L. Root

TRI-UNIVERSITY MESON FACILITY

TRIUMF

ANNUAL REPORT
1968

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

DECEMBER 1968

T R I - U N I V E R S I T Y   M E S O N   F A C I L I T Y

ANNUAL REPORT

1968

J.J. Burgerjon

Editor

Postal Address:

TRIUMF
University of British Columbia
Vancouver 8, B.C.
Canada

December 1968

F O R E W O R D

1968 has seen the commencement of a new Canadian project — TRIUMF, in which the scientists of four universities in western Canada have joined together to produce an exciting new research facility, too large in scope and too demanding of scientific effort to have been mounted by any one of them.

As a joint interuniversity and interdisciplinary venture its organization and progress will be watched across Canada. TRIUMF's success could establish a pattern for other large scale co-operative ventures in Canada and not only in science.

I am happy to record that in its first eight months TRIUMF has proceeded smoothly toward its goals. This annual report documents the build-up of the TRIUMF staff and the status of the design work and planning associated with the project. It sums up a promising start to a new direction for nuclear science in western Canada.

Chairman of the Board of Management

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SUMMARY

This report reflects a sharp rise in activities following the announcement on April 16 by the Honourable Jean-Luc Pepin, Minister of Energy, Mines and Resources that funds had been approved. Shortly afterwards, the terms of reference of the TRIUMF Board of Management were ratified by the Boards of Governors of the four participating universities, and the Board proceeded to appoint an Operating Committee for the project.

Group leaders responsible for the different areas of research and development were appointed. Progress in the cyclotron and beam transport design has been increasing during the latter part of the year as specialist staff have joined. A Building Committee has been set up and a conceptual building and site layout completed. Specifications for the first stage Office/Laboratory building are ready for call of tenders. A Safety Committee has been appointed and has prepared a proposal concerning the safety requirements of the facility. Engineering firms have been awarded contracts for detailed design of the buildings, cyclotron and ancillary equipment. A project management office has been set up and has completed a first critical path schedule. Five Users Groups have been organized among the interested scientists in the North West. These groups have been examining the experimental use of the facility and the conceptual building layout.

Special mention must be made of the completion of the first TRIUMF physics experiment. With extraordinary help from the Rutherford Laboratory, using their Proton Linear Accelerator precise measurements have been made of the lifetime of the H^- ion under conditions which pertain to the outer orbit radius for TRIUMF. These measurements were completed most expeditiously and in time to make the necessary adjustments to the cyclotron parameters without delay to our project.

On the basis of progress we have already made, I am confident that 1969 will see us a substantial way towards completion of the engineering design of TRIUMF.

J.B. Warren

J.B. Warren
Director

1. ORGANIZATION

The TRIUMF Board of Management was constituted in the spring of 1968 and meets about once a month to transact the business of the project. The Board makes policy decisions concerning the operation of the project as executed through the Director. The present membership of the Board is

University of Alberta:	Dr. J.T. Sample Dr. Max Wyman Dean D. Ross
Simon Fraser University:	The Honourable Mr. Justice A.E. Branca (Chairman) Dean Lionel Funt Mr. Mark Collins
University of Victoria:	The Honourable Mr. Justice J.G. Ruttan Dean R.T.D. Wallace Dr. J.L. Climenhaga
University of British Columbia:	Dean W.M. Armstrong Mr. Alan McGavin Dr. G.M. Volkoff (Secretary)

In April 1968, the TRIUMF Board of Management appointed the Director and the members of the Operating Committee. Prof. J.B. Warren was appointed Director of TRIUMF, Prof. E.W. Vogt was appointed Associate Director, and Mr. J.J. Burgerjon was appointed Chief Engineer. The TRIUMF Operating Committee was constituted to consist of two TRIUMF employees (the Director, who acts as chairman and votes only in case of a tie, and the Chief Engineer, who does not vote) and one member from each of the four TRIUMF universities. The initial university members are:

Prof. G.C. Neilson	University of Alberta
Prof. B.D. Pate	Simon Fraser University
Prof. R.M. Pearce	University of Victoria
Prof. E.W. Vogt	University of British Columbia

The following four persons were appointed as alternates:

Prof. W.K. Dawson	University of Alberta
Prof. R.G. Korteling	Simon Fraser University
Prof. L. Robertson	University of Victoria
Prof. K.L. Erdman	University of British Columbia

Detailed terms of reference of the Board of Management and the Operating Committee are to be found in TRIUMF Newsletter #5 (June 15, 1968). The Operating Committee normally meets on the second Wednesday of each month at one of the TRIUMF universities.

An Organization Diagram is shown in Figure 1.1.

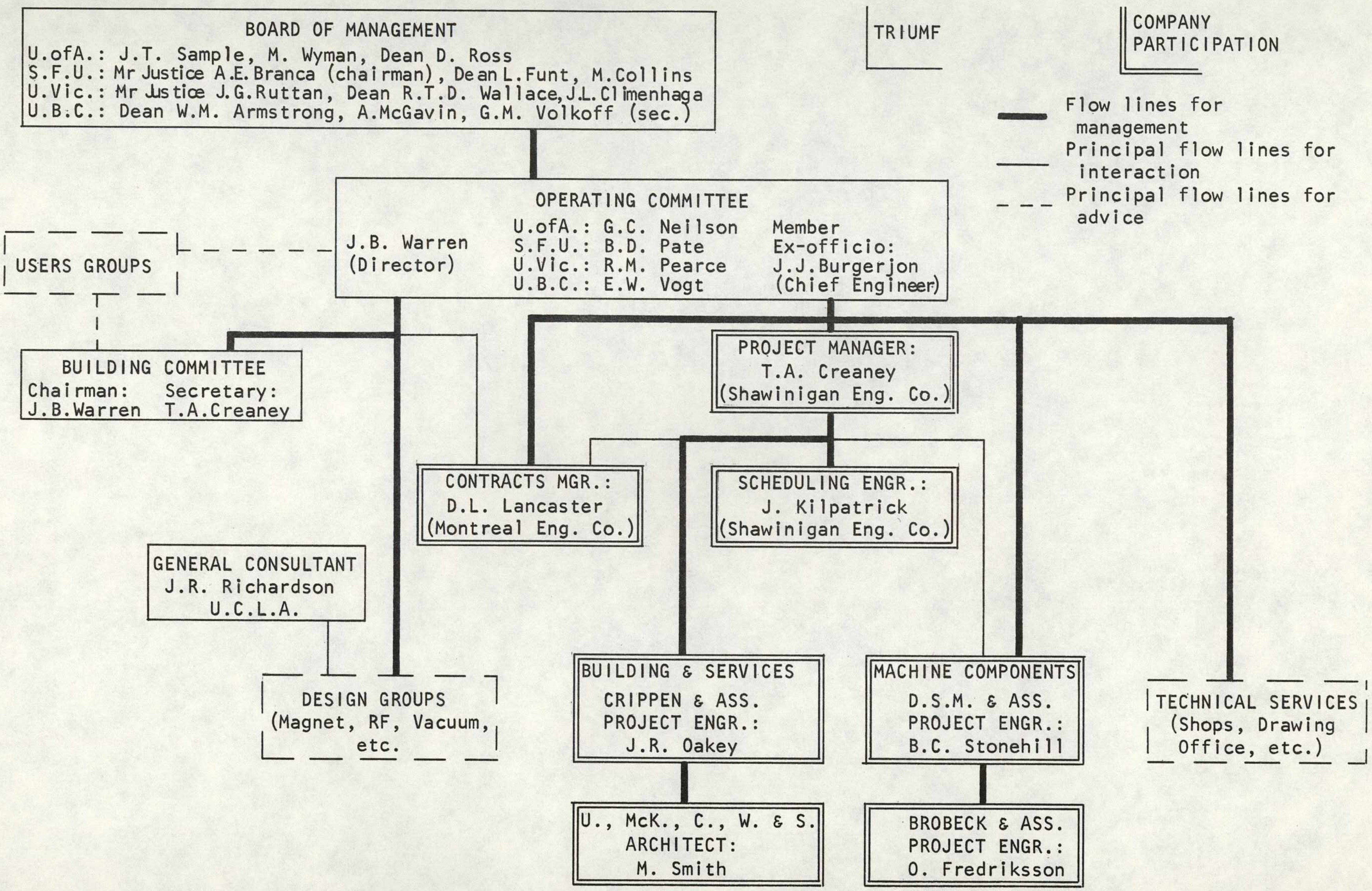

Figure 1.1 TRIUMF PROJECT ORGANIZATION

2. USERS GROUPS

At the general meeting of TRIUMF scientists held in May 1968, it was decided to set up Users Groups in four areas of interest:

1. Proton Users Group
2. Meson Users
3. Slow Neutron Users
4. Radiochemical Users

Subsequently, a fifth group was added:

5. Radiobiological and Radiotherapy Users

The purpose of these groups has been to formulate the requirements for research in these five fields, to indicate the beam properties and targets required, as well as other facilities needed in the various experimental areas. These requirements will be examined as to feasibility and cost, and incorporated into the building design by the building committee.

2.1 P Area Users Group

This group comprises those who wish to use primary protons for their experiments. It comprises:

G. Roy, Chairman	UofA:	Physics	G.R. Mason	UVic:	Physics
W.K. Dawson		Physics	L.P. Robertson		Physics
W.J. MacDonald		Physics	S.A. Ryce		Chemistry
G.C. Neilson		Physics	R.M. Pearce		Physics
W.C. Olsen		Physics	E.G. Auld	UBC:	Physics
J.T. Sample		Physics	G.M. Bailey		Physics
G. Stinson		Physics	M.K. Craddock		Physics
			G.M. Griffiths		Physics
A.S. Arrott	SFU:	Physics	G.H. Mackenzie		Physics
J.M. D'Auria		Chemistry	K.C. Mann		Physics
R.G. Korteling		Chemistry	P.W. Martin		Physics
B.D. Pate		Chemistry	E.W. Vogt		Physics
			D.C. Walker		Chemistry
			B.L. White		Physics

D.O. Wells	University of Manitoba, Physics
R.R. McLeod	Western Washington State College, Physics
H.F. Batho	B.C. Cancer Institute
J. Jovanowich	University of Manitoba, Physics

Since the responsibility for the layout of the P area lies with the University of Alberta TRIUMF group, meetings of this group took place at Edmonton on November 1 and December 13. Discussion centred around

a) the need for high energy resolution for nuclear structure studies, and means for achieving ±200 keV or even ±50 keV were described;

b) the ultimate need for a beam of polarized protons, and also neutrons, and provision of a polarized proton target;

c) the provision of an activation target assembly before the beam passes into the beam dump;

d) the provision of a scattering chamber with very thin targets for studies of reaction products, particularly from heavy nuclei; and

e) the upper limit of beam current required for most of this research was recommended as 10 μA.

The use, design and cost of a magnetic spectrograph, and beam requirements, were also mentioned in a preliminary way.

2.2 Meson Users Group

This group comprises:

G. Jones, Chairman	UBC:	Physics	W.J. MacDonald	UofA:	Physics
E.G. Auld		Physics	G.C. Neilson		Physics
D. Axen		Physics	W.C. Olsen		Physics
D. Beder		Physics	D. Shepherd		Physics
M.K. Craddock		Physics	K.G. Standing		Physics
K.L. Erdman		Physics			
R. Johnson		Physics	R.G. Korteling	SFU:	Chemistry
D.L. Livesey		Physics			
G. Mackenzie		Physics	R. Cobb	UVic:	Physics
K.C. Mann		Physics	J.S. Leung		Physics
E.W. Vogt		Physics	D. Lobb		Physics
D.C. Walker		Chemistry	G.R. Mason		Physics
J.B. Warren		Physics	R.M. Pearce		Physics
			C.E. Picciotto		Physics
			L.P. Robertson		Physics

(cont'd.)

D.O. Wells	University of Manitoba, Physics
J.Jovanovich	University of Manitoba, Physics
E.P. Hincks	Carleton University, Physics
R.R. McLeod	Western Washington State College, Physics
H.F. Batho	B.C. Cancer Institute
E. Blackmore	RHEL
D. Measday	CERN

At its first meeting, held November 22 at UBC, a general discussion took place as to the nature of the experiments possible with stopping and fast pions and muons, to gauge in part the relative interest in these beams. Few experimenters were interested in the provision of fast muons. Criteria as to intensity and energy resolution were discussed as well as ways to achieve the desired performance, with minimum beam contamination.

2.3 Slow Neutron Users Group

This group comprises those interested in the provision of slow neutrons for diffraction and scattering studies in solid state physics and chemistry:

D.W. Hone	Chairman	Royal Roads Military College	
J.K. Cochran		SFU:	Physics
R.R. Haering			Physics
C.H.W. Jones			Chemistry
B.D. Pate			Chemistry
S.A. Ryce		UVic:	Chemistry
A.V. Bree		UBC:	Chemistry
K.B. Harvey			Chemistry
J. Trotter			Chemistry
R.R. McLeod		Western Washington State College	

Meetings have been held at SFU on October 2, November 6 and December 4. SFU have the responsibility for the neutron target moderator and shield design to accommodate the needs of both this group and the radiochemical group. Discussion has been concerned with the nature of the experiments to be undertaken, the neutron flux requirements for these experiments (10^{12} minimum) and the experimental space needed. The arrangement of beam ports to provide the flux with minimum gamma ray background in the detectors has also received attention. It also appears that there is little experimental interest in a neutron time of flight facility, so this may be deleted from the plans for the facility.

2.4 Radiochemistry Users Group

The area of responsibility of this group is to ensure that provision would be made for

a) experiments involving neutron or proton fluxes at the beam dump, excluding the slow neutron beam experiments, and

b) handling, storage, hot and low level laboratories for beam targets, nuclear chemistry and radiation chemistry studies in all experimental areas.

The group comprises:

D.C. Walker, Chairman	UBC	R.G. Korteling	SFU
L.G. Harrison			
C.A. McDowell		A.C. Riddiford	UVic
		S.A. Ryce	
G.R. Freeman	UofA		
H.E. Gunning			

Dr. R. Morrison — Vancouver General Hospital

Meetings have been held on October 16, November 13 and December 11. The experiments proposed fall into four categories:

a) Activation analysis
b) Isotope production
c) Recoil chemistry
d) Radiation damage and radiation chemistry

The irradiation facilities requested for this work comprise both "rabbits", i.e. about one-inch diameter ports with pneumatically driven carriages, and "thimbles", a hole directed into the radiation region from above, as listed below:

a) 6 rabbits (3 temporarily plugged, for later expansion of activation analysis facilities) in the thermal neutron flux of 0.03 eV

b) 3 rabbits (2 temporarily plugged, for later activation analysis service) in fast neutron flux, mostly >20 MeV energy neutrons

c) 1 thimble, 2 inches diameter in thermal neutron flux

d) 1 thimble, 1 foot diameter in thermal neutron flux

e) 1 thimble, 1 foot diameter in fast neutron flux

f) 1 rabbit, 6 inches diameter hole with top as large as possible in proton flux

g) 1 thimble, 6 inches diameter in fairly clean positive and negative pion flux of high intensity

A desire for pulsed beam operation in range 1-100 microseconds at repetition rates up to 1000 per sec was also expressed for radiation chemistry experiments using protons and mesons.

2.5 Radiobiology and Radiotherapy Users Group

It has been recognized for several years that beams of stopping negative pions give an excellent distribution of dose with depth as a relatively large fraction of the energy available on capture in a nucleus appears as kinetic energy of nuclear fragments of short range. Moreover, the Oxygen Enhancement ratio, which is the ratio of the dosage required to produce a given destruction of cells which are anoxic to those which are fully oxygenated, is very favourable for heavily ionizing particles. For these reasons, with the expectation of a negative pion beam of adequate intensity from TRIUMF for useful radiotherapy investigations, a Radiobiology and Radio-Therapy Users group has been set up, comprising:

Dr. J.M.W. Gibson, Chairman	B.C. Cancer Institute
H.F. Batho	B.C. Cancer Institute
N. Auersperg	Cancer Research Centre, UBC
D.H. Copp	Dept. of Physiology, UBC
A.M. Evans	B.C. Cancer Institute
G.B. Friedmann	Dept. of Physics, UVictoria
K.O. Kornelsen	B.C. Cancer Institute
L.G.S. Newsham	Dept. of Physiology, UAlberta
T.R. Overton	Dept. of Radiology, UAlberta
S. Rowlands	Divn. of Medical Biophysics, UCalgary
J.W. Scrimger	Dr. W.W. Cross Cancer Institute, Edmonton
S.R. Usiskin	Dr. W.W. Cross Cancer Institute, Edmonton
D. Walker	Dept. of Chemistry, UBC
J. Weijer	Dept. of Genetics, UAlberta
D.M. Whitelaw	Dept. of Medicine, UBC
M.E.J. Young	B.C. Cancer Institute

A draft report was prepared for this group which met on November 20. Following this, a revised version was prepared in the form of a proposal for a design study.* This proposal has been submitted to the Medical Research Council and will also be submitted to the National Cancer Institute.

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* "Proposal for an Engineering Design and Cost Study for a Radiobiology and Radiotherapy Facility using a Negative Pi-Meson Beam from TRIUMF"

3. ENGINEERING AND PROJECT MANAGEMENT

Proposals for Engineering Services and Project Management were received from nine Canadian and three U.S. firms. Evaluation of these proposals showed that the Canadian firms lacked sufficient in-house capabilities and accelerator expertise for a project of this type. The U.S. firms could satisfy this requirement much better, but it was felt that by accepting one of their proposals an unnecessarily large amount of engineering services would have to be imported which could very well be provided by Canadian firms.

After careful consideration, it was decided that it would be in the best interest of TRIUMF to run the project under its own management but to obtain the necessary staff from the Shawinigan Engineering Company Limited (SECo) and the Montreal Engineering Company Limited (MECo), both of Montreal. The former provided the Project Manager and the Scheduling Engineer, and the latter, the Contracts Manager. These people will work in the TRIUMF office for the duration of the project until commissioning. Mr. T.A. Creaney assumed his position of Project Manager in August.

The Toronto firm of Dilworth, Secord, Meagher and Associates Limited (DSM) was selected for the detailed design of the cyclotron and ancillary equipment. Their Vancouver branch has been made their headquarters for the project. The firm completed a conceptual design study on support structures and jacks earlier this year. Engineering design of the cyclotron proper was started in September under the direction of Mr. B.C. Stonehill.

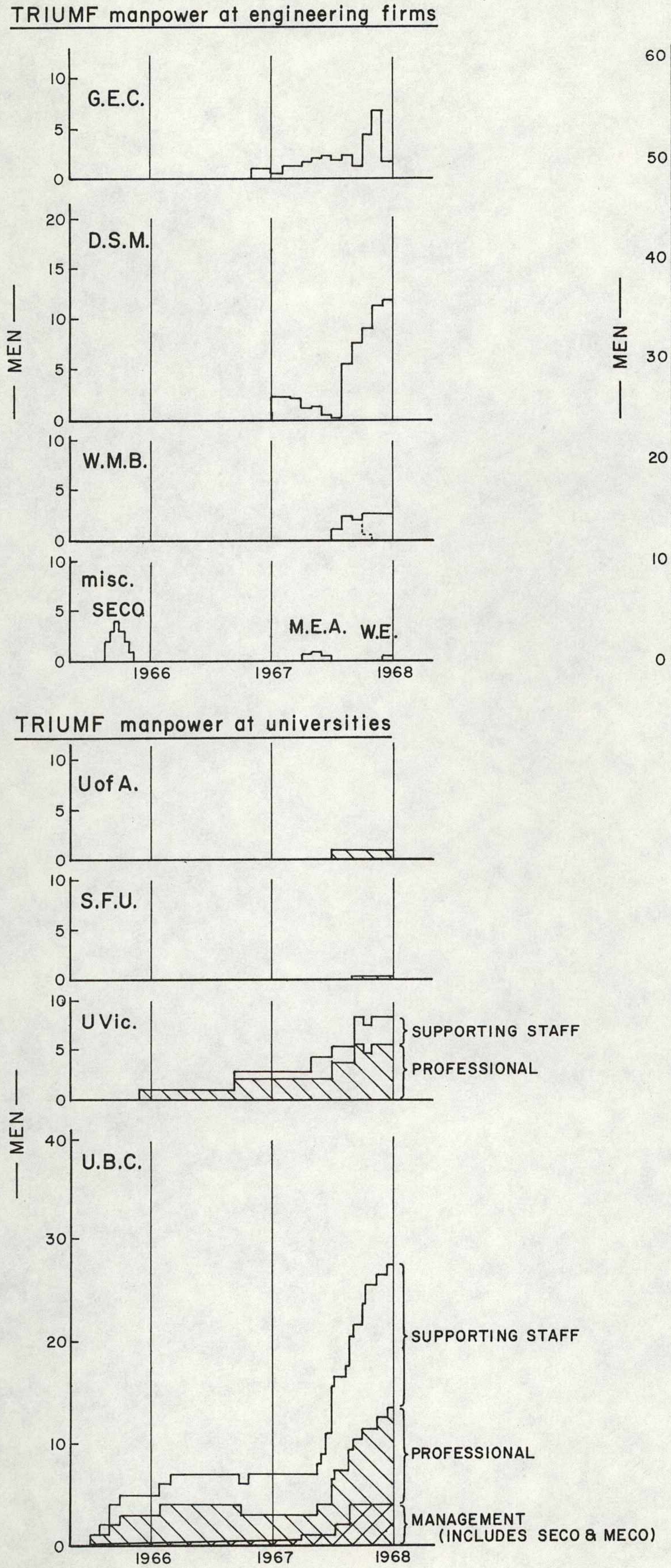
The Berkeley (California) firm of William M. Brobeck & Associates (WMB) will provide miscellaneous specialist cyclotron engineering expertise during the conceptual stage of the engineering design. One of the firm's senior engineers, Mr. O.K. Fredriksson, has been attached to DSM's Vancouver office.

The Vancouver firm, G.E. Crippen & Associates Ltd. (GEC), was selected for the design of buildings and shielding. They completed a conceptual design study on buildings and site layout this summer and prepared the detailed drawings and specifications for the Office, Laboratory and Workshop building in November, under the direction of Mr. J.R. Oakey.

The Boston firm, Magnetic Engineering Associates, Inc., completed a preliminary study on magnet construction. Wright Engineers Limited of Vancouver has been awarded a contract for a conceptual design study of the vacuum pumping system, with the Boston firm, Arthur D. Little Inc., participating in the design of cryogenic pumping equipment.

Figure 3.1 shows graphs of the manpower effort directed towards realization of the facility as contributed by TRIUMF staff at the four universities and by consulting engineers firms.

The relationship between engineering firms and TRIUMF is shown in the Organization Diagram in Figure 1.1.



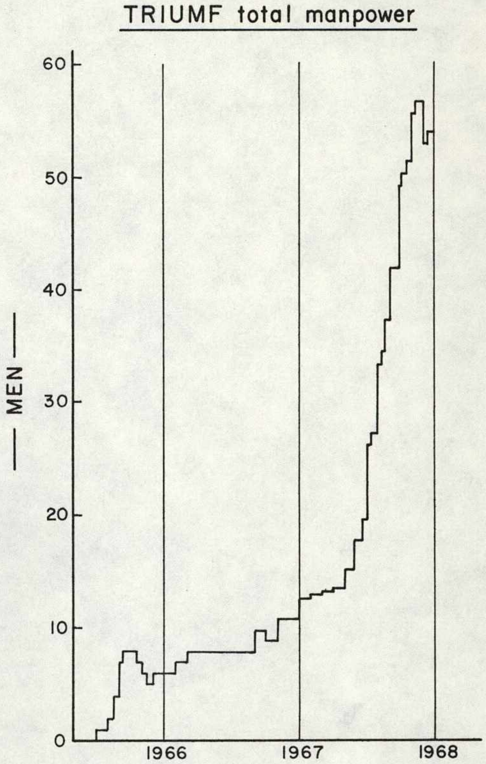


Figure 3.1

MANPOWER RESOURCES

Only staff supported by TRIUMF funds is recorded on these graphs.

4. BUILDINGS AND SITE LAYOUT

TRIUMF site planning and building design are under the general supervision of the TRIUMF Building Committee comprising

Dr. J.B. Warren	TRIUMF	Chairman
Mr. J.J. Burgerjon	TRIUMF	
Dr. W.K. Dawson	University of Alberta	
Dr. R.G. Korteling	Simon Fraser University	
Dr. L.P. Robertson	University of Victoria	
Dr. E.G. Auld	University of British Columbia	
Mr. T.A. Creaney	TRIUMF	Secretary

The Interim Report on "Reappraisal of Beams, Building and Site" (I-67-1), which reviewed both the long-range situation as it might be in the late nineteen seventies and the initial building requirements, received mainly favourable comment coupled with some detailed suggestions. Following this, a careful study was made of the optimum site plan with regard to the overall safety requirements.

4.1 Main Buildings

GEC have prepared a detailed conceptual design report with cost estimates for the revised site and building layout. This conceptual design does not represent a frozen design; it does, however, provide a working basis for the Users Groups which have been set up to formulate the experimenters requirements in more detail. It is anticipated that these requirements will be known by December 31, 1968, that after careful assessment by the Building Committee as to cost, etc. of incorporating these requirements, a decision will be made by the Operating Committee as to what facilities can be provided at the outset. The final plan will be presented for approval to all TRIUMF users at the annual meeting to be held in May 1969.

Particular mention must be made of the assistance rendered by Mr. I. Thorson of the Chalk River Laboratories of Atomic

Energy of Canada in estimating the shielding requirements of the accelerator. Throughout this conceptual design phase of the main accelerator and beam facilities, the consideration of Safety in all its aspects has been paramount. Much attention has been given to incorporating safety into the building design; all recommendations of the Safety Committee are incorporated into the design of the building and layout of the facility.

4.2 Office, Laboratory and Workshop Building

The design of the Office, Laboratory and Workshop building has been completed and was approved for construction by the UBC Board of Governors.

This building will be the first structure to be erected at the TRIUMF site, on the UBC South Campus, and will serve as the headquarters from which all activity in the design, development and construction of the facility is to be directed.

It will contain offices for the project's design and management groups, most of which will be used by the experimental groups after commissioning of the project.

Laboratory and workshops will be used for development work and for testing equipment to be incorporated into the main facility.

A call for tenders for construction of the building will be issued in December, and construction is expected to start in February 1969.

The building provides a total area of about 19,000 square feet at an estimated cost of $500,000, and is scheduled for completion and occupancy by the TRIUMF staff in September 1969. Figure 4.1 shows an artist's impression of the building.

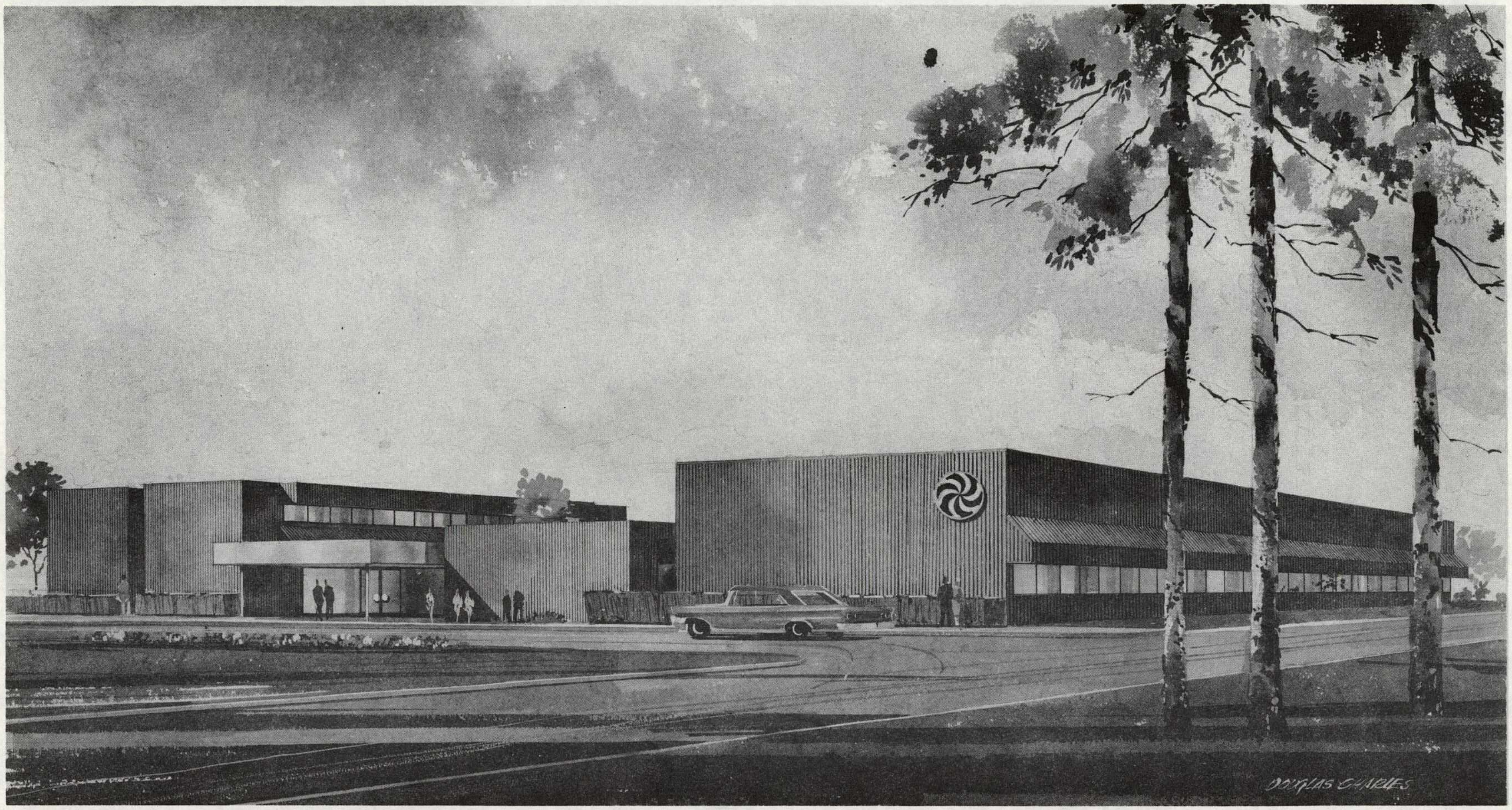


Figure 4.1 ARTIST's IMPRESSION OF OFFICE, LABORATORY AND WORKSHOP BUILDING.
Architectural design by: Underwood, McKinley, Cameron, Wilson & Smith

5. H^- DISSOCIATION EXPERIMENT

During the period August to mid-October 1968, an experiment to measure the lifetime of H^- ions in magnetic fields was carried out using the 50 MeV proton linear accelerator at the Rutherford High Energy Laboratory. This machine together with a stripping magnetic field of ~ 22 kilogauss produced electric fields in the rest frame of the H^- ions in the same region as those expected for the TRIUMF cyclotron, namely about 2 MV/cm.

The H^- ions were produced by charge exchange in a 25 cm long gas adder canal containing water vapour at a pressure of about 200 microns. The canal was installed between the injector and the first accelerating tank. A Y-box in the bending magnet allowed the H^- and proton beams to be deflected down the -15° and +15° beam lines, respectively. An average H^- rate of 10^5/sec at an energy of (49.5 ±.1) MeV was obtained at the experimental area. The protons were dumped in a concrete cave.

The stripping magnet was capable of producing a maximum field of ~ 23 kilogauss. Field profiles were obtained with a Hall probe calibrated against an NMR probe. Field values were within 1% of peak value over a region ±3 cm along the beam direction, ±8 cm horizontally normal to the beam, and ±1.3 cm in the vertical direction (all measurements referred to the geometrical centre of the magnet). Profile measurements were made prior to the experiment and were checked with an NMR probe following the experiment. Field values were reproducible to ±20 gauss.

The deflected H^- beam and the "straight-through" gas-stripped H° beam were detected by fast counter telescopes. An argon-methane ion chamber was used to check the efficiency of these telescopes.

Because of design limitations, the largest field for which the deflected H^- beam could be monitored was ~ 21.7 kG.

An acoustic spark chamber was used to detect gas-stripped background and electric-stripped ions. The chamber was triggered by the passage of a particle through a ΔE-E particle identification system which was placed immediately behind the chamber.

H^- lifetimes were extracted from the data in two independent ways. The first related a narrow strip at the peak of the observed distribution on the detector plane to an element of the particle trajectory in the magnetic field. A value of lifetime, τ, was obtained from

$$\frac{\Delta N(H^\circ)}{N(H^-)} = \frac{\Delta s}{v\gamma\tau}$$

where $\Delta N(H^\circ)$ is the number of counts in the strip, Δs is the trajectory length corresponding to the width of the strip, $N(H^-)$ is the number of H^- ions detected, and v and γ are, respectively, the speed of the particle and the Lorentz factor.

The second method of analysis used a known (or assumed) expression for the lifetime as a function of electric field. The expected number of stripped ions was calculated using the measured field profile. An experimental lifetime, τ_{exp}, is obtained from

$$\frac{N(H^\circ)_{calc}}{N(H^\circ)_{exp}} = \frac{\tau_{exp}}{\tau_{calc}}$$

where $N(H^\circ)_{calc}$ and $N(H^\circ)_{exp}$ are the predicted number and total number of stripped ions, respectively, in the spark chamber, and τ_{calc} is an average lifetime in the stripping field region which is approximately equal to the lifetime at the peak field if the stripping field drops off sufficiently rapidly. Using new values of τ_{exp} obtained in this manner, a new functional dependence of lifetime on electric field can be obtained and the process can be repeated until convergence is obtained.

For each approach, it is necessary to include loss of particles due to gas stripping. To that end, a gas stripping lifetime of $\tau_g = 7.09 \times 10^{-4}$ seconds was measured for the experimental conditions.

Both approaches were used for the treatment of data. Electric stripping lifetimes obtained from each method were consistent to within 10%. Figure 5.1 shows our experimental data together with those of Cahill *et al.*[1] An expression for the lifetimes of the Hiskes' form [i.e. $\tau(\varepsilon) = (A/\varepsilon) \exp (B/\varepsilon)$] was fitted to our data. This fit together with the prediction of Hiskes are also shown in the figure.

At the present time, we are unable to explain the discrepancy between our results and those of Cahill *et al.*[1] A detailed report of the experiment is being prepared for publication.

We would like to thank Professor W.D. Allen of the PLA laboratories for making the machine available to us for these measurements. We would also like to thank Dr. W.J. McDonald for his assistance during the planning stages of the experiment and for suggesting the second method of analysis. We are also very grateful to Mr. Frank Swales, Mr. Ted Wallis, and the rest of the PLA staff for their invaluable help without which this experiment would never have been completed.

1 Cahill, T.A., Richardson, J.R. and Verba, J.W., Nucl. Inst. Meth. 39, 278 (1966).

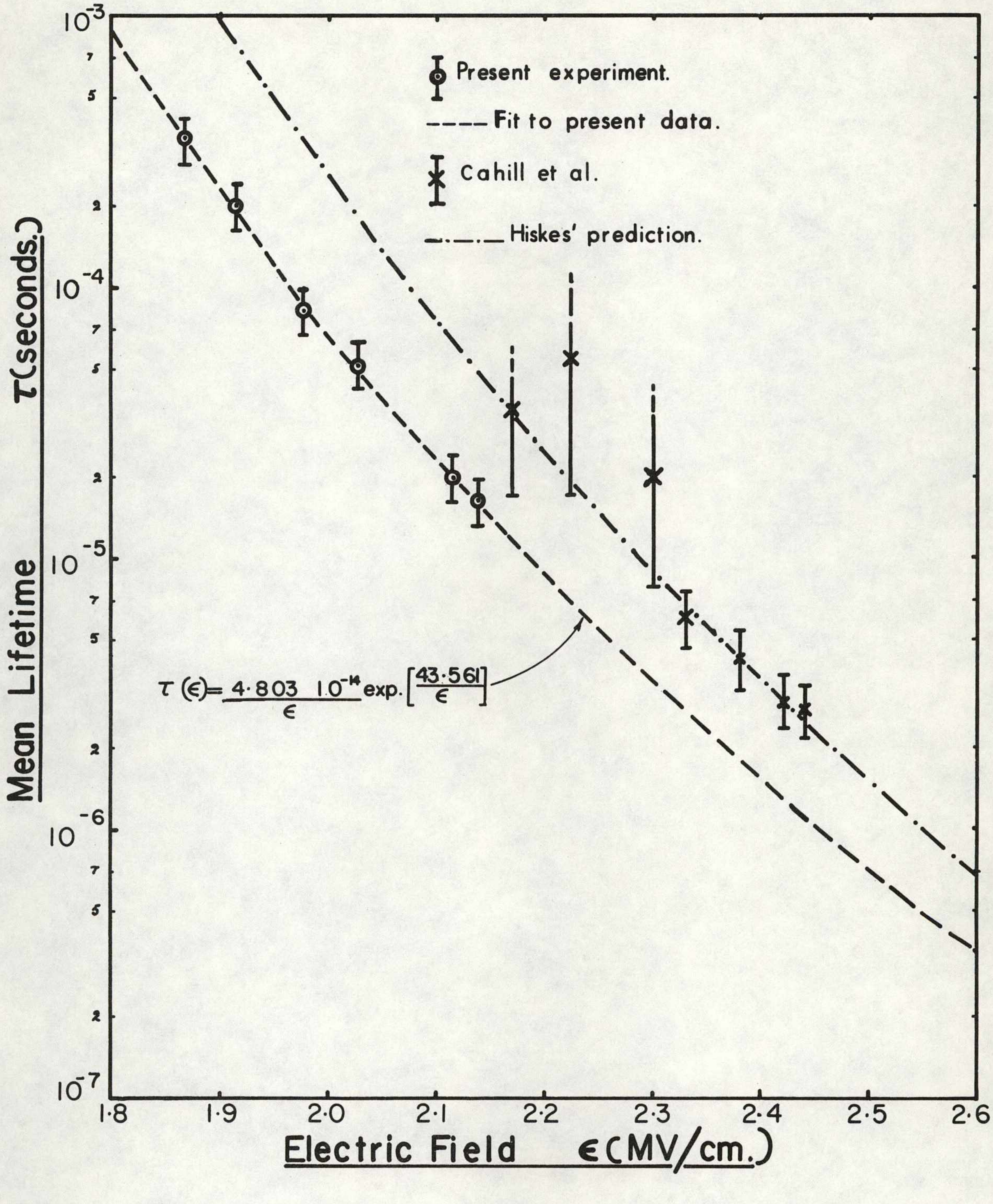


Figure 5.1 Experimental H^- lifetimes as a function of electric field as determined in this experiment and in that of Cahill et al.[1] Error bars shown on our data are ±20% which is indicative of of experimental accuracy. The prediction of Hiskes and that from a fit to our data are also shown.

6. CYCLOTRON AND ANCILLARY EQUIPMENT

The results of the H^- dissociation experiment required a downward correction of the magnetic field, necessitating a 4% increase in machine diameter. By simply increasing the scale factor for the model study by 4%, virtually no time was lost in making this change at a time when engineering on the core construction has barely started, while the model has produced a field with satisfactory focusing properties for particles of 500 MeV.

The extra cost caused by the increase in size goes almost entirely to the magnet cores. The latest estimate for the cost of the machine is now $8,406,000 as compared to $7,975,000 (1966 dollars) a year ago. This extra cost will be offset by savings in other areas of the project.

With this change it is now felt that radiation and activation in the machine is well under control, and may be further decreased by providing a thin vacuum chamber wall where the stripped ions hit the chamber and by providing a suitable absorber (graphite) around it.

Earlier this year DSM completed a conceptual design study of the structure to support the 2000-ton atmospheric load on the vacuum chamber and the design of a synchronized elevating jack system required for assembly and servicing of the machine.

6.1 Magnet

6.1.1 Magnet Model

Before the results of the H^- ion lifetime were known the model design had reached a point where the orbit stability criteria had been achieved over the whole energy range from injection to 500 MeV, and the isochronous condition was within reach of being realized. This design was based on a maximum magnetic field of

5.93 kG. On the extrapolation of the H^- lifetime data available before October 1968, a maximum magnetic field of 6.10 kG would cause a total beam loss of 20%. Because of the uncertainty of these results, the maximum allowable magnetic field was reduced to 5.93 kG. The results of the recent H^- dissociation experiment indicate that the maximum field must be reduced to 5.76 kG to maintain the total beam loss below 20%.

A reduction in the maximum magnetic field implies a proportional reduction in the average magnetic field and hence an increase in the radius for a 500 MeV H^- ion. As mentioned above, this was done by increasing the scale factor from 20 to 20.8, thus allowing continued use of the present model magnet. The new radius for the 500 MeV H^- ion is 311 inches.

Model measurements since this change have achieved a certain amount of success. The orbit stability criteria have been maintained under the new scale factor. The isochronism condition is about 50% nearer realization than it was before the change.

Various other measurements done during the year included:

a) Measurement of the magnet fields in the extraction region for the calculation of extracted beam trajectories.

b) Study of the effect the steel support structure has on the median magnetic field. Various alternative structure designs suggested by DSM have been tested.

6.1.2 Central Region Magnet Model

Because of the special problems associated with the beam injection and beam stability during the first few turns of acceleration after injection an 1:8 scale model of the first 40" of the cyclotron magnet was constructed. This is shown in Figure 6.1. To achieve the required azimuthal variation in the magnetic field, magnet wedges were inserted in the gap on alternate sectors. These wedges will be located inside the vacuum chamber and can be seen in Figure 6.1.

6.1.3 Magnet Core Construction

DSM recently started the design of the six magnet cores, which may weigh as much as 4000 tons. The larger steel firms of the world that could supply all or some of this steel in heavy plate, forgings or castings have been visited in Canada, the U.S., England, Germany and Japan. Several Canadian firms have shown serious interest in the machining of the cores.

6.1.4 Main Coil Construction

WMB completed the conceptual design for the main coils which is unique for its construction, consisting of six 60° sectors bolted together by large numbers of bolts. This alleviates the problem of mechanically supporting one set of coils on six separate sectors and makes it possible to "wind" the coils at the factory.

6.2 Central Region

6.2.1 Central Orbits

Computer studies of ion orbits in the central region of the cyclotron have been continued, using the electric potential data measured on our electrolytic tank model at the University of Maryland. The initial aim is to find an orbit which asymptotically loses its eccentricity as acceleration progresses. In order to achieve this

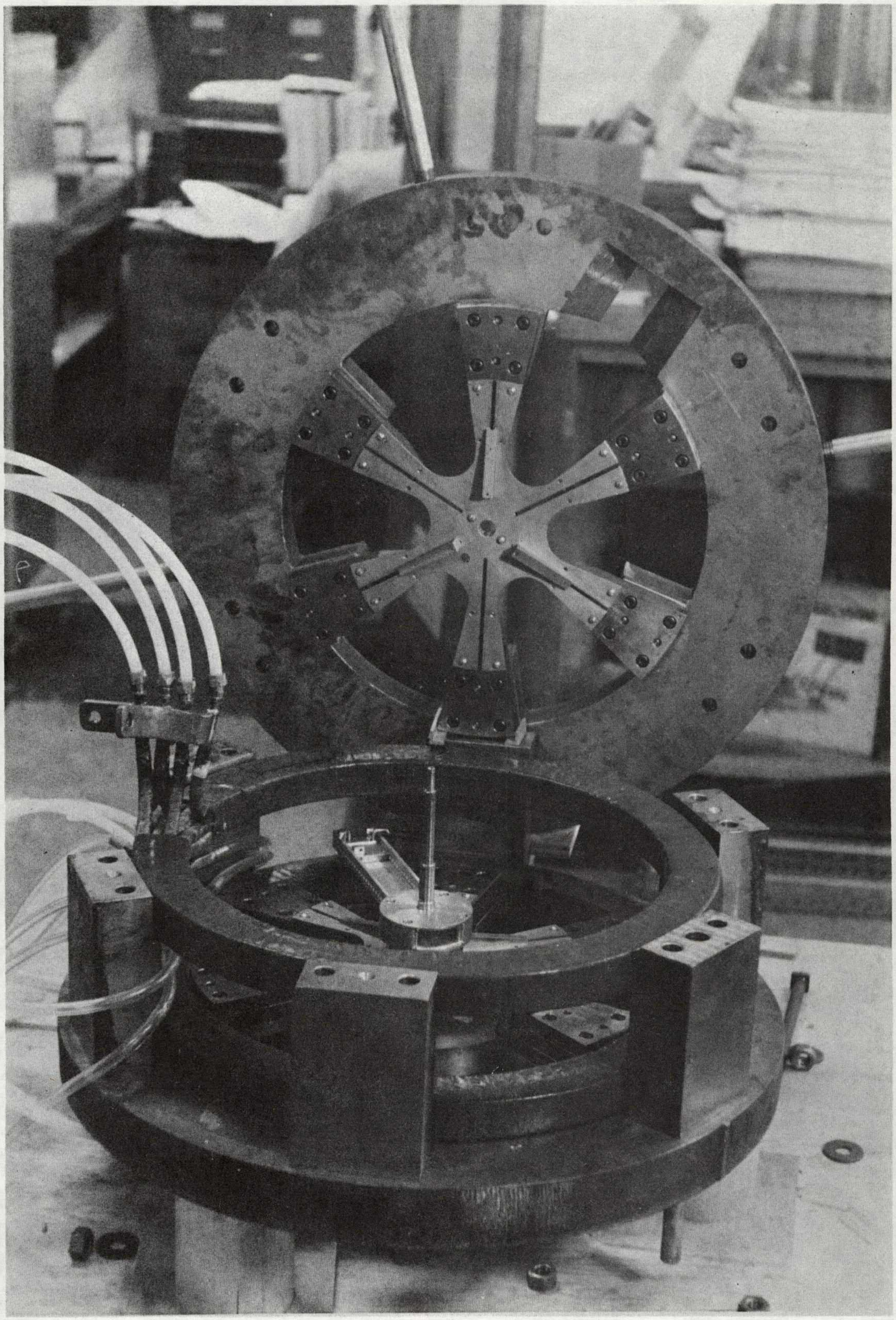


Figure 6.1 CENTRE MAGNET MODEL
Scale 1:8

for starting points inside the centre post, it was necessary to relocate the first harmonic "injection gap" closer to the main dee gap; fortunately this could be arranged by means of the computer, without reconstructing the model. Running a centred orbit back inside the centre post then showed that the injection energy required was 148 keV.

With this injection energy ions with phases between -55° and +35° of the peak phase are given enough energy to clear the centre post on the first turn; however, only phases between ±20° lead to well centred orbits. Variations in starting position have also been studied, showing that a beam with the emittance of the Cyclotron Corporation H^- ion source (0.7" wide at injection) is well behaved radially, remaining within a 0.5" wide envelope out to 6 turns. Moreover, non-linear effects cause only a slight distortion of the phase space occupied by the beam.

Vertical motions in the beam are more of a problem because the electric focus in the first few accelerating gaps are phase dependent and relatively strong compared to the magnetic forces. Preliminary studies with a thin lens approximation to the dee gaps show that the injected beam shape required to match the focusing properties of the cyclotron is strongly dependent on these electric forces. A complete treatment must await measurement of the electric potential in three dimensions on an updated model.

6.2.2 Inflector

A spiral electrostatic inflector is used to bend the vertically injected beam into the cyclotron. It now appears that a 72° spiral (with only a quarter of the twist of that illustrated in last year's report) will be adequate and should be easier to machine. The UBC Mechanical Engineering Department has assisted us greatly by trying out various methods of construction; several full scale models of the electrode surfaces have been produced on their tape controlled milling machine, one of which is shown in Figure 6.2.

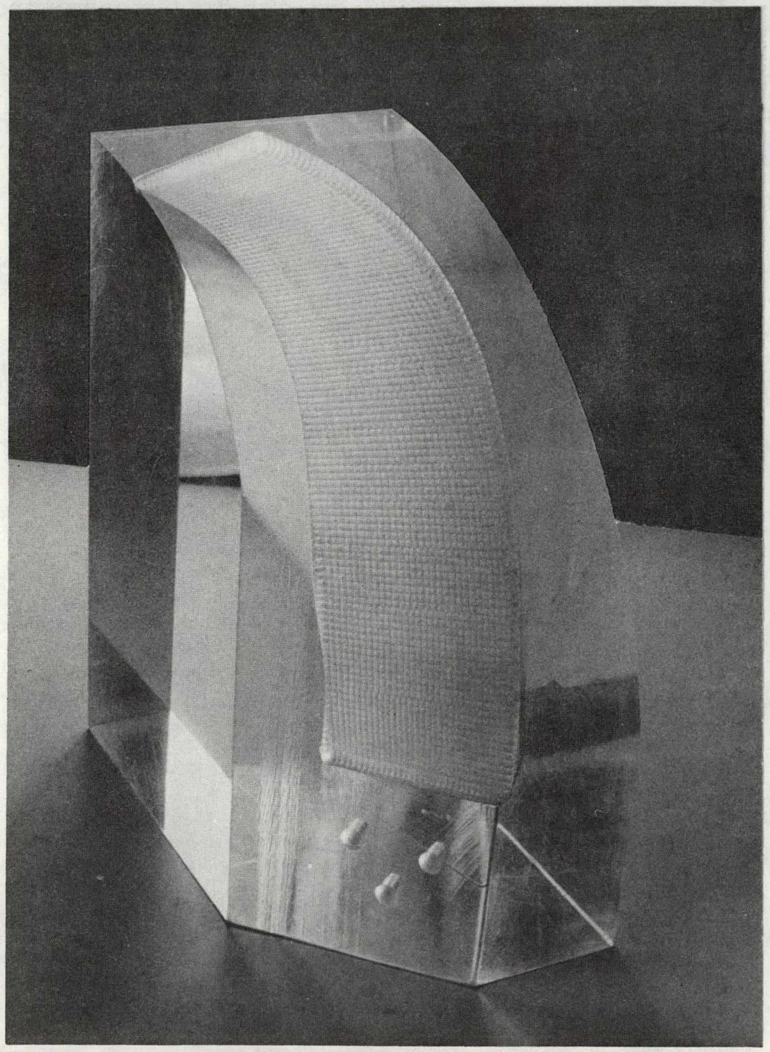
6.2.3 Ion Source

An ion source warranted to produce 2 mA of H^- ions with an emittance at 150 keV of 45 mm-mr (horizontal) and 60 mm-mr (vertical) is manufactured by Cyclotron Corporation of Berkeley, California. This ion source has been used by Cyclotron Corporation in the axial injection mode as the injector for their 15 MeV cyclotron. They were able to extract up to 45 μA of H^- from the accelerator at 15 MeV energy. This suggests that this type of ion source may be suitable for the TRIUMF accelerator.

6.3 RF System

Work on the RF section of the accelerator was largely limited to a study of the parameters associated with the RF resonators in the machine. Various concepts proposed by WMB and DSM were studied, using plywood - copper-clad models. One of these was an "open" resonator structure consisting of tubes. Electrostatic plots of the fields associated with such a structure indicated that such structures were unacceptable due to the magnitude of the varying median plane electric fields present.

<u>1/4 Scale Model</u>. The quarter scale cavity model was cut into sections of scale size which could easily be fabricated in the full scale machine. The problems of tuning such a tightly



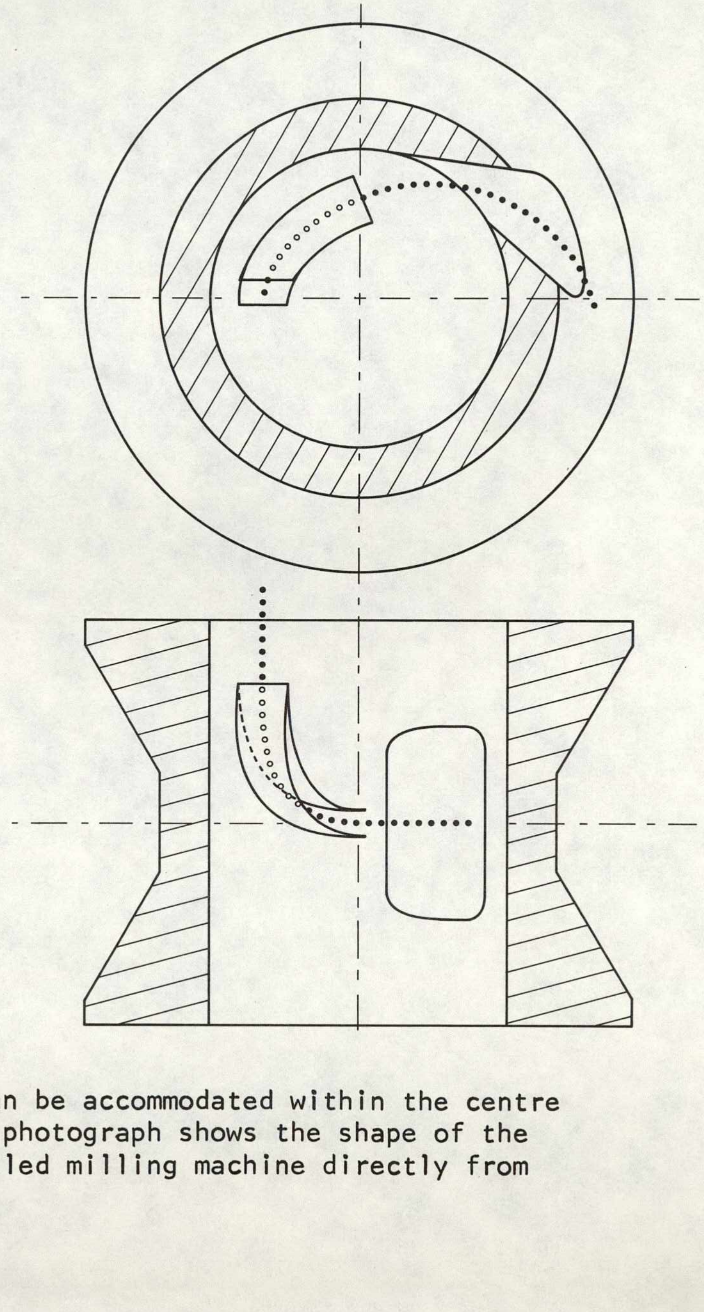


Figure 6.2 The drawing shows an inflector design that can be accommodated within the centre post. The injection energy is 148 keV. The photograph shows the shape of the outer electrode as produced on a tape controlled milling machine directly from the computed data.

coupled multi-tuned system were investigated, and the performance of the sections when excited at different locations was studied. The shape of the end of the sector at the edge of the magnet (tapered to fit into the circular vacuum tank) was modeled to give a uniform field at the D gap.

1/2 Scale Model. A 1/2 scale model has been constructed to obtain more accurate and reliable results than obtainable from the 1/4 scale model, due to the difficulties caused by its operating frequency of approximately 100 MHz.

Full Scale Model. A 48" wide full scale section of the cavity was constructed to measure the Q, power levels, and tuning arrangements required in the resonators. These measurements were made both for a resonating structure having a uniform gap and for a structure in which the gap narrowed at the open end of the resonator. The frequency and voltage variations produced by tuning panels inserted into the resonator at various positions and by tuning plugs at the shorted end were investigated. It should be noted that the use of ceramic insulators in the structure to produce dimensional stability had a marked effect on the Q. The maximum RF voltage used on this prototype section was 10 kV peak, which was attained at a power level of 900 watts total power into an Eimer 304 TH triode. The measured Q of the RF cavity at this power level was 5400.

6.4 Vacuum System

The gas density requirements for the vacuum chamber have been studied in relation to the predicted gas composition of the residual gas load from baked and unbaked surfaces. A gas composition having the same effectiveness for stripping H^- ions as 7×10^{-8} Torr of nitrogen is the latest design criteria. For this gas density condition an extracted beam of 750 μA at 400 MeV can be obtained, which is the design value for RF beam loading.

Following discussions with N. Milleron (LRL, Berkeley) and G. Lewin (Princeton University), it was decided to proceed with an engineering design study of a cryogenic pumping system with a 20°K surface and an 80°K shield. Helium and hydrogen are to be pumped using several small liquid nitrogen trapped oil diffusion pumps which can be conveniently located between the tie rods of the support structure. The cryogenic surfaces will provide sufficient pumping speed to reach the required gas density within fifteen hours of pumping. This system will be compared with several 35" liquid nitrogen trapped oil diffusion pumps on the basis of certain criteria for pumpdown time, maintenance requirements, radiation damage, level of contamination and compatiblity with other cyclotron components. Engineering Note TRI-EN-68-23 includes an evaluation of the following pumping methods which appear to be unsuitable for the cyclotron vacuum chamber: turbomolecular, titanium sublimation, ion, cryosorption and cryopumping at 4.2°K and 2.5°K.

No final design has been developed for the 54 ft seal but the use of a polyurethane elastomer, formulation 3000/AH-18, is now being investigated, since it is resistant to the radiation levels in TRIUMF for several years and has outgassing properties similar to viton. Engineering Note TRI-EN-68-27 describes some of the problems associated with several seal designs which are under consideration.

A 1/20 scale model of the vacuum chamber has been assembled and leak tested. The purpose of the model is to simulate the pumpdown performance of the chamber as a function of seal materials, cleaning techniques and bakeout conditions of the resonators and chamber walls. Preliminary data indicate that the magnitude and percentage composition of the outgassing load from stainless steel used for the pumping system design is realistic. Simulation and comparison of the 35" diffusion pumping system and the 20°K cold gas refrigeration pumping system can be achieved with the model. Testing of non-evaporable getter pumps and 2.5°K cryopumps, on loan from manufacturers, will be made after the full-scale simulation tests of chamber performance have been completed. The getter pump may be particularly suitable for handling the hydrogen gas load in the injection beam line.

Figure 6.3 shows the vacuum chamber model and its associated equipment.

6.5 Beam Transport

A suitable beam transport system has been designed for the primary beam line into Area I and the neutron facility. The The system allows pion production targets of up to 20 gm/cm^2 of carbon to be inserted before the beam dump.

Theoretical studies have been made in two areas. It has been shown that identity transformation cannot be done in both transverse planes by doublets or triplets, but that there is a double infinity of solutions using four magnets. Solutions to the problem of phase space ellipse matching have been obtained using thin lens doublets (in certain cases where the solutions exist) and triplets.

6.6 Extraction

A program based on GOBLIN has been written to calculate the trajectory of the stripping foil in the accelerator given the cross-over point.

Calculations using the Mk IV. magnet fringe field indicate that extraction is possible over an energy range 200 MeV to 500 MeV (and possibly lower energies). A program has been

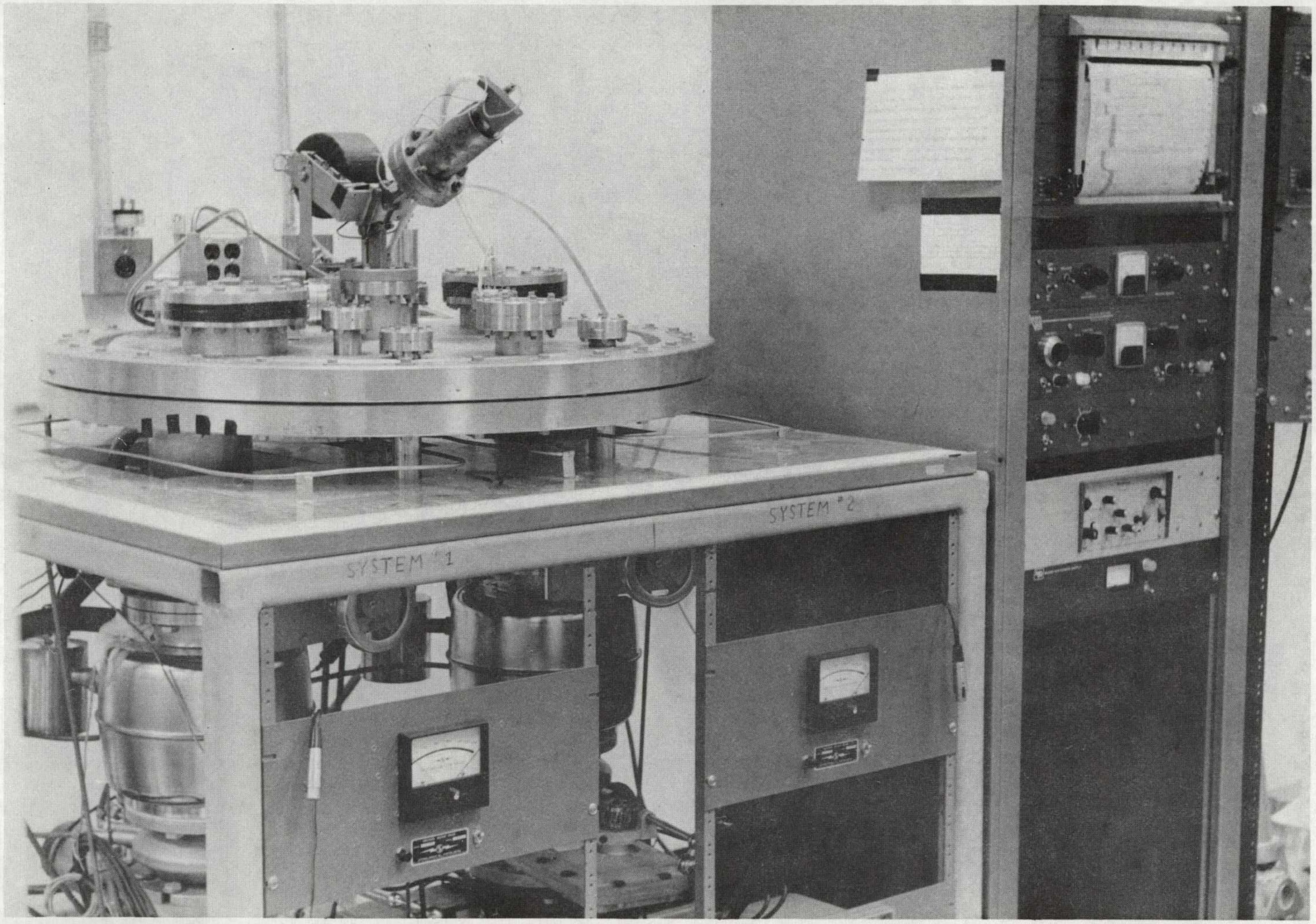


Figure 6.3 1:20 SCALE VACUUM CHAMBER MODEL WITH RESIDUAL GAS ANALYZER

written to calculate the beam optical properties of these trajectories.

A novel frictionless pulley has been designed and constructed. It has been used to perform floating wire measurements on this model magnet to supply a check of the programs used for calculating the extraction trajectories.

6.7 Control and Instrumentation

Initial work on control design was started in September and some conceptual ground work has been accomplished. It is reasonable to report a few general plans of the control system.

Figure 6.4 displays the accelerator complex equipment divided into units. The division is made along natural cyclotron component divisions and is similar to responsibility divisions which have been established for the development work. Typical communication times between the units and the control room are also shown. Short communication times necessary for safe operation of the cyclotron will be "hard-wired" controls connecting dependent units (μsec). Display information (sec) and initial condition parameter transmission (msec) to the cyclotron units will utilize a digital control console-computer combination located in the control room.

At this time a set of standardization rules are being developed pertaining to Analogue and digital commands and data within the units as well as those connecting the units to each other and to the control console. The basic design philosophy will allow systematic control system updating as cyclotron development progresses.

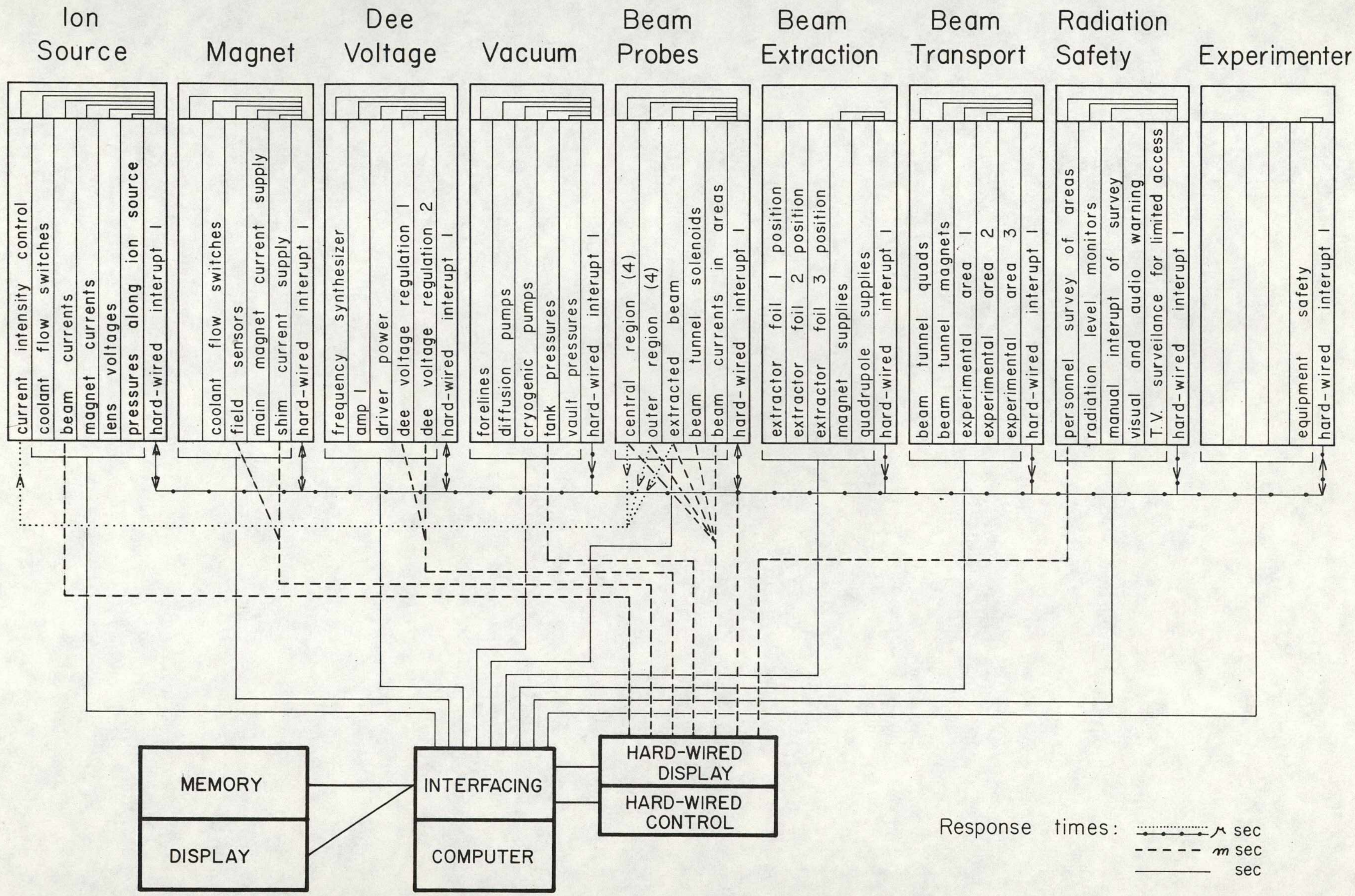


Figure 6.4 BLOCK DIAGRAM CONTROL SYSTEM

7. NUCLEAR EQUIPMENT DEVELOPMENT

A particle analysis/time of flight system is under development for application at the TRIUMF facility in studies of nuclear fragments from high energy reactions. The components for a particle analysis system have been assembled including solid-state counter telescopes, a particle identification logic unit, and a 10" scattering chamber. The particle identification control unit is capable of specifying the type (A and Z) and energy of charged particles incident upon the counter telescope system, based upon an empirical range-energy approximation relationship. This system has been initially tested on the bench and is currently being further tested on nuclear fragments produced in low energy nuclear evaporation and fission processes. The second stage of development, now beginning, will incorporate a time of flight system to extend the range of particle identification.

8. SAFETY

The TRIUMF Safety Committee was formed during this year with the following composition:

Brian D. Pate	Simon Fraser University	Chairman
R.T. Morrison	Director, Nuclear Medicine Vancouver General Hospital	
R.R. Johnson	UBC, Physics Department	
T.A. Creaney	TRIUMF	

The Committee has prepared a preliminary version of the Safety Regulations and Procedures for TRIUMF for discussion internally within the TRIUMF project and with the Accelerator Safety Advisory Committee of the AECB. This document covers all aspects of safety of the TRIUMF site, accelerator beam handling and experimental program both during normal operation of the machine and during emergencies.

The Committee has been concerned with the interaction of safety requirements and building construction features, particularly those of the office building for which the design is well advanced.

The control system of the cyclotron and of the beam lines, discussed in section 6.7, interacts very strongly with radiation safety and access control to hazardous areas. These matters are being considered together with the associated instrumentation.

Conversations have taken place with both Federal and Provincial authorities regarding the disposal of radioactive material from the TRIUMF site. The appropriate authorities have been urged to make proper provision for this service at a convenient distance from the site well before the machine start-up period, after which sizable disposal operations will become necessary.

9. SCHEDULE

The TRIUMF project from the development design concept through engineering and construction to commissioning is being scheduled and controlled by use of critical path networks. These networks integrate the work of the design groups at the four universities and consulting engineers into the overall project network.

The critical path for the project is determined by the long delivery time for the machined magnet cores, preceded by magnet model studies, and by the various assembly and test procedures that cannot be done simultaneously, such as field measurements, vacuum tests and RF tests. At this time, maximum effort is concentrated on the magnet design. Each component will be tested to the maximum possible extent before assembly in the vault so as to reduce the time for final tests, when the various components have to interact with each other. Figure 9.1 shows a drastically simplified version of the network diagram indicating only major activities.

Each contractor and major equipment supplier will be required as part of his contract to submit network schedules of their work for incorporation into the TRIUMF master network. In this way TRIUMF, through its management group, will be able to monitor their progress to ensure that each contractor is meeting his schedule and that target dates are met.

SECo's Project Schedule Evaluation computer program "PROSE", previously used on ING and other major projects, will be used for processing scheduling information. This program will be set up at UBC as soon as the new computer is operative. Meanwhile the networks are processed on SECo's computer in Montreal.

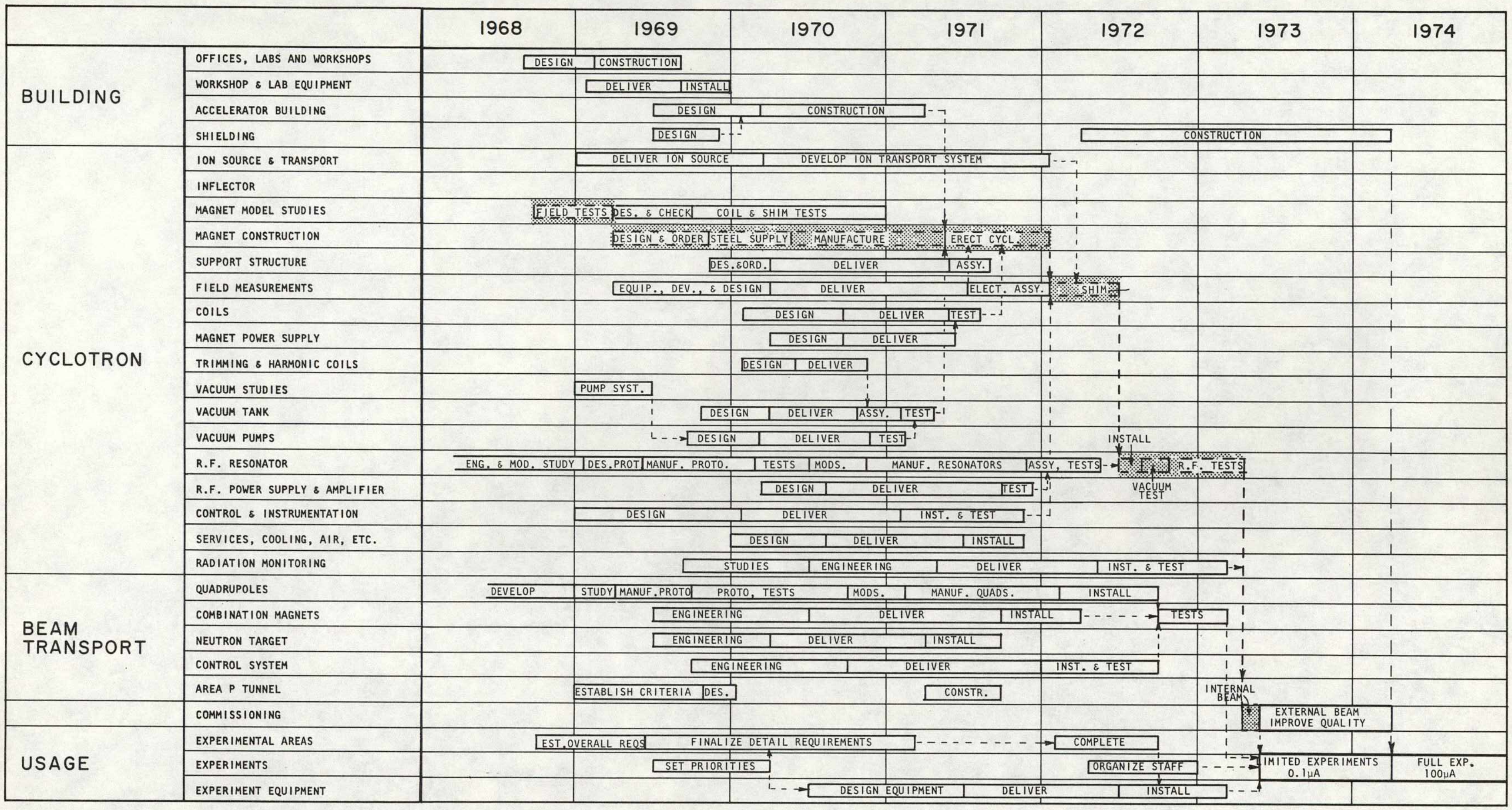


Figure 9.1 Major events and activities from TRIUMF's Critical Path Networks

10. TEMPORARY ACCOMMODATION

To accommodate the UBC TRIUMF group prior to completion of the Office, Laboratory and Workshop building, the Physics Department made available in the Hennings Building three 1500 sq.ft. laboratory rooms, a 600 sq.ft. area in the basement, and some offices.

The basement area was converted into a three-man workshop, and a mezzanine floor was built over the wood workshop to compensate for the space given to TRIUMF. The cost to TRIUMF for these modifications was about $30,000.

Two of the laboratory rooms accommodate model studies, and the third one is used as a four-man drawing office and as the project management office.

The University of Victoria bought a trailer as temporary housing for their expanding group. This trailer is later to be used as a local control room in the experimental facility.

11. CONFERENCES

	TRIUMF Delegates
Fourth International Vacuum Congress Manchester, U.K., April 1968	1
Conference on Analysis of Magnetic Fields Reno, Nevada, September 1968	1
First LAMPF Users Meeting Los Alamos, N.M., June 1968	2
LAMPF Physics Users Study Group Los Alamos, N.M., August 1968	1

12. REPORTS

TRI-68-1	Conceptual Design Study for the Support Structures, Elevating Jacks and Levelling Jacks for a 500 MeV H^- Cyclotron
TRI-68-2	Building Concept with Cost Estimates, Site Exploration and Engineering Data for a 500 MeV H^- Cyclotron Facility
TRI-68-3	Conceptual Design Study and Cost Estimate for the Main Coils for a 500 MeV H^- Cyclotron
TRI-68-4	Shielding and Activation in a 500 MeV H^- Cyclotron Facility
TRI-68-5	A Computer Program for Beam Transport Calculations
TRI-68-6	Ellipse Matching with Doublet or Triplet Thin Quadrupole Lenses
TRI-68-7	A Program to Calculate the Phase Space Acceptance of a Beam Handling System - Theory and Preliminary Results
TRI-68-8	Preliminary Design of Transport Systems for TRIUMF Beam Line I
TRI-68-9	Magnet Systems for the Transport of Ion Beams with No Change of Properties

12. STAFF

UBC

Faculty:

Name	Position	Area	% TRIUMF Payroll	From	Until
J.B. Warren	Professor	Director	100		
G. Jones	Assoc. Professor	(Control)	0		
D.L. Livesey	Professor	(Field Measurements)	0		Jul 1
B.L. White	Assoc. Professor	(Ion Source)	0		
E.W. Vogt	Professor	Assoc. Director	0		
K.L. Erdman	Professor	(RF)	50		
M.K. Craddock	Assoc. Professor	(Beam Dynamics)	100		
E.G. Auld	Asst. Professor	(Magnet)	100		
R. Johnson	Asst. Professor	(Control)	0	Sep 1	
D.A. Axen	Asst. Professor	(H^- Experiment)	0		
J.R. Richardson	Visiting Professor	(Consultant)	100	Oct 1	Dec 31

Graduate Students:

Name	Position	Area	% TRIUMF Payroll	From	Until
S. Oraas		(Magnet)	100		
R.J. Louis		(Beam Dynamics)	100		
L. Freisen		(Magnet)	100	Sep 1	
A. Prochazka		(RF)	100	Oct 1	
L.W. Root		(Beam Dynamics)	100	Oct 1	

TRIUMF (Vancouver)

Name	Position	Area	% TRIUMF Payroll	From	Until
J.J. Burgerjon		Chief Engineer	100		
Vivienne Harwood	Research Associate	(Vacuum)	100		
M. Linton	Computer Analyst		100	May 15	
G. Mackenzie	Asst. Professor	(Magnet)	100	Sep 8	
R. Gummer	Research Associate	(RF)	100	Nov 15	
A.J. Otter	Research Engineer	(Magnet)	100	Dec 16	
M.R. Haines	Research Assistant	(Magnet)	100		
M. Heinrich	Research Assistant	(Machinist)	100		
L.A. Udy	Research Assistant	(Draftsman)	100		
H. Hansen	Research Assistant	(Draftsman)	100		
D.W. Ramsbottom	Research Assistant	(RF)	100		Oct 1
A.T. Bowyer	Research Assistant	(Draftsman)	100	May 27	
Ada Strathdee	Secretary		100	Jun 12	
Beverly Little	Secretary		100	Jun 14	
D.C. Smith	Research Assistant	(Workshop Supvr)	100	Jul 1	
J.C. Yandon	Research Assistant	(Vacuum)	100	Jul 1	
S. Paul	Research Assistant	(Machinist)	100	Aug 15	
N. Rehlinger	Research Assistant	(Magnet)	100	Aug 27	
P. van Rookhuyzen	Research Assistant	(Chief Draftsman)	100	Oct 1	
S. Scherrér	Research Assistant	(Magnet)	100	Oct 8	
Irene Shepert	Secretary		100	Oct 8	

Attached Staff

Name	Position	Area	% TRIUMF Payroll	From	Until
D.L. Lancaster	Contracts Manager	(MECo)		Jul 9	
T.A. Creaney	Project Manager	(SECo)		Aug 22	
J. Kilpatrick	Scheduling Engineer	(SECo)		Aug 22	

TRIUMF (Vancouver) cont'd.

Summer Students:			% TRIUMF Payroll	From	Until
L. Hives		(Magnet)	100		
J. van Laar		(RF)	100		
Anne Koritz		(Library)	100		

U-Vic

Faculty:

R.M. Pearce	Professor	(Op/Com and Beam Optics)	33-1/3		
L.P. Robertson	Assoc. Professor	(Extraction	0		
D.E. Lobb		(Beam Optics)	0		
Eleanor Batho	Computer Programmer		100	Jul 1	

Graduate Students:

N. Al-Qazaz		(Beam Optics)	100		
D. Smith			100	Sep 1	
T.C. Ng			100	Sep 1	

TRIUMF (Victoria)

R. Cobb	Post-Doctoral	(Field Measurements)	100		
M.F. Tautz	Research Associate	(Beam Optics)	100		Oct 1
J.S. Leung	Post-Doctoral	(Muon Channel)	100	Sep 1	
B. Gray	Computer Programmer		100	Oct 1	
J. Nelson	Technician		100	May 1	
Julia Hunt	Secretary		100	Sep 1	

Summer Students:

P. James		(Beam Optics)	100		
R. Harrison		(Beam Optics)	100		

SFU

Faculty:

B.D. Pate	Professor	(Op/Com & Safety)	0		
R.G. Korteling	Asst. Professor	(Bldg.Committee)	0		
J.M. D'Auria	Asst. Professor	(Nucl. Equip. Dev.)	0		
A.S. Arrott	Professor	(Neutron Target)	33-1/3	Sep 1	

TRIUMF (Burnaby)

Sureyya Barken	Research Associate	(Nucl. Equip. Dev.)	100	Nov 29	

U-Alberta

Faculty:			% TRIUMF Payroll	From
G.C. Neilson	Professor	(Op/Com & H^- Exp.)	0	
W.K. Dawson	Professor	(Control & Computing)	0	
W. Olsen	Assoc. Professor	(H^- Experiment)	0	
G. Roy	Asst. Professor	(Vacuum & H^- Exp.)	0	
W. MacDonald	Asst. Professor	(H^- Experiment)	0	

TRIUMF (Edmonton)

G. Stinson	Post-Doctoral	(H^- Experiment)	100	July 1

14. FINANCIAL STATEMENT[1]

A. Prior to funding:

	1 April 1966 31 March 1967	1 April 1967 31 March 1968
GRANTS TO TRIUMF		
Atomic Energy Control Board	$100,000	$100,000
National Research Council	15,000	
University of British Columbia		44,000
Simon Fraser University		20,000
University of Victoria		10,000
Total	$115,000	174,000
Balance previous year		2,600
		$176,600
EXPENDITURES[2]		
Cyclotron Magnet	$ 53,000	$ 13,400
Accelerator Physics	400	5,400
Cyclotron RF System		4,900
Beam Transport System	5,600	6,700
Cyclotron Vacuum System		21,000
Library	200	600
Engineering & Drafting	900	900
Publications	1,300	2,200
Salaries	30,400	61,400
Travel, Conferences	2,500	2,600
Travel, General	1,000	2,400
Engineers Firms	12,500	40,000
Miscellaneous	4,600	7,300
Balance	2,600	7,800
Total	$115,000	$176,600

[1] This is not an audited statement.

[2] Payments plus commitments.

B. After funding:

Major code breakdown:	A PAYMENTS on Sep. 30	B COMMITMENTS on Oct. 31	A + B EXPENDITURES
	1 April 1968 - 30 September 1968 (Preliminary)		
Neutron Facility	$ 3,100	$ 300	$ 3,400
Nuclear Equipment Development	4,030	-	4,030
Proton Facility	2,000	1,000	3,000
Accelerator Physics	52,526	33,349	85,875
Cyclotron Structural & General	1,000	85,435	86,435
Cyclotron Magnet	42,153	99,064	141,217
Cyclotron RF System	6,472	51,658	58,130
Cyclotron Vacuum System	17,477	30,693	48,170
Beam Transport	28,946	22,350	51,296
Computer Facilities	765	4,590	5,355
Workshops	37,605	14,687	52,292
Engineering and Drafting	8,524	15,402	23,926
Administration and Gen. Expense	25,658	72,995	98,653
Library and Publications	804	664	1,468
Miscellaneous Expenses	37,350	-	37,350
Temporary Accommodation	9,310	21,159	30,469
Radiation Shielding	431	-	431
Buildings and Services	20,118	10,003	30,121
Board of Management	-	148	148
Total	$298,269	$463,497	$761,766

Minor code breakdown:

Payroll	$ 84,237	$124,458	$208,695
Consultants	2,997	1,752	4,749
Engineers Firms	35,615	284,425	320,040
Building Construction	9,198	21,197	30,395
Equipment	101,052	20,937	121,989
Supplies	29,357	8,698	38,055
Furniture	22	457	479
Travel, General	10,074	1,441	11,515
Travel, Conferences	845	-	845
Telephone	3,173	-	3,173
Xerox and Printing	1,001	-	1,001
Miscellaneous	20,698	132	20,830
Total	$298,269	$463,497	$761,766