-83.]

These μSR studies have now established that 'ring' as well as 'side-chain' free-radicals containing muonium are formed in allyl benzene, \( \text{C}_6\text{H}_5\text{CH.CH.CH}_3 \). This finding contrasts nicely with the results in the fully conjugated molecule styrene (\( \text{C}_8\text{H}_8\text{CH.CH}_2 \)) where only one of six possible radicals appeared in μSR [Can. J. Chem. 59, 3261 (1981)]. It means that intramolecular relaxation/rearrangement can dominate over the position-of-primary-attack in determining which Mu-radical is actually observed on the μSR time-scale - especially when delocalization of the free electron spin is possible.

The chemical reaction of muonium with ethylene was studied in samples of amorphous SiO₂ powder (mean grain diameter 7 nm). Experiment 191 characterized these samples and the diffusion and trapping behaviour of muonium adsorbed on the surfaces of the powder grains below 100 K. The muonium spin relaxation rates were measured as a function of temperature for several concentrations of ethylene deposited on the SiO₂ surface (<3% of a monolayer). A big increase of the relaxation rates with \( \text{C}_2\text{H}_4 \) concentration was found over the whole temperature range (see Fig. 56).
At room temperature, where both the muonium and the ethylene are desorbed, the measured bimolecular rate constant of $7.1(4) \times 10^{-12} \text{ s cm}^{-3} \text{ mol}^{-1}$ agrees with the results obtained in the gas phase by Garner et al. This shows that the SiO$_2$ powder is equivalent as a moderator to the nitrogen used in the gas phase studies. At low temperatures (<70 K) the change of the reaction rate with temperature qualitatively confirms the diffusion and trapping model developed for the interpretation of the Expt. 191 data. A quantitative interpretation will have to wait for the results of longitudinal and zero field measurements to identify nonchemical contributions to the muonium relaxation rates.

An attempt to resolve the hyperfine splitting of the muonium substituted ethylene radical on the surface was not successful. With one monolayer of C$_2$H$_4$ adsorbed at 150 K the reaction rate is still slow enough to average out any radical frequencies.

**Experiment 290**

*Positive muon probing soliton in polyacetylene*  
(K. Nagamine, Tokyo)

During this period of beam time we have conducted the following two successful measurements concerning positive muon spin relaxation and rotation in trans- and cis-polyacetylene.

**Diffusion properties of the muon-produced soliton in trans-polyacetylene**

We have measured the longitudinal spin relaxation functions of positive muons injected into trans-(CH)$_x$ at various temperatures and external fields. They showed nonsingle-exponential functions (see Fig. 57) and were fitted by a model which takes into account both the on-chain diffusion and the disappearance of the muon-produced soliton by adopting a relaxation function of the form

$$\exp\left[-R_0/D_3(1-\exp(-D_3 t))\right].$$

As shown in Fig. 58 it was found that the on-chain diffusion rate $D_3$ is almost constant from 29 K to 290 K while the disappearance rate $D_3$ slightly increases with temperature.

**Electronic structure of muonium radical in cis-(CD)$_x$**

The state of the muon in cis-polyacetylene was probed by the muon spin rotation method.
under high transverse magnetic field. The experiment was carried out at the TRIUMF M20 channel. There the transversally spin polarized surface muon was stopped in a polyacetylene target of a stack of thin films (in total $2 \times 2$ cm$^2$), which was placed in the centre of the superconducting Helmholtz coil. Muon spin rotation was measured for stretched cis-(CD)$_x$, nonstretched cis-(CD)$_x$, nonstretched cis-(CH)$_x$, and also nonstretched trans-(CD)$_x$ for comparison. The applied magnetic field was 16.6 kG. The typical Fourier power spectrum for the time range from 10 to 250 ns is shown in Fig. 59. The two distinct peaks from the $v_{12}$ and $v_{34}$ rotation in high transverse field are clearly visible, also the bare muon frequency of $v_\mu$ at 225 MHz. For these components we determined the frequency, relaxation rate and initial amplitude. From these frequencies the hyperfine coupling constants were obtained whose results are summarized in Table VII.

The observed hyperfine interaction of 91 MHz is about one-third of that in alkaline radicals and one-half of the conjugated radicals.

The smallness of $A_0$ in cis-polyacetylene may be due to the longer length of the conjugation. The unpaired electron can be more easily delocalized on a few carbons near the muon. To explain this result quantitatively we use the well-known localization parameter $p$ as the existing probability of the unpaired electron on the $\alpha$-carbon of the radical. Since $A_0$ for the muonic radical with the fully localized unpaired electron on one carbon is considered to be around 450 MHz we can estimate $p$ to be around 0.22 in cis-polyacetylene.

### Table VII

<table>
<thead>
<tr>
<th>Temperature</th>
<th>$a$/MHz</th>
<th>$\chi^+$/s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CD)$_x$ nonstretched</td>
<td>RT</td>
<td>91.0(0.2) 29(1)</td>
</tr>
<tr>
<td>stretched</td>
<td>RT</td>
<td>90.6(0.4) 32(2)</td>
</tr>
<tr>
<td>nonstretched</td>
<td>20 K</td>
<td>106.4(0.8) 30(2)</td>
</tr>
<tr>
<td>(CH)$_x$ nonstretched</td>
<td>RT</td>
<td>90.6(2.2) 37(5)</td>
</tr>
</tbody>
</table>

Data acquisition for Expt. 296 on M15 is complete; the preliminary results based on online data analysis are presented. Figures 60–62 are Arrhenius plots of the preliminary bimolecular reaction rate constants; the ethylene measurements performed under Expt. 147 are included in Fig. 60. Figures 60 and 61 clearly show that nonlinear Arrhenius behaviour is a common feature of muonium addition reactions to unsaturated hydrocarbons. The curvature is interpreted in terms of quantum tunnelling. The dominance of quantum tunnelling suggests that the barrier to muonium addition is located in the reactant valley, i.e. the barrier is early. This is equivalent to stating that the radical complex is loose, consistent with the results for the analogue H reactions [Lee et al., J. Chem. Phys. 68, 1817 (1978)].

Figure 60 shows that there is no significant difference between the Mu reaction rate constants with ethylene and fully deuterated ethylene. This lack of a secondary isotope effect is consistent with the experimental H atom results of Sugawara et al. [Chem. Phys. Lett. 78, 259 (1981)], and inconsistent with the theoretical results of Nagase et al. [J. Am. Chem. Soc. 101, 61 (1979)]. These discrepancies indicate an inaccuracy in the ab initio potential for this reaction.

It is also interesting to note that the reaction rate constants for the isomers allene (aka propadiene CH$_2$=C=CH$_2$) and propyne (CH$_3$=C=CH) are virtually identical. In fact, it was necessary to show these data on separate plots, Figs. 60 and 61, in order to show them clearly. Since both molecules have cylindrical symmetry with one $\pi_x$ and one $\pi_y$ bond each, perhaps considerable specificity of reactive encounters to particular collision
Fig. 60. Preliminary rate constants for muonium addition to allene and fully deuterated ethylene compared with the corresponding rate constants with ordinary ethylene measured in Expt. 147. Note the absence of any strong secondary isotope effect between the two forms of ethylene.

geometries accounts for their nearly identical kinetic behaviour.

The results shown in Fig. 62 are rather curious. Mu addition to CO is temperature independent over 330°; in fact, it does not even reflect the $T^{1/2}$ dependence of velocity, resulting in a negative activation energy of about 0.5 kcal/mole. This indicates great specificity in the reactive collisions possibly due to shape resonances at very low collision energies or a very limited range reactive rovibrational states of the CO molecule. $SO_2$ shows similar behaviour below 350 K, probably for similar reasons. Although not conclusive the analogous H atom reaction rate constant measurements indicate a small or possibly negative activation energy for these reactions. The Mu + $SO_2$ reaction rate constant data above 350 K are not understood. Unfortunately, $SO_2$ is both highly reactive and unstable; it is possible that the high temperature data are due to products of $SO_2$ reaction on the aluminum target vessel walls, perhaps with the liberation of O. An off-line study of this system should reveal if this is the case. If the data are in fact due to Mu addition to $SO_2$, then the high

Fig. 61. Preliminary rate constants for muonium addition to acetylene, propyne and propene. The propyne data are almost coincident with that in Fig. 60 for the isomer allene (note the different scales in Figs. 60 and 61).

Fig. 62. Preliminary rate constants for muonium addition to acetone vapour, $SO_2$ and CO. Note that these rates are more than a factor of 10 slower than those in Figs. 60 and 61. Possible explanations for the temperature independent CO and two-component $SO_2$ and acetone data are given in the text.
temperature data are very interesting indeed. The most probable explanation is that Mu attack on the S atom has completely different Arrhenius behaviour to Mu attack on the O atoms, and thus the observed behaviour is simply a sum of two exponentials. Presumably, the temperature-independent unactivated low temperature data is dominated by Mu attack on 0 while the activated high temperature data is dominated by Mu attack on S. A similar explanation applies to the acetone data of Fig. 62, again with the low temperature data corresponding to Mu attack on O, and the high temperature activated data being due to Mu attack on C. In the case of acetone it is believed that the data are correct, without any interferences due to acetone decomposition, etc. at high temperature.

In general, the bimolecular reaction rate constants for additional reactions such as those of this study are expected to show a dependence on the moderator pressure below about 200 torr. Most of the measurements reported here were done in N₂ at 500–1000 torr. The rate constants were checked in all cases over a pressure range of a factor of about 4.5, and no pressure dependence was detected. In fact, it is expected that the μSR technique will show no pressure dependence at any moderator pressure since it is analogous to H atom maser measurements [e.g. Gordon et al., Chem. Phys. 35, 79 (1978)]. Verification of this expectation of pressure independence over all pressure ranges is technically difficult and beam time intensive, and was beyond the scope of Expt. 296. However, in performing the low pressure measurements that were done it became apparent that with the high quality beam available on M15 it would be possible to push the measurements to considerably lower pressures than 100 torr of N₂. This may be attempted under a new experimental proposal.

Experiment 307
The effects of large oscillating fields in low frequency double electron muon resonance
(T.L. Estle, Rice)

Experiment 307 received its initial beam time from May 8–13 on M15 channel. Although many of the planned measurements required use of a spin rotator, which was not available, we obtained more and better data with the single initial muon polarization than we anticipated. Consequently we met most of the original experimental goals and exceeded many.

We proposed to test the feasibility of a study of the phenomena associated with spin precession in a magnetic resonance experiment using a large oscillating field. The results not only demonstrate that such a study is feasible, but they constitute such an extensive study themselves and agreed with theory so well that no more studies are planned.

Experiment 307 obtained transverse-field μSR (muon spin rotation) spectra of the triplet in muonium (in fused quartz) in a low static magnetic field and a comparable oscillating magnetic field (this procedure is sometimes referred to as DEMUR for double electron muon resonance). The oscillating field was applied parallel to the initial muon polarization and the muon beam and had a frequency (7 MHz) comparable to the muonium triplet Larmor frequency. Since μSR provides information about the frequencies and amplitudes of the precessional components of the muon spin, we were able to determine experimentally the nature of the triplet precession on and near magnetic resonance with an oscillating field.

Precessional components at the frequency of the oscillating field and its third harmonic were observed, each flanked by a pair of lines whose separation from the applied radio frequency is the Rabi frequency, the Larmor frequency of the triplet in the field which results when the oscillating field is made stationary by an infinite series of rotating coordinate transformations. The lower Rabi side band of the fifth harmonic of the radio frequency was also observed. The higher frequencies were realised for the larger values of the oscillating field (amplitudes up to about four times the static field were employed). For the larger values of the oscillating field, the frequency at resonance (resonance in this experiment corresponds to the Rabi frequency being a minimum when only the static field is varied) was not the Larmor frequency but a higher frequency. This shift is known as the Bloch-Siegert shift and becomes quite large for the larger values of the amplitude of the oscillating field.

In addition to the resonance discussed above, which corresponds to absorption or emission of one quantum from the radio-frequency field, we observed the three-quantum transition. Again the odd harmonics of the radio frequency are obtained, each flanked by a pair of Rabi side bands. The three-quantum transition also had a Bloch-Siegert shift of the resonance upward in frequency. However,
the shift was less than for the one quantum transition.

A detailed comparison of the observed frequencies and amplitudes with theory gives agreement to within experimental uncertainty. The only aspect of the experiment which was not ideal in its simplicity was the observation that the lines at the radio frequency and its harmonics became narrower while the Rabi side bands became broader as the oscillating field was increased. It appears that this can be adequately accounted for by inhomogeneity in which the region of space in which the muons stop.

Experiment 325
Ultra-low energy muon production
(D.R. Harshman, UBC)

In July the first observation of slow \( \mu^+ \) emission, as well as the first observation of Mu\(^-\) in vacuum, were reported [TRIUMF EEC meeting]. These discoveries were made using a lithium-fluoride (LiF) single crystal with the \(<100>\) axis normal to the surface. In addition, the \( \mu^+ \) time-of-flight (TOF) spectrum for LiF indicated a very sharp cut-off in the low energy muon distribution. Since LiF was the only target tried at that time, the actual origin of the low energy muons was left unclear. There were two possibilities suggested at that time:

1) actual surface emission (possibly corresponding with the band gap emission model described in the original proposal)
2) a manifestation of an enhanced acceptance of the electrostatic lens for low energy epithermals

If the \( \mu^+ \) emission results correspond to a solid-state phenomenon, the sharp cut-off at low energies may be explained by the finite chemical lifetime for muonium, which has been observed in other alkali-halides [Morozumi et al., submitted to Phys. Rev. Lett.]. These initial results were reported in a Paris workshop in early September [Harshman, Proc. European Workshop on the Spectroscopy of Sub-Atomic Species in Nonmetallic Solids, in press].

To discriminate between the two possible origins a Monte Carlo simulation was run which predicts a flat distribution in the number of transmitted low energy epithermals below ~200 eV, thereby lending support to the first possibility. In addition, later (November) experiments were performed again on LiF as well as on \( z \)-cut quartz (SiO\(_2\)) and copper (Cu). Since the band gap energy of SiO\(_2\) is ~9 eV and the chemical lifetime for muonium in quartz is infinite, the band gap emission model would predict SiO\(_2\) to exhibit a low emission probability, but a much more pronounced diffusion tail, as compared to LiF. For Cu no emission was expected.

The latest results for LiF, SiO\(_2\) and Cu are shown in Fig. 63. Notice that the TOF spectrum for LiF shows a distinctively sharp slow muon distribution on top of a broad epithermal background. The SiO\(_2\) data, on the other hand, show a comparatively broader distribution and a larger contribution from very slow events. As mentioned, these slow events may be attributed to the diffusing ensemble, making these data consistent with band gap emission. However, the effect of charging may also introduce some perturbations. Finally, the Cu data indicate only epithermals (i.e., no slow component), again in accordance with a band gap emission model. The observed slow \( \mu^+ \) rate, obtained by subtracting the Cu spectrum from the LiF data, is \((1.6\pm0.35)\times10^{-7}\) per incident \( \mu^+ \).

The simple 'one shot' band gap emission model discussed in the original proposal has recently come under some criticism because of the unlikely prospect of finding a hole at the bottom of the valence band. A 'recombination assisted diffusion' model (assuming relaxed holes) may represent a more accurate picture of the physics involved. An alternative suggestion is that the slow \( \mu^+ \) component is due to epithermal \( \mu^+ \) which fall below the band gap energy \( E_g \); above \( E_g \) energy loss occurs primarily through electron-hole pair production, whereas below \( E_g \) energy is lost at a comparatively lower rate through shower excitation. This process would also exhibit a strong correlation with the band gap energy but would not be strongly diffusion dependent.

The Mu\(^-\) flux was also measured for each of these three targets and the TOF spectra are shown in Fig. 64. The observed Mu\(^-\) ion rate for LiF was found to be \((1.6\pm0.21)\times10^{-7}\), equal to the corresponding slow \( \mu^+ \) rate. By comparison, the Mu\(^-\) flux for Cu was found to be roughly the same as that found for LiF, while the data taken with SiO\(_2\) indicate a factor of ~3 reduction.

From these results one can conclude that the slow \( \mu^+ \) emission observed in LiF (and perhaps also in SiO\(_2\)) is indeed a solid-state
phenomenon. The $\mu^+$ emission results obtained were also found to be consistent with a band gap correlation model. In addition, the Mu$^-$ data clearly indicate a dependence on the target medium, but do not shed any definitive light on the actual origin of the Mu$^-$ emission.

Although the $\mu^+$ emission rates obtained are relatively small, standard technology could increase this by a factor of about 10,000. This research will therefore proceed in two complementary directions; the first involves the detailed investigation of the physics of emission and the second is concerned with enhancing the emission yields by increasing the surface area of the moderator targets.

Experiment 340
Muon molecular ions and ion-molecule reactions
(D.G. Fleming, UBC)

In the past two years we have established that the diamagnetic signal from positive muons stopped in the noble gas moderators He, Ne and Ar is due to the formation of the $\mu^+$ molecular ions $[\text{HeMu}^+]^*$, $[\text{NeMu}^+]^*$ and
[ArMu+]*, in ro-vibrational excited states, in analogy with their well known protonic cousins. The μSR signal due to these species is very long lived, \( T_2 \sim 50 \mu s \), but upon the addition of some reactive agent 'X' capable of undergoing thermal charge exchange, a dramatic relaxation of the μSR signal is seen, as shown in Fig. 65, for \( X = \text{CH}_3\text{NO}_2 \) in He.

It is noted that there are two relaxations in Fig. 65, a 'fast' one (\( \lambda_f \)) and a 'slow' one (\( \lambda_s \)), which can be phenomenologically described by the μSR signal.

\[
S(t) = (A_f e^{-\lambda_f t} + A_s e^{-\lambda_s t})(\cos \omega_D t + \phi_D) \tag{1}
\]

where \( A_f \) and \( A_s \) are the initial amplitudes of the fast and slow components, respectively, and \( \omega_D \) and \( \phi_D \) are the precession frequency and initial phase of these components. As outlined in the 1984 Annual Report [see also Fleming et al., Chem. Phys. 82, 75 (1983)] the data can be most easily described in terms of the following simple model (exemplified for the [NeMu+]* ion),

\[
\begin{align*}
[\text{NeMu}^+]* + X & \rightarrow \mu + X^+ + Ne \\
& \rightarrow \mu X^+ + Ne \\
& \rightarrow \mu + X^+ + Ne
\end{align*}
\]

where \( k_c \) and \( k_t \) are bimolecular rate constants for thermal charge exchange and muon transfer, respectively, while \( k_q \) is a 'quenching' rate constant with moderator \( M(\text{He},\text{Ne},\text{Ar}) \). Since neither of the reaction channels labelled \( k_q \) or \( k_t \) for most \( X \) can give rise to loss of \( \mu^+ \) polarization, the fast relaxation apparent in Fig. 65 must be due to \( k_c \) alone, which can be described by

\[
\frac{d[\text{Ne}^+]}{dt} = k_c[\text{NeMu}^+]*[X] \tag{2}
\]

There are 3 main predictions of this simple model which can be tested by experiment: (1) a plot of \( \lambda_f \) vs. \( [X] \) should yield a straight line with intercept \( k_q M \) and slope \( (k_c+ k_f) \); (2) the amplitude \( A_f = \lambda_c / \lambda_T \), where \( \lambda_c = k_c[X] \), \( \lambda_q = k_q M \), \( \lambda_t = k_t[X] \) and \( \lambda_T = \lambda_c + \lambda_q + \lambda_t \) should increase with increasing \( [X] \); and (3) the amplitude \( A_s = (\lambda_q + \lambda_T) / \lambda_T \) should decrease with increasing \( [X] \). Much of the data are in fact qualitatively consistent with these expectations, as indicated by Fig. 66 which presents a plot of the relaxation rate \( \lambda_f \) vs. \( [\text{CH}_3\text{NO}_2] \) recently obtained in 3 atm of He moderator.

However, while it has some encouraging features to recommend it, the simple model described above has a number of serious deficiencies which have been revealed by our recent and now more complete set of data: (1) the 'intercept' \( k_q M \) should be independent of \( X \) but this is not the case; indeed, there may be no intercept at all, the data instead showing pronounced curvature in some cases as \([X] + 0\) (an example can be seen in the 1984 Annual Report for the reaction of [NeMu+]* with \( \text{Xe} \)); and (2) the relaxation rate \( \lambda_f \) should increase with \( M \) but it now appears that it in fact decreases with increasing \( M \).

Despite our present lack of knowledge of a detailed model to fit the data, the simple model...
model does provide a reasonable interpretation of the results with which the measured relaxation rate $\lambda_f$ can be compared with theory. In particular, from the slope of the plots of $\lambda_f$ vs. $[X]$ (e.g. Fig. 66) the experimental rate constant $k_{\text{exp}} = (k_c + k_t)$ can be compared with either the simple Langevin rate constant $(k_L)$ for molecules with zero dipole moment (e.g. Xe) or with the average dipole orientation (ADO) rate constant $(k_{\text{ADO}})$. This comparison is shown in Table VIII for a variety of reagents X.

Table VIII. Muon molecular ion reaction rates$^a$ for [HeMu$^+$]* and [NeMu$^+$]* with reagent 'X', room temperature

<table>
<thead>
<tr>
<th>Reagent</th>
<th>$k_{\text{exp}}$</th>
<th>$k_{\text{theory}}$</th>
<th>$k_{\text{exp}}$</th>
<th>$k_{\text{theory}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_3$</td>
<td>40±5</td>
<td>40</td>
<td>26±3</td>
<td>24</td>
</tr>
<tr>
<td>CH$_3$NO$_2$</td>
<td>60±6</td>
<td>80</td>
<td>35±5</td>
<td>40</td>
</tr>
<tr>
<td>Si(CH$_3$)$_4$</td>
<td>28±4</td>
<td>41</td>
<td>20±3</td>
<td>20</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>&lt;0.03</td>
<td>--</td>
<td>&lt;0.03</td>
<td>14</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>15±2</td>
<td>17</td>
<td>11±2</td>
<td>9.2</td>
</tr>
<tr>
<td>C$_2$H$_2$</td>
<td>&lt;0.03</td>
<td>26</td>
<td>&lt;0.03</td>
<td>14</td>
</tr>
<tr>
<td>Kr</td>
<td>&lt;0.05</td>
<td>(19)$^b$</td>
<td>0.4±0.02</td>
<td>(9.2)$^b$</td>
</tr>
<tr>
<td>CO</td>
<td>&lt;0.05</td>
<td>(18)$^b$</td>
<td>&lt;0.03</td>
<td>(9.7)$^b$</td>
</tr>
<tr>
<td>CF$_4$</td>
<td>16±2</td>
<td>27</td>
<td>6±1</td>
<td>13</td>
</tr>
<tr>
<td>H$_2$</td>
<td>&lt;0.03</td>
<td>(19)$^b$</td>
<td>&lt;0.03</td>
<td>(16)$^b$</td>
</tr>
</tbody>
</table>

$^a$in units of 10$^{-10}$ cc molec$^{-1}$ s$^{-1}$.

$^b$should not give any reaction (endothermic).

As stated in the 1984 Annual Report, the agreement between theory and experiment is generally 'state-of-the-art' in ion-molecule reactions, but there are now a number of exceptions as well as general trends in such a comparison that are worthy of mention:

1. In every case we have studied now the reaction rate of the [HeMu$^+$]* ion is faster than that for the corresponding [NeMu$^+$]* ion, as predicted by theory.

2. Molecules with permanent dipole moments are invariably faster than those without, again consistent with theory. The most dramatic example of this is for CH$_3$NO$_2$, which has the largest dipole moment of all the reactants 'X' studied to date, $\mu=4D$.

3. There are a number of cases now to complement our earlier result for CH$_3$ which show no fast relaxation $(k < 0.03\times10^{-10} s^{-1})$, even though they are exothermic for thermal charge exchange – CH$_4$, C$_2$H$_6$ and H$_2$O. This means that either the thermal charge exchange cross section is unusually small $(k_c \sim v_a c)$ or that the muon transfer channel $(k_t)$ is unusually large. Two other cases, H$_2$ and CO, also show no fast relaxation but this is an expected result since both these molecules are endothermic to charge exchange.

All of the above results were obtained at room temperature. A measurement of the temperature dependence of these ion-molecule reaction rates is also required though, since it may allow us to discriminate between different theories which predict dramatically different results at low temperatures [e.g. Clary, Molec. Phys. 54, 605 (1985)]. Since the simple Langevin rate is temperature independent, it is only molecules with permanent dipole moments that can be expected to give rise to temperature-dependent rate constants; in the ADO theory, e.g., this dependence is $T^{-1/2}$. Figure 67 shows results for the T dependence of the ion-molecule reaction rates of [NeMu$^+$]* with X=Ne, N$_2$O and NH$_3$ at three temperatures, T ~ -95°C, 25°C and 200°C. The solid lines are fits to a $T^{-1/2}$ dependence. As expected, Ne with zero dipole moment shows no effect whereas NH$_3$, with an appreciable dipole moment ($\mu=1.9D$) does show one.
Fig. 67. Temperature dependence of the experimental ion molecule rate constants for the reaction of \([\text{NeMu}^+]\) + X = Xe, N\textsubscript{2}O and NH\textsubscript{3}. The solid line is a fit of the data to a \(T^{-1/2}\) dependence.

Experiments 345, 346
Heavy fermion conductors (D. Noakes, UBC)

Heavy fermion conductors are believed to have extremely high densities of conduction electron states at the Fermi energy, and these states, having f-electron character, should be quite magnetic. From these properties we expect to find large muon Knight shifts in these materials.Muon Knight shift data (in 3.5 kG transverse field) for polycrystalline samples of CeCu\textsubscript{6}, CePb\textsubscript{3} and UPt\textsubscript{3} covering the temperature range from 10 to 300 K were taken in July. UPt\textsubscript{3} is a heavy fermion superconductor; CePb\textsubscript{3} is a strange system which seems to order antiferromagnetically in low field but which may become superconducting in large applied magnetic field. CeCu\textsubscript{6}, while a heavy fermion conductor, remains normal and paramagnetic down to low temperature.

Gaussian envelopes fit the \(\mu\)SR data much better than exponential envelopes in all samples (except near 300 K, where the muon may start hopping). This indicates that the relaxation observed is due to distributions of frequencies (inhomogeneous broadening, which may be due to nonuniformity of the demagnetization field in the sample, or due to true distributions of Knight shifts) and not due to any spin fluctuation effects. CePb\textsubscript{3} demonstrates this best, while exhibiting the most complicated behaviour of the three samples. Figure 68 shows the Knight shift(s) in CePb\textsubscript{3} deduced from fits to the data. From room temperature down to 140 K one signal with small shift is sufficient to fit the data, but not below 140 K. Below 140 K two signals, with different shifts, are sufficient to fit the data well, but only down to 90 K. From 80 K down to 35 K three signals can fit the data, but below 35 K even a three-signal model cannot fit the data well! There is at least one signal with large negative shift and at least one signal with even larger positive shift, and some signal in between. All are collapsed to near zero shift above 120 K, but the splitting increases as temperature decreases, and we are progressively more able to resolve the different contributions. Figure 69 shows the distributions of shifts implied by the fits to 90 K (two signal) and 80 K (three-signal). The detection of both large positive and large negative

Fig. 68. \(\mu\)SR frequency shifts (with respect to copper) of signals resolved in a polycrystal of CePb\textsubscript{3} in 3.5 kG transverse field.

Fig. 69. Apparent frequency (with respect to copper) distributions of fits to CePb\textsubscript{3} \(\mu\)SR spectra (3.5 kG TF) at 80 and 90 K.
Knight shift in a material (with the relatively simple Cu$_3$Au cubic crystal structure) is surprising. This material is difficult to make, however, so we must worry about impurity phases. Single crystals are not yet available.

UPt$_3$ clearly shows two signals at all temperatures, one with a large negative shift as shown in Fig. 70. The Knight shift is always expected to be proportional to susceptibility, as a first approximation, but this is a hexagonal material with substantial anisotropy in its susceptibility between hard axis and easy plane. Since the large-shift signal is roughly proportional to the easy plane susceptibility, we may be resolving the difference between differently oriented microcrystals in our sample. We plan to measure $K_y$ on a single crystal of UPt$_3$ in the future.

CeCu$_6$ appears to show only one, low shift, signal from room temperature down to 40 K. However, the relaxation rate of the nearly Gaussian envelope versus temperature (Fig. 71) resembles the bulk susceptibility. In CePb$_3$ an extra (n+1) signal was never necessary until the relaxation rates in the current model (n) exceeded 0.3 $\mu$s$^{-1}$ (beyond which a new beat became visible at the end of our 10 $\mu$s histogram). In CeCu$_6$ the single-crystal relaxation rate only exceeds 0.3 $\mu$s$^{-1}$ for the two spectra below 40 K, and for those two spectra better fits are obtained with a two-signal model, where the new signal is weak but at large negative shift. Single crystals of CeCu$_6$ have only recently become available, so it has only recently been found that this orthorhombic material again displays large anisotropy in susceptibility, but this time with a unique easy axis. Thus we might find a strong, large-shift signal when we apply the field along the easy axis of a single crystal, which we again plan to do in future runs.

Experiment 347
Spin dynamics in crystalline and amorphous DyAg
(D. Noakes, UBC)

The first data for this experiment were taken on channel M15 in August, consisting of zero field (ZF) and 50 G longitudinal field (LF) $\mu$SR runs, and testing of $\mu$SR in up to 3.5 kG LF in these samples. In a polycrystalline ingot of DyAg the muon spin polarization in the paramagnetic state is fully resolved and decays exponentially, from room temperature down to near the Néel temperature of 60 K (the muon spin relaxation time decreasing to near 0.5 $\mu$s at the bottom of this range). Immediately below 60 K the shape of the relaxation function changes, displaying fast, partially resolved initial relaxation followed by a more slowly relaxing tail. No frequency due to a unique ordered-state field was seen. Preliminary fits assuming a Lorentzian field distribution are fairly good, but with characteristic widths of only about 100 G, whereas kilogauss local fields are expected from the nearest dysprosium moments. Also, up to 3.4 kG LF applied well above the ordering temperature produced only a very small effect on the $\mu$SR spectrum (suggesting that in the paramagnetic state either the width of the local field distribution is much greater than 3.4 kG, or that the dysprosium moment fluctuation rate is much greater than 50 MHz, which is quite likely), while 1.0 kG applied at
17 K (Fig. 72) almost completely 'decoupled' the muon (implying a local field distribution width less than a kilogauss and only slow fluctuations). It may be that the muon sits at a site where the static conduction electron polarization in the ordered state is small and in which the summed dipole field from the ordered moments nearly cancels.

The thickest film of amorphous DyAg on silver backing successfully synthesized for this experiment was thinner than the stopping length of our usual 4.1 MeV surface muons. For this sample the M15 channel was retuned to lower momentum until almost all of the asymmetry at room temperature was in a simple exponential fast relaxing signal attributable to dysprosium moments (leaving a small asymmetry very slowly relaxing signal which we chose to decouple by applying 50 G LF). The paramagnetic state μSR is faster in this material than in the polycrystalline analogue, and full initial asymmetry is resolved only down to about 150 K. From 100 K down to the 'ferromagnetic' ordering temperature (near 18 K) the muon asymmetry relaxes to zero within the 10 ns apparatus dead time after the muon stops in the sample. Below the ordering temperature, however, a reduced asymmetry signal is observed with a relaxation time of less than a microsecond (Fig. 73). Application of 3.5 kG LF well above the ordering temperature has, again, only a slight effect.

Having seen effects of kilogauss longitudinal fields that should be useful in determining the magnitudes of the local fields at the muon sites in these materials, we will study them in more detail in the ordered states of both crystalline and amorphous DyAg in future beam time. In the longer term we will wish to measure μSR in these materials in longitudinal fields of at least 10 kG (perhaps as much as 60 kG) in high-field μSR apparatus now being developed by R. Kiefl of TRIUMF.

The simple spin system $^{19}$F:μ⁺:F⁻ coupled by dipole-dipole interactions between the muon and the fluorine nuclei has been observed in transverse field muon spin rotation (TF-μSR) and zero field muon spin relaxation (ZF-μSR) studies of single crystals of LiF, NaF, CaF₂ and BaF₂. In TF the μ⁺ precession frequency splits into three or more frequencies depending upon the crystal orientation; in ZF the dipolar spin Hamiltonian generates coherent oscillations of the muon polarization (see Fig. 74). With increasing temperature this coherence is progressively disrupted by μ⁺ hopping above ~250 K. We conclude that dilute H⁺ ions may form similar hydrogen bonds between adjacent F⁻ ions in all metal fluoride crystals.
Nuclear hyperfine parameters of muonated free radicals have been measured using a novel level crossing resonance (LCR) technique developed recently here at TRIUMF [Kreitzman et al., Phys. Rev. Lett. (in press)]. Figure 75 shows the LCR spectrum for the muonated free radical $^{13}C_6F_6Mu$. The signal is the integrated forward-backward muon decay asymmetry, modulated by a small field (±5 mT), and thus is approximately equal to the derivative of the asymmetry with respect to applied field. The modulation field is necessary to remove systematic errors inherent in the integral technique which yields a 100-fold increase in the data rate compared with the more standard time differential technique.

The resonances in Fig. 75 occur at field values where a muon transition frequency ($\nu_M^z$) matches a corresponding nuclear transition frequency ($\nu_N^z$), where ± signs refer to the $z$ component of electron spin ($S_z = \pm 1/2$). On resonance there is a near degeneracy or level crossing between two muon-nuclear-electron spin levels. This results in flip-flop oscillations between the muon and the nucleus which are otherwise suppressed. The positions of level crossing resonances allow an accurate determination of the magnitude and sign of the nuclear hyperfine parameters relative to the muon hyperfine parameter.

Some possible applications of the technique are 1) to test calculations on electronic structure of muonium-like systems; 2) to aid in making site assignments for the muon since the LCR spectrum is far more distinctive than the muon hyperfine parameter alone; and 3) to determine reaction channels in solid state or radical chemistry. This last point arises because LCR can be used to study muonium defect centres or radicals which form several microseconds after the muon enters the target.

Level crossing resonances were also detected for the $(CH_3)Mu-C(CH_3)_2$ radical and for the anomalous muonium centre in GaAs. More details on the experiment and the results will be presented in a forthcoming publication.
THEORETICAL PROGRAM

Introduction

The Theory group at TRIUMF exists to provide a focus for theoretical research and a group of active researchers who are interested in the physics relevant to the experimental program and the proposed KAON factory. As befits a laboratory with as wide a range of activities as TRIUMF, the interests of the Theory group are quite broad, ranging from condensed matter (pSR) to high-energy particle physics. The Theory group has four permanent staff members: H.W. Fearing (group leader), B.K. Jennings, J.N. Ng and R.M. Woloshyn. In addition we have research associates (approximately seven at any one time) and one or two long-term visitors. During this year our research associates have been G. Belanger (from November), M. Celio (from August), E.D. Cooper, W. Dickhoff (from August), S. Godfrey (from October), J. Thaler, R.E. Turner (to September), W. Wilcox (to September). Our long-term visitors have been A. Gal (from September), S. Gurvitz (to August), and R. Machleidt (to September). Five graduate students, R. Bates, G. Couture, D. Hamilton, J. Kopcs and R. Workman, are being supervised by Theory group members. Interactions and collaborations are also maintained with theorists from the nearby universities.

In addition to their active research program the theorists are involved in a number of laboratory activities including the Long-Range Planning Committee and the KAON Factory Steering Committee. Organization of the TRIUMF seminars is also handled by the Theory group. This and the summer theoretical visitors program have brought a large number of visiting theorists to TRIUMF. Following is a list of theoretical visitors for the year:

H. Baer, N. de Takacsy, G. Karl
W. Bauhoff, M. Dillig, F. Khanna
W. Benenson, M. Frank, B. Kiester
C. Bernard, J. Friar, R. Koniuk
R.K. Bhaduri, T. Goldman, L. Krause
F. Bickerstaff, J. Greben, J-M. Laget
B. Blankleider, A. Green, E. Loman
E. Bleszynski, M. Gross, R. Mackenzie
M. Bleszynski, W. Haxton, K. Maltman
P. Blunden, K. Holinde, O.V. Maxwell
R.N. Boyd, C. Horowitz, B. McKellar
J. Cohen, N. Isgur, H. McManus
S. das Gupta, P. Kalyniak, G.A. Miller
M. Moravcsik, A. Rinat, A. Svarc
M.V.N. Murthy, E. Rost, Y. Takahashi
M. Oka, R. Rueckl, P. Tandy
E. Oset, P. Sauer, R. Thaler
F. Osterfeld, L.M. Sehgal, A.W. Thomas
J. Piekarewicz, J. Sheppard, J. Vergados
J. Potvin, E. Siciliano

As usual the Theory group has been very active and we briefly describe below the specific research proposals undertaken during the year.

Nuclear structure

△ isobar degrees of freedom in low-energy nuclear physics

Nuclear matter

(W.H. Dickhoff; H. Müther, Tübingen)

Microscopic many-body calculations using realistic NN interactions have been performed to calculate the density dependence of the particle-hole interaction which on the Fermi surface can be represented by Landau-Migdal parameters. The strong influence of △-isobar nucleon-hole excitations is treated on the same footing as the nucleonic ones. Treating short-range correlations on the G-matrix level, the long-range correlations are consistently treated by calculating the RPA self-screening to all orders. At all considered densities ρ (1/2ρ0<ρ<3ρ0) isobar effects are important, leading for example to an increase of the gN4 Landau parameter from 0.26 for the G matrix to 0.43 at normal nuclear density ρ0. Nevertheless, at momentum transfers ~kF, an enhancement of pionic excitations remains although pion condensation is strongly screened.

Similar calculations have been performed for polarized liquid 3He (W.H. Dickhoff, A. Polls, H. Müther) in order to assess the role of collective excitations in experimentally accessible infinite Fermion systems.

Finite nuclei (W.H. Dickhoff; P. Czerski, F. Faessler, H. Müther, Tübingen)

Whereas △ isobars are important in nuclear matter simply because momentum is a good quantum number and enhancement of pionic excitations inevitably appears at high momentum transfer, there is no a priori reason to expect that these long-range correlations...
Extension of many-body methods for finite nuclei

Self-consistent medium polarization in RPA (W.H. Dickhoff, W. Hengeveld, K. Allaart, Amsterdam)

RPA calculations in nuclei have been performed mostly with phenomenological residual interactions with some degree of success. Using a microscopically derived residual interaction (G matrix) one is just as (un)successful in light nuclei ($^{16}$O), but in heavy nuclei these interactions turn out to be too attractive, leading to imaginary eigenvalues for natural parity excitations ($0^+, 2^+, 3^-$). A systematic improvement on the G matrix as a residual interaction has been formulated which takes the RPA self-screening into account to all orders. The RPA method is therefore extended to include the treatment of energy-dependent interactions. In fact one of the advantages of this method is that it couples the lp-h excitations systematically to 2p2h excitations which appear as poles in the residual interaction. It is shown that these screening terms restore the stability of RPA calculations by applying this method to $^{56}$Ni (for which the lowest 2+ becomes unstable in RPA). In addition it is shown that a fragmentation of magnetic strength occurs which distributes the lp-h M1 strength over 2p2h excitations, showing that this scheme has the possibility to calculate the ph fragmentation of magnetic strength into many-particle many-hole excitations.

Giant resonances and medium polarization (W.H. Dickhoff, W. Hengeveld, K. Allaart, Amsterdam)

Giant resonances have been calculated up to now only within the standard RPA formulation using adjusted residual interactions. If one wants to gain more insight into the actual microscopic structure of these excitations and intends to perform a microscopic calculation starting from the underlying nucleon-nucleon force, one observes again that on the level of the G matrix one overestimates the attraction for the isoscalar giant resonances, e.g. the GDR and GMR (for the low-lying states) whereas too much strength is found in the GDR and the Gamow-Teller case in the case of $^{48}$Ca. Inclusion of the self-screening restores the bulk of the $2^+$ strength to $\sim 2h\omega$ excitation energy, providing a broadening, i.e. fragmentation, of the strength which is consistent with the width found in experiment. In the case of the $0^+$ (GMR) no strong concentration of strength is found when the screening is included; instead $0^+$ strength is calculated to be widely fragmented into many 2p2h-like excitations also consistent with experimental observations for $^{48}$Ca and lighter nuclei. For the Gamow-Teller strength this extended RPA method provides also strong fragmentation of the strength roughly in agreement with shell-model results. 20% of the sum rule strength is, however, moved to higher energies ($> 20$ MeV) leaving 80% in the low-energy domain. Although this might not be enough quenching compared with the experimental results, it must be pointed out that also no significant additional quenching for the M1 state in $^{48}$Ca is calculated. Since within this method only ph-fragmentation-type ground-state correlations are included, one may conclude that one should consider in addition particle-particle ground-state correlations and incorporate them into the description to explain the additional quenching.

The nuclear structure of $^{160}$Ca (W.H. Dickhoff)

Over the years double closed shell nuclei like $^{160}$ and $^{40}$Ca have defied a truly microscopic picture of their excitation spectra. It is shown that the many low-lying normal parity $T=0$ excitations can be explained microscopically by extending the RPA once again, not only including the exchange of the RPA phonons between particles and holes but also allowing the coupling to two phonon excitations in the residual interaction. Iteratively one would proceed then as follows in an actual calculation: firstly with standard RPA one can generate low-lying $3^-$ and $1^-$ $T=0$ states; from these one can construct 2 phonon states $0^+, 2^+, \ldots$ which in the next step are included in the residual interaction and therefore will be generated by a next
Diagonalization.
The attraction which brought down $3^-$ and $1^-$ will now also bring down $0^+$ and $2^+ T=0$ states. These four phonons are then enough to generate the whole excitation spectrum of $^{16}O$ up to 14 MeV as is illustrated in Fig. 76. This relatively simple picture gives then a comprehensive understanding of the structure of $^{16}O$. It also explains why the isovector states are not influenced too much because the original interaction (G matrix) is not attractive for $T=1$ states and in addition two $T=0$ phonons cannot couple to $T=1$ which is necessary to allow mixing.

Fig. 76. 'Final' diagonalization for $^{16}O$. For each $J^n$ the left column gives the experimentally observed levels. The right column contains the usual $lplh$ unperturbed energies (dashed lines) as well as unperturbed two-phonon energies (full lines). In the ideal case of an exact calculation the final diagonalization will produce the left columns from the 'unperturbed' right columns.

Extension of many-body methods for nuclear matter (W.H. Dickhoff, A. Polls, A. Ramos, Barcelona)

The study of infinite many-body systems at low temperatures (quantum liquids and gases) has been extended in recent years to new systems like nuclear spin-polarized liquid $^3$He or electron spin-polarized deuterium. These new systems will allow for more extensive tests of our microscopic description of infinite systems. Also recent focus on nuclear matter occupation probabilities in connection with missing single-particle strength makes the study of infinite systems an important part of the attempt to understand many-body systems in general.

The Green's function method is capable of determining the momentum distribution and the effective mass in a concise manner. It has been shown, however, that more careful treatment of the energy dependence in the self-energy leads to considerable differences in these quantities as compared to the standard hole-line expansion prescription. It is therefore natural to extend the treatment of the pp ladder approximation (G matrix) to include the full dressing of the single-particle propagators inside the G matrix. A method for this has been devised and is presently studied. This extended self-consistency goes beyond the simple picture of the occupied Fermi gas since it determines the occupation probabilities of all momentum states self consistently and (without a phase transition) only the discontinuity in the occupation probability remains, which for some systems like normal $^3$He is considerably smaller (experimentally) than the transition of $1^+ 0$ in the free Fermi gas.

Scattering and reactions on nuclei
(p,γ) reactions in a relativistic 'Dirac phenomenology' approach (H.W. Fearing, E.D. Cooper, J. Iqbal)

One of the most interesting, and yet controversial, developments of the past several years has been the use of the so-called Dirac phenomenology approach for proton nucleus elastic, and quite recently, inelastic scattering [McNeil et al., Phys. Rev. Lett 50, 1439 (1983); 50, 1443 (1983); Phys. Rev. C 27, 2123 (1983)]. In this approach, at least in initial calculations, the on-shell nucleon-
nucleon amplitudes are used as input in an impulse approximation. Strong vector and scalar effective potentials are generated and the scattering wave functions are four-component objects obtained by solving the single particle Dirac equation in the presence of these scalar and vector potentials. This approach has been seemingly quite successful in describing spin observables in proton nucleus elastic scattering. The approach is controversial because much of the effect comes in some way from the antiparticle contributions, contrary to intuition, and because many of the same results can be obtained also in a nonrelativistic approach using density-dependent interactions [von Geramb, Proc. of the Univ. of Alberta/TRIUMF Workshop on Studying Nuclei with Medium Energy Protons, TRI-83-3, p.1 (1983)].

To test some of these assumptions, a relativistic (p,γ) calculation is being developed, using an analogous approach. The trick here is to choose variables in momentum space which make the impulse amplitude, in this case that for NN + NNY, simple. The complications then get shifted to the nuclear wave functions which become several dimensional Fourier transforms of the four-component wave functions obtained by solving the Dirac equation in the presence of the strong scalar and vector potentials. The angular momentum algebra then becomes quite complicated. With this technique, however, the complicated nuclear part has to be done only once, and in principle one can easily add new diagrams to the basic interaction, thus making it easy to test the importance of various ingredients of the interaction. One can also use the same nuclear part for different reactions as for example (e,e'p), or by adding distortion (p,γ'), or with some changes in the final wave functions, reactions like (p,p'γ) or (p,p'y). In each case the model will contain enough of the ingredients of the Dirac approach that one may gain insight into why such approach works or where it fails.

At present much of the formalism of this calculation has been developed and the next major problem is to organize efficiently the computation so it can be done with available resources. Much of the complication comes from the sums over partial wave series, and from the radial integrals. The latter entails doing many integrals with products of two or three spherical Bessel functions. A stable recursion technique has been found to do these integrals (and in general integrals involving N Bessel functions, N=1, 2, 3,...). Also the observation that each integrand, while only (usually) conditionally convergent can be cut off at a radius just outside the nucleus without affecting the final answer makes calculation of the integrals from which the others can be found by recurrence much easier.

Simultaneously we have explored a coordinate space technique for handling the multidimensional integrals appearing in the amplitudes. This technique entails turning integrals into solutions of a differential equation which can be solved using the algorithm developed by Thorlacius and Cooper [TRIUMF preprint TRI-PP-85-85]. The main advantage of this formalism is that of speed. In this approach different Feynman diagrams are constructed by means of sequential subroutine calls to the subroutines written to handle the various vertices. If desired, formalisms involving many nucleons can be incorporated. Anticipated cpu time (VAX 11/780) will be of the order of 2N min per Feynman diagram, where N is the number of nucleons actively involved in the calculation. [Inclusion of form factors is possible and will increase the time in an additive way (i.e., a one-nucleon calculation with a form factor will take the same time as a two-nucleon calculation].

On the role of antinucleons in Dirac phenomenology (E.D. Cooper, B.K. Jennings)

It has recently been pointed out by Thies [SIN preprint 85-10] that in so far as proton elastic scattering is concerned the iterated spin-orbit potential gives rise to contact terms in a multiple scattering series which entail scattering from two nucleons at the same point in space. From the experience of pion-nucleus elastic scattering it is known that such terms are spurious and should be set (by hand) to zero. Thies shows that this procedure when applied to the proton elastic scattering gives results which are indistinguishable from those of Dirac phenomenology. Thies then concludes that the antinucleons are forming some sort of short distance regulator in the theory and will be irrelevant once some other regulatory mechanism (such as short-range anticorrelations) is used.

We have examined this idea in the context of the full Feynman propagator and have shown explicitly that the role of the antinucleons is exactly as Thies has said. We find that the antinucleons remove spurious short-ranged structure in the nucleon propagator which is
connected with relativistic kinematics and is of a range of about a fifth of a fermi. Since this 'smoothing at short distances' is inherent in the propagator we conclude that Thies's ideas will not just apply to elastic scattering but to all of hadronic-based nuclear physics. We have quantitatively examined Thies's idea that short-ranged anticorrelations present in nuclear matter will provide a regulating mechanism but have concluded that they only eliminated about a quarter of the spurious structure.

Thus we conclude there is either some other regulating mechanism present or the antinucleons really are present in nuclei to the extent predicted in Dirac phenomenology.

The Dirac DWBA for proton inelastic scattering to collective states (E.D. Cooper; H.S. Sherif, R.S. Sawafita, J.I. Johansson, Alberta)

A peculiar adding Hamiltonian prescription for a system involving one fermion and one boson leads to the Dirac DWBA for proton nucleus inelastic scattering to collective states. The resultant expression for the Dirac DWBA resembles that used in distorted wave impulse calculations. Calculations have been done as a function of energy for the lowest-lying collective states in calcium and lead, with so far encouraging results for both cross sections and analysing powers.

Proton elastic scattering in the Dirac optical model (E.D. Cooper; A. Kobos, H.S. Sherif, J.I. Johansson, Alberta)

The systematics of the Dirac optical potential for proton elastic scattering for intermediate energies have been examined. A table of Dirac optical model parameters has been produced for use in Dirac DWBA calculations.

The (p, π⁺) reaction at TRIUMF energies (E.D. Cooper, A. Matsuyama)

A fairly successful model for describing differential cross sections and analysing powers at low pion energies (less than 50 MeV) can now be extended to the Δ-dominance region. The relativistic (Dirac) based code of one of the authors (EDC) has been combined with a code which can generate pion elastic scattering wave functions in the Δ-hole model. As a result, in a fairly consistent way some of the Feynman diagrams which contribute to the (p, π) reaction can be calculated. These diagrams, which include the so-called 'projectile emission' piece of a two-nucleon calculation, are expected to be the most important for transitions to the ground state of 170 where there is not much configuration mixing contamination between the initial and final nuclei. Preliminary results have shown this model to agree qualitatively with the older model at pion energies of around 50 MeV, which is quite surprising (and reassuring) since the parametrization of the nonresonant background potential in the Δ-hole part of the calculation is not optimally parametrized for this low energy.

Δ-nucleus double charge exchange (N. de Takacsy, McGill; B.K. Jennings)

Much excitement has been generated in the last few years looking for six-quark effects in nuclear physics, with various effects claimed to be definite signatures of this. One such effect is the relatively large forward angle cross section for pion double charge exchange at low energy [Navon et al., Phys. Rev. Lett. 52, 105 (1984)]. It has been claimed that this cross section can only be explained through the use of six-quark clusters [Miller, Phys. Rev. Lett. 53, 2008 (1984)]. However, before claiming evidence for exotic effects it is necessary to calculate the nonexotic effects carefully.

In pion double charge exchange it is necessary for the pion to interact with at least two nucleons so that two-particle correlations are important. Elastic pion scattering is sensitive mainly to the spin-isospin correlations. Double charge exchange, however, is equally sensitive to the scalar-isoscalar correlations, and this has been excluded in most calculations to date. We have shown that including these effects increases the forward cross section and eliminates the need for six-quark effects.

Nuclear optical potential (M.J. Iqbal; S. Wallace, Maryland)

Derivation of the scalar and vector optical potentials, used in the Dirac phenomenology, from a more microscopic theory based on meson exchange theory of the nuclear forces is of fundamental importance. First-order calculations based upon a meson exchange model were published (Iqbal, Phys. Lett. 158B, 1(1985)). Higher-order calculations have been completed and will be published shortly.
Pion production on nuclei
(M.J. Iqbal; G.E. Walker, Indiana)

The Iqbal-Walker model for pion production on nuclei has been successful in predicting cross sections for \(^{12}\text{C}(p,\pi^+)\text{^{13}C}(9/2^+\)) at 354 MeV. Asymmetry calculations have recently been completed and results look good. The first paper about this work was recently published [Phys. Rev. C 32, 556 (1985)]. The ongoing research in this area includes a comprehensive study of the analysing power data at various energies and more calculations for \(^{150}(p,\pi^+)\text{^{170}(11/2^-)}\) reactions. This experiment will be done at TRIUMF in the near future.

Photon elastic scattering from nuclei
(M.J. Iqbal; M. Dillig, Erlangen)

With the availability of high energy, high intensity tagged photon beams at different laboratories in the world, elastic photon scattering from nuclei has become possible. This is an extremely interesting reaction to study, for example \(\Delta\) propagation and \(\Delta\)-nucleus interaction at peak \(\Delta\)-production energy. In this case, unlike that of pions, there are no distortion effects and gauge-gauge-invariant \(NN\) vertices are well known. Also this reaction is interesting from the point of view of quark substructure of nucleons, as a photon has no quark substructure and the photon-quark interaction is known.

Preliminary calculations have been finished and these results will be submitted for publication soon.

Λ-nuclear physics and hypernuclei

Λ-nuclear physics
(A. Gal, TRIUMF and Hebrew Univ.)

Antinucleon-nuclear optical potentials play an important role in the intriguing possibility of materializing neutron-antineutron oscillations in nuclei. These oscillations were evaluated [Dover et al., Phys. Rev. C 31, 1423 (1985)] by solving the appropriate inhomogeneous wave equation for the antineutron in typical nuclei. Constraints on the \(N\bar{N}\)-free oscillation lifetime in terms of the \(N\) annihilation lifetime of these nuclei were derived, and are considered among the most reliable and significant ones for this fundamental problem.

We have also investigated [Baltz et al., Phys. Rev. C 32, 1272 (1985)] the possibility that a nucleus containing a single antinucleon may exhibit some relatively long-lived excited states. For the optical potentials mentioned above the annihilation widths of strongly bound (nonCoulomb) \(N\) states are generally large. Yet some possible exceptions to this rule may occur when the \(N\) is bound to a light nuclear core which is not spin and isospin saturated. We obtained cross-section estimates for the formation of \(N\)-nuclei via the \((p,p)\) and \((p,n)\) reactions on nuclear targets with \(A = 3, 4\) and 16.

\(\Lambda\) hypernuclei
(A. Gal, TRIUMF and Hebrew Univ.)

Considerable experimental work on the spectroscopy of \(\Lambda\) hypernuclei has recently been directed towards the formation of particle-stable excited states in p-shell hypernuclei and, subsequently, measuring in coincidence with the production pion the \(\gamma\) radiation by which these \(ls_\Lambda\) states decay to the \(\Lambda\) hypernuclear ground state. These measurements called for a complementary theoretical work in order to deduce the spin dependence of the \(\Lambda N\) force that gives rise to the doublet splittings and spin values thus unravelled. We discussed these questions [Millener et al., Phys. Rev. C 31, 499 (1985)], demonstrating the existence of \(\Lambda N\) force parameters that can account for our present knowledge of \(ls_\Lambda\) states and which characterize the spin dependence of the \(\Lambda\)-nucleus in the nuclear p shell. The central spin-spin and the \(\Lambda\) spin-orbit matrix elements are most strongly constrained by existing data. The spin dependence is weak in the sense that \(ls_\Lambda\) doublet splittings are generally predicted to be of order 100 keV. Detailed consideration was given to those \(\gamma\)-ray transitions, the observation of which would best serve to further constrain the spin dependence of the \(\Lambda N\) interaction, particularly the tensor interaction about which very little is known empirically.

The usefulness of producing \(\Lambda\) hypernuclei with stopped kaons has recently been stressed following some related measurements at KEK. We have embarked on a comprehensive study of \(\Lambda\) (and \(\Sigma\)) hypernuclear production in \((K^-\pi)\) reactions with stopped kaons [Gal, Int. Symp. on Hypernuclear and Kaon Physics, Brookhaven (Sept. 1985); Nucl. Phys. A, in press], in order to update earlier calculations by treating realistically the kaon atomic wave functions and pion distorted waves. The \(\Lambda\)-hypernuclear yields were calculated within
the distorted wave impulse approximation (DWIA) and found to be weaker than the Σ-hypernuclear yields, in $^{12}$C and on neighbouring targets, by more than an order of magnitude, particularly because the outgoing pion wave is strongly damped due to the proximity to the 3,3 resonance, and are sensitive to the choice of pion optical potential. We have made contact with some old and new experimental results for $^{12}$C and used our calculations as means for providing new spectroscopic information in this hypernuclear system.

$\Sigma$ hypernuclei

(A. Gal, TRIUMF and Hebrew Univ.)

Several intriguing questions stand out in the field of Σ-hypernuclear physics, as listed in a review talk in the PANIC 1984 Conference in Heidelberg [Gal, Nucl. Phys. A434, 381c (1985)]. These are the questions of narrow widths, isospin vs. charge basis descriptions and Σ-nuclear spin dependence, in particular the Σ-nuclear spin-orbit coupling. Our work in this field during 1985 has touched on two of these aspects, as described below. Recently the usefulness of producing Σ hypernuclei with stopped kaons has been demonstrated at KEK. We have studied in detail [Brookhaven Symposium; Nucl. Phys. A, in press], within the DWIA, the production of $^{12}$Be at rest in order to understand quantitatively the features of the measured $\pi^-$ spectrum and to provide the spectroscopic calculations carried out subsequently [Dover et al., Phys. Rev. Lett. (in press); Gal, Int. Conf. on Hadronic Probes and Nuclear Interactions, ASU, Tempe, March, AIPCP 133 (AIP, New York, 1985), p. 30] with reliable branching ratios for Σ-hypernuclear production in the various possible multipolarities.

1) Width. Recent claims that Σ-nuclear unstable bound states are unlikely to produce peaks in $(K^-, \pi^-)$ hypernuclear excitation functions are discussed in Proc. Brookhaven Symposium. Some limitations of the present one-channel calculations, as well as possible extensions beyond these limitations, are pointed out.

2) Spin-orbit. In a recent collaboration [Dover et al., Phys. Rev. Lett. (in press)] we have argued that existing Σ-hypernuclear data do not unambiguously determine the Σ-nuclear spin-orbit splitting (SOS) in the p shell, by providing a detailed demonstration of the complexity involved in deciphering the $^{12}$Be spectrum. A precise determination of the Σ-nuclear SOS is extremely interesting in the context of differentiating between consequences of one boson exchange (OBE) models and quark models. It need not be correct, however tempting it may be, to assign the spin dependence revealed in Σ-hypernuclear spectra exclusively to the SOS. A strong spin dependence of the ΣN effective interaction arises naturally as well in OBE models. It is therefore important to treat the various spin-dependent terms in the Σ-nucleus effective interaction on an equal footing. Indeed, we have calculated relative intensities for $(K^-, \pi^-)$ spectra at rest and in flight for several realistic effective interactions and suggest definitive tests for the Σ-nuclear SOS from $(K^-, \pi^-)$ measurements on $^7$Li and $^{13}$C targets.

Hadron structure

High spin mesons to probe confinement

(S. Godfrey)

Nonrelativistic quark models incorporating the properties expected from quantum chromodynamics have been very successful in describing heavy quark systems. The charmonium (cc) and beautyonium (bb) mesons have quark-antiquark separation in the range of 0.25 to 1 fm, and consequently the properties of these states reflect the properties of the qq interaction at these distances. To probe the properties of the confinement potential at larger distances we must study hadrons composed of the lighter u, d and s quarks and in particular the orbitally and radially excited mesons. Because the orbital excitations are expected to be easier to find experimentally through the use of partial-wave analysis, we concentrate on them. They will reveal important information about the interquark potential—both its shape and its Lorentz structure.

To study the Lorentz structure of the potential consider the ordering of a meson multiplet for a given $L_J$ with $J = L-1, L, L+1$. If the potential is vector in nature the ordering of low-$L$ mesons will persist to high $L$ while if the potential is scalar in nature the ordering will invert for some value of $L$. It is important to confirm the expected behaviour of the confining potential or discover where theory no longer agrees with experiment to help understand the nature of confinement [Godfrey, Phys. Lett. 162B, 367 (1985)].

Recently a calculation of the predicted mass of high-spin mesons was completed using a
relativized quark model [Godfrey, Phys. Rev. D 31, 2375 (1985)]. The results of the analysis are presented in Fig. 77. The conclusion one draws is that it should be possible to observe high-spin mesons, the most important requirement being sufficiently high statistics that can disentangle the complicated structure present in the high-energy final states. The study of these high-spin mesons will reveal important information about the nature of confinement at large distance, both the strength of the interaction and also its Lorentz structure. This should be possible with the advent of high-intensity kaon factories.

$^3S_1 - ^3D_1$ mixing and E1 radiative transition in charmonium (S. Godfrey; G. Karl, Guelph; P.J. O'Donnell, Toronto)

Nonrelativistic potential models have been very successful in describing the charmonium ($c\bar{c}$) and beautyonium ($b\bar{b}$) systems. It is useful to see how far one can go with this approach and to further test a model of hadrons it is necessary to look at their internal structure. One sensitive test of this structure is to look at decays and electromagnetic couplings. To this end we studied the electromagnetic transitions $\psi \gamma \rightarrow \gamma \psi$ and $\psi \gamma \rightarrow \gamma \phi$ as a sensitive test of the $^3D_1$ admixture in the $\psi$ (mainly $^3P_0$ $c\bar{c}$) and $\psi'$ (mainly $^3P_1$ $c\bar{c}$) states of charmonium [Z. Phys. C (in press)]. The E1 width for $n^3S_1 \rightarrow ^3P_J$ as well as the associated photon angular distributions have been discussed previously, but a systematic analysis including the $^3D_1$ mixing has not yet been presented. It is possible that this mixing might help explain the discrepancy between the measured rates and previous calculations for the E1 transition being considered. Further, by wave function orthogonality, obtaining an estimate of this mixing would give an estimate of the $^3S_1$ admixture in the $\psi''$ state (mainly $^1D_1$) which would help to explain its large leptonic width.

The $^3D_1$ content of the $\psi$ was found to be large, but the estimate is very sensitive to the photon angular distribution. More precise measurements, which will be performed at the Beijing $e^+e^-$ collider, could help to explain the large $\psi$ leptonic width.

Optimum channels for exotic (4$q\bar{q}$) $Z^*$ baryons
(S. Godfrey; K. Maltman, LANL)

The notion that ordinary hadrons are composed of quarks carrying a confined SU(3) colour degree of freedom leads to the possibility that the physical hadronic spectrum contains multi-quark states whose valence contributions differ from conventional mesons and baryons. Of special interest in this regard are the so-called exotic states whose quantum numbers cannot be produced in either $qqq$ or $q\bar{q}$, since such states represent unambiguous evidence for the presence of multiquark physics.

We investigated the possibility of exotic, negative parity, strangeness +1 (4$q\bar{q}$) baryons (traditionally called $Z^*$ resonances) deeply bound with respect to available asymptotic hadron thresholds, in the context of the constituent quark model. Such states should be more accessible to experiment than those above ordinary hadronic thresholds, for which fall-apart decay modes exist, and unlike weakly bound states should be unambiguously predictable. We found that the $I=1$ $S=5/2$ $\Lambda K^*$ resonance is the strongest candidate for such a state and may be found in processes such as $N\pi+X\bar{K}$ or $NK+X\pi$ where polarization measurements might allow one to identify an $I=1$ $J^P = 5/2^-$ state recoiling against $\bar{K}$ or $\pi$. An $I=0$, $S=3/2$ state is possible although less strongly indicated and it is unlikely that any other (4$q\bar{q}$) $Z^*$ states exist [Maltman and Godfrey preprint TRI-PP-85-62].

$M^*\Lambda K^*$ matrix elements in a relativized quark model (S. Godfrey)

At present one of the preoccupations of particle physics is looking for effects in conflict with the standard model. There are two
approaches to this search, to go to higher and higher energies looking for new particles and interactions, or alternatively, to look for violations of standard model physics in low energy phenomenology. Ultimately, the high energy route will be necessary to disentangle new effects, but until the necessary energies are realised low energy phenomenology can give us a window to new physics or at least put bounds on what is possible. One of the most sensitive tests for new physics is in the K°-K° system where new interactions can contribute to the \( \langle K^0 | H_{\text{eff}} | K^0 \rangle \) matrix element and hence to the \( E_{\text{L}} - E_{\text{R}} \) mass difference and to CP violation. This has led to bounds on, for instance, left-right symmetric theories of the electroweak interaction, on supersymmetric theories, and on composite theories. More recently it has been pointed out that there exists the possibility of observing mixing effects and CP-violating effects in the B°-B̄° and B^0-B^- systems. These bounds should be improved in the near future with large data samples of B° mesons.

In addition, bounds on mixing effects in the D^0-D̄^0 system can also put constraints on model building. Given the importance of having an accurate estimate of the M_{K°-K°} amplitudes the relativized quark model has been used to calculate the matrix elements of various operators for the K°-K°, D^0-D̄^0, B°-B^0, and B^0-B^- systems which arise in effective Hamiltonians of new interactions [Phys. Rev. D (in press)]. The purpose was to present the results along with the uncertainties so that they are available to others. The pseudoscalar meson decay constants \( f_p \) were first calculated using various approximations to set the scale of the matrix elements' magnitude and to estimate their accuracy. The matrix elements were then calculated, again using various approximations. Indications were found that in the relativized approach there are significant enhancements of the results compared to naive calculations. If one takes this mock-meson approach seriously then these enhancements exist. Although the quantitative results may be altered by a more rigorous treatment the qualitative results of the model will remain. These would lead to significant enhancements of new effects which would put tighter constraints on new physics than is currently expected and could have important consequences in evaluating the prospects for new interactions. As an illustration, it was found that the right-handed W boson of left-right symmetric theories must have a mass of at least 4.7 TeV. As indicated by this example, because of the uncertainties in the matrix elements one should take results which use hadronic matrix elements as order of magnitude estimates at best.

Isospin violations in mesons and the constituent quark model (S. Godfrey; N. Isgur, Toronto)

The idea that isospin violations in hadrons are at least partially due to the intrinsic mass difference of the up and down quarks is now fairly well accepted. One approach to the study of such isospin violation is via constituent quark models based on QCD. We considered such calculations in the meson sector using a relativized quark model in order to study possible effects due to p/m being of order unity in light quark systems. We place special emphasis, in fact, not on the quality of our results, which are comparable to those obtained before in the nonrelativistic model, but rather on a constraint that isospin splittings put on quark models. We find that the observed splittings require that the constituent masses of the u and d quarks lie in a narrow range around 250 MeV, thereby revealing some important facets of the structure of QCD in the confinement regime.

Heavy flavour signatures for gluinos (S. Godfrey; B. Campbell, Alberta)

With the recent developments in supersymmetric theories of the fundamental interaction, the issue of methods of identification of the new particles predicted by these theories has become of considerable interest. With this motivation we have considered the decay of gluinos into a photino (assumed to be the lightest supersymmetric particle) and heavy quarks. For heavy gluinos we found that there is a significant branching ratio to heavy quark flavours which may in turn be used to tag the the gluino decay. The production of gluinos in e^+e^- colliders at the Z° peak was studied along with their signature in the final state.

We also studied gluino production in pp colliders and found that existing data can extend the lower limit of gluino masses which will be further extended at the Fermilab Tevatron.

Potential model for quark confinement (J. Thaler, M.J. Iqbal)

A static quark potential model, which consists of a scalar linear confinement potential and a vector one-gluon-exchange
potential, was used with a relativistic wave equation to describe heavy quarkonium bound states. In this model the long-range part of the quadratic terms was suppressed by a glueball-exchange mechanism.

Quarkonium decay in a boundary condition model
(J. Thaler, M.J. Iqbal)

A previously derived quark potential model was extended to include the possibility of hadronic decays for the unstable states. The decay mechanism is described by a boundary condition model motivated by the string model.

Lattice quantum chromodynamics
(W. Wilcox, R.M. Woloshyn)

A lot of progress has been made in our numerical study of QCD on a lattice during the past year. This is mainly due to the installation of a Cyber 205 supercomputer at the University of Calgary. The University of Calgary gave us free access to this system during the first half of the year.

Our study of the pseudoscalar meson electric form factor and charge radius has been completed. The first results appear in Phys. Rev Lett. 54, 2653 (1985). Form factors and charge radii were calculated in a model with SU(2) colour using both the Wilson and staggered schemes for putting fermions on the lattice. The final results are shown in Fig. 78. At smaller values of pion mass (i.e., at smaller quark masses) the Wilson and staggered schemes give compatible results. The calculated charge radius is encouragingly close to the experimental value.

Some preliminary work was done on the calculation of mesonic M1 decay rates (e.g., ρ → γπ). The calculation of this amplitude is feasible although it is subject to larger statistical and systematic errors than the form factor. Calculation of the final results awaits the availability of more computer time.

**Hadron-hadron scattering**

**Proton-proton bremsstrahlung**
(H.W. Fearing, R.L. Workman)

The nucleon-nucleon interaction is probably the most fundamental of the few-body reactions and nucleon-nucleon bremsstrahlung is in principle the simplest way to investigate the off-shell aspects of this two-nucleon force. It was thus very puzzling that as of the most recent experiment [Rogers et al., Phys. Rev. C 22, 2512 (1980)] a few years ago essentially all data could be reproduced by purely on-shell soft photon calculations [Fearing, Phys. Rev. C 22, 1388 (1980)]. This held even for the old TRIUMF experiment where older potential model calculations had indicated that there should be sensitivity to off-shell effects. A two-pronged attack was mounted on this problem. First a new experiment was planned by a TRIUMF group [Expt. 208, P. Kitching, spokesman], one which would measure for the first time the analysing power using polarized protons. Second we started a new and modern potential model calculation. We hoped to include all effects which might be important, but which had not been included in one calculation before and to use a modern potential such as the Paris or Bonn potentials which have never been applied to bremsstrahlung, though are considered the state-of-the-art potentials.

This calculation is now essentially complete. The various corrections have been calculated including the relativistic spin corrections, which are the most important, Coulomb corrections, one-pion exchange for the higher partial waves, correct relativistic transformations, and a number of other relativistic effects not originally envisioned. A result has been obtained for the Paris, the Bonn, and for a modernized Reid soft core potential.

The results are very striking. First there remains a large difference between the potential model calculation and the soft photon results, particularly for the analysing power, which indicates a strong sensitivity
of the process to non soft photon contributions. Second, both Paris and Bonn potentials give very nearly the same results for the cases which have been considered so far. In retrospect this can be understood, since the off-shell behaviour of the two potentials is quite similar.

Within the past month or so first results from the new TRIUMF experiment have become available. The comparison with theory is quite exciting: the data essentially track the predictions of our potential model calculation. Thus one clearly sees in the analysing power non soft photon behaviour, for essentially the first time.

A few interesting things remain to be done. First, we should do a more systematic comparison of Paris and Bonn results to see if we can find some corner of phase space where the experiment could distinguish between the off-shell behaviour of the two potentials. Second, although the calculation is gauge invariant, there are additional gauge terms coming from momentum-dependent parts of the potential which should be included. Derivation of such terms is an interesting problem in principle. They are important also in the general two-nucleon electromagnetic current needed for, say, electron-deuteron scattering. Their calculation is not straightforward; recent preprints by Riska [Helsinki preprint HU TFT-84-48 (Oct. 1984)] and by Arenhövel and collaborators [Buchmann et al., Mainz preprint MKPH-T-85-2 (1985)] have obtained different results.

Phenomenological form for the $n + p \rightarrow d + \gamma$ cross section

(H.W. Fearing, A. Thorlacius)

There has been a great deal of interest in recent years in high momentum transfer processes of which $(p, \pi)$ is a notable example. However, $(p, \gamma)$ reactions also involve similar large momentum transfers. We were thus led some time ago to extend our distorted wave impulse approximation (DWIA) calculation of $pd \rightarrow \gamma$ [Fearing, Phys. Rev. C 16, 313 (1977)] to the similar reaction $pd \rightarrow \gamma$.

As input for this DWIA calculation one needs the $np \rightarrow d \gamma$ cross section. Until recently there have been gross discrepancies among the various experiments. Over the last year or so, however, several new experiments have been completed which now nearly agree, so for the first time it has been possible to find a consistent representation of the cross section data in the medium energy range. Such representation was necessary for the DWIA calculation mentioned above and should be useful to others for similar calculations or for making qualitative estimates of the cross section in regions where it has not been measured. Thus this was written up separately and has now been submitted for publication [Thorlacius and Fearing, TRIUMF preprint TRI-PP-85-84].

General features of off-shell amplitudes

(H.W. Fearing)

A paper [Fearing et al., Phys. Rev. D 29, 2612 (1984)] has recently been completed and published which analyses the general relativistic and nonrelativistic structure of off-shell amplitudes for a variety of spin situations and develops rules for counting the appropriate number in each case. More recently some applications of this technique to the nucleon-nucleon problem have been examined. Such general off-shell amplitudes would be useful, for example, for a relativistic model of $p\gamma$ and are needed for extensions of the Dirac approach to $p$-nucleus scattering.

A related problem concerns the off-shell extension of nonrelativistic amplitudes. One needs to be able to vary such extensions in order to test sensitivity to off-shell effects in processes such as $p\gamma$. The usual technique is to make a short-range transformation on the coordinate space wave function such that the phases remain the same. For the $p\gamma$ calculation described elsewhere in this report, however, one needs to vary the amplitude directly. The off-shell amplitude can be written as an on-shell amplitude times a half-shell function $f$, so one wants to vary $f$. However, $f$ is constrained by unitarity and satisfies a Lippmann-Schwinger type integral equation, so arbitrary variations are not allowed. For a simple case it has been possible to obtain a general form for the transformations of $f$ which satisfy all of the constraints. If this can be extended to the general case, it should make practical studies of off-shell sensitivity in our $p\gamma$ calculation and in similar calculations formed in terms of amplitudes instead of wave functions.

Few-body kaon reactions

(H.W. Fearing, R.L. Workman)

One area which may become increasingly important at TRIUMF if plans for a KAON factory proceed as hoped is the study of strange particles and particularly kaons. This pro-
vides a motivation for looking at some simple kaon reactions and presents an opportunity to explore some exciting physics in an entirely new area. At the same time it provides a chance to apply some of the techniques learned in nonstrange processes to new problems. Of particular interest are the reactions \( Kp \rightarrow \Lambda \gamma \) and \( Kd \rightarrow \Lambda n \gamma \). Little has been done on these, either theoretically [Burkhardt et al., Nucl. Phys. A440, 653 (1985); Akhiezer et al., Sov. J. Nucl. Phys. 27, 115 (1978)] or experimentally [Lowe et al., Nucl. Phys. B209, 16 (1982)], but there is a proposal at Brookhaven National Lab [AGS proposal 811, B.L. Roberts, spokesman, (Jan. 1985)] involving a number of people from the TRIUMF/UBC group to measure both of these reactions, so new data may be available over the next few years.

The \( Kp \) reaction is important as input for the \( Kd \) process but is also interesting in itself, since it seems to be very sensitive to the properties and perhaps the quark structure of the poorly understood \( \Lambda(1405) \) resonance. The \( Kd \) reaction on the other hand may give information about the \( \Lambda \)-neutron interaction. Using stopped kaons and looking at the high energy end of the gamma spectrum, one may learn about the low energy \( \Lambda \)-neutron scattering just as the reaction \( \pi d \rightarrow \pi n \gamma \) has given information on the \( n-n \) scattering length and effective range [Gabioud et al., Nucl. Phys. A420, 496 (1984)]. With kaons captured in flight one can explore the possibility of exotic \( \Lambda-n \) resonances, which have been suggested in a variety of quark models [Dalitz, Nucl. Phys. A354, 101 (1981)].

The first step is to analyse the simpler \( Kp \) reaction and so we have tried to understand and extend the one existing modern calculation [Burkhardt et al., Nucl. Phys. A440, 653 (1985)] which is based on evaluation of a series of diagrams involving as intermediate states \( \Lambda, \Sigma, K^*, N^* \) and perhaps others. It turns out that the reaction is very sensitive to the \( \Lambda(1405) + \Lambda \gamma \) coupling and in fact a measurement of the rate can be interpreted as a measurement of this essentially unknown coupling. One next must extract from this calculation an appropriate operator to use for the \( Kd \) reaction. The one previous calculation [Akhiezer et al., Sov. J. Nucl. Phys. 27, 115 (1978)] used a very simple \( \sigma e \) form, but for an accurate calculation this probably is not sufficient and it will presumably be necessary to develop a more elaborate form analogous to the recent form used for kaon photoproduction [Adelseck et al., Ohio Univ. preprint (1985)]. Other features such as the effect of D-state components of the deuterium wave function or properties of the initial kaon state will also have to be considered.

Thus, though this area of research has just begun, it offers very interesting and exciting possibilities for exploring new physics, which we anticipate will be pursued in the coming year.

Meson-baryon scattering

(B.K. Jennings; E.A. Veit, Porto Alegre, Brasil; A.W. Thomas, Adelaide)

The cloudy bag model has been applied to \( \pi \)-nucleon and kaon-nucleon scattering with considerable success. The fit to the kaon-nucleon scattering amplitudes is reasonable although there is clear evidence that the spin-orbit force is too weak. In pion-nucleon scattering there is a problem with the s-wave (see the following contribution) but the \( P_{33} \) and the small p-wave scattering length are quite good. The \( P_{11} \) channel is quite poor due to an inadequate treatment of the Roper resonance and the inelasticity.

S-wave pion-nucleon scattering in the context of the cloudy bag model

(E.D. Cooper, B.K. Jennings)

The cloudy bag model calculations for S-wave \( \pi-N \) scattering which were done at the same time as those for the higher partial waves did not give a good agreement with the experimental data (either scattering lengths or energy dependence). We have examined the problem and concluded that, at least for S-waves, higher-order effects are important. Working with a chirally invariant Lagrangian we have considered all effects of second order \( (1/f)^4 \) explicitly and have approximately included effects of terms of still higher order. It appears to be very important to choose carefully which higher-order diagrams to include and which to neglect. In particular one must choose a set of diagrams whose sum exhibits unitarity; otherwise the phase shifts will not come out to be real. The other, equally important, consideration is that of PCAC. We must be careful to include diagrams whose sum has an isoscalar piece which goes to zero in the limit of soft pions (at least as fast as \( m_\pi \)). In order to satisfy this latter requirement we have observed that using a K-matrix formalism is superior to that of a Lipmann-Schwinger equa-
tion technique since it not only imposes unitarity on the T matrix but also approximately allows for PCAC to be satisfied in all orders. We have also found an interesting connection with the meson exchange picture, specifically the Bonn potential. The Bonn potential gives a terrible description of pion-nucleon S-wave scattering, which can be attributed to the fictitious 'sigma' meson used to describe nucleon-nucleon scattering. The cloudy bag model contains diagrams analogous to 'sigma' meson exchange, but these diagrams do not form a chirally invariant set. When other diagrams are included in the cloudy bag picture the disagreement with experiment goes away; however, in the Bonn meson-exchange picture there are no corresponding diagrams, meaning that the Bonn meson-exchange picture as it presently stands does not lead to calculations which satisfy PCAC.

Theory of mesonic and dibaryonic excitations in the πNN system (T.-S.H. Lee, ANL; A. Matsuyama)

A πNN theory, incorporating mesonic and dibaryonic excitation mechanism, is introduced to give a unified description of πNN systems. The mesonic mechanism is built into the theory by extending the conventional meson theory of nuclear force to include the isobar Δ excitation. The dibaryonic excitation at short distance is introduced according to current understandings of six-quark dynamics. The resulting scattering equations satisfy the two- and three-body unitarity relations. These equations consist of two-body coupled-channel equations and Faddeev-type three-body equations, both of which can be solved by well-established numerical method. Using this formulation we have studied (1) validity of coupled-channel method in NN elastic scattering, (2) nonresonant pion production mechanism on NN elastic scattering, (3) exclusive NN + πNN reaction in the intermediate energy.

P-matrix approach to pion hadron scattering (M.J. Iqbal, B.K. Jennings)

With the advent of the quark model it has become clear that any scattering of the elementary hadrons has to be described in terms of their respective quark substructure. P-matrix formalism of Jaffe and Low [Iqbal and Jennings, submitted to Phys. Lett. B] is such an attempt. This model is based upon the ideas of more familiar matching radii models e.g. R-matrix and F-matrix formalisms of 'conventional' nuclear physics. A specific model of pion hadron scattering was developed which allowed explicit construction of the P matrices of Jaffe and Low in the interior and exterior regions. We found that only under the extremely simplified assumption of no correlations between quarks and antiquarks in the inside region can one identify P-matrix poles with bag model primitives. For low-energy pion-nucleon scattering different models for the pion substructure gave identical low energies πN phase shifts. Thus P-matrix formalism has no predictive power for low energy hadron scatterings.

2π-exchange pair contributions in the quark model (J. Thaler)

The 2π-exchange pair contribution to the NN interaction for a pseudovectorial pion coupling is studied in the constituent quark model and compared with results from elementary nucleons. It is found that the quark structure of the nucleons increases this interaction at intermediate ranges, where the overlap of the nucleons is negligible.

Coulomb corrections to α-α phase shifts (J. Thaler)

Realistic NN potentials like the Paris and the Bonn potential give different results for the peripheral α-α phase shifts at low energies, with resulting consequences for the polarization of α particles. To study the hadronic α-α interaction in more detail, Coulomb correction in this system has been considered and compared with model-independent predictions.

Electroweak interactions

Neutral currents and extra Z°'s in E6 (S. Godfrey and G. Belanger)

Interest in E6 unified theories was renewed when it was found that E6×E6 superstring theories led to a gauge theory with E6 symmetry after compactification to four dimensions. The E6 gauge symmetry is broken at or below the Planck scale to an extended standard model which possesses at least an SU(3)×SU(2)×U(1)×U(1) symmetry. These theories imply the existence of new exotic fermions and of at least one additional neutral heavy gauge boson Z'. This new gauge boson could possibly have a mass as low as 150 GeV. The lower bound on the mass of Z' is obtained by fitting the data to the various neutral current parameters. The couplings of Z' to the fermions are determined in E6 theories and
depend on the pattern of symmetry breaking. In some cases the couplings of \( Z'\) to the fermions will be such that the neutral current parameters will allow for a mass of \( Z'\) slightly above the one of \( Z^0\). The effects of the new boson can be detected by searching for deviations from the standard model predictions in new experiments. We calculate the longitudinal polarization asymmetry, i.e. the difference between the cross section for left and right-handed polarized initial beam, in various symmetry-breaking schemes of \( E_6\). Such experiments with polarized \( e^+e^-\) beams will be performed at SLC.

The effects of anomalous \( Z^0\) decays on neutrino counting near the \( Z^0\) peak
(S. Godfrey, J. Ng; P. Kalyniak, Carleton)

Determining the number of neutrinos is important in understanding the number of generations and ultimately constructing a more complete theory of the fundamental interactions. At present we have bounds on the number of neutrinos from cosmological arguments and also from the \( Z\) boson width. A potentially more accurate method, which can be performed at LEP at CERN and at SLC at SLAC, is to measure accurately the cross section \( e^+e^- + Z^0\gamma \) followed by \( Z^0 + \nu\bar{\nu}\). Motivated by the so-called anomalous \( Z^0\) decays observed by UA1 and UA2 at CERN we considered how a new, presently unknown, interaction could affect the \( e^+e^- + \gamma\nu\bar{\nu}\) cross section. This could be viewed in different ways: 1) How could one minimize the adulteration of a new interaction on neutrino counting? 2) Could the measurement be used as a means of looking for new physics?

In performing this calculation we parameterized the \( Z^0 + \ell\bar{\ell}\gamma \) vertex by an effective Lagrangian, \( \mathcal{L}_{\text{eff}} \), and constrained the parameters of \( \mathcal{L}_{\text{eff}} \) by the ratio \( \Gamma(Z + \ell\bar{\ell}\gamma)/\Gamma(Z + \ell\bar{\ell}) \), Bhabha scattering, and low energy \( \nu\mu\) scattering data. We found that the effect on neutrino counting can be significant but depends on the magnitude and signs of the parameters in \( \mathcal{L}_{\text{eff}} \). If one's interest is in determining \( \lambda_0 \) and one wants to avoid the possible adulteration from \( \mathcal{L}_{\text{eff}} \) the value of \( E_{\text{c.m.}} = 100\ \text{GeV} \) appears to be most suitable. We also found that accurate measurements of the cross section \( \sigma(e^+e^- + \nu\gamma\gamma) \) at the \( Z^0\) peak can be used as a sensitive test for new physics [Z. Phys. C (in press)].

Intermediate-mass standard Higgs boson production in polarized \( e^+e^-\) colliders (R. Bates, UBC; J. Ng)

We have calculated the production rate of the standard Higgs boson \( H^0 \) in the mass range of 40 to 150 GeV/c\(^2\) in \( e^+e^- \) annihilation to \( H^0\ell\bar{\ell} \) where \( \ell = e, \mu, \nu \). It is found that \( H^0\nu\bar{\nu} \) is the best mode for the discovery of the \( H^0 \). Polarized beams are useful for filtering out the background. We have corrected an error in the literature by Jones and Petcov who calculated a similar process previously.

Nonstandard Higgs scalar and pseudoscalar boson production in \( e^+e^-\) and ep colliders (R. Bates, UBC; J. Ng)

The production rate for \( 0^- \) and \( 0^+ \) Higgs bosons in the two-Higgs doublet extension of the standard is calculated to be about 0.8 pb in ep colliders and less in \( e^+e^-\) colliders for mass range of 40-250 GeV/c\(^2\). Enhancement due to possible large Yukawa couplings of these bosons to the \( t \) quark is employed. The standard Higgs boson production rate is an order of magnitude smaller for this mass range.

Higgs boson to two-photon decay widths in supersymmetric theories (R. Bates, UBC; P. Kalyniak, Carleton; J. Ng)

The Higgs boson to two photon is phenomenologically important if it can be enhanced. The signal of two back-to-back photons is spectacular. Also a large width will enhance the production rate of the boson in \( e^+e^-\) and ep colliders. We calculated this rate in the minimal supersymmetric SU(2) x U(1) theory. By using the superfield techniques we establish that this width is nonvanishing in the supersymmetric limit. This construction is proven by explicit Feynman diagram calculation in the physical Wess-Zumino gauge. This is in contrast to other 3-point functions that are calculated such as the \( g-2 \) of the lepton which vanishes in the supersymmetric limit.

We have also extended the calculation to a realistic SU(2) x U(1) gauge theory with broken supersymmetry being induced by supergravity. It is found that a supersymmetric Higgs boson can have larger two-photon widths than the standard nonsupersymmetric Higgs boson. However, the nonsupersymmetric two-Higgs doublet model gives the largest two-photon widths.
Axions and familons in muonium
(G. Bélanger and J. Ng)

We have constructed the general effective interaction of familons and axions with the muon and the electron. Muonium-antimuonium transitions can be induced by familon exchange. The singlet and triplet states of muonium receive contributions from both axions and familons. We have also calculated the contribution of the familon to $e^-e^+\mu^-\mu^+$ scattering. Numerical values of the constraint on the familon and axion couplings from the above processes are now being determined.

Heavy ion collisions

Heavy ion scattering at intermediate energies
(W.H. Dickhoff; A. Faessler, H. Trefz, Tübingen)

The scattering process of two nuclei is one of the most difficult many-body processes one can address because of the multitude of final states which can be reached in such collisions. In order to understand the experimentally observed elastic and inelastic cross sections as well as total cross sections a program has been developed (Tübingen) which constructs the optical potential of two nuclei on the basis of a generalized local density approximation. Within an energy-density formalism it is possible to relate locally the two densities of the heavy ions to Fermi momenta in nuclear matter separated by an average relative momentum which is directly related to the beam energy. For such a nuclear matter configuration the complex energy density is calculated by applying Brueckner theory. This approach should therefore make sense when the dominant reaction mechanism is provided by individual nucleon-nucleon collisions (modified by Pauli-blocking etc.) Indeed in Fig. 79 the total reaction cross section for $^{12}$C+$^{12}$C demonstrates that at intermediate energies this is indeed the case (dashed curve). These calculations are performed by using the complex optical potential generated from this nuclear matter description. Obviously at low energy the reaction mechanism has still another component not considered up to now. Indeed strong inelastic excitations of (mainly) the $2^+$ ($E_x=4.44$ MeV) state in $^{12}$C occur at lower energies which are not taken into account by this nuclear matter description. Including such collective excitations in coupled-channels leads to good agreement for both the elastic and inelastic cross section at $E_{LAB} = 1016$ MeV. In addition the reaction cross section at lower energies is enhanced (full curve) bringing the theory in rather good agreement with experiment.

Two particle correlations in relativistic heavy ion collisions (B.K. Jennings; D.H. Boal, J.C. Shillock, Simon Fraser)

The first data collected and analysed in relativistic heavy ion collisions was the particle spectrum. The shape of the spectrum was mainly sensitive to the temperature achieved in the collision region. More recently the emphasis has shifted to the measurements of two-particle correlations. The results here seem to be mainly sensitive to the size of the interaction region. There are two approaches to calculating the correlation function. One is the thermal model and the other is the Hanbury-Brown/Twiss description based on final-state interactions. We have shown that the two models give similar results. When the source size is not too small the correlation function, in both models, is just proportional to the derivative of the phase shift, and thus there is a simple expression for the correlation

Fig. 79. The reaction cross section for $^{12}$C+$^{12}$C as a function of beam energy per nucleon is displayed. The dashed curve shows the results including only the energy dependent volume optical potential. The full curve displays the results for the coupled channel calculation including the collective $2^+$ and $3^-$ states. One sees that the drop in the reaction cross section is mostly due to the decreasing importance of collective excitations in this reaction as a function of energy.
function. When there is an attractive potential with a bound state the two particles may be anti-correlated the same as for a repulsive potential.

Muon spin rotation

Spin dynamics of muons in solids
(M. Celio; P.F. Meier, S. Vogel, Zürich)

In the last years many experimental methods have been developed to measure the time-dependent polarization of positive muons which stop in solids. These measurements yield information about the local magnetic fields at the muon site and about the diffusion of the muons through the host.

Recently A. Abragam pointed out that the well-known solid state level-crossing method, commonly used in NMR, could be successful in μSR too. First experiments have been performed at TRIUMF for the case of copper, and the results have been analysed with the aid of a phenomenological formula.

We have generalized our previous numerical calculations and we have been able to calculate from first principles the polarization function \( p(t) \) for a muon interacting with several nuclear spins and in the presence of a longitudinal field. For the case of a muon located at the tetrahedral site we could explicitly calculate \( p(t) \) and we predicted quantitatively the resonance behavior at a field of about 80 G in copper. Presently we are extending these calculations to the case of a muon located at the octahedral interstitial site.

Starting from the calculated static relaxation function \( p(t) \), one can obtain the corresponding quantity for a muon diffusing through the lattice by solving a strong collision model.

We hope that a comparison of these calculations with the level-crossing experimental data will allow one to a better understanding of the controversial diffusion of muons in copper below 10 K.

Master equations and spin dynamics
(M. Celio; D. Loss, Zürich)

In the first part of this work we critically compared three different perturbation treatments concerning the time evolution of open systems. The conventional perturbation theory, the usual master equation and its more recent memoryless version were discussed both formally and with the aid of simple examples in the field of spin dynamics. The difficulty of constructing convenient Markov approximations as found by the three different methods was discussed; in particular we investigated whether the Markov solutions preserve positivity or not.

In the second part of this work the theory of master equations was applied to some problems of spin dynamics. We discussed the quadrupolar relaxation of nuclei having spin \( \frac{1}{2} \), examined the spin relaxation of positive muons in the intermediate regime between static behavior and fast diffusion, and we finally generalized our previous model on muonium depolarization in solids. Our purpose was to demonstrate the remarkable flexibility of the master equation approach and to show that this 'exotic' theory can lead to useful results in practical cases.

Numerical techniques

Numerical integration of the Schrödinger equation
(E.D. Cooper, E. Thorlacius)

The standard technique in nuclear physics for integrating the radial Schrödinger equation is to use the Numerov Method. A variation on this technique is examined which leads to a new algorithm, which is almost as simple to use, is self starting and for the same accuracy allows one to use a step size about three times larger than the simple Numerov method. The method can also be used in coupled channel situations and for integrating the Dirac equation once it has been reduced to two-component form. Tests have shown the method to produce a time saving of at least a factor of 2 and often close to 5 for the same precision.
INTRODUCTION

The Applied Programs Division had a productive year. The number of patients and their case histories in pion therapy indicated that such therapy is superior to other radiation treatments for the types of tumours treated. The steady operation of the CP-42 cyclotron has allowed AECL to plan its sales contracts with assurance, and production of \(^{123}\)I with the CP-42 cyclotron has increased so that now the system is capable of producing 5 Ci batches. An on-site program of \(^{123}\)I labelling to supply \(^{123}\)I radiopharmaceuticals was begun by AECL. The CP-42 cyclotron target cave was expanded so that up to 9 beam lines and their target stations can be installed and operated. The fraction of CP-42 time allocated to TRIUMF research has been directed toward the production of PET radiopharmaceuticals, and the routine fluorodopa production has now been automated. PET research concentrated on studies of dementia and movement disorders. A number of subjects who were exposed to neurotoxin MPTP were examined with PET scans and demonstrated a reduced uptake of fluorodopa in a similar way as shown in Parkinson's disease. While beam line 2C is being commissioned, labelling kits for the production of phenyl fatty acid and its analog radiopharmaceuticals have been developed. Radioisotopes produced from TRIUMF are thus being packaged in a convenient way for the medical community before the isotopes leave TRIUMF.

BIOMEDICAL PROGRAM

In 1985 the pion radiotherapy program continued the treatment of brain and pelvic tumours. Another 32 patients were treated bringing the total to 100 since May 1982. As we now enter the fourth year of patient treatments, we feel we have accumulated enough data to claim that pion radiotherapy is superior to conventional radiation for the types of tumours that we investigated. The present data also appear to indicate that the survival probability of brain patients increases steadily with increasing pion treatment doses so we are still in the process of optimizing the treatment schedule (dose and fraction) and methods of patient immobilization. The brain tumour treatment dose has now reached 2.4 Gy per fraction for 15 fractions, while the pelvic tumour dose has also increased to 15 fractions from 12 since June. A list of patient treatments for 1985 is shown in Table IX.

In April a special set-up procedure was initiated to monitor the accuracy of patient positioning during pion treatment. A diagnostic X-ray unit was installed in the treatment room. Pictures were taken of all the patients in the immobilizing shells on the treatment couch as each was set up ready for pion irradiation. The patient bone structure in each of these pictures was then analysed to determine the error in the set-up, and the patient position was readjusted when necessary. This was performed for all the patients in every treatment dose fraction for the June-August run. The result indicated that the accuracy for the pelvic patient position was in the order of 1 cm. The brain patients were immobilized with a much more rigid thermoplastic system, hence the accuracy was in the order of 1-2 mm, and adjustments were seldom required.

Table IX. Summary of TRIUMF pion patient treatments for 1985.

<table>
<thead>
<tr>
<th>Run</th>
<th>Patient</th>
<th>Fraction finished/intended</th>
<th>Total days</th>
<th>Dose/fraction ((\pi^+) rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar</td>
<td>X pelvis</td>
<td>11/12</td>
<td>17</td>
<td>250</td>
</tr>
<tr>
<td>May</td>
<td>X brain</td>
<td>15/15</td>
<td>21</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>21</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>19</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>23</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>21</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>18</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>17</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>12/12</td>
<td>14</td>
<td>240</td>
</tr>
<tr>
<td>Jun</td>
<td>X brain</td>
<td>15/15</td>
<td>19</td>
<td>240</td>
</tr>
<tr>
<td>Aug</td>
<td>X brain</td>
<td>15/15</td>
<td>29</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>8/8</td>
<td>20</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>7/7</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>21</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>20</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>21</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>21</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>18</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>7/7</td>
<td>18</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>8/8</td>
<td>18</td>
<td>194</td>
</tr>
<tr>
<td>Nov</td>
<td>X brain</td>
<td>15/15</td>
<td>22</td>
<td>240</td>
</tr>
<tr>
<td>Dec</td>
<td>X brain</td>
<td>15/15</td>
<td>23</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>14.5/15</td>
<td>23</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>23</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>1/1</td>
<td>22</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>14/15</td>
<td>22</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>22</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>26</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>27</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>24</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>23</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X brain</td>
<td>15/15</td>
<td>22</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>22</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>X pelvis</td>
<td>15/15</td>
<td>22</td>
<td>220</td>
</tr>
</tbody>
</table>

aRepeat patient
These verification and adjustment procedures were conducted with the patient in the irradiation position which, unfortunately, is at the point where the neutron and gamma background is the highest in the treatment room (0.5-1.0 mSv mrem/h). This is probably the main reason why two of the biomedical staff registered an unusually high personnel dose of about 5 mSv for two consecutive quarters. These doses were only the gamma component of the background dose. From our past experience the neutron background dose is usually 4 to 6 times that of the gamma background dose. However, as pointed out by the TRIUMF safety group, these Li TLD gamma personnel dosimeters may be particularly sensitive to neutrons.

During the November-December run the verification procedure was therefore greatly simplified and the brain patients were only checked once at the first dose fraction. Improvements are being made to the pelvic shells so that verification can be eliminated altogether next year.

It was discovered at the beginning of the year that the foundation block under dipole B2 had swollen and had expanded upward. The block also appeared to be cracking up as is clearly visible to any visitor to the beam line 1A tunnel. This is presumably due to some chemical reaction after prolonged absorption of water which was delivered periodically from water leaks in the M8 channel directly above this block. This expansion must have taken place over many years and is expected to account for many of the vacuum and water leaks as well as other misalignment problems in the M8 channel. In particular, this explains why the readout of the quadrant chambers on Q5 was drifting continuously towards the upper quadrants during the last several years. A beam axis survey indicated that the second half of the M8 channel has shifted upward by as much as 1.5 cm. This concrete block was chipped away and replaced by steel jacks in April and the second half of the channel was realigned in September.

Animal radiobiological experiments are also conducted in the channel after the daily patient operation. A mouse gut system is being used by a visiting Japanese group to investigate the dependence of biological effect on the volume of the pion treatment fields. Another group from Los Alamos is using a rat spinal cord system to look at the late effect of pion irradiation on the central nervous system.

42 MeV CYCLOTRON

Operation

1985 was the second full year of cyclotron operation. As during the first year the machine has been operating every week of the year. It delivered 637 mAh of beam, an increase of 37% over the first year. The machine was used 90% of the time for radioisotope production for AECL's Radiochemical Company and 10% of the time for the production of positron emitters for the PET program at the UBC hospital.

Figure 80 illustrates the weekly beam production during the year. The first six months show fairly the cyclotron's increasing productivity. After that the demand for beam decreased because more beam time was used for gas targets, which cannot absorb the maximum available beam current. The low productivity during weeks 40–47 was caused by the target cave shutdown followed by a failure of the rf system that delayed coming up to normal production by a few weeks. During the cave shutdown almost all production for AECL and PET was maintained with targets in the cyclotron vault. The exception was one AECL isotope which, while not the most profitable, happened to require much high power beam time.

Failures

Dee insulator failures are still a problem, but there was one 4-month period without any such failures and one of the insulators has now lasted almost two years. Other more serious failures were due to vacuum leaks,
one of which resulted in flooding the cyclotron tank with cooling water, and an rf failure caused by an aging oscillator tube.

Improvements

A Mark II solids target station was installed in the cyclotron vault in June, thus eliminating many of the failures that plagued the Mark I version. The failure-prone bellows assemblies at beam ports #7 and #13 have been replaced by more rugged devices. All exit port slits and beam line collimators as supplied by the manufacturer have been replaced by a better design.

Expansion

In October the target cave was shut down and the Mark I solids target station and the PET gas target were removed. A switching magnet* with potential for 9 beam lines was installed, along with a Mark II solids target station, a new PET gas target for $^{18}$F production, an H$_2$O target for $^{15}$O production and a gas target for $^{15}$O production. Monitor boxes, each containing a scintillator and a beam scanner, have been installed or are available for all beam lines. The new cave layout is illustrated in Fig. 81. Commissioning of the switchyard and target systems was straightforward, and the Mark II solids target station and the new neon gas target are again in regular use.

RADIOISOTOPE PROCESSING (AECL)

High intensity beam for the production of isotopes in the 500 MeV facility is available on a schedule which is not ideally suited for use in routine medical applications. However, TRIUMF's consistent performance against plan has enabled AECL to make firm commitments based on future schedules and TRIUMF's reliability has been well demonstrated. This has resulted in an increased demand for $^{127}$Xe. The $^{127}$Xe back-up arrangement with Brookhaven National Laboratory has worked well for both parties in 1985.

The CP-42 cyclotron, which is the workhorse for isotope production, performed well in 1985 and a number of improvements for machine reliability were made as well as development of the facilities in the target cave. This work which was completed in November was accomplished without any extended cyclotron shutdown but with limited production over a 6–8 week period. Back-up arrangements ensured that all contractual commitments were met. In addition to the routine production of $^{201}$Tl, $^{123}$I, $^{111}$In, $^{67}$Ga and $^{57}$Co the CP-42 was used to make $^{205}$Pb, which is being used as a tracer by geological survey laboratories for the analysis of minerals by mass spectrometry.

A number of improvements to the yield of $^{123}$I from a $^{124}$Xe gas target were made in 1985 and the system in use at year-end is able to produce batches of 5 Ci of $^{123}$I. In the unlikely event of a catastrophic failure resulting in release of target gas to the cyclotron vacuum chamber, a system was installed to allow the costly charge ($\$50,000$) of $^{124}$Xe to be recovered. This was successfully tested this year when the window cooling system failed prior to the installation of appropriate interlocks. Negotiations are under way with prospective purchasers of this patented technology.

An active $^{123}$I labelling program was initiated in 1985. The aim is to be able to supply a number of $^{123}$I radiopharmaceuticals to hospitals in Canada from the facilities at TRIUMF. $^{123}$I hippuron for renal studies will be routinely available in May 1986, and it will be followed by brain-imaging $^{123}$I amphetamine and $^{123}$I phenyl fatty acids for heart imaging. Preliminary work is under way with estrodiol for tumour imaging in ovarian cancer. It is hoped that future close co-operation with hospitals in the Vancouver area will lead to the evaluation of some unique $^{123}$I-labelled compounds for brain scanning.

500 MeV RADIOISOTOPE PRODUCTION

Proton irradiation facility for solids

The year 1985 was the sixth year of operation for the 500 MeV isotope production facility. The facility performed without failures and received 170 mAh, which is about the same as last year. The use of the facility is illustrated as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>mAh to facility</th>
<th>Targets irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>51</td>
<td>40</td>
</tr>
<tr>
<td>1981</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td>1982</td>
<td>120</td>
<td>49</td>
</tr>
<tr>
<td>1983</td>
<td>142</td>
<td>70</td>
</tr>
<tr>
<td>1984</td>
<td>172</td>
<td>82</td>
</tr>
<tr>
<td>1985</td>
<td>218</td>
<td>90</td>
</tr>
</tbody>
</table>

*Supported in part by a grant from the Mr. and Mrs. P.A. Woodward's Foundation.
This year's targets consisted of 12 indium targets for the production of $^{109}$Cd and 87 CsCl targets for the production of $^{127}$Xe.

**Gas target**

The $^{18}$F gas target, after its partial repair in 1984, has been available as a back-up for the 41 MeV $^{18}$F gas target. To protect the target from unnecessary activation and to avoid unnecessary degrading of the proton beam, it was parked just outside the beam early in the year. The target was not used in 1985. Recently it developed a small leak in the helium-cooled windows.

**POSITRON EMISSION TOMOGRAPHY (PET)**

The PET program continued in 1985 with support from the final installment of Medical Research Council Special Project Grant SP-7. In April the program was site visited by a team from MRC in connection with our application for grant renewal. As a result, the special project grant was renewed for three more years, with a substantial budget increase.

The PETT VI positron emission tomograph built at TRIUMF in 1982 continued to work in exemplary fashion this year. During this year the
procedures for scan data acquisition and subsequent analysis were both moved from the Department of Electrical Engineering VAX 11/750 computer to a similar system in the UBC Acute Care Hospital, previously acquired by the PET group via MRC capital funding. At the time of this consolidation networking was installed to provide for convenient file transfers between the two computers and TRIUMF as well as software improvements leading to accelerated and automated data acquisition procedures.

The program of tomograph physics research continued this year, with emphasis upon the understanding of noise propagation from various sources through the image production process. The variation in noise (variance) as a function of radius for a cylindrical source was studied (see Figs. 82 and 83) and the separate contributions to the variance distribution from clinical emission data and from transmission data (used to correct for gamma-ray attenuation in the emission process) were determined (see Fig. 84). Following this separation strategies were developed to reduce overall image noise content, and in particular the effect of smoothing of the transmission data was shown to reduce image noise by up to a factor of 15 (see Fig. 85) without loss of image resolution. These data were presented in two papers before the IEEE Nuclear Science Symposium.

The program of chemical research into the synthesis of new scanning agents continued, with improvements in the procedure for synthesis of 6-fluorodopa and developments in the synthesis of $^{11}$C-carboxy-labelled-dopa. The procedure for transport of $^{15}$O-labelled-oxygen gas from TRIUMF to the hospital via the pneumatic transport system was almost ready by year's end. Progress was also made on the synthesis of $^{75}$Br-labelled-spiroperone as well as other neurotransmitter scanning agents.

In the program of medical research via positron emission tomography the main emphasis was placed on dementia (particularly Alzheimer's disease and schizophrenia) and on

![Fig. 84. Variance images representing noise distribution due to (a) noise in emission data and (b) noise in transmission data for fluorodopa PET slice data as shown in Fig. 86.](image-url)
movement disorders (dystonia, Parkinson's disease, Huntington's disease, and others); lesser amounts of scan time were also devoted to epilepsy, brain tumours, depression, and some cerebral vascular diseases.

Most of the scans were acquired with $^{18}$F-2-deoxy-2-fluoro-D-glucose and $^{18}$F-6-fluorodopa as scanning agents, with a lesser number of scans acquired via $^{15}$O-labelled-water. The respective physiological functions studied were regional cerebral glucose metabolism, dopamine synthesis rate and blood flow. At the beginning of December a total of 272 subjects had been scanned, including normal volunteers and subjects suffering from the above diseases.

In the program of research into Alzheimer's disease data were published this year demonstrating the correlation between the extent of the reduction of glucose metabolism (particularly in the parietal and temporal lobes of the brain) and the progressive dementia exhibited by Alzheimer's subjects. The PET technique coupled with the FDG scanning agent appears to distinguish brain atrophy, exhibited both by the normal elderly and subjects suffering from Alzheimer's disease, from the reduced glucose metabolism characteristic of the latter group.

In the movement disorder research program extensive use was made this year of the 6-fluorodopa scanning agent particularly in studies of Parkinson's disease. Particularly interesting studies were conducted upon subjects from California who had been exposed to the neurotoxin MPTP, which has been implicated in an epidemic of Parkinsonism amongst users of 'synthetic heroin'. It was shown that subjects exposed to this material exhibited substantial reduction in fluorodopa uptake into the striatum of the brain (the region also implicated in natural Parkinson's disease) whether or not they displayed symptoms of that condition (see Fig. 86). These results were published in the context of a possible origin for natural Parkinson's disease in an article in Nature (September).

Progress in the medical research program via PET was again this year largely limited by the availability of beam time for PET on the CP-42 cyclotron, although neon gas target installed in beam line 1A of the 500 MeV TRIUMF cyclotron also contributed to the program. The productivity of the CP-42 cyclotron for PET was materially improved toward the end of this year by the installation of a switching magnet, built with significant support from the Mr. and Mrs. P.A. Woodward's foundation. This magnet, which is described in detail elsewhere, removed the
difficulties associated with PET targets being mounted in tandem with AECL targets for commercial radioisotope production. It also will permit the installation of multi-target systems (economizing personnel radiation exposures during service) and will also facilitate the rapid switching of beam between targets required for short PET irradiations.

This year progress also continued on developments towards a second higher-resolution PET camera, employing novel detector technology. This work, which was supported by the B.C. Science Council, is described in the following section.

During the year 15 full papers and 15 abstracts were published from the PET program, both in the basic science and in the medical science literature (see Appendix A).

Whole body tomograph development

An extensive computer simulation has been completed to design a new type of scintillation camera for nuclear medicine [Rogers et al., submitted to Phys. Med. Biol.]. The aim of the design is to adapt the Anger camera to perform well at higher gamma energies, especially 511 keV. Such a design should provide an economic alternative to the small-crystal ring tomograph for PET, as well as improved efficiency for single photon ECT in the energy range 140-511 keV. A prototype has been constructed to test the new ideas arising from the design study. The prototype incorporates a 5 cm thick sodium iodide scintillator coupled to a rectangular array of 64 small photodetectors. Intrinsic position resolution measurements, as well as a variety of other measurements, have been performed at gamma-ray energies of 122 keV and 514 keV.

As shown in Fig. 87 the design incorporates a thick crystal of thallium activated sodium iodide (NaI), as needed to obtain good efficiency of gamma rays of energies above 140 keV. To obtain good spatial resolution from such thick crystals it should be useful to measure the depth-of-interaction of the gamma rays in the scintillator. This will allow correcting for the depth-dependent distortion that otherwise would spoil the spatial resolution. The new camera incorporates a specular reflector on the gamma-ray entrance window in the form of a plastic corner reflector sheet, similar to the reflectors commonly used as warning reflectors on bicycles. The corner reflector sheet refocuses the reflected light back to its point of origin and thus minimizes the lateral spreading of the light which eventually reaches the PMT cathode surface. In addition, a fiberoptic plate light filter is used to collimate the light reaching the photomultiplier tubes (PMTs). Scintillation light will be detected in one or more multiwire anode tubes of the type announced last year by the Hamamatsu company. These tubes image the cathode charge on a position-sensitive anode composed of parallel wires. Independent x- and y-images may be obtained for wire spacings on the order of 1 cm. Each set of parallel wires images the integral of the cathode charge along the adjacent strip photodetectors of width and spacing equal to the wire-to-wire separation. These crossed-wire imaging PMTs provide an economical way to sample a two-dimensional light distribution at small (~1 cm) intervals. Each wire will be connected to a charge-sensitive ADC.

Spatial resolution measurements were made on the prototype with collimated gamma-ray beams of 122 keV and 514 keV. The results of these measurements were reported at the 1985 meeting of the IEEE Nuclear Science Symposium [Rogers, IEEE Trans. NS-33 (in press)].

A U.S. patent has been applied for to cover the new detector design [J.G. Rogers and D.P. Saylor, "Method and Apparatus for 3-d Enclosing", Serial No. 723,342, filed April 15, 1985]. A similar patent application will also be filed in Canada.

Spatial resolution measurements were made on the prototype with collimated gamma-ray beams of 122 keV and 514 keV. The results of these measurements were reported at the 1985 meeting of the IEEE Nuclear Science Symposium [Rogers, IEEE Trans. NS-33 (in press)].

A U.S. patent has been applied for to cover the new detector design [J.G. Rogers and D.P. Saylor, "Method and Apparatus for 3-d Enclosing", Serial No. 723,342, filed April 15, 1985]. A similar patent application will also be filed in Canada.
TRIM PROGRAM

The TRIM radioxenon processing microcomputer arrived in the spring and its programming is nearly complete. The TRIM safety report was submitted to TSAC and conditionally approved. Final approval awaits complete process control documentation and a demonstration.

The TRIM group, in collaboration with AECL and the University of Alberta, organized the International Symposium on Radiohalogens in Banff, September 10-11; 65 scientists from 8 countries attended and 27 papers were presented, two from the TRIM group.

The TRIM radiopharmaceutical programme has supplied $^{123}$I phenylpentadecanic acid and its $\beta$ methyl analog for heart research at Vancouver General Hospital and St. Paul's Hospital. Two grants have been awarded to UBC researchers for these projects. One completed project utilized the $\beta$ methyl analog for SPECT tomographic studies of infarcted hearts in dogs. Projects still under way include metabolic studies and assessment of heart response to cardioplegia and heart transplant procedures. Metabolic studies with the lactone analogs are more than half completed.

The brain imaging compound N-isopropyl para-$^{123}$I-iodoamphetamine (IMP) continued to be supplied for stroke evaluation. The supply of meta-$^{123}$I-iodobenzylguanidine (MIBG) was initiated. MIBG is useful for imaging the adrenal glands and certain tumours: neuroblastoma and pheochromocytoma. Initial human imaging has been carried out and additional work is anticipated.

Kit type labelling of important $^{123}$I pharmaceuticals was advanced. These pharmaceuticals include phenyl fatty acids, IMP, MIBG and Hippuran. A nuclear medicine technologist has worked one day per week to supply $^{123}$I pharmaceuticals to UBC researchers. Research commenced on new $^{123}$I compounds for labelling the heart and parathyroid.
The reliability of operation continued at a level comparable to the one achieved in 1984, as shown in Fig. 88. A total integrated current of 331 mAh was delivered in 25.5 weeks of high intensity beam operation, 13.5 weeks were dedicated to polarized beam and 13 weeks to shutdowns for maintenance and developments. Out of 6049 h of scheduled beam time the cyclotron was actually producing beam over 5407 h, corresponding to a reliability factor of 89.5% (88.5% in 1984). During 1984 322 mAh had been delivered during 35 weeks leaving eight weeks for polarized operation and nine weeks for shutdown maintenance and developments. In 1985, with the cyclotron producing more beam in less time, more time was available for both polarized beam and developments, both in greater demand. However, the production of good quality proton beams down beam line 4 became more difficult as a result of the lower split ratio (below 1/10^5). The radiation levels in the tank at the beginning of the shutdowns were higher than normal due to the more concentrated high intensity beam production. Developments to improve low split ratio, beam quality and beam losses in the tank are well under way.

RF amplifiers, probes, diagnostics and ion sources were the systems causing most downtime. Probes in particular form a system which, because of the difficult maintenance in the cyclotron tank environment, should receive greater emphasis for improved reliability in the future. During 1985 higher priority was dedicated to a few crucial developments aimed at increased beam capability. It should be noted that maintaining a reliable level of operation while the system is being developed and modified is a challenging task which will become more difficult in the years to come.

A large fraction of the shutdown time for developments was dedicated to the installation and testing of the elements which will allow extraction of a 100 μA H⁻ beam for injection into an accumulator ring. At the end of the fall shutdown an H⁻ beam completely separated from the cyclotron circulating beam (see Fig. 92) was produced at 450 MeV. The technique used the v_r = 1.5 resonance excited by a 11.5 MHz radial rf perturbation and a positive voltage electrostatic channel. If the H⁻ beam is well separated from the

---

**Fig. 88.** Beam charge delivered and hours of operation over the past several years. Milestones in extracted peak current are also indicated. The histogram shows the charge delivered per month.
Another highlight was the installation in the completed so that the desirable rf flat-topping
During the coming year it is planned to
ments caused by power on-off variations.
A system of rf booster cavities, to be inst-
installed in the outer region to increase the
energy gain per turn and the separation be-
tween successive turns, will improve the ex-
traction efficiency even further. In addition
this system will allow a three-fold redu-
duction in the electromagnetic stripping
losses in the present 500 MeV mode of op-
eration. One of these boosters and its 160 kW
amplifier are under construction. Testing
and installation are planned for 1986-87.

Another highlight was the installation in the
cyclotron tank of a new resonator segment
which has been developed according to tight
specifications in terms of flatness, tip
rigidity, cooling on both rf side and beam
side, and mechanical stability against dis-
tortions due to rf heating and vibrations
produced by perturbations in the water cool-
ing circuits. The unit is operating at full
power according to expectations with tem-
p eratures below 30°C on both sides of the canti-
levered structure. Vibrations around
0.0005 in. and a flatness within ±0.020 in.
have been measured. The segment reduces the
change in tip position of the adjacent seg-
ments caused by power on-off variations.
During the coming year it is planned to
replace at least eight segments, first in
those regions where the rf leakage is causing
the largest thermal distortions. A new
mechanical tuning system on the ground arm of
the new segments will also provide additional
rf tuning capacity.

Since an adequate replacement segment for
reliable and stable operation has now been
achieved, studies and modifications necessary
for the incorporation of the third harmonic
excitation of the cavity should soon be com-
pleted so that the desirable rf flat-topping
mode of operation can be tested and imple-
ment ed in the cyclotron in parallel with the
 gradual replacements of the resonators. A
significant milestone in this direction was
obtained in a teststand cavity consisting of
two cyclotron segments placed symmetrically
above each other and connected by side flux
coupling guides. A stable, flat-topped
waveform was produced and maintained at full
power and 80 kV voltage. Multipactoring
problems were overcome and automatic feedback
loops for phase and amplitude controls were
realized and optimized. In another effort, on
the 1:10 model, solutions for a uniform third
harmonic voltage behaviour along the dee gap
were explored and the study on how to reduce
parasitic modes of the fundamental and third
harmonic continued. Replacement of the cen-
tral region segments to adjust the resonating
frequency to the one of adjacent segments is
planned for the cyclotron. Third harmonic
tests commenced at full voltage in the main
machine, but at pulsed power.

Intermediate milestones were achieved in two
new major projects which were started last
year to improve the basic performance of the
probes-diagnostic system and of the vacuum
system. An improved low energy probe was
commissioned and is now available to operat-
ors and machine physicists. Proper rf con-
nection to the resonator surface allows this
probe to be moved without destructive inter-
ference within the rf leakage field. In the
vacuum system diffusion pumps are gradually
replaced by cryopumps to eliminate the danger
of oil contamination and increase the pumping
speed for hydrogen. With three cryopumps
installed last year the pumping speed for
hydrogen was increased by a factor of two to
three, reducing substantially the time re-
quired to reach operating pressures (a few
10⁻⁸ Torr) after shutdowns. In particular
the vacuum in the ±30 kV spiral inflector
region was greatly improved, with greatly
reduced arcing occurrence.

The Ion Source Injection Line group has im-
proved intensity and quality for both polar-
ized and unpolarized beams. Development of
an optically pumped polarized source in the
laboratory showed intensities at least five
times larger than the existing state-of-the-
art Lamb-shift sources and polarization above
60%. It is now planned to install the source
in the new 300 kV terminal to optimize emitt-
ance and overall performance with respect to
the cyclotron and provide an operational
source within the next two years. A new
multi-CUSP H⁺ source, capable of three times
more beam in a $0.15 \times 0.15 \text{ mm}^2 \text{ mrad}^2$ cyclotron acceptance was also tested in the laboratory and is being installed in the new 300 kV terminal. The terminal itself was successfully tested at full voltage and is now being connected to the existing injection line through a new, 10 m long injection line section. It is planned to complete the third source terminal by the spring of 1986 and to commission the CUSP source for higher intensities or better brightness thereafter.

Several minor projects were completed. For instance, the Plant group greatly improved the purity and resistivity of the water circulating in the active cooling systems, completely eliminating quadrupole or magnet plugging due to contamination of the water. The Cyclotron Development group has been able to improve the display and interpretation of machine parameters using the VAX 730, making life of operators and machine physicists easier. The Control group was asked as usual to do miracles to incorporate new systems and new diagnostics in a saturated control system needing, more and more urgently, substantial updating. The Remote Handling group performed some of their routine vault operations from the remote console in the remote handling building.

**BEAM PRODUCTION**

1985 was a very good year for beam production. Total production was 331,161 µAh which was 83% of the scheduled production. This was another record-setting year for TRIUMF. The previous record for best year set in 1984 was 322,373 µAh which was 80% of the scheduled production. The unpolarized beam production is shown in Fig. 89. A weekly production record of 21,047 µAh was set in week #30, and it was almost equalled in week #33 with 20,800 µAh. The previous weekly best had been just under 18,000 µAh. 140 µA extracted down beam line 1A with 50% transmission in the cyclotron was routine operation.

The total hours of operation are shown in Fig. 90. 5407 h of beam was available for 89.5% of the scheduled hours of operation. The operating record for 1985 is broken down in Fig. 91. These figures are very similar to 1984.

The major difference in 1985 is that 1647 h of polarized beam compared to 1046 h of polarized beam in 1984 was delivered to experimenters. There was polarized operation for four weeks before the spring shutdown, for four weeks in the early summer between high current runs at the end of beam schedule #59, and for four weeks at the end of beam schedule #60 before the fall shutdown. The polarized runs were characterized by very little downtime due to source troubles and currents available to 500 nA.

The total downtime for the year was 504 h compared with 540 h in 1984. RF had problems throughout the winter and spring with water leaks in the power amplifiers; then in the fall water leaks in the transmission line caused a number of insulators to fail. ISIS had numerous failures of the HV power supply during the fall and had difficulty with the POLISIS start-up in the summer. Following the spring shutdown a number of cyclotron probes failed because of some magnetic cable which was used for their drives. Extraction probe 4 was unreliable until a complete rebuild in the fall shutdown. There was a very quick start-up following the fall shutdown.

**Fig. 89.** 1985 beam delivery.

**Fig. 90.** 1985 hours of operation.
Table X shows the scheduled and delivered beam to each experiment for the year. A 'P' indicates polarized beam.

A brief summary of the year's operation is:

Cyclotron ON
- Beam to experimenters: 4794 h
- Development: 388 h
- Tuning: 225 h
- Total: 5407 h

Cyclotron OFF
- Shutdown: 2039 h
- Maintenance: 492 h
- Downtime: 504 h
- Overhead, start-up, etc.: 294 h
- Total: 3329 h

PROJECTS

Alternative extraction system

Much progress was made this year towards our goal of proving the feasibility of continuously extracting 100 μA of H⁻ ions from TRIUMF. The highest profile achievements occurred during the two successful experimental tests in March and November. In March an 11.5 MHz rf deflector exciting a νᵣ = 1.5 resonance was successfully tested. A measurement was performed to evaluate the effect of placing in the beam a septum of effective thickness of 1 mm. The septum was simulated by a 1 mm wide stripping foil. For a radial field impulse of 1.1 kV/cm over 1 m the beam intercepted by this foil was reduced from ~50% to <15%. In November a dc deflector was added with only 30 kV/cm on the dc deflector and 1.3 kV/cm on the rf deflector. 62% of the H⁻ beam was separated 15 mm from the internal circulating beam, as shown in Fig. 92. More details about these measurements and about their agreement with calculations are given in the Beam Development section of Accelerator Research Division.

The 11.5 MHz, 0.5 m long rf deflector (RFD) operated up to 27 kV stably and reliably generating a radial field of 2.4 kV/cm across the 10 cm radial gap between the hot electrode and the grounded outer electrode (Fig. 93). An open C-type structure was used. To suppress the rf leakage the electrodes are completely enclosed except for beam entrance and exit. The unit, very simple and lightweight, is connected to a cylindrical coaxial...
<table>
<thead>
<tr>
<th>Experiment*</th>
<th>Channel</th>
<th>Scheduled h</th>
<th>Scheduled μAh</th>
<th>Delivered h</th>
<th>Delivered μAh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meson Hall:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tune</td>
<td>M9</td>
<td>161.0 + 200.0 P</td>
<td>1610.0</td>
<td>126.0 + 167.1 P</td>
<td>838.3</td>
</tr>
<tr>
<td>Tune</td>
<td>M11</td>
<td>161.0 + 139.5 P</td>
<td>1610.0</td>
<td>126.0 + 110.2 P</td>
<td>838.3</td>
</tr>
<tr>
<td>Tune</td>
<td>M13</td>
<td>161.0 + 150.0 P</td>
<td>1610.0</td>
<td>126.0 + 120.2 P</td>
<td>838.3</td>
</tr>
<tr>
<td>Tune</td>
<td>M15</td>
<td>712.5 + 150.0 P</td>
<td>46035.0</td>
<td>566.9 + 146.7 P</td>
<td>33863.8</td>
</tr>
<tr>
<td>Tune</td>
<td>M20</td>
<td>161.0 + 150.0 P</td>
<td>1610.0</td>
<td>126.0 + 120.2 P</td>
<td>838.3</td>
</tr>
<tr>
<td>C</td>
<td>M15</td>
<td>11.0</td>
<td>1100.0</td>
<td>11.2</td>
<td>1319.9</td>
</tr>
<tr>
<td>K</td>
<td>M20</td>
<td>127.0</td>
<td>20320.0</td>
<td>133.6</td>
<td>18450.0</td>
</tr>
<tr>
<td>N</td>
<td>M20</td>
<td>127.0</td>
<td>20320.0</td>
<td>123.3</td>
<td>16386.0</td>
</tr>
<tr>
<td>OMNI</td>
<td>M15</td>
<td>104.0</td>
<td>16640.0</td>
<td>91.7</td>
<td>11170.2</td>
</tr>
<tr>
<td>104</td>
<td>M9</td>
<td>2540.0</td>
<td>348390.0</td>
<td>2275.3 + 26.5 P</td>
<td>279275.8</td>
</tr>
<tr>
<td>147</td>
<td>M15</td>
<td>380.0</td>
<td>55740.0</td>
<td>356.1</td>
<td>46634.4</td>
</tr>
<tr>
<td>150</td>
<td>M20</td>
<td>275.0</td>
<td>41460.0</td>
<td>242.3</td>
<td>30380.4</td>
</tr>
<tr>
<td>157</td>
<td>M20</td>
<td>127.0</td>
<td>18480.0</td>
<td>124.5</td>
<td>15459.9</td>
</tr>
<tr>
<td>199</td>
<td>M13</td>
<td>656.0</td>
<td>102880.0</td>
<td>615.6</td>
<td>80743.0</td>
</tr>
<tr>
<td>202</td>
<td>M13</td>
<td>246.0</td>
<td>34510.0</td>
<td>220.1</td>
<td>27822.7</td>
</tr>
<tr>
<td>205</td>
<td>M11</td>
<td>798.5</td>
<td>92870.0</td>
<td>634.6</td>
<td>62533.4</td>
</tr>
<tr>
<td>230</td>
<td>M20</td>
<td>155.0</td>
<td>13010.0</td>
<td>108.5</td>
<td>6684.5</td>
</tr>
<tr>
<td>239</td>
<td>M20</td>
<td>115.0</td>
<td>16320.0</td>
<td>108.1</td>
<td>13475.6</td>
</tr>
<tr>
<td>241</td>
<td>M20</td>
<td>324.0</td>
<td>32600.0</td>
<td>309.3</td>
<td>29587.4</td>
</tr>
<tr>
<td>245</td>
<td>M15</td>
<td>109.5</td>
<td>15330.0</td>
<td>102.4</td>
<td>11756.6</td>
</tr>
<tr>
<td>246</td>
<td>M13</td>
<td>545.5</td>
<td>57450.0</td>
<td>412.2</td>
<td>34349.0</td>
</tr>
<tr>
<td>249</td>
<td>M9</td>
<td>286.5</td>
<td>35030.0</td>
<td>270.5</td>
<td>31378.7</td>
</tr>
<tr>
<td>249/277</td>
<td>M9</td>
<td>104.0</td>
<td>12460.0</td>
<td>84.8</td>
<td>9621.6</td>
</tr>
<tr>
<td>254</td>
<td>M13</td>
<td>127.0</td>
<td>20320.0</td>
<td>133.6</td>
<td>18450.0</td>
</tr>
<tr>
<td>260</td>
<td>M15</td>
<td>93.0</td>
<td>13020.0</td>
<td>82.4</td>
<td>13227.8</td>
</tr>
<tr>
<td>260</td>
<td>M20</td>
<td>131.5</td>
<td>18410.0</td>
<td>108.5</td>
<td>13247.8</td>
</tr>
<tr>
<td>261</td>
<td>M20</td>
<td>271.0</td>
<td>36070.0</td>
<td>235.6 + 26.5 P</td>
<td>28486.2</td>
</tr>
<tr>
<td>262</td>
<td>M20</td>
<td>148.5</td>
<td>10560.0</td>
<td>100.0</td>
<td>5967.3</td>
</tr>
<tr>
<td>270</td>
<td>M11</td>
<td>506.0</td>
<td>80960.0</td>
<td>492.3</td>
<td>67261.2</td>
</tr>
<tr>
<td>276</td>
<td>M15</td>
<td>204.5</td>
<td>28770.0</td>
<td>191.3</td>
<td>22471.2</td>
</tr>
<tr>
<td>276</td>
<td>M20</td>
<td>58.0</td>
<td>9280.0</td>
<td>44.2</td>
<td>5023.7</td>
</tr>
<tr>
<td>278</td>
<td>M13</td>
<td>127.0</td>
<td>17780.0</td>
<td>115.7</td>
<td>13577.4</td>
</tr>
<tr>
<td>279</td>
<td>M11</td>
<td>138.0</td>
<td>19320.0</td>
<td>137.9</td>
<td>19256.6</td>
</tr>
<tr>
<td>281</td>
<td>M11</td>
<td>116.0</td>
<td>16240.0</td>
<td>117.3</td>
<td>16161.5</td>
</tr>
<tr>
<td>285</td>
<td>M13</td>
<td>266.0</td>
<td>37240.0</td>
<td>228.7</td>
<td>31232.5</td>
</tr>
<tr>
<td>286</td>
<td>M15</td>
<td>150.0</td>
<td>21920.0</td>
<td>141.4</td>
<td>17538.3</td>
</tr>
<tr>
<td>286</td>
<td>M20</td>
<td>127.0</td>
<td>17780.0</td>
<td>115.7</td>
<td>13577.4</td>
</tr>
<tr>
<td>288</td>
<td>M15</td>
<td>161.0</td>
<td>24380.0</td>
<td>137.9</td>
<td>14708.9</td>
</tr>
<tr>
<td>289</td>
<td>M20</td>
<td>127.0</td>
<td>20320.0</td>
<td>133.1</td>
<td>19350.7</td>
</tr>
<tr>
<td>291</td>
<td>M15</td>
<td>11.0</td>
<td>1540.0</td>
<td>11.0</td>
<td>1459.1</td>
</tr>
<tr>
<td>291</td>
<td>M20</td>
<td>46.0</td>
<td>7360.0</td>
<td>18.2</td>
<td>1629.5</td>
</tr>
<tr>
<td>296</td>
<td>M15</td>
<td>335.0</td>
<td>44800.0</td>
<td>268.3</td>
<td>31419.6</td>
</tr>
<tr>
<td>296</td>
<td>M20</td>
<td>150.0</td>
<td>21000.0</td>
<td>146.2</td>
<td>20715.7</td>
</tr>
<tr>
<td>304</td>
<td>M15</td>
<td>81.0</td>
<td>12960.0</td>
<td>79.2</td>
<td>10699.3</td>
</tr>
<tr>
<td>306</td>
<td>M13</td>
<td>271.0</td>
<td>36070.0</td>
<td>235.6 + 26.5 P</td>
<td>28486.2</td>
</tr>
<tr>
<td>307</td>
<td>M15</td>
<td>104.0</td>
<td>13795.0</td>
<td>79.9</td>
<td>9053.9</td>
</tr>
<tr>
<td>322</td>
<td>M11</td>
<td>449.5</td>
<td>61060.0</td>
<td>407.7 + 26.4 P</td>
<td>49555.4</td>
</tr>
<tr>
<td>323/285</td>
<td>M13</td>
<td>35.0</td>
<td>2800.0</td>
<td>32.7</td>
<td>3583.6</td>
</tr>
<tr>
<td>325</td>
<td>M20</td>
<td>402.5</td>
<td>49170.0</td>
<td>360.8</td>
<td>41835.2</td>
</tr>
<tr>
<td>332</td>
<td>M11</td>
<td>70.0</td>
<td>9800.0</td>
<td>59.6</td>
<td>9595.2</td>
</tr>
<tr>
<td>336</td>
<td>M15</td>
<td>251.0</td>
<td>37400.0</td>
<td>257.8</td>
<td>35576.5</td>
</tr>
<tr>
<td>336</td>
<td>M20</td>
<td>115.0</td>
<td>16100.0</td>
<td>111.7</td>
<td>14574.9</td>
</tr>
<tr>
<td>337</td>
<td>M11</td>
<td>633.5</td>
<td>82430.0</td>
<td>584.4</td>
<td>70931.2</td>
</tr>
</tbody>
</table>

Table X. Beam to experiments for 1985.
<table>
<thead>
<tr>
<th>Experiment*</th>
<th>Channel</th>
<th>Scheduled</th>
<th>H</th>
<th>Delivered</th>
<th>μAh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>h</td>
<td>μAh</td>
<td>h</td>
<td>μAh</td>
</tr>
<tr>
<td>340</td>
<td>M20</td>
<td>139.0</td>
<td>19460.0</td>
<td>139.0</td>
<td>19097.5</td>
</tr>
<tr>
<td>346</td>
<td>M15</td>
<td>116.0</td>
<td>16240.0</td>
<td>110.7</td>
<td>15234.9</td>
</tr>
<tr>
<td>347</td>
<td>M15</td>
<td>187.0</td>
<td>26960.0</td>
<td>190.9</td>
<td>25580.0</td>
</tr>
<tr>
<td>349</td>
<td>M15</td>
<td>81.0</td>
<td>8100.0</td>
<td>72.9</td>
<td>7732.3</td>
</tr>
<tr>
<td>350/351</td>
<td>M13</td>
<td>772.5</td>
<td>90310.0</td>
<td>748.9</td>
<td>86525.6</td>
</tr>
<tr>
<td>361</td>
<td>M15</td>
<td>116.0</td>
<td>16240.0</td>
<td>117.3</td>
<td>16161.5</td>
</tr>
<tr>
<td>362</td>
<td>M20</td>
<td>81.0</td>
<td>11340.0</td>
<td>80.8</td>
<td>10839.8</td>
</tr>
<tr>
<td>365</td>
<td>M9</td>
<td>116.0</td>
<td>3480.0</td>
<td>112.5</td>
<td>4493.6</td>
</tr>
<tr>
<td>377</td>
<td>M11</td>
<td>92.0</td>
<td>12880.0</td>
<td>81.4</td>
<td>10588.1</td>
</tr>
<tr>
<td>CO/787</td>
<td>M11</td>
<td>243.0</td>
<td>150.0 P</td>
<td>23800.0</td>
<td>228.0 + 120.2 P</td>
</tr>
<tr>
<td>208</td>
<td>1B</td>
<td></td>
<td></td>
<td></td>
<td>843.9 P</td>
</tr>
<tr>
<td>301</td>
<td>1B</td>
<td></td>
<td></td>
<td></td>
<td>322.4 P</td>
</tr>
<tr>
<td>356</td>
<td>1B</td>
<td></td>
<td></td>
<td></td>
<td>223.5 P</td>
</tr>
</tbody>
</table>

**Proton Hall:**

<table>
<thead>
<tr>
<th>Perm. magnet</th>
<th>4A</th>
<th>35.00</th>
<th>4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 test</td>
<td>4A</td>
<td>0.0 P</td>
<td>3.0 P</td>
</tr>
<tr>
<td>190</td>
<td>4A</td>
<td>228.0 P</td>
<td>217.1 P</td>
</tr>
<tr>
<td>287 development</td>
<td>4A</td>
<td>12.0 P</td>
<td>4.4 P</td>
</tr>
<tr>
<td>PI production</td>
<td>4B</td>
<td>35.0</td>
<td>27.1</td>
</tr>
<tr>
<td>Calibrate</td>
<td>4B</td>
<td>4.0</td>
<td>1.2</td>
</tr>
<tr>
<td>CHARGE3</td>
<td>4B</td>
<td>575.5</td>
<td>453.9</td>
</tr>
<tr>
<td>FPP</td>
<td>4B</td>
<td>115.0 + 23.0 P</td>
<td>70.0 + 8.9 P</td>
</tr>
<tr>
<td>IBP</td>
<td>4B</td>
<td>35.0 P</td>
<td>29.0 P</td>
</tr>
<tr>
<td>MRS</td>
<td>4B</td>
<td>156.5 + 34.0 P</td>
<td>73.6 + 14.1 P</td>
</tr>
<tr>
<td>n,p development</td>
<td>4B</td>
<td>35.0</td>
<td>29.4</td>
</tr>
<tr>
<td>p,n</td>
<td>4B</td>
<td>307.5</td>
<td>158.6</td>
</tr>
<tr>
<td>142</td>
<td>4B</td>
<td>321.0</td>
<td>253.8</td>
</tr>
<tr>
<td>207</td>
<td>4B</td>
<td>127.0 P</td>
<td>101.1 P</td>
</tr>
<tr>
<td>221</td>
<td>4B</td>
<td>8.5 + 70.0 P</td>
<td>9.2 + 58.5 P</td>
</tr>
<tr>
<td>234</td>
<td>4B</td>
<td>230.0</td>
<td>172.8</td>
</tr>
<tr>
<td>236</td>
<td>4B</td>
<td>127.0 P</td>
<td>114.2 P</td>
</tr>
<tr>
<td>252</td>
<td>4B</td>
<td>173.0</td>
<td>116.3</td>
</tr>
<tr>
<td>265</td>
<td>4B</td>
<td>278.0</td>
<td>221.4</td>
</tr>
<tr>
<td>267</td>
<td>4B</td>
<td>46.0</td>
<td>42.7</td>
</tr>
<tr>
<td>272</td>
<td>4B</td>
<td>173.0 P</td>
<td>161.2 P</td>
</tr>
<tr>
<td>282</td>
<td>4B</td>
<td>69.0</td>
<td>60.3</td>
</tr>
<tr>
<td>283/295</td>
<td>4B</td>
<td>233.5 P</td>
<td>186.9 P</td>
</tr>
<tr>
<td>294</td>
<td>4B</td>
<td>276.0 P</td>
<td>193.5 P</td>
</tr>
<tr>
<td>298</td>
<td>4B</td>
<td>81.0</td>
<td>49.3</td>
</tr>
<tr>
<td>300</td>
<td>4B</td>
<td>116.0 + 116.0 P</td>
<td>80.9 + 96.1 P</td>
</tr>
<tr>
<td>324</td>
<td>4B</td>
<td>315.0 + 47.0 P</td>
<td>233.1 + 36.7 P</td>
</tr>
<tr>
<td>335</td>
<td>4B</td>
<td>126.0 P</td>
<td>110.8 P</td>
</tr>
<tr>
<td>338</td>
<td>4B</td>
<td>127.0 P</td>
<td>119.0 P</td>
</tr>
<tr>
<td>121</td>
<td>4A/2</td>
<td>69.0 P</td>
<td>56.9 P</td>
</tr>
<tr>
<td>182</td>
<td>4A/2</td>
<td>116.0</td>
<td>86.6</td>
</tr>
<tr>
<td>190</td>
<td>4A/2</td>
<td>142.5 + 171.5 P</td>
<td>106.6 + 122.3 P</td>
</tr>
</tbody>
</table>

*See Appendix C for experiment title and spokesman.*

95
Fig. 94. Sketch of experimental electrostatic deflector.

A short section of a dc deflector (DCD) was assembled and installed at the end of the March shutdown. The device was positioned against the tank wall away from the circulating beam and provided useful information on voltage holding, temperature and insulator lifetime in the tank environment. In particular it pointed out the need for a higher capacity cooling system.

The rf deflector used in October was similar to the one used in March except for its location in the cyclotron and the 500 MeV beam allowed through the deflector. In addition beam sensing monitors were added to protect the RFD against beam damage. The DCD (Fig. 94) consisted of a 0.9 m long septum and a positive antiseptum separated by 13 mm. Both electrodes are curved to follow the orbit of the circulating beam. An opening for the exiting proton beam extracted upstream by the septum protecting stripping foil has been provided for in the support structure. The septum is made of 121 molybdenum foils 5 mm wide and 0.076 mm thick separated by 2 mm gaps. They are positioned within an accuracy of ±0.03 mm by two matching stainless steel templates 10 cm apart, cut to follow the calculated shape of the circulating orbit. The first and last seven foils are insulated for diagnostic purposes. In addition a 2 mm wide foil was placed at the exit of the septum perpendicular to the beam and used as a positioning device. The DCD included two remotely controlled radial drives that allowed 5 cm of motion at both ends.

During the test a mechanical fault in the RFD limited the peak voltage to 14 kV, half that achieved in March. Despite this a separation of the extracted beam from the circulating beam of 15 mm was achieved with only 30 kV/cm on the DCD. The October test will be repeated in March 1986 with improved components.

Magnetic channel

A 0.2 Tm magnetic channel to be inserted downstream of the DCD is presently being designed for testing in October 1986. The three dimensional magnetic field analysis program GPUN is being used in the design. The channel will consist of epoxy-insulated, water-cooled copper conductors mounted on an adjustable positioning table.

rf booster cavities

The frequency of the booster cavity designed to increase the energy gain per turn three-fold was chosen at 92 MHz, four times the fundamental rf frequency. One prototype cavity for optimizing the resonant frequency and performing other rf tests in a cyclotron simulation chamber was manufactured. The final cavity will be split into two separate units mounted on the cyclotron chamber and lid, respectively. The rf transmitter is presently being designed in collaboration with the University of Manitoba.

A preliminary layout of the extraction elements in the cyclotron chambers is shown in Fig. 95. In the final configuration for H− extraction all elements will have permanently allocated ports for power, services and diagnostics. At present the changes to the cyclotron are kept to a minimum. The booster will be the first unit permanently installed. This will require new ports to be cut in the cyclotron tank.

Resonator improvement program

As described in the preceding annual report a new prototype hot arm for a resonator segment was designed and two complete segments were constructed in the latter part of 1984. The new design was for improved performance over that of the original segments in the areas of dynamic stability (reduced tip vibration), long-term stability (freedom from creep) and
Fig. 95. Preliminary layout of the extraction elements in the cyclotron chambers.

profile (parallel rf hot and ground panels). The first of the two segments was used in a test facility to verify performance prior to installation in TRIUMF, while the second one was installed for operation in TRIUMF in position 3L5 (quadrant 3, lower segment No. 5) in February.

A segment of the original design was compared with one of new design for stiffness, vibration frequency and vibration amplitude in laboratory measurements. Similarly, the original segment in position 2L4 was compared with the new segment installed in position 3L5 under, as near as possible, identical conditions. The results are shown in Table XI.

The vibration measurements in TRIUMF were made with the lid up. Latched/unlatched refers to the rf contact bars between adjacent tips in the resonator being in place/removed.

Note that measurements of the prototype and an original segment in the laboratory showed a factor of >50 reduction in tip vibration amplitude. This improvement was achieved by the simplified water flow pattern in the rf panel and by the stiffer strongback. On installation in TRIUMF it was found that tip vibrations were larger than the laboratory measurements. Two possible reasons are (1) the higher energy content (turbulence) of the TRIUMF water system and (2) the coupled drive input through the water from the other vibrating hot arms. A factor of 2 reduction in amplitude was achieved here even with this single segment (one of 10 in an octant). Vibration levels at segments number 5, since they are located at the centre of octants of original segments, are the greatest existing in the cyclotron.

By measuring the temperature rise in the cooling water of the strongback and its flow rate, the power produced by rf leakage could be measured accurately for the first time. Since the leakage current peaks in resonators 4 and 5, the measured value of the absorbed power resulted larger in this location than originally estimated: 1200 W. This value led to the 9°C rise noted in Table XI between the rf panel side of the strongback and the beam side where the leakage currents flow. This rise led to a tip deflection in excess of 1 cm, a value too large for practical operation.

Prior to the installation of this new segment in TRIUMF thermal measurements were made in the vacuum test facility. Rf leakage was simulated by strip heaters attached to the beam side of the strongbacks of the new prototype as well as to a segment of the original design. Tip optical targets were installed. Tip deflections were measured with a telescope and monitored as a function of the heat load. Results showed tip migration of the same order as the original hot arm, however with a much shorter time constant because of the water cooling. Tip migrations were ~0.070 in. for a heat load of 110 W, the estimated leakage power. At this time it was decided to proceed with the installation of the new prototype segment at location 3L5, which was the hottest strongback in the machine (130°), to gain knowledge of the behaviour of this unit under actual operating conditions.

Meanwhile, to reduce this temperature differential in the strongback and the resulting tip deflection, the second part of the plan for the improved design was carried out: a water-cooled beam-side copper panel was added that absorbs the energy from the rf leakage. The contacts from the copper panel to the strongback have quite low thermal conductivity. The strongback structure was not cooled directly since it is isolated between the cooled beam side and rf panels. By isolating...
Table XI. Comparison of the characteristics of a newly installed resonator segment with an original one.

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>New segment - February 1985</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prototype test</td>
<td>Installed in TRIUMF</td>
</tr>
<tr>
<td>Tip stiffness (lb/in.)</td>
<td>55</td>
<td>143</td>
</tr>
<tr>
<td>Hot arm weight (lb)</td>
<td>456</td>
<td>559</td>
</tr>
<tr>
<td>Vibration frequency (Hz)</td>
<td>4.75</td>
<td>5.4</td>
</tr>
<tr>
<td>Tip vibration amplitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(in., peak-to-peak)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No damper (lab)</td>
<td>0.0050</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>With damper (lab)</td>
<td>0.0010</td>
<td>--</td>
</tr>
<tr>
<td>No damper, unlatched</td>
<td>0.0026</td>
<td>--</td>
</tr>
<tr>
<td>With damper, unlatched</td>
<td>0.0010</td>
<td>--</td>
</tr>
<tr>
<td>With damper, latched</td>
<td>0.0005</td>
<td>--</td>
</tr>
<tr>
<td>Temperature rise in</td>
<td>105°C</td>
<td>--</td>
</tr>
<tr>
<td>strongback</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

the strongback and not cooling it the difference in temperature between its top and bottom surfaces is kept to a quite small value thus leading to small deflection of the tip. A test panel was constructed that represented one-quarter of the area of the strongback; a heating element was suspended above it with suitable surrounding reflectors. Thermal equilibrium tests in vacuum were conducted to determine the temperatures that could be expected in this strongback structure. An electrical resistance radiant heater was used to simulate the rf leakage. Thermocouples were used to monitor metal and water temperatures. Heat loads were applied equivalent to ~2000 W for the entire strongback. With a water flow of 5.5 L/min through the beam-side panel temperatures in the strongback rose to 9°C above water temperature reaching equilibrium about six hours after the test started but with less than 0.5°C gradient, top-to-bottom, in the structure.

Based on these results the prototype hot arm design was completed with the beam side panel; construction of one hot arm began in July and was completed in August. The new beam side panel hot arm was combined with an original root/ground arm and installed into the large vacuum test facility for rf tests. Again a large resistance heater was suspended above the beam-side panel to simulate rf leakage. Tip motion could be monitored with a telescope by observing the hot arm tip target through a port in the tank. Movements of 0.005 in. could be measured. With an equivalent rf leakage heatload of ~2000 W and tip voltage >100 kV tip migrations were less than 0.010 in. (compared with movements as great as 0.125 in. for hot arm tips in the original segments).

Further testing in the laboratory for dynamic tip stability (tip vibrations due to water flow excitation) gave tip peak-to-peak vibration levels at 5.4 Hz of approximately 0.0001 in; this compares with 0.003 to 0.005 in. for an original hot arm. This new segment was installed in position 3L5 of the TRIUMF resonator during the October shutdown. Again, measurements of the vibration levels were made after the new segment was installed. The levels were quite similar to those observed for the February segment: 0.0005 in. (peak-to-peak) compared with 0.0001 in (peak-to-peak) measured in the laboratory prior to installation.

In actual operation at full rf power the thermal behaviour and tip deflection have been, as expected, markedly different from that of the segment without a water-cooled beam-side panel. The temperature rise above inlet water temperature of the beam-side panel has been less than 9°C. The temperature difference in the strongback top-to-bottom is less than 1°C. The maximum tip deflection observed is less than 0.030 in. in taking the rf system from power off to full power. Most or all of this motion is believed to be
caused by the motion of the original segments 3L4 and 3L6, which mechanically connect to 3L5 at the tip.

As a result of the good results achieved in the laboratory, and later in the tank, it was decided to construct four new upper segments. These units will have a beam-side panel on the hot arm and also a new ground arm and root shorting plane. The new ground arm will have a hinged panel to allow for rf frequency tuning. The units will be installed during the spring 1986 shutdown. The four symmetric units (lower side) will follow.

New projects

A new section in the Cyclotron Division was created to co-ordinate various projects undertaken by the Division that are not directly related to cyclotron day-to-day operation or its performance upgrade. Two projects in this category are the post-accelerator studies for the proposed ISOL facility and high power ferrite tuned cavity studies for KAON factory synchrotrons.

ISOL post-accelerator

The ISOL facility proposed for installation on beam line 4A includes the unique feature of a post-accelerator to accelerate the low velocity singly charged radioactive ion beams from the ISOL to energies sufficient for nuclear reaction studies, particularly those of interest in nuclear astrophysics.

Starting with a survey of existing heavy-ion linear accelerators for stable ion beams, a conceptual design of a linac suitable for the radioactive ISOL beams was developed. The ion beam from the ISOL has an energy and minimum charge-to-mass ratio considerably lower than the injection beams at existing heavy ion linacs. For this and other reasons a relatively new type of linear accelerator structure - the radio-frequency quadrupole (RFQ) is proposed as the initial accelerator stage. In this structure radio-frequency electric fields are used for transverse focusing as well as for longitudinal bunching and acceleration.

Development of the post-accelerator conceptual design was aided by a TRIUMF/CRNL shared cost design study contract with the Accelerator Physics Branch at CRNL. Beam dynamics calculations carried out under this contract show that a linear accelerator consisting of a 9.2 m RFQ followed by a 15.5 m drift tube linac (DTL), both operating at 23 MHz (and together requiring approximately 1.3 MW of rf power), would satisfy the basic ISOL post-accelerator specification, i.e. to accelerate singly charged ions with \( A < 60 \) from an energy of 1 keV/nucleon to 1 MeV/nucleon.

A gas stripper is proposed between the RFQ and DTL to raise the ion charge to mass ratio \( (q/A) \) for the heavier ions. For ions with \( A < 20 \) no stripper would be necessary, so accelerated beams at the full intensity available from ISOL would be available for many of the proposed important astrophysics experiments. For the heavier ions some beam intensity is sacrificed in the stripper in the interest of reduction of the overall length and cost of the linac.

Variable output energy from the linac can be accomplished by dividing the DTL into eight independently powered units. By turning off the rf drive to the units successively, starting with the highest energy unit and partially powering the last powered unit, a smooth energy variation of the output beam from 0.27 MeV/nucleon to 1 MeV/nucleon is possible.

Energy spread of the output beam can be reduced by using either of two debuncher cavities. One for energies less than 0.5 MeV/nucleon is located at the end of the DTL while the other for the higher energies is located after a 9 m drift distance from the DTL output. In either case the debunchers reduce \( \Delta E/E \) from <0.02 at the DTL output to <0.004.

Accelerator cavity for synchrotron Booster ring

The reference design of the ferrite tuned cavity for the KAON factory Booster ring is similar to the cavity used in the Fermilab booster synchrotron. Although we will ultimately require larger ferrite rings than are used at Fermilab, we have nevertheless obtained from Fermilab some of their spare rings, for use in test cavities to verify design procedures.

A model of a conceptual design of the Booster ring cavity is being constructed of copper-covered cardboard tubing. Twelve Fermilab ferrite rings will be assembled in a coaxial structure to provide tuning. The ferrites will be biased up to full current to provide the full range of permeability variation. The rf measurements will, however, only be done
at low power signal levels. Results from these tests will be used to construct a test facility capable of providing full rf power density in the ferrites for the required frequency tuning range.

**CYCLOTRON**

**Cyclotron development**

During 1985 the proportion of scheduled accelerator time devoted to machine development was substantially increased while maintaining the same total beam production. This was achieved in part by bringing the machine to full operating current more efficiently after beam-off periods. Tuning times were substantially reduced by the increased use of computer acquisition, analysis and display of probe scans, in particular the internal beam phase and the vertical beam position. In the injection line developments were carried out to improve beam position, intensity and timing information of nonintercepting monitors. With the success of the resonator improvement programme increased emphasis is being placed on rf studies, both experimental and computational, of modifications which will be required in the cyclotron in order to implement the flat-topped mode of rf operation.

**rf studies**

In the rf teststand a pair of full-scale resonator segments with side flux guides were assembled and tested for fundamental and third harmonic behaviour. A stable, flat-topped waveform was achieved at full power (80 kV). Feedback loops for amplitude stabilization of both the fundamental and third harmonic waveforms were implemented in a prototype control system. In another control loop the phase of the third harmonic was locked to the fundamental. Coarse cavity tuning to maintain a 3:1 resonant frequency ratio was carried out by manually adjusting the shape of the ground arm. The anticipated problems associated with multipactoring at the third harmonic voltage and frequency were overcome by using the fundamental fields to clear the electron emissions associated with multipactoring, thus enabling the third harmonic signal to be applied continuously at any voltage.

Experiments aimed at improving the rf voltage uniformity along the dee gap, particularly for the third harmonic frequency were carried out on the 1:10 model. Figure 96 shows the effect of removing the conical structure in the #1 segment ground arms, while Fig. 97 shows the dramatic improvement obtained by reducing the length of the #1 segments.

Two methods of tuning the cavity to provide simultaneous resonance conditions for the fundamental and third harmonic were studied. Calculations were made of the effect of ground arm deflections on both the fundamental and third harmonic resonant frequencies. Both SUPERFISH and transmission line approximation calculations show that by flexing the ground arm at 1.25 m from the tip, it is possible to change the fundamental frequency without affecting the third harmonic. An alternative method of adjusting the resonant frequency ratio $f_3/f_1$ with the use of a tuning stub coupled to one resonator segment.
(2L3) was tested on the 1:10 scale model. Using this method all moving parts of the tuning mechanism are located outside the main vacuum tank. With a single stub it was possible to obtain a frequency shift of 1.4 MHz, equivalent to a tuning range of 0.2%, with no significant effect on the fundamental frequency or the Q of the resonant cavity. The effect of the single stub on the voltage distribution along the dee gap was small.

Minimization of the amount of the rf leakage energy which flows out of the rf cavity into the beam gap region is crucial for the present mode of operation and for the third harmonic program. The code RFQ3D was used to investigate the effect of the different dee voltage profiles on leakage suppression. The results indicate that by using a highly non-uniform voltage profile a reduction in the (fundamental) leakage of 3 dB was obtained. In the 1:10 model an attempt is being made to cancel the leakage with a distributed 23 MHz source of opposite phase. Preliminary results show that the predominant TM310 mode can be reduced between 3 and 6 dB (30 to 50% in voltage) by using 1 or 3 cancelling sources. This reduction is very sensitive to the phase of the cancellation sources.

Diagnostics

A number of new developments and improvements were made on beam current diagnostics in the ISIS and primary beam lines. A prototype dc beam current transformer for use in beam line 1 has been tested on the bench. The device uses two μ-metal toroidal cores in a magnetic amplifier circuit to sense dc beam. The system can resolve current changes of 3 μA independent of the applied ion source current modulation normally required for ac current transformers and the device is therefore suitable for interlock and target protect systems. Also this monitor will allow production of continuous beam from the cyclotron, without the present 10 μs, 1 kHz hole structure which is undesirable for stable rf. Further work to improve the stability of the system is required before installation in the beam line. The existing toroid amplifiers in the ISIS beam line do not have good noise immunity and have proved unsatisfactory for beam current measurements on beam line 2C. The detector circuits for these amplifiers were modified to lock on to the ISIS pulser, resulting in an improvement of a factor of 10 in the signal-to-noise ratio. The new design has been tested on beam line 2C and will be implemented in the ISIS beam lines.

A nonintercepting beam position monitor has been designed, constructed and installed in the ISIS beam line. Test programs have been written to acquire and filter the monitor data using both a first-order Kalman filter and adaptive exponential filter algorithms, and to display and update the centroid on a graphics terminal. The resolution of the device is 1 mm, using beam currents of 10 μA.

Data acquisition

Experimental and theoretical efforts towards understanding the behaviour of the cyclotron and its component systems were greatly enhanced by means of the recently installed computer acquisition and analysis systems which provide high level language capabilities for physicists, engineers and operators concerned with the study of the machine. The system consisting of a VAX computer and associated peripherals is connected by means of two independent CAMAC systems to both the main machine and subsystems under development in a number of laboratory areas. The system is connected to the TRIUMF Ethernet local area network. A fibre optic CAMAC connection to the CRM laboratory has provided the data acquisition and control access needed to measure the emittance of a high intensity CUSP source under development. The VAX 730 system has been expanded with the addition of a fibre optic CAMAC link to the microprocessor laboratory in trailer Hh. During machine shutdowns the link hardware can be moved to the cyclotron vault, to provide access to experimental equipment near the machine. The computer system has been expanded with the addition of microVAX computers which will be used to provide more rapid response for time critical measurements, such as probe scans. Use of the VMS operating system has allowed the running of software from a number of other laboratories, and allows cyclotron investigators to take advantage of complex beam and magnet codes without modification or conversion.

A number of data acquisition and analysis software packages have been written for the VAX 11/730:

- PSU: This general purpose probe scan software utility provides for the acquisition and storage of up to 10 cyclotron parameters, each of which may be sampled for probe increments as small as 0.001 in. Options for digital filtering and smoothing of the data have been developed. The data are stored in a format compatible for post-analysis by the
OPDATA utility. Figure 98 shows a scan of the vertical centre of gravity of the beam from a radius of 145 to 305 in.

- MWC: Readout, storage display, hardcopy and data reduction software have been written to analyse data from any of the beam line multi-wire chamber profile monitors. Figure 99 shows a plot of the vertical and horizontal centroids at 4BM5, with fitted full width half maxima, peak position and centroids.

- WSU: A software package was developed to accompany the CUSP source wire scanner set-up. The program is known as WSU (wire scanner utility). WSU controls the wire scanners, data acquisition and graphical display of new or old data. WSU can also be set up to automatically transfer data to more powerful computers if emittance calculations using tomography are desired.

- SES: To control the CUSP source slit scanner a software package called SES (slit emittance scanner) was developed. SES controls the motion of the probe, the voltage on the scanning plates, data acquisition, graphical display of new or old data and emittance calculations on new or old data.

- BL4: This set of routines is used to record, save and restore BL4 tunes, from 200 to 500 MeV.

- F0ILl(or 4): This module is used to confirm the selection of the foil for stripper 1 (or 4) and to determine its type.

- INFLEC: This program is used to monitor central region parameters (inflector/deflector skimmers and vacuum, tank vacuum, ISIS skimmers) versus time to determine correlations with inflector spark rates.

- SENDHLL/RCVHLL: This pair of routines is used to transfer files between the VAX 730 and the ECLIPSE S130.

Fig. 98. Plot of the vertical beam centroid vs. radius obtained with the VAX probe scan utility PSU.

Fig. 99. Vertical and horizontal beam profiles acquired and analysed with the VAX-based multi-wire chamber utility MWC.
• SCANCP is used to vary individual correction plate voltages, while monitoring the readback voltages on the remaining plates, to measure cross talk between plates and sparking rates.

• T1DATA is used to log 1AT1 data, including protection monitor, ion chamber, beam spill, total current and halo monitor readouts, to study the causes of target aging and damage.

• RFT: This routine presents a continuously updated display of resonator strongback temperatures on an outline of the lower resonator segments.

**rf operation**

Faults in the rf system that caused loss of cyclotron operating time were caused by 1) the fine frequency tuning system of the resonator, 2) water leaks, 3) electrical component failures, and 4) water heat-exchanger coolant leaks.

Wear in the bearings of the 6 in. valve that controls the fine tuning, by controlling the return water pressure of the resonator, led to erratic operation and instability of the control system. The valve was replaced. In addition, a modification of the method of coarse tuning in which greater use was made of the eight motor-driven tips for segments was initiated. The result was a requirement for less motion of the water valve leading to improved stability of the tuning servo system and fewer losses of rf voltage.

Water leaks in the power amplifiers and the transmission line were the major cause of rf downtime this year. Pinhole leaks through silver solder joints that had been in continuous service for about 12 years were the principal problem.

Similarly, microcracks in the heat exchangers of the water loads containing the sodium nitrate coolant led to failures that required the heat exchangers to be replaced. In addition, corrosion of solder joints in copper piping for the sodium nitrite solution was a significant but relatively minor problem.

The second largest cause of downtime was from electrical component failures: surge resistors in the power supply and vacuum capacitor in the power amplifier output circuits and in the combiner that link the four power amplifiers to the resonator. The most expensive single item was the failure of two of the 4CW250,000B power amplifier tubes. Both tubes failed with grid-filament shorts. However, the failures were after rather extraordinary numbers of hours: 35,000 in one case and 72,000 in the other. The second tube had been in service continually from the beginning of the project.

In the existing rf system the original manufacturer considering that the system operated always at a single frequency and nearly constant power provided no simple method of tuning the four power amplifiers or of adjusting the output combiner networks. As a result the system must operate partially off-tune and out-of-balance for long periods of time during cyclotron operation with substantial waste of power. As a first step to solve these problems directional couplers were added in all of the input and output transmission lines - 22 in total. In addition pick-up probes for the input and output of each amplifier - 8 in total - were added to permit phase and amplitude measurement of the voltages in each amplifier.

With the addition of phase and voltage detectors located at the rf console the complete system tuning and balance may be monitored and corrected if need be during operation.

**Vacuum upgrade**

The 3500 l·s⁻¹ turbopump and the 5000 l·s⁻¹ cryopump purchased last year were installed on the cyclotron during the spring shutdown. The pumping speed for hydrogen for each pump was measured, after calibrating the tank low pressure and inflector ion gauge for H₂. The turbopump achieved 1470 l·s⁻¹ and the cryopump 3500 l·s⁻¹. (The nominal speeds are not achievable due to conductance losses.) The speed of the cryopump was again measured after 2000 h of operation and no decrease was found. These pumps (which are in addition to the existing pumps) do not greatly affect the base pressure, but the time to reach the 10⁻⁸ Torr region after a lid-up is reduced from eight days to one and a half.

The performance of the cryopump was such that another 5000 l·s⁻¹ unit was purchased, as well as a smaller one to replace the inflector box diffusion pump. These were installed in October and are performing well. In particular the inflector box reaches acceptable pressure many days more quickly than before, and the box pressure in this region is reduced by a factor of two. A third large cryopump is now on order, to be installed in the
next shutdown. It is anticipated that by the end of 1986 we will have eliminated diffusion pumps, reduced the high-current operating pressure by a factor of two, and the pumpdown time from atmosphere by nearly an order of magnitude compared with conditions before the upgrade was begun.

Probes and diagnostics

Developments

The diagnostics upgrade major project, a part of the Five Year Plan, became active April 1. New diagnostic equipment is required to improve reliability of operation and reproducibility of beam. 1985 saw the installation of the new low-energy probe LE2 and an improved design 'flip-coil' extraction system for beam line 2C. Both have been well proven and are in use. To investigate the potential damage due to rf leakage in the area of the proposed new 2C extraction probe, a 'dummy' probe was installed during the October shutdown. Essentially a copper box with thermocouples, the dummy probe was left in the tank and has indicated reasonable temperatures. The new probe, scheduled for October 1986, will have a continuous energy range similar to beam lines 4 and 1, rather than the four single energy 'flip coils' presently in service.

Extraction foil selection reliability will be improved by a 'shake-proof' cartridge for beam line 1 and a rotating carousel for beam line 4. Design is completed on both projects with machining under way. Design is under way to modify the extraction probe 4 arm to accommodate a -0.875 travel in 'L' which will be required when beam line 4 modifications for longitudinal polarization are implemented. Also being designed is an additional first turn radial flag, which will be installed opposite to the existing one to be part of the system defining beam centring and phase space acceptance at injection. A study on remote handling of probes in general, and the next low-energy probe LE1 in particular (scheduled for 1986), has begun.

Improvements include the completion of the remote periscope operation project with position control and video display in the control room, procurement of an equipped work space in the remote handling basement, and assembly and installation of a remote handled installation jig for the new extraction probe 1 all-metal gate valve.

New projects in the machine shop for next year are a scanning wire type beam line monitor and an ion chamber back-up spill monitor for installation outside the tank wall.

Operation

1985 saw smooth operation of probes with only two unplanned beam interruptions. Following the spring shutdown both extraction probes required replacement of the stainless steel drive cables after failures revealed that the 304 SS cables installed during routine overhaul in the spring were magnetic. The high-energy probe HE2 failed after its newly installed halo scraper damaged a limit switch. Planned maintenance and repairs scheduled for both shutdowns included overhaul of the water cooled pop-in probe, centring probes, the LAM11 multiwire monitor and the extraction probes, including the extraction probe 4 gate valve and its support trolley. Deterioration of rubber-tired aluminum wheels in this trolley had caused probe misalignment and eventually a minor leak of the gate valve seal. The trolley wheels have been upgraded to solid stainless steel from rubber-tired aluminum.

Procurement of extraction foil material (pyrolytic graphite) became a minor problem with uncertain deliveries from the only known supplier. Investigation into manufacturing possibilities at the UBC Chemistry Department is under way. Also use of amorphous graphite foil is under study; amorphous graphite foil is available from several suppliers.

Engineering physics

The ongoing tasks assigned to the group continued much as before, with emphasis on improved reliability.

The operation of the inflector/deflector system was very good. Standard assembly checks were performed on the system removed for inspection each shutdown. A substantial improvement in operation was achieved by replacing the cyclotron centre diffusion pump with a new cryopump which reduced the operating pressure by almost a factor of 10. This has resulted in faster electrode conditioning, making it possible to inject earlier than before after a tank vent. Another benefit should be longer insulator lifetime, from both a reduced operating pressure and an oil-free vacuum. A new winching system was installed and commissioned which improves the handling of the lower assembly for service.
The new inflector teststand was used to test the new insulators and to precondition them before installation. It was also used for testing other components required for cyclotron use.

The resonator wireway sections for the correction plates were all replaced with a new design described earlier. New tank wireways (from the resonator to the feedthrough) and feedthroughs were installed in two octants. The remaining six octants will be completed as radiation dose permits. The correction plate performance has improved with these upgrades as is indicated by the reduced number of shorted plates during operation. The next step to improved stability will focus on the power supplies.

The periscope upgrade program was completed during the spring shutdown. A control system allows control and readback of the vertical, azimuthal and focal positions for each periscope from a remote console in the main control room. Electronic level sensors are available to correct alignment survey measurements for periscope tilt errors. The new system was used extensively throughout the year, and it turned out to be a very powerful tool. About eight resonator surveys were done remotely from the control room. In addition it was also very useful in checking out diagnostic probe operations, in particular the faults with the drive cable on extraction probe 4. The periscopes were used several times to observe extraction probe foil pickups and beam line 2C foil operations. There are plans to implement an image enhancement system sometime in the next year.

The cyclotron simulation chamber magnet was designed, and the magnet steel, power supply, rails and ancillary equipment have been procured. Upon delivery of magnet coils the system is expected to be operational in January 1986.

The thermocouple system required only routine maintenance, and its operation was very reliable.

The group was assisted by a UBC co-op student who carried out measurements on improved interim strippers for beam line 2C. Based on the results two units were designed, built, installed and successfully tested in the cyclotron.

The contributions of the EP group to the alternative extraction system task force are included in that particular section of this report.

ION SOURCES AND INJECTION SYSTEM

Ion source developments

The construction of the third high voltage terminal has progressed rapidly and is presently nearing completion. High voltage tests in the spring confirmed that the design innovations in the transformer and the high voltage dome were operating according to specification. The beam line extension design and component manufacture were completed. It is anticipated that the line will be constructed and ready for commissioning during spring 1986. As a result of the encouraging results from the CUSP source prototype, a decision was made to place this source in the new terminal and commission simultaneously the terminal, CUSP source and Westinghouse interlock controller remotely with the new ion source III controls program being developed by the Technology and Administration Division. By year-end the CUSP source was in the terminal undergoing final adjustments and tests for vacuum leaks. The control and interlock systems were tested in the dome across the fibre optics link.

A dc volume H⁻ source, employing samarium cobalt permanent magnets for multiCUSP plasma confinement, was constructed and successfully tested in the CRM ion source laboratory in collaboration with a few world experts on H⁻ sources. As a result TRIUMF will be the first accelerator to use a volume H⁻ dc CUSP source. The source and testbed are shown schematically in Fig. 100.

This source provides three times more H⁻ beam within the cyclotron acceptance than the existing Ehlers' PIG source. At present operating currents the filament lifetime should be at least three times longer than the Ehlers' source. A maximum extracted H⁻ current of 4.2 mA, corresponding to a current density of 12 mA/cm², was obtained. The beam emittance and brightness were measured as a function of current density and beam fraction (Fig. 101).

A major milestone was also achieved with the optically pumped polarized ion source. A scattering chamber was set up in the laboratory to measure the asymmetric neutron distribution in the reaction $^3\text{H}(\vec{d},n)^3\text{He}$ with tensor polarized $D^*$. It can be reasonably
argued that the $H^-$ vector polarization would be three times the $D^+$ tensor polarization. This measurement allowed us to establish as a lower limit that at least 62% of the sodium polarization is transferred to the proton beam. The experimental arrangement is shown in Fig. 102.

The polarized neutral beam intensity and emittance were measured. It is now apparent that the source should be tested and optimized with the cyclotron. A significant improvement in sodium polarization was obtained with an intra-cavity etalon which allowed a closer overlap between the laser bandwidth and the sodium D1 absorption linewidth. The results are plotted in Fig. 103.

![Diagram](image)

**Fig. 100.** Schematic diagram of the multiCUSP ion source, extraction system and diagnostic geometry.

**Fig. 101.** Normalized beam emittance vs. current density at several beam fractions.

**Fig. 102.** Schematic of optically pumped polarized source and neutron scattering chamber.

**Operational performance**

The ion source and injection system operation was satisfactory throughout the year. The occasional but infrequent breakdowns which have been experienced highlighted the areas where improvements are desirable. One of the weak points was the filament power supply. It is being redesigned and tests are scheduled for 1986.

The third buncher, built in the previous year, was installed in the chopper box in place of the chopper plates and tested.
Fig. 103. Measured polarization of a sodium vapour target vs. the target thickness for optical pumping with ~30 GHz and ~6 GHz bandwidths at the sodium D1 absorption line with and without a viton wall liner.

A new series of high voltage power supplies, designed and built by Spellman Corp. according to TRIUMF's specification, were bench tested. This series will replace the present CPS beam line power supplies. Among the advantages are the small size allowing the 'beehive' packaging, repairability of the module and remote read-out of the load current.

PRIMARY BEAM LINES

In the past year the program to improve the reliability of beam line operation has continued. That this program is beginning to reap rewards has been indicated by the generally smooth beam line operation encountered this year. Little work was required in the areas of beam line optics and tuning; rather, most time was spent in upgrading diagnostics and services and in the design of equipment to make operations easier in the future.

Again this year the major accomplishment was the extraction of 200 µA of beam on beam line 1A and its delivery to the experimental target locations. The feat was accomplished this year with little of the trauma felt previously.

Beam line 1A

Throughout this past year beam line 1A has operated very reliably. A suitable tune corresponding to the TRANSPORT calculated tune for a large vertical spot at the LAT1 target position was re-established. It was shown that this tune also minimized beam spills along the beam line.

Because of this reliable operation most effort went into improving the diagnostics and services of the beam line. A new LAT2 target was installed following which the alignment of both the LAT1 and LAT2 targets was checked; it was found that the new target was positioned the same as the old one. A new TNF protect monitor (IAM12) was installed and calibrated after enduring the usual aging effects. It is now working satisfactorily. A new monitor was installed at the IAM9 location. This monitor can be filled remotely as can other monitors on the beam line which are inaccessible because of their locations in the shielded beam line area.

During the year a software routine was developed for scanning targets and measuring monitor and secondary channel rates. This allows the absolute positions of the monitors and channels to be determined relative to the target.

Operationally the major improvement has been in the conductivity of copper active system. This has reduced contamination of the water and has resulted in it not being necessary to back-flush or chemically clean any of the magnets. In addition, no magnet cooling problems have been encountered. This is the first year that there have been no such problems, particularly in the warmer-than-normal summer months.

The improved water quality has also been noted in the cleanliness of the water filters on the inlets of the magnets. These filters have also been changed from a 75 µ phonolic to a 20 µ cotton media.

In high current operation a critical component is the aluminum window at the entrance to the TNF. The window separates beam line and TNF vacua. During the 200 µA tests its temperature rose to a maximum of 48°C. This result was consistent with previous measurements of a temperature rise of the window of 0.1°C per microampere of extracted current.
The three experiments which ran on beam line 1B this year did not require significant development of new facilities for the beam line. The ppy experiment (#208) completed data-taking using the tunes developed in 1984; the \( \pi^0 \) production experiment (#302) had a small cylindrical \( \text{LH}_2 \) target followed by a short air gap to facilitate detection of protons at forward angles. Inclusive particle production (Expt. 356) ran with a scattering chamber borrowed from beam line 4B.

Beam line 4

The improvement of beam quality in beam line 4 is being pursued in several directions. Vertical and horizontal slits were installed in the vault section to allow variable collimation of the beam. Tests as to their effectiveness are under way. A channel plate monitor capable of subnanosecond timing was installed to allow precision measurement of the extracted beam phase. An aluminum foil was placed over the unused part of the extraction horn port, corresponding to energies above 510 MeV, in order to strip neutrals originating in the tank along the line of sight of the beam lines. This seems to have been effective in reducing noise levels in beam line 4B.

Work has started on designs for reconfiguration of the vault section of beam line 4 in order to achieve longitudinal polarization. Modifications include a 5° rotation of the initial section to allow room to insert two superconducting solenoids. The 5° rotation means that a movable \( \text{H}_0 \) stripper will be needed since the neutral trajectory will then overlap with extracted energies near 400 MeV.

Beam line 2C

The responsibility for the operation of beam line 2C has been transferred to the Cyclotron Division this year. This means that the cyclotron operators will be responsible for the complete operation of the beam line as well as the production of radioisotopes. To implement this program the complete protocol for target operations was specified and a decision was taken to develop processor-guided control rather than manual operation. The result of this decision is that the functions of targets safety and control were divided between two microprocessors. At year's end the targets safety programming was virtually complete and the major portion of targets control remains to be completed.

A prototype target of natural lithium bromide has been developed, tested for longevity in the laboratory, and installed in the beam line. As with the other four beam line 2C targets, the remote handling capability for this target was fully exercised in the cyclotron vault.

Various remote handling improvements for highly active components were finished during the year. The 25-ton spent targets storage block was completed and has been placed in the meson hall extension. The steering magnet and beam monitor module was redesigned to permit remote removal from the beam line.

A major impediment to regular production has been the lack of a reliable, nonintercepting, total current monitor which can operate at currents <1 \( \mu \)A. The solution to this problem
was obtained this year with the development of a gated induction toroid which is synchronized with the 10 μs by 1 kHz injection beam interruption at the cyclotron ion source. The work was done by the Cyclotron Division and the testing occurred on beam line 2C. Average beam currents as low as 0.2 μA have been measured.

A variable energy stripping mechanism has never been constructed for beam line 2C because of the unavailability of manpower. Also extended beam line operation has been excluded until this year because the excitation coils of the discrete energy strippers overheat. During the summer, however, a study of these problems resulted in an improved discrete energy stripper design which will allow production running for an indefinite time. The mechanism was constructed, extensively tested and installed in the cyclotron.

Thermal neutron facility (TNF)

The TNF has functioned reliably as usual. A larger heat exchanger was installed during a shutdown to cope with increasing beam power, which would cause cooling water temperature problems during hot weather.

CONTROL SYSTEM

1985 has been an eventful year for the Controls group. Physically there have been major changes. The hardware group - now four technicians (one on leave at SIN) and a BCIT co-op student - moved to trailer Gg. There they are closer to Electronic Shop assembly, repair and test facilities, as well as to some members of the Electronic Development group. Unfortunately, they are no longer as close to the control room, an inconvenience which we have had to learn to accommodate. With the departure of the hardware group from the vicinity of the control room their former laboratory was converted into a programming (terminal) room and occupied by the four Controls group programmers.

Another important physical change, long planned, was completed in 1985 when the control room east wall was relocated to the west. The area is now more logically divided into a control (operations) room and a computer room, and longstanding environmental problems have been addressed. The control room can be kept relatively warm, dark and quiet (a womb-like environment for operators) while the computer room can be kept cool, light and, unfortunately, noisy. With relocation of the wall came significant improvement in air conditioning and a reduction in downtime previously attributable to high temperatures in the control room.

The expanded terminal area for Controls programmers was required because of our conversion to a new, multi-user programming system. Terminals have been connected to this system using terminal servers on the now partially commissioned local controls Ethernet segment. The system is fully disc and magnetic tape based, and a celebration was held at the end of January to mark the final phasing out of punched cards and paper tape. Six cabinets of cards - the fruit of close to 15 years of programming effort - were sold for less than $100. Unfortunately, the new system, running under Data General AOS on an Eclipse S130 computer, has proved unsatisfactorily slow, lengthening turnaround and hence reducing productivity during limited available maintenance hours. Apparently more contemporary methods require more contemporary machines, and a request has been submitted for a 32-bit MV4000 for program development. A benchmark test run in the fall showed an improvement of a factor of four can be expected for routine linking tasks, with no modifications required to existing programs or facilities.

The development by the group of an active MCA bus repeater has permitted the programming system to be linked directly with control system computers, which allows control system program loading directly from the programmer's system - no medium (paper or magnetic tape) is required. Moreover, completion of the MCA bus has resulted in simplification of system reload procedures and allowed the group to aspire to a 'one-button' reload procedure for all control system computers. A goal for 1986.

Another milestone achieved in 1985 was the retirement of the last of the original Supernovas, in service since 1971. Low-level control system tasks are now carried out by functionally equivalent but more recent Nova 4s. Use of these computers has resulted in a considerable saving of precious computer room rack space. Further space saving has been achieved by the introduction of small 20 MB Winchester technology disc drives to replace the current much bulkier 10 MB cartridge disc drives used for on-line applications.
Expansion of the low-level system of minicomputers has three prerequisites: expansion of the high-speed direct memory access (MCA) bus connecting these computers; expansion of the multiport memory system accessed by them; and exploitation of the expanded executive crate reported last year. The expansion of the MCA bus by use of an active repeater has been reported above. A new multiport memory system, once again packaged in a CAMAC crate but this time allowing up to 32 ports and, incidentally, having a memory capacity of 64 Kwords per module, has been designed. At year's end a two-port wire-wrapped prototype had been successfully tested, and manufacture and installation of the new system was expected in the second quarter of 1986. Finally, the executive crate CAMAC interface, expanded to three crates late in 1984, now connects six Nova 4s, two Eclipse S130s, a VAX 11/730, a microVAX I, and, shortly, a microVAX II (for secondary channel control) to the seven parallel branch central CAMAC system.

There have been two significant changes to this CAMAC system in 1985. The majority of installed CAMAC modules were designed and built before the advent of 'X'. In a two-day maintenance tour de force the hardware group modified over 80% of these modules to provide an 'X' response - the remainder to be done when possible during 1986. The corresponding software change - detecting the X response and reacting to its absence - has not been done. A second major change to the CAMAC configuration was the introduction of a serial highway for control of the third ion source. The serial highway is driven by a commercial (Kinetics 3992) serial branch driver from an existing crate in the parallel system. At present this branch consists of only two crates - one at ground potential and one, driven over a fibre optic segment, in the new source cage at 300 keV. If this scheme proves successful, it is planned to extend the serial highway to include all three source cages, thereby interfacing them all in a standard way. Introduction of a serial highway with the resultant potential for adding a large number of additional crates - a potential expected to be realized in the source environment - necessitated major changes in the manner of storing and interpreting addresses in control system tables. A temporary solution allowing the addition of only 7 crates has been implemented.

Preliminary analysis suggests that the serial highway can be run bit serially without adversely affecting performance, and that has been the first implementation. Conversion to byte serial is of course possible if required. It also appears more efficient to allow the central control system to do all serial high- way operations rather than doing some lower level microprocessor (TRIMAC) data gathering. This too can be modified if needed.

Installation of the third ion source has necessitated other developments by the Controls group. Most notable has been development of a protocol to communicate with the Westinghouse programmable logic controller (PLC) which is being used for digital and interlock control. The central system communicates in an (almost) transparent manner, via a CAMAC memory, to a ground potential TRIMAC which uses a CAMAC parallel I/O system to send and receive messages via a Westinghouse I/O module (SIM) to the Westinghouse controller. Messages are then passed optically to I/O modules in the source. This system, in all its glorious complexity, had been fully tested by the end of 1985.

A second activity related to the source project has been development of a new beam diagnostic and interlock system to be based upon a multi-range amplifier (TRAC-32) developed by the Electronics Development group and a TRIMAC, locally checking beam losses and transmissions and taking appropriate action.

In 1985 as in all previous years the majority of Controls group activities has been in support of routine operation, maintenance, improvement of system and operational features, and support of miscellaneous new facilities and requirements.

System improvements, most of which are largely transparent to users (who, in our case, are primarily cyclotron operators), included modification of the harmonic coils programs to reference the MPM tables; moving the cyclotron current integrators and timers as well as more of the system commands into the 'high level language' computer; addition of a data acquisition task to the display computer; and implementing a new reservation module with a time out feature. Operationally, among other things, the Hall probe measuring system was expanded, a new 'time-of-flight' system implemented, and a disc log of all system error and alarm messages was instituted to allow later fault and/or performance analysis. In addition to work related to the third source considerable effort was expended in support of rf and dc deflector tests in the
fall shutdown and of the new slit system installed in beam line 4V. In addition, first experiments were conducted towards running the polarized ion source in a fast automatic program made for the proposed parity experiment.

The above list is only representative of the support activities provided by the Controls group in 1985. The primary measure of success is the continued low cyclotron downtime occasioned by control system failures. In the first three quarters of 1985 this amounted to a total of only 22.5 h, or 4% of total unscheduled cyclotron downtime.

OPERATIONAL SERVICES

Ancillary systems

1985 was an extremely busy year. Several major projects were completed. The two largest jobs were the upgrade of all five TRIUMF deionized cooling water systems' resistivity and the modification of rooms 35 and 37 into a clean room facility. The five low conductivity cooling water systems were all upgraded with installation of larger deionizing capacity. Water quality has improved to over 10 MΩ/cm resistivity on copper active, aluminum active and meson hall systems. ISIS and copper nonactive are now about 8 MΩ/cm. All had previously been around 1 MΩ/cm or less. Problems of magnet plugging in beam line 1A have disappeared with the improved water quality. Guy LeDalic, on exchange from CERN, was instrumental in the completion of this job.

Rooms 35 and 37 in the main office building have been converted into a clean room facility. For the most part modification of existing HVAC equipment was possible, thus reducing costs. Some growing pains still exist, mostly due to the new equipment performance requirements, but are expected to subside with time.

Several smaller projects were also completed. The Interlab fume hoods were re-ducted to the relocated roof exhaust fans, and services re-supplied. New trailer HH computer room was air conditioned. A new roof exhaust fan was provided to the M15 building to reduce the summertime temperatures. A failure detection switch was installed on the beam line 1A exhaust fan.

Power supplies

During 1985 the Power Supply group finished commissioning and installation of M15 beam line power supplies. In addition a 100 kW experimental supply was installed to power the Helmholtz coil. Power supply configurations for beam line 4B were changed by adding 4 new CTS power supplies which permit independent control for 4BQ9, 10, 13, 14. The 4VSNO supply was changed to a current linking shunt, resulting in better stability of the 4VQ1-4VSM0 combination. Work was done on 4WB1 power supply to more effectively balance the transistor pass bank currents to enable the supply to run at the 1000 A level. The 4CM1 power supply was modified to use a dc current transducer as a current feedback element to improve stability. Current transducers were also incorporated in key M13 power supplies resulting in improved stability which was necessary for QQD. The Chicago magnet power supply (master) was rebuilt along the lines of previous Brentford conversions resulting in a vast improvement in terms of reliable operation. The chronic motor-driven pre-regulator brush problem was solved by incorporating cooling fans for direct brush cooling.

In the main magnet power supply a hose replacement program started with the replacement of the Strato Flex hose which was prone to becoming brittle resulting in pinhole leaks, with silicon hose. A significant number of copper pinhole leaks developed this year in heat sink assemblies which required heat sink replacement. These leaks appear to be the result of erosion due to turbulence and corrosion due to extended exposure to poorly deionized water. With the recent improvements in water quality it is hoped that at least the corrosion rate will decline; however, we may still be faced with a major heatsink replacement program as the equipment becomes older.

The rest of the group's activities involved experimental support.

Vacuum and liquid helium

The vacuum system operated well for most of the year, the only downtime of consequence occurring in June when the in-service B-20 failed unexpectedly. There was substantial damage to the machine and a protracted wait
for spare parts. Changes and improvements to the system are discussed in the vacuum upgrade section of this report.

The liquid helium plant operated well during the year, and in spite of ever-increasing demand all requests for liquid were met. The total of liquid delivered this year is 44,516 l. This is an 11% increase over last year and very close to the practical limit of the system.

Remote handling

Cyclotron

The major activity of the spring shutdown was replacement of 3L5 resonator with a Mark II prototype. Additional work included installation of a beam line 4 H^0 beam stripper flag and four new Cu beam blocker assemblies. Commissioning of the new R/H service bridge carrier was completed during this shutdown.

Between shutdowns the lower resonator handling trolley was upgraded for compatibility with the programmable controller. Work continued on prototype tooling for remote cutting of tank access ports, and two additional active-component storage coffins were constructed.

The fall shutdown saw a flurry of remote handling tank activities during its brief three-week period. 3L5-Mark II prototype resonator was replaced. The alternative extraction DCD was removed, and both prototype DCD and RFD boosters installed and subsequently removed. Exit horn #2 mirror box and stiffening column were removed, providing access for magnetic field measurements, and a fifth Cu beam blocker installed at beam line 2 exit horn. Extraction 1 gate valve was replaced with a new valve and improved remote handleable base; extraction IV valve was removed for replacement of a leaking 'C'-seal. Five new style shadow shields were installed for evaluation. A limited test of the tank perimeter vacuum seal handling equipment proved operational feasibility.

Beam lines

During the first quarter M9 and M20 beam blocker shaft seals, wipers and cooling lines were repaired. The 1AM11 monitor was transferred to the hot cell for repair, and assistance was provided by Remote Handling with the installation of the 4VSLX and 4VSLY slits in the beam line.

In the second quarter activity was made with the development of indium flange seal surface cleaning tools and a remote operable flange separation tool. A vacuum leak in M11 between the slits box and M11Q1 magnet required replacement of the seal. Remote Handling assisted with the removal of a beam line 2C vault beam line monitor box for installation of a toroid monitor.

Third quarter activities included beam line 2C monitor chamber removal to 'free' a jammed monitor assembly, and M8B1 vacuum box neutral beam port cover removal in conjunction with the fall shutdown M8 realignment. 1AM9 monitor was removed from the beam line for replacement of the toroid.

In 1985 two prototype beam line servicing robot arms were assembled, a master controller and 'backdrive' teach-lead-through were fine tuned, and the first fully operable master-slave control unit was completed and demonstrated.

Hot cells

Routine target cassette changes and additions were performed in the hot cell throughout the year. The 1AT1 protect monitor was replaced, and the monitor plate pack on 1AM11 removed and the monitor made available for installation of a new pack assembly. The 4VSLX and 4VSLY assemblies were examined to confirm the feasibility of remote slit removal. The 1AT2 target was removed from service and is presently under repair in the hot cell. The new 'spare' 1AT2 target is now commissioned.

A high-pressure air compressor/storage tank was received and installed to replace the pneumatic pressure amplifiers servicing beam line 1A target areas; the amplifiers will remain in standby service.

Construction of new cell facilities has begun in the meson hall extension with the layout of the hot and warm cell complex. All new cell modular shielding blocks, the roof sections and partition wall have been completed. The hot/warm cell area crane support structure is under construction.
During 1985 the work of the Experimental Facilities Division continued on many fronts: commissioning of new facilities, upgrades of existing facilities, increased support to the experimental programme and design studies towards future facilities. A number of significant achievements were made including the successful commissioning of the charge exchange facilities for (p,n) and (n,p) spectroscopy, the installation of the focal plane polarimeter on the MRS, and the operation of a polarized deuterium target for pion deuteron studies. All of these endeavours have already made their mark on the TRIUMF experimental programme.

In the meson hall the M15 channel, initially commissioned last year, was completed with the installation of the final section and the two dc separators. The design performance is described later in this section. Although muon spin rotation using the pair of dc separators has become a routine part of the channel operation, some improvements to the voltage holding of the separators remains to be done to permit rotation by the full 90°. The M9 channel continued to operate almost entirely for the $\mu + e$ conversion experiment using the TPC. Some problems were encountered with the rf separator after a long period of successful operation. A new project to install a superconducting solenoid on this channel to produce low momentum (~40 MeV/c) polarized decay muons has been initiated as a result of a Japanese proposal to provide funding for the solenoid and refrigerator with TRIUMF providing the remaining components and the installation. The present design of this channel is discussed elsewhere in this report.

There was strong competition for beam time on the M1 channel with the present interest in pion deuteron studies. During the fall shutdown the rear half of the channel was reconfigured to change the position of a sextupole. This change is predicted to produce a smaller beam spot at the target focus as well as allowing the channel to operate to a pion energy of 300 MeV by reducing several quadrupole strengths. After a brief tuning run it was found that the beam spot was essentially the same as previously but it is hoped that the improvement will come with more tuning effort. The QQD spectrometer was used for a major fraction of the beam time on M13. A significant improvement has been the operation of a high-rate wire chamber at the second dispersed focus of the channel to allow data-taking with the momentum slits opened by tagging the pion momentum.

A detailed summary of the first results from the charge exchange facility using the MRS spectrometer is given later in this section. Both (p,n) and (n,p) reactions can be studied over the TRIUMF energy range with subMeV resolutions. For proton elastic and inelastic scattering the MRS routinely provides an energy resolution of 100 keV. Some realignment of the quadrupoles in the six quadrupole twister has improved the agreement between computed and empirical beam line tunes. A focal plane polarimeter consisting of four large-area horizontal drift chambers detecting protons scattered from a carbon slab was installed and successfully used in several experiments. Its performance is outlined later in this section. To enable a complete set of polarization transfer experiments a new project has started to provide a longitudinally polarized proton beam on beam line 4B. This project requires the vault section of the beam line to be rotated to allow for the installation of a pair of superconducting solenoids. The proposed schedule calls for the installation of these items in the fall 1986 shutdown.

In another project on beam line 4A the downstream end of this beam line is being redesigned for the installation of the TISOL facility. This facility consists of a target/ion source for the production of radioactive ion beams and a short mass spectrometer line to analyse these beams. The beam line 4A shielding will be extensively modified in the spring 1986 shutdown for this installation.

The cryogenic targets group were called upon to provide a number of conventional cryogenic targets for experimenters during the year but put most of their effort on the commissioning of the polarized deuterium target. This work culminated in the successful operation of the target for an experiment on M1 with a vector polarization about 35% leading to a tensor polarization of about 10%.

The $\mu$SR group successfully commissioned their OMNI apparatus, a general purpose $\mu$SR spectrometer which utilizes the spin-rotated
surface muon beams on M15 and M20, and placed an order for a $^3$He/$^4$He dilution refrigerator capable of cooling samples to 10 mK.

A new project for both TRIUMF and the Experimental Facilities Division was initiated in 1985. Funded by NSERC this project involves the design and construction of components for a 50 MeV H$^-$ transfer line for HERA, the e-p collider presently being constructed at the DESY laboratory in West Germany. This 80 m long beam line will transport beam from the exit of a linac to the injection, via charge exchange, into a proton synchrotron. The project will be approximately two years in duration.

**EXPERIMENTAL SUPPORT**

**Data acquisition systems**

George Ludgate joined the Data Acquisition Software group in November 1984. Under his direction work started in 1985 on a VAX-based data acquisition system to replace the now aging PDP 11/34 systems. Two VAXes were purchased during the year. The first, a VAX 11/750 with a 6250 bpi tape drive and a 480 Mb disc drive, is presently being used to develop the new software and is destined to be the host for the first implementation. The second, a MicroVAX II, is being used for semi-on-line analysis of $\mu$SR experiments by M15 and M20 users. This latter type of computer is likely to become the backbone host of all other data acquisition systems implemented after the first. Both computers are attached to the site-wide DECNET system with node names MAX and M15VAX, respectively.

For event-by-event experiment the VAX will be provided with a front-end processor to handle the real time requirements of event gathering, event rejection, data buffering and data transfer into VAX memory. The front-end processor will be implemented by installing a CES Starburst into a System Crate – a popular CAMAC architecture. Both the host VAX and the Starburst would be control sources in the System Crate and both would be able to access every element of the CAMAC hardware, concurrently if necessary. The architecture calls for the VAX to control the Starburst and to arrange for data to be transferred into the VAX memory by programmed-transfer or DMA. The Starburst would in turn be a slave of the VAX and handle the real world tasks of data acquisition listed above.

The CES Starburst uses the Digital Equipment Corporation DCJ11 microprocessor, which is a PDP 11 on a single chip. With 128 kb of memory and register-to-register transfer times of 200 ns this single-width CAMAC unit is presently the most powerful available for front-end work and matches the software development expertise of the group exactly – being similar to the PDP 11/34. The Starburst is fully controllable from the CAMAC dataway and dependent on the VAX for downloading its software.

The VAX 11/750 was equipped mid-year with a System Crate containing

- an AMC-11, for DMA transfers from CAMAC into the VAX memory
- the PTI 11C and D System Crate interface modules that make the System Crate 'look' like a UNIBUS device to the VAX
- an IVG interrupt vector generator
- a manual test controller
- a Starburst with 128 kb of memory
- a CES programmable LAM grader
- an MX-CTR-3 executive controller

for development work. Graham Waters (Technology Division) will be writing diagnostic software for the combined VAX/System Crate and the modules listed above. In addition he is investigating ways of downloading stand-alone programs into Starburst memory and starting them. Software was obtained from CERN to allow the initial development work to get under way. This included a System Crate driver for the VAX and a full set of CAMAC access subroutines that conform to the international standard.

The VAX 11/750 also forms the cornerstone for software development effort. PASCAL was selected for this project, being a better software engineering language than FORTRAN or C. A PASCAL compiler was made available on the VAX 11/750 for development work and any user with an account on that VAX is able to use it.

In recognition of the importance associated with developing a VAX-based system a fourth programmer/analyst position was created in the Software group. This position was filled mid-year and prompted the beginning of the software implementation.

The techniques of structured analysis and design are being used to model the system to be built. Two reports describing the
methodology and the system and processor requirements were written and submitted to the CFAT Committee. A later report detailing the process requirements on the VAX was circulated in draft.

By year's end the architecture of the new system was firm and work had started on implementing the structure of the design in preliminary PASCAL code. The operating system for the Starburst was written earlier in the year and requires only small changes to bring it into line with the overall design evolved at year-end. The basic architecture calls for a loosely coupled set of cooperating processes executing concurrently on the VAX. One process would control and interface the CAMAC system for the other processes. A second process would be the hub of a message-passing system and is designed to inform other processes, or users on terminals, of events (signalled by messages) happening to the set of processes. A third process would write raw data or processed data to tape or disc for later analysis. In addition one or more analysis processes (interactive or batch) could be used to process the data before writing to tape or for display purposes only. The processes exchange data by using pointers to a shared global region of VAX memory, rather than copying the data into and out of mailboxes. The architecture allows for a maximum of 4 concurrent experiments using the Starburst. Each experiment is termed a partition and each partition could have a set of data acquisition and analysis processes as described above (subject to a restriction of 1 tapedrive per VAX).

MULTI development

A dataspace module (64 kilowords) has been added to several of the existing PDP 11 data acquisition systems. This memory is used by a modified MULTI to store the on-line histograms freeing up 64 kilowords of PDP 11 memory for other resident or transitory tasks.

DECNET was added to four of the PDP-11s and the DA task was modified to allow spooling of raw data to tape and VAX discs. This feature allows users to employ the power of the VAX cluster for semi-on-line analysis of their data during set-up or running of an experiment.

A new version of the DA task was written to support the System Crate CAMAC architecture. This need arose when experimenters required CAMAC crates to be remote from the data acquisition PDP 11, but close to their apparatus. The selection of the System Crate architecture was made in coordination with its relevance to the future VAX-based data acquisition systems.

In addition to these major changes a number of minor improvements were made and are reported in the quarterly TRIUMF Progress Summary.

Computing facilities at TRIUMF (CFAT)

This year has seen significant developments in the area of computing facilities at TRIUMF (CFAT). The number of VAX family systems (including microVAXes) has more than doubled to about 10 on site. This reflects the addition of the 8600 to the data analysis centre, a 750 for data acquisition development, and four microVAX II systems for a variety of applications. A second major development has been the dramatic expansion of the Ethernet local area network which has also more than doubled to over 20 nodes at present. These factors led to a substantial overlap in the issues which came before the CFAT committee and the VAX steering committee. As a result the two committees were merged and re-organized to achieve a better overview with a more comprehensive mandate. Details of several aspects covered by CFAT, such as the data analysis centre, data acquisition systems and the controls system are described elsewhere in this report (pp. 157, 114 and 154, respectively).

The new CFAT committee reports to the Associate Director/Science Division Head and is comprised of a number of working groups who report to the committee. These groups are VAX management, future systems, data acquisition development and support, applications software support, networks, hardware standards and evaluation, software standards and control systems.

One of the issues which emerged shortly after the 8600-780 VAX cluster was commissioned was the need for a policy on disc space management. The problem was partly addressed by allowing groups with ongoing large requirements to purchase discs to be attached to the system. Another approach has been to invoke more stringent limits on allocations in terms of block-days. The new cluster also forced a major expansion of the PACK 2000 terminal multiplexer system and a decision to move to 2400 bps capable modems.
The networks subcommittee has been very active in evaluating the growing spaghetti of network links to other laboratories and facilities worldwide. In addition to the local PACX and Ethernet links, users can presently transfer messages and/or files via KERMIT, VAXNET, FTP, PSIPAD (X.29) or EAN(CDN) including a gateway to BITNET. Planned future extensions include a direct BITNET link, the US DECNET network and the HEPNET.

Nucleonics and IAC

During unpolarized beam operation use of Pool nucleonics modules continues to be above the 95% level. 370 new modules were added to the Pool database during 1985, taking the total number of modules over the 4000 mark. This included final purchase of LeCroy 624, 825 and 7791 modules which have been taken out of production. Spare components have been purchased for all modules to ensure that they have an operational life in excess of five years assuming typical periods between failures.

Evaluations during the year have resulted in adoption of the Tennelec TC455 quad 200 MHz constant fraction discriminator and Ortec 474 timing filter amplifier as new Pool standards and the LeCroy 612A ×10 photomultiplier amplifier being retained in preference to the Phillips Scientific 776 module. Many other evaluations await full engineering and user studies.

During the year several new automated testing routines were developed for a variety of CAMAC modules. These have resulted in faster and more stringent tests of modules.

The new Instrumentation Pool nucleonics upgrade concentrated on HYTEC system crate modules for implementation of the CAMAC parallel branch highway on the existing PDP 11/34A-based data acquisition systems and future VAX-based systems. Additional modules have been purchased for evaluation to enable CAMAC crates in the experimental areas to be interfaced with the data acquisition computers.

Remote CAMAC crates will contain a large number of programmable modules to perform first level trigger decisions. These modules typically consume a lot of power, so high-power CAMAC crates have been purchased for evaluation. A selection of programmable modules have also been purchased for user evaluation.

Detectors facility

This year we have completed stainless steel gas distribution systems for the proton and meson halls. Gas chromatographic analysis indicates that contamination found with plastic piping has been eliminated. The new tubing contributes less than 1 ppm of oxygen to the gas stream. We also have reorganized the gas distribution systems to improve safety, reliability, gas quality and ease of operation. Copper tubing manifolds for each gas type have been installed on the perimeter of each annex. Each cylinder cuts in automatically when the first cylinder is depleted. Portable bubblers using thermoelectric cooling have been constructed and will complement the portable gas mixing units. The recirculation unit for the TPC including an oxygen purifier is in operation, allowing important savings in gas expenses.

A rigorous test of the effects of freon concentrations in gas mixtures on the performance of our standard wire chambers was conducted. A 0.8% freon concentration produced better resolution, lower chamber currents, longer plateaus, decreased Malter effect and decreased chamber damage.

Many of our gas purity problems have been solved by switching to a new supplier. Gas chromatograph analyses indicate that gases from the new supplier are significantly purer, particularly organic gases.

We have continued our policy of lending wire chambers to experimental groups, averaging 270 chamber-days per month, or 9 chambers on loan at any given time. Maintenance and preparation of these chambers requires about 40% the time of a technician. At times we have been unable to provide the chambers requested by experimentalists, and in the future we may request experiments to contribute financially to the construction of more standard chambers.

We have built 340 scintillation counters, about the same number as last year. Local manufacture of standard bases for scintillation counters is almost complete and the first units will arrive at the beginning of 1986.

Research and development

We have finished work with the one-dimensional position-sensitive photomultiplier. The results are very encouraging and have been
Fig. 104. Event histogram for 3 positions of a point light source. \( G_2 \) is the calculated centre of gravity obtained from the anode signals of the position-sensitive photomultiplier. All 10 anodes were used and the light source was a thin plastic scintillator irradiated with \( ^{106}\text{Ru} \).

published in NIM and presented at the last Nuclear Science Symposium. Resolutions of 1.3 mm have been obtained (see Fig. 104). Two manufacturers are now constructing them, and also two-dimensional devices. We have received two of these tubes and have started testing them together with the PET group at TRIUMF. New developments in fibre scintillators will benefit from these devices.

We have begun development of a very high rate wire chamber with space resolutions of about 1 mm and operational rates higher than scintillators. The mechanical design has been finished and a very fast preamplifier has been built and tested successfully.

MWPC facility

The majority or our time this year was spent in constructing chambers for the MRS spectrometer. Six Los Alamos type drift chambers were assembled for the MRS polarimeter, and two complete front-end chambers were constructed for the MRS spectrometer.

The polarimeter drift chambers use a difference signal from the cathode wires to solve for left-right ambiguity in the drift cells. Unless the winding accuracy is better than ±0.0005 in. evaluation of the left-right ambiguity requires a software gain correction for each anode wire. We were only able to achieve an accuracy of ±0.003 in. on winding these chambers so the software gain correction was needed, and works satisfactorily.

A second version of the MRS front-end chamber has been designed and constructed. This version is much easier to maintain than the one in use last year. Two complete front-end chambers are operating, and enough anode and cathode planes have been made to build eight chambers. The front-end chambers failed very quickly at the beginning of this year, but after installing protection diodes to protect the preamp transistor and adopting a careful cleaning procedure the chambers are now operating relatively trouble free.

Numerous development projects were undertaken, many of which were satisfactorily completed.

MESON HALL

M9 channel

The major activity on M9 this year was completion of data-taking for the \( \mu\rightarrow e \) conversion experiment (104) in the TPC. This was accomplished despite the first serious difficulties with the rf separator encountered since its installation in 1982. These problems required some major repairs and improvements to the old transmitter, and normal operation was more or less restored although further problems remain to be overcome.

The Hall probes were utilized with a new current supply, allowing a better and independent monitor of all but the first two quadrupoles in the beam line.

A major project to redevelop M9 was begun, centred around a 6 m superconducting solenoid offered by a group from the University of Tokyo. TRIUMF has undertaken to incorporate the solenoid in a channel facility to produce low momentum (\( \sim 40 \text{ MeV/c} \)) polarized decay muons for a program of \( \mu\text{SR} \) physics. The current effort is to produce a workable design to include the solenoid for decay muon beams between 40 and 80 MeV/c, along with a second leg which would allow direct beams of pions, surface and cloud muons. One possible layout is shown schematically in Fig. 105. The project is expected to be complete in the fall of 1987.

Plans for the upgrade of the TPC for future experiments are also being formed. A number of possibilities are being considered which could allow experiments with any of the beams produced by the new M9.
During 1985 the M11 channel was heavily subscribed with experiments. Experiment 205 (tensor analysing power in pion deuterium scattering) was completed in March and April. Experiment 322 (measurement of $\pi^- p$ differential cross sections) ran in May and June, partly due to the delay of the polarized deuterium target. Experiment 270 (test of charge symmetry by a comparison of $\pi^- d + n$ with $\pi^+ d + p$) ran in July and August. Experiment 337 (measurement of tensor observables in the $\pi^+ d$ elastic scattering reaction) ran in October and November. Finally Expts. 279 (nonanalog pion single charge exchange) and 281 (pion absorption reactions $^6\text{Li}(\pi^+,X_1)X_2$) each received one week of beam in December.

In January and February we completed an extensive tuning run. The main diagnostic tool used was a temporary slit installed in the entrance to the first bending magnet 11B1. This enabled us to obtain a unique solution to the septum and 11B1 settings. This indicated our previous tunes had the septum mistuned by 6%. This correction had a marked effect on the channel optics. In addition to the elimination of quadrupole steering and a reduction in spot size, the position and focus at the midplane in $x$ and $y$ were much improved. In fact we are considering installing a remotely insertable slit for future diagnostic work.

During 1985 we made two independent measurements of the M11 beam line momentum to establish a good pion energy calibration. The first method was to measure the energy of the ions ($^4\text{He}^+, ^3\text{He}^+, ^4\text{He}^+$) in the beam with a silicon surface barrier detector. The second method was to measure the TOF difference of protons versus pions over the length of the channel. Good agreement between our two methods was obtained at the two momenta at which the TOF measurements were made: we can say with some confidence that the pion energy is known to ±0.3 MeV. Details of the calibration are available in the M11 operation manual.

In the fall shutdown the rear half of the channel was reconfigured to insert a sextupole between Q4 and Q5 (see beam optics section). The advantage of the reconfiguration was that the second-order terms predicted by TRANSPORT and REVMOC decrease dramatically. Also the quadrupole strengths needed for Q4 and Q5 are considerably less than previously, enabling the channel to run to a higher energy. The present energy limit is 300 MeV pion energy. The only limit for 350 MeV pion energy now is the septum magnet power supply.

After the reconfiguration there was a brief 3 day tuning run. The preliminary results were disappointing in that the beam spot was larger than predicted. The beam was found to be diverging in horizontal width upstream of the focus which was not sensitive to quadrupole settings. This is likely due to an unidentified high-order optics term. Due to experimental pressure from the Expt. 337 users who had a working polarized deuterium target it was decided to defer more complete tuning to early 1986.

In the fall shutdown the rear half of the channel was reconfigured to insert a sextupole between Q4 and Q5 (see beam optics section). The advantage of the reconfiguration was that the second-order terms predicted by TRANSPORT and REVMOC decrease dramatically. Also the quadrupole strengths needed for Q4 and Q5 are considerably less than previously, enabling the channel to run to a higher energy. The present energy limit is 300 MeV pion energy. The only limit for 350 MeV pion energy now is the septum magnet power supply.

In January and February we completed an extensive tuning run. The main diagnostic tool used was a temporary slit installed in the entrance to the first bending magnet 11B1. This enabled us to obtain a unique solution to the septum and 11B1 settings. This indicated our previous tunes had the septum mistuned by 6%. This correction had a marked effect on the channel optics. In addition to the elimination of quadrupole steering and a reduction in spot size, the position and focus at the midplane in $x$ and $y$ were much improved. In fact we are considering installing a remotely insertable slit for future diagnostic work.

Since the initial tuning of the channel in 1980 with an alpha source several physical changes in the beam line have been made. Also the requirements for high resolution have become more exacting. Hence a programme to establish a new optimum resolution beam tune has been started. In order not to affect adversely the experimental programme beam time has been limited to when polarized beam is delivered to beam line 1A. We have chosen to study the dispersed foci (at F1 and F2) by measuring the energy of the protons present in the $\pi^+$ beam, using a Si(Li) detector purchased for the purpose. Achromatic foci are measured using MWPC. As an example of this technique we show in Fig. 106 the line of

Fig. 105. Proposed layout of new M9 channel.
settings for optimum resolution at F1, of Q1 versus Q2 and the resolution measured along this line. Figure 107 shows the vertical F1 profile width along this same line of optimum resolution. For a vertical focus at F1, Q1 is about DAC 733 (i.e. the minimum in Fig. 107), and hence for a horizontal focus (i.e. optimum measured resolution at F1) Q2 is about DAC 532. Table XII compares our new tune at 128 MeV/c with the alpha tune scaled up to the same momenta. Only small changes are found. A second high flux tune has been established where the arbitrary requirement for a vertical focus at the intermediate foci is dropped. About 6% more flux is obtained.

Further investigations of the effects of the sextupoles are planned.

During this year we have upgraded the coils on Q4 and have started on an upgrade of the control system. The new control system should be able to cycle the elements in a reproducible way and hence allow a closer correspondence of the bender magnetic field and the beam momentum.

**M15 channel**

While the successful commissioning of an interim version of M15, described in the 1984 annual report, was a tribute to the efforts of a great many people working on the project, much work remained to be done this year to complete the channel as designed.

The final section of M15 (Q9-Q17 plus two dc separators) was installed in the January-February shutdown, except for the high voltage power supplies which were delayed by the suppliers. A couple of borrowed 60 kV power supplies allowed the delivery of a clean surface muon beam to the experimenters during the spring.

The installation of the separator high voltage power supplies took place during late spring. Unfortunately, sparking in the high voltage stacks prevented muon spin rotation of more than about 30° during the late summer beam schedule. Studies of the performance...
of M15 during May indicated that the beam luminosity was poor due to multiple scattering in the 'thick' separator windows which were 0.00035 in. Kapton; these results were confirmed by a recalculation of the effects of multiple scattering. The separator windows were replaced in the late summer with 0.00006 in. polyester, and two of the three windows were mounted on valve mechanisms to allow their retraction for optimal luminosity of subsurface muons (see Table XIII).

The fall shutdown saw the correction of the high voltage stack sparking problems by the Beam Lines group, construction of a proper counting room for the M15 experimenters, and the installation of a 100 kW power supply to energize experimenter spectrometer magnets. The interaction of the crossed magnetic and electric fields above about 33 kV/cm limited muon spin rotation by the dc separators at 28.6 MeV/c to about 75° in November. However, the stability of the separator high voltage appears to be improving over time with their 'high voltage conditioning'. By year-end spin rotation at 28.6 MeV/c became routine, limited to 80° by an electrical problem with the separator magnet power supplies which is scheduled for correction in February 1986. At present it appears that 90° spin rotation will be accomplished on M15, as designed, without any major rework of the system beyond some very patient conditioning.

Work remaining to be done on M15 in 1986 is of a minor nature: some improved X-ray shielding around the separators, installation of air conditioning in the counting room, and some minor improvements to the experimental services and cabling. It is planned to begin development work for a muon kicker to physically eliminate muon pile-up thereby turning M15 into a 'magic' muon channel.

What of the performance of M15? It was indicated in the 1984 annual report that the position acceptance of M15 may not meet the design values of Table XIII. Given that the proton beam is constrained in normal operation to 0.5 cm x 0.5 cm on the production target, it is clear that the M15 acceptance exceeds the production target dimensions.

As shown in Table XIII, M15 meets the design flux and luminosity when the proton beam is 'ideal' as assumed in the calculations. In practice such a beam is only available at low intensities (<20 μA); at higher intensities the proton beam density is reduced by increasing the spot size to increase target life and is centred on the target rather than focused on the top. This results in an M15 flux reduction of about 40% and a luminosity reduction of about 50%. It should be noted that this result for high intensity operation does not indicate any misalignment of M15. Rather, the surface muon production mechanism is greatly enhanced due to geometrical effects with optimal positioning of the proton beam. It may be possible to lower the 1AT1 production target by 2.5 mm without affecting the fluxes seen on M11 and M13 while recovering part of the lost M15 flux. A new target presently being fabricated to withstand greater proton beam densities may also offset part of this loss.

Finally, a significant development by the Controls group has had a tremendous impact on the operation of M15 - the development of a simple automatic tuning program. This allows the experimenter to optimize 20 or more elements in about 15 min, a task which may take more than 2 h to perform by hand without as much precision. This program has allowed experimenters to push the performance of M15 towards its limits by quickly developing tunes to stop muons in very thin targets (Expt. 304 used a 1 mg target!), focus the beam on a very small spot with minimal beam halos, etc. It is clear that without such a tool it is unlikely that M15 would ever realise its full potential in day-to-day operation.

QQD spectrometer

During 1985 the QQD spectrometer was employed three times in M13. The first period was in the March-April intense beam period for DCX on $^{26}$Mg (Expt. 246) and for test runs on elastic and inelastic scattering from $^{20,22}$Ne (Expts. 202, 203) and $^{12}$C (Expt. 278). The spectrometer was installed again in the June-July intense beam period for elastic scattering from $^{3,4}$He at 25-50 MeV (Expt. 285). The third installation was for the intense beam period of November-December for DCX on $^{18}$O at 35 and 65 MeV and for DCX on $^{54,56}$Fe at 50 MeV (Expts. 350/351). Some of the beam time in each of these beam periods was used for development work. The limited rate capabilities of the tuning apparatus meant that M13 studies could only be done with small channel acceptances. This often gave tuning results at variance with the beams used in actual experiments and hence to the decision to employ for tuning studies primary beams of low intensity, i.e. polarized beam. For the results of the M13 tuning see p. 118. The QQD developments are described below.
Table XIII. M15 characteristics with full momentum bite (10%) for 28.6 MeV/c muons normalized to 100 μA of protons on 1 cm carbon at 1AT1.

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>position acceptance, FW(3/4)M</td>
<td>2.5</td>
<td>&gt;0.7a</td>
</tr>
<tr>
<td>bend plane (cm)</td>
<td>0.62</td>
<td>1.0</td>
</tr>
<tr>
<td>nonbend plane (cm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With the present 0.00006 in. separator windows:

<table>
<thead>
<tr>
<th>µ⁺ flux 1000/s</th>
<th>1410</th>
<th>1350±60</th>
<th>820±40</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam spot, FWHM (cm)</td>
<td>1.13 X</td>
<td>-</td>
<td>1.52 diameterc</td>
</tr>
<tr>
<td></td>
<td>1.55 Y</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>central beam spot area (cm²)</td>
<td>1.75</td>
<td>-</td>
<td>1.81</td>
</tr>
<tr>
<td>fraction of total flux in central beam spot (%)</td>
<td>57</td>
<td>-</td>
<td>51</td>
</tr>
<tr>
<td>average luminosity in central beam spot 1000/s/cm²</td>
<td>460</td>
<td>430±50</td>
<td>230±10</td>
</tr>
</tbody>
</table>

With the previous 0.00035 in. separator windows:

<table>
<thead>
<tr>
<th>µ⁺ flux 1000/s</th>
<th>1260</th>
<th>1285±65</th>
<th>750±40</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam spot, FWHM (cm)</td>
<td>2.25 X</td>
<td>2.03 diameterc</td>
<td>2.70 diameterc</td>
</tr>
<tr>
<td></td>
<td>2.25 Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>central beam spot area (cm²)</td>
<td>5.1</td>
<td>3.2</td>
<td>5.7</td>
</tr>
<tr>
<td>fraction of total flux in central beam spot (%)</td>
<td>66</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>average luminosity in central beam spot 1000/s/cm²</td>
<td>165</td>
<td>145±10</td>
<td>60±5</td>
</tr>
</tbody>
</table>

aProjection at 30° to proton beam vertical plane; >1.4 cm in proton beam vertical plane. 1AT1 targets are too small to measure the M15 bend plane vertical acceptance.

bIdeal = 1.5 mm x 1.5 mm proton beam focused at the top of the target; normal = 2.5 mm x 5 mm proton beam centred on the target; i.e. centred 3 mm below the target surface.

cMeasured with circular collimators rather than wire chamber.

A small drift chamber was developed and employed in place of the usual WC1 for the ³He elastic scattering experiment to enable data-taking at angles as far forward as 15°. Figure 108 shows schematically the wire layout of the x-plane of this chamber. An identical plane was used for the y-axis. This chamber was tested with several types of gases. The poor, but not unexpected, position resolution with helium isobutane as the drift gas means that this chamber will only be useful for experiments such as He elastic scattering where momentum resolution is not of paramount importance. The delay line chambers regularly employed at this position have proven to be sufficiently insensitive to the helium magic gas problems for continued use where momentum resolution is required although the achievable forward angles will continue to be limited.

The spare front-end delay line chamber has been rewound with active wires only in the necessary region for use at the WC1 position. This was done to reduce the sensitivity of this detector to stray particles when running.
The ySR facility reached three milestones during 1985: 1) commissioning of the new general purpose μSR spectrometer (OMNI), 2) specification and placing of the order for a dilution refrigerator system, and 3) upgrading the PDP-11 data acquisition systems to use CES histogramming memories.

The new OMNI magnet spectrometer was built to take full advantage of TRIUMF's unique spin-rotated surface muon beams on M15 and M20. By injecting the beam along the field axis, transverse field μSR experiments are possible with low energy muons in moderately high magnetic fields. The OMNI magnets consist of three pairs of Helmholtz coils. The main coils produce a field of up to 4.6 kOe parallel to the incident muon beam. The other pairs of coils generate up to 250 Oe perpendicular to the muon beam in the horizontal and vertical direction.

OMNI has been designed with a modular approach to accommodate a wide variety of experimental set-ups and to allow fast switching between them. Base plates have been built for fast alignment on M15 and M20. OMNI is equipped with the following peripheral equipment: 3D-Hall probes, He flow cryostats with access parallel and perpendicular to the muon beam, a 'Super Varitemp' cryostat with room temperature access to the sample position for very fast sample change, temperature control systems, a residual gas analyser with turbomolecular pumping station, and plastic scintillator systems for various experiment geometries. Since spring OMNI has been scheduled routinely on M15 and M20 for solid-state physics and liquid chemistry μSR experiments.

A 3He/4He dilution refrigerator system has been specified and ordered. It will reach sample temperatures of 10 mK and permit top-loading of samples from room temperature. It will initially be operated together with OMNI. The design allows for future upgrade to superconducting coils for high field capability.

The data acquisition systems on M20 and M15 have been running for a year with the new LeCroy 4204 time digitizers. These were developed based on specifications of the TRIUMF detector for positive pions during the running of Expts. 350/351. The result has been data-taking with a flux of 3.5 MHz since the M13 F1 slit can be opened to 30 mm (2.5%).
pSR groups. During the spring shutdown the DAS software was upgraded to collect data in CES 2161 histogramming memories. This set free PDP 11 memory for permanent DECNET installation. The data acquisition systems now also support LeCroy 3512 ADCs and multiple clock, multiple ADC, multiple memory set-ups. The POTBOX secondary channel control program for M15 and M20 was revised. Alarm functions now allow limit checking on power supplies.

PROTON HALL

Charge exchange facility for (p,n) and (n,p) spectroscopy

During the past year a new facility has been commissioned for the study of (p,n) and (n,p) reactions at TRIUMF energies. For (p,n) studies the system utilizes the MRS to detect recoil protons from a hydrogenous radiator placed at the entrance to the MRS. For (n,p) measurements the MRS is used to detect reaction protons when the neutron detector radiator is replaced by some other target of interest. In either mode the system relies on the existing detector and data acquisition system of the MRS to detect the protons of interest. A layout of the system mode is shown in Fig. 109.

(p,n) mode

In the (p,n) mode the target to be studied, T_{pn}, is mounted on the incident beam line over the pivot of the MRS. After passing through the target the proton beam is bent through an angle of 20° to clear the MRS carriage and focused to a beam dump by a pair of clean-up quads (not shown in Fig. 109). The bending magnet is a specially designed dipole suspended from a bridge structure over the MRS pivot. It is very compact in order to remove the proton beam from the zero degree line in as short a distance as possible behind T_{pn}. The effective length of the dipole is 63 cm with a maximum field of 2.1 T and a vertical aperture inside the vacuum vessel of 7.0 cm. Neutrons from T_{pn} are incident on the recoil proton radiator T_{np} which is mounted on the MRS carriage at a distance of 92 cm from T_{np}. Protons from the H(n,p)n reaction in T_{np} are then detected with the normal MRS counter system.

The detector system for (p,n) measurements is shown in Fig. 110. This is the normal MRS detector system with the addition of a veto scintillator VS and recoil scintillator RS which is the target T_{np} in Fig. 109. The veto counter VS is a scintillator 3 x 5 x 0.16 cm just in front of RS. RS is a plastic scintillator 2 cm wide x 4 cm high and 2 cm thick. In this mode the normal trigger requirement is (not VS)x(RS)x(SP_{0-9}). If desired, any or all of FECΦ, S_1, S_2 and X_1 can be included in the trigger requirement. The thickness of the recoil scintillator corresponds to an energy loss of about 10 MeV for 200 MeV protons. The actual energy loss in the scintillator is measured by the light output which

(n,p) mode

The detector system for (n,p) experiments. The elements VS, RS, SP_{0-9}, S_1 and S_2 are plastic scintillators while FECΦ, X_1, U_1, X_2 and U_2 are wire chambers.
Count rates are readily estimated from the geometry of the system and the known \( H(n,p) \) cross section. The following experimental parameters illustrate typical operation:

- \( T_{pn} \), \( 7\text{Li}, 100 \text{mg/cm}^2 \)
- \( \sigma(0^\circ), 200 \text{MeV} \)
- \( T_{pn} - T_{np} \) distance 92 cm
- \( T_{np} \) 2cmx4cmx2cm CH
- MRS acceptance 2.5 msr
- Beam current 100 nA
- Neutron flux on \( T_{np} \) 2.2 \( \times \) 10^5/s
- Count rate in \( H(n,p) \) recoil peak 1.4/s

The final count rate estimate assumes a wire chamber efficiency of 60% and deadtime losses of 10%.

Resolution. In measurements to date resolution has been limited by energy spread in the incident beam and target thickness. In typical operation beam energy spread is controlled by using a dispersed beam on a strip target to obtain \( \Delta p/p \approx 0.1\% \). Better resolution is available at the cost of reduced beam on target. Contributions from the pulse height resolution of the recoil scintillator signal are expected to amount to about 300 keV at 200 MeV beam energy. This has not been verified directly, but results are consistent with this estimate. Experience has shown that resolution of about 1 MeV is usually obtained in on-line analysis during the experiment. More careful off-line analysis permits correction for a variety of small effects which results in an improvement of 10 to 30% in final resolution. An example of a spectrum with resolution of 700 keV is shown in Fig. 23 of the report on Expt. 265 (p. 29).

In the \( (n,p) \) mode the target \( T_{np} \) is mounted above the MRS pivot and rotates with the MRS as indicated in Fig. 109. The target \( T_{pn} \) (usually \( 7\text{Li} \)) and the beam bending magnet are correspondingly moved 92 cm upstream along the beam line. Thus a change from \( (p,n) \) to \( (n,p) \) mode requires repositioning of the bender, the beam dump and clean-up quadrupoles.

In addition, the counter system is modified as indicated in Fig. 112. In addition to the standard MRS detector system a second front-end counter with four wire planes FECM is located 27 cm ahead of FEC\( \Phi \). A plastic scintillator 1/32 in. thick is mounted between FEC\( \Phi \) and FECM for use in the fast trigger. The target chamber permits up to six targets, labelled \( T_A - T_F \) to be mounted in the counter gas between wire counter planes labelled \( Y_A \) to \( Y_F \). Another wire counter \( Y_V \) is used as a veto counter and the whole array is preceded...
Fig. 112. The detection system for (n,p) experiments.

The detection system for (n,p) experiments is carried out with a plastic scintillator veto VS. Data readout and on-line processing are carried out with the same system as in the (p,n) mode.

Three important features of the system should be noted. First, the second front-end chamber permits improved ray-tracing back to the target, to define the point of origin of particles entering the MRS. The use of the segmented target permits the use of targets with total thickness up to the order of 1 g/cm² without serious loss of resolution due to target thickness. Finally, targets of different materials can be mounted in a single stack, permitting easy and accurate comparison of cross sections. In practice, one target is normally CH₂ so that cross sections can be measured relative to the known H(n,p) cross sections.

A spectrum obtained with ⁷Li for Tⁿ and CH₂ for Tⁿp is shown in Fig. 113. It is very similar to that obtained with the plastic scintillator in the (p,n) mode as shown in Fig. 111. Note, however, the reduction in the relative height of the peak due to ¹²C(n,p) since Tⁿp is now CH₂ rather than CH.

Count rates and resolution are comparable to those for (p,n) measurements. Background arises from reactions in the counter gas and components of the wire counters in the target stack. At some point this background will limit measurable cross sections, but present results indicate that this will be at the level of a few µb/sr/MeV, at least for light targets.

Most of the examples referred to above have been measurements at 200 MeV and 0°. At present the system has been used at energies up to 450 MeV in the (p,n) mode and 400 MeV in (n,p). Measurements have been made to 15° in both modes. Resolution of about 1 MeV was readily achieved in both modes at higher energies. At higher energies count rates are limited because of room background arising from the beam dump. It is expected that this problem will be addressed in the near future.

The successful commissioning of the charge exchange facility establishes an absolutely unique opportunity for nuclear spectroscopy at TRIUMF. The initial experimental results reported elsewhere (Expts. 265, 266 and 267) are very promising.

**Beam line 4A**

In order to determine all polarization components of the polarized beam a new 4A in-beam polarimeter was installed in beam line 4A. It is located between 4AQ5 and the SFU scattering chamber. The monitor 4AM4 had to be moved downstream of the SFU scattering chamber. The commissioning of the polarimeter, which in design is similar to the new beam line 4B polarimeter, is scheduled for early 1986.
The new in-beam polarimeter (IBP2), which monitors pp elastic scattering under 17° (lab) to the left, right, up and down with respect to the proton beam, was installed at 4BT1 in early January. The monitor was commissioned and calibrated (Faraday cup) at incident proton energies of 200, 350 and 500 MeV during three shifts of unpolarized beam. The successful commissioning of the monitor allowed its use in all scheduled experiments.

Neutron facility

After the successful completion of Expt. 121 (Test of charge symmetry breaking in np elastic scattering) in January, the detector system and frozen spin target were removed from beam line 4C. One of the two large neutron detectors was subsequently shipped to Los Alamos, to be used in Expt. 815 (pp → pnπ+). The POLYFLO gas lines to the wire chamber systems in the proton hall were replaced by stainless steel pipes over a period of three weeks during the February/March shutdown. This eliminates oxygen contamination of the wire chamber gas mixtures. In order to make room for the new (p,n) beam dump the Expt.121 electronics racks and the 4C fence and gate had to be rearranged. The neutron polarimeter was moved 1.5 m downstream along the 9° neutron line.

In preparation for Expt. 190 (Radiative capture np → dγ) the LH2 support structure and target were installed and aligned. Subsequently the detection system of Expt. 190 was surveyed in place and cabled up. The electronics was set up in the racks previously used by Expt. 121. After successful completion of Expt. 190 preparations were undertaken to install equipment and electronics for Expts. 182 and 332 (A_{nn} in np elastic scattering and a measurement of R_{f}/D_{f} in np elastic scattering, respectively).

MRS

The completion last year of the medium resolution spectrometer (MRS) upgrade project has resulted in a productive year of operation during which good quality data were recorded for a variety of experiments. These results are described elsewhere in this report. Meanwhile the performance and reliability of the instrument have been steadily improved.

An energy resolution of 100 keV is now routinely achieved in the large angle configuration (LAC). This capability has been extended down to 4.5° in small angle configuration (SAC) through modifications to the target chamber that allow the front-end drift chamber to be mounted much closer (70 cm) to the target. Scattering angles less than 3° are still accessible in a modified vacuum configuration but at some cost to the energy resolution. Further improvements to SAC operation are under way. A new open-sided quadrupole magnet has been designed and is now being fabricated. When it replaces the present spectrometer quadrupole, it will allow the beam to pass unobstructed to a shielded beam stop while the spectrometer is detecting scattered particles at angles as small as 3°.

The performance of the spectrometer drift chambers has also been improved. An initial problem associated with the low gas pressure front-end chamber (FEC) was limited operating lifetime in the presence of large proton fluxes due to accumulation of contamination on the wires. This problem has been alleviated by two factors. Replacement of a FEC can now be accomplished quickly as a result of a redesign of the gas enclosure and vacuum coupling hardware. Also the lifetime has been extended by careful cleaning of the wires before initial use. A lifetime of a week in the presence of a 2 MHz proton flux has been achieved. The immunity to extraneous tracks of the vertical drift chambers (VDC) at the focal plane has been considerably improved by software changes to better exploit the excellent redundancy of the data from chambers of this type. Now the efficiency of the focal plane instrumentation remains above 80% in the presence of primary beam intensities of several hundred nanamperes. This has been especially important when the spectrometer is used as part of the nucleon charge exchange facility when the primary beam is stopped inside the proton hall.

There have been improvements to the primary beam line associated with MRS operation. An outstanding problem with the six-quadrupole dispersion twister has been resolved. This problem was that large departures from the computed tunes for the twister were required in order to obtain acceptable optical properties. This was found to be due in large part to severe internal misalignments of the poles in several of the magnets. During the October shutdown all six magnets were removed and their poles were optically aligned to an...
accuracy of 100 μm. This has resulted in a considerable reduction in the discrepancy between the computed and empirical twister tunes.

An unusual feature of the beam line enhances the capability of the facility to measure very small yields at large scattering angles. The quadrupole doublet downstream of the target is now mounted on rails so that it can approach the target as the spectrometer moves to larger angles. This reduces beam spill due to multiple scattering of the beam by relatively thick targets.

Finally, the data acquisition system software has been enhanced in a number of ways that improve operational efficiency. Through more efficient use of memory, the block size of data on magnetic tape has been doubled resulting in reduced tape consumption and increased data rates. Also more memory space is now available for on-line event analysis. General system reliability is now improved.

Focal plane polarimeter for the MRS

At intermediate energies spin-dependent and spin-independent parts of the NN interaction are of comparable magnitude. Measurements of spin observables in N-nucleus scattering are thus of great importance for a quantitative understanding of the N-nucleus interaction. For example, measurements of the spin rotation function Q have played a major role in the recent development of relativistic models of elastic N-nucleus scattering. The commissioning of a focal plane polarimeter for the medium resolution spectrometer (MRS) during the spring and summer has provided TRIUMF users with a powerful tool to investigate all aspects of the N-nucleus interaction.

The polarimeter exploits nearly the full momentum acceptance of the MRS (typically ±4%). It utilizes measured asymmetries (left–right and up–down) in inclusive scattering from carbon to determine both components of the polarization normal to the particle trajectory. At TRIUMF energies the analysing power averaged over useful nuclear scattering angles between 5° and 20° varies between 0.3 to 0.5. Depending on the incident energy, the maximum carbon thickness is limited by multiple scattering to 4.5 to 13.5 cm, and scattering efficiencies between 1 to 5% are typically obtained.

Up to four slabs of carbon scatterer are mounted as 'drawers' in a support cage which also holds two large trigger scintillators and four large-area (50 cm by 90 cm) horizontal drift chambers, D1–D4. All charged particles passing through the polarimeter produce a trigger, and a dedicated microprocessor (CES Starburst J-11) is used to examine wire positions from D1–D4 and select a small sample of useful scattering events.

In off-line analysis the delay-line chambers D1–D4 exhibit a position resolution of better than 0.5 mm. The ambiguity as to whether the particles pass left or right of the anode wire was resolved reliably by observing the small difference in the pulse height induced in neighbouring pairs of cathode wires [see Henderson et al., BAPS 30, 1250 (1985)]. For a valid event the particle's direction before scattering is defined by a linear track through two previously existing vertical drift chambers (VDC1 and 2) and through D1, that after scattering by a linear track through D2–D4. The angular resolution observed with 400 MeV protons (0.3° projected in x or y) is consistent with multiple scattering estimates.

The performance of the polarimeter is illustrated by results obtained for elastic scattering of 290 MeV protons from $^{208}$Pb (Expt. 294). Using an unpolarized beam the sideways polarization after scattering, $P_s$, is expected to vanish. The fact that $P_s$ is effectively zero (see Fig. 114) demonstrates that instrumental asymmetries are small. In Fig. 115 we compare the polarization $P$ at 290 MeV, and the analysing power $A_y$ at 300 MeV from a previous experiment [Hutcheon et al.], to theoretical curves representing the same fitted relativistic optical potential. The equality, $P = A_y$, is obviously well fulfilled. This comparison provides an excellent test of the performance of the polarimeter over a wide range of counting rates employed during Expt. 294 (up to 300 kHz).

Several novel types of MRS experiments have now become feasible as a direct consequence of the completion of the polarimeter: a) measurements of spin-flip probabilities in small-angle inelastic proton scattering (Expt. 272); b) measurements of the spin rotation parameter Q in elastic proton scattering from spin-zero targets (Expt. 294); c) comparisons of polarization and analysing power in inelastic proton scattering (Expt. 324); d) observation of deuteron polarization in the pp + d reaction (Expt. 300). The full potential of the focal plane polarimeter...
will be realised when modifications to the beam line 4B layout make it feasible to transport longitudinally polarized beam to the MRS target location.

TISOL/ISOL

In June a proposal (entitled the TRIUMF-ISOL facility) to produce intense, variable energy radioactive ion beams was formally submitted to TRIUMF. Isotopes produced in targets bombarded with the TRIUMF proton beam will be transported as intense, mass-separated beams of variable energy to the experimental areas. The target assembly will be installed near the end of beam line 4A while most of the facility will be housed in a new building attached to the north wall of the present experimental proton hall (see Fig. 116).

The proposed facility will be unique. It will consist of a high yield on-line isotope separator (ISOL) and a post-accelerator with variable output energy from 100 to 1500 keV/amu. The isotope production rate will surpass that of any other ISOL in operation or actively planned in the world. The post-accelerated radioactive beam will itself be unique, offering new opportunities for research in fields ranging from medical physics and chemistry to nuclear astrophysics. In particular, it will permit for the first time the mounting of experiments of low intrinsic sensitivity, the production of radioactive targets of isotopically pure nuclides, and the investigation of nuclear reactions involving short-lived isotopes. The post-accelerator will be ideal for the investigation of nuclear reactions of particular interest for nucleosynthesis in stars. This will be the first and, for the foreseeable future, the only facility where such systematic studies can be carried out.

Although much of the technology for ISOLs and post-accelerators is well developed, the TRIUMF-ISOL will operate in very different conditions. The ISOL will be situated in a radioactively hostile environment which will be more severe than in any existing facility. The post-accelerator must be capable of efficiently accelerating a wide variety of low energy ions. Careful studies will be required and the testing of new design concepts may be necessary.

An important starting point in this major project is the installation and operation of a small ISOL to perform a range of necessary engineering R&D and feasibility studies for the major facility; to develop new types of ion sources particularly suited for low Z elements like N, O, F and Ne; and to gain operational experience with such devices.
General characteristics of this small test system (TISOL) - and possible impact on beam line 4A - are described below.

TISOL is being designed to handle up to 1 μA of protons into targets around 1 g/cm². Heavy-element targets, leading to the production of gaseous alpha emitters (radon), will be avoided. The target will be located at the old SFU gas jet position in a self-contained chamber, separated from the beam line by thin windows and gate valves.

The reaction products diffusing out of the thick targets are ionized and then extracted (at 20 keV) into a vertical-bend, magnetic mass-separator. The resolution of this system is expected to be modest (M/ΔM ~ 500). The separated, isotopic ion beam will exit above the (4A) shielding blocks and will be bent horizontally into various experimental test stations.

It is planned initially to use a surface ionization ion source, which is optimal for alkali and alkaline elements. Based upon the experience at ISOLDE (CERN) typical peak yields expected are approximately 10⁶ atoms/(μA s) for ²⁵Na or 10⁶ atoms/(μA s) for ³⁷Li from a heavy target and 10⁸ atoms/(μA s) for ¹²₉Cs from a molten La target. Plasma ion sources and a new electron cyclotron resonance (ECR) ion source are being designed and tested, for installation after the initial testing of the TISOL with the surface ionization system. The latter is expected to be very efficient for low Z, gaseous elements.

Several modifications are planned to the layout of beam line 4A and surrounding block shielding to allow access to the back end of 4A and the TISOL position while beam line 4B is running. A small beam-blocker will be installed after the SFU scattering chamber, and the stairs will be modified to allow entry to two places in the area. It is planned that the maze connecting area 4A with 4B will be moved.

Dual arm spectrometer system/second arm spectrometer (DASS/SASP)

On July 9 an integrated proposal for a second arm spectrometer (SASP) was presented before the LRPC. This instrument would be pivoted at 4BT2, and combining it with the MRS, which is also pivoted at 4BT2, would give the lab a dual arm spectrometer system (DASS). It is envisaged that the SASP instrument by itself could be used for the study of (p,π), (p,n) and (n,p) reactions. The large solid angle of this instrument would facilitate the gathering of statistics on these reactions and make the use of the beam time more efficient. When SASP is combined with the MRS to form DASS the study of reactions of the type (p,2p), (p,πx), (p,p'x) will also be possible. The energy region which is available to study these reactions is the current TRIUMF cyclotron energies 200-500 MeV. It turns out that this energy range is optimum for (p,2p) because of the greater nuclear penetration of protons of this energy due to a minimum in the nucleon-nucleon cross section. It also turns out that this energy range is also
ideal for studying the \((p,\pi)\) reaction mechanism due to the dominance of the \(\Delta\), expected at \(T_p = 350\) MeV. With these features in mind, combined with the available polarized beams and the focal plane polarimeter on the MRS, it is hoped that TRIUMF will acquire a new powerful nuclear physics facility.

The current SASP design being considered is shown in Fig. 117. It has a Q-clamshell configuration. The optics of this system were worked out by H. Enge and S. Yen. The specifications of the design are given in Table XIV. The current timetable for this project calls for a large effort starting in fiscal 1987-88 subject to favourable reviews by various committees next year (most notably the July 1986 EEC). The review by the LRPC was favourable. The current progress for fiscal 1986-87 will be limited to an engineering effort.

**TARGETS**

**Polarized targets**

Large frozen spin target. During January the target was operated in beam line 4A/2 for the final calibration run of Expt. 121, with the cell filled with carbon beads. The target was then dismantled and moved to storage.

Polarized deuteron target. The various components which had been fabricated in 1984 were assembled into a complete target early in the year. There was then a difficult period of commissioning, lasting for six months, during which the DMR system was extensively modified to minimize its impact on the operation of the dilution refrigerator. At the same time techniques were developed to enhance the tensor polarization of the target by burning selected portions of the DMR spectrum. In September the maximum vector polarization of \((-36\pm4)\%\) was achieved in \(\text{Bu(D10)}\cdot 5\%\ D_2\). In October the target was installed in M11 for Expt. 337. During the course of the experiment the vector polarization was \((-32\pm4)\%\), and data were taken to determine the tensor polarization of the burned spectrum by means of the \(\pi+d \rightarrow 2p\) reaction.

Cryogenic targets and devices

**Liquid deuterium neutron production target.** The target was operated successfully and without incident for six separate runs of Expts. 121, 182 and 190. For the final run in December the target was filled with liquid hydrogen rather than liquid deuterium.

**Liquid hydrogen target.** There are three liquid hydrogen targets at TRIUMF. Services to operate these targets are permanently installed in beam line 4A/2, beam line 1B, M11 and M13. One target had been installed in beam line 1B last year and it was operated for the final run of Expt. 208 in June. It was then fitted with a new target flask and vacuum vessel and operated for one run of Expt. 301 in the same beam line. Following this run the target was removed from beam line 1B and prepared for Expt. 297 which is to be run in M20A in January. This preparation also involved installation of all the

### Table XIV. SASP design specifications.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>central momentum</td>
<td>600 MeV/c maximum</td>
</tr>
<tr>
<td>momentum bite</td>
<td>±10%</td>
</tr>
<tr>
<td>solid angle</td>
<td>12 msr at (p = 594) MeV/c</td>
</tr>
<tr>
<td></td>
<td>9.6 msr at (p = 660) MeV/c</td>
</tr>
<tr>
<td></td>
<td>8 msr at (p = 726) MeV/c</td>
</tr>
<tr>
<td>resolution</td>
<td>2.5 (E^{-4}) (\Delta p/p ) at (p = 594) MeV/c</td>
</tr>
<tr>
<td></td>
<td>1.7 (E^{-4}) (\Delta p/p ) at (p = 726) MeV/c</td>
</tr>
<tr>
<td>D/M</td>
<td>5.74 cm/%</td>
</tr>
<tr>
<td>flight path</td>
<td>6.81 m at 660 MeV/c</td>
</tr>
<tr>
<td>angular acceptance</td>
<td>±85 mr in bend plane</td>
</tr>
<tr>
<td></td>
<td>±43 mr in nonbend plane</td>
</tr>
<tr>
<td>focal plane tilt</td>
<td>45°</td>
</tr>
<tr>
<td>total bend angle</td>
<td>90°</td>
</tr>
</tbody>
</table>
services required to support the target in this new location. The second target (called TINA) was installed in beam line 4A/2 and operated for five separate runs of Expts. 182 and 190. Between two runs of Expt. 190 the target was briefly removed, fitted with a new target flask and vacuum vessel, and operated for one run of Expt. 270 in M11.

The third target (called Drake) was installed in M11 and operated for the final run of Expt. 205 with liquid deuterium. It was then fitted with a double cell for the simultaneous liquefaction of $^{20}$Ne and $^{22}$Ne and operated in M13 in conjunction with the QOD for one run of Expt. 202.

The design of a liquid hydrogen target for use in the TPC has been completed.

**Liquid $^3$He target.** The design of a new cryostat for this target was completed and the cryostat was manufactured in the TRIUMF shop during the spring. The target was commissioned and installed in M13 where it was operated for one run of Expt. 285, being filled first with $^3$He and then with $^4$He. It was then operated in the same location for one run of Expt. 199.

**Superconducting solenoids.** The BASQUE solenoid remains in storage. The JANIS solenoid was operated in beam line 4A for Expts. 121, 182 and 190. It was also operated at 4BT1 in conjunction with Expt. 300.

**Meson production targets**

A back-up 1AT2 meson production target structure has been completed and commissioned in beam line 1A. Parts for a similar back-up target for 1AT1 are on hand, and assembly and commissioning of this target will be carried out early next year.

Development of rotating water cooled and driven targets for high beam current densities is continuing. A prototype will be ready for 'in-beam' tests next spring.

**EXPERIMENTAL FACILITIES ENGINEERING**

**Magnets and beam lines**

In the early part of the year projects reported in the last report were completed. These include the new beam dump for the $(p,n)/ (n,p)$ facility which was mounted in the proton hall. A pair of 8 in. 'clean-up' quadrupoles was installed and the facility completed. During the year thermal neutron shielding has been added around the dump to reduce background noise in the various experimental detectors.

The M15 beam line was completed and successfully commissioned, but the dc separators needed special attention to reach their design voltage of 400 kV.

In the two shutdowns the M8 beam line was improved. The special TRIUMF 'heavy concrete' blocks have the unfortunate characteristic that they expand when they are wet. This has caused beam line elements to move, and M8B2 was found to be 0.75 in. out of alignment. The support block had considerable surface cracks but its centre was solid. The bad block was removed by a combination of jacking, chiselling and drilling, and M8B2 was realigned in the fall shutdown. The beam line valve was moved further downstream to reduce radiation damage to the 'O'-ring seal.

The M13 upgrade was continued by changing the coils on M13Q4 to ones with three cooling circuits per coil. An automatic drive was added to the QOD spectrometer.

The M11 beam line was modified by inserting a sextupole magnet between M11 Q4 and Q5, requiring that the dipole be moved downstream. This modification has the advantage of reducing the current required in M11Q4 which was limiting the upper energy limit of the channel.

The proposed TISOL facility at the end of beam line 4A requires changes to the shielding block layout and area access in the proton hall. A new layout and access concept has been proposed and approved (Fig. 118). It will be possible to enter the end of the present beam line 4A when beam line 4B is receiving beam. A 90° dipole and four quadrupoles were acquired from the University of Colorado; they will be used as the main elements in the TISOL line. The dipole magnet will be modified by increasing its air gap and pole shape. This work is well in hand.

The Design Office CAD system installed this year was extremely valuable for looking into the rearrangement of shielding blocks to achieve a satisfactory maze and shielding covering.

TRIUMF has received approval and funding from NSERC on behalf of the IPP to design and supply a transfer line between a 50 MeV proton
linear accelerator and DESY III as part of the Canadian contribution to the HERA project in Hamburg. Designs have been completed for two ±30° dipoles, 20 quadrupole magnets and a small steering dipole. A prototype steerer has been built and surveyed and bids have been requested for the other magnets. Preliminary work has started on the vacuum system and diagnostic devices. These components are scheduled to be shipped to Germany at the end of 1986.

Assistance was given to the ISOL group in the preparation of their proposal by contributing to the cost estimates, layouts and concepts. Input to the KAON factory proposal was provided, with preliminary magnet designs, costings and proposed layouts. The experimental hall layouts and alignment concepts were investigated together with requirements for buildings and services.

The designs for the longitudinal polarization in beam lines 4 have been started. The layout in the vault section is slowly converging and bids have been requested for the two superconducting solenoids and filling systems, Fig. 119. This work will require the complete rebuilding of the vault section of beam line 4. A new crane has been ordered, to be installed in the northwest corner of the vault, to facilitate this installation.
Magnet measurements

The programs POISSON and GFUN were used to complete field calculations on two types of H⁻ extraction magnets for the KAON factory cyclotron extraction study, some three-dimensional gradient coils for an NMI system, the effect of the pole holes on the magnetic field of the HASIMAG dipole, the use of cobalt pole tips in the (p,n)(n,p) magnet, and a small superconducting solenoid for the new M9 channel. A program SUPERMAG was written, which can be used to assist in the engineering design of superconducting magnets. It has been used to study a number of superconducting magnets, including superferric combined functions magnets and various superconducting solenoids.

Heat transfer measurements between 77 K and 4.2 K and 283 K and 77 K were completed on various types of multilayer insulation. As can be seen from Fig. 120 the insulation appears to work well at LN₂ temperatures for up to about five layers, but with more layers no improvement is seen. At LHe temperatures multilayer insulation makes the heat transfer worse. We are studying the reason for this and will be doing some further tests on some other types of insulation. We found the lowest heat transfer occurred when self-adhesive aluminized 3M tape was used on the two surfaces.

Field surveys and other checks were completed on all of the M15 magnets and various other magnets, such as twister quadrupoles, Sagané magnet and CUSP magnet. A portable data-taking system which can be used for doing magnet surveys in situ, e.g. in a beam line or at another laboratory, is being developed.

Fig. 120. Effect of multilayer insulation between a) 77 K and 4.2 K, b) 283 K and 77 K.
The Division has been involved in three major activities this year - the 1985 Particle Accelerator Conference, the KAON Factory proposal and the Alternative Extraction project. In addition there have been the regular activities of Beam Development on the cyclotron and beam lines, Beam line Diagnostics and Computing Services.

Much of the spring was taken up with preparations for the Accelerator Conference, hosted by TRIUMF at the Hotel Vancouver from May 13-16. The attendance (1011) was a record, as was the number of papers submitted (796). Members of the Division were involved in the organization, particularly computerized data management, and also provided 7 contributed papers. Following the conference 12 delegates stayed on for a two-week workshop to review the proposed design of the KAON Factory accelerators. Some significant advances were made, particularly in the design of an rf accelerating system that would remain stable under high beam loading. The summer was devoted to putting together the printed proposal for the KAON Factory accelerators. A draft version was first circulated for comments and then the corrected word processor files were transmitted electronically to a typesetting machine. This proved very successful with plain text but much less so with special symbols, equations and tables.

Major progress was made on the Alternative Extraction project in demonstrating the feasibility of extracting H⁻ ions efficiently from the cyclotron. During the spring shutdown a prototype rf deflector was installed and tested with complete success. Operating at 11.5 MHz, the deflector drives the vᵣ=3/2 resonance near 430 MeV to produce a large coherent oscillation and improved turn separation. The test confirmed theoretical expectations that the losses on an extraction septum would be reduced by a factor of 5, and that the energy spread in the extracted beam is improved. During the fall shutdown an electrostatic septum deflector was also installed and underwent initial tests. Calculations have also progressed, showing for instance that simultaneous use of the rf booster cavities and rf deflector can significantly enhance the turn dilution and the extraction efficiency for H⁻ ions.

In ISIS the performance of the new 'third' buncher has been as expected, giving a 25% improvement in current for narrow phase-width beams. Aberrations in the electrostatic quadrupoles have also been studied and turn out to be of consequence when high voltages are used.

A number of other accelerator beam dynamics studies have been carried out:

- design of cyclotrons as one possibility for a two-stage ISOL post-accelerator at TRIUMF.

- simulation of injection into the Rutherford SNS (Spallation Neutron Source (synchrotron, identifying irregularities in the observed time spectra as the result of emittance mismatch.

- studies of rf programmes for the EHF (European Hadron Facility) synchrotrons and SSC (Superconducting Super Collider) booster synchrotrons.

Plans for producing longitudinally polarized beam on beam line 4B have been further refined; to ensure that the horizontal, vertical and momentum phase planes are decoupled at the MRS, one vault quadrupole must be slightly rotated, as well as the twister.

A new double-arm M9 channel has been designed. One arm incorporates the new superconducting solenoid decay muon channel; the other will transport pions and cloud and surface muons to the TPC. Achromatic and dispersed tunes will be available on both legs. In the Mil channel insertion of a special front-end slit has at last allowed the optic axis to be defined and the optimum settings of the septum and 11B1 dipole to be determined.

A number of new monitors have been developed by Beam Line Diagnostics. A prototype ion chamber spill monitor for scraper foils operated successfully and a permanent version is under assembly. A prototype scanning wire is also under assembly, offering advantages over harps. A secondary emission 'button' monitor on the 1AT2 target ladder is more linear with intensity than the 1AT2 Cerenkov but presently gives too high a signal when beam strikes the target cooling water. Experimental work has started on a minimally intercepting profile monitor for beam line 4B-MRS. Several electronic modules have been designed, built and made operational.
The Computing Services group's major efforts this year have been in improving external communications abilities and graphics support. International network calls have rapidly grown in importance and implementation of the UBC EAN messaging system has been particularly useful. Graphics support has been provided for a large variety of terminals, plotters and printers on site and the graphics packages have been made available to a number of external users.

**BEAM DEVELOPMENT**

**Cyclotron**

*ISIS electrostatic quadrupole aberrations*

The aberrations of the ISIS electrostatic quadrupoles (1 in. radius aperture × 4 in. long) are being studied in detail. Both analytic calculation and RAYTRACE runs through fields generated by RELAX3D indicate that the worst aberration is the one which we label the 'velocity gain' aberration. This is where the particle which enters the quadrupole is speeded up or slowed down by the electrostatic field. The result is that particles which are defocused spend less time in the quadrupole than those which are focused. This aberration is third order and can seriously distort emittance figures if the beam is too large. Specifically, preliminary results indicate that with the present 0.5 in. × 0.5 in. collimators quadrupole voltages should be no higher than ~3 kV. Implications for the new section of ISIS beam line, whose quadrupoles will run at 6 kV, are being investigated.

*ISIS third buncher*

The new buncher operates on the fundamental harmonic and is situated 2.5 m above the inflector. It supplements the existing bunching system which consists of first harmonic and second harmonic bunchers located, respectively, 21 m and 16.5 m from injection. With the cyclotron set up to accept only 5.5° FWHM of rf phase, the new buncher increased the extracted current by 25%. Under normal high-current operating conditions (30° phase acceptance) the third buncher gave no improvement in extracted current. Both of these results are consistent with space charge calculations [Baartman et al., Proc. Tenth Int. Conf. on Cyclotrons (IEEE, New York, 1984) p. 158]. Further tests are planned.

**Alternative extraction program**

The two programs being pursued at present are the extraction of a continuous beam of \( H^+ \) ions with energy in the region of 450 MeV and the addition to the cyclotron of auxiliary 'booster' rf cavities to increase the energy gain per turn at energies greater than 350 MeV. The concepts were described in the Annual Report for 1984 and considerable progress, both theoretical and experimental, has been made in 1985.

In summary an rf device, RFD, is used to produce a radial electric field component with a frequency a half-integer multiple of the \( H^+ \) ion orbit. This field is located at the radial resonance \( v_r = 3/2 \) and induces a coherent radial beam oscillation. About 100 turns later the radius gain per turn from precession is much greater than that from energy gain and the fraction of beam that would be intercepted by the protection foil of the septum of an electrostatic deflector, DCD, is reduced significantly.

The rf booster cavities, RFB, operate at the fourth harmonic of the main rf. Each cavity should provide an additional energy gain similar to the existing acceleration system. The additional radius gain per turn would also reduce septum losses and the reduced number of turns significantly reduce electromagnetic stopping losses during regular operation.

Both a prototype RFD and DCD have operated successfully in the cyclotron. A fifth harmonic booster cavity was built for tests at signal level and a fourth harmonic cavity is under assembly for experiments in the cyclotron during 1986. An alternative design has been produced for a magnetic channel with a coaxial form and cos\( \theta \) winding distribution. Advantages include a lower weight and reduced field leakage. In addition a magnetic field survey has been carried out along the expected extraction trajectory in and beyond exit horn II for more realistic computer calculations.

Results of calculations and experiments are given below; details of hardware development are given in the Cyclotron and Experimental Facilities Division sections.

**Calculations**

The optimum voltage and position of the RFD were investigated using the ray-tracing code GOBLIN.
Fig. 121. Comparison of RFD-produced turn dilution patterns for (a) RFB off and (b) RFB on (150 kV) for the same effective RFD strength (110 V/mm

The voltage cannot be increased indefinitely. The RFD generated coherent oscillation balloons the orbits beyond the unperturbed equilibrium orbit. This reduces the separation generated by the DCD. For an $E_{rf}\times L$ product larger than 200 V/mm-m and for realistic DCD strengths an adequate separation at the first magnetic channel is not possible.

Extraction efficiency depends on the reduction in radial beam density, or 'dilution', achieved by the RFD at the azimuth of the stripping foil shadowing the DCD septum. Since $v_r = 3/2$ the dilution patterns observed at one azimuth can be produced for three RFD positions 120° apart. The incorporation of the 6-fold main field structure results in the optimum turn dilution conditions occurring at azimuths $100^\circ + n\times120^\circ$ downstream from the RFD.

The linear particle tracking code COMA uses a matrix approach and has been altered to include the radial and azimuthal kicks from the RFD, the RFB and the DCD. The code has been transferred to TRIUMF's VAX 8600 computer where 200 particle turns/cpu s are processed.
energy spread in the extracted 445 MeV beam of 85 kV (FWHM), a factor of three down from the RFD off condition. This means that the RFD could be utilized independent of alternative extraction work by beam line 4 users interested in low energy spread.

RFD and DCD. During the October shutdown the DCD was operated together with the RFD. Figure 123 shows the layout of equipment and diagnostic probes for the experiment. The stripped beam from the septum protection foil was extracted down beam line 1. Differential probe HE2 was used to determine beam density modulations with radius, to position the septum protection foil and septum, and to measure extraction efficiency (transmission through the protection foil and DCD). An HE2 scan with DCD positioned and powered to 35 kV is shown in Fig. 124. The small plateau in the total current at the extraction radius gives the extraction efficiency, in this case 65%. Due to electro-mechanical problems both the RFD and the DCD operated at ~50% of their design limits resulting in this low extraction efficiency. Also it appears that the projected thickness of the septum was larger than hoped for, due to positioning diagnostics that proved redundant. This experiment will be repeated in March 1986. Computer simulations predict that with improved performance from components an extraction efficiency of >85% can be expected.

The October shutdown was also utilized for measuring the magnetic fields in exit horn II along the postulated path of the extracted H+ beam. Large areas of this field had never been measured. The measured fields will now be incorporated into our orbit codes to help simulate the extraction process.

ISOL post-accelerator

A proposed on-line scientific isotope production and separation facility would be enhanced by accelerating the low energy 60 keV ($\beta = 1$ to $5 \times 10^{-3}$) singly charged ($q/m = 1/6$ to $1/80$) ions produced by a highly efficient source to energies of ~1 MeV/amu.

A preliminary survey in 1983 indicated that the only operating machines which could provide initial acceleration in this range were two low frequency RFQs. Starting with advice from those laboratories a preliminary design
Fig. 125. Separation produced by a +30 kV/cm, 85 cm long DCD one and a half turns after the deflection. (a) shows the result as measured in October; (b) shows the results of a computer simulation using COMA.

study was completed this year which showed that a series of linear accelerators could satisfy the specifications. This is reported in the Cyclotron Division section of this report (p. 99).

It also appears that two cyclotrons in series would also be adequate. The first, with $B_p = 2 \text{Tm}$, would receive the beam axially injected from the source and accelerate it with separated turns to 0.1 MeV/amu. At this energy it could be stripped to a higher charge state and a second cyclotron accelerate it to ~1 MeV/amu. The first machine could use a superconducting magnet, the second may use a superconducting or a separated sector conventional magnet.

The low $q/m$ means an ion orbit frequency lower than usual, ~2 MHz, and leads to more difficult prebunching before injection.

The radioactive beam intensity will be quite low, $10^8-10^{10}$ ions/s. Single passage through a medium thick enough to strip ions to the equilibrium distribution of charge states will reduce the beam fraction in the desired charge state to <40%. If, instead, the beam were to recirculate several times through a thinner stripper and if the beam in the desired charge state were to be extracted continuously then the fraction can increase to 90%. This is because ions in other states have subsequent opportunities to change to the desired one. This benefit is illustrated in Fig. 126.

Modelling synchrotron injection

The spallation neutron source (ISIS) at Rutherford Appleton Laboratory (UK) is designed around a 50 Hz synchrotron which accepts protons from a linear accelerator at 70 MeV and accelerates them, presently, to 550 MeV. The linac frequency is several orders of magnitude higher than the synchrotron rf (1.35 MHz; $\hbar=2$) and consequently the injected beam appears to be cw. Injection typically takes place over ~300 $\mu$s, or 200 synchrotron turns when the magnetic field approaches the bottom of its sinusoidal cycle. The rf voltage is 3 kV defining a bucket $\pm \pi$ in phase and with a fairly narrow energy acceptance. Measurements of the line density, or charge distribution with phase, made shortly after injection and during the first 1 ms of acceleration showed some very irregular distributions with phase.
Our Monte Carlo program BAS, written to simulate cw accumulation in a dc ring, was modified to include the effects of acceleration but not space charge. Using SNS data kindly provided by ISIS staff we simulated their injection and acceleration process. The code predicted distributions extremely close to those measured [Fig. 127 (a)-(c)]. The irregularities arise from the synchrotron energy acceptance being wider than the linac beam over most of the phase band and from the low value of synchrotron tune, typically 0.003. The latter also allows coherent oscillations or nonadiabatic displacements with respect to the bucket to be established fairly easily. This can also lead to loss of beam at times when the rate of displacement of the bucket, due to acceleration, is high.

Primary beam lines

Longitudinal polarization on beam line 4B

A mechanism for the production of longitudinal polarization on beam line 4B was reported last year. It was noted that there was no problem in its production but there was a problem in its use with the MRS.

The solenoid-dipole solenoid-dipole system which produces longitudinal polarization also couples horizontal, vertical and momentum phase spaces. The MRS requires that horizontal phase space be decoupled from vertical and momentum phase spaces and that vertical phase space be decoupled from horizontal space. A compromise solution has been found which accomplishes these conditions except for a slight coupling of horizontal divergence to momentum.

This solution requires that the vault quadrupole immediately upstream of the first solenoid be rotated slightly (±10°). As at present, rotation of the twister is also necessary. Quadrupole gradients required by this solution are attainable with existing quadrupoles. Further, it has been shown that the system allows operation of beam lines 4A and 4B in 'normal' achromatic and dispersed (4B only) modes. Both beam lines may also be operated so as to produce (horizontal) transverse polarization.

Secondary channels

M9 channel redesign

In the fall of 1987 channel M9 will be replaced by a superconducting solenoid decay muon channel (see Fig. 105, p. 118). The front end has two quadrupoles and a 30° bending magnet. A 30° bend was chosen so that it will be possible to construct another leg at
60°. That leg will be connected to the present M9 extension, which incorporates the rf separator. The TPC can then stay in its present position for experiments with pions. The superconducting solenoid has a 12 cm bore, is 6 m long and has a field of 5 T. The muon spot at the end of the solenoid has 5 cm diameter and a divergence of 500 mr FWHM. We try to transport as many muons as possible with a second solenoid (1 m long, 30 cm bore and 1 T magnetic field) which gives about twice the acceptance of a conventional quadrupole doublet.

There are two legs after the last 45° bend. The 60° bend which follows was chosen to make best use of existing free space in the meson hall. The leg which has the bend to the left is for 40 MeV/c negative muons. Maximum luminosity is 200 k/s in 25 cm² at a distance of 1 m from the last quadrupole for a 100 µA proton beam. The maximum flux is 400 k/s. The other leg is for 77 MeV/c negative muons. Maximum luminosity is 1600 k/s in 100 cm² at a distance of 1.6 m from the last quadrupole. The maximum flux is 2500 k/s.

An important requirement is a dispersed focus where a slit can be placed to influence the transmitted momentum bite. This focus will be immediately after the last bend in both legs. For each leg there will be two tunes. There is an achromatic tune which gives a large acceptance and a large momentum bite of approximately 10%. The chromatic tune gives a dispersed focus after the last bend for a smaller angular acceptance. The minimum momentum bite is 3% \( \Delta p/p \).

**M11 pion channel**

For some time steering problems have been observed in the channel. These were attacked in a tuning session during January by installing a vertical slit at the entrance of the first 60° dipole (11B1). When the jaws immediately downstream of the septum magnet were closed the two apertures defined the central trajectory at the entrance of 11B1. The midplane wire chamber and another located at the 0° port of the second 60° dipole (11B2) defined the exiting trajectory when 11B2 was turned off. In this manner it was possible to determine the settings of the septum and 11B1 as a function of that of quadrupole 1AQ9. When the septum and 11B1 were properly adjusted steering problems disappeared.

A minor shuffle of the components of the channel was suggested following the tuning run. The new configuration would see the last sextupole of the existing channel moved to a location between its fourth and fifth quadrupoles. Separation of these quadrupoles decouples them, thus reducing their pole-tip fields. This in turn results in smaller second-order aberrations. In addition to increasing the upper limit for pion energy to above 350 MeV it was predicted that a higher luminosity beam spot would be obtained at the experimental target location.

During the September shutdown the proposed channel modification was made. A short tuning session became available in November during the start of post-shutdown machine operation. Predicted beam quality at the experimental target was not obtained. Steering problems had returned and there was a question of beam stability on the pion production target. During a much more intensive tuning session in the new year these problems will be studied.

**BEAM LINE DIAGNOSTICS**

*High intensity*

Several development runs have achieved ~200 µA cw and thermal damage has been observed on those secondary emission foils that span the entire beam spot (2x7 mm). The foils are 25 µ aluminum and had been used to estimate the total beam current for the protect monitors. This signal is now derived from a capacitive pick-up. The bandwidth and signal processing are not yet ideal and the intensity signal obtained shows some dependence on the beam pulse time structure. However, once the machine is tuned up for high current delivery the pulse width remains constant.

The restoration of high current operation after the April shutdown was prolonged due to sparking of the TNF protect monitor. Both this device and the TNF beam line window were newly installed, the window being changed from radiation cooled stainless steel to thicker aluminum edge cooled by water. It seems that the lower operating temperature and greater mass of the new aluminum window increased the outgassing time, as has been observed in other accelerator situations. In these circumstances it is important that multipole secondary emission devices operating in the local vacuum be designed to minimize the volume of any regions of low field gradient (i.e. saddle points in potential).
All our secondary emission monitors are constructed with a washer to form a grounded band around the insulation between bias and signal plates. A wiring error on one of the LAT1 protect monitors left the washers floating with respect to ground. The leakage current normally conducted to ground was transmitted through ceramic insulators to the signal plate. It was found that the leakage varied with time; it increased with beam current and interestingly enough decreased once the beam was turned off, according to the rate shown in Fig. 128. It was thought that this may be due to backscattered beam rendering the insulators radioactive. Short half-life components of the radioactivity would decay and produce ionization within the insulator permitting it to act as a semiconductor and conduct. Once the beam was turned off the number of such isotopes in the insulator will decrease exponentially and the resistivity will return to its normal value. The decay scheme in Fig. 128 was analysed to determine whether or not the observed half-lives would correspond to expected isotopes. At least two half-life components are seen and these could correspond to some of the reactions shown in Fig. 128.

**Low intensity**

It was shown that the channel plate system used for high resolution timing is not very sensitive to visible light but is to ultraviolet wavelengths. A UV laser has been used to pulse the channel plate during bench tests.

A channel plate with retractable target has been installed in the vault section of beam line 4. The resolution is ~200 ps but the peak is often superimposed on a broad background of unknown origin. The latter seems not to be directly related to H0 loss in the cyclotron, to local vacuum nor to beam scattering from the beam pipe near the monitor, but arises from beam halo scattered upstream and travelling roughly parallel to the beam pipe. Lead shielding improved the situation.

Some nuclear structure physicists wish to monitor the energy spread of the low current, ~1 nA, extracted beam. At split ratios below $10^{-6}$ this beam can often include extensive tails or satellite peaks. This spectrum can fluctuate rapidly. A profile monitor located at a dispersed focus could supply this information but any device must be of low mass so as not to degrade the beam quality. The device sketched in Fig. 129(a) was installed in beam line 4B to gather information about rates from a thin wire secondary particle generator. From Fig. 129(c) it can be seen that the rate from the residual gas is greater ($10^{-6}$ torr); however, the scintillator accepts particles generated by the gas over a much longer beam interaction region. A segmented scintillator and multianode PM tube will be used to check spatial resolution.

**Instrumentation**

Profile monitors have replaced the SEM split plate devices at the exit of the combination magnets. The latter provided a useful measure of extracted beam intensity for cyclotron experiments that required frequent energy changes. The accurate beam line intensity monitors are usually placed after experimental targets and require beam line re-tuning when the energy changes. A device to integrate the charge from gas filled or SEM profile monitors was tested last year. Several have been manufactured and can be multiplexed to any profile monitor and the current read through the computer control system. The refresh time ranges from 2 to 500 ms depending on the beam intensity and type of monitor.

The current-limiting resistors are being moved, for new or replacement monitors, from a location close to the monitor head back to the bias supply located on a mezzanine. This facilitates the detection of a low bias mode of operation of the monitor and a trip point can be set; however, it affords less protection should nonstandard power sources be used.
Fig. 129(a). Geometry of a low mass profile monitor.

Fig. 129(b). 50 μ section target; each section is wider than the beam diameter.

High bandwidth amplifiers were installed for all the cyclotron high energy probes and for the new low energy probe. Time-of-flight information can be obtained at all energies, useful for isochronism.

Flexible multiconductor cable with Kapton insulation for radiation resistance is now used for cyclotron probe current and thermocouple signals.

Previously six pneumatically inserted 'pop-in' probes with several fingers gave beam intensity and vertical width information at several fixed energies. The multiple fingers have been replaced by a single tantalum foil to give a more accurate measure of beam current. Vertical height and width information is still available by scanning the multifinger high energy probe.

Fig. 129(c). Photomultiplier count rate as beam is scanned horizontally across the target.

**COMPUTING SERVICES**

*Hardware*

The UBC Computing Centre has expanded its facilities by installing a 40 megabyte Amdahl 5840+, resulting in approximately 50% more CPU capacity. A floating point system FPS-164 /MAX array processor with a peak calculating power of 55 Mflops was connected to the Amdahl and made available to a group of UBC, SFU and TRIUMF scientists.

At TRIUMF relief to the heavily overloaded VAX 780 (JACK) was provided by the clustered installation of a VAX 8600 (ERICH), thus resulting in a five-fold increase in computing power. An Ethernet now interconnects approximately 20 computers at TRIUMF. DECNET provides an almost transparent connection between them (including the UVic Physics VAX which is connected via DATAPAC's X.25).

The development of a high speed gateway to UBC has been switched from the PDP11/24 to the VAX 780.

The Gandalf PAXC has been upgraded to a PAXC-2000 with a remote shelf (connected via an optical fibre link) allowing up to 128 terminals to be connected to a trailer outside the fence. The dial-up lines to the PAXC were upgraded by the installation of 4 U.S. Robotics Courier 2400 Bd modems with the V.22 standard (the V.32 standard for 4800 and 9600 Bd modems should result in a further upgrade next year as prices continue to fall).
Two HP pen plotters, one a 6 pen manual paper feed, the other an 8 pen automatic paper feed, were also connected to the VAX cluster.

The obsolete VT640 terminals have been supplemented by about 30 CIT-467 colour graphics terminals, and more recently by the Pericom MG-200s and the Plessey PT100Gs which are high resolution (1024×768) monochrome graphics terminals. The search for a terminal 'standard' is becoming more difficult with the increased pace of technology. An Amiga personal computer is currently being exploited for its high speed graphics capabilities in present 3-D views of 'wire frame' type of plots, on-line display of control parameters and image processing.

Software

PSI now works with international calls, thus allowing X.29 (virtual terminal) connections from the VAX 780 to SIN, DESY, KEK, etc. The 'Coloured Book' software has been replaced by the EAN software messaging system (developed by the UBC Computer Science Department) based on the X.400 standard and is rapidly becoming the standard for file transfers to/from other accelerator laboratories.

The number of graphics devices supported for use on the VAX has continued to expand and now include the VT640 (both Retrographics and Pericom), CIT-467, Tektronix 4010 and 4107, VS11, Plessey's PT100G, DEC's VT241, HP's Thinkjet, Laserjet(+) and pen plotters, ZETA plotter, Printronix, LA100/12/50/120 and the QMS printer.

The Collected Algorithms from the Association for Computing Machinery for the last 10 years have been made available on the VAX. The CERN library for the VAX has been updated with emphasis on implementation of GEANT3, a system of detector description and simulation tools for experimental physicists.

UBC now provides support to those wishing to use either the Cyber 205 supercomputer in Calgary or the FPS-164. UBC's TEXTFORM has been considerably enhanced and was used to produce the publication-quality text on the Xerox 9700 laser printer for the 'camera-ready' publication of the 1985 Particle Accelerator Conference which was held this year in Vancouver. UBC also subscribed to the library of the Numerical Algorithms Group - the NAG library. UBC now also provides a trial on-line consulting service via $MESSAGE and $FSMESSAGE.

Fig. 130. Sample showing the flexibility of the graphics editor EDGR.

Many enhancements have been made to the VAX graphics editor EDGR, the general plotting program PLOTDATA and the vector manipulation program OPDATA. Users are urged to read the extensively updated manuals on these utilities. Figure 130 illustrates the flexibility of the current graphics package. In this case the graphics editor EDGR was used to assemble various drawings produced by itself and other utilities to make a hardcopy on the HP Laserjet+

REPLAY, an interactive program for data handling to display histograms, scatterplots, contour plots, etc., has been converted to use the current graphics package (GPLOT).

KAON FACTORY STUDIES

This year has seen the completion of the TRIUMF proposal for a KAON factory. Although some features will be familiar from previous reports, it seems appropriate here to review the designs and parameters finally chosen for the accelerators and experimental facilities.

To accelerate the 100 μA proton beam from TRIUMF to 30 GeV a chain of 5 fast-cycling synchrotrons and dc storage rings is proposed. 450 MeV H+ ions from TRIUMF are injected by
stripping into the Accumulator ring. A 50 Hz Booster synchrotron then accelerates the proton pulse to 3 GeV, where the frequency swing is almost complete. In the main tunnel (170 m radius) are the Collector ring, which collects 5 Booster pulse trains, the 10 Hz Driver synchrotron and the dc Extender ring, where beam is stored for slow resonant extraction. The rings use separated function lattices, designed for very high transition energy. Dual frequency magnet power supplies provide a 3:1 rise:fall ratio, reducing the peak rf voltage requirements to 600 kV for the Booster (46-61 MHz) and 2400 kV in the Driver (61-63 MHz). Rf beam splitters will be used to program beam bunches between 4 proton lines and vary the pulse spacing from 16 ns to 64 ns.

Main accelerator and injector

The KAON factory is designed to provide 100 μA proton beams at 30 GeV, in order to produce intense fluxes of high energy kaons, stopping kaons, antiprotons and neutrinos. The significant (80-fold) improvement over beams which have been available in this energy region (≤8×10¹² p/s) will make possible experiments which have hitherto been impractical.

In light of these specifications the KAON factory accelerator system has been based on a rapid cycling (10 Hz) 30 GeV proton synchrotron. The fast cycling rate keeps the charge per pulse down to N = 10 μC (6×10¹³ protons) and restricts the time available for instabilities to develop. The circulating current is 20% higher than that in the Argonne IPNS and not quite double the 1.5 A at which the CERN PS operates. Intensity-dependent effects, such as tune shift, instabilities and beam loading, therefore lie in a well-understood region. The higher average current is made possible not only by the higher cycling rate but also by the higher injection energy which limits the space charge tune shift Δν ~ -N/β²γ³ (β and γ are the usual relativistic speed and energy parameters).

The TRIUMF cyclotron provides the basic performance required for the KAON factory injector - H⁻ beams at energies up to 520 MeV, with currents of up to 140 μA scheduled routinely. The only question is how to match this cw machine, producing a continuous stream of beam bunches at 23 MHz, with a 10 Hz synchrotron accelerating 3 μs long pulses every 100 ms? Fortunately the key to an answer is already available in the use of H⁻ ions in the cyclotron. If these are injected into the first synchrotron stage by stripping them to protons as they pass through a thin foil, Liouville's theorem on phase space conservation may be circumvented and beam injected over the many thousands of turns required. If the small emittance beam from the cyclotron is 'painted' over the much larger KAON factory acceptance, the average number of proton passages through the foil - and the consequent damage to it - can be reduced to such a level that foil lifetimes will exceed one day.

At present the stripping process is used for extracting protons from the cyclotron; a new extraction system will be required to extract the H⁻ ions intact. Studies - both theoretical and experimental (see p. ) - indicate that this should be straightforward, especially if beam is extracted at 440 MeV, taking advantage of radial precession induced by the ν₁ = 3/2 resonance nearby. Extracting below 500 MeV will also avoid most of the beam spill caused by Lorentz stripping of the H⁻ ions in the cyclotron's magnetic field, which amounts to 8% between 440 and 500 MeV but only 1% below 440 MeV. The β²γ³ factor is 3 times larger at 440 MeV than at 200 MeV.

Booster synchrotron and storage rings

The choice of a high cycling rate for the synchrotron immediately implies a need for high energy gain per turn and therefore high rf voltage (several thousand kV). To ease this requirement an asymmetric magnet cycle will be used with a rise time 3 times longer than the fall; this reduces the voltage required by one third and the number of cavities in proportion.

There are two additional challenges presented by the rf system. One is associated with the high beam current, implying an rf power capability well above the 3 MW in the beam itself. The other is the frequency swing, which amounts to a factor 1.37 from 440 MeV to 30 GeV. In order to separate the problems of providing high rf voltage and power from that of providing frequency swing, an intermediate Booster synchrotron is proposed to accelerate the proton beam from 440 MeV to 3 GeV. This would cover almost the entire frequency range (a factor 1.33), but involve only 300 kW beam power and require only 580 kV rf voltage (again with a 3:1 asymmetric magnet cycle). The Booster would be 5 times smaller than the main 'Driver' synchrotron (radius 34 m rather
Table XV. Synchrotron design parameters.

<table>
<thead>
<tr>
<th></th>
<th>Booster</th>
<th>Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3 GeV</td>
<td>30 GeV</td>
</tr>
<tr>
<td>Radius</td>
<td>$4.5R_T = 34.11$ m</td>
<td>$22.5R_T = 170.55$ m</td>
</tr>
<tr>
<td>Current</td>
<td>100 $\mu$A $= 6 \times 10^{14}$/s</td>
<td>100 $\mu$A $= 6 \times 10^{14}$/s</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>50 Hz</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Charge/Pulse</td>
<td>2 $\mu$C $= 1.2 \times 10^{13}$/ppp</td>
<td>10 $\mu$C $= 6 \times 10^{13}$/ppp</td>
</tr>
<tr>
<td>No. Superperiods</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>No. Focusing Cells</td>
<td>24</td>
<td>48</td>
</tr>
<tr>
<td>Maximum $\beta_x \times \beta_y$</td>
<td>15.8 m $\times$ 15.2 m</td>
<td>38.1 m $\times$ 37.5 m</td>
</tr>
<tr>
<td>Dispersion $n_{\text{max}}$</td>
<td>4.0 m</td>
<td>9.09 m</td>
</tr>
<tr>
<td>Transition $\gamma_t = 1/\sqrt{n}$</td>
<td>9.2</td>
<td>$\infty$</td>
</tr>
<tr>
<td>Tunes $v_x \times v_y$</td>
<td>$5.23 \times 6.22$</td>
<td>$11.22 \times 12.18$</td>
</tr>
<tr>
<td>Space Charge $\Delta v_y$</td>
<td>-0.15</td>
<td>-0.09</td>
</tr>
<tr>
<td>Emittances $e_x \times e_y$ at Injection $e_{\text{long}}$</td>
<td>$139\pi \times 62\pi$(pm)</td>
<td>$37\pi \times 16\pi$(pm)</td>
</tr>
<tr>
<td>$\Delta v_y$</td>
<td>0.064 eV-s</td>
<td>0.192 eV-s</td>
</tr>
<tr>
<td>Harmonic</td>
<td>45</td>
<td>225</td>
</tr>
<tr>
<td>Radiofrequency</td>
<td>$46.1 + 61.1$ MHz</td>
<td>$61.1 + 62.9$ MHz</td>
</tr>
<tr>
<td>Energy gain/turn</td>
<td>210 keV</td>
<td>2000 keV</td>
</tr>
<tr>
<td>Max RF Voltage/turn</td>
<td>576 kV</td>
<td>2400 kV</td>
</tr>
<tr>
<td>RF cavities</td>
<td>$12 \times 50$ kV</td>
<td>$18 \times 135$ kV</td>
</tr>
</tbody>
</table>

than 170 m), so that 5 pulses from it would completely fill the Driver circumference, but would cycle 5 times faster at 50 Hz. The Driver itself is left with a 2400 kV voltage requirement but a frequency swing of only 3%. The use of a Booster also allows the aperture and cost of the main ring magnets to be significantly reduced - the diameter of the beam being reduced by adiabatic damping during passage through the Booster.

Figure 131 shows the proposed layout, with the Driver encircling the present cyclotron buildings. The chief parameters of the two synchrotrons are listed in Table XV.

The conventional 'flattening' of the magnet cycle would reduce the 100 $\mu$A from the TRIUMF cyclotron to average beam currents at 30 GeV of only 50 $\mu$A for neutrino production (fast extraction) or 33 $\mu$A for counter experiments (slow extraction). Instead, it is proposed to follow each of the three accelerators by a relatively inexpensive dc storage ring, so that the TRIUMF cyclotron would be followed by a chain of 5 rings, as follows:

A Accumulator: accumulates cw 440 MeV beam from cyclotron over 20 ms periods

B Booster: 50 Hz synchrotron; accelerates beam to 3 GeV

C Collector: collects 5 Booster pulses and manipulates longitudinal emittance

D Driver: main 10 Hz synchrotron; accelerates beam to 30 GeV

E Extender: 30 GeV storage ring for slow extraction.

![Fig. 131. Proposed layout of the accelerators and cross sections through the tunnels.](145)
As can be seen from the energy-time plot (Fig. 132) this arrangement allows the cyclotron output to be accepted without a break, 100 μA from the cyclotron can be accelerated and the B and D rings to run continuous acceleration cycles; as a result the full 100 μA from the cyclotron can be accelerated to 30 GeV for either fast or slow extraction.

The Accumulator is mounted directly above the Booster in the small tunnel and the Collector and Extender rings above and below the Driver in the main tunnel (Fig. 131). Identical lattices and tunes are used for the rings in each tunnel, providing structural simplicity, similar magnet apertures and straightforward matching for beam transfer.

**rf system and time structure of the beam**

To minimize beam loss, bucket-to-bucket transfer is planned between the rings. To achieve this at injection into the Accumulator ring the rf frequency must be a simple multiple of that of the TRIUMF cyclotron, 23.05 MHz. Double this frequency has been chosen, 46.1 MHz, making the frequency at top energy 62.9 MHz. Our Booster cavity designs are based on the fast cycling (30-53) MHz cavities at the Fermilab Booster, while the cavities for the A, C, D and E rings are based on those in the Fermilab main ring.

In order to populate all the rf buckets, which are spaced only half as far apart as those at the extraction radius \( R_T \) in the cyclotron, the radius of the A and B rings is chosen to be an odd half-integer multiple of TRIUMF's, 4.5 \( R_T = 34.1 \) m. The circumference will then contain 45 rf buckets, each of which receives a bunch on alternate turns. Pulse programming at the ion source (a 110 ns gap at 1.024 MHz) will be used to keep a group of 5 adjacent buckets empty in the A ring; this provides \( 110 \) ns for the extraction kicker field to rise, allowing the beam in the 40 filled buckets to be extracted cleanly. This 40-full + 5-empty bucket pattern is retained through the B, C, D and E rings, serving the same purpose for injection and extraction kickers, although the gap shrinks to 80 ns at 30 GeV. Each bunch in the fast extracted beam from the Driver is 2.6 ns long. In the Extender the bunch length can be adjusted to users' requirements by changing the transition energy.

As far as possible the rf voltages in the Booster (Fig. 133) and Driver are programmed to give constant bucket area, while the buckets are designed to be 80% full, giving high bunching factor \( B_f \), low tune shift, low charge density and good Landau damping. Towards the end of the acceleration period the bucket areas are allowed to increase to avoid the voltage dropping below that induced by the beam. In both rings the consequent bunch shortening leads to longitudinal instability which can be cured by active damping by feedback. For this to work in the Driver, however, it is first necessary to increase the longitudinal emittance by a factor 3. This will be achieved in the Collector, e.g. by modulating the phase of a high harmonic cavity to 'shake' the buckets.

In all 5 rings beam loading is high, with the fundamental component of the beam current exceeding that of the generator current by a factor 10 at some point in the cycle. To
Ensure stability of the low level feedback loops controlling the rf vector and tuning, it will be essential to equip the final power amplifier with fast rf feedback with sufficient gain to reduce the apparent Q of the cavity-amplifier system as seen by the beam. The B and D rings will also require one-turn-delay feedforward compensation to cope with the periodic transients caused by the 5-empty/40-full bunch pattern.

Control of high intensity beams

Successful operation of a high intensity accelerator depends crucially on minimizing beam losses and the activity they produce. Sources of loss must be controlled or eliminated, the beam and any spill must be carefully monitored, losses must be localized through the use of collimators and beam dumps, suitable materials must be used for absorption and shielding of spilled beam and, where activation cannot be avoided, equipment must be capable of being handled remotely. Careful attention to these features in the case of the TRIUMF cyclotron has enabled twice the originally specified beam current to be accelerated while exposing personnel to less radiation. The same principles will be followed for the five rings of the KAON factory accelerator.

Several processes which give rise to losses in existing machines have been avoided entirely in this design. The use of H+ ions for injection into the Accumulator ring will almost entirely eliminate injection spill. The use of bucket-to-bucket transfer between the rings will avoid the losses inherent in recapturing coasting beams.

The magnet lattices are designed to place transition energy γt above top energy in all the rings, thus avoiding the instabilities and losses associated with zero phase focusing. Moreover, with the beam always below transition, it is no longer advantageous to correct the natural chromaticity, so that sextupole magnets are needed only for error correction, and geometric aberrations of the beam are essentially reduced to zero. High-γt lattices are obtained mainly by creating a superperiodic structure with missing magnet cells and by choosing the horizontal tune just below the number of superperiods. The empty cells provide natural spaces for the installation of rf cavities and injection and extraction equipment.

Because dispersion suppressors are not used and the synchrotron tune is relatively large in the Booster (νs = 0.04) synchrobetatron coupling must be carefully considered there. The coupling can be suppressed by arranging the rf cavities with a certain superperiodicity, for a reasonable tolerance on rf voltage errors.

Beam instabilities

Beam instabilities will be suppressed or carefully controlled. Although all 5 rings have large circulating currents, the rapid cycling times give the instabilities little time to grow to dangerous levels. The most serious instabilities will be those driven by the parasitic modes of the rf cavities. In rings A, C and E these resonances can be made harmless by tuning them so that they lie between coupled bunch mode frequencies (these are revolution harmonics for longitudinal modes and revolution harmonics minus the betatron frequency for transverse modes). In rings B and D the rf frequency varies as β and the total change from injection to extraction is large compared with the revolution frequency. It is unavoidable, then, that a given parasitic cavity mode is crossed during the course of acceleration by many coupled bunch modes. The best one can do is to ensure that resonances are swept through quickly, i.e. to make sure that the parasitic resonances fall between neighbouring coupled bunch modes at times when β=0 (injection and extraction). Typical impedances for cavity parasitics (10^5 Ω for longitudinal and 10^8 Ω/m for transverse) when used to calculate coupled-bunch mode growth rates give e-folding times which are small compared with the synchrotron period. In order to bring the growth rates down to a level that can be actively damped with feedback systems, it will first be necessary to damp the cavity parasitics passively by a factor of about 100 using the standard techniques (Landau damping by octopoles, bunch-to-bunch population spread, and active damping by electronic feedback).

The longitudinal microwave instability is a separate case because of its rapid growth rate. It will be avoided by making the longitudinal emittance sufficiently large at every point of the cycle and by minimizing the high frequency impedance of the vacuum chamber as seen by the beam.

At this stage of the design it is not possible to make accurate estimates of beam blow-up due to instabilities or nonlinear resonances, but to be safe, the magnet apertures have been designed to accommodate a 50%
growth in the horizontal and 100% growth in the vertical beam emittance.

Should the beam become unstable at any time through component failure or power excursions, each of the five rings is equipped with a fast abort system which will dump the entire beam safely within one turn.

**Beam switchyard**

During this past year designs have been finalized for beam transport systems to the kaon experimental area. As shown in Fig. 134, four beam lines are envisaged, two of which (A and C) would be installed initially.

Beam extracted from the Driver ring is separated by rf and electrostatic separators into two vertical bunches. One of these is deflected by a Lambertson magnet to provide the initial horizontal separation of beam line A from beam line C. Further (horizontal) separation is obtained with a 7.5° achromatic section. A series of quadrupole doublets transports this beam to the experimental target on beam line A. Beam line C is fed by that bunch which passes through the Lambertson magnet undeflected. Succeeding quadrupoles transport this beam to the target location. Both beam lines are designed to produce a beam 3 mm in diameter at their target.

Future plans would provide two additional beam lines (B and D) to the experimental hall. Of these, beam line B is the simplest to install. By pulsing on and off the second dipole of the achromatic section of beam line A, beam may be directed along beam line B. Although the beam will not be achromatic at the target on this beam line, the configuration allows one to attain the required 3 mm diameter beam spot at the experimental target.

Because of the layout proposed for the experimental area it is difficult to provide an additional beam line. One solution is to bring beam line D above beam line C. This is accomplished by inserting a vertical dogleg in a long straight section of beam line C. By tilting the dipoles of the dogleg it is possible to obtain sufficient vertical separation to clear subsequent transport elements of beam line C and, at the same time, induce sufficient horizontal deflection so as to cause the two beam lines to diverge. Although beam in beam line D is dispersed in both the horizontal and vertical planes, it is possible to produce a 3 mm diameter beam spot at the experimental target.

**Experimental facilities**

The fast extracted beam from the Driver will be switchable on a pulse-by-pulse basis between the Extender and the neutrino production target. A wideband toroidal magnetic horn will be installed, providing a factor 20 gain and a flux of $10^{13} \, \nu_\mu/\text{cm}^2/\text{day}$ at the detector, ~100 m downstream. The slow extracted beam from the Extender will at first supply two and later four proton lines in the main experimental area (Fig. 135). Beam splitting using either electrostatic or rf separators is being considered; the latter
Fig. 135. Proposed layout of the experimental area.

offers cleaner separation (bunch by bunch) but less flexibility in the split ratio. There will be one thick target station per proton line, with the beam stop located as close as possible. This arrangement saves further transport of poor quality proton beams and minimizes production of decay muons. Each target station will supply at most two forward take-off channels, typically one high- and one low-momentum channel. Details are given in Table XVI. The secondary channels are designed for a 10-fold improvement in beam purity, at the expense of somewhat less than the nominal 100-fold increase in intensity. The 1.5 GeV/c and 2.5 GeV/c channels will have two-stage separation. The 0.7 GeV/c channel will have a pre-separation stage designed to eliminate those pions not coming directly from the target and believed to be the major source of contamination. The design of targets and beam dumps to absorb the 3 MW beam power presents some challenges but appears to be possible and practical. One target design consists of a 6 cm (one interaction length) hollow tungsten cylinder fitted with turbine blades and simultaneously rotated and cooled by water flow.

<table>
<thead>
<tr>
<th>Beam line</th>
<th>Momentum range (GeV/c)</th>
<th>Takeoff angle</th>
<th>Separators/length (m)</th>
<th>Solid angle*</th>
<th>Momentum acceptance $\left(10^8 K^+ / s\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>0.4 - 0.7</td>
<td>10°</td>
<td>1/18</td>
<td>6</td>
<td>5%</td>
</tr>
<tr>
<td>K2</td>
<td>0.7 - 1.5</td>
<td>0°</td>
<td>2/30</td>
<td>1.6</td>
<td>3.8%</td>
</tr>
<tr>
<td>K3</td>
<td>1.25 - 2.5</td>
<td>0°</td>
<td>2/54</td>
<td>0.5</td>
<td>4%</td>
</tr>
<tr>
<td>K4</td>
<td>2.0 - 6.0</td>
<td>0°</td>
<td>1/115</td>
<td>0.08</td>
<td>3%</td>
</tr>
<tr>
<td>K6</td>
<td>&lt; 20</td>
<td>0°</td>
<td>0/48</td>
<td>0.16</td>
<td>8%</td>
</tr>
<tr>
<td>K0</td>
<td>0.5 - 10.0</td>
<td>6°</td>
<td>0/20</td>
<td>0.03</td>
<td>Wide</td>
</tr>
<tr>
<td>Muon</td>
<td>0.0002 - 0.03</td>
<td>135°</td>
<td>1/18</td>
<td>35</td>
<td>10%</td>
</tr>
</tbody>
</table>

*Quantities are specified at maximum momentum value.
Last year's summary for the Technology and Administration Division ended on a suspenseful note. We finished the year somewhat bloodied, not quite knowing how the serious shortfall in general on-site computing power would be lessened. The Five Year Plan approved in September 1984 included a major project slated to start in April 1985 which over a three-year period would provide a major addition to TRIUMF's computing resources.

By budget preparation time in February DEC had announced the VAX 8600 with vague words about its performance and disturbing words about delivery dates. Delivery did not seem probable until at best early in the following calendar year and, indeed, there was a finite chance it would not occur until our next fiscal year. Prior to the VAX 8600 announcement we had been exploring solutions with other computer vendors. IBM in particular was starting to look like a possibility. Conversion problems involved with a nonDEC system were uppermost in our minds but did not seem insurmountable. During the difficult budget-setting process all these uncertainties led to defunding of the project for 1985/1986.

All this certainly didn't solve the problem so work on finding a solution continued as though the defunding had not occurred. Our negotiations with IBM continued in order to better understand both price/performance figures and compatibility aspects. Working with DEC we endeavoured to get more information about technical aspects of the 8600. We actively sought performance figures for the 8600 that had been measured by users.

DEC and IBM were kept fully informed of the state of negotiations with both parties. By late April the IBM proposal was starting to look like a real possibility. Perhaps because of this DEC started supplying more useful information and delivery dates started moving towards real time.

When DEC promised delivery of an 8600 by mid-June an order was placed contingent upon our running some benchmarks to verify that our job mix would get the advertised speed enhancement over the 780. In early May DEC arranged time for us on a newly delivered 8600 in the Toronto area. Since the tests verified DEC's numbers, the order was made firm and the machine delivered in mid-June as promised. Needless to say there was some scrambling to find the down payment - but it was done.

It should be added that throughout the negotiations IBM representatives were most helpful and their sales people had good and readily available technical backup when needed. The contrast with DEC, especially in the initial phases, was remarkable.

On the administrative side the item left pending was the hope that the new in-house administrative data processing system would be used 'in anger' starting April 1, 1985. It was! But not without a few difficulties, ranging all the way from system software errors to users' difficulties with different, and initially inadequate, reports. During the year most of these problems were gradually solved and new ones rose to take their place. An interesting and welcome difficulty has been caused by the fact that comparisons with previous years (which are very useful in predicting our fiscal year-end state) are difficult because our financial information is now up to date and not about two to four weeks old, so things look worse than they really are! In the coming year we hope to have most of the Stores programs on the new system as well as some of the cost centres.

SITE SERVICES

Safety program

TRIUMF received a new consolidated operating licence from the Atomic Energy Control Board early this year. The new licence covers the operation of both the 500 MeV and 42 MeV cyclotrons and has only a few global restrictions. The TRIUMF operating parameters are now specified in a new document entitled 'TRIUMF Operating Specifications' which may be amended by the TRIUMF Safety Advisory Committee (TSAC). The TSAC reviewed and approved several new projects, among them the new TRIUMF isotopes for medicine (TRIM) laboratory and the (p,n)(n,p) facility in the proton hall.
Interlocks

There were no major changes in the central safety system hardware or logic. However, the process for generating the interlock logic was moved from the Univ. of British Columbia Computing Centre to the TRIUMF VAX. The process was streamlined and simplified so that the translation from mnemonics to I/O numbers and internal variables and the compilation of the Boolean logic equations are now one continuous process rather than several discrete steps.

Radiation monitors

The new radiation monitoring system was completed this year after the beam spill monitoring function had run in parallel with the hard-wired readouts for several months. The hard-wired readouts were finally removed in October, greatly reducing the amount of cabling and freeing some much needed space in the control room. The radiation monitoring display computer was put on the TRIUMF Ethernet/Decnet network and some work started towards implementing a data-logging task.

Personnel dosimetry

The total man-dose for 1985 was 920 mSv compared to 640 mSv in 1984. The breakdown according to group is given in Table XVII. Figure 136 shows the dose frequency distribution of individual annual dose equivalents. The total cumulative neutron dose was 13.2 mSv which is only a small fraction of the dose due to gamma/beta fields.

Radiation monitoring

Radiation field measurements in the cyclotron tank during the two shutdowns this year clearly demonstrated the effects that the running schedule can have on the residual radiation field. Although both shutdowns were preceded by periods for which the integral of the extracted beam current was comparable, during the period preceding the fall shutdown most of the integral was accumulated in the last two months before the shutdown. As a result the residual fields during the fall shutdown were twice as high as those during the spring shutdown.

Assaying laboratory

Two full loads of radioactive waste were prepared for shipment to Chalk River Nuclear Laboratories. SAMPO, a computer program for the analysis of gamma-ray spectra from germanium detectors, was installed on the VAX. This allowed the analysis of samples of irradiated lead for estimating the activity production in the thermal neutron facility lead target. These spectra typically have more than one hundred peaks, many of them overlapping.

There was also some work done on a neutron spectrometer using proton recoils in NE213.

Table XVII. Cumulative dose (DRD) for TRIUMF groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Programs</td>
<td>102.9</td>
</tr>
<tr>
<td>Operations (500 MeV)</td>
<td>94.4</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>54.3</td>
</tr>
<tr>
<td>Remote Handling</td>
<td>50.1</td>
</tr>
<tr>
<td>AECL</td>
<td>45.4</td>
</tr>
<tr>
<td>RF</td>
<td>40.4</td>
</tr>
<tr>
<td>Engineering Physics</td>
<td>34.8</td>
</tr>
<tr>
<td>Safety</td>
<td>32.9</td>
</tr>
<tr>
<td>Vacuum</td>
<td>30.4</td>
</tr>
<tr>
<td>Beam Line Engineering</td>
<td>27.8</td>
</tr>
<tr>
<td>Plant</td>
<td>19.2</td>
</tr>
<tr>
<td>Design Office</td>
<td>17.3</td>
</tr>
<tr>
<td>PET</td>
<td>15.8</td>
</tr>
<tr>
<td>Experimenters</td>
<td>14.9</td>
</tr>
<tr>
<td>Cyclotron Development</td>
<td>14.3</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>10.3</td>
</tr>
<tr>
<td>Others</td>
<td>68.6</td>
</tr>
<tr>
<td>Total</td>
<td>673.5</td>
</tr>
</tbody>
</table>
The code FLYSPEC, a simpler version of FERDOR, was implemented on the LSI-11 in order to unfold the recoil spectra.

Industrial safety

TRIUMF first aid attendants treated 126 work-related injuries this year, approximately 11% less than the total treated in 1984. Injuries to outside contractors comprised 13% of the total, and another 5% of treatments were to students and visitors. Time lost due to injury for this period was 27.5 days, up 35% from 1984. Further medical treatment was required in 14% of the cases, down 36% from last year.

As in previous years hand injuries continued as the major component of the treatment total (50%); eye injuries constituted 6% (down from 11% in 1984); and back injuries 12% of the total. For all injuries in 1985 9% were disabling (lost-time injuries), up from last year (3.5%).

During 1985 six of the 10 fire alarms initiated were false. There were two cases of minor fires resulting from the ignition of combustibles during 'in situ' welding operations, and a car caught fire in the parking lot. In all instances fires were extinguished by TRIUMF personnel with no damage to TRIUMF property.

The TRIUMF Accident Prevention Committee (TAPC) continued to hold regular site safety inspections and monthly meetings. The committee is represented on the TRIUMF Safety Advisory Committee (TSAC) by its chairman.

Building program

Construction

During 1985 construction of the meson hall extension and the meson hall service annex was finished. This essentially completes Phase II of the TRIUMF building program as funded by the Provincial Government. Only limited resources are left for the interior finishing and the installation of services for the meson hall service annex as space is assigned to various users and service requirements are determined. The meson hall extension has added approximately 8000 ft² of crane-covered working space to the TRIUMF accelerator building, and the three floors of the meson hall service annex have added an additional 12,000 ft² of floor space.

Design

Building designs and preliminary drawings for a proposed ISOL facility (isotope separation on line) were produced for inclusion in the proposal 'The TRIUMF-ISOL Facility'. This facility would be housed in a three-storey building 40 ft wide by 220 ft long, located along the north wall of the existing accelerator building.

Layouts and key sections for the KAOI factory project were produced for inclusion in the proposal, showing injection structure, tunnel cross section and required site acquisition.

Preliminary design drawings for a 20-unit extension of the TRIUMF House on Agronomy Road in the University Endowment Lands were also prepared during the year. The detailed design and contract supervision is being done by an external architectural consultant under UBC Physical Plant Department, the owners of the building. This project was made possible by a grant from the University of Alberta for $250,000, spread over two years, which covers approximately half of the project cost.

Mechanical engineering

Second arm for the MRS. Conceptual design study was completed for the mechanical requirements to accommodate a second spectrometer arm, to operate simultaneously with the MRS spectrometer on the same target. Several modifications to the existing MRS frame are needed to meet the specified requirements of the second arm.

Sagané magnet. Modifications have been made to increase the pole gap and to enable the magnet to be used in two planes of operation.

Cyclotron gas stripper. A feasibility study of a gas stripper has been done for the small split ratio beams in the cyclotron (see TRI-DN-85-34). The study indicates that, using the best possible techniques, it is impractical for use in the TRIUMF cyclotron.

High temperature gas target. For the experiment on kinetic isotope effects in Mu+H₂ and Mu+D₂ reactions hydrogen gas at pressures of 7 to 14 atm and heated to a maximum of 900 K and 500 K, respectively, is required. The gas reaction chamber is 10 in. diameter by 25 in. long. To obtain uniform temperature in the gas the chamber is contained within a vacuum vessel containing six layers of heat
shields. The critical design factor was reduction of the mass of windows and shielding to minimize the incoming beam scatter. 900 K at 7 atm was a critical design requirement for safety of operation. Detailed design is complete and procurement and manufacture are under way.

**MRS horn window redesign.** The MRS horn window (the final window before the detectors) requires a change in width and addition of a moving remotely operated beam shield on the vacuum side.

**500 MeV irradiation facility.** The cooling system was upgraded to meet a) very hot weather affecting the supplied cooling water, b) higher beam currents, and c) beam striking the target rims thereby increasing the total heat input. Simultaneous occurrence this summer raised temperatures to the maximum allowable levels. The system was modified to install a larger heat exchanger.

**Planning**

In 1985 considerable effort was spent in planning and co-ordinating the shutdown activities for the spring and fall shutdowns, five year plans, cost estimates for ISOL and KAON factory proposals and PERTs related to the cyclotron and experimental facilities and support. Three papers were presented - at Calgary, INTERNET-85, 8th World Congress on Project Management at Rotterdam, and at Denver in the conferences organized by the Project Management Institutes (PMI) at regional and international level. These papers dealt with the project management techniques, tools and concerns for research organizations.

Progress on each PERTed project is generally described elsewhere in this report under the activities of the principal group involved. A list of projects which required a large part of Planning's efforts is as follows:

- Cryogenic targets (hydrogen, NASA $^3$He, etc.)
- $(p,n)(n,p)$ facility
- Brookhaven experiment (drift chamber, photon end cap, veto, etc.)
- HERA project

Shutdowns were scheduled in the spring and fall. The highlights of these shutdowns are as follows:

The February shutdown lasted for about six weeks (February 6-March 20). Beam production was on schedule in spite of several problems towards the end of the shutdown which required raising the lid three times in the last week of the shutdown. The rf deflector, the dummy dc deflector, third ISIS buncher and 4V slits were installed. Also a newly designed standard resonator segment #5 was installed. In the meson hall the major activity was the final phase of installation of components in the M15 building. The first stage of the $(p,n)(n,p)$ facility installation, focal plane polarimeter work and 4AM8 work was done in the proton hall.

The fall shutdown began October 2, and tank work took place during the week of Oct 7-13. There were several problems with the rf transmission line and in tuning the machine for AES tests. In spite of tuning problems the AES tests were completed and beam production started as scheduled on November 13, and in the first week of production we were able to deliver 122% of scheduled microampere hours. Major activities in the tank were replacement of the 3L5 resonator with a cooled beam panel and installation of LE2 and the rf and dc deflectors with controls.

The meson hall shutdown started September 10 and continued through to October 18. Major jobs in the meson hall were M8B2 alignment, M8 gate valve replacement and M13Q4 coils replacement. M11 components were rearranged to improve the beam spot, and a spare T1/T2 target was commissioned. In the proton hall the 4A polarimeter and the $(p,n)(n,p)$ facility were installed and the twister elements were realigned.

**Cost centre planning**

In the design office one designer was assigned to Applied Programs and CP-42 activities. Design for the dipoles and quadrupoles for the HERA transfer line (for DESY) were accommodated in the design office without a
major effect on the schedules of other TRIUMF projects.

The workload in the machine shop remained very heavy and as projected an equivalent of 3-4 man-years of work was subcontracted to meet various schedules for developments and installations.

CONTROLS, ELECTRONICS AND COMPUTING

The Controls, Electronics and Computing section provides service to a variety of TRIUMF groups and experiments, and its contribution is reported in detail in other parts of this report. Only a brief overview is presented here.

Controls

The last of the venerable control system Supernovas was retired in 1985, and more easily maintainable Nova 4 computers took over their low-level functionality. The Controls hardware group moved to Trailer Gg in TRIUMF suburbia, where they are now conveniently close to the electronics shop and maintenance facilities (and inconveniently distant from the control room). The software group thereby acquired a terminal area where program development at last proceeds without the use of paper tape or punched cards. Reason enough to make 1985 memorable! The new, multi-user disc-based programming system has proven slow, and the requirement for a 32 bit programming system has become apparent. As has been the custom, the group maintained one BCIT co-op student position throughout 1985. One technician has spent most of 1985 on leave as part of the SIN-TRIUMF technician exchange program, and there have been two changes in personnel within the group. A detailed description of the work of the Controls Group in 1985 can be found in the Cyclotron Division section of this report.

Electronics

In the fall a new leader was appointed to head the Electronics Development group, which at that time included 10 engineers and 11 assignable technicians, as well as 11 technicians working in the electronics shop. The group continued to play an educational role by supporting graduate, co-op and summer students. During the summer months the microprocessor lab had no less than 4 students - a University of Alberta engineering co-op student, a BCIT controls co-op student, a VCC computing practicum student, and a Vancouver high school student participating in the University of Waterloo summer program. The office and laboratory space for the microprocessor laboratory was consolidated in a new trailer in the spring, making room for expansion of the detector development area and addition of a clean room for further exploitation of gallium arsenide technology.

The Electronics Development group assisted the TRIUMF community in a large number of projects during 1985. These range from independent local control systems to the development of front-end electronics for experimental data acquisition systems and support for the fast-growing TRIUMF data communications networks. A more detailed report of the activities of the group in 1985 is given in the Electronics section below.

Computing

In 1985 the section relinquished its direct responsibility (though most assuredly not its interest) for software support of data acquisition systems. On the other hand, 1985 was a particularly eventful year for the Data Analysis Centre, where a VAX 8600 was installed and clustered with the venerable VAX 11/780, and the problem of a critical dearth of CPU cycles was replaced by an equally severe problem of insufficient disc space. The DA Centre also oversaw an explosive growth in local and remote communications, including expansion of the DECNET/ Ethernet LAN to a two-segment, 20-node system; installation of a Gandalf PACX 2000 multiplexing system; and participation in a veritable alphabet soup of international data, mail and message systems.

Details of progress during 1985 can be found in the section on the Data Analysis Centre (p. 157).

Electronics

The Electronics Development group has provided support to the Cyclotron, Science, Applied and Experimental Facilities Divisions in 1985, as well as completing a number of projects of its own. Progress on most of these projects is reported in the appropriate sections, and only a brief summary is given below.
Accelerator systems

The major activities of the Cyclotron Division in 1985 all required the support of the Electronics group. The alternative extraction system program culminated in tests of the rf and dc deflection systems in the fall. The rf deflector was powered from the ISIS rf shelf, having been integrated by the group with the ISIS rf system. The dc deflector required beam diagnostics and probe biasing, which were provided by modules developed and installed by the group. Positioning was controlled from the central control room by a CAMAC-based motor control system designed by the group. Work is in progress to support further tests with these systems in 1986.

A detailed study of the ISIS beam line diagnostic system begun in 1984 identified the major sources of noise and offsets. Minor system changes resulted in significant improvements, with the result that useful current measurements in the lowest amplifier ranges can now be made. The major undertaking begun as a result of this study has been development of a 32-channel CAMAC multi-decade auto-ranging amplifier which measures currents up to 3 mA and down to a sensitivity of about 10 nA. The device, known as TRAC-32, is based upon a Micro-Networks MN 5420 chip. By the end of 1985 prototype testing was complete, and PC layout nearly ready to proceed to manufacture. Use of this amplifier in conjunction with a local TRIMAC for the I3 diagnostic system will significantly reduce the number of modules and complexity of that system. If this application is successful, use will be expanded to replace existing systems.

The support provided by the Electronics Development group towards installation of the third ion source has not been limited to the diagnostic system. A major effort has been directed at the problem of interfacing the Westinghouse programmable logic controller chosen for digital and interlock control within the source to the central control system. This has involved programming the Westinghouse to interpret messages received from a CAMAC output register and building an optical link to allow the Westinghouse computer at ground potential to talk to its input/output devices in the source. This system had been fully tested for a single device by the end of 1985, with the anticipated difficult operational lessons still to be learned in 1986. In addition a slit control system for use in making emittance measurements on the CUSP source was commissioned in the ion source laboratory in the summer and will be installed for use at the source in the spring of 1986.

The group supported the Cyclotron Division in a number of smaller projects. With the retirement of the old beam spill monitor system, the 11/73-based safety system was finally fully commissioned and left to the Safety group. Several improvements were made to the tank vacuum system upgrade which was completed in 1984. These included work on language conversion of some of the software, major rewiring of the system break-out panels, and system modifications as required in support of the installation of cryopumps. A new portable tank periscope control system was designed and installed to assist in tank diagnostics and service.

A number of other projects undertaken by the group in 1985 will have wide application but were initiated primarily in connection with Cyclotron Division projects. These include development of a nonvolatile CAMAC memory and a new CAMAC-CAMAC communication system based on that memory and using a fibre optic link to ensure that each memory is automatically and transparently kept as a copy of the other. A new STD-based MUX/ADC system is under development to replace the (obsolete) analogic systems now in the central control system where there are large concentrations (>64) of channels. This will be used in the new ISIS beam line system, as will a light link driver developed for use with the serial CAMAC branch servicing I3 and the Westinghouse PLC controller to I/O module (SIM) link.

Experimental facilities

The CAMAC-based 'universal target controller' (UTC), successfully completed in 1984, has had widespread application in 1985. These controllers impose a continuing maintenance load, as each application requires some individual tailoring, but this has always been possible easily, and on schedule. A version of the UTC for use with the ultra high purity gas system to be used on Expts. 297 and 249 had been developed and tested by the end of 1985. The most interesting development in the area of target support has been the initiation of a project to add a logging capability to UTC installations. This will be done using an IBM PC (portable), the first such application of a PC to a local control system (but not the last, see below).
Also in the domain of target support the deuterated frozen spin target control system was installed on M11 during the October shutdown. The system uses two TRIMACs and one Starburst to control the polarization monitor (NMR device). The TRIMACs handle the frequency synthesizer and transient recorder used to gather NMR data. The Starburst handles front end NMR signal processing. Final analysis is performed by a host PDP 11.

Other activities in support of the Experimental Facilities Division have included completion of the (interim) control system for M15. This included expansion of the Gould/Modicon programmable logic controller system beyond its originally intended application to the vacuum system to include control and protection of the separators. A TRIMAC-based automatic beam tuning system was also commissioned on M15, and has proved very successful.

Motor systems for the new 4V slits were commissioned in 1985, and another system for rotation of 4VQ3 in association with the longitudinal polarization facility is now being planned. The magnet survey system has been upgraded with a new translator box.

Work is also well under way on a thick-film technology based amplifier for use with delay-line chambers, and support of the MRS focal plane polarimeter acquisition system is continuing. As we begin 1986 three major projects in support of Experimental Facilities are gathering steam. These are the development of a new secondary beam line control system, which will be based upon a microVax II integrated with the central control system at the executive crate level; assistance with the design and implementation of the new VAX-based data acquisition system; and support of TISOL. It is our present intention to support the latter with a stand-alone system using an IBM PC, and to use the opportunity to learn more about the potential for use of PCs and PC operating systems in control applications.

Applied Program

Throughout 1985 the group has provided continued maintenance support for the PET project as required. In addition, a stand-alone control system was provided to the PET Chemistry group to assist with the production of 2-deoxy-2-fluro-D-glucose (FDG). The manual method of production has been replaced with a computer automated system. Computer hardware based on the S100 bus, and software written in FORTRAN and 8080 Assembler, provide sequential execution and monitoring of time-regulated steps. Level, temperature and flow transducers provide closed-loop feedback for process termination. The results of each step of the process are logged on a disc drive for later retrieval. An interactive mimic display using rudimentary VT100 line graphics is provided.

One engineer has continued to be seconded full time for the development of the TRIM radioxenon process control system. This facility is based upon a PDP 11/73, and control programs are under development in the microprocessor laboratory. The group is also providing some consulting advice and testing related to proposed improvements in the CP-42 control system. The gallium arsenide laboratory (reported on elsewhere) is also a collaboration with the Applied Programs Division.

Microprocessor Laboratory

The principal activities of the microprocessor laboratory during 1985 may be grouped into three major areas: support and application of different processor families; support and application of programmable logic controllers, and motor control systems.

The group is having to deal with the fact that applications in growing numbers are being found for three different processor families: the TRIMAC, the IBM PCs and the DEC 11/73, packaged either as a CAMAC module (Starburst) or stand-alone. While the TRIMAC has been very well supported from both the hardware and software standpoints, the group's resources are being stretched to provide equivalent support for the newer families. The need for establishing standards in languages, operating systems, protocols, interfaces and libraries is apparent. It has been decided that the TRIMAC will continue to have a useful role to play, but that its development systems should in future be based on IBM PCs. Several IBM-to-CAMAC interfaces have been successfully tried (including a TRIMAC acting as an RS232 auxiliary controller), and a PC has been attached to the TRIUMF Ethernet LAN. The search for an appropriate multitasking operating system is on. The group's experience with the Starburst has made it a resource for Starburst users all over North America.

The group has now had experience in the application of three different commercial
programmable logic controllers: Westinghouse (source 3), Gould (M15), and Mitsubishi (periscope). Experience so far has been satisfactory, but it is clear that where systems do not simply stand alone, considerable effort may be required to implement an easy interface to associated systems. The cost of this effort should not be ignored in estimating the cost of proposed applications. Another hidden cost in money and effort is that of a human interface. Finally, we have come to be wary of the very serious speed limitations imposed by these systems.

A number of projects undertaken by the group involve motor control systems. In 1985 we installed systems to control the 4V slits, the emittance slits for the CUSP source, the dc deflector and some target ladders. Under development are systems for the 4VQ3 twister, secondary channel slits and jaws, and the extraction electrode for TISOL. A standard system configuration and protocol has been developed for these applications, which is transparent (at a high enough level) to the selection of synchronous or asynchronous motors. In the interests of economy and power conservation a new translator system has been developed as a co-op student project for use in appropriate applications.

Conclusion

In addition to the activities outlined above, the group's involvement with FASTBUS accelerated in 1985. The first gate array ADI chips designed at TRIUMF were produced by Fujitsu and forwarded to Fermilab for testing. The TRIUMF/Brookhaven collaboration has led to our more active involvement in FASTBUS system support for data acquisition.

The group's CAD facility was used to full capacity in the last months of 1985, the schematic capture system being in use an average of 56 h/week. This has led to a decision to purchase a more modern, more fully integrated CAD/CAM system, incorporating auto placement and auto-routing. By the end of 1985 a decision on which of the contending systems to recommend was imminent. The group also provides technical consulting services to stores personnel, as well as some project scheduling to supplement the work of Planning.

Thus in 1985 the activities of the Electronics Development group were many and varied, and the prospects for 1986 are as varied and interesting.

The VAX 8600 was delivered early in June along with an intelligent disc server - the HSC50. By the end of June TRIUMF's VAX cluster - consisting of the current VAX 11/780, in which was installed an additional four megabytes of memory donated by DEC, the HSC50 with one new and the three 456-megabyte discs which had been connected to the 780 - was made available to users. Due to the increased CPU power of the 8600, some four times that of the 780, users were able to increase their productivity by a significant amount. So much so that disc space became scarce. To alleviate the storage problems three new 456-megabyte discs were purchased for the cluster - one public scratch disc and two private discs by the Brookhaven and Simon Fraser University experimental groups. With four scratch discs users have been able to dump their data from tapes to disc and do analysis quite efficiently. Currently the two public user discs are full due to users archiving their files on disc.

The communications system has been upgraded by trading in the PACX IV for a PACX 2000 which will handle more terminals and computers, higher throughput, and provide the ability to tune the characteristics of the PACX interface to the equipment type. In addition a fibre optic link was installed between the PACX's main CPU in the computer room and a remote controller in one of the trailers. The remote permits local connections without additional cabling to the computer room. New modems have been installed which operate at 300, 1200 or 2400 baud for faster throughput for off-site computer users.

The new version of the VAX operating system has opened up some new communications procedures:

- The VAX 11/750 located in the Physics Department at the University of Victoria is now part of the TRIUMF LAN. This was accomplished through a DATAPAC link between the 780 and the 750 with DECNET and PSI.
- The VMS mail utility now supports message transfers to any other VAX-run DECNET and PSI connected to a commercial packet switching network. The ability to make international calls has been facilitated by the upgrading of the DATAPAC protocols in western Canada.
• A local DECNET link using an asynchronous terminal port (9600 baud) has been established between the 780 and the PET microVAX 2. This cheapnet link allows the microVAX to access any other computer on the LAN.

ADMINISTRATION

Business Office

The support given to users by the Business Office kept pace with growing demands for usage of the facilities. The number of accounts for NSERC and other institutions together increased by 12 to 143.

The quantity of paperwork generated by the users, which in turn determines the resultant workload handled in Accounting, Purchasing and Stores, was as follows (actual number of transactions and in per cent of total workload):

<table>
<thead>
<tr>
<th></th>
<th>NSERC</th>
<th>Other Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase orders</td>
<td>404 (4.6%)</td>
<td>858 (9.7%)</td>
</tr>
<tr>
<td>Requisitions</td>
<td>1523 (20.4%)</td>
<td>996 (13.4%)</td>
</tr>
<tr>
<td>Cost centre work orders</td>
<td>235 (11.0%)</td>
<td>208 (9.7%)</td>
</tr>
<tr>
<td>Invoices</td>
<td>716 (4.5%)</td>
<td>1632 (10.3%)</td>
</tr>
<tr>
<td>Stores issues*</td>
<td>1966 (12.1%)</td>
<td>1602 (9.8%)</td>
</tr>
</tbody>
</table>

*Issues averaged 2 line-items each.

In terms of number of transactions processed NSERC and other institutions accounted for 9.6% and 10.5% of the workload, respectively. When applied to computer usage to support these transactions these percentages translate to:

<table>
<thead>
<tr>
<th></th>
<th>NSERC</th>
<th>Other Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU time (h)</td>
<td>7.6</td>
<td>10.1</td>
</tr>
<tr>
<td>Lines printed</td>
<td>2,129,300</td>
<td>2,812,800</td>
</tr>
<tr>
<td>Pages printed</td>
<td>51,759</td>
<td>68,373</td>
</tr>
<tr>
<td>Terminal time (h)</td>
<td>1,310</td>
<td>1,730</td>
</tr>
</tbody>
</table>

NSERC accounts consist of all grants forming part of the NSERC Common Grant to TRIUMF. Other institutions are all other users' accounts.
1985 PARTICLE ACCELERATOR CONFERENCE

A major activity for many TRIUMF staff this year was the organization of the 11th Particle Accelerator Conference, held at the Hotel Vancouver from May 13-16. This was the first time that this biennial meeting has been held outside the United States, and TRIUMF was honoured to have been chosen as host. In spite of the extra travelling required, both attendance and contributions set new records, testifying to the continuing vitality of the field.

Reports on particle physics projects at the conference included the Fermilab Tevatron (Energy Saver and $p$ source), CERN ACOL and LEP, Stanford SLC, DESY HERA and KEK TRISTAN. A special session was devoted to superconducting super colliders, both American and European. For nuclear physics there were reports on the Chalk River superconducting cyclotron, the ANL ATLAS linac, the Darmstadt SIS synchrotron and on possible relativistic heavy ion colliders. Accelerators are playing an increasingly large role in other fields as well. Two intense pulsed neutron sources have come into operation - the Rutherford SNS and the Los Alamos PSR. Accelerator radiation sources, both synchrotron- and free-electron-laser-based, are revolutionizing optical and X-ray spectroscopy; projects for 6 GeV synchrotrons are under consideration both in the USA and in Europe. Light- and heavy-ion accelerators are being developed for inertial confinement fusion. Novel accelerators are being designed for radiation therapy, isotope production and radiation processing. The greatest challenge, however, remains to reach the very highest energies; for this the novel techniques of laser-driven plasma heat-wave, wake-field and two-beam accelerators have been showing some promise.

The meeting was the largest yet in the series, with 1011 registrants. Of these, 249 came from outside the United States, maintaining the international flavour that the conference has acquired over the years. There were 66 invited talks and 730 contributed abstracts, of which 45 were presented orally and 529 in poster sessions. 94 papers were submitted for publication only, while 62 were eventually withdrawn. The Organizing Committee's decision to extend the period of the conference from the traditional three days to four made it possible to accommodate all this material in two parallel oral and two parallel poster sessions. The proceedings were published in October in two volumes of 2352 pages altogether. The total number of authors was 1825.

A further advantage of the four-day conference was that it provided the opportunity for an evening event in addition to the traditional banquet - in this case a barbecue and tour of TRIUMF. This event in itself, occurring on the first evening, was something of a triumph of logistics: over 900 visitors were wined, dined and shown around by a small army of volunteer guides (about 70 in all). At the banquet Dr. Erich Vogt gave a memorable and entertaining speech on "Accelerators - Instruments and Symbols for Power", which is recorded for posterity in the proceedings.

Unfortunately there isn't room to mention all 137 staff members, wives and summer students who helped to make the conference run smoothly, but special credit must go to those who undertook special responsibilities:

- Joop Burgerjon (Arrangements Chairman)
- Corlin Bordeaux (Treasurer)
- Shirley Sargent (Accounting)
- Lorraine King (Registration)
- Shayna Ramdeen (Travel)
- Corrie Kost (Data Management)
- Rom Balder (Data Management)
- Joe Chuma (Data Management)
- George Ludgate (Printing & Mailing)
- Alan Otter (Posters)
- Paul Schmor (Audio-Visual)
- Milos Zach (Exhibits)
- David Gurd (Social Events)
- Elizabeth Bordeaux (Companions)
- Michael La Brooy (Publicity)
- Ada Strathdee (Editor)

ACCELERATED RADIOACTIVE BEAMS WORKSHOP

The 3rd Radioactive Beams Workshop was held from September 5-7 at Parksville, British Columbia, Canada. The organizing committee consisted of C. Barnes (Caltech), L. Buchmann (Toronto/SFU), J.M. D'Auria (SFU) and C. Rolfs (Münster). Funding for the workshop was provided by NSERC (Canada), NSF (U.S.A.), DFG (West Germany), TRIUMF and Simon Fraser University.

Approximately seventy physicists, chemists and engineers from various sub-disciplines...
participated in the meetings which consisted of thirty invited talks and nine contributed talks in six sessions (over three days). In addition, two evening sessions were devoted to intensive discussions on technical topics related to the program. The overall objective for the workshop was to explore the theoretical justification and experimental feasibility of installing a radioactive ion beam (RIB) accelerator facility at the output of the proposed on-line isotope separator (ISOL) at TRIUMF. Thus sessions were devoted to theoretical nuclear astrophysics, methods of generating intense beams of selected radioisotopes, different methods of accelerating such radioactive ion beams to energies of interest, and different aspects of the experimental systems required to perform such studies. In addition other applications of such accelerated beams were presented as well as reports from other laboratories attempting such studies. The evening sessions were devoted to discussing in detail anticipated problems with developing sources of the radioactive ions as well as arriving at a consensus for the required specifications of the accelerator facility.

Overall it appeared that the workshop generated a great deal of enthusiasm and support for the proposed systems and the possibility of performing these important although difficult experiments. The consensus was that the experimental program was quite exciting and feasible. A variety of possible and intriguing solutions for accelerating the very low velocity radioactive ions generated by an ISOL device at TRIUMF were uncovered although it was apparent that the RFQ-linac approach appeared the most viable at this time. It was agreed that such a RIB facility would be unique in the world and attract a large number of new scientists to TRIUMF to perform studies that are not now part of the experimental program.

The proceedings from this workshop are now a TRIUMF report [TRI-85-1] and copies are available. Individuals wishing additional information on the possibility of performing experiments on the proposed RIB facility should contact J.M. D'Auria/SFU.

TRIUMF USERS GROUP ANNUAL GENERAL MEETING

The annual general meeting was held at TRIUMF on December 3 immediately preceding the winter EEC meeting. Featured speakers were Dr. E. Adelberger (Univ. of Washington), who discussed symmetry principles in subatomic physics in a particularly clear manner, and Dr. G. Ewan (Queen's Univ.), who gave a very informative talk on selected topics in underground physics.

The evening dinner at the UBC Faculty Club was followed by a discussion led by Dr. E. Vogt and centred around questions posed by the users. The discussion ranged over many topics from TRIUMF House to the KAON factory and was not only informative but even entertaining.

Users' business

The TRIUMF Users Executive Committee (TUEC) supported financially the workshop on muon spin resonance (μSR) techniques organized by J. Brewer as well as the first Lake Louise Winter Institute to be held in February 1986.

For the first time, TUEC was invited to submit names of persons to sit on the expanded Operating Committee. Dr. Y. Shin (Univ. of Saskatchewan) was suggested for a two-year term and Dr. B. Robertson (Queen's Univ.) for a one-year term. Drs. E. Ansaldo (Saskatchewan) and T. Drake (Toronto) agreed to serve as alternates.

Remote users were especially glad to hear that the University of Alberta had decided to make a major contribution toward construction of a new wing to TRIUMF House. Construction was under way by year-end and is expected to be completed by the summer of 1986.

Long Range Planning Committee

TUEC extends its thanks to the Long Range Planning Committee (LRPC) for the detailed reports it has produced and particularly for its renewed efforts to effectively anticipate future developments within TRIUMF. The membership of the LRPC in 1985 was:

A.W. Stetz
Chairman
Oregon State University

O. Häusser
Secretary
Simon Fraser University

A. Astbury
E.W. Blackmore
K.-L. Erdman
K. Gotow
W.T.H. van Oers
C.A. Wiedner
R.M. Woloshyn
P. Kitching
(ex officio)

University of Victoria
TRIUMF
Univ. of British Columbia
Virginia Polytechnic Inst. & State Univ.
University of Manitoba
MPI Heidelberg
TRIUMF
TRIUMF
Two members retired this year: Dr. A. Stetz and Dr. R.M. Woloshyn, and the Users Group wishes to express sincere thanks for their efforts over the last three years on the LRPC.

TUEC is pleased to note that Dr. M. Blecher (VPI) and Dr. B. Jennings (TRIUMF) have agreed to serve on the LRPC beginning in 1986.

Election of TUEC for 1986

The 1986 TUEC membership will be

E.L. Mathie
Chairman
Univ. of Regina

C. Waltham
Assoc. Chairman
Univ. of British Columbia

E. Ansaldo
Univ. of Saskatchewan

J. Crawford
McGill University

P. Schmor
TRIUMF
ORGANIZATION

Board of Management

The Board of Management of TRIUMF manages the business of the facility and has equal representation from each of the four universities. At the end of 1985 the Board comprised:

University of Alberta
Dr. J.G. Kaplan
Dean W.J. McDonald
Dr. G.C. Neilson Chairman

Simon Fraser University
Dr. T. Calvert
Dean B.P. Clayman
Dr. G. Ivany

University of Victoria
Dr. A. Astbury
Dean A.T. Matheson
Dr. L.P. Robertson Vice-Chairman

University of British Columbia
Dr. M. Belkin
Dr. K.L. Erdman
Dean P.A. Larkin

Non-voting members: Dr. J.J. Child, National Research Council
Dr. P.A. Redhead, National Research Council
Dr. E.W. Vogt, Director, TRIUMF
Dr. P. Kitching, Assoc. Director, TRIUMF
Ms. M.K. James, TRIUMF Secretary

Changes in board membership were: Dr. A. Astbury and Dean A.T. Matheson replaced Dr. C.E. Picciotto and Dr. R.R. Davidson as University of Victoria members; Dr. T. Calvert and Dr. G. Ivany replaced Dean J.F. Cochran and Dr. J.M. Webster as Simon Fraser University members.

The board met four times during the year.

Administration

Under the directorship of Dr. E.W. Vogt, all TRIUMF personnel are organized into six divisions, with division heads and the administration branch as follows:

Division Head, Science Division
Dr. P. Kitching
Division Head, Applied Programs Division
Dr. R.R. Johnson
Division Head, Cyclotron Division
Dr. G Dutto
Division Head, Experimental Facilities Division
Dr. E.W. Blackmore
Division Head, Accelerator Research Division
Dr. M.K. Craddock
Division Head, Technology and Administration Division
Dr. W.K. Dawson
Chief Financial Officer
Mr. C.W. Bordeaux
Personnel Officer
Ms. P. Adams

Operating Committee

The Operating Committee of TRIUMF is responsible for the operation of the facility. It reports to the Board of Management through its chairman, the Director, Dr. E.W. Vogt. In 1985 the membership was broadened: in addition to the four voting members, one from each of the four universities, three new voting members joined the committee, two representing the interests of external users and one representing TRIUMF staff. The Associate Director is a
Members of the committee (alternate members in parentheses) at the end of 1985 were:

- Dr. E.W. Vogt Chairman
- Dr. P. Kitching ex-officio
- Dr. J.M. Cameron Director
- Dr. R.G. Korteling Associate Director
- Dr. D.A. Bryman University of Alberta
- Dr. D.A. Hasinoff Simon Fraser University
- Dr. M.D. Hasinoff University of Victoria
- Dr. Y.M. Shin University of British Columbia
- Dr. B.C. Robertson Queen's University
- Dr. D.A. Bryman University of Victoria (Dr. G.A. Beer)
- Dr. M.D. Hasinoff University of British Columbia (Dr. G. Jones)
- Dr. Y.M. Shin University of Saskatchewan (Dr. E.J. Ansaldo)
- Dr. B.C. Robertson Queen's University (Dr. T.E. Drake*)
- Mr. K. Reiniger TRIUMF
- Ms. M.K. James Secretary TRIUMF
- Dr. J.J. Child ex-officio National Research Council

Changes in 1985 other than the extended membership: Dr. J.M. Cameron replaced Dr. G. Roy as senior member for the University of Alberta, with Dr. D.A. Hutcheon being appointed as alternate; Dr. R.G. Korteling replaced Dr. J.M. D'Auria as senior member for Simon Fraser University, with Dr. P.W. Percival being appointed as alternate.

TRIUMF Safety Advisory Committee

The TRIUMF Safety Advisory Committee (TSAC) consists of:

- Mr. I.M. Thorson Chairman
- Dr. M. Adam TAPC Chairman, Applied Programs Division
- Mr. J.W. Carey Cyclotron Division
- Dr. M.W. Greene Director, Occupational Health & Safety
- Dr. J.A. Macdonald Experimental Facilities Division
- Mr. L. Moritz Head, TRIUMF Safety Group
- Mr. A.J. Otter Experimental Facilities Division
- Mr. D. Pearce Cyclotron Division
- Dr. T. Ruth Applied Programs Division
- Mr. R. Thaller AECL-Radiochemical Company
- Mr. J.S. Vincent Applied Programs Division
- Dr. P. Walden Science Division
- Mr. N. Zach Cyclotron/Accelerator Research Division
- Ms. K.J. Majetic Secretary

Observers

- Dr. P. French
- Dr. B. Phillips
- Dr. R. Walker
- Mr. O. Knezevic

AECB
B.C. Ministry of Health
AECL
Workers' Compensation Board of B.C.
Experiments Evaluation Committee

Dr. A.W. Thomas Chairman University of Adelaide
Dr. R. Abegg (ex officio) TRIUMF
Dr. D. Ashery Tel-Aviv University
Dr. J. Beauchamp California Institute of Technology
Dr. J. Cramer University of Washington
Dr. N. Davison (ex officio) University of Manitoba
Dr. J. Deutsch Université Catholique de Louvain
Dr. L.G. Greeniaus Secretary TRIUMF
Dr. P. Kitching (ex officio) TRIUMF/University of Alberta
Dr. J.-M. Poutissou (ex officio) TRIUMF
Dr. R. Redwine Massachusetts Institute of Technology
Dr. R.H. Schuler University of Notre Dame
Dr. M. Stott Queen's University
Dr. K. Wolf Texas A&M University
Dr. T. Yamazaki University of Tokyo

μSR Subcommittee:

Dr. M. Stott Chairman
Dr. J. Beauchamp
Dr. P. Kitching (ex officio)
Dr. R.H. Schuler
Dr. T. Yamazaki
Dr. R. Kief1 Secretary

Biomedical Experiments Evaluation Committee

Dr. L.D. Skarsgard Chairman B.C. Cancer Foundation
Dr. M.J. Ashwood-Smith University of Victoria
Dr. H.C. Johns Ontario Cancer Institute
Dr. R.R. Johnson TRIUMF/University of British Columbia
Dr. T.R. Overton University of Alberta
Dr. A.W. Thomas University of Adelaide
Dr. E.W. Vogt TRIUMF
Dr. D.C. Walker University of British Columbia
Dr. G.F. Whitmore University of Toronto

164
Appendix A

PUBLICATIONS

Journal publications:

Experimental


*deceased


Theoretical


C.Y. Cheung, S.A. Gurvitz and A.S. Rinat, Probability current conservation imposed on

Review articles:


D.H. Boal, Energetic particle emission in nuclear reactions, ibid., 85.

Applied


In press and preprints:

Experimental


P.L. Walden, Explanation of the observation of a T=2 state of $^{14}$C via the $^{13}$C(p,$\pi^+$)$^{14}$C reaction (submitted to Phys. Rev. Lett.). [TRI-PP-85-31]


[TRI-PP-85-99]


[TRI-PP-85-105]


[TRI-PP-85-50]

C. Cernignoi, N. Grion, G. Pauli, R. Rui and R. Cherubini, Inclusive neutron, proton and...
deuteron energy spectra from stopped $\pi^-$ absorption in $^6$Li, $^9$Be, $^{16}$O and $^{27}$Al (Nucl. Phys. A, in press).


Theoretical


S. Godfrey, G. Karl and P.J. O'Donnell, $^3S_1 - ^3D_1$ mixing in charmonium and EL radiative transitions (Z. Phys. C, in press).


W. Hengeveld, K. Allaart and W.H. Dickhoff, Effects of medium polarization on giant resonances in $^{48}$Ca (submitted for publication).

C. Picciotto and J. Kopac, CP violation with three generations of Majorana neutrinos (submitted for publication).

C. Picciotto and J. Kopac, Rate suppression with three generations of Majorana neutrinos (submitted for publication).

C. Picciotto, Fits to $\pi^- p$ bremsstrahlung (submitted for publication).


A.S. Rinat, The ratio of the structure functions of n and p and its relevance for the EMC effect (submitted for publication).


M. Celio and D. Loss, A critical comparison between different perturbation treatments (submitted to Phys. Rev. A).


Applied


W.R.W. Martin and D. Li, Present use of MRI and PET scans in neurology, in Medicine North America (in press).


**Conference presentations:**


A. Gal, Probing the nuclear medium with kaons, ibid., 30.


P. Kitching, Polarized proton experiments at TRIUMF, ibid., 311.


D.H. Boal, A cascade approach to thermal and chemical equilibrium, RHIC Workshop, Brookhaven, April 15-19. [TRI-PP-85-34]


R.E. Laxdal and G.H. Mackenzie, Beam dynamics of rf devices to improve the efficiency of proposed H− extraction from TRIUMF, ibid., 2453. [TRI-PP-85-40]

D. Raparia, C.W. Planner, G.H. Mackenzie and J.R. Richardson, Efficient capture in an Accumulator ring of 20,000 turns of beam injected from TRIUMF, ibid., 2456. [TRI-PP-85-39]

D. Dohan, K. Fong and R. Hutcheon, Modelling the TRIUMF rf cavity using the code RFQ3D, ibid., 2933.

T. Enegren, L. Durieu, D. Michelson and R.E. Worsham, Development of flat-topped rf voltage for TRIUMF, ibid., 2936. [TRI-PP-85-45]

K. Fong, D.A. Dohan, V. Pacak and R. Hutcheon, Model study on the reduction of rf leakage in the TRIUMF cyclotron, ibid., 2939. [TRI-PP-85-43]

G. Stanford, R. Worsham, K. Fong and S. Hutton, A new and improved rf resonator segment for the TRIUMF cyclotron, ibid., 2942. [TRI-PP-85-44]


E.W. Blackmore, Radiation effects of protons on samarium-cobalt permanent magnets, ibid., 3669. [TRI-PP-85-48]


R. Machleidt, The meson theory of nuclear forces and nuclear matter, Workshop on Relativistic Dynamics and Quark-Nuclear Physics, Los Alamos, June. [TRI-PP-85-68]


K. Nagamine, Recent topics in muon spin polarization phenomena and μSR experiments, ibid.


C.D.P. Levy, M. McDonald, P.W. Schmor and J. Uegaki, Status of the TRIUMF optically pumped polarized H− ion source, ibid. [TRI-PP-85-74]


E. De Vita, A magnetic channel for the extraction of H^- ions, ibid. [TRI-PP-85-80]

D.E. Lobb, Computer calculations of superferric magnet field quality, ibid. [TRI-PP-85-81]


A. Gal, Calculation of hypernuclear production with stopped kaons, ibid. [TRI-PP-85-87]

A. Gal, Relevance of Σ unstable bound states to (K^-,π^-) reactions, ibid. [TRI-PP-85-88]


M. Salomon and J. Marans, Position identification of gamma rays and electrons with a multianode photomultiplier, ibid. [TRI-PP-85-91]


G. Waters, G. Wait and D.A. Hutcheon, Experience with the CES STARBURST, ibid. [TRI-PP-85-93]

J.G. Rogers, Testing an improved scintillation camera for PET and SPECT, ibid. [TRI-PP-85-95]


R. Dubois et al., SLD liquid argon calorimeter prototype test results, ibid. [TRI-PP-85-97/SLAC-PUB-3813]

M.R. Palmer, M. Bergstrom, B.D. Pate and M.P. Beddoes, Noise distribution due to emission and transmission statistics in positron emission tomography, ibid.


Abstracts presented at meetings by members of the PET program:

S.J. Purves, J.A. Wada, W. Ammann, W.B. Woodhurst, D. Li, B.D. Pate and W.R. Martin, PET scans before and after anterior corpus collosum section, American Epilepsy Society.


J. Balatoni, M.J. Adam and L.D. Hall, Synthesis of fluorinated vinylestradiol derivatives
by the cleavage of vinyl-tin bonds with acetyl hypofluorite, Radiohalogen Symposium, Banff.

M. J. Adam, B. Abeysekera, T. J. Ruth, J. R. Grierson and B. D. Pate, Synthesis of \( 6-(^{18}\text{F})L \)-fluorodopa using \( ^{18}\text{F} \) labelled acetyl hypofluorite, Society of Nuclear Medicine, Houston.


### TRIUMF

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. Abegg</td>
<td>R. Lee</td>
</tr>
<tr>
<td>G. Azuelos</td>
<td>G.A. Ludgate</td>
</tr>
<tr>
<td>J.L. Beveridge</td>
<td>J.A. Macdonald</td>
</tr>
<tr>
<td>R.F. Blaby</td>
<td>G.H. McKenzie</td>
</tr>
<tr>
<td>E.W. Blackmore</td>
<td>J. McIlroy</td>
</tr>
<tr>
<td>C.W. Bordeaux</td>
<td>C.A. Miller</td>
</tr>
<tr>
<td>M. Comyn</td>
<td>L. Moritz</td>
</tr>
<tr>
<td>M.K. Craddock</td>
<td>J.N. Ng</td>
</tr>
<tr>
<td>W.K. Dawson</td>
<td>T. Numao</td>
</tr>
<tr>
<td>D.A. Dohan</td>
<td>C. Oram</td>
</tr>
<tr>
<td>J. Doornbos</td>
<td>A.J. Otter</td>
</tr>
<tr>
<td>G. Dutto</td>
<td>J.M. Poutissou</td>
</tr>
<tr>
<td>H.W. Fearing</td>
<td>J.G. Rogers</td>
</tr>
<tr>
<td>D. Garner</td>
<td>T.J. Ruth</td>
</tr>
<tr>
<td>D.R. Gill</td>
<td>M. Salomon</td>
</tr>
<tr>
<td>L.G. Greeniaus</td>
<td>P. Schmor</td>
</tr>
<tr>
<td>D.P. Gurd</td>
<td>G. Smith</td>
</tr>
<tr>
<td>D.A. Hutcheon</td>
<td>I.M. Thorson</td>
</tr>
<tr>
<td>K.P. Jackson</td>
<td>V.K. Verma</td>
</tr>
<tr>
<td>B.K. Jennings</td>
<td>J.S. Vincent</td>
</tr>
<tr>
<td>R.R. Johnson</td>
<td>E.W. Vogt</td>
</tr>
<tr>
<td>R. Keitel</td>
<td>G.D. Wait</td>
</tr>
<tr>
<td>K.R. Kendall</td>
<td>P. Walden</td>
</tr>
<tr>
<td>R. Kief1</td>
<td>G. Waters</td>
</tr>
<tr>
<td>P. Kitching</td>
<td>R. Woloshyn</td>
</tr>
<tr>
<td>C.J. Kost</td>
<td>M. Zach</td>
</tr>
<tr>
<td>M. La Brooy</td>
<td></td>
</tr>
</tbody>
</table>

### Simon Fraser University

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.S. Arrott</td>
</tr>
<tr>
<td>D. Boal</td>
</tr>
<tr>
<td>J. Brodovitch</td>
</tr>
<tr>
<td>J.M. D'Avoria</td>
</tr>
</tbody>
</table>

### University of Victoria

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Ahmad*</td>
<td>D.E. Lobb</td>
</tr>
<tr>
<td>A. Astbury</td>
<td>G. Marshall*</td>
</tr>
<tr>
<td>G.A. Beer</td>
<td>G.R. Mason</td>
</tr>
<tr>
<td>D. Britton*</td>
<td>A. Olin*</td>
</tr>
<tr>
<td>D.A. Bryman*</td>
<td>C.E. Picciotto</td>
</tr>
<tr>
<td>G.B. Friedmann</td>
<td>P.A. Reeve*</td>
</tr>
<tr>
<td>T.A. Hodges</td>
<td>L.P. Robertson</td>
</tr>
<tr>
<td>R. Keeler</td>
<td>C.S. Wu</td>
</tr>
</tbody>
</table>

### University of British Columbia

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Altman*</td>
<td>D.F. Measley</td>
</tr>
<tr>
<td>E.G. Auld</td>
<td>Y. Miyake</td>
</tr>
<tr>
<td>D.A. Axen</td>
<td>C.B.W. Ng</td>
</tr>
<tr>
<td>J.H. Brewer</td>
<td>D. Noakes</td>
</tr>
<tr>
<td>C.F. Cramer</td>
<td>B.D. Pate</td>
</tr>
<tr>
<td>D.G. Fleming</td>
<td>I. Reid*</td>
</tr>
<tr>
<td>D. Harshman</td>
<td>M. Senba</td>
</tr>
<tr>
<td>M.D. Hasinoff</td>
<td>C. Virtue</td>
</tr>
<tr>
<td>C. Jones</td>
<td>D.C. Walker</td>
</tr>
<tr>
<td>S. Kreitzman*</td>
<td>C.E. Waltham*</td>
</tr>
<tr>
<td>P.W. Martin</td>
<td>J.B. Warren</td>
</tr>
<tr>
<td>C.A. McDowell</td>
<td>B.L. White</td>
</tr>
</tbody>
</table>

### University of Alberta

<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.B. Cairns</td>
<td>W.C. Olsen</td>
</tr>
<tr>
<td>J.M. Cameron</td>
<td>J. Pasos</td>
</tr>
<tr>
<td>J.B. Elliott</td>
<td>G. Roy</td>
</tr>
<tr>
<td>P.W. Green</td>
<td>D.M. Sheppard</td>
</tr>
<tr>
<td>F.C. Khanna</td>
<td>H. Sheriff</td>
</tr>
<tr>
<td>W.J. McDonald</td>
<td>J. Soukup</td>
</tr>
<tr>
<td>G.A. Moss</td>
<td>G.M. Stinson*</td>
</tr>
<tr>
<td>G.C. Neilson</td>
<td>J. Uegaki*</td>
</tr>
<tr>
<td>A.A. Noujaim</td>
<td>J.S. Wesick*</td>
</tr>
</tbody>
</table>

*at main site Vancouver
†B.C. Cancer Control Agency

Experimentalists from other institutions based at main site:

- N.E. Davison (Chairman 1985), D. Bandyopadhyay, C.A. Davis, P.R. Poffenberger, W.D. Ramsay, University of Manitoba
- R. Poutissou, Université de Montréal
- N. Stevenson, University of Saskatchewan
- R. Helmer, University of Western Ontario
Other institutions

Canada

C.Y. Kim, University of Calgary
A.L. Carter, Carleton University
H.C. Lee, Chalk River Nuclear Laboratories
J.W. Scrimger, R.C. Urtasun, S.R. Uaiskin, Cross Cancer Institute, Edmonton
P. Depommier, J. Lessard, Université de Montréal
M.S. Dixit, C.K. Hargrove, National Research Council
D.L. Livesey, University of New Brunswick
H. Blok, Novatrack Analysts Limited
G.T. Ewan, B.C. Robertson, Queen's University
E.L. Mathie (Chairman 1986), G. Huber, G.J. Lolos, S.I.H. Naqvi, V. Pafilis, Z. Papandreou, University of Regina
E.J. Ansaldo, Y.M. Shin, Univ. of Saskatchewan
J.T. Sample, Research Secretariat of B.C.
M. Krell, K.E. Newman, Université de Sherbrooke
R. Azuma, T.E. Drake, L.R. Kilius, University of Toronto
R.T. Morrison, Vancouver General Hospital

United States

R.F. Marzke, Arizona State University
K.W. Jones, Brookhaven National Laboratory
A. Rosenthal, Brooklyn College, CUNY
K.H. Chang, California Institute of Technology
K. Aniol, M.P. Epstein, D.J. Margaziotis, California State University
F.F. Brady, University of California, Davis
W.P. Lee, University of California, Irvine
E. Ichon, B.M.K. Nefkens, J.R. Richardson, University of California, Los Angeles
S. Jha, University of Cincinnati
J.J. Kraushaar, D.A. Lind, T. Masterson, J.R. Shepard, C.D. Zafiratos, University of Colorado
X. Aslanoglou, H.S. Plendl, Florida State University
R. Piercy, University of Florida
J. Clark, General Physics Corporation
E.R. Siciliano, University of Georgia
J.M. Stadlbauer, Hood College
Y.K. Lee, Johns Hopkins University
P. Tandy, Kent State University

United States (cont'd)

J.W. Blue, Lewis Research Center, NASA
L.E. Agnew, H.L. Anderson, J.S. Fraser, R.E.L. Green, C.Y. Huang, K. Jones, N.S.P. King, R.J. Macek, Los Alamos National Laboratory
R.P. Redwine, Massachusetts Institute of Technology
F.D. Becchetti, University of Michigan
H.B. Willard, National Science Foundation
B. Bassalleck, B. Dieterle, University of New Mexico
R.E. Segel, K.K. Seth, Northwestern University
F.E. Bertrand, B. Burks, C. Glover, D.J. Horen, T.P. Sjöreen, Oak Ridge National Laboratory
B.C. Clark, T.R. Donoghue, Ohio State University
J. Lisanti, D.K. McDaniels, University of Oregon
K.S. Krane, R. Landau, A.W. Stetz, L.W. Swenson, Oregon State University
R.F. Carlson, University of Redlands
S.A. Dodds, G.S. Mutchler, D.P. Spencer, Rice University
R. Ferguson, C. Glashausser, A. Green, Rutgers University
J.R. Chen, State Univ. of New York, Geneseo
R. Dubois, Stanford Linear Accelerator Center
R. Bryan, Texas A&M University
V.G. Lind, R.E. McAdams, O.H. Otteson, Utah State University
M. Blecher, K. Gotow, D. Jenkins, Virginia Polytechnic Institute and State University
I. Halpern, E.M. Henley, University of Washington
A.S. Rupaal, Western Washington University
W.C. Sperry, Central Washington University
C.F. Perdrisat, M. Eckhause, R.T. Siegel, College of William and Mary
T.C. Sharma

Overseas

D.V. Bugg, R. Gibson, Queen Mary College, London
N.M. Stewart, Bedford College, London
A.S. Clough, J.R.H. Smith, University of Surrey
A.N. James, University of Liverpool
J. Källne, JET Joint Undertaking, Abingdon
C. Amsler, CERN
Overseas (cont'd)

R. Engfer, Universität Zürich
J. Domingo, SIN
G.R. Plattner, Universität Basel
L. Antonuk, P. Couvert, CEN Saclay
R. Grynszpan, CNRS Vitry
J. Tinsley, SATURNE
J. Deutsch, Univ. Catholique de Louvain
H. Postma, Technische Hogeschool Delft
R. van Dantzig, IKO Amsterdam
J.I.M. Botman, Technische Hogeschool Eindhoven
J. Bailey, DESY
C. Weidner, Max-Planck Institut
J. Ernst, Inst. f. Strahlen-und-Kernphysik, Bonn
J. Niskanen, University of Helsinki
D. Horváth, Central Research Institute for Physics, Budapest
M. Furic, Inst. R. Boskovic
C. Cernigoi, N. Grion, R. Rui, Ist. di Fisica Trieste
A. Bracco, Università di Milano
J. Alster, D. Ashery, S.A. Wood, Tel-Aviv University
B. Olaniyi, University of Ife
J. Greben, CSIR/NRIMS, Pretoria
A.H. Hussein, Univ. of Petroleum & Minerals, Dahren, Saudi Arabia
C. Yamaguchi, KEK
K. Nagamine, T. Yamazaki, University of Tokyo
K. Sakamoto, Japanese Federal Government
Y.P. Zhang, IHEP, Peking
A.W. Thomas, A.C. Williams, Univ. of Adelaide
J.D. King, K.J. Raywood, B.M. Spicer, University of Melbourne
I.R. Afnan, Flinders Univ. of South Australia
### EXPERIMENT PROPOSALS

The following lists experiment proposals received up to the end of 1985 (missing numbers cover proposals that have been withdrawn or replaced by later versions or rejected or combined with another proposal). Page numbers are given for those experiments which are included in this annual report.

<table>
<thead>
<tr>
<th>Experiment Proposal</th>
<th>Authors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low-energy pi nuclear scattering [completed], K.L. Erdman, R.R. Johnson (Univ. of British Columbia), T. Masterson (Univ. of Colorado), P. Walden (TRIUMF)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3. The study of fragments emitted in nuclear reactions [completed], R.E.L. Green, R.G. Korteling (Simon Fraser University), K.P. Jackson (TRIUMF), L. Church (Reed College)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>6. Studies of the proton- and pion-induced fission of light to medium mass nuclides [completed], B.D. Pate (Univ. of British Columbia), H. Blok (Novatrack), H. Dautet, F.M. Kiely (Simon Fraser University), Z. Fraenkel (Weizmann Institute)</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>9. A study of the reaction $\pi^- + p + \gamma + n$ at pion kinetic energies from 20-200 MeV [completed], K. Aniol (California State Univ.), A. Bagheri, M.D. Hasinoff, D.P. Measday (Univ. of British Columbia), J.-M. Poutissou, M. Salomon (TRIUMF), R. Poutissou (Univ. de Montréal), B.C. Robertson (Queen's University)</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>10. Positive pion production in proton-proton and proton-nucleus reactions [completed], E.G. Auld, R.R. Johnson, G. Jones (Univ. of British Columbia), T. Masterson (Univ. of Colorado), P. Walden (TRIUMF)</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>11. Nuclear spectroscopic studies of short-lived radioactive products of high energy reactions [completed], J.M. D'Auria, H. Dautet (Simon Fraser University), K.P. Jackson (TRIUMF)</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>14. The interaction of protons with very light nuclei in the energy range 200-500 MeV [completed], J.M. Cameron, G.A. Moss, G. Roy (Univ. of Alberta), L.G. Greeniaus, D.A. Hutcheon, C.A Miller, J.G. Rogers (TRIUMF), M. de Jong, W.T.H. van Oers (Univ. of Manitoba), C. Goulding (Los Alamos National Laboratory), A.W. Stetz (Oregon State University), J. Kibble (JET Joint Undertaking)</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>15. A proposal to study quasi-free scattering in nuclei [completed], J.M. Cameron, W.K. Dawson, P. Kitching, W.J. McDonald, G.C. Neilson, W.C. Olsen, G.M. Stinson, (Univ. of Alberta), E.D. Earle (Chalk River Nuclear Labs), D.A. Hutcheon, C.A. Miller (TRIUMF), J.T. Sample (Research Secretariat of B.C.), A.W. Stetz (Oregon State University), A.N. James (Univ. of Liverpool)</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>21. Optical activity induced by polarized elementary particles [completed], L.D. Hayward, D.C. Walker (Univ. of British Columbia)</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>22. Negative pion capture and absorption on carbon, nitrogen, and oxygen [passed to Biomedical Experiments Evaluation Committee], H.B. Knowles (Washington State University)</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>23. Study of decay modes a) $\pi^0 \rightarrow 3\gamma$, b) $\pi^+ \rightarrow e^+ + \nu_e + \gamma$, c) $\pi^+ \rightarrow \pi^0 + \gamma_e$ [completed], P. Depommier, J.P. Martin, R. Poutissou (Univ. de Montréal), D. Bryman (TRIUMF-Univ. of Victoria), J.A. Macdonald, J.-M. Poutissou, M. Salomon (TRIUMF), M. Dixit (National Research Council), M.D. Hasinoff, D.F. Measday (Univ. of British Columbia)</td>
<td></td>
<td>23</td>
</tr>
</tbody>
</table>

178
26. Measurement of the differential cross-section for free neutron-proton scattering and for the reaction $D(n,p)\alpha$ [completed], L.P. Robertson (Univ. of Victoria), C. Amsler (CERN), E.G. Auld, D.A. Axen, (Univ. of British Columbia), D.V. Bugg, J.A. Edgington (Univ. of London, QMC), A.S. Clough (Univ. of Surrey), J.R. Richardson (UCLA), N.M. Stewart (Univ. of London, Bedford College), J. Va'vra (SIN)

27. Measurement of the polarization in free neutron-proton scattering [completed], D.A. Axen, E.G. Auld (Univ. of British Columbia), C. Amsler (CERN), D.V. Bugg, J.A. Edgington (Univ. of London, QMC), A.S. Clough (Univ. of Surrey), J.R. Richardson (UCLA), L.P. Robertson (Univ. of Victoria), G. Roy (Univ. of Alberta), N.M. Stewart (Univ. of London, Bedford College), J. Va'vra (SIN)

35. A study of positive muon depolarization phenomena in chemical systems [completed], J.H. Brewer, D.G. Fleming Y.C. Jean, D.C. Walker, J.B. Warren (Univ. of British Columbia), K.M. Crowe (Lawrence Berkeley Laboratory)

40. A proposal for neutron experiments at TRIUMF [completed], D.A. Axen, M.K. Craddock (Univ. of British Columbia), I.M. Blair (AERE Harwell), D.V. Bugg, J.A. Edgington (Univ. of London, QMC), A.S. Clough (Univ. of Surrey), N.M. Stewart (Univ. of London, Bedford College), J. Va'vra (SIN)

41. a) Radiative capture of pions in light nuclei [completed], b) Charge exchange of stopped negative pions [completed], J.-M. Poutissou, M. Salomon (TRIUMF), D. Berghofer, M.K. Craddock M.D. Hasinoff (Univ. of British Columbia), R. MacDonald (Univ. of Alberta)

42. $^3\text{He}$: a) Strong interaction shift, b) Neutron-neutron scattering length [completed], G.A. Beer, S.K. Kim, G.R. Mason, R.M. Pearce, C.E. Picciotto, L.P. Robertson, C.S. Wu (Univ. of Victoria), D. Bryman, A. Olin (TRIUMF-Univ. of Victoria), J.A. Macdonald, J.S. Vincent (TRIUMF), M. Dixit (National Research Council), M. Krell (Univ. de Sherbrooke)

46. Hyperfine splitting in polarized muonic $^{209}\text{Bi}$ atoms [completed], G.T. Ewan, H.B. Mak, B.C. Robertson (Queen's University), G.A. Beer, G.R. Mason, R.M. Pearce* (Univ. of Victoria), A. Olin (TRIUMF-Univ. of Victoria), D.G. Fleming (Univ. of British Columbia), K. Nagamine, T. Yamazaki (Univ. of Tokyo)

47. Photon asymmetry in radiative muon capture [completed data taking], J.H Brewer, M.D. Hasinoff (Univ. of British Columbia), R. MacDonald (Univ. of Alberta), K. Krane (Oregon State University), J.-M. Poutissou (TRIUMF)

48. Fertile-to-fissile conversion in electrical breeding (spallation) targets [completed], I.M. Thorson, F.M. Kiely (Simon Fraser University), B.D. Pate (Univ. of British Columbia)

52. Measurement of the $\pi^+\rightarrow\nu\nu$ branching ratio [completed], D. Bryman, A. Olin (TRIUMF-Univ. of Victoria), J.A. Macdonald (TRIUMF), G.R. Mason (Univ. of Victoria), D. Berghofer (Univ. of British Columbia), M. Dixit (National Research Council)

53. Emission of heavy fragments in pion absorption [completed], D.R. Gill, M. Salomon, E.W. Vogt (TRIUMF), P.W. Martin, G. Jones (Univ. of British Columbia)

54. $\pi^\pm$ reaction cross-section measurements on isotopes of calcium [completed], K.L. Erdman, R.R. Johnson (Univ. of British Columbia), J.L. Beveridge (TRIUMF)

55. $\mu^-$ capture in deuterium and the two-neutron interaction [completed], J.M. Cameron, W.J. McDonald, G.C. Neilson (Univ. of Alberta), H.W. Fearing (TRIUMF)
56. A study of the decay of the muon [completed], M.D. Hasinoff, D.F. Measday (Univ. of British Columbia), R. MacDonald (Univ. of Alberta), P. Depommier (Univ. de Montréal), J.-M. Poutissou, M. Salomon (TRIUMF)

57. Search for $\mu^+ + e^+ + \gamma$ decay mode [completed], P. Depommier, J.P. Martin, R. Poutissou (Univ. de Montréal), J.-M. Poutissou (TRIUMF)


59. Investigation of the (p,2p) reactions on $^3$He, $^3$H and $^4$He [completed], D.K. Hasell, W.T.H. van Oers (Univ of Manitoba), J.M. Cameron, G.A. Moss (Univ. of Alberta), R. Abegg, L.G. Greenlaws, J.G. Rogers (TRIUMF), M.B. Epstein, D.J. Margaziotis (Califomia State Univ.), A.W. Stetz (Oregon State Univ.)

60. Study of muonium formation in MgO and related insulators and its diffusion into a vacuum [completed], J.H. Brewer, D.G. Fleming, G. Jones, J.B. Warren (Univ. of British Columbia)

61. Pre-clinical research on the $\pi^-$ beam at TRIUMF [active], J. Brosing, C.J. Eaves, R.W. Harrison, M. Korbelik, G.K.Y. Lam, B. Palcic, K.R. Shortt, L.B. Skarsgard (B.C. Cancer Foundation), B.G. Douglas, R.O. Kornelsen, M.E.J. Young (B.C. Cancer Control Agency), R.M. Henkelman (Univ. of Toronto)

65. Radiosensitivities of tumours in situ to $\pi$-meson irradiation [completed], S. Okada, K. Sakamoto, N. Suzuki (Univ. of Tokyo), T. Ono (Univ. of Alberta)

66. Survey of p-p bremsstrahlung far off the energy shell [completed], J.G. Rogers, H.W. Fearing (TRIUMF), J.M. Cameron, A.N. Kamal (Univ. of Alberta), J.V. Jovanovich (Univ. of Manitoba), J.R. Richardson (UCLA), A.W. Stetz (Oregon State University), A. Szyjewicz (Univ. of Saskatchewan)

71. Muon spin rotation project [completed], J.H. Brewer, A. Duncan, D.G. Fleming, D.L. Williams (Univ. of British Columbia), M. Doyama, R. Hayano, K. Nagamine, T. Yamazaki (Univ. of Tokyo), B.D. Patterson (Univ. of Zurich)

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

73. Artificial muon polarization [completed], R. Hayano, K. Nagamine, N. Nishida, T. Yamazaki (Univ. of Tokyo), J.H. Brewer, D.G. Fleming, M.D. Hasinoff (Univ. of British Columbia), H.B. Mak (Queen's University)

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

75. The d(p,$p^+$)t pion production reaction for high momentum transfer [completed] P. Kitching, W.C. Olsen (Univ. of Alberta), E.G. Auld, G. Jones (Univ. of British Columbia), H.W. Fearing, D.A. Hutcheon, P. Walden (TRIUMF), T. Masterson (Univ. of Colorado), C.F. Perdrisat (College of William and Mary)

77. Evaporation-cooled metallic cesium target assembly for production of $^{123}$I [completed], J.W. Blue, (NASA), T.A. Hodges (Univ. of Victoria), D. Lyster, R.T. Morrison (Vancouver General Hospital), J.S. Vincent (TRIUMF), J.B. Warren (Univ. of British Columbia), W. Wiesehahn (Simon Fraser University)
78. Importance of defects in μ+SR in metals [completed], T. Yamazaki, K. Nagamine (Univ. of Tokyo), B. Bergrersen, J.H. Brewer, D.G. Fleming, L.C. Vaz (Univ. of British Columbia), A.T. Stewart (Queen's University)

79. (Experiment 'X') Low energy π production as a function of energy at 500 MeV and below [completed], G.A. Beer, G.R. Mason, R.M. Pearce, A. Olin (Univ. of Victoria), D.A. Bryman, B. Olin (TRIUMF-Univ. of Victoria), J.-M. Poutissou, J.S. Vincent (TRIUMF), R.R. Johnson, J.B. Warren (Univ. of British Columbia), P.W. James (Atomic Energy of Canada Ltd.)


81. Bound muon decay in nuclei [completed], J.H. Brewer, M.D. Hasinoff, T. Suzuki (Univ. of British Columbia), J. Alster (Tel-Aviv Univ.), K. Nagamine (Univ. of Tokyo), J.-M. Poutissou (TRIUMF)

82. The (μ+,d) reaction on light nuclei [deferred], K.L. Erdman, R.R. Johnson, H.R. Johnston (Univ. of British Columbia), T. Masterson (Univ. of Colorado), V.G. Lind, R.E. McAdams, O.H. Otteson (Utah State University), J.S. Vincent (TRIUMF)

83. Elastic and inelastic scattering of polarized protons from calcium and lead [completed], D.A. Hutcheon, C.A. Miller (TRIUMF), J.S. Blair (Univ. of Washington), P. Kitching, R. Liljestrand, W.J. McDonald, G.C. Neilson, H. Sherif, G.M. Stinson (Univ. of Alberta), D.K. McDaniels (Univ. of Oregon)

84. Proton radiography studies at TRIUMF [completed], E.W. Blackmore, G.H. Mackenzie (TRIUMF, Univ. of Victoria)

85. Systematic studies of total muon capture rates [completed], R. Hayano, K. Nagamine, T. Yamazaki (Univ. of Tokyo), J.H. Brewer, F. Entezami, D. Garner, D.P. Measday, S. Stanislaus (Univ. of British Columbia)

86. Rare electromagnetic decays of pionic atoms [completed], M.D. Hasinoff, E. Mazzucato, D.F. Measday (Univ. of British Columbia), N. Salomon (TRIUMF), P. Depommier, R. Poutissou (Univ. de Montréal), B. Bassalleck (Univ. of New Mexico), T. Marks (Los Alamos National Laboratory)

87. Studies of (p,d) reactions in nuclei [completed], A.N. Anderson, J.M. Cameron, W.K. Dawson, P. Kitching, W.J. McDonald, C.C. Neilson, W.C. Olsen, O. Hausser (TRIUMF-SFU) J.A. Macdonald (TRIUMF), A. Mireshghi (Univ. of California)
101. Investigation of $(\pi, 2\pi)$ reaction [letter of intent], E.G. Auld, R.R. Johnson, G. Jones (Univ. of British Columbia), P. Walden (TRIUMF)

102. Absolute cross sections of $^{12}$C$(\pi^\pm, \pi^\pm)^{11}$C reactions at low energy [completed], R.E.L. Green, R.G. Korteling (Simon Fraser University), G.W. Butler, B.J. Dropesky, C.J. Orth, R.A. Williams (Los Alamos National Laboratory), R.M. Henkelman (Univ. of Toronto)

103. Search for target spin dependence in proton elastic scattering [completed], D.P. Gurd, G.A. Moss, G. Roy, H. Sherif, G.M. Stinson (Univ. of Alberta)


105. Backward inclusive scattering [completed], G. Roy, G.A. Moss (Univ. of Alberta), J.L. Beveridge, D.A. Hutcheon, R.M. Woloshyn (TRIUMF)

108. Meson cascade studies [deferred], G.A. Beer, G.R. Mason (Univ. of Victoria), D. Bryman, A. Olin (TRIUMF-Univ. of Victoria), M. Dixit (National Research Council), S.N. Kaplan, C. Wiegand (Lawrence Berkeley Lab.), J.A. Macdonald (TRIUMF), W.C. Sperry (Central Washington University)

110. Microdosimetry of $\pi^-$ beam at TRIUMF [active], A. Ito, H. Koyama (Univ. of Tokyo)

111. Study of the absorption of $\pi^-$ at rest in $^4$He, $^9$Be, $^{12}$C, $^{14}$N and $^{16}$O [completed], C. Cernigoi, N. Grion, G. Pauli, R. Rui (Univ. di Trieste and INFN), R. Cherubini (Lab Nazionali di Legnaro INFN and Univ. de Padova), D. Gill (TRIUMF), W. Gyles (Univ. of British Columbia)

113. A proposal for $^3$He(p, p)$^3$He at backward angles [completed], J.M. Cameron, G.A. Moss (Univ. of Alberta), B.S. Bhakar, B.K.S. Koene, W.T.H. van Oers (Univ. of Manitoba), M.B. Epstein, D.J. Margaziotis (California State University), R. Abeeg, L.G. Greeniaus, D.A. Hutcheon, C.A. Miller (TRIUMF), J. Källne (JET Joint Undertaking) B.T. Murdoch (Schlumberger Well Systems), A.W. Stetz (Oregon State University)

114. The (p, 2p) reaction on $^3$He and $^4$He [completed], B.K.S. Koene, W.T.H. van Oers (Univ. of Manitoba), M.B. Epstein, D.J. Margaziotis (California State University), G.A. Moss (Univ. of Alberta), L.G. Greeniaus, J.G. Rogers (TRIUMF), B.T. Murdoch (Schlumberger Well Systems)

115. Neutral pion production from $^{209}$Bi at intermediate proton energies [completed], J.M. D'Auria, D. Boal (Simon Fraser University), T. Ward (Indiana University), A. Yavin (Tel-Aviv University)

117. Single particle inclusive spectra of light fragments over their entire energy range [active], R.E.L. Green, R.G. Korteling (Simon Fraser University), K.P. Jackson (TRIUMF)

119. Small angle scattering of thermal neutrons for the study of magnetism and liquid crystals [active], A.S. Arrott, J.F. Cochran, S.D. Hanham, B. Heinrich, M.J. Press (Simon Fraser University), B.D. Patterson (Univ. Zürich)

182
120. A study of the production and decay of $^{11}$Be with intermediate-energy protons [completed], K.P. Jackson (TRIUMF)

121. Test of charge symmetry in n-p scattering [completed data taking], G.R. Plattner (Basel Univ.), J. Birchall, N.E. Davison, W.T.H. van Oers (Univ. of Manitoba), D.A. Axen (Univ. of British Columbia), J.L. Beveridge, C.A. Miller, J.G. Rogers Miller (TRIUMF), W.J. McDonald, G.A. Moss, G. Roy, G.M. Stinson (Univ. of Alberta), L.P. Robertson (Univ. of Victoria), H.E. Conzett (Lawrence Berkeley Laboratory), S. Mango (SIN)

122. A μSR investigation of dipolar fields in cobalt [completed], A.S. Arrott (Simon Fraser University), B.D. Patterson (Univ. Zürich)

123. Observation of $e^+$ channeling from stopped $\mu^+$ in a crystalline host [completed], A.S. Arrott (Simon Fraser University), B.D. Patterson (Univ. Zürich)

124. Excitation of giant multipole resonances by intermediate energy protons [completed], F.E. Bertrand, E. Gross, D.J. Horen, T. Sjoreen (Oak Ridge National Laboratory), L. Lisantti, D.K. McDaniels, J. Tinsley (Univ. of Oregon), L.W. Swenson (Oregon State Univ.)

126. Measurement of the line shape of pionic X-rays [deferred], A. Olin (TRIUMF-Univ. of Victoria), G.A. Beer, G.R. Mason, R.M. Pearce* (Univ. of Victoria), M. Dixit (National Research Council), J.A. Macdonald (TRIUMF)

127. Measurement of the strong interaction shift in pionic deuterium [completed], G.A. Beer, G.R. Mason, R.M. Pearce* (Univ. of Victoria), A. Olin (TRIUMF-Univ. of Victoria), M. Dixit (National Research Council), E. Klempt (Univ. Mainz), J.A. Macdonald (TRIUMF), C. Wiegand (Lawrence Berkeley Laboratory) A.W. Thomas (Univ. of Adelaide)

128. Variation of muonic X-ray intensities with atomic number [completed], G.A. Beer, G.R. Mason (Univ. of Victoria), A. Olin (TRIUMF-Univ. of Victoria), M. Dixit (National Research Council), J.A. Macdonald (TRIUMF), W.C. Sperry (Central Washington Univ.), C. Wiegand (Lawrence Berkeley Laboratory)

129. Quasielastic pion scattering at resonance energies for light T=0 nuclei [deferred], B. Barnett, K.L. Erdman, B. Gyles, R.R. Johnson (Univ. of British Columbia), G. Azuelos, D. Gill, E.W. Vogt, P. Walden (TRIUMF), D. Ashery, A. Errell, A. Yavin (Tel-Aviv Univ.), B. Bassalleck (Univ. of New Mexico), T. Masterson (Univ. of Colorado), A.W. Thomas (Univ. of Adelaide)

130. The energy dependence of the polarization parameter in proton-proton scattering [completed], D.A. Axen, E.G. Auld (Univ. of British Columbia), D.V. Bugg, J.A. Edgington, W.R. Gibson (Univ. of London, QMC), A.S. Clough (Univ. of Surrey), N.M. Stewart (Univ. of London, Bedford College), M. Comyn, G. Ludgate (TRIUMF), J.R. Richardson (UCLA), L.P. Robertson (Univ. of Victoria)

131. A study of ($\pi$,γ) reactions on $^3$H and $^6$Li at intermediate energies [completed], J.M. Cameron, P. Kitching, W.J. McDonald, G.M. Stinson, I.J. Van Heerden (Univ. of Alberta), A.W. Stetz, L.W. Swenson (Oregon State University), D.A. Hutcheon, C.A. Miller, H.W. Fearing (TRIUMF)

132. Differential cross section of the reaction pp $\rightarrow d\pi^+$ between lab proton energies of 325 to 500 MeV [completed], P.L. Walden (TRIUMF), E.G. Auld, R.R. Johnson, G. Jones (Univ. of British Columbia)

134. Measurement of the eta parameter in muon decay [completed data taking], J.A. Bistirlich, K.H. Crowe, C.J. Martoff, J.M. Miller, W.A. Zajc (Lawrence Berkeley Laboratory), C.M. Clawson (Univ. of California, Berkeley), J.H. Brewer (Univ. of British Columbia)

138. Surface muon studies of germanium [completed], K.M. Crowe, S.S. Rosenblum (Lawrence Berkeley Laboratory), C.M. Clawson (Univ. of California, Berkeley), J.H. Brewer (Univ. of British Columbia)

139. Macroscopic diffusion of positive muons in aluminum [completed], K.M. Crowe, S.S. Rosenblum (Lawrence Berkeley Laboratory), C.M. Clawson (Univ. of California, Berkeley), J.H. Brewer (Univ. of British Columbia)

140. Transfer effects for stopping $\mu^-$ in $H_2$-$D_2$ mixtures [completed], M.D. Hasinoff, D.F. Measday (Univ. of British Columbia), J.-M. Poutissou, M. Salomon (TRIUMF), V. Highland (Temple University)

141. Muonic hydrogen at STP - A feasibility study [deferred], J.H. Brewer (Univ. of British Columbia), C. Oram (TRIUMF)

142. A study of the single scattering mechanism for non-evaporative fragment emission [active], D. Boal, R.E.L. Green, R.G. Korteling (Simon Fraser University), K.P. Jackson (TRIUMF)

143. A study by recoil detection of proton-induced reaction on $^9$Be [completed], K.P. Jackson (TRIUMF), D. Boal, J.M. D'Auria, R.E.L. Green, R.G. Korteling (Simon Fraser University)

144. Studies of ($\bar{p},d$) reaction in nuclei [completed], J.M. Cameron, P. Kitching, R. Liljestrand, W.J. Mcdonald, G.C. Neilson, W.C. Olsen, D.M. Sheppard, G.M. Stinson (Univ. of Alberta), J.J. Kraushaar, J.R. Shepard (Univ. of Colorado), D.A. Hutcheon, C.A. Miller, J.G. Rogers (TRIUMF), C. Stronach (Virginia State University), D.K. McDaniels, J. Tinsley (Univ. of Oregon)

145. The neutron and gamma-ray correlation in the negative pion capture in $^{165}$Ho and $^{181}$Ta [completed], Y.K. Lee, R. Levin, L. Madansky (Johns Hopkins University)

146. The formation and reactivity of muonium in the gas phase [active], J.H. Brewer, D.G. Fleming, R.J. Mikula, D.P. Spencer, J.B. Warren (Univ. of British Columbia), D.M. Garner, R. Kiefl (TRIUMF)

147. $\mu$SR studies of phase transition [completed], M. Doyama, R. Nakai, R. Yamamoto, T. Yamazaki (Univ. of Tokyo), J.H. Brewer, H. Schilling, J.L. Williams (Univ. of British Columbia)

148. Utilization of backward muons to study muonium reaction intermediates [completed data taking], J.A. Bartlett, J.C. Brodovitch, S.K. Leung, K.E. Newman, F.W. Percival (Simon Fraser University), D.G. Fleming, D.C. Walker (Univ. of British Columbia)

149. Interaction of muons with fissile nuclides II [completed], A. Olin (TRIUMF-Univ. of Victoria), S. Ahmad, G.A. Beer, R.M. Pearce* (Univ. of Victoria), J.C. Brown (Lawrence Livermore Lab), S.N. Kaplan (Lawrence Berkeley Lab), O. Häusser (TRIUMF-SPU), J.A. Macdonald (TRIUMF)


151. Elastic scattering of protons from $^3$He [completed], W.T.H. van Oers, D.K. Hasell (Univ. of Manitoba), J.M. Cameron, G.A. Moss (Univ. of Alberta), R. Abegg,
154. Muonium in solids [completed], J.H. Brewer, D.G. Fleming, H. Schilling, D.P. Spencer, D.L. Williams (Univ. of British Columbia), K.M. Crowe, S.S. Rosenblum (Univ. of California), C.M. Clawson (Univ. of California, Berkeley), Y.J. Uemura, T. Yamazaki (Univ. of Tokyo), R. Kiefl (TRIUMF)

155. Study of deep hole states in $^{40}$Ca with $(p,2p)$ reaction [completed], P.W. Green, P. Kitching, W.J. McDonald, W.C. Olsen, D.M. Sheppard, J. Soukup, G.M. Stinson, I.J. van Heerden (Univ. of Alberta), D.A. Hutcheon, C.A. Miller (TRIUMF), A.N. James (Univ. of Liverpool)

156. Deuteron production in proton-nucleus collisions [completed], J.M. Cameron, P. Kitching, R. Liljestrand, W.J. McDonald, W.C. Olsen (Univ. of Alberta), J. Källne (JET Joint Undertaking), C.F. Perdrisat (College of William and Mary)

157. The chemistry of muonium atoms in condensed media [active], J.H. Brewer, D.G. Fleming, B.W. Ng, R. Rist, D.C. Walker (Univ. of British Columbia), D. Garner (TRIUMF), Y.C. Jean (Univ. of Missouri-Kansas City), Y. Ito (Univ. of Tokyo), P.W. Percival (Simon Fraser University)

158. Study of the reactions $p^2H + d \rightarrow n$ and $p^3He + t \rightarrow p$ [completed], J.M. Cameron, P. Kitching, W.J. McDonald, W.C. Olsen, H. Wilson (Univ. of Alberta), I. van Heerden (Univ. of Alberta and Suni), C.F. Perdrisat (College of William and Mary), H.W. Fearing, C.A. Miller (TRIUMF), J. Källne (JET Joint Undertaking)

159. $p\bar{p}$ and $p\bar{d}$ interactions at threshold [completed], E.G. Auld, D.A. Axen, K.L. Erdman, J.B. Warren, B.L. White (Univ. of British Columbia), M. Comyn (TRIUMF), G.A. Beer (Univ. of Victoria), W. Dahme (Münich University), U. Gastaldi, G. Graff, H. Kalinowsky, E. Kayser, E. Klempt, R. Landua, R.W. Wodrich, R. Schulze (Univ. Mainz), C.J. Martoff (Lawrence Berkeley Lab), C. Sabev (Univ. of Geneva), P. Truol (Univ. Zürich)

160. Studies of some ternary magnetic superconductors with muons [completed], C.Y. Huang (Los Alamos National Laboratory), J.H. Brewer, H. Schilling (Univ. of British Columbia), C.W. Clawson (Univ. of California, Berkeley), K.M. Crowe, S.F. Kohn, S.S. Rosenblum (Lawrence Berkeley Laboratory), A. Schenck (SIN)

161. Studies of spin dynamics of some amorphous spin glasses with muons [completed data taking], C.Y. Huang (Los Alamos National Laboratory), J.H. Brewer, H. Schilling (Univ. of British Columbia), C.W. Clawson (Univ. of California, Berkeley), K.M. Crowe, S.E. Kohn, S.S. Rosenblum (Lawrence Berkeley Laboratory), A. Schenck (SIN)


164. Measurement of the $1/E$ dependence in $^7Li(p,n)^7Be$ reactions [completed], J.M. D'Auria, M. Dombsky (Simon Fraser University), T. Ward (Indiana University), T. Ruth (TRIUMF)

166. Neutron-nuclear structure with pions [completed], B. Barnett, K.L. Erdman, W. Gyles, R.R. Johnson (Univ. of British Columbia), D.R. Gill, E.W. Blackmore (TRIUMF), E.L. Mathie (SIN), D. Ashery (Tel-Aviv Univ.), N. Grion (INFN and Univ. di Trieste), J.J. Kraushaar, T. Masterson (Univ. of Colorado), C.A. Wiedner (Max Planck Institut), S.A. Martin (KFA Jülich)

168. 2S muonium production from thin foils [completed], R. Kiefl, C.J. Oram (TRIUMF), J.H. Brewer, A. Fry, J.B. Warren (Univ. of British Columbia), G.M. Marshall (Univ. of Victoria)


173. Measurement of pionic 4–3 X-ray transitions in heavy nuclei [completed], A. Olin (TRIUMF-Univ. of Victoria), G.A. Beer, G.R. Mason (Univ. of Victoria), P.R. Poffenberger (Univ. of Manitoba), J.A. Macdonald, T. Numao (TRIUMF), B. Olaniyi (Univ. of Ife)

174. Spin dependence of the pp+pm± reaction [completed], D.A. Axen, C. Waltham (Univ. of British Columbia), D.V. Bugg, J.A. Edgington (Univ. of London, QMC), N.M. Stewart (Univ. of London, Bedford College), M. Cosyn, G. Ludgate (TRIUMF), J.R. Richardson (UCLA), L.P. Robertson (Univ. of Victoria), R. Dubois (SLAC)


177. Proton radius determinations for C, N and O [completed], B. Barnett, K.L. Erdman, B. Gyles, R.R. Johnson, (Univ. of British Columbia), E.W. Blackmore, D.R. Gill (TRIUMF), G. Lolos (Univ. of Regina), J. Alster (Tel-Aviv Univ.), N. Grion (INFN and Univ. di Trieste), J.J. Kraushaar, T. Masterson (Univ. of Colorado)

178. Nuclear radius studies in the Ca region [completed], B. Barnett, K.L. Erdman, B. Gyles, R.R. Johnson (Univ. of British Columbia), E.W. Blackmore, D.R. Gill (TRIUMF), G. Lolos (Univ. of Regina), N. Grion (INFN and Univ. di Trieste), J.J. Kraushaar, T. Masterson (Univ. of Colorado), S. Martin (KFA Jülich), C. Weidner (Max Planck Institut)


183. Inelastic pion scattering [deferred], I. Halpern, M. Khandaker, D.W. Storm (Univ. of Washington)

184. Investigation of the $^3P_0 + ^2H + ^3H + n^+$ reaction from 275 to 450 MeV using polarized protons [completed], E.G. Auld, G. Giles, C. Jones, W. Ziegler (Univ. of British Columbia), P. Walden (TRIUMF)
185. Precise measurement of the polarization parameter $\xi$: A search for the effects of a right-handed gauge boson in $\mu^+$ decay [completed], J. Carr, G. Gidal, A. Jodidio, K. Shincky, H.M. Steiner, D. Stoker, M. Strovink, R.D. Tripp (Univ. of California/LBL), C. Oram (TRIUMF), B. Gobbi (Northwestern Univ.)

186. Measurement of collision induced deexcitation rates of the 2S state of muonic helium [active], M. Eckhause, K. Giovanetti, D. Hertzog, D. Joyce, J. Kane, W. Phillips, R. Siegel, W. Vulcan, R. Welsh, R. Whyley, R.G. Winter (College of William and Mary)

187. Pion production from $^{10}$B and $^{16}$O bombarded with polarized protons [completed], E.G. Auld, G. Giles, G. Jones, B. McFarland, W. Ziegler (Univ. of British Columbia), G. Lolos (Univ. of Regina), W. Falk (Univ. of Manitoba), P. Walden (TRIUMF)

188. Radiochemical study of $\sigma_E(E)$ for $^{209}$Bi$(p,\pi^- x n)^{210-211}$At reactions from threshold to ~0.8 GeV [completed], J.M. D'Auria, M. Dombsky (Simon Fraser University), J. Clark (LAMPF), T. Ward (Indiana University), A. Yavin (Tel-Aviv Univ.)

190. Radiative polarized neutron capture on protons [completed data taking], J.M. Cameron, P. Kitching, W.J. McDonald, J. Soukup, J. Uegaki (Univ. of Alberta), I.J. Van Heerden (Southern Nuclear Inst.), R. Abegg, D.A. Hutcheon, C.A. Miller (TRIUMF), A.W. Stetz (Oregon State Univ.), Y.M. Shin (Univ. of Saskatchewan)

191. Muons and muonium on surfaces [completed], J.H. Brewer, D. Harshman, J.B. Warren (Univ. of British Columbia), C.J. Oram (TRIUMF), K.M. Crowe (Lawrence Berkeley Lab), G. Dash (Univ. of Washington), W.S. Glausinger, R.F. Marzke (Arizona State Univ.)

192. Measurement of the pion production asymmetries from the reaction $^3p + d + r^+ + n$ with a polarized proton beam between energies at 400 to 520 MeV [completed], D. Ottewell, P.L. Walden (TRIUMF), W. Falk (Univ. of Manitoba), G. Giles, G. Jones, W. Ziegler (Univ. of British Columbia), G. Lolos (Univ. of Regina)

194. The $pd + tr^+ + n$ reaction at 330, 470 and 500 MeV [active], R. Abegg, L.G. Greeniaus, D.A. Hutcheon, C.A. Miller (TRIUMF), J.M. Cameron, W.J. McDonald, G.A. Moss, W.C. Olsen, G. Roy, J. Uegaki (Univ. of Alberta), C.A. Davis (Univ. of Manitoba)

195. $^{24}\text{Mg}(p,p')^{24}\text{Mg} + ^{12}\text{C} + ^{12}\text{C}$ [active], R. Abegg, L.G. Greeniaus, D.A. Hutcheon, C.A. Miller (TRIUMF), J.M. Cameron, W.K. Dawson, G.A. Moss, G. Roy, H. Sherif, J. Uegaki, H. Wilson (Univ. of Alberta), C.A. Davis (Univ. of Manitoba)

196. Measurement of pionic X-rays in $^{23}\text{Na}, ^{24}\text{Mg}$ and $^{27}\text{Al}$ [active], A. Olin (TRIUMF/Univ. of Victoria), J.A. Macdonald, T. Numao (TRIUMF), G.A. Beer, G.R. Mason (Univ. of Victoria), B. Olaniyi (Univ. of Ife), P.R. Poffenberger (Univ. of Manitoba)

197. A precise measurement of the Lamb shift in muonium in the 2S state [letter of intent], J.H. Brewer, A. Fry, J.B. Warren (Univ. of British Columbia), R. Kiefl, C. Oram (TRIUMF)

198. $n-p$ total cross section in pure spin states [letter of intent], D.A. Axen, F. Entezami, C. Waltham (Univ. of British Columbia), J.A. Edgington (Univ. of London, QMC), M. Comyn, G. Ludgate (TRIUMF), L.P. Robertson (Univ. of Victoria)

199. A study of low energy pion absorption in $^3\text{He}$ [active], J. Alster, D. Ashery, L. Lichtenstadt, M.A. Moinester (Tel-Aviv Univ.), B. Barnett, W. Gyles, R.R. Johnson, H. Roser, R. Taciak (Univ. of British Columbia), A. Altman (TRIUMF-UBC), D. Gill, J.S. Vincent (TRIUMF), K. Aniol (California State Univ. LA), S. Levenson (Northwestern Univ.)

202. Nuclear radii measurements in the A~20 region [active], T.E. Drake, R. Sobie (Univ. of Toronto), A. Altman (TRIUMF-UBC), M.A. Moinester (Tel-Aviv Univ.), B. Barnett,
J. Coopersmith, K.L. Erdman, W. Gyles, R.R. Johnson, R. Tacik (Univ. of British Columbia), G.A. Beer (Univ. of Victoria), E.W. Blackmore, D. Gill (TRIUMF) A. Olin (TRIUMF/Univ. of Victoria) S. Martin (KFA Jülich), C. Wiedner (Max Planck Institut)

203. Inelastic pion scattering on neon isotopes [active], T.E. Drake, R. Sobie (Univ. of Toronto), A. Altman, M.A. Moinester (Tel-Aviv Univ.), B. Barnett, J. Coopersmith, K.L. Erdman, W. Gyles, R.R. Johnson, R. Tacik (Univ. of British Columbia), E.W. Blackmore, D. Gill (TRIUMF), S. Martin (KFA Jülich), C. Wiedner (Max Planck Institut), B.H. Wildenthal (Michigan State University)

204. Strong interaction shift and width in pionic $^{22}$Ne atoms [completed data taking], G.A. Beer, G.R. Mason (Univ. of Victoria), A. Olin (TRIUMF/Univ. of Victoria), T.E. Drake, R. Sobie (Univ. of Toronto), B. Olaniyi (Univ. of Ife)

205. Tensor analysing power in pion deuterium scattering [active], L. Dallin, K. Itoh, Y.M. Shin (Univ. of Saskatchewan), B. Barnett, K.L. Erdman, W. Gyles, R.R. Johnson, R. Tacik (Univ. of British Columbia), E.W. Blackmore, D.R. Gill, G.D. Wait (TRIUMF), C. Lolos (Univ. of Regina), K. Antol (California State Univ. LA), T.E. Drake (Univ. of Toronto), S. Martin (KFA Jülich)

206. A study of $(p,n)$ and related reactions [active], D. Boal, J.M. D'Auria, R.E.L. Green, R.G. Korteling (Simon Fraser University), K.P. Jackson (TRIUMF), R. Helmer (Univ. of Western Ontario)

207. $^{48}$Ca$(p,p')^{48}$Ca$(1^+)$ [completed data taking], R. Abegg, D.R. Gill, C.A. Miller (TRIUMF), J.M. Cameron, P. Kitching (Univ. of Alberta), C.A. Davis (Univ. of Manitoba), J. Coopersmith, R.R. Johnson (Univ. of British Columbia), G. Berg, S. Martin (KFA Jülich), J. Lisantti (Univ. of Oregon), M.A. Moinester (Tel-Aviv Univ.), R. Santo (Munster Univ.)


211. The neutron and gamma ray correlation in the $\pi^-$ and $\mu^-$ captures in medium-heavy nuclei [completed data taking], T.J. Hallman, Y.K. Lee, R. Levin, L. Madansky, E. McIntyre (Johns Hopkins University), G.R. Mason (Univ. of Victoria), K.S. Kang (Kang Neung Univ.), B. Olaniyi (Univ. of Ife).

212. In search of a tredecabaryon resonance [completed], R. Abegg, K.P. Jackson, C.A. Miller (TRIUMF), D. Boal, J.M. D'Auria, R.E.L. Green, R.G. Korteling (Simon Fraser Univ.), R. Helmer (Univ. of Western Ontario)

213. Absorption at rest of $\pi^-$ in $^4$He and $^6$Li [completed data taking], C. Cernigoi, N. Grion, G. Pauli, R. Rui (INFN and Univ. di Trieste), R. Cherubini (National Lab of Legnaro/Univ. di Padova), D.R. Gill (TRIUMF), W. Gyles (Univ. of British Columbia)


217. Low energy, electromagnetic pion form factors [completed data taking], J.-M. Poutissou (TRIUMF), P. Gumplinger, D. Ila, A.W. Stetz (Oregon State Univ.), M.D. Hasinoff (Univ. of British Columbia), T. Mulera, V. Perez-Mendez, A. Sagle (Lawrence Berkeley Lab)

218. Pion production from $^{12}$C and $^{10}$B with polarized protons of 350 MeV [active], G. Lolos (Univ. of Regina), G. Giles, R.R. Johnson, G. Jones, B. McFarland (Univ. of British Columbia), D. Ottewell, P. Walden (TRIUMF), R.D. Bent (IUCF), W. Falk (Univ. of Manitoba)

219. The chemistry of pionic hydrogen atoms [completed data taking], D. Horváth (Budapest Central Research Inst. for Physics), D.F. Measday, S. Stanislaus (Univ. of British Columbia), M. Salomon (TRIUMF), K. Aniol (California State Univ. LA)

220. Temperature dependence of the spin exchange cross sections between muonium and alkali metal [completed data taking], D.J. Arseneau, D.G. Fleming, M. Senba (Univ. of British Columbia), D.M. Garner (TRIUMF)

221. Temperature dependence of the spin exchange cross sections between muonium and alkali metal [completed data taking], D.J. Arseneau, D.G. Fleming, M. Senba (Univ. of British Columbia), D.M. Garner (TRIUMF)

222. Search for evidence of a delta-nucleus intermediate state in proton elastic scattering [completed data taking], C.A. Davis, W.P. Lee, W.T.H. van Oers (Univ. of Manitoba), H.O. Meyer (IUCF), P. Schwandt (Indiana University), K.P. Jackson (TRIUMF), H.W. Roser (Univ. of British Columbia)

223. The $^2$H(p,2p) reaction and momentum distributions of the deuteron [completed data taking], H.P. Gubler, W.P. Lee, W.T.H. van Oers (Univ. of Manitoba), C.F. Perdrisat (College of William and Mary), J.M. Cameron (Univ. of Alberta), M.B. Epstein, D.J. Margaziotis (California State University), H. Postma (Technical University Delft), A.W. Stetz (Oregon State Univ.), R. Abegg (TRIUMF)

224. Inclusive pion scattering from light nuclei [completed data taking], K.G.R. Doss, I. Halpern, M. Khandaker, D.W. Storm (Univ. of Washington), J.F. Amann (Los Alamos National Laboratory)

225. Search for isovector properties of IBA nuclei [deferred], J. Alster, J. Lichtenstadt, M. Moinester, (Tel-Aviv Univ.), G. Azuelos, D.R. Gill (TRIUMF), B.M. Barnett, W. Gyles, R.R. Johnson, H. Roser, R. Tacik (Univ. of British Columbia), S. Martin (KFA Jülich), R. Sobie (Univ. of Toronto), K. Aniol (California State Univ. LA)

226. Study of neutron/proton transition amplitudes in $^{14}$C using 50 MeV pions [completed data taking], R.R. Johnson, H. Roser, R. Tacik (Univ. of British Columbia), K. Aniol (California State Univ. LA), J. Alster, J. Lichtenstadt, M.A. Moinester (Tel-Aviv Univ.), G. Azuelos, D.R. Gill (TRIUMF), S. Martin (KFA Jülich), R. Sobie (Univ. of Toronto), H.W. Baer (LAMPF)

227. Elastic and inelastic scattering of polarized protons from $^{10}$B [completed data taking], P.R. Andrews, S.M. Banks, P. Lewis, V.C. Officer, G.G. Shute, B.M. Spicer (Univ. of Melbourne), C.W. Glover (IUCF)


229. Muonic molecule formation rates in HD gas [completed data taking], K. Aniol (California State Univ. LA), F. Entezami, D.F. Measday, C. Virtue (Univ. of British Columbia), D. Horváth (Central Research Institute, Hungary), M. Salomon (TRIUMF), J. Smith (Univ. of Surrey), S.E. Jones (Idaho National Engineering Lab), B.C. Robertson (Queen's University)
231. Studies of light pionic atoms [active], G.A. Beer, G.R. Mason, G.M. Marshall (Univ. of Victoria), A. Olin (TRIUMF/Univ. of Victoria), J.A. Macdonald (TRIUMF), E. Klempt (Johannes Gutenberg University, Mainz), G. Wiegand (Lawrence Berkeley Lab), K. Wetzel (Univ. of Portland), W.C. Sperry (Central Washington University), B.H. Olaniyi (Univ. of Ife)

232. Muon Knight shifts in metals [completed data taking], J.H. Brewer, E. Koster, D. Llewelyn-Williams (Univ. of British Columbia)

233. Vector analysing power and spin transfer parameters for the \( ^3\)d + \( ^3\)pp reaction [active], E.G. Auld, P. Couvert, R.R. Johnson, G. Jones, B. McParland (Univ. of British Colombia), D. Ottewell, P. Walden (TRIUMF), G. Lolos (Univ. of Regina), W. Falk (Univ. of Manitoba)

234. Study of simple features of the A(p,\( p^-\))A+1 reaction in the (3,3) resonance region [active], R.D. Bent (IUCF), G.J. Lolos (Univ. of Regina), G.E. Walker (Indiana University), P. Couvert, G. Giles, G. Jones, B. McParland, W. Ziegler (Univ. of British Columbia), J. Iqbal, P. Walden (TRIUMF), W.R. Falk (Univ. of Manitoba)

235. (p,p') reactions in nuclei [active], R.E. Azuma, T.E. Drake, J.D. King, S.S.M. Wong, X. Zhu (Univ. of Toronto), K.P. Jackson, S. Yen (TRIUMF), A. Zaringhalan (Bell Laboratories)

237. Proton-nucleus interaction [active], R.E. Azuma, T.E. Drake, J.D. King, S.S.M. Wong, X. Zhu (Univ. of Toronto), S. Yen (TRIUMF)


239. Muon spin relaxation studies of spin glasses and random spin systems [completed data taking], Y.J. Uemura (Brookhaven National Lab), J.H. Brewer (Univ. of British Columbia), K.M. Crowe (Lawrence Berkeley Lab), T. Yamazaki (Univ. of Tokyo), Y. Miyako. K. Katsumata (Univ. of Hokkaido), Chikazawa (Muroran Inst. of Technology)

241. Temperature dependence of reaction rate constants for muonium addition reactions in liquid phases [active], K.L. Cheng, R.L. Ganti, Y.C. Jean (Univ. of Missouri-Kansas City), B.W. Ng, D.C. Walker (Univ. of British Colombia), J.M. Stadlbauer (Hood College)

242. Radiochemical study of the \( (p,p') \) reaction on bismuth [completed data taking], J. D'Auria, M. Dombsky (Simon Fraser University), T. Ruth (TRIUMF), T. Ward (IUCF), A. Yavin (Tel-Aviv University)

243. Energy and angle dependence of the \( ^6\)Li(\( p^+,\)He)\( ^3\)He reaction [active], G. Huber, G.J. Lolos, S.I.H. Naqvi, Z. Papandreou (Univ. of Regina), E.G. Auld, P. Couvert, R.R. Johnson, G. Jones, B.J. McParland (Univ. of British Columbia), D. Ottewell, P.L. Walden (TRIUMF)

244. \( \mu^+ \) spin relaxation in \( Y_2\)Co\( _5 \) and ternary magnetic superconductors [active], E.J. Ansaldo (Univ. of Saskatchewan), C.Y. Huang (Los Alamos), J.H. Brewer, D.R. Harshman, M. Senba (Univ. of British Columbia), K. Crowe (U.C. Berkeley), S.S. Rosenblum (Lawrence Berkeley Lab)

245. Muon spin rotation studies of unsupported and supported platinum catalysts [active], W.S. Glauinger, R.F. Marzke (Arizona State University), E. Ansaldo (Univ. of Saskatchewan), J.H. Brewer, D. Harshman, S. Kreitzman, D. Noakes, M. Senba (Univ. of British Columbia), R. Keitel (TRIUMF)

190
246. The double charge exchange reaction at \(T = 50\) MeV on \(^{16}\text{O}\) using the QCD spectrometer [active], E.W. Blackmore, D.R. Gill (TRIUMF), K.L. Erdman, R.R. Johnson, H. Roser, R. Tacik (Univ. of British Columbia), A. Altman (TRIUMF-UBC), M.A. Moinester (Tel-Aviv University), S. Martin (KFA, Jülich), C.A. Wiedner (MPI, Heidelberg), T. Drake, R. Sobie (Univ. of Toronto), T.G. Masterson (Univ. of Colorado)

247. Precise measurement of muon decay asymmetry parameter \(\delta\) [completed data taking], J. Carr, G. Gidal (Lawrence Berkeley Lab), A. Jodidio, K.A. Shinsky, H.M. Steiner, D. Stoker, M. Strovink, R.D. Tripp (Univ. of California, Berkeley/LBL), B. Gobbi (Northwestern University), C.J. Oram (TRIUMF)

248. A study of the \(\pi^+ - e^+\nu_e\) decay [active], J.A. Macdonald, T. Numao, J.-M. Poutissou (TRIUMF), D.A. Bryman, A. Olin (TRIUMF-Univ. of Victoria), M.S. Dixit (NRC)


250. Charge-exchange coincident with X/gamma-rays in pionic phosphorus [completed data taking], J.H. Bailey (DESY), G.A. Beer, G.R. Mason (Univ. of Victoria), D.F. Measday (Univ. of British Columbia), A. Olin (TRIUMF/Univ. of Victoria), M. Salomon (TRIUMF), P.R. Poffenberger (Univ. of Manitoba)

251. Coincident optical and X-ray transitions in muonic helium [deferred], J.M. Bailey (DESY), C.J. Oram (TRIUMF), G.M. Marshall (Univ. of Victoria), J.D. Silver, D.N. Stacey (Oxford University)


254. Total reaction cross sections on nuclei in the 50-80 MeV range [active], E. Friedman (Hebrew University Jerusalem), D. Gill (TRIUMF), R.R. Johnson, M. Rozon (Univ. of British Columbia), J. Lapointe (Univ. of Laval), A. Altman (TRIUMF-UBC)

255. A study of pion absorption on two nucleons, each from a different shell, through the \(^{16}\text{O}(\pi^+, 2p)^{18}\text{N}\) reaction [active], A. Altman (TRIUMF-UBC), R.R. Johnson, H. Roser, R. Tacik (Univ. of British Columbia), D.R. Gill, U. Wienands (TRIUMF), D. Ashery (Tel-Aviv Univ.), K. Aniol (California State Univ. LA), C.A. Wiedner (MPI Heidelberg), T. Drake, R. Sobie (Univ. of Toronto), N. Grion (UBC and INFN Trieste)

256. Pion radiative capture in \(^3\text{He}\) and \(^{15}\text{N}\) [deferred], D.F. Measday, F. Entezami, M.D. Hasinoff, S. Stanislaus (Univ. of British Columbia), M. Salomon, J. Vincent (TRIUMF)

257. Radiative decay of the \(A\) resonance [active], D.F. Measday, F. Entezami, S. Stanislaus (Univ. of British Columbia), M. Salomon (TRIUMF)

258. The reaction of muonium with hydrogen peroxide in water [active], J.A. Bartlett, J.-C. Brodovitch, S.-K. Leung, K.E. Newman, P.W. Percival (Simon Fraser Univ.)
261. Muon spin rotation of paramagnetic solutions [active], J.A. Bartlett, J.-C. Brodovitch, S.-K. Leung, K.E. Newman, P.W. Percival (Simon Fraser Univ.)

262. Muonium-radical formation mechanism [active] B.W. Ng, D.C. Walker (Univ. of British Columbia), Y. Miyake (TRIUMF), R. Ganti, Y.C. Jean (Univ. of Missouri-Kansas City), J.H. Stadlbauer (Hood College), Y. Katsumura (Univ. of Tokyo), D. Livesey (Univ. of New Brunswick), R. Catterall (Univ. of Salford)

263. The pion-nucleus interaction [active], T.E. Drake, R. Schubank, R.J. Sobie (Univ. of Toronto), R.R. Johnson (Univ. of British Columbia), D. Gill (TRIUMF)

264. The proton-nucleus interaction [active], R.E. Azuma, L. Buchmann, T.E. Drake, J.D. King, L. Lee, S.S.M. Wong, X. Zhu (Univ. of Toronto), C.A. Miller, S. Yen (TRIUMF)

265. The \( (p,n) \) reaction as a probe of isovector effective interactions at TRIUMF energies [active], W.P. Alford, R.L. Helmer (Univ. of Western Ontario), R.E. Azuma, D. Frekers (Univ. of Toronto), J. D'Auria, O.F. Håusser (Simon Fraser Univ.), K.P. Jackson, S. Yen (TRIUMF)

266. Initial studies of the \( (n,p) \) reaction on light nuclei [active], K.P. Jackson, S. Yen (TRIUMF), W.P. Alford, R.L. Helmer (Univ. of Western Ontario), J.M. D'Auria, O.F. Håusser (Simon Fraser Univ.)

267. Isovector \( T_y \) transitions in \( \text{fp} \) shell nuclei studied by the \( (n,p) \) reaction [deferred], J. D'Auria, O. Håusser (Simon Fraser Univ.), K.P. Jackson, C.A. Miller, S. Yen (TRIUMF), A. Altman (TRIUMF-UBC), W.P. Alford, R.L. Helmer (Univ. of Western Ontario), I.S. Towner (Chalk River Nuclear Labs)

268. Enhancement of \( 1^+ \) states in \( ^{208}\text{Pb} \) \( (n,p) \): A search for the \( \Delta \) [deferred], K.P. Jackson, C.A. Miller, S. Yen (TRIUMF), O. Håusser (TRIUMF-SFU), W.P. Alford, R.L. Helmer (Univ. of Western Ontario)

269. Inelastic pion scattering from \( ^{30}\text{Si} \) at \( T_\pi \approx 50 \text{ MeV} \) [deferred], C.A. Wiedner (MPI Heidelberg), K. Erdman, B. Forster, R. Tacik (Univ. of British Columbia), A. Altman (TRIUMF-UBC), D.A. Gill, U. Wienands (TRIUMF), T. Drake, R. Sobie (Univ. of Toronto)

270. Test of charge symmetry by a comparison of \( \pi^-d+nn \) with \( \pi^+d+pp \) [active], A.D. Eichon, J. Engelage, G.J. Kim, A.A. Mokhtari, B.H.K. Nefkens, J.A. Wightman, H.J. Ziolk (UCLA), R.R. Johnson, G. Jones (Univ. of British Columbia), A. Altman (TRIUMF-UBC), W.J. Briscoe, C.J. Seftor, M.F. Taragin (George Washington University), T.E. Drake (Univ. of Toronto), D.R. Gill (TRIUMF), J.R. Richardson (TRIUMF-UCLA), P. Truöl (Univ. Zürich), K. Aniol (California State Univ. LA)

271. Study of isovector giant resonances via the \( (n,p) \) reaction at 200 and 500 MeV, [deferred], P.R. Andrews, S.M. Banks, P.B. Foot, B. Lay, P. Lewis, V.C. Officer, G.C. Shute, B.M. Spicer (Univ. of Melbourne)

272. Transverse spin flip probabilities in \( ^{24}\text{Mg} \) and \( ^{48}\text{Ca} \) [deferred], D. Häusser (Simon Fraser University), R. Abegg, K.P. Jackson (TRIUMF), W.P. Alford (Univ. of Western Ontario), C.A. Wiedner (MPI, Heidelberg), T.E. Drake (Univ. of Toronto), J. Lisanti, D. McDaniel, J. Tinsley (Univ. of Oregon)

273. Triplet \( \mu^-p \) absorption in \( H_2 \) gas [letter of intent], J. Bailey (DESY), G. Azuelos, C. Oram (TRIUMF), J. Brewer, K. Erdman (Univ. of British Columbia), K. Crowe (Univ. of California, Berkeley)

274. Singlet final state interaction in the \( pp\rightarrow pn^+ \) reaction [active], E.G. Auld, P. Couvert, G. Jones, W. Ziegler (Univ. of British Columbia), W. Falk (Univ. of Manitoba), P. Walden (TRIUMF), G. Lolos (Univ. of Regina)

276. Diluted magnetic semiconductors [active], E.J. Ansaldo (Univ. of Saskatchewan), J. Bailey (DESY), J.H. Brewer, D. Harshman, S. Kreitzman, D. Noakes, M. Senba (Univ. of British Columbia), R. Keitel (TRIUMF), K.M. Crowe (Univ. of California, Berkeley), J. Furdyna (Purdue Univ.), Y.J. Uemura (Brookhaven National Laboratory), T.L. Estle (Rice Univ.)

277. The branching ratio of the rare decay \( \pi^0 + e^+e^- \) [active], M.D. Hasinoff, C. Waltham (Univ. of British Columbia), D.A. Bryman, E. Clifford (TRIUMF-Univ. of Victoria), G. Azuelos, T. Numao, J.-M. Poutissou (TRIUMF), P. Depommier, H. Jeremie, R. Poutissou (Univ. de Montréal), C.K. Hargrove, H. Mes (National Research Council), B. Robertson (Queen's University), T.A. Mulera, V. Perez-Mendez (Lawrence Berkeley Laboratory), M. Blecher (Virginia Polytechnic Inst.), A.W. Stetz (Oregon State Univ.)

278. Inelastic scattering of 30 and 50 MeV \( \pi^+ \) projectiles from the \( O^+_2 \) state in \( ^{12}C \) [active], L. Buchmann, T.E. Drake, L. Lee, R.J. Sobie (Univ. of Toronto), D.R. Gill, B. Jennings (TRIUMF), R.R. Johnson (Univ. of British Columbia), N. de Takacsy (McGill University)

279. Non-analog pion single charge exchange total cross section on \( ^7Li \) at low energies [active], B.J. Dropesky, G.C. Giesler, M.J. Leitch, Y. Ohkubo, C.J. Orth (LAMPF), A. Olin (TRIUMF/Univ. of Victoria), R.E.L. Green, R.G. Korteling (Simon Fraser Univ.)

280. Study of giant isovector spin resonances via the \((p,n)\) and \((n,p)\) reactions at 350 MeV [deferred], J. Alster, N. Auerbach, M.A. Moinester, S. Wood, A.I. Yavin (Tel-Aviv Univ.), A. Altman (TRIUMF-UBC), O. Hüsser (Simon Fraser Univ.), A. Moalem (Ben-Gurion Univ. and SFU), W.P. Alford (Univ. of Western Ontario), A. Klein (Univ. of Georgia)

281. Investigations of pion absorption reactions \( ^6Li, ^{12}C(\pi^+, X)_X \) [active], X. Aslanoglou, G. Huber, G.J. Lolos, S.I.H. Naqvi, V. Paflis, Z. Papandreou (Univ. of Regina), D. Gill, D. Ottewell P.L. Walden (TRIUMF), E.G. Auld, R.R. Johnson, G. Jones (Univ. of British Columbia)


283. (Combined with 295)

284. A study of the decays \( \pi^+ \rightarrow e^+e^-\nu \) and \( \pi^+ \rightarrow e^+\gamma \) [deferred], M. Blecher (Virginia Polytechnic Inst. & State Univ.), D.A. Bryman, E. Clifford, P. Schlatter (TRIUMF-Univ. of Victoria), M. Dixit, C.K. Hargrove, H. Mes (NRC), G. Azuelos, T. Numao, J.-M. Poutissou (TRIUMF), P. Depommier (Univ. de Montréal), A. Burnham, M.D. Hasinoff, C. Waltham (Univ. of British Columbia), T. Mulera, V. Perez-Mendez (Lawrence Berkeley Laboratory)

285. Elastic scattering of pions by \( ^3\He \) for pion energies between 20 and 50 MeV [active], K.M. Crowe, C.A. Meyer (Univ. of California, Berkeley), D.R. Gill, D. Healey, U. Wiemands (TRIUMF), R.R. Johnson (Univ. of British Columbia), A. Altman (TRIUMF-UBC), N. Grion (UBC and INFN Trieste)

286. Quantum diffusion of muons and muonium [active], K.M. Crowe (Univ. of California, Berkeley), J.H. Brewer, D. Harshman, S.R. Kreitzman, M. Senba, D.P. Spencer, D.L.L. Williams (Univ. of British Columbia), R. Keitel (TRIUMF), E.J. Ansaldo (Univ. of Saskatchewan), J. Bailey (DESY), K. Nagamine (Univ. of Tokyo)

288. Muonium reaction rates on surfaces [active], R. Keitel (TRIUMF), J.H. Brewer, D.R. Harshman, D.N. Noakes, M. Senba (Univ. of British Columbia), K. Nagamine (Univ. of Tokyo), E.J. Ansaldo (Univ. of Saskatchewan)

289. Studies of positive muon states in alkali halides and other insulators by advance $\mu$SR methods [active], K. Ishida, Y. Kuno, T. Matsuzaki, Y. Morozumi, K. Nagamine, K. Nishiyama, T. Yamazaki (Univ. of Tokyo), J.H. Brewer (Univ. of British Columbia)

290. Positive muon probing soliton in polyacetylene [active], K. Ishida, Y. Kuno, T. Matsuzaki, K. Nagamine, H. Shirakawa, T. Yamazaki (Univ. of Tokyo), J.H. Brewer (Univ. of British Columbia)

291. $\mu$SR studies on spin dynamics in mixed antiferromagnets with competing anisotropies [active], A. Ito, E. Torikai (Ochanomizu Univ.), K. Ishida, Y. Kuno, T. Matsuzaki, K. Nagamine, T. Yamazaki (Univ. of Tokyo), J.H. Brewer (Univ. of British Columbia)

292. $\mu^+\text{SR}$ of graphite intercalation compounds [active], K. Ishida, T. Konod, Y. Kuno, T. Matsuzaki, K. Nagamine, T. Yamazaki (Univ. of Tokyo), J.H. Brewer (Univ. of British Columbia)

293. Spin observables for elastic and inelastic proton scattering from $^{28}$Si and $^{208}$Pb at 300 MeV [active], R.L. Auble, F.E. Bertrand, B.L. Burks, C.W. Glover, E.E. Gross, D.J. Horen, R.O. Sayer (Oak Ridge National Laboratory), O. Häusser, K. Hicks (TRIUMF/Simon Fraser Univ.), A. Moalem (Ben Gurion Univ. and SFU), U. Wienands (TRIUMF/UBC), J. Lisantti, D.K. McDaniels, J. Tinley (Univ. of Oregon), I. Bergqvist (Univ. of Lund), E. Rost, J.R. Shepard (Univ. of Colorado)


295. A measurement of the inclusive pion production from $^{16}$O and the associated particles in coincidence with the pions [active], E.G. Auld (Univ. of British Columbia), C.A. Miller, S. Yen (TRIUMF), G. Gaillard (Univ. of Alberta), E.G. Auld, P. Treille (Univ. of British Columbia), K. Hicks (Simon Fraser Univ.), R. Schubank (Univ. of Toronto), R. Henderson (Univ. of Melbourne)

301. The reaction ppm near threshold [active], F. Entezami, D.F. Measday, S. Stanislaus (Univ. of British Columbia), D. Horváth (Central Research Inst. for Physics, Budapest), J. Uegaki (Univ. of Alberta)


304. Muonium-antimuonium conversion [active], A. Olin (TRIUMF/Univ. of Victoria). C.J. Oram (TRIUMF), G.A. Beer, G.M. Marshall, G.R. Mason, J. Mildenberger (Univ. of Victoria), D.R. Harshman, J.B. Warren (Univ. of British Columbia), S. Ljungfelt (Univ. of California, Berkeley)

306. Pion transfer in gaseous mixtures [active], K.A. Aniol, M.B. Epstein, D.J. Margaziotis (California State Univ. LA), M. Salomon (TRIUMF), F. Entezami, D.F. Measday, T. Noble, S. Stanislaus, C.J. Virtue (Univ. of British Columbia), D. Horváth (Central Research Inst. for Physics, Budapest)

307. The effects of large oscillating fields in low frequency double electron muon resonance [active], S.A. Dodds, T.L. Estle, S.L. Rudaz, D.P. Spencer, Q. Zhu (Rice Univ.), J.H. Brewer, D. Harshman, S.R. Kreitzman, D. Noakes (Univ. of British Columbia), R. Keitel (TRIUMF), E.J. Ansaldo (Univ. of Saskatchewan), R.H. Heffner (LAMPF)

309. Transfer reaction studies with radioactive targets [deferred], E. Hagberg, J.C. Hardy, H. Schmeing (Atomic Energy of Canada Ltd.), G. Audi (Lab. René Bernas, Orsay)

310. Production of a $^{211}$Rn/$^{211}$At generator for radiochemical experiments [deferred], M. Adam, J. Grierson, T.J. Ruth (TRIUMF), K. Krohn (Univ. of Washington)

311. Nuclear reactions of astrophysical interest with accelerated radioactive beams [deferred], R. Azuma, L. Buchmann, J. King (Univ. of Toronto), J. D' Auria (Simon Fraser Univ.), C. Rolfs (Univ. of Münster), M. Wiescher (Mainz Univ.), M. Arnould (Univ. Libre de Bruxelles), T. Ward (IUCF), C. Barnes (California Inst. of Technology), R. Boyd (Ohio State Univ.)

312. Low energy ion scattering using ISOL [deferred], S.R. Morrison, W. Sears (Simon Fraser Univ.)

313. Delayed neutron studies at TRIUMF-ISOL [deferred], P.L. Reeder, R.A. Warner (Pacific Northwest Laboratory)

314. Production of radioactive targets for nuclear structure studies [deferred], C. Bourgeois, P. Kilcher, G. Rothbard, B. Roussire, J. Sauvage-Letessier, M. Vergnes (IPN, Orsay), H. Dautet (McGill University)


316. Collinear laser spectroscopy of radioactive beams [deferred], F. Buchinger and FRL Research Team (McGill University)

317. Spectroscopic studies of nuclear properties [deferred], L.R. Kilius, A.E. Litherland (Univ. of Toronto), FRL Research Team (McGill University), M. Pearson (Univ. de Montréal)
319. Analysing powers for the inelastic continuum in $^{60}$Ni and $^{208}$Pb [active], K. Lin, J. Lisantti, D.K. McDaniels (Univ. of Oregon), I. Bergqvist, A. Brockstedt, B. Jakobsson (Univ. of Lund), O. Häusser (Simon Fraser Univ.) F. Bertrand, B. Burks, E. Gross, C. Glover, D. Horen, R. Sayre (Oak Ridge National Lab), L. Swenson (Oregon State Univ.)
320. Muonium spin rotations in condensed phases methane [deferred], R.L. Ganti, Y.C. Jean, K. Venkateswaran (Univ. of Missouri-Kansas City), Y. Miyake, D.C. Walker (Univ. of British Columbia), J.M. Stadlbauer (Hood College)
321. Measurement of $\pi^+p$ differential cross sections at $T_\pi = 90$ MeV [active], J. Brack, J.J. Kraushaar, R.J. Peterson, R.A. Ristinen, J.L. Ullmann (Univ. of Colorado), D.R. Gill, G. Smith (TRIUMF), R.R. Johnson (Univ. of British Columbia), K.H. Hicks (Simon Fraser Univ.)
322. Giant resonance study with $75$ MeV $\pi^+$ [active], D.R. Gill, G.R. Smith, U. Wienands (TRIUMF), K.L. Erdman, N. Hessey, R.R. Johnson, D. Mills, M. Rozon (Univ. of British Columbia), A. Altman (TRIUMF-UBC), T.E. Drake (Univ. of Toronto)
323. Determination of muon-neutrino mass [active], C.Y. Kim (Univ. of Calgary), D. Garner, R. Keitel (TRIUMF), Y.M. Shin (Univ. of Saskatchewan)
324. Ultra-low energy muon production ($\mu$SOL) [active], J.H. Brewer, D.G. Fleming, D.R. Harshman, S.R. Kreitzman, D.R. Noakes, I.D. Reid, M. Senba, J.B. Warren (Univ. of British Columbia), J.L. Beveridge, R. Keitel, C.J. Oram (TRIUMF), A.S. Arrott (Simon Fraser Univ.), D.P. Spencer (Rice Univ.), E.J. Ansaldo (Univ. of Saskatchewan), A.P. Mills, Jr. (Bell Laboratories), A.S. Rupaal (Western Washington Univ.)
325. Study of the $^{16}$O, $^{28}$Si and $^{40}$Ca at $T_\pi = 240$ and 280 MeV [active], N. Grion (UBC and INFN Trieste), D. Gill, G. Smith, U. Wienands (TRIUMF), N. Hessey, R.R. Johnson, M. Rozon, P. Trelle (Univ. of British Columbia), A. Altman, (TRIUMF-UBC), R. Rui (Univ. di Trieste)
326. The $^4$He($\pi^+\pi^0$)$^4$He reaction and the EELL effect [active], K. Itoh, Y.M. Shin, N. Stevenson, D. Tokaryk (Univ. of Saskatchewan, D. Gill, B. Jennings, D. Ottewell, G. Wait (TRIUMF), R.R. Johnson (Univ. of British Columbia), A. Altman (TRIUMF-UBC), T. Drake, D. Frekers, R. Schubank (Univ. of Toronto), D. de Takacsy (McGill Univ.)
327. Spin observables for inelastic proton scattering from $^{12}$C at 400 MeV [active], A. Celler, O. Häusser, K.H. Hicks (Simon Fraser Univ.), A. Moalem (Ben Gurion Univ. and SFU), D. Tokaryk (Univ. of Saskatchewan, D. Gill, B. Jennings, D. Ottewell, G. Wait (TRIUMF), R.R. Johnson (Univ. of British Columbia), A. Altman, (TRIUMF-UBC), R. Rui (Univ. di Trieste)
331. Spin transfer in the $^3\Lambda + \ ^3\Sigma$ reaction [active], R.R. Johnson, G. Jones, P. Trelle (Univ. of British Columbia), M. Comyn, P. Delheij, D. Healey, D. Ottewell, G. Smith, G. Wait, P. Walden (TRIUMF), W. Falk (Univ. of Manitoba), G. Lolos, E. Mathie, P. Tervisidis (Univ. of Regina)


333. A search for the high frequency parts of the giant resonances [active], A. Moalem (Ben Gurion Univ./SFU), A. Celler, O. Hrusser, K.H. Hicks (Simon Fraser Univ.), G. Azuelos, K.P. Jackson, C.A. Miller (TRIUMF), K. Lin, J. Lisantti, D. McDaniels (Univ. of Oregon), R. Sawafta (Univ. of Alberta), W.P. Alford (Univ. of Western Ontario), R. Henderson (Univ. of Melbourne), M. Moinester (Tel-Aviv Univ.), I. Bergqvist (Univ. of Lund)

335. Energy dependence of isoscalar and isovector $1^+$ excitations in $^{28}\text{Si}(\pi,p')$ [active], A. Celler, O. Hrusser, K. Hicks (Simon Fraser Univ.), A. Moalem (Ben Gurion Univ./SFU), K.P. Jackson, C.A. Miller, S. Yen (TRIUMF), R. Sawafta (Univ. of Alberta), S. Yen (TRIUMF), W.P. Alford, R. Helmer (Univ. of Western Ontario), R. Henderson (Univ. of Melbourne), C. Gümther (Univ. of Bonn), R. Dymarz (McMaster Univ.)

336. Muon Knight shift near a metal-nonmetal transition [active] J.H. Brewer, D. Harshman, S.R. Kreitzman, D.R. Noakes, M. Senba, D.L. Williams (Univ. of British Columbia), R. Keitel (TRIUMF), E.J. Ansaldo (Univ. of Saskatchewan), D.P. Spencer (Rice Univ.), K.M. Crowe (Univ. of California, Berkeley), R. Mota (Brazil)


338. Proton scattering from $^{208}\text{Pb}$ and $^{90}\text{Zr}$ at large momentum transfer [active], R. Azuma, T.E. Drake, L. Buchmann, R. Dymarz, D. Frekers, J.D. King, L. Lee, S. Wong (Univ. of Toronto), R. Abegg, K.P. Jackson, C.A. Miller (TRIUMF), A. Scott (Univ. of Georgia), M. Whiten (Armstrong College), H. von Geramb (Univ. Hamburg)


340. $\mu^+$ molecular ions and ion molecule reactions in gases [active], D. Arseneau, D.C. Fleming, L.Y. Lee, I.D. Reid, M. Senba (Univ. of British Columbia), D. Garner, W.X. Kuang (TRIUMF)

341. Excited state production in proton induced nuclear reactions [active], W. Benenson, C. Bloch, E. Kashy, D. Morrissey (Michigan State Univ.), D. Boal, J. D'Auria, R.C. Korteling, (Simon Fraser Univ.), R. Helmer (Univ. of Western Ontario)

342. Dynamics of muon-produced soliton in polyacetylene [active], Y. Kuno, T. Matsuzaki, K. Nagamine, K. Nishiyama, T. Yamasaki (Univ. of Tokyo), K. Ishida (Inst. of Phys. and Chem. Research), H. Shirakawa (Univ. of Tsukuba), J. Brewer (Univ. of British Columbia), R. Kiefl (TRIUMF)

197
343. Negative pion inelastic scattering from $^2$H, $^3$He and $^4$He at 100 MeV. [deferred],
I. Halpern, M. Khandaker, T. Murakami, D. Rosenzweig, D. Storm, D. Tieger (Univ. of Washington)

344. Excitation of 'stretched' particle-hole states in charge-exchange reactions
[active], B. Anderson, R. Madey, R. McCarthy, N. Plumley, J. Watson (Kent State Univ.), W. Alford (Univ. of Western Ontario), O. Hüscher (Simon Fraser Univ.),
K.P. Jackson, C.A. Miller (TRIUMF)

345. Muon spin relaxation studies of uranium-based heavy fermions [active], G. Aeppli,
D. Abernathy (AT&T Bell Labs), Y.J. Uemura (Brookhaven National Lab), J.H. Brewer,
D. Noakes (Univ. of British Columbia), E. Ansando (Univ. of Saskatchewan),
E. Bucher (Univ. of Konstanz), J. Kossler (College of William and Mary)

346. Muon spin rotation and relaxation in heavy fermion cerium compounds [active],
Y.J. Uemura (Brookhaven National Lab), G. Aeppli, D. Abernathy, B. Batlogg,
J. Remeifka (AT&T Bell Labs), J.H. Brewer, D. Harshman, S. Kreitzman, D.R. Noakes,
M. Senba (Univ. of British Columbia), W.J. Kossler, B. Hitti, J. Kempton (College of William and Mary), R. Keitel, R. Kiefl (TRIUMF), E.J. Ansando (Univ. of Saskatchewan),
Y. Oonuki, T. Komatsubara (Tsukuba Univ.), E. Bucher (Univ. of Konstanz)

347. Spin dynamics in amorphous rare earth intermetallics [active], L. Asch,
O. Hartmann, R. Wüpppling (Univ. of Uppsala), K. Nagamine, K. Nishiyama, T. Yamazaki
(Univ. of Tokyo), E.J. Ansando (Univ. of Saskatchewan), R. Keitel (TRIUMF)

348. The diamagnetic $\pi^+$ state in alkali halide and related metal halide crystals
[active], E.J. Ansando (Univ. of Saskatchewan), J. Brewer, B. Forster, D. Harshman,
R. Keitel, R. Kiefl (TRIUMF), K. Nagamine (Univ. of Tokyo)

350. Study of the energy dependence of the $^{18}$O$(\pi^+,\pi^-)^{18}$Ne reaction at the low energy
region [active], A. Altman, R.R. Johnson, N. Hessey, F.M. Rozon, M. Sevior, R.P. Trelle,
U. Wienands (Univ. of British Columbia), D.R. Gill, G.R. Smith (TRIUMF),
T. Anderl (KFA Jülich-Univ. of British Columbia), N. Grion (INFN Trieste), H. Rui
(UBC-INFN Trieste), E. Piasetzky (Tel-Aviv Univ), M. Leitch (Los Alamos National Lab)

351. Study of the $(\pi^+,\pi^-)$ DIAS reaction on $^{34}$S and $^{56}$Fe at 50 MeV [active], A. Altman,
N. Hessey, R.R. Johnson, M. Sevior, F.M. Rozon, R.P. Trelle (Univ. of British Columbia),
D.R. Gill, G.R. Smith (TRIUMF), T. Anderl (KFA Jülich-Univ. of British Columbia), N. Grion (INFN Trieste), H. Rui (UBC-INFN Trieste),
E. Piasetzky (Tel-Aviv Univ), M. Leitch (Los Alamos National Lab)

352. Zero degree radiative capture of neutrons [active], G.W.R. Edwards, J.M. Cameron,
J. Collot, H. Fielding, G. Gaillard, J. Wesick (Univ. of Alberta), R. Abegg,
G. Greeniaus, D.A. Hutcheon, C.A. Miller (TRIUMF), N.E. Davison (Univ. of Manitoba)

354. Study of nuclear structure and density dependence of the effective interaction for
the N=50 isotones [active], R.E. Azuma, L. Buchmann, T. Drake, D. Frekers,
A. Galindo, L. Lee, R. Schubank, S. Wong (Univ. of Toronto), R. Abegg, K.P. Jackson,
C.A. Miller, S. Yen (TRIUMF)

355. Exchange effects in $0^+ \rightarrow 0^-$ inelastic scattering [active], R.E. Azuma, L. Buchmann,
T.E. Drake, D. Frekers, A. Galindo, J.D. King, L. Lee, R. Schubank, S.S.M. Wong,
X. Zhu (Univ. of Toronto)

356. Y-scaling in inclusive proton scattering from $^9$Be and $^{12}$C at 300 MeV [active],
A. Moalem (SFU/Ben-Gurion Univ.), O. Hüscher (SFU-TRIUMF), R. Abegg, K.P. Jackson,
357. Measurement of $B^+(GT)$ for $^{26}\text{Mg}$ and $^{19}\text{F}$ using the (n,p) reaction [active], W.P. Alford, R.L. Helmer (Univ. of Western Ontario), R.E. Azuma, D. Frekers (Univ. of Toronto), B.A. Brown (Michigan State Univ.), A. Celier, G.P. Hüsuser, K. Hicks (Simon Fraser University), G.T. Ewan (Queen's Univ.), K.P. Jackson, C.A. Miller, S. Yen (TRIUMF), B.H. Wildenthal (Drexel Univ.)


359. The spin response of $(fp)$ shell nuclei [active], R. Ferguson, C. Glashausser (Rutgers Univ.), O. Hüsuser (SFU-TRIUMF), S.K. Nanda (Univ. of Minnesota), K.W. Jones (Los Alamos National Lab), A. Moalem (SFU/Ben-Gurion Univ.), K. Hicks M. Vetterli (Simon Fraser Univ.), R. Abegg, K.P. Jackson, C.A. Miller (TRIUMF), W.P. Alford (Univ. of Western Ontario), R. Henderson (Univ. of Melbourne), J. Lisanti (Univ. of Oregon)


361. Muonium in water [active], J. Bartlett, J-C. Brodovitch, M. Harston, S-K. Leung, P.W. Percival (Simon Fraser University), K. Newman (Univ. de Sherbrooke)

362. High pressure muon spin resonance in liquids [active], J. Bartlett, J-C. Brodovitch, M. Harston, S-K. Leung, P.W. Percival (Simon Fraser University), K. Newman (Univ. de Sherbrooke)

363. Photon asymmetry measurements in radiative muon capture in heavy nuclei [active], T. Gorringe, M. Hasinoff, A. Pouladdej, C. Virtue, C. Waltham (Univ. of British Columbia), G. Azuelos (TRIUMF), B. Robertson (Queen's University), D. Horváth (Central Research Inst. for Physics, Budapest)

365. Search for tetaneutrons using the $^4\text{He}(\pi^-,\pi^+)n$ reaction [active], D. Armstrong, T. Gorringe, M. Hasinoff, C. Waltham, J.B. Warren (Univ. of British Columbia), G. Azuelos, J.A. Macdonald, T. Numao, J.-M. Poutissou (TRIUMF), D. Bryman (TRIUMF-Univ. of Victoria), R. Poutissou (Univ. de Montréal)

366. Measurement of $d\sigma/dt$ and $A_{NO}$ to exclusive states of $^{16}\text{O}(p,\pi^+)^{17}\text{O}$ between 250 and 450 MeV [active], M.J. Iqbal, P. Walden, S. Yen (TRIUMF), E.G. Auld (Univ. of British Columbia), R. Bent (IUCF), W. Falk (Univ. of Manitoba), K. Hicks (Simon Fraser Univ.), G. Lolos (Univ. of Regina)

367. Resolved nuclear hyperfine structure of anomalous muonium in semiconductors [active], R.F. Kiefl, R. Keitel (TRIUMF), E.J. Ansaldo (Univ. of Saskatchewan), J.H. Brewer, S. Kreitzman, G. Luke, D.R. Noakes (Univ. of British Columbia), T.L. Estle, D.P. Spencer (Rice Univ.), T. Matsuzaki, K. Nishiyama (Univ. of Tokyo)

368. Charge symmetry breaking in n(p,d)$\pi^0$ at 477 MeV [active], R. Abegg, L.G. Greeniaus, D.A. Hutcheon, C.A. Miller (TRIUMF), J.M. Cameron, P.W. Green, C. Lapointe, G.A. Moss, G.M. Stinson (Univ. of Alberta), C.A. Davis, W.T.H. van Oers (Univ. of Manitoba)
369. Charge symmetry breaking in n-p elastic scattering at 350 MeV (deferred),
P.W. Green, C. Lapointe, W.J. McDonald, G.A. Moss, R. Tkachuk (Univ. of Alberta),
R. Abegg, L.G. Greimiaus, C.A. Miller (TRIUMF), J. Birchall, C. Davis, W.D. Ramsay,
W.T.H. van Oers (Univ. of Manitoba)

370. On the applicability of the macroscopic DWBA formalism for $^{58}$Ni at 200 and 400 MeV
[active], J. Lisantti, D.K. McDanielis (Univ. of Oregon), C. Clover, L.W. Swenson,
Y. Xiao (Oregon State Univ.), F. Bertrand, B. Burks, D. Horen (Oak Ridge National
Lab), I. Bergqvist (Univ. of Lund), O. H"ausser, K. Hicks, (Simon Fraser Univ.)

371. Muonium in micelles [active] K. Venkateswaren, D.C. Walker (Univ. of British
Columbia), J.M. Stadlbauer (Hood College), B.W. Ng (Univ. of Toronto), R. Ganti,
Y.C. Jean (Univ. of Missouri-Kansas City), Wu Zhenna (USTC, Hefei)

372. Single pion production in np scattering [active], J. Birchall, C.A. Davis,
N.E. Davison, W.R. Falk, W.D. Ramsay, W.T.H. van Oers (Univ. of Manitoba),
D.A. Hutcheon, C.A. Miller, P.L. Walden (TRIUMF)

373. Low energy pion scattering and pionic atom anomaly [active], D.R. Gill, A. Olin,
G.R. Smith (TRIUMF), A. Altman, R.R. Johnson, M. Rozon, M. Sevior, R.P.
Trelle, U. Wienands (Univ. of British Columbia), T. Anderl (KFA J"ulich-UBC),
N. Grion (INFN Trieste), R. Rui (UBC-Univ. Trieste)

374. Non-analog DCX, the $^{16}$O($^{+}, ^{-}$)$^{16}$Ne reaction [active], D.R. Gill, G.R. Smith
(TRIUMF), A. Altman, R.R. Johnson, F.M. Rozon, M. Sevior, R.P. Trelle, U. Wienands
(Univ. of British Columbia), T. Anderl (KFA J"ulich-UBC), N. Grion (INFN Trieste),
R. Rui (UBC-Univ. Trieste)

375. Few body physics via the pion deuteron breakup reaction [active], G. Huber,
G.J. Lolos, E.L. Mathie, S.I.H. Naqvi, V. Pafitis, Z. Papandreou (Univ. of Regina),
G. Jones, M. Sevior, F. Trelle (Univ. of British Columbia)

376. $S^+_8$ strength in $^{90}$Zr(n,p) [active], K.P. Jackson, C.A. Miller, S. Yen (TRIUMF),
B. Spicer, R. Henderson (Univ. of Melbourne), M. Moinester, A.I. Yavin (Tel-Aviv
Univ.), W.P. Alford, R. Helmer (Univ. of Western Ontario), A. Celler, O. H"ausser,
K. Hicks (Simon Fraser Univ.), T.E. Drake, D. Frekers, J.D. King (Univ. of
Toronto)

377. Test of charge symmetry in nd elastic scattering [active], D. Gill, D.F. Ottewell,
G.R. Smith, P.L. Walden (TRIUMF), A. Altman, R.R. Johnson, G. Jones, F. Tervisidis,
P. Trelle (Univ. of British Columbia), J.J. Kraushaar, R.J. Peterson,
R.A. Ristinen, J.L. Ullmann (Univ. of Colorado)

378. Study of $^{48}$Ti(n,p) as a test of lifetime calculations for the double beta decay of
$^{48}$Ca [active], W.P. Alford, R. Helmer (Univ. of Western Ontario), K.P. Jackson,
C.A. Miller, S. Yen (TRIUMF), O. H"ausser (SFU-TRIUMF), A. Celler, K. Hicks
(Simon Fraser Univ.), D. Frekers (Univ. of Toronto), B.A. Brown (Michigan State
Univ.), C.D. Zafiratos (Univ. of Colorado)

379. Investigation of the relation between Gamow-Teller strength and (p,n) cross sections
at small momentum transfer [active], W.P. Alford, R. Helmer (Univ. of Western
Ontario), J. Watson (Kent State Univ.), C.D. Zafiratos (Univ. of Colorado),
K.P. Jackson, C.A. Miller, S. Yen (TRIUMF), A. Celler, O. H"ausser K. Hicks (Simon
Fraser Univ.), D. Frekers (Univ. of Toronto), B.A. Brown (Michigan State Univ.),
R. Henderson (Univ. of Melbourne)

381. Measurement of spin observables using the (p,p'γ) reaction [deferred], K. Hicks,
A. Celler, O. H"ausser, M. Vetterli (Simon Fraser Univ.), R. Abegg, K.P. Jackson,
C.A. Miller, S. Yen (TRIUMF), R. Jeppesen, R. Ristinen, J. Shepard, J. Ullmann
382. Measurements of the spin rotation parameter Q at 200 MeV as a test of Pauli blocking in elastic proton-nucleus scattering [active] A. Celler, O. Häusser, K. Hicks, M. Ji, K. Lin, M. Vetterli (Simon Fraser University), R. Abegg, K.P. Jackson, C.A. Miller (TRIUMF), R.S. Henderson (Univ. of Melbourne), R. Sawafta (Univ. of Alberta), W.P. Alford (Univ. of Western Ontario), C. Glover (Oak Ridge National Lab), J. Lisantti, D.K. McDanels (Univ. of Oregon), L.W. Swenson (Oregon State Univ)

383. A test of the Gamow-Teller sum rule from measurements of the $^{54}$Fe(n,p) and (p,n) reactions at 290 MeV [active], A. Celler, O. Häusser, K. Hicks, M. Ji, K. Lin, K. Lin, M. Vetterli (Simon Fraser Univ.), K.P. Jackson, S. Yen (TRIUMF), W.P. Alford, R. Helmer (Univ. of Western Ontario), D. Frekers (Univ. of Toronto), R. Henderson (Univ. of Melbourne), F. Osterfeld (KFA Julich)

384. Abysmal astrophysics: the (n,p) reaction on $^{56}$Fe and $^{58}$Ni [active], K.P. Jackson (TRIUMF), W.F. Alford, R. Helmer (Univ. of Western Ontario), R.E. Azuma, L. Buchmann, C. Campbell, D. Frekers, J.D. King (Univ. of Toronto), A. Celler, O. Häusser, K. Hicks, M. Vetterli (Simon Fraser Univ.), R. Henderson, B. Spicer (Univ. of Melbourne)

385. Muon spin depolarization in Xe up to 5 atm [active], D. Arseneau, D. Fleming, L.Y. Lee, I. Reid, M. Senba, R.E. Turner (Univ. of British Columbia), D. Garner (TRIUMF)

386. Electron-muon drag in conductors [active], K.M. Crowe, A.M. Portis (Univ. of California, Berkeley), E.J. Ansaldo (Univ. of Saskatchewan), J.H. Brewer, S.R. Kreitzman (Univ. of British Columbia), R. Keitel (TRIUMF)

387. Measure of Birks factor in TMP [active], A. Astbury, M. Fincke-Keeler, R. Keeler, G.R. Mason, L. Robertson (Univ. of Victoria), D. Schinzel (CERN), A. Gonidec (LAPP, Annecy), C. Oram (TRIUMF)

388. Muon spin rotation of paramagnetic solution [active], K. Newman (Univ. de Sherbrooke), J. Bartlett, J.-C. Brodovitch, M. Harston, S.-K. Leung, P. Percival (Simon Fraser Univ.)

*deceased