Chapter 2

The Vision: Giving Canada the Advantage, 2010–2015

Chapter 2

The Vision: Giving Canada the Advantage, 2010–2015

Introduction

In order to seed discoveries and maintain one of the highest standards of living in the world, Canada must be aggressive in investing in fundamental and translational research. This research requires state-of-the-art infrastructure and highly skilled workers who are interconnected with each other and the world's scientific and technical research network. As a national laboratory with deep roots in the academic community, TRIUMF is ideally positioned to play a lead role in this effort.

TRIUMF is one of the world's leading subatomic physics laboratories. It brings together dedicated physicists and interdisciplinary talent, sophisticated technical resources, and commercial partners in a way that has established the laboratory as a global model of success. With its large user community, composed of international teams of scientists, post-doctoral fellows, and graduate and undergraduate students, TRIUMF pursues a rich portfolio of physics, chemistry, nuclear medicine, and materials science research. The advances ensuing from this research will enhance the health and quality of life of millions of Canadians, launch new high-tech companies, create new high specificity drugs, help us to understand the environment, enable the development of new materials, and spur the imaginations of our children who want to know their place in the universe.

The TRIUMF Five-Year Plan report presents a strategy for achieving this vision. Building on TRIUMF's international reputation and partnerships with universities, industry, and the global research community, key opportunities will be exploited with potentially breakthrough results for Canada. TRIUMF is an international leader in research with rare-isotope beams, focusing on advances in nuclear physics and material sciences. The vision includes significantly expanding those capabilities including new applications in the medical use of rare isotopes, with TRIUMF developing Canadian leadership in nuclear medicine in a revolutionary era in this field. TRIUMF continues to pursue its internationally leading role in particle physics, including hosting an information technology centre connected to the world-wide network of centres being deployed to analyze the next generation of particle physics data. GRID computing technology being developed for particle physics at TRIUMF will be critical to the success of Canadian science, business, and academia.

In all areas of the TRIUMF Five-Year Plan, there is substantial potential for industrial partnerships, skill enhancement, product development, and commercial spinoffs. For example, the nuclear medicine revolution will drive the need for a new generation of small cyclotrons with connected chemistry on a chip (so called microfluidics) that would be placed in every hospital in Canada. Exploitation of Canadian accelerator expertise, coupled with advances in biomarkers connected to new medical isotopes, will be necessary to develop such a product. Seeding this effort will have tremendous return on investment for Canada and, again, TRIUMF is well positioned to lead the effort.

Above all, the Five-Year Plan is a call for action. The present moment represents a tremendous opportunity for TRIUMF—and Canada—to make a global impact. This opportunity arises from key investments made in the past by the Government of Canada and the Province of British Columbia. This opportunity should not be lost.

2.1

The Way Forward

TRIUMF's operations are supported through a contribution via the National Research Council (NRC) Canada in five-year funding increments. The present performance period completes March 31, 2010. This report reviews recent accomplishments, proposes a plan for 2010–2015, and summarizes the resource needs. In the context of the laboratory's mission, TRIUMF's five-year planning process has identified targeted opportunities that are ripe for exploitation: they build on TRIUMF's successes, play to Canadian strengths, and promise high-impact results.

The goals of the TRIUMF Five-Year Plan are:

- Substantially expand TRIUMF's rare-isotope beam program;
- Lead the coming revolution in nuclear medicine;
- Expand Canadian access to international science;
- Pursue advanced accelerator technologies;
- Exploit targeted opportunities for commercialization with partners such as Advanced Applied Physics Solutions, Inc.; and
- Train the next generation of leaders in Canadian science, technology, and innovation.

To achieve these goals, the plan proposes a set of interconnected facilities and capital initiatives (see Figure 1). The plan includes an electron linear accelerator (e-linac) with a new target station; the initial stage would be completed by 2013. This facility will launch a new thrust in the rare-isotope program,

Timeline of TRIUMF

Early Cyclotron Era

BC Nuclear Physicists agree on Meson Factory

1965

UBC, Victoria, and SFU establish TRIUMF
AECB awards $100k
Alberta joins joint venture

1966

approximately doubling the beam time available to Canadian researchers. The accelerator developments will cement TRIUMF's and Canada's role as leaders in the international accelerator network. A new specialized actinide beam line, also exploiting the new target station, would be constructed and operational by 2015. The electron linear accelerator and new proton beam line, together with the new target station, are tightly linked and use overlapping space and common infrastructure.

In life sciences, the plan calls for an initiative in nuclear medicine supported by new facilities, strategic hires, and enhanced partnerships. In addition to

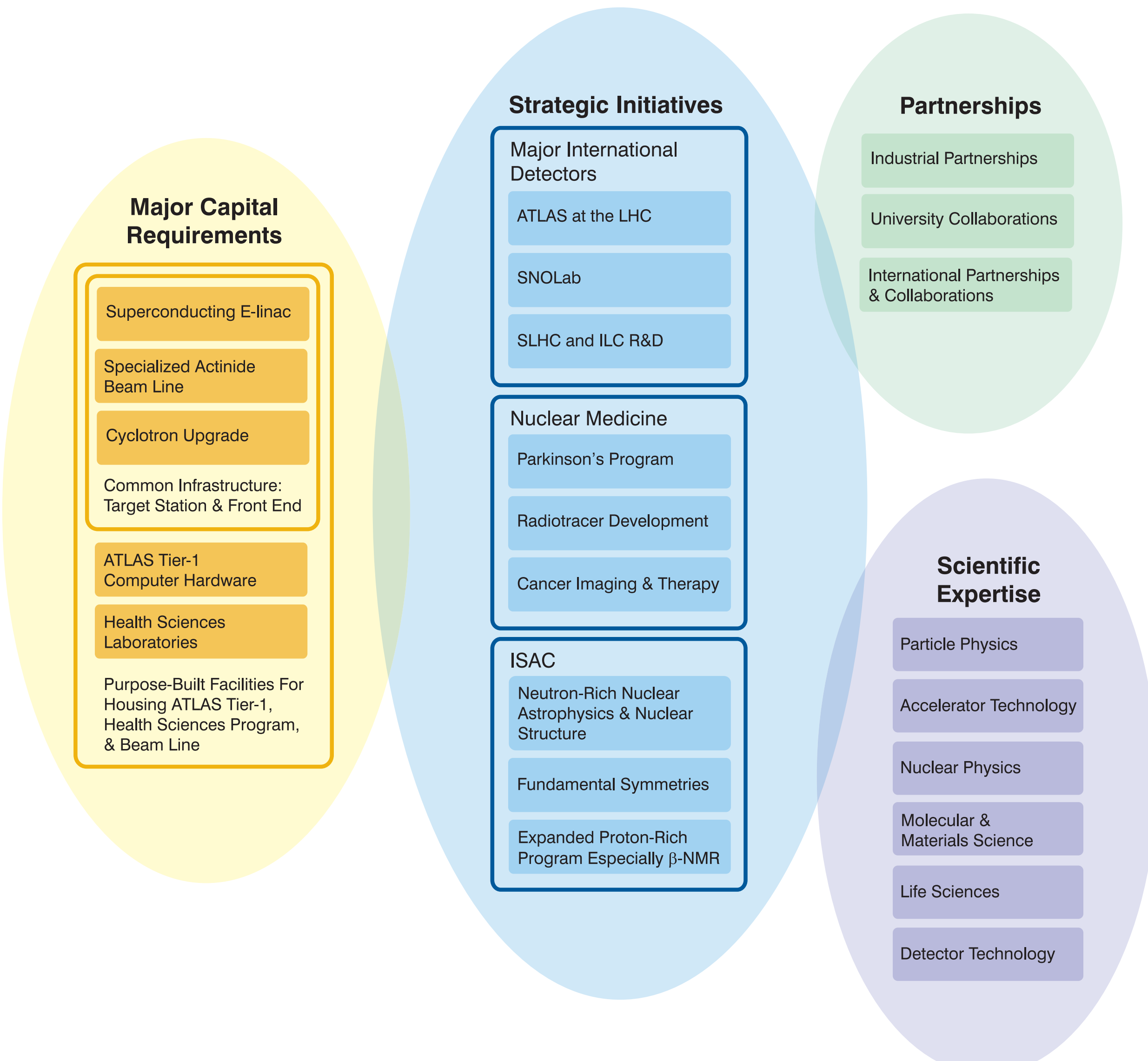


Figure 1: The TRIUMF Five-Year Plan in schematic form. The proposed strategic initiatives will draw on TRIUMF's established partners and scientific expertise and will be supported by new capital investments.

Early Cyclotron Era

AECB awards second $100k
TRIUMF publishes first annual report
1967

Federal government $19M 5 year award
John Warren becomes first Director of TRIUMF
1968

exploiting the new accelerators for research with novel medical isotopes, TRIUMF proposes to lead a national effort with the University of British Columbia to advance the development of new radiotracers for medical imaging.

The plan calls for full support of the expanded ATLAS Tier-1 Data Centre, including strong intellectual contributions to the emerging field of GRID computing. Coupled with the Centre, TRIUMF will establish an ATLAS national analysis centre. In addition, TRIUMF will perform accelerator development in support of future particle physics initiatives. Finally, the plan calls for TRIUMF to support university and SNOLAB collaborations through detector development and other infrastructure support.

The total funds sought to fulfill this vision are $328 million over five years. Cognizant of the necessary constraints that must be considered in the public policy arena, the report also includes an analysis of several different implementation strategies that explore various tradeoffs and reduced-scope programs.

The Five-Year Plan has been carefully evaluated and reviewed by a series of committees including the TRIUMF Policy and Planning Advisory Committee, the TRIUMF Users' Group, and international committees of technical experts. The strengths and weaknesses of the proposed projects, international interest, competitiveness, and the potential for commercial and industrial benefits were all evaluated. The ability of TRIUMF to efficiently manage the program was also a crucial part of building the proposed program.

2.2

Alignment with Canada's Science and Technology Strategy

TRIUMF's proposed program is well aligned with Canada's priorities outlined in *Mobilizing Science and Technology to Canada's Advantage*, released in 2007. This report outlines the advantages to Canada of a strong science and technology enterprise. It is organized around four principles: promoting world-class excellence, focusing on priorities, encouraging partnerships, and enhancing accountability; and three competitive advantages: the knowledge advantage, the people advantage, and the entrepreneurial advantage. In this section, the TRIUMF plan is discussed in terms of this framework, focusing first on the four core principles and then on the three competitive advantages.

Principle: Promoting World-Class Excellence

TRIUMF's research programs are internationally recognized for excellence and innovation. TRIUMF's impact on Canada's status as a gateway to interna-

PEOPLE

THE UNIVERSITY OF GUELPH

Nuclear Structure Group

The University of Guelph joined the TRIUMF consortium as an associate member in 2003. TRIUMF has helped the Group develop a strong research program in nuclear structure and, in return, the Group has increased TRIUMF's presence in central Canada.

The Group performs research in nuclear structure, precision tests of the standard model, and nuclear astrophysics in TRIUMF's ISAC-I and ISAC-II facilities. Since the appointments of Dr. Carl Svensson in 2001 and Dr. Paul Garrett in 2004, the Group has grown to seven full-time graduate students, two post-doctoral fellows, and several undergraduate students. The Group is very active in the TIGRESS and 8π collaborations, with Dr. Svensson as Principal Investigator for both. Dr. Garrett is also the Principle Investigator for the DESCANT project.

The superallowed Fermi β-decay program using the 8π spectrometer and fast-tape-transport system located at GPS1 has been a prime focus of the Group's research. To date, this research has been the subject of four M.Sc. and one Ph.D. theses, with another Ph.D. pending. The nuclear structure program, using both the 8π and TIGRESS spectrometers, has been the subject of one M.Sc., with two M.Sc. theses and one Ph.D. in progress. The Rn EDM and DESCANT design work is the basis of research for another two M.Sc. students. ■

tional science and technology programs is significant. The laboratory attracts world-class researchers to Canada while simultaneously recruiting and training Canadians in internationally leading fields. For example, TRIUMF attracts hundreds of top international researchers to Canada to use the laboratory's world-leading ISAC rare-isotope beams, while also enabling Canadian scientists to play leading roles in breakthrough projects abroad such as the ATLAS project at the Large Hadron Collider (LHC), the largest scientific undertaking in history, or the new Japan Proton Accelerator Research Complex (J-PARC) neutrino project in Japan. TRIUMF also supports Canadian researchers who are designing and building state-of-the-art experiments for SNOLAB.

Principle: Focusing on Priorities

TRIUMF's expertise and capabilities have led to a high demand from the Canadian and international community for support of many diverse projects. TRIUMF has established a robust review process for picking key projects that will have the most significant national and international impact. Part of the process is working with the university community to develop the NSERC Subatomic Physics Long-Range Planning Committee report and then using the resulting plan in setting TRIUMF's own priorities.

> "The most important things happening in the world today won't make tomorrow's front page.… They'll be happening in laboratories—out of sight, inscrutable and unhyped until the very moment when they change life as we know it. Science and technology form a two-headed, unstoppable change agent."
>
> **— Joel Achenbach, *Washington Post* staff writer**

Principle: Encouraging Partnerships

TRIUMF has a strong history of partnerships with universities, international research organizations, and industry. Indeed, a consortium of universities formed the lab. Four recent members of the consortium are highlighted in boxes in this section. University partnerships include the ATLAS Tier-1 Data Centre funded by the Canada Foundation for Innovation via Simon Fraser University. The Centre has a world-leading GRID computing technology capacity, and by 2011 will house Canada's largest academic computer, with a storage capacity of up to 15 petabytes (15 million gigabytes). TRIUMF also has strong partnerships with Canadian industry that are discussed in a later subsection. In

Early Cyclotron Era

Central region produces 100 μA
1973

The cyclotron produces first beam
1974

the current Five-Year Plan, new initiatives with AAPS, Inc. and PAVAC Industries, Inc. will significantly increase TRIUMF's commercial partnerships.

Principle: Enhancing Accountability

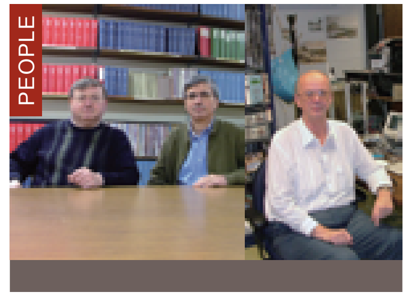
TRIUMF has a 40-year history of using public funds responsibly, the result of a strong review system, and a well-established accounting system. The laboratory's progress and accomplishments are carefully monitored by three oversight committees: the Advisory Committee on TRIUMF; the multi-Agency Committee on TRIUMF, which is chaired by the President of the National Research Council, and on which both the President of NSERC and the Deputy Minister of Industry Canada sit; and, the TRIUMF Board of Management, which represents the university joint venture. TRIUMF's success in meeting the goals of the last Five-Year Plan contribution agreement is shown in Section 2.4.

Advantage: Global Excellence in Research

TRIUMF will contribute to Canada's global excellence in research in the following ways:

- Excel globally in research areas of national priority;
- Provide leadership and intellectual contributions for the development of innovative techniques and technologies;
- Engage in the continued development of GRID computing technology;
- Increase scientific publications, citations, and involvement in international conferences; and
- Increase investment in key areas ripe for discovery.

TRIUMF is one of the leading laboratories in the world for studying rare isotopes, and in some instances is the best. Scientists at TRIUMF are able to study the conditions of supernovae explosions—the deaths of super massive stars—in the laboratory. Using rare-isotope beams, researchers can explore the origin of the chemical elements heavier than iron such as copper, silver, and gold. Investment worldwide in this rare-isotope research will exceed C$4 billion in the next decade. These discoveries will feed into the knowledge base for next-generation nuclear reactors, will help us understand the behaviour of advanced materials under extreme conditions, and will train people for the nuclear industry. By connecting subatomic physics with research in other areas, TRIUMF will continue to develop and contribute to research in materials and to a world-renowned life sciences program that utilizes medical isotopes combined with positron emission tomography (PET) detectors. TRIUMF's experimental facilities and the core scientific programs of particle and nuclear physics are finding new and crucial applications in the studies of molecular and materials science, as well as nuclear medicine. With over a thousand users, from international teams of scientists to post-doctoral fellows and graduate and undergraduate students, TRIUMF brings together human talent and sophisticated technical resources (see Figure 2).



L'UNIVERSITÉ DE MONTRÉAL

Particle Physics Group

The collaboration between the Particle Physics Group of l'Université de Montréal and TRIUMF began in the 1970s with experiments on rare pion and muon decays. In 2007 l'Université de Montréal became a full member of the TRIUMF Joint Venture. This change reflects broad recognition and integration of the particle physics research programs at TRIUMF and Montréal and joint work on the ATLAS experiment in particular.

The Group also collaborates with TRIUMF on detector research and development through the Laboratory of Advanced Detectors Development (LADD) program, which is supported by the Canada Foundation for Innovation. One LADD antenna is based in Montréal and another at TRIUMF.

The Group's researchers use TRIUMF infrastructure for access to the ATLAS Tier-1 Data Centre. The Group and TRIUMF also collaborate on TIGRESS, TACTIC, ALPHA, and PIENU, as well as life sciences projects. In the future, the collaboration will broaden to include research in biophysics, imaging, nuclear medicine, the International Linear Collider, and SNOLAB experiments.

TRIUMF's resources benefit all senior researchers, as well as graduate students and post-doctoral fellows. Recent TRIUMF hires who did their graduate work at l'Université de Montréal are Dr. Isabel Trigger and Dr. Reda Tafirout. ■

Early Cyclotron Era

1975: Proton science program starts; First polarised proton beam; First μSR experiment at TRIUMF

1976: Pierre Elliot Trudeau official dedication; Dr. Erich Vogt appointed an Officer of the Order of Canada; Jack Sample becomes director of TRIUMF

SAINT MARY'S UNIVERSITY

Subatomic Physics Group

Saint Mary's University became an associate member of TRIUMF in 2004. The affiliation with TRIUMF has enhanced Saint Mary's University activity in subatomic physics. Two subatomic physicists at Saint Mary's University, Drs. R. Austin and R. Kanungo, use the ISAC facility. A third scientist, Prof. J. Clyburne, is actively involved in the μSR program.

For Dr. Austin, the high-quality rare-isotope ion beams delivered to the 8π, GPS, and TIGRESS facilities are especially attractive. Rare isotopes studied through decays and Coulomb excitation reactions give Dr. Austin and her collaborators insights into the nuclear equation of the state far from stability, near where elements are created in stars. Six undergraduates have worked with Dr. Austin at TRIUMF.

TRIUMF has also played a pivotal role in Dr. Kanungo's research career. The laboratory's ISOL-type rare-isotope beam facility attracted her to pursue her research in Canada. TRIUMF's high-quality and high-intensity beams have inspired her to start a program of transfer reactions for unstable nuclei.

Dr. Jason Clyburne holds a Tier-II Canada Research Chair in Environmental Science and Materials. His research interest is in materials chemistry. He uses muonium to generate highly reactive radicals and studies their structure using a suite of techniques broadly known as μSR. ■

TRIUMF focuses on what is important. Its research efforts target selected key scientific questions considered to be most important by the Canadian and international scientific community. These research thrusts are drawn from the NSERC Long-Range Plan for subatomic physics, the community-based decadal plan for condensed matter and materials science, and the research statement of the Michael Smith Foundation grant for research at the Pacific Parkinson's Research Centre.

1. Search for the new physics that must lie beyond the standard model of particle physics and determine the role of the elusive neutrino in the evolution and fate of the universe.

2. Identify and characterize the dark matter that is believed to make up most of the matter in the universe. Seek to connect its existence to processes beyond the standard model.

3. Probe the origins of the heavy elements which are believed to have been made in the fiery deaths of massive stars.

4. Understand and master the process by which simple underlying interactions give rise to complex phenomena.

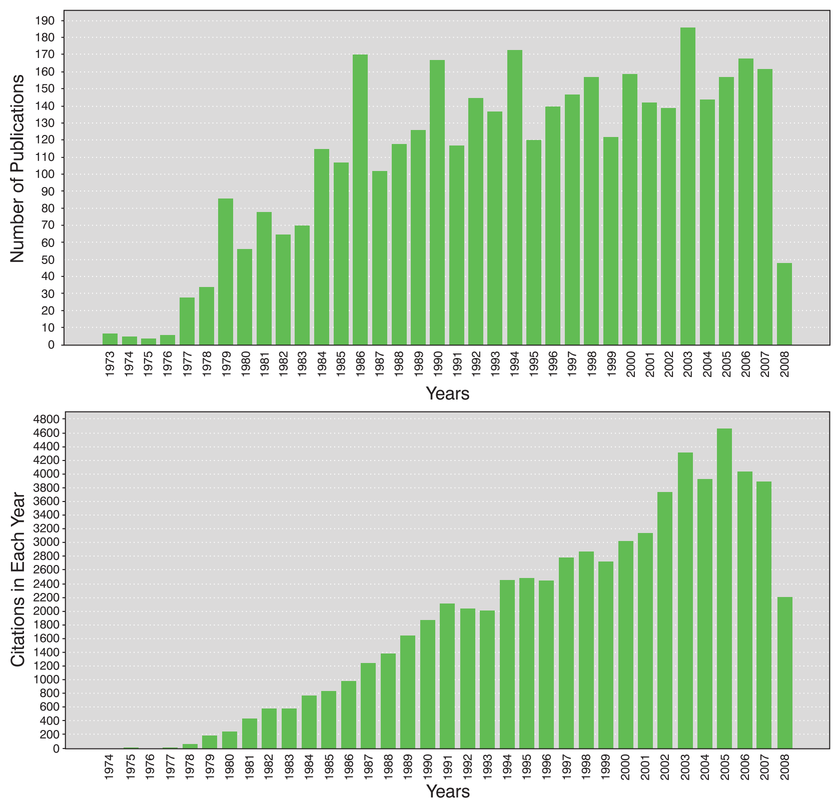


Figure 2: TRIUMF publications and citations since 1973 and 1974 respectively. The TRIUMF science program has produced 900 scientific publications in the last 5 years and more than 4,000 since 1973. NOTE: at the time of preparation, totals for 2008 were not yet available.

5. Identify and control the underlying biochemical and biological mechanisms that contribute to the onset of neurological disease or lead to cancer

TRIUMF's unique capabilities and resources allow Canada unprecedented access to these compelling topics. For instance, through ISAC at TRIUMF and ATLAS at the LHC, Canadians are able to probe the particle and nuclear physics of the first 400,000 years of the history of the universe as well as the ongoing stellar furnaces that power the stars and create the heavier elements found on earth and elsewhere around the universe. The formation of heavy atomic nuclei and our understanding of the fundamental physics behind the structure of nuclei are areas where we seem to be on the edge of much deeper understanding, where important measurements are within our grasp. Additional discussion of these five scientific drivers is provided in Section 2.5.

Advantage: Enabling and Equipping the Next Generation of Leaders

TRIUMF will contribute to the development of Canada's students and science and technology workforce in the following ways:

- Attract international scientists and students to work at TRIUMF;
- Enhance Asia-Pacific scientific personnel exchange;
- Create undergraduate and graduate student research opportunities;
- Establish initiatives to attract and retain talent from traditionally under-represented communities;
- Increase the engagement of Canadian universities in the TRIUMF program; and
- Participate in international student research exchange.

TRIUMF attracts talent from around the globe to Canada: more than 500 top graduate students, post-doctoral fellows, and researchers perform research at TRIUMF each year. For example, TRIUMF has recently recruited two of the world's most elite scientists from the United States and Germany, respectively, to lead core programs at the laboratory. TRIUMF also hosts major international conferences that attract the international science and technology community to Canada. Nearly 600 accelerator physicists will attend LINAC08 in Victoria. In 2009, the International Particle Accelerator Conference will attract 1,500 scientists to Vancouver, and, in 2010, 800 physicists will attend the International Nuclear Physics Conference, also in Vancouver. Not only do TRIUMF conferences support the Canadian tourism industry, they also showcase Canada as a premier destination for advanced research and technology.

TRIUMF is a high-tech engine of employment and training. It supports over 350 regular, full-time scientific and technical staff. The laboratory is a common destination for graduating engineers and technicians because the challenging technical environment ensures competitive training. These highly

PEOPLE

JON STOESSL

Professor
Director, Pacific Parkinson's Research Centre

Jon Stoessl received his M.D. from University of Western Ontario (UWO) in 1979, followed by an internship at McGill University, and a neurology residency at UWO. In 1984, he moved to the University of British Columbia and spent two years working with Donald B. Calne and the PET program.

Dr. Stoessl pursued further training in neuropharmacology in England after which he joined the faculty at UWO. In 1996, he returned to UBC, where he currently directs the Pacific Parkinson's Research Centre, which uses PET as its major research tool to investigate the causes of Parkinson's, the basis for complications of advanced disease and its treatment, and the role of dopamine in signaling reward and expectation. The Centre's research is supported by a Team Grant from the Canadian Institutes of Health Research, a Research Unit Award from the Michael Smith Foundation for Health Research, a Centre Grant from the Pacific Alzheimer Research Foundation, and numerous operating grants.

The Centre's research program is inextricably linked with TRIUMF's Life Sciences program and heavily dependent upon its expertise in the development, production, and delivery of radiotracers.

Jon holds a Tier-1 Canada Research Chair. In 2007, he was appointed a Member of the Order of Canada. ■

Early Cyclotron Era

First new pion/muon beam line, M13
Pion cancer therapy program starts
1979

Prince of Wales starts medical isotope flow
PET camera construction begins (2nd in Canada)
TPC built to study rare decays (1st use in an experiment)
1980

CARL SVENSSON

Professor, University of Guelph

Carl Svensson received his B.Sc. and Ph.D. degrees in physics from McMaster University in 1995 and 1998, respectively. His Ph.D. thesis, "Collectivity in A ~ 60 Nuclei: Superdeformed and Smoothly Terminating Rotation Bands," used the Canadian 8π Gamma-Ray Spectrometer at the Tandem Accelerator SuperConducting Cyclotron facility at the Chalk River Laboratories, as well as the US Gammasphere Spectrometer, to study the microscopic structure of collective motion in nuclei. Following a post-doctoral fellowship at Lawrence Berkeley National Laboratory, Dr. Svensson joined the faculty at the University of Guelph in 2001.

Drawn by the unique research opportunities available at TRIUMF, Dr. Svensson was instrumental in relocating the Canadian 8π Spectrometer to TRIUMF and establishing it as a major international user facility at ISAC-I. In 2003, he and collaborators from TRIUMF and six Canadian universities received a C$8.063M six-year Major Installation Grant from NSERC to construct TIGRESS experiments at ISAC-II.

Carl is the winner of the John Charles Polanyi Prize in Physics (2001), a prestigious E.W.R. Steacie Memorial Fellowship (2008), and the Herzberg Medal (2008). ■

skilled personnel then move on to successful careers in other sectors of business. TRIUMF trains the next generation of leaders; it attracts students to Canada to learn from the best. More than 50 students per year participate in on-site internships and co-op programs.

TRIUMF proposes to expand its ability to attract, train, and retain highly skilled talent for Canada, doubling the present number of about 500 students and scientists per year who perform research at the facility. First, with the proposed expansion of the capacity and capability for rare-isotope beams experiments, TRIUMF will attract the best and brightest international students the Canadian university program. Second, the construction of the e-linac and the addition of the dedicated actinide beam line, TRIUMF will become a premier facility in the world for nuclear physics and thereby a destination of choice for workers in science, technology, engineering, and medicine.

In addition to these two programs, TRIUMF's programs in modern GRID computing for the LHC and nuclear science will prepare personnel for high-paying careers in information and communication technologies and nuclear power and engineering.

> "At the recent National Summit on American Competitiveness, retired chairman and chief executive of IBM Louis Gerstner remarked that, "In a knowledge-based global economy, skills are what matter" in the long run."

Advantage: Bridging the Academic and Commercial Sectors

TRIUMF will contribute to Canada's entrepreneurial competitiveness in the following ways:

- Triple the economic impact from technology transfer and commercialization with partners such as Advanced Applied Physics Solutions, Inc. (AAPS);
- Forge new industrial partnerships related to TRIUMF's world-recognized leadership in medical-cyclotron design;
- Establish a major new partnership with India in accelerator science;
- Connect radiotracer know-how with drug-development activities at the major pharmaceutical companies; and
- Establish a new partnership with MDS Nordion in radiotracer development.

The TRIUMF science research program serves as a springboard for developing innovations that lead to the commercialization of research. A number of Canadian companies, MDS Nordion, D-Pace, PAVAC Industries, ACS, and

AAPS, have benefited from the expertise TRIUMF has developed. For instance, the BC-based company D-Pace was started after Dr. Morgan Dehnel graduated with his Ph.D. based on work at TRIUMF. D-Pace now licenses TRIUMF-developed technologies and has contracted to provide a dozen high-value ion sources to Japan. This partnership won national recognition in 2007 with the NSERC Synergy Award. TRIUMF's "nose" for good business also led to a renewal of its highly successful, 30-year-old relationship with MDS Nor-

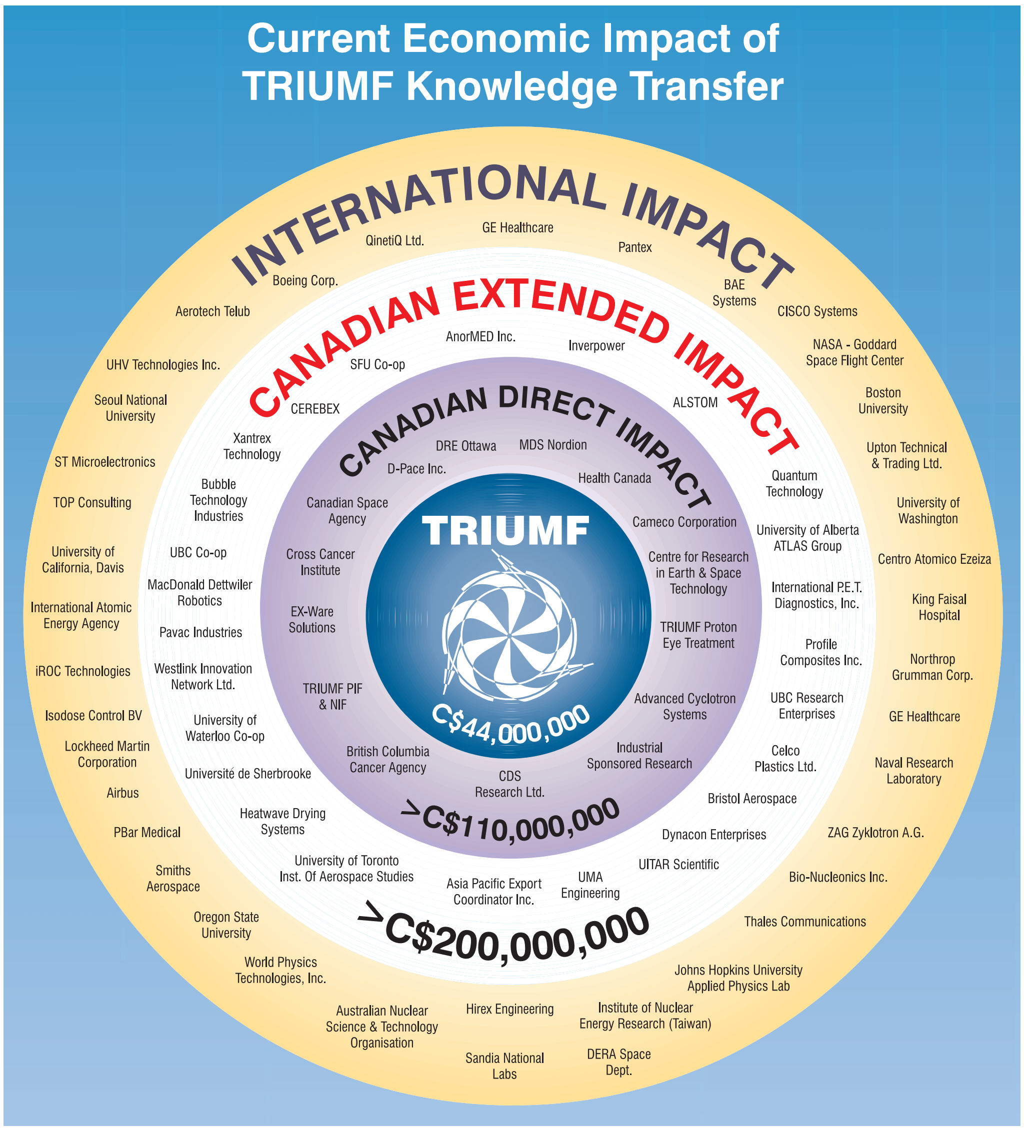


Figure 3: The innermost ring shows the annual public investment in TRIUMF via the NRC contribution agreement. This investment results in jobs, purchase orders, and other contract work. The surrounding rings show the activities resulting from TRIUMF programs that increase the sum of economic activity. For example, in the Canadian Direct Impact domain, fees paid by the BC Cancer Agency to purchase FDG for PET scans are included.

THE UNIVERSITY OF TORONTO

Particle Physics Group

The University of Toronto (U of T) has been involved with TRIUMF since the laboratory's founding in the 1970s and in 2000 joined the TRIUMF Joint Venture as a full member university. The group has played key roles in both TRIUMF's development and its leadership with roles during the development of TRIUMF's nuclear astrophysics program.

In the 1990s, when U of T reduced its effort in nuclear physics and built up a larger effort in particle physics, TRIUMF provided infrastructure support for the large instruments needed for these experiments. In particular, TRIUMF has provided significant resources to the construction of the ATLAS detector, the highest priority particle physics experiment for both U of T and Canada. From 1995 to 2007, U of T's Dr. R. Orr served as the ATLAS Canada spokesperson. The ATLAS Tier-1 Data Centre sited at TRIUMF was launched in 2006 with support from the Canada Foundation for Innovation (CFI) and the B.C. Knowledge Development Fund. The U of T was one of the principle supporters for this initiative and serves as a national institutional user.

Members of the Group have played various roles within TRIUMF governance. As one example, Dr. P. Sinervo was chair of the NRC Advisory Committee on TRIUMF from 1999 to 2004 and has been a member of its Board of Management since 2004. In 2002, TRIUMF and the U of T agreed to create a joint appointment, currently filled by Dr. P. Savard (pictured above), who works on the ATLAS project.

dion and a second Synergy Award. The TRIUMF/MDS Nordion partnership for the production and sales of accelerator-based medical isotopes generates more than \$25-\$30 million of private revenue each year. The next generation of business deals, commercialization agreements, and innovations is at hand.

> "The standard of living in Western Europe and the United States has been sustained for several decades by new products, services and businesses, the result of leading-edge research and development. — **Bill Destler, President of Rochester Institute of Technology, quoted in "A new relationship," *Nature* 453:12 853 (2008).**"

The impact of TRIUMF's activities on the economy of Canada is quite broad. In terms of direct impact, the high degree of leveraging applied to the public investments is impressive. Figure 3 captures this type of direct economic impact on several different scales, showing that a federal investment through NRC of about \$44 million stimulates more than \$200 million of economic activity for Canada. In addition, Figure 4 shows TRIUMF 5-year accumulated economic impact, exceeding more than \$500 million in 2005–2010 and projected to double to more than \$1 billion in the next five years.

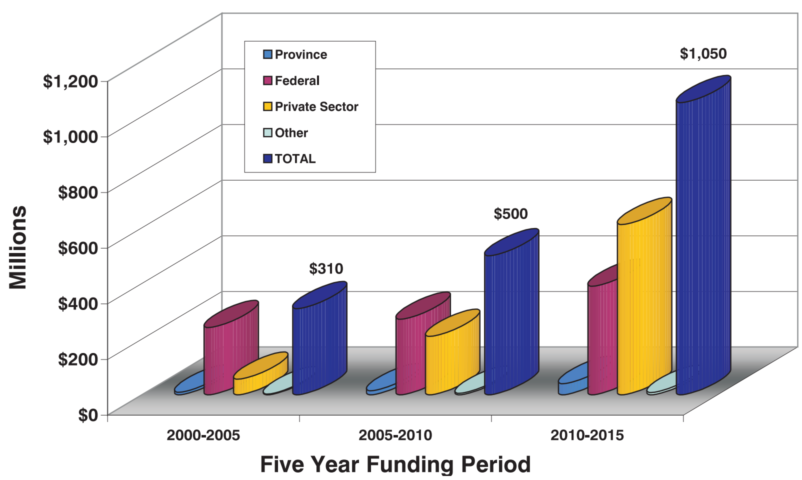


Figure 4: History of TRIUMF-driven investments, separated by source, in five-year periods, including provincial contributions and federal investments by NRC, CIHR, NSERC, and CFI. The private sector category totals activity directly attributed to TRIUMF, such as sales of medical isotopes by MDS Nordion using contract staff from TRIUMF.

2.3

Gateway to Global Science & Technology

TRIUMF serves as a key broker for Canada in global research in particle, nuclear, and accelerator physics. In addition to its core research programs, TRIUMF provides the scientific and technical staff needed to support Canadian scientists and students performing experiments at international facilities, such as the LHC at CERN, in Geneva, Switzerland, and the J-PARC facility in Japan. In return, scientists come from abroad to TRIUMF and Canada to conduct experiments and share their research. These international collaborations engage Canadian scientists and allow Canadian industry to benefit from the rapid advances and progress made in research from all over the world (see Figure 5). These collaborations include university groups, research organizations, and the high-tech international industry.

While the world community works collaboratively, there is also intense international competition in leading fields. For TRIUMF, this is particularly true for the ISAC program (see Figure 6) where rare-isotope beam physics is recognized as having enormous discovery opportunities, commercial potential, and security implications. As a result of this potential, France, Germany, Japan, and the United States are constructing new facilities at considerable expense. The European Union is also considering a major facility named EURISOL. TRIUMF has leading detector facilities and the knowledge to produce rare isotope beams, but the window of opportunity to exploit ISAC before the world catches up is limited. TRIUMF must exploit its current facilities while building the next generation of rare-isotope beam drivers during this five-year plan to keep Canada at the forefront of international rare-isotope science for the next decade.

> The 2008 report of the Working Group on Nuclear Physics to the OECD's Global Science Forum stated, "The new facilities and upgrades that are now under consideration will ensure the continuing success of nuclear physics, with an estimated investment worldwide of four billion US$ during the next decade. The discoveries and technical advancements that will result from the implementation of the global roadmap for nuclear physics will make important contributions to other scientific fields and national and societal priorities. The forefront research facilities in the global roadmap are needed to attract and train a next generation of scientists for research and national needs."

Figure 5: TRIUMF's partners around the world.

Figure 6: Leading international rare-isotope beam facilities. The proposed US FRIB facility has not yet been sited.

Young National Laboratory Era

NRC adds Tech Transfer to TRIUMF mandate
Regina becomes associate member
1989

TR30 installed
ISAC design starts
1990

2.4

A Proven Track Record

Review and oversight processes have been put in place to ensure that TRIUMF's responsibilities are being carried out. These reviews show that TRIUMF meets and exceeds expectations. The extensive system of advisory committees, well populated by world-leading experts, is a key mechanism for TRIUMF to remain at the forefront of global research activities. Each committee meets at TRIUMF, takes written and oral testimony, and then prepares a written report for the director or the president of the NRC summarizing their views on the present program and recommendation for moving forward most effectively. These meetings are typically public and well attended by members of TRIUMF's scientific and technical staff as well as collaborators from nearby universities and research centres. These advisory committees serve as an effective conduit for keeping TRIUMF scientists abreast of global advances and vice versa. For instance, the Accelerator Advisory Committee, presently chaired by Mark de Jong of the Canadian Light Source, provides technical and strategic advice to the TRIUMF accelerator division as it undertakes projects both on- and off-site. The Canadian physics community also has a direct connection to the laboratory through the Policy and Planning Advisory Committee, composed of members from 15 Canadian universities. The local community stays involved via a Citizen's Advisory Board (see Box 2.1).

The Government of Canada provides funding for TRIUMF through a Contribution Agreement between TRIUMF and the NRC. TRIUMF is accountable to NRC for all its financial and scientific activities, and the Contribution

Agreement identifies specific obligations TRIUMF must undertake and complete successfully within NRC-specified timelines (see Table 1). TRIUMF reports to NRC every four months on its success in meeting the Contribution Agreement deliverables and reports the expenditures incurred to do so. In addition, TRIUMF submits an annual audited financial report to NRC. TRIUMF also reports on its scientific and financial progress in meeting its obligations to the Advisory Committee on TRIUMF (ACOT), which meets twice a year. The Agency Committee on TRIUMF (ACT) also meets semi-annually to review TRIUMF's financial progress and technology transfer activities. The Peer Review Committee meets once every five years and reports to NRC on all TRIUMF activities carried out during the five years under review.

The TRIUMF Five-Year Plan proposes a common vision to all partners, and its success will depend on the support of all stakeholders. Each agency faces its own set of objectives, constraints, and funding mechanisms. TRIUMF's success is attributable to the past success of these partnerships. For example, the

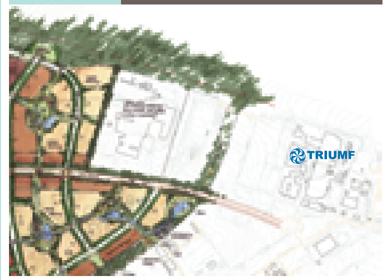
NRC Deliverable	TRIUMF Completion
Completion of 20 medium beta accelerator cavities by the end of 2006.	All 20 cavities were completed early in 2006.
Completion of 20 high beta accelerator cavities in 2009.	TRIUMF has qualified the supplier and ordered the 20 cavities. On March 31, 2008, the cavities began arriving on site and installation and testing began. The project has a planned completion date of early 2009.
Completion of the accelerator cooling system in 2008.	Cooling system was fully installed, tested and commissioned by early 2008.
Commission of one experimental location to provide unique exotic isotope beams to approved high profile experiments by the end of 2006.	The MAYA detector was installed on SEBT2 in 2006 and a successful experiment was performed in early 2007.
Commission 3 experimental locations to provide unique exotic isotope beams to approved high profile experiments by the end of 2009.	The 3 experimental locations are: • SEBT2 – MAYA detector installed and ran an experiment in 2007 • SEBT3 – TIGRESS ran an experiment in the fall of 2007 • SEBT1 – HÉRACLES is being refurbished and will be installed on SEBT1, which will be constructed in 2008. The first experiment will be in early 2009. A fourth experimental location is planned. • SEPT3B – is scheduled for completion in 2009. EMMA detector is under construction and its first experiment will take beam in late 2009.

Table 1: TRIUMF's deliverables for 2005–2010 as described in the NRC Contribution Agreement.

ATLAS Tier-1 Data Centre was initially funded by CFI in 2007. The ATLAS-Canada collaboration chose to site the Centre at TRIUMF because of the existing infrastructure and technical expertise as well as its synergies with the experimental program. The province of British Columbia provided matching funds in addition to the industrial vendor IBM. CFI provided operating funds for about five years; these funds covered the costs of commissioning and preliminary operations. As the CFI award period ends in 2011, responsibility for the ATLAS Tier-1 Data Centre will naturally transition to TRIUMF and its university members. As proposed in this plan, support for the operations and personnel costs of the Centre are requested through the NRC Contribution Agreement. When the ATLAS experiment begins collecting data in late 2008, NSERC-funded faculty and research scientists from around Canada will rely on the Centre to conduct their work. TRIUMF serves as the natural vehicle for what is truly recognized as a joint initiative of CFI, NRC, NSERC, and the Government of British Columbia.

Historically, the BC provincial government has supported the capital infrastructure requirements for buildings and physical plants needed for TRIUMF. The proposed five-year vision depends on a continuation of this agreement: the expansion of the nuclear medicine program requires a new building; the planned growth of the ATLAS Tier-1 Data Centre requires serviced floor space; and the proposed new beam lines require an underground tunnel to connect the main accelerators with the experimental end stations. It is anticipated that these elements of this TRIUMF Five-Year Plan will be supported through negotiations with the provincial government.

Box 2.1



Part of the Community

TRIUMF is located on the south campus of the University of British Columbia (UBC). Its two closest neighbours are also research institutes: the NRC Institute for Fuel Cell Innovation and FPInnovations. Nestled alongside the Pacific Spirit Regional Park, this industry, technology, and innovation area is attracting a growing number of Vancouver residents. UBC has recently constructed new homes for a neighborhood.

TRIUMF is an active and responsible member of this expanding community. TRIUMF staff members live in the area and serve as informal TRIUMF ambassadors for the residents and their civic association, the University Neighbourhoods Association (UNA). Many residents have already taken a TRIUMF tour or attended a Saturday morning lecture. During summer 2008, TRIUMF and UNA launched an evening lecture series held in the neighbourhood's Old Barn Community Centre. The lectures are aimed at a family audience and provide the residents a chance to learn more about TRIUMF's work.

In September 2008, TRIUMF will participate in the annual Barn Raising, at which more than 3,000 people are expected. In addition to contributing planning and logistical support, TRIUMF will present free public tours and demonstrations of physics and radiation safety.

TRIUMF has organized a Citizens Advisory Board, which will provide guidance and advice to the TRIUMF director to ensure that community concerns and ideas are addressed.

2.5

Scientific Motivation for the Plan

This section discusses each of the science questions in more detail, emphasizing the importance and relevance to Canada of the pursuit of these research thrusts.

1. What new physics lies beyond the standard model of particle physics? Does the elusive neutrino have a role in the evolution, and fate, of the universe?
2. What is the mysterious dark matter that is believed to make up most of the matter in the universe? Does it have a role in the processes beyond the standard model?
3. How and where are the heavy elements produced?
4. How do simple underlying interactions lead to complex phenomena?
5. What are the underlying biochemical and biological mechanisms that contribute to the onset of neurological disease or lead to cancer?

What New Physics Lies Beyond the Standard Model of Particle Physics?

For more than a century, physicists have sought a unified theory to explain all the fundamental forces and particles in the universe. The result is a stunningly successful theory that reduces the complexity of microscopic physics to a set of concise laws. Nevertheless, these same quantum ideas fail when applied to cosmic physics. Some fundamental pieces are missing; gravity, dark matter, and dark energy must have quantum explanations. Despite these deficiencies, the standard model of particle physics, which has been primarily tested at LEP and the Tevatron program at Fermilab near Chicago has successfully predicted new particles and their interactions to fantastic accuracy (see Box 2.2). Canada has had a key role in this work.

Without an additional ingredient, the standard model has difficulty explaining or even accommodating the non-zero masses of the matter particles and the weak force carriers. Theorists overcome this challenge using the Higgs mechanism, which gives the "vacuum" an energy density and properties to interact with massless particles to give them an apparent mass as their progress is slowed by "dragging" on the vacuum. This mechanism predicts the masses of the weak force carriers, but the masses of the matter particles are simply inserted into the standard model in an *ad hoc* way that leads one to assume there must be more fundamental interactions that explain how mass is created. Even with this trick, the standard model does not explain how interactions evolve at energies above the masses of the W and Z satisfactorily, referred to as the "Terascale" (see Figure 7).

Measurements currently constrain the Higgs mass to be less than about 200 GeV/c^2 and it should be directly observable at the LHC over the next few

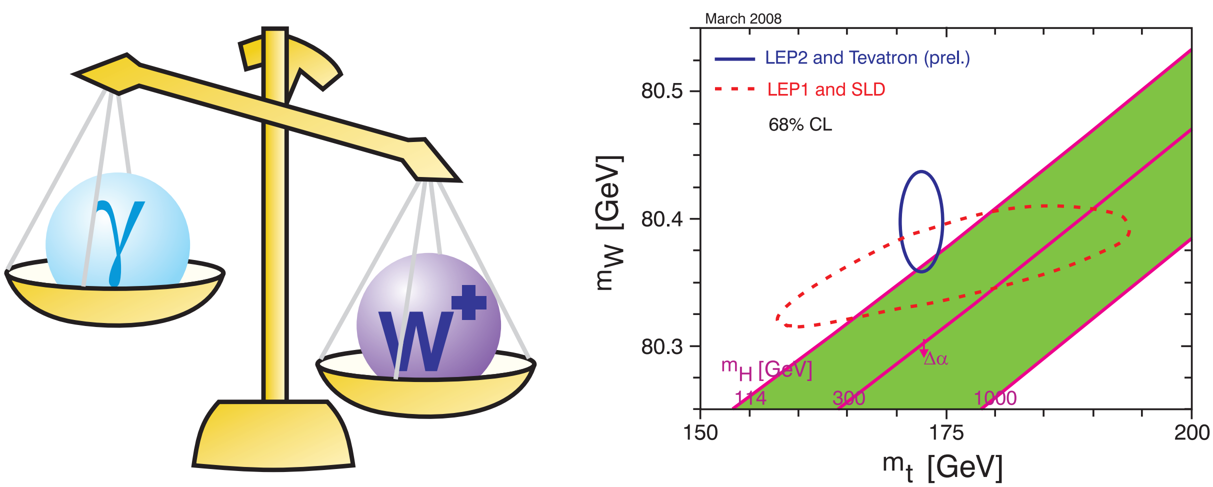


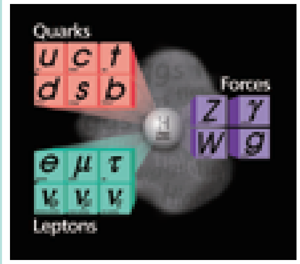
Figure 7: The Higgs mechanism gives mass to the elementary particles and, in turn, has its mass constrained by other measurements. Direct measurements of the W and top-quark mass are shown in the blue ellipse, while indirect constraints from precision measurements affected quantum-mechanically by the W and top masses are contained in the red dotted region. Also shown are contours of Higgs masses, illustrating that the Higgs mass must be below about 200 GeV/c^2 for the standard model to be consistent.

years. The discovery of the Higgs would confirm that the standard model is the correct description of matter and forces at lower energies. Nevertheless, the standard model has too many free parameters to be satisfying: a theory is desired which can predict more of what we do observe and more of what is still beyond the reach of our experiments. It is also very difficult to keep the theory quantum mechanically stable if there isn't new physics within the energy reach of the LHC. Possible models of new physics include supersymmetry (which stabilizes quantum mechanics with new particles) or models with large extra spatial dimensions beyond the three presently known (which requires a completely new theory of quantum gravity that could be observable at the LHC). TRIUMF has been key to Canadian participation in LHC accelerator construction, and now hosts the ATLAS/LHC Tier 1 computing centre and Canadian ATLAS analysis centre. TRIUMF enables the more than 150 Canadian scientists, post-doctoral fellows, and students at 10 universities to be leaders in the most exciting era in fundamental interaction physics in decades.

Another recent success in experimental probes has been the confirmation that neutrinos have mass and that the different neutrino flavours mix. These observations from the Sudbury Neutrino Observatory (SNO) and Japanese Super Kamiokande experiments have revolutionized our understanding of the neutrino. While neutrinos must have non-zero masses to mix, we do not understand how they, or the other matter particles, acquire mass. Neutrino masses are much smaller than the masses of any other particles, and that seems unnatural. Two prongs of experimental neutrino physics are proceeding that will address the critical behaviour of this elusive particle: long-baseline neutrino beam measurements like the T2K project in Japan, and experimental searches for the conversion of neutrinos into their anti-particle in the SNOLAB project. The TRIUMF vision includes critical contributions to both these projects.

This scientific quest is inspiring and profound for many people and Canada's strong role in it attracts the best and brightest to join the research teams directly or to explore careers in science, technology, engineering, and mathematics. The mind-stretching possibilities regularly challenge the limits of technology in new ways that give rise to breakthrough innovations.

Box 2.2



Standard Model of Particle Physics

The standard model of particle physics has evolved over the past four decades with the goal of describing the universe at its most elementary level. The main ingredients are the "matter" particles, including the electron and the "up" and "down" quarks that make up the proton and neutron, as well as the force carriers such as the photon of electromagnetism. The electron has a partner called the "neutrino," which was first inferred from missing energy in nuclear decays, but which has since been observed in experiments both at accelerators and in deep-underground, low-background facilities such as the Sudbury Neutrino Observatory.

Matter particles may be grouped into three generations. These additional generations include heavier versions of the electron called the muon and tau lepton, each with its corresponding neutrino, as well as the strange, charm, bottom, and top quarks. The massless photon is now known to have not only massless counterparts called gluons, which mediate the strong force that holds protons and neutrons together, but also close siblings called the W and Z bosons that mediate weak nuclear interactions and have masses nearly 100 times larger than a hydrogen atom. The source of these masses is critical to our completion of the standard model. The missing piece is called the Higgs boson. If it exists, Canadian scientists will be members of the team who will observe it at the CERN Large Hadron Collider. U.S. Under Secretary for Science Raymond Orbach refers to the Higgs boson as the "discovery of the century." ■

In a report to the US government, committee chair and Princeton University President Emeritus Harold T. Shapiro wrote, "Particle physics plays an essential role in the broader enterprise of the physical sciences. It inspires US students, attracts talent from around the world, and drives critical intellectual and technological advances in other fields." **— National Research Council, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*, Washington, D.C.: National Academies Press, 2006, p. 2.**

What is the Mysterious Dark Matter that is Believed to Make Up Most of the Matter in the Universe?

Dark matter and dark energy are critical to our understanding of the evolution of the universe. Dark matter was first hypothesized as an explanation for

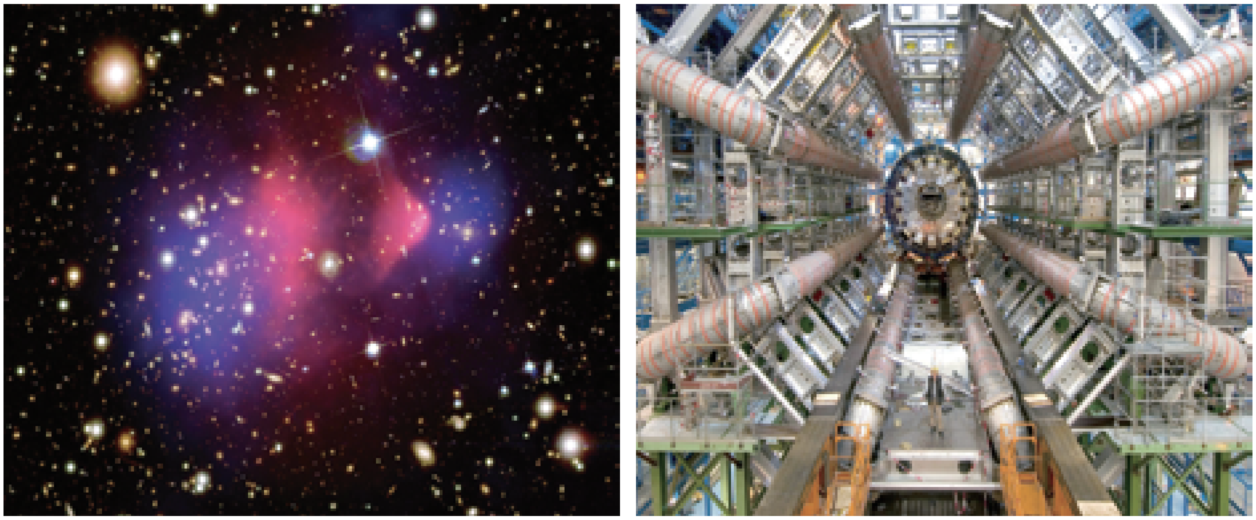


Figure 8: NASA composite image of the Bullet Cluster is shown on the left. The distribution of visible matter from X-ray observations is in red, and the total mass distribution of dark matter inferred from gravitational lensing of distant galaxies is in blue. The analysis is strongly indicative of dark matter dominating the mass of the cluster. The ATLAS detector under construction is shown on the right in this CERN image.

observed rotation curves of galaxies which defied ordinary gravity; more matter was present in the galaxies than was visible to our telescopes. The existence of dark matter has been more recently confirmed by studies of distant objects as shown in the NASA image of the bullet cluster in Figure 8.

We do not know the composition of dark matter even though it accounts for about 80% of the mass of universes, with the remaining 20% composed of stars, planets, and interstellar dust. Many studies of Big Bang cosmology have indicated that the dark matter must be composed of weakly interacting particles with masses in the range of a few hundred GeV/c^2 (1 GeV/c^2 is the mass of a hydrogen atom). This is an exciting prospect because detection of such particles is within the reach of our next generation of low-background underground experiments at SNOLAB.

New particles with masses near 100 GeV/c^2 could also be directly produced in the LHC. Indeed, theories of physics beyond the standard model, especially supersymmetry, contain new particles which would be exactly what is required to act as dark matter in the universe. This could lead to the tremendously exciting prospect of both measuring relic dark matter at SNOLAB while simultaneously producing and studying dark matter at ATLAS. TRIUMF will empower all of these Canadian researchers by providing the needed engineering and infrastructure resources in both of these pioneering projects.

This research thrust is driven by the basic human desire to know the universe; in addition to the intellectual and cultural benefits of pursuing the mystery of dark matter, Canadians can expect to reap the benefits of new ultra-sensitive detector technologies developed along the way.

> “As a national endeavour, particle and nuclear physics has significant value for Canada. The 2006 report *Perspectives on Subatomic Physics in Canada 2006–2016* of the NSERC Long-Range Planning Committee stated, “In this century, subatomic physics will change our understanding of the world and help establish our place in the cosmos. Canadians must participate in these discoveries.” **— Subatomic Physics Long-Range Planning Committee, *Exploring the Subatomic Realm*, Ottawa: Natural Sciences and Engineering Research Council, 2006, p. 1.**”

How and Where are the Heavy Elements Produced?

While scientists have made excellent progress over the past 50 years in determining the origin of the light elements, just where the heaviest elements were created remains elusive. That is, scientists cannot say for certain where metals

Box 2.3

Nuclear Physics and Rare Isotopes

Nuclear physics is the study of the principles that govern phenomena of the nucleus, and rare-isotope science is the study of the behaviour and interactions of those nuclei that are unstable, exotic, and rare. By studying physical processes that transform nuclei into other nuclei, scientists learn how to control and predict these phenomena and learn about the origins of the chemical elements in the universe. The study of rare isotopes allows scientists to expand the understanding of nuclear physics in two general ways: (1) rare isotopes present “extremes” to physicists and thereby leverage the testing of the basic understanding of nuclear physics, and (2) rare isotopes themselves play an important role in extreme environments like those inside stars, supernovae, or nuclear reactors.

The field of rare-isotope science can be described in the following way: Atoms that make up everyday matter on earth are predominantly stable: that is, they retain their identity in terms of their elemental and chemical nature (the number of neutrons and protons remains constant over time). The nuclei located at the centre of each atom comprise over 99.9% of the mass of the visible universe; however, many other nuclei can be formed and play important roles.

These nuclei are exotic isotopes (having different numbers of neutrons) of the stable atoms found on earth. These nuclei are quite rare because they are radioactively unstable and decay away into other more common nuclei. These rare isotopes still play an important role in the evolution of the universe, from allowing the sun to shine to fueling the explosions of supernovae. These nuclei, when created on earth, also have important applications such as in nuclear medicine. ■

like copper, gold, and silver come from. Even though the precise location of this heavy-element formation is unknown, it is believed to have taken place through the *r*-process, a series of rapid neutron fusion reactions in a very hot environment with an extremely high density of free neutrons that produces heavy, radioactive nuclei not occurring naturally on earth (see Box 2.3). In this process, once all the free neutrons were captured, the radioactive nuclei decayed, yielding roughly half of the elements heavier than zinc.

Although the rough outline of the *r*-process is adequately understood, the details, such as where and how it occurs, are not. For this reason, astronomical observations are crucial. For example, Figure 9 shows a supernova remnant located in the Large Magellanic Cloud, a small satellite galaxy of the Milky Way about 160,000 light years from earth. The remnant consists primarily of gas streaming outward from the centre at a speed of nearly 10,000 km per second. As revealed by the colours in the image, this supernova remnant contains vast amounts of hydrogen, oxygen, and sulfur. In addition to these elements, smaller quantities of the heavy elements such as gold produced by the rapid capture of neutrons are presumably dispersed by the explosion into the interstellar medium, where they mix with the ejecta of previous supernova explosions and enrich the stars that will form from this material. Measurements of the abundance patterns of the elements heavier than barium in the oldest stars in the Milky Way Galaxy reveal that these old stars exhibit very similar abundance patterns as newer stars while they pre-date the mixing and dispersion of the heavier elements by any other process. These striking similarities represent strong evidence that the *r*-process produces the heaviest elements in nearly the same way every time and that this production is associated with massive stars, whose short lives end in cataclysmic supernova explosions.

Figure 9: LMC N 49, an expanding remnant of a core-collapse supernova that exploded more than 100,000 years ago. Now more than 40 light years across, this expanding cloud of gas and dust carries the elements produced in the explosion into interstellar space where they can be incorporated into succeeding generations of stars and planets. Credit: NASA and The Hubble Heritage Team (STScI/AURA).

Montréal becomes full member | Synergy Award TRIUMF/D-PACE
Nigel Lockyer becomes Director of TRIUMF
First ISAC-II experiment, $^{11}Li(p,t)^{9}Li$ measurement with MAYA
Mass measurement of ^{11}Li (shortest-lived ever measured)

World Leading ISOL Facility Era

TUDA measurement of $^{18}F(p,\alpha)^{15}O$
TRIUMF forms AAPS, Inc. with CECR
R&D partnership with VECC, India begins
Mass measurement of ^{6}He (lightest ever so measured)
First proton beam on actinide target

2007 2008

Theoretical models of exploding stars have been investigated extensively, but all of the detailed models constructed to date have difficulties generating the conditions that lead to the r-process. These calculations require knowledge of the physical properties of nuclei that have never even been observed, let alone studied in detail. Only by systematically measuring the properties of the highly unstable, neutron-rich nuclei believed to take part in the r-process can one hope to arrive at a quantitative understanding of the relative abundances of the different elements produced and pinpoint the astronomical sites where it occurs. TRIUMF will contribute significantly to our understanding of the formation of the heavy elements by studying the masses and lifetimes of neutron-rich heavy nuclei produced with the proposed e-linac photo-fission driver.

> In 2008, the European Physical Society released a position paper on "Energy for the Future." Included in the report's recommendations was the following, "A research, development, and demonstration for the nuclear option [for electric power generation] also requires support for basic research on nuclear and relevant materials science, since only in that way will needed to find novel technological solutions be obtained."

Understanding the complex reaction mechanisms of nucleosynthesis will shed light on technological problems as diverse as nuclear-materials engineering, optimization of the fuel cycle in nuclear power plants, and modeling of non-linear, dynamical systems. Breakthroughs in this area can even address long-standing questions about the origins of life.

How Do Simple Underlying Interactions Lead to Complex Phenomena?

Complex phenomena are commonplace in nature, whether they are patterns of weather, the properties of solids, or the behaviour of the excited states of nuclei. Behind these complex phenomena, there are frequently very simple rules. For example, the basic interaction between electrons, and between electrons and atomic nuclei, is quite simple, but out of this simplicity comes the whole complexity of molecular and materials science. Two examples of TRIUMF's contribution to this quest are highlighted below. The example from materials science is the occurrence of superconductivity at liquid nitrogen temperatures (high-temperature superconductors) and the example from nuclear physics is halo nuclei (nuclei with neutrons orbiting a core nucleus).

Superconductivity

Electronic conductors (metals and semiconductors) are solids in which some of the electrons are free to move from atom to atom, accounting for many of their characteristic properties such as their high optical reflectivity and, of course, their electrical conductivity. In fact, in a pure, highly ordered crystal at low temperature, they can travel through thousands or even millions of atoms without scattering, either from other electrons or from the atomic nuclei. In some metals at even lower temperatures, however, the mobile electrons do begin to interact. Surprisingly, this interaction is often attractive in contrast to that between free electrons which is repulsive and leads to a pairing of electrons at a special kind of phase transition (like the condensation of water vapour to liquid) where the free electrons condense into a superfluid (a liquid with no viscosity) that conducts electricity with no losses at all, i.e., the material has become a superconductor. The attractive interaction that pairs the electrons in conventional (low-temperature) superconductors like mercury or niobium requires the medium of intervening atomic nuclei and results in electron pairs that have a simple symmetry called *s*-waves.

In some unconventional electronic conductors, however, the electrons are strongly interacting, even at ambient temperature. Such interactions often inhibit the mobility of the electrons and result in a material that is magnetic, with each of the localized electrons contributing as a tiny magnet to the overall magnetism of the material. Through chemical modification, it is possible to introduce mobile electrons into such materials. It is found that this rapidly destroys the static magnetism and yields rather poorly conducting metals or semiconductors; however, the conductivity occurs not through mobile independent electrons but through a fluid of strongly interacting, nearly localized electrons. In some very special cases, these electrons also exhibit a superconducting transition, which can occur at much higher temperatures than the conventional superconductors. In the case of the highest temperature superconductors, the mobile electrons reside in a square lattice of copper oxide, and the paired electrons have a more complex symmetry called *d*-wave. The unconventional symmetry of the electron pairs is clear evidence that the attractive interaction is not the conventional one involving only the underlying lattice of atomic nuclei. It is thought that the attractive interaction originates in the magnetic interactions that characterize the material in the absence of mobile electrons, but much remains to be understood.

> A 2007 report assessing the case for a next-generation rare-isotope facility in the United States concluded that, "Nuclear structure and nuclear astrophysics constitute a vital component of the nuclear science portfolio in the United States. Moreover, nuclear-structure-related research provides the scientific basis for important advances in medical research, national security, energy production, and industrial processing." **— National Research Council, *Scientific Opportunities with a Rare-Isotope Facility in the* United States, Washington, D.C.: National Academies Press, 2007, p. 3.**

Experiments done at TRIUMF's Centre for Molecular and Materials Sciences (CMMS) have been extremely important in the study of high-temperature superconductors and related "strongly correlated electron systems." For example, there are many questions about how an interface with another material or a free surface will modify the properties of such systems. For the copper oxide high-temperature superconductor, the *d*-wave electron pairing is destroyed by scattering from any interface that cuts the copper oxide square lattice diagonally. Such an exotic superconductor may seem unlikely, but similar complex magnetic superconductors have been found by another team of CMMS researchers using μSR.

Mastering the art and science of high-temperature superconductivity is key to eventually designing materials that would be superconducting at "room" temperature. Such breakthroughs would enable, for instance, huge savings in electrical-power transmission over the large distances from power generation plants.

Halo Nuclei

Although discovered two decades ago, halo nuclei are an exotic form of nuclear matter that continue to defy the considerable scientific efforts focused upon them. Only recently have intense beams at TRIUMF made many experimental investigations possible. Teetering on the edge of nuclear stability, the properties of halo nuclei have long been recognized as one of the most stringent tests of our understanding of the nuclear force. In such exotic nuclear systems, the binding energy of one or more nucleons is sufficiently low such that a "halo" of nuclear matter is formed in the classically forbidden region surrounding a tightly bound core. Lithium-11 belongs to a special category of halo nuclei called Borromean, after the Borromeo family's coat of arms symbol that shows three rings linked in such a way that breaking one link, frees the other two. That is, the two-body siblings formed by removing one neutron (^{10}Li) or the ^{9}Li nucleus (2n) are unbound as separate entities. Recently, interest in this archetypical two-neutron halo ^{11}Li has been renewed because of improved measurements of its halo-neutron correlation (the MAYA experiment at ISAC) and charge radius. The latter allows one to distinguish the tight core of protons and neutrons and the satellite neutrons of the halo.

The charge-radius determination was made using measurements of isotope shifts. This method uses state-of-the-art atomic physics methods, both experimental and theoretical, to probe the atomic nucleus. These experiments address key questions such as how big the ^{11}Li nucleus and its halo are, and how the halo neutrons correlate to each other and the core. However, the answers are limited by the knowledge of the mass of ^{11}Li. Because of conflicting experimental results, the knowledge of the mass of ^{11}Li has been historically poor. However, very recently, first measurement of the ^{11}Li mass using a new state-of-the-art Penning trap spectrometer was carried out at the TITAN facility at ISAC. Penning traps are the most precise devices for making mass measurements, but were until now not able to trap these light unstable atoms. TITAN holds two world records in this area: it has measured the shortest-lived and the lightest isotopes. With a half-life of only 8.8 milliseconds, ^{11}Li is the shortest-lived isotope whose mass has been so precisely measured. Using these results, a new two-neutron separation energy (which indicates how tightly the two halo neutrons are bound to the core) of 369.15(65) keV for ^{11}Li is obtained (see Figure 10).

Halo nuclei represent an extreme of nuclear matter that tests the mathematical models of nuclear physics in new ways. Improvements in understanding nuclei will shed light on material behaviour in high neutron flux situations such as the next generation of nuclear reactors. Insights derived from this research will contribute to the next generation of technologies that could incor-

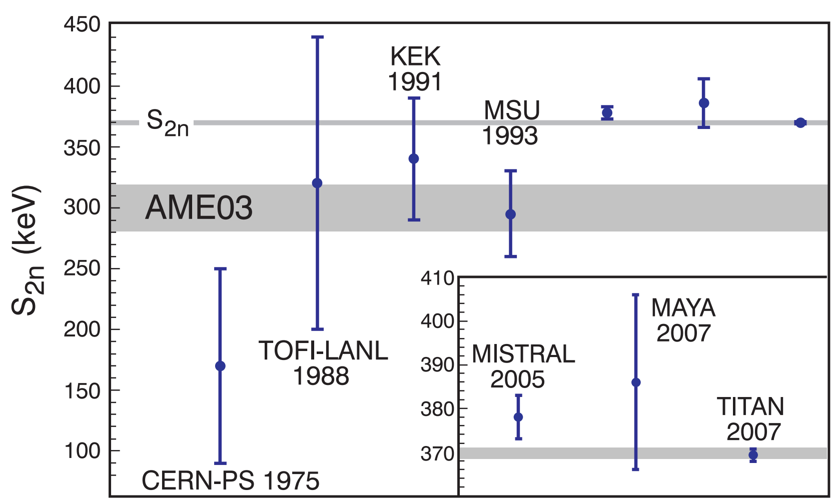


Figure 10: Measurements of the two-neutron separation energy made at TRIUMF in late 2007 using the TITAN experiment. These measurements not only show that the world average was inaccurate; they also dramatically improve the overall precision.

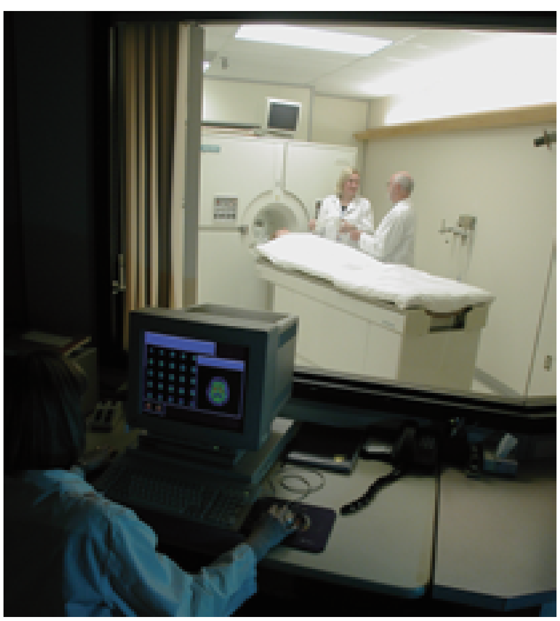
porate a small number of basic principles to deliver sophisticated performance (such as in nanoscale science and technology).

What Are the Underlying Biochemical and Biological Mechanisms that Contribute to the Onset of Neurological Disease or Lead to Cancer?

A nuclear medicine revolution is underway. Advances in biomarkers connected to radioisotopes are expected to allow the observation of the metabolism of disease and the detailed construction of tumours. TRIUMF is perhaps better positioned than any laboratory in the world to take full advantage of this revolution, which would include the production of a new generation of mini-cyclotrons, highly engineered target assemblies, as well as the radio and cold chemistry needed to generate the radiotracers. Two areas where radiotracers are making a large impact are Parkinson's disease and cancer imaging and therapy.

Parkinson's Disease

Parkinson's disease (PD) is one of the most common neurodegenerative disorders, with a prevalence of 1-2 in every 100 people over 65 years old in the Canadian population. The origins and the mechanisms of PD are not completely understood, although it is now recognized that gene mutations can



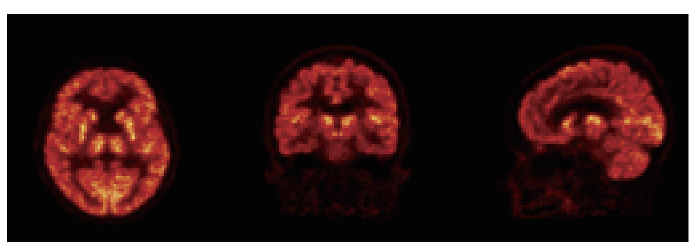


Figure 11: PET scan of a patient showing the exam room in a research clinic; a PET scan showing metabolic activity in the brain is shown on the right.

contribute to its development. PD is a complex disorder or syndrome where clinical symptoms appear when there is already significant degeneration of the dopamine producing neurons. No efficient treatment is currently available. Using PET scans (see Figure 11) to image subjects who are genetically at risk provides an excellent opportunity to investigate pre-clinical changes, with the ultimate goal of understanding the disease's etiology and associated neurochemical changes. This work might ultimately allow the use of neuroprotective therapies designed to halt or slow disease progress prior to symptom development in subjects at risk. TRIUMF's partnership with the Pacific Parkinson's Research Centre in this area has identified commonalities among Parkinson's, Alzheimer's, and even some mood disorders such as depression and compulsive gambling.

> PET scans using ^{18}F-FDG can spot various types of dementia early, according to results of a 548-patient study that appeared in the Journal of Nuclear Medicine. Using "optimized analysis" of FDG-PET scans "allows one to accurately detect and classify different types of dementia, including AD, frontotemporal dementia and Lewy body dementia at the very mild stages of disease," said the lead researcher from the New York University School of Medicine. **— Reuters News Release, New York University School of Medicine, 27 March 2008.**

Cancer Imaging and Therapy

Currently, approximately 3,000 patients (including several hundred children) each year benefit from ^{18}F-FDG produced by TRIUMF in partnership with the BC Cancer Agency (BCCA). The BCCA has purchased a TRIUMF-designed cyclotron from Advanced Cyclotron Systems, Inc. (a Canadian company) that should be commissioned in about one year and housed in its own facility.

With the recent addition of a research chair in functional cancer imaging and the purchase of a small animal micro-PET/CT scanner at the BCCA, the scope of the TRIUMF life sciences program will extend into cancer research. TRIUMF will be providing isotopes for pre-clinical and clinical research to BCCA, such as ^{18}F-Fluoroestradiol (for breast cancer imaging) and ^{18}F-EF5 (hypoxia imaging). A new BCCA program will be identifying key genes associated with breast cancer, using high-throughput genome-wide siRNA screening. By selectively inactivating individual genes through thousands of iterations, researchers can identify key genes that are essential for breast cancer growth and proliferation. The proteins associated with these genes can then be identified and characterized, and complementary radio-labelled probes can be designed to interact with these proteins for diagnostic or therapeutic purposes.

The combination of world-class expertise in isotope production using cyclotrons, basic target research, radiochemistry, instrumentation research, molecular biology of cancer, pre-clinical expertise in imaging, advanced cancer therapeutics, and clinical imaging research is unique. Both TRIUMF and the BCCA have expressed a keen interest in expanding their collaboration to advance cancer research.

Advanced clinical research using nuclear-medicine will drive breakthroughs in medical imaging, diagnosis, and therapy by revealing the biomolecular origins of neurological disease and cancer. Improved health care and substantial savings in disease treatment are expected by using PET imaging techniques for early detection.

> "We now have the opportunity to develop highly personalized medicine, in which each patient and disease can be individually characterized at the molecular level to identify the treatment strategies that will be most effective. Nuclear medicine techniques that image biochemical function *in vivo* can facilitate the development and implementation of such tailored treatment.
> **— U.S. National Academies, Advancing Nuclear Medicine through Innovation, Washington, D.C.: National Academies Press, 2007, p. 8.**"

2.6

Conclusion

TRIUMF is a unique vehicle for bringing together the public and private sectors for research and innovation. By taking on the technical challenges necessary to probe some of the most compelling questions in physical science, the laboratory stretches not only its own technical capabilities but also those of its commercial and business partners. The result is a robust network of organizations (see Figure 12) all striving for innovative breakthroughs using an unconventional mix of academic knowledge, the wisdom of experience, and sheer creative talent.

The plan presented is bold. It is a plan that will transport the laboratory to a significantly higher level of international recognition and leadership, which is what Canada needs if it is to be among the leaders in the quest for knowledge economies. It is a plan that will build on the success of the existing program, the high quality human capital available in Canada, and the potential of our universities' finest students. It is a plan that will attract the best and brightest from around the world to Canada to create a new team to execute the plan and move Canada forward. It is a plan that will meet the expectations of Canadians in their country.

> "The book on the 21st century is, of course, yet to be written, but if history teaches any lesson it is that no nation has an inherent right to greatness. Greatness has to be earned and continually re-earned. In fact, few nations, great or ordinary, have survived to enjoy the third century of their existence. Nations that take their technologic leadership for granted will be particularly vulnerable in this fast-moving global community... **— Mr. Norman Augustine, retired chairman and chief executive officer, Lockheed Martin Corp.**"

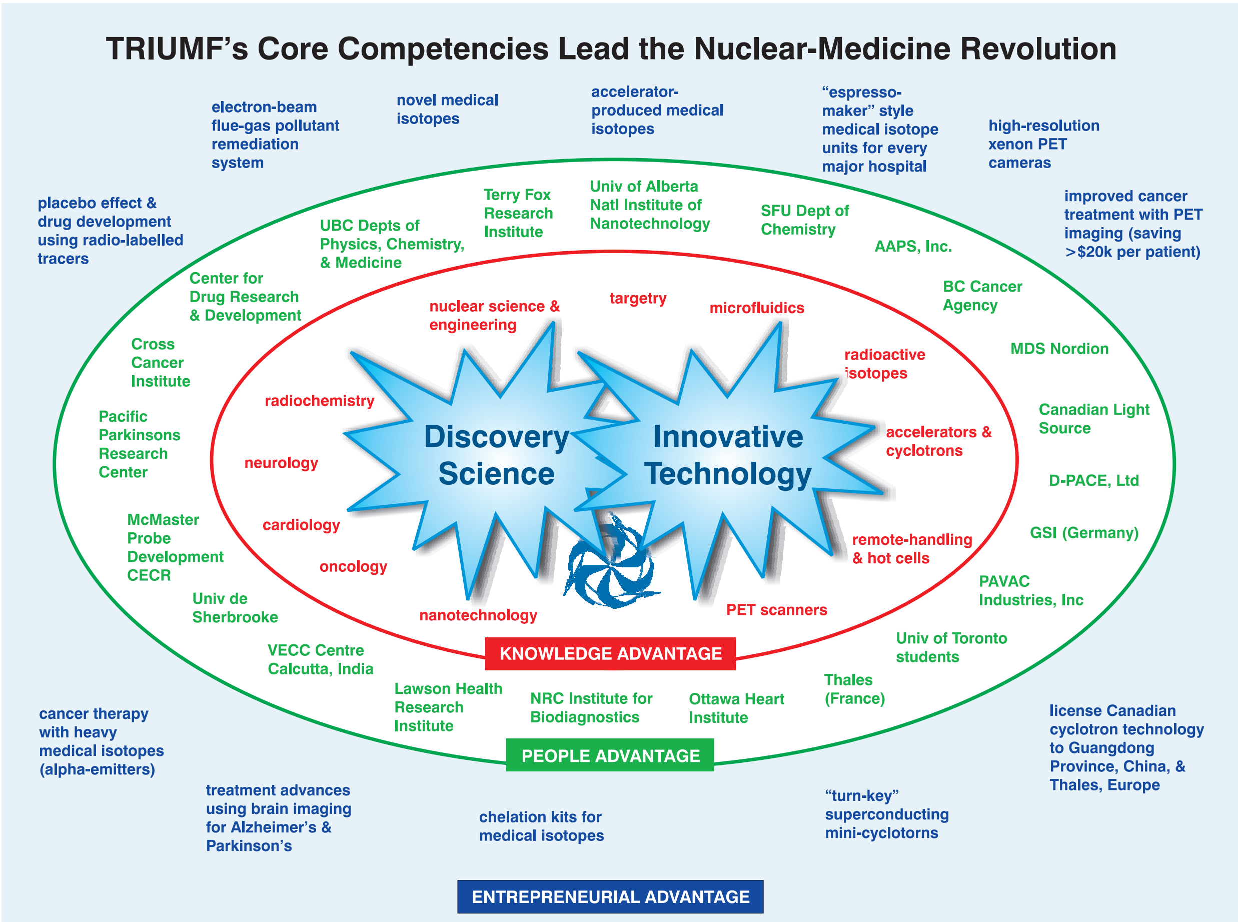


Figure 12: Example of TRIUMF's network of science and technology resources, partnerships and connections, and entrepreneurial opportunities in the area of nuclear medicine. Because of TRIUMF's core competencies in accelerators, isotopes, and radiochemistry, it is poised to make pivotal contribution to the Canadian revolution in nuclear medicine. This is only possible because of TRIUMF's network of partners, all of whom contribute to the progress of the science, technology, and engineering workforce of the country.