TRIUMF 1986-87

Annual Financial and Administrative Report

including summaries of
pure research activities, and
practical applications of research

TRIUMF

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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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TRIUMF Information Office.

Editor: Michael La Brooy

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Associate Director, TRIUMF

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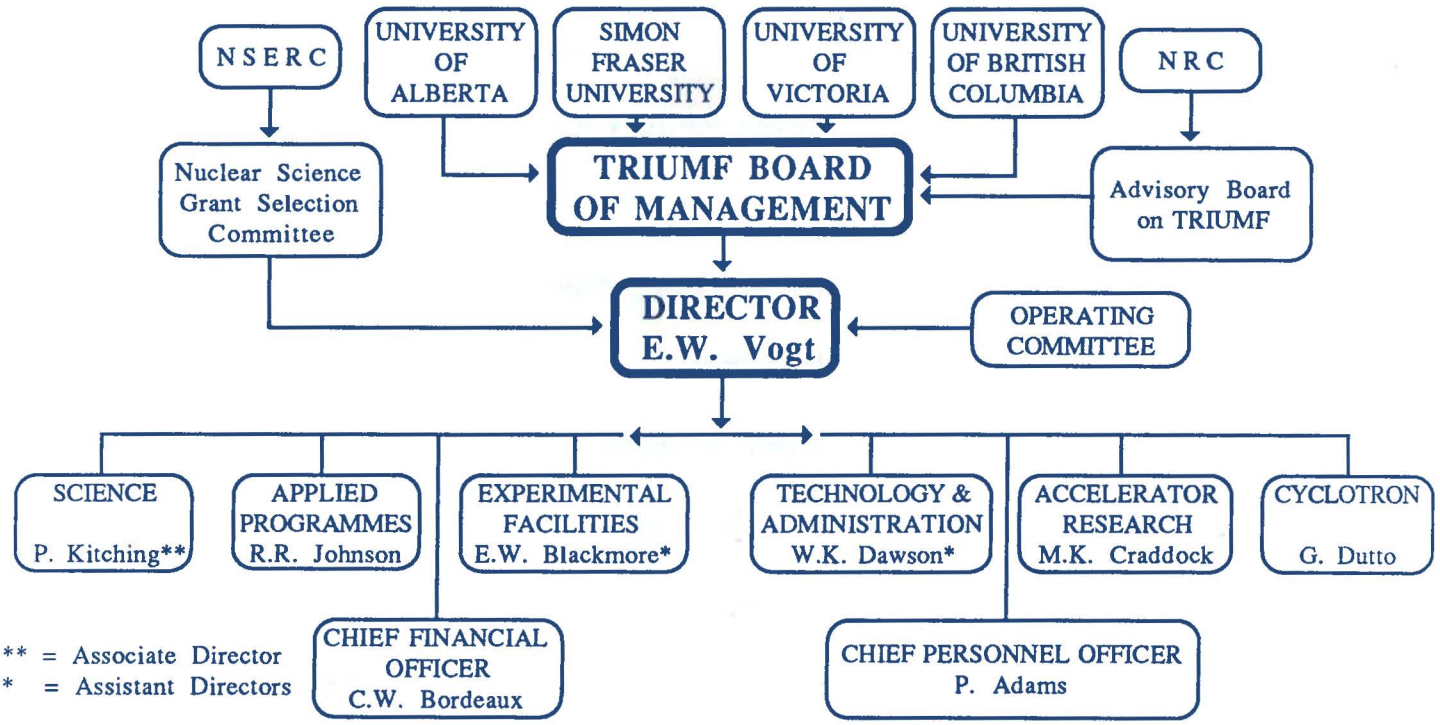

Director's Report

In this year TRIUMF's science moved on impressively, its future hopes for a KAON Factory advanced significantly and TRIUMF's financial resilience was severely tested.

The financial test occurred in the third month of the financial year, when the programme of fiscal restraint introduced by Ottawa to reduce federal deficits suddenly emerged in amplified form for TRIUMF: a decision was made to cut NRC's funding of TRIUMF by 14%. It became evident that such a reduction would have unacceptable consequences, whereupon the friendly and prompt intervention of NRC halved the cut for 1986/87. At the end of the financial year the federal Minister of State for Science, the Honourable Frank Oberle, restored the temporary 7% fix to TRIUMF's ongoing base budget. The net result, then, was a year of financial trauma and, for the immediate future, a plateau in TRIUMF's growth, which had previously extended for a full decade.

The principal effect of the fiscal restraint programme on TRIUMF was to slow down the development of new facilities needed to provide the present TRIUMF programme with its competitive edge in world science. The number of weeks of cyclotron operation and the total amount of beam delivered to experimentalists was almost as high as for 1985-86.

Fortunately TRIUMF had just installed some superb new facilities, so the science produced and the interest of scientific users in making new proposals at TRIUMF did not flag during the year. Especially in the proton hall -- not covered in the scientific vignettes described in this report -- new combinations of beams and large facilities placed TRIUMF in the front rank of laboratories now addressing the physics of atomic nuclei. A full description of this new work and of the whole TRIUMF research programme of the past year is given in the scientific Annual Report for 1986, which is now available.

TRIUMF's muons, which receive some special attention in this report, are achieving an important place as probes of materials. From the way in which they are produced through the decay of pions, they are, in effect, little spinning magnets pointing in a known direction. They can then be placed inside solid materials, for example, to provide information at a submicroscopic level about the magnetic fields inside.

This capability leaped into the limelight several months ago, when some astonishing new materials suddenly emerged from laboratories around the world -- high-temperature superconductors, capable of conducting electricity in a "frictionless" way at temperatures significantly above the ultra-cold regime in which they were previously known. TRIUMF's muon beam lines at once became a centre to which many of the world's laboratories brought their latest new materials for study. These materials have enormous potential for the development of high technology in Canada. The international use of TRIUMF's equipment in this way shows the importance of having world-class facilities in our own country to which people and ideas come from abroad.

During the year very significant strides took place toward the funding of TRIUMF's KAON Factory. This major upgrade of TRIUMF will require a partnership between the governments in Ottawa and Victoria. The Province of B.C. made a firm commitment to provide the buildings and civil construction (at an estimated cost of $87 million) and put the project at the top of the list of undertakings it now seeks to share with Ottawa. It will be the centre-piece of the Province's new high-technology strategy. The arguments for funding will rest solidly on the economic benefits provided by the project, and on its role in economic diversification for Western Canada.

Erich Vogt

TRIUMF Users' Group

[Names of 1987 Users' Group Executive Committee (TUEC) are underlined]

TRIUMF

R. Abegg
G. Azuelos
J.L. Beveridge
R.F. Blaby
E.W. Blackmore
P. Blunden
C.W. Bordeaux
M. Butler
M. Comyn
M.K. Craddock
W.K. Dawson
P. Delheij
D.A. Dohan
J. Doornbos
G. Dutto
F. Entezami
H.W. Fearing
D. Garner
D.R. Gill
L.G. Greeniaus
D.P. Gurd
K. Hicks
D.A. Hutcheon
K.P. Jackson
B.K. Jennings
R.R. Johnson
R. Keitel
K.R. Kendall
R. Kiefl
P. Kitching
S.R. Koscielniak
C.J. Kost
M. La Brooy
R. Lee
G.A. Ludgate
J.A. Macdonald
G.H. McKenzie
J. McIlroy
C.A. Miller
B. Milton
L. Moritz
J.N. Ng
T. Numao
C. Oram
A.J. Otter
D. Ottewell
J.B. Pearson
J.M. Poutissou
J.G. Rogers
T.J. Ruth
M. Salomon
P. Schmor
G. Smith
I.M. Thorson
V.K. Verma
J.S. Vincent
E.W. Vogt
G.D. Wait
P. Walden
G. Waters
U. Wienands
R. Wittman
R. Woloshyn
S. Yen
M. Zach

Simon Fraser University

A.S. Arrott
D. Boal
J. Brodovitch
J.M. D'Auria
O. Hausser
R. Jeppesen
R.G. Korteling
P.W. Percival
M. Vetterli

Experimentalists at main site from other institutions

D. Bandyopadhyay, J. Birchall, C.A. Davis, W.D. Ramsay, U. of Manitoba
R. Poutissou, Universite de Montreal
N. Stevenson, University of Saskatchewan

University of Alberta

E.B. Cairns
J.M. Cameron
J.B. Elliott
P.W. Green
F.C. Khanna
W.J. McDonald
G.A. Moss
E.A.K. Negm
G.C. Nielson
A.A. Noujaim
W.C. Olsen
J. Pasos
N. Rodning
G. Roy
D.M. Sheppard
H. Sherif
J. Soukup
G.M Stinson
J. Uegaki
J.S. Wesick
Y. Ye

University of Victoria

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

University of British Columbia

A. Altman
E.G. Auld
D.A. Axen
J.H. Brewer
C.F. Cramer
D.G. Fleming
E. Grochowski
D. Harshman
M.D. Hasinoff
G. Jones
S. Kreitzman
A. Larabee
P.W. Martin
C.A. McDowell
D.F. Measday
Y. Miyake
C.B.W. Ng
D. Noakes
B.D. Pate
I. Reid
M. Senba
V. Sossi
R.P. Trelle
C. Virtue
D.C. Walker
C.E. Waltham (Chairman, '87)
J.B. Warren
B.L. White
H.K. Yen

B.C. Cancer Foundation

G.K.Y. Lam
L.D. Skarsgard
M.E.J. Young (B.C. Cancer Control Agency)

TRIUMF Users' Group -- Other Institutions

Canada

J.K. Porter, AECL
C.Y. Kim, University of Calgary
A.L. Carter, Carleton U.
M.S. De Jong, H.C. Lee, J.A. Sawicki, Chalk River Nuclear Laboratories
J. Battista, J.W. Scrimger, R.C. Urtasun, S.R. Usiskin, Cross Cancer Institute, Edmonton
B.S. Bhakar, N.E. Davison, W.R. Falk, J. Jovanovich, R.H. McCamis, S.A. Page, J.P. Svenne, W.T.H. van Oers, U. of Manitoba
J. Crawford, J. Lee, B. Margolis, S.K Mark, R. Moore, K. Oxorn, McGill U.
P. Depommier, J. Lessard, Universite de Montreal
M.S. Dixit, C.K. Hargrove, W.R. Jack, National Research Council
D.L. Livesey, U. of New Brunswick
H. Blok, D.D. Burgess, H.L. Rosenauer, Novatrack Analysts Limited
G.T. Ewan, B.C. Robertson, Queen's U.
E.L. Mathie (Chairman 1986), G. Huber, G.J. Lolos, S.I.H. Naqvi, V. Pafilis, Z. Papandreou, U. of Regina
E.J Ansaldo, Y.M. Shin, U. of Saskatchewan
J.T. Sample, Research Secretariat of B.C.
M. Krell, K.E. Newman, Universite de Sherbrooke
R. Azuma, T.E. Drake, L.R. Kilius, J.D. King, U. of Toronto
R.T. Morrison, Vancouver General Hospital
W.P. Alford, U. of W. Ontario

Overseas

D.V. Bugg, R. Gibson, Queen Mary College, London
N.M. Stewart, Bedford College, London
A.S. Clough, M.R. Harston, J.R.H. Smith, U. of Surrey
A.N. James, U. of Liverpool
J. Kallne, JET Joint Undertaking, Abingdon
C. Amsler, CERN
R. Engfer, Universitat Zurich
W. Bertle, J. Domingo, H.J. Leisi, L. Rezzonico, SIN
G.R. Plattner, Universitat Basel
L. Antonuk, P. Couvert, B. Mayer, CEN Saclay
F. Loyer, GANIL
R. Grynszpan, CNRS Vitry
J. Tinsley, SATURNE
J. Deutsch, Universite Catholique de Louvain
H. Postma, Technische Hogeschool Delft
R. van Dantzig, IKO Amsterdam
J.I.M. Botman, Technische Hogeschool Eindhoven
J. Bailey, DESY
C. Weidner, Max-Planck Institut
J. Ernst, Inst. f. Strahlen-und-Kernphysik, Bonn
T. Anderl, U. of Bonn
J. Niskanen, U. of Helsinki
D. Horvath, Central Research Institute for Physics, Budapest
M. Furic, Inst. R. Boskivic, Zagreb
I. Enchevich, Sofia U.
C. Cernigoi, N. Grion, R. Rui, Ist. di fisica Trieste
J. Greben, CSIR/NRIMS, Pretoria
V. Paticchio, INFN, Bari
A. Bracco, Universita di Milano
J. Alster, D. Ashery, M.A. Moinester, A. Stern, S.A. Wood, A.I. Yavin, Tel-Aviv U.
B. Olaniyi, U. of Ife
A.H. Hussein, U. of Petroleum & Minerals, Bahren, Saudi Arabia
N.S. Zhang, Y.P. Zhang, IHEP, Beijing
A.W. Thomas, A.G. Williams, U. of Adelaide
S.A. Long, K.J. Raywood, G.G. Shute, B.M. Spicer, G.N. Taylor, U. of Melbourne
I.R. Afnan, Flinders U. of South Australia
M. Vincente, Facultad de Fisica, Spain
C. Yamaguchi, KEK
N. Nishida, Tokyo Inst. of Technology
T. Azuma, K. Nagamine, T. Yamazaki, U. of Tokyo
R. Kadono, Meson Sci. Lab., Tokyo
K. Sakamoto, Japanese Federal Government

United States

R.F. Marzke, Arizona State U.
E.K. McIntyre, Boston U.
K.W. Jones, Brookhaven National Laboratory
A. Rosenthal, Brooklyn College, CUNY
K.H. Chang, California Institute of Technology
K. Aniol, M.P. Epstein, D.J. Margaziotis, California State U.
F.P. Brady, U. of California, Davis
W.P. Lee, U. of California, Irvine
A. Eichon, B.M.K Nefkens, J.R. Richrdson, U. of California, Los Angeles
S. Jha, U. of Cincinnati
J.J. Kraushaar, D.A. Lind, R. Loveman, T. Masterson, R.A. Ristinen, J.R Shepard, C.D. Zafiratos, U. of Colorado
B.H. Wildenthal, Drexel U.
X. Aslanoglou, H.S. Plendl, Florida State U.
R. Piercy, U. of Florida
J. Clark, General Physics Corporation
F.T. Baker, E.R. Siciliano, U. of Georgia
J.M. Stadlbauer, Hood College
R.D. Bent, B. Blankleider, G.T. Emery, W.P. Jones, H.O. Meyer, M.E. Rickey, P. Schwandt, E.J. Stephenson, T. Ward, Indiana U.
Y.K. Lee, Johns Hopkins U.
C. Chu, P.J. Gareri Jr., W.W Mayes II, L.S. Pinsky, L. Tang, U. Houston
B.D. Anderson, R. Madey, P. Tandy, J.W. Watson, Kent State U.
C. Clawson, K.M. Crowe, G. Gidal, S. Kaplan, S. Ljungfelt, R.H. Pehl, V. Perez-Mendez, S. Rosenblum, H. Steiner, M.W. Strovink, R. Tripp, Lawrence Berkeley Laboratory
J.W. Blue, Lewis Reearch Center, NASA
L.E. Agnew, H.L. Anderson, J.S. Fraser, R.E.L. Green, R.C. Haight, C.Y. Huang, K. Jones, N.S.P. King, R.J. Macek, Los Alamos National Laboratory
R.P. Redwine, Massachusetts Institute of Technolgy
F.D. Becchetti, U. of Michigan
W. Benenson,E. Kashy, A. Pradhan, G.D. Westfall, Michigan State U.
J. Jean, U. Missouri, Kansas City
H.B. Willard, National Science Foundation
B. Bassalleck, B. Dieterle, U. of New Mexico
R.E. Segel, K.K. Seth, Northwestern U.

[Continued on page 6]

Facilities

In June 1986 TRIUMF's management heard of the National Research Council's $2 million reduction in our budget, and immediately postponed many of the planned improvements in facilities. This year, therefore, did not see the introduction of as many innovations as usual.

Buildings

The building programme of the past few years ended with the completion of the meson hall service annex. In part of this area we installed the "hot cell" and the "warm cell", small shielded rooms with thick lead glass windows, formerly on the floor of the main meson hall. They are used for the remote handling of radioactive materials, e.g. beam line targets or other objects that have been subjected to radiation.

Much of the routine work of building wire chamber detectors has also moved to the annex, and a new clean room is now available.

Other Innovations

At TRIUMF much effort goes into refining, stabilizing and generally improving the characteristics of the primary beams from the cyclotron. Often this is achieved through a series of small improvements that add up to a significant advance. This year, however, saw us taking a major step -- the completion of a **third source for the hydrogen ions** that are accelerated in the machine. Its main purpose is to increase -- eventually up to twentyfold -- the intensity of the primary proton beam (i.e. the number of particles accelerated each second). Initial tests were successful, and we expect in the coming year to obtain beam currents up to 500 microamperes. This is five times the level envisioned when the cyclotron was built!

In **meson hall**, the major change is the upgrading of the M9 beam line. This will end up as a source of low-energy, negative muons, with a very high luminosity (i.e. a very "bright" beam), and will complement the positive muon beam we already have in the M15 line. One of the main components of M9 is the million-dollar superconducting solenoid to be contributed by Japan. Since any superconducting device requires cooling with liquid helium to very low temperatures, a helium compressor has already been installed in a small new building attached to meson hall. We expect to complete this project in 1987-88.

Several changes appeared in proton hall. The **TISOL facility**, which can provide accelerated beams of heavy ions, was lowered into place in beam line 4A during the spring shutdown. The equipment had already been tested: it successfully separated beams of rubidium-85 and rubidium-87, and also provided pure beams of cesium and other heavy isotopes.

The dominant object in proton hall is the **medium resolution spectrometer**. This two-storey-high giant can be moved along a circular track so as to collect and measure particles scattered at specific small angles from the target in beam line 4B. It can now be used in a "large-angle mode" for certain studies, that is to say, at angles greater than 15 degrees from the incoming proton beam.

Many of the experiments in proton hall involve the use of **polarized beams or targets**. (Polarized particles have their spin axes parallel, and all of them spin in the same direction.) A strong magnetic field will polarize the particles in a target but then, unless the target is kept at a very low temperature, the polarization disappears rapidly when the field is removed. Therefore, to complete the repertoire of choices available to experimenters, we once more have a large (around 50 ml) **frozen-spin target** that can be cooled to 0.04 degrees Kelvin. In addition, the incoming proton beam can now be **polarized longitudinally** (i.e. with the spin axes in the direction of motion). Previously, only vertically or horizontally polarized beams were possible.

This longitudinal polarization facility was completed in about two years, once more demonstrating TRIUMF staff's remarkable ability to achieve their goals rapidly!

TRIUMF Users' Group (continued from page 5)

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B.C. Clark, T.R. Donoghue, Ohio State U.
J. Lisantti, D.K. McDaniels, U. of Oregon
X.Y. Chen, F. Farzanpay, P. Fuchs, K.S. Krane, R Landau, A.W. Stetz, L.W. Swenson, Oregon State U.
R.F. Carlson, U. of Redlands
J.M. Clement, S.A. Dodds, T.L. Estle, G.S. Mutchler, D.P. Spencer, Rice U.
R. Fererson, C. Glashausser, A. Green, Rutgers U.
J.R. Chen, State U. of New York, Geneseo
R. Dubois, Stanford Linear Accelerator Center
R. Bryan, Texas A&M U.
V.G. Lind, R.E. McAdams, O.H. Otteson, Utah State U.
M. Blecher, K. Gotow, D. Jenkins, Virginia Polytechnic Institute and State U.
I. Halpern, E.M. Henley, U. of Washington
A.S. Rupaal, Western Wasington U.
W.C. Sperry, Central Washington U.
D. Humphrey, W. Kentucky U.
C.F. Perdrisat, M. Eckhause, R.T. Siegel, College of William and Mary
T.M. Huber, U. of Wyoming
T.C. Sharma

Applied Programmes

Positron Emission Tomography

The PET research programme, run in collaboration with the University of British Columbia's Health Sciences Centre hospital (where the tomograph is actually located), continues to probe the frontiers of knowledge.

One area of such investigation is the mechanism of artificially induced Parkinson's disease. About two years ago, researchers in California discovered that MPTP (a contaminant in some batches of illegal, synthetically produced heroin) had caused symptoms very much like Parkinson's in several heroin addicts. Some of these young addicts were sent to Vancouver for PET scans on our machine, and it was found that their brain lesions were identical to those of older patients who had Parkinson's disease. (The medical detective work involved was described in a recent NOVA television programme called "The Case of the Frozen Addict".) Follow-up work on this problem has involved the PET scanning of monkeys with this artificially induced disease, using F-6-fluorodopa (with fluorine-18) produced at TRIUMF.

Radiopharmaceuticals containing oxygen-15 and fluorine-18 were used to take PET scans of 36 patients from Guam, where the incidence of Parkinson's disease is about 100 times greater than normal, presumably due to some unknown dietary factor.

The TRIUMF PET group has also recently prepared a pharmaceutical form of EDTA containing gallium-68, and this is now available at the UBC hospital. It will be used in the study of the breakdown of the blood-brain barrier, e.g. in multiple sclerosis or in brain tumours.

During March 1987 the science ministers of all the provinces held their annual meeting in Vancouver. At a special dinner given by the Provincial Government on this occasion, five exhibits on high technology in B.C. were presented, including a display and a short video programme about PET.

Neutron Activation Analysis

Novatrack, a private firm, uses the TRIUMF neutron facility for neutron activation analysis of the metal content of thousands of samples each year. Most of these are mineral samples, and Novatrack has noted a considerable increase in demand for gold analysis recently. This year the company has begun to analyse biological samples, also by this method.

Pion Therapy for Tumours

During 1986-87 a significant number of additional patients was treated. The biomedical facility made an excellent recovery from a setback of a few months early in the year, caused by a magnet failure in its beam line.

At the beginning of 1987, an important biological experiment was conducted by visiting scientists from Los Alamos. It involved the pion irradiation of the spinal cords of several rats. A 1-cm length was irradiated in each rat, and the experimenters were to observe the animals over the next six months to compile data on the long-term effects of pion irradiation on their central nervous systems. Knowledge of this kind is essential in planning the correct treatment for brain tumour patients.

Isotope Production

The Radiochemical Co. of Atomic Energy of Canada Ltd. sold radioisotopes worth over three million dollars during this year. The firm received a licence to manufacture hippuran containing iodine-123, and it has been marketing this product since September 1986. It also made an Investigational New Drug submission for N-isopropyl-p-iodoamphetamine (IMP) containing this isotope. IMP is useful in assessing cerebral ischemia and regional brain perfusion in various disease states. It can show abnormalities in the brain at once (unlike CT scans), thereby permitting surgery promptly, when such intervention can do the most good -- immediately after a stroke, for example. The firm also reports a growing demand for xenon-127, which is used for lung ventilation studies.

Electronics and Processing Laboratories

Activities in these laboratories focused on our recently developed gallium arsenide charge-coupled devices. The Processing Laboratory fabricated these, and worked on developing a Ga As strip for possible application as a detector; Electronics concentrated on implementing the CCD transient digitizer, and on completing the electronics for a special new drift chamber (a sensitive particle detector), to be used in an important experiment at Brookhaven in which many TRIUMF scientists are participating.

Pure Research at TRIUMF

The Year of the Muon

What exactly is a muon? In a nutshell, it is an unstable, heavy brother of the electron, (e). The muon (μ), in turn, has an even more massive, unstable brother called a tau particle.

Each of the three has an extremely light (possibly massless, probably stable) partner called a neutrino; and each, with its neutrino, constitutes one "generation" of a class of particles called leptons.

TRIUMF's interest in muons stems from our abundant production of pions: in a vacuum, most electrically charged pions rapidly break down into muons (and antineutrinos), thereby allowing us to create intense beams of both positively and negatively charged muons (μ+ and μ-). In two millionths of a second, these muons will themselves break down into positrons or electrons (plus more neutrinos), but that flicker of time is enough to allow TRIUMF's researchers to use muons for a dazzling variety of purposes: as probes of the magnetic properties of materials; as substitutes for bonding electrons in the study of chemical bonds, reactions, and free radicals; as clue-bearers in the "lepton generation puzzle"; and as catalysts in the controlled fusion of hydrogen atoms.

Muons and μSR

All in all, the muon is a versatile beast. At TRIUMF we can persuade positive muons (μ+) to travel as 100% spin-polarized beams whose decay products (positrons) are emitted preferentially along the muon spin axis. This makes possible the use of muons as extremely delicate probes of the microscopic properties of ordinary matter, in an assortment of experimental techniques known collectively as μSR. To the μSR experimenter, the μ+ is a light isotope of the proton that can be implanted into any material, when it will reveal many things about its immediate environment. When TRIUMF was built, few dreamed of the breadth of applications that μSR would one day enjoy; in fact, the TRIUMF μSR programme began with the last-minute addition of a beam line built with borrowed, antique components. But the proof of the wine is in the drinking, and as the potential of μSR in chemisty and condensed-matter physics became more apparent, TRIUMF developed better and more sophisticated facilities for its exploration. Today we enjoy one of the best-equipped μSR laboratories in the world; and the past year has produced the best vintage ever for μSR at TRIUMF.

High-Temperature Superconductors

The past year brought the world a breakthrough of tremendous technological importance: high-temperature superconductivity. Collaborators at AT & T Bell Labs in the USA produced one of the first high-temperature superconductors, containing oxides of lanthanum, strontium and copper, and superconducting up to 38 degrees Kelvin. Since the muon has long been recognized as a microscopic probe of internal magnetic fields in solids, it is not surprising that a sample was rushed to TRIUMF in January 1987 for examination by μSR. Preliminary studies on this material, and on other similar ones (containing yttrium, barium and copper oxides, and superconducting up to 90 degrees Kelvin) from Bell Labs, UBC and Tokyo, have revealed important magnetic properties of the new superconductors and demonstrated the utility of μSR for such investigations. Extensive experiments on magnetically ordered samples of the new materials are now under way; these measurements are particularly exciting since magnetism may play an important role in the mechanism for superconductivity. In some cases the samples are simultaneously antiferromagnetic and superconducting, so conventional methods for measuring the magnetization are not applicable.

Chemistry with Muons

An atom or a molecule which has an odd number of electrons, one of which is unpaired, is given the special name "free radical". Most free radicals are vey reactive creatures which exist only as transient intermediates of chemical reactions. It is precisely this role of reaction intermediate that interests chemists as they study how molecules rearrange themselves to form other molecules. For example, plastics such as nylon are the products of free radical chain reactions.

The unpaired electron of a free radical endows it with a magnetic nature, called paramagnetism, and this is the basis of the primary technique for observing free radicals, called electron paramagnetic resonance, or EPR. About two years ago the famous French physicist, A. Abragam, one of the fathers of magnetic resonance, suggested that a special kind of magnetic resonance experiment called "level crossing resonance" (LCR) could be applied to studies with muons. These ideas were first exploited by some TRIUMF researchers who then extended the application of LCR to the study of free radicals formed by the chemical reaction of muonium atoms (which are free radicals) with molecules possessing double or triple bonds. These muon magnetic resonance measurements have succeeded (where conventional EPR measurements have failed) in determining the unpaired electron density on the carbon atoms of certain radicals. Already μLCR has identified radicals that have been predicted but have eluded previous experimental detection. Whereas EPR is mostly applied to the liquid and solid phases, it is almost impossible to perform in the gas phase except with a couple of two-atom radicals. Muon LCR, on the other hand, has been successfully applied to a study of gaseous ethylene under a wide variety of conditions, and the technique seems to have almost limitless application in the gas phase.

TRIUMF researchers have been able to seize the initiative with studies using μLCR, and presently enjoy a modest lead over other laboratories. This work was pioneered at TRIUMF and was the highlight of the most recent (June 1986) international conference on muon spin rotation in Upsala, Sweden. Such a happy situation required not only the seed ideas and their nurturing by innovative scientists, but also some significant technical opportunities: a very high magnetic field (as can be produced only by a superconducting solenoid) was available through colleagues at the University of Tokyo; the most intense, pure beams of low-energy muons are available at TRIUMF, which is the world leader in this type of beam technology; and an energetic and innovative technical support group was quickly able to adapt data acquisition and control systems to exploit the new spectroscopy.

μSR Facilities at TRIUMF

The two developments mentioned above underline the dual emphasis of μSR: on one hand, μ+ and the muonium atom (μ+ with e-) represent a simple, light isotope of hydrogen, whose behaviour in matter is a subject of wide interest; on the other hand, the μ+ is a unique microscopic probe of magnetism and related phenomena in solids.

There are now two beam lines (M15 and M20) regularly delivering intense beams of highly polarized, positively charged muons to μSR experimenters. A third channel, M9, which has been redesigned especially for polarized negative muons (μ-), will soon permit development of the μ- as a probe complementary to the μ+, no doubt with comparable impact. The whole μSR facility, which has been under development for the last three years, is now nearing completion, and the next few years will see several new, specially built pieces of equipment being used in a profusion of muon experiments. The potential for progress has never been so great.

Rare Decays of Muons

One of the most powerful and successful ideas physicists have used to understand the fundamental aspects of nature is the concept of symmetry. This often manifests itself in nature as some observable property that is conserved, e.g. when experiments show some property of a system (such as a specific group of particles) to be stubbornly constant, it suggests there may be an underlying symmetry that is characteristic of the system. By understanding the symmetry relations among particles and the interactions between them, it has been possible to recognize the laws of nature which govern the existence and behaviour of those particles.

In the realm of leptons, a puzzle exists that has interested physicists at TRIUMF and world-wide. As mentioned earlier, leptons are found as three "generations". For example, the electron and its neutrino form the first (lightest) generation, and the muon with its neutrino form the corresponding members of the next. Members of each generation appear to be absolutely identical to the corresponding members of the others, except for their mass. Unlike the quarks, however, the members of one lepton generation apparently never decay entirely into the corresponding members of another generation: there always remains at least a neutrino from the original generation. Yet, so far, no theoretical understanding for this has been established -- no known symmetry seems to underlie this conservation or, for that matter, to explain why there are three generations.

How could this be? One approach has been to say that a complete transformation between generations is not really forbidden, but only highly inhibited by some unknown mechanism. Several mechanisms have been postulated, in which the exchange between lepton generations takes place at some very low level. So experimenters are confronted with a search for a very rare process in order to be able to choose which theory may be correct.

The muon is a promising place to start looking. Though it is an "exotic" fundamental particle, it is comparatively plentiful in nature (from cosmic rays), and easy to produce in large numbers at TRIUMF, so that a thorough search for a rare or "forbidden" process can be carried out.

Physicists at TRIUMF have just completed a five-year search, using a highly sensitive detector called a time projection chamber to examine over a million million muons for evidence that one of them converted into an electron (and no muon neutrinos) while briefly trapped in orbit around the nucleus of an atom of titanium. No such evidence was found, leading to the conclusion that this conversion occurs, if at all, less than one time in 200,000,000,000.

In another experimental tack, the normal decay of the muon has been examined in detail to search for evidence of some exotic neutral particle which would explain the generation puzzle. (Several of these are postulated by the different theoretical models.) In this search too, no evidence was found.

These negative results, taken together with other experimental results, put increasingly severe constraints on the possible theories which could be correct. They represent significant steps on the way to unravelling the puzzle. In turn, refinements to the overall understanding of fundamental particles will be made, with possible implications in astrophysics and cosmology.

Muon-Catalysed Hydrogen Fusion

The fusion of hydrogen nuclei to form a helium nucleus is the source of the sun's energy; if we could carry out this reaction under control, the world's energy problem would be solved!

The nucleus of a normal hydrogen atom consists simply of a single proton, (p); but hydrogen also has two heavier isotopes, known as deuterium, (d), and tritium, (t), in which the proton is accompanied by, respectively, one or two neutrons. In a hydrogen molecule, two nuclei (which may be any combination of p, d or t) are bound together by two orbiting electrons.

Thirty years ago, researchers discovered that a μ- could catalyse the fusion of a proton and a deuteron, releasing 5 MeV of energy. The basic process is easy to envisage: if a muon replaces one of the electrons binding the atoms together in a p-d molecule, the muon's large mass makes its orbit so small that the nuclei it encircles may be forced together, eventually to fuse. The reaction remained an academic curiosity, however, because of its very low rate. In the last few years, muon-catalysed, controlled fusion has become a very lively area of research because of newly discovered properties of the d-t system. Tritium is an unpleasant, radioactive material, so experimenters had been hesitant to pursue research with that isotope until a Russian theoretician, Ponomarev, suggested that it might have all the necessary characteristics for practical applications of the fusion reaction.

For a muon-catalysed fusion to be useful, three important conditions must be met. First, the fusion rate must be fast; d-t fusion is much faster than p-d fusion because the former is a strong interaction process, whereas the latter goes via the electromagnetic interaction. Secondly, the muon must form the d-μ-t molecule in much less time than its own lifetime -- two microseconds -- so that each muon can catalyse many fusions in succession. Thirdly the μ- must not stick to any of the fusion products, since this would terminate the series. Ponomarev suggested that all these conditions were satisfied with d-μ-t, and later experiments showed that up to 200 fusions could be catalysed by a single muon.

At TRIUMF we have studied two aspects of the problem, using a gas consisting of hydrogen-deuterium molecules (HD) to avoid the difficulties associated with tritium. We have shown that the rate of formation of the p-μ-d and the d-μ-d molecules depends on whether one has HD molecules or a mixture of hydrogen and deuterium molecules. We have also studied these reaction rates for excited states of the exotic atoms, and it seems that this aspect is very important for understanding the overall reaction rates.

UBC and California State University are collaborating to continue the investigation of these reactions, and several groups around the world are also performing experiments. The present results tell that we are still a long way from solving the energy shortage, but Petrov, in Russia, has already outlined a fusion reactor which is within a factor of 5 or 10 of being viable. Whatever the technological outcome, the topic is rich with interesting problems in the physics and chemistry of exotic atoms, so a continuing effort in this area can be expected for years to come.

Financial Review

Fiscal year 1986-87 was a financially turbulent year. Based on a funding formula for operations and major projects costs in effect for about a decade, it was assumed that the contribution by the National Research Council of Canada (NRC) would amount to $28,100,000. In June 1986, three months into the fiscal year, TRIUMF was informed by NRC that the contribution for 1986-87 would be $24,100,000. Improved management information systems, through the effective use of an IBM S38 computer, packaged software from Response Services Ltd. and internal programming to integrate all administrative services, helped considerably in reponding quickly and efficiently to these severe perturbations. The finanacial statements confirm that expenses remained within the approve budget. The major cutbacks in Operations were in minor projects, and development and site services. The initial Major Projects budget was reduced substantially as well.

In addition to NRC's cutback, TRIUMF experienced a cutback in funding from the Natural Sciences and Engineering Research Council (NSERC). It should be noted that NSERC supplies additional financial support to TRIUMF by funding TRIUMF-related experiments administerd by other intitiutions, and reported on in the financial statements of those institutions.

Another source of substantial support to TRIUMF, not reported as revenue because the funds are administered elsewhere even though 90% of the work is done at TRIUMF, is the Medical Research Council of Canada. It is fully acknowledged that its suppport represents a significant contribution to the overall TRIUMF research programme.

Atomic Energy of Canada Limited (AECL) is reported on separetly because it is the major commercial user of TRIUMF facilities. Operations are progressing satisfactorily. Its sales of radioisotopes continue to increase considerably each year, and prospects for the coming years are equally promising. The flow of funds through TRIUMF fluctuates because by far most of AECL's transactions are handled by its administration located on the TRIUMF site. Only those services required directly from TRIUMF are reported on here.

Through the Universities Council of British Columbia, the Province of British Columbia approved a building programme. The total approved amount to date is $7,475,500. This building programme was completed in fiscal 1986-87.

The number of transactions handled on behalf of affiliated institutions continues to grow. The 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 at acceptable levels. The funding of TRIUMF operations seems to have stabilized, including funding for the 1987-88 fiscal year. Subsequent years are under discussion. It is expected that the Federal Government will continue to support TRIUMF at a level sufficient to maintain the high international standing TRIUMF has achieved, including the requisite upgrading of the facilities.

Source of Funds (millions of dollars)

National Research Council	$26.10	80.40%	80.60%
Natural Sciences and Engineering Research Council	2.70	8.31	10.05
Affiliated Institutions	1.78	5.48	3.50
Atomic Energy of Canada Ltd.	1.53	4.71	3.38
Province of British Columbia	.18	.55	1.93
Miscellaneous	.17	.55	.54

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, 1987 and the statements 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 financial statements present fairly the financial position of TRIUMF as at March 31, 1987 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 29, 1987

TRIUMF
STATEMENT OF COMBINED FUNDING AND EXPENDITURES
FOR THE YEAR ENDED MARCH 31, 1987

	1987 $	1986 $
FUNDING		
National Research Council	26,095,459	26,715,000
Natural Sciences & Engineering Research Council	2,699,402	3,331,140
Atomic Energy of Canada Limited	1,529,850	1,118,838
Province of British Columbia	182,751	637,661
Affiliated institutions	1,775,880	1,164,795
Investment income	171,321	182,946
	32,454,663	33,150,380
EXPENDITURES		
Building construction	479,518	600,352
Communication	287,042	353,445
Computer	2,213,794	1,330,593
Equipment	2,407,915	2,563,400
Lease payments - Atomic Energy of Canada Limited	650,284	538,762
Power	1,723,386	1,743,371
Salaries and benefits	18,993,755	18,314,043
Supplies and services	6,165,691	7,213,574
	32,921,385	32,657,540
EXCESS (DEFICIENCY)	(466,722)	492,840
LESS: DEFERRED FUNDING - NRC	154	2,613
(DEFICIT) SURPLUS FOR THE YEAR	(466,876)	490,227
SURPLUS - BEGINNING OF YEAR	1,354,605	864,378
SURPLUS - END OF YEAR	887,729	1,354,605

TRIUMF
STATEMENT OF FINANCIAL POSITION
FOR THE YEAR ENDED MARCH 31, 1987

	1987 $	1986 $
A S S E T S		
CASH AND TEMPORARY INVESTMENTS	1,852,163	2,162,215
ACCOUNTS RECEIVABLE	208,690	–
TOTAL ASSETS	2,060,853	2,162,215
L I A B I L I T I E S A N D S U R P L U S		
ACCOUNTS PAYABLE	470,056	374,494
DEFERRED FUNDING - NRC	154	2,613
DUE TO UNIVERSITIES		
The University of Alberta	2,845	21,793
The University of Victoria	37,287	11,428
The University of British Columbia	635,741	362,552
Simon Fraser University	27,041	34,731
	702,914	430,504
SURPLUS (DEFICIT)		
Natural Sciences and Engineering Research Council	782,605	1,205,856
Atomic Energy of Canada Limited	(59,222)	(127,040)
Province of British Columbia	853	3,554
Affiliated institutions	96,121	54,044
TRIUMF surplus	67,372	218,190
	887,729	1,354,604
TOTAL LIABILITIES AND SURPLUS	2,060,853	2,162,215

ENCUMBRANCES AND COMMITMENTS (note 3)

NATIONAL RESEARCH COUNCIL
STATEMENT OF FUNDING AND EXPENDITURES
FOR THE YEAR ENDED MARCH 31, 1987

	1987 $	1986 $
DEFERRED FUNDING - BEGINNING OF YEAR	2,613	Nil
FUNDING		
Cash contribution	26,092,846	26,715,000
TOTAL APPROVED CONTRIBUTION	26,095,459	26,715,000
EXPENDITURES BY ACTIVITY AREA		
Salaries	15,870,489	15,483,321
Power	1,723,386	1,743,370
Administrative and overhead	1,649,306	1,642,870
Cyclotron and facilities operation	2,557,293	2,522,223
Site services	465,198	771,167
Support services	1,592,556	1,511,117
Major projects	2,302,837	2,402,731
Minor projects and development	312,764	902,686
	26,473,829	26,979,485
Funds recovered -		
Cost centres	378,524	267,098
TOTAL EXPENDITURES	26,095,305	26,712,387
DEFERRED FUNDING - END OF YEAR	154	2,613
EXPENDITURE BREAKDOWN BY PROGRAM ELEMENT		
Basic support	17,960,295	18,233,314
Facility development	4,319,778	4,766,184
Experimental support	3,815,232	3,712,889
	26,095,305	26,712,387
EXPENDITURE BY OBJECT		
Buildings	(211)	139,810
Communications	238,728	325,685
Computer	2,056,352	1,082,757
Equipment	1,946,618	2,219,822
Power	1,723,386	1,743,371
Salaries and benefits	15,943,828	15,534,200
Supplies and services	4,186,604	5,666,742
	26,095,305	26,712,387

TRIUMF
NOTES TO FINANCIAL STATEMENTS
FOR THE YEAR ENDED MARCH 31,1987

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 sources and purposes of these funds are:

(a) National Research Council
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) Atomic Energy of Canada Limited
Advances and reimbursements for expenditures undertaken on its TRIUMF project.

(d) Province of British Columbia
Funding by the Ministry of Universities, Science and Communication for construction of certain buildings.

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

(f) TRIUMF
Investment income for discretionary expenditures.

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 Inventories
  Expenditures on capital assets and inventories are expensed as incurred.

- Operating and Capital Leases
  Lease payments are expensed as incurred.

3. ENCUMBRANCES AND COMMITMENTS

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

	1987 $	1986 $
National Research Council	1,365,000	2,230,000
Natural Sciences and Engineering Research Council	311,000	240,000
Atomic Energy of Canada Limited	39,000	39,000
Affiliated institutions	55,000	919,000
Universities Council of British Columbia	–	3,000
	1,770,000	3,431,000

4. NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL - SURPLUS

TRIUMF administers the Common Grant on behalf of the individual grantees using the TRIUMF facilities. The surplus funds at the fiscal year end are composed of:

	1987 $	1986 $
Funding unexpended	1,149,948	1,455,049
Grant accounts overexpended	(367,343)	(249,193)
Surplus - end of year	782,605	1,205,856
Number of grants awarded during year	47	50
Number of grants administered throughout year	78	67

5. AFFILIATED INSTITUTIONS - SURPLUS

The surplus funds at the fiscal year end are composed of:

	1987 $	1986 $
Funding unexpended	462,951	592,203
Funding receivable	(366,830)	(538,159)
Surplus - end of year	96,121	54,044