TRIUMF

Annual Financial & Administrative Report

TRIUMF is Canada's national laboratory for particle and nuclear physics, managed as a joint venture by a consortium of Canadian universities. It is operated under a contribution from the Government of Canada through the National Research Council of Canada.

Front Cover: 8π Spectrometer Inner Support Structure (see page 3)
Inside Front: RFQ with TRIUMF Staff
Inside Back: CAT & PET Scans
Back Cover: Opening of ISAC Building
By The Honourable John Manley,
Minister of Science and Technology

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TRIUMF Table Of Contents

In Support of Basic Science............

At the risk of boring regular readers, if such a person exists, it appears appropriate to return yet again to the issue of "Science and Technology"; their interdependence and their clear separability.

Late in 1999 the Advisory Commission of Science and Technology (ACST) put in place an Expert Panel charged with examining Canadian engagement in International Science and Technology. ACST represents to some extent the ultimate advisory group for science and technology in Canada; chaired as it is by the Industry Minister and advising directly the Prime Minister. Its expert panels are loaded with experts; nonetheless it seemed prudent to try to emphasize the point that previously within the Canadian system it was not apparent that any distinction was made within an item often referred to singly as "SandT". A letter was sent to the panel members asking that on this occasion, could we not separate science and technology and consider each on its individual merits?

A few replies were received from panel members but perhaps the most revealing came from Allan Bromley of Yale, an expatriate Canadian and erstwhile Science Advisor to Ronald Reagan during his term as President of the United States. At the risk of possibly destroying some friendships, a couple of paragraphs from Bromley's letter read as follows:

> *"You may recall that while I was Director of OSTP, I published the first ever statement of the U.S. Technology Policy, to emphasize the fact that science policy and technology policy were two very different, although complementary, beasts.*
>
> *I, too have been disturbed that in the only meeting that we have had, thus far of the Expert Panel, by the tight coupling that appears to exist in Canada between scientific research in the universities and national laboratories, and the short-term needs of industry. Unfortunately, I believe that in some quarters there is a distinct lack of understanding of one, or indeed, both of these activities."*

I am sure that all of us as children have been taken to a park or public place during the holiday season, and stood before a Christmas Tree brilliantly lit in the cold night air by hundreds of lights. In the dark, the lights take their shape from the branches of the tree which support them. They can be very pretty and quite distracting; sometimes they are multi-coloured, sometimes all white, sometimes they flash to capture our attention. There is a great deal of ingenuity.

However, we should never lose sight of our tree, and as the old Christmas carol "O Tannenbaum" has it:

"O Christmas Tree, O Christmas Tree,
thy leaves are so unchanging
Not only green when summer's here,
but also when tis cold and drear"

The tree will outlive all of us, and its beauty will be a source of awe for countless generations of children; such is the beauty of science. But what of our lights? Without the tree for their form, they would collapse into a shapeless pile of broken bulbs and twisted wires; such is technology without science. Perhaps the analogy is a little heavy handed, but personal experience has proved that the point on science and technology is not made subtly.

If there is interdependence between technology and science, then there is also an often overlooked interdependence among the sciences. There appears to be a belief that one need only pump large sums of money into the medical and biological sciences, and solutions will emerge to all of the diseases which plague and shorten our lives on the planet. Nothing could be further from the truth.

Recently Harold Varmus, a Nobel Laureate in medicine, and an ex-director of the National Institutes of Health in the U.S. wrote a piece in the Washington Post making the case that it was not sufficient to provide generous increases in NIH funding; other agencies supporting basic science must receive increases too. A couple of paragraphs from his article make the point very eloquently.

"I first observed the interdependence of the sciences as a boy when my father - a general practitioner with an office connected to our house - showed me an X-ray. I marveled at a technology that could reveal the bones of his patients or the guts of our pets. And I learned that it was something that doctors, no matter how expert with a stethoscope or suture, wouldn't have been likely to develop on their own."

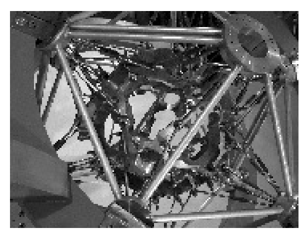
"Medical advances may seem like wizardry. But pull back the curtain, and sitting at the lever is a high energy physicist, a combinational chemist or an engineer. Magnetic resonance imaging is an excellent example. Perhaps the last century's greatest advance in diagnosis, MRI is the product of atomic, nuclear and high energy physics, quantum chemistry, computer science, cryogenics, solid state physics and applied medicine."

Early in 2000 TRIUMF received renewed and increased funding from the Federal Government. We are extremely grateful for this vote of confidence in our laboratory. However, for some of us who wrote the words, made the presentations and argued the case, these funds are awarded for one reason only; they are in support of basic science.

Alan Astbury

Gordon Ball

8π Spectrometer Inner Support Structure

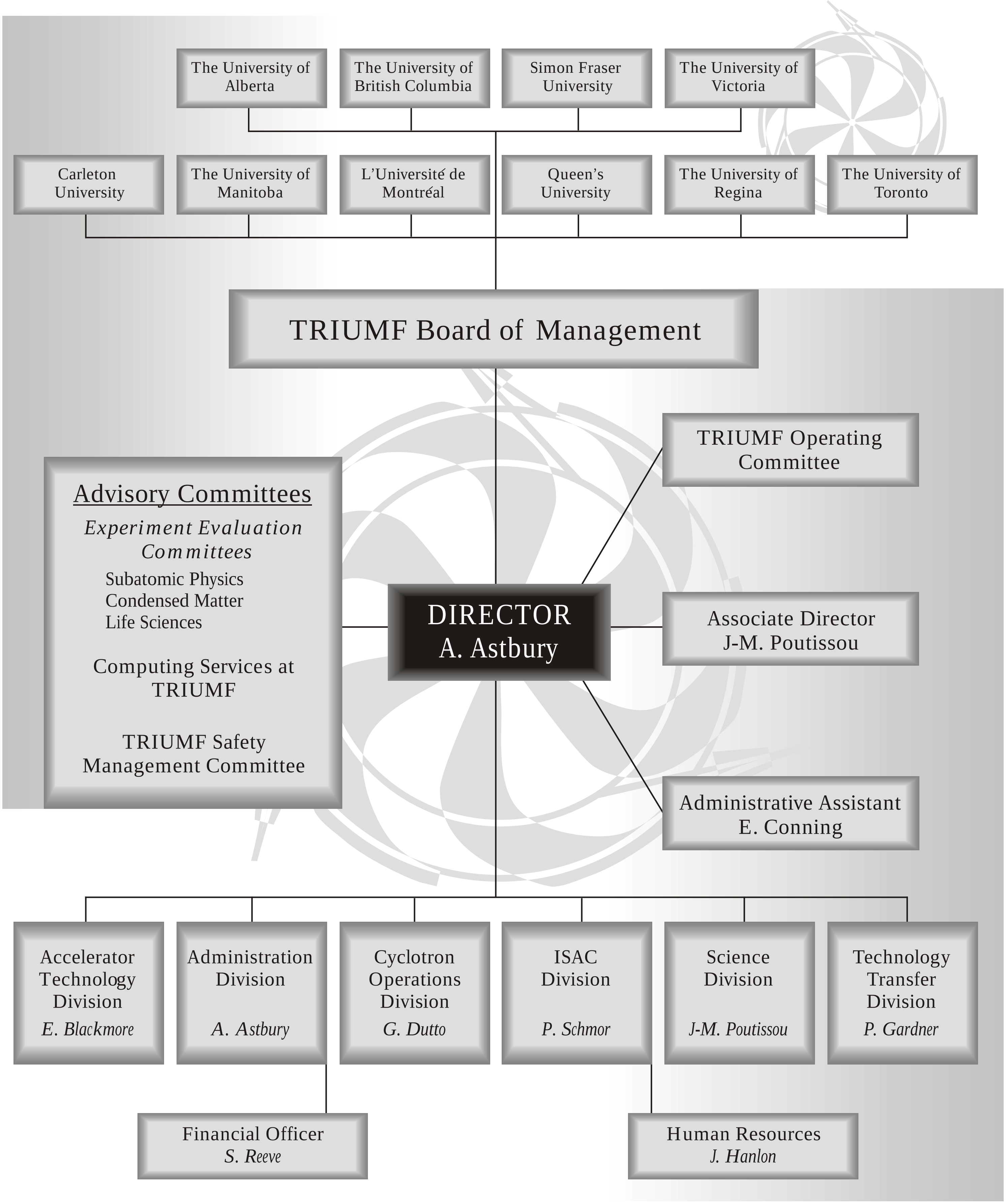


First assembled in Chalk River in 1985 the 8π gamma-ray spectrometer was a world-class, state-of-the–art device and was widely recognized as the best second-generation gamma-ray spectrometer ever built. It was designed by Canadian physicists to pursue gamma-ray spectroscopy studies of the structure of highly excited and often highly deformed rapidly rotating nuclei. During the past 15 years 8π experiments carried out by Canadian and international collaborations have led to the observation of many new phenomena and resulted in more than 150 scientific publications.

The name 8π was coined by Otto Hausser (1937-1998) a well-known TRIUMF physicist and comes from the structure and functionality of the device. The first of its two subsystems is an inner spherical shell consisting of 72 Bismuth Germanate (BGO) detectors used to measure the number and the total energy of all gamma-rays (4π detection) emitted as a target nucleus decays to its lowest energy (ground) state. The second is an array of 20 High Purity Germanium (HPGe) detectors used to measure very precisely the energy of one or more of these gamma-rays. Gamma rays that do not deposit all their energy in a HPGe detector are eliminated by surrounding BGO detector shields - 4π suppression.

Because of its versatility the 8π spectrometer remained a competitive instrument even when third generation gamma-ray spectrometers became available in the early nineties. With the closure of Chalk River's TASCC in 1997 the 8π spectrometer was moved to the Lawrence Berkeley National Laboratory where it received extensive use. In March 2000, the 8π returned to Canada where it is being reconfigured to optimize its performance for a vigorous program of decay studies with the non-accelerated radioactive beams available in the low-energy area of ISAC. A key element of this program will be superallowed Fermi beta decay studies that lead to precision tests of the Standard Model (see the 1998-1999 TRIUMF Financial Report, page 8).

TRIUMF Organization Chart



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Centre for Subatomic Research
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Chair Elect	*J.H. Brewer*
Liaison Officer	*M. Comyn*
Members	*L. Buchmann*
	A. Konaka
	N. Rodning
	G. Marshall
	B. Turrell

The TRIUMF Users' Group is defined as follows in its own Charter:

The TRIUMF Users' Group (TUG) is an organization of scientists and engineers with special interest in the use of the TRIUMF facility. Its purpose is:

- *to provide a formal means for exchange of information relating to the development and use of the facility;*
- *to advise members of the entire TRIUMF organization of projects and facilities available;*
- *to provide an entity responsive to the representations of its members for offering advice and counsel to the TRIUMF management on operating policy and facilities.*

Membership in TUG is open to all scientists and engineers interested in the TRIUMF programme. In 1999 TUG had 388 members from 23 countries.

The TRIUMF Users' Executive Committee (TUEC) is a committee of elected members whose role is to represent the interests of TUG to the TRIUMF administration. Among other things, TUEC maintains the TRIUMF Users' Web site at http://www.triumf.ca/tug where detailed information is available about its membership, that of related committees, and various TUG activities, some of which have recently been:

Annual General Meeting

In 1999 the TUG Annual General Meeting was held on December 13 in conjunction with the Silver Anniversary celebration of the first extraction of a full energy proton beam from the TRIUMF cyclotron (December, 1974). The venue was moved to the new ISAC experimental hall. A large group was in attendance, including many who were present at the original beam-on occasion. M.K.Craddock, E.W. Vogt, J.J. Burgergon, D.P. Gurd and P. Depommier, among others, gave reminiscences.

Director Search

In 1999, TUEC interacted with the Chair of the Search Committee for the next TRIUMF Director in an effort to ensure that Users would have an opportunity to meet the candidates and offer their suggestions to the Search Committee in a open fashion. The following year, candidates for Director met with TUEC and explained their visions of the future of TRIUMF; their views were also presented to the entire TRIUMF community in open forum. The Search Committee subsequently considered all input and will soon present their recommendations to the Board of Management.

User Survey

A Web-based survey of User interests and priorities is currently being conducted in conjunction with membership renewal at the TUG Web site. The statistics to date can be viewed at http://www.triumf.ca/tug/tugstats.php3.

Jess Brewer, TUEC Chair Elect

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June 2, 2000

AUDITOR'S REPORT

To The Joint Venturers of TRIUMF

The accompanying condensed financial statements have been prepared from the statement of financial position of TRIUMF as at March 31, 2000 and the statement of combined funding/income and expenditures and changes in fund balances for the year then ended. We have audited those financial statements and reported thereon without reservation on June 2, 2000.

In our opinion, the accompanying condensed financial statements are fairly stated in all material respects in relation to the financial statements from which they have been derived.

PricewaterhouseCoopers LLP

SUMMARY COMPARISON WITH LAST YEAR'S FUNDING

	1999/2000		1998/99	
SOURCE OF FUNDS	**$,000**	**%**	**$,000**	**%**
NATIONAL RESEARCH COUNCIL	34,318	72.41%	35,000	78.74%
NSERC	7,663	16.17%	5,317	11.96%
MDS NORDION INC	2,166	4.57%	2,135	4.80%
AFFILIATED INSTITUTIONS	2,219	4.68%	1,427	3.21%
COMMERCIAL REVENUE	710	1.50%	382	0.86%
INVESTMENT AND OTHER INCOME	317	0.67%	189	0.43%
TOTAL	47,393	100.00%	44,450	100.00%

TRIUMF
Statement of Financial Position
As at March 31, 2000

	2000	1999
	$	$
Assets		
Cash and temporary investments	5,788,363	3,163,093
Funding receivable	1,140,137	1,110,824
Total assets	6,928,500	4,273,917
Liabilities		
Accounts payable	1,583,136	1,158,007
Funds received in advance	713,123	1,087,926
	2,296,259	2,245,933
Due to (from) joint venturers		
The University of British Columbia	(125,309)	(68,790)
The University of Alberta	(7,981)	(1,435)
The University of Victoria	15,566	(3,558)
Simon Fraser University	9,087	(3,606)
	(108,637)	(77,389)
	2,187,622	2,168,544
Fund Balances		
Restricted		
Natural Sciences and Engineering Research Council Fund	3,900,561	1,619,300
MDS NORDION Inc. Fund	100,000	100,000
Provincial Government Building Fund	–	18,422
Affiliated Institutions Fund	143	143
	4,000,704	1,737,865
Other		
Commercial Revenue Fund	2,981	(163,918)
General Fund	424,761	162,243
Intramural Accounts Fund	312,432	369,183
	740,174	367,508
	4,740,878	2,105,373
Total liabilities and fund balances	6,928,500	4,273,917

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TRIUMF
Statement of Combined Funding/Income and Expenditures and Changes in Fund Balances
For the year ended March 31, 2000

	2000	1999
	$	$
Funding/income		
National Research Council Fund	34,318,000	35,000,000
Natural Sciences and Engineering Research Council Fund	7,662,451	5,316,980
MDS NORDION Inc. Fund	2,165,597	2,135,100
Affiliated Institutions Fund	2,219,207	1,426,588
Commercial Revenue Fund	710,283	382,092
General Fund	317,043	189,465
	47,392,581	44,450,225
Expenditures		
Buildings and improvements	336,485	486,013
Communications	147,478	180,131
Computer	958,288	1,008,277
Equipment	5,847,332	4,570,966
Power	1,808,363	1,538,542
Salaries and benefits	25,344,385	24,901,116
Supplies and other expenses	10,314,745	11,681,969
	44,757,076	44,367,014
Excess of funding/income over expenditures for the year	2,635,505	83,211
Fund balances - Beginning of year	2,105,373	2,022,162
Fund balances - End of year	4,740,878	2,105,373

PRICEWATERHOUSECOOPERS

TRIUMF
Notes to Financial Statements
March 31, 2000

1. Nature of operations

TRIUMF is Canada's national laboratory for particle and nuclear physics, owned and operated as a joint venture by the University of Alberta, the University of Victoria, Simon Fraser University and the University of British Columbia, under a contribution from the National Research Council of Canada. As a registered charity, TRIUMF is not subject to income tax.

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 only the assets, liabilities, funding and expenditures of the activities carried on under the control of TRIUMF and do not include the other assets, liabilities, revenues and expenditures of the individual joint venturers.

Sources of funding include grants and contributions from the National Research Council, the Natural Sciences and Engineering Research Council, and governments; advances and reimbursements from other sources; royalty income; and investment income. TRIUMF has established a number of separate funds to account for various funding sources. The sources and purposes of these funds are:

National Research Council Fund (NRC)

Funding of operations, improvements and development, expansion of technical facilities (buildings excluded), and general support for experiments.

Natural Sciences and Engineering Research Council Fund (NSERC)

Funding to grantees for experiments related to TRIUMF activities. These funds are administered by TRIUMF on behalf of the grantees.

MDS NORDION Inc. Fund

Advances and reimbursements for expenditures undertaken at its TRIUMF site.

Provincial Government Building Fund

Funding from the Province of British Columbia for the construction of new facilities and the upgrade of existing facilities.

Affiliated Institutions Fund

Advances and reimbursements for expenditures undertaken on behalf of various institutions from Canada and abroad for scientific projects and experiments carried out at TRIUMF.

Commercial Revenue Fund

Royalties, revenue and expenditures relating to commercial activities and technology transfer.

General Fund

Investment income for discretionary expenditures incurred by TRIUMF.

Intramural Accounts Fund

Net recoveries for internal projects and services. The recoveries of expenditures are charged to the appropriate TRIUMF funding source by Intramural Accounts.

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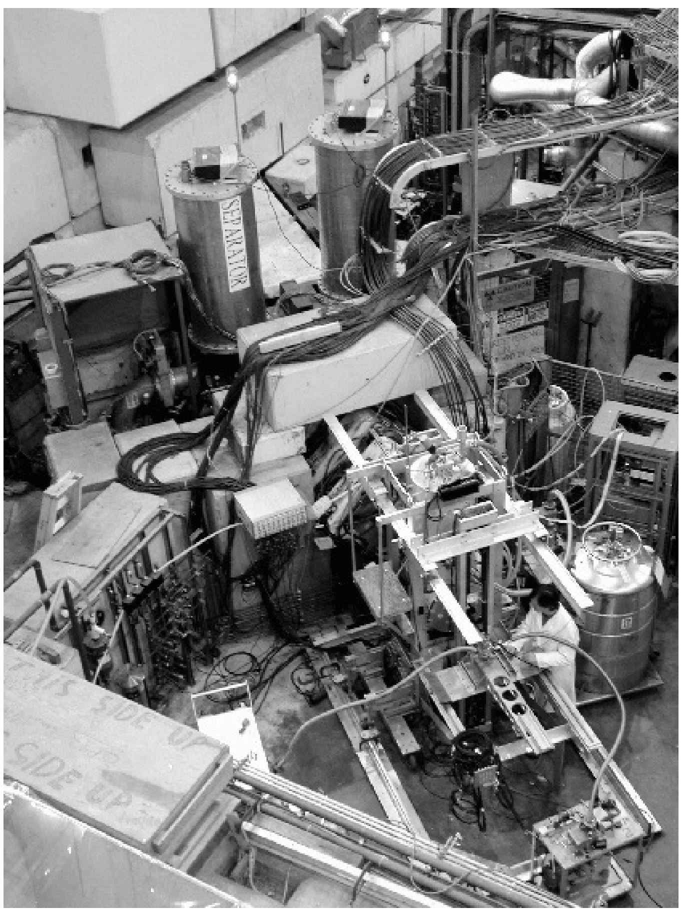
The μSR programme at TRIUMF has as its primary objective the pursuit of basic research in a broad range of disciplines using the muon and its spin as a probe of both the condensed matter physics and the chemistry of materials. Muons are nature's exquisite magnetic and electronic quantum probes which, when harnessed by a meson-producing accelerator like that found at TRIUMF, enable researchers to wield a uniquely sensitive and versatile experimental tool in the fields of condensed matter physics and chemistry. This prototypical atomic probe, best thought of as a hydrogen-like center, can extract a characterization of the microscopic magnetic or electronic environment which is often very difficult (or indeed impossible) to obtain by other means.



The Helios general purpose 6 Tesla μSR spectrometer being set up on the M20 beamline. This spectrometer is the work horse of the μSR Facility.

To facilitate these research objectives with maximum efficiency, TRIUMF and NSERC (*via* an MFA grant) have cooperated to support a dedicated μSR User Facility that coordinates, maintains and develops μSR infrastructure for a large international user group. The active involvement of the user group itself, with intellectual and financial contributions, further provide invaluable support helping to ensure the success and vitality of the Facility.

Modern muon science in Canada had a humble beginning in 1975, shortly after TRIUMF became operational, when a joint UBC (Dept. of Chemistry), UC Berkeley and University of Tokyo collaboration built and commissioned "from scratch" the M20 muon channel. In the ensuing two decades a multidisciplinary team of scientists from around the world has been working at TRIUMF to develop the techniques and facilities of what has come to be known as Muon Spin Rotation\Relaxation \Resonance or μSR, a sibling to magnetic resonance. Today, TRIUMF's μSR User Facility, the only one of its kind in the Americas and one of only two comparable centers in the world, provides intense muon beams, state-of-the-art instrumentation and expert help to over 130 scientists from 15 countries on 5 continents (half of whom are Canadian) who use this unique experimental method in a wide range of disciplines. Indeed, in a recent NSERC review of condensed matter physics (http://cephid.physics.utoronto.ca/Review/cmprev.pdf) the TRIUMF μSR User Facility was repeatedly hailed as a major Canadian success story.

The nature of the science that is pursued at TRIUMF using μSR in the various disciplines is summarized below.

High Temperature and Exotic Superconductivity:

These superconductors belong to the

the type II class, where internal magnetic fields are compressed into distributions of vortex lattices. The shape and dynamics of these lattices reflect the fundamental interactions which are responsible for the superconducting behaviour. Measurement of the microscopic magnetic field distribution within these materials allows for the simultaneous determination of the two most significant parameters which characterize superconductors, namely the penetration depth and the coherence length of the Cooper pair electrons. As an example of μSR's impact in this field a measurement in 1992 effectively eliminated the possibility that fractional statistics quasiparticles, known as anyons, were responsible for high-T_c (critical temperature) superconductivity. More recent tests of the SO(5) theory of high T_c materials have been performed using a specialized high timing resolution spectrometer. It is expected that with the continued discovery and production of new families of high T_c materials demand for beam time will not abate since μSR is now considered an essential technique for the characterization and study of these important materials.

Magnetism:

The study of magnetism is the most common area of application of μSR at TRIUMF, again due to the sensitivity of the muon and its capability to probe both the static and dynamic local field distributions. The more fundamental issues underlying the magnetism are, however, those of the electrons and their correlations. Muons have been put into almost every conceivable magnetic or quasi-magnetic material in order to map out microscopic field distributions and compare the results with theoretical calculations. Of late, much active research is being carried out in random geometrically frustrated systems which pose formidable theoretical and experimental barriers to effective understanding.

Chaotic (Frustrated) Systems:

The theory of systems which “cannot collectively decide” what to do is realized in a system of interacting spins on a lattice structure in which each neighbour is trying to *convince* a particular spin to do something else. The characterization of ultra-low temperature spin fluctuations in frustrated magnetic systems reflects such a situation. It constitutes a fascinating physical system in which chaotic motion persists to temperatures only a few tenths of a degree above absolute zero. μSR plays a central role in observing such phenomena.

Muons / Hydrogen in Semiconductors:

Introduction of hydrogen in the process of semiconductor fabrication is a very common method of passivating active electrical impurities. The microscopic details of how this occurs are not accessible by standard magnetic resonance techniques, simply because the hydrogen concentrations are so low. Conversely, muons (which act as a light hydrogen isotope) in semiconductors are easy to detect and μSR has provided most of the microscopic information which is relevant to hydrogen in these materials. Studies on a broad range of technologically important semiconductors have yet to be completed. Specialized μSR methods (only readily available at TRIUMF) are a major component of current work, ensuring sustained activity in this field into the next several years.

Diffusion:

The mass of the muon, approximately $1/9^{th}$ the proton's mass and 200 times that of an electron is conveniently intermediate with respect to these two fundamental particles. As such it is found that the (quantum) diffusion of the muon can manifest itself with behaviour that is characteristic of either extreme. This capability is at the heart of the versatility of μSR in the study of the diffusion of simple impurities. μSR experiments have in fact inspired much of the modern theory on this subject.

Chemistry: Relevance to Reaction Kinetics and Free Radicals:

The H atom is the lightest of all atoms and arguably the building block for all of chemistry. The study of the ultra-light H isotope, Muonium (Mu) has therefore had a major impact on the fields of physical chemistry which are concerned with understanding the roles of hydrogen and its reactions. One example is the use of the Mu+H2 data as a fundamental benchmark for theoretical studies of chemical reaction dynamics.

Examples of a more applied nature abound. Muonium studies of chemical reactions in supercritical water are the sole technique available to study a simple hydrophobic solute (H atom) in water over a wide range of temperature and pressure, sub- and supercritical. The knowledge gained from such work is required for the development of supercritical water reactors for the destruction of toxic waste. Catalysis dynamics have also been explored with μSR, used to measure radical diffusion in powders and zeolites, analogues of air borne pollutants. Lastly, polyatomic radicals are key intermediates in combustion and atmospheric chemistry, yet the best tool for their study, electron spin resonance, is essentially impotent in the gas phase. In contrast, μSR is well able to study radicals in the gas phase since it focuses on the muon as a probe, not the unpaired electron which is subject to many more direct interactions.

A dilution fridge 5 Tesla μSR spectrometer, nicknamed Pandora. This device is used to carry out experiments at temperatures as low as 10 millikelvin above absolute zero.

Fullerene Systems:

These systems are touted to be among the new generation of leading edge high tech materials for the 21st century. μSR allows the observation of muonium in metallic Fullerene. Because of the unique signature of muonium, it can be used as a microscopic probe to "look" inside the Fullerene cage thereby gaining valuable information on this new and exciting class of molecules.

Conclusion:

μSR basic research at TRIUMF encompasses a wide variety of condensed matter physics and areas of physical chemistry which are particularly amenable to study with muons. The μSR User Facility provides a technically sophisticated level of access to an active user community which continues to expand in both Canadian and international participation. Within the course of these endeavours, the Facility further actively encourages and promotes the training of graduate students in the science and technology involved. These two central themes; the pursuit of scientific knowledge, and the preparation of an emerging generation of scientists and knowledgeable individuals; are indeed a reflection (differing in scale and focus) of the essence of TRIUMF itself.

Roger Poirier

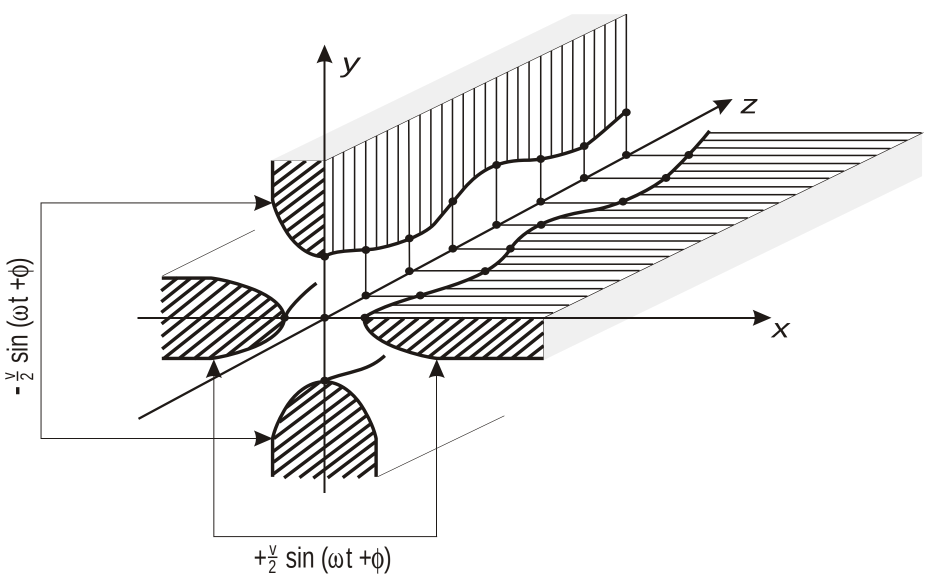
The successful operation of the Isotope Separator and Accelerator (ISAC) facility depends very heavily upon two specially designed systems. One is the target assembly (described in the next article) where many different isotopes can be produced by bombarding various elements with the 500 MeV proton beam from the TRIUMF cyclotron. The other device, the Radio Frequency Quadrupole (RFQ), is used as the first step in increasing the energy of the isotopes extracted from the target.

The principal requirement placed upon the RFQ was that it be able to accelerate all singly charged ion beams consisting of isotopes whose mass is less than 30 atomic mass units. Hence most isotopes involved in the chains of nuclear reactions occurring in explosive astrophysical sites would become available for study. The energy of these isotopes had to be raised from 2 keV per mass unit, their energy after being extracted from the target assembly and then ionized, to 150 keV per mass unit. An ensuing acceleration stage, the Drift Tube Linac (DTL), raises the final energy to ten times this, 1500 keV per mass unit.

The RFQ linear accelerator (linac) structure is a Russian invention proposed by M. Kapchinskii and V. A. Teplyakov in 1970. It is a focusing structure with acceleration introduced as a perturbation in its shape. What was realized was that if a sinusoidal voltage is applied to pairs of electrodes in a quadrature arrangement (four electrodes at 90^0 to one another, with the same voltage applied to each facing pair, the voltage on one pair being exactly the opposite of that on the other pair, see figure), the transverse electric field would focus ions travelling along the axial region in a manner similar to the action of a magnetic quadrupole lens. If the electrodes are given a constant radius then only a radial focusing force is present. However if the electrodes are given a sinusoidal-like variation in radius along their lengths then a longitudinal accelerating field is produced in addition to the transverse focusing field. As a result the isotopes can be accelerated while being kept in a well focused beam.

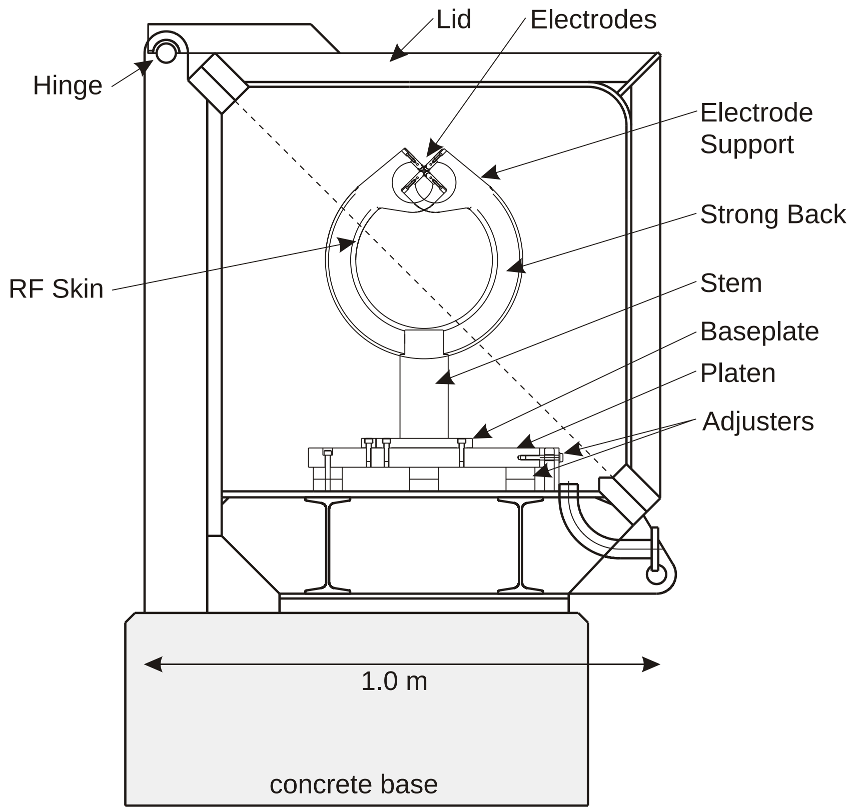
The design of the RFQ was dominated by three considerations. First the high mass-to-charge ratio of the isotopes, 30, dictated a low operating frequency to achieve adequate transverse focusing. Next, the required beam intensity could only be achieved by using continuous wave (CW)(i.e., not pulsed) operation. Finally there was the perennial need to minimize cost, mainly by reducing the length of the structure. No single feature of the TRIUMF RFQ gives it exceptional status, but the combination of novel features and unusual design parameters makes it unique.

In order to meet these criteria an operating frequency of 35.3MHz was chosen. The 8-meter long vacuum tank that houses the RFQ



The horizontal and vertical electrodes of the RFQ have an equal but opposite alternating voltage applied to them. They are shaped to both focus and accelerate the ion beam that runs along the Z axis.

is square in cross-section and split diagonally by an "O" ring flange into two parts, the base and the lid. This then allows full and easy access to the RFQ structure. A total of 19 rings spaced 40 cm apart support the sinusoidal-like shaped electrodes. The electrodes, made of tellurium copper, are machined and profile cut on a numerically controlled machine to a tolerance of about 25 mm. The wavelength of the scallops varies from a few millimeters at the low energy (beam entrance) end to somewhat over 7 cm at the high energy end while their depth goes from about 0.4 to 1.0 cm.



Cross sectional sketch of the RFQ box and one of the 19 electrodes support rings. The support and RFQ structures are combined and are much larger than the electrodes themselves. An indication of the complexity of the RFQ can be obtained from the inside front cover photo showing all the people who were involved in its design, construction, and installation standing around the 8-meter long device.

Proper operation of the RFQ depends strongly upon the exact alignment of all the pieces of the structure. This was achieved by the combination of a design sensitive to the alignment requirement with carefully controlled manufacturing, installation, and final adjustment procedures. All component manufacturing was carried out by companies in the Vancouver area. The alignment process involved the construction of a solid base, maintenance of tight manufacturing tolerances, assembly using jigs and fixtures, and electrical discharge machining of the critical mounting surfaces for the electrodes. The positioning of all elements is within 0.08 mm over the entire 8-meter length of the structure. This measured mechanical alignment was confirmed electrically by measuring the uniformity of the electric field strength along the entire length of the RFQ. Beam dynamics calculations indicate that at this degree of alignment beam defocusing is less than 1%, a very acceptable value.

Although the required mechanical alignment was achieved and confirmed electrically, the final proof was with a series of beam tests. The results demonstrated a strong confirmation of both the beam dynamics design and the engineering concept and its realization.

Electric fields associated with the RF in the RFQ are high enough to extract electrons from the interior surface by field emission, resulting in the so-called dark currents. These dark currents, whose intensity increases exponentially with the length of the structure, divert a large part of the RF energy from the electrodes where it is needed. In order to compensate for this, much more RF energy has to be supplied by the RF amplifier. At 8 meters the problem is a severe one. However, a conditioning program of high-power pulsing followed by CW operation has all but eliminated the dark currents, leading to a successful 150 hour continuous test run at the full power of 75 KW.

Marik Dombsky

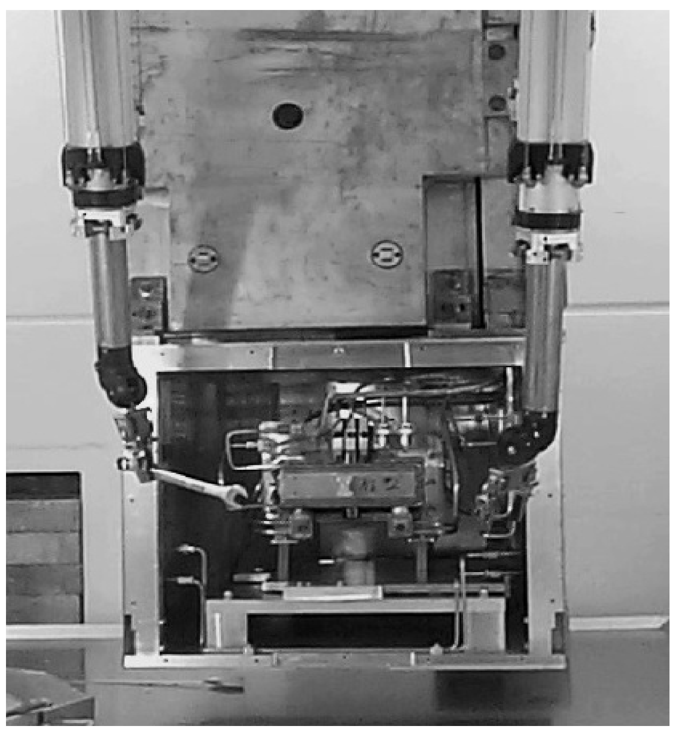
The ISAC facility at TRIUMF was designed to provide the world's most intense beams of accelerated radioactive isotopes for a wide range of experimental programs. ISAC employs the ISOL (Isotope Separation On-Line) technique where short lived isotopes are continuously produced, ionized and transported as a focused beam. The production of such beams begins at the ISAC targets, where the isotopes of interest are formed in nuclear reactions when the 500 MeV proton beam from the TRIUMF cyclotron strikes the target material. The radioactive isotopes of interest are (generally) short lived, many with half lives of only milliseconds. To produce a useful beam of short lived isotopes, it is necessary to have a target material that both produces the desired isotopes in large amounts and releases them on a time scale that is short in comparison to their half life.

Target materials are chosen such that the desired product isotope is formed with a high probability. The production rate can be increased by increasing both the proton beam flux on target and the target thickness. The ISAC target stations have been designed to withstand proton beam currents of up to 100 μA on thick targets. Such beam currents are two orders of magnitude higher than any existing thick target proton beam based ISOL facility. To withstand the intense radiation produced in the target-beam interaction region, ISAC targets are constructed using only metallic and ceramic components that will not easily suffer radiation damage. Radiation shielding is provided by suspending the target and closely coupled ion source in a vacuum, beneath approximately 2 meters of steel shielding. In such an environment, the targets must operate reliably for extended periods of time with no direct intervention. Furthermore, once irradiated, a target can only be handled by means of remote manipulators in a specially constructed hot cell. The hot cell operator conducts all target manipulations while viewing through a lead glass window with a radiation attenuation equivalent to 1 meter of concrete.

ISAC hot cell remote manipulators being used to exchange an irradiated ISAC target. The window attenuates radiation equivalent to 1 meter of concrete.

ISAC target containers are 19 mm diameter tubes up to 19 cm in length. The target material is sealed inside with only a 3 mm diameter opening available for the products to escape into the ion source. The containers are fabricated from tantalum metal and are resistively heated to temperatures up to 2200° C. The high temperature is required to vaporize the product species, drive them out of the target material and transport them as rapidly as possible to the ion source. The product atoms must first diffuse out of the target material then effuse out of the target container through a series of collisions with target material and container walls. Target materials are chosen to be compatible with a fast product diffusion from the host matrix and with a low surface adsorption time for wall collisions during transport. Since the products are constantly undergoing radioactive decay, each delay, no matter how short, has a cumulative effect on the ultimate product yield. Target materials that will withstand elevated temperatures without evaporating are refractory metals such as niobium, zirconium, tantalum or tungsten. Such metals, in the form of thin (0.025 mm) foils, can be stacked inside the target container. Alternatively, certain high temperature ceramics such as oxides, carbides and nitrides can be used. Some examples are calcium oxide (CaO), silicon carbide (SiC) and aluminum nitride (AlN). Ceramics are pressed into thin pellets and stacked inside the target container cylinder.

As proton beam currents rise to approach the 100 μA level, target heating ceases to be a necessity and is replaced by the need for target cooling. The power deposited in the target by high intensity proton beams can be on the order of several kilowatts, enough to vaporize the target material. Hence, at the higher beam currents heat must be removed from the target requiring new target designs. Initially, ISAC began operation with 1 μA proton beam currents using target designs that required resistive heating to achieve the desired temperatures. With experimental requirements for intense beams of short lived isotopes such as ^{38m}K ($t_{1/2}$ = 924 ms), ^{74}Rb ($t_{1/2}$ = 65 ms) and ^{8}Li ($t_{1/2}$ = 840 ms), increased proton currents became necessary. With only minor modifications, ISAC targets designed for 1 μA proton beam currents were successfully operated for extended periods using 10μA currents. Later, during beam development periods, the same targets were shown to operate at 20 μA currents. To date, world record beams of ^{74}Rb (8600/s) were achieved with a 20 μA proton beam on a niobium foil target of only 11.5g/cm^2 thickness. This target was operated at the 10 μA level from November 1999 to June 2000 receiving a cumulative beam dose of 9063 μA-hr corresponding to 2 ´ 10^{20} protons on target. The target was still operational when it was removed from service. Record yields of the extremely short lived ($t_{1/2}$ = 8.6 ms) isotope ^{11}Li (11000/s) were also achieved with a 20 μA proton beam on a 21.5 g/cm^2 tantalum foil target. Future target development will continue to focus on designs capable of using the 100 μA potential of ISAC.



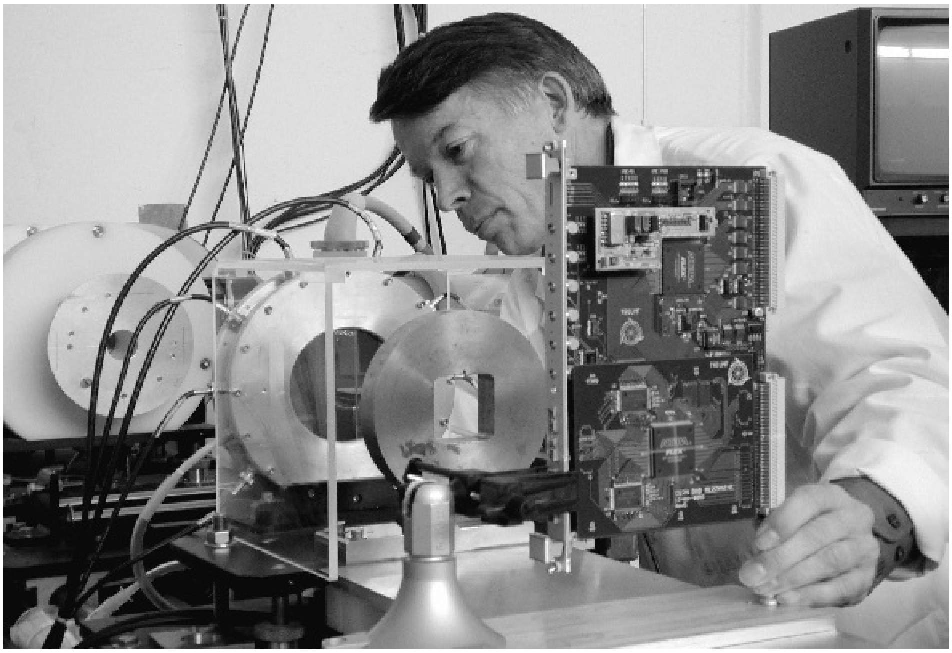
View inside the hot cell showing the remote manipulators being used with tools to make a watertight connection for the target cooling system.

Ewart Blackmore

The first satellites sent into orbit discovered intense radiation regions around the earth - the so-called Van Allen belts. There are three types of particles involved: protons, electrons and heavy ions. The protons and electrons are trapped by the earth's magnetic field into two toroidal bands, the nearest at an altitude of about 3200 km although significant fluxes extend into lower earth orbits such as those used by space shuttles or space stations. These particles originate in the sun and are produced with notably increased intensity during periods of solar activity, such as solar flares. Heavy ions are mainly galactic in origin.

Dense clouds of electrons can cause damage to space craft by charging components to different voltages causing electrical breakdown, and this was the cause of the failure of the ANIK satellites. Protons and heavy ions can significantly interrupt the operation of sensitive electronic equipment on spacecraft, high altitude aircraft and satellites by producing single event upsets, where a computer memory bit is flipped to the opposite state by the interaction of a charged particle. At higher fluences protons can cause radiation damage to electronics and optical equipment and deliver serious biological doses to astronauts.

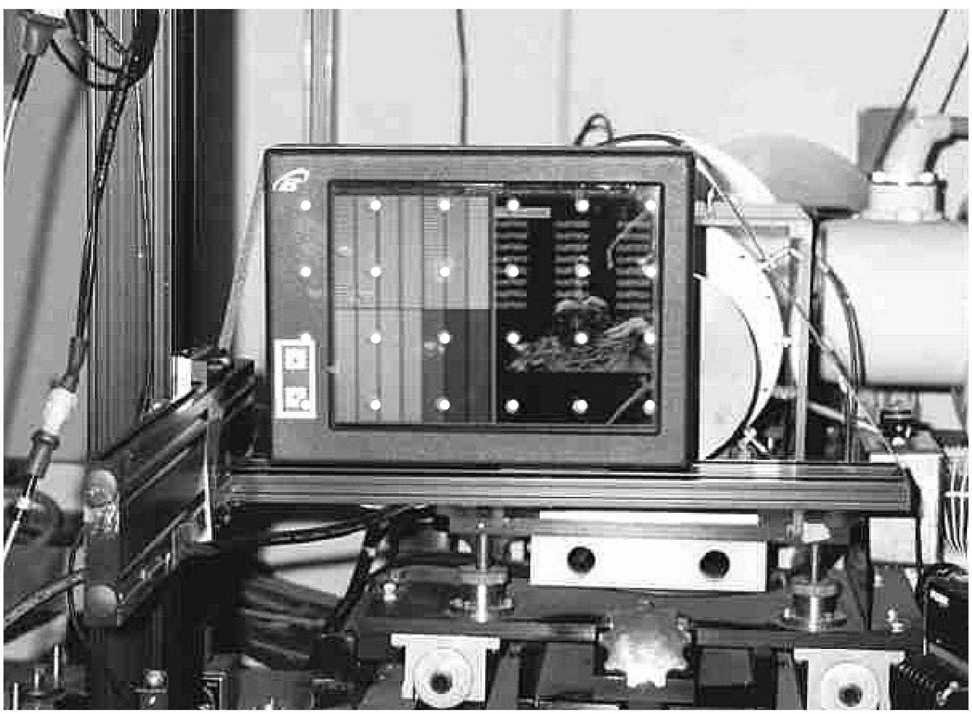
The spectrum of trapped protons in earth orbits peaks in the 10-100 MeV energy region and drops by about 90% at 500 MeV. TRIUMF's variable energy capability, up to 500 MeV, is ideal for studies of radiation effects of protons (and neutrons) in space. The Proton Irradiation Facility (PIF) was designed specifically for single event upset studies and characterization of electronic components for the space environment. Basically PIF allows the bombardment of electronic devices, detector components, and other materials with protons of a specific energy from the main cyclotron to simulate the proton fluxes in space. PIF can provide a radiation dose in a few minutes that is comparable to several years of exposure received in space. Current interest is focused on determining how various electronic devices, intended for use in space will withstand radiation. Biological studies are also being carried out, including cell irradiations to measure the biological effect of protons.



Electronics board with device (microprocessor) to be tested aligned with respect to the proton beam using a laser cross-hair.

Designers of electronic components have found that the use of commercial-off-the-shelf (COTS) components are frequently required to meet performance specifications of spacecraft. Radiation-hardened (RH) components are available but are costly and may be several generations behind the state-of-the-art COTS technology. For instance, the latest RH computer is comparable in performance with a 486 PC and costs about one hundred times more.

As electronic devices become more sophisticated and compact and technologies move toward higher densities of components on a chip, radiation effects have become more of a problem. Experience has shown that the effects on components can vary a lot from one manufacturer or fabrication technology to another. Therefore, the standard practice is for satellite designers to test and characterize electronic components for radiation effects. Tests in particle beams in the laboratory can quantify these effects and help determine which are the most reliable devices. In addition, there is interest in understanding the various damage mechanisms to different types of electronic devices. Studies over a wide range of proton energies provide the needed information.



Testing of a flat-screen video monitor planned for use in the International Space Station. One by one each dot on the monitor is aligned with respect to a 5 cm square uniform proton beam using an X-Y positioning table and the devices in that area checked for radiation effects.

PIF's high energy beam line, which delivers proton energies between 150 MeV and 500 MeV, was financed in part with a grant from the Defense Research Establishment Ottawa (DREO) and the Canadian Space Agency. This complements the Proton Therapy Facility's beam line, located in the same room, which provides protons with energies up to 120 MeV. Although this beam line is used on a regular basis for proton treatments of ocular melanoma, it can be easily reconfigured for electronics testing.

Commercial companies and institutions from Canada, USA, and the UK routinely employ TRIUMF's PIF to test some of their electronic equipment. There is an hourly charge for beam usage for commercial users, with beam scheduled several times per year for this work. Recent users include DREO (Canada), MacDonald Dettwiler Space and Advanced Robotics (Canada), NASA/Goddard Space Flight Center (USA), Boeing Space Group (USA), and DERA Space Department (UK). Typical studies include single event upsets in memory chips such as SRAMs and DRAMs, response of optoelectronic devices, radiation damage to charged couple devices (CCDs), and high energy neutron and proton response in bubble detectors. In one recent study the group from MD Robotics irradiated all parts of a Pentium™ PC in a proton beam to check for the most sensitive components. In some cases individual chips were irradiated and in other cases, such as for the flat screen monitor, a beam of about 5 cm by 5 cm was swept across the device. More than one hundred separate irradiations were carried out.

Solar Neutrino Problem

Byron Jennings & Lothar Buchmann

One of the outstanding problems in physics for many year has been the solar neutrino problem. Briefly stated, the measured number of neutrinos reaching the earth differs greatly from what is expected.

The neutrino can be pictured as a very light electron without an electrical charge. The electron has two heavier sibling particles known as the muon and the tau that differ from it mainly in mass. Similarly there are three known kinds of neutrinos, called the electron neutrino, muon neutrino and tau neutrino. Until recently, there was no experimental evidence that all neutrinos were not massless like the photon. One source of evidence that the neutrinos do have mass could, in fact, be the solar neutrino problem.

The sun is a prodigious source of energy. Its origin was a mystery until Einstein's famous equation $E = mc^2$ and nuclear energy were discovered. In the 1930s Hans Bethe developed the basic theory of how protons and neutrons in the sun combine to form light nuclei thereby producing energy which eventually reaches the earth as heat and light. For this work Bethe received the Physics Noble prize in 1967.

What does the sun being powered by nuclear energy have to do with the previously mentioned neutrinos? Several of the nuclear reactions that produce solar energy also produce neutrinos or produce nuclei that decay producing neutrinos. (See diagram on next page.) Thus, if the sun really does shine by nuclear energyit must be producing neutrinos by the billions. But, why are we not aware of them? Neutrinos interact very weakly; so weakly that they are the only particle that can travel from the deep interior of the sun to us without being absorbed by the mass of intervening matter. Most of the neutrinos that do reach the earth go straight through as if the earth was a transparent window. The few that do interact produce so small an effect that it is lost in the general noise of all the other interactions going on.

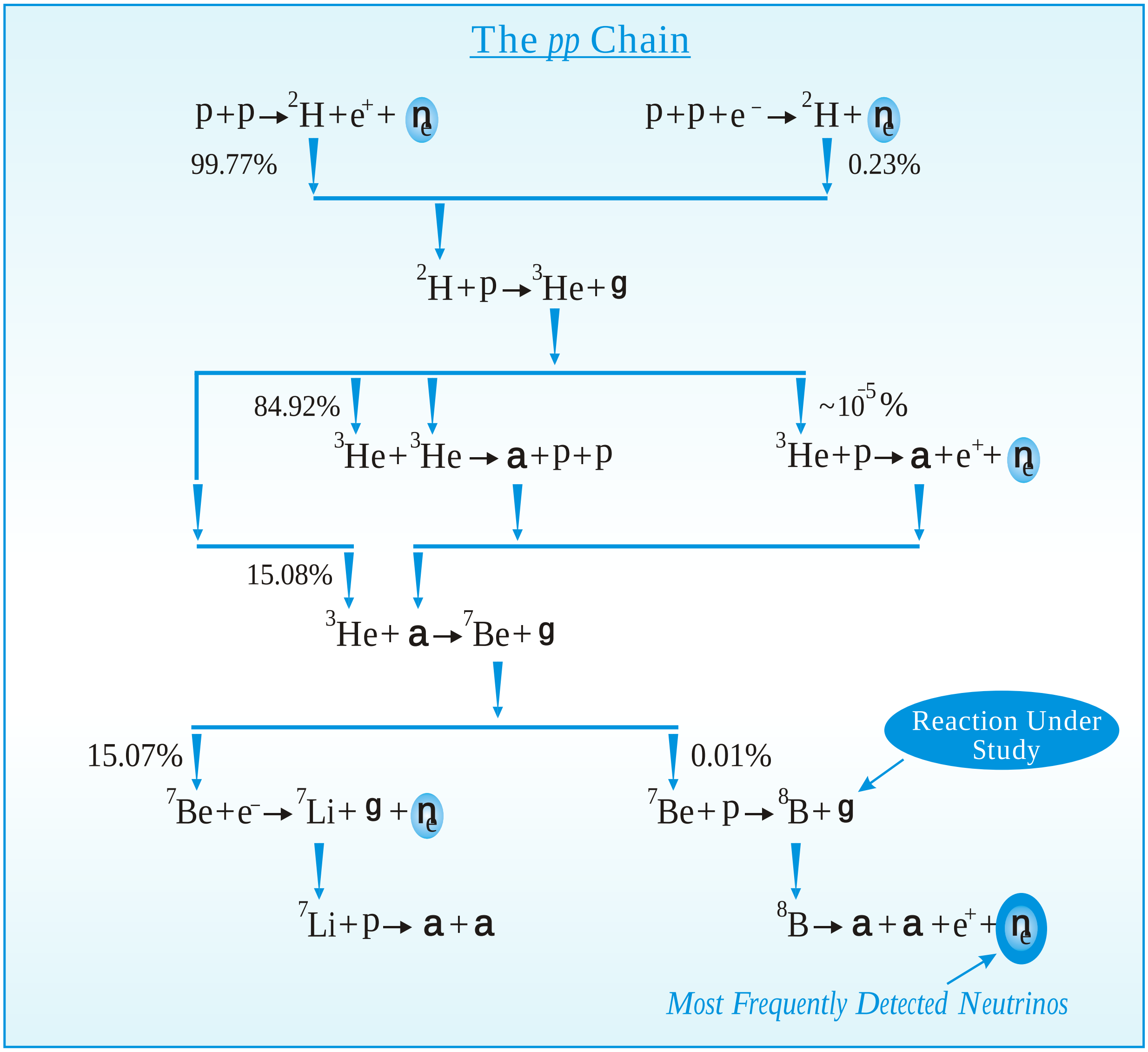
There has been a series of experiments dedicated to the detection of solar neutrinos. Since the neutrinos interact very rarely with matter the detectors must be large. For example, the Sudbury Neutrino Observatory uses 1000 tonnes of heavy water. To shield the detector from cosmic rays, which would otherwise swamp the neutrino signal, neutrino detectors are located underground. In the case of Sudbury the detector is 6800 feet underground in a nickel mine.

The first experiment was done by Ray Davis in 1968 using 600 tons of dry cleaning fluid (containing chlorine) in the Homestake mine. Onlyone-thirdof the predicted number of neutrinos were observed. Later experiments used either water or gallium for the detector. They, too, found the number of neutrinos observed to be much less than predicted.

Assuming all of the measurements to date are not grossly inaccurate there are three possible causes for the incorrect prediction; either we do not understand how our detectors work, or we do not understand how the sun works, or we do not understand the neutrino. The latter is the current favorite. In particular, neutrinos produced by the proton-proton reaction chain are directly related to the amount of energy produced by the sun. Since the energy production is well known it is difficult for any plausible solar model to explain the neutrino measurements.

The current detectors are sensitive only to electron neutrinos, the type produced in the sun. This looks like a perfect match. However, if somewhere between being created in the sun and arriving at detectors on earth the electron neutrino changes into a muon neutrino then it would not be detected. This type change can only happen if the electron and muon neutrinos have different, non-zero, masses. If this change of neutrino type is confirmed it would be an exciting increase in our understanding of how nature works. The observatory in Sudbury should shortly be sensitive all three neutrino types and will be able to tell if neutrinos are changing type.

At the back of one's mind there is always a niggling worry. Have we missed something trivial? Have we correctly predicted the num-



The *pp* chain – nuclear reactions in the sun that lead to the production of a-particles and heat. The directed lines link a reaction product to its later use.

The sun consists almost entirely of an extremely dense plasma of fast moving protons whose collisions produce very small amounts of heavier elements. The *pp* chain starts with protons (p) combining in two different ways to form deuterons (^{2}H) plus electron neutrinos, n_e. These deuterons then combine with more protons to form an isotope of helium, ^{3}He, and gamma rays (g). In turn, either two of the ^{3}He combine to form an alpha (a) particle and two protons or, very rarely, ^{3}He combines with protons to produce a-particles and n_e. Some of the a-particles so produced then combine with the remaining ^{3}He, 15.08%, to form an isotope of beryllium, ^{7}Be, and gs. Most of the ^{7}Be combines with electrons (e^-) to form lithium (^{7}Li) along with gs and n_e. The ^{7}Li then fuses with a proton to yield 2 a-particles. A small fraction of the ^{7}Be fuses with protons to form an unstable isotope of boron, ^{8}B, which then decays into two a-particles, an e^+ and a n_e. All the a-particles then go on to be involved in further collisions which lead to heavier elements being formed.

In the *pp* chain n_e are produced by five different reactions, but only two produce them at energies to which detectors on earth are sensitive. Of the two, the fusion of ^{3}He and protons occurs a thousand times less frequently than the breakup of ^{8}B which itself is a relatively rare event (0.01%). While the breakup of ^{8}B supplies only a very small amount of the total solar energy, it provides the overwhelming majority of the electron neutrinos that we measure.

ber of neutrinos produced in the different nuclear reactions that are believed to occur in the sun? The easiest to detect neutrinos are those from the decay of ^{8}B. While this is by no means the predominate source of neutrinos, these neutrinos have an energy that makes detectors especially sensitive to them.

^{8}B is produced in a nuclear reaction when a proton is absorbed by ^{7}Be emitting a photon (γ ray). This reaction produces only a negligible fraction of the total energy of the sun and is largely irrelevant to other solar properties. Thus, if we have the reaction rate incorrect, even by a factor of 10, there will be little effect on other solar observables such as the amount of energy reaching the earth. The amount of ^{8}B produced is, however, directly proportional to the ^{7}Be(p,γ)^{8}B reaction rate.

Thus much of the solar neutrino problem is only a problem if we think we know the ^{7}Be(p,γ)^{8}B reaction rate reliably. This rate must be determined from terrestrial measurements since, as we previously noted, the other solar observables are not sensitive to this reaction rate.

In order to obtain an improved value for the ^{7}Be(p,γ)^{8}B reaction rate an experiment has been initiated by TRIUMF physicists in collaboration with the University of Washington, Seattle, USA, to measure this reaction cross section at a temperature (energy) as close as possible to that in the sun. One of the challenges of these measurements is the production of a pure ^{7}Be target since ^{7}Be is an unstable nucleus with a 53 day half-life.

The TRIUMF team has developed a process that yields high purity ^{7}Be radioactive targets. It makes use of the intense proton beam available from the TR13 cyclotron at TRIUMF. This beam is used to bombard lithium which, by the ^{7}Li(p,n)^{7}Be reaction, produces the required isotope. In order to produce adequate amounts of ^{7}Be a high-power proton beam has to be used. It is stopped in the lithium resulting in the generation of much heat. A special target holder has been designed that provides helium cooling of the front of the target and water cooling of its back. Beam heating causes the lithium to melt and solder to the front zirconium foil. There have been many activation runs, some as long as 20 hours which is long compared to the typical one-hour PET runs at the TR13 (see following article).

After the proton bombardment the next step in the process is to separate the ^{7}Be from the lithium as well as from any trace elements found in the target or introduced by the processing. These impurities lead to large uncertainties in the reaction rate measurement. Because the lithium sample is very radioactive at this point, the entire ^{7}Be target separation process must be carried out in a shielded handling box.

The ^{7}Be targets are taken to the Nuclear Structure Laboratory at the University of Washington, Seattle where they are bombarded by the variable, low-energy, high resolution proton beam from the Tandem Van de Graaff accelerator. In order to determine the reaction rate the amount of ^{7}Be in a target and its thickness must be measured along with the number of protons hitting the target and the resulting number of ^{7}Be(p,γ)^{8}B reactions. Special care must be taken in order to eliminate or greatly reduce any systematic errors. For example, during a run the amount of ^{7}Be in the target is periodically determined by measuring its radioactivity and a special system has been devised to ensure that the beam intensity is constant over the entire area of the target. A run consists of a series of 2- second target bombardments followed by the rapid movement of the target out of the beam and counting of the α-particles that result from the 0.8 s half-life decay of ^{8}B. While the target is out of the beam, a measurement of the beam intensity is made. Also a number of different targets will be used. With all these and other precautions it is expected that the error in the reaction rate measurement will be less than 5%, a factor of four improvement over the current value.

Data taking and systematic error studies are currently underway and expected to conclude in the next year.

The PET program in Vancouver was established in 1980 as a collaboration between TRIUMF, Canada's National Laboratory for Nuclear and Particle Physics, and several departments within the Faculty of Medicine at the University of British Columbia. This Group's program is dedicated to basic research in neurology and psychiatry.

The major thrust of our research efforts is directed at understanding the causes and progression of diseases, such as Parkinson's, of the dopamine and serotonin systems.

Research techniques employed by the Group include positron emission tomography (PET), molecular biology, experimental surgery, and the study of disease incidence among populations. All of these are integrated in a setting where a major effort is invested in clinical expertise, so that carefully characterized patients from the Movement Disorders, Schizophrenia, and Mood Disorders Clinics have the opportunity to participate in research.

The Neurodegenerative Disorder Centre at UBC is studying the origins, progression and treatment of Parkinson's disease. The PET investigations are conducted with a wide range of tracers designed to probe the nerve cells associated with movement (dopaminergic system). The Centre operates a Movement Disorder Clinic where full assessment of disease severity includes determining clinical rating scales and video taping of the patients. The Centre is set up to perform clinical trials with pharmaceuticals.

Investigators from the Department of Psychiatry at UBC are studying schizophrenia and mood disorders using tracers to assess the effect of a number of drug treatments. In addition, there is a study on the changes in brain chemistry associated with electroconvulsive therapy in Parkinson's Disease (PD) patients.

The TRIUMF chemistry group routinely prepares radioactive tracers to study the various brain regions involved with motor control and the system involved with mood. Automated systems are in use for the syntheses. An active program explores the development of sensors for the feedback controls required in automation of the chemical process.

The PET group has a dedicated radioisotope production cyclotron, the TR13, a negative ion machine that can extract two simultaneous beams of 13 MeV protons with beam currents up to 50 μA. The TRIUMF cyclotron and chemistry labs are located some 3 km from the University Hospital where the tomograph is located. An underground pipeline connecting the 2 sites enables us to send the prepared radiopharmaceuticals to the hospital in less than 2 minutes.

TR13 cyclotron, designed and constructed at TRIUMF, used to produce radioisotopes for the PET program.

The scanning program began in 1983 with the TRIUMF built PETTVI camera. Early successes of the program led to support from the Medical Research Council of Canada, the BC Provincial Government and UBC for the acquisition of the ECAT 953B tomograph in 1991. This tomograph has full 3D-acquisition capability enabling us to perform multiple studies with minimal radiation exposure to the subjects because of the increased sensitivity associated with 3D scanning as opposed to the traditional 2D scanning. We are also involved with the characterization of a dual-head coincidence camera at one of the local community hospitals. The characterization of these simple, less capable, but nonetheless clinically useful cameras and their quantization algorithms were developed by TRIUMF scientists and engineers.

Using [F-18]-Fluorodopa the Group employed PET to detect the occurrence of nerve cell damage in subjects who were clinically normal - the first direct evidence of preclinical disease. The discovery shed new insight on disease origins or cause, and established a method for identifying preclinical nerve cell damage. In PET studies combined with postmortem analysis the Group was the first to demonstrate a direct linear correlation between the measures of fluorodopa (FD) uptake and nerve cell counts, thereby providing a firm basis for *in vivo* quantification of pathology in the brain. This work was predicated upon the development of a graphical method for analysis of FD PET to generate a striatal uptake constant, which was also accomplished by the Group.

The Group was the first to undertake long-term sequential PET studies. Extending these studies with clinical correlations and a large cross-sectional study, the Group suggested that the progression of PD may be initially rapid, with an eventual tendency to approach the normal age-related rate of decline of the nerve cell population associated with movement. This conclusion led to a model of disease origin that envisioned the cause of PD as a transient environmental risk factor that killed some neurons, spared others, and also damaged some in such a way that their life expectation was reduced. According to this hypothesis, individual susceptibility was under genetic control.

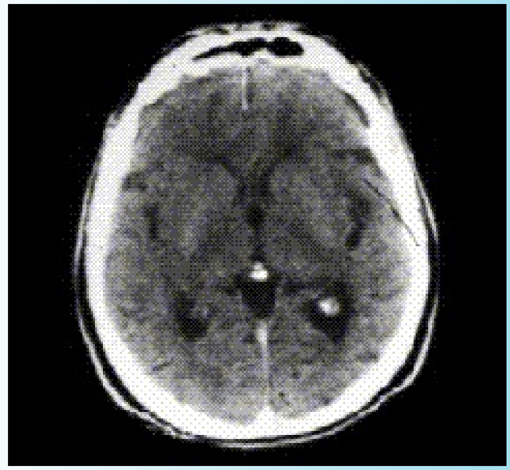
In this context, the Group has shown that transient exposure to a nerve cell toxin (MPTP, found in some badly prepared illegal street drugs) in human subjects leads to progressive clinical and PET deterioration that cannot be explained in terms of sequestration of the toxin followed by slow release. Recent human postmortem examinations by Langston et al have confirmed the presence of active neuronal degeneration in 2 patients, several years after taking MPTP. These observations, taken together, force a reappraisal of traditional concepts on the cause and progression of PD adding further to our "event" hypothesis.

Also, in keeping with the "event" hypothesis, the Group has shown, by PET, that viral attack on the part of the brain controlling movement in human subjects can cause selective asymmetric damage to the brain (one side more affected than the other) with a pattern similar to that which characterizes PD. We have since identified a second young patient with viral infection that resulted in a transient Parkinsonian syndrome. Some mild Parkinsonian deficits persisted and PET, after the acute stage of the illness, revealed a pattern of asymmetrically reduced striatal FDOPA uptake with a pattern as seen in early PD. These findings raise the possibility that viral infection may be one of several causes of PD.

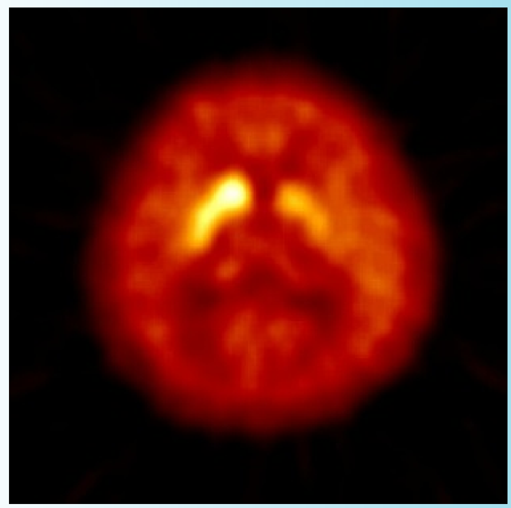
TRIUMF personnel are involved in all aspects of this research effort from conceptual design of the biological questions through the daily operation of the various pieces of equipment and data interpretation. The PET group has recently made a successful grant application for a new higher resolution tomograph that will enable us to probe ever deeper into the biochemistry of the brain. All of these efforts are supported through grants from the Canadian Institutes of Health Research, the Canadian Foundation for Innovation and the BC Knowledge Development Fund and private foundations such as the Pacific Parkinson's Research Institute as well as TRIUMF.

Tomography involves the measurement of electromagnetic radiation combined with a mathematical algorithm to give a view of a thin axial section of the body. In CAT (Computed Axial Tomography) Scans the relative intensities of X-rays that traverse the body from many different directions are used to reveal, by calculation, a detailed image of soft tissue, bone and blood vessels. In PET Scans the detected radiation comes from a source inside the patient. A radioactive element which decays by positron emission is inserted into the compound of interest and injected into the patient. Positrons decay by emitting two gamma rays that go off in opposite directions and are detected by a circular array of detectors around the patient. With the appropriate algorithm the locations and relative amounts of the injected compound can be determined. In contrast to CAT Scans, PET Scans reveal function, not structure.

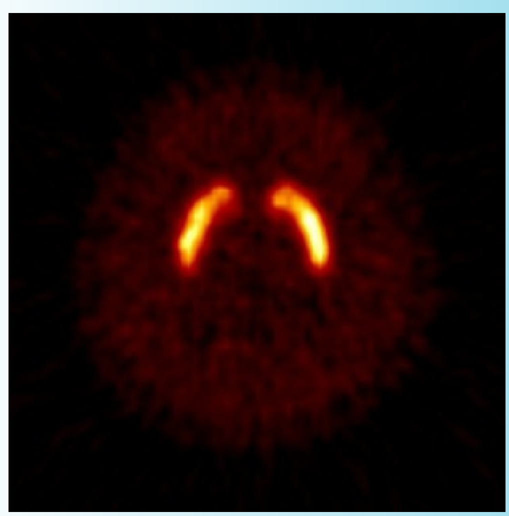
The images to the right are all oriented so that they show a thin section through the head, just above the ears with the front of the head at the top. The two PET scans use tracers that accumulate in the basal ganglia, the nerve switch yard for movement commands between the brain and the rest of the body. The amount of the injected compound present is indicated by colour, with white being the most, red the least, and black none. Presynaptic activity is revealed by a FDOPA scan. It shows the asymmetry typical of idiopathic Parkinson's disease (PD) as well as a reduction of activity towards the rear of the head. Postsynaptic activity is revealed by using raclopride instead of FDOPA. Here we see an increase in the activity on the right side where there was a decrease in FDOPA. This is a compensatory mechanism in the brain that, at this stage, provides full control over movement. The patient was an eight-year old girl who showed signs of PD during an acute viral attack which disappeared as the attack subsided. However as the scans show, damage was done, compensation can only do so much, and she will likely suffer from PD at an early age.



CAT Scan Image



Presynaptic (Fdopa) PET Scan Image



Postsynaptic (Raclopride) PET Scan Image