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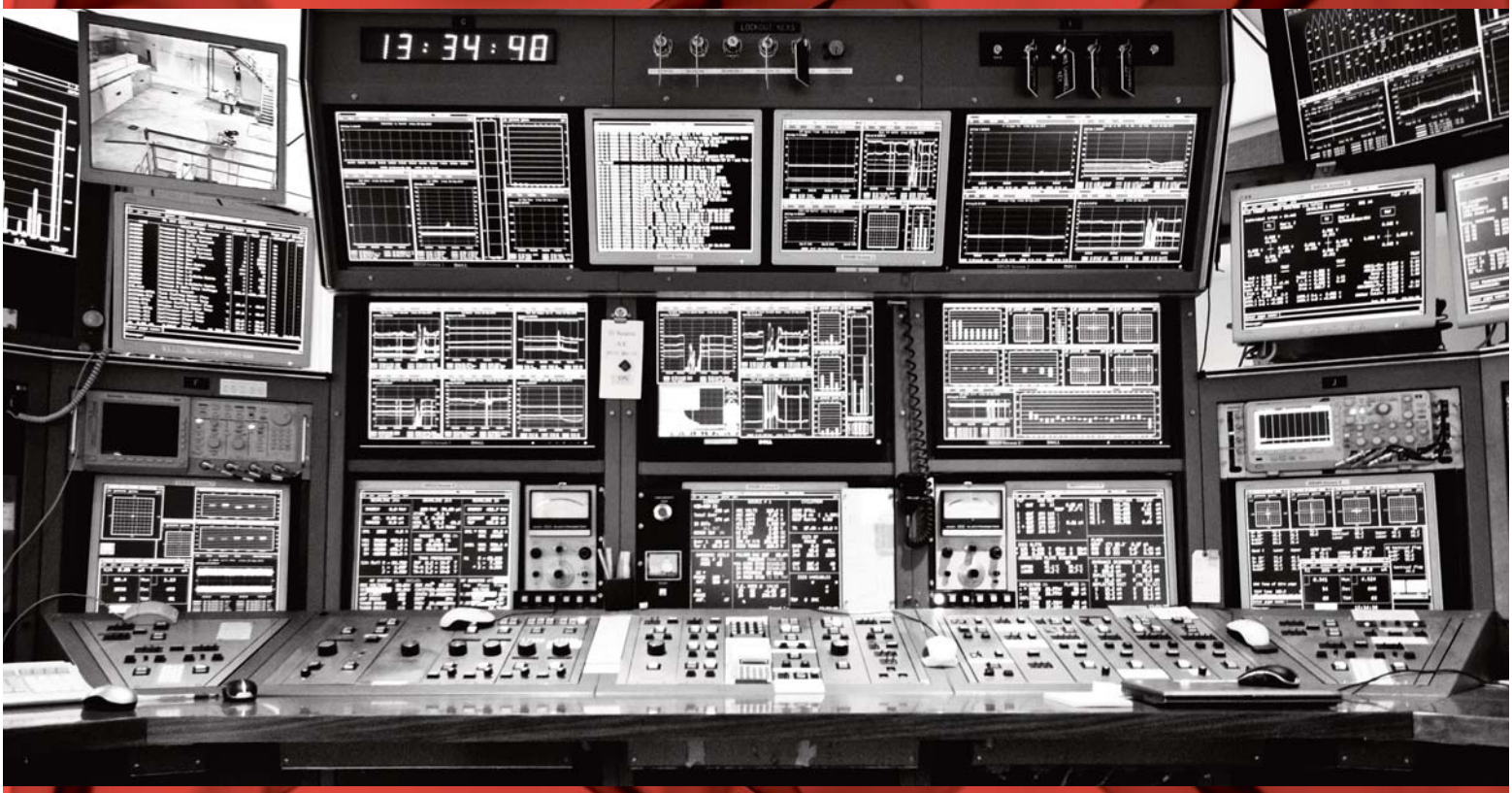
The Vision

Accelerating Science for Canada 2015–2020



Photographer: J. Benjamin

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TRIUMF is Canada's national laboratory for particle and nuclear physics, renowned for its groundbreaking contributions to accelerator-based physics, nuclear medicine, and molecular and materials science research. Established in the late 1960s in Vancouver by three British Columbia universities, TRIUMF is now owned and operated by a consortium of 18 Canadian universities. It collaborates with numerous universities, research institutes, and companies around the world.

Five-Year Plan 2015–2020 proposes the realization of the decadal vision laid out in 2008 with the last five-year plan. This next step in TRIUMF's success story delivers on the promises made and gives Canada world-leading capabilities to make discoveries, attract and retain global talent, and enhance international competitiveness. In this vision, Canada capitalizes on historical strengths in basic research in subatomic physics. It couples this with applications to nuclear medicine and molecular and materials science. Leading universities and companies in the country are joining forces with TRIUMF to fuel the knowledge economy with science, technology, and innovation.

This chapter reports on TRIUMF's track record of excellence and key accomplishments under Five-Year Plan 2010–2015. These results position Five-Year Plan 2015–2020 as a natural extension to fulfill the decadal vision and to position TRIUMF for the next decade. This chapter also examines TRIUMF's alignment with Canada's objectives in science and technology and discusses the resource requirements to address the proposed 2015–2020 milestones.

2.1 EXPLORING FOREFRONT SCIENCE

In the first moments after the Big Bang, matter and antimatter were formed from energy in equal amounts. In principle, all particles should have been annihilated with their antiparticles again, leaving nothing behind but energy. Obviously this didn't happen because we are left here to wonder what made one in a billion particles survive. Modern science tells us that the cause must lie in a small asymmetry in nature that led to the conversion of a tiny fraction of antiparticles to their partner particles, but what caused this asymmetry between matter and antimatter remains a mystery. Neutrinos, those elusive almost weightless particles streaming by the trillions through us every second, may hold the key to solving this puzzle.

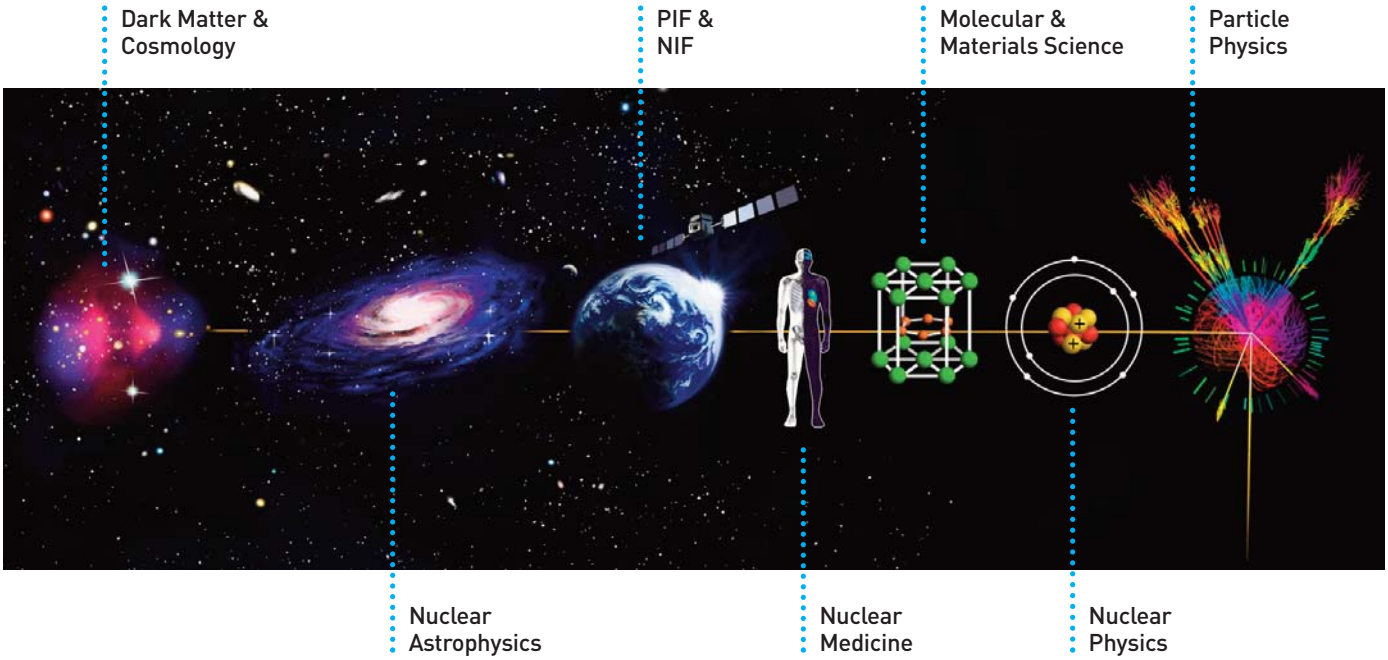
But there is more to the question "How did it all start?" One of the most fundamental open challenges in science is to discover from whence the elementary particles get their mass and why their masses stretch over such an enormous range (neutrinos are nearly massless while the top quark is nearly 175 times heavier than a proton). The mechanism that gives these elementary particles their mass, the so-called Higgs mechanism, was predicted decades earlier and was recently confirmed by the observation of a Higgs boson at the Large Hadron Collider (LHC) at CERN, thus establishing the last missing piece in the Standard Model of particle physics. However, we still do not know why particles have such vastly different masses.

There is clear evidence from astronomical observations that there has to be yet another type of invisible matter besides the particles we know, the so-called "dark matter." We still do not know what these mysterious dark matter particles are and yet we think that our Milky Way Galaxy is embedded in a sphere of these particles. We know that they are all around us but just barely interact with our normal visible matter aside from gravitational attraction. Various theories beyond the Standard Model predict dark matter

particles as well as a whole zoo of new particles in models named supersymmetry, composite Higgs, or technicolour. If confirmed, these models would essentially double the number of particle types that we know about. Together with university colleagues, Canadian scientists at the Perimeter Institute for Theoretical Physics and TRIUMF are working together on such theoretical models. Their predictions are being tested by experiments with large detectors deep underground at SNOLAB, and over the next five years these experiments will reach sensitivities that either allow for the discovery of dark matter particles or exclude a large fraction of theoretical models. Either way, something will change in our understanding of the universe. At the same time, the ATLAS experiment will try to detect the creation of dark matter particles produced in the collisions of the high-energy proton beams circulating in the 27 km circumference of the LHC.

Indirect hints for new particles may also become visible through high precision experiments that study properties of atomic nuclei or neutrons, looking for deviations of properties from those predicted in the Standard Model. TRIUMF is already carrying out the first high-precision experiments on atomic nuclei at its ISAC facility. The Advanced Rare IsotopE Laboratory (ARIEL) facility, when completed with two new isotope-production beam lines (one with electrons and one with protons), will drive multi-user capability and will provide the much larger amount of beam time needed to make ground-breaking discoveries possible. Likewise, the new Japanese-Canadian facility for ultra-cold neutrons (UCN) at TRIUMF will enable such studies on the neutron itself, a simpler system than complex atomic nuclei. The UCN facility will enable prize-worthy discoveries once it reaches its full capability.

As the universe expanded and cooled, protons and neutrons formed, followed by the first isotopes of the light elements hydrogen, helium, and lithium. This all happened in the first three minutes of the universe and it took about 400 million years until heavier elements from beryllium to iron were formed in the first stars. Stars continue to produce these elements to this very day, more than 13 billion years after the Big Bang. However, it remains unclear where in the universe the elements from iron to uranium were formed. This includes trace elements important for life (e.g., zinc, copper, selenium, iodine) and the majority of noble metals (e.g., silver, platinum, and gold). While we know that these elements have to be formed within a few seconds in cataclysmic events like supernova explosions of massive stars or mergers of



The spectrum of TRIUMF's research activities viewed through the lens of the size of the system being studied, well correlated with the evolution of the universe.

neutron stars, the models of such events don't reproduce our observations. A key to solving this mystery lies with the properties of very short-lived nuclei that are produced for brief moments in these explosive events. They are fittingly called rare isotopes. TRIUMF is already among the best facilities in the world to produce and study these rare isotopes and the electron linear accelerator (e-linac) at the heart of the ARIEL facility was conceived to solve this mystery.

TRIUMF's Five-Year Plan 2015–2020 presents a strategy that puts the laboratory at the scientific forefront, in a position to address—and even answer—these questions. This plan extends a vision for Canadian research that was launched in 2008. In this vision, Canada capitalizes on historical strengths in basic research in subatomic physics and couples these strengths with applications to nuclear medicine and molecular and materials science. This vision is becoming a reality: Canadian scientists are making their marks on the world stage with internationally recognized contributions to the discovery of the Higgs boson and crucial neutrino properties, to the trapping of antihydrogen, to advancing isotopes for science and medicine. They are developing and, successfully transferring advanced accelerator technology to the market. Canadian universities and research facilities are attracting talent from around the world.

2.2 ENJOYING A TRACK RECORD OF EXCELLENCE

Through a mixture of the curiosity-driven research of universities and the outcome-driven development of industry, TRIUMF has a track record for delivering high-quality results. Measured by progress on milestones in the five-year funding agreements, by meeting deadlines and expectations for Canadian participation in international projects, or by performance indicators that measure the outputs of scientific research, TRIUMF continues to be successful.

This section reports on TRIUMF's performance in two ways: (1) progress on achieving the five-year milestones identified in the 2010–2015 Contribution Agreement, and (2) performance indicators in each of the three areas of TRIUMF's impact—advancing knowledge, creating future leaders, and generating societal and economic growth.

2.2.1 PROGRESS REPORT ON MILESTONE DELIVERABLES FOR 2010–2015

The NRC Contribution Agreement for 2010–2015 defined a set of milestone deliverables for TRIUMF. Progress is reported at time of writing (September 2013). See Figure 1 for an overview of TRIUMF's research programs.

1) In Particle Physics, TRIUMF will support the Canadian community in alignment with the subatomic-physics Long Range Plan. In particular, TRIUMF will support extracting and analyzing the physics from the T2K experiment in Japan, the ATLAS and ALPHA experiments at CERN, and the PIENU experiment at TRIUMF.

TRIUMF has been effective in enabling the success of the Canadian particle physics community. For instance, the laboratory provided hardware, computing power, and intellectual leadership to Canada's participation in the Japan-based neutrino-physics experiment T2K. In July 2013, a TRIUMF post-doctoral researcher (Michael Wilking) was selected by the international collaboration to announce breakthrough

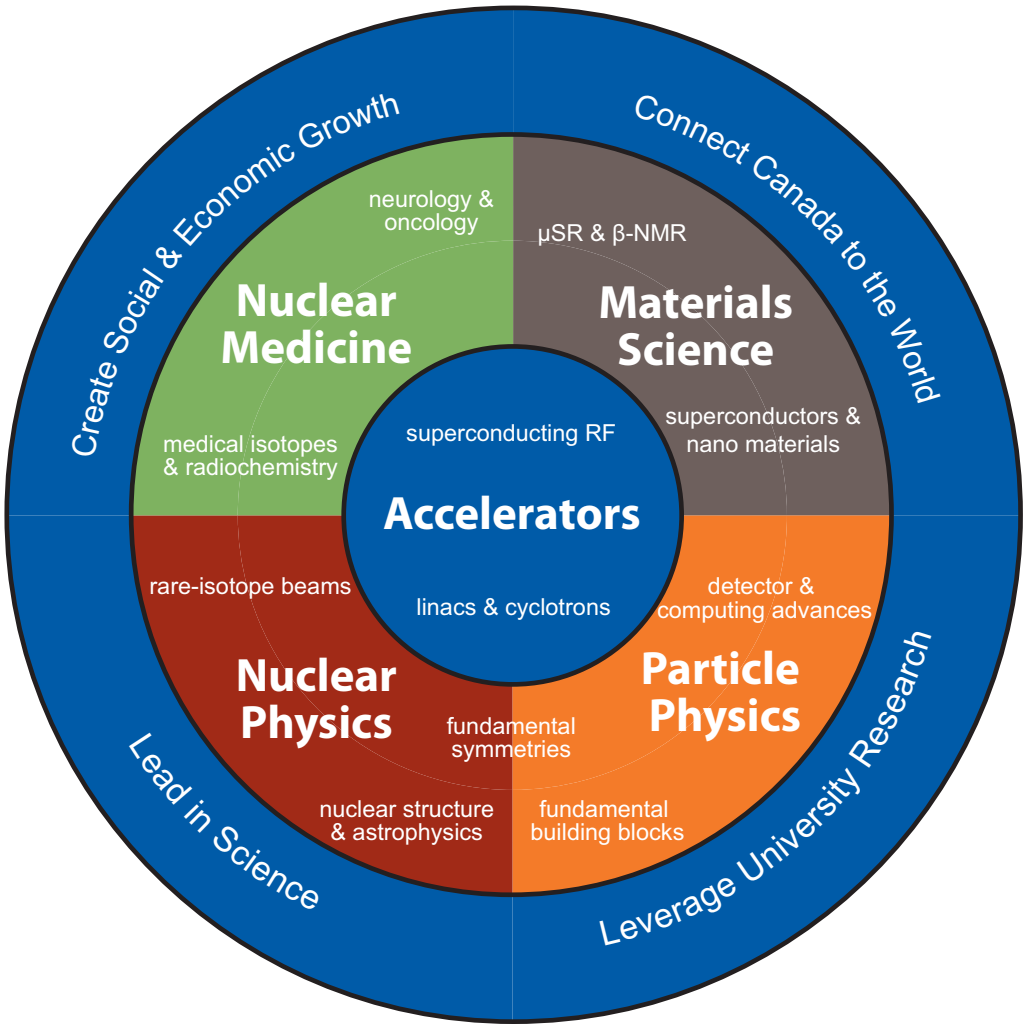


Figure 1: An overview of TRIUMF's research programs, driven by accelerators and delivering value for Canada.

scientific results at a physics conference in Stockholm, Sweden. Wilking reported T2K's unequivocal observation of the appearance of electron neutrinos in a beam of muon neutrinos created on the other side of Japan. This is the first observation of this phenomenon in such an experiment, and it opens the doors to the understanding of matter-antimatter asymmetry in the Universe.

For ALPHA, TRIUMF provided key intellectual and engineering leadership for the experiment's success in trapping antihydrogen, a result ranked as the top physics breakthrough of 2010 by Physics World magazine. The experiment seeks to establish if this antimatter behaves exactly like normal matter hydrogen; the Canadian team is led by TRIUMF scientist Makoto Fujiwara. Furthermore, TRIUMF spearheaded the subsequent measurement of the "chemistry" of antihydrogen atoms (i.e. the spectroscopy of electron energy levels) in mid-2012, and provided critical engineering support in late 2012 to complete a complex contribution of hardware for the next-generation of the experiment.

For the ATLAS experiment at CERN's LHC, TRIUMF played and continues to play a key role in Canada's involvement. CERN has become a global laboratory for particle physics with close to 10,000 scientists and students participating from more than 600 institutions in 113 countries around the world.

Not only has TRIUMF spearheaded Canadian participation since 1995 (with contributions to the accelerator, detector, and worldwide computing grid), but TRIUMF scientists have also led key physics analysis working groups within the collaboration of 3,000 scientists (and TRIUMF/SFU researcher Michel Vetterli now chairs the overall publications board of the entire collaboration and a TRIUMF/UofT researcher Pierre Savard will be convener of the ATLAS Higgs physics group starting in October 2013). The result was the confirmed discovery of a brand-new particle in July 2012, now identified as a Higgs boson (thanks in part to ground-breaking research by TRIUMF post-doctoral researcher Doug Schouten). The ATLAS Tier-1 Data Centre (operated by a consortium of universities led by SFU and hosted at TRUMF) provided critically needed computing resources in the final months before the announcement. The Tier-1 Centre is one of only ten such centres in the world. These centres are the foundation of the LHC Worldwide Computing Grid that supply data for the Tier-2 and Tier-3 centres at universities around the world.

2) In Nuclear Physics, TRIUMF will support the Canadian and international community in alignment with the subatomic-physics Long Range Plan. In particular, TRIUMF will develop rare-isotope beams from actinide targets required for the ISAC experimental program. TRIUMF will complete the installation and commissioning of EMMA and IRIS by 2013.

TRIUMF provides rare-isotope beams to the global nuclear physics community. Since April 1, 2010, TRIUMF has delivered close to 8,000 hours of isotopes for nuclear physics including several running periods each year using exotic heavy isotopes derived from actinide targets. A number of high-profile results were achieved. TITAN has been very productive with 13 publications since 2010, including internationally highly recognized mass measurements of very neutron-rich calcium isotopes demonstrating the relevance of three-nucleon forces in heavy nuclei. The installation and commissioning of IRIS was completed in 2012, and first experiments with the halo-nucleus lithium-11 were carried out. Experiments with TUDA and DRAGON capitalized on the high-intensity fluorine-18 beams to study the nuclear reactions in Nova explosions. TITAN, the 8π spectrometer and laser spectroscopy were used in a concerted effort for precision studies of super-allowed beta-decays to test fundamental symmetries of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix. First trapping and laser spectroscopy were performed on francium isotopes, critical for precision experiments searching for physics beyond the Standard Model. The magnets and high-voltage electric dipoles required for the EMMA experiment have been delayed by the European vendor. TRIUMF has recently received the last components and will finish the assembly and commissioning of the experiment in 2014.

TRIUMF STUDENT IS RUNNER-UP FOR "CANADA'S SMARTEST PERSON"

17 March 2012

In March, TRIUMF research assistant Laura Suen competed and placed runner-up in the CBC television special "Canada's Smartest Person" next to CFL defensive linebacker Peter Dyakowski. Laura was compelled to try her hand at the competition given her incredible breadth of experience: at 23, she holds separate Bachelors degrees in journalism, physics and cellular biology, as well as minors in economics and mathematics. At TRIUMF, Suen works with the ALPHA-Canada collaboration adding a laser spectroscopy system to the ALPHA experiment at CERN for the study of antihydrogen. "TRIUMF is one of my favourites, of all the places I've worked in because of the flexibility and the environment," she said. "It's amazing how they always encourage you to learn. I love the encouraging, positive atmosphere that truly differentiates TRIUMF as a research institute in Canada."

3) In Nuclear Medicine, TRIUMF will support the development of Canadian leadership in nuclear medicine and molecular imaging. In particular, TRIUMF will complete development of the localized Good Manufacturing Practice laboratory. TRIUMF will produce medical isotopes for the Pacific Parkinson's Research Program and will develop and deliver medical isotopes for research with the British Columbia Cancer Agency (BCCA).

TRIUMF's role in the physics and chemistry of radioisotopes for nuclear medicine has blossomed. With support from Western Economic Diversification Canada, TRIUMF completed upgrades of its infrastructure to create laboratory space operating consistently with Good Manufacturing Practices guidelines in summer 2011. TRIUMF also joined forces with industrial partner Nordion, Inc., via an NSERC Cooperative Research & Development award, to complete refurbishment and commissioning of a new radiochemistry lab in the MHESA area.

Since 2008, TRIUMF has provided 3,900 runs of medical isotopes for the Pacific Parkinson's Research Program and 1,200 runs for the BC Cancer Agency (BCCA). TRIUMF has also provided proton irradiation therapy for 40 patients with ocular melanoma.

TRIUMF has galvanized a Canadian team of four institutions to develop a modern-day, accelerator-based alternative production technology for the world's most popular medical isotope (technetium-99m) that avoids the use of nuclear reactors and highly-enriched, weapons-grade uranium. The technology is now being deployed and packaged for commercialization in the private sector.

4) In Materials and Molecular Science, TRIUMF will support the scientific community and, in particular, will complete the construction and commissioning of the M9A and M20 muon beam lines in 2012.

The M20 muon beam line upgrade was supported by a Canada Foundation for Innovation (CFI) project led by Simon Fraser University. The project was successfully completed and commissioned in 2012. Already 15 experiments have been carried out since October 2012, predominantly focusing on materials science and chemistry but also including first tests of muon-irradiation of electronics components for industry. All the components of the M9A muon beam line have been installed in the Meson Hall in 2012. However, ageing components of the main proton beam line for the Meson Hall have hampered efforts to operate the M9 meson-channel and thus off-line commissioning has been postponed to 2013, while efforts are underway to restore operation to this important and unique meson channel.

5) For the Advanced Rare IsotopE Laboratory supported by multiple agencies and partners, TRIUMF will meet the following milestones:

a) Fabrication and assembly of the first Injector Cryomodule and a 30 kW beam test will be completed by March 31, 2012.

b) Civil construction of the ARIEL facility will be nominally complete by March 31, 2013.

c) Installed in the Proton Hall, the e-linac will deliver low-current beams at 25 MeV by March 31, 2014.

d) Electron beams at 25 MeV, 100 kW will be delivered by March 31, 2015.

ARIEL is Canada's flagship in advancing isotopes for science and medicine, funded by the CFI to a university consortium led by the University of Victoria and a substantial investment by the Government of British Columbia. The facility will ultimately nearly triple TRIUMF's capacity for generating isotopes. The present phase of the project was not fully funded until July 2010, after the Contribution Agreement deliverables were negotiated. Civil construction of the ARIEL facility started in 2011 with excavation starting November 1, 2011. The buildings were substantially completed and transitioned into commissioning and nominal operations in August 2013.

Based on a revised opportunity analysis in late 2010, the University of Victoria and CFI agreed to a revised intermediate schedule for design, assembly, and commissioning of the e-linac. Essentially, TRIUMF was able to pursue a higher-power electron source and set of radio frequency power elements that impacted the first 18 months of schedule but will lead to substantial cost savings in the completion of the e-linac. The injector cyromodule installation and 100 kW beams will now be ready in September 2014.

2.2.2 PERFORMANCE INDICATORS FOR FIVE YEARS 2008-2012

The enterprise of scientific research produces a triple impact by advancing knowledge, creating future leaders, and generating societal and economic growth. Taken together, these outcomes motivate public investment. Public policy researchers have sought to build a predictive, quantitative model that connects inputs (e.g., investments, scientific and technical staff, or infrastructure) to outputs (e.g., publications, trained students, or industrial partnerships) and longer-term outcomes such as standards of living and economic competitiveness. Common sense suggests that some key performance indicators that measure outputs are positively correlated with longer-term outcomes.

Indicators that measure TRIUMF's productivity over the past five years (April 2008–March 2013, inclusive) are presented in the discussion below. One limitation of this approach is the challenge of attribution—that is, identifying which publications, students, or companies were directly and uniquely impacted by TRIUMF's activities.

Advancing Knowledge

In 2008–2012, TRIUMF delivered more than 12,500 hours of isotope beams for nuclear physics and 28,000 hours for materials science research to about 3,000 scientists and students who visited TRIUMF to conduct their research.

During the 2008–2012 period, TRIUMF expanded its scientific publication output from about 900 in 2003–2007 to more than 1,300 for the current period (see Figure 1). Of these papers, more than 50 have been already cited more than 50 times. By 2013, the 2008–2012 publications had been cited more than 13,000 times while in 2008 the 2003–2007 publications received just above 7,000 citations. An independent study (see Appendix 7.6) reported that TRIUMF is one of Canada's top three most productive publishers of high impact papers in particle and nuclear physics and is, in general, among the top five of a set of a dozen international comparators in terms of citation impact.

> Given the increasing internationalization of science, it is worthy of note that Canadian researchers are very active in collaborating with their global counterparts, as evidenced through their participation in international co-publications.
>
> Science, Technology and Innovation Council: Aspiring to Global Leadership 2012 report.

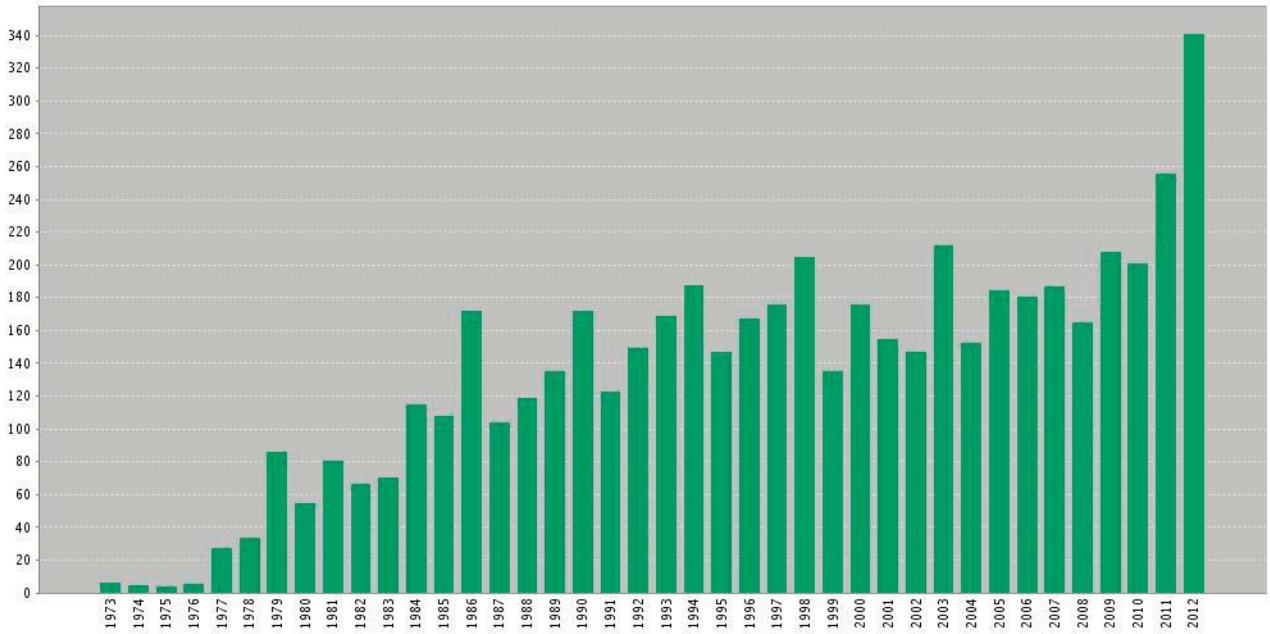
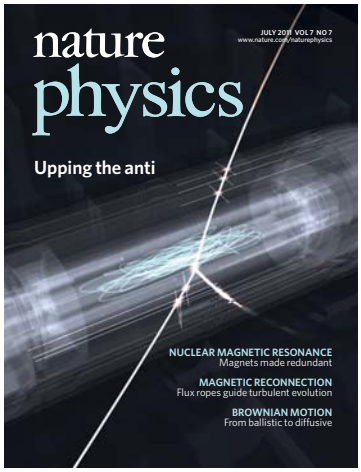
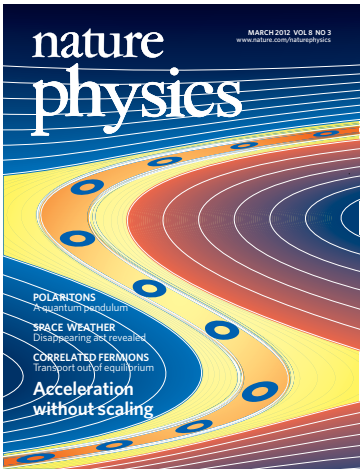


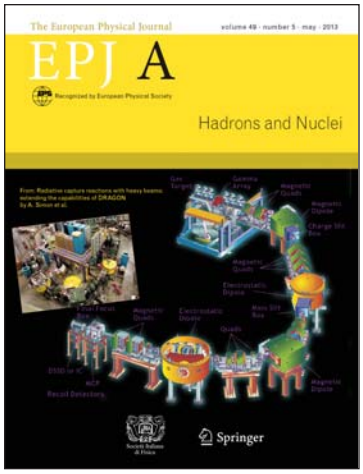
Figure 1: Time series of the annual number of scientific publications with an acknowledged TRIUMF co-author for the past 40 years based on a query from Web of Knowledge databases.

TRIUMF enabled Canadian leadership in a number of key scientific pursuits:

- Discovering and confirming the existence of a Higgs boson via ATLAS at CERN while also searching for new phenomena beyond the Standard Model of particle physics;
- Trapping and probing the "chemistry" of antihydrogen via ALPHA at CERN;
- Unequivocally confirming neutrino appearance after flavour changing via T2K in Japan;
- Being among the world leaders in precision mass-measurements of short-lived rare isotopes;
- Confirming the role of three-body forces within the atomic nucleus using rare calcium isotopes;







- Making highest precision measurements of superallowed beta-decays on several nuclei;
- Conducting critical measurements of the properties of exotic halo nuclei; and
- Measuring critical nuclear reaction rates for hydrogen and helium burning in stars and stellar explosions.

Creating Future Leaders

TRIUMF provides direct research experiences for high-school, undergraduate, and graduate students and manages a portfolio of informal science education programs. During the 2008–2012 period, these activities resulted in the following outputs.

- 12 high-school students, 370 undergraduate students and 195 graduate students conducted research projects at TRIUMF leading to more than 85 M.Sc. and Ph.D. theses; in addition 45-50 post-doctoral fellows were resident at TRIUMF each year;
- 350 undergraduate and high-school students participated in Virtual Researcher on Call, Scientists in the Schools, ATLAS Master Classes, and Let's Talk Science programs involving TRIUMF scientists;
- 225 high-school physics teachers participated in three TRIUMF-led professional development days (2008, 2010, 2012) in coordination with the BC Association of Physics Teachers;
- 2,500 people attended public science lectures as part of programs at Science World British Columbia, Global Civic Society's Public Salon, Saturday Morning Physics Lectures, and TEDxStanleyPark; and
- 2,800 people toured TRIUMF as part of its public tours program each year; 25,000 people interacted with TRIUMF booths and activities at events such as the University Neighbourhoods' Association Annual Barn Raising, Wesbrook Village Festival, Telus World of Science Community Science Days, BC Year of Science exhibitions, and the American Association for the Advancement of Science Family Science Days.

Cover stories of prestigious science journals that feature TRIUMF-enabled research.

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Cover 3: European Physical Journal A, Volume 49, Issue 5, May 2013, cover page, © 2013. With kind permission of the European Physical Journal (EPJ).

Cover 4: Copyright © 2010 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

The American Association for the Advancements of Science (AAAS) held its annual meeting in Vancouver in February 2012, returning to Canada for the first time in 30 years. As a member of the Canadian steering committee and chair of the local organizing committee, TRIUMF helped set a conference record for attendance. TRIUMF facilitated the participation of the Governor General of Canada and partnered with the BC Innovation Council to organize and support the participation of 200 BC high-school students in the conference.

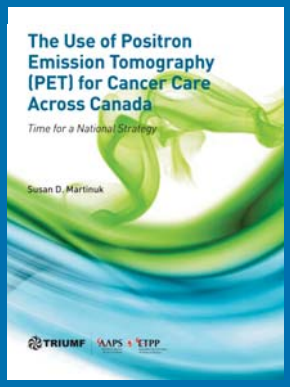
Generating Societal and Economic Growth

The third public benefit of basic research is the fuel for innovation that drives societal and economic growth. TRIUMF generates societal growth through its programs that impact healthcare and quality of life. TRIUMF generates economic activity not only through its science and technology programs that use public funds to challenge, stretch, and expand the private sector's capabilities but also through collaborative research agreements and technology transfers.

In 2008, TRIUMF was awarded $14.95 million by the Networks of Centres of Excellence program to launch a Centre of Excellence for Commercialization and Research called Advanced Applied Physics Solutions, Inc. (AAPS). By bringing together a board of experienced business leaders and a small staff of trained business professionals, AAPS has significantly expanded TRIUMF's ability to connect and impact Canada's industrial sector.

During the 2008–2012 period, TRIUMF and AAPS achieved the following results.

- Treated 40 patients successfully for ocular melanoma;
- Provided more than 5,200 production runs of medical isotopes for the Pacific Parkinsons' Research Program and the BC Cancer Agency;
- Launched 4 spin-off companies (IKOMED Technologies, Inc.; Micromatter, Inc.; CRM Geotomography Technologies, Inc.; and ARTMS, Inc.);
- Entered into two technology-transfer agreements with Canadian industry for development of new product lines (Advanced Cyclotron Systems, Inc.; PAVAC Industries, Inc.) and developed one technology (cyclotron-based production of technetium-99m) for commercialization;



TRIUMF & AAPS JOINTLY RELEASE REPORT ON STATUS OF PET IMAGING FOR CANCER ACROSS CANADA

14 Feb 2012

TRIUMF, together with Advanced Applied Physics Solutions Inc. (AAPS Inc.) released a report entitled: "The Use of Positron Emission Tomography (PET) for Cancer Care Across Canada: Time for a National Strategy". The report, prepared for the organizations by independent medical-research consultant and well-known writer Susan Martinuk, outlines fundamental differences in the availability and uptake of Positron Emission Tomography (PET) in cancer care across Canada.

According to Martinuk, "PET is revolutionizing clinical cancer care in the United States and Europe, yet many Canadian doctors and policy officials continue to see PET as experimental and unproven technology. Cancer patients can suffer because of this reluctance." She reports that she was surprised at the variability among provinces in the utilization of, and access to, this key diagnostic technology.

Martinuk added, "This report is not the last word; it's the start of something. Our intention is to move the conversation forward by engaging the provincial health authorities, the practitioners, and the patients."

CANADIAN SOLUTION TO MEDICAL ISOTOPE CRISIS DEMONSTRATES THAT CITIES COULD PRODUCE THEIR OWN MEDICAL ISOTOPES

09 June 2013

With Canadian-developed tools and technology, a national team led by TRIUMF has reached a crucial milestone in developing and deploying alternatives for supplying the key medical isotope technetium-99m (Tc-99m). The team used a medical cyclotron that was designed and manufactured by Advanced Cyclotron Systems, Inc. (ACSI) of Richmond, BC, and successfully achieved large-scale production of Tc-99m, sufficient for an urban area the size of Vancouver. With a half-life of six hours, the isotope could also be shipped to more remote locations. This achievement eliminates the need for nuclear reactors to produce isotopes, which use weapons-grade uranium.

Paul Schaffer, head of TRIUMF's Nuclear Medicine Division and principal investigator for the project, said, "This achievement is a crucial step on the road to meeting Canada's isotope needs after the NRU ceases production in 2016." In addition to TRIUMF, the team includes experts at the BC Cancer Agency, the Centre for Probe Development and Commercialization (CPDC), and the Lawson Health Research Institute.

- Generated $9.0M of commercial revenue largely from royalty agreements for production of medical isotopes, and industry fees for irradiation of aerospace and high-performance computing components;
- Achieved direct GDP impact of $424.9 million and a total GDP attributable to TRIUMF and AAPS of $941.1 million over the past decade; and
- Generated more than 11,700 person years of employment over the past decade.

One example of this impact is the growth of technology-transfer recipient PAVAC Industries, Inc., based in Richmond, BC. After working with TRIUMF to learn how to manufacture superconducting radio-frequency (SRF) accelerator cavities, the company has doubled in size in two years to 50 employees. In addition to winning the only non-Chinese contract for the manufacture of spoke SRF cavities for a Beijing project with the technical and engineering backing of TRIUMF, Ralf Edinger, president and CEO, has a goal of growing the business to more than $100 million revenues by 2017 and employing over 200 staff by adopting TRIUMF's cryomodule technology.

> In 2010, physics-based industries generated 3.8 trillion Euro of turnover (revenue), representing over 15% of total turnover within Europe's business economy. Turnover per person employed in the physics-based sector substantially outperforms the construction and retail sectors. The physics-based sector can therefore be viewed as a highly productive part of the European economy.
>
> European Physical Society, "The importance of physics to the economies of Europe," 2013.

2.3 ALIGNING WITH CANADA'S PRIORITIES, 2015–2020

TRIUMF's proposed program is well aligned with Canada's priorities outlined in the report *Mobilizing Science and Technology to Canada's Advantage*, released in 2007. 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. The following discusses how TRIUMF's Five-Year Plan 2015–2020 will adhere to these four principles and act on all three advantages.

> Scientific discovery, technological breakthroughs, and innovation are the primary engines for expanding the frontiers of human knowledge and are vital for responding to the challenges and opportunities of the 21st century.
>
> "Science and Technology Priorities for the FY 2014 Budget," Memorandum from the U.S. Office of Management and Budget Director, Sylvia Burwell.

2.3.1 PRINCIPLE: PROMOTING WORLD-CLASS EXCELLENCE

TRIUMF inspires and helps Canadians perform at world-class levels of scientific and technological excellence. TRIUMF's technical and engineering skills and capabilities are unique in Canada and were critical to Canada's participation and success in discovering the Higgs boson at CERN in Switzerland via the ATLAS experiment, making the breakthrough observation of neutrino "appearance" in Japan via the T2K experiment, trapping antihydrogen at CERN via the ALPHA experiment and pursuing the

OLIVER STELZER-CHILTON ELECTED TO IPP COUNCIL

06 July 2012

Oliver Stelzer-Chilton, TRIUMF Research Scientist and a member of the ATLAS experiment at CERN—which played an integral role in the discovery of the Higgs-like particle that was announced in early July—was recently elected as a member of the Institute of Particle Physics (IPP) council.

IPP is a Canadian organization that serves to maximize the impact of Canadian particle physics through an exceptional group of IPP research scientists that play key roles in the organization's high priority projects and long-term planning goals. Dr. Stelzer-Chilton is one of eight exceptional research scientists from across Canada that serves as a council member of the IPP.

Dr. Stelzer-Chilton also plays a large role in the ATLAS experiment at CERN. He plays a part in the management in the Exotics Group and, together with a local team from TRIUMF and Simon Fraser University, as a researcher in the Higgs Group. In October 2011, he was appointed the Convener of the Exotics subgroup that focuses on exotic decays with leptons.

three-body forces that underpin the glue that holds nuclei together in the centre of atoms via the TITAN experiment at TRIUMF's ISAC facility.

The engine of TRIUMF is the main cyclotron, the world's largest such device, which has been operating steadily since 1974. The cyclotron was recognized as one of eleven Canadian IEEE Engineering Milestone Awards in 2010 and was decorated again in 2012 with one of six awards from the Engineering Institute of Canada on the occasion of that institute's 125th anniversary.

Scientists and students working at TRIUMF have received national and international awards including Vanier Canada Graduate Scholarships, American Physical Society fellowships, Japan's Bunka Korosha prize, the CAP-TRIUMF Vogt Medal and CAP Brockhouse Medal, and Radio Canada's "Scientist of the Year" award—to name just a few. Moreover, TRIUMF promotes Canada's reputation by organizing and hosting prestigious global scientific conferences. In addition to the AAAS meeting mentioned above, TRIUMF brought the International Nuclear Physics Conference (2010), Low Energy Antiproton Physics Conference (2011), Physics at the Large Hadron Collider Conference (2012), and International Conference on Cyclotrons and their Applications (2013) to Canada.

Finally, TRIUMF's contribution to Canadian scientific prowess has been recognized by an independent advanced bibliometric study that found TRIUMF to be the third-most productive publisher in Canada in its fields of expertise and consistently among the top six among international comparators in terms of citation impact and prestigious-journal publication patterns.

2.3.2 PRINCIPLE: FOCUSING ON PRIORITIES

The recent report of the Council of Canadian Academies *The State of Science and Technology in Canada, 2012* identified six areas of Canadian research strength that rival the best in the world. The field of physics and astronomy was identified as one of the fields in which Canada excels; moreover, the sub-field of particle and nuclear physics was identified as one of the key drivers of this performance.

As Canada's national laboratory for particle and nuclear physics, TRIUMF seeks to connect the established research excellence in particle and nuclear physics to business relevance, directly attacking the innovation gap in Canada. TRIUMF leverages Canada's existing strengths to seize new opportunities, from using particle-physics detector technology to improving mineral exploration procedures and airport security to using high-power accelerators to address energy production technologies. The Government of Canada has announced its intention to cease producing medical isotopes with a subsidized nuclear reactor in Chalk River using highly enriched, weapons-grade uranium imported from the U.S. TRIUMF has been at the head of a national effort to develop modern alternatives for Canadians which can be licensed elsewhere around the world.

By focusing on these priorities, TRIUMF's proposed Five-Year Plan 2015–2020 will enhance Canada's competitive advantage.

2.3.3 PRINCIPLE: ENCOURAGING PARTNERSHIPS

TRIUMF operates with a network of academic, government, and industry partners across Canada and around the world (see Chapter 3). The strategic value of these connections is immeasurable. Within Canada, TRIUMF brings together the research capabilities of 18 different universities in a seamless enterprise that builds on the strengths of nearly a dozen different public agencies.

Canada is home to three complementary institutes that drive leadership in subatomic physics with different approaches: the Perimeter Institute for Theoretical Physics with analytic and computational models and predictions, SNOLAB for deep-underground science, and TRIUMF for accelerator-based

experiments, science, and technology. While bilateral activities already existed (TRIUMF works with Perimeter on LHC-related theory and is involved in several SNOLAB detector projects), these three have taken the partnership to the next level by inaugurating a yearly international summer school for particle physics, named TRISEP, to inspire the next-generation of Canadian students and create the future leaders of the field. The new program was inaugurated in summer 2013.

Internationally, TRIUMF attracts foreign investment for its programs. Japan is contributing $4 million to a University of Winnipeg project at TRIUMF that is co-supported by the Canada Foundation for Innovation, Japan's KEK laboratory is planning to install its first international office at TRIUMF, and agencies from the U.S., Germany, U.K., and Japan have invested $3.75 million in experimental facilities at ISAC. TRIUMF also builds relationships in global markets for Canadian businesses. For example, with the assistance of TRIUMF, partner company PAVAC Industries, Inc., in Richmond, BC, was the only non-Chinese company selected to supply an advanced-technology accelerator component to a major Beijing-based accelerator project. TRIUMF has teamed up with the Kavli Institute for the Mathematics and Physics of the Universe to create an international joint position, a first for Canada and Japan, to strengthen the collaboration in neutrino physics. (The incumbent is an American researcher who will eventually have the choice to stay in Japan or return to Canada as a TRIUMF researcher. The competition is on.) TRIUMF's network includes 75 universities, research institutes, global laboratories, and companies around the world.

2.3.4 PRINCIPLE: ENHANCING ACCOUNTABILITY

TRIUMF is federally regulated by the Canadian Nuclear Safety Commission. Based on a strong record, the laboratory was awarded a ten-year operating license in 2012 instead of the usual five-year term. TRIUMF's Board of Management undertook a governance review and now operates an Executive Committee that convenes between Board meetings to enhance agility and response time. TRIUMF has implemented formal project management methods across its entire operation in order to more effectively manage project resources. During tough economic times and constrained investments, TRIUMF controlled costs, improved efficiencies, and delivered a larger program than ever before.

A healthy scientific enterprise offers three distinct advantages: advancing knowledge, creating future leaders, and generating societal and economic growth. Five-Year Plan 2015–2020 promises to distinctly elevate Canada in all of these areas.

YAMAZAKI AWARDED BUNKA KOROSHA PRIZE

24 March 2010

Established in 1951, the Government of Japan annually recognizes a "Person of Cultural Merit" with the Bunka Korosha Award, one of Japan's highest honours. Earlier this year, a former TRIUMF researcher Toshimitsu Yamazaki was distinguished for his unique contributions in the promotion and advancement of contemporary physics.

During the celebrations, Professor Yamazaki continually praised the value of Canada-Japan collaboration in science throughout his career; the celebratory reception was held at the Canadian Embassy in Tokyo. His association with the Canadian research community can be traced back to the late '60s when he established the techniques of using muon beams for studying a wide variety of processes involving magnetism, spin physics, and materials science. At TRIUMF, Yamazaki developed such a facility and planted the seed for what is now a very successful program in muon spin resonance. This is one of only four such facilities around the world, which attracts more than 100 foreign researchers to Canada every year.

2.3.5 KNOWLEDGE ADVANTAGE: ADVANCING GLOBAL EXCELLENCE IN RESEARCH

TRIUMF's proposed Five-Year Plan 2015–2020 will place Canada at the front of the pack of nations pursuing isotopes for science and medicine. The flagship ARIEL project is globally unique and will give Canada the advantage in understanding the creation of the chemical elements in neutron-star mergers and discovering cracks in seemingly fundamental laws governing the universe. Based on an analysis of competing capabilities being developed at other facilities, Canada will have a distinct opportunity to exploit its head start with ARIEL to make breakthrough discoveries.

TRIUMF's support will also continue to drive Canadian leadership in international scientific collaborations such as ATLAS at the LHC, the antihydrogen ALPHA experiment, and the Japan-based neutrino T2K collaboration.

The primary public benefit of basic research is the advancement of knowledge through discovery and synthesis. TRIUMF monitors its impact on Canadian leadership in advancing knowledge using a quantitative set of advanced bibliometric indicators, performance measures of delivered beams to users, and a qualitative set of indicators (awards, journal cover stories, prestigious lectures, and so on) measuring of Canadian leadership in emerging science topics.

2.3.6 PEOPLE ADVANTAGE: CREATING FUTURE LEADERS

Nothing happens without people, and nothing improves without the dedication and focus of talented people. Through programs that offered direct research experiences to high-school students, undergraduates, and graduate students and informal science-education activities, TRIUMF's talented researchers touched the lives of thousands over the last five years (see Section 4.3 for a full report). Young researchers at TRIUMF work in an international, multi-disciplinary competitive environment supported by mentorship and supervision. Post-doctoral fellows at TRIUMF have become some of Canada's leading researchers (e.g., Malcolm Butler, Peter Blunden, Randy Lewis, Shelley Page, Ritu Kanungo).

Five-Year Plan 2015–2020 will continue to utilize TRIUMF's existing pool of talent to not only secure a competitive position in relevant areas of science and technology, but also inspire and attract the next-generation of leaders. With a new partnership that connects the laboratory and its international network of scientific leaders to the science education and outreach prowess of Telus World of Science in British

152ND NOBEL SYMPOSIUM INVITES JENS DILLING

11 October 2012

On June 13, 2012, TRIUMF researcher Jens Dilling attended the 152nd Nobel Symposium in Gothenburg, Sweden. The Nobel Symposia is a program that brings together world experts to discuss breakthroughs and progress in areas of science. Participation is by invitation only. The focus of this year's symposium was Physics with Radioactive Beams. The Nobel Community for Physics was in attendance to gauge and evaluate the field. Dr. Dilling shared his research on Probing the Nuclear Interaction through Precision Mass Measurements. Another Canadian and TRIUMF collaborator, Dr. Ritu Kanungo of Saint Mary's, also participated in the symposia.

The 152nd Nobel Symposia manifested the increasing international interest and investment in nuclear physics. According to Dr. Dilling, radioactive beams are in high demand because of their threefold benefit: intellectual gain, development of nuclear medicine, and advancement in materials science.

Columbia, TRIUMF will share the process of research and innovation with thousands of students and families over the next five years. A new online, recorded-seminar archive will make these events and other lectures at TRIUMF available to Canadians across the country.

With university-based colleagues, TRIUMF is leading the preparation for an international graduate school program at UBC in the framework of an NSERC CREATE program, called ISOSIM that will provide multi-disciplinary and multi-sector research and learning experiences to graduate students around the theme of advancing isotopes for science and medicine. The program includes an exchange program for the students with several institutions of the German Helmholtz Association and Siemens Foundation.

TRIUMF maintains a vigorous visiting-scientist program, hosting not only hundreds of scientists and students coming each year to TRIUMF to conduct experimental research but also researchers visiting for longer periods to share their knowledge and learn new skills. As Canada's scientific and technology workforce becomes more globally integrated (both personally and digitally), the importance of workforce mobility will be replaced by workforce "global access," meaning that leading organizations will be distinguished by their connections and networking across the globe on strategic topics. Capitalizing on Canada's strength in subatomic physics, TRIUMF will engage world-leading scientists and students in its research program, enabling Canadian students to establish and develop the key relationships that will elevate their careers.

> "[T]hese realities imply that Canada's prosperity will depend, more than ever, on an innovative economy. Innovation drives our ability to create more economic value from an hour of work."
>
> Innovation Canada: A Call to Action, Expert Panel Report of the Review of Federal Support to Research and Development, 2011.

2.3.7 ENTREPRENEURIAL ADVANTAGE: GENERATING SOCIETAL BENEFIT AND ECONOMIC GROWTH

TRIUMF has a long history and unique expertise in the accelerator-based production of isotopes used for nuclear imaging and tumour treatment. The year 2013 marks 35 years of cooperation with Nordion, Inc., in the technology-partnership framework that produces 15% of the isotopes exported from Canada. Where does this happen? At TRIUMF, with the lab's expert staff at the tiller and guiding Nordion's production to reliable and reproducible success. This core expertise in accelerator production of isotopes has recently been employed by TRIUMF in service of Canadian national objectives to develop alternative technologies for the production of technetium-99m, an isotope that presently requires nuclear reactors and highly enriched, weapons-grade uranium to manufacture.

Other technologies spinning out of the TRIUMF enterprise involve the use of cosmic-ray muons to enhance mineral explorations below ground, improve airport security, and reduce radiation exposure to patients during routine fluoroscopy and medical-stent procedures.

Together with its commercialization partner Advanced Applied Physics Solutions, Inc. (AAPS), TRIUMF proposes to double its commercial revenues by leveraging relationships with existing industrial partners by 2020. AAPS will focus on developing platform technologies in the areas of accelerators and beams and radiation detection and control. Applications presently being explored in the natural resources and

healthcare sectors will mature. Five-Year Plan 2015–2020 proposes to deploy TRIUMF's network of universities and international labs so that opportunities for development, commercialization, and marketing are seized. AAPS will manage a formidable intellectual property portfolio with a dozen industrial partners invested in key opportunities.

> Accelerators began to generate wealth for industry – and rewards for society – 60 years ago. Worldwide, around 20,000 accelerators now produce, sterilise or examine 400 billion Euro worth of goods each year. And that doesn't include the 10,000 accelerators made for medical use in the world's hospitals.
>
> Statement prepared by the European Strategy Group for Particle Physics for the special European Strategy Session of Council in Brussels on 30 May 2013.

2.4 REALIZING THE VISION

TRIUMF's Five-Year Plan 2015–2020 lays out a vision that will extend Canada's premiere position in particle and nuclear physics and bring its efforts in nuclear medicine and molecular and materials science to the next level of national impact and relevance.

The three major themes remain the drivers for the laboratory into the next decade:

Advancing isotopes for science and medicine;

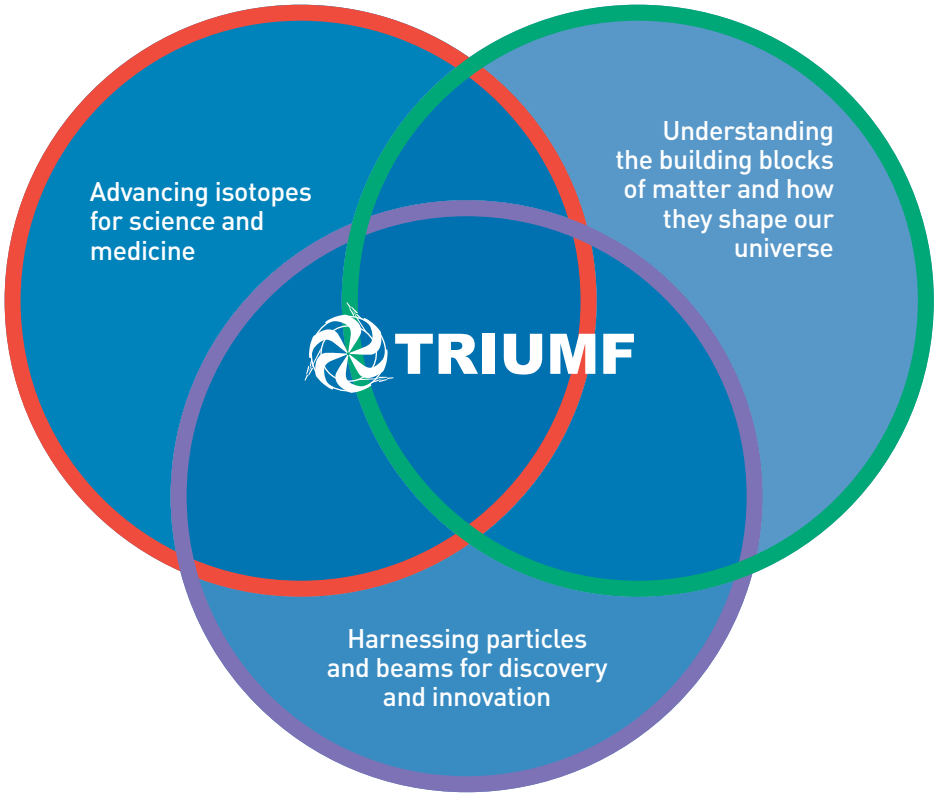
Understanding the building blocks of matter and how they shape our universe; and

Harnessing particles and beams to drive discovery and innovation.

Five-Year Plan 2015–2020 will transition TRIUMF from a major era of construction to one of exploitation and operation with discovery science being performed in all scientific areas.

With ample beam from the e-linac, the β-NMR facility will exploits its full potential as a user facility for molecular and materials science. The rare-isotope beam program will start, supported by a strong effort in theory, to exploit multi-user operation and explore nuclei along the astrophysical r-process. The UCN facility will begin its search for the neutron electric dipole moment.

On the international front, the period 2010–2015 has been one of exploitation of the investments made in the past with ATLAS and T2K firmly in their data-taking and discovery phase, guided by the local theory efforts. The period 2015–2020 will see further exploitation but also preparations for the next big steps in the worldwide efforts to unravel the most foundational principles of the universe. ATLAS and T2K will undergo upgrades in which TRIUMF will again play a significant role, and new major initiatives like LHC upgrades, the linear collider (LC), and the Hyper-Kamiokande are being discussed for construction in the next decade. TRIUMF is poised to be a relevant partner for these endeavours.



TRIUMF will build on its successes in developing new technologies for accelerator-based medical isotope production and elevate Canada and its isotope related industry into leading positions. With the much-expanded capabilities for materials characterization, Canada will be able to instantly follow up on the development of new materials, impacting progress in a broad range of fields including quantum computing, microelectronics, and energy storage.

Building on the completion of the ARIEL facility and its e-linac, TRIUMF will investigate the next steps in facility development that will keep it at the forefront of accelerator-based research and technology, and ahead of its competitors.

Through all of these activities, TRIUMF will continue to advance knowledge on the highest level; to create the next-generation of leaders in science, industry, and health; and to generate societal and economic impact for the betterment of Canada.

2.5 IMPLEMENTING THE PLAN

TRIUMF's strategic plan for the 2015–2020 period fulfills the decadal vision launched in 2010. This ambitious plan will have optimal impact in the three major themes and will maximize the return on the investments made by both Canadian taxpayers as well as several international partners, including Germany, India, Japan, CERN, U.K., and U.S. These investments have led to a Canadian leadership position in physics and astronomy and, in particular, particle and nuclear physics. To convert this intellectual leadership into full value for the Canadian economy, continued investment is necessary. We must seize the advantage while it is available.

> **In particular, the (U.S.) nation benefits from government funding for basic and applied research in areas in which the private sector does not have the economic incentive to invest.**
>
> Science and Technology Priorities for the FY 2014 Budget,"
> Memorandum from the U.S. Office of Management and Budget, Director Sylvia Burwell.

The highest priority for TRIUMF in the next five-year period is the completion of the ARIEL facility and the launch of experiments exploiting its new scientific capabilities. At the same time TRIUMF must capitalize on past Canadian investments in three areas: (1) high-profile international efforts in particle physics, in particular, ATLAS, T2K, ALPHA, and SNOLAB (2) the rare-isotope experiments at ISAC, and (3) the user Centre for Molecular and Materials Science. The laboratory will also leverage international investments in Canada with the Japanese-Canadian facility for ultra-cold neutrons. At the same time, TRIUMF will continue to be an essential partner for Canadian universities to connect to the world in particle and nuclear physics and will facilitate these universities' ambitions to play visible roles in large international detector projects.

TRIUMF's Five-Year Plan 2015–2020 also calls for the staff and funds to operate its facility at maximum capacity while completing ARIEL. This will allow for investments in refurbishments or replacements of aged infrastructure needed to continue carrying out an already excellent scientific program as well as to make modest investments in a few strategic program enhancements. Operating at full capacity will enable the lab to keep up its scientific competitiveness around the world as well as substantially increase the social and economic benefits it brings to Canada.

Canada's scientific competitiveness will be enhanced even more through an expansion of the Canadian ATLAS Tier-1 Data Centre (for which TRIUMF will provide infrastructure as well as staff and funds for operation) and an upgrade of the liquid helium and beam line infrastructure for the new facility for ultra-cold neutrons. A targeted handful of joint faculty positions with member universities will strategically strengthen Canadian research. For instance, consider the following: the leader of the Tier-1 Data Centre is Michel Vetterli, jointly appointed to TRIUMF and SFU's Department of Physics; Canada's involvement in the Japan-based T2K experiment is driven by Dean Karlen, jointly appointed to TRIUMF and University of Victoria's Department of Physics and Astronomy; Paul Garrett, who transitioned from a joint position to a full faculty position at the University of Guelph's Department of Physics leads the DESCANT project at TRIUMF adds critical neutron-detection capabilities to experiments at the TIGRESS facility.

Canada's leadership in the production and beneficial use of medical isotopes will be fortified by the creation of an Institute for Accelerator-Based Medical Isotopes (IAMI), with a new medical cyclotron for which TRIUMF will provide staff for operation and isotope processing. Intensifying industrial partnership activities to allow TRIUMF-developed technologies to get to the market will further increase TRIUMF's economic impact. Finally, TRIUMF will address key deferred maintenance issues to ensure reliability and competitiveness including refurbishment of existing space.

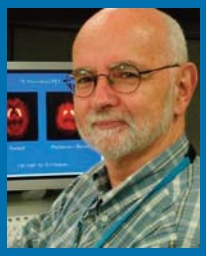
The outcomes of Five-Year Plan 2015–2020 are, simply put, enhanced excellence: enabling Canadian scientific research that leads the world in terms of journal publications and impact; inspiring, attracting, and training the next-generation of leaders at a new level; and substantially progressing on connecting research excellence to business relevance in accelerator-based science. With full investment, the new Plan will:

- Enhance productivity from 1,300 scientific publications to 1,500 such papers with experiments at CERN running full steam along with expanded capacity and capability at ARIEL and ISAC;
- Expand networking and collaboration in the Canadian subatomic physics community to move from 15% contributing authorship to 20%;
- Engage 675 students in direct research experiences, 100 more than 2010–2015;
- Excite 35,000 people through informal science education activities including laboratory tours, public science lectures, and community events; and
- Enlarge economic impact by $50 million per year, adding a $500 million impact within Canada over the next decade.

Realizing the vision for ARIEL and for Canada's success in connecting research excellence with business relevance will require coordinated investments by the Government of Canada (via the NRC Contribution Agreement, Canada Foundation for Innovation, Natural Sciences and Engineering Research Council, Western Economic Diversification Canada, and Natural Resources Canada) and the provincial governments.

To realize the full potential of Five-Year Plan 2015–2020, an investment of $290M in 2015–2020 by the Government of Canada via the NRC Contribution Agreement is requested. In concert, the University of Victoria will lead a consortium of TRIUMF member and associate member universities to seek funding from the Canada Foundation for Innovation (CFI) for the capital needed for the completion of the ARIEL facility (about $32M). TRIUMF, along with regional collaborators will pursue capital funding ($2M-$3M) from Western Economic Diversification Canada, the Government of British Columbia, and the private sector for a new TR-24 cyclotron as part of a regional centre of excellence called the Institute for Accelerator-based Medical Isotopes. CFI funding will also be sought by the respective Canadian collaborations for ATLAS detector upgrades and Tier-1 expansion, T2K and ALPHA upgrades, the neutron EDM experiment at the UCN facility, as well as a number of smaller initiatives.

This request for NRC-contributed funds may appear as a substantial increase compared to the $222.3M of the 2010–2015 period; however, it should be noted that the NRC contribution to TRIUMF's core operations has been flat-flat for 10 years (i.e., constant in nominal terms). TRIUMF has not been able to keep pace with utility prices and other cost-of-business increases and has little capacity to maintain competitive salaries. To set the scale, ordinary economic progress (inflationary adjustments at less than



TOM RUTH APPOINTED TO UN IAEA BOARD

06 June 2013

Recognized internationally as an expert on nuclear medicine and medical isotopes, TRIUMF's Dr. Thomas J. Ruth has been appointed to serve from 2013 to 2015 as the Canadian representative member of the United Nations International Atomic Energy Agency's (IAEA) Standing Advisory Group for Nuclear Applications (SAGNA).

Dr. Ruth has been an integral part of operating the TRIUMF medical isotope cyclotron for routine production of clinical research isotopes for the Pacific Parkinson's Research Centre as well as the BC Cancer Agency. Dr. Ruth's work has helped to advance Canada's profile on the international stage as a key contributor to the development of alternative production methods of medical isotopes such as Technetium-99m and Molybdenum-99 that are used in early detection and diagnosis of disease and cancer.

As the sole Canadian representative on the 20 member advisory committee, Dr. Ruth is looking forward to learning more about how others are advancing radioisotope applications, and sharing his experiences and expertise in turn.

2.0% per year) would have moved TRIUMF's annual core operating budget from $44.5M in FY2005 to $53.1M in FY2015, meaning that the buying power of FY2005 would be worth $282M for Five-Year Plan 2015–2020.

TRIUMF has been able to carry out a successful program in the current 2010–2015 period through substantial funding beyond the NRC Contribution Agreement, in particular from CFI for the first phase of ARIEL and Natural Resources Canada (NRCan) for the accelerator-based production of technecium-99m. Just as other institutions did in response to the global economic downturn, TRIUMF deferred certain maintenance items and sought new efficiencies in order to operate with reduced staff levels and reduced buying power while driving enhanced scientific productivity, relevance, and impact.

While the TRIUMF research program is broad, the NRC contributed funds are used for the core program of operating the accelerator complex, maintaining the laboratory infrastructure, and supporting a lean management and administration. In Five-Year Plan 2010–2015, a major activity has been the labour to design and construct ARIEL as an in-kind contribution to the CFI-supported project. Figure 1 shows the deployment of the workforce supported by the NRC funds for FY2012 and projected for FY2017. Although the nuclear-medicine and materials-science programs are crucial drivers of the laboratory's output, most of their manpower funding comes from outside the NRC Contribution Agreement. The proposed contribution for particle physics increases because of the inclusion of the ATLAS Tier-1 Data Centre staff in the 2015-2020 Contribution Agreement.

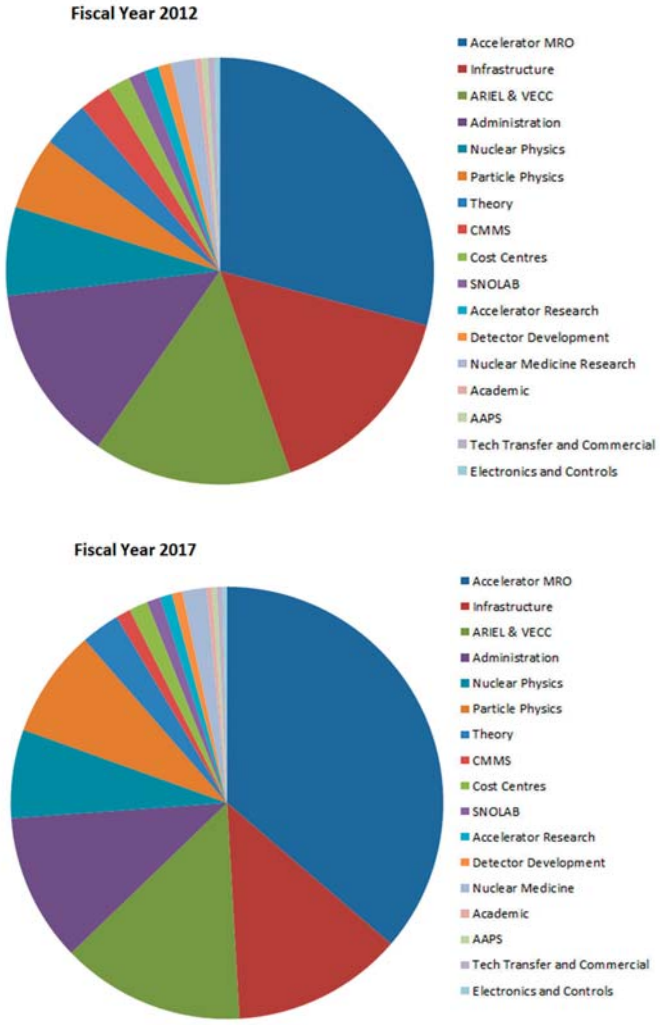


Figure 1: Allocation of TRIUMF's work force supported through NRC funds by major program area; FY2012 actuals (upper) and FY2017 projections (lower). Five-Year Plan 2015–2020 proposes to add about 35 FTEs (presently supported by temporary funds from other sources) onto the NRC salary budget. Note: MRO = maintenance, repair, and operations.

A principal aspect of the proposed Five-Year Plan 2015–2020 is baseline budget support for additional key staff (~35 FTEs) that are presently funded through temporary CFI-IOF funds (for ARIEL and the ATLAS Tier-1 Data Centre) and NRCan. These existing resources will be depleted by the end of FY2014. With new facilities like ARIEL and UCN becoming operational, the need to support the operating staff for the ATLAS Tier-1 Data Centre, and the opportunity to generate long-term benefits for Canada through an increased effort in nuclear medicine via a partnered Institute for Accelerator-based Medical Isotopes (IAMI), these highly skilled staff members should be transitioned onto TRIUMF's core operating budget funded through the NRC Contribution Agreement. Section 6.4.2 offers an array of three budget scenarios and discusses the impact on realizing this vision. A continuation of the past decade of flat-flat core operating funding (i.e., without any adjustments for inflation) compromises many of the objectives presented above.

2.6 LOOKING A DECADE AHEAD

An investment in science is an investment in the future. But what will the future hold? Where will Canada and TRIUMF be a decade from now, when this Five-Year Plan is complete, and the next one is already in full swing? This section sketches the future a decade from now.

TRIUMF will drive significant progress for Canada in three areas: understanding the basic building blocks that shape our universe, advancing isotopes for science and medicine, and harnessing particles and beams for science and innovation.

Over the next ten years, TRIUMF will continue to advance Canada's impact in particle and nuclear physics and build upon its already significant worldwide reputation for top-level science and innovation. The ARIEL facility will produce beams for advanced materials research, nuclear-structure physics, nuclear astrophysics, fundamental symmetries, and the medical isotopes of tomorrow. These outcomes will launch a suite of advanced programs that will train the future scientists, engineers, technicians and students that Canada will require to face the challenges of the future. In the process of completing the ARIEL project, TRIUMF will co-develop with industry several advanced technologies that will become globally significant. Furthermore, the ARIEL project will position Canada with some of the most advanced accelerator technologies in the world, allowing our industries to stretch the Canadian footprint in particle and nuclear physics even farther. In nuclear medicine, TRIUMF will have commercialized new technologies for producing today's medical isotopes and will have uncovered designer isotopes that hold the promise for effective therapies.

As noted in the 2012 Council of Canadian Academies report, Canada excels globally in particle and nuclear physics research. Over the next decade, TRIUMF in Vancouver, along with the Perimeter Institute for Theoretical Physics in Waterloo, and SNOLAB in Sudbury, will provide Canada with a unique combination of facilities to unravel the leading questions in subatomic physics.

From the discovery of the Higgs boson to trapping of antimatter, CERN will continue to be at the forefront of particle physics. Canada will continue to contribute and benefit by its association with CERN via TRIUMF and its collaborating universities because it provides a superb training ground for science and engineering students. A decade from now, Canada will be involved in upgrades for the LHC and the ATLAS detector as the international research teams take advantage of expanded capabilities at the accelerators and detectors. TRIUMF will have coordinated industrial involvement and demonstrated Canadian excellence in technical and engineering capabilities.

New detectors presently coming online or being designed will be working full steam in SNOLAB, searching for dark matter particles and teasing out the nature of the neutrino. A decade from now, these experiments may have breakthrough discoveries and the next generation of investigations will be underway. In Japan, neutrinos will have been fully characterized and a massive new detector called Hyper-Kamiokande could be coming online.

The ultra-cold neutron facility, a new collaborative effort between Japan and Canada, addresses fundamental questions about the basic laws of our universe. A decade from now, TRIUMF will have

set new constraints on or possibly even measured the electric dipole moments of the electron, neutron, and atom radon. Together with various other precision experiments at TRIUMF and abroad, these efforts will place Canada in a unique and powerful position to search for physics beyond the Standard Model.

The three physics thrusts of rare-isotope science are fundamental symmetries, nuclear astrophysics, and nuclear structure. ARIEL will enable TRIUMF to provide multiple rare-isotope beams simultaneously, some generated from the electron accelerator and some from the main proton cyclotron. These multiple beams will allow Canadian and international researchers to pursue experiments that will probe the details of what happens in stellar super-explosions that created the heavy chemical elements (heavier than iron) that make up our Solar System and that will test the fundamental symmetries of our basic physical laws. One of the "holy grails" of isotope research is to develop a complete and accurate mathematical description of any nucleus; new and more beams will move this vision within reach.

As the ARIEL facility matures over the next decade, plans to design the next logical phase will be fleshed out. The ideas are simple. ARIEL will be producing some of the most intense beams of rare isotopes in the world. Other labs use storage rings of rare isotopes to increase the effective intensities to drive new sets of higher-energy experiments for nuclear astrophysics. Stored beams of rare isotopes and counter-rotating electrons can be used to probe the structure of isotopes with exquisite details. At ARIEL it will become possible to pass these beams through a thin target and produce even more exotic beams than are talked about today. These ideas are already being proposed in China (CIAE), India (VECC), and Korea (RISP), as these countries try to proceed directly to the next-generation isotope accelerators. TRIUMF's goal is for Canada to play a recognized role in this future pursuit.

In the decade beyond, one possible expanded direction for the ARIEL e-linac would be to pursue a free-electron laser (FEL). A FEL is a tool to explore the inner workings of atoms and molecules in regions where tabletop lasers cannot probe. This potential avenue would require a modest addition to the accelerator and several state-of-the-art instrument suites to trap the molecules for study. TRIUMF already has significant atom-trapping capabilities (both neutral and charged ion traps are in use). The FEL facility with atom trapping would be unique in North America and would drive new directions in biological, atomic and molecular physics and nanoscale research. A number of Canadian and U.S. researchers have already expressed an interest in an FEL at TRIUMF.

Nuclear medicine at TRIUMF will continue to grow as we strengthen the bonds between TRIUMF, the BC Cancer Agency, the Pacific Parkinson's Research Centre, and local businesses. In other areas, such as developing new targets for advanced isotopes, TRIUMF will continue to leverage its work with private-sector partners, thus becoming the "Silicon Valley" of isotopes, or "Isotope Valley". Having achieved commercial success for accelerator-produced Tc-99m by 2016, TRIUMF will have turned its attention to global markets and the development of new medical isotopes that serve specialized purposes in diagnostic imaging and even therapy. A decade from now, at least one therapeutic isotope will be produced at TRIUMF for experimental testing with partners. TRIUMF will be addressing at least one new biological question for degenerative brain diseases that will require a number of new "designer molecules" presently not in our chemistry kit, expanding from the current work in the dopamine system to full mastery of the serotonin system. In oncology, TRIUMF will have driven the development of a new oxidative stress tracer.

TRIUMF has established an international reputation for technology transfer, especially its 35 year partnership with Nordion for producing medical isotopes. TRIUMF is also strongly associated with the small medical cyclotrons manufactured in Canada by ACSI. A decade from now, TRIUMF will have been involved in several technology transfer activities involving both new ion sources and enhanced diamond-like carbon foils for small medical cyclotrons. Formed five years ago, AAPS, Inc. will be self-sufficient and will routinely make investments in TRIUMF technologies in partnership with industrial partners to bring new products to market. These products will be rooted in TRIUMF's expertise in accelerators, isotopes, and radiation detection and control.

By the end of the next decade, TRIUMF's partnerships will have transformed into a "science leading to business" model similar to one that is working now in India. These new partnerships will expand to include the research collaborations with China, Japan, and Korea. The existing strong partnership with Japan in neutrino science, accelerator physics, and fundamental symmetries will lead to several programs that will be jointly managed and coordinated. Japan's leading high-energy physics lab KEK will establish a field office at TRIUMF, the first of its kind. Similarly, TRIUMF's role in driving university-campus-based research will expand.

The Linear Collider (LC) project, a next generation 30-km long electron-positron particle collider, will be a truly international laboratory (possibly hosted by Japan) to answer a simple physics question: What are the properties of the new Higgs boson and what does it tell us about the rest of the universe? TRIUMF is being invited to play a role in the initial project, largely following from the highly successful accelerator contributions to the LHC at CERN and building on the recent accomplishments here in Canada for ARIEL's electron accelerator. The LC project will open up new and exciting opportunities for Canadian researchers and students as well as for the Canadian high-tech industry. Construction on the LC will start once international agreements have been reached (~3 to 4 years), and the facility will take ten years to build but Canada, via TRIUMF, will be there when it is.

The outlook for TRIUMF for the next ten years and beyond is remarkably rich in opportunity. The particle physics program, driven by our advanced accelerator and detector technologies, is in demand all over the world. The science and technology opportunities at CERN with the LHC and in Japan with the LC are truly exciting and unparalleled. The ARIEL project is certain to meet its potential as a leading facility in isotopes for science and medicine as is its advanced-materials program. The flexible nature of the facility allows for the expansions in the next-generations of isotope science and in photon science with a free electron laser. Nuclear medicine will continue to impact the lives of Canadians. Most importantly, TRIUMF will be a premier platform upon which young Canadian scientists and engineers will be trained in a research arena where they work with, and compete with, the best researchers in the world using the latest technologies. Their future discoveries and skills will surely prepare us well for the challenges of the 21st century.

2.7 SUMMARY

Five-Year Plan 2015–2020 lays out a vision that is well aligned with Canada's priorities for science and technology and builds on TRIUMF's track record for excellence. It is a forward-looking strategy that will strengthen Canada's leadership in nuclear and particle physics while further elevating its relevance in the applications of isotopes for nuclear medicine and materials science. TRIUMF exemplifies the role of national and international partnerships in science and technology for the benefit of society and the economy. Five-Year Plan 2015–2020 represents an opportunity to invest into Canada's future leaders and to maximize the return on investments made in the advancement of knowledge, the development of high technology, and its transfer to industrial partners.