TRIUMF

Experimental Facilities at TRIUMF

Edited by

R.M. Pearce

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Physics Department
University of Victoria

MESON FACILITY OF:

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

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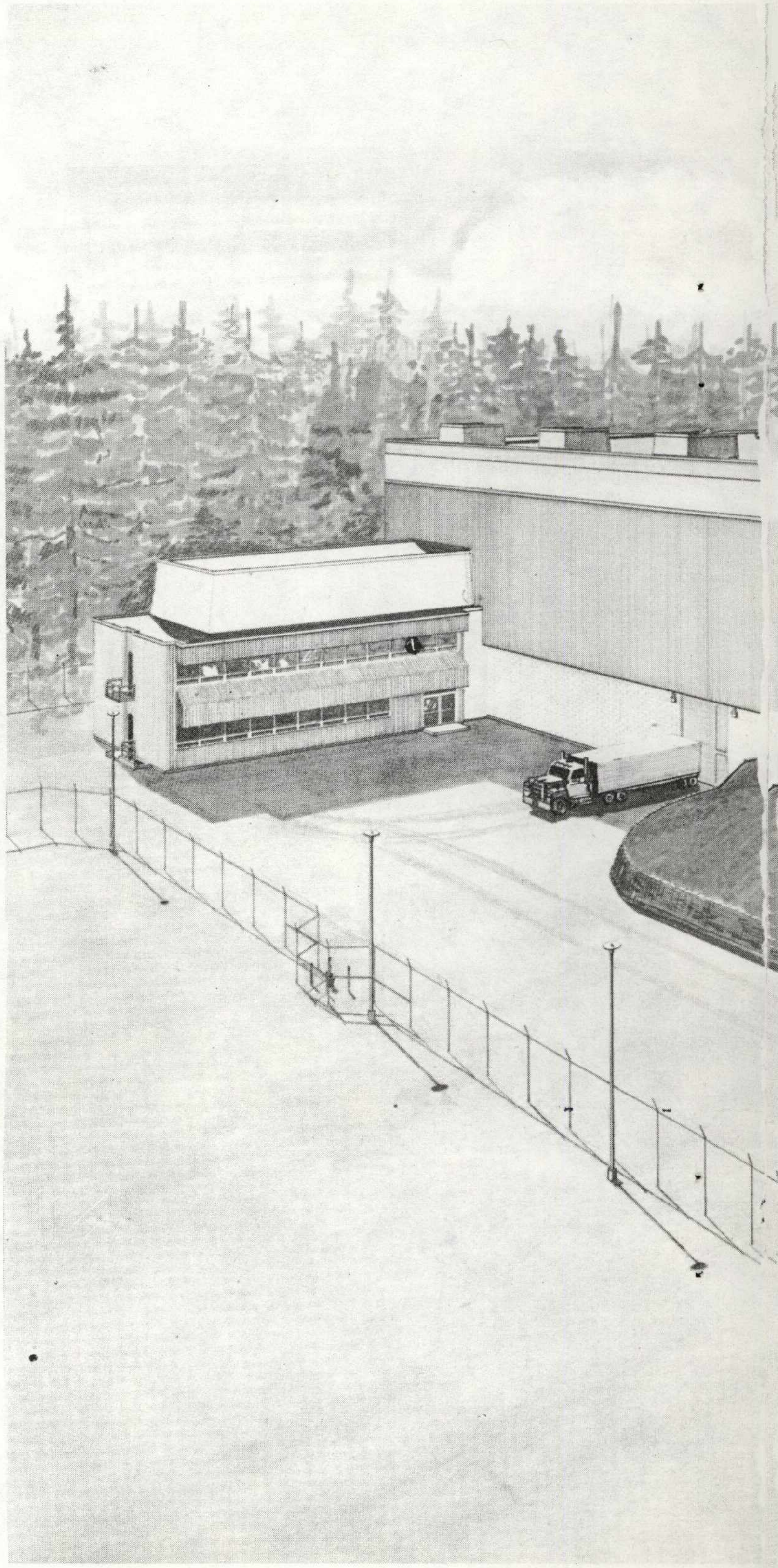
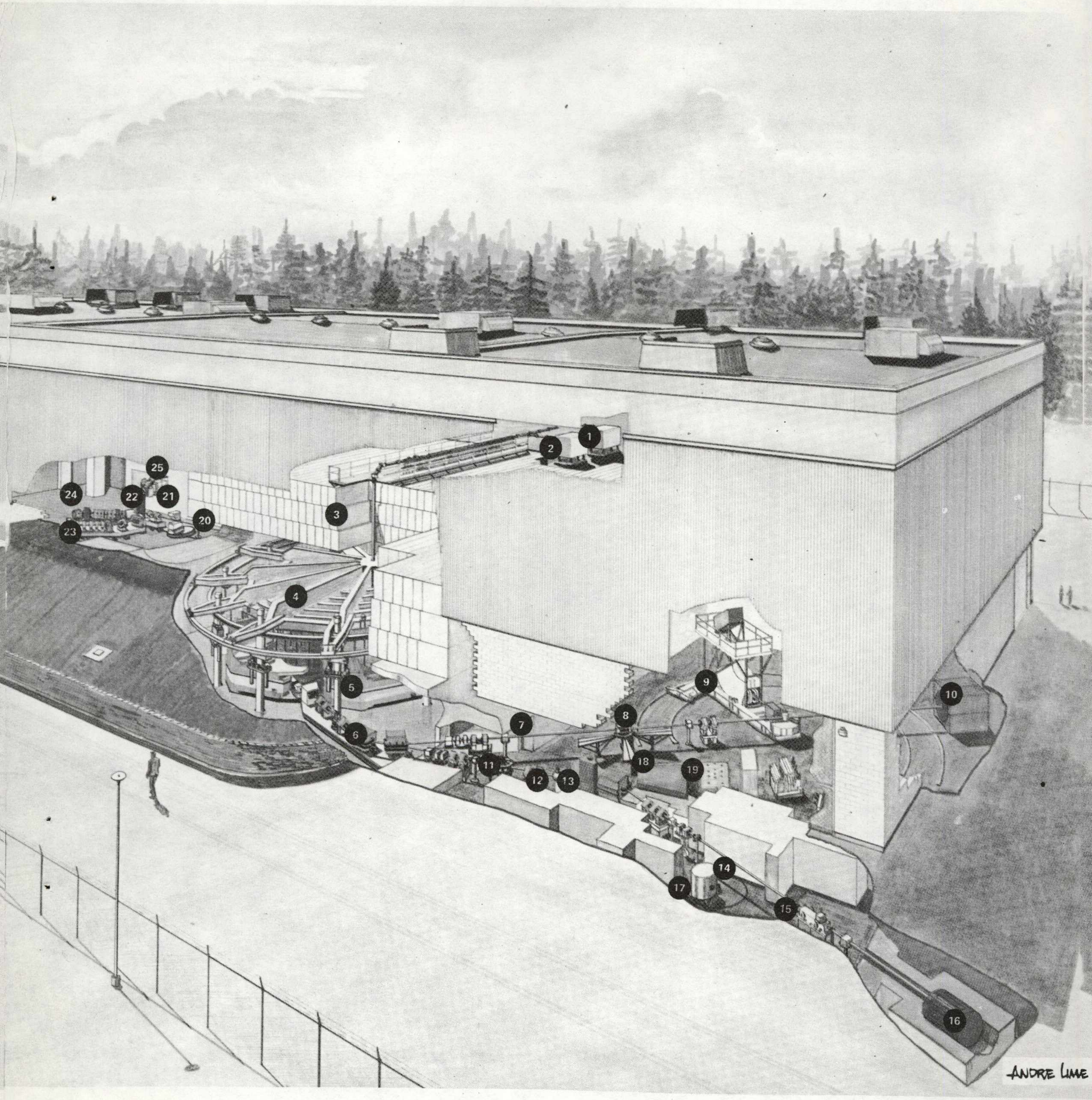
1. Polarized H^- ion source
2. Unpolarized H^- ion source
3. Injection beam line
4. Cyclotron support structure
5. Cyclotron magnet sector
6. Beam line IV
7. Beam line IVb
8. Proton target with scattering stand
9. Proton spectrometer
10. 100 nA beam dump
11. 60 in. scattering chamber
12. Superconducting solenoid
13. Liquid deuterium target
14. Beam line IVa
15. Time-of-flight mass identification facility
16. 10 μA beam dump
17. Fertile to fissile conversion studies
18. Neutron collimator
19. Spin precession magnet
20. Beam line I
21. Pion spectrograph
22. Meson target T2
23. Stopped π/μ channel
24. MSR channel
25. Medical channel

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8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
ANDRE LIME

CONTENTS

1. INTRODUCTION

TRIUMF is a sector-focused cyclotron for 525 MeV protons, constructed on the University of British Columbia campus in Vancouver by the University of Alberta, Simon Fraser University, the University of Victoria and the University of British Columbia with funds provided by these universities and the Atomic Energy Control Board of Canada. The first external beam was extracted late in 1974. At the time of writing, the beam current is being increased while machine development and the installation of shielding take place. The ultimate design current is 100 μA.

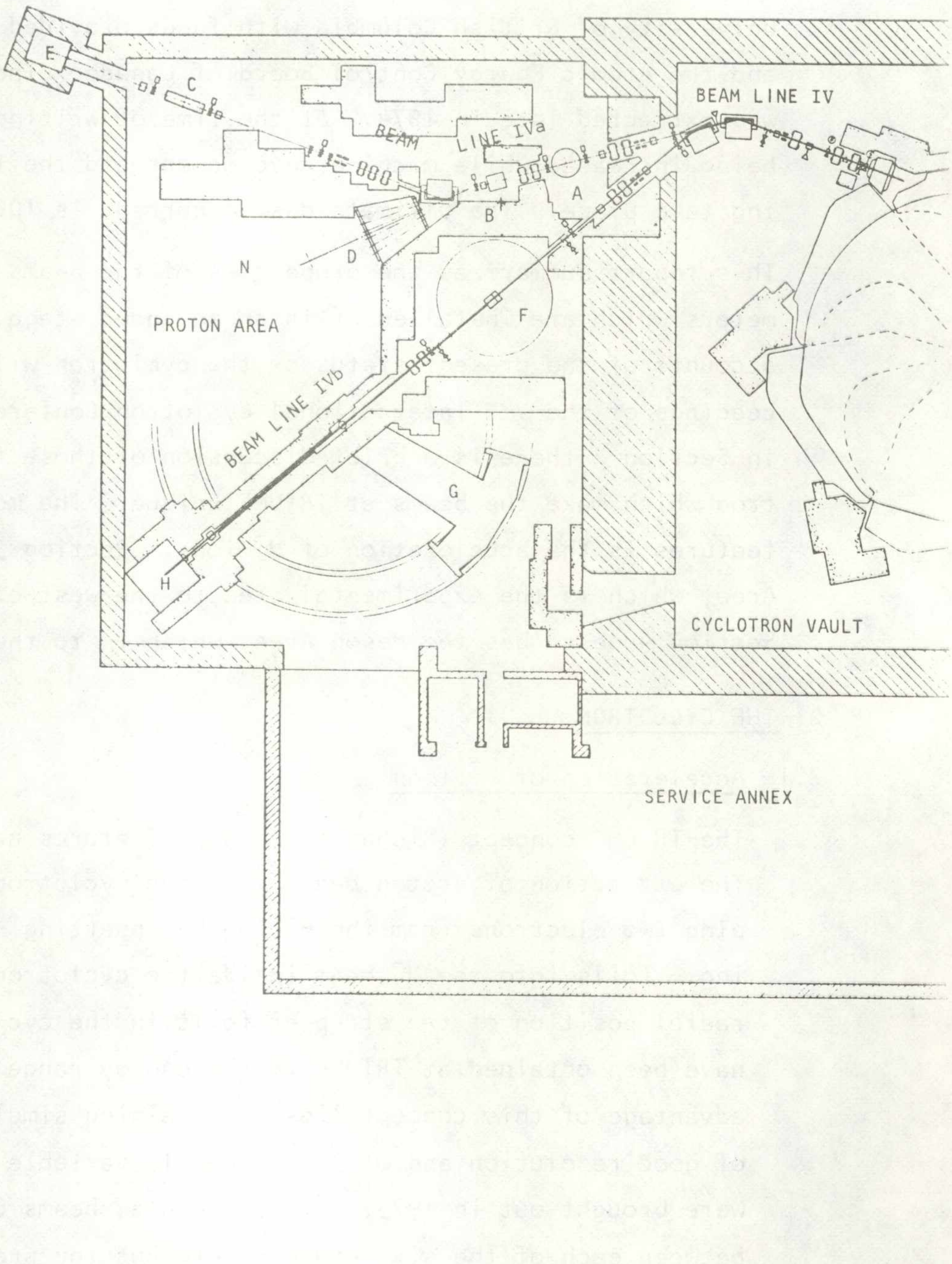
This report summarizes the properties of the beams, channels and spectrometers which are installed or in an advanced stage of planning. Full accounts of the present status of the cyclotron will appear in the Proceedings of the VII International Cyclotron Conference, Zurich (1975). In Section 2 there is a brief discussion of those features of the cyclotron which make the beams at TRIUMF unique. The most important of these features is the acceleration of H^- ions. Section 3 describes the Proton Area, which is the experimental area to the west of the cyclotron, and Section 4 describes the Meson Area, which is to the east (cf. Fig. 1).

2. THE CYCLOTRON

2.1 Acceleration of H^- Ions

The TRIUMF concept (Richardson, 1963) features acceleration of H^- ions. The extraction of proton beams from the cyclotron is effected by stripping two electrons from the H^- ion by inserting - or partially inserting - foils into the H^- beam inside the cyclotron. By varying the radial position of the stripper foils in the cyclotron, proton beams have been obtained at TRIUMF in the energy range 180 to 520 MeV. The advantage of this concept lies in obtaining simultaneous proton beams of good resolution and of independently variable energy. Two beams were brought out in 1975. (In principle, beams could be brought out between each of the six return yokes, but the presence of the resonators interferes with some potential extraction positions and the number of beams which can be extracted is probably limited to four. Space has been left for expansion of the building north and south.)

- A 60 in. scattering chamber
- B Super-conducting solenoid
- C Time-of-flight mass identification facility
- D Neutron collimator
- E 10 μA beam dump
- F Proton target with scattering stand (PT1)
- G Proton spectrometer
- H 100 nA beam dump
- I Meson target (T2)
- J Stopped π/μ channel
- K MSR facility
- L Medical channel
- M TINA and π production experiments
- N BASQUE experiments



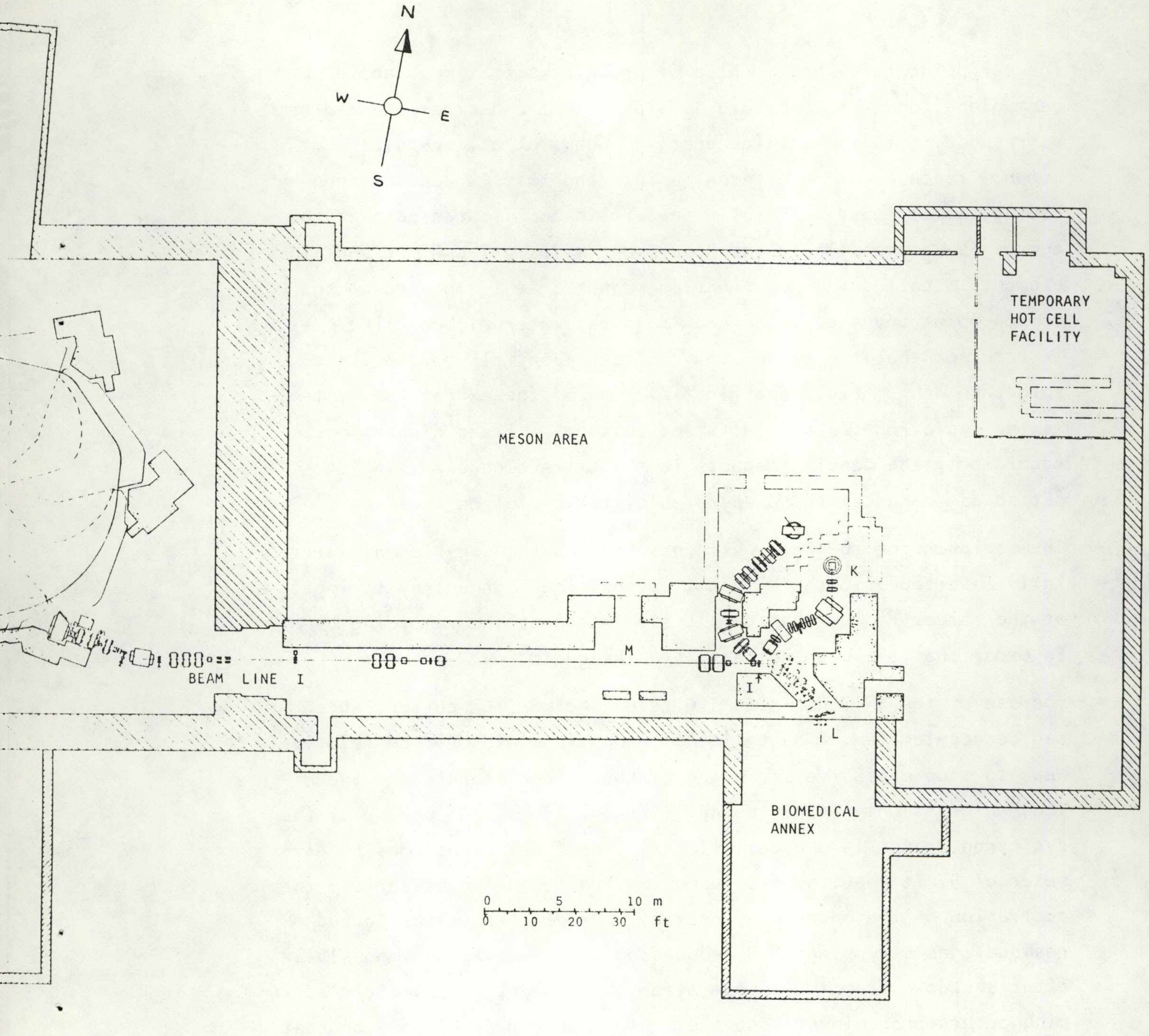

N
W
E
S
TEMPORARY
HOT CELL
FACILITY
MESON AREA
K
M
BEAM LINE I
I
L
BIOMEDICAL
ANNEX
0 5 10 m
0 10 20 30 ft

Fig. 1

The stripping foils are mounted on probe arms that move above the beam plane, and the foils are lowered into the beam at the radius corresponding to the desired energy. Beams of all energies must somehow reach a common external point, and this is accomplished by having the stripper foil follow a certain complicated path as the energy is changed (Tautz and Robertson, 1970). The first beamline element is called the "combination magnet"; it is located at the common point and steers the beam down the external beam line. It is required that the system from the stripper foil to the first target be achromatic. The first element of the extraction system is the cyclotron field itself, and this has a fixed dispersion. Accordingly the bending magnets in the extraction beam line are set so as to cancel the dispersion of the cyclotron field.

The stripper for the beam which has the lower energy is only partially inserted into the H^- beam, whereas the high energy stripper at the larger radius must completely intercept the remaining beam in order that the beam not activate the cyclotron.

The use of the H^- ion places limits on the maximum current which can be accelerated. The cyclotron magnetic field must be relatively weak to stop excessive stripping of the second electron on the H^- ion, which is only weakly bound (Stinson, 1969). As a result, the cyclotron magnet is unusually large. The final magnet design diameter of 57 ft resulted from choosing the following criterion: the activation of the machine by neutral hydrogen from electric and residual gas stripping of H^- should not make servicing impossible after shutdown from 100 μA operation. (However, the electric stripping occurs predominantly at the maximum energy and it may be that operation at a few hundred microamperes is possible with H^- energy reduced to 450 MeV.)

The design current of 100 μA may also be close to the limit of performance of the thin stripping foils, which must be radiation cooled. Unfortunately, the two stripped electrons spiral in the magnetic field, giving up all their energy (250 keV/electron for 500 MeV ions) in repeated passages through the foil.

2.2 Radio Frequency

The feature which interests us here is that the resonators are quarter wave stubs with the open end on the dee-gap. This makes possible the addition of a third harmonic ($3\lambda/4$ in the same resonator) to flatten the RF waveform. This should greatly ease some problems (Dutto, 1972) in obtaining large phase acceptance and good energy resolution. Third harmonic operation is planned for 1976.

The accelerating dees are unusual in that they are also the resonators. This is made possible by the large size of the vacuum tank and by choosing the RF frequency to be 23.075 MHz, which is a factor five times the orbit frequency.

2.3 Proton Beams

Beams of independently variable energy have been simultaneously extracted into beam line I and beam line IV in 1975. When tune-up of the cyclotron is completed the raw proton beam from a wide (i.e. greater than the separation of the centers of two consecutive orbit separations) stripper is expected to have a full width of ± 600 keV. This resolution is based on the estimated emittance at 500 MeV which is 1.2 π mm mrad axially and radially.

Since the cyclotron is isochronous, the macroscopic duty cycle is 100%. The beam characteristics have been discussed by Richardson (1969), Richardson and Craddock (1969), and Dutto *et al.* (1972). The microscopic duty cycle will be approximately 13%, or 5 nsec every 43 nsec, without the third harmonic in the RF. But it is planned to operate as soon as possible with the third harmonic, and in this case the microscopic duty cycle will be increased to 20%, or 9 nsec every 43 nsec. This information is summarized in the first line of Table 2.3.

Table 2.3

Summary of the Main Characteristics at 500 MeV

for the Tuned-up Extracted Proton Beams

Mode of Operation	Full Width Energy Spread (keV)	Phase Acceptance	Estimated Intensity (μA)	Microscopic Duty Factor (%)
Raw Beam	± 600	± 23°	100	13
		± 35° (3rd)	100	20
Low Energy Slits 0.032 in.	± 100	± 1.8°	2	1
		± 14° (3rd)	16	8
Separated Turn Acceleration	± 50	± 0.5°	5	0.3
	± 25	± 6.7° (3rd)	30	3.7

(3rd) indicates that the proper mixture of third harmonic of the RF voltage is used.

Two methods of improving the energy resolution are planned. These are made possible by the use of H^- ions (cf. § 2.1). In the method called "low energy slits", two pairs of slits (i.e., stripping foils) are used at about 15 MeV to reduce the amplitude of the radial oscillation of the beam envelope, and incidentally the intensity. The method in the table called "Separated Turn Acceleration" would normally entail severe tolerances on the magnetic field and resonator voltage. However, the use of the third harmonic RF (cf. § 2.2) greatly relaxes these tolerances. Separated orbit operation promises the best resolution, 90 keV at 500 MeV, and has the advantage that it could be used with the polarized ion source.

Both methods of improving the resolution are being carried forward and a choice will be made between them after some operating experience.

2.4 Proton Beamline Monitors

Several types of monitors are used for external proton beam measurements. The most widely used device is the multiwire chamber (MWC) which provides horizontal and vertical beam profiles of 1 mm, 3 mm or 5 mm resolution. For low beam currents ($\lesssim$ 500 nA), gas-filled, sealed ionization chambers (MWIC) are used, and at high currents ($\gtrsim$ 500 nA) secondary emission chambers (MWSEM) are used. The charge collected by each wire of an MWC is integrated individually for a fixed interval and then a complete chamber scan is read out to an oscilloscope. Further information on beam shapes can be obtained with scintillation screens viewed by TV cameras.

Total current and beam centering information comes from split plate secondary emission monitors (SPSEM). These devices consist of five thin Al foils, the second and fourth of which are split along the vertical and horizontal beam centers, respectively, and collect secondary electrons emitted by the other foils when the beam passes through the chamber. They are operable over the entire beam current range. The difference currents (left-right and down-up) are minimized to center the beam and the sum of all four currents is proportional to the beam intensity.

3. THE PROTON EXPERIMENTAL AREA

As indicated in Fig. 1, the proton experimental area lies to the west of the cyclotron vault. It is in this area that the primary proton beam will be utilized in nuclear physics and nuclear chemistry experiments. The proposed experiments can be roughly divided into two groups - those requiring high beam currents ($\lesssim$ 10 μA of 500 MeV protons) and those requiring low beam currents ($\lesssim$ 100 nA of 500 MeV protons).

3.1 Beam Line IVa

The high intensity line, designated beam line IVa, enters the north-east corner of the area, passes through two experimental locations, and is then deflected so as to exit from the area in the north-west corner, passing through two possible experimental locations along its path. The beam is dumped in a beam dump external to the building.

The first target location outside the vault on beam line IVa is a large (60" ϕ) scattering chamber (§ 3.8) which will be used in fission and spallation experiments. At the next experimental location is a liquid deuterium target cell (§ 3.6) to be used in the measurement of various neutron and proton scattering parameters. These will use both unpolarized and polarized primary beams and, for the latter, a superconducting solenoid is installed between the two targets in order to provide spin-flip of the incident beam. A neutron collimator follows the LD_2 target and is used to select an appropriate beam to strike a liquid hydrogen target.

Following the LD_2 target the primary beam is bent towards the northwest corner of the experimental area. Near the point of exit, an irradiation cell (§ 3.9) is positioned. Nuclear fragments recoiling out of a target foil are swept away in a continuous gas flow and taken elsewhere for analysis. Mid-way between this target and the preceding bending magnet, allowance has been made for the insertion of a total neutron cross section experiment. It is planned to stop the beam in this facility when such measurements are being made.

Beam line IVa has a 10 cm diameter beam tube to the exit of the irradiation cell. From that point to the point of exit from the experimental area, a 20 cm diameter beam tube is used. Both the scattering chamber and LD_2 target can operate simultaneously. It may even be possible to operate the irradiation cell at the same time.

3.2 Beam Line IVb

By powering another dipole in the cyclotron vault, extracted beam can be sent down beam line IVb, the low intensity line. This line cuts almost diagonally across the proton experimental hall and beam is dumped in an internal 100 nA dump. Two experimental locations are placed on this line.

Beam line IVb has been designed to be run in either a dispersed or an achromatic mode. Operation in the dispersed mode will be primarily used for beam diagnostic work. When running dispersed, a horizontal magnification of 0.75 and a dispersion of 12.5 cm/% can be attained at the first target location on the beam line. This allows determination of the energy spread in the extracted beam. In addition the line can be run achromatically in a double spatial or double angular focus mode. This mode of operation can allow determination of the beam size and divergence at the stripper foil. Thus all phase space characteristics of the extracted beam can, in principle, be determined.

For experimental use, however, beam line IVb will be normally run in an achromatic mode with a double waist at the first target position (§ 3.3). Since experiments proposed for this location are of the elastic and quasi-elastic scattering varieties, good angular resolution is required and, in the double waist mode, beam divergence on target is $\lesssim \pm 2$ mr. Both solid and liquid (^{3}He) targets will be used.

The second target location will be that of the proton high resolution spectrometer (§ 3.3).

Up to a point approximately 4 m past the first target location on this line all quadrupoles and beam tubes are 10 cm diameter. Beyond that point, because of the multiple scattering in the target, 20 cm diameter beam tube and quadrupoles are required. In general, operation of either target on this line precludes operation of the other.

3.3 First Target on Beam Line IVb

At the PT1 position on beam line IVb (Fig. 1) is located a general purpose scattering stand suitable for a variety of proton scattering experiments. The scattering stand consists of a circular table 1.28 m in diameter. On the table is mounted a rectangular vacuum box which can accommodate a variety of target changing mechanisms. Thin windows allow charged particles to emerge from the box into air at angles in the range $\theta = 37°-102°$ and $\theta = 146°-170°$. A special extension can be attached downstream of the box to allow charged particles to emerge at small angles to the beam ($\theta = 3°-13°$). The beam enters and exits in a 4" diameter vacuum pipe which is coupled to the box on either end.

Around the central table is a circular track on which roll four movable booms to carry the detection apparatus. Each boom can be remotely positioned at one degree intervals anywhere in the horizontal plane. The angles are digitally encoded and presented to the acquisition computer via a CAMAC interface module. The booms have been used to carry detector telescopes designed for observing proton elastic scattering, various quasi-elastic reactions, and (p,π) reactions. Detectors can conveniently be mounted on the booms at distances from 0.6 m to 3.0 m from the target.

3.4 Proton Spectrometer

The high resolution spectrometer (Stinson and Reeve, 1972; Stinson and Kitching, 1972) is designed for particles with $B\rho$ = 36.36 kG-m; *viz.* 500 MeV protons, 295 MeV deuterons, 205 MeV tritons, etc. The final version of the spectrometer will be in a vertical quadrupole-dipole-dipole system similar to that of LAMPF. A major factor in the choice of a vertical system was the conservation of floor space. The spectrometer bottom frame and the $\sim$ 10 m radius track on which it rotates are now in place. A schematic elevation is shown in Fig. 3.4. The quadrupole preceding the bending magnets provides an intermediate focus in the non-bend (y) plane between the two dipoles. By providing this intermediate image, the quadrupole also makes possible a larger non-bend plane angular acceptance and the use of smaller magnet gaps. Dipole edges are wedged to provide the additional requirements at the detector of a point-to-point imaging ($x/\theta_o = 0$) in the bend plane and parallel-to-point imaging ($y/y_o = 0$) in the non-bend plane. Table 3.4 compares the spectrometer specifications with those of LAMPF.

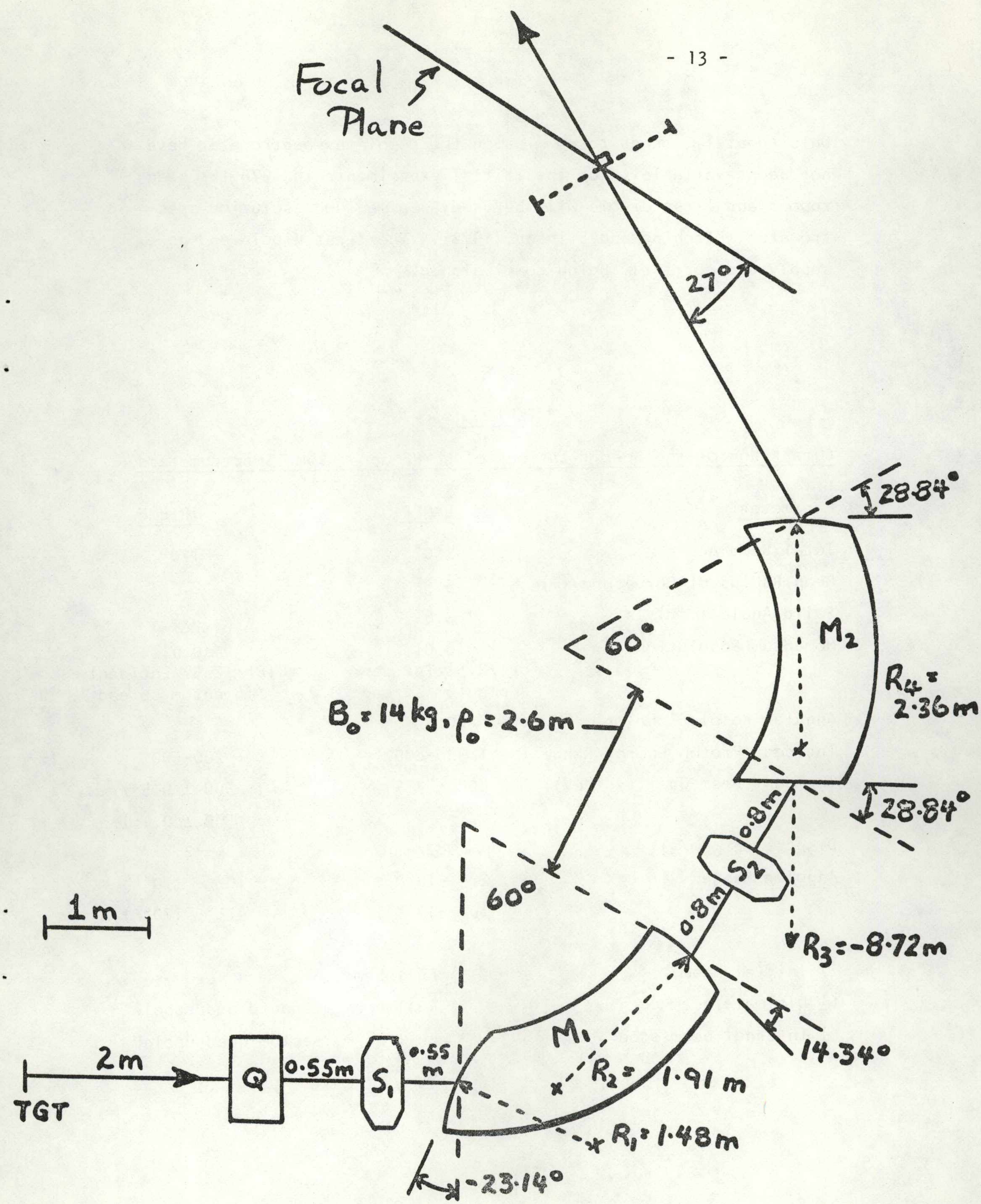

Focal Plane
27°
28.84°
60°
M2
R4 = 2.36m
B0 = 14 kg, ρ0 = 2.6m
28.84°
0.8m
S2
60°
0.8m
1m
R3 = -8.72m
M1
14.34°
2m
Q
0.55m
S1
0.55 m
R2 = 1.91 m
TGT
R1 = 1.48m
-23.14°

Fig. 3.4

Unfortunately, funds to commission the complete spectrometer have not been available. For the initial experiments in 1976 the quadrupole and first dipole will be used as a medium resolution spectrometer (Kitching and Stinson, 1972). The first dipole and power supply are currently being commissioned.

Table 3.4

Comparison of the Specifications of LAMPF and TRIUMF Spectrometers

Parameter	LAMPF	TRIUMF
Total Bend Angle	150°	120°
Mean Radius of Curvature (m)	3.5	2.5
Solid Angle (msr)	3.6	3.5
Momentum Resolution	≦±0.01% for ±2.5% incident momentum spread	≦±0.01% for ±2.5% incident momentum spread
Angular Resolution (mr)	0.8	≦ 2
Incident Proton Energy Range (MeV)	300-800	200-500
Incident Beam Quality (MeV)	800 ± 3.5	500 ± 0.5[1] 500 ± 0.1[2]
Dispersion (cm/%)	18.2	12.8
Angular Range	2.5°-10°[3] 10 -170°[4]	10° - 170°[5] 4.5°- 170°[6]

1) Initial beam

2) Ultimate beam

3) Internal beam stop

4) Full beam

5) Full beam standard quadrupole

6) Full beam "septum-quadrupole"

3.5 Polarized Proton Beams

H^- beams with approximately 100 nA intensity and polarization exceeding 75% with the same emittance and duty cycle as the unpolarized beam will be injected in the fall of 1975.

The polarized beam is being commissioned as soon as possible since it is compatible with the minimum shielding which will be available in the early stages of operation. The TRIUMF polarized ion source which has been built and tested at the University of Alberta is of the Lamb-shift type, using the fast zero-crossing technique (sona method) for the sake of simplicity. A high powered duoplasmatron furnishes the primary beam. Spin reversal is accomplished by reversing the fields inside the source itself in order to eliminate beam focusing effects. The entire source is enclosed in a Faraday cage held at 300,000 volts, to yield the injection energy required for TRIUMF.

Some degree of spin precession will be necessary in order to correct for that precession caused by the fringing fields of the cyclotron. This will be accomplished by a Wien filter operating on the 300 keV beam. Also the beam will be tailored to give the desired pulse lengths by a chopper-buncher system, again operating on the 300 keV beam.

Polarized protons may also be produced by scattering the unpolarized primary beam from a liquid hydrogen target at 15°; this produces a beam polarization of 51% at 500 MeV (Robertson, 1970).

3.6 Liquid H_2/D_2 Target

This target, which is shown in Fig. 3.6 (Hodges, 1973), is a *production* target located in beam line IVa (cf. Fig. 1) for neutrons from the D(p,n)2p reaction at 0°, for polarized protons from $p(p,\vec{p})$ near 15°, and polarized neutrons from $D(p,\vec{n})2p$ near 27° or $D(\vec{p},\vec{n})2p$ near 10%.

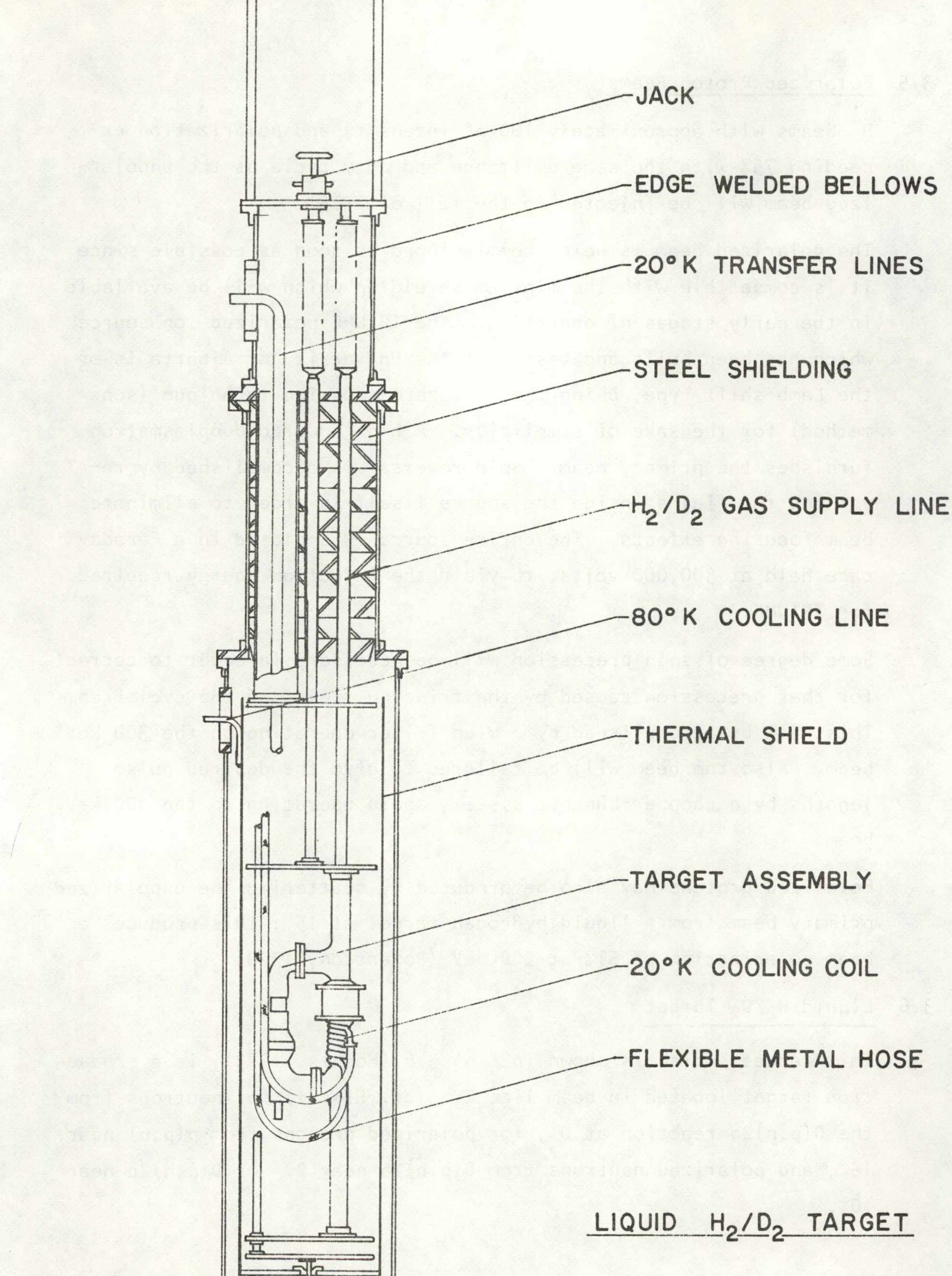


Fig. 3.6 Mechanical Layout of Complete Target Structure

A set of three target thicknesses and a no-target position will be remotely selectable by the experimenter. The targets are fabricated with an all-welded construction from thin (0.001" at beam entry and exit) stainless steel. To prevent boiling or large density changes in the liquid along the beam path, the liquid is cooled $\sim 3°$ below its boiling point and circulated round the target-cooler loop by a small fan. The beam spot on target is 0.4 cm x 1.0 cm; maximum dissipation is 100 watts. The large cryogenic capacity (from the standby Philips B20 cryogenerator for cyclotron vacuum system) allows fast cooling and condensing at start-up. Cooldown is aided by circulation fan running in the gaseous H_2/D_2. The estimated startup time is 6 hours.

The total H_2/D_2 inventory is 4.0 liquid litres, of which $\sim$ 50% is liquid in the target during operation. The system is always above atmospheric pressure to insure against air in-leaks.

3.7 Neutron Beams

A neutron beam from the reaction $D+p \rightarrow 2p+n$, essentially monoenergetic and variable in energy (Measday, 1966), will be produced by bombarding the liquid deuterium target.

The reaction at 0° is characterized by a high energy peak which has a theoretical width of 1.2 MeV at 150 MeV. Approximately 85% of the neutrons are within 10 MeV of the maximum energy. The yields expected for an incident beam of 10 μA are shown in Table 3.7.1.

Table 3.7.1

Unpolarized Neutron Beams

Reaction: D(p,n) 2p @ 0°

Target: LD_2 (5 MeV energy loss)

Proton beam intensity: 10 μA

Neutron beam characteristics

Ep	200	500	MeV
$\overline{E}n$	197	497	MeV
ΔEn(FWHH)	∼ 6	6	MeV
Target length	5	10	cm
Yield into ±0.3°	0.6	1.0	10^8 n/sec
Flux at 8 meters	0.7	1.2	10^6 n/sec-cm^2

It is seen that yields of the order of 10^8 neutrons into a 1° cone are expected.

Polarized neutrons are produced in the same D(p,n)2p reaction at an angle of 27° with polarization of 34%; however, the energy peak is significantly broader at this angle. An estimate by Measday suggests the peak may be as much as 40 MeV wide at 500 MeV.

Polarized neutron beams can also be produced using the polarized proton beam and the liquid deuterium target in the reaction $D(\vec{p},\vec{n})2p$. The polarization transfer is expected (Robertson, 1970) to be 25% at 0°, giving a neutron yield of 2.5 x 10^6 n/sec into a 1° cone with polarization 20%. At a production angle of 8°, using the rotation transfer parameter, a polarized beam of 1.8 x 10^6 n/sec can be produced with polarization of 75%. Although the intensity is two orders of magnitude lower than polarized neutron beams produced from unpolarized proton beams, the energy width of the peak is an order of magnitude better. The polarized beams available from TRIUMF are summarized in Table 3.7.2.

Table 3.7.2

Polarized Beams Available from a Polarized Ion Source

Beam	Polarization	Source	E MeV	ΔE FWHH MeV	Yield p/sec
Protons	80-90%	Polarized Ion Source	500	±0.6	6 × 10'' (emittance 1.5π mm mrad)
		Reaction*			
Neutrons	20%	D(p,n) @ 0°	495	± 3	2.5×10^6 into ±0.5°
	75%	D(p,n) @ 8°	491	± 6	1.8×10^6 into ±0.5°

* Yield calculated for 1.7 gm/cm^2 LD_2 target

3.8 Scattering Chamber

A thin-target scattering chamber at TRIUMF is installed in beam line IVa as shown in Fig. 1. The chamber has 0.1° accuracy.

The 60'' inside diameter should allow most fragment emission studies to be done inside the chamber where remote positioning of the solid-state detectors allows all angles to be studied with one set-up. The large diameter allows for rudimentary time-of-flight to be done inside the chamber as an aid in identifying the fragments. For accurate time-of-flight studies using extension arms, 6'' bore access ports are available at 16 angles between the beam entrance and exit ports. The scattering plane is 12'' from the bottom of the ring and 8'' from the top.

An unusually large number of rotating elements — four besides the target — should allow one to do coincidence studies with the option of remotely adding or removing time-of-flight, which can degrade other system parameters for certain measurements. Ample targeting should be provided by a target ladder with 16'' of 4'' wide target space available.

The four detector arms may be changed to suit particular experiments. They mount on four stepped accurately concentric rings which have tapped holes for securing the arms. Remote control of the six required motions is by stepping motor.

3.9 A Gas Jet - Mass Identification Facility

A gas jet recoil transport system is being coupled with a time-of-flight mass identification facility to perform spectroscopic studies of interesting short-lived nuclides. At present the irradiation cell of the gas jet is located on beam line IVa (Fig. 1) to intercept the high-energy, high-intensity proton beam. Radioactive reaction products recoiling out of a pre-selected target are carried approximately 100 feet to a collection site located in an area of low background. This transport is achieved rapidly ($\lesssim$ 2 sec) and efficiently ($\sim$ 70%) by heavy massive species in the carrier gas.

At the collection site various detection systems can be positioned for complete spectroscopic studies (α, β, γ, n) of radioactive reaction products. Alternatively, a time-of-flight mass identification facility is being assembled for positioning at this site also. This facility will allow precise determination of the mass of radioactive products transported to the collection site.

The principle of operation is based upon measuring the time of flight of the heavy fragment of a radioactive decay process occurring at the collector, over a known distance under a pre-determined acceleration field of about 20 kV. This time, which is related to the fragments mass, is generated with a start signal provided by the associated decay process, e.g. α, β, X ray, γ ray, registered in an appropriate detector. The stop signal is provided by the interaction of the heavy fragment in a chevron detector at the end of the flight path. Isotopic identification can be achieved by using an X-ray detector for start signals.

Crucial to the precise mass determination and optimal operation of the chevron detector is the achievement of pressures in the range of 10^{-6} torr in the time-of-flight system, given that the carrier of the jet system is flowing ($\sim$ 40 cc/sec). This facility is presently being commissioned.

3.10 Fertile to Fissile Conversion

Simon Fraser University, under contract with Atomic Energy of Canada Limited, is engaged in a program to study the properties of large targets of U, Th and Pb (with and without a surrounding light water moderator) under bombardment with protons of energies between 350 and 500 MeV.

The experimental data are of interest in connection with a conceivable off-line nuclear-breeding scheme.

The target support structure, moderator tank, and target have been designed and are being constructed. Installation of experimental facilities at TRIUMF is proceeding. No plans exist for using the facility other than the purposes of the AECL contract.

4. THE MESON AREA

4.1 General

The area which is seen to the east of the cyclotron in Fig. 1 is designated the Meson Area. Fig. 1 shows the present configuration: beam line I is a high intensity proton beam running in a tunnel (§ 4.2) along the south wall to a single meson production target called T2 (§ 4.3). Channels (§ 4.5, 4.6, 4.7) from the target deliver pion and muon beams to the experimental areas. Sufficient shielding on beam line I is now thought to be in place to allow operation to the 300 nA level and it is hoped the shielding can be supplemented to increase the current to 10 μA by the spring of 1976. These currents up to 10 μA are being stopped temporarily in the shield of meson source T2 (Fig. 4.4). The final plan for

100 μA operation is to dump it in a "thermal neutron facility" complete with irradiation facilities, built in the east end of the building. (There is a need for such facilities since western Canada has no nuclear reactors.) The target shield at T2 was designed for 20 g/cm^2 targets at 100 μA, and is adequate for completely stopping beams only up to a maximum of 10 μA. Consequently before 100 μA operation is achieved, the thermal neutron facility and the extension of beam line I past T2 must be commissioned.

Because of a shortage of funds for the experimental facilities, target T1, planned for the long section of beam line I upstream of T2 (Fig. 1), has not been installed and work on the high resolution π channel (§ 4.6) has been temporarily stopped.

4.2 Beam Line I Tunnel

Beam line I runs 12 ft north of the building wall, 4½ ft above the floor. The tunnel is ∿ 16 ft wide and 8 ft high. The south wall of the tunnel is formed by the building wall, and the north by movable blocks which will total 18 ft in thickness when full power is reached (Thorson, 1968). The overhead beams rest on a corbel which is 8 ft above the floor in the south wall. The floor is an integral part of the building wall and is 5 ft thick under the tunnel. For threshold π production experiments using the initial low proton currents, a thin target position and a temporary cave have been installed upstream of T2 (Fig. 1).

4.3 The Meson Production Targets

Target T1 in beam line I will be limited in thickness to 4 g/cm^2 and will provide mesons for the high resolution channel which will be in the southwest corner of the meson area (Fig. 1). Target T2, which is now installed, will be limited in thickness to the equivalent of 20 g/cm^2 of carbon and will provide mesons for the stopped π/μ channel seen to the north and to the biomedical channel to the south.

The two targets have the same basic design shown in Fig. 4.3 (Hodges, 1970). There is a ladder of stainless steel target cassettes, but water cooling is directed only to the cassette currently in the beam line. Vertical motion by a remotely operated jack can bring a selection of thick, thin, beryllium or copper targets into the beam. Molybdenum windows separate the assembly from the beamline vacuum. The windows are cooled by a flow of helium, feeding a helium atmosphere which provides a cushion in case of ruptures in the coolant sheath.

Handling is a problem. For instance, the radiation field at 1 meter from 1 cm Cu target one day after shutdown from 100 μA is 100 Rh^{-1} (Thorson, 1972). The target assembly can be lifted into a vertical flask. All connectors to the target assembly are on top.

4.4 The Target Shield for T2

Fig. 4.4 shows the conceptual design of the shield for target T2, which is now installed. It consists of three steel cans containing steel and lead with a total weight of 85 tons. It is pierced by holes for the proton and meson lines and forms the vacuum vessel itself. It is sufficiently thick that it can be handled, for relocating or for disposal, after the induced activity has built up. An alternative demountable shield concept was discarded because of the cost and complication of devices capable of handling the induced activity which will be of the order of 100 rads per hour at 1 meter.

Vertical holes are provided for the target assembly and meson channel beam blockers. The medical channel blocker is currently carrying the temporary proton beam stop. In the future, when the beam is not stopped in T2, it will carry a collimator which is needed to scrape the proton beam scattered by the target and thereby reduce activity induced further down the beam line. The most active components are the target assembly, collimator, and beam stop; these are handled vertically with an overhead flask.

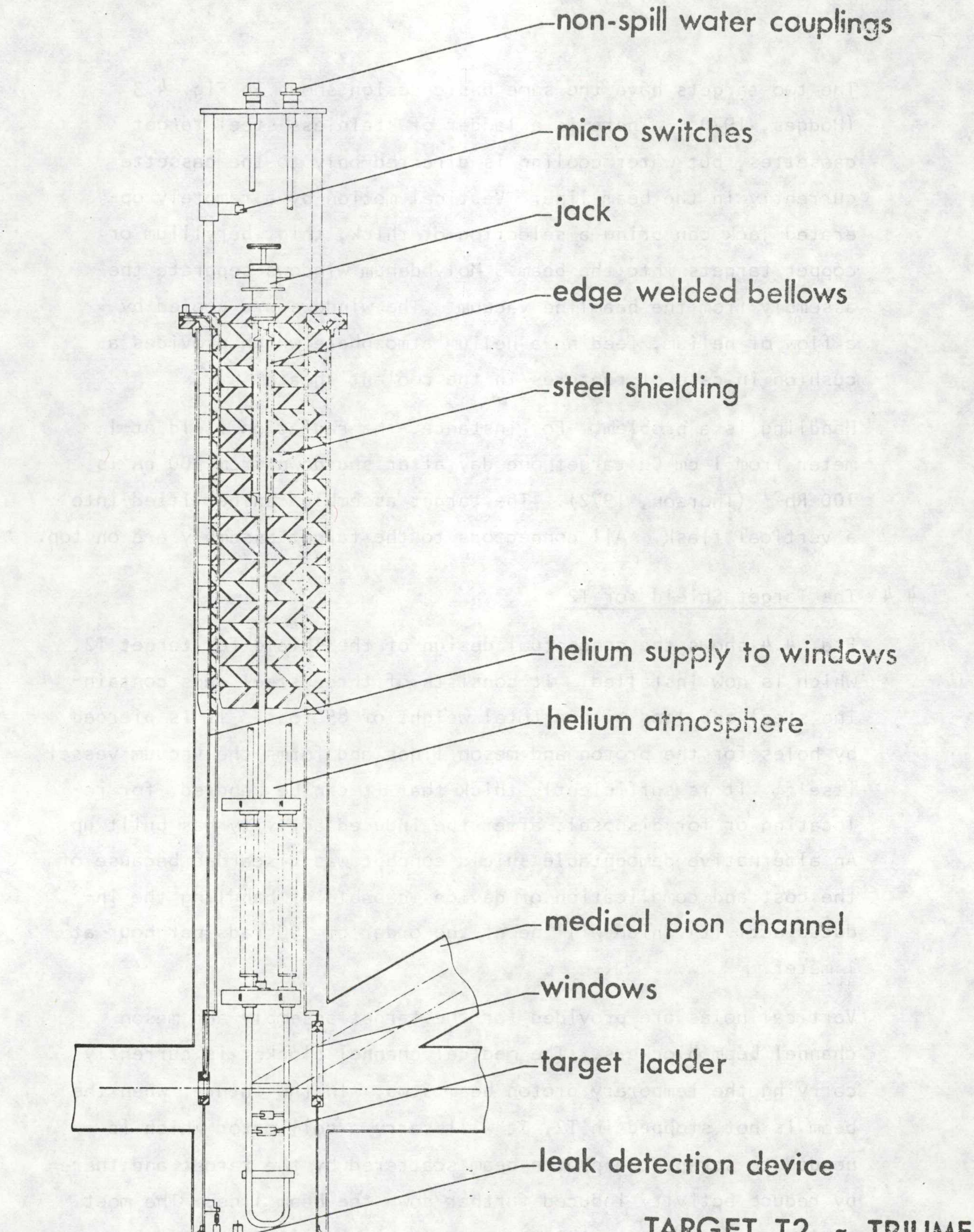

non-spill water couplings
micro switches
jack
edge welded bellows
steel shielding
helium supply to windows
helium atmosphere
medical pion channel
windows
target ladder
leak detection device
one foot
TARGET T2 - TRIUMF

Fig. 4.3

85 TON
PROTON STOP AND MESON SOURCE

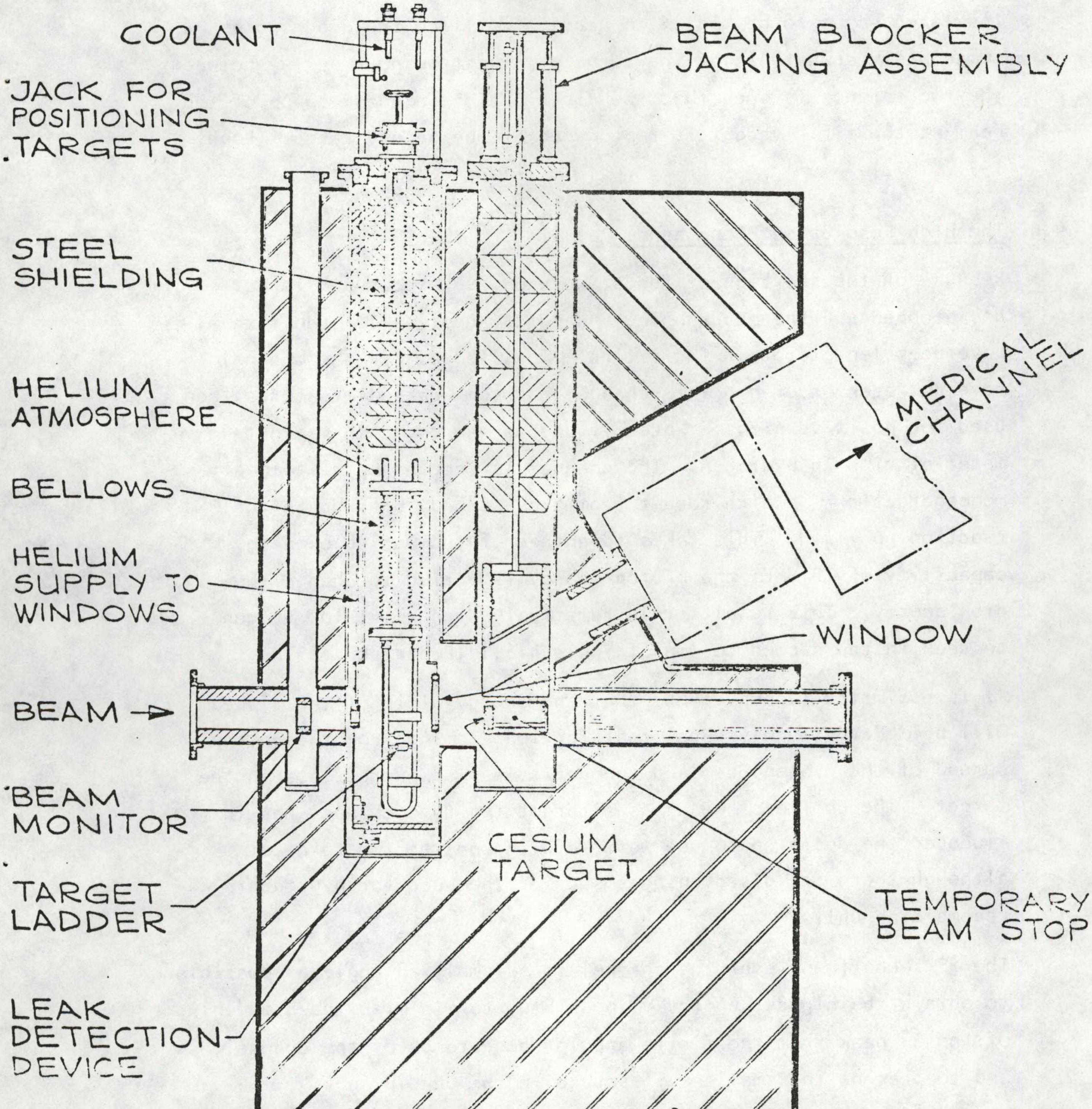


Fig. 4.4

4.5 The Proton Beam Line

The quadrupoles in the proton beam line are 4" bore before the T1 position and 8" afterwards. The combination magnets are mineral insulated so as to be radiation hard, as will be the quadrupoles immediately downstream of the targets. The transport system between the two targets is such that the distribution in phase space of the beam at the first target is reproduced at the second target (Lobb, 1971, 1972).

4.6 The High Resolution Pion Channel at T1

Because of the shortage of funds, work on the septum and target T1 has stopped and the quadrupoles and power supplies for the channel have been lent to other facilities. The dipoles for the channel have not been ordered. This channel has some unusual features when used for positive pions. Water is used as a convenient target material rich in hydrogen. The channel is focused on the almost monoenergetic π^+ which result from the two-body breakup in the reaction $pp \rightarrow \pi^+ d$. This takes advantage of the variable energy capability of TRIUMF; the proton energy is varied to change the pion energy. This results in a relatively high π^+ yield, as can be seen in the second column of Table 4.6.1 (Robertson, 1970).

It is estimated (Jones, 1969) that the energy width of the π^+ beam will be 3 MeV, roughly equal contributions coming from the energy spread of the proton beam and the variations of energy loss in the target. The choice of water as a target for this channel has influenced the decision to use water cooling on the two targets, although there are disadvantages such as the need for hydrogen-recombining units.

The π^+ takeoff angle of the channel is as small an angle as possible to obtain the highest energy π^+ possible, to minimize the broadening of the π^+ peak from the finite angular acceptance of the channel, and to present the smallest π^+ source in the bend plane.

Table 4.6.1

Positive Pion Yields at T1

	π^+		π^-	
T_π	H_2O	Be	D_2O	Be
MeV	$10^7\ \pi^+$/MeV.sec		$10^6\ \pi^-$/MeV.sec	
250	5*	1.2	0.5	0.7
200	33	2.4	1.5	2.4
150	19	2.4	2.6	3.6
100	8	1.5	2.1	3.0
50	3	0.6	1.7	3.0

Yields into 5 millisteradians @ 0°
Proton Beam Current 100 μA (* 10 μA)
Targets D_2O, H_2O: 3.7 gm/cm^2
Be: 4.6 gm/cm^2

The final design parameters (Reeve, 1972) are given in Table 4.6.2. The proton beam is a narrow vertical ribbon which passes undeflected on the zero field side of a septum magnet (cf. Fig. 4.6). The pions pass the other side of the septum and get bent 15°. A quadrupole precedes the septum: it does not affect the proton beam since the beam is on the axis, but it doubles the vertical plane acceptance and increases the pion takeoff angle from 2.5° to an effective angle of 5.6°, which eases the septum design.

The proton beam at the target will be a vertical ribbon of dimension 1 mm by 10 mm (Lobb, 1972). The setting of the quadrupole between the target and the septum presents a problem in that it accepts both pions for the channel and protons for main beam line. The quadrupole will be set (Lobb, 1972) so that pions of the energy of interest see a specified k-value (square root of the ratio of field gradient to the particle rigidity). The k-value seen by the protons depends on the relation between the π^+ and d energies in the pp $\rightarrow$ πd

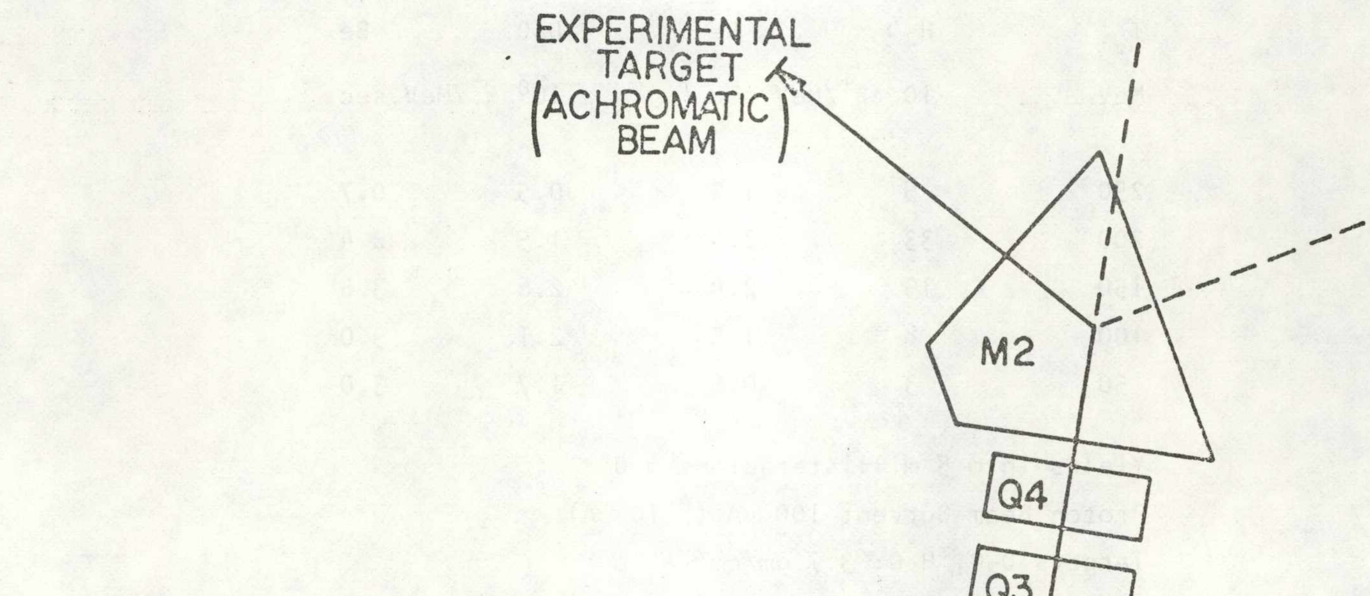

EXPERIMENTAL
TARGET
(ACHROMATIC
BEAM)
M2
Q4
Q3
MIDPLANE
M1
Q2
Q1
SEPTUM
PRODUCTION
TARGET
Q
PROTON BEAM

Fig. 4.6

reaction. A consistent set of settings of the quadrupoles between T1 and T2 has been calculated (Lobb, 1972) to retain the proton focus at T2 for all π energies.

Table 4.6.2

Summary of Channel Performance

Parameter	Position in Channel	
	midpoint	end
Mx	- 0.22	0.46
My	-	-
D (cm % P_o)	1.42	0.02
R_{26} (mr/% P_o)	5.6	1.7
1st order resolution (± % P_o)	0.02	-
2nd " " "	< 0.36*	-
± x (cm)	0.2	0.05
± y (cm) max values	6.5	4
± x' (mr) max values	70	45
± y' (mr)	17	17
Ω (msr)	-	10.5
ε_x (πmmmr)	-	440
ε_y (πmmmr)	-	800
ΔP (± % P_o)	-	5
Length (m)	6.0	11.1

* System not optimized for 2nd order.

4.7 The Stopped π/μ Channel

The stopped π/μ channel shown in Fig. 4.7 is primarily designed to provide stopping π and μ beams of either polarity but, because of the temporary suspension of work on the high resolution channel (§ 4.6), it will also be used for π scattering experiments. The quadrupoles are 12" in diameter, B1 and B2 have 10" gaps, and B3 has a 12½" gap. The maximum momentum is 160 MeV/c.

The channel is seen to have the large take-off angle of 135°. This should reduce the flux fast neutrons from the target by about three orders of magnitude compared to the forward direction. Also the use of a 135° take-off angle greatly reduces the electron contamination according to preliminary results. The LASL data gave some indication that the pion production may be isotropic below 100 MeV/c. This has been confirmed by a recent experiment at SREL and TRIUMF. Finally, the use of a large take-off angle will present a relatively smaller projected π source to the channel.

The large take-off angle would not be suitable for high energy muons but there have been no requests for energetic muons at TRIUMF. Details of the construction have been given by Beer (1974).

Modes of Operation

1) When operating in the mode for stopping μ's with low π, n and γ contamination, the channel consists of three sections:
   - a π injection system (Q1 Q2 B1 Q3 B2 Q4 Q5) which is designed to be achromatic to maximize the flux;
   - a straight section (Q6 Q7 Q8) which, together with Q4 and Q5, allows in-flight decay of the π's; and
   - a momentum selection magnet (B3) to select the lower momentum μ's from π's which decay into the backward cone.

   The vacuum in the channel extends downstream to a window after Q8. A helium bag may be used in B3.

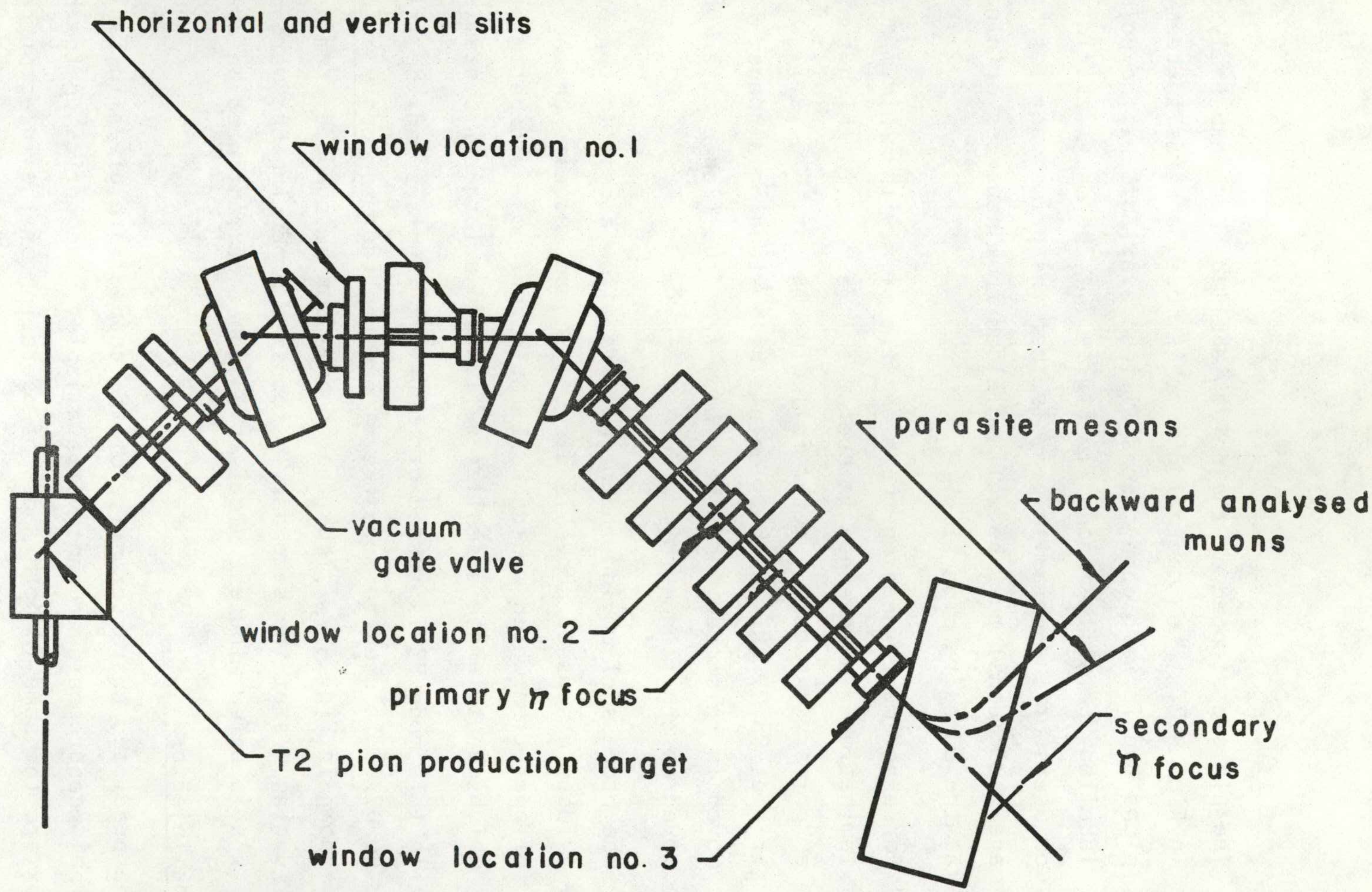


Fig. 4.7 **STOPPED π-μ CHANNEL**

The μ's are stopped at the point labelled "backward analysed μ's" in Fig. 4.7. When operating in this mode, a parasite beam of pions and forward-decay muons will be available at the point labelled "parasite mesons" in Fig. 4.7. The only restriction on users of the parasite beam is that the prime user (of backward analysed muons) must be well shielded from neutrons originating at the parasite pion stop.

2) For experiments needing the highest π flux with minimum μ contamination, the channel is operated in a mode in which there is a "primary π focus" 1 meter following Q5 (cf. Fig. 4.7). The triplet Q6 Q7 Q8, which is on a single stand on airpads, is removed in this mode, and the window from the flange after Q8 is moved to the flange following Q5.

The process of moving the magnets to allow access to the primary π focus discussed above is disruptive and suggests another mode of operation which would be suitable for those π experiments which can tolerate a smaller π flux and a larger μ contamination.

3) In this mode B3 is turned off but left in place and the triplet Q6 Q7 Q8 is used to move the π focus to the "secondary π focus" shown in Fig. 4.7. Thus the channel can be changed from producing π's at the secondary π focus to producing backward-decay μ's in a few minutes, since only magnet current need be changed.

The Injector

The predicted characteristics of the channel are given in Table 4.7. Final measurements are not yet available. The optics up to the slit box are the same in both modes of operation of the injector region. Beyond the slits the design has been optimised to suit either the backward muon users or the pion users. The momentum spread of the beam in the second half of the channel and 2nd order effects can be controlled using the slits.

Table 4.7

Optics of M9 Injector Region

Parameter	Midplane Slit Position	End Muon Mode	End Pion Mode
Foci	x and y	none	x and y
Magnifications	$M_x = .69$	-	$M_x = 1.46$
	$M_y = -3.7$	-	$M_y = .97$
Dispersion (cm/%P_o)	0.8	0.00	0
R_{26} (mr/%P_o)	8.3	1.2	2.1
Waists	y	x	y
Solid Angle (mstr)	-	25	25
Momentum Acc. (± %P_o)	-	14	14
Length (m)	3.74	7.9	8.4
Typical 1st order x (±cm)†	-	4	5
Typical 1st order y (±cm)	13	13	0.5
Typical 2nd order x (±cm)† (ΔP = ±7%, $\Delta x'$ = ±21 mr)	-	6	7
Typical 2nd order y (±cm)	-	13	0.5
1st order resolution with† ±3.6 cm long source (%P_o)	± 3		

† These values for a 10 cm long production target.

To maximize the flux of backward muons, one must inject as large an emittance pion beam as possible into the straight section Q6 Q7 Q8. The results of the optimised calculations are shown in Table 4.7.

4.8 The Biomedical Pion Channel

The medical channel delivers a π^- beam from the T2 target into the biomedical annex. It is funded by the B.C. Cancer Foundation and the Health Resources Fund to investigate the effectiveness of pions for radiotherapy. A period of particle counting experiments, dosimetry, cellular and animal radiobiology will precede the human radiotherapy. The biomedical facility, like the rest of TRIUMF, is open to any users on the basis of acceptance of a written experimental proposal.

The channel has a vertical takeoff of 30°. It is an achromatic system consisting of two 45° bending magnets, three 12" aperture quadrupoles, two 8" quadrupoles, and two sextupoles for the correction of second order aberrations (Fig. 4.8).

Table 4.8

Biomedical Pion Channel Characteristics

Takeoff angle: 30° in forward direction

Distance from T2 target to first quadrupole: 1 meter

Beam acceptance: 10 msr

Momentum resolution: ± 1%

Momentum acceptance: ± 10%

Maximum pion energy: 110 MeV

Size of uniform radiation field: continuously variable up from 3 x 3 cm

Spatial uniformity of beam: ± 5%

Maximum dose rate: 20 rads/min

Total length of channel: 8 meters

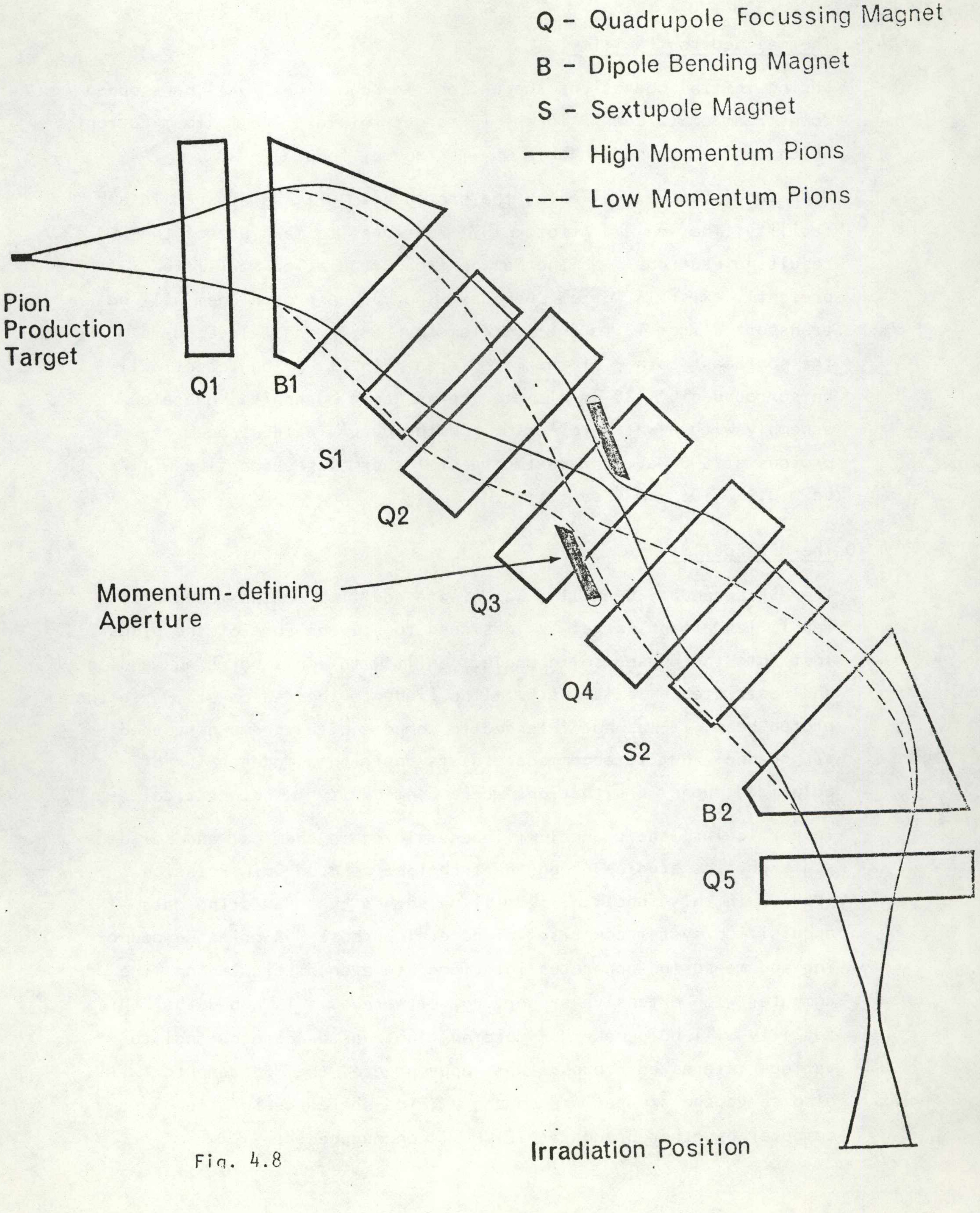

Q – Quadrupole Focussing Magnet
B – Dipole Bending Magnet
S – Sextupole Magnet
High Momentum Pions
Low Momentum Pions
Pion Production Target
Q1
B1
S1
Q2
Momentum-defining Aperture
Q3
Q4
S2
B2
Q5
Irradiation Position

Fig. 4.8

4.9 Thermal Neutron Facility

During initial operations the protons in beam line I will be stopped downstream of target T2 in the T2 target shield. The maximum current which can be stopped in this way is thought to be 10 μA.

When funds become available, the proton beam will be stopped in a facility (Thorson and Arrott, 1971) designed to make use of the resulting neutrons. No thermal neutron irradiation facilities presently exist in Western Canada. The 100 μA proton beam will be transported from T2 to a 15 cm diameter Pb-Bi target located in the southeast corner of the meson area (Fig. 1). The target will be surrounded by 120 cm diameter heavy water, graphite moderated assembly with a water reflector. With 100 μA incident beam of protons at 500 MeV, the maximum useful thermal neutron flux will be $\sim 0.9 \times 10^{13}$ cm^{-2} sec^{-1}.

4.10 The MSR Facility

The MSR secondary beam line was a late addition to the meson area facilities around target T2, designed to salvage some of the pions lost into the unused solid angle. Built with small borrowed magnets and restricted by existing beamline plans to the region at 55° to the proton beam, it was not intended to compete with the main stopped π/μ channel, but to accommodate users desiring a modest flux of polarized muons in situations where beam purity is not critical.

In particular, the channel will be employed in chemical and solid state physics studies using the technique of Muon Spin Rotation (MSR). In this function, it will be served by an existing data acquisition system comprised of general purpose MSR-oriented counting and measuring apparatus interfaced to a sophisticated on-line computer with extensive supporting software. It is hoped that this facility will help make MSR more available as a research tool to various interested groups. When appropriate, the MSR computer will also serve the stopped π/μ channel. Time-shared use of the MSR computer by other groups at TRIUMF is encouraged.

The MSR channel is designed to be used as a muon channel in two modes. In the "conventional mode", positive or negative pions are collected into a crudely momentum-selected beam and allowed to decay into muons, which are then momentum analyzed to form a polarized muon beam. When optimally tuned for muons from forward-decaying pions, the channel should produce on the order of 5×10^5 μ^+/sec and 10^7 π^+/sec into a 10 cm × 10 cm target at 100 μA proton current. For a "backward muon" tuning, the equivalent muon rates are about a factor of 5 lower, but the pion contamination is small. Rates for negative pions and muons are about a factor of 3 lower in general.

In the "Arizona Mode", positive muons from the decay of pions at rest in the surface of the production target are collected directly into a nearly monochromatic beam of very low energy (4.1 MeV). These highly polarized muons can be stopped in a thin foil or a few inches of gas at atmospheric pressure, and are particularly useful for MSR studies in gases and rare solids. Negative muons cannot be obtained in this fashion, due to capture of the stopped π^- by nuclei. Since only those pions which stop just at the surface of the production target contribute to the muon flux, rates in this mode are apt to depend critically upon target geometry, and are difficult to estimate reliably. By selecting an optimal target shape it should be possible to obtain rates at least competitive with those expected in the "conventional mode".

The channel could also be used for pions in many applications where a muon contamination is not harmful; the pion momentum is variable from essentially zero up to about 170 MeV/c, with a normal resolution of approximately ± 2.5%.

5. INSTRUMENTATION POOL

A pool of nucleonic instrumentation is available to users on a rental basis. Basically, the pool is intended as a store of nucleonic instrumentation available for use by scientists at TRIUMF in approved experiments. While "new" (i.e., during the first four years of residence of such instrumentation at TRIUMF), the instrumentation will be rented at a rate of 2% of the capital cost of the instrumentation per month for the first three years, decreasing to 1% per month for the fourth year. After the instrumentation has been "paid off" it would be available free of charge to approved users. TRIUMF instrumentation in use in an experimental program is to be returned to the pool upon completion of that program. Until the inventory of instrumentation in the pool is built up, requests for such "rented" instrumentation must be submitted by the users to the pool at the budget time. All instrumentation purchased by the pool will be subject to detailed acceptance tests.

The TRIUMF electronics shop will endeavor to provide free maintenance of all nucleonic instrumentation owned by TRIUMF, in use on experiments, providing such instrumentation is described in Table 5, "TRIUMF Pool Standard Nucleonic Instrumentation". Non-standard instrumentation can also be submitted to the shop for repair. In this case, users will be assessed costs at the current rate.

Table 5

TRIUMF Pool Standard Instrumentation (1 July 1975)

1. RACKS

Premier Metal Housings (Montreal)	Type 000003070

2. POWER SUPPLIES, BINS and CRATES

NIM bins	
Bin and power supply: B.L. Packer	Bin NB10 200 W power supply 1001
CAMAC crate	
Crate: GEC Elliott	VC0011/CP1
Power supply: B.L. Packer	1031 BC (300 W)
Photomultiplier high voltage:	Power Designs 1570
High voltage distribution:	TRIUMF THV100

3. PHOTOMULTIPLIERS and HOUSINGS

2 in. 12-stage, bi-alkali photomultipliers:	RCA 8575R or RCA 8850R
Housings:	N.P.W. England Ltd.

4. NIM MODULES

Fast NIM

Discriminators, quad updating:	LRS 621L	
bridged input version:	LRS 621L/4	
quad zero-cross:	EGG T140 NL	
constant faction:	ORTEC 453, 463	
AND (coincidence) gates:		
Triple 4-fold logic:	LRS 465	
(Dual 4-fold majority logic LRS 364 and 365 accepted, but not recommended)		
Dual 4-fold overlap:	TRIUMF B024	
Quad 2-fold overlap:	TRIUMF B042	
Quad 2-fold AND/OR (updating):	LRS 622	
(LRS 322A accepted but not recommended)		
OR gates and logic fan-out:		
Logic 8-fold fan-out	TRIUMF 14X2951	EGGF304 and LRS 429
OR gate: Dual 4-fold	TRIUMF 14X3001	under evaluation
Linear Fan-In/Fan-out	LRS 428	
(LRS 127 and 128 accepted but not recommended)		
Linear gate:	Borer 330	
Linear gate and stretcher (integrator):	EGG LG 105/N	

4. NIM MODULES (continued)

Level converter (NIM Fast← →Slow):	LRS 688 AL and EGG L1380/NL
Gate pulse and delay generator:	EGG GG202
Scaler (visual display) 100 MHz, 6 digit Dual unit: (ORTEC 772 accepted but not recommended)	 Joerger VS
Variable delay units (cable-switched) Passive '64 nsec'	 TRIUMF BO 07
Variable attenuators (50 Ω):	LRS A101 L
Fast pulse generator (Berkeley):	BNC 8010
High resolution ADC: 10-bit amplitude encoder (requires scaler for read-out):	 EGG EA 101/N
High resolution TDC: 10-bit time encoder (requires scaler for read-out):	 EGG ET 102/N
Spark chamber TDC (routing unit), clock generator (up to 200 MHz) and scaler required. Dual unit:	 TRIUMF BO 0100

Slow NIM

gated biased amplifier	ORTEC 444
research amplifier	450
timing filter amplifier	454
delay line amplifier	460
delay amplifier	427A
linear gate	426
linear gate and stretcher	442
fast coincidence	414A
universal coincidence	418A
time-to-pulse height converter	467
gate and delay generator	416A
precision pulse generator	419
5 kV power supply	459
constant fraction timing SCA	455
digital current integrator	439

5. CAMAC MODULES

coincidence buffer (pattern unit) dual 12-fold:	EGG C212
multi-ADC, octal 8-bit units:	LRS 2248 or NE 9040
multi-TDC, quad 9-bit:	LRS 2226A
octal 10-bit:	LRS 2228
scalers, hex 24-bit, 100 MHz:	Kinetics 3615
crate A controller: (GEC Elliott accepted but not recommended)	Kinetics 3900
TTY output:	NE 7061-1
16-bit (relay-type) output register:	GEC OD 1606
24-bit (TTL) output register	GEC PR 612
24-bit in/out (TTL) register:	NE 9017
24-bit input gate SEC	PG 604
dual 24-bit input gate:	Jorway 61-1
16-fold fast NIM out, SEN:	OR 0207
256-bit input gate (for MWPC) GEC:	IG 256

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