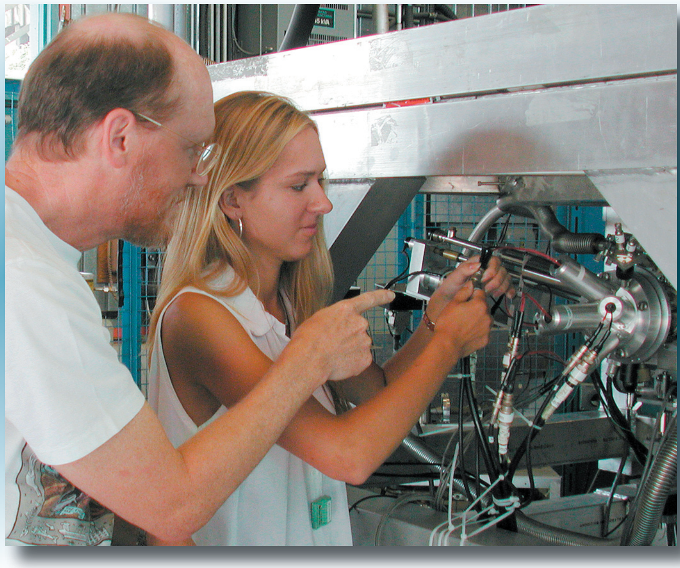
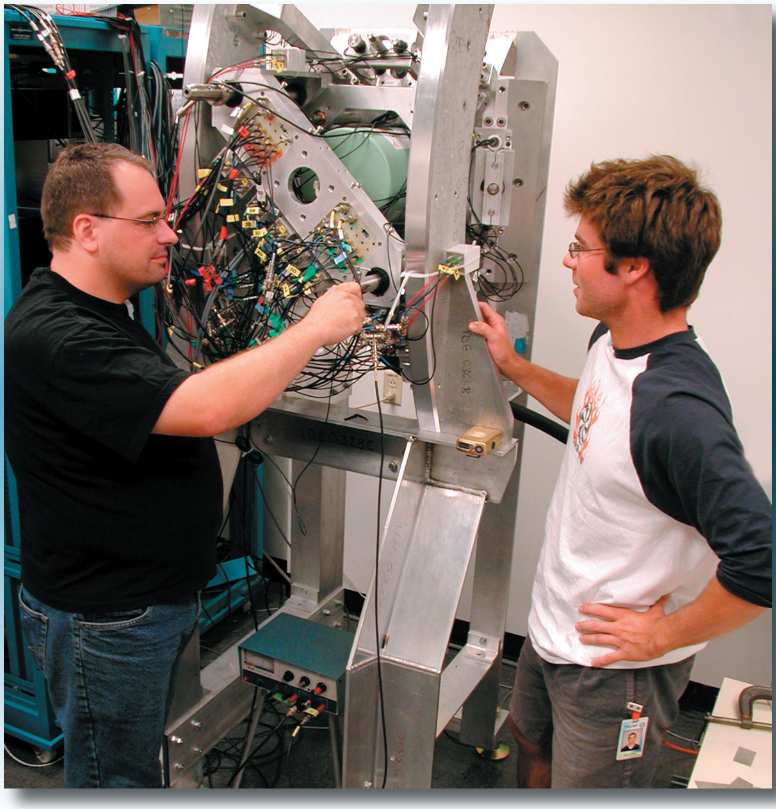
TRIUMF

Annual Financial & Administrative Report 2003-2004

The Future: an Exciting Place



Reka Moldovan is the winner of the first annual TRIUMF High School Fellowship award, administered through the Innovation and Science Council of British Columbia. Reka was chosen from a group of 99 top secondary school students from across British Columbia to spend a six-week work term at TRIUMF which she spent working with TRIUMF's MuSR program. Reka recently graduated from a Kelowna High School and will be attending the University of British Columbia this fall.



Nick Cowan (on right) is an honours physics student who recently completed his BSc at McGill University. Nick spent his summer work term at TRIUMF working with the TIGRESS group and will be starting graduate school, this fall at the University of Washington, concentrating on high-energy physics. As the winner of the best student talk at TRIUMF, Nick will be attending the Western Regional Nuclear & Particle Physics Conference in spring 2005 at TRIUMF's expense.

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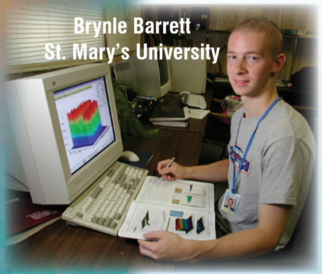
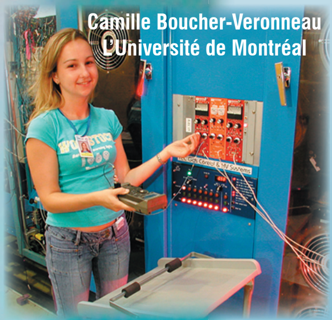
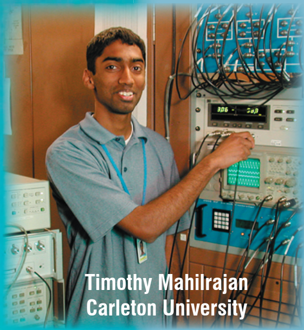


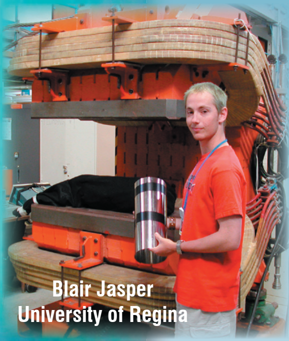
Brynle Barrett
St. Mary's University



Camille Boucher-Veronneau
Université de Montréal



Timothy Mahilrajan
Carleton University



Blair Jasper
University of Regina

Tudor Costin
University of
British Columbia

About the Cover

Each year about 70 undergraduate students from all across Canada participate in either summer employment or co-op programs sponsored by TRIUMF. Of these students five, one from each region of Canada - Atlantic Canada, Quebec, Ontario, the Prairie Provinces and British Columbia, are selected for special, four-month research scholarships. In addition to the usual summer student benefits, these students receive a scholarship on completion of a report on their work at TRIUMF. Candidates must be enrolled in the second or higher year of a program in physical sciences or engineering at a Canadian University.

Editor: Ken Dawson
Coordinator: Shirley Reeve
Design/Layout: Mindy Hapke

Director's Report

TRIUMF, one of Canada's premier international scientific institutions, is a national institution serving the needs of university scientists from across Canada. It is supported by a renewable five-year federal government financial contribution channeled through the National Research Council. The current funding cycle covers the period 2000-2005. During this period, many of the challenges identified for this five-year funding cycle have been successfully met. Highlights include the development of ISAC as the world's leading exotic-isotope production facility, and, based on Canadian know-how, the design and construction of advanced equipment for the world's largest scientific project, the Large Hadron Collider (LHC), based at CERN in Geneva.

Alan Shotter
TRIUMF Director

Looking to the Future

The last two years have seen the Canadian scientific community collaborate with TRIUMF staff to develop a scientific plan for the next funding cycle, 2005-2010. The main features of this plan are completion of the ISAC facility to ensure it firmly establishes and maintains world leadership; an increase in the capabilities of the MuSR facility for material science and chemistry; increased capacity for radioisotope production for the life science program so, among other things, to take optimal advantage of two new PET scanners; and to make strong Canadian contributions to some exciting projects at other national laboratories around the world. The plan identifies TRIUMF as the Canadian centre for the world computing grid network that will handle the vast data outflow from the ATLAS experiment at CERN's LHC. Among other activities, the plan identifies important Canadian contributions to the rare K-decay experiment at Brookhaven in the USA and to an experiment in Japan, which is a natural extension of the highly successful and visible Canadian program at SNO, located in Sudbury, Ontario. Technology transfer and outreach activities are important components of the plan.

The plan has been reviewed by panels of internationally renowned scientists and has been given their very strong support. It is an ambitious plan but it is a realistic one, building on TRIUMF's past and present record of achievement. It will deliver first-rate science at an internationally competitive cost in a timely and efficient manner, and will ensure for the Canadian Government, and therefore the tax payer, the highest return on their previous investment in TRIUMF. The plan is under active consideration by the Federal Government and, if accepted, the plan will ensure that the Canadian scientific community using TRIUMF will continue to be competitive at the highest international levels.

Highlights of the Year

The ISAC program reached a milestone during the year with the completion of the ISAC-II building, which was formally opened by the Premier of British Columbia, the Hon. Gordon Campbell. A number of other prominent provincial ministers as well as several hundred guests attended the opening ceremony. The ISAC science program received a significant boost by the commissioning of a major piece of equipment, the 8π spectrometer, which from startup is proving an exceptional tool to probe the properties of the exotic nuclei produced at TRIUMF. Other tools being developed include TITAN, TRIUMF's Ion Trap facility for Atomic and Nuclear science, which will probe the limits of existence of nuclei, and TIGRESS, TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer, which will be used to probe the structure of exotic nuclei. All these projects involve many physicists from across Canada and around the world.

Another major milestone during the year was the completion of the construction and delivery of 52 warm quadrupole magnets for the Large Hadron Collider at CERN. Due to the very exacting specification of these magnets, producing the magnets was a real challenge, and it is a tribute to TRIUMF and Alstom staff in Tracy, Quebec that the magnets were delivered to CERN on time and on budget.

The MuSR program has been part of TRIUMF's scientific portfolio for many years. Each year exciting new work continues to flow from this program that is relevant to fundamental physics, material science, chemistry and nuclear physics. For such a wide field, it is difficult to pick examples, but perhaps the work identifying a new test of quantum electrodynamics concerning the behaviour of the muon under extremely high electric and magnet fields, and the use of muons to help understand industrial catalysts, shows just how wide the field has become.

The life science program took a major leap forward with the delivery of two new PET scanners. One of these scanners, the High Resolution Research Tomograph, will enable the human brain to be probed to a higher level of precision than ever before. The other scanner, the MicroPET, is a small animal scanner that will expand the collaborative network using PET for *in-vivo* biochemical studies and will include oncology as well as the established collaboration with the neuroscience community.

TRIUMF has a number of commercial licensees for its technologies that range from life sciences to environmental protection techniques. According to the latest statistics from the Association of University Technology Managers (AUTM), TRIUMF ranks second in Canada in terms of Gross Licence Income received as a percentage of Total Sponsored Research.

A good example of this technology transfer is that during the year MDS Nordion commissioned their third small commercial cyclotron at the TRIUMF site. This TR30 machine is based on a TRIUMF design and built by a local company, Advanced Cyclotron Systems Inc.; some of the work was subcontracted to another TRIUMF licensee, Dehnel Consulting Ltd., of Nelson, B.C. With the addition of this third cyclotron, MDS Nordion will supply about 50,000 medical patient doses per week, in Canada and around the world, from the TRIUMF site.

Another example of where TRIUMF expertise has been vital to an outside organization is the strong collaboration that has been established with the B.C. Cancer Agency to set up a new Centre of Excellence in Functional Imaging.

The new TRIUMF Outreach Program is in its second full year of operation. New initiatives such as the Teacher Internship Program continue to attract interest among high school teachers, with a dozen teachers from all over British Columbia waiting to take part. The NALTA high school cosmic-ray detector project is set to take off in 2005, with detectors waiting for installation at science centres across Canada. TRIUMF and the Innovation and Science Council of British Columbia awarded TRIUMF's first High School Fellowship to student Reka Moldovan, who was selected from amongst 99 top students from across British Columbia for a six-week research experience at TRIUMF and a $3,000 scholarship.

This has been a successful year for TRIUMF in terms of scientific achievement. The evolving activities at TRIUMF act as a natural magnet for young people. With TRIUMF's new scientific five-year plan in place for 2005-2010, we will be well placed to continue to be one of Canada's premier international scientific institutions for many years to come and continue to attract and train Canada's best young scientists.

TRIUMF Organization Chart

TRIUMF Users' Group

The TRIUMF Users' Group (TUG) has 319 registered members from 25 different countries. They are all involved in experimental, theoretical or engineering development projects at TRIUMF or at international offsite projects, which have a strong TRIUMF component. Each year this group elects the TRIUMF Users' Executive Committee (TUEC) to manage the day-to-day affairs of the group and organize group meetings. Another function of TUEC is to provide liaison between users and TRIUMF management.

Currently TUEC has the following membership:

Chair: Jeff Sonier (Simon Fraser University)
Past Chair: Des Ramsay (University of Manitoba)
Tracy Porcelli (University of Northern British Columbia)
Alison Laird (University of York, UK)
Chair Elect: Jens Dilling (TRIUMF)
Alan Chen (McMaster University)
Pierre Bricault (TRIUMF)

TUG's mandate includes the provision of a formal means for exchange of information relating to the use and operation of the facility. It also plays an important role in making new and existing users aware of the features of TRIUMF experimental facilities and how to access them, as well as keeping all users informed about the status and planning of new facilities.

Jens Dilling
Chair Elect

TUG was founded in 1972 to serve the medium-energy physics and proton-scattering communities. Over the last few years the research focus at TRIUMF and therefore the needs of TRIUMF's user community has changed as the majority of on-site research is centred at the ISAC and MuSR facilities. Since the still growing MuSR community is long-standing at TRIUMF, TUG has evolved to meet most of their needs. On the other hand, the ISAC community, which started less than five years ago with the first experiments at ISAC, has been less well served by TUG.

One of the main points of discussion during the last Annual General Meeting (Dec. 2003) was this change in the user base, and if a general user group could satisfy the needs of all users at TRIUMF. It was agreed that this should be possible, especially if more open and lively interaction between users and user representatives took place.

The principal difference between earlier experiments at TRIUMF and current ones at ISAC and MuSR is their duration and turn-around time. The configuration and requirements of medium energy physics experiments change little over periods of months to years while those of ISAC and MuSR experiments now change in days or weeks. In order to better serve users with these shorter term requirements, TUEC meets quarterly and has taken a more active role in assisting users to make full and effective use of TRIUMF facilities. Users are asked to submit their needs and points of concern prior to each TUEC meeting so they can be included on the agenda. These points are discussed and the consensus of the group conveyed to the TRIUMF Director. TUG has a representative on TRIUMF's Operating Committee (OPCOM), which meets bi-monthly and is an effective forum where many user concerns can be resolved.

Due to the addition of new devices and the complexity of the ISAC facility, teething problems do arise. This is reflected in many users' concerns. In order to fulfil its mandate, TUEC responds promptly, for example by supplying input reflecting users' needs to a prioritizing committee (Beam Development Strategy Group) for the development of new radioactive beams, and by being part of the review panel of the general ISAC operation. For both functions TUEC sees its role as not only pointing out problems but also offering possible solutions.

TUEC has undertaken to produce an updated version of the TRIUMF User Guide (previous edition was 1987). It will also carry out a survey to determine where users see TRIUMF's future developments as input for the next Long Range Planning Committee.

AUDITORS' REPORT

To the Joint Venturers of TRIUMF

The accompanying summarized statement of financial position and combined statement of funding/income and expenditures and changes in fund balances are derived from the complete financial statements of TRIUMF as at March 31, 2004 and for the year then ended on which we expressed an opinion without reservation in our report dated May 21, 2004. Those financial statements were prepared to comply with section 7 of the TRIUMF joint venture agreement and the contribution agreement with the National Research Council of Canada, and are prepared using the basis of accounting as referred to in note 2 to the accompanying financial statements. The fair summarization of the complete financial statements is the responsibility of management. Our responsibility, in accordance with the applicable Assurance Guideline of the Canadian Institute of Chartered Accountants, is to report on the summarized financial statements.

In our opinion, the accompanying financial statements fairly summarize, in all material respects, the related complete financial statements of TRIUMF in accordance with the criteria described in the Guideline referred to above.

The summarized financial statements, which have not been, and were not intended to be, prepared in accordance with Canadian generally accepted accounting principles, are intended for the information and use of the Joint Venturers and the National Research Council of Canada. Furthermore, the summarized financial statements do not contain all the disclosures required by Canadian generally accepted accounting principles. Readers are cautioned that these financial statements may not be appropriate for their purposes. For more information on TRIUMF's financial position. results of operations and changes in fund balances, reference should be made to the related complete financial statements.

PricewaterhouseCoopers LLP

Chartered Accountants
Vancouver, B.C.
May 21, 2004

TRIUMF

Statement of Financial Position
As at March 31, 2004

	2004 $	2003 $
Assets		
Cash and temporary investments	4,688,950	3,844,414
Deposits	300,000	-
Funding receivable	924,672	1,651,824
Total assets	5,913,622	5,496,238
Liabilities		
Accounts payable	1,061,965	1,129,736
Funds received in advance	1,278,190	1,328,150
	2,340,155	2,457,886
Due to (from) joint venturers		
University of British Columbia	(89,432)	121,176
University of Alberta	(2,202)	(18,718)
Carleton University	-	(4,589)
University of Victoria	(1,523)	(22,094)
Simon Fraser University	(3,253)	(32,467)
	(96,410)	43,308
	2,243,745	2,501,194
Fund Balances		
Restricted		
Natural Sciences and Engineering Research Council Fund	2,628,181	1,789,374
MDS NORDION Inc. Fund	100,000	100,000
Canadian Fund for Innovation	(27,065)	-
Affiliated Institutions Fund	-	143
	2,701,116	1,889,517
Other		
Commercial Revenue Fund	355,499	(31,383)
General Fund	10,574	98,534
TRIUMF House Fund	110,391	-
Intramural Accounts Fund	492,297	1,038,376
	968,761	1,105,527
	3,669,877	2,995,044
Total liabilities and fund balances	5,913,622	5,496,238

TRIUMF

Statement of Combined Funding/Income and Expenditures and Changes in Fund Balances

For the year ended March 31, 2004

	2004 $	2003 $
Funding/income		
National Research Council Fund	40,000,000	41,000,000
Natural Sciences and Engineering Research Council Fund	5,704,966	6,078,010
MDS NORDION Inc. Fund	3,727,465	4,419,985
Canadian Fund for Innovation	1,495,216	-
Province of British Columbia Building Fund	-	7,949,145
Affiliated Institutions Fund	1,391,060	2,148,275
Commercial Revenue Fund	1,048,967	804,885
General Fund	120,281	129,505
	53,487,955	62,529,805
Expenditures		
Buildings and improvements	1,642,048	8,912,172
Communications	157,365	163,419
Computer	1,063,457	1,420,213
Equipment	8,478,874	9,785,926
Power	1,843,775	1,943,129
Salaries and benefits	31,760,528	30,379,144
Supplies and other expenses	7,867,075	8,506,051
	52,813,122	61,110,054
Excess of funding/income over expenditures for the year	674,833	1,419,751
Fund balances - Beginning of year	2,995,044	1,575,293
Fund balances - End of year	3,669,877	2,995,044

Economic Dependence

TRIUMF's operations are funded under a contribution from the Government of Canada through the NRC. TRIUMF is economically dependent upon this funding source for its ongoing viability. On February 22, 2000, the Government of Canada announced a commitment of $200M to fund TRIUMF over the next five years, from April 1, 2000 to March 31, 2005. Management has no reason to believe that ongoing funding from the government will not continue into the future after the expiry of the above commitment.

TRIUMF

Notes to Financial Statements
As at March 31, 2004

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, Carleton University, 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 20% interest in all the assets and is responsible for 20% 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 of Canada, 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 the 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.

Canadian Fund for Innovation (CFI)

Funding to grantees for capital projects 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 and other sources for the construction of new 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.

TRIUMF House Fund

Contributions from unrestricted funds for the construction of TRIUMF House.

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.

2. Significant accounting policies

Basis of presentation

These financial statements have been prepared in accordance with section 7 of the joint venture agreement (note 1) and the contribution agreement with the National Research Council of Canada, and follow Canadian generally accepted accounting principles for not-for-profit organizations as referred to in the Canadian Institute of Chartered Accountants Handbook, except that all property, plant and equipment purchased or constructed for use at TRIUMF and related decommissioning costs (if any) are expensed in the period in which the costs are incurred.

Paul W. Percival

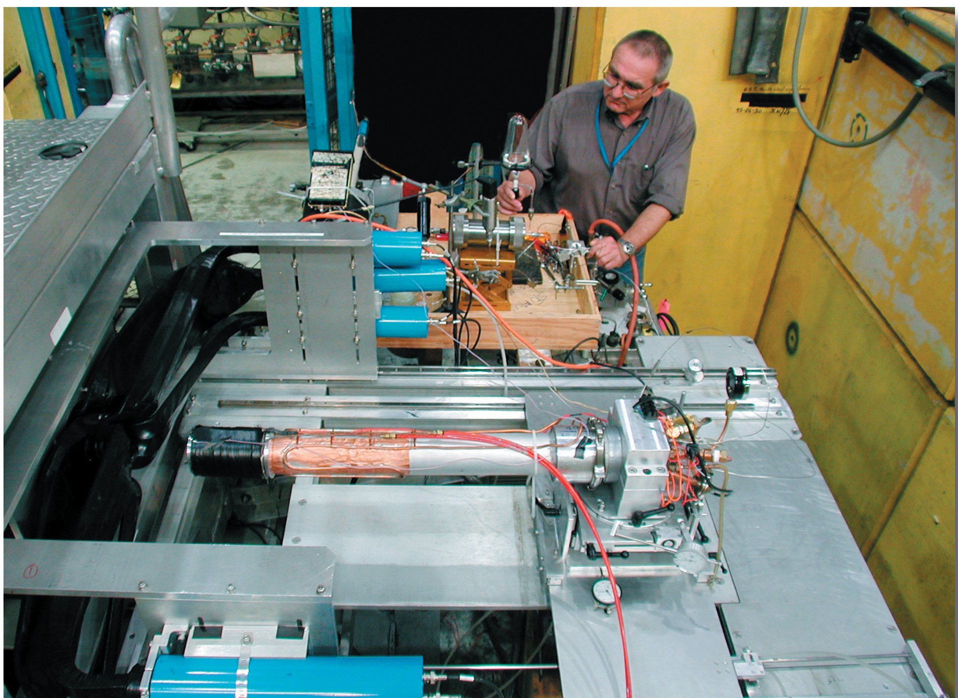
Chemistry in a Pressure Cooker

Free Radical Chemistry under Hydrothermal Conditions

What is the connection between safe destruction of chemical weapons, the development of next-generation nuclear power stations and bacteria which live only near undersea volcanic vents? Answer: they all involve chemistry in superheated water, i.e., in liquid water at temperatures well above its normal boiling point of 100°C. The water remains a liquid because it is under pressure; the combination of high temperature and high pressure is often termed hydrothermal conditions.

These are obviously natural conditions for volcanic vents in the ocean floor, but why choose high temperature and pressure for power generation and waste destruction? In the former case the fundamental consideration is efficiency. A nuclear reactor is a concentrated source of energy, but before this energy can be distributed it must be converted to electricity. This is accomplished by heating water under pressure in the reactor and then allowing it to expand in a steam turbine which drives an electric generator. A fundamental principle of thermodynamics (the 2nd Law) states that the maximum efficiency of a heat engine (the turbine) depends on the upper and lower temperatures reached by the working fluid (the water/steam); the greater the difference in temperature, the greater the efficiency. In practice the lower temperature is set by the available cooling – for Ontario power stations this is either Lake Ontario or Lake Huron. Therefore, to improve efficiency engineers look at the high temperature part of the cycle, where pressurised water is heated by flowing through the nuclear reactor. For CANDU reactors the water typically reaches 320°C and 100 atmospheres pressure leading to a theoretical maximum efficiency of less than 50%. It should be stressed that this is the ideal thermodynamic efficiency, and no amount of lubrication or mechanical tinkering can improve on this. The wasted energy is in the form of chaotic motion (heat), as opposed to the concerted motion capable of doing work. The next generation design of nuclear power stations aims to push the upper temperature to 500 or 600°C. If that is achieved the improved efficiency would generate more electrical power from the same size of reactor.

So why not go ahead and design a pressurised water reactor that operates under these more efficient conditions? Here’s where safety and reliability come into consideration. Water at high temperatures and pressures is known to be an extremely corrosive material. What should the pipes be made of, to safely transport the corrosive superheated water around the system? Can corrosion be reduced by adding inhibitors to the water? If so, what happens to these inhibitors when they pass through the high radiation flux of the reactor? It is questions such as these that motivate studies of hydrothermal chemistry. Some initial answers can be found by straight-forward experiments: “Pressure-cook” samples of different



Dr. Jean-Claude Brodovitch injects a sample of water into the high pressure apparatus, which is the barrel shaped assembly shown in the foreground, temporarily withdrawn from the superconducting magnet and detector assembly (on the left).

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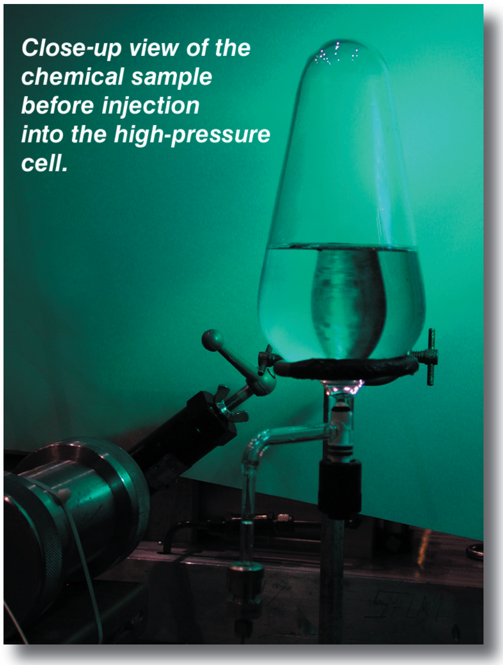
metals and inspect them for signs of damage. However, trying to predict the behavior of a solution of corrosion inhibitors at different temperatures and pressures, with and without irradiation by ionising particles, requires a very complex model which includes many different physical parameters whose values are mostly unknown. The situation is particularly complicated for problems concerning potential radiation damage, since the relevant reactions involve highly reactive free radicals. Ideally one wants to study these processes in real-time; in practice this is next to impossible.



Close-up view of the chemical sample before injection into the high-pressure cell.

Safety and efficiency are also paramount when one considers methods to destroy hazardous waste. Volatile organic compounds from laboratories and homes (cleaning fluids, paint thinners, etc.) are usually incinerated, but what about more hazardous material? The Chemical Weapons Convention requires the U.S. to destroy over 30,000 tons of chemical weapons by April 2007. However, the residents of Tooele, Utah became a little nervous when they found out that the U.S. Army was burning sarin (6,000 tons) and VX nerve gas (7,600 tons) in their neighborhood. The problem with incineration is that you start with a controlled quantity of flammable liquid, mix it with air, expose it to a flame, and hope that by the time the very large volume of gaseous products reaches the smoke stack there is nothing nasty left over. In Canada, PCBs and ozone-depleting chemicals are burnt at the Swan Hills facility in Alberta. The license requires 99.9999% destruction. From time-to-time the facility has been shut down because environmental monitoring showed that toxic by-products (e.g. dioxins and furans) had been released. Scientists, who understand risk and realise that 100% efficiency is never attainable, are less concerned about such events than the general public. Chemists routinely handle bucketfulls of such "deadly" chemicals without any consequences to themselves or others. On the other hand, because of the much higher risk, disposal of tons of nerve agents has to be dealt with in better ways.

An alternative to incineration is supercritical water oxidation (SCWO). From the chemical point of view the toxic organic material is still burned (oxidised), but it is done under water! This is possible because of the remarkable change in properties of water as it is heated to its so-called supercritical state. Under normal conditions water dissolves ionic materials (salts) but it does not mix with non-polar organics (oils). However, supercritical water is much less polar and behaves more like an organic solvent. This means it readily dissolves chemical warfare agents and other toxic materials, which can then be destroyed by the addition of oxygen or other oxidising material. The main products are the same as for incineration in air: carbon dioxide and water. However, in water the toxic elements (chlorine in PCBs, sulphur in mustard gas, phosphorus in nerve agents) are precipitated in harmless form as inorganic salts.

The idea of burning material under water seems contradictory but it has been shown to work. It is even possible to sustain a flame in water at high temperatures and pressures (typically 600°C and 300 atmospheres pressure). This can be done by piping oxygen into hot water containing a hydrocarbon such as methane. The flame is similar to a regular natural gas flame burning in air, except that in supercritical water the oxygen is inside the flame and the combustant is in the "atmosphere" around it.

The most important aspect of SCWO technology is that the oxidation process occurs in a sealed vessel – a giant pressure cooker – so the hazardous material remains contained until after tests confirm its destruction. The necessary engineering technology has been developed over the past decade, and SCWO

Paul W. Percival

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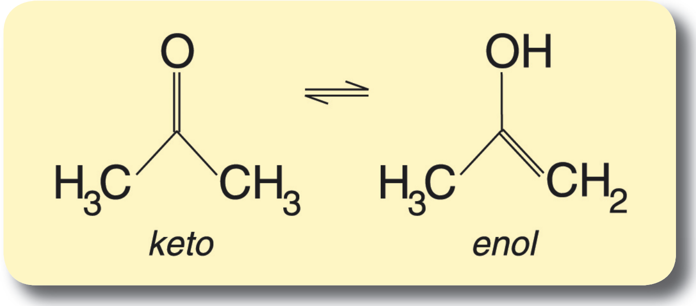
is being implemented in a full-scale pilot plant facility at the Blue Grass Army Depot in Kentucky.

However, the chemical details are far from clear. It is possible to find the best operating conditions to destroy a specific agent by trial and error, but to predict what happens to a wide variety of hazardous materials requires detailed chemical knowledge and modelling. Like the radiolysis problem mentioned earlier, combustion involves free radical intermediates whose properties and behavior under hydrothermal conditions are mostly unknown.

This is the motivation for carrying out detailed chemical studies of hydrothermal systems, but how to do it is no simple matter! Most studies to date have relied on end-product analysis and modelling to infer multi-step reaction sequences. Much better would be direct measurement of reaction intermediates in real-time in situ. The modern chemist has a variety of spectroscopic tools that are usually applied to such problems; tools that permit the identification and monitoring of different chemical species according to their specific molecular properties, such as the vibration frequency of particular chemical bonds. The problem is that the application of these conventional techniques is often limited by the technical demands of the harsh environment. For example, how do you get light in and out of a pressure cooker? Even special optical windows made of sapphire or diamond are corroded by supercritical water.

TRIUMF has particular expertise at probing chemistry in extreme environments by using μSR, a magnetic resonance technique that uses the muon as a spin probe. Since a positive muon can act as the nucleus of a hydrogen-like atom, muonium (Mu), it can be used to study H atom reactions and free radicals incorporating H. High-energy muons can be created to penetrate into a pressure vessel and thermalise in the material of interest. The window of a pressure cell is made of titanium and is over 2 mm thick. Muons have a mean lifetime of only 2.2 microseconds, but when they decay they emit positrons, most of which have enough energy to pass through the walls of the pressure cell and thus carry information to the outside. The apparatus is placed in a large electromagnet so that the muon spins precess with frequencies characteristic of their chemical environment. In this respect the technique is similar to the well-known magnetic resonance imaging (MRI) used in medicine.

Muons are particularly effective at "spying" on free radicals, for which other techniques are less effective. Consider, for example, what happens when a hydrogen atom reacts with acetone in water. Under normal conditions the acetone exists in the keto form, with a minuscule amount in the enol form. At higher temperatures it is expected that the equilibrium shifts towards the enol:



The reaction of a hydrogen atom with the enol form is much faster than for the keto form, but ironically, the same free radical product is formed. By studying the two reactions with muonium it is possible to tell them apart – reaction with the keto form gives the radical with Mu attached to the oxygen atom, whereas reaction with the enol results in incorporation of Mu in a methyl (CH_3) group. Experiments at TRIUMF have clearly shown that the keto route is dominant at low temperatures but that above 250°C the enol adduct is formed. This was a completely novel result; literature data on the keto enol equilibrium by conventional means is limited to 55°C!

The practical problems of studying complex chemistry in a SCWO waste destruction facility are similar to those facing the designers of CANDU-X, the next generation of Canadian nuclear reactors. Kinetic data on radiolysis transients (H atoms, hydroxyl radicals, hydrated electrons, etc.) is so difficult to obtain that the current generation of pressurised water reactors is based on AECL models of water chemistry that rely on extrapolation of lower temperature measurements. TRIUMF measurements

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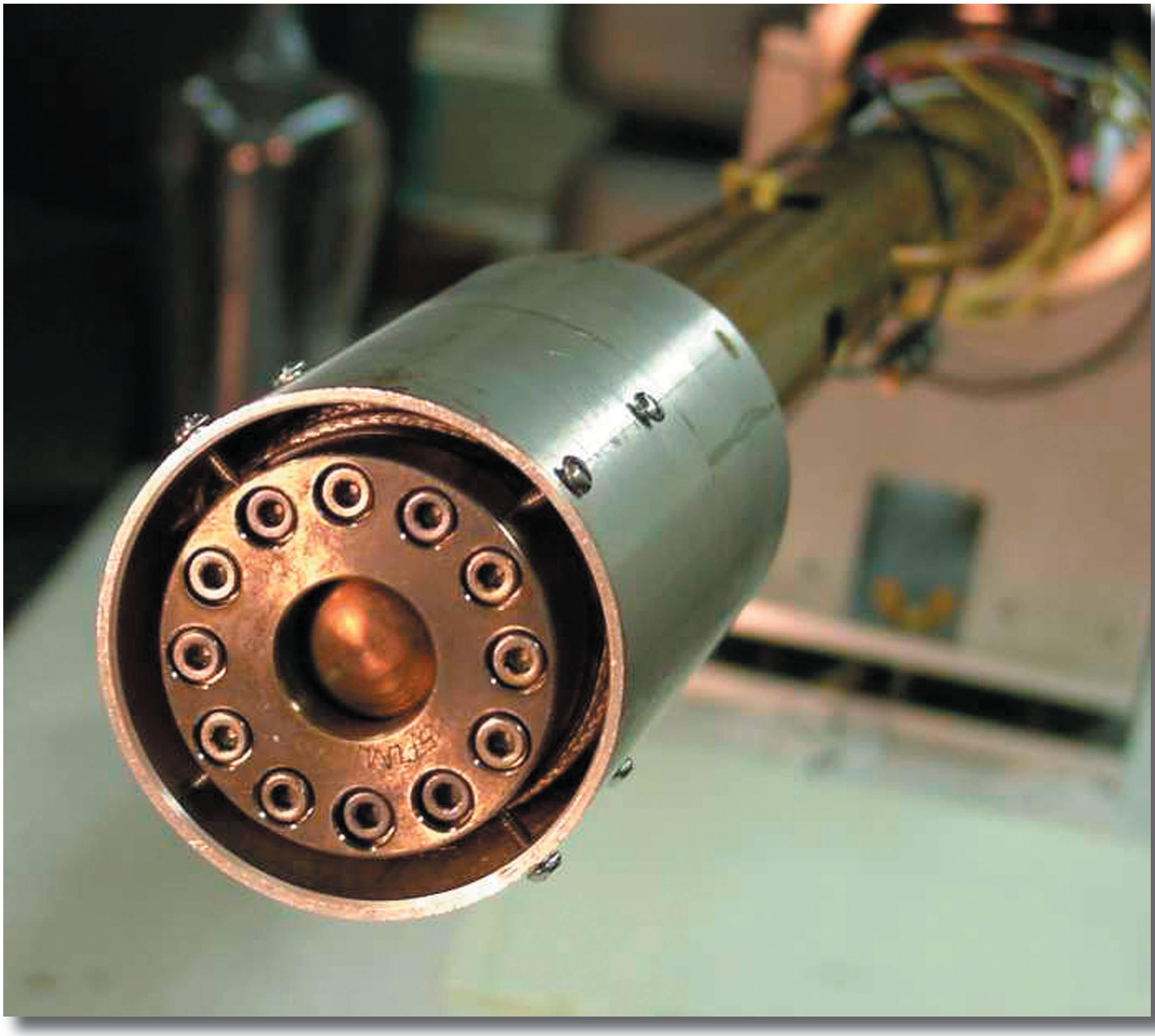
Free Radical Chemistry under Hydrothermal Conditions



Muon's-eye view of the target cell, which is made of titanium and can withstand pressures of 500 atmospheres at temperatures up to 500˚C. The dome shaped window (in the middle) is over 2 mm thick.

on muonium kinetics have shown that the AECL extrapolations fail at high temperature, where there is a transition from liquid-like to gas-like behavior. At one time AECL was a world leader in high temperature water radiolysis, but personnel have since been directed to other projects. As a consequence, reactions of H atoms and other radiolysis transients have only been studied at temperatures up to about 200°C, far below the 500 to 600°C being considered for CANDU-X, and even below the limit (450°C) reached in muonium kinetics studies.

The muonium chemistry research mentioned in this article was carried out by a team from the Chemistry Department of Simon Fraser University supported by the TRIUMF Centre for Molecular and Materials Research. The existence of the latter support group is an essential prerequisite in bringing to TRIUMF experts in the particular scientific problems under study. The success of the UBC and SFU muonium chemistry groups has demonstrated that TRIUMF is much more than a facility for nuclear and particle physics.

Paul Percival is a Professor of Chemistry at Simon Fraser University.

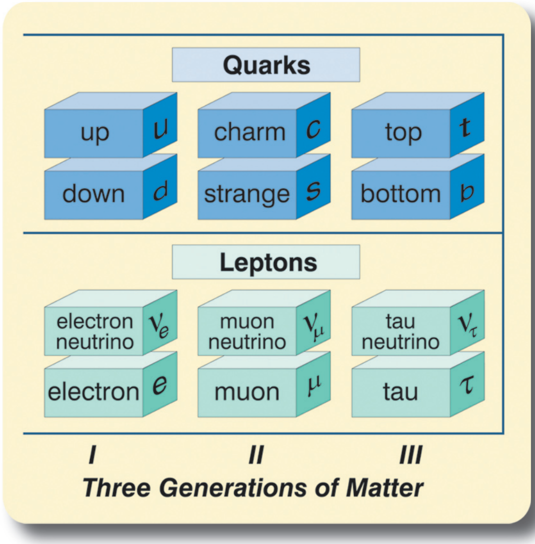
Glen Marshall

TWIST: The TRIUMF Weak Interaction Symmetry Test

Symmetries provide us with insights into fundamental principles of nature. A symmetry in subatomic physics is a similarity that exists when some natural phenomenon is looked at from a different point of view, in a mirror rather than directly, for example. The similarity often points to a deeper understanding of the intrinsic properties of subatomic particles and their interactions. Symmetries predict the way these particles interact with each other, and so can be tested with high precision in experiments at accelerators such as the ones at TRIUMF.

The TRIUMF Weak Interaction Symmetry Test (TWIST) is an example of such an experiment. It is designed to measure accurately the distributions in energy and angle of positrons (e^+, the positively charged antimatter twin of the electron) produced when heavier positive particles called muons (μ^+, named for the Greek letter, mu) disintegrate. Like electrons, muons can be either negatively or positively charged. They are produced in great numbers when the TRIUMF proton beam strikes a target of graphite or beryllium. Muons live only about two millionths of a second on average before disappearing or decaying. When a muon decays, it produces two neutral, almost massless particles called neutrinos, as well as an electron or positron depending on the charge of the original muon, in order that electric charge be conserved. This decay is an example of what physicists call the "weak interaction", which is also responsible for a type of radioactivity known as beta decay. Along with the very closely related "electromagnetic interaction", responsible for gamma radioactivity, it can be calculated very precisely using only a few measured parameters as input. This is in contrast to the more complicated "strong interaction", describing alpha radioactivity and other processes involving nuclei and their constituents.

Unlike beta decay, muon decay does not involve any strongly interacting particles. It is one of very few weak interactions that is free of the potentially more complicated effects of strong interactions. The muon is a very interesting particle in other respects, too. While its ultimate raison d'être is not clear, it does fit neatly into the scheme of fundamental subatomic particles which includes all known weakly interacting leptons and strongly interacting quarks. The graphic shows the muon in its place within the second of three known generations of leptons and quarks. First generation particles make up all of the matter of our everyday world, while the muon is the lightest, most easily studied particle in the second. There is the hope that detailed study of muons will help us understand



The fundamental particles of the Standard Model.

why the second and third generations exist, an important question whose answer still eludes us. The muon has some other advantageous characteristics. It has the property of intrinsic angular momentum called spin, which results in the muon having an orientation or direction in space. Our understanding of the weak interaction to date is very much dependent on characteristics related to spin.

A very general space-time symmetry predicts the distribution in angle and energy of the positrons produced when muons decay, where the positron angle is measured with respect to the direction of the muon spin. The prediction is made in terms of the symmetry of the interaction itself, plus the space and spin characteristics of the particles taking part, the muon, positron, and the two neutrinos. So far, of those possibilities allowed by this quite general symmetry, only a very limited type has been observed; this limitation is considered to be evidence of a more specific, restrictive symmetry. But what is it and why is it so restrictive?

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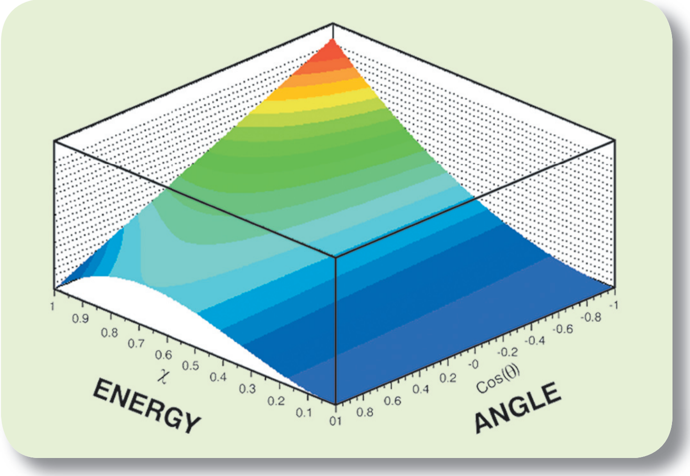
To explain this and other observations, physicists use what has come to be known as the Standard Model. While it has been very successful and has survived many tests since it was devised about forty years ago, it is considered to be only an approximation to a more complete and correct explanation. Many parameters of the model, such as the masses of the fundamental particles, are not predicted but rather have to be inserted to match observation. To help us to decide which of the many possible alternatives are closest to what nature really looks like, we search for examples in which the model might fail. By finding failures we narrow down the options for the correct theory. Much of the research in subatomic physics today is aimed at finding the limitations of the Standard Model, searching at the extremes of our knowledge for some place where it might not be valid. The TWIST experiment is one of these tests, accurately measuring muon decay, looking for symmetry properties not contained in the Standard Model but which would be perfectly compatible with a more general symmetry.

We can plot the Standard Model prediction of the distribution in energy and angle of positrons from muon decay, as shown in the figure. The energy is shown in terms of a number x, ranging from near zero up to its maximum of one. The angle φ, between the positron direction and the muon spin direction is plotted in terms of a function cos(θ), which is convenient because it produces a flat line if positron emission is equally likely in all directions. As you can see, the Standard Model prediction is by no means flat in either x or cos(θ), due to the specific symmetry it assumes.



The Standard Model prediction of the distribution in energy and angle of the positron from muon decay.

From previous experiments, we know that this distribution is correct to an accuracy of a few parts per thousand. The goal of TWIST is to increase the accuracy to a few tenths of parts per thousand, to search for a possible failure of the Standard Model and a hint at what might be beyond. While this is technically very challenging, it is well matched to the abilities of TRIUMF and its facilities, where precisely defined high intensity beams of muons can be produced and high-precision detection systems to measure the decay can be designed and built.

The cyclotron at TRIUMF provides a source of very highly polarized (spin-aligned) low-energy muons, called "surface muons" because they originate at the surface of the target struck by the cyclotron's proton beam. These muons are guided by a beam line toward a high-purity spin-preserving material surrounded by an array of precision detectors. The muons slow down and come to rest at the very centre of the detector array which measures the energy and direction of emission of the positrons produced in the decay of the muons. The angle θ mentioned above can also be determined since the distribution of spin direction of all the muons is known. As shown in the artist's depiction of the TWIST spectrometer, the set of detectors is inside a high magnetic field of two Tesla, or about fifty thousand times the strength of the earth's magnetic field, produced by a large superconducting magnet originally built for the medical diagnostic application of Magnetic Resonance Imaging (MRI).

The array of detectors is shown in the photo (see next page), arranged in its cradle prior to installation in the magnet. Comprised of about five thousand wires, each with a hair-like diameter of fifteen thousandths of a millimeter and located to a precision of a few thousandths of a millimeter, the array is able to locate the position of the positron from muon decay at many points along its track in the magnetic field. This is accomplished by electronically measuring and recording several thousand bytes of information

Glen Marshall

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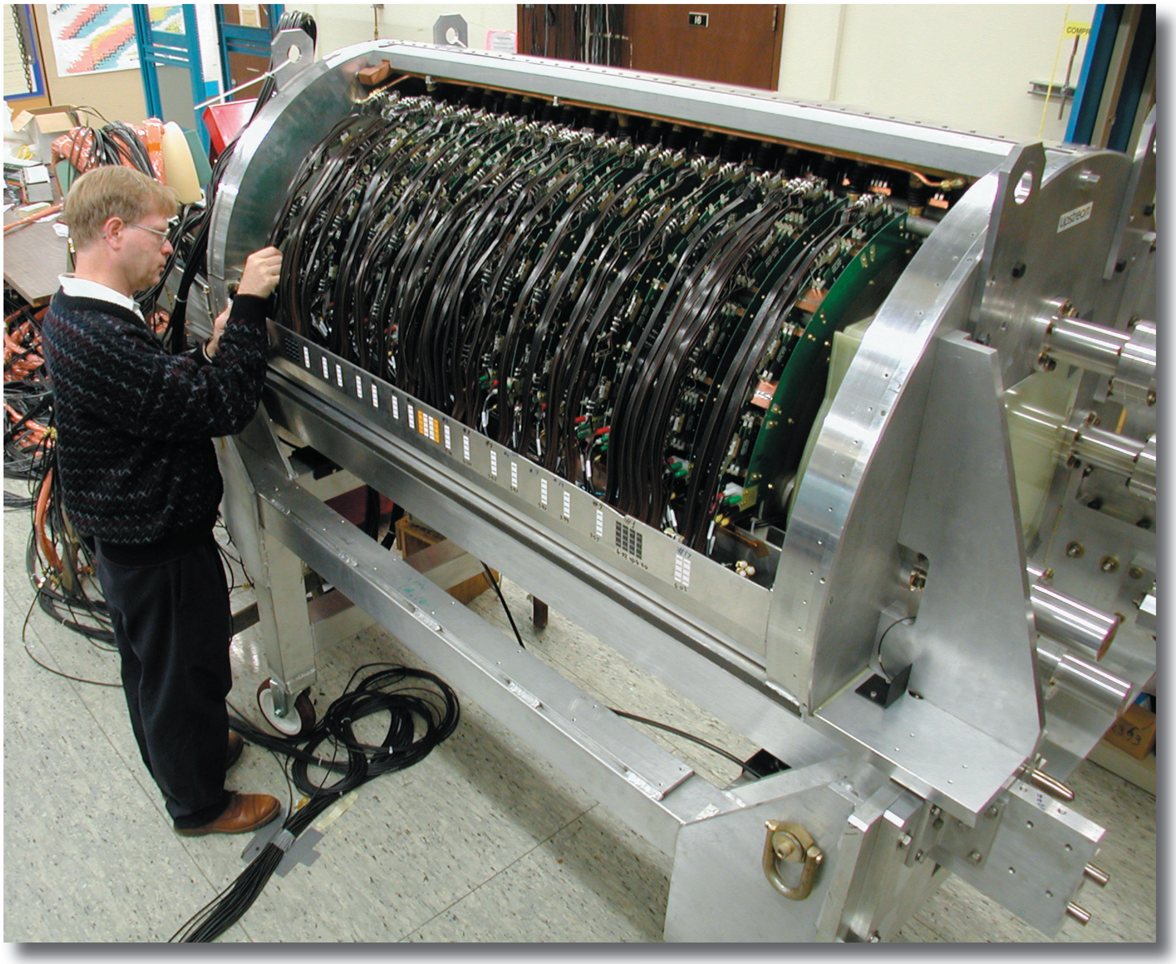

TWIST detector planes in their cradle which slides into the superconducting magnet.

for each muon decay. From the path of the track and its curvature in the magnetic field, the initial direction or angle, and the energy of the positron can be deduced. Each second, the data from decays of several thousand muons are recorded; in an hour the equivalent of about thirty audio CDs of information is stored for later analysis.

Based on the measured track coordinates from each of these millions of decays, a computer must analyze and calculate each positron's energy and initial angle. This massive task can be accomplished only with a very powerful computing installation. For this, TWIST relies on the WestGrid distributed computing environment recently installed at UBC. Analyzing data tracks is only part of the task for these processors; it is also necessary to carry out detailed simulations of the decays as they would be seen in the TWIST spectrometer, assuming that the Standard Model is valid, and to analyze the simulated data in exactly the same way as the real data. After careful verification of the simulation's validity, the results are compared with experimental data in a way that is "blind", that is, the scientists cannot anticipate whether the comparison does or does not support the Standard Model until the final step.

The huge amount of data recorded by TWIST is necessary to achieve our goal of a high accuracy measurement of muon decay. In the first place it is important to reduce what are known as statistical uncertainties arising from statistical fluctuations in numbers of events of any particular characteristic. All measurements which count numbers, for example consumer or political opinion polls, must assess these kinds of uncertainties, and there are well accepted methods to do so. There exists another class of uncertainties, called systematic uncertainties,

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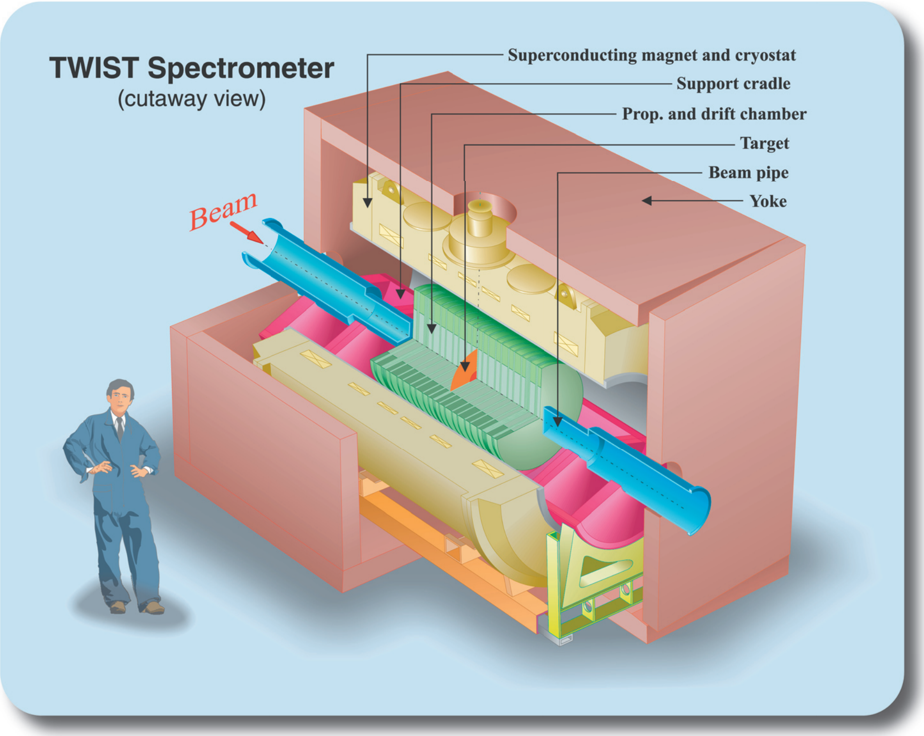
which are more challenging for this experiment. They result from, for example, incorrect calibrations or uncontrollable changes in experimental conditions. With its high data rate, TWIST can achieve adequately small statistical uncertainties. However, systematic uncertainties pose a set of quite different problems requiring individual solutions. They will eventually set the limit to the precision of the result which can be achieved.

Evaluating and reducing systematic uncertainties is made easier with the availability of large amounts of data. For example, the effect of a variation in the muon beam position on each parameter describing muon decay can be deduced by actually changing the muon beam position and repeating the measurement. Often, the change can be exaggerated by different amounts. Then, by controlling the position of the beam very carefully, and by assessing how much movement might still be present in the real beam, it is possible to estimate the amount by which the decay parameter could be affected. Not only can this be accomplished with experimental data, but the use of large sets of simulated data is also essential. Variations are introduced into the simulation which correspond to real changes in the experiment. After verifying that the changes in simulated data are consistent with corresponding real data sets, the simulation can be used for more extensive studies of systematic errors and uncertainties.

Many other possible uncertainties exist. They range from specific detector characteristics such as position calibration and resolution to atmospheric density which affects detector response as well as the spatial distribution of muons at the time of decay. Where possible, variables contributing to systematic errors are controlled to the degree required to make the errors insignificant; otherwise, the contributing variables are monitored with a precision that allows the estimation of their effect on the measurement.

The substantial analysis tasks required are well underway. The TWIST collaboration consists of about 40 scientists, engineers and technicians who come from TRIUMF and the Universities of Alberta, British Columbia, Montréal and Regina in Canada, Texas A&M and Valparaiso in the United States, and the Kurchatov Institute in Russia. The group includes five graduate students and three postdoctoral research associates.

The first results from TWIST are expected in late 2004. They will improve upon previous measurements, but the eventual goals of the project will be accomplished only after several more years of data taking and detailed analysis. Will the symmetry of the Standard Model survive in muon decay, or will there be some feature of the more general symmetry that is revealed?



Arrangement of target, detector chambers and magnet for TWIST.

Follow the future of TWIST at http://twist.triumf.ca

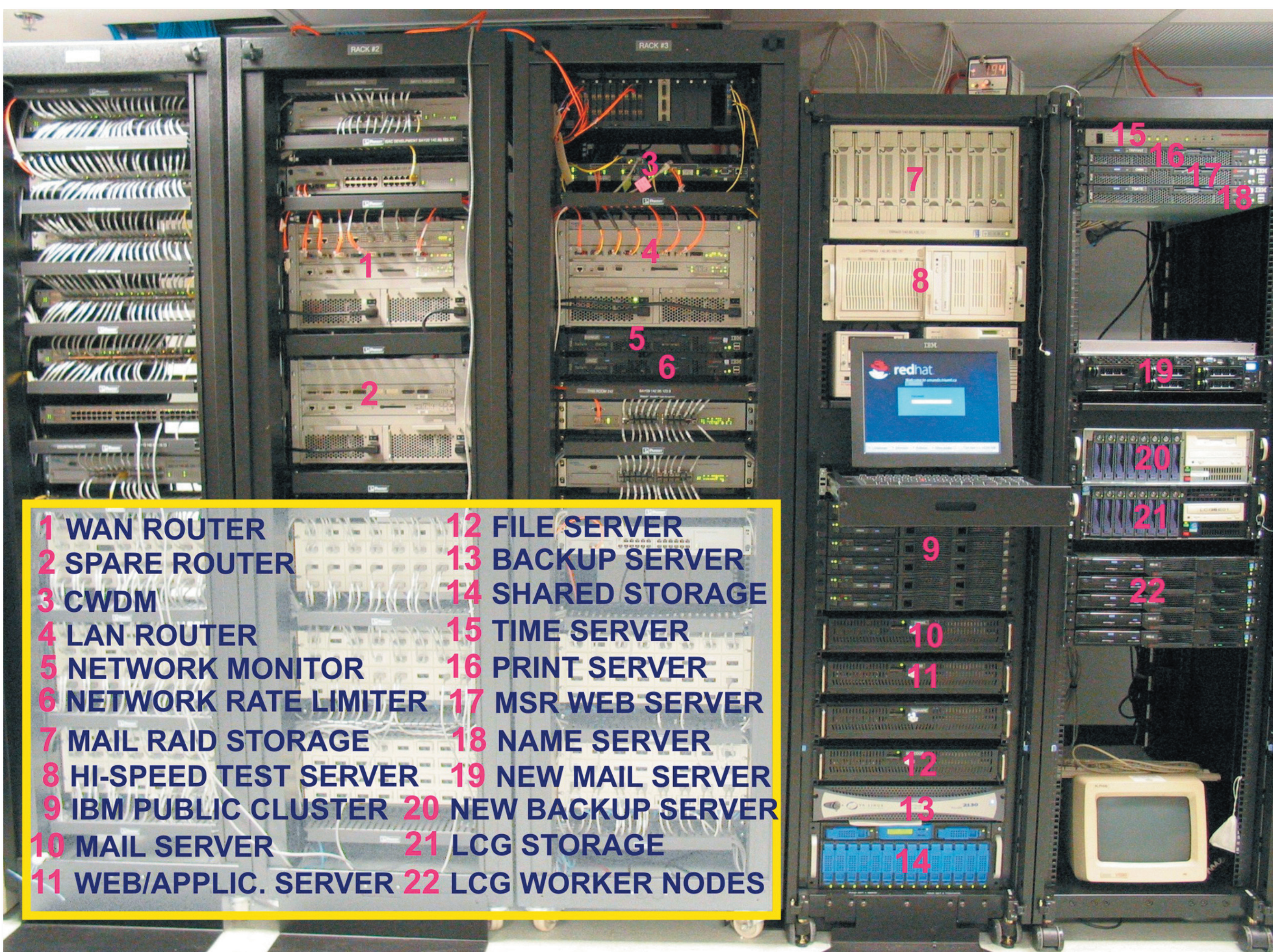
Glen Marshall is a Research Scientist at TRIUMF.

Corrie Kost

Providing the Best in Computing and Networking Environment

Computing support is an essential element of all scientific endeavors. This is especially true for research facilities such as TRIUMF where computers, in addition to their role in collecting and recording data from experiments, are used to assist in the design of equipment and the selection, exchange and analysis of massive amounts of data from experiments carried out at TRIUMF and other laboratories around the world.

TRIUMF's computing support group, although small, has its roots firmly founded in the time when the facility was under construction more than 30 years ago. Back then, computing hardware support was provided by facilities housed at UBC and the main function of the group was to support simulation and analysis of measurements relating to the design and construction of "the world's largest cyclotron". It was some 6 years after TRIUMF became operational that we acquired our first local central computing facility in 1980 – a VAX-780. TRIUMF's international stature required access to a global interconnecting network long before such a facility became commercially available. Hence networks used were largely user-developed ones. By 1984 we were doing remote logins and file transfers on a global scale (albeit at a rate which pales by today's standards). Two years later the global mail facility, GMAIL, was up and running. Linux, now the dominant open-source operating system at most high-energy physics laboratories, was inevitable after



The main components of TRIUMF's central computing facility - notably the time, name, backup, mail, print, web, file, application and compute servers.

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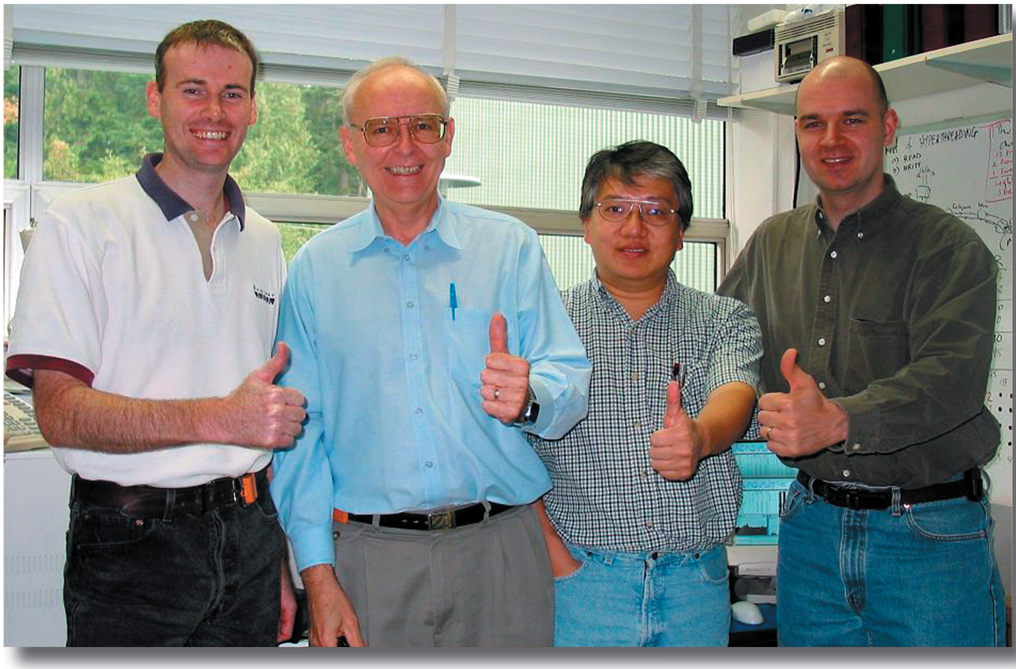
Providing the Best in Computing and Networking Environment

UNIX was declared the preferred operating system back in 1991. This occurred at the inaugural meeting at the Fermi National Accelerator Laboratory in the US of the High Energy Physics Unix Coordination group (HEPiX). Since then TRIUMF has twice hosted this important meeting.

It was the high-energy physics community together with key developments at CERN that spawned what is now the world-wide-web. The web has had a profound impact at TRIUMF and continues to do so, since the web's collaborative, open, sharing nature aligned well with the international scope of the work done at TRIUMF. However, the open nature and extensive connectivity to the world has not been without some drawbacks. Complicating factors such as spam and viruses have led to what can, at best, be termed "challenging and interesting times"!



The TRIUMF team that established the data transfer record. From left to right Steve McDonald from TRIUMF, Corrie Kost from TRIUMF, Wade Hong from Carleton University and Bryan Caron from the University of Alberta/TRIUMF.

Since 1980 computing hardware resources at TRIUMF have more than doubled every 2 years. As well, the diversity of computing support is expanding; on-site wireless internet access for laptops, email access from any browser anywhere in the world, and contributions to world-class software such as GEANT4, ACCSIM and PHYSICA. The latter provides a high level, interactive programming environment for sophisticated mathematical analysis. PHYSICA consists of a fully procedural programming language, with built-in user-friendly graphics and capabilities. Combining an accessible user interface along with comprehensive mathematical and graphical features, PHYSICA provides a general purpose research tool for scientific, engineering and technical applications.

TRIUMF has also made important contributions to GEANT4, a large software toolkit for simulating particle interactions in matter, with applications in high energy physics (such as simulations of the ATLAS detector at the Large Hadron Collider), space science, nuclear medicine, accelerator design, radiation physics, and other fields. The software, developed using object-oriented design and current software engineering methodologies, is the product of an international collaboration formed by individuals from a number of cooperating institutes, mainly high-energy physics experiment teams and universities. It is one of the world's largest academic software collaborative efforts to date. It was built on the accumulated experience in Monte Carlo simulations of many physicists and software developers around the world. TRIUMF was approached to join this collaboration in its early stages, in part because a number of its scientists and engineers were experts in the field and were thus able to contribute immediately. The R&D phase of the project was completed in late 1998 with delivery of the first production release. TRIUMF remains very active in the present collaboration by continuing the development and refinement of the software and providing ongoing maintenance and user support.

Corrie Kost

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Martin Pinard, President of Silicon Graphics Canada presenter of the 2003 CANARIE award for new technology to Corrie Kost who led the TRIUMF team.

ACCSIM is a product of TRIUMF's computational physics expertise as well as its contacts with CERN and other laboratories where synchrotrons and storage rings are designed, constructed and operated. It was originally created as a simulation of a proposed accumulator ring designed to store large numbers of protons from the TRIUMF cyclotron, but soon thereafter was generalized and applied to other high-intensity proton rings, both existing and proposed, in Europe, the U.S.A., and Japan. The aim of the program is to provide as detailed and comprehensive a simulation as possible, within the limits of reasonable computing time on typical desktop computers. Thus ACCSIM includes not only "tracking" calculations to follow the trajectories of particles in the ring, but also simulations of interactions of the particles in the beam of various types including "space charge" effects caused by electric forces between charged particles, a topic of great concern to designers of the current generation of proton rings. This program is now joined by similar simulation programs developed at other accelerator labs, in what has become a very active sub-field of computational accelerator physics. Because of its scope and relative ease of use, ACCSIM remains extremely popular and is still in continuous development. It is currently in use by accelerator physicists at TRIUMF, CERN, KEK and JAERI (Japan); BNL, LANL and ORNL (U.S.A.); and recently IHEP (China).

On the communications front a major milestone (which set a number of world records) was reached when, as a demonstration held in conjunction with the iGrid2002 conference in Amsterdam, 1 Terabyte of simulated ATLAS experimental data was transferred from TRIUMF to CERN, a span of some 12,000km, using a 2.5Gbps dedicated fibre link, at a rate equivalent to transferring the entire contents of a CD in under 8 seconds or a full length DVD movie in 1 minute. In recognition of this accomplishment CANARIE, Canada's advanced internet organization, conferred the team with the 2003 IWAY award for "New Technology Development". The next phase, planned for summer 2004, will use 10Gbit end-to-end "lightpaths" and attempt to improve the record by a factor of 5 to 10. All this is preparatory to plans to transfer a significant fraction of the many petabytes (million-gigabytes) of data to be generated by the CERN ATLAS experiment beginning in 2007.

A proposal that TRIUMF serve as ATLAS Canada's regional data centre is now under active consideration. If approved, by 2007 TRIUMF would be the home for a large computer cluster, comprised of 1000's of CPUs. One of the main physics goals of the ATLAS collaboration is to discover and study the yet-to-be-found Higgs particle, the key to why fundamental particles have mass. In the figure on page 20 note the presence of the LCG facility – which represents Canada's (albeit currently somewhat token) contribution to the Large Hadron Collider (LHC) Computing Grid (LCG)

Providing the Best in Computing and Networking Environment

for the ATLAS experiment. This experiment is the largest collaborative effort ever mounted in physics, involving some 2000 physicists from 34 countries including an active Canadian group supported by TRIUMF.

There were two significant computing support events last year. The first was moving TRIUMF's Computing Services from the Chemistry Annex, its home for over 20 years, to the new ISAC-II building over the weekend preceding April 1, 2003. This involved not only moving people but all the network equipment and computers. As well, support had to be provided for hundreds of additional network connections for occupants of this new building. It all went as planned – except for one ironic event. After years of living with the flaky air-conditioner in the old facility, the new building's air-conditioning unit failed the day after we moved in all the computing equipment – due to a single line of bad code in its control system!

The second major event was the inauguration of WestGrid, a $48 million computing complex spread across Alberta and British Columbia, which now allows access by TRIUMF staff to high-performance computing. Grid-Computing, that is, the ability to readily use computers and networks located at multiple sites, will be an essential element of the WestGrid initiative. From TRIUMF's perspective, the most heavily used component has been the blade-based 1008 3.06GHz Xeon CPU cluster installed at UBC. Experience acquired on WestGrid will be an invaluable stepping stone to establishing the ATLAS regional centre at TRIUMF.

Locally, the emphasis recently has been upgrading the site's network infrastructure to a 1Gbit fibre backbone, with 10/100Mbit to the approximate 800 devices sitting on the network. In anticipation of future needs, the new ISAC-II has been wired to allow Gigabit to the desktop when the need arises. As well, legacy, overloaded, unreliable, and obsolete equipment continued to be replaced. In the past, TRIUMF computing services has, every 18 months, typically purchased a new machine consisting of the best hardware available at the time and installed the most recent CERN-supported release of the Linux operating system. This year a new approach was taken by purchasing a small cluster of Linux machines. Now new and more powerful worker nodes can be added and defective and/or obsolete nodes culled with almost complete transparency to the users. By implementing the OpenMosix kernel

Replacing a defective member of a cluster.

on the head node, automatic process migration to the least busy participating worker nodes can occur, thus maintaining an even load across the cluster. Traditional batch support is also provided. This ability to perform as a traditional batch computer cluster as well as an automatic load sharing interactive cluster, is both unique and advantageous. It allows growth as required, with minimal effort and disruption to the users. It also improves reliability by avoiding the expensive and troublesome tear-down and rebuild approach of the past.

The accomplishments of TRIUMF's Computing Services group has, as is evident from the above brief description, played a vital role in TRIUMF's ability to carry out world-class physics and attract international scientists to TRIUMF to carry out their research programs. The group's software contributions are also playing an important role in many laboratories around the world, further enhancing TRIUMF's well-deserved reputation.

Corrie Kost is a Research Scientist at TRIUMF in charge of Computing Services, supporting infrastructure and all aspects of scientific computing.

Gordon Ball

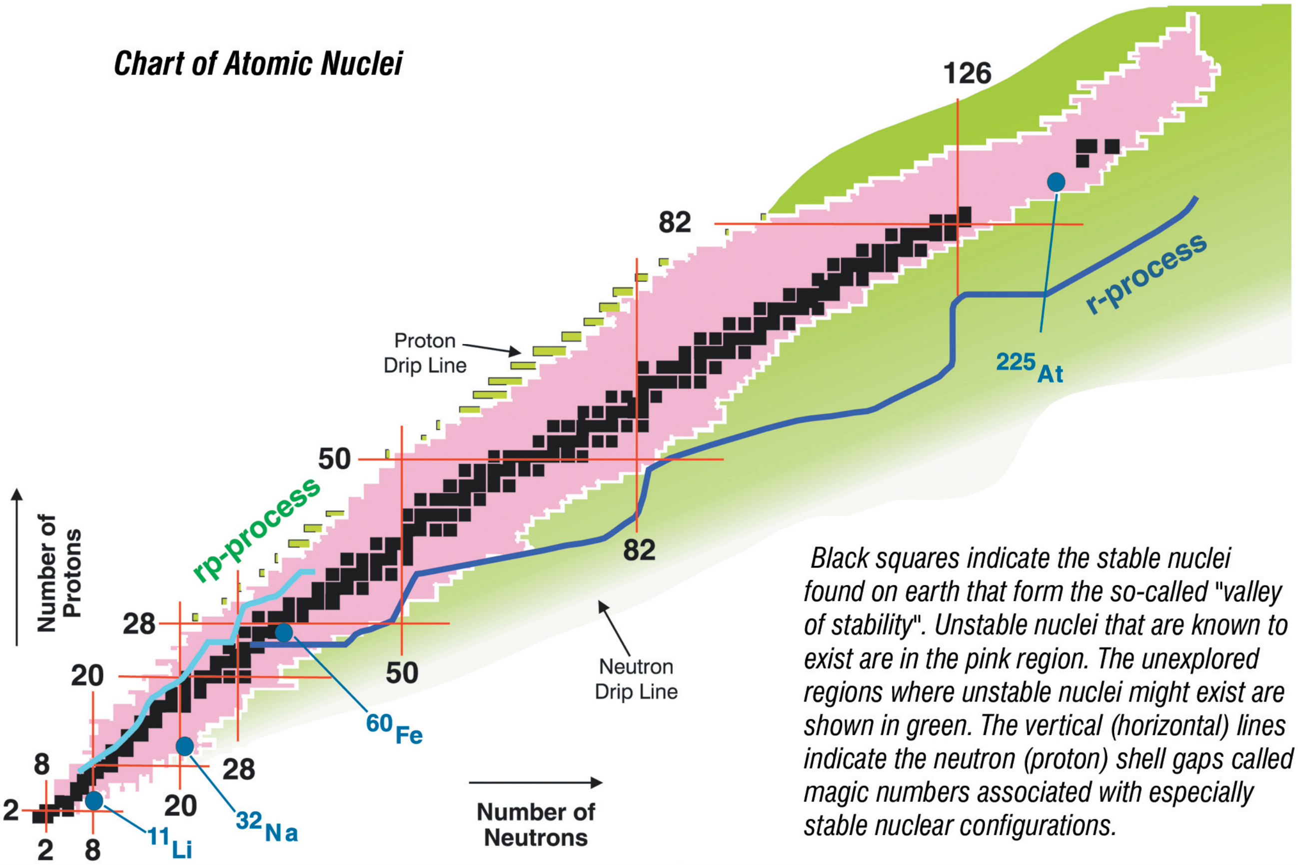
The 8π Gamma-Ray Spectrometer: A Versatile Tool for Radioactive Decay Studies at ISAC

On earth there are only about 250 stable isotopes. These nuclei form what is called the valley of stability on the chart of atomic nuclei. However, about 5000 unstable nuclei can also exist for periods of time ranging from millennia to small fractions of a second. The TRIUMF Isotope Separator and Accelerator (ISAC) facility produces a wide variety of these exotic unstable nuclei which have either an excess of protons (proton-rich) or neutrons (neutron-rich). Usually a neutron-rich nucleus tries to reach stability by converting a neutron into a proton; a proton-rich nucleus does the opposite, converting a proton into a neutron. In both cases the imbalance in the number of protons and neutrons is reduced. Neutron-to-proton conversion occurs by emission of an electron while proton-to-neutron conversion involves the emission of a positron, the positively charged antiparticle of the electron. Together the electron and positron are referred to as beta particles. They are accompanied by neutrinos, chargeless and nearly massless particles that are incredibly difficult to detect.

The nucleus that is left after the beta particle and neutrino emission is often in one of a restricted number of excited quantum states. Gamma rays of well-defined energies are then rapidly emitted to get rid of this excess energy. For nuclei that are far from stability it is likely that the resultant nucleus is also unstable and the process repeats itself until stability is reached.

By studying the beta decay of exotic isotopes we can determine many of their properties such as: how long they live, how heavy they are, what holds them together, how stable they are, and what is their shape. Of particular interest are the nuclei far from stability near the limits of nuclear existence (drip lines) which are expected to exhibit new structures and new collective modes. A knowledge of the properties of these nuclei is essential for our understanding of the fundamental nature of nuclear matter and the synthesis of elements in the universe.

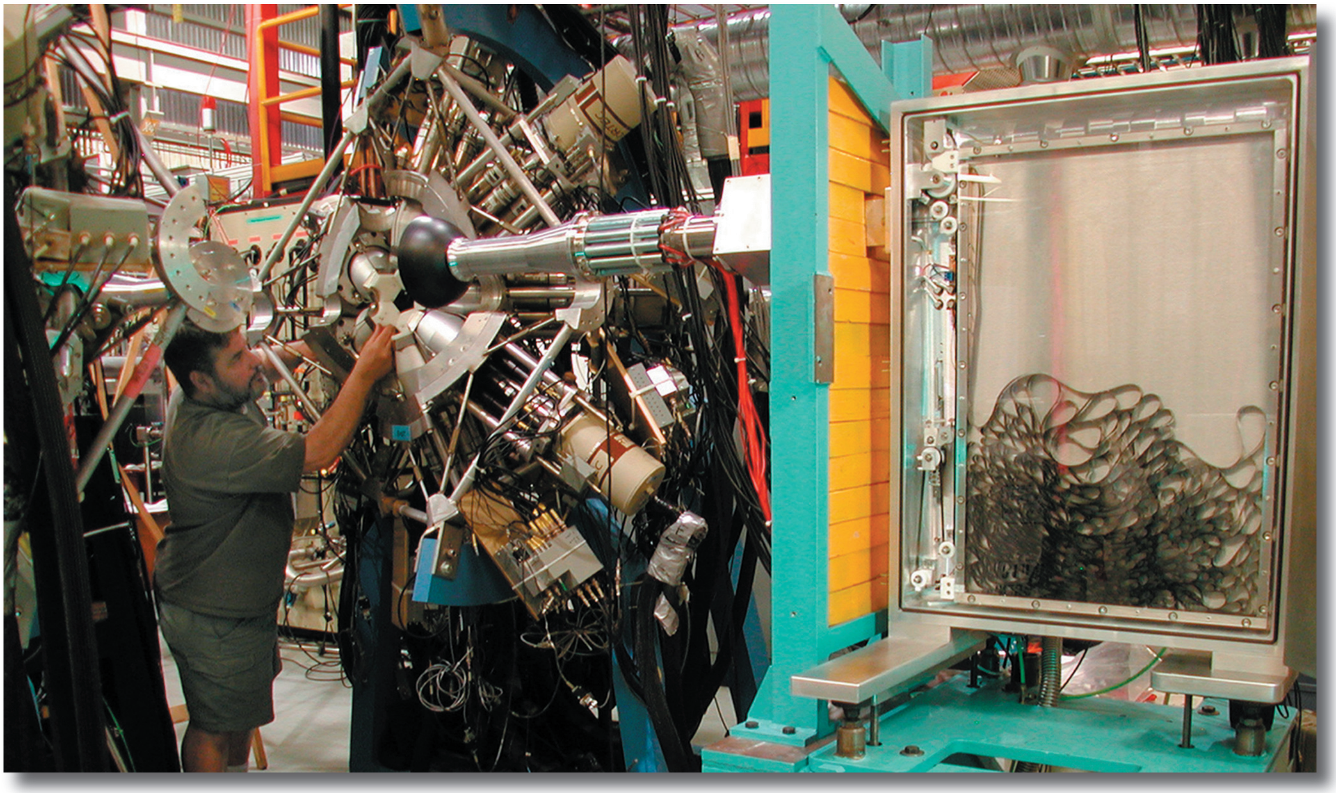
The upgraded 8π spectrometer is the most powerful gamma-ray spectrometer in the world dedicated to decay studies of exotic nuclei produced



Black squares indicate the stable nuclei found on earth that form the so-called "valley of stability". Unstable nuclei that are known to exist are in the pink region. The unexplored regions where unstable nuclei might exist are shown in green. The vertical (horizontal) lines indicate the neutron (proton) shell gaps called magic numbers associated with especially stable nuclear configurations.

Gordon Ball

The 8π Gamma-Ray Spectrometer: A Versatile Tool for Radioactive Decay Studies at ISAC



Downstream view of the 8π spectrometer and SCEPTAR with the moving tape collector in the open position. A continuous loop of tape is drawn from the centre of SCEPTAR into the top of the collector box by a computer controlled drive wheel and falls by gravity to the bottom of the box. The tape is pulled from the bottom of the box through a narrow slit and fed through a tensioning device before returning to SCEPTAR.

by the on-line isotope separation technique at facilities such as ISAC. The nuclei of interest span almost the entire periodic table from ^{11}Li (Lithium 11) to ^{225}At (Astatine 225) and have half-lives as short as 3 thousandths of a second to as long as a million years. Our research program is broadly based with important experiments now underway in the fields of nuclear structure, nuclear astrophysics and fundamental interactions.

Designed by Canadian physicists in 1985, the 8π−spectrometer was a world class, state of the art device and was widely recognized as the best second-generation gamma-ray spectrometer ever built. In March 2000, the 8π was moved to TRIUMF and reconfigured to optimize its performance for beta-decay studies with the low-energy radioactive beams from ISAC. In its new configuration the 8π spectrometer is comprised of a close-packed array of 20 High Purity Germanium (HPGe) detectors used to measure very precisely one or more gamma rays emitted by a decaying nucleus. The detectors are positioned at the hexagonal faces of a truncated icosahedron (a soccer ball geometry consisting of 20 hexagons and 12 pentagons). Some gamma-rays do not deposit all their energy in a HPGe detector resulting in an incorrect value for their measured energy. These are eliminated by detecting any ongoing scattered gamma radiation in surrounding Bismuth Germanate (BGO) shields (Compton-suppression shields).

During the past year, the versatility and sensitivity of the 8π-spectrometer has been improved significantly by the addition of SCEPTAR (Scintillating Electron Positron Tagging Array) a compact (5 cm diameter) inner array of 20 plastic scintillator detectors that is used to detect the beta particle emitted by the decaying nucleus. SCEPTAR is one of the smallest and most complex plastic scintillator arrays to be designed and fabricated at TRIUMF. The light produced when the beta

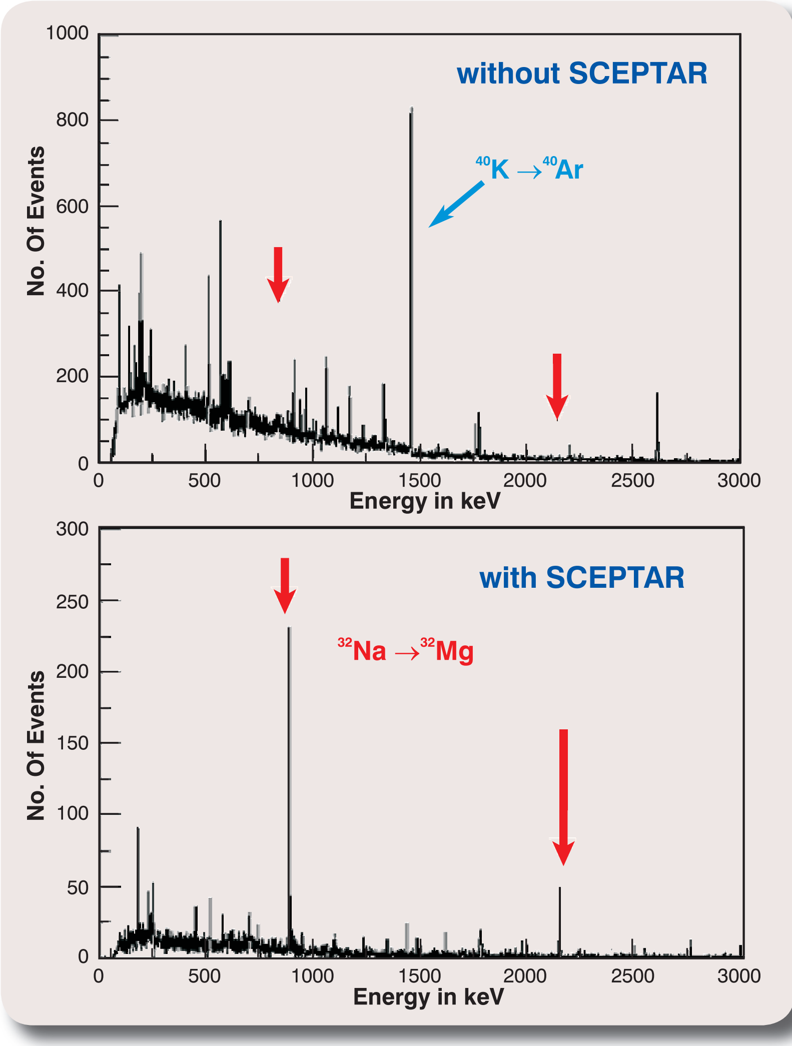
Gordon Ball

The 8π Gamma-Ray Spectrometer: A Versatile Tool for Radioactive Decay Studies at ISAC

particles pass through the thin (1.5 mm) scintillator detectors is collected from one edge by segmented acrylic light guides which are contoured and subsequently glued to 1 cm diameter acrylic rods which transport the light to phototubes located outside the vacuum chamber. The SCEPTAR array is mounted inside a spherical 16 cm diameter Delrin vacuum chamber that is divided into two hemispheres for easy access.

By using SCEPTAR to detect beta particles in coincidence with gamma rays, it is possible to reduce by a factor of one thousand, the background gamma rays detected in the 8π spectrometer that come from cosmic rays and naturally occurring radioactive isotopes such as ^{40}K (Potassium 40) found in concrete. As a result, it is now possible to study the decay of exotic nuclei near the neutron drip line such as ^{32}Na (Sodium 32) that are only produced at a rate of about one atom per second.

Recently, the spectrometer was used to determine that a beam of ^{26}Al (Aluminum 26) required for nuclear astrophysics experiments (see Financial Report 2000-2001) can be produced at ISAC. The Galactic distribution of ^{26}Al, which is believed to be produced in Supernovae, is a sensitive probe of nucleosynthesis in the interstellar medium averaged over the last million years. This isotope, whose half-life is 740,000 years, beta decays to stable ^{26}Mg (Magnesium 26) with the emission of a 1.809 MeV (million electron volt) gamma ray that has been detected by space based gamma-ray observatories. Since the half-life of ^{26}Al is very long, normal methods could not be used to determine if the mass 26 beam from ISAC of about 100 million ions per second was ^{26}Al or ^{26}Mg. The difficulty is caused by the fact that in an ensemble of 500 billion ^{26}Al atoms, only one will decay every minute. However, by implanting the ions into a metallic foil for several hours and observing the decay with the 8π and SCEPTAR for about 12 hours it was possible to confirm that the ISAC beam was indeed ^{26}Al.



Gamma ray spectra observed with the 8π spectrometer in a study of the beta decay of ^{32}Na with a beam of about one atom per second. The spectrum obtained without using SCEPTAR is dominated by background gamma-rays that come from cosmic-rays and naturally occurring radioactive isotopes such as ^{40}K found in concrete. By selecting only those gamma-rays found in coincidence with beta particles detected by SCEPTAR the gamma ray spectrum of ^{32}Na clearly emerges.

Often the exotic nuclei which one wishes to study decay to other longer-lived radioactive nuclei. In time this results in a high background rate of unwanted gamma rays reducing the sensitivity of the instrument. To avoid this problem a moving-tape collector system has been built that removes long-lived decay products from the view of the detector array. Low-energy radioactive beams from ISAC are focused at the center of the SCEPTAR chamber and

The 8π Gamma-Ray Spectrometer: A Versatile Tool for Radioactive Decay Studies at ISAC

deposited onto a 13 mm wide, 50 µm thick mylar tape that is fed from a large storage chamber located behind a lead shielding wall approximately 2m from the center of the array. The storage chamber contains approximately 150m of tape in a continuous loop. After collecting a sample of the nuclei of interest on the tape for a short time the beam is turned off, the decay of these nuclei can be measured both while the beam is on and for a short time after. Then the tape is moved and the cycle is repeated. In this way, the problem caused by the build-up of longer-lived radioactive nuclei is avoided.

Further upgrades to the 8π are being carried out. They include the replacement of one-half of SECPTAR with lithium drifted silicon counters to detect conversion electrons and the addition of an array of Barium Fluoride detectors positioned at the pentagonal faces of the 8π soccer ball geometry to measure the lifetimes of short-lived (from about 10 to 1000 picoseconds) excited nuclear states populated in the beta-decay of exotic nuclei.

An important element of the experimental program will be superallowed Fermi beta decay studies that lead to precision tests of the validity of the Standard Model (see Financial Report 1998-1999). In these experiments the 8π group are pioneering the development of new techniques for high-precision lifetime and branching ratio measurements.

The 8π group is a large international collaboration formed by scientists from TRIUMF, six Canadian Universities (The University of Guelph, McMaster University, Simon Fraser University, Queen's University, The University of Toronto and St. Mary's University) and several laboratories and universities in the US, UK, Austria and Germany.

Gordon Ball is a Research Scientist at TRIUMF.

There are currently 10 approved experiments that will use the 8π spectrometer. Some of the topics that will be addressed include:

Lifetime measurements for long-lived isotopes such as ^{32}Si (Silicon 32), ^{41}Ca (Calcium 41) and ^{60}Fe (Iron 60) used to date geological and astrophysical processes,

Probing the nuclear shell structure of light neutron-rich nuclei such as ^{32}Na (Sodium 32) and ^{22}N (Nitrogen 22),

The search for new high-K isomers in ^{170}Dy (Dysprosium 170) and ^{174}Er (Erbium174) (high K isomers are long-lived excited states of exotic nuclei whose structure hinders their decay),

The search for octupole deformation (pear shaped nuclei) in odd-mass $^{219\text{-}225}$Rn (Radon 219-225) isotopes, and

High-precision studies of superallowed beta-emitters such as ^{34}Ar (Argon 34) and ^{62}Ga (Gallium 62).

Philip Gardner

Transferring Knowledge from TRIUMF into the Community

TRIUMF is a fundamental research facility for sub-atomic physics. Prior to 1995, the NRC Contribution Agreement specified that TRIUMF could only use the funds for fundamental research, which meant that any applied research and development work had to be 'bootstrapped' from internally generated funds. The current Contribution Agreement, signed by the National Research Council in 2000, specifies five fields of work that TRIUMF must perform, one of which is that TRIUMF commercialize technology for the economic benefit of Canada.

The structure of TRIUMF as an operating research facility means that the staff must be primarily employed to work on specific projects on a full-time basis. Consequently there are only very limited resources available to apply to commercial development work and technology transfer activities. The unique resources of TRIUMF are founded in the skill set of the staff – a facet that is well recognized internationally – but to apply any of those unique skills to commercial contracts or collaborative R&D would mean that TRIUMF puts at risk the "must perform" targets in fundamental research set by the NRC-TRIUMF Contribution Agreement.

By its nature, fundamental physics research discoveries have tended to lead their commercial application by a significant length of time, albeit that lead time has decreased significantly in the past four or five decades. Discoveries in fundamental physics research have resulted in major advances for society. Familiar examples range from Lord Thompson's discovery of the electron in 1898 that led to the commercial cathode ray tube, and later to the omnipresent television and computer screen, to Tim Berners-Lee's creation of the World Wide Web at the big European CERN physics research facility in 1989. What is frequently not recognized is the extensive research and development effort that such commercial applications require over many years.

Sir Isaac Newton's oft quoted statement. "If I have been able to see further than others, it is because I have stood on the shoulders of giants", applies as much to contemporary researchers as it did when he himself uttered the words. The incredible technical advances that are now a commonplace part of our everyday lives would not have been possible without the works of such people as Faraday, Maxwell, Röntgen, Becquerel, and Bloch and Purcell. While it would be inappropriate to place the research at TRIUMF alongside such giants, the laboratory does provide Canada with collaborative participation in the international community of leading physics and physicists. The research projects pursued at TRIUMF attract an amazing collage of scientists from all around the world; visiting Nobel Laureates are not an unusual presence in the corridors of this quiet Canadian laboratory. Indeed, there are niches of research in which TRIUMF occupies the leading edge, and serves as an attraction to top international scientists. This led a recent externally appointed international review panel to refer to TRIUMF as the "jewel in the crown of Canadian research".

In this scientific environment, what then should, and can, be the role of commercial and economic activity at TRIUMF? In setting up the technology transfer office in 1989, TRIUMF adopted policies similar to current university policies in terms of intellectual property (IP) ownership and commercialization practice, with the inventor assigning the IP to the laboratory in return for TRIUMF's funding of the patenting costs, and the sharing of any resulting royalty after those costs have been recovered. We have carefully studied the composition, policies, practices and achievements of most of the other universities and research facilities in Canada, and to some extent, around the world. Because of our entirely different employment structure compared with universities, spin-offs and start-ups have been relatively few. Most TRIUMF staff have dedicated their professional lives to the incredible challenges of their fundamental research, rather than the general commercial arena.

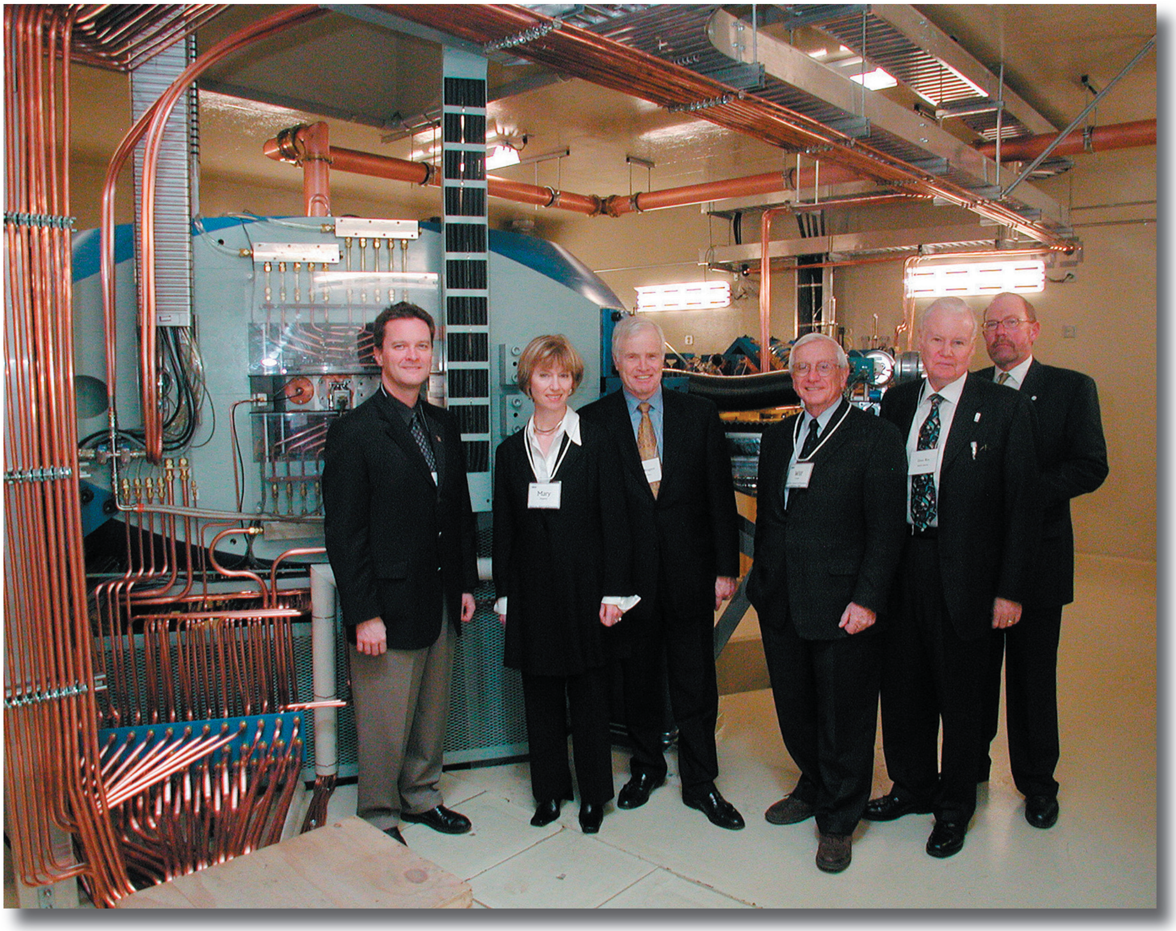
Nevertheless, TRIUMF has been able to make some major contributions to the Canadian economy and our general living standards. Some years ago, the laboratory was able to take advantage of its patents for a concealed narcotics and explosives detector, and supply subcontract work for the main U.S. contractor to develop the product for the U.S. government (as a

Transferring Knowledge from TRIUMF into the Community

Canadian institution, TRIUMF was not eligible to be the prime contractor). Similarly, TRIUMF designed and transferred the knowledge to build commercial cyclotrons to a Canadian company that is now one of the leading cyclotron manufacturers in the world.

MDS Nordion celebrated 25 successful years of collaboration with TRIUMF.

Research into the Life Sciences has occupied a special role at TRIUMF ever since the U.S. inventors of Positron Emission Tomography (PET) medical imaging equipment recognized the laboratory's skill sets, and sent TRIUMF the drawings of one of the earliest versions of their design in the early 1980s. TRIUMF successfully completed the first Canadian built PET scanner in 1982, and, in collaboration with the University of British Columbia (UBC) Department of Medicine, has been performing internationally recognized research into Parkinson's disease and other neurological disorders. However, with the usual lag period between research and



From left to right the Hon. Colin Hansen, BC Minister of Health Services; Mary Mogford, Director on the Board of MDS Inc., John Rogers, President and CEO of MDS Inc., Wilf Lewitt, Board Chairman of MDS Inc., Don Rix, Board Chairman of MDS Metro Lab Services, Jerry Porter, General Manager of MDS Nordion in Vancouver at the opening of Nordion's new radioisotope production cyclotron at TRIUMF.

During the 1990s, the TRIUMF-MDS Nordion relationship evolved to become one of the best examples of successful technology transfer in Canada. With the dedication and skill of TRIUMF's staff, on the equipment and operations sides as well as through assignment of commercial innovations, MDS Nordion has become the leading supplier of cyclotron isotopes in the world, currently providing doses for up to 45,000 medical procedures each week from its TRIUMF site. On December 12, 2003,

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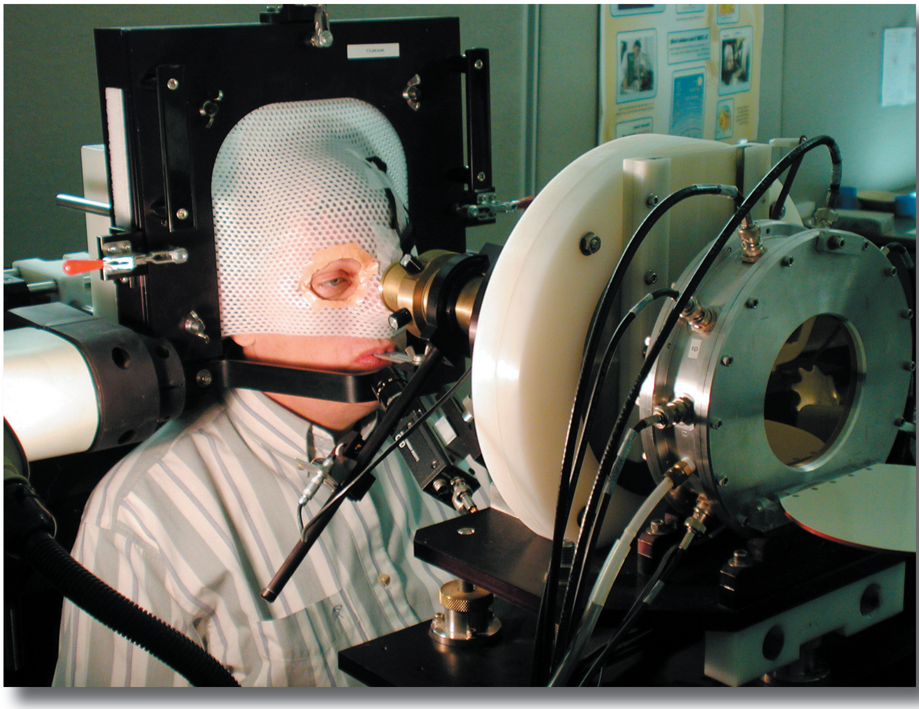
application, only now is TRIUMF in a position to start commercializing some of its work in these areas.

The British Columbia Cancer Agency, with funding from the Woodward Foundation, has joined with TRIUMF to provide the only proton irradiation facility in Canada for the clinical treatment of ocular melanomas. Patients suffering from this potentially life threatening cancer, who are unable to avail themselves of the facility at TRIUMF, have the choice of having their eye(s) removed (most common), having irradiation treatment if it is possible to insert a small plate behind the tumor, or traveling to the U.S. for the same treatment that is offered at TRIUMF. The B.C. Cancer Agency treatment at TRIUMF is over four days, usually Thursday through Sunday, is painless with no discomfort for the patient's four fifteen-minute sessions.



Patient receiving treatment at TRIUMF, Canada's only proton therapy treatment facility for ocular melanomas. The clinical facility is operated by the British Columbia Cancer Agency.

At the request of the Canadian Space Agency, TRIUMF also developed a proton irradiation facility to provide radiation hardness testing for equipment destined for use in space. Currently the laboratory has major industrial customers from both Europe and North America who pay to come to the laboratory to test their components before they are sent into space.

In addition to its strong international collaborations in fundamental research (TRIUMF is unique in being designated a non-national participant in CERN, facilitating the work of Canadian scientists at that world leading facility), the laboratory has embarked on collaborative research with institutions and industry as much as resources can possibly allow. These have resulted in a number of successful new ventures.

Transferring knowledge to Canadians and the Canadian economy from TRIUMF has taken a number of forms. Since its inception, literally thousands of students have spent time at the laboratory as summer students, co-op students or as graduate students, pursuing research that would lead them to advanced degrees at Canadian or international institutions. It has often been suggested that young people carry technology in a manner similar to the way bees carry pollen – put them in an environment where it is around and it just seems to stick.

TRIUMF also has been able to transfer knowledge directly to Canadian industry through its policy of contracting out its equipment requirements whenever reasonably possible. Given the complexity of much of the research equipment at TRIUMF, this has often required the laboratory's designers and engineers to work closely with suppliers, explaining and demonstrating innovative techniques. The result of this policy has been that TRIUMF has consistently managed to obtain close to 80% of its purchases from Canadian suppliers from coast to coast. In turn, a number of these suppliers have been able to develop new product expertise that has had a major effect on their role in the international market place.

The following are two examples of TRIUMF technical knowledge that has been successfully transferred from laboratory to external enterprise.

Philip Gardner

Transferring Knowledge from TRIUMF into the Community

Dehnel Consulting Ltd.

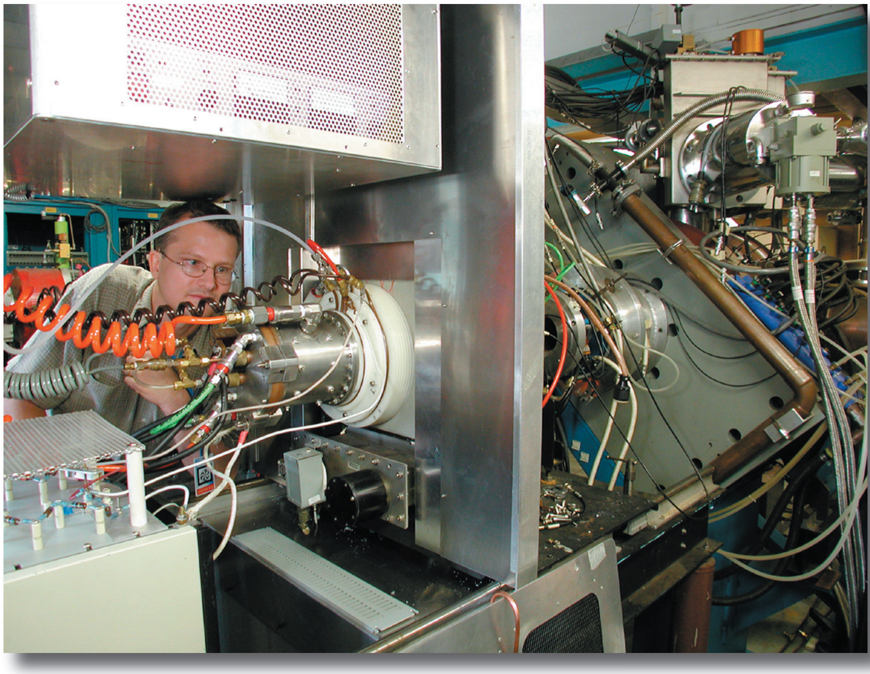
In 1995, Dehnel Consulting Ltd. (DCL) was incorporated in Nelson, B.C. with a vision to provide state-of-the-art engineering services to the particle accelerator industry. Dr. Morgan Dehnel, president and founder, is a UBC graduate who completed his doctoral thesis at TRIUMF in the area of charged-particle optics. Over the last nine years, Morgan has worked closely with a number of TRIUMF staff as DCL expanded and mentored up-and-coming designers and engineers. In addition, Morgan has extended his scientific impact on this beautiful south-eastern British Columbia town by supporting local educational initiatives through guest lectures to high school students, a science column in a weekly newspaper, science fairs, and career expositions.

DCL specializes in complete beamline system designs as well as accelerator/beamline component designs for commercial cyclotrons. Such designs include quadrupole and dipole magnets, vacuum boxes, and beam diagnostic devices. DCL is internationally recognized, and hires out its highly knowledgeable and professional staff to work with engineers and managers of other companies, most notably in the semiconductor industry (ion implanter) and at institutes, such as INER in Taiwan.

DCL has been selling its Beamline Simulator© software, developed through an NRC-IRAP grant, to companies and institutions worldwide. This dynamic interactive software simulates charged-particle transport systems, and allows users to tune a beamline in a "live" and interactive manner similar to being in a control room, which makes it a valuable training and troubleshooting tool. DCL's software clients are located all over the world, in such countries as Japan, Germany, Denmark, Taiwan, the United States, as well as Canada. The Beamline Simulator© software has recently been licensed to AccelSoft (USA), a company that markets and sells a complete suite of accelerator software modeling tools.

Today, DCL offers courses that give an overview of the theory of ion source operation, injection systems, cyclotron acceleration and beamlines to industry accelerator operations groups. DCL is also expanding into the ion implantation and radiation processing fields, which use electrons or x-rays to irradiate food and/or medical equipment (i.e. syringes) in order to kill microbes. The company is currently focusing on solidifying its business and marketing strategies for the next few years, with plans to increase its international business and market share.

The years of close cooperation between TRIUMF and DCL took a major step forward in December 2001 when DCL licensed a group of cyclotron components technologies from TRIUMF. With the help of Pantechnik, a French manufacturer and seller of positive ion sources, DCL plans to market and sell the ion source technology it has licensed from TRIUMF in Europe and Asia in the near future. In April 2003, DCL presented TRIUMF with the first royalty cheque from sales of the licensed ion source technology, followed by a second one in January 2004.



Dr. Morgan Dehnel at the ion source test-stand.

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Transferring Knowledge from TRIUMF into the Community

Not only does DCL have a positive effect on the local economy of South-eastern British Columbia where it is located, it is also successful in exporting Canadian technology services, and in contributing to the overall Canadian economy.

The Effects of Copper on Marine Phytoplankton

TRIUMF supports a variety of life sciences research by providing researchers with the necessary assistance, materials, equipment, and facilities for their projects. One current project will focus on the global carbon cycle and the role of copper in the high-affinity iron uptake system of marine phytoplankton.

Every year, the burning of fossil fuels contributes to increasing levels of carbon dioxide (CO_2) in the Earth's atmosphere, which is considered to play a large role in global warming. If the levels of CO_2 continue to increase at a constant rate, the Earth's temperature could increase by 4 degrees celsius by 2100, a result that could significantly affect the ecology of the earth.

Carbon dioxide in the atmosphere also comes from the deep ocean through CO_2 exchange between the upper ocean and the atmosphere. This is controlled by what is known as the global carbon cycle, made up of the solubility and biological pumps. The solubility pump moderates CO_2 in the atmosphere through gas exchange and is mainly a temperature driven process, while the biological pump is controlled by phytoplankton in the ocean. Marine phytoplankton are single-celled organisms that have inhabited the earth's oceans for millions of years. Similar to plants, phytoplankton use photosynthesis to convert CO_2 into sugars, which they then process as food. The more phytoplankton in the ocean, the more CO_2 is pulled from the atmosphere and converted into organic matter.

Today's atmospheric CO_2 level is around 360 parts per million (ppm). Without the contribution of phytoplankton in the ocean, the Earth's atmospheric CO_2 would be significantly higher (modeling estimate >500 ppm). However, at maximum efficiency, the biological pump could reduce CO_2 in the atmosphere by more than 100 ppm.

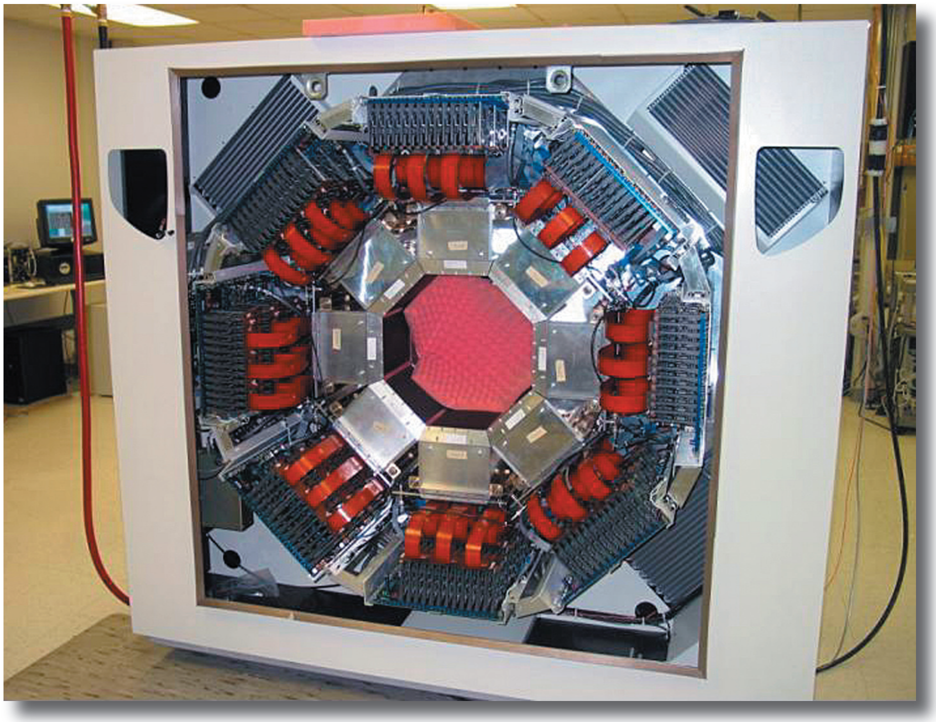
It has been determined in previous studies that there is a correlation between the levels of dissolved iron (Fe) in the seawater and the amount of CO_2 in the surrounding atmosphere. In areas of high Fe concentration, such as oceans subject to high airborne dust inputs from nearby deserts, the amount of phytoplankton increased and the amount of CO_2 in the surrounding atmosphere decreased. One example is the South Ocean Iron Release Experiment in 1999, where it was observed that phytoplankton biomass increased roughly 600%, and levels of CO_2 in the surrounding atmosphere dropped nearly 40 ppm. These phytoplankton were able to better absorb nutrients, which resulted in increased efficiency in the biological pump. To fully understand the impact on the growth and cellular physiology of marine phytoplankton, it is critical to determine the metabolic processes that control the uptake and utilization of Fe by these organisms.

SFU graduate student, Suzi Lapi, preparing materials for the phytoplankton studies.

Transferring Knowledge from TRIUMF into the Community

Preliminary data suggests that copper (Cu) plays an essential role in the ability of these organisms to acquire the minute concentrations of dissolved Fe in surface waters. Cu may also play a role in photosynthesis that is unrelated to Fe uptake.

This project is led by Professor Maria Maldonado, of the Department of Earth and Ocean Sciences at the University of British Columbia. In collaboration with UBC Ph.D. student Shannon Harris, Prof. Maldonado hopes to elucidate the role of Cu in the high-affinity Fe uptake system of marine phytoplankton: to determine Cu nutrition of these organisms via their mechanisms of Cu uptake and kinetics of Cu transport, and to investigate possible substitutions of Fe by Cu in various biochemical pathways. The results of this research project may provide insights into new ways to alleviate global warming caused by increased CO_2 in the atmosphere.



The new high-resolution positron emission tomograph (PET) at UBC consists of 120,000 detector elements, compared to only 280 in the first one which was built by TRIUMF in the early 1980s. TRIUMF scientists work closely with medical personnel at UBC on adding to our knowledge of diseases such as Parkinson's.

TRIUMF will support Professor Maldonado's research by assisting in producing, incorporating, and detecting ^{64}Cu as a marker for Cu dynamics studies, as well as providing other materials, facilities, and/or equipment needed to carry out the research. TRIUMF has been involved in a number of these types of research projects because of its unique ability to provide short-lived cyclotron isotopes that are suitable as markers. It is an ongoing role that the facility believes is a fundamental social responsibility to assist with research projects that have potential impact on the overall Canadian way of life.

Summary

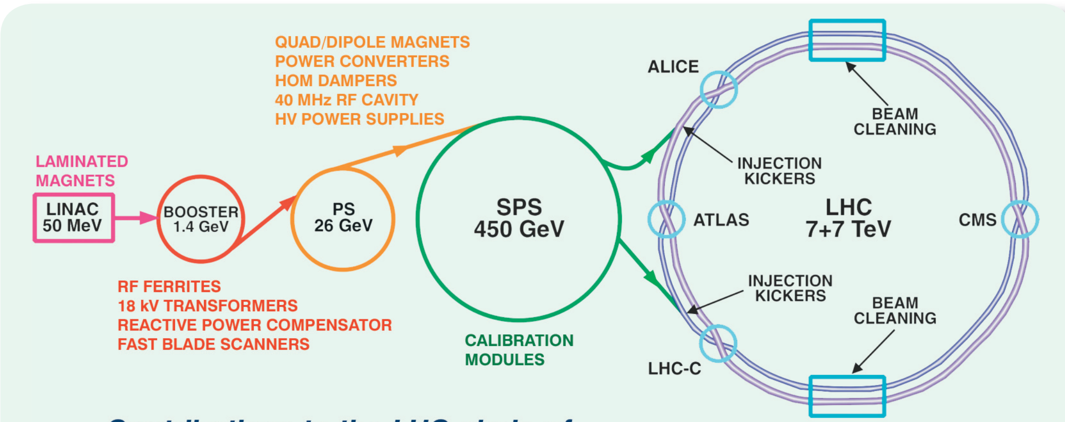
Scientific research at TRIUMF has provided a vast store of knowledge that has been applied throughout the Canadian economy in such diverse fields as health care and pollution control. Numerous sectors of society across the country, from students and health care patients to large exporting companies, have benefited from seemingly esoteric research into sub-atomic physics that is conducted at this unique Canadian facility. In dollar terms, in the current year alone, Canadian companies will ring up sales approaching $65 million from products and services that are based on the application of technological developments achieved by TRIUMF staff. In addition, numerous Canadian companies are utilising techniques that originally were derived from research at TRIUMF. But the dollar figures by themselves cannot reflect the social impact that TRIUMF engenders on the thousands of students, teachers and visitors that pass through its doors each year, and on the tens of thousands of Canadians whose critical health care is improved by the high level of medical advances in Canada because of the TRIUMF knowledge base.

Philip Gardner is the head of the Technology Transfer Division at TRIUMF.

Ewart Blackmore

TRIUMF Completes its Major Contributions to the LHC Project at CERN

CERN is the world's largest particle physics laboratory, located in Geneva, Switzerland and funded by 20 European Member States. CERN is also known as the place where the world wide web was born. In 2004 it will be celebrating its 50th anniversary. The exciting new project at CERN is the construction of the Large Hadron Collider or LHC. Completed in 2007 it will be the most powerful instrument ever built to investigate the fundamental properties of matter. The collider is built in a 27 km tunnel located about 80 m below the countryside near the French-Swiss border.



Contributions to the LHC chain of accelerators made by TRIUMF over the period 1995-2005.

Canadian scientists have a long history of working at CERN and are participating in ATLAS, one of the major experiments at the LHC. In 1995 Canada joined other non-Member state countries such as U.S.A., Japan, Russia and India in contributing to the construction of the LHC. Canada's contribution amounts to $41.5M over the period 1995-2005 and is being coordinated by TRIUMF. These contributions are "in-kind" and are typically accelerator components designed by TRIUMF in collaboration with CERN and produced by Canadian industry. A significant part of the ATLAS detector was also designed and built at TRIUMF.

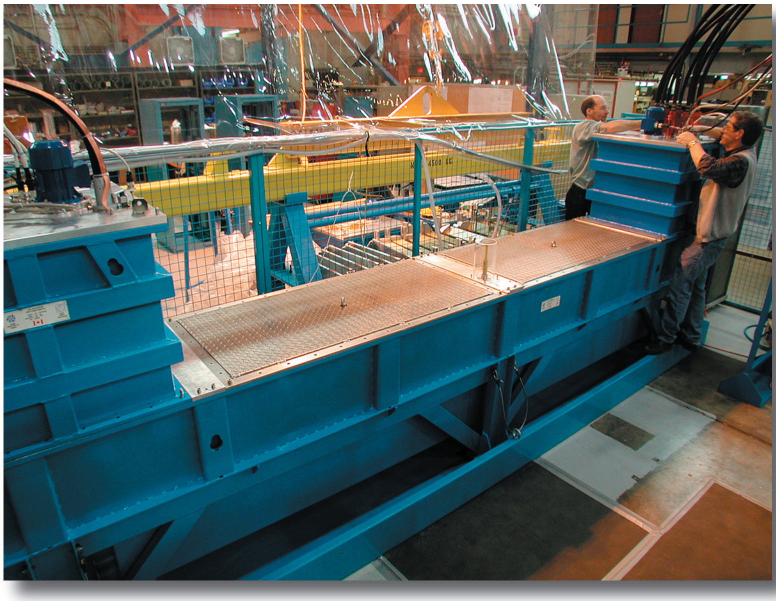
The largest piece of Canada's contribution to the LHC was completed in August 2003 with the delivery of the last of 52 twin-aperture quadrupole magnets to CERN. These warm magnets (48 plus 4 spares) will be installed in the two beam cleaning sections of the LHC. Most of the 27 km ring is made up of very special superconducting magnets to transport and focus the beams. However these magnets must be protected from any lost beam during acceleration or they will cease to be superconducting. This protection is accomplished with a series of collimators in part of the ring where copper-coiled magnets that can absorb the beam heating are used for beam transport. The twin-aperture quadrupole magnets are the main focusing elements in these beam cleaning sections.

The magnets, based on a CERN design, were made by ALSTOM Canada in Tracy, Quebec with considerable input and design assistance from TRIUMF and CERN engineers. Their small apertures (46 mm) and high magnetic field gradient (35 T/m) meant that the 3.4 long modules had to be assembled with unusually high tolerances to achieve the necessary field quality. This has taken some time to achieve.

Members of the ALSTOM Canada assembly team beside the last series magnet prior to shipping.

TRIUMF Completes its Major Contributions to the LHC Project at CERN

A prototype magnet was completed and shipped to CERN in May 1998 for mechanical and magnetic field measurements. As these measurements showed that the desired field quality had not been met, improvements were made in the design and assembly of the magnet laminations for higher precision. These changes led to the first series magnet, which was completed in March 2001 and fully met the specifications. ALSTOM then proceeded to meet and eventually surpass their planned production rate of two magnets per month. Mechanical measurements were carried out at the factory to qualify the magnets prior to shipping and detailed magnetic field measurements were made a CERN.



One of the pulse-forming network tanks being set up for high voltage testing at TRIUMF.

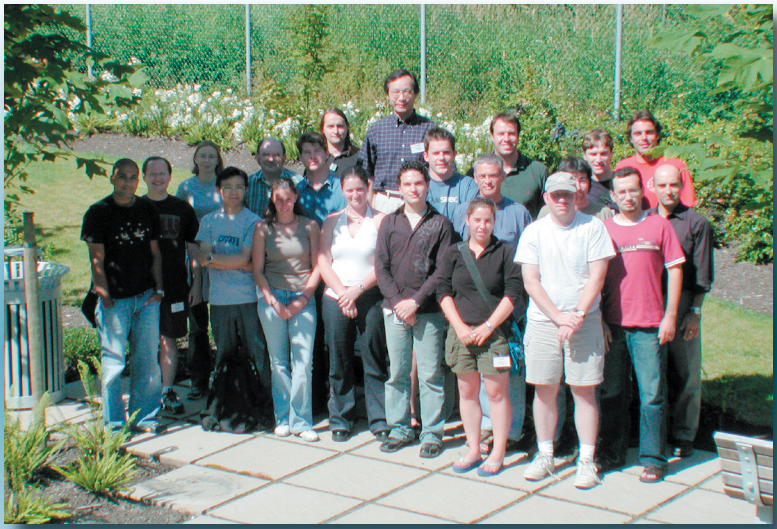
Autumn 2003 also saw the finalization of another aspect of the cleaning insertions to which TRIUMF physicists have made a significant contribution – the arrangement of the 48 quadrupole modules and 40 collimators to produce efficient beam cleaning. In collaboration with CERN, TRIUMF has been responsible for developing a computer code to determine the optimum positions for the horizontal, vertical and skew collimator jaws.

The remaining large contribution from TRIUMF is the equipment for the LHC injection kickers. These are the devices that insert the beam from the Super Proton Synchrotron (SPS) into the LHC rings. They consist of pulsed power supplies and pulse-forming networks that produce a fast high-current pulse to drive special ferrite magnets. This is not hardware that can be easily produced in industry so this equipment had to be developed and fabricated in-house. Five of the nine pulse-forming networks (PFNs) were successfully tested during 2003 and the remainder will be tested in early 2004. The TRIUMF ATLAS shipping container was given to the Kicker group after the last shipment of the ATLAS detector components from TRIUMF to CERN in 2003. The roof and door of the container were modified for shipping of kicker components with a new shock absorbing frame. The first shipment of four of the resonant charging power supplies left TRIUMF in October and arrived at CERN by year-end. The PFNs will be shipped two at a time, in subsequent shipments. The turn-around time for the container is approximately three months.

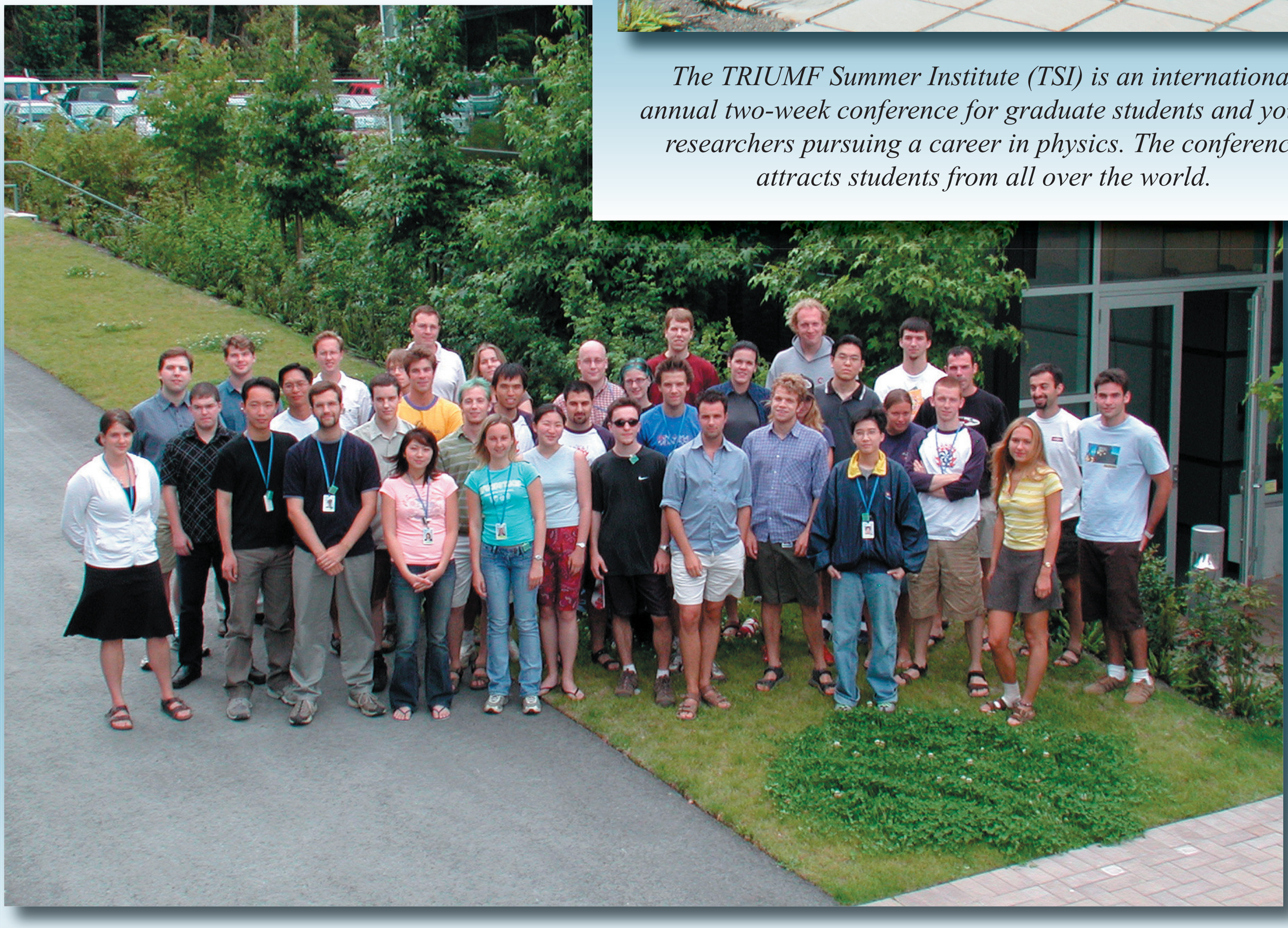
Canada's involvement in the ATLAS detector also made considerable progress in 2003. The hadronic endcap calorimeter modules produced at TRIUMF, which were all at CERN at the beginning of the year, were integrated with European manufactured modules and assembled into four large doughnut-shaped rings. Two of these rings were installed in the first endcap detector cryostat, while the other two await installation in 2004. Forward calorimeters produced at Carleton and Toronto have been shipped to CERN and used for beam calibration tests during the summer. These calorimeters fit inside the ring of the TRIUMF produced calorimeters. During 2003 the calorimeters for both endcaps were made fully ready for insertion. The large underground hall for the ATLAS detector in the LHC tunnel is now ready for occupancy and the massive detector assembly has started. Everything is aimed at being ready to observe the first proton-proton collisions in 2007.

Ewart Blackmore is head of the Accelerator Technology Division at TRIUMF.

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.



The TRIUMF Summer Institute (TSI) is an international annual two-week conference for graduate students and young researchers pursuing a career in physics. The conference attracts students from all over the world.



TRIUMF trains graduate and doctoral students for careers in physics. TRIUMF also employs approximately 70 undergraduate and co-op program students each year through student employment programs.

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