TRIUMF

Financial and Administrative Annual Report 1984–1985

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Canada's national meson facility, managed as a joint venture by:

University of Alberta

University of Victoria

Simon Fraser University

University of British Columbia

Operated under a contribution from the National Research Council of Canada

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This Report is intended for the general public. An Annual Scientific Report is also available containing detailed technical information on the 1984 activities. Both reports are available through the Information Office.

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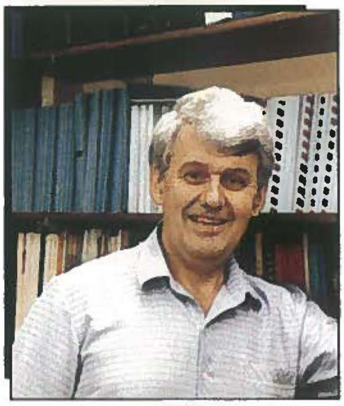
Director's Report



Erich Vogt
Director

These are heroic times for the study of subatomic matter. TRIUMF's flourishing experimental programme is in the centre of a worldwide effort which has, over the past few years, made stunning advances in our understanding of nature's basic building blocks (quarks and leptons) and of the forces that govern them. This annual report is intended to convey some of TRIUMF's important contributions to the field and to describe the ancillary research enterprises which accompany the main, basic research work.

The recent advances have unified everything we know about elementary particles but have also upset many of our cherished beliefs. On the one hand there emerged, over several decades, the discovery of many hundreds of "elementary" particles, some related to the familiar proton and neutron and some related to the pions which TRIUMF now produces so copiously. The former of these families of particles was called "baryons" and the latter, "mesons". On the other hand we had learned how to describe the properties of atomic nuclei in terms of neutrons and protons bound together by a strong nuclear force, the meson exchange force.

Now we know that all of the mesons and baryons—including the neutron and proton—are really composites built of smaller particles called quarks. Further, the strong force is that between the quarks, and it seems to obey the same kind of mathematics as the weak nuclear force (responsible for radioactive decay) and electromagnetism. The unification of the various forces received dramatic confirmation in 1983 with an experiment at CERN (the European research centre in Switzerland) which found the W and Z particles—very heavy particles which were predicted from the theory that unified the weak nuclear force with electromagnetism. For that achievement Carlo Rubbia and Simon van der Meer received the 1984 Nobel prize in physics. A TRIUMF physicist, Alan Astbury (now a Professor at the University of Victoria), was the co-leader of that crucial experiment.

A parallel experiment at TRIUMF gained worldwide attention for showing that all the W particles spin around their axes in a left-handed sense (i.e. where the thumb of the left hand points in the direction of motion, and the fingers curl in the direction of spin).

With these new advances there are now more important new questions than ever before. For nuclear physics one must ask whether a simpler description can be achieved, based on the quark constituents of the neutrons and protons. In TRIUMF's proton hall, on which we focus in this report, there are some splendid new tools (spectrometers and polarimeters) to address such questions. This work is now being carried forward via a large number of approved experiments involving scientists from around the world.

Similarly, in the TRIUMF meson hall many important experiments probe the physics of quarks and leptons.

Most of the action directed toward this exciting new physics is taking place at a small number of international centres based on large accelerators. The greatest benefits in people and ideas occur around such sites. Canada is fortunate in having its own major centre, TRIUMF, as a home base for this work and as a focal point for vigorous future attack in this fundamental science.

The heart of the entire facility is the giant TRIUMF cyclotron, shown here with beam line 4 and sector 5 of the magnet in the foreground. An idea of its scale can be obtained from the step-ladder on the left. Each sector weighs about 670 tons, giving the magnet a total weight of 4000 tons. Also visible are the support structures and jacks that enable the upper part of the magnet to be lifted for servicing.

Because the cyclotron emits harmful radiation when in use, the whole area is heavily shielded with huge concrete blocks, and this vault is accessible for only a few weeks each year, when the facility is shut down for servicing. Most visitors, therefore, can never get a direct glimpse of this wonderful machine.

Facilities

At a research laboratory like TRIUMF, there are many changes in the course of a year. Equipment is improved, extensions are built, new records are achieved. Only some of the highlights can be mentioned here.

Cyclotron

The primary products of the TRIUMF facility are, of course, beams of protons. Since each proton carries a unit of positive electric charge, a proton beam (consisting of billions of protons per second travelling in the same direction) is equivalent to a tiny electric current flowing down the beam line. The strength of a beam is, in fact, measured in millionths of an ampere (called microamperes, and written μA), and the total beam output is reckoned in microampere-hours (μAh).

Recently it has almost become an annual tradition at TRIUMF to supersede the previous year's beam production, and 1984-85 was no exception. Once again a record number of μAh was delivered to the various experiments. Also, a record beam strength was achieved for a short period: on 25 July 1984, a 500-MeV proton beam current of 208 μA was extracted for half an hour.

Ongoing studies of the cyclotron included an investigation of new ways of extracting the beam. The TRIUMF cyclotron was designed to accelerate H^- ions (i.e. a proton with two planetary electrons) and to extract a proton beam by stripping off the electrons. This eliminated certain technical difficulties common to cyclotrons that accelerated protons. However the most effective technique to accumulate particles at "TRIUMF energy" for further acceleration as high-intensity beams (in a KAON factory, for instance, as discussed later in this report), or for the provision of pulsed beams, is by exploiting the charge-changing process for *injection* into a second device. This would require H^- ions to be extracted intact, i.e. near the outer edge of the cyclotron, some device would have to bend the beam out through an exit window. However, successive turns of the beam are very close, and the deflection device could block a substantial amount. Can such losses be avoided?

A technique was devised to accomplish this using a radio frequency deflector, and this was successfully demonstrated in March 1985. It appears that we may expect better than 90% extraction efficiency. The next experiment will test this deflector and a prototype electrostatic deflector together, to determine whether they will separate the final turn cleanly from the circulating beam.

An alternative, or additional, method to increase the turn separation by increasing the energy gain per turn (using devices called booster cavities) is also being pursued, and will likely be tested next year. Its use should reduce the electromagnetic losses in the cyclotron and improve the stability of operation.

Studies have started on methods to extract beams with small split ratio while retaining beam quality.

New Facilities

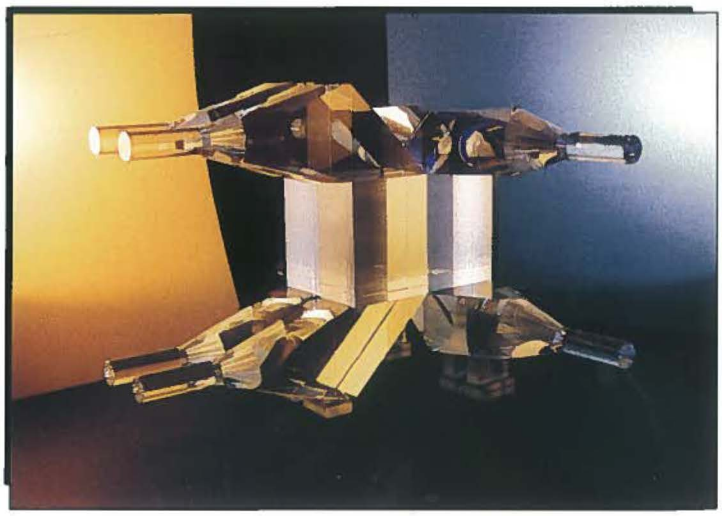
(i) The Upgraded Medium Resolution Spectrometer

To convey an impression of the recent advances in this area one must outline the essential features of a typical experiment. A beam of protons of fixed velocity is extracted from the cyclotron, transported to the experimental area, and allowed to impinge on a thin foil made of the material whose atomic nucleus is under investigation. The vast majority of these protons pass straight through the foil with only a slight loss in velocity and almost no change in direction. Very occasionally, however, a proton passing close to one of the neutrons or protons contained in that nucleus, is deflected through a significant angle, and may lose much of its velocity. The experiment consists of measuring at a fixed angle the probability of scattering as well as the distribution of velocities of the scattered protons. Such measurements are then repeated for different values of the angle through which the scattering occurs. The spectrometer is the device used to detect the scattered protons, and its "resolution" is a measure of the precision with which the velocity of the scattered protons can be determined.

The highlight of the year in the proton hall was the completion of the upgrade of the Medium Resolution Spectrometer and the achievement of an energy resolution of 100 keV—a fivefold improvement. Last year the six-quadrupole beam twister and new scattering chamber for this spectrometer were installed. This year the remaining components, new focal plane and front-end detectors, were commissioned. Several experiments using this significant improvement in resolution have already been completed and two new initiatives which make use of the MRS have started.

One of these, called the (p,n)(n,p) facility, makes it possible to study in a new energy range those reactions

Construction of the meson hall extension



Scintillation detector

in which an incoming proton leads to the ejection of a neutron from a nucleus, or vice versa. This spectrometer is used to measure the momentum of recoil protons from neutrons striking a plastic scintillator (detector) in the first case, or of the scattered protons in the second case.

The other initiative is the development of a focal plane polarimeter for the spectrometer, and the first tests were successfully carried out on this device this spring. (Photos of part of this equipment appear in the next section of this report, under "Pure Research".)

(ii) Surface Muon Beam Line

Last year we described the experimental hall that was built, and the design work done, to serve a new beam line—M15. This new line is devoted to surface muons, and was completed this year. Several experiments are under way.

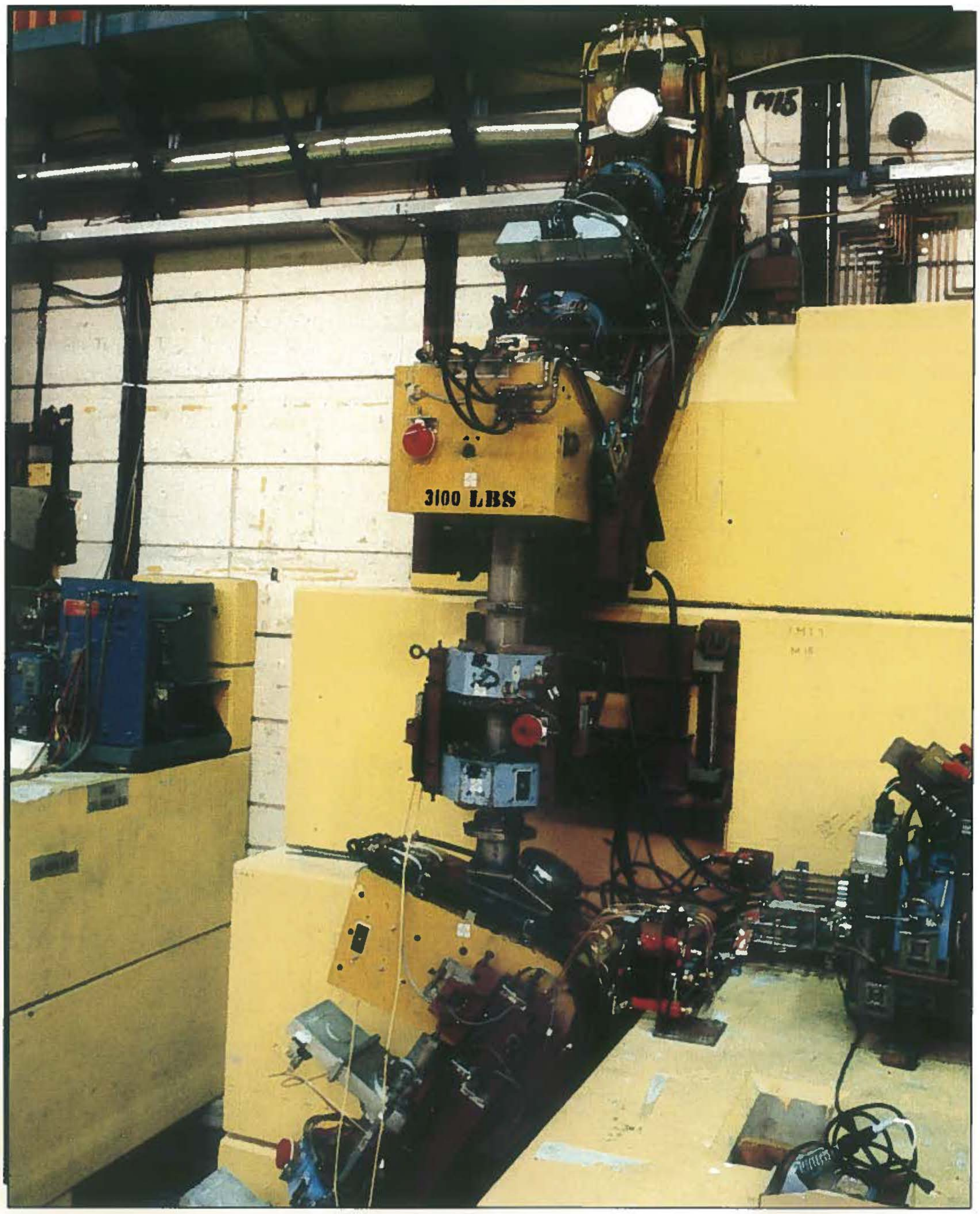
The use of muons at TRIUMF was described in our Annual Report of 1982-83. To produce them, the proton beam is first directed at a suitable target to generate positively charged pions, which decay after a few billionths of a second into positive muons and other particles. Those pions which initially had very low energy (velocity) will decay within the surface of the target material, yielding what we call "surface muons". Such muons are valuable for experiments because they all have the same relatively low energy, and also because they are polarized (i.e. they all spin with their axes parallel).

This beam line has a number of features which make it unique in the world at the present time. The first two quadrupoles in the channel are permanent magnets rather than conventional electromagnets. The compact size of these magnets, made from samarium-cobalt, allows them to be placed very close to the meson production target so that more muons can be collected. At the other end of the channel a pair of electrostatic separators is used to provide a high-luminosity, transversely polarized, pure surface muon beam.

Building Programme

The main item was the completion of the structure for the extension at the meson hall's eastern end. After the installation of all the necessary services, this will go a long way toward reducing the present congestion on the floor of the hall.

Pac Man



The new muon line, M15

Pure Research: Proton Probes

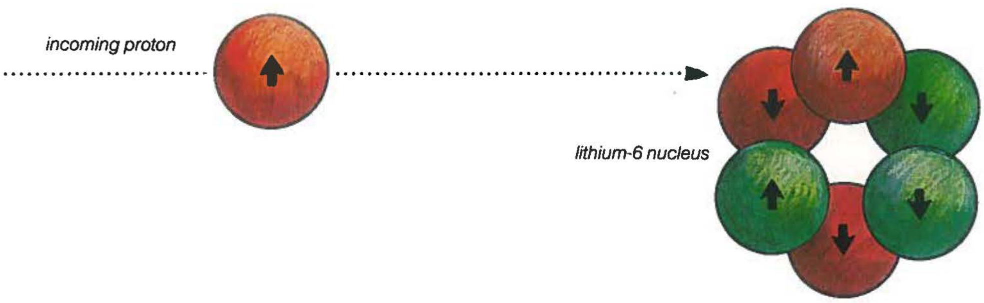
The 1980-81 Report focused on the initial studies at TRIUMF using the primary proton beam to investigate the physics of the atomic nucleus. Major improvements to the existing medium resolution spectrometer (MRS), and the commissioning of both a (p,n) facility (i.e. one where a proton striking a target causes a neutron to be emitted) and a focal plane polarimeter for the spectrometer, have been mentioned earlier in this report. These recent developments place TRIUMF at the forefront of this very active area of research. It is therefore most appropriate that in this year's Report, attention be once again directed at studies where a proton beam is used as a probe.

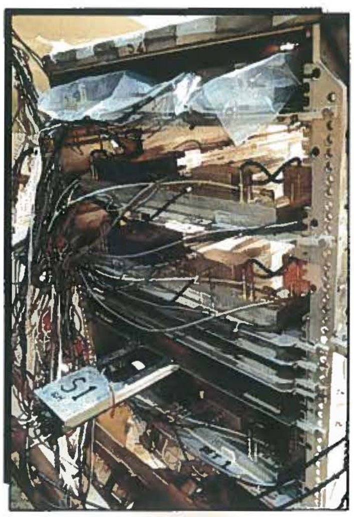
Recently, considerable interest has focused on the use of protons in the range of velocities produced by the TRIUMF cyclotron as a particularly versatile probe of the properties of complex nuclei. (This includes all nuclei having more than five or six nucleons.) The natural starting point for most detailed descriptions of nuclei involves the assumption that the constituents are simply neutrons and protons. An essential prerequisite to the use of protons as a nuclear probe has therefore been an extensive study of the basic interactions between two protons, and between a proton and a neutron. Such investigations formed an important part of the early experimental programme at TRIUMF.

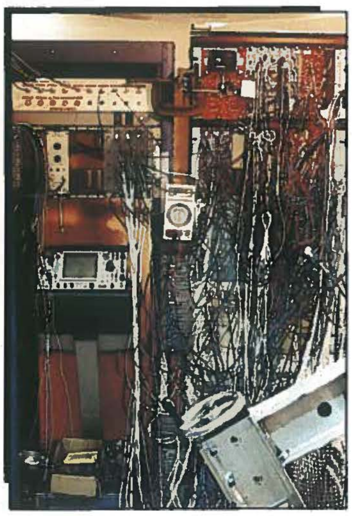
For each nucleus there is one arrangement of the constituent nucleons which involves the minimum possible total energy, and which hence is the most stable. There exist, however, almost countless possible rearrangements corresponding to excited states of that nucleus, and the properties of each of these states are potential objects of investigation. Insight, however, is often best obtained by focusing attention on those excited states of the nucleus that involve the simplest possible alterations of the most stable arrangement. One such rearrangement involves an excited state identical to the stable state except for the reversal in the direction of the spin of only one of the constituent nucleons. Excited states of this kind in many nuclei have been identified. The recent improvements in the proton facilities at TRIUMF can each be brought to bear on the search for such needles in the nuclear haystack.

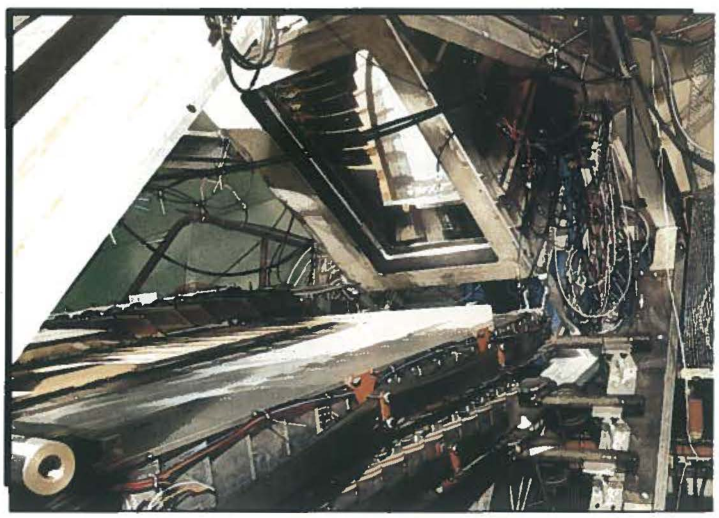
The "resolution" of a spectrometer refers to its ability to distinguish between particles travelling at almost the same velocity. The smaller the velocity difference that can be detected, the greater the resolution. The improvements to the resolution of the medium resolution spectrometer (MRS) greatly facilitated the initial investigations at TRIUMF of this simple kind of nuclear excitation. States of this kind previously known to exist in isotopes of carbon, magnesium, silicon and calcium have been reliably identified on the basis of precise velocity measurements, with protons incident at velocities throughout the range of values available at TRIUMF. These experiments quantitatively establish the effectiveness of the proton as a probe at these velocities.

One distinctive feature of the specific kind of nuclear excitation mentioned above, is that if such a state is formed in the scattering of protons, an essentially identical state will be produced in a neighbouring nucleus in a reaction in which the incident proton is converted into an emitted neutron. The study of such reactions, with reasonable resolution of the velocity of









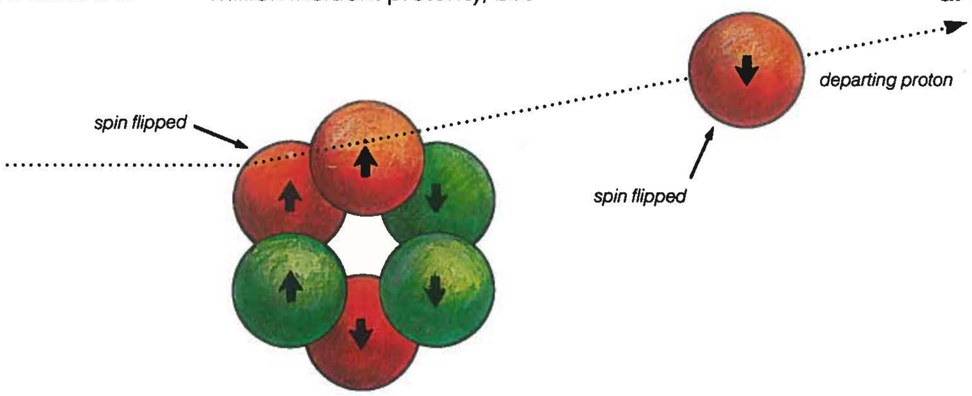
the emitted neutron, is now a unique capability of TRIUMF. The first experiment of this kind recently completed at TRIUMF utilized a radioactive isotope of carbon as the target.

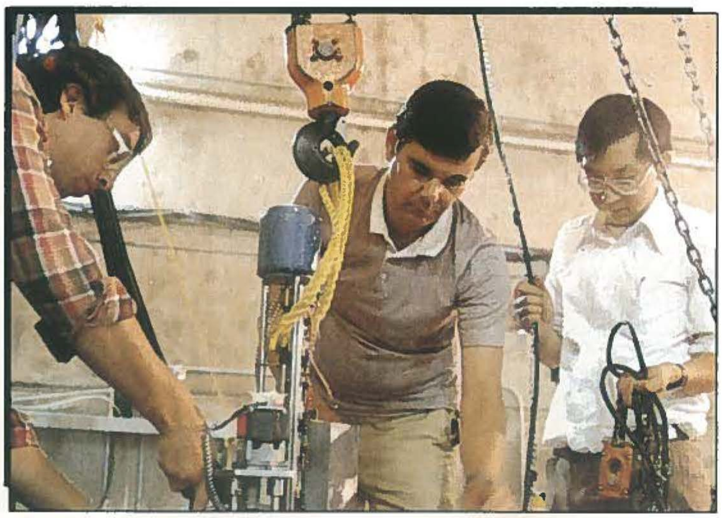
A second useful characteristic of reactions in which the scattering of a proton from a nucleus is accompanied simply by the change in direction of the spin of one of the constituent nucleons, is exploited in experiments with the new MRS polarimeter. (A polarimeter identifies the directions of spin— up or down—of the particles passing through it.) These reactions involve a corresponding reversal (in the opposite sense) of the spin of the incident proton. Hence if the protons are incident with their spins all pointing up, most of the protons should be emitted with their spins pointing down. The availability of proton beams with a preselected spin direction has long been a feature of experiments at TRIUMF. Through the availability of a device to determine the spin directions of the scattered protons, a new opportunity has been created to identify specific types of nuclear excitation. Such experiments involving an international collaboration of scientists have recently been initiated.

The experiments mentioned above have been chosen to illustrate the variety of techniques that now can be used at TRIUMF to investigate a common problem. Similarly, the upgraded facilities are being used on a wide range of problems. An additional example is the study of violent collisions in which the incident proton is scattered through a large angle, but the internal motion of the constituents of the target nucleus remains undisturbed. Such events are rare (being detected typically once for every hundred million million incident protons), but two competing theoretical descriptions of the process predict quite different characteristics for this kind of event. Two recent TRIUMF experiments are among the few detailed studies of such rare events. A longer-term objective in such studies of violent collisions is the quest for evidence of the influence of quarks, the constituents of the nucleons.

Although many of the experiments with the proton beam at TRIUMF make use of the upgraded MRS and its related facilities, there is also an active ongoing programme in other experimental areas, including one of the beam lines in the meson hall. As a recent example one should mention a detailed study (with a polarized proton beam) of collisions between two protons which result in the creation of an additional photon. It is essential that investigations of the structure of complex nuclei proceed in conjunction with further efforts to understand the basic interaction between two nucleons.

The future of experiments with proton beams at TRIUMF is most promising. The upgraded MRS and the related new facilities have only very recently been commissioned. Even as they are further developed and fully exploited, important new initiatives are being proposed. One of these involves an extremely sensitive test of parity conservation, a fundamental symmetry usually ascribed to the collision between two protons. A second is an ambitious scheme to make TRIUMF the premier facility in the world for the production of isolated samples of a vast array of radioactive isotopes. Future Annual Reports will feature these activities, or others brought to prominence by the level of activity in the field and the unique opportunities at TRIUMF.





Research scientists—replacing the target.

Applied Programmes

In past years we have presented in this section brief accounts of all the applied programmes, rather than concentrating on one single area (as in the section on Pure Research). Though this approach has its merits, it does not allow the reader to appreciate the full scope of some of these programmes. This year, therefore, we present the usual summaries followed by a more detailed account of one particular topic—the production of radioisotopes by Atomic Energy of Canada Ltd. at TRIUMF's facilities.

On another note, it is interesting to realize the kind of collaboration that can arise between different applied programmes. An example of this is mentioned in the summary on Pion Therapy for Tumours.

Positron Emission Tomography

This year was a busy one for the TRIUMF-UBC Programme on Positron Emission Tomography, with the TRIUMF-built PET VI tomograph performing in exemplary fashion in the UBC Health Sciences Centre Hospital, and a steady flow of radiopharmaceutical scanning agents being delivered from their production site at TRIUMF to the hospital by means of the 2.4-kilometre-long pneumatic transfer system. By the end of this year, close to 200 patients and normal volunteers had participated in the PET research programme, and as a result 14 papers were published in research journals and 22 papers presented at conferences.

Emphasis this year was placed on studies of dementia (and particularly Alzheimer's disease and schizophrenia) as well as on movement disorders (Parkinson's disease, Huntington's disease, dystonia, and other less common conditions). At the same time other studies were conducted in collaboration with the pion therapy programme, as well as on epilepsy and cerebro-vascular disease.

Among some notable studies were those of subjects from California who had been exposed to the neurotoxin MPTP, an impurity in certain hallucinogens. These scans, conducted with 6-fluorodopa, revealed destruction of brain cells in the striatum in patients so exposed, including those who had developed artificial Parkinson's disease (see illustration).

This year also saw a successful application to the Medical Research Council for a renewal of a three-year grant to support operation of this programme.

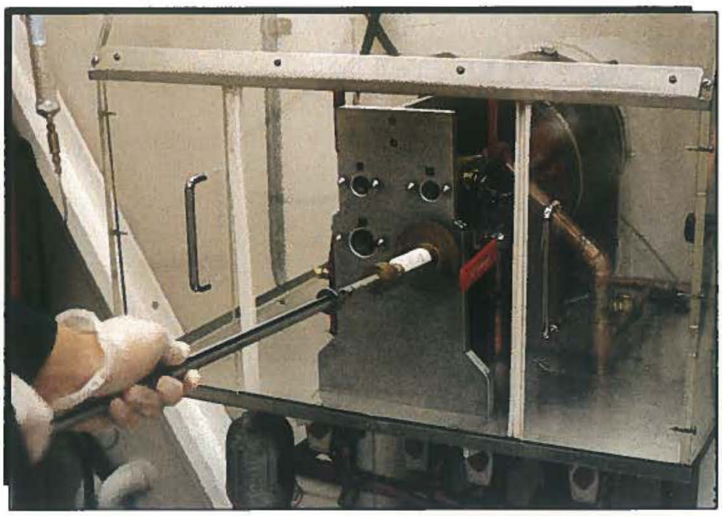
Trim

The TRIM programme of iodine-123 radiopharmaceuticals has continued heart-imaging research using fatty acids and has also expanded in the brain- and tumour-imaging areas. Both lactone-derived and phenyl fatty acids are available on demand. Research is directed toward heart imaging by SPECT (Single Photon Emission Computed Tomography), and toward evaluating heart physiology after infarct or transplantation. New compounds of iodine-123 are being developed. One of them ("IMP") is now available on demand for human brain imaging, where it is useful in early stroke evaluation. The newest addition ("MIBG") is specific for the adrenals and certain tumours (pheochromocytoma and neuroblastoma).

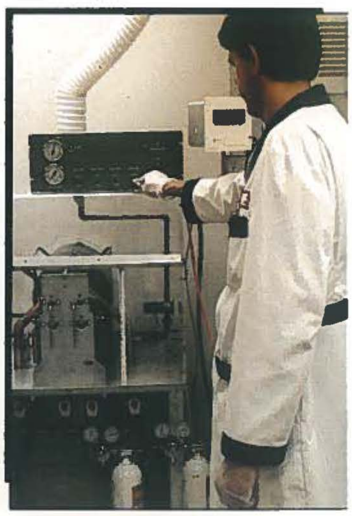
Electronics

Twenty or thirty years ago, experimenters recorded nuclear reactions by taking thousands of photos of the trails left by particles in bubble chambers or cloud chambers. Today, such devices are obsolete: particles are tracked with electronic equipment. As the nuclear and particle experiments become more complex, increasing demands are placed on the electronic circuitry that serves the numerous particle detectors used, and the computers that record the signals

After the isotope has been incorporated into a pharmaceutical and purified, it is sealed in a vial, which is placed in a white holder—the "rabbit".



The rabbit is pushed into a pneumatic line, using a special rod.



A switch is pressed, and a surge of compressed air sends the rabbit off to the UBC Health Sciences Centre, 2.5 km away. It will arrive in about two minutes, and the isotope will be used at once.

from these detectors. Some of the circuits that are required are not available even from nucleonics companies. Requirements of speed, miniaturization, and high signal resolution, can be all met only by developing microcircuitry specially for nuclear detectors. TRIUMF now has a thin- and thick-film laboratory to satisfy such needs. The laboratory prepares circuits whose individual components are extremely small (often less than a thousandth of a millimetre) and that operate in time intervals shorter than a billionth of a second. The circuits are interfaced and housed within the particle detectors themselves.

The laboratory, in collaboration with the Communications Research Centre in Ottawa and with the Electrical Engineering Department of the University of British Columbia, has successfully produced a charge coupled transient-digitizing circuit component in gallium arsenide material. There are many possible applications for this kind of device; one similar to that shown in the photo may be used as an interface for an experiment to measure rare kaon decays, at Brookhaven National Laboratory in the USA. These devices will be assembled locally.

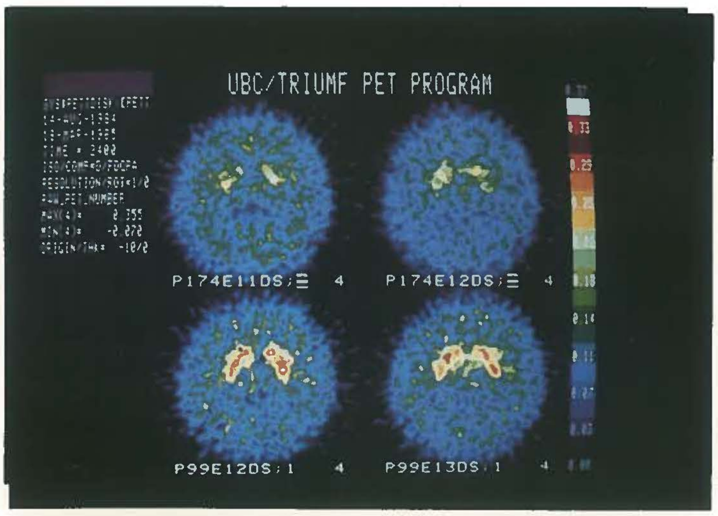
Pion Therapy For Tumours

This programme has reached a grand total of 69 patients treated since its inception in May 1982, after providing therapy for 30 during 1984. Of those treated last year, 15 had tumours in the brain, five had them in the bladder, and five in the rectum. Four patients had prostate tumours, and in one case the affected organ was the skin. This illustrates the diversity of conditions for which this kind of therapy is being evaluated.

The method of treatment is based on irradiating the tumour with a beam of negatively charged pions. These tiny particles (each having only about one seventh the mass of a proton) do relatively little damage as they pass through living tissue, but at the end of their brief lives they become devastating to nearby cells as they "explode" within the tumour like so many submicroscopic depth charges. (In 1984 TRIUMF released a new four-page brochure for the public, describing pion therapy in simple language.)

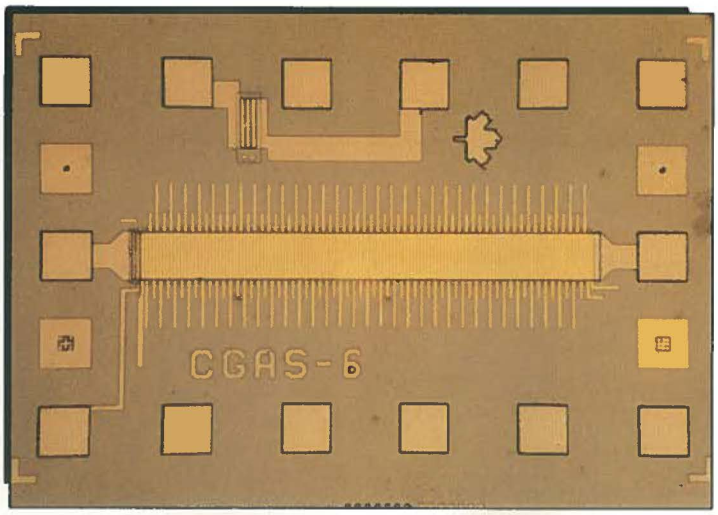
Despite the greater number of patients treated, the programme has had to grapple with a few difficulties. Several minor hardware breakdowns —vacuum leaks, water leaks, electrical short-circuiting and the like—led to the loss of some treatment days. Another problem is that with larger tumours now being treated, longer irradiation times are required (a record 13-cm-diameter tumour recently required 1.5 hours), and this leads to greater radioactivity being induced in the patients. (The half-life is fairly short, though—about 10 to 20 minutes— and the phenomenon is probably due to the formation of carbon-11 by some of the pions stopping in the tissue. To reduce the effects on both staff and the patients' family members, such patients are being isolated in a shielded room for about 30 minutes after treatment.) This radioactivity was, however, put to good use in some cases, in a collaboration with the TRIUMF-UBC PET team. Several brain tumour patients were taken to the nearby university hospital for PET scans immediately after therapy. From these scans it was possible to reconstruct the actual spatial distribution of the pions that arrived in the zone being treated, and this will provide important input for future therapy.

To the non-scientist, the concept of pion therapy is clearly one which grips the imagination, as this area usually generates the greatest number of questions during the regular public tours of TRIUMF.



Upper: PET axial section images at different levels through the striatum of a subject exposed to the neurotoxin MPTP, obtained with scanning agent 6- ^{18}F-fluoro-dopa.

Lower: Similar images from a normal subject.



Part of a charge-coupled device designed by electronics laboratory

Commercial Radioisotope Production at TRIUMF

Atomic Energy of Canada Limited now has worldwide markets for the isotopes produced in the facilities at TRIUMF. This was the first year of full isotope production capability since the operating licence was granted, and seven isotopes were in routine production. These were either sold directly to customers or transferred within the company for the manufacture of "added value" products, such as industrial sources or radiopharmaceuticals.

Using isotopes produced at TRIUMF, AECL has now established itself as a supplier of radiopharmaceuticals to hospitals throughout Canada despite fierce competition from the United States companies which had previously supplied all of Canada's requirements.

There were two notable achievements this year: direct sales to customers were $1.1 million; and a novel method of making iodine-123 was developed, with high-level production starting in August 1984. Worldwide process patents have been applied for, and serious negotiations have started with prospective purchasers of the technology.

Production processes

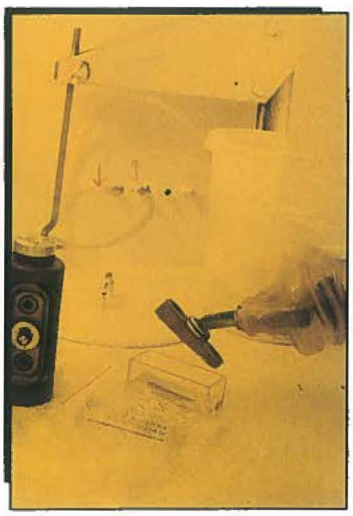
The main accelerator at TRIUMF produces beams of high-energy protons which can be used to make radioactive isotopes by a process called spallation. In this process, high-energy protons collide with the nuclei of atoms in a specific target material, and several complex reactions may take place. This yields a target containing many isotopes, from which the desired product is separated and purified. There is interest from research groups for the supply of several isotopes which may be produced by spallation at TRIUMF. Accordingly, AECL has developed the capability of producing copper-67, germanium-68, strontium-82, cadmium-109, and xenon-127, but only two are currently commercially viable—xenon-127 and cadmium-109.

The workhorse for isotope production is a 42 MeV cyclotron, a compact commercial unit supplied by the Cyclotron Corporation. The cyclotron is operated and maintained by TRIUMF Applied Programme employees under the direction of Joop Burgerjon, and this year it was operational for the entire 52 weeks. This demanding schedule is required for the production of isotopes used in routine medical applications.

In addition to the routine production of thallium-201, iodine-123, indium-111, gallium-67, and cobalt-57, AECL has produced lead-205, which is being used as a tracer by geological survey laboratories for the analysis of minerals by mass spectrometry. In the energy range of this compact cyclotron, products are formed by direct nuclear reaction, and the isotope mixture from which the product is to be separated may be relatively simple. To achieve this, however, enriched target material may be required, and this is costly. An example of direct nuclear reaction is the preparation of thallium-201. The starting material is thallium-203. It absorbs a proton and ejects three neutrons to yield lead-201, which is radioactive and has a half-life of 9.4 hours. This lead isotope decays to thallium-201, which has a half-life of 73 hours. In the shorthand of the physicist, this is written as:

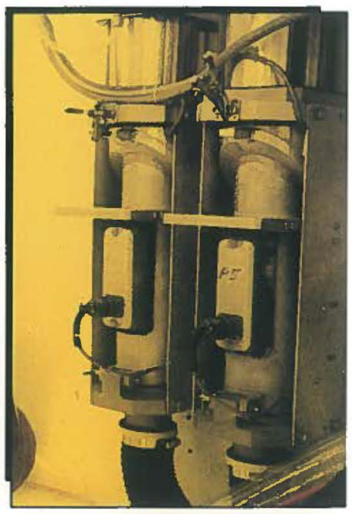
$$^{203}T\ell\ (p,3n) \rightarrow {}^{201}Pb \xrightarrow{T1/2\ =\ 9.4\ h} {}^{201}T\ell\ (T1/2\ =\ 73\ h)$$

1 The targets are prepared for irradiation by operators using remote control of mechanical arms in hot cells.



2 Watching through a 30-cm slab of lead glass, an operator guides the mechanical hand to pick up the target and place it in a cylindrical holder (left).

3 The holder is placed in a section of the pneumatic line, which is then swung up on its hinge...



4...and the target is on its way to the cyclotron. After irradiation, it is returned to the hot cell and handled in the same way.

Natural thallium contains only 29.5% of thallium-203. To optimize the production of thallium-201, the target material is concentrated to greater than 97% thallium-203, and costs $2500 per gram. In such a case it is economically critical that target material be recovered in high yield for re-use, and procedures have been developed that retrieve 95% without sacrificing product yield.

Most of the products are used in routine medical diagnostic applications. Iodine-123 and indium-111 are employed clinically at present to a relatively limited degree. However, both these isotopes are the subject of active research: indium-111 for use in labelling monoclonal antibodies which will locate tumours more effectively; iodine-123 for use in a wide variety of labelled compounds which will give the nuclear medicine physician unique information about a patient. The exciting developments in iodine-123 production technology at TRIUMF will be considered in a little more detail.

Iodine-123

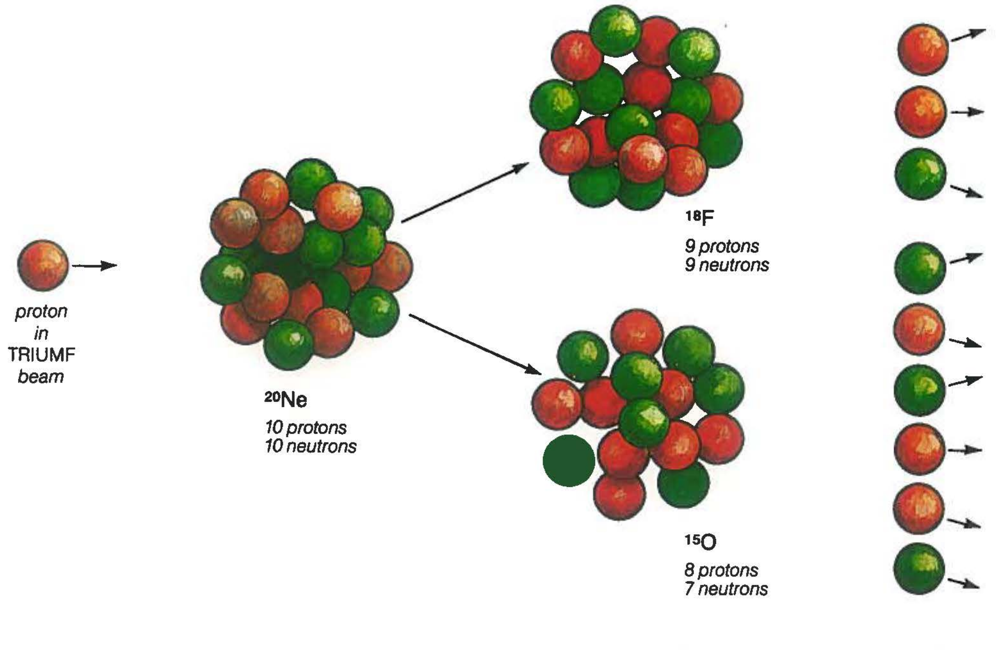
It is relatively easy to label organic compounds with iodine, and because of the specificity that a labelled compound may have, unique clinical information may be obtained. The half-life and the decay characteristics of iodine-123 make it particularly suitable for patient imaging. The potential for this isotope was recognized more than twenty years ago, but the unavailability of a pure product up to now has limited even research on applications.

Prior to AECL's demonstration of a new production method, there were two ways of making commercially useful quantities of iodine-123: with a compact cyclotron and a tellurium-124 target, or with a 70 MeV proton beam and natural iodine as the target atom. Compact cyclotrons are reliable production units in widespread use, but with a tellurium-124 target, the iodine-123 is contaminated with impurities which made it very difficult to get good images of small organs. 70 MeV protons are available from an accelerator such as the main TRIUMF cyclotron or from medium-energy cyclotrons. Reliability has shown itself to be the problem in this case, since production is required several days per week every week of the year, and on a schedule that fits in with airline timetables. Product made by this method has no imaging problems.

The new AECL method employs a compact cyclotron. Highly enriched xenon-124 is used as target material. The cost of the target gas is $280,000 per litre, and the key to the process is the ability to handle such costly gas without losing substantial quantities. Product made by this route has virtually no impurities, and gives first-class images. Furthermore, the administration of this material to a patient (rather than iodine-123 prepared with a 70 MeV proton beam) results in halving the total radiation dose to the patient, due to the absence of unwanted radioactive impurities.

Isotope Applications

Product	Half-Life	Application
Thallium-201	73 hours	Heart imaging
Xenon-127	36.4 days	Lung ventilation studies
Iodine-123	13.2 hours	Thyroid scanning (labelled compounds)
Indium-111	68 hours	Tumour imaging (monoclonal antibodies)
Cadmium-109	464 days	X-ray fluorescence sources
Gallium-67	78.3 hours	Tumour imaging
Cobalt-57	271 days	Calibration sources



Spallation reactions

TRIUMF Organization


E.W. Vogt


P. Adams


E.W. Blackmore


C.W. Bordeaux

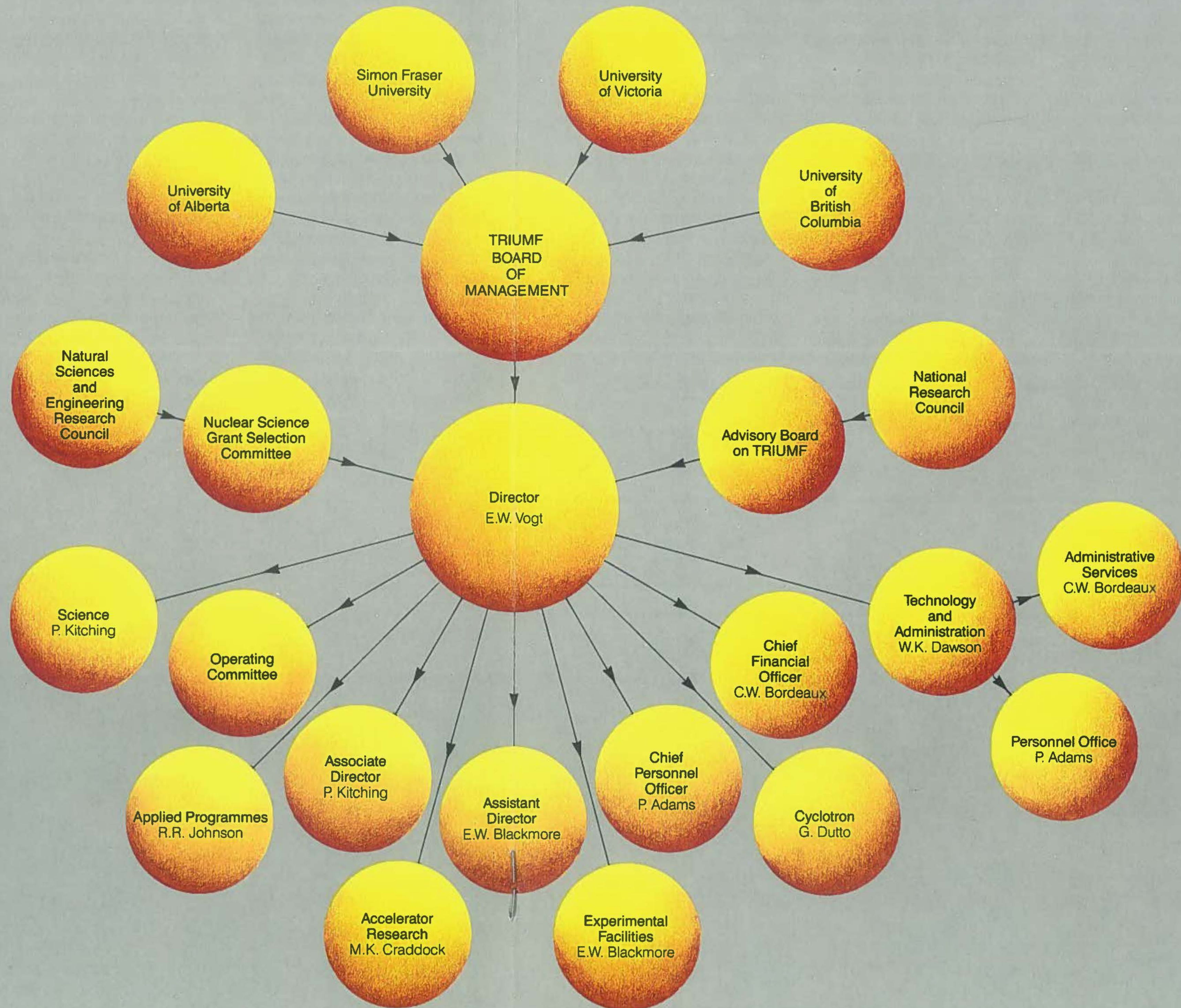

M.K. Craddock


W.K. Dawson


G. Dutto


R.R. Johnson


P. Kitching



Financial Review

Requirements were defined for expanded Management Information Systems (MIS) necessitated by the transfer in 1983-84 of some financial responsibilities from the University of British Columbia to TRIUMF. An IBM System 38 computer was purchased to process all financial information, and programming of revised MIS was begun, for implementation in 1985-86. Some small changes in the financial report were introduced in accordance with the new requirements, as explained in the notes to the financial statements.

Increases in receipts occurred in all areas of funding, resulting in a total increase of 15.42%:

- The contribution from the National Research Council (NRC) increased by 9.84%, in line with the Five-Year Plan projections. NRC funds all TRIUMF's operations, maintenance, development and capital expansion. NRC funding this year represented 77.3% of the total funds received. In 1983-84 it was 81%. This fluctuation is due primarily to increased support by NSERC (see below) and increased receipts from all other sources of funds.
- The principal financial support for experiments performed under the aegis of TRIUMF is provided by the Natural Sciences and Engineering Research Council (NSERC). Its funding comes under the TRIUMF Common Grant, which is administered by TRIUMF, on behalf of the grantees, in accordance with guidelines received from NSERC. The total funds available increased by 28.09%, and the actual allocation of grant funds increased by 24.08% over 1983-84. NSERC supplies additional financial support to TRIUMF by funding TRIUMF-related experiments administered by other institutions.
- Atomic Energy of Canada is reported on separately, because it is the major commercial user of TRIUMF facilities. Their construction phase was completed in 1983-84. Operations are progressing satisfactorily. Their sales of radioisotopes increased considerably over the previous year, and prospects for the coming years are equally promising. The flow of funds through TRIUMF seems to have stabilized: an increase in receipts of 3.91% was recorded.
- Through the Universities Council of British Columbia, the Province of British Columbia approved a building programme to keep pace with expansion as reflected in the TRIUMF Five-Year Plan (next page). The total approved amount to date is $7,475,500. Construction of new buildings continued throughout 1984-85, resulting in substantial completion of the total approved building programme.
- A continued growth in transactions on behalf of affiliated institutions is being experienced: in 1982-83 there were 39 such accounts, in 1983-84 there were 51, and now there are 67. Receipts increased by 81.69% over last year. These receipts consist of imprest funds and reimbursements for expenditures undertaken on behalf of these institutions, from Canada and abroad, for their TRIUMF projects. Expenditures in the Statement of Combined Funding and Expenditures are within budget.

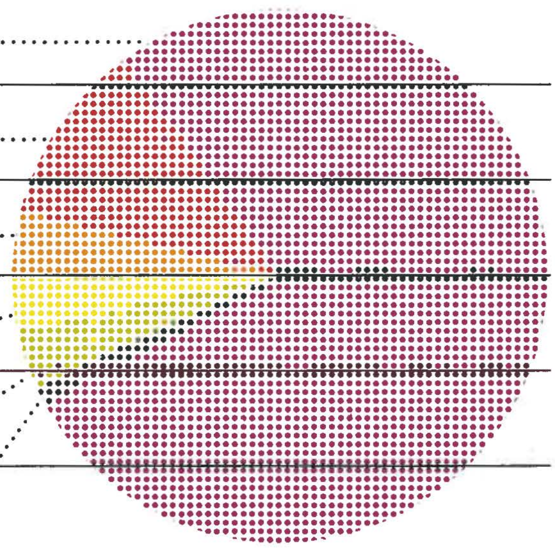
In line with the Five-Year Plan projections (next page), a general increase in activities led to hiring of additional staff, which is reflected in increased salary expenditures, within approved limits.

A successful year was experienced in that all major obligations were met and expenses were at acceptable levels. The forecast for next year, fiscal 1986, is for a continued real growth in funding from NRC and NSERC, the completion of the approved construction funded by the Province of British Columbia and the usual support from all institutions using TRIUMF facilities.

Source of Funds

(Millions of dollars)

National Research Council	$25.52	77.31%
Natural Sciences and Engineering Research Council	3.63	11.0%
Atomic Energy of Canada Limited	1.29	3.92%
Affiliated Institutions	1.24	3.76%
Province of British Columbia	1.09	3.31%
Miscellaneous	.23	0.70%
	$33.01	100.00%



Five-Year Plan

Each year TRIUMF, in collaboration with its users, prepares a rolling Five-Year Plan. This plan, which is submitted to the NRC Advisory Board on TRIUMF each fall, must satisfy constraints in the allocation of funds in each of three broad areas, namely the basic support and operation of the existing facility, the development of new facilities which enhance TRIUMF's capabilities, and support of the experimental programme. In each of these areas the plan forecasts two types of expenditures—general operations and major projects. A major project has a clearly established goal and timetable. Project goals will generally provide specific benefits to users, e.g. by enhancing the reliability or performance of a certain part of the cyclotron itself, or by providing a new or improved facility for experiments. At any one time there are about 15 active major projects. While major projects involve only about 15% of the total budget, they are a vitally important factor in maintaining the excellence of TRIUMF.

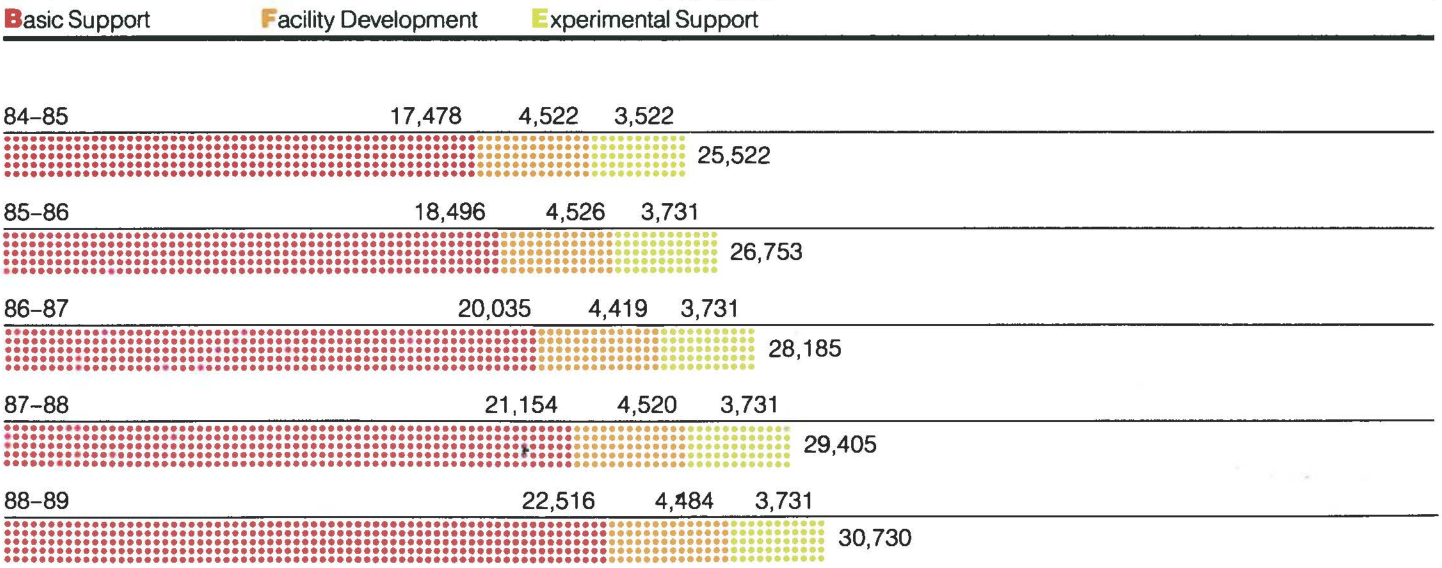
TRIUMF Five-Year Plan

Thousands of 1984 dollars

	1984–85	1985–86	1986–87	1987–88	1988–89
Basic Support	17,478	18,496	20,035	21,154	22,516
Facility Development *(excluding KAON Factory)*	4,522	4,526	4,419	4,520	4,484
Experimental Support	3,522	3,731	3,731	3,731	3,731
Total	25,522	26,753	28,185	29,405	30,730

TRIUMF Five-Year Plan

Thousands of 1984 dollars



Financial Statements

TRIUMF Statement of Combined Funding and Expenditures for the year ended March 31, 1985

	1985	1984
Funding		
National Research Council	**$25,522,000**	$ 23,235,000
Natural Sciences and Engineering Research Council	**3,634,731**	2,837,619
Atomic Energy of Canada Limited	**1,293,465**	1,082,286
Province of British Columbia	**1,093,149**	633,882
Affiliated Institutions	**1,240,664**	682,841
Investment income	**229,739**	129,772
	33,013,748	28,601,400
Expenditures		
Building construction	**1,245,086**	737,625
Communication	**249,671**	189,461
Computer	**344,440**	270,545
Equipment	**2,044,595**	2,548,460
Facilities in progress	**2,227,238**	1,698,310
Lease payments – Atomic Energy of Canada Limited	**641,095**	564,185
Minor construction	**24,452**	55,546
Power	**1,613,071**	1,496,663
Salaries and benefits	**15,635,058**	13,916,630
Sessional and occasional staff costs	**1,508,839**	1,239,448
Supplies and expenses	**6,485,705**	5,855,809
	32,019,250	28,572,682
Excess of funding over expenditures	**994,498**	28,718
Less funds balance end of year – Note 3	**817,334**	68,673
(Increase) decrease in deficit for the year	**177,164**	(39,955)
(Deficit) surplus beginning of year	**(130,120)**	(90,165)
(Deficit) surplus end of year	**$ 47,044**	$ (130,120)

Auditor's Report

Board of Management
TRIUMF

We have examined the statement of working capital position of TRIUMF as at March 31, 1985 together with the statement of combined funding and expenditures and the National Research Council statement of funding and expenditures for the year then ended. Our examination was made in accordance with generally accepted auditing standards and accordingly included such tests and other procedures as we considered necessary in the circumstances.

In our opinion, these statements present fairly the working capital position of TRIUMF as at March 31, 1985 and its funding and expenditures for the year then ended in accordance with the accounting policies set out in Note 2 applied on a basis consistent with that of the preceding year.

Spicer MacGillivray

Vancouver, Canada
June 1st, 1985

Spicer MacGillivray
Chartered Accountants

TRIUMF Statement of Working Capital Position for the year ended March 31, 1985

		1985	1984
Assets	**Cash and temporary investments**	**$1,200,034**	$ 204,646
	Accounts receivable	**51,498**	—
	Funds recoverable		
	Province of British Columbia	**195,545**	105,451
	Natural Sciences and Engineering Research Council	**134,066**	113,275
	Atomic Energy of Canada Limited	**17,612**	24,209
	Affiliated Institutions	**171,033**	135,138
		518,256	378,073
	Due from universities		
	The University of Victoria	**3,167**	—
	The University of Alberta	**11,449**	19,914
		14,616	19,914
	Total assets	**1,784,404**	602,633
Liabilities	**Due to National Research Council**	—	1,372
	Due to universities		
	The University of Victoria	—	9,410
	The University of British Columbia	**84,390**	232,227
	Simon Fraser University	**20,830**	16,396
		105,220	258,033
	Accounts payable – Note 4	**296,550**	27,974
	Funds unexpended		
	Natural Sciences and Engineering Research Council	**991,626**	378,131
	Affiliated Institutions	**343,964**	67,243
		1,335,590	445,374
	Total Liabilities	**1,737,360**	732,753
	Working capital surplus (deficit) – TRIUMF	**$ 47,044**	$ (130,120)

National Research Council Statement of Funding and Expenditures for the year ended March 31, 1985

	1985	1984
Funding		
Funds unexpended at beginning of year	**$ 1,372**	$ 25,050
Cash contribution	**25,520,628**	23,209,950
Total approved contribution	**25,522,000**	23,235,000
Expenditures by activity area – Note 2		
Salaries	**14,693,105**	13,209,563
Power	**1,613,072**	1,496,663
Administrative and Overhead	**1,764,159**	1,559,417
Cyclotron and Facilities Operation	**2,525,012**	2,643,092
Site Services	**495,098**	761,004
Support Services	**1,699,661**	1,455,296
Major Projects	**2,381,228**	1,674,472
Minor Projects and Development	**670,967**	809,767
	25,842,302	23,609,274
Funds Recovered – cost centres	**301,666**	375,646
– from TRIUMF funds	**18,636**	—
	25,522,000	23,233,628
Funds unexpended (overexpended) end of year	**$ —**	$ 1,372
Expenditure breakdown by program element:		
Basic Support	**$ 17,151,135**	$ 16,091,550
Facility Development	**4,804,884**	3,890,657
Experimental Support	**3,565,981**	3,251,421
	$25,522,000	$23,233,628
Expenditure by object:		
Communications	**$ 224,033**	$ 167,682
Computer	**281,369**	191,595
Equipment	**1,503,295**	2,001,407
Facilities in progress	**2,227,238**	1,698,310
Insurance	**67,102**	61,019
Minor construction	**24,451**	55,546
Power	**1,613,071**	1,496,663
Salaries and benefits	**13,889,174**	12,452,212
Sessional and occasional staff costs	**839,339**	757,250
Supplies and expenses	**4,852,928**	4,351,944
	$25,522,000	$23,233,628

Note 1:

Organizational Structure

TRIUMF is a Joint Venture established by The University of Alberta, The University of Victoria, Simon Fraser University and The University of British Columbia, having as its goal the establishment and continuance of a national meson facility for Canada.

Note 2:

Accounting Policy

All transactions are recorded on an accrual basis. Expenditures on capital assets and inventories are expensed as incurred.

The expenditures by activity groupings on the National Research Council Statement of Funding and Expenditures follow the classifications adopted by the Advisory Board on TRIUMF.

In addition, certain comparative figures on the Funds Statements have been changed to conform to the current presentation.

Note 3:

Summary of End-of-Year Funds Balance	**1985**	1984
Funds Unexpended		
National Research Council	$ —	$ 1,372
Natural Sciences and Engineering Research Council	**857,560**	264,856
Affiliated Institutions	**172,931**	—
	1,030,491	266,228
Funds Overexpended		
Atomic Energy of Canada Limited	**17,612**	24,209
Affiliated Institutions	—	67,895
Province of British Columbia	**195,545**	105,451
	213,157	197,555
Funds Balance	**$ 817,334**	$ 68,673

Note 4:

Commitments and Contingencies

a) In addition to the accounts payable reflected on the Statement of Working Capital Position, there are outstanding commitments representing the estimated costs of unfilled purchase orders and contracts placed as at the fiscal year-end.

National Research Council	**$ 1,781,000**	$ 1,197,000
Natural Sciences and Engineering Research Council	**80,000**	131,000
Atomic Energy of Canada Limited	**19,000**	18,000
Province of British Columbia	**390,000**	23,000
Affiliated Institutions	**70,000**	30,000
	$2,340,000	$1,399,000

At March 31, 1985, there were additional outstanding commitments in the amount of $799,000 for expenditures in the 1986–87 and 1987–88 fiscal years.

A Kaon Factory

The Five-Year Plans described in the Financial and Administrative Reports of the past few years have included proposed expenditures toward creating a KAON Factory at the TRIUMF site. (The word KAON here is an acronym for *K*aons, *A*ntiprotons, *O*ther hadrons, and *N*eutrinos.) The Plans have suggested that these expenditures should begin (though initially at a low level) in 1985-86. Early in 1985, a detailed proposal for the construction of such a facility was being prepared for submission to the National Research Council later in the year.

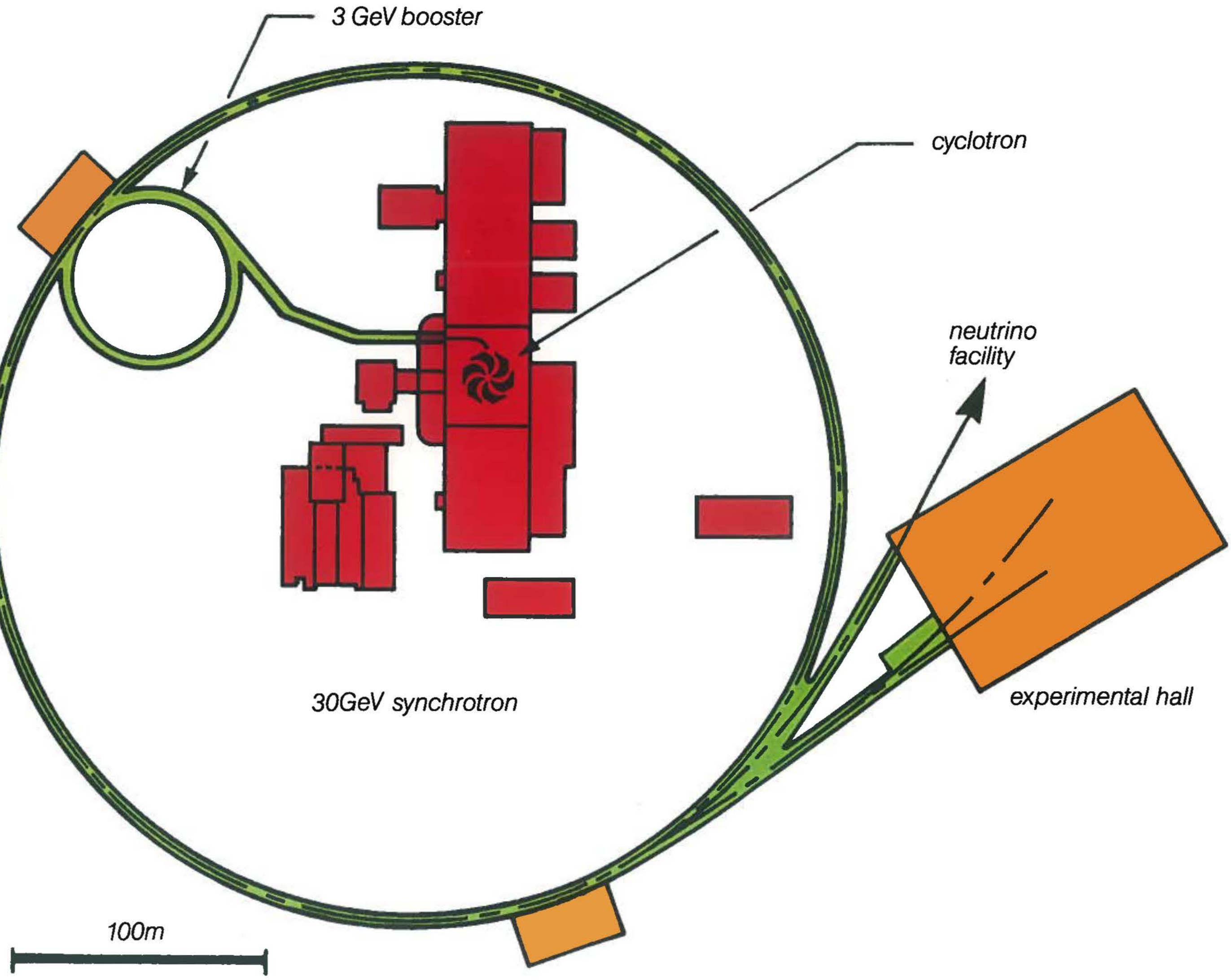
What exactly is a KAON Factory, and what has led to this proposal? To understand the background, one must first look at what TRIUMF is capable of now, and at the direction being taken by the large nuclear and particle physics facilities (both existing and proposed) elsewhere in the world.

In 1968, when the government of Canada made a decision to build a first-class, intermediate-energy physics research laboratory in Vancouver, the intention was to create a special, unique, and versatile facility. Unlike most other accelerators, the TRIUMF cyclotron was designed to accelerate *negatively charged* hydrogen ions. Because of this, it is easy to extract several beams of protons (each beam at a different energy) simultaneously from the cyclotron. Also, it was to accelerate particles to about 75 percent of the speed of light. This was not as fast as the output of some powerful synchrotrons and linear accelerators elsewhere, but our cyclotron would instead handle vast *numbers* of particles: a thousand times more per second than most others in the world at that time. In turn, this intense beam of protons would be used to generate several beams of pions (or pi-mesons), for use in a variety of experiments. Because of this abundant production, TRIUMF was referred to as a "meson factory", being one of only three such facilities in the world. This feature was important. It would allow us to do a different kind of research. This way, Canada could make a unique contribution to a fundamental and important area of scientific knowledge. We would not compete with other facilities, built at much greater expense by wealthier countries, but our work would complement theirs. From a world viewpoint, Canada's expenditure would be modest, but commensurate with our population and resources.

TRIUMF was built, the first proton beam emerged in 1974, and the work carried out since then has clearly placed Canada amongst the world leaders of research in nuclear and particle physics. During the same decade, worldwide research has led to the advent of completely new explanations of nature's basic building blocks (now identified as quarks and leptons), and of the relationships between the forces which govern them. These explanations have, however, also raised a myriad of new questions. The scientific community is now looking at ways of finding answers to those questions, and the next "generation" of research projects is now under way. A new era is beginning, with giant new accelerators and colliders either proposed or already being built by the other leaders in this field.

With the KAON Factory proposal, TRIUMF's scientists are suggesting a means by which Canada can participate in this new phase in her own unique way, without entering into the very expensive race to build enormous facilities. (Some of the giant accelerators or storage rings under construction elsewhere are underground doughnut-shaped tunnels, lined with hundreds of precision electromagnets and other equipment, and measuring up to 100 km in circumference!) Essentially, the proposal is to use part of TRIUMF's present output of accelerated negative hydrogen ions to feed a further series of relatively small accelerator rings and storage rings, so as to boost the final particle energy to 30 GeV—a sixtyfold increase. This would allow for the production of kaons (a different kind of meson, containing a "strange" quark, and much more massive than a pion), as well as antiprotons, neutrinos, and some other particles. The term "factory" is used again here because, as in the past, TRIUMF's unusually intense primary beams allow for the creation of vast numbers of the particles of interest. A KAON Factory would therefore hold a position amongst the new generation of accelerators in the world similar to that which TRIUMF now holds amongst the existing ones: it would cater to those types of experiments which require intense beams and huge numbers of accelerated particles, rather than those which demand the highest particle energies. It would thus be possible to attack a number of fundamental problems which have hitherto been bypassed for lack of appropriate particle beams. If a KAON Factory is to be built in the world, it would be logical to locate it at one of the existing meson factories so as to make use of its present primary accelerator (as a jumping-off point), as well as the pool of technical expertise that has been developed over the years.

Building the proposed KAON Factory at TRIUMF would mean expansion of the present facilities as shown in the site plan. A system of five rings would be required, located in two tunnels, the largest being about 340 metres in diameter and encircling (underground) little more than the present buildings and parking lot. The construction would be completed in six or seven years, during which TRIUMF's annual budget would be approximately double that of the present year. TRIUMF's management believes that on purely economic grounds, the extra expenditures would be more than justified by the primary and secondary job-creation that would result, as well as by numerous spin-off benefits to high-technology industry, e.g. the creation of an expertise in fabrication and servicing of precision electromagnets. Besides this, there are also considerations of national pride and prestige, and the long-term benefits which have always resulted (sometimes in unanticipated fields) from investment in scientific research.



Users Group

Chairman 1985: N.E. Davison *Chairman 1984:* R. Abegg

University of Alberta

R. Abegg
(Chairman 1984)
E.B. Cairns
J.M. Cameron
J.B. Elliott
P.W. Green
L.G. Greeniaus
D.P. Gurd
D.A. Hutcheon
F.C. Khanna
W.J. McDonald
C.A. Miller
G.A. Moss
G.C. Neilson
W.C. Olsen
A.A. Noujaim
J. Pasos
G. Roy
D.M. Sheppard
H. Sherif
J. Soukup
G.M. Stinson
J. Uegaki
J.S. Wesick

University of British Columbia

A. Altman
E.G. Auld
D.A. Axen
J.H. Brewer
C.F. Cramer
F. Entezami
D.G. Fleming
D. Harshman
M.D. Hasinoff
G. Jones
S. Kreitzman
P.W. Martin
C.A. McDowell
D.F. Measday
Y. Miyake
B.W. Ng
D. Noakes
B.D. Pate
J.M. Poutissou
I. Reid
M. Senba
G. Smith
D.P. Spencer
P. Walden
D.C. Walker
C.E. Waltham
J.B. Warren

Simon Fraser University

A.S. Arrott
D. Boal
J. Brodovitch
J.M. D'Auria
R. Green
O. Häusser
K.P. Jackson
R.G. Korteling
K.E. Newman
P.W. Percival

University of Victoria

S. Ahmad
A. Astbury
G.A. Beer
D.A. Bryman
R. Dubois
G.B. Friedmann
T.A. Hodges
R. Keeler
D.E. Lobb
G. Marshall
G.R. Mason
T. Numao
A. Olin
C.E. Picciotto
P.A. Reeve
L.P. Robertson
C.S. Wu

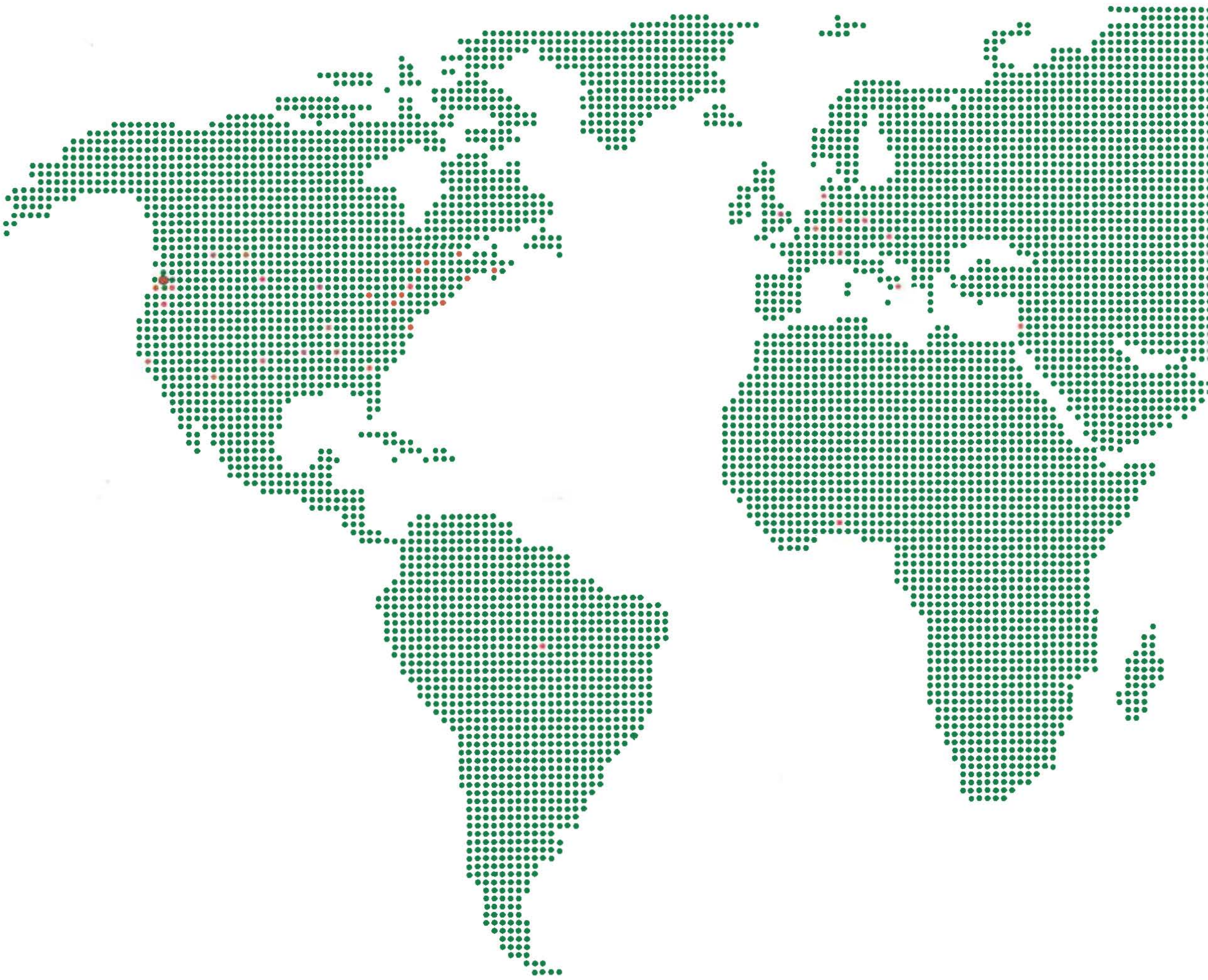
B.C. Cancer Foundation

G.K.Y. Lam
L.D. Skarsgard
M.E. Young*

** B.C. Cancer Control Agency*

TRIUMF

G. Azuelos
J.L. Beveridge
R.E. Blaby
E.W. Blackmore
C.W. Bordeaux
M. Comyn
M.K. Craddock
W.K. Dawson
D.A. Dohan
J. Doornbos
G. Dutto
H.W. Fearing
D. Garner
D.R. Gill
R.R. Johnson
R. Keitel
R. Kiefl
P. Kitching
C.J. Kost
R. Lee
G.A. Ludgate
J.A. Macdonald
G.H. Mackenzie
J. McIlroy
L. Moritz
J.N. Ng
C. Oram
A.J. Otter
J.G. Rogers
T.J. Ruth
M. Salomon
P. Schmor
I.M. Thorson
V.K. Verma
J.S. Vincent
E.W. Vogt
G.D. Wait
G. Waters
R. Woloshyn
C. Yamaguchi
M. Zach



Other Institutions

Canada

C.Y. Kim, *University of Calgary*
A.L. Carter, *Carleton University*
H.C. Lee, *Chalk River Nuclear Laboratories*
J.W. Scrimger, R.C. Urtasun, S.R. Usiskin, *Cross Cancer Institute, Edmonton*
B.S. Bhakar, J. Birchall, W.R. Falk, J. Jovanovich, R.H. McCamis, J.P. Svenne, W.T.H. van Oers, N.E. Davison *(Chairman 1985)*, D. Bandyopadhyay, C.A. Davis, W.P. Lee, P.R. Poffenberger, *University of Manitoba*
J. Crawford, J. Lee, B. Margolis, S.K. Mark, R. Moore, K. Oxorn, *McGill University*
P. Depommier, L. Lessard, R. Poutissou, *Université de Montréal*
M.S. Dixit, C.K. Hargrove, *National Research Council*
D.L. Livesey, *University of New Brunswick*
H. Blok, *Novatrack Analysts Limited*
G.T. Ewan, B.C. Robertson, *Queen's University*
G. Huber, G.J. Lolos, E.L. Mathie, S.I.H. Naqvi, V. Pafilis, Z. Papandreou, *University of Regina*
E.J. Ansaldo, Y.M. Shin, N. Stevenson, *University of Saskatchewan*
J.T. Sample, *Research Secretariat of B.C.*
M. Krell, *Université de Sherbrooke*
T.E. Drake, *University of Toronto*
R.T. Morrison, *Vancouver General Hospital*
W.P. Alford, *University of Western Ontario*

Overseas

D.V. Bugg, R. Gibson, Queen Mary College, London
N.M. Stewart, *Bedford College, London*
A.S. Clough, J.R.H. Smith, *University of Surrey*
A.N. James, *University of Liverpool*
J. Källne, *JET Joint Undertaking, Abingdon*
C. Amsler, *CERN*
R. Engfer, *Universität Zürich*
J. Domingo, *SIN*
G.R. Plattner, *Universität Basel*
L. Antonuk, P. Couvert, *CEN Saclay*
R. Grynszpan, *CNRS Vitry*
J. Tinsley, *SATURNE*
H. Postma, *Technische Hogeschool Delft*
R. van Dantzig, *IKO Amsterdam*
J.I.M. Botman, *Technische Hogeschool Eindhoven*
J. Bailey, *DESY*
C. Weidner, *Max-Planck Institüt*
J. Niskanen, *University of Helsinki*
D. Horváth, *Central Research Institute for Physics, Budapest*
M. Furic, *Inst. R. Boskovic*
C. Cernigoi, R. Rui, *Inst. de Fisica Trieste*
N. Grion, *Università di Trieste and INFN*
A. Bracco, *Università di Milano*
J. Alster, D. Ashery, S.A. Wood, *Tel-Aviv University*
B. Olaniyi, *University of Ife*
J. Greben, *CSIR/NRIMS, Pretoria*
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Ten Years Ago: A Milestone for Canada

On Sunday, 15 December, 1974, a small group of scientists working in the control room at TRIUMF gazed intently at a TV screen, as one of them adjusted the knobs and switches on the panel in front of him. Suddenly a glow appeared in the centre of the screen. It was 2:39 in the afternoon—a historic moment for TRIUMF. The glow meant that at last—after seven years of hard preparatory work—they had succeeded in extracting a beam of protons from the world's newest and largest cyclotron. The emerging proton beam had been aimed at a strip of scintillator foil which had a TV camera trained on it, and the image in the control room of the resulting glow was the signal they had all been waiting for.

Rapidly the word went out to TRIUMF's "parents"—the universities in Victoria, Edmonton and Vancouver. Several dozen people gathered in the control room, and bottles of champagne soon appeared! Feelings ranged from relief to excitement to euphoria. Later in the afternoon the press arrived, and there was a moment of embarrassment when it was found that the glow could no longer be seen on the monitor. (It was subsequently found that a piece of loose metal had fallen down inside the cyclotron and had temporarily blocked the beam.) However, the story was accepted and the achievement was announced to the world that day.

The picture below was taken during the celebration in the control room on December 15, 1974. At the centre, Dr. Erich Vogt (then chairman of TRIUMF's Board of Management) has his hand on the shoulder of Dr. J. Reginald Richardson, the director at that time, who had been at the controls for the crucial operations that day. Dr. Richardson was also the scientist who, years earlier, had conceived and designed the "pinwheel" arrangement of magnets that ended up as the TRIUMF cyclotron.

About two months later, TRIUMF achieved a world "first" with the extraction of two beams (at different energies) simultaneously from the cyclotron. The colour photo, taken around that time, shows Dr. Richardson at the control panel.

The tenth anniversaries of these events occurred during the past year. Special ceremonies and a science symposium were planned for the summer of 1985, to celebrate the advances and accomplishments during these ten years of scientific research at TRIUMF.

The celebration in the TRIUMF control room after the first beam was extracted.

Top: Dr. Richardson at the controls in early 1975, soon after the cyclotron became operational.