TRIUMF 1988-89

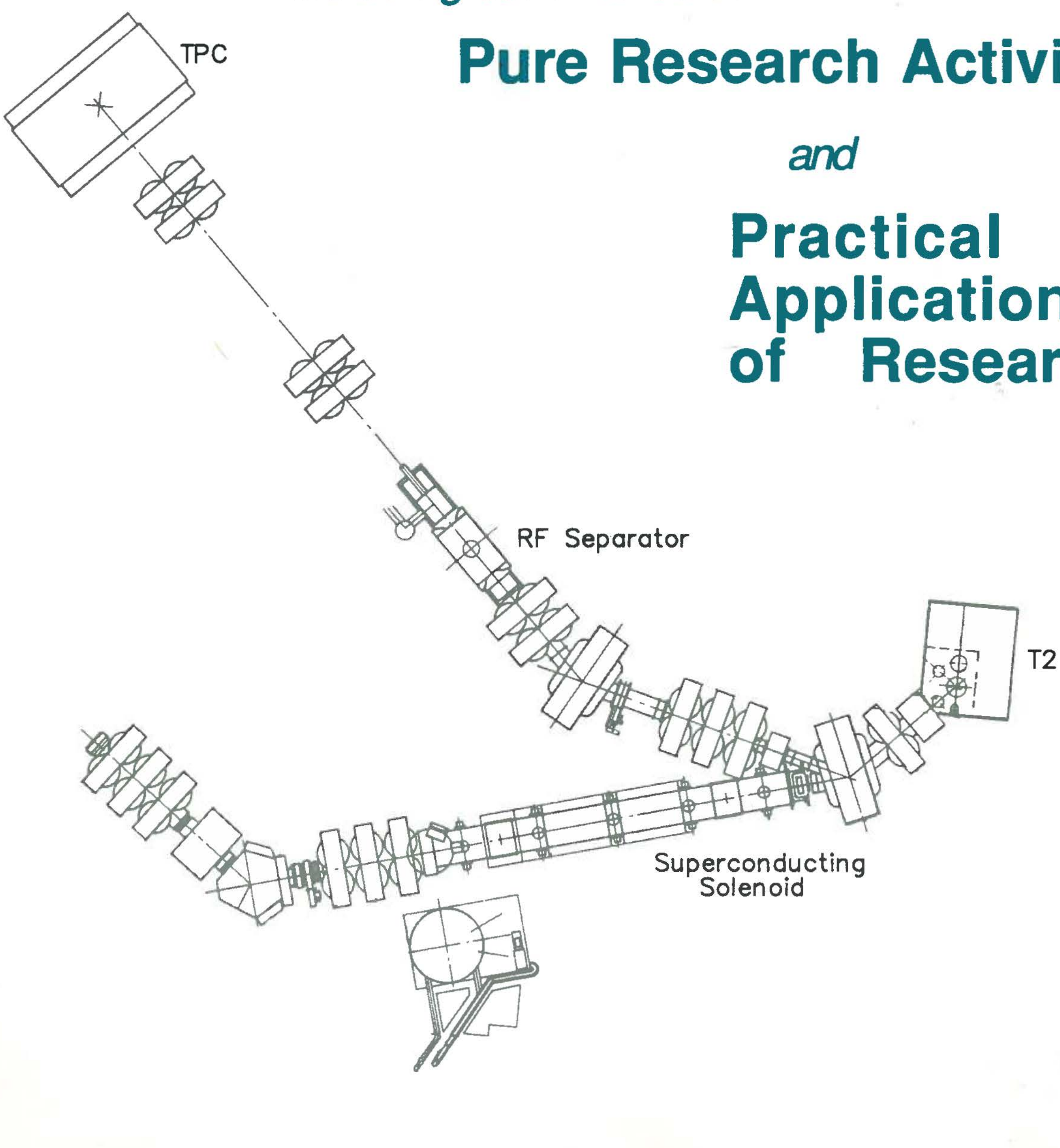
Annual Financial and Administrative Report

Including summaries of

Pure Research Activities

and

Practical Applications of Research



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TRIUMF is Canada's national meson facility, managed as a joint venture by a consortium of Canadian universities. It is operated under a contribution from the National Research Council of Canada.

Consortium Members:
University of Alberta
University of Victoria
Simon Fraser University
University of British Columbia

Associate Members:
University of Manitoba
Université de Montréal
University of Toronto

The Financial & Administrative Annual Report is prepared by the

TRIUMF Information Office

Editor: Michael La Brooy

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FRONT COVER

One of the memorable events of 1988-89 was the completion of the upgraded beam line M9B, which will provide a beam of negatively charged muons of an intensity never before available at TRIUMF.

The cover shows a drawing of the layout of the new facility, including the million-dollar superconducting solenoid (magnet) donated by Japan, which forms the heart of this beam line.

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Director's Report

In this annual report we get a brief view of a slice of TRIUMF's programme rather than an overview of all TRIUMF's science. Each year TRIUMF publishes separately a complete review of all its scientific activities. This **scientific** annual report is available to all interested persons through the TRIUMF Information Office.

The proton hall experiments which are glimpsed in this report cover an area of science which is just now in full flourish. TRIUMF offers a unique combination of facilities which, on the world scene, is now very timely in addressing urgent new questions about the building blocks and fundamental forces that lie at the heart of matter. With its variable-energy, high-quality beams and its polarized protons, TRIUMF's proton hall draws visiting scientists from all corners of the globe. In the context of the world effort in nuclear physics, this proton hall promises to be on centre stage for another decade or so. It is basic science at its best, with world-class ideas, ingenious new instruments, and international teams of outstanding scientists. We hope our brief glimpse conveys some of that excitement.

In the year covered by this report, TRIUMF was preoccupied by a new burst of activity directed toward achieving its KAON Factory. The governments in Ottawa and Victoria jointly funded the eleven-million-dollar Project Definition Study (PDS) for KAON, intended to solve the crucial problems related to the design of this challenging project. The PDS also includes formal consultations by Canada with the prospective foreign partners for KAON. Although this will be a Canadian project, the target is to receive a third of KAON's total construction costs ($621 million) from abroad. The KAON Factory is a project which will, for the next decade or more, put Canada on the world map in science, and which will bring a flow of people and ideas into Canada.

TRIUMF's staff, which remained roughly constant throughout the year, not only operated TRIUMF's usual facilities and took on the extra work of the PDS, but it also accepted as overload a considerable new effort in technology transfer. Together with a Vancouver-area company, EBCO, TRIUMF is developing a special cyclotron for the commercial production of radioisotopes. Basic science goes hand in hand with commercial high technology.

It is our intention that this Annual Financial and Administrative Report for TRIUMF convey to Canadians impressions of an important science enterprise of which they can be proud.

Erich Vogt

Pure Research at TRIUMF

The Physics Programme with TRIUMF's Proton Beam

When a beam of light shines on an object, it is *scattered* in all directions by that object. This phenomenon allows us to see our surroundings, because our eyes can gather some of this scattered light from the various objects around us. In the same way, physicists can direct beams of very fast subatomic particles at nuclei, and detect the scattered particles to "see" the basic constituents of matter.

How can such beams of particles — tiny bits of matter — act like light, which is a form of energy? The theory of quantum mechanics tells us of a phenomenon called particle-wave duality: particles sometimes act like particles, but they can also exhibit the properties of waves. For example, a beam of subatomic particles such as electrons can be diffracted in the same way as light (i.e. the beam spreads out as it passes a sharp edge). As the energy (velocity) of a particle beam is increased, the apparent "wavelength" becomes shorter, which means that one can distinguish smaller and smaller objects (much smaller than with light). Hence, to look at the structure and properties of a specific atomic nucleus, we aim a beam of high-velocity particles at a target composed of that type of atom, and examine the scattering patterns of the particles.

The TRIUMF cyclotron accelerates protons to 3/4 the speed of light, and thus acts as a very powerful microscope to see into the heart of matter. Although much of the activity at TRIUMF depends on using this proton beam to create secondary beams of other subatomic particles such as pions and muons, there is a strong programme which uses the proton beam directly to study nuclei. Some aspects of this proton physics programme are discussed here.

Quasi-Elastic Scattering and the Nucleon-Nucleon Force

It has long been known that a typical atom is composed of a cloud of negatively charged electrons orbiting a very small, positively charged nucleus containing protons and neutrons. What forces are at work here? Since the opposite electric charges in a nucleus and in its electrons attract each other, it is easy to understand how this attractive force holds a nucleus and its electrons together. On the other hand, *like* charges repel each other. The positively charged protons in a nucleus *should* be pushed apart. In fact the opposite is true: a nucleus is very dense, occupying only one million-millionth of the total volume of an atom, so that we must postulate the existence of another force that can bind together the components of the nucleus. This is the **strong** nuclear force, which is many times more powerful than the electrostatic force, but which acts only at very short distances. Physicists have been studying the strong nuclear force for many years. The simplest way to go about this is to scatter single nucleons (protons and neutrons) from other single nucleons, without interference from other particles. TRIUMF has a long tradition of work in this field of nucleon-nucleon scattering.

We are very interested in finding out how the nuclear force between two specific interacting nucleons is modified by the presence nearby of other particles, as in a typical nucleus. To understand how we study this problem, consider the various possible results when a nucleus is struck by a proton. These are shown in the figure, where the probability of an event occurring is plotted on the vertical axis, and the energy transferred to the nucleus during that event is shown on the horizontal axis.

• The simplest event occurs when the proton rebounds from the nucleus as a whole, *leaving it unchanged*. This is analogous to a billiard ball bouncing off a bowling ball, and is called **elastic scattering**.

• Secondly, the incoming proton can excite *one* of the nucleons in the nucleus to a state with higher internal energy. The outgoing proton therefore has *less* energy, and the scattering process is termed **inelastic**. Since there are many particles and discrete states in a nucleus, there are many different ways in which inelastic scattering can occur, and so there are many narrow peaks in this part of the figure.

• There is another possibility: the nucleus can be excited as a whole. Since the proton here interacts with many particles, it loses more energy than when only *one* nucleon is excited. This manifests itself as several broad bumps, called **resonances**, in the spectrum.

• Next comes a class of events in which the incoming proton bounces from a single nucleon, *knocking it out of the nucleus*. The knocked-out nucleon recoils at roughly the same energy as if it had been alone, isolated from the rest of the nucleus. This process resembles elastic nucleon-nucleon scattering, and is therefore called **quasi-elastic scattering**. It is shown to the right of the resonance region in the figure.

• At a still higher level of energy transfer, processes occur in which the nature of the target nucleon itself is changed by the incoming proton.

One can study how the nucleon-nucleon force is modified in the nucleus by comparing **quasi-elastic** scattering to the **elastic** nucleon-nucleon scattering. Both reactions involve the scattering of one nucleon from another. Hence, any differences can be ascribed to the fact that the presence of other particles changes the way in which the two nucleons interact in quasi-elastic scattering. Such comparisons have been carried out recently at TRIUMF, where beams of *polarized* protons have been used. (Subatomic particles possess a property called spin. Nucleons can exist in one of two states of spin: spin up or down. In a normal proton beam, there are as many particles with their spin up as with their spin down, and the beam is said to be *unpolarized*. On the other hand, if one state is more populated than the other, the proton beam is *polarized*.) Although this complicates things experimentally — one must expend much time and effort to produce an imbalance in the spin populations — it clarifies the theoretical treatment of the results.

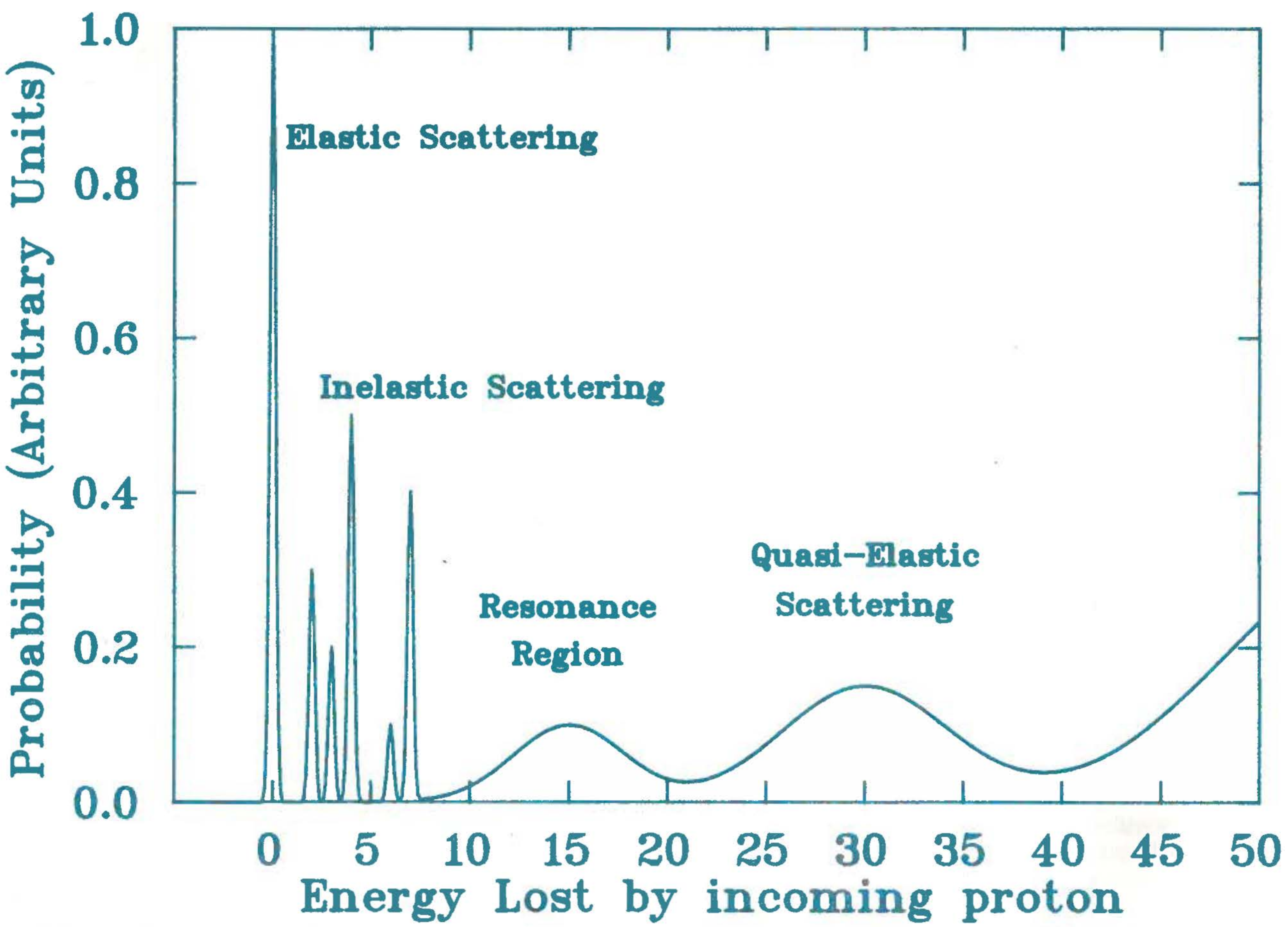
Pure Research at TRIUMF

One of TRIUMF's beam lines was recently upgraded, and this now allows us to produce beams of polarized protons with their spin axes pointing in any chosen direction. Such flexibility has allowed TRIUMF physicists to make the most complete and thorough measurements of the quasi-elastic process to date, and these provide stringent tests that can be applied to the present theories of nuclear scattering, to determine which of these theories best describes experimental results.

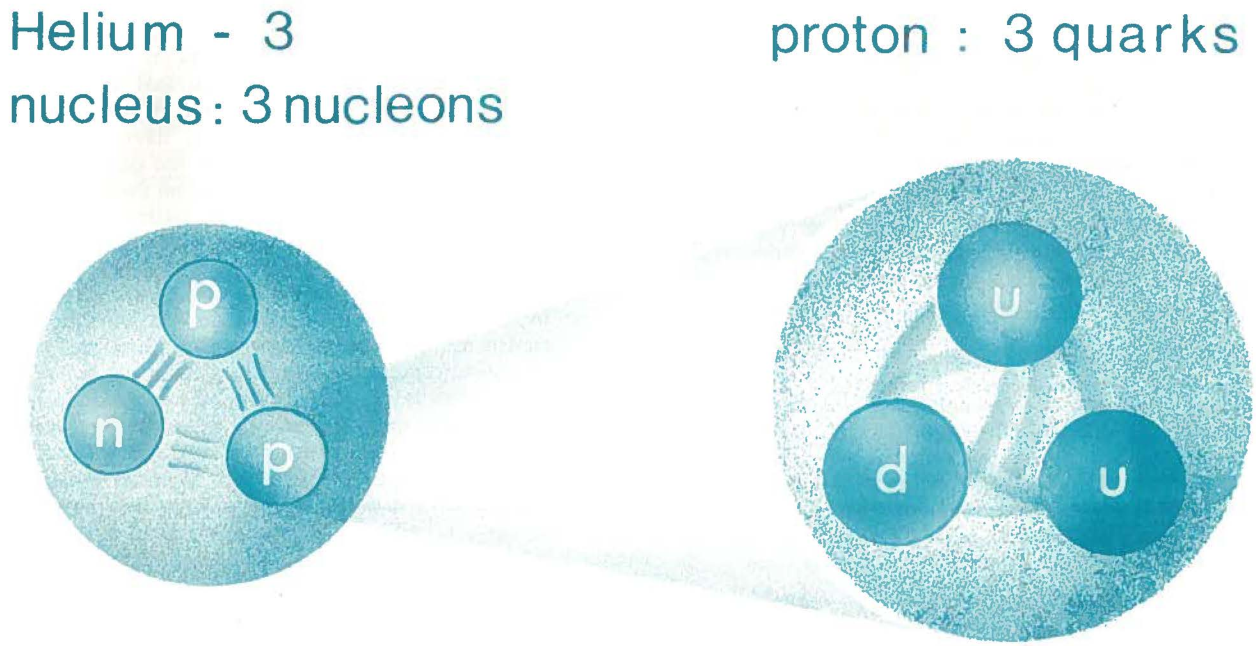
A significant development which has begun in the proton hall is the installation of a second-arm spectrometer which will work in conjunction with the existing medium resolution spectrometer (MRS). Using these spectrometers simultaneously, we will be able to look at quasi-elastic scattering and detect both outgoing particles — the original proton and the knocked-out nucleon. This will better characterize the quasi-elastic process, and will serve to clarify the various theories of the nuclear force.

Polarized Helium-3 and the Structure of Nucleons

If one looks at matter at the smallest level, it becomes apparent that nucleons are not fundamental particles but are made up of smaller constituents, the quarks. Traditional nuclear physics has studied the structure of nuclei in terms of protons and neutrons, and their interaction. However, to have a satisfactory knowledge of nuclear structure, we must not only identify the building blocks and discern the forces between them, but also understand the nature of the constituents themselves. Hence, inferring the properties of nucleons in terms of the underlying quark substructure has become an important goal of nuclear physics.



Pure Research at TRIUMF



One question of nucleon structure has received much attention: How is the spin of a whole nucleon generated? Is it due to the spins of the quarks? As mentioned earlier, nucleons can have either spin up or spin down, and the quarks have similar spin characteristics. In general, a particle with spin tends to pair itself with a similar particle of opposite spin, resulting in a net spin of zero for the pair. Every nucleon is made up of three quarks. In one simple, proposed model, two of the quarks are paired (zero net spin) and the nucleon's spin is generated by the third, left-over quark. However, recent experiments have indicated that the spin of the proton does *not* come from the spin of quarks at all, but is produced in some other way. It is extremely important to understand the source of nucleon spin, since it is a fundamental property of nature. In pursuit of this, TRIUMF physicists are involved in an experiment in Germany whose goal is to measure the spin content of the proton and the neutron. This involves scattering polarized electrons from polarized protons and neutrons.

How can we make targets of polarized protons and neutrons for such experiments? Single protons form the nuclei of hydrogen atoms, and because these are stable, it is relatively easy to produce polarized proton targets. However, isolated neutrons will decay to other particles within minutes, and it is not possible to make a stable polarized neutron target. Is there a way around this difficulty? Perhaps so, if we take advantage of a similarity between the **quark model of a nucleon** (described above) and the **helium-3 nucleus.**

As shown in the figure, each of these consists of three smaller particles. Helium-3 consists of two protons and one neutron. Like quarks inside a nucleon, the two protons can pair with each other to produce zero net spin, leaving the lone neutron to bring about the spin of the whole nucleus. Therefore, it may be that the use of a polarized helium-3 target will actually provide polarized neutrons. (This assumption is essentially borne out by the properties of helium-3.) However, this model is only approximate: the two protons are, in fact, paired for only about 90% of the time. To interpret the results of the experiment in Germany with any certainty, we must have a very exact knowledge of how well the polarized helium-3 mimics a polarized neutron. In addition to their collaboration in the German experiment, therefore, TRIUMF physicists have undertaken the precise measurement of the spin properties of helium-3. This is done by scattering polarized protons from a polarized helium-3 target built specially for this purpose. In this way TRIUMF is contributing to the advancement of physics, not only through its own work but through international collaboration.

The experiments mentioned above are only a small part of the proton physics programme at TRIUMF. There is an ongoing programme to study the nuclear force through nucleon-nucleon scattering; in addition, the programme using the nucleon charge-exchange facility continues to flourish. We have also built a prototype device (TISOL) that uses the proton beam to produce exotic nuclei, many of them with very short half-lives. The study of their interactions will have applications in astrophysics. Many improvements have been made to the proton hall facilities in the last few years, and TRIUMF can look forward to continued success in the rich field of proton physics.

Applied Programmes

Whole-body PET scanner

The Tomograph Development Group at TRIUMF is striving to develop a new type of instrument for imaging chemical (i.e. radiopharmaceutical) distributions in the human body. Whereas the original PETT IV scanner is a typical tomograph (which means that it produces images showing the location of chemicals in **thin slices** of the body), the new design is a **positron volume imaging** (PVI) camera: it will make images of the exact locations of chemicals in large, three-dimensional sections of the patient's body. The pictures, which are formed by a new software computer algorithm invented at TRIUMF, are initially constructed in the memory of a computer. From the 3-D images in memory, various projections and views of the image may be displayed in different formats on a colour TV screen. We are constructing a prototype PVI scanner to test the hardware and computer software concepts, which are the essential components of the new PVI camera. The mechanical gantry to hold the electronic components has been completed. The following components will be added to the gantry: detectors to register the positions of the radioactive chemicals by detecting the radiation they emit; data acquisition electronics, which records everything picked up by the detectors from the patient, rather like a time exposure on film; image formation software, to transform the list of detections into a 3-D image in memory; and display software that makes various pictures of the stored image. Improvements and developments of all these components are being made at TRIUMF in an effort to perfect the new PVI camera design, and the imaging technique. Making such faithful 3-D pictures of the chemical functioning of sections of the body is an important step in expanding positron imaging from its present role as a university-based research tool to a routinely used clinical tool in all hospitals.

Pion Therapy: Clinical Trial Begins

The first cancer patients were treated by pion therapy at TRIUMF over seven years ago. This was, and still is, a rare method of treatment, possible only where a suitably intense, uniform beam of pions can be produced, i.e. at the world's three "meson factories". Pion therapy is, in fact, available only at one other facility in the world — the Paul Scherrer Institute (formerly called S.I.N.) near Zurich.

By March 1989, Dr. George Goodman and his team had treated about 190 patients at TRIUMF, most of them suffering from glioblastoma brain tumours. During this period they accumulated a great deal of information, e.g. they now know that the treatment is best given in 15 fractions over a three- to four-week period, and they know the most effective dose of radiation for a tumour. The results of the TRIUMF pion treatments were so impressive (compared to conventional radiotherapy with gamma rays) that a clinical trial was arranged, and is presently under way.

In a clinical trial, one group of patients is treated by the conventional method while another group, matched as well as possible to the control group, is treated by the experimental method. The results are then subjected to rigorous statistical analysis, to determine whether the new treatment really offers an advantage over the conventional one. The trial is expected to be completed by early 1991, and the verdict is eagerly awaited by all those involved with this fascinating research application.

A new venture: TR30 Cyclotron

The manufacture and sale of radioisotopes is one of the fastest-growing fields of enterprise in the business world today. Some isotopes are best produced by shooting neutrons at suitable target atoms, and these can be manufactured in nuclear power plants or in small atomic piles. But others are produced more easily by bombarding targets with low-energy protons, such as those provided by a small cyclotron.

This year saw the beginning of a new venture, as TRIUMF utilized its expertise and long experience with cyclotrons to enter a collaboration that will lead to the manufacture of a new line of these machines. The TR30 is a compact, new, particle accelerator designed at TRIUMF. It will be manufactured by EBCO Industries, a Vancouver-area company that made many parts of TRIUMF's giant cyclotron 18 years ago. Simple to operate and very reliable, the machine exemplifies the cutting edge in cyclotron technology.

The TR30 has one outstanding feature: very few protons are lost during acceleration. Thus, though it yields an intense beam of low-energy protons, there is very little stray radiation, and this means a safer working environment.

NORDION International Inc., a radiopharmaceutical company which already produces radiopharmaceuticals at the TRIUMF site, has agreed to buy the first TR30 so as to increase its capabilities. NORDION will use this machine to produce Thallium-201, an isotope used specifically for heart studies, and Iodine-123, used for many diagnostic tests, including tumour imaging.

Because of the rapid growth of isotope sales, a large potential market exists for the cyclotron, and EBCO Industries will be marketing these around the world.

Can TRIUMF become a Proton Therapy Centre?

While TRIUMF and PSI are the only two pion cancer therapy facilities, there are 14 locations in the world where proton therapy can be provided. Low-energy protons have characteristics very different from pions, the chief one being that when protons pass through tissue they deposit their energy in an extremely narrow band. This means that they are ideal for treating thin or flat tumours, like those that occur in the eye.

This year TRIUMF took a step in the direction of becoming a proton therapy centre: a series of tests was carried out in beam line 1B in the meson hall, to determine the feasibility of providing a suitable beam for proton therapy directly from our cyclotron. The tests were successful, and an application is now being prepared to seek funding for a therapy facility.

Facilities

Intense Polarized Ion Source

TRIUMF's normal (unpolarized) beam is extremely intense. However, a polarized beam is required for some experiments, and this has a far lower intensity (as measured by beam current, or the number of particles accelerated per second). To improve this situation, a new intense polarized ion source was installed in 1988, and work continues on making it operational. It will produce 5 to 10 times more current than the present Lamb-shift polarized source, and it can reverse the polarization direction with no change in ion beam properties, making it very useful for high-precision experiments. The polarization comes from circularly polarized laser light, which is absorbed by sodium vapour in the source. This energy is then transferred to the hydrogen ion beam. Physicists from KEK in Japan and Los Alamos in the U.S., among others, have shown much interest in this project and have collaborated with us to perfect it. In addition, the computer control required for the laser system has provided TRIUMF with an interesting challenge that has been well met with limited manpower.

FACILITY TOURS AND VISITORS

The number of visitors to TRIUMF set another record in 1988 calendar year. A total of 3,684 persons toured the site, including 2,036 members of the general public, 1,392 students (we had enthusiastic school groups from as far away as Inuvik, northern B.C. and the U.S.), 116 VIPs, and 140 visiting scientists (i.e. other than those running experiments here).

Many MPs or MLAs visited us to learn more at first-hand about the KAON Factory proposal — for instance, the four Western Canadian premiers toured our site in May, taking time out from their 1988 annual get-together in Nanaimo.

Radio Frequency Improvements

The cyclotron accelerates particles by means of an extremely powerful electric field oscillating rapidly between the two "dees" inside its huge vacuum tank. (This is called a radio frequency, or rf, because the frequency of oscillation is in the same range as that used for radio communications — about 23 MHz.) The rf is needed only in the "acceleration gap" inside the machine, but some of the energy of this oscillation inevitably spills across the entire interior of the vacuum tank, and this can have some unwanted effects: for instance, it induces heating in some equipment, and affects the operation of delicate, current-measuring probes. This year, remote-controlled, motorized equipment was introduced on the cyclotron to minimize this rf leakage, thus making the whole machine run more smoothly.

(Incidentally, to produce this rf legally, TRIUMF is actually required to hold a radio station licence: at two megawatts, we are the most powerful radio station in Canada, though no measurable signal is transmitted outside the cyclotron building — it would not really be considered "easy listening" anyway!)

TISOL

TISOL (an acronym for Test Isotope Separation On-Line) continues to develop, and this year it reached new milestones. It has now operated successfully as an isotope separator for a considerable number of elements.

Using a heated-surface ion source, we measured production yields for about 95 isotopes of 10 elements, from lithium (element #3) to francium (element #87). These included some with extremely short half-lives, such as sodium-24m — a metastable isotope with a 20-microsecond half-life — as well as both neutron-rich and proton-rich isotopes that were close to the limits of stability. (Nuclei with proton/neutron ratios outside these limits do not exist.)

In some cases the yields we obtained are comparable to those produced at the world's only other operational high-intensity, thick-target facility, "ISOLDE" at CERN. TISOL is now in the process of developing other types of ion sources so as to expand the range of radioisotopes available as ion beams, and we are also initiating an experimental physics programme based upon the isotopes already observed.

SASP for DASS

TRIUMF is building a new magnetic spectrometer called SASP, an acronym for the Second Arm SPectrometer. SASP will be the second spectrometer to be installed at one of the main target locations in our proton hall. The first is called the MRS, an acronym for Medium Resolution Spectrometer. (The name is an anachronism, since this spectrometer has been upgraded and its resolution is really quite good now.) The two spectrometers will observe the same target simultaneously and thus create a new experimental facility called DASS, the Dual Arm Spectrometer System. It will be a large particle spectrograph with two arms, the MRS and SASP. The installation is a three-year project that began this year, and a more detailed account of it will be given in a later Annual Report.

The Official Opening of the M9 Beam Line, 8 December 1988

TRIUMF's New Negative-Muon Beam Line

One of the more important innovations in facilities at TRIUMF this year was celebrated on 8 December, 1988, with the official opening of the upgraded M9B beam line and a technical seminar on muon science. This line will now provide a uniform, intense beam of polarized, **negatively charged** muons. It complements the M15 beam line for polarized **positive** muons that was opened a few years ago, and which has proved to be so fruitful in a variety of applications. The heart of M9B is a large superconducting solenoid contributed by Japan. In fact, this whole beam line has many Japanese connections: the solenoid was built by the Mitsubishi Corp., the helium compressor (which provides the liquid helium to cool the solenoid to superconducting temperatures) was constructed and installed by Micom, and many Japanese scientists have run experiments on it since it came into use. Representatives from Mitsubishi and Micom attended the opening ceremony, together with those from Tokyo University and KEK (the Japanese subatomic research centre), and from the provincial government and Canada's National Research Council.

The rebuilding of this beam line adds considerably to TRIUMF's versatility, and many important experiments are scheduled in the near future, including one to investigate muon-catalysed fusion of hydrogen isotopes.

PDS — The Project Definition Study

The **KAON Factory Project Definition Study** (KAON PDS) is an $11 million project, jointly funded by the Governments of Canada and of British Columbia. Announced in July 1988, the study will examine in detail certain aspects of the TRIUMF proposal, in order to provide important information to the Federal Government prior to its decision on funding the KAON Factory project.

The budget for the study was put in place on 1 October 1989, and will terminate on 28 February 1990.

Facets of the Project Definition Study

The KAON PDS has a number of components which can be summarized under the following major headings:

International Consultations — During the course of the KAON PDS a formal delegation from Canada will endeavour to ascertain what contributions might be made to the KAON Factory by other nations, should Canada decide to go ahead with the project.

Industrial Capability — Will Canadian industry be able to build the major components of the KAON Factory? A special study will attempt to document this, and in addition to identify technologies that may be enhanced during the construction phase.

Legal and Environmental Impacts — One of these two studies looks at the legal consequences of building and operating the facility. The other examines in detail the impact on the local environment — effects on wildlife, ground water, noise levels, etc. — and will identify how any adverse effects could be minimized.

Economic Assessment — Here an attempt is made to understand the economic benefits which would be produced, both in British Columbia and in all of Canada, by the construction and eventual operation of the KAON Factory.

Technical Design and Prototypes — This part of the study occupies approximately 50 TRIUMF staff, a Project Management team, and a number of consultant engineering firms. The aim is to obtain a design for the accelerator complex, together with the best estimate of the capital and operating costs. In order to be more certain of the costs, and to gain some experience with the more challenging of all the devices that must be constructed, a number of prototypes of various selected components will be built by industry and tested during the KAON PDS.

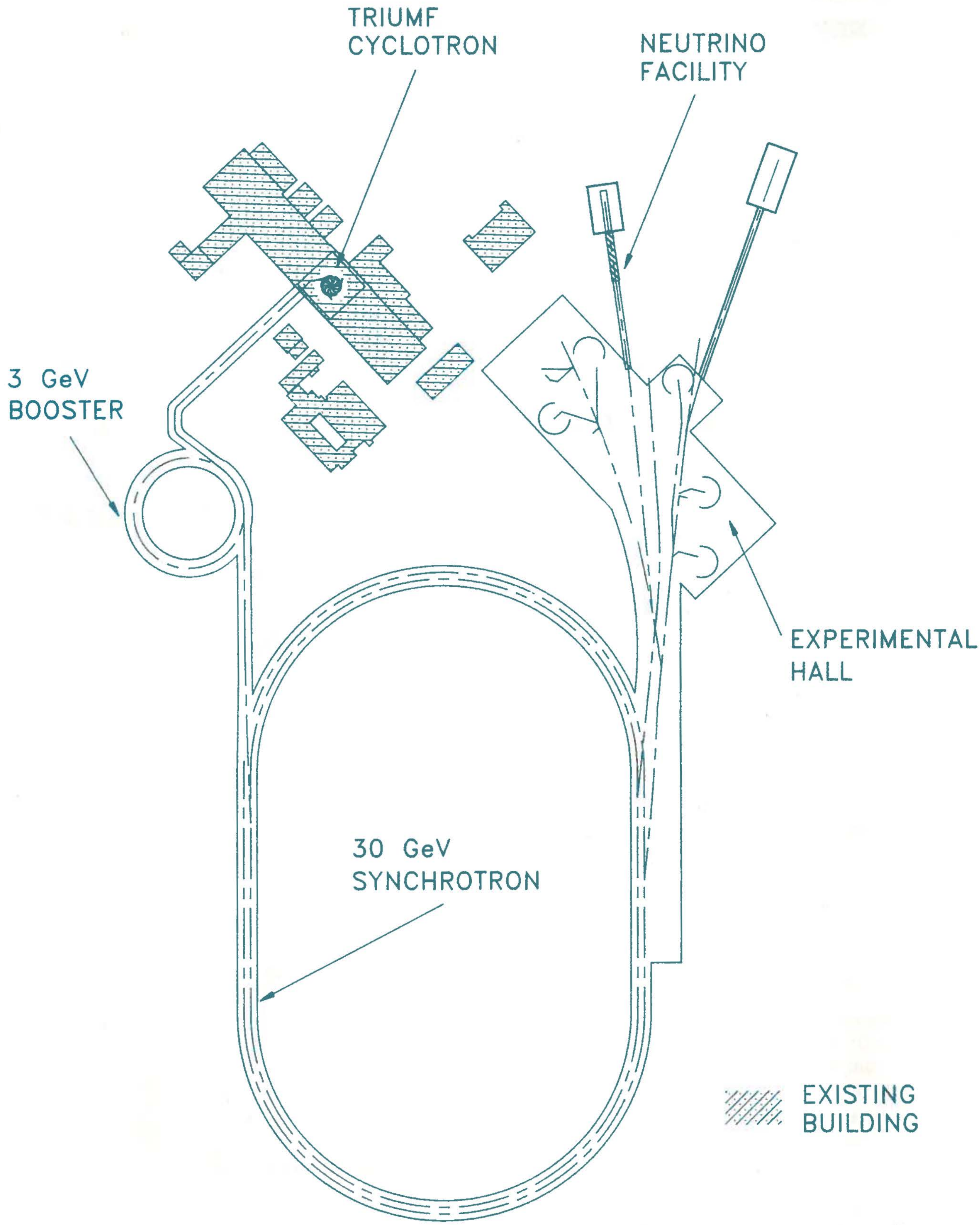
Proposed Layout of the KAON Factory

The final layout of the proposed facility is shown in the figure. Basically, the KAON Factory will use three accelerators working in sequence to raise the energy of each proton in the beam to 30 GeV: the output of the original TRIUMF cyclotron will be the feedstock for the Booster synchrotron, which in turn will feed the Driver synchrotron. After each of these accelerators, however, the accelerated particles will be held temporarily in a storage ring, to await the next phase of the process. Here is the complete sequence:

The TRIUMF cyclotron injects protons into the Accumulator (A-ring) at about 450 MeV. The beam is then passed to the Booster synchrotron (B-ring), which cycles at 50 Hz and accelerates to 3 GeV. Both these beam line rings are housed in the small, circular tunnel. For the next phase, the 3-GeV beam is transferred to the large, racetrack-shaped tunnel enclosing the remaining three beam lines (which we still call "rings" although they are oval in shape).

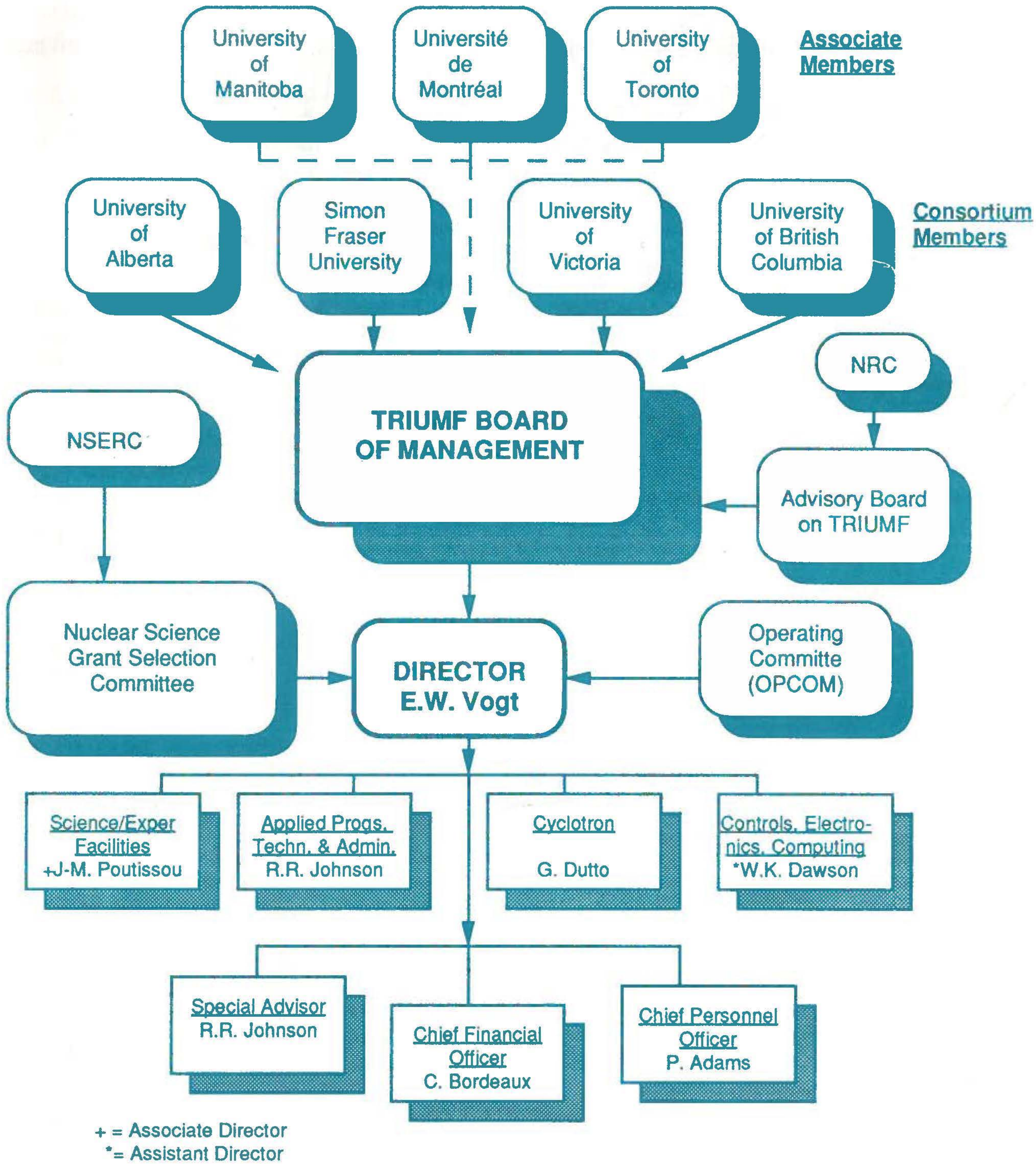
The beam is collected in the C-ring before the final acceleration to 30 GeV in the Driver Synchrotron (D-ring), which cycles at 10 Hz. The final proton beam can be extracted directly from the D-ring over a short, pulsed duration, or it may be passed to the E-ring, from which it can be extracted over an extended period of time to yield essentially a dc beam for experiments. The scale of the complex is set by the racetrack, which is approximately one kilometre in circumference.

The KAON PDS is managed by a Steering Committee made up of representatives from the Federal and B.C. Provincial Governments. It is chaired by an independent chairman, selected for the task by the two governments. The Steering Committee will produce its summary reports covering all aspects of the KAON PDS by 28 February 1990. The supporting documents will include all the detailed reports of consultants, plus the technical reports resulting from the detailed design and prototype studies.


TRIUMF
CYCLOTRON
NEUTRINO
FACILITY
3 GeV
BOOSTER
EXPERIMENTAL
HALL
30 GeV
SYNCHROTRON
EXISTING
BUILDING

Organization Chart

March 1989



Financial Review

Ongoing constraints in operating funding would have resulted in massive layoffs had it not been for the relief afforded by two new projects. As a result, it was possible to keep the highly trained cadre of staff intact in anticipation of a decision by the Federal Government on a substantial upgrading of the facilities. Considerable financial support from abroad is virtually assured when approval to upgrade to a KAON Factory is given.

One of the two new projects is the KAON Factory Engineering Design and Impact Study, funded jointly by the Federal Government and the Province of British Columbia on a 50-50 basis. The study, referred to in the financial statements as the Federal Project Definition Study and the Provincial Project Definition Study, has a total funding of $11 million, of which $6,851,000 is allocated to TRIUMF for a period ending in fiscal year 1989-90. In fiscal year 1988-89 the allocation amounted to $3,859,500.

The other new project is an agreement with EBCO Industries Ltd. of Richmond, B.C., to provide technical assistance and experienced staff to manufacture a 30 MeV cyclotron for the use of NORDION International Inc., situated on the TRIUMF site. This project will come to its completion in FY 1990-91.

The Medical Research Council of Canada continued to provide substantial support. Those funds are administered elsewhere and are therefore not reported here. The same holds true for funding by the Natural Sciences and Engineering Research Council of TRIUMF-based experiments administered elsewhere, as distinct from those administered at TRIUMF. NORDION International Inc., formerly Atomic Energy of Canada Limited, is still the major commercial user of TRIUMF facilities. The flow of their funds through TRIUMF fluctuates because the great majority of their transactions are handled by their administration located on the TRIUMF site. Only those services required directly from TRIUMF are reported here. Royalty payments of $143,000 were received from NORDION International Inc.

The number of transactions handled on behalf of affiliated institutions has stabilized, with the exception of those for USSR institutions, whose activities at TRIUMF are steadily increasing. The receipts consist of imprest funds and reimbursements of expenditures on behalf of these institutions, from Canada and abroad, for their TRIUMF projects. A contribution of about $1 million was received from Japan in the form of a gift of a superconducting beam line of that value. This is not reported in the financial statements because no fund transactions took place.

Expenditures in the Statement of Combined Funding and Expenditures are at acceptable levels. It is expected that the Federal Government will reintroduce support to TRIUMF at a level sufficient to maintain the high international recognition TRIUMF has achieved, and that this support will include the requisite upgrading of the facilities.

C.W. Bordeaux

Chief Financial Officer

Source of Funds (millions of dollars)

Source	1988-89 Rec'd	1988-89 %	1987-88 Rec'd	1987-88 %
National Research Council	$26.51	69.17	$25.90	80.58
Natural Sciences and Engineering Research Council	3.27	8.53	3.04	9.46
Fed. Project Defn. Study	1.97	5.14	—	—
Prov. Project Defn. Study	1.89	4.94	—	—
NORDION International Inc.	2.39	6.23	1.33	4.14
Affiliated Institutions	1.37	3.57	1.69	5.26
EBCO Industries Ltd.	0.55	1.43	—	—
Investment & other income	0.38	0.99	0.18	0.56
	$38.33	100%	$32.14	100%

[Editor's Note: Funding received for the Project Definition Study is included for 1988-89 in this table, and represents about 10% of the total. Because of this extra item, comparisons between years of the **percentages** of TRIUMF funding received from other sources may be misleading.]

Coopers & Lybrand | chartered accountants | a member firm of Coopers & Lybrand (International)

AUDITORS' REPORT TO
THE BOARD OF MANAGEMENT
TRIUMF

We have examined the statement of financial position of TRIUMF as at March 31, 1989 and the statements of funding and expenditures and changes in fund balances 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 financial statements present fairly the financial position of TRIUMF as at March 31, 1989 and its funding and expenditures for the year then ended in accordance with the accounting policies set out in note 2 to the financial statements applied on a basis consistent with that of the preceding year.

Coopers & Lybrand

Vancouver, B.C.
May 23, 1989

[Editor's note: The following pages present *excerpts of the auditors' report* prepared by Coopers & Lybrand. Persons wishing to see the entire report should contact the TRIUMF Business Office.]

TRIUMF
STATEMENT OF COMBINED FUNDING AND EXPENDITURES AND CHANGES IN FUND BALANCES FOR THE YEAR ENDED MARCH 31, 1989

	1989	1988
	$	$
FUNDING (note 2)		
National Research Council	26,510,000	25,900,000
Natural Sciences & Engineering Research Council	3,267,370	3,037,458
Federal Project Definition Study	1,965,000	—
Provincial Project Definition Study	1,894,500	—
Nordion International Inc.	2,392,645	1,332,119
Affiliated institutions	1,374,226	1,694,270
EBCO Industries Ltd.	550,737	—
Investment income	381,266	211,927
	38,335,744	32,175,774
EXPENDITURES		
Building construction	394,005	18,835
Communications	374,481	304,622
Computer	3,549,490	1,410,500
Equipment	2,503,859	2,250,614
Lease payments — Nordion International Inc.	651,800	578,508
Power	1,701,079	1,664,174
Salaries and benefits	21,201,294	19,238,755
Supplies and expenses	6,950,892	6,652,007
Salary recoveries	(1,180,340)	—
	36,146,560	32,118,015
EXCESS OF FUNDING OVER EXPENDITURES FOR THE YEAR	2,189,184	57,759
LESS: DEFERRED FUNDING	(57)	(216)
FUND BALANCES — BEGINNING OF YEAR	945,272	887,729
FUND BALANCES — END OF YEAR	3,134,399	945,272

TRIUMF
STATEMENT OF FINANCIAL POSITION
AS AT MARCH 31, 1989

	1989 $	1988 $
ASSETS		
CASH AND TEMPORARY INVESTMENTS	1,442,824	1,428,446
FUNDING RECEIVABLE (Note 3)	2,425,288	360,341
TOTAL ASSETS	3,868,112	1,788,787
LIABILITIES AND FUND BALANCES		
ACCOUNTS PAYABLE	494,000	251,922
DEFERRED FUNDING		
National Research Council	28	216
Federal Project Definition Study	11	—
Provincial Project Definition Study	18	—
	57	216
DUE (FROM) TO UNIVERSITIES		
The University of Alberta	(49,131)	(2,245)
The University of Victoria	2,549	(12,512)
The University of British Columbia	288,135	598,641
Simon Fraser University	(1,897)	7,493
	239,656	591,377
FUND BALANCES		
Natural Sciences and Engineering Research Council	1,273,386	888,488
Federal Project Definition Study	545,883	
Provincial Project Definition Study	688,844	
Nordion International Inc.	192,960	(272,520)
Affiliated institutions	(91,813)	77,175
Intramural Accounts	(23,250)	85,331
EBCO Industries	(23,636)	
TRIUMF	572,025	166,798
	3,134,399	945,272
TOTAL LIABILITIES AND FUND BALANCES	3,868,112	1,788,787

ENCUMBRANCES AND COMMITMENTS (note 4)

NATIONAL RESEARCH COUNCIL
STATEMENT OF FUNDING AND EXPENDITURES
FOR THE YEAR ENDED MARCH 31, 1989

	1989 $	1988 $
DEFERRED FUNDING - BEGINNING OF YEAR	216	154
FUNDING		
Contributions	26,509,784	25,899,846
TOTAL APPROVED CONTRIBUTION	26,510,000	25,900,000
EXPENDITURES BY ACTIVITY AREA		
Salaries	17,265,523	16,268,280
Power	1,701,079	1,664,174
Administrative and overhead	1,527,613	1,421,919
Cyclotron and facilities operation	2,451,503	2,577,707
Site services	827,906	441,196
Support services	1,664,502	1,772,096
Major projects	2,200,164	1,633,376
Minor projects and development	352,826	305,625
	27,991,116	26,084,373
Funds recovered — salaries and cost centres	1,481,144	184,589
TOTAL EXPENDITURES	26,509,972	25,899,784
DEFERRED FUNDING — END OF YEAR	28	216

	1989 $	1988 $
EXPENDITURES BY OBJECT		
Buildings	271,440	11,736
Communications	273,786	224,893
Computer	2,026,137	1,134,800
Equipment	1,757,125	1,888,754
Power	1,701,079	1,664,174
Salaries and benefits	17,359,275	16,339,027
Supplies and expenses	4,301,470	4,636,400
Salary expenditure recovered	(1,180,340)	—
	26,509,972	25,899,784

[**Editor's note:** The section below has not appeared in previous Annual Reports. It provides financial information on the Project Definition Study of the proposed TRIUMF KAON Factory. Funding for this study was announced jointly by the Federal Government and the Government of B.C. in July 1988, and an account of progress appears on pages 10—11.]

STATEMENT OF FUNDING AND EXPENDITURES AND CHANGES IN FUND BALANCE FOR THE YEAR ENDED MARCH 31, 1989

Column A: Total allocated project funding and expenditures
Column B: Less: outstanding commitments at March 31, 1989

FUNDING	**$ A**	**$ B**	**$ (1989)**
Contributions	1,965,000	—	1,965,000
EXPENDITURES			
Buildings	4,086	4,086	—
Computer	400,614	40,368	360,246
Equipment	635,067	413,573	221,494
Salaries and benefits	472,573	—	472,573
Supplies and services	452,649	87,856	34,793
	1,964,989	545,883	1,419,106
Excess of funding over expenditures for year	—	—	545,894
LESS: Deferred funding	11	—	(11)
COMMITMENTS (note 4)		545,883	—
FUND BALANCE — END OF YEAR			545,883

PROVINCIAL PROJECT DEFINITION STUDY

FUNDING	**$ A**	**$ B**	**$ (1989)**
Contributions	1,894,500	—	1,894,500
EXPENDITURES			
Buildings	120,000	—	120,000
Computer	293,433	480	292,953
Equipment	177,062	152,317	24,745
Salaries and benefits	428,033	—	428,033
Supplies and services	875,954	536,047	339,907
	1,894,482	688,844	1,205,638
Excess of funding over expenditures for year	—	—	688,862
LESS: Deferred funding	18	—	(18)
COMMITMENTS (note 4)		688,844	—
FUND BALANCE — END OF YEAR			688,844

TRIUMF
NOTES TO FINANCIAL STATEMENTS
FOR THE YEAR ENDED MARCH 31, 1989

1. JOINT VENTURE OPERATIONS

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 facility for research in intermediate energy science under a contribution from the National Research Council of Canada.

Each university owns an undivided 25% interest in all the assets, and is responsible for 25% of all liabilities and obligations, of TRIUMF, except for the land and buildings occupied by TRIUMF, which are owned by the University of British Columbia.

These financial statements include the statements of fund transactions of TRIUMF. The source of funding includes grants and contributions from NRC, NSERC and governments, advances and reimbursements from other sources, and investment income. The sources and purposes of these funds are:

(a) National Research Council (NRC)
Funding for operations, improvements and development; expansion of facilities (buildings excluded); and general support for experiments.

(b) Natural Sciences and Engineering Research Council
Funding to grantees for experiments related to TRIUMF activities. These funds are administered by TRIUMF on behalf of the grantees.

(c) Federal Project Definition Study
Funding provided by the federal government to research and define the financial and scientific requirements of the proposed KAON factory.

(d) Provincial Project Definition Study
Funding provided by the provincial government to research and define the financial and scientific requirements of the proposed KAON factory.

(e) NORDION International Inc.
Advances and reimbursements for expenditures undertaken on its TRIUMF project.

(f) Affiliated Institutions
Advances and reimbursements for expenditures undertaken on behalf of various institutions from Canada and abroad for their TRIUMF projects.

(g) Intramural Accounts
Recoveries for expenditures undertaken by TRIUMF providing services to all TRIUMF users on site.

(h) EBCO Industries Ltd.
Advances and reimbursements for expenditures undertaken on the 30 MeV cyclotron project.

(i) TRIUMF
Investment income and other income (royalties) for discretionary expenditures incurred by TRIUMF.

TRIUMF
NOTES TO FINANCIAL STATEMENTS
FOR THE YEAR ENDED MARCH 31,1989
(CONTINUED)

2. SIGNIFICANT ACCOUNTING POLICIES

As a non-profit organization, TRIUMF follows generally accepted accounting principles as referred to in the CICA Handbook except for:

- Capital Assets and Supplies
  Expenditures on capital assets and supplies are expensed as incurred.
- Operating and Capital Leases
  Lease payments are expensed when incurred.

3. FUNDING RECEIVABLE

Funding receivable comprises amounts billed or receivable from (payable to):

	1989 $	1988 $
NSERC	601,149	360,341
Federal Project Definition Study	829,733	
Provincial Project Definition Study	398,500	
NORDION International Inc.	243,881	
Affiliated Institutions	(73,861)	
EBCO Industries Ltd.	425,886	
	2,425,288	360,341

4. ENCUMBRANCES AND COMMITMENTS

In addition to the accounts payable reflected on the statement of financial position, outstanding encumbrances and commitments, representing the estimated costs of unfilled purchase orders and contracts placed as at the fiscal year end, comprise:

	1989 $	1988 $
National Research Council	636,000	2,839,000
Natural Sciences and Engineering Research Council	86,000	206,000
Federal Project Definition Study	546,000	—
Provincial Project Definition Study	689,000	—
NORDION International Inc.	9,000	52,000
Affiliated institutions	47,000	73,000
EBCO Industries Ltd.	15,000	—
	2,028,000	3,170,000

5. NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL — FUND BALANCE

	1989 $	1988 $
Funding unexpended	1,519,722	1,149,987
Grant accounts overexpended	(246,336)	(261,499)
Fund balance — end of year	1,273,386	888,488
Number of grants awarded during year	49	49
Number of grants administered throughout year	88	88

6. AFFILIATED INSTITUTIONS — FUND BALANCE

The fund balance at the fiscal year end comprises:

	1989 $	1988 $
Funding received in advance	404,427	534,186
Expenditures recoverable	(496,240)	457,011
Fund balance — end of year	(91,813)	77,175

1989 TRIUMF Users' Group Executive Committee (TUEC)
Chairman: S.A. Page
Associate Chairman: D.R. Gill
Members: C.A. Davis, P. Green, G.D. Wait
Liaison Officer: M. La Brooy

TRIUMF Users' Group

(March 1989)

583 members from 153 institutions, 24 countries

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P. Blunden
C.W. Bordeaux
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R. Keitel
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E.J. Kim
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D. Pearce
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M. Sevior
G. Smith
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G. Stinson
I.M. Thorson
A. Trudel
E. van Meijgaard
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D. Vetterli
M. Vetterli
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E.W. Vogt
G.D. Wait
P. Walden
C. Waltham
U. Wienands
N. Wilkinson
R. Wittman
R. Woloshyn
J. Worden
S. Yen
M. Zach

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D.J. Mack
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G.C. Nielson
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B. Pointon
S. Sun-Mack
D. Webster

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C.A. McDowell
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Y. Miyake
B.A. Moftah
M. Pavan
C. Ponting
J. Roy
D. Sample
V. Sossi
S. Stanislaus
A. Templeman
K. Venkataswaran
D.C. Walker
J.B. Warren
P. Weber
B.L. White
B. Yang
H.K. Yen

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B.S. Bhakar
D.J. Birchall
C.A. Davis
N.E. Davison
W.R. Falk
K.M. Furutani
J. Jovanovich
S.A. Page
W.D. Ramsay
A. Sakulovick
K.S. Sharma
V. Sum
J.P. Svenne
W.T.H. van Oers
J. Zhao

U. de Montréal

G. Belanger
P. Depommier
J. Lessard
R. Poutissou

U. of Toronto

R. Azuma
C. Chan
T.E. Drake
L.R. Kilius
J.D. King

TRIUMF Users' Group—Other Institutions

Canada

B.C. Cancer Foundation — L.D. Skarsgard
U. of Calgary — C.Y. Kim
Cancer Control Agency — H. Shirato
Carleton U. — A.L. Carter, C. Virtue
Chalk River Nuclear Laboratories — M.S. De Jong, H.C. Lee, D. Noakes, J.A. Sawicki, I.S. Towner
Cross Cancer Institute, Edmonton — J.W. Scrimger, R.C. Urtasum, S.R. Usiskin
EBCO Industries — J.T. Sample
Imaging Rsrch Ctr. — E. Grochowski, B. Pate
McGill U. — J. Crawford, J. Lee, B. Margolis, S.K. Mark, R. Moore, K. Oxorn
National Research Council — M.S. Dixit, C.K. Hargrove, W.R. Jack
Nordion Intern'l Inc. — J.K. Porter
Novatrack Analysts Limited — H. Blok, D.D. Burgess, H.L. Rosenauer
Queen's U. — G.T. Ewan, B.C. Robertson, M.J. Stott
U. of Regina— G.J. Lolos, E.L. Mathie, S.I.H. Naqvi, V. Pafilis, Z. Papandreou, D.M. Yeomans
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Université de Sherbrooke — K.E. Newman
Vancouver General Hospital — R.T. Morrison
U. of W. Ontario — W.P. Alford

Outside Canada

Australia

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Flinders U. of South Australia — I.R. Afnan
U. of Melbourne — S. Koutsoliotias, S.A. Long, S. McDonald, K.J.Raywood, G.G. Shute, B.M. Spicer, G.N. Taylor

Belgium

Université Catholique de Louvain — J. Deutsch

Bulgaria

Sofia U. — I. Enchevich

China

Academia Sinica — X-D. Jiang, Y.P. Zhang
Inst. Atom. Energy — Yong-Shun Wu
IHEP, Beijing — Chaoquing Chan, Z.H. Ding, J. Lu, N.S. Zhang

Finland

U. of Helsinki — J. Niskanen

France

CEN Saclay — P. Couvert, B. Mayer
Centre d'Etudes — R. Grynszpan
GANIL — F. Loyer

Germany

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Karlsruhe — E.T. Boschitz
KFA Julich — S. Martin
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Inst. f. Theor. Phys. — H.M. Hofmann
TH Darmstadt — H. Wortche
Tech. Inst. Munich — T. von Egidy
Tubingen U. — G. Wagner

Hungary

Central Research Institute for Physics, Budapest — D. Horvath

Israel

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Soroka Med. Ctr. — M.R. Quastel
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INFN, Bari — N. Grion, V. Paticchio
Universita di Milano — A. Bracco, L. Rossi

Japan

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Nat. Res. Inst. Police Science — K. Kuroki
Osaka U. — F. Fujimoto, N. Matsuoka, T. Novo, H. Sakai
RIKEN — K. Katsumata
Tohoku U. Hosp. — Y. Hosoi, K. Sakamoto, R. Sujita
U. of Tokyo — I. Masahiko, K. Nagamine, S. Nakamura, H. Outa, S. Sakamoto, T. Yamazaki, Y. Yamazaki, H. Yasuoka
Tokyo Inst. of Technology — H. Miyatake, N. Nishida
Tokyo Metropol. Inst. — H. Toki, M. Toki

Netherlands

NIKHEF — R. van Dantzig
Technische Hogeschool Delft — H. Postma
Technische Hogeschool Eindhoven — J.I.M. Botman

Nigeria
U. of Ife — B. Olaniyi
Poland
Inst of Nucl. Stud. — S. Burzynski
Warsaw U. — J. Miszczak, A. Sliwinski
Saudi Arabia
U. of Petroleum & Minerals, Bahren — A.H. Hussein
Spain
Valencia U. — J.M. Nieves, E. Oset, M. Vincente
Sri Lanka
P. Lumumba U. — K. Jayamanna
Switzerland
Universitat Basel — G.R. Plattner, I. Sick
CERN — C. Amsler, P. Gumplinger, G. Waters, M. Zanolli
Inst. for Int. Enrg. Phys. — W. Gruebler
PSI — R. Abele, W. Bertle, B. Blankleider, J. Domingo, H.J. Leisi, E. Morenzoni, L. Rezzonico, A. van der Schaaf
Universitat Zurich — R. Engfer, I. Reid
Union of S. Africa
CSIR/NRIMS, Pretoria — J.M. Greben
United Kingdom
Bedford College, London — N.M. Stewart
JET Joint Undertaking, Abingdon — J. Kallne
U. of Liverpool — A.N. James
Queen Mary College, London — D.V. Bugg, W.R. Gibson
Rutherford — S. Cox
U. of Surrey — A.S. Clough, M.R. Harston, J.R.H. Smith

United States
Arizona U. — T. Bowen, P. Halverson, K.R. Kendall, R.F. Marzke, J.R. Tinsley, T. Wu
Arizona State U. — J. Comfort
California Institute of Technology — K.H. Chang, A. Gonzales
California State U. — K. Aniol, M. Epstein, E.F. Gibson, D.J. Margaziotis
U. of California, Davis — F.P. Brady
U. of California, Irvine — W.P. Lee
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Carnegie Mellon — P.D. Barnes
U. of Cincinnati — S. Jha, J.M. Oostens
U. of Colorado — J. Brack, X.Y. Chen, S. Holbraten, M. Kohler, J.J. Kraushaar, D.A. Lind, R. Loveman, T. Masterson, R.A. Ristinen, J.R. Shepard, R. Smythe, K. Vaziri, C.D. Zafiratos
U. of Florida — R. Piercy
Florida State U. — X. Aslanoglou, H.S. Plendl
General Physics Corporation — J. Clark
U. of Georgia — F.T. Baker
Gustav Adolphus Coll. — T.M. Huber
Harvard — T. Chupp
Hood College — J.M. Stadlbauer
U. Houston — C. Chu, P.J. Gareri Jr., W.W. Mayes II, L.S. Pinsky, L. Tang, Y. Tzamouranis
Idaho Nat. E.L. — A.J. Caffrey
Indiana U. — R.D. Bent, G. Huber, W.P. Jones, J. Lisantti, H.O. Meyer, M.E. Rickey, R. Sawafta, P. Schwandt, E.J. Stephenson
U. Illinois — P.T. Debevec
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