TRIUMF

ANNUAL REPORT
1969

MESON FACILITY OF:

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

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T R I U M F

ANNUAL REPORT

1969

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Editor

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F O R E W O R D

The last annual report documented the commencement of TRIUMF as an interuniversity venture with the object of building a major physics research facility. We are pleased to be able to report that the pattern established by TRIUMF has been followed by the formation of two further co-operative projects - WESTAR which will pursue astronomical research at the Mt. Kobau site, and WCUMBO which will build a marine biological station on the west coast of Vancouver Island.

Plans for adding a radiobiology-radiotherapy unit to the TRIUMF main building are now well advanced. A beam of π^- mesons will be used for research and therapy. The B.C. Cancer Research and Treatment Foundation and the Health Resources Fund are jointly supporting this development. A further broadening of the scope of the project into applied science areas will likely result from isotope production using the main proton beam with subsequent processing in the radiochemistry area.

In conclusion, I should like to pay tribute to my predecessor as Chairman, the Honourable Mr. Justice Angelo E. Branca, who guided TRIUMF through its formative period.

W. M. Armstrong

Chairman of the Board of Management

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SYNOPSIS OF THE YEAR

PREFACE

Several major events took place in this our second year since the funding of our project. On May 5th, in perfect weather, we were honoured by the presence of the Honourable Jean-Luc Pepin, Minister of Industry, Trade and Commerce, at a tree-planting ceremony at TRIUMF Circle. The ceremony coincided with our Annual Meeting at which invited papers were given by K.M. Crowe (Lawrence Radiation Laboratory), E. Zavattini (CERN and Brookhaven National Laboratory), A.M. Poskanzer (Lawrence Radiation Laboratory), and S. Devons (Columbia University).

Not many months later, in October, we moved into the TRIUMF Office and Laboratory Building. We are grateful indeed to the Physics Department of the University of British Columbia for generously providing the space to build up our group and for making us feel at home. Our new quarters have given the project a greater coherence and a centre for all participants. The sylvan surroundings of our site are much appreciated, though next year the relative quiet will be disturbed when excavation of the hole for the accelerator commences.

The magnet design has been completed and contract negotiations are now under way; it is gratifying that there will be a very high Canadian content in the contract. The design of all aspects of the cyclotron, beam lines and overall facility has progressed most satisfactorily and on schedule. During the year the decision was taken to build a full-scale model of the central region of the cyclotron. It is expected that this will result in a considerable saving of time during the commissioning phase of the cyclotron. The work of our Engineers reached its peak towards the end of the year; conceptual studies are increasingly being replaced by detailed drawing assignments.

Studies directed towards the establishment of tolerances in the various machine parameters have led to a better realization of the full potential of TRIUMF in energy resolution and in maximum beam current possible at various energies. These possibilities are most exciting and no doubt our Users will make full use of them in the course of time.

J.B. Warren
Director

1. ORGANIZATION

During the year there have been a number of changes on both the Board of Management and the Operating Committee.

1.1 Board of Management

The Honourable Mr. Justice Angelo E. Branca resigned as Chairman and member of the Board following his retirement from the Board of Governors of Simon Fraser University. Mr. Allan M. McGavin resigned from the Board on being elected Chancellor of the University of British Columbia. Their services and advice during the critical organizational period were most valuable and were much appreciated. The vacancies on the Board were filled by Mr. Cyrus H. McLean and Mr. R.M. Bibbs as representatives of Simon Fraser University and the University of British Columbia, respectively.

Deputy President W.M. Armstrong of the University of British Columbia was elected Chairman of the Board.

The constitution of the Board is now as follows:

University of Alberta:	Dean Kenneth B. Newbound Dr. J.T. Sample President Max Wyman
Simon Fraser University:	Mr. Mark Collins Dean Lionel Funt Mr. Cyrus H. McLean
University of Victoria:	Dean J.L. Climenhaga The Hon. Mr. Justice J.G. Ruttan Dean R.T.D. Wallace
University of British Columbia:	Prof. W.M. Armstrong (Chairman) Mr. R.M. Bibbs Dr. G.M. Volkoff (Secretary)

1.2 Operating Committee

Dr. B.D. Pate of Simon Fraser University went on sabbatical leave to Orsay and his place was taken by Dr. R.G. Korteling.

The Committee (alternate members in parentheses) is now composed of:

Dr. J.B. Warren	Chairman	
Dr. R.G. Korteling	Simon Fraser University	(Dr. A.S. Arrott)
Dr. G.C. Neilson	University of Alberta	(Dr. W.K. Dawson)
Dr. R.M. Pearce	University of Victoria	(Dr. L.Robertson)
Dr. E.W. Vogt	University of B.C.	(Dr. K.L. Erdman)
Mr. J.J. Burgerjon	Chief Engineer	

Mr. J.E.D. Pearson of the UBC Department of Physics resigned as Interim Secretary to the Committee after having served during the first eighteen months of operation. Mr. N. Brearley has taken his place as Secretary.

2. PLANS FOR THE TRIUMF FACILITY

The five Users Groups have spent the year in formulating their requirements as far as experimental facilities are concerned and in particular in discussing with the Building Committee the sizes, shapes and services of their respective areas. In consultation with the Operating Committee, they are now engaged in determining a schedule for the availability of the various proposed beams from the cyclotron and for installation of the various experimental facilities. Members of the groups are listed in Appendix A.

2.1 Meson Users Group
(G. Jones, University of British Columbia, Chairman)

A conceptual layout for the meson area involving the use of two meson production targets in the proton beam has been developed.

From the first target two beam lines are envisaged. One will be used for transmitting to the experimental area pions in the energy range 100-250 MeV, and the other for pions of energy below 100 MeV. Since these channels will represent the high resolution pion facilities in the project, they will be associated with the first pion production target along the proton beam line, a target of thickness corresponding to 4 g/cm^2 of carbon. In order to maximize the positive pion flux available from this target, it is intended to have the ability to use water as a target material. In such a target the primary production mechanism is the well-known $p + p \rightarrow d + \pi^+$ reaction.

The second meson production target will be thicker (about 20 g/cm^2 of carbon, equivalent) and utilized, in conjunction with appropriate transport systems, for the production of "stopped" pions and muons in addition to providing a high intensity lower energy pion beam for bio-medical use.

2.2 Radiochemistry Users Group
(D.C. Walker, University of British Columbia, Chairman)

During the year plans for the Chemistry Annex building were developed. An area of 4000 sq ft is devoted solely to radiochemical laboratories together with two hot cells for handling very active materials. The laboratories are designed in such a way that future expansion can be readily accommodated.

The neutron target will include the main proton irradiation facility. However, for more controlled studies of reactions under proton bombardment a facility will be provided adjacent to the neutron beam dump in the P Area. Meson irradiation will be carried out at suitable places on the meson secondary beams.

2.3 Slow Neutron Users Group
(D.W. Hone, Royal Roads Military College, Chairman)

The requirements of the group were outlined in a report issued at the beginning of the year. The minimum thermal neutron flux expected is about $(10^{12}/4\pi)$n cm^{-2} sec^{-1} sr^{-1} which, for a 2 deg cone, is equivalent to about 7.6×10^7 n cm^{-2} sec^{-1}. Thermal energies will be required in all beam ports. In addition, there will be one port having a flux peaked at 0.125 eV (approximately 1500°K) rather than at the normal thermal energy of about 0.025 eV. No provision is being made for purification of the beams; experimenters are expected to make their own arrangements for taking cadmium-difference measurements, for example.

Five beam ports are planned. Two ports corresponding to the two different energy peaks (thermal and 1500°K) will be used for neutron diffraction studies of magnetic structure. These ports will have openings of sizes up to about 2 in. by 6 in. and may be as much as 20 ft in length, thus giving a cone of one-half degree, assuming uniform cross-section along the length. A third port similar to the preceding will be used for neutron diffraction studies of crystal structures. One port is required for neutron capture γ-ray spectroscopy, and a fifth port will be used for neutron scattering spectroscopy.

2.4 Radiobiology and Radiotherapy Users Group
(J.M.W. Gibson, B.C. Cancer Institute, Chairman)

Grant funds of $20,000 were sought to carry out an "Engineering Design and Cost Study for a Radiobiology and Radiotherapy Facility Using a Negative Pi-Meson Beam from TRIUMF". The National Cancer Institute approved a grant of $16,000, plus additional funds for travel as required, with the recommendation that Dr. G.F. Whitmore be called in as a consultant on the radiobiological aspects of the project.

A preliminary application was made to the Health Resources Fund for a grant to cover half the total cost of the proposed Radiobiology-Radiotherapy Laboratory. This grant was approved in principle in April 1969. Further funds will be made available by the B.C. Cancer Treatment and Research Foundation.

In consultation with Dr. Whitmore the laboratory was increased from two to three storeys and, to fit in with the overall TRIUMF plans, the upper floor was enlarged. The increase in size plus an increase in the shielding required has increased the estimated cost from $488,000 to approximately $700,000. The Health Resources Fund have indicated that they will be prepared to increase their grant accordingly.

Part of the grant from the National Cancer Institute has been used to cover the cost of the basic design of the beam transport system required to deliver a suitable beam of negative pions to the proposed laboratory. This design is now well advanced.

2.5 Proton Users Group
(W.C. Olsen, University of Alberta, Chairman)

Discussions were held concerning the general plan for the proton area and the shielding problems that will exist there, with particular emphasis on costs and priorities. Attention was also devoted to major facilities for the proton area, such as the beam lines into the area, beam dumps and computers.

Proposed experimental facilities for the proton area include: a scattering chamber with time-of-flight extension arms for heavy-particle identification and the study of high isobaric spin states in fission fragments and other charged particle reactions; liquid hydrogen and deuterium targets for the production of secondary beams of unpolarized and polarized neutrons and of polarized protons; a pion spectrometer for the study of pion production by neutrons and protons; a medium resolution, large solid angle, magnetic system for the study of elastic, inelastic and quasi-elastic proton scattering; a high resolution proton spectrometer to exploit the extremely good energy resolution (ultimately expected to be ±25 keV) of the primary proton beam and an irradiation facility for activation studies.

The proton area will be divided into two regions: the 10 μA region into which proton beams of up to 10 μA may be directed, and the 1 μA region, which will accommodate beams limited to a maximum intensity of 1 μA. Each of these beams will be stopped in external beam dumps.

3. CONSTRUCTION

The Office and Laboratory Building was essentially completed in October. The contract for construction was awarded to Stevenson Construction Co. Ltd. in the amount of $521,000, and work on the building commenced in February. Supervision of construction was provided by G.E. Crippen & Associates, assisted by the Department of Physical Plant, University of British Columbia.

The major effort on the main building during the year has been directed towards defining the requirements for the cyclotron and primary beam lines, the service annex, the chemistry annex, and the medical facility. The gross area of the building was reduced some 20 per cent, and a number of features were deferred, to meet budgetary requirements. The building was moved 10 ft to the west to make room for a possible on-site electrical sub-station at the east end of the high bay. The goal is to present a final architectural scheme early in 1970 and work on the selection of materials, and the preparation of drawings is now in hand.

Figure 3.1 shows the relationship of the main building to the existing buildings, and indicates the disposition of its component parts. An elevation of the building is shown in Figure 3.2.

Early in 1970 the contract for excavation work related to the machine vault and main building will be let, following which tenders for the building shell, in which the assembly of the cyclotron will take place, will be called.

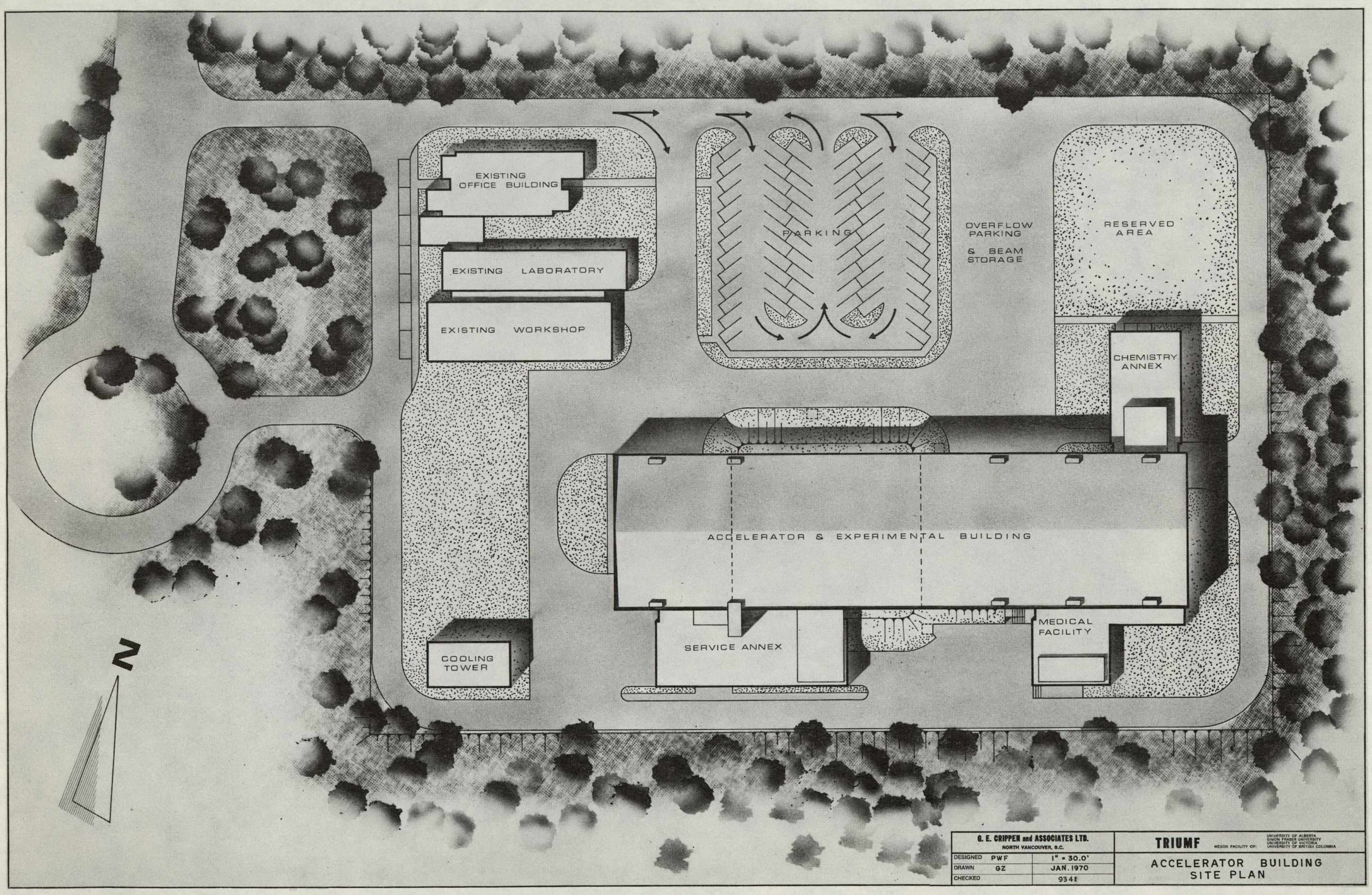

Figure 3.1 Plan view showing site development

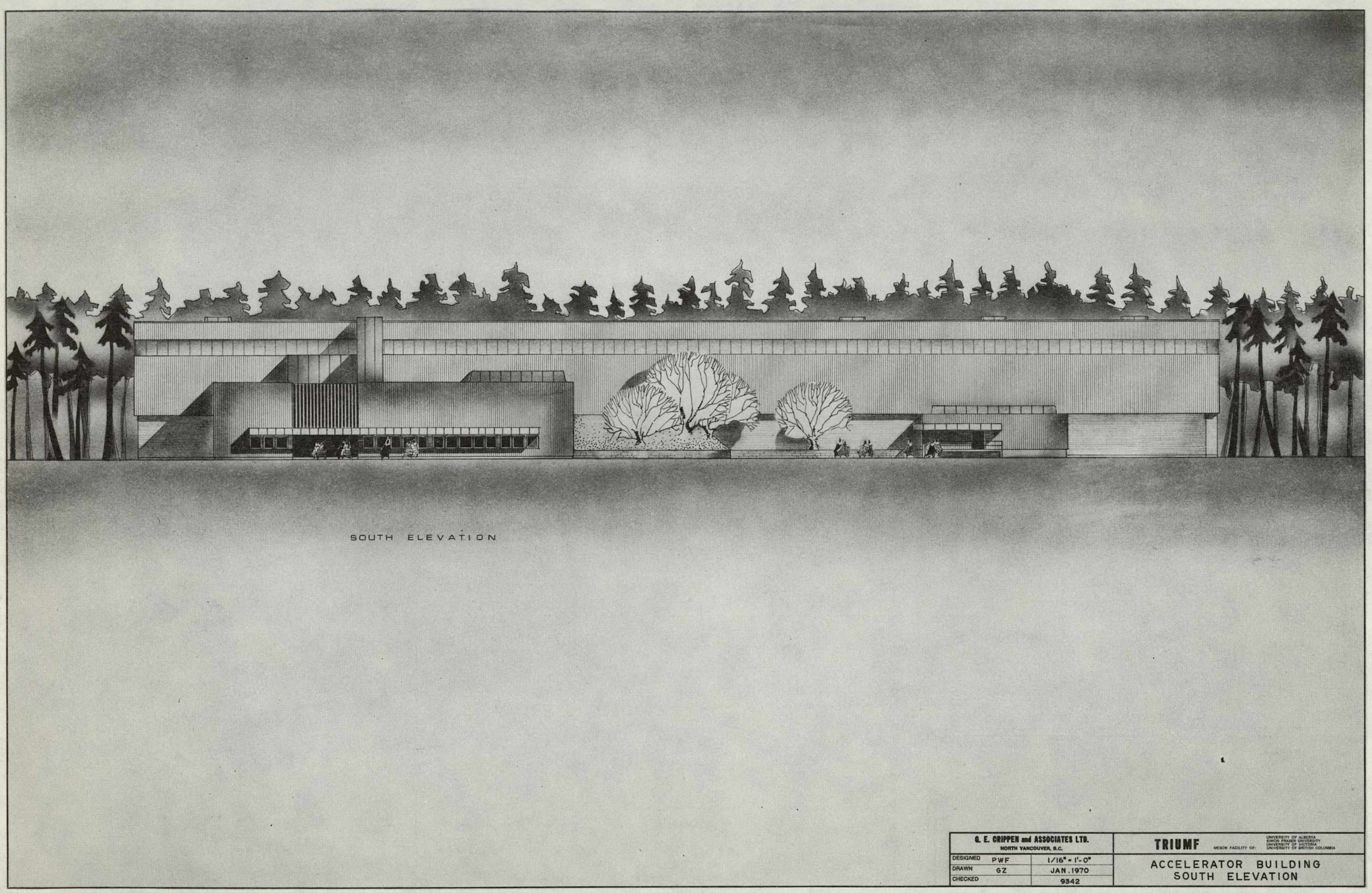

Figure 3.2 South elevation of the main building

4. CYCLOTRON AND ANCILLARY EQUIPMENT

The magnet design work was completed on schedule in preparation for the calling of magnet tenders. Applying the results of the H^- dissociation experiment [Nucl. Instr. and Meth. 74, 333 (1969)] to further magnetic field measurements, indications are that beam power loss due to that cause will now be reduced to 6%. With gas-stripping beam loss still 4%, the total beam power loss in the machine will be 10%, as compared with the original design value of 20%.

Model studies have shown that it will be possible to excite the resonators in the third harmonic mode of the fundamental RF waveform. This adds a unique feature to the TRIUMF design, as adding the third harmonic results in a flat-topped waveform with increased phase acceptance and subsequent improvement in properties such as energy spread and duty factor. Modifications have been made to the machine design so as to accommodate the third harmonic component.

It has been necessary to increase the machine diameter to 314 in. in order both to improve focusing and to decrease the average magnetic field and thereby reduce electric stripping of the H^- ions. As a result, a heavier support structure will be required in order to accommodate the increased atmospheric load, now about 2700 tons. At the same time, the magnet levelling jack system was replaced by a less costly static system which is capable of absorbing moderate earthquake shocks without damage to the machine components.

Allowance has been made for the incorporation of a maintenance bridge which can be withdrawn from a pocket in the vault wall and which will bridge the machine from centre post to return yokes in the jacked-up condition (Figure 4.1). This allows a man to do maintenance operations swiftly and, if necessary, with his body protected by 2 in. of lead.

The optimum orientation of the resonators in relation to the magnet, and of the magnet in relation to the vault, have been fixed,

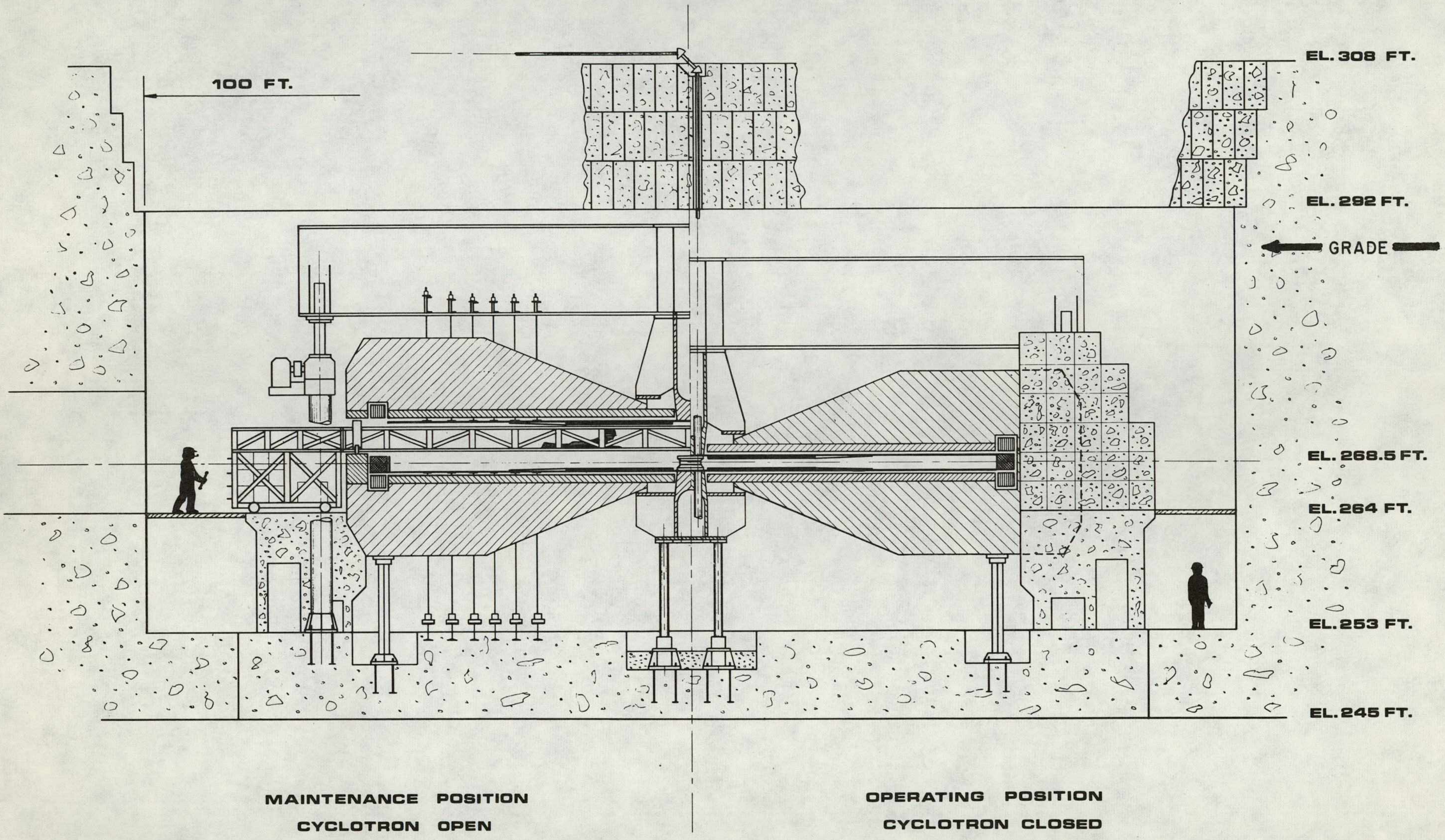

Figure 4.1 Vertical section through the cyclotron showing the maintenance bridge

as well as the position of the combination magnet for Beam Line 1. The machine and vault layout is shown in Figure 4.2. Appendix B lists the principal machine specifications.

4.1 Magnet

4.1.1 Model Studies

On April 1, 1969 the Mk VI-1 (scale = 20:1) model was finally shaped in such a way as to achieve a magnetic field that was isochronous to ±100 G and that focused the H^- beam to 505 MeV with a total beam loss of 12% due to H^- dissociation. The detailed design of the magnet was started on the basis of these results.

Further adjustments to the Mk VI-1 pole piece have made possible the beam characteristics in the following table:

Radius 500 MeV	Beam Loss at 500 MeV due to electric dissociation	Maximum kinetic energy	Beam Loss at maximum kinetic energy
312.5 in.	6%	500 MeV	6%
306.0 in.	20%	540 MeV	55%

In order to obtain this variability of energy the field gradient produced by the trim coils must increase with increasing radius.

In October a six-sector model based on the detailed design of Dilworth, Secord, Meagher and Associates (DSM) was assembled and its field measured. The dimensions of the cyclotron magnet had been adjusted to take into account the extra perforations due to the tie rods and bolts that were not included in the Mk VI-1 model. The magnetic field of the new model reproduced the field

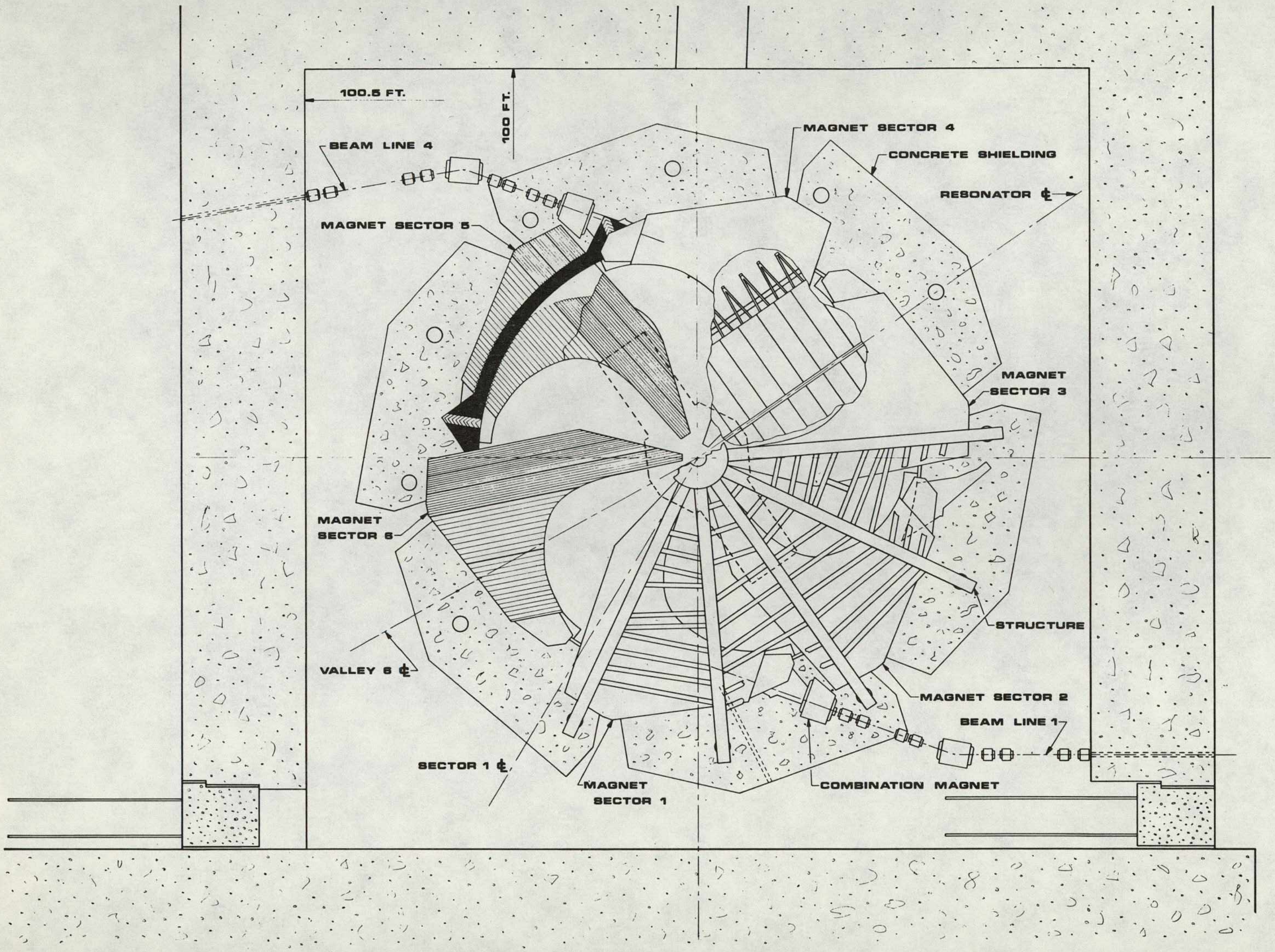

Figure 4.2 Plan of the cyclotron in the vault. The dotted outline of the centre indicates the area of the Central Region Model.

of the Mk VI-1 model to better than ±1%. A photograph of the model is shown in Figure 4.3.

The magnetic field in the 8:1 central region magnet model has been tailored to a satisfactory shape by using wedges which project into the main magnet gap. These wedges are compatible with the RF cavity design, although their use implies a special design for the four central sections of the cavity.

4.1.2 Magnet Construction

To make possible an increase in the Canadian content of magnet fabrication and at the same time reduce cost, the return yoke was redesigned for 3 in. and 5 in. plate. Each sector of the magnet is made up of ten pre-assembled blocks, each of which weighs less than 100 tons, as dictated by the maximum crane capacity. The pole pieces are made from 10 in. plate which will be flame cut to the required shape.

The support structure will be made of mild steel which affects the magnetic field of the magnet. These effects have been measured on the 20:1 model, and it has been determined that they can be corrected during the shimming of the cyclotron magnet.

The main coil detailed design has been started by DSM following the conceptual design established by William M. Brobeck & Associates (WMB). There is an economic advantage in using welded rather than bolted connections, and it appears that the number of turns should be made as small as possible consistent with other limitations.

Trim and harmonic coils were modelled on the 20:1 magnet and their design requirements were reappraised. The

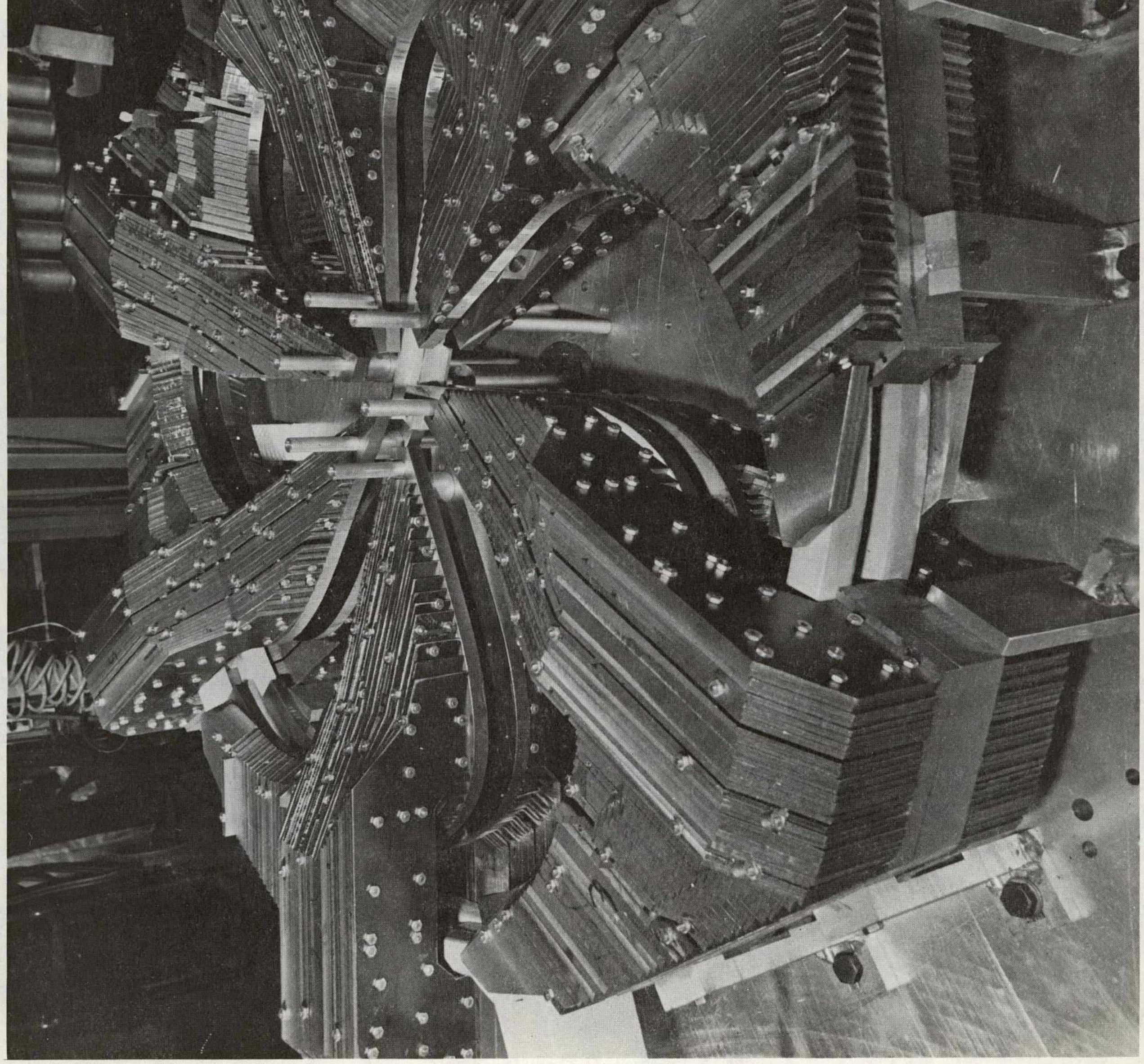

Figure 4.3 A photograph of the Mark VI-1 (scale = 20:1) magnet model

results showed that fewer ampere-turns would be needed, so that the power consumption has been substantially reduced and direct water cooling is no longer required.

The combination magnet will be designed as an H-frame, uniform field, rectangular magnet which will be operated at 0.7 kG for 500 MeV and at 10 kG for 150 MeV. The H-frame was chosen as it appeared from model tests to affect the main field less when energized than the C-frame design.

4.2 Ion Source and Injection System

Design studies, scheduling and procurement for the ion source and injection system of the Central Region Model are now in progress. Similar studies for the main accelerator have also commenced.

WMB completed a conceptual design study of the ion source and injection system. The result of this study is being used as a first-order solution of the design problem. Cost, scheduling and technical support estimates made in this study are being used as first-order quantitative estimates of those aspects of the work.

During the year it was decided to increase the injection energy from 150 keV to 300 keV in order to reduce beam blow-up due to space-charge effects and to obtain a smaller emittance. The beam transport line requires multiple focusing elements; electrostatic lenses rather than quadrupoles will be used in order to keep costs down.

Plans are being made to include a facility for chopping and bunching the beam in the injection line. This will result in an increase of average current and meet the requirements for separated orbit operation. In addition, a fast deflector may be included in order to permit pulsed beam operation.

Negotiations were started with the Cyclotron Corporation, Berkeley, California, with a view to purchasing a version of their design of an Ehlers-type H^- source, guaranteed to deliver 2 mA of H^- at 12 keV with an emittance of approximately 2.1 cm rad $(eV)^{\frac{1}{2}}$.

4.3 Beam Dynamics

4.3.1 Central Region

As mentioned above, a major design change this year was the increase in injection energy to 300 keV in order to improve cyclotron performance. The higher energy should permit a 40% increase in the RF microstructure duty factor, through better orbit centring and reduced transverse electric forces at the dee gaps. It should also reduce space charge effects and ease injection through the strong fringe field of the magnet. The larger radius of the initial orbit also allows the hollow centre post to be replaced by a solid one (Figure 4.4), giving a stronger though asymmetric central support. The equipotential lines shown in the figure, representing the accelerating field between the dees, were computed using a three-dimensional relaxation code [D. Nelson, H. Kim and M. Reiser, IEEE Trans. Nucl. Sci. NS-16 (3), 766 (1969)]. This method gives the values both off and on the median plane, and it is not only capable of greater accuracy than electrolytic tank measurements but enables the effects of modifications to be more quickly determined. The first orbit calculations with this field, recently made, confirm the correct positioning of the first accelerating gaps and the centring of ions at the peak of the RF voltage wave.

The vertical forces at the dee gaps are an important factor in the central region because of their strength and phase dependence. A computer code was developed

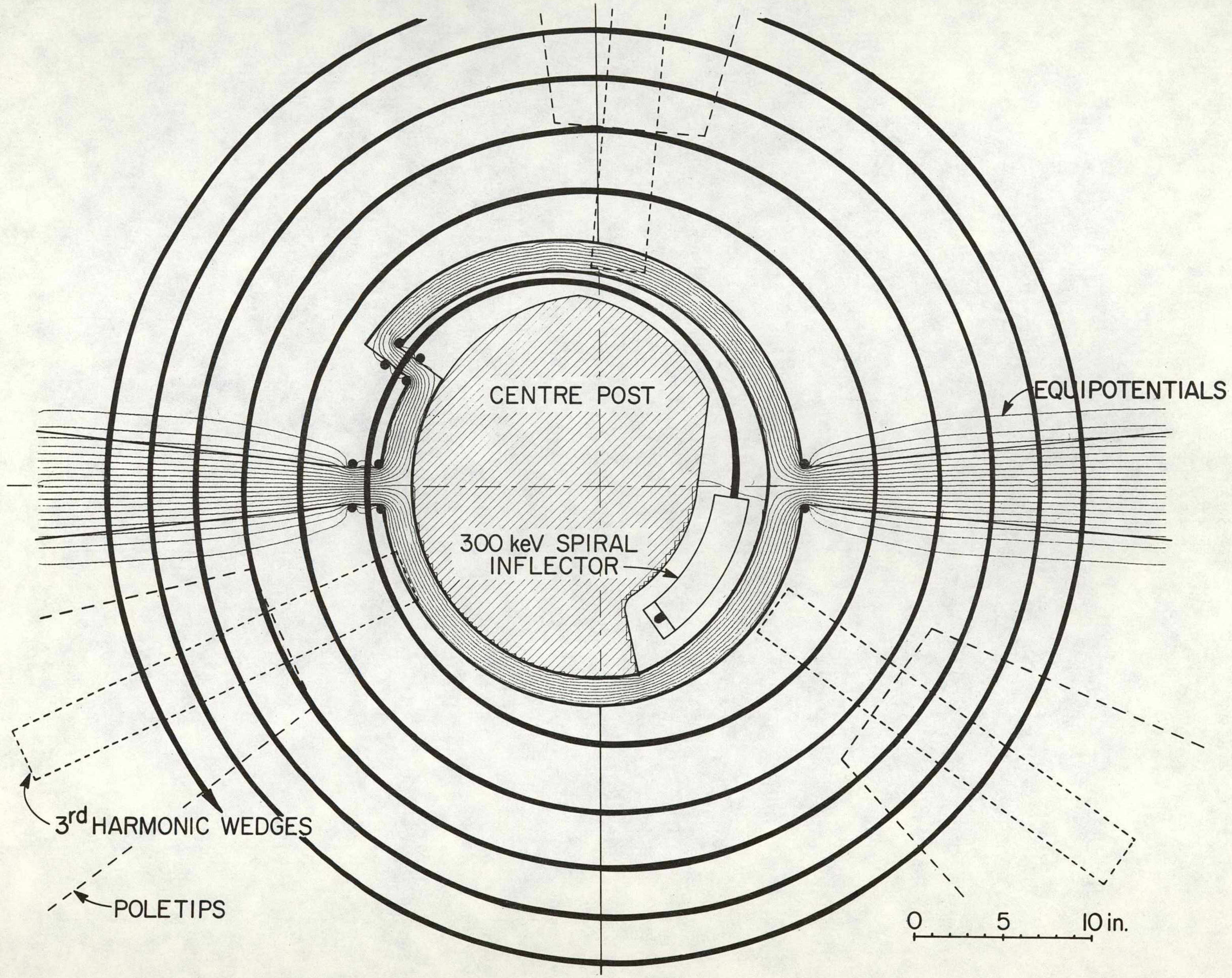

Figure 4.4 Orbits in the central region of the cyclotron

to track beams from injection through these gaps, using the standard thick lens approximations [M.E. Rose, Phys. Rev. 53,392 (1938); B.L. Cohen, Rev. Sci. Inst. 24, 589 (1953)], and to match them to the constant focusing in the cyclotron ($\nu_z \simeq 0.3$) to produce a constant envelope beam there. The injection admittance thus determined varied very little in shape over a phase range +60 deg to -15 deg (-5 deg for 150 keV) or to -45 deg with 20% third harmonic (180 deg out of phase) added to the RF. A preliminary study of the vertical ion motion through the dee gaps using fields calculated by the relaxation code has since shown certain deviations from the thick lens formulae; these studies continue.

The relaxation code is also being used to determine the field in the spiral electrostatic inflector - a problem not readily amenable to model measurement. A preliminary insight into its optical focusing properties has been obtained by tracking the beam emittance (a six-dimensional hyperellipsoid in phase space) through a field obtained by analytical expansion about the central spiral.

Measurements of the magnetic field around the axis show that it is significantly non-uniform over the height of the inflector. Also the off-axis injection of the beam leads to its spiralling inwards by about 20% as it approaches the median plane. These effects will be dealt with by modifications to the inflector design, and possibly by special deflectors as well.

4.3.2 Orbit Dynamics in the Cyclotron

The results obtained from the model magnet studies are described in Sec. 4.1. These rely on certain improvements in interpolation, smoothing and isochronism which have been made in the magnetic field analysis and orbit codes.

Anomalous orbit properties at the field measurement radii (e.g. spikes in ν_z of ±0.1) were traced to inaccuracies in the radial field gradients produced by the single four-point interpolation technique. They were found to be best removed by evaluating the gradients half-way between the grid radii and making a second four-point interpolation in that array.

Because the field measurements are Fourier analyzed independently at each radius, some noise appears in the radial variation of the Fourier amplitudes and phases. This is removed by a technique similar to Verster's [N.V. Verster and H.L. Hagedoorn, Nucl. Inst. and Meth., 18, 19, 327 (1962)] except that the phase changes are required to be approximately the same for all harmonics at each radius to make the corrections physically reasonable.

The original field correction procedure to give isochronous equilibrium orbits [M.M. Gordon and T.A. Welton, ORNL-2765], dealing with only one measurement radius at a time, was found inadequate for TRIUMF, where the deeply scalloped orbits cross several such radii. Instead, the effect of changing the average field at one radius on the periods of neighbouring equilibrium orbits is computed; this is repeated for other radii and the resulting system of linear equations is solved for the required field changes. A hundredfold improvement has been obtained - the integrated phase-slip from 0 to 500 MeV being now better than 5 deg.

A program has also been written to calculate the trim coil currents required to isochronize a given measured field using measured trim coil fields. A least squares method is used, similar to Berg's [R.E. Berg, H.G. Blosser and M.M. Gordon, IEEE Trans. Nucl. Sci. NS-13(4), 394 (1966)], except that a small fraction of the sum of the squares of the currents in the minimization is included as a much faster method of avoiding high current solutions, yet with negligible effect on the isochronism obtainable. In a test case with 54 trim coils the error bumps remaining did not exceed 3 G-in.

4.3.3 High Energy Resolution Beams

When higher resolution is required, slits will be placed at low energy to limit the radial emittance, enabling 6 μA to be extracted with ±150 keV resolution. With the planned addition of third harmonic to the RF cavity separated-turn acceleration will be possible out to maximum energy with the magnet and RF control technology available today; 30 μA should be obtainable with ±25 keV total energy spread and a ±7 deg phase spread. A third scheme, using slits at the final radius, can give two high current, low resolution beams and a simultaneous low current beam with ±60 keV total spread. These performance figures assume that space charge effects are negligible - a matter at present under study.

4.4 RF System

During the course of the year the RF group constructed six different half-scale models of the resonator sections from ½ in. plywood coated on the active cavity surfaces with 0.005 in. of soft copper sheet having a measured conductivity equal to that of electrolytic copper. The models varied from a full half resonator section (one side of the accelerating structure) to resonators only sufficiently large to allow measurements to be made of the voltage gradients at the centre post in the proposed central region geometry.

Mechanical design of the resonators has been undertaken by DSM, with the assistance of WMB. They will be fabricated from silver-aluminum roll-bond sheet in which cooling water channels are formed. No insulators are used, the resonators being cantilevered from supports at the tie rod locations. Tuning is done by means of adjustable flaps on the ground plane at the high voltage end. In order to reduce the physical size of the resonators they are operated at 23 MHz, the fifth harmonic of the ion rotation frequency, so that $\lambda/4$ is about 9 ft.

The allowable mechanical deflections required to maintain the specified voltage tolerances have been determined from tests on models, and have been found to be within the capability of the design. It was also shown that a single coupling loop feeding one resonator will be sufficient because of the high hot arm-hot arm capacitance and the tight coupling of the resonator system.

Further tests have shown that it is possible to couple both the fundamental and the third harmonic into the cavity, thus achieving a flat-top waveform. In order to maintain a high Q for the third harmonic the shape of the resonator at the machine perimeter will be rectangular rather than tapered as was originally proposed.

Eight full-size prototype resonator sections have been ordered, and a 200 kW amplifier is under construction. These will be used for tests in the Central Region Model.

4.5 Vacuum System

A 20:1 scale model of the TRIUMF vacuum chamber was built and used for tests of chamber pump-down performance with two different pumping system designs. Large liquid nitrogen trapped oil diffusion pumps, and a 20°K cryopumping system having auxiliary means for pumping hydrogen, were compared for their ability to achieve the design criterion of an equivalent nitrogen stripping cross-section pressure of 7×10^{-8} Torr after 15 hours of pumping.

Measurements have been made of the outgassing rates of stainless steel and of the gas loads from various radiation-resistant elastomers, in particular polyurethane. The predicted pump-down performance based on measured outgassing rate data, has been compared with the observed performance of the model chamber and its system. The effect of different chamber exposure conditions on pump-down time has also been measured. The results of these investigations are discussed in Report TRI-69-7.

A conceptual design study of the vacuum pumping system by Wright Engineers Limited of Vancouver, Arthur D. Little, Inc. of Cambridge, Mass., and TRIUMF was issued as Report TRI-69-9. Estimates of capital and annual operating costs were made for two systems, 20°K cryopumps with auxiliary trapped diffusion pumps and large liquid nitrogen trapped oil diffusion pumps. The study recommended that the cryoline concept using a turbine cryogenerator capable of supplying both the 20°K and 80°K load should be adopted. The use of auxiliary liquid nitrogen trapped oil diffusion pumps has been studied for pumping hydrogen and helium both during normal operation and resonator bakeout. The traps located behind valves are to be used for pumping water vapour during the defrost cycle of the cryoline. Although the need for this type of pumping system has been established, there is still interest in using an oil-free method of pumping hydrogen, such as titanium sublimation pumping, during normal operation in order to eliminate any possibility of contamination of the chamber in the event of a catastrophic accident.

4.6 Extraction

Field measurements on the Mk VI 20:1 scale model accelerator magnet have been used to determine the optical properties of the extracted beams passing through the fringe field for extracted beam energies from 150 to 500 MeV. Stripping foil positions as a function of energy and transfer matrices for these trajectories have been calculated for a number of positions of the cross-over point for the two directions of motion of the ions in the accelerator. The components of the transfer matrix vary little with position of the cross-over point. For the case where the direction of the orbits in the accelerator is opposite to the pole spiral, there is a smaller variation in the matrix elements with extracted beam energy. However, the direction of the orbits has been chosen to be the same as the pole spiral because this requires a smaller angle of bend in the combination magnet to make the 150 MeV and 500 MeV trajectories colinear, and thus enables a narrow extraction horn to be fitted to the accelerator vacuum tank. Of the six possible beams, the orbit direction chosen will permit four to be extracted over the full energy range and two, in the region of the resonator gap, with a reduced energy range. Studies of the optical properties of these orbits show that second-order effects are small for the beam emittances expected from the accelerator.

4.7 Beam Transport

The preliminary design (TRI-68-8) of the transport system for proton beam line 1 was reviewed by WMB who recommended that quadrupoles be of 21 in. effective length with 6 in. or 8 in. apertures, that the extraction section of the system should consist of a single 30 deg bending magnet rather than two 15 deg bending magnets, and that to avoid edge focusing rectangular rather than wedge bending magnets should be used.

These recommendations have been investigated using updated fringe field data and a system geometry compatible with the present layout of the vault and experimental areas. The 30 deg bending magnet has been replaced by a 19.8 deg bending magnet and the location of the first pion production target has been displaced downstream by approximately 26 ft. Conceptual design studies are now in progress for the Beam Line 1 tunnel.

Extraction systems which use a single bending magnet to compensate for dispersion introduced by the fringe field, followed by achromatic bending sections for momentum analysis, have been considered for the 1 μA and 10 μA beams to the P Area.

A system has been designed to transport a pion beam into the medical area, and conceptual design studies are under way for the proton targets, for target shields and for various channels to provide high resolution π beams and beams of stopped π and μ. A long helical quadrupole has been studied (TRI-69-10) as a potential component of a μ channel. The system was found to have stronger focusing qualities than a comparable alternating gradient system, particularly at large displacements, and to have a large acceptance. However, the shape of the acceptance volume in phase space was found to be unsuitable and the system was discarded.

A general first-order beam transport program (TRANS) has been written following the pattern of the program TRANSPORT; and ACCEPTANCE, a program which calculates the phase space acceptance of a beam transport system, was written and issued as a TRIUMF Report (TRI-68-7).

A three-dimensional magnetic field surveying system has now been completed and tested. The important effect of probe motion on field readings has been studied and a method of treating the resulting errors found. A computer program to edit and convert the recorded data has been written.

4.8 P Area Beam Dumps

There are three 'levels' of dump required: 10 μA, 1 μA and 1 nA. The first two need spheres of the order of 30 ft in diameter, and attention has been directed mainly to them since they are large enough to affect the building plans.

A 500 MeV proton can be stopped in less than a foot of iron by a combination of nuclear and ionizing interaction. However, the nuclear interactions give rise to neutrons having energies up to that of the original proton. These lack the ionizing property of the protons and, in a sense, are never stopped but can only be disposed of exponentially. The nuclear interaction cross-sections for these high energy neutrons in all materials are relatively low, so that a relatively large thickness of shielding material is required for any given reduction in intensity. Further, the neutrons are not confined to a beam but are emitted in all directions; thus a large volume of material is needed. The neutrons from a 10 μA 500 MeV proton beam, stopped in just about any material, require an attenuation factor of the order of 10^{-13} to 10^{-14}. This would require a sphere of concrete about 53 to 59 ft in diameter; denser material such as iron or iron ore can be used alone or mixed in with concrete for a reduction in size and cost.

There have been several concepts explored, the latest of which is shown in Figure 4.5. It is basically a pot of iron ore, of density 4 g cm^{-1}, with a copper target inside a concrete enclosure near the bottom. The pot is roughly cylindrical with a diameter of 22 ft and a depth of 22 ft. The inset shows a possible location for the 10 μA dump, outside the north wall of the P Area. This concept and others are now under review by the Proton Users Group.

4.9 Neutron Facility

A concept has been evolved for the final target facility. The primary functions of the final target are: to stop the proton beam, to dissipate the heat generated, and to contain the radiations produced. The principal radiations arise from the very

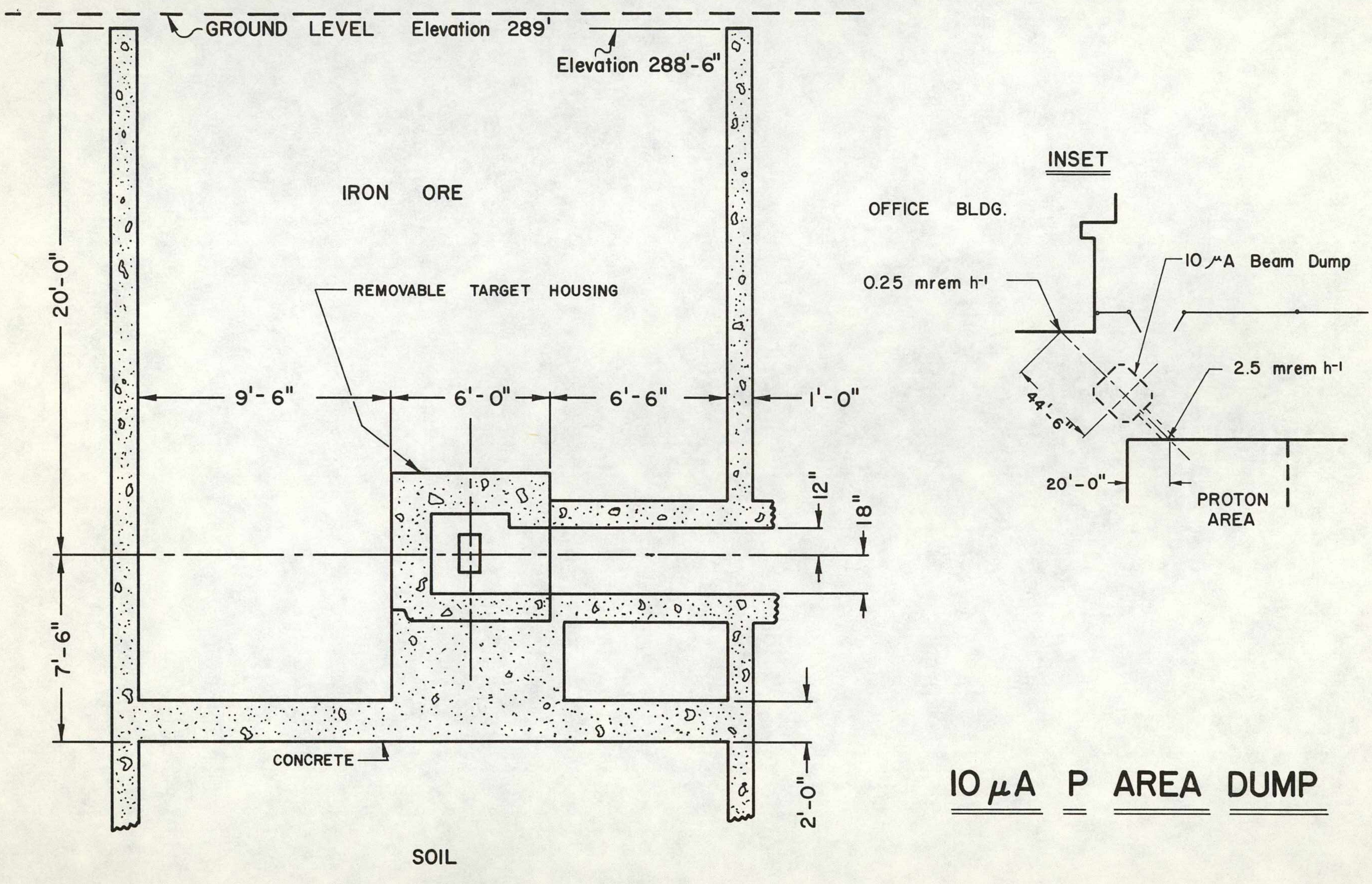

Figure 4.5 Construction and location of 10 μA P-area beam dump

fast neutrons whose penetrating power is greater than radiation encountered in reactors. The secondary function of the final target is to utilize the proton beam, the various parts of the neutron spectrum from very high to thermal energies, and the substantial γ-ray and meson fluxes. A section through the neutron target is shown in Figure 4.6.

In general terms the design features the final target buried at a depth of 25 ft near the bottom of and centred in a large (approximately 55 ft x 55 ft) concrete-walled pool. The principal shielding materials are concentric regions of iron, magnetite and dirt. The magnetite and dirt are saturated with water. There is a central vertical column (approximately 13 ft in diameter) which is made of iron around the target, and of concrete up to the general set-up area at ground level.

The final target itself is liquid metal (isotopic lead or a lead-bismuth alloy) contained in an oxidized zircalloy can (length approximately 20 cm, radius approximately 7 cm). The can is cooled by circulating D_2O and is surrounded by a moderating assembly of D_2O with a reflector of graphite and water. Beam tubes through the vertical column provide access to various radiations. An experimental room on top of the vertical column has thick walls and stops for the beams. The target and moderating assembly are at the bottom of a $2\frac{1}{2}$ ft diameter tube which is perpendicular to the proton beam and inclined at an angle of about 45 deg to the vertical. The upper end of this tube terminates in the side of a vertical swimming pool which is adjacent to the hot cells. The slanted tube is water filled to within about a foot of the target. This tube permits maintenance of the target, modification of the geometry of the moderator, and provides the versatility of a swimming pool reactor. A chamber for production of proton-rich isotopes is provided immediately in front of the target can. An additional proton irradiation facility is being considered for a

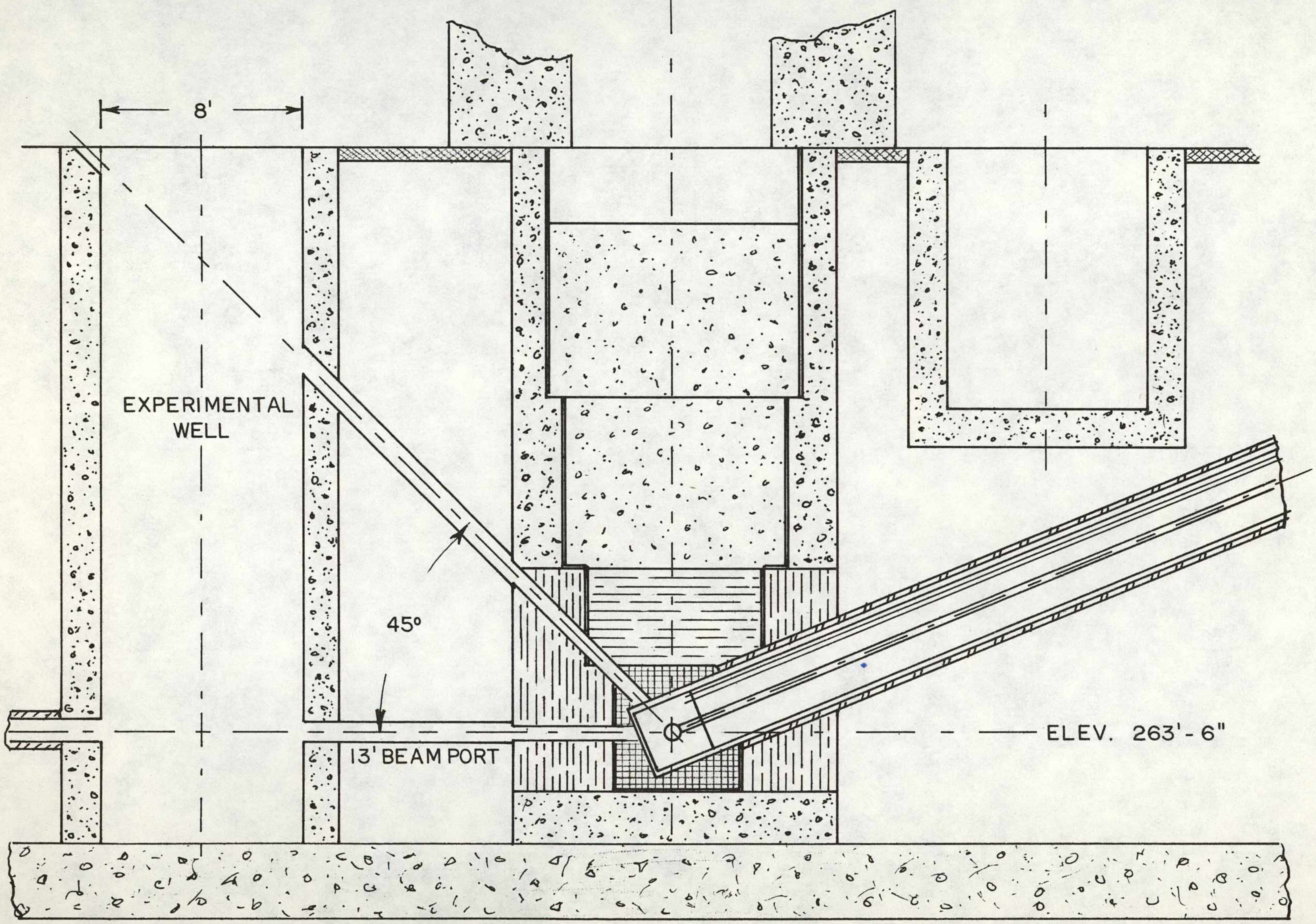

Figure 4.6 Vertical section through the neutron target

position closer to the meson target. A beam tube with a maximum flux of cascade neutrons is in line with the proton beam line on the downstream side of the target can. This tube terminates in a vertical well for the introduction of collimators, samples and detectors. Rabbit tubes enter the moderator assembly, some coming down the slanted water tube into the D_2O, others entering the graphite reflector, and one being a very fast through-tube in the horizontal plane. Additional beam tubes for thermal neutron experiments are either horizontal or at 45 deg to the vertical. The horizontal beams are directed tangential to the target can, pass through vertical experimental wells, and are caught in the main shielding. Diffraction experiments will use horizontal axes and the experimental plane will be vertical. The experimental wells are 8 ft in diameter and are centred about 19 ft from the target.

The flux levels depend upon the proton energy and current, but approximately 1 kW of protons produces 10^{14} fast neutrons sec^{-1} and 10^{13} very fast (cascade) neutrons sec^{-1}. The thermal flux for a D_2O-graphite system is between 1 and 2 neutrons cm^{-2} sec^{-1} for every 10^3 fast source neutrons sec^{-1}. Thus with a beam power of 200 kW unperturbed thermal fluxes of 2 to 4×10^{13} neutrons cm^{-2} sec^{-1} are obtained. At the D_2O-graphite boundary (30 cm outside the target can) where there is 1 neutron cm^{-2} sec^{-1} for every 10^3 fast source neutrons sec^{-1} the epithermal flux group has 1 neutron cm^{-2} sec^{-1} for every 10^5 fast source neutrons sec^{-1}, and the fast group has 3 neutrons cm^{-2} sec^{-1} for every 10^5 fast source neutrons sec^{-1}. At this same point the cascade flux (at 90 deg) is 1/3 neutron cm^{-2} sec^{-1} for every 10^5 fast source neutrons sec^{-1}. In the graphite reflector the epithermal neutron flux decreases with respect to the thermal flux by a factor of five more but the ratios of thermal neutrons to fast neutrons to cascade neutrons remain about the same.

The maximum fast flux is comparable to the maximum thermal flux reaching 2×10^{13} neutrons cm^{-2} sec^{-1} near the target can for a full power of 200 kW into the target. The cascade flux just beyond the target should reach about 10^{12} neutrons cm^{-2} sec^{-1} at full power.

4.10 Control and Instrumentation

A conceptual design study was completed and published in a report (TRI-69-8) which outlines the general philosophy for facility control. Enough detail has been included to indicate the feasibility of the approach. Detailed design has begun in order to implement the approach detailed in the report.

Both personnel safety and machine safety systems will be hard-wired. The personnel safety system will be based on a system of controlled access areas, while radiation levels throughout the facility will be routed through area safety units to central control. Violation of a personnel interlock, or a change in radiation levels beyond prescribed limits, will result in interruption of beam delivery to the entire facility. The machine safety system will be based on beam characteristics. Both relative and absolute beam intensity limits are proposed. A beam shut-off time of about 300 μsec is adequate for machine protection, but personnel protection requires the shortest possible beam shut-off time.

A computer-based scanning and digitizing system is proposed for the ion source and injection system. Such a system will permit fast and flexible data processing, and equipment development will be simplified. The radio frequency will be a fixed reference to which the main magnetic field will be controlled. The main magnet will be regulated by either a current shunt, an NMR probe, or both. Trim and harmonic coils will be current regulated. A scanning system will monitor temperatures by measuring the coil voltages and currents and calculating the coil resistance. Beam diagnostics probes will be mounted at 90 deg intervals, two probes will measure beam current and two will be shadow probes. High energy beam transport optics will be set using one-word memories at power supplies. A slow scanning system will be used to log optics parameters. Diagnostic devices which are proposed include position, profile and intensity monitors.

A completely manual central control system is not practical for this installation since it would involve unreasonable setting times and maintenance requirements for the 300 set points. Computer control which is redundant in CPU and I/O capability has been proposed. Operation communication with devices will proceed through the central control system using CRT-keyboard-shaft encoder stations. An integrated TV display system using standard TV monitors is proposed. TV camera output, computer graphics and analog signals from diagnostic devices all will be handled by the same system.

Few if any control loops will be closed at commissioning. Data logging will be performed by a digital data acquisition system. Set points will be controlled by an operator using a digital link. As machine development progresses, control loops may be closed by computer.

5. SAFETY

Members of the Safety Advisory Committee met with the Accelerator Safety Advisory Committee of the Atomic Energy Control Board in Ottawa in April. A further joint meeting of the two committees was held in Vancouver in June at which all aspects of TRIUMF safety were reviewed. Following this meeting the Accelerator Safety Advisory Committee gave approval in principle to the TRIUMF safety program.

During the latter part of the year the Safety Committee has been concerned with reviewing the building plans from the safety point of view. Close liaison is maintained with bodies such as the Workmen's Compensation Board, the University Fire Department, and the Provincial Fire Marshal's Office.

During the year the Committee concentrated on those decisions, such as the location of emergency exits, required before the plans for the shell of the main building could be finalized. Decisions concerning arrangements within the building which will not be frozen by building design have been deferred for later consideration. The Committee has attempted in all cases to arrive at decisions in keeping with the safety design philosophy but at the same time has sought to reach conclusions which were not unnecessarily expensive or restrictive.

6. CENTRAL REGION CYCLOTRON MODEL

Early in the year it was decided to combine together the various full-scale prototype tests that had been proposed and to build a Central Region Model. The first stage of the model will consist of a vacuum tank with prototype resonators and will be used for studying the RF properties of the resonators under operating conditions. On conclusion of the resonator tests a magnet will be installed and the centre region of the resonators will be modified to permit insertion of the centre post and inflector. It will then be possible to accelerate H^- ions from an external ion source for ten orbits in order to study those beam properties near the centre, such as centring, focusing and stability, which largely determine beam quality throughout the acceleration and deflection process.

At this time the major components for the first stage of the Central Region Model have been designed and ordered: the vacuum tank, the prototype resonators, the vacuum pumping system, the support structure, and the anode power supply for the 200 kW RF power source, the latter to be built in-house. Figure 6.1 shows the detailed assembly of the model.

Tests on the vacuum tank and system are scheduled to commence in February 1970, to be followed by installation of the prototype resonators in May 1970. Tests on the resonators should be completed by October 1970, and the balance of the year's experimental program will be occupied in testing vacuum sealing methods and cryopumping systems. Installation of the magnet should commence in December 1970.

In summary, the Central Region Model will provide a facility on which several cyclotron components, such as resonators, RF power source, vacuum equipment, ion source, injection beam transport components, inflector, resonator centre structure (beam slits) and beam diagnostic equipment, can be tested, and consequently valuable

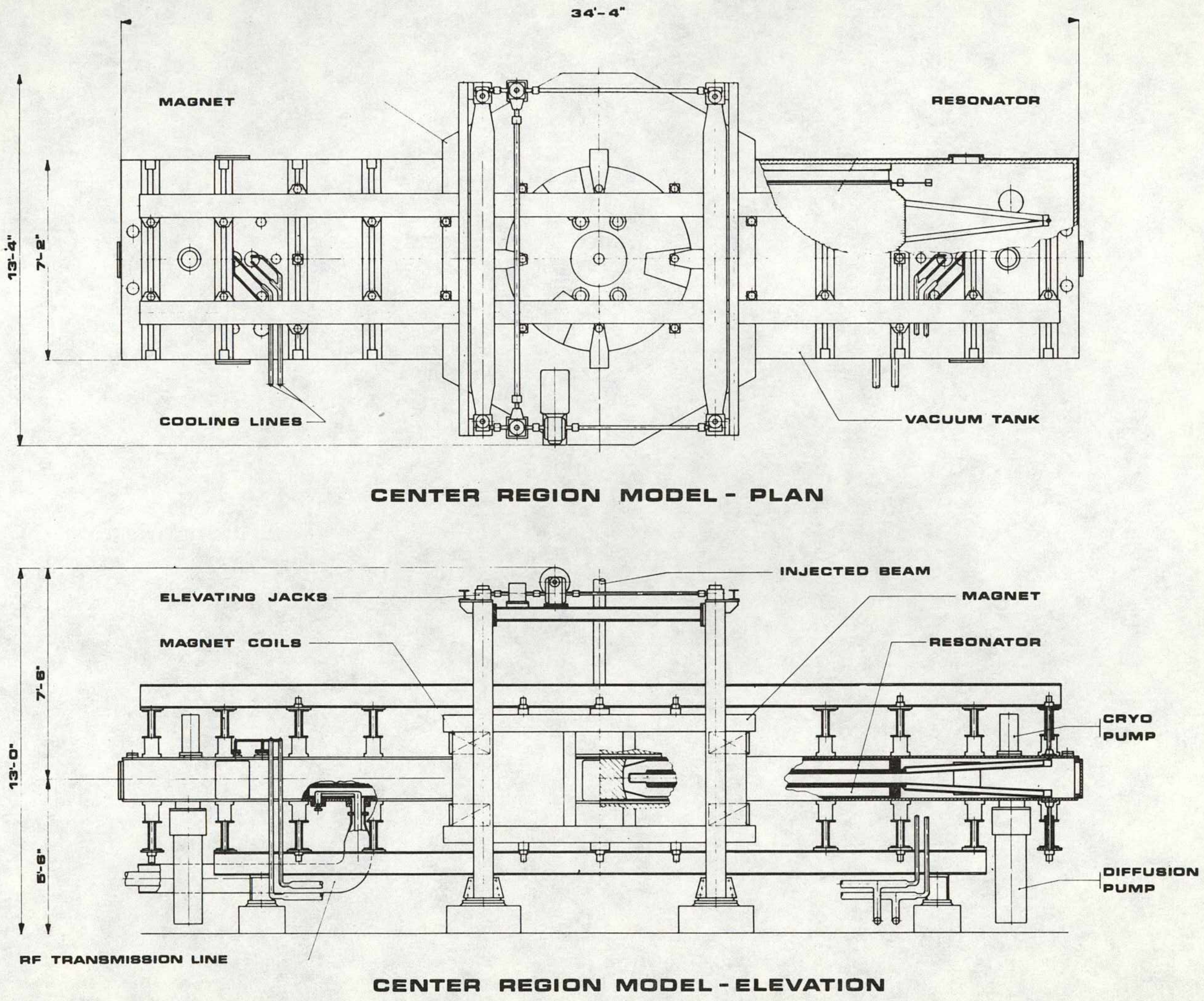

Figure 6.1 Assembly of the Central Region Model. The top of the model can be raised to permit access.

time during commissioning of the machine can be saved. In addition, it will provide a continuing facility for cyclotron improvement studies after the machine becomes operational, thus avoiding interruption of the experimental program.

7. PROJECT MANAGEMENT AND ENGINEERING

TRIUMF's Project Management Office is staffed by engineers on detached assignment from two consulting engineering firms: Shawinigan Engineering Company, Ltd. and Montreal Engineering Company, Ltd., both of Montreal, Quebec. These engineers are responsible for overall project supervision, contract management, accounting, purchasing and expediting, and scheduling. The group was instrumental in reducing delays in the construction of the Office, Laboratory and Workshop building to less than six weeks on a very tight construction schedule. An accounting system has been established which incorporates data from TRIUMF and the four co-operating universities, and from which cash flow projections and reports on expenditures can be generated.

7.1 Engineering

Most of the engineering contracts for the cyclotron during this year were placed with the prime engineering consultants, Dilworth, Secord, Meagher and Associates Limited (DSM) of Toronto, in the form of conceptual, preliminary and detail design assignments. William M. Brobeck & Associates (WMB) of Berkeley, California, have completed several conceptual design studies for special cyclotron and beam transport equipment; while Wright Engineers Limited of Vancouver, in co-operation with Arthur D. Little, Inc. of Cambridge, Mass. assisted in a study on various vacuum pumping concepts. The results of these assignments were reported in Section 4. Engineering for buildings and services is the responsibility of G.E. Crippen & Associates Ltd. of North Vancouver.

The consulting engineers' future effort will, in principle, be concerned with the detail design of the major cyclotron components - magnet cores, coils, support structure, vacuum chamber, resonators, etc., with conceptual design of special cyclotron equipment (e.g. beam probes and stripping foil mechanisms) as required. As the TRIUMF group is built up to full strength, the detail design (as well as some construction) of special cyclotron equipment will be undertaken in-house.

7.2 Schedule

Scheduling for the project is now being controlled by critical path techniques, the amount of detail displayed on the schedule being varied in accordance with progress on the design of the facility. During the year the computer program PROSE (Shawinigan Engineering Co.) was adapted to run on the IBM 360/67 computer installed at the Computing Centre of the University of British Columbia, and the updating calculations for the critical path network are now being done there.

The following table indicates the target and actual dates for the major points on the schedule in 1969:

	Schedule Date	Actual Date
Magnet model performance tests complete	April	April
Resonator prototype specifications	May	July
Vacuum system concept	June	August
Cyclotron general design	August	August
Magnet specifications	August	August
Beam transport concept	October	October
Magnet contract awarded	October	Pending (Dec.31)
Construction - Office and Laboratory block	September	October

7.3 Manpower

Figure 7.1 charts the manpower allocated to the project at the four universities and at the various consulting engineering firms.

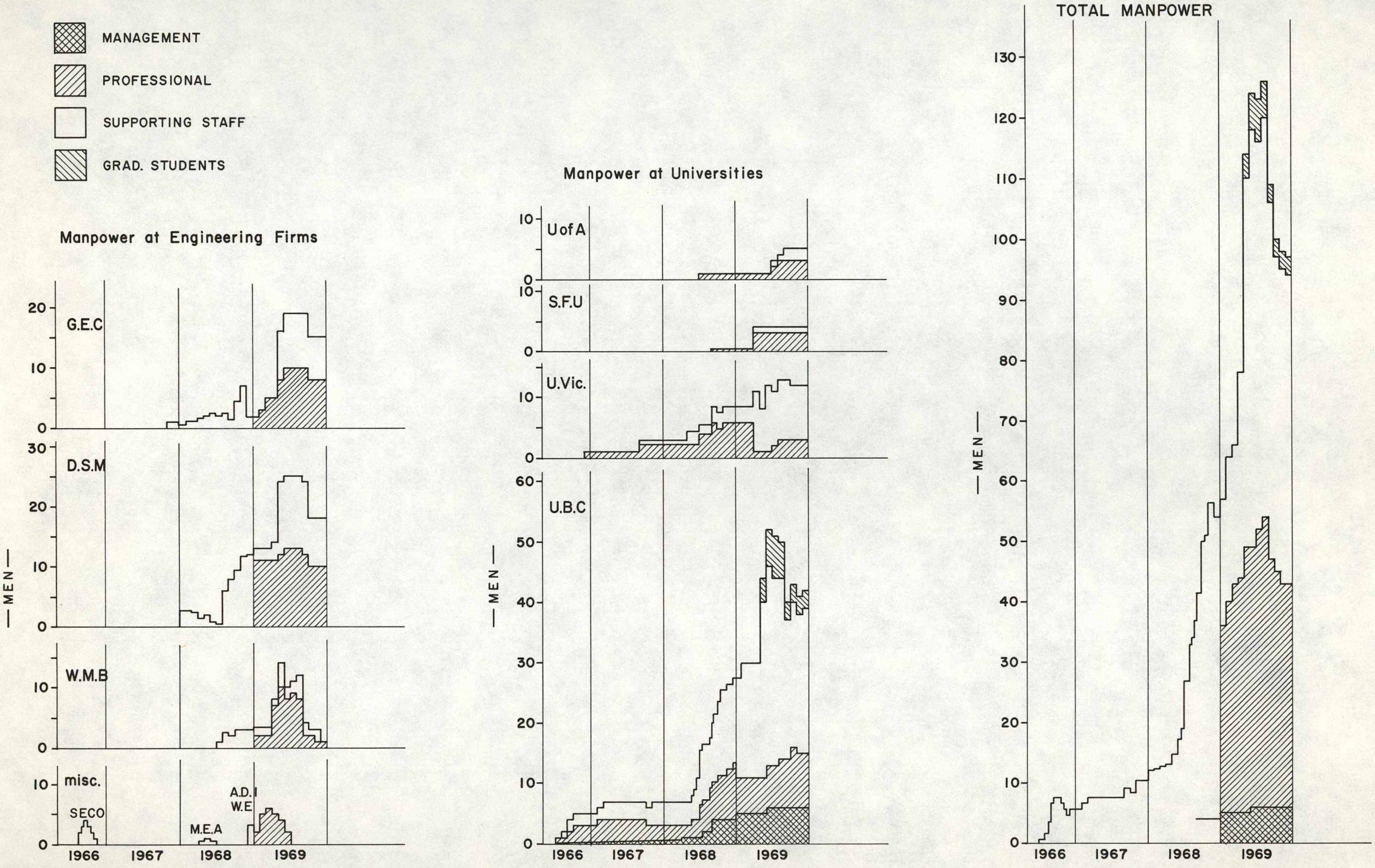

Figure 7.1 Manpower Resources

8. CONFERENCES ATTENDED AND PAPERS READ

Canadian Association of Physicists, Western Region Nuclear Physics Conference, Vancouver, B.C.	February
Particle Accelerator Conference, Washington, D.C. M.K. Craddock and J.R. Richardson: "Magnetic field tolerances for the TRIUMF 500 MeV H^- cyclotron"	March
Conference on High Energy Physics, Cambridge, U.K.	March
Canadian Association of Physicists Congress, Waterloo, Ont.	June
Canadian Nuclear Association Conference, Montreal, Que. J.J. Burgerjon and B.C. Stonehill: "TRIUMF Progress Report"	June
International Conference on High Energy Accelerators, Yerevan, Armenia, USSR	August
International Conference on Nuclear Structure, Montreal, Que.	September
Third International Conference on High Energy Physics and Nuclear Structure, New York J.B. Warren: "Tri-University Meson Facility"	September
International Conference on Cyclotrons, Oxford, U.K. J.B. Warren: "The TRIUMF Project" M.K. Craddock, R.J. Louis and M. Reiser: "H^- injection into the central region of the TRIUMF cyclotron" J.R. Richardson and M.K. Craddock: "Beam quality and expected energy resolution from the TRIUMF cyclotron" L.P. Robertson, E.G. Auld, G.H. Mackenzie and A.J. Otter: "Extraction of multiple beams of various energies from the TRIUMF negative ion isochronous cyclotron" K.L. Erdman, A. Prochazka, O.K. Fredriksson, R.E. Thomas and W.A. Grundman: "A 'square-wave' RF system design for the TRIUMF isochronous cyclotron" E.G. Auld, S. Oraas, A.J. Otter, G.H. Mackenzie, J.R. Richardson and J.J. Burgerjon: "Design of the 4000-ton magnet for the TRIUMF cyclotron"	September
Engineering Institute of Canada, Vancouver, B.C. T.A. Creaney: "The TRIUMF Project"	September
American Vacuum Society, Seattle, Washington	October
American Nuclear Society, San Francisco, California	November

9. REPORTS

TRI-69-1	Electrical Dissociation of H^- Ions by Magnetic Fields
TRI-69-2	A Method of Locating the Magnetic Centre of a Quadrupole Magnet
TRI-69-3	Magnetic Field Mapping System; An Operation & Service Manual
TRI-69-4	Polarization Measurements for $pp \rightarrow \pi^+D$
TRI-69-5	Magnet Core Construction Concept for a 500 MeV H^- Cyclotron
TRI-69-6	Energy Resolution in a 500 MeV H^- Cyclotron
TRI-69-7	Vacuum System Design Study for a 500 MeV H^- Cyclotron Using a Scaled Model of the Vacuum Chamber
TRI-69-8	Conceptual Design Study for the TRIUMF Control System
TRI-69-9	Conceptual Design Study for the Vacuum Pumping System for a 500 MeV H^- Cyclotron
TRI-69-10	Phase Space Acceptance of a Helical Quadrupole Channel of Finite Length

10. STAFF

UBC

Faculty:

Name	Position	Area	% TRIUMF Payroll	From	Until
J.B. Warren	Professor	Director	100		
G. Jones	Professor	(Control)	0		
D.L. Livesey	Professor	(Field Measurements)	0		
B.L. White	Professor	(Ion Source)	0		
E.W. Vogt	Professor	Assoc. Director	0		
K.L. Erdman	Professor	(RF)	0		
M.K. Craddock	Assoc. Professor	(Beam Dynamics)	100		
E.G. Auld	Asst. Professor	(Magnet)	0		
R.R. Johnson	Asst. Professor	(Control)	0		
D.A. Axen	Asst. Professor	(Vacuum)	0		
J.R. Richardson	Visiting Professor	(Consultant)	100	Apr 1	Jun 30

Graduate Students

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

TRIUMF (Vancouver)

Name	Position	Area	% TRIUMF Payroll	From	Until
J.J. Burgerjon	Chief Engineer		100		
Vivienne Harwood	Research Assoc.	(Vacuum)	100		Nov 30
M. Linton	Research Assoc.	(Computing)	100		
G.H. Mackenzie	Research Assoc.	(Beam Dynamics)	100		
R. Gummer	Research Assoc.	(RF)	100		
A.J. Otter	Research Engineer	(Magnet)	100		
D. Sloan	Research Assoc.	(Control)	100	Apr 1	
M. Zach	Research Engineer	(CRM)	100	Jun 1	
R. Poirier	Research Engineer	(RF)	100	Jul 1	
N. Brearley	Reports and Documents		100	Aug 1	
E.W. Blackmore	Research Assoc.	(CRM)	100	Aug 15	
P. Faulconer	Consulting Architect		80	Sep 15	
J.W. Carey	Plant Engineer		100	Oct 14	
M.R. Haines	Research Asst.	(Magnet)	100		Jun 30
J.C. Yandon	Research Asst.	(Vacuum)	100		
N. Rehlinger	Research Asst.	(Magnet)	100		
S. Scherrer	Research Asst.	(Magnet)	100		Nov 28
M. Sanderson	Research Asst.	(Magnet)	100	Apr 8	Nov 7
K. Poon	Research Asst.	(Magnet)	100	Jun 1	
D.A. Beale	Research Asst.	(RF)	100	Oct 1	
J. Fawley	Research Asst.	(RF)	100	Dec 1	
P. van Rook	Research Asst.	(Chief Draftsman)	100		
L.A. Udy	Research Asst.	(Draftsman)	100		
H. Hansen	Research Asst.	(Draftsman)	100		
A.T. Bowyer	Research Asst.	(Draftsman)	100		

TRIUMF (Vancouver) cont'd.

			% TRIUMF Payroll	From	Until
D.C. Smith	Research Asst.	(Workshop Supervisor)	100		
M. Heinrich	Research Asst.	(Machinist)	100		Jan 29
K. Dusbaba	Research Asst.	(Machinist)	100		
S. Olsen	Research Asst.	(Machinist)	100	Mar 10	
A. Amstutz	Research Asst.	(Machinist)	100	Aug 11	
Ada Strathdee	Secretary		100		
Beverly Little	Secretary		100		Sep 30
Darlene Anderson	Secretary		100	Jan 22	
Irene Shepert	Secretary		100		Jul 23
Louise Guthrie	Secretary		100	Aug 18	Nov 4
Lynne Bass	Accountant		100	Sep 8	
Nancy Palmer	Secretary		100	Nov 17	
Else Elden	Secretary		100	Dec 2	

Attached staff:

T.A. Creaney	Project Manager	(SECo)			
D.L. Lancaster	Contracts Manager	(MECo)			Apr 1
A.D.G. Robinson	Contracts Manager	(MECo)		Feb 10	
J. Kilpatrick	Scheduling Engineer	(SECo)			
D.A. Calder	Civil Engineer	(SECo)		June 1	

UVic

Faculty:

R.M. Pearce	Professor	(Beam Transport)	33-1/3	(till May)	
L.P. Robertson	Assoc. Professor	(Extraction	33-1/3	(from Sep)	
D.E. Lobb	Asst. Professor	(Beam Transport)	0		
G.R. Mason	Assoc. Professor		0		
G.A. Beer	Asst. Professor		0	Aug 1	
C.S. Wu	Asst. Professor		0		
C.E. Picciotto	Asst. Professor		0		

Graduate Students:

N. Al-Qazzaz			0		
P. James			0		
R. Harrison			100		
K. Kong			100	May 1	
S.T. Lim			100	Sep 1	
D. Smith			0		

TRIUMF (Victoria)

T.A. Hodges	Research Engineer	(Target)	100	Jul 1	
M.F. Tautz	Research Assoc.	(Beam Optics)	100		
P. Reeve	Research Assoc.	(Beam Optics)	100	Dec 1	
R.W. Cobb	P.D.F.	(Magnet Measurements)	80	(from Sep)	
W. Sperry	P.D.F.	(Secondary Beams)	100	Sep 1	
T. Witten	P.D.F.	(Secondary Beams)	100	Sep 1	
C. Chan	Senior Programmer		33-1/3		
D. Hunt	Programmer-Analyst		100	May 1	
J. Nelson	Technician		100		
Julia Hunt	Secretary		100		

			% TRIUMF Payroll	From	Until
SFU					
Faculty					
B.D. Pate	Professor (on leave, 1969-70)		0		
R.G. Korteling	Asst. Professor		0		
J.M. D'Auria	Asst. Professor	(Nucl. Equip. Dev.)	0		
A.S. Arrott	Professor	(Neutron Target)	0		
TRIUMF (Burnaby)					
S. Barken	Research Assoc.	(Nucl. Equip. Dev.)	100		Nov 30
I.M. Thorson	Research Assoc.	(Shielding & Activation)	100	Sep 1	
S. Gujrathi	Research Asst.		100		
UAlberta					
Faculty					
G.C. Neilson	Professor	(Operating Committee)	0		
W.K. Dawson	Professor	(Control & Computing)	50		
J.T. Sample	Professor	(Board of Management)	0		
W.C. Olsen	Assoc. Professor	(Proton Users Group)	0		
G. Roy	Asst. Professor	(Vacuum)	0		
W.J. McDonald	Asst. Professor		0		
G.A. Moss	Asst. Professor	(P Area Exp. Apparatus)	0		
D.M. Sheppard	Asst. Professor	(P Area)	0		
TRIUMF (Edmonton)					
G. Stinson	Research Assoc.		100		
B.L. Duelli	Research Assoc.	(Diagnostics)	100	Aug 1	
P. Kitching	Research Assoc.		50		
E.B. Cairns	Research Asst.		100		
J.B. Elliott	Research Asst.		0		
R. Popik	Research Asst.		0		
L. Holm	Research Asst.		0		
Greta Tratt	Secretary		0		
Elsie Hawirko	Secretary		0		
Audrey Forman	Secretary		100		

11. FINANCIAL STATEMENT

Statement of revenue and expenditures April 1, 1968-March 31, 1969:

Revenue

Atomic Energy Control Board Grant	$ 975,000
Interest	27,760
Total	$1,002,760
Add: Balance carried forward from previous year*	29,413
	$1,032,173

Expenditures

Salaries	$ 239,795
Engineering contracts	245,795
Construction contracts	-
Experimental equipment	123,947
Consultants' fees	60,449
Expendable supplies	47,315
Travel	32,914
Telephone	4,807
Printing and copying	5,361
Other	24,955
Total	$ 785,338
Add: Balance on hand	246,835
	$1,032,173

*This figure does not agree with the balance for 1967/68 shown in the last annual report. The financial statement in that report was a preliminary version.

Expenditures by major and minor codes, April 1, 1969-Dec. 31, 1969:

	A Payments at Dec. 31	B Commitments at Dec. 31	Total (A + B)
Major code breakdown:			
Project management	$ 193,761	$ 78,837	$ 272,598
Buildings	915,866	493,903	1,409,769
Cyclotron	748,820	605,197	1,354,017
Experimental facilities	130,451	37,683	168,134
Technical services	108,266	19,873	128,139
Experiments and equipment	15,974	10,393	26,367
	$2,113,138	$1,245,886	$3,359,024

Minor code breakdown:

Payroll	$ 342,676
Engineering services	865,417
Construction payments	490,396
Development equipment	69,266
Capital equipment	176,574
Consultants' fees	79,084
Travel	53,112
Telephone	4,679
Printing and copying	8,015
Other	23,919
	$2,113,138

Appendix A

USERS GROUPS AND COMMITTEES

1. USERS GROUPS

1.1 Meson Users Group

W.J. McDonald	UAlberta	Physics	G. Jones (Chm)	UBC	Physics
G.C. Neilson			E.G. Auld		
W.C. Olsen			D.A. Axen		
D. Sheppard			D.S. Beder		
			M.K. Craddock		
R.G. Korteling	SFU	Chemistry	K.L. Erdman		
			R.R. Johnson		
N. Al-Qazaz	UVic	Physics	D.L. Livesey		
G.A. Beer			K.C. Mann		
D.E. Lobb			P.W. Martin		
G.R. Mason			J.M. McMillan		
R.M. Pearce			E.W. Vogt		
C.E. Picciotto			B.L. White		
L.P. Robertson			J.B. Warren		
			D.C. Walker		Chemistry
R.W. Cobb	TRIUMF	Victoria	E.W. Blackmore	TRIUMF	Vancouver
W. Sperry			G.H. Mackenzie		

D.W. Hone	Royal Roads Military College	Physics
H.F. Batho	British Columbia Cancer Institute	
E.P. Hincks	Carleton University	Physics
D.O. Wells	University of Manitoba	Physics
J. Jovanovich	University of Manitoba	Physics
D. Measday	CERN	
N. Tanner	Nuclear Laboratory, Oxford	
H.B. Knowles	Washington State University	Physics
J.E. Rothberg	University of Washington	Physics
R.R. McLeod	Western Washington State College	Physics
R. Atneosen	Western Washington State College	Physics

1.2 Radiochemistry Users Group

G.R. Freeman	UAlberta	Chemistry	D.C. Walker (Chm)	UBC	Chemistry
H.E. Gunning			L.G. Harrison		
			C.A. McDowell		
J.M. D'Auria	SFU	Chemistry	S. Zbarsky		Biochemistry
R.G. Korteling					
C.H.W. Jones					
G. Bushnell	UVic	Chemistry	R. Morrison	Vancouver General Hospital	
S.A. Ryce					

1.3 Slow Neutron Users Group

D.W. Hone (Chairman)	Royal Roads Military College	
J. Trotter	UBC	Chemistry
D.C. Walker		
A.V. Bree		
K.B. Harvey		
C.A. McDowell		
L.W. Reeves		

B.D. Pate	SFU	Chemistry
C.H.W. Jones		
A.S. Arrott		Physics
R.R. Haering		
L.P. Robertson	UVic	Physics
S.A. Ryce		Chemistry
G.R. Freeman	UAlberta	Chemistry
R.R. McLeod	Western Washington State College	

1.4 Radiobiology and Radiotherapy Users Group

J.M.W. Gibson (Chairman)	B.C. Cancer Institute	
A.M. Evans		
D.M. Whitelaw		
R.O. Kornelsen		
M.E.J. Young		
H.F. Batho		
N. Auersperg	UBC	Cancer Research Institute
R.L. Noble		
H. Stich		
D.C. Walker		Chemistry
I.McTaggart-Cowan		Grad.Studies
J.F. McCreary		Medicine
J.B. Warren		Physics
D.H. Copp		Physiology
V.J. Okulitch		Science Fac.
W.S. Hoar		Zoology
R. Morrison	Vancouver General Hospital	
B.L. Funt	SFU	Science Fac.
B.D. Pate		Chemistry
W.G. Fields	UVic	Biology
R.M. Pearce		Physics
L.P. Robertson		
D.E. Lobb		
G.B. Friedmann		
D.W. Hone	Royal Roads Military College	

D.M. Ross	UAlberta	Science Fac.
G.R. Freeman		Chemistry
J. Weijer		Genetics
W.C. MacKenzie		Medicine
E.E. Daniel		Pharmacology
A.A. Noujaim		Physiology
L.G.S. Newsham		Physiology
T.R. Overton		Radiology
J.R. Nursall		Zoology
R.F. Ruth		Zoology
J.W. Scrimger	Dr. W.W. Cross Cancer Institute, Edmonton	
S.R. Usiskin		
D.L. Weijer	University Hospital, Edmonton	
B.G. Wilson	UCalgary	Arts&Sciences
R. Church		Biology
J.B. Cragg		Biology
W.A. Cochrane		Medicine
S. Rowlands		Medicine
C.E. Challice		Physics
T.D. Cradduck	Foothills Hospital, Calgary	
H.E. Duggan		

1.5 Proton Users Group

J.T. Sample	UAlberta	Physics Nuclear Research Centre
W.J. McDonald		
W.C. Olsen		
G.C. Neilson		
G.A. Moss		
D.M. Sheppard		
G. Roy		
G.M. Stinson		
P. Kitching		
J.B. Elliott		
E.B. Cairns		
C.R. James		Elec. Eng.
F.E. Vermeulen		Elec. Eng.
G.R. Freeman		Chemistry
T.R. Overton	UAlberta Hospital - Clinical Sciences	

E.G. Auld	UBC	Physics
D.A. Axen		
M.K. Craddock		
G.M. Griffiths		
R.R. Johnson		
G. Jones		
K.C. Mann		
P.W. Martin		
E.W. Vogt		
J.B. Warren		
B.L. White		
D.C. Walker		Chemistry
E.W. Blackmore	TRIUMF	Vancouver
G.H. Mackenzie		

B.D. Pate	SFU	Chemistry
J.M. D'Auria		
R.G. Korteling		
A.S. Arrott		Physics
I.M. Thorson		

G.R. Mason	UVic	Physics
L.P. Robertson		
R.M. Pearce		
D.E. Lobb		
S.A. Ryce		Chemistry

R.R. McLeod	Western Washington State College	Physics
R. Atneosen	Western Washington State College	
H.B. Knowles	Washington State University	Physics
D.O. Wells	University of Manitoba	Physics
J.V. Jovanovich	University of Manitoba	
H.F. Batho	British Columbia Cancer Institute	
J.R. Richardson	UCLA	Physics

2. COMMITTEES

2.1 Building Committee

J.B. Warren	(Chairman)	TRIUMF	Vancouver
J.J. Burgerjon		TRIUMF	Vancouver
E.G. Auld		UBC	Physics
J.M. D'Auria		SFU	Chemistry
L.P. Robertson		UVic	Physics
W.J. McDonald		UAlberta	Physics
H.F. Batho		B.C. Cancer Institute	
T.A. Creaney	(Secretary)	TRIUMF	Vancouver

2.2 Safety Committee

H.F. Batho	(Acting Chairman)	B.C. Cancer Institute	
J.H. Smith		B.C. Dept. of Health Services & Hosp. Ins.	
R.R. Johnson		UBC	Physics
H.E. Rankin		Royal Roads, Physics	
W. Rachuk		UBC	Radiation Protection Officer
R. Morrison		Vancouver General Hospital	
T.A. Creaney	(Secretary)	TRIUMF	Vancouver

2.3 Experimental Instrumentation Committee

W.K. Dawson	(Chairman)	UAlberta	Physics
J.M. D'Auria		SFU	Chemistry
D.A. Axen		UBC	Physics
G. Jones		UBC	Physics
W.C. Olsen		UAlberta	Physics
G.R. Mason		UVic	Physics

Appendix B

TRIUMF SPECIFICATIONS

Extraction energy range	200 - 500 MeV
Maximum beam current allowable (epoch D)	200 μA at 500 MeV
	400 μA at 450 MeV
	750 μA at 300 MeV
Energy resolution	±600 keV (±50 keV sep. turns)
Maximum beam loss at 500 MeV	4 μA by gas stripping
	16 μA by electric stripping
Maximum operating pressure	7×10^{-8} Torr air
Maximum magnetic field	5.76 kG
500 MeV beam average radius	314 in.
Orbit scalloping at 500 MeV	-3.1, +2.5 in.
Orbit separation (400 keV at 500 MeV)	0.065 in.
Injection energy	300 keV
H^- ion source beam emittance	2.5π in. mrad at 12 keV
Internal beam emittance at T MeV	$0.16\pi \sqrt{50/T}\,(1 - T/4000)$ in. mrad
Vertical oscillation frequency ratio ν_z	0.35 ± 0.07
Vertical oscillation amplitude	$(0.25 \pm 0.03)/\sqrt{\gamma}$
Radial oscillation frequency ratio $\nu_r \simeq \gamma$	1.0 to 1.59
Radial oscillation amplitude	$0.15/\gamma$ in. ($0.03/\gamma$ in. for sep. turns)
Allowable phase excursion	±5° (±1° for sep. turns)
Phase acceptance	50° (14° for sep. turns)
MAGNET:	
Number of sectors	6
Width of sector at 311 in.	36.4°
Mean spiral angle at 311 in.	70°
Average magnetic field at 314 in.	4.561 kG
Average magnetic field at centre	2.977 kG
Magnet gap	20.8 in.
Pole plate radius	338 in.
Main coil radius	348 in.
Main coil cross-section	20 x 20 in.
Main coil excitation	720,000 ampere-turns
Main coil power	2500 kW
Magnet weight	4000 tons
Circular trim coils - number & total power	54 - 110 kW
Harmonic coils - number & total power	72 - 110 kW
RF:	
Ion rotation frequency	4.53 MHz
Harmonic	5th
Radio-frequency	22.66 MHz
Frequency variation	+3%
Dee voltage peak to ground	100 kV
Maximum energy gain per turn	400 kV
RF power input	1400 kW
Beam aperture	4 in.
Dimensions of each dee	122 in. x 636 in.
Fraction of third harmonic (68 MHz)	20% (11.32% for sep. turns)