RECENT DEVELOPMENTS AT TRIUMF

Karl L. Erdman*

Abstract

The beam currents and their quality at TRIUMF have been steadily improved since the accelerator began operations shortly before the last Conference. The high current beam stop has now been completed and currents of over 100μ amperes have been accelerated. The accelerator routinely delivers beams of 150 nanoamperes of polarized protons. The addition of new beam lines and the improvements in transmission and stability have continued in an orderly fashion to the expected full capability envisaged by the proposers of the negative ion cyclotron meson facility.

1. Introduction

At the Cyclotron conference held in Zurich in 1975 a report on the first operation of the TRIUMF accelerator was given by J.R. Richardson[1] who was, at that time, the director of the facility. It was most gratifying for him to see his ideas for using H- acceleration vindicated. A beam of up to 525 MeV protons was extracted from the machine by the use of thin aluminum and carbon stripping foils positioned at various radii in the vacuum tank.

Since that time the machine has been operated in a program in which two thirds of the time has been directed to beam production and one third to machine study and technical improvements and modifications. There have been two 6-week periods per year during which the machine has been shut down for modifications in the cyclotron. Modifications to the experimental areas are done during these shutdown periods.

Operating beam currents have been increased slowly from the initial 10 nanoamperes to 20 microamperes during the last 3 years with short periods of high current operation. In July of 1977 the first beam of over 100μ amperes was extracted and since that time stability and quality of the high current beam has been steadily improved as will be reported in other papers at this conference.[2-3]

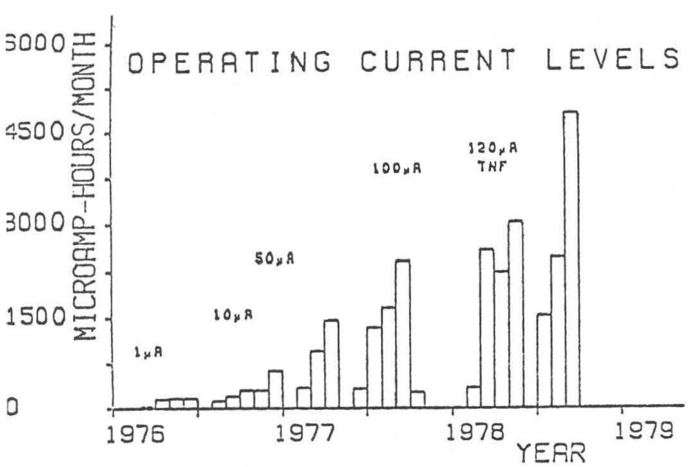

Figure 1: Monthly microampere hours delivered to experimenters

The polarized ion source of the Lamb shift type which was put into operation shortly after the delivery of the first beam to the experimental areas also has been steadily improved. A DC beam of 1μ ampere of 70% to 80% polarized H- ions is now regularly delivered by the ion source and a beam of 200 nanoamperes has been delivered to the experimental areas. This has made possible a variable energy neutron beam created by charge exchange in a liquid deuterium target.

The transmission through the cyclotron has also been improved until with the buncher in operation a transmission of over 30% of the beam from the ion source through the cyclotron at a beam current of 20 microamperes has been obtained. A more detailed description of this achievement is given in another paper at this conference.[2] The total current from the ion source is routinely 600μ amperes.

A study has been made of the possible improvements to energy stability and to the possibility of single turn extraction. The use of slits at the centre of the machine has allowed an impressive scan of the beam current as a function of beam radius to be made. (Figure 2) A discussion of this will also be given in a separate paper at this conference.[3]

2. Facility Development

The facility presently consists of two experimental areas, one dedicated primarily to nucleon-nucleon interactions and nuclear physics and the second to pion and muon reaction studies.[4] The layout of the experimental halls and the extracted beam lines is illustrated in Figure 3. During the summer of 1978 two additional extraction ports were installed on the machine at the side of extraction port two. The primary purpose of these ports was to provide beams for isotope production.

A bending magnet in beamline 1 allows for a second nucleon-nucleon interaction area and the extraction of two simultaneous independently variable energy polarized proton beams.

A second target station has been constructed into beamline 1 for two additional secondary meson channels which are presently under construction. One of these channels is a backward-going slow pion-muon channel with an acceptance of 30 milli-steradians and the other is a zero degree forward takeoff pion channel having high resolution.

The beam stops at the end of the nucleon-nucleon interaction area are both carbon blocks in iron shields buried outside of the building. They are capable of stopping 10μ amperes and 100 nanoamperes of beam, the lower figure being for the beam stop on the line servicing the broad range spectrograph. The experimental floor is excavated 12 meters below ground level.

* TRIUMF, Vancouver, B.C., Canada
Associate Director, Facilities

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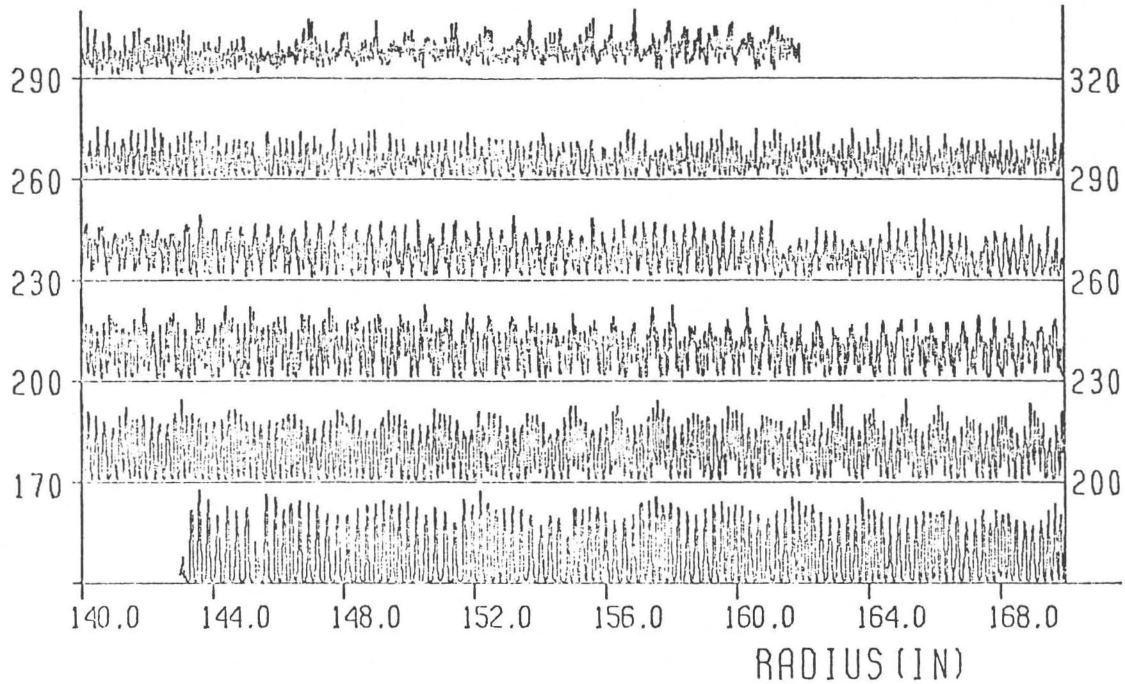

Figure 2: Radial scan of the circulating beam in the TRIUMF cyclotron from 143 inches to 315 inches

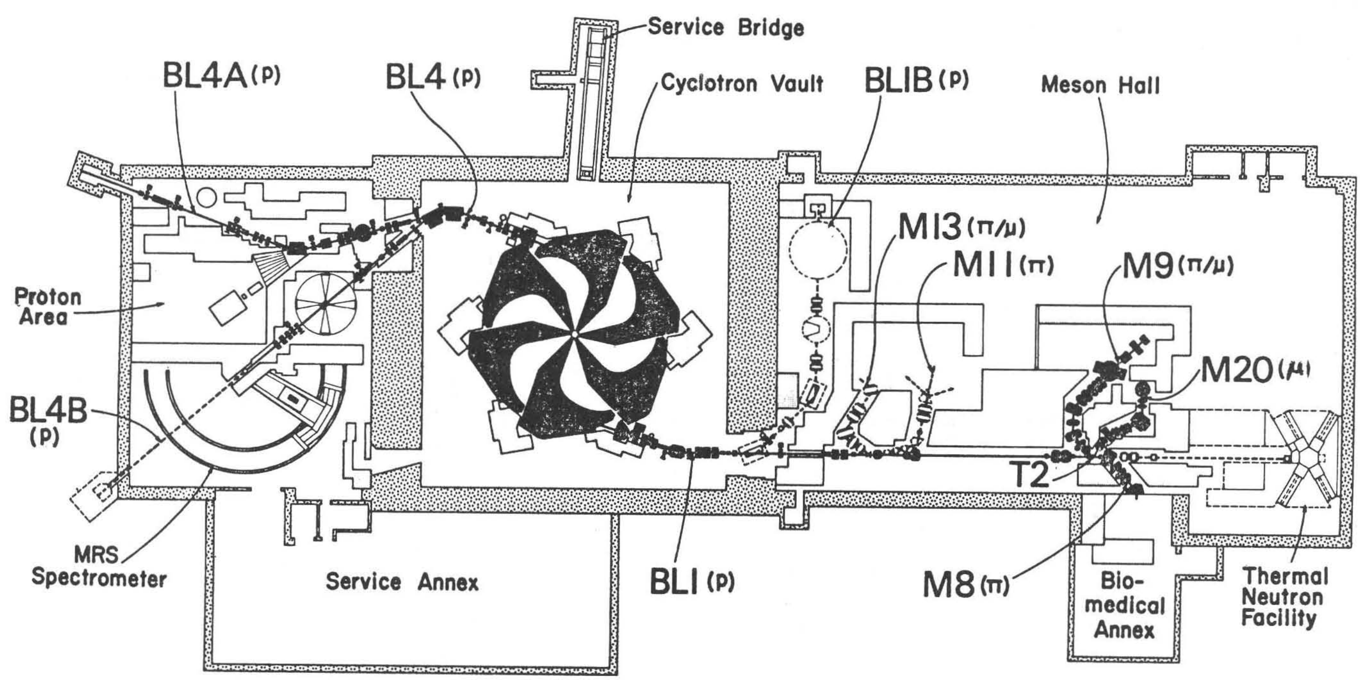

Figure 3: Layout of the TRIUMF Experimental Areas

The beam stop at the end of beamline 1 has been upgraded to take beam currents of up to 400 microamperes and has been provided with a D_2O moderator and neutron ports to provide a facility for neutron experiments of various kinds.

An internal beam dump capable of handling 10 nanoamperes of beam has been installed at the end of the nucleon-nucleon channel in the meson area.

The original target BL1T2 in the meson area, and its three associated secondary meson channels, remain unchanged.

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3. Thermal Neutron Facility

Since the stopping of the beam at the end of the beam line 1 at high currents leads to usable neutron fluxes, it was decided to design a beam stop[5] that would allow the stopping of 400μ ampere beams and optimize the neutron fluxes obtainable.

The thermal neutron facility is shown in Figure 4. It consists of a thin-walled stainless steel flask filled with lead. The flask is connected to a vacuum system through pipes passing through an 8 meter water tank in which the flask is immersed. The lower half of the flask is in a separate compartment filled with D_2O to optimize the thermal neutron flux. Various ports for rabbit systems, slow neutron channels and fast neutron channels penetrate the two-meter primary steel shield surrounding the double-walled water tank. (Figure 5) The performance of the lead beam stop during beam-on periods is shown in Figure 6.

The lead in the flask becomes molten to its upper surface at a beam current of 20μ amperes. Cooling is achieved by convection in the lead and by conduction through the steel container near the upper surface on the lead where it is molten. As the current is increased to 100 microamperes the temperature in the centre of the lead where the beam is being stopped increases to 500°C. At this current the bands of melted, convecting lead contacting the stainless steel flask are 2 cm wide, as could be seen in tests simulating the action of the beam. The width of the molten contact area increases with beam current.

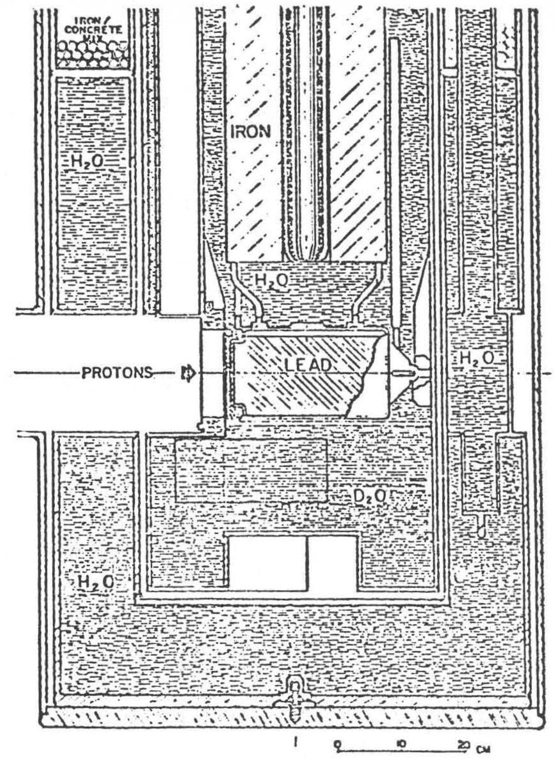

Figure 4: The thermal neutron target, moderator and reflector assembly

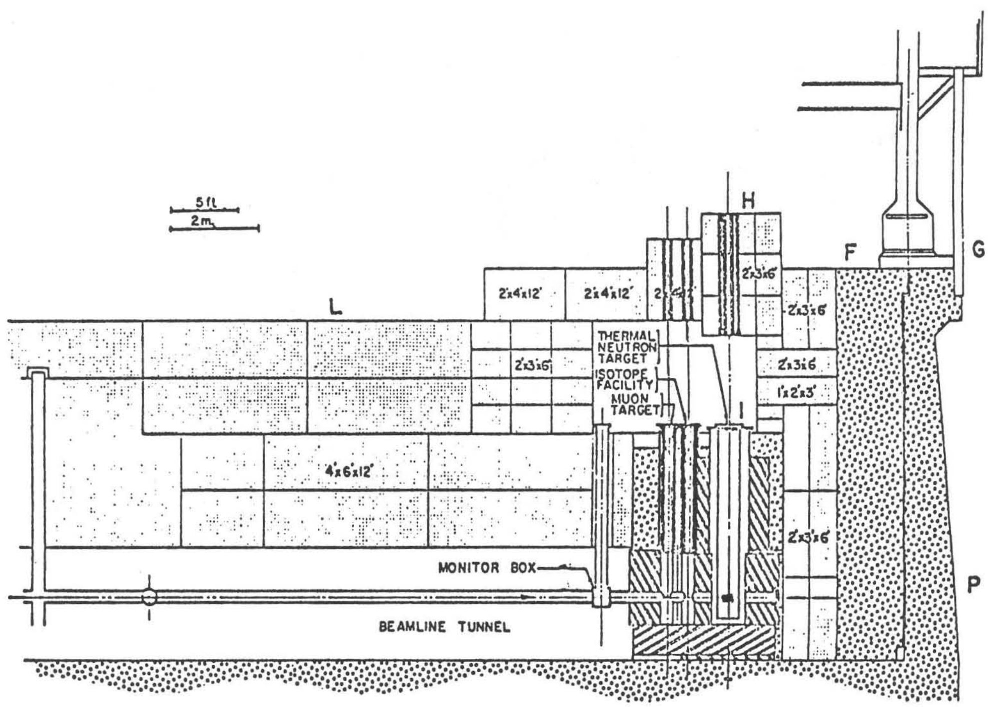

Figure 5: The thermal neutron facility and connecting beam line. Vertical cross-section along beam line.

After several runs of 100μ amperes the lead flask was removed from the water vessel and inspected for distortions or indications of thermally-induced stresses. No distortions of any kind were seen. It appears that the system will work as designed as a high current beam stop.

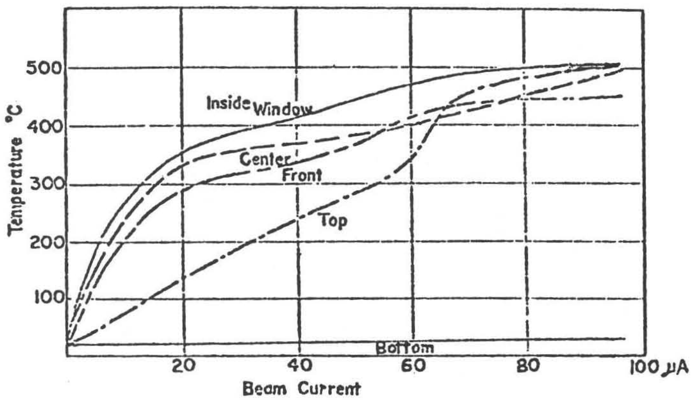

Figure 6: The operating temperatures in the TNF as a function of beam current

4. Low Energy Extracted Beams

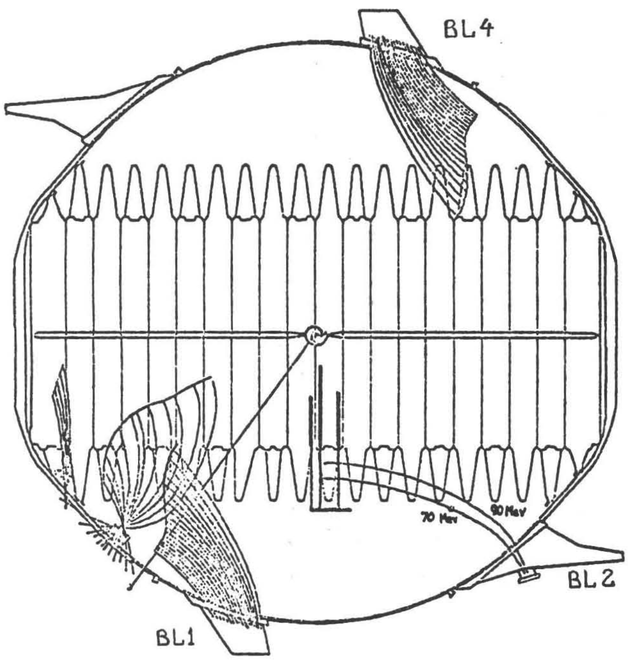

Figure 7: Extracted beams from TRIUMF

In Figure 7 it is possible to see the position of the low energy extracted beam ports added to beam port 2 on the cyclotron tank. Beams to these ports were successfully extracted from the inner orbits of the cyclotron at 70 and 90 MeV. The beams were measured at the new extraction ports by profile monitors and the profiles are seen in Figures 8 and 9.

The beams were viewed on wire chambers with a 3 mm wire spacing positioned at the extraction port. The amplitude of the current on each wire is seen in the oscilloscope picture. The external beamlines for these ports have not been installed but the successful extraction has now made TRIUMF the only cyclotron that has simultaneously extracted three beams of different energy and intensity. It also allows an energy variability of the extracted beam from 70 MeV to 525 MeV

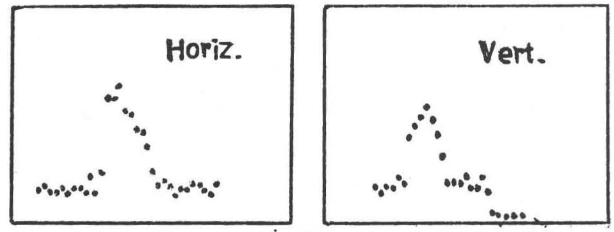

Figure 8: Beam profile of extracted 70 MeV beam. Wire spacing 3 m.m.

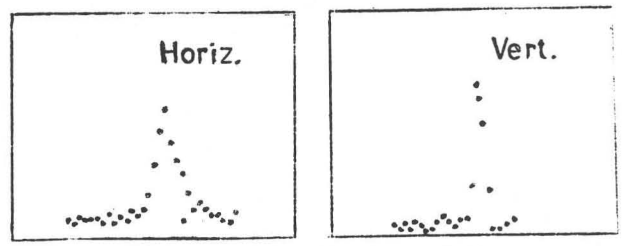

Figure 9: Beam profile of extracted 90 MeV Beam. Wire spacing 3 m.m.

in a continuous fashion in one cyclotron. The maximum stable ratio between two beams has been improved to $1:10^4$. (Figure 10) The low intensity beam was varied while the high intensity beam was held constant in the exercise. The stability problems are discussed in another paper at this conference.[3]

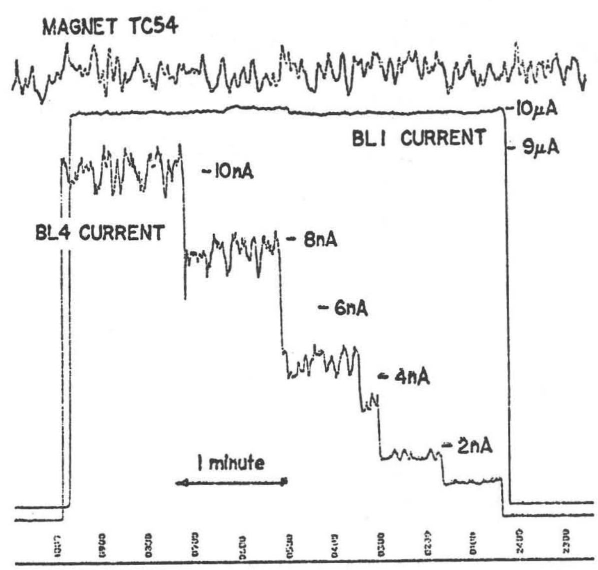

Figure 10: Variation of the split ratio of extracted beam at a level of $1:10^4$

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5. 5:1 Pulser

Two pulsers have been inserted into the injection line of the TRIUMF ion source and injection system. The first one is in the ion source (macro-pulser) and it operates at a rate of 1 kilocycle. It has a duty factor which varies from 1% to 99%. It is used to change the beam intensity in achieving a 100μ ampere tune and the gap in the beam current at the 99% duty factor is seen by toroidal magnetic pickups and cylindrical capacitive pickups. This feature is used in various tuning, current measuring and stabilization procedures as described in other papers in this conference.[3]

The micropulser operates on the beam microstructure and is capable of passing one pulse in five in the RF cycle. Since the rotation frequency is one fifth of the RF frequency, instead of 5 spokes in the rotating charge cloud, there is only one. The beam suppression during the operation of this pulser is seen in Figure 11 which shows the capacitive pickup signal with and without the micropulser in operation. The suppression factor was measured in the experimental area on the M9 channel and Figure 12 shows the appearance of the secondary beam in the 5:1 mode of operation. The suppression factor is better than 2×10^{-7}, the limit of sensitivity of the measurement.

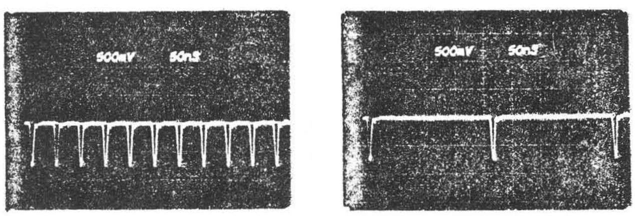

Figure 11: Capacitive pickup signal on the extracted beam in BL1.

6. Cryopumping

The cyclotron has been operating with a cryopumping system consisting of 80°K and 20°K cryopanels. During the pumpdown cycle the tank is heated to 70°C by circulating hot water for 12 hours at which time the base pressure reaches 2×10^{-7} Torr and the cyclotron can be put into operation. After continuous operation for a month the base pressure reaches 2×10^{-8} Torr. Since the activation by gas stripping is comparable to that by electromagnetic stripping at high gas pressures, and the activation of the cyclotron tank poses a serious problem, it was decided to install liquid helium cooled cryopumps into the cyclotron to reduce the base pressure much more quickly by pumping off the hydrogen produced through the dissociation of the absorbed water in the tank. A prototype pump consisting of a cylindrical container for liquid helium, having a diameter of 1 meter and a height of 10 cm with a chevron baffle cooled to 80°K in front of the pumping surface was installed in the tank during the spring shutdown in 1978. This system has now been tested. The base pressure rapidly reaches 2×10^{-8} Torr after the bakeout is finished. The boil-off rate for the liquid helium is between 1 to 5 litres per day.

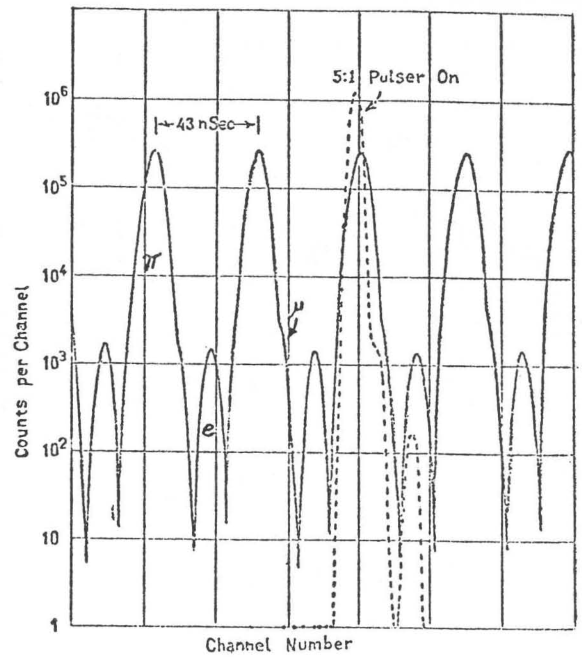

Figure 12: Secondary beam production during operation of the 5:1 pulser

7. Energy Resolution

The turn pattern obtained in the cyclotron by the use of slits is seen in Figure 2. The single turn structure is clearly seen to 200 MeV and the separation is quite good to full energy. A spectrum taken of a target with the broad range spectrograph is displayed in Figure 13.

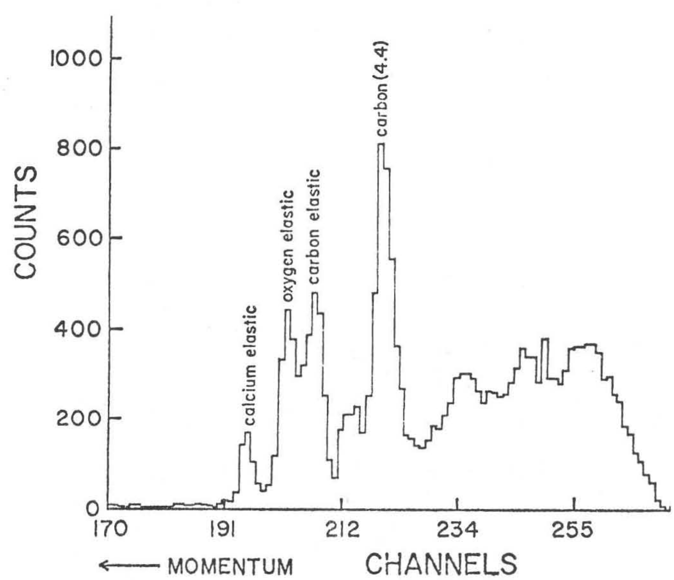

Figure 13: MRS energy resolution test using energy slits in the cyclotron

The resolution at 200 MeV was 650 KeV of which most was due to the instrumental resolution and not the energy resolution of the cyclotron. Since the acceleration voltage of the machine is now 160 KeV per revolution, single turn extraction has been achieved at that energy. The figure indicates that further tuning will be necessary before it is achieved at full extraction energy.

8. Applied Program

The installation of the 70 and 90 MeV extracted beams and the isotope production targets at the TNF and at the end of beamline IV marked the beginning of the applied program at TRIUMF. Isotopes will be produced at the cyclotron and will be marketed by the AECL Commercial Products Division. TRIUMF has entered into an arrangement with AECL-CP in which a new, small, isotope production cyclotron will be installed at the facility to back up periods when the main machine is shut down for maintenance. This 200μ ampere 42 MeV, negative ion machine will be purchased from the Cyclotron Corporation.

A neutron activation analysis group has been set up to do commercial analyses using the rabbit system of the thermal neutron facility.

Neutron beams will also be produced with the 42 MeV machine for the purposes of cancer therapy and the necessary additions of laboratory space and treatment rooms for these purposes has been authorized.

9. Conclusions

The major objectives listed in the conclusions at the end of the summary paper on TRIUMF[1] have been achieved. The running at full intensity requires the completion of remote handling equipment for the cyclotron. Although the 3rd harmonic system has been tested at low power it has not yet been put into operation. These are the two remaining machine developments necessary to bring the cyclotron up to the capabilities initially envisaged for it. The increase of the beam current to 400μ amperes awaits the development of an improved ion source.

References

1. J.R. Richardson, The Status of TRIUMF, 7th International Conference on Cyclotrons and their Applications, (Birkhauser, Basel, 1975) 41.

2. M.K. Craddock, K.L. Erdman, and J.T. Sample, Basic and Applied Research at the TRIUMF Meson Factory, Nature, Vol. 270, pp. 671-676, December, 1977.

3. E.W. Blackmore, P. Bosman, R. Burge, G. Dutto, D. Gill, G.H. MacKenzie and P.W. Schmor, Achievement and Control of the 100 μA Beam at TRIUMF, this conference.

4. E.W. Blackmore, M.K. Craddock, G. Dutto, C.J. Kost, G.H. MacKenzie and P.W. Schmor, Measurements and Corrections to the Beam Behaviour in the TRIUMF Cyclotron, this conference.

5. A.S. Arrott, R.E. Blaby, J.J. Burgerjon, T.A. Hodges, R.R. Langstaff, T.L. Templeton and I.M. Thorson, The TRIUMF Thermal Neutron Facility, TRIUMF Internal Report, TRI-77-1, 1977.

** DISCUSSION **

D. CLARK: Could you explain how you would store the beam and pulse it using the fringing field of the cyclotron?

K. ERDMAN: The beam is not stored in the fringing field but in the main cyclotron field. It turns out that if you can adiabatically decrease the RF acceleration field to zero, the beam spreads out longitudinally around the ring. That means that you can in fact store the beam by decreasing the RF field at some radius so that the beam accelerates quite rapidly, slows down into this mode, and you can calculate the length of time it takes. It turns out that you can store about a thousand revolutions this way.

Now because it's a negative ion cyclotron, and if the beam quality is good, you can put plates vertically, one above the beam and one below it, and give it a vertical kick into the stripping foil. In principle you can get all the stored beam out in one turn. So you get a real compaction. It looks like a beautiful way to provide a pulsed neutron source.

D. STORM: Will you describe the pion beams that are available at present?

K. ERDMAN: We have had only 3 pion channels operational since the machine came into operation: M8, M9 and M20. The beam currents are shown in Table 1. We are presently constructing two additional channels on the new target station in beam line I. These are called M11 and M13. M13 is a low energy pion channel with a maximum energy of 50 MeV with an acceptance of 30 millisteradians. The fluxes are quite similar to what one gets on the M9 channel, according to our calculations extrapolated from the target thicknesses used on M9. It will become operational at the end of this year. The acceptance and flux of M11 are shown in Table 1.

H. WILLAX: What are typical values for operational beam intensity ratios if you use simultaneously the high energy beam and a 70 MeV beam?

K. ERDMAN: We haven't used the 70 MeV beam operationally. It has been extracted from the machine and measured but we have no external beam line yet. The extracted beams can be varied in any ratio up to $1:10^4$. The stability level is 10% at the extreme ends of the ratio.

[DISCUSSION continues on next page.]

** DISCUSSION (continued) **

M.S. AL-GHAZI: What isotopes do you hope to produce with your new cyclotron? What are the problems involved in handling your ^{123}I target? What markets are you aiming at? How long will it take you to recover the costs of the project?

K. ERDMAN: We hope to produce all the isotopes that are produced by a cyclotron that can go to 42 MeV. Now that does not include I^{123} except on an emergency basis, because for that the best energy is of course around 70 MeV. We will be producing isotopes for sale by AECL-CP under contract to them so we won't do processing or marketing. They are paying for the cost of the facility. We have encountered no unsolvable problems in handling the ^{123}I. It is produced by proton bombardment of a liquid cesium target in our prototype tests. We bubble the iodine out of the cesium target with helium gas and the system works quite nicely. Initial production will be ^{123}I (with our 70 MeV beam) and Th.

W. JOHO: Coming back to your plans for a storage mode, you mentioned that you can store 100 mA at the extraction radius. Could you comment on the difficulties with transverse space change and losses due to residual gas and Lorentz stripping.

K. ERDMAN: The calculations we have done have been preliminary only and seem to indicate no problem. We have not gone into the details as to what the limits are. The beam is stored where the Lorentz stripping is small. The gas pressure may have to be lowered over the present pressure but the storage time is equal to the present acceleration time of the beam at TRIUMF and so the gas stripping would only double the present losses at high energy due to the pressure and they are already negligible. The beam spreads out in phase to fill the whole 360° of the revolution due to the increase in phase width as the energy gain per turn decreases.