TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

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01 February 2008

MEMORANDUM

TO: **Colin Gay, *Chair,* Policy and Planning Advisory Committee (PPAC)**
FROM: **Nigel Lockyer, *Director,* TRIUMF**
RE: **Charge to PPAC for its March 14-15, 2008, meeting**

TRIUMF is currently preparing its five-year plan for the years 2010-2015. This is part of the process for obtaining TRIUMF funding for that time period. The plan includes a number of new initiatives and the continuation of many ongoing projects. Not all the projects or programs that have been proposed for inclusion will make it into the final plan. As part of the vetting process PPAC is being asked to review the projects and programs for their suitability to be included.

PPAC will be assessing whether and to what extent TRIUMF should be involved in these projects and programs. The vision, projects, and programs are to be judged considering three criteria:

1. Potential for scientific impact[a];
2. Benefit to the Canadian university research community; and
3. Benefit to broader Canadian society[b].

#1. PPAC will be presented with the Director's vision for the future of TRIUMF. Please comment on this vision, and on the match of the projects and project categories with that vision.

#2. A key section of the five-year plan document will be a discussion of how TRIUMF works with and engages the university community. Please critique this section for style and substance.

#3A. The non-CFI programs have been divided into categories. Within each category, use the above criteria to give the relative importance of each program and comment on the relative and absolute allocation of resources required for each project or program. Similarly, rate the relative importance of the different categories and comment on the relative allocation of resources for each category.

#3B. For the proposed CFI projects, please rank the projects according to the above criteria.

#4. For all programs and projects, please critique the arguments presented to justify them.

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[a]Including feasibility, strength of investigator group, and resource requirements
[b]Including training highly qualified personal, technology transfer, and medical advances

A Vision for TRIUMF 2010-2015

Discoveries at TRIUMF in the next decade will be the feedstock for translational research that will impact and advance all of Canada. These advances will enhance the health and quality of life of millions of Canadians, seed new high-tech companies, create new high specificity drugs, help us to understand the environment, advance computer GRID technology, enable the development of new materials, and spur the imaginations of our children who want to know their place in the universe. This vision is ambitious but within reach if we fully exploit the present moment.

With over a thousand users, comprised of international teams of scientists, postdoctoral fellows, graduate and undergraduate students, working along side their Canadian counter parts, TRIUMF brings together human talent and sophisticated technical resources. Together, the TRIUMF community participates in theoretical and experimental tests of materials, develops radiotracers and couple them to biologically specific molecules, studies the details of exploding stars, and probes nature's deepest secrets of unstable nuclei.

TRIUMF is one of the world's leading laboratories for studying rare nuclei. Accelerator scientists at TRIUMF are able to reproduce the conditions of supernovae explosions—the deaths of super massive stars—in the laboratory. This environment allows researchers to explore the origin of the chemical elements heavier than iron such as gold, silver, and uranium. Investment world-wide in this area of research will exceed $2B in the next decade. These discoveries will feed into the knowledge base for next-generation nuclear reactors and will help us understand the behaviour of advanced materials under extreme conditions. By connecting researchers in subatomic physics with others, TRIUMF develops and contributes to research in materials (bulk and surface effects in extreme conditions) and to a world-renowned life-sciences program that utilizes medical isotopes combined with positron emission tomography (PET) detectors.

The 21st century promises a revolution even more exciting in terms of our gains in fundamental knowledge of atomic matter, energy, space-time, and our understanding of the universe than all previous centuries combined. We now know that visible matter—the nuclei of our sun, the stars of the galaxies, the planets, the oceans, and even life itself—represents just 5% of the matter in the universe. In the last century, Einstein introduced us to the equivalence of mass and energy and the concept of space-time. Today, TRIUMF and Canadian scientists are working hand-in-hand with researchers from around the world at the Large Hadron Collider (LHC) at CERN, the largest accelerator and most ambitious scientific project undertaken by humanity. This team is poised to answer age-old mind bending questions: What is mass? Are there observable extra dimensions of space, hidden now from our view? Can this mysterious "dark matter" of the universe be produced in the laboratory? Simultaneously an international team located here in Canada, including TRIUMF scientists, is planning and designing experiments to search for this missing matter at SNOLAB, the new underground laboratory in Sudbury Ontario.

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. TRIUMF has a proven track record in both these areas. TRIUMF is known around the world for its unique relationship with MDS Nordion, a global health and life-science company. Through the spin-off of TRIUMF's medical-isotope technology to MDS Nordion, Canada has established a leadership position in the export of accelerator-generated longer-lived medical isotopes. The value to the Canadian economy over the last 20 years is worth over a billion dollars in today's market. TRIUMF has won the NSERC Synergy award twice for its partnerships with start-up companies. Another recent success is the formation of the company Advanced Applied Physics Solutions (AAPS), which is expected to identify and commercialize industrial applications in medical accelerator technologies, the mining industry, and new materials. Simultaneously, TRIUMF is launching new initiatives with the BC Cancer Agency and MDS Nordion in radiotracer development.

The proposal outlined here requests about 8% growth per year over 5 years. This growth will help keep Canadian researchers competitive with new U.S. initiatives in the physical sciences (doubling of the federal budget over a decade) as well as those elsewhere around the world. This plan charts a path from discovery in subatomic physics, accelerator technology, detector development, materials, and radiotracer development through to knowledge transfer, training, and product development. This proposal builds and expands upon TRIUMF's growing collaborations with Asia and other world-wide partners and the existing highly sophisticated detector and accelerator infrastructure and expertise at TRIUMF to achieve these goals. The following initiatives capitalize on TRIUMF's strengths and significantly enhance its ability to provide tools and resources to the Canadian community.

- We propose a new, world-class, megawatt electron linear accelerator (e-linac) using the latest superconducting radiofrequency (SRF) technologies to complement the existing proton cyclotron accelerator. TRIUMF uniquely houses Canada's state-of-the-art accelerator infrastructure and resources that are capable of designing, building, and commissioning a new world-class machine. This project will also bring together a diverse group of world-leading scientists in particle physics, nuclear physics, condensed-matter physics, and life science as well as members of the Canadian Light Source accelerator community. The new accelerator will allow the creation of neutron-rich nuclear states never produced before. The e-linac will produce new isotopes for research in medical imaging and therapy, and will generate unprecedented quantities of an isotope needed for the study of magnetic properties of nano-material surface interfaces. The SRF technology has applications for the International Linear Collider (ILC), the upgrade to the LHC injector complex at CERN, and numerous other SRF projects around the world including "compact light sources", and 4th generation energy-recovery light sources. The core SRF technology of this accelerator will lead to spin-off applications for Canadian industry. It will connect Canadian scientists and industry to the latest opportunities using accelerators around the world.

- We propose an initiative in radiotracer development that more than doubles the TRIUMF life-sciences program by expanding from neurodegenerative diseases into cancer imaging and therapy. This initiative involves bringing together a national collaboration of universities, health institutes, and health industry partners focused on molecular imaging using novel radioisotopes and designer molecules with high specificity. Expansions are planned for highly qualified personnel in nuclear medicine imaging, radio-chemistry, and biochemistry.

- We propose a major new thrust in interdisciplinary physics, utilizing laser technology and rare isotope beams to advance the quest to discover the violation of fundamental symmetries. The ultimate goal is an understanding of the behavior of antimatter. This program will require new high-power target technology not available anywhere else in the world that utilizes high currents of protons impinging on uranium-carbide targets. The combination of this initiative and the e-linac will more than triple TRIUMF's ability to provide the Canadian and international communities with the tools needed to advance their research programs in nuclear physics and selected materials-physics techniques.

- We propose to develop an ultracold-neutron facility in a major new collaboration with several Japanese laboratories and universities. There is great interest world-wide in very cold (slowly moving) neutrons. TRIUMF has the required high-current proton beams to leverage the success of the UCN "cryogenic" technique developed in Japan. The science program would initially search for violations of fundamental symmetry. This work would complement and enhance Canada's reputation in this important expanding field of physics. The ultracold neutrons will also be used for precision tests of gravity and to search for extra dimensions of space. Bringing the ultracold neutrons into collision with rare-isotope beams generated by the e-linac is also being investigated as a unique facility in the world.

- We propose to continue our pursuit of the universe's secrets by studying physics phenomena at the highest energies available. Discoveries at the LHC will shed light on this quest in 2009-2010. The world community will be ready to select the next steps, such as a major new initiative called the International Linear Collider (ILC) or whether the LHC accelerator and detectors will be upgraded to enhance their sensitivitiy. Canadian scientists are leaders in the international design effort for the ILC. The ILC is an ambitious project, initiated by all three regions of the world and Canadian scientists and industry are well positioned to contribute to the SRF-based linear accelerator and detectors.

- We propose a major engineering and detector development program aimed at SNOLAB. Canada has already invested substantial funds to build this world-class underground laboratory. TRIUMF is uniquely positioned to assist the university partners to develop and build novel detectors, and develop ultra-low radioactive laboratories for SNOLAB.

TRIUMF is internationally recognized as a unique world-class accelerator physics laboratory in Canada. It represents an investment by Canadian citizens of over $1 billion if built today. TRIUMF provides advanced research opportunities for graduate and undergraduate university students from all across the nation, from St. Mary's in Halifax to the University of Victoria. TRIUMF provides the needed high-tech infrastructure and design resources not available at Canadian universities because of the large and complex scale of the experiments. These resources enable research opportunities for hundreds of Canada's best scientists at the vanguard of their fields of study. Primarily because of its reputation as one of the premier rare-isotope beam facilities in the world, TRIUMF attracts over 500 researchers, postdoctoral fellows, and students from outside Canada each year to its facility to collaborate with Canadian scientists in research. Over two thousand visitors come to TRIUMF each year to visit and tour the facility.

This vision offers distinct advantages to Canada in the following areas.

- Entrepreneurial Advantage
  - Quadruple the economic impact from technology transfer and commercialization via AAPS
  - Forge new industrial partnerships related to our world recognized leadership in medical cyclotron design
  - Establish a major new partnership with India in accelerator science
- Knowledge Advantage
  - Act as the hub for the nuclear medicine revolution in Canada
  - Establish major research initiatives in radiotracers
  - Connect radiotracer know-how with "big pharma"
  - Explore new accelerator methods for producing medical isotopes
  - Expand TRIUMF's world recognized position in GRID information technology
  - Double number of publications and citations
- People Advantage
  - Double the number of international scientists and students
  - Double the number of Asian scientists working at TRIUMF
  - Triple the number of graduate student opportunities
  - Double undergraduate student research opportunities
  - Launch a new initiative in Aboriginal recruiting for coop students
  - Engage all major Canadian Universities across the 5-regions

The requested increased investment in research, when combined with Canada's commitment to higher education, expanded national technical infrastructures such as the Canarie network, and broad support for further growth in the high-tech industrial base, will enable Canada to seize the economic and social benefits about to emerge in the next decades from breakthrough science discoveries. Canada and its workforce must be amongst the global leaders in subatomic physics in order it to keep pace with the fast changing world of high-tech and to be able to bridge interdisciplinary programs in materials research, molecular imaging, and new cancer therapy techniques. The benefits to present and future Canadian society will be well worth the investment.

TRIUMF's Role in the Canadian University Research System

Introduction

The Canadian research enterprise is largely driven by the research programs of the Canadian universities. In many fields, especially nuclear and particle physics, the quest to unlock deeper secrets exceeds the resources of a single institution. A national laboratory, working closely with the university community and drawing together the strengths and capabilities of many institutions, is required. In the context of the Canadian nuclear physics community, this requirement led to the founding of TRIUMF in 1968. Initially launched by three universities as a local facility for intermediate-energy nuclear physics, the laboratory has now grown to be a truly nationwide effort, engaging Canada from sea to sea with seven member universities and six associate members. It has also expanded from nuclear physics to include particle physics, molecular and materials science, and life science. TRIUMF with its user community leads Canada in addressing a wide range of the important science and technology questions that transcend the capabilities of individual institutions.

TRIUMF's contribution[1] to the Canadian academic community is, in its fields of expertise, crucial in allowing Canadian researchers to make world-leading advances in science. TRIUMF possesses a unique combination of resources, including engineering staff, detector expertise, specialized machine shop equipment, particle beams, and clean rooms. University-based researchers are drawn to work with TRIUMF because these resources and capabilities simply are not available at their home institutions. Scientists at TRIUMF become the key points of contact. This fosters collaborative partnerships among Canadian researchers and between Canadian researchers and their international colleagues.

In deciding which projects to undertake TRIUMF has a policy of only supporting projects that have been independently peer reviewed by the scientific community. TRIUMF is part of that scientific community. In the field of subatomic physics, TRIUMF scientists participate along with the university-based physicists in developing the NSERC Long-Range Plans for subatomic physics. These community-based plans discuss the long-term objectives of the field are used when developing TRIUMF's own priorities. The university community has always been involved in the decision-making process at TRIUMF and recently, a new committee, the Policy and Planning Advisory Committee, has been established to foster increased university input into TRIUMF policy and planning decisions.

[1]In this section, only TRIUMF's contribution to Canadian research capabilities is discussed. The contribution to training highly qualified personnel will be discussed in another section of the Five-Year Plan report.

TRIUMF adds significant value to the Canadian academic community in a number of areas including molecular and materials science, subatomic physics, and the life sciences. However, its largest impact is in subatomic physics. To quantify this impact, consider the NSERC grants awarded to subatomic physics in fiscal year 2006—2007 (similar results hold for other years[2]). During that year, the total NSERC budget for subatomic physics was $22.4 million. Of this amounts, approved proposals with at least one TRIUMF-supported signatory accounted for $12.1 million dollars while those without a TRIUMF signatory but which used TRIUMF facilities in some manner accounted for another $4.6 million. Taken together, 74% of the NSERC budget for subatomic physics involves TRIUMF. If theory grants are excluded, TRIUMF's involvement with experimental subatomic physics is 86% ($16.4 out of $19.3 million). Included in this figure are projects like TIGRESS and ATLAS but also projects like the Sudbury Neutrino Observatory (SNO) where TRIUMF supports two scientists and supplies some infrastructure. TRIUMF is involved in a large fraction of the Canadian experimental subatomic-physics program.

The CFI program has had a dramatic impact on the Canadian university research program. Although TRIUMF cannot apply directly for CFI funds[3], TRIUMF's capabilities have been expanded because a number of universities have elected to compete for—and win—support for projects that are then based at TRIUMF. Over the five-year period under discussion, CFI awards totaling more than $30 million were used by universities to expand the capabilities and competencies at TRIUMF. Examples are the ATLAS Tier-1 Computing Centre, the M-20 beamline, the Laboratory for Advanced Detector Development, and projects led by researchers at St Mary's University. These CFI proposals were successful in part because of the support from TRIUMF.

TRIUMF is well recognized as a key element of the national research portfolio in subatomic physics.[4] The molecular, materials, and life sciences programs at TRIUMF exploit the unique beams and expertise at TRIUMF to provide specialized tools to the university research community. These specialized tools allow crucial insights that would not otherwise be possible. In materials science, the unique facilities are the muon beams, radioactive ion beams, and the associated instrumentation.[5] Many of the techniques used at muon facilities worldwide were developed at TRIUMF. Working with TRIUMF, the university user community pioneered this area of condensed-matter research. As a result, TRIUMF remains one of two leading centers worldwide. Members of the university community use the TRIUMF facility, bringing key samples to TRIUMF, to supplement techniques available at their home institutions or at other laboratories.

The TRIUMF Life Sciences program is built on TRIUMF's unique ability to use its accelerator technology to produce isotopes, radiopharmaceuticals, and radiotracers for the

[2] Appendix B in the full Five-Year Plan report will contain this information.

[3] CFI funding is only available to university researchers; TRIUMF cannot apply directly for a CFI award. However, university teams may apply for CFI awards with projects to be based at TRIUMF.

[4] A subsequent draft of this chapter will include descriptions of and quotations from the Institute of Particle Physics and the Canadian Institute of Nuclear Physics.

[5] These comments will be expanded in other sections of the full Five-Year Plan report.

diagnosis and treatment of disease. The centerpiece of this program is a joint TRIUMF-university venture—the TRIUMF/UBC PET Centre—that studies the origins, progression and treatment of Parkinson's disease and other neurological diseases such as Alzheimer's. The PET Centre, established in 1980, also dedicates substantial resources to basic research in psychiatry, the genetic causes of neurodegeneration, and diabetes. It is one of only a few centres in the world capable of this broad, successful multi-disciplined research program. The PET Center depends critically upon TRIUMF and its production of the isotopes. In 2005, the British Columbia Cancer Agency, the Vancouver Hospital and Health Sciences Centre, and the TRIUMF/UBC PET Centre opened a Centre of Excellence for Functional Cancer Imaging. This Centre of Excellence, with the first publicly funded PET/CT scanner in British Columbia, will improve cancer diagnosis and treatment for patients, build research programs for the discovery, development, and application of new radiotracers and promote collaboration with the national and international network of functional imaging programs.

Examples of TRIUMF's Relationship with University Partners

TRIUMF has a wide range of resources including high quality beams of protons, muons, and radioactive isotopes; detectors to be used in conjunction with these beams; facilities for making detectors; and detector components. Because TRIUMF is driven by a large user community, it can maintain specialized equipment and resources that are utilised sequentially by different groups. In addition to the physical plant there are the human resources that include research scientists, engineers, and people with technical expertise in various relevant areas.[6] Salary support (in whole or in part) for about fifteen scientists resident at Canadian universities is provided by TRIUMF. This strengthens the scientific and intellectual ties between TRIUMF and the Canadian universities. As an active research center, TRIUMF maintains an atmosphere that promotes intellectual activity through seminars, visitor programs, and workshops. Tying it all together is a management structure geared to maximizing the science impact for Canada.[7]

TRIUMF's role, in the academic context, is to work with the Canadian research community to enhance Canada's scientific productivity. TRIUMF's core contribution to the research enterprise is its supply of resources that can be applied coherently to a diverse set of endeavours. TRIUMF's collaborations span medical techniques, accelerator research, chemistry, molecular and materials science, nuclear physics, and particle physics experiments at foreign laboratories. Flexibility in interacting with this diverse community is one of TRIUMF's strengths.

This section describes three of the most prevalent approaches, the first of which describes the approach typically used for TRIUMF nuclear physics experiments, the second for large international experiments performed at foreign laboratories, and the third for experiments in molecular and material science performed at TRIUMF.

[6]The specifics of TRIUMF's human capital will be detailed elsewhere in the Five-Year Plan report.

[7]TRIUMF's management and administration will be described elsewhere in the Five-Year Plan report.

1. For collaborations undertaking subatomic research at TRIUMF the laboratory provides particle beams of the desired species, intensity, and energy. Typically these collaborations include a TRIUMF scientist and a specialized apparatus that is already commissioned and operational. In instances where new equipment is being used it is typical that TRIUMF personnel are heavily involved in the specification, design, procurement, and commissioning of the new equipment. The actual equipment for individual experiments and most of the detector facilities are funded from outside resources, either Canadian or foreign.
2. For experiments at foreign laboratories, TRIUMF normally contributes in the areas of design, fabrication, and installation of portions of the experimental apparatus. In several instances there has also been a contribution of systems, such as a set of magnets or power supplies, for the accelerator being custom built for the experiment. In large collaborations TRIUMF scientists often assume senior roles in the management of the collaboration.
3. For experiments in molecular and materials science, university based teams provide the samples to be studied, while TRIUMF provides the beam, detection equipment and data acquisition program. Typically, the focus is on a specific scientific problem (for example high temperature superconductivity or novel magnetic materials) requiring multidisciplinary investigation. TRIUMF acts as a user facility providing valuable and frequently unique services, but it is often one of several resources used by the group of experimenters.

In Table YY, contributions that TRIUMF brings to collaborations are listed vertically and several major collaborations are listed horizontally. This table is by no means a complete list of all collaborations but is included to provide insight into the diversity of our collaborative model.

Collaboration Or Facility	Major Detector Contribution	Major Accelerator Contribution	Beam or Isotopes	TRIUMF Scientist	Canadian Intellectual Leadership
HERMES					
BaBar					
ATLAS					
T2K					
TIGRESS					
G0, Qweak					
µSR Facility					
Accelerator R&D					
Medical Technology					

TABLE YY: The diverse nature of the collaborations in which TRIUMF is involved. Vertically the representative collaborations are listed, while horizontally the typical contributions of TRIUMF are listed. Areas coloured blue indicate that in these experiments this aspect the contribution is strong.

Contributions to Canadian Academic Leadership

From the extensive work described in this five-year plan it is clear that Canadians have, through TRIUMF, played a leading role in a wide variety of internationally recognized scientific endeavors. Many of these would not have been possible without TRIUMF. In the first instance, the primary community is the research community at the universities within the TRIUMF consortium. In the second instance, it is other members of the Canadian research community. A typical participant in TRIUMF from the Canadian research community uses not just one of the physical resources but rather accesses a number of different physical resources and also obtains technical support and collaborates with on-staff scientists. In fact, TRIUMF often provides a project engineer who coordinates the project and resources.

TIGRESS

TIGRESS is a state-of-the-art gamma-ray escape suppressed spectrometer for use at the ISAC facility.[8] A preliminary CFI grant through the University of Guelph for $0.6 million was used for initial prototyping. Subsequently a collaboration headed by Carl Svensson, consisting of eight university-based and two TRIUMF-based physicists, applied for NSERC funding in the autumn of 2002. NSERC awarded the collaboration eight million dollars over six years. This award is the largest single NSERC grant for nuclear physics ever awarded. A follow up CFI grant through St. Mary's University added an additional third of a million dollars for electronics. Presently 8 of the 12 modules of the full spectrometer are on site and three experiments have been performed.

This collaboration—university-based and led—has had substantial TRIUMF contributions. First and foremost, the project depended on the existence of the ISAC beams at TRIUMF. As part of providing the beam for this experiment, TRIUMF built a dedicated beam line. Secondly, TRIUMF provided specialized dedicated laboratory services and personnel—engineering support, design office and machine shop time, and installation technicians. While these services may be routinely available at laboratories, the size of the TIGRESS project meant that these contributions were substantial. Finally, two TRIUMF research scientists, Greg Hackman and Gordon Ball, oversaw the day-to-day management of the project and did a lot of the hands-on work that was necessary to make the spectrometer a reality. Thus, Canada's ability to design, build, and operate the TIGRESS experiment depended upon TRIUMF.

TIGRESS with its the auxiliary detectors provides a world-leading detector system to exploit the beams that only ISAC can supply. This unique combination of detectors and beams was only possible because TRIUMF, NSERC, CFI, the Canadian university research community, and their foreign collaborators worked together for a common good.

[8]The TIGRESS spectrometer is described in more detail elsewhere in the full Five-Year Plan report.

ATLAS

The ATLAS collaboration comprises (as of October 2007) about 2,000 scientific authors from 167 institutions in 37 countries. In terms of people, Canada represents 4% of the collaboration. The Canadian involvement started in 1991 with R&D involvement from the University of Victoria and the University of Montreal. TRIUMF joined the team in 1994 and led the Canadian contribution to the LHC accelerator itself. TRIUMF has subsequently been a major player in the experiment and presently hosts one (and the only one in Canada) of the 10 ATLAS Tier-1 computing centres that process the data from the experiment. With the support of NSERC, Canadians made major contributions to the construction of ATLAS—and this effort had a very significant TRIUMF component. Canadians were prominent in the construction of ATLAS primarily in the end-cap calorimeters, but more recently have significant involvements in the luminosity monitor (LUCID), the diamond beam-conditions monitor, and the trigger. Without TRIUMF's specialized capabilities, these contributions—and hence any involvement—would not have been possible.

The Canadian group in ATLAS comprises about 150 people, of whom 41 are university faculty or TRIUMF scientists. The TRIUMF involvement includes five Canadian faculty members who are TRIUMF-University joint appointments, and five TRIUMF resident research scientists. This group is heavily involved in the management of ATLAS Canada (see table ZZ). Four Canada Research Chairs (Brigitte Vachon, Wendy Taylor, Manuella Vincter, and Matt Dobbs) are members of the ATLAS collaboration, as are 5 of the 8 Institute of Particle Physics (IPP) scientists (François Corriveau, Rob McPherson, Steve Robertson, Randy Sobie, Richard Teuscher).

Scientist	**Position in ATLAS Canada**	**Relationship with TRIUMF**
Rob McPherson	Spokesperson/Principle Investigator	TRIUMF resident
Doug Gingrich	Deputy Spokesperson	TRIUMF-University joint appointment
Mike Vetterli	Computing Coordinator	TRIUMF-University joint appointment
Isabel Trigger	Physics Coordinator	TRIUMF Scientist

Table ZZ. Listing of the four principle management positions in ATLAS Canada.

It is difficult to provide meaningful quantitative measures of Canadian involvement in the ATLAS experiment. Presently, Canada's participation in the senior management of the collaboration exceeds what might be expected by its 4% involvement in the overall project. Canadians hold two of the 63 senior ATLAS positions—these leadership positions require approval of the full collaboration. This includes the Collaboration Board Chair, C. Oram, for 2006-2007. Over the past 15 years or so, the Canadian fraction of the leadership has fluctuated but has been consistently high.

βNMR/ βNQR

As implemented at TRIUMF, β-detected nuclear magnetic resonance (βNMR) uses a low energy ISAC radioactive ion beam as a novel depth-resolved local probe of the properties of thin films and heterostuctures. This is an extremely technologically-important field of materials science. The βNMR team consists of three principal investigators from TRIUMF-member universities: A. MacFarlane (UBC, Chemistry), R. Kiefl (UBC, Physics) and K. Chow (Alberta, Physics). The development of this novel technique has been driven by these three researchers, with TRIUMF playing an enabling role.

While the primary isotope of interest, ^8Li, is easily produced by the ISAC surface ionization source at TRIUMF, these experiments require a *spin-polarized* beam. This has been achieved through the efforts of TRIUMF scientist P. Levy using an in-flight laser polarization scheme. This complex task is now routine and highly reliable.

βNMR uses low energy beams to study phenomena in thin structures (less than about 200 nm thick and as thin as 2 nm). It thus requires an ultrahigh vacuum sample environment with residual pressures in the range of 10^{-9} Torr. The design challenges imposed by such criteria necessitated a significant investment, largely by TRIUMF, in design and construction of specialized beam lines. In addition, the TRIUMF Centre for Molecular and Materials Science (CMMS) contributed significantly with technical personnel supported by NSERC's MFA program. For example, the system providing the radiofrequency magnetic field essential for many measurements was designed by CMMS leader Syd Kreitzman. Importantly, TRIUMF has also contributed half the salary of a post doctoral fellow position for the development of βNMR. The series of scientists that have occupied this position have contributed significantly to technical advances as well as the scientific productivity of the programme.

The novel technique of zero field beta-detected pure-nuclear *quadrupole* resonance (βNQR) was first demonstrated at TRIUMF [Salman et al., Phys. Rev. B **70**, 104404 (2004)] in a second spectrometer. The βNQR spectrometer has recently been upgraded with (NSERC funded) cryogenic and (TRIUMF funded) deceleration capabilities enabling this totally new technique to be fully exploited in the study of materials. To maximize the use of valuable ISAC beams, the βNMR team (with TRIUMF technical support) implemented a fast electrostatic switch, allowing the near simultaneous operation of the two spectrometers, effectively doubling the available experimental time.

The financial contribution of university researchers to this effort has been largely through NSERC funded personnel in the form of graduate students, post doctoral fellows and undergraduate students as well as NSERC supported CMMS personnel. However, recently infrastructure funding (in excess of $100k since 2005) has been obtained from the NSERC RTI programme to develop spectrometer capabilities.

The βNMR facility provides an excellent example of the enabling role of TRIUMF in research that would be inconceivable in its absence. It also illustrates the potential synergies that exist when university based research operates in concert with the scientific expertise and infrastructural capabilities of a national facility like TRIUMF.

TRIUMF as Canada's Gateway to the World

The pursuit of key questions in physics requires the pooled talents and resources of multiple nations. As a national laboratory on the global stage, TRIUMF is Canada's keystone in international subatomic-physics and provides a specialized facility for the international molecular and materials science community. It enables Canadian scientists to make leading contributions in international science projects both in Canada and abroad. Furthermore, by connecting to world-leading efforts, Canadian researchers not only maximize their accomplishments but also access developments across the globe. Ultimately, by having a globally competitive research program with strong international connections, TRIUMF helps attract and retain the best talent to Canada.

What are the benefits to Canada of an international program?

Science, by its very nature, is not confined by international boundaries. Not only does the intellectual quest of science unite humanity, but also it increasingly requires the combined efforts of many nations to move forward. No country can insulate itself from the global scientific community without seriously handicapping its own scientific and technological ability. This is especially true for a country like Canada with only a modest percentage of the global research community. International connections provide contact with the very best talent, increase the opportunities for collaboration, and allow access to facilities that Canada by itself could never afford. They also allow Canada to attract, train, and retain our brightest minds. Through its strong international connections, TRIUMF, like the Canada Research Chairs (CRC) program, helps attract and retain stellar scientists who would otherwise be lost to Canada.

Moreover, international connections and collaborations are the precursors to international business and trade. These strong international connections help Canadian industry benefit from progress made in research from all over the world. For instance, TRIUMF has partnered with a local company, PAVAC, to develop Canadian capability in the manufacture of high-technology superconducting radiofrequency cavities (see section 5.3). This initiative would not have been possible without TRIUMF's collaborations with scientists and technical experts based in Germany, Italy, and the USA.

What does it mean to have an international program?

International partnership is a two-way street. In order to participate on the international stage and reap the rewards, Canada must make contributions commensurate with the level of its involvement and expected return. Our national laboratories TRIUMF and SNO/SNOLAB are Canada's contribution to the set of global subatomic-physics facilities. These laboratories have unique capabilities and strong international reputations because of sound investments at the provincial and federal levels and the combined efforts of the Canadian scientific community. Internationally leading scientists come to Canada to perform experiments at these laboratories. However, partnership in the international science community also requires involvement in and contributions to projects located outside Canada. The resulting combination of on-shore and off-shore facilities provides the necessary balance, attracting the best scientists to Canada while enabling the best Canadian scientists to work either at home or abroad.

The international collaborations fostered by TRIUMF extend beyond subatomic physics. For example, the TRIUMF Centre for Molecular and Materials Science (CMMS) benefits from its strong international user community. In the last five years 84 of its experiments[1] had Canadian participation, 56 Japanese, 33 European, 22 American and 3 South American.

Gateway to the Global High-Technology Community

Canada's world-leading expertise in key areas makes it a welcome member of international scientific collaborations, and in turn we benefit by accessing significantly more expertise and technology than would be possible if all developments were done domestically. TRIUMF is the lynchpin of this international involvement fostering two-way information flow. It has memoranda of understanding with thirty-two foreign institutions in sixteen different countries and has played key roles in Canadian involvement in international projects[2] in Europe, Japan and the United States. Canada would not have had the same level of visibility or influence in these international experiments without the many TRIUMF contributions detailed elsewhere in this report. These contributions were only possible because TRIUMF combines the traditional strengths of a national laboratory with strong ties to the university research community.

Conversely, foreign collaborators are attracted to TRIUMF by its facilities and expertise. These visitors include senior scientists, post-doctoral fellows, students, and technical experts. Visitors come for lengths of time from a day to a year or two. Some bring equipment or materials, but all bring knowledge or expertise that strengthens the local scientific community.

Examples

International collaborations in science arise for three primary reasons:

- The specialised nature of the facility merits only a few sites worldwide. The original TRIUMF meson factory, ISAC and the TRIUMF Centre for Molecular and Materials Science fall in this category.
- The undertaking benefits from, but does not require, the pooling of intellectual and physical resources to complete the task expeditiously. The international aspects of the undertaking tend to be limited in this case but the benefits are very real as seen in the example of TITAN given below.
- The undertaking is too large for any one country to successfully accomplish alone. Therefore, many countries must contribute to the enterprise, from detector

[1]For this draft, the numbers are obtained from an analysis of Molecular and Materials Experiments Evaluation Committee proposals.

[2]These projects include ATLAS, T2K, BABAR, HERMES, G0 and Qweak. Additional analysis will be presented in Appendix B of the full Five-Year Plan report.

and accelerator development, to construction, to the extraction of the physics results. The ATLAS and T2Kexperiments, described below, are examples of this.

Canada, through TRIUMF, is involved in partnerships following each these models at a level appropriate for the size of the country. Several examples are highlighted here.

The TITAN Facility

The TITAN project exemplifies the role that TRIUMF plays as a beacon attracting international expertise in order to achieve Canadian objectives. Not only was this Canadian project significantly enhanced by foreign hardware and expertise, but the facility has also achieved global preeminence regularly attracts foreign researchers. TITAN, was first proposed in 2002 as a spectrometer for short-lived isotopes using a Penning trap. What distinguishes it from any other mass spectrometer is its ability to traphighly-charged ions; all other such spectrometers work with singly or double charged ions. The critical component that provides the "charge-state boosting" is the electron beam ion trap (EBIT). Canada had limited expertise in the design and construction of an EBIT and one had never before been coupled to a rare-isotope beam facility. These challenges were overcome thanks to TRIUMF's connection to the Max-Planck Institute for Nuclear (MPI-K) Physics in Heidelberg, Germany. The Heidelberg EBIT group was developing a system for deployment at DESY. A joint project was initiated and a memorandum of understanding was signed outlining the tasks of the two partners, MPI-K and TRIUMF. TRIUMF provided expertise for coupling trap systems to an accelerator based beam line and MPI-K contributed its unique EBIT expertise. Two identical EBIT systems were built at Heidelberg; one was shipped to Hamburg and the other delivered to TRIUMF. During the entire two-year construction and commissioning phase, the TITAN group stationed a post-doctoral researcher and a graduate student in Heidelberg. In the final stage, two TRIUMF scientists joined them. Both the student and the post-doc have returned to Canada bringing their newly acquired expertise. A group from Heidelberg came to help set-up their equipment and integrate it into the TITAN experiment. A second Canadian postdoctoral researcher, who had previously worked at Heidelberg, is now in charge of the TITAN-EBIT and brings unique expertise to TRIUMF. In the mean time, having successfully operated the system at TRIUMF and researchers from MPI-K are planning to carry out experiments in Vancouver. Moreover, upgrades at ISAC now foresee an EBIT charge breeder based on the local expertise gained as a result of this international collaboration.

The ATLAS Experiment

The ATLAS experiment at CERN is an example of TRIUMF's role as the keystone[3] of Canadian participation in the world's largest scientific endeavors. ATLAS was conceived to undertake the incredible task of searching for, and understanding, the origin of mass, the highest priority in particle physics. To obtain the high energy needed for this quest an accelerator, the Large Hadron Collider (LHC) based on novel superconducting magnet technology,required an international collaboration. The experiment has taken a decade and a half to design, build, and commission even with the combined efforts of

[3]See also the discussions of ATLAS elsewhere in the full Five-Year plan report.

2000 scientists and a corresponding army of technical staff. Every country with a significant scientific community, including Canada, became involved.

With the resources and talent of TRIUMF at its disposal, the Canadian particle physics community was able to actively participate in the ATLAS and LHC projects. TRIUMF accelerator physicists had unique expertise for the design and construction of critical parts of the accelerator. The resulting accelerator contributions were a necessary part of the Canadian investment in the project. TRIUMF scientists and technical staff were also crucial helping the Canadian university community contribute to the design, construction, and commissioning of the ATLAS detector. TRIUMF is home to a CFI funded Tier 1 computing centre for ATLAS. This centre will pre-process the raw data from the experiment prior to analysis by Canadian and foreign researchers. It will also provide domestic detector experts access to raw data for detailed calibration and monitoring. Canada is now in a position to reap the scientific rewards of this monumental international undertaking. The rewards promise to be the most exciting advances in decades to our understanding of the fundamental nature of matter. Not surprisingly four CRC chairs are involved in this exciting research, and TRIUMF has managed to attract back to Canada a CERN staff member, Dr. Isabel Trigger, to lead Canadian analysis efforts of ATLAS data.

T2K

Neutrino physics illustrates the international nature of science and how Canada plays a leading role in international projects. Discoveries of neutrino oscillations in solar and atmospheric neutrinos by Super-Kamiokande (Japan) and SNO (Canada) opened an exciting new era in neutrino physics. Building on these successes, TRIUMF and Japanese scientists initiated the T2K long baseline neutrino project in 2000. This project has become the flagship neutrino project and has grown into an international collaboration of 12 countries from Europe, Japan, and North America including all the G8 nations. The Canadian group introduced key components of the experimental design including: the off-axis beam concept; ν_{ue} appearance analysis method with water Cerenkov detectors; and CP violation studies. These have become standard tools in all next generation neutrino oscillation projects.

TRIUMF accelerator/beam-line expertise provided critical input to the neutrino beam-line design, including a concept for dual kickers to abort and extract the beam, novel optics to transport the 1 MW primary proton beam , and a feasibility study for an innovative focus/bending combined function magnet. Handling of the extremely high radiation is paramount at a neutrino facility. For this TRIUMF engineers, in collaboration with KEK (Japan) and Rutherford Appleton Laboratory group (UK), contributed to the design and construction of the remote handling mechanism in the target station.

For the detector construction, the Canadian group is in charge of some of the most challenging and critical items of the project: the time projection chamber (TPC), fine-grained calorimeter (FGD), and optical transition radiation detector (OTR). These projects are lead by university researchers: TPC by D. Karlen (Victoria); FGD by S. Oser

(UBC); and OTR by S. Bhadra (York). These high-profile international contributions were only possible with strong support from TRIUMF whose high quality work and expertise are recognized internationally. At the same time, accumulated detector expertise such as precision machining of the large TPC, development of scintillator extrusion techniques and fabrication of readout electronics, will be important assets for future Canadian projects.

The high profile Canadian role in the T2K collaboration attracted excellent young scientists to Canada, such as S. Oser (UBC, CRC Chair, Sloan Fellow) and Hirohisa Tanaka (UBC, IPP research scientist).

Collaboration with the Variable Energy Cyclotron Centre in India

The Variable Energy Cyclotron Centre (VECC) in Kolkata is managed and operated by the India Department of Atomic Energy. The main accelerator at the centre was commissioned in 1980. VECC is presently planning to construct not only a superconducting cyclotron but also several rare-isotope beam accelerators. TRIUMF's technical expertise in accelerator systems and its reputation for scientific excellence make it a natural partner for the VECC research program. VECC and TRIUMF are both members of the world-wide Tesla Technology Collaboration (TTC), a collaboration of 45 institutes engaged in free exchange of knowledge and technology aimed at applications of superconducting RF accelerator technology. A formal collaboration (Memorandum of Understanding) in superconducting radio frequency technology between TRIUMF and VECC is being prepared.

TRIUMF and VECC are both developing plans to build new 50-MeV superconducting radio frequency electron linear accelerators, referred to as "e-linac photo-fission drivers," to produce rare isotope beams using actinide targets. The collaboration with VECC will allow the TRIUMF e-linac project to proceed on a faster time schedule by sharing technical know-how, resources, and costs. This arrangement benefits VECC in similar manner. The Canadian and Indian e-linac facilities would follow the OECD recommendation that rare isotope beam (RIB) facilities are regionally based.

The goal of the first phase of the partnership is for VECC and TRIUMF to develop jointly a single cavity horizontal test cryomodule (HTC). Two will be built; one for VECC and the other for TRIUMF. The cavities will be constructed by a local company, PAVAC, in Richmond, B.C., thus bring industrial activity and know how to Canada. TRIUMF and VECC will fully develop all aspects of cavity production: high-level and low-level RF techniques, power distribution schemes, and 2K cryogenics implementation. Scientific and engineering staff of VECC and TRIUMF will collaborate and work together to develop the design and subsequently build the required infrastructure. It is expected that Indian physicists and engineers will make extended visits to TRIUMF to share and jointly develop technical expertise. This partnership will be an example of TRIUMF's ability to attract foreign-based researchers and investments to Canada.

Contents

Accelerators On Site

TRIUMF has an enormous core competency in accelerator science and technology. The laboratory works with many different partners in the research and industrial community. The accelerators on site are used heavily by the broader Canadian community as well as international visitors. The core of TRIUMF's future program is determined, in a large way, by the accelerator programs it maintains locally.

Driven by the need for accelerators to explore key science questions, TRIUMF operates the world's largest cyclotron. The cyclotron is the main engine as it supplies intense beams of protons to a variety of end stations. The cyclotron could be refurbished and upgraded in the next five-year plan to buttress and expand its capabilities.

For years, TRIUMF accelerators have reliably delivered beams to all the experimental stations. However, the scientific potential of the experimental apparatus available and being built (especially at ISAC) can be exploited much more efficiently should TRIUMF be able to provide more beam time or expand the variety of available rare isotopes. The existing configuration only allows one exotic beam available at a time and cannot satisfy these two demands. Moreover, development of new isotope beams competes for beam time with experiments because it is done at the same target stations which are used for production. A resolution of this challenge is proposed by providing two more driving beams to ISAC: one with a new proton beam line from the cyclotron, which would require a corresponding intensity upgrade to this main "engine" of the lab, and another one with a new electron accelerator based on superconducting technology. Two new ISAC target stations would be built to be compatible with either of these primary beams. This would dramatically increase the variety of rare isotopes and their intensity based on usage of an actinide target combined with the e-linac (the latter which would open the door to neutron-rich nuclei). New target stations will satisfy needs for the new exotic beams development capacity and allow three simultaneous radioactive ion beams delivered to the experimenters. To support three simultaneous beams in three experimental areas: for low, medium and high energy installations, a substantial upgrade of the accelerator front end would be required. It would include new mass separators, charge state breeders, beam transport lines and switchyards, RFQ and DTL linear accelerators, and low beta section of the superconducting linac.

These proposed accelerator infrastructure upgrades would allow TRIUMF to establish a unique, world leading research program in nuclear astrophysics and fundamental symmetries utilizing both neutron-rich and neutron-deficient nuclei through 2020 and beyond.

Accelerator Operational Requirements

JUSTIFICATION

Accelerator operation will need to expand under the new Five Year Plan to support the suite of new initiatives. A cyclotron intensity upgrade will allow higher injected H^- intensities into the cyclotron to support high intensity beams into the four beam lines (BL1A, BL2A, BL2C and BL4N). The new high intensity electron linac will deliver beams to one of the new target stations. Rare-isotope beam (RIB) production will expand from one production target at any given time to three targets in simultaneous production. The ISAC beams capability will increase from one RIB and one stable beam simultaneously to up to three RIB beams simultaneously with two of the RIBs accelerated.

The Accelerator Division maintains, repairs, and operates TRIUMF's accelerators on a "round-the-clock" basis with an operations group and support staff totalling approximately 120 FTEs. The new initiatives will require augmented resources to provide a comparable level of service as is now provided to existing facilities. The actual operation of the facility would most efficiently be done by an amalgamation of the operations groups in a single, expanded control room. The technology of the cyclotron controls make a remote operation upgrade costly and time consuming so it would be effective to site combined control room in the cyclotron building adjacent to the existing one.

The electron linac will be installed with an EPICS control interface as will all of the ISAC upgrades. Even though the beam delivery network is significantly expanded (one new cyclotron beam line, one new driver and beam line, two new targets and RIB beams) the number of operators will not have to expand in direct proportion since the accelerator readiness and tuning for technical equipment across the site will not be done simultaneously.

RESOURCE REQUIREMENTS

It is envisaged that one shift supervisor and four operators per shift would be sufficient to run the facility with an expanded beam delivery team of beam physicists to offer expert tuning and daily interaction. Three new beam physicists at a postdoctoral fellow or junior researcher level would be required to handle the expanded beam delivery network. Presently TRIUMF employs 23 operators. Full staffing of five operators per shift would require 25 operators. In addition two more maintenance coordinators and one trainer would be required over the present staffing levels giving a total of five new FTEs required for operations and three FTEs in beam delivery to handle the expanded infrastructure.

The technical teams for maintaining and monitoring the facility will need to be expanded particularly in the ISAC target stations and target production but also in controls, vacuum, cryogenics, RF, safety, and beam lines. Three simultaneous beams capability means three times the number of targets and target hall activities. It is expected that the new target stations would be designed to facilitate faster target turn around and reduce the possibility of loose contamination. In general the technology that is being proposed in the Five Year Plan is not unique to TRIUMF and new hires need not be required at the senior level but could be sourced to fill junior and intermediate ranks. It is anticipated that two new hires would be required in the target hall, two in target production, two in controls, one in RF, two in safety, two in vacuum/cryogenics, one in beam lines, and one in diagnostics for a total of 13 new FTEs in the technical support groups. The extension of the TRIUMF control room would require ~300k$ of renovations and installations.

The total additional FTE's required is estimated to be 21 (5 in Operations, 3 in beam delivery, 13 in technical support groups).

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
These upgrades to the core TRIUMF infrastructure would be required in order for the broader community of researchers to fully exploit the other initiatives proposed for TRIUMF.

BROADER IMPACTS
The accelerator division trains many students and postdoctoral fellows.

Cyclotron Refurbishing & Upgrade

In broadest terms, the TRIUMF 500-MeV cyclotron is the main engine of the laboratory. It provides beams to many end users. At present, the throughput of TRIUMF in subatomic physics, life sciences, and molecular and materials science, is limited by the productivity of the main cyclotron.

JUSTIFICATION

The TRIUMF on-site scientific program is based on primary proton beams delivered to different experimental areas from the 500-MeV cyclotron. Presently the cyclotron routinely provides of 250 μA of proton beams simultaneously to three major destinations: 110 μA to the Meson Hall for the TRIUMF Center for Molecular and Material Sciences (TCMMS); 75 μA to the ISAC rare-isotope beam (RIB) production targets for nuclear astrophysics; and 65 μA to the Solid Target Facility (STF) for medical-isotope production. In order to maintain and improve accelerator facilities TRIUMF has had a program for refurbishing and upgrading old and obsolete equipment for a number of years. This program incorporates the required elements necessary to provide the capability to reliably deliver higher proton currents (300 μA) to existing facilities. An extended upgrade path for new facilities will only be possible if accompanied with cyclotron extracted beams capacity expanded to 400 μA. The high intensity upgrade work was deferred at the beginning of the 2005-2010 five-year-plan due to insufficient resources.

A new beam line to feed 100 μA of protons into two additional ISAC RIB production targets is a major focus for the cyclotron high intensity upgrade. The beam line itself, which includes new transport optics and 200 μA beam dump for tuning purposes is described in a separate section and not evaluated for resource need here. However, in order to meet high intensity goal some of the existing cyclotron components need to be upgraded: addition of a high intensity (10 mA, using existing technology) H-minus ion source, injection line high intensity upgrade, RF system improvement for 50% power enhancement, extraction probes and foils development for multiple beams extraction at different energies. Engineering infrastructure upgrades will also be required to support the refurbishing program.

RESOURCE REQUIREMENTS

The majority of personnel resources required for these activities are included in the section describing operational requirements. However the expanded service areas with added ISAC facilities have significantly diverted resources and delayed many planned refurbishing actions as the required technical staff increase was not funded in the present 5-year plan. In order to adequately support the refurbishing and upgrade activities additional personnel resources are required:

- 3 FTE for 300 μA stage of refurbishing program;
- 2 FTE for 400 μA stage of intensity upgrade.

The first stage of the program will require \$4 million and will be accomplished within about the first three years. The second stage calls for another \$3 million with expenses spread over whole 5 year cycle. The durations of many activities are determined not only by personnel and fiscal resources, but also by limited windows of opportunities for accelerator development during running periods and upgrades during shutdowns, and important dose implications involved with these activities.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

Simply put, these upgrades would allow a greater number of users to access the unique resources of TRIUMF's high-intensity beams. Although not quite accurate, the upgrade in beam current would allow nearly tripling the ISAC scientific throughput.

BROADER IMPACTS

Upgrades to the TRIUMF cyclotron as well as refurbishing would require additional workforce. Traditionally, the Accelerator Division recruits 8-10 undergraduate students each year and involves them in upgrade projects during 4-month co-op work terms. This gives them an excellent training opportunity in the high-tech environment and with highly qualified supervision. Moreover, high-technology engineering and technology jobs such as these continue to be in demand across Canada and North America. It is likely that the competition for the new positions would attract talented individuals from the region.

ISAC-III Front-End

JUSTIFICATION
A key proposal in the TRIUMF 2010-2015 Five Year Plan is the delivery of three simultaneous rare-isotope beams (RIBs) to three experimental areas on site. The expansion requires the addition of two new driver beams and two new independent actinide target areas plus a front end capable of delivering the new beams to the experiments. The experimental areas are the low energy area receiving beam at source potential, the medium energy area for beams in the energy range from 0.15 to 1.5 MeV/u and the high energy area for beams near the Coulomb barrier. The new installation will be compatible with production and acceleration of all masses as required by the experimental program.

Mass-separator: Each of the new targets will be outfitted with an extraction beam line and pre-separator housed in shielded caves and designed for servicing by remote manipulators. The pre-separated beams would then pass through individual mass separators. The separators would be identical to reduce design time and would provide a resolution of ~2500 for standard tunes and beam emittances with the capability of providing resolutions of ~10000 for low emittance beams. The transmission through the separators in high resolution mode would be improved with the installation of an RF cooler after the pre-separator.

LEBT: Low energy beam transport lines would be added to bring the beams from the exit of the mass separators to the ISAC experimental floor level. The new downstairs LEBT lines would have the capability to switch beam from either new target to either of the new lines running upstairs to give sufficient flexibility to best match a target with an experimental destination. Since the low energy area has the largest build up of experimental infrastructure it is proposed that a second LEBT line be added from the LEBT switchyard to the low energy area. One of the new downstairs LEBT lines would be equipped with a Charge State Booster to allow acceleration of a second beam in the accelerator chain.

Charge State Booster: Presently an ECRIS charge state booster is being installed in the ISAC mass-separator room to permit acceleration of ions with mass greater than 30 given by the design of the existing RFQ. Studies indicate that most probable charge states from the ECRIS are in the range of A/q<=9. To permit a second simultaneous accelerated beam we propose to add a second charge state booster. The initial design calls for a duplication of the present ECRIS source. A potential alternative would be an EBIS source but the final decision would be based on the performance of the existing source and the world-wide progress in developing an EBIS in CW mode. The LEBT with the CSB installed would be required to have a vacuum of <1e-7Torr to help transport the high charge state beams.

Post-accelerator: Presently the accelerated beams in ISAC go through both the existing RFQ (A/q<=30) and DTL (A/q<=6) on the way to either the medium energy area or high energy area. For high energy area beam delivery the beam from the ISAC DTL is transported north through the S-bend transfer line to the SC-linac. In order to accelerate two beams simultaneously it is proposed to add a new accelerator front-end fed from the new LEBT switchyard. An RFQ compatible with accelerating ions of A/q<=9 takes the beam to 150 keV/u. A new line running north of the existing RFQ will provide separate paths for ISAC-I and ISAC-II accelerated beam delivery and allow simultaneous acceleration. A switchyard at 150 keV/u will permit either of the RFQ beams to be chosen for acceleration to ISAC-I or II. The new accelerator leg will be composed of a room temperature DTL for acceleration to 700 keV/u and a low beta section of the ISAC-II SC-linac to bring the A/q<=9 ions to ~1.5 MeV/u for injection into the rest of the SC-linac.

RESOURCE REQUIREMENTS

TRIUMF expertise exists in all aspects of the proposal since the concept copies technology that has already been developed in ISAC. It is anticipated that three new beam physicist FTE's plus 12 new technical FTE's over and above present staffing at the junior or intermediate level would be required to design, fabricate and install the proposed installation. These personnel would be absorbed in technical support and beam delivery after the installation period was completed. We would propose to build a single mass separator and LEBT line to the low energy area first as well as the north extension line to the low beta SC-linac section. The new low energy section would allow the possibility of at least one RIB beam full time to the low energy area. Presently the accelerated beams are limited to A/q<=6 and the north leg would allow the acceleration of heavier masses. The last stage of the installation would see the second mass-separator, CSB and beam line from downstairs and the installation of the second RFQ to add the third simultaneous beam. The new installation would require ~10M$ with 1M$ each for mass separators, CSB and RFQ, 1.5M$ each for the LEBT and MEBT transport lines and 2M$ each for the DTL and low beta SC-linac.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

As described above, these additional target stations would not only improve the flexibility of TRIUMF beams for the community but would also enhance the productivity.

BROADER IMPACTS

Developing the technology for implementing this solution will press the limits of TRIUMF know-how and would distinguish Canadian capabilities ever more so in the world. A number of engineering and technology students would participate in various aspects of the work and would receive valuable training.

Actinide Target Stations

JUSTIFICATION

The TRIUMF-ISAC facility is dedicated to the production of rare isotope beams (RIBs) for a large variety of physics programs among them the nuclear astrophysics and nuclear physics. The 500 MeV H^- cyclotron is utilized as a driver for production of TRIUMF's exotic beams. The proton beam impinges onto a thick target of high Z material. The rare isotopes created during the impact are released to the ion source to produce an ion beam followed by a mass analyzer for beam selection.

At present, only one RIB can be delivered at a time, creating a long list of experiments waiting for beam time. For the next five-year plan, it is proposed to build two new target stations allowing the delivery of three simultaneous RIBs to users. In addition to the existing ISAC-I target station, two more target stations would be added, each compatible with either 100 μA of proton beam from the cyclotron new beam line or 10 mA of electron beam from a new electron superconducting linac. 50-MeV electrons will drive photo-fission of U nuclei and thus produce exotic ions. As such, the new target stations have to be fully compatible with uranium carbide target operation.

The new proton beam line will utilize the extraction mechanism for the old beam line BL4 that is no longer in operation since the activity in the proton hall has stopped in 1999. The proposed beam line, contrary to existing ISAC BL2A, will be fully achromatic. This option increases the cost of the beam line but it offers the advantage of more stable beam in a view of small acceleration conditions fluctuations in the cyclotron. The new beam line BL4Np will deliver protons with energy ranging from 450 to 500 MeV. Since the electron momentum at 50 MeV is very small compared to proton we will install a dedicated electron beam line in parallel to the proton beam line.

After analysis of the actual ISAC target station operation, the major drawback has been the fact that the target box is not hermetically sealed, posing a slight risk of contamination and making operation of air-sensitive material such as uranium carbide a potential hazard. The second issue is the fact that the mechanical and electrical services have to be connected and disconnected manually, which creates delays for the target exchange. In the new design these issues would be addressed by having a completely hermetic containment box that will house the target/ion source assembly and the services will be provided remotely. These improvements would allow for changing the target within 2 days instead of 3 to 4 weeks required at present.

The proposed target stations will also be compatible with operation of normal target with proton beam up to 200 μA at 450 MeV. For the electron induced fission, the number of induced photo-fissions was estimated by integrating the braking radiation distribution and the giant dipole resonance cross section. For the 10 mA electron beam at 50 MeV, 1.4×10^{14} photo-fission/s are predicted.

RESOURCE REQUIMENTS

The total cost of the facility is about $18 million. The estimate includes the new beam lines, proton and electron, the target stations including the services infrastructure, high voltage Faraday cage, laser ion source laboratory, target preparation stations, nuclear ventilation, cooling, hot-cells, shielding, safety monitoring and decontamination facility.

To operate the facility, new personnel are needed for the targets preparation, fabrication and conditioning. A second laser ion source laboratory is foreseen requiring staff to operate and maintain the laser system. Also we will need staff for beam identification and yield measurement. Target hall activity and hot-cell operation require new personnel. The addition of two new target stations will increase the need for safety surveyors and mechanical maintenance of the new ventilation system. Overall additional staff requirement is 13 FTEs.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

As described above, these improvements to the TRIUMF on-site accelerator capabilities are envisioned to dramatically enhance the scientific productivity of ISAC programs in fundamental symmetries, nuclear structure, and nuclear astrophysics.

BROADER IMPACTS

Students and skilled labourers would gain high-technology training.

Proton and Neutron Irradiation Facilities

SCIENTIFIC JUSTIFICATION

TRIUMF provides a valuable service in delivering beams of protons and neutrons for radiation testing of electronics for space, avionics, and ground level applications. In space, proton energies ranging from 20 to 500 MeV can damage the functioning of electronic devices through single event effects such as upsets or latchup, total dose or displacement damage. TRIUMF's cyclotron produces proton beams in this energy range and can simulate the radiation effects of a 10-year space mission in a matter of minutes.

A neutron beam is also available with an energy spectrum matched to the atmospheric neutron spectrum and can be used for testing avionics and ground-based electronic systems. Some biological experiments are also carried out with both protons and neutrons.

RESOURCE REQUIREMENTS

The proton irradiation facility makes use of beam lines BL2C and BL1B with BL2C used about 1 week per month and BL1B used for 1-2 weeks before cyclotron shutdowns. BL2C operating at 116 MeV is used to produce a low flux, large area neutron beam that is in increasing demand for ground level system tests.

The beam dump on BL1A produces an atmospheric spectrum of neutrons up to about 450 MeV with intensity higher than the main competition at Los Alamos. This is used for device testing as access to this beam is restricted to smaller devices. This operation is completely parasitic whenever BL1A is operating.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

Each year about 60 physicists and engineers from 20-25 companies, laboratories and universities make use of the irradiation facilities. Most users pay a commercial rate but one collaboration has experiments approved by the EEC. Canadian companies include MDA. Canadian Space Agency, ABB-Bomem and universities of Toronto, Western, Calgary and Edmonton. International users include Sandia Laboratories and Cisco Systems (US), CEA and iRoC (France) and Qinetiq (UK).

INVESTIGATORS (GRANT-ELIGIBLE)

Several university groups working on space instrumentation, electronics and radiobiology make use of the irradiation facilities and have graduate students involved.

BROADER IMPACTS

These facilities have provided significant commercial revenue to TRIUMF since startup in 1995. As the only facility in Canada with proton and neutron beams in the right energy range this is an important service to the community. The increasing demand from foreign groups indicates that the TRIUMF facilities are unique in the world.

Accelerators Off Site

TRIUMF has an enormous core competency in accelerator science and technology. In the next five-year plan, the specialized skills and equipment at TRIUMF could be used to contribute to a number of off-site accelerator projects. A key initiative under preparation as a national CFI proposal is the electron linac (e-linac). The e-linac initiative would further build the superconducting radiofrequency expertise at TRIUMF and bring the laboratory closer to the core technology of the International Linear Collider. TRIUMF could also become involved in planned accelerator upgrades at the proton-based accelerator complex J-PARC in Japan. Across the other ocean, CERN is pursuing several exciting projects that would be enhanced by TRIUMF participation. These range from activities such as the ELENA "de-celerator" to pivotal contributions in upgrades to the Large Hadron Collider, dubbed "sLHC."

ILC/SRF Machine Contribution

SCIENCE

The driving motivation behind present-day particle-physics experiments is to discover physics beyond the Standard Model. In the *electroweak-sector*, where great successes of the past decades have predicted and verified the unification of the electromagnetic and weak nuclear forces, precision measurements at the CERN Large Electron Position Collider (LEP) and the Fermilab proton-antiproton collider (Tevatron) demand there be either a light Higgs particle with a mass of less than 200 GeV or a physical system mimicking its interactions. At the same time the requirement that the theory be stable even with a Higgs, as well as the observation of cold dark matter in the universe, compellingly point to new physics at the *Terascale*.[1] Much as LEP complemented the discoveries at hadron colliders the International Linear Collider (ILC) will be needed to make precise measurements of new phenomena that are likely to be seen at the LHC.

The ILC is the planned next-generation electron-positron collider. Unlike the LHC proton collider, the ILC will accelerate the electrons in a straight line. This is necessary because the much lighter electrons lose large amounts of energy due to synchrotron radiation when bent in a magnetic field. A very high energy electron beam in a circular accelerator loses more energy than can practically be replaced. The ILC is a one-shot device, using large electric field gradients to accelerate the particles to energies that probe Terascale physics in a facility of practical length. The ILC baseline design uses 1.3 GHz superconducting radio-frequency (SRF) accelerating cavities with electric field gradients in excess of 30 million volts per metre (MV/m). Using some 20 km of these cavities the ILC is designed to produce collisions having centre-of-mass energies between 500 and 800 GeV allowing the study of new physics seen at the LHC.

There is now an ILC reference design. Detailed engineering will be completed by 2012. Following this, the ILC funding, site selection and international construction partnerships will be clarified, and construction started. The period 2010—2015 will see the completion of R&D for the ILC component fabrication, particularly the SRF cavities and provided a decision to build, the start of major construction.

RESOURCE REQUIREMENTS

The 1.3 GHz SRF being adapted for use in the e-linac has its origins in the technology proposed for the ILC. The current e-linac design foresees the use of several nine-cell ILC SRF cavities for its main accelerating structure. Presently Pavac Industries of Richmond BC is supplying the first niobium superconducting cavities made in Canada to TRIUMF as part of the ISAC-II heavy ion accelerator. The development of Pavac as a vendor to supply the SRF cavities for the e-linac could eventually lead to a Canadian vendor

[1] The "Terascale" refers to energies of one Trillion electron-volts, or 1 TeV, where 1 electron-volt is the energy an electron gains when accelerated across 1 volt. Viewed in terms of length scales, 1 TeV corresponds to probing distances of 10^{-19} metres, about 10,000 times smaller than an atomic nucleus.

capable of providing SRF cavities for the ILC. This would put Canada in an ideal position to make a significant, in-kind, contribution to the ILC should it go forward. During the period 2010–2015 the resources being devoted to the design, prototyping and evaluation of SRF cavities produced at Pavac can serve double-duty: for the e-linac and as Canada's contribution to the global ILC effort. However, the accelerating gradient required for the e-linac (10-15 MV/m) is significantly lower than that required for the ILC (32-35 MV/m). Thus, as the e-linac construction gets underway, assuming Pavac has qualified as a supplier, additional effort will be necessary to qualify them as a viable supplier of the, higher gradient, ILC SRF cavities.

R&D dedicated to the development of ILC cavities would begin in the second half of the 2010–2015 planning period and would result in much of the infrastructure developed for the e-linac. To push to higher gradients and/or test the new ideas that may be necessary to reliably, and affordably, achieve the gradients necessary for the ILC will require continued R&D into cavity surface treatment and RF testing. To support these efforts a dedicated 9-cell vertical cryostat will need to be maintained. To properly exploit such a facility and make reasonable progress will require 2 FTE of physicist effort (likely from four, or more, individuals), 2 FTE technicians as well as the on-going support of the SRF group that will then be focused on the commissioning of the e-linac cavities. It is likely that this effort will benefit from the continued collaboration from members of the Canadian university community.

RELATIONSHIP TO BROADER CANADIAN COMMUNITY

There has been significant involvement in the ILC physics studies and detector development by members of the Canadian community (listed on the ILC-detector one-pager). With the proposal of the e-linac there has been growing interest in the development of SRF technology in Canada. This new thrust has stimulated significant additional interest from both the machine group at TRIUMF, from researchers at the Canadian Light Source (CLS) as well as from members of the Canadian particle physics community. There is the possibility of establishing graduate programmes at one or more Canadian universities providing opportunities to train new accelerator physicists and providing the manpower to take advantage of accelerator R&D infrastructure at TRIUMF. High-energy physics is reaching the limit of current accelerator technologies. New ideas and R&D will be necessary if the field is to continue to thrive. Canadians must remain at the forefront of these innovations if we are to benefit from their spin offs.

TRIUMF and Canada have been full members of the ILC Global Design Effort since its inception in 2005. TRIUMF recently joined the TESLA Technology Collaboration—a world-wide R&D consortium with the twin goals of enhancing the capabilities of SRF technology, while also industrialising the production of SRF cavities to make the technology more affordable. With these steps TRIUMF is in the process of returning Canada to the forefront of high energy accelerator R&D.

INVESTIGATORS

Orr, Trischuk (Toronto); Fong, Koscielniak, Laxdal, Lockyer, Sekachev (TRIUMF); Mattison, McKenna (UBC); Karlen (Victoria).

BROADER IMPACTS

The development of high-energy particle accelerators has underpinned all of the advances in particle physics since the end of the Second World War. This effort has led to countless technological spin-offs with applications to areas as diverse as bio-physics and materials science (light sources), medicine (photon and proton therapy machines) as well as other industrial applications (electron-beam sterilisation of food, cutting, welding, etc.). None of these applications were likely to have been conceived were it not for the pre-existence of the underlying accelerator technology. Twenty of thirty years from now technological and industrial applications from today's accelerator technology—including SRF—are likely to be just as pervasive.

The stewardship of accelerator-based physics in Canada lies at TRIUMF. While the CLS was built using Canadian machine expertise it relied heavily on foreign industry to supply crucial elements of the machine. Working with Canadian industry (such as Pavac) to develop SRF production capability in Canada has significant long-term benefits. SRF technology is already the basis for the next generation of light sources (the XFEL facility under construction at DESY) while even higher intensity sources are likely to couple SRF technology with energy recovery linacs. If Canada is to continue to play a role, consistent with its status as a leading industrialised nation, TRIUMF must continue to push the boundaries of particle acceleration technology today, in order to ensure we have the capability to reap fully the industrial and societal benefits tomorrow.

ELENA

SCIENTIFIC JUSTIFICATION

Since it was first proposed in the 1930s the possibility of making significant amounts of antimatter in the laboratory, studying its properties and dreaming of its eventual applications has been a high-profile thread in physics. With the appearance of positron storage rings in the 1970s and anti-proton sources at CERN and Fermilab in the 1980s, it has become possible to study anti-matter in detail. In the late 1990s groups at CERN were able to decelerate and trap antiprotons, and compare their properties with normal protons. Precision matter-antimatter comparisons have also been made of electrons and positrons and of positive and negative muons. These are key tests of our understanding of physics. A comparison of the properties of antihydrogen and hydrogen provides a direction to advance this understanding, and it is being vigorously pursued by the ALPHA, ATRAP, and ASACUSA experiments at CERN.

The 10^{-9} asymmetry between matter and anti-matter in the Universe is not understood. Our underlying model of all particle interactions assumes that the universe is symmetric under the exchange of charge (C), parity (P) and time-reversal (T). The CPT theorem demands that for each particle (or element) the equivalent antiparticle (or anti-element) has the same mass, lifetime, and spin but an opposite value for all of the additive quantum numbers. Through much of the 20th century it was assumed that the universe was CP-invariant. However the discovery of a small (10^{-3}) CP asymmetry in the decay of *K*-mesons in the 1960s opened the door to a possible explanation for the matter anti-matter asymmetry. Recent measurements of the CP asymmetry in *B*-meson decay have shed further light on the subject. Still the experimental proof (or disproof) of the validity of the overall CPT symmetry may be the key to answering fundamental questions such as the matter–antimatter asymmetry in the universe.

The anti-protons used to make anti-hydrogen are first captured and stored in a 3.5 GeV/c storage ring. The are then decelerated down to 0.1 GeV/c in the anti-proton decelerator (AD) ring. They are next passed through a degrader foil reducing their kinetic energy a factor of 1000 to a few keV of kinetic energy. From there they can be trapped in conventional atomic traps where anti-hydrogen can be formed. Unfortunately the degrader foil technique results in only 10^{-4} anti-protons being slowed enough to be captured. The Extra Low-ENergy Antiproton decelerator (ELENA) project proposes to replace the brute-force, degrader step with an additional storage ring, capable of decelerating anti-protons from 5.3 MeV (kinetic energy, the current AD extraction energy) to about 1 keV. It would include an electron-cooling device which would further focus and intensify the anti-proton beam increasing the useful anti-proton (and hence ultimately anti-hydrogen) yield by a factor of 1000 (or more) relative to the current degrader scheme. While other improvements would be necessary to make CPT tests with anti-hydrogen competitive with current CPT tests in the *K* and *B*-meson measurements ELENA would go a long way to bridging the gap and the direct tests of CPT in anti-hydrogen will provide a complementary experimental window on the matter anti-matter asymmetry of the Universe.

Since July 2007, several important events have taken place: (1) A feasibility and cost study, funded and conducted by CERN's accelerator division, has been released ; (2) Swapan Chattopadhyay , the new director of UK's Cockcroft Accelerator Institute, has expressed strong interest in the lab's substantial involvement in ELENA ; (3) The chair of CERN's scientific committee (SPSC) expressed strong support in response ; (4) Andy Sessler of LBL, and Dieter Moehl of CERN, together with the AD community, are initiating formation of an international accelerator collaboration on ELENA. These initiatives by top accelerator physicists further strengthen the case for TRIUMF's accelerator contribution, which even with a modest cost, will allow participation in an international network of accelerator physics efforts.

RESOURCE REQUIREMENTS
Key areas in which TRIUMF has expertise and could contribute are the low-energy electrostatic beam lines, and possibly the injection/ejection kickers. The CERN-AD technical team has requested assistance in these areas. Other possible areas of TRIUMF contributions include beam dynamics, beam diagnostics, and magnet design and construction.

The details of the ELENA collaboration are currently being worked out, and various funding options are being considered. CERN has already indicated its willingness to carry out the ELENA upgrade if a significant fraction of the resources can be found externally—a task left for the collaboration. A minimum contribution from TRIUMF would be approximately 10 person-months for design (e.g., a physicist) and drawing (CAD) of the optics and the necessary diagnostics for the beamlines. Construction of key components and/or all of the beamlines at TRIUMF would require machine shop, and mechanical tech time totaling 1 to 3 person-yr. Other contributions such as kickers would be possible depending on the resource availability.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
Antimatter physics is an emerging area of science. The scientific objectives address deep questions, the techniques are ground-breaking, and the scientific appeals are wide-reaching. Canadians, constituting 25 to 30% of both ATRAP and ALPHA experiments, are playing leading roles in the field. This proposal will allow TRIUMF to make focused, yet visible contributions to a dramatic enhancement in antimatter physics opportunities. These contributions are in the areas where TRIUMF accelerator expertise is being actively sought after. The proposal also serves to expand the TRIUMF community by bringing a significant set of active university-based Canadian physicists into a TRIUMF-related project.

Eric Hessels (York) is one of the leaders of the ATRAP experiment and has acquired significant CFI-funding for the detector apparatus. Makoto Fujiwara (TRIUMF) has led the Canadian involvement in ALPHA and has received $0.95M of support through an NSERC Special Research Opportunity providing anti-proton beam monitors, an external counter-system to detector anti-hydrogen annihilations as well as pieces of the ALPHA DAQ system.

INVESIGATORS (GRANT-ELIGIBLE)
Calgary: Thompson
Montreal: Martin
SFU: Hayden
TRIUMF: Baartman, Barnes, Doornbos Gill, Fujiwara, Kurchaninov, Olchanski, Olin, Storey, Thompson
UBC: Hardy, Jones
Windsor: Drake
York: Hessels, Menary, Storry

BROADER IMPACTS
The anti-hydrogen experiments have the potential to answer fundamental questions about atomic matter anti-matter asymmetry. In the long run they may become competitive tests of CPT invariance. They provide ideal opportunities for the training of graduate students in small, but international collaborations which attract and train some of the best and brightest students and postdoctoral fellows in state-of-the-art atom-trapping and particle detector techniques including digital electronics, data-acquisition and cutting edge computer simulation and analysis techniques.

J-PARC

SCIENTIFIC JUSTIFICATION

The data taking of the first phase of the T2K neutrino oscillation experiment is on schedule to start data taking in 2009 and to continue for approximately five years. It will provide precision measurement of the atmospheric mixing angle θ_{23} in ν_μ disappearance and observation of non-zero mixing angle θ_{13} in the search for $\nu_\mu \rightarrow \nu_e$ appearance. If the mixing angle θ_{13}**,** which is not known from solar or atmospheric neutrino experiments, is large enough to be observed by T2K, it could lead to a search for charge-parity (CP) symmetry violation in lepton sector in a second phase. Sufficient statistics for the CP violation search would require an upgraded beam power, increasing from 0.75 MW for T2K phase one to 4 MW for T2K phase two and an upgrade of the 50 ktonne Super-Kamiokande to 500 ktonne Hyper-Kamiokande. An option of having a detector in Korea is also considered to untangle the degeneracy between CP violating phase and the mixing angle θ_{13}. CP violation in the lepton sector is one of the most popular mechanisms to explain the Baryon asymmetry of the universe.

RESOURCE REQUIREMENTS

TRIUMF accelerator physicists have been involved in the beam dynamics design of the J-PARC accelerator. TRIUMF is in a good position to contribute to the beam dynamics study during the J-PARC accelerator operation and identify the way to the intensity upgrade. TRIUMF contribution to critical hardware required for intensity upgrade, such as the transverse damper system which was considered for the current 5-year plan, would be a possibility. Canadian involvement in the detector upgrade for the T2K phase 2 is also expected during the next 5-year plan period. The priority of the upgrade has to wait for the initial phase results, but potential upgrade in the near and far detectors as well as beam monitoring systems are expected.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

TRIUMF involvement in the upgrades to the J-PARC accelerator would not only increase the prowess of the Canadian—led experiment T2K, but would also further grow the lab's accelerator science and technology team. This core capability at TRIUMF is in demand around the world.

INVESIGATORS (GRANT-ELIGIBLE)

Alberta: Kitching
British Columbia: Hearty (also IPP), Oser, Tanaka (also IPP)
Regina: Barbi, Mathie, Tacik
Toronto: Martin (also IPP)
TRIUMF: Henderson, Helmer, Konaka, Kurchaninov, Miller, Poutissou, Poutissou, Retiere, Yen
Victoria: Karlen (also TRIUMF), Roney
York: Bhadra

BROADER IMPACTS

The T2K project contributes significant in the training of undergraduate students, graduate students, and post docs.

sLHC Accelerator

SCIENTIFIC JUSTIFICATION

The future of physics at the energy frontier, in particular our understanding of the mechanism of electro-weak symmetry breaking, will be determined by the results of the LHC program. The initial phase of the LHC will be completed in approximately 2015. It is foreseen to then increase the instantaneous luminosity of the LHC by about one order of magnitude in order to extend its energy reach for new physics processes, and to investigate new physics discovered at the LHC with higher precision. This new phase is the sLHC. In 2007, the CERN member states approved 240M Swiss Francs (CHF) of new funding to consolidate the LHC injection chain and to begin developing and constructing upgrades needed for the sLHC, and Canada via TRIUMF was invited to engage in this process. CERN will replace the initial parts of the LHC injection chain including the linear accelerator with a new 160 MeV accelerator (LINAC4), the Booster accelerator with a superconducting proton linear accelerator reaching 5 GeV (SPL), and the Proton Synchrotron with a new higher-energy and high intensity synchrotron reaching 50 GeV (PS2). TRIUMF was already a key contributor to the LHC, with providing about $40M of equipment for the LHC from 1995 to 2005. TRIUMF has critical intellectual expertise in the key accelerator physics areas needed for the sLHC-era upgrades to the CERN accelerator complex, and is well positioned to be a leading player in this central and high-profile project at the cutting edge of international accelerator and particle physics. The LHC and sLHC will be the forefront international particle physics and accelerator projects over the next decade, and TRIUMF leadership in this program will cement its role in the world-wide science laboratory community.

There are significant intellectual contributions to the accelerator physics of the sLHC upgrades, beyond the particle physics goals of the project itself. For the SPL, a critical area will be the design of $\beta<1$ superconducting RF cavities which TRIUMF would pursue together with Pavac. Areas include RF modeling and engineering, damping and tuning studies, and optimization of cavity design for fabrication. For the PS2, TRIUMF's accelerator group has strong interests in several areas including machine lattice studies. TRIUMF's expertise, partly from the design of KAON which would have been very similar to PS2, makes the accelerator group international experts in this type of accelerator.

RESOURCE REQUIREMENTS

The resources for sLHC accelerator upgrades will include both the personnel from the accelerator group and capital contributions, plus some allowances for travel to CERN and other meetings. The SPL project will require about 2 FTE-years from accelerator physicists, plus similar contributions from technical support personnel. Capital contributions for the SPL R&D work would be several $100k during the design and prototyping phase. The PS2 project requires about 2 FTEs spread over the next two years to identify areas where TRIUMF could contribute and seriously engage in the design.

With the design of the SPL and PS2 completed early in the TRIUMF 2010-2015 five-year-planning period, direct capital contributions will be needed to complete the projects. The establishment of TRIUMF as leaders in the design efforts will position us very well to engage local industry in the sLHC, seeded by the Canadian capital investment. While CERN and its member states will carry the brunt of the sLHC cost expected to exceed 500 MCHF, a contribution from Canada via TRIUMF of around $20M would firmly fix Canada, TRIUMF and Canadian industry in the sLHC project.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
The TRIUMF accelerator group is Canada's leading accelerator design team. Its expertise is invaluable to the entire Canadian research community. Maintaining a firm engagement in the international accelerator community via leading projects such as the sLHC ensures that the TRIUMF accelerator group remains among the world's leaders in this critical field. Accelerator physics is cross-disciplinary, and is essential to particle physics, nuclear physics, materials science and health physics.

The ATLAS physics programme at the LHC and sLHC has broad support across Canada, having 10 major Canadian Universities involved with more than 40 grant eligible physicists including 4 CRC Chairs.

INVESTIGATORS (GRANT-ELIGIBLE)
TRIUMF Accelerator Group Participating in SLHC
sLHC involved: Rick Baartman, Yu-Chiu Chao, Dobrin Kaltchev, Shane Koscielniak, Robert Laxdal

ATLAS-Canada
Gingrich (also TRIUMF), Moore, Pinfold (Alberta); Axen, Gay (UBC); Asner, Oakham (also TRIUMF), Vincter (Carleton); Corriveau (also IPP), Dobbs, Robertson (also IPP), Vachon, Warburton (McGill); Azuelos (TRIUMF), Couture, Leroy, Martin (Montreal); Benslama (Regina), O'Neil, Vetterli (also TRIUMF) (SFU); Bailey, Krieger, Orr, Savard (also TRIUMF), Sinervo, Teuscher (also IPP), Trischuk (Toronto); Kurchaninov, Losty, Oram, Tafirout, Trigger (TRIUMF); Albert, Astbury, Keeler, Kowalewski, Lefebvre, McPherson(also IPP); Sobie (also IPP) (Victoria); Bhadra, Taylor (York).

BROADER IMPACTS
Accelerator physics has impacts across many areas of society. Particle accelerators started in particle and nuclear physics facilities, but the technology was quickly commercialized in areas as diverse as cathode-ray-tubes, beam welding systems, medical diagnostics, medical isotope production, material science facilities such as the Canadian Light Source, and many more. The accelerator community is international by nature, and maintaining a leading position in the world-wide accelerator effort is critical to maintaining Canada's continued success in this critical field. Involving Canadian industry in the sLHC program will elevate and enhance its role in this competitive international area, leading to significant new contacts and opportunities in the future.

ATLAS Tier-1 Centre

SCIENTIFIC JUSTIFICATION

The ATLAS experiment at the Large Hadron Collider (LHC) at CERN will study proton-proton collisions at the highest energy ever achieved in the laboratory. The ATLAS detector will observe the particles emerging from the roughly 900 million proton-proton collisions per second. Although fast electronics will filter the events so that only those that are of interest will be recorded on computer tape, ATLAS will produce 3.5-5 petabytes of data per year (one petabyte is one million gigabytes). If these data were stored on DVDs, it would take a stack as high as the CN tower every year. In addition, secondary data sets will be produced that could double the amount of data.

In order to analyze this enormous amount of information, CERN is coordinating an international network of large high-performance computing centers that are linked by "grid" tools, such that they act as one huge system. This network is called the Worldwide LHC Computing Grid (WLCG). For ATLAS, ten Tier-1 centers have been built to store and reprocess the raw data. Canada is providing one of these Tier-1 centers at TRIUMF. In addition, we are also building Tier-2 centers in the universities to further process the results of the Tier-1 analysis and extract ground-breaking physics results from the data. The Tier-2 centers will also be the primary site for computer simulation of ATLAS, which is an integral part of the data analysis.

The TRIUMF Tier-1 centre coupled to the University Tier-2 centres gives Canadian physicists a completely "made-in-Canada" ability to analyze ATLAS data. With the ability to prioritize a fraction of our resources for Canadian use, these facilities and support personnel give us a strong competitive advantage for obtain first, best ATLAS physics results in Canada.

RESOURCE REQUIREMENTS

Resources for the ATLAS Tier 1 analysis centre were requested in the 2005-2010 TRIUMF five-year plan and ranked as a top priority project. After the Spring 2005 budget was announced, it was decided to seek alternative funding for the Tier 1 centre. Funding was eventually secured from CFI and the provincial BCKDF fund, conditional on TRIUMF and its member universities agreeing to fund the Tier 1 centre after the end of the CFI funding cycle in 2010. TRIUMF and the university joint venture universities agreed to this condition.

The precise computing requirements needed for the ATLAS Tier 1 centre, as well as the other projects, are very difficult to estimate many years in advance. The computing resource needs are increasing approximately linearly with time, while the costs are reducing. Personnel costs remain approximately constant. The current CFI EOF award with BCKDF matching funds will provide sufficient funds to support the ATLAS Tier 1 centre through 2011. In addition to computing hardware, the operations costs of the centre include personnel. These range from technical personnel such as system administrators, database and network experts to user analysis support personnel. No additional resources for computing beyond ATLAS are currently foreseen for the Tier 1.

PROJECT		Costs	Notes
	Hardware	$10,500,000	Includes renewal
ATLAS Tier 1	Operations	$6,000,000	Assumes 2%/year increase for personnel
	Infrastructure	$1,500,000	
TOTAL		**$18,000,000**	

Table: Expenses for computing dedicated to the external particle physics program.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

ATLAS-Canada includes 10 university groups and TRIUMF, including more than 40 grant-eligible investigators, 20 postdoctoral fellows, and 60 graduate students. The number of graduate students in ATLAS-Canada is growing quickly, with many of the best and brightest students attracted by the highly-visible LHC physics programme. The Tier 1 computing and analysis centre at TRIUMF is the backbone of ATLAS data distribution in Canada. Coupled with the Tier 2 facilities which are parts of the CFI NPF facilities and the university-based Tier 3 centres, the Tier 1 gives us a completely "made-in-Canada" physics analysis capability.

INVESTIGATORS (GRANT-ELIGIBLE)

Alberta: Gingrich (also TRIUMF), Moore, Pinfold
British Columbia: Axen, Gay
Carleton: Asner, Oakham (also TRIUMF), Vincter
McGill: Corriveau (also IPP), Dobbs, Robertson (also IPP), Vachon, Warburton
Montreal: Azuelos (TRIUMF), Couture, Leroy, Martin
Regina: Benslama
Simon Fraser: O'Neil, Vetterli (also TRIUMF) plus new hire starting summer 2008.
Toronto: Bailey, Krieger, Orr, Savard (also TRIUMF), Sinervo, Teuscher (also IPP), Trischuk
TRIUMF: Kurchaninov, Losty, Oram, Tafirout, Trigger plus two new hires starting summer 2008.
Victoria: Albert, Astbury, Keeler, Kowalewski, Lefebvre, McPherson (also IPP), Sobie (also IPP)
York: Bhadra, Taylor

BROADER IMPACTS

The TRIUMF Tier 1 data analysis centre is vital to the success of ATLAS-Canada physics output. Beyond this, the Tier 1 provides a vital centre for the training of computing professionals, undergraduate and graduate students. The Tier 1 centre is a centre-piece for the deployment of so-called "computing grid" technology in Canada.

Life Sciences

The mission of the TRIUMF Life Science Program is to exploit the unique nuclear technologies available to researchers in the Canadian Life Science community in general and the Pacific Parkinson's Research Community the BC Cancer Research Centre.

The Life Science Program along with its collaborators at the Pacific Parkinson's Research Centre and the BC Cancer Agency are working with colleagues across Canada and internationally to advance the field of functional imaging by developing the necessary tools in order to probe the pathologies associated with neurodegeneration and the spread of cancer.

The projects proposed for the next 5 year plan provide for a wide ranging effort in the development of new tracers as well as establishing new platforms for the more efficient preparation of new and existing tracers. For example by miniaturizing the preparation of tracers the specific activity is increased and thus lowering the amount of material in the final product, all of which can enhance the time line for first in human studies.

The research associated with radionuclide production is of great interest both nationally and internationally. Very few centres in the world have the technological resources required to establish the optimal production conditions for these important radionuclides. It is recognized that the use of radionuclides for therapy is the next major step in nuclear medicine. The limited success thus far has been due in part to the lack of availability of a wide range of high specific activity radionuclides with the appropriate physical characteristics for cell kill. TRIUMF's new e-linac and actinide target system will represent a new source of these nuclides which can be mined from the targets for research at TRIUMF and other places.

This next 5 years will see major advances in functional imaging and the use of radioactivity for the treatment of disease. TRIUMF is poised to lead the way for Canada and internationally.

Functional Imaging at TRIUMF

SCIENTIFIC JUSTIFICATION

The development of new radiotracers requires validation through in vivo studies in animal models of the functional system of interest. The TRIUMF program is exploring unique tracers for neurodegeneration and cancer biology. The Pacific Parkinson's Research Centre though its collaborations has access to genetically modified mice that express changes in the rodent brain that can be used to enhance our understanding of human disease. The proposed facilities will accelerate the translation from bench to bedside.

RESOURCE REQUIREMENTS

This resource requires the acquisition of PET/CT and SPECT/CT scanners. Depending upon the state of development the multi-modality scanning equipment could include MRI instead of CT. The MRI device would enhance the functional imaging capabilities. Small animal facility for housing appropriate small animals for the study underway such as genetically modified mice. One TRIUMF senior scientist, one postdoctoral fellow, one physics technician, one animal technician.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The TRIUMF Life Sciences program partners with the BC Cancer Agency and the UBC Pacific Parkinsons Research Centre. This regional team can lead Canada, and in fact, compete globally, by further developing small animal imaging capabilities centered on validating the use of new radiotracers and exploring animal models of disease. Small animal imaging at the front-end of radiotracer development shorten the time-line in bringing a new tracer from the bench to its use in human studies. In addition, TRIUMF will be in a unique position to house and study genetically modified rodents of specific disorders related to the prime mission of the Life Science program, neurodegeneration and cancer. This component relies on the availability of the radiotracers labs. TRIUMF's role in developing small animal imaging capability is therefore driven by its broader program in radiotracer development and partnering with its collaborators in academia and industry.

INVESTIGATORS (GRANT-ELIGIBLE)

Dr. Francois Benard (BCCA), Dr. Jon Stoessl (PPRC), Dr. Vesna Sossii (Physics., UBC), Dr. Doris Doudet (Medicine, UBC), Dr. Michael Adam (TRIUMF). Dr. Thomas Ruth (TRIUMF)

BROADER IMPACTS

A TRIUMF-led Canadian win in this area could have profound healthcare-delivery and economic (e.g., technology licensing) benefits for decades to come.

Instrumentation for Medical Imaging

SCIENTIFIC JUSTIFICATION

Molecular imaging combines the use of biomarkers (radiolabeled compounds or tracers) with nuclear imaging technology such as positron emission tomography (PET) or single-photon emission computed tomography (SPECT). Clinicians use molecular imaging to learn more about how changes in the intake of certain molecules correlate with symptoms exhibited by patients, for example in neurodegenerative diseases, such as Parkinson's disease (PD). PET and SPECT imaging can also be used for cancer staging by identifying cells with low sugar intake.

Traditionally PET and SPECT detectors employ solid scintillating crystals as their detector media, which have a number of limitations including poor energy and timing resolutions, as well as parallax errors and the inability of reconstructing Compton interactions. Improvements over the traditional technology are highly desirable in order to enhance the image quality and drastically reduce the radioelement activity injected to the patient. Detector developments are foreseen in three different technologies relying on the synergy with developments for physics applications. (1) New detectors using liquid xenon (LXe) have good time, energy and position resolution from the scintillation information alone, but also allow for charge collection which provides precise 3-D spatial resolution, greatly improved energy resolution and the ability of reconstructing individual Compton interactions. (2) New scintillator crystals coupled to new photo-sensors such as the Multi-Pixel Photon Counters used for the T2K experiment will improve very significantly the timing resolution and to a lesser extent the energy resolution of traditional PET detectors, while enabling operation in Magnetic Resonance Imaging magnets. (3) Solid state detectors such as CdZnTe are expected to replace crystals for SPECT as they offer superior performances. Characterization of the CdZnTe manufactured locally in British Columbia is hence of prime interest.

RESOURCE REQUIREMENTS

TRIUMF is expected to provide test equipment, technical manpower for detector fabrication and readout, as well as scientific manpower for detector design and operation as well as data analysis. A research scientist focusing solely on medical imaging applications would significantly enhance the impact and visibility of TRIUMF. Test equipment and supplies (500k$/year) for the early stage of the R&D are also needed from TRIUMF, while grants from CHRP will be applied for once a proof of principle is demonstrated. The Liquid Xenon project will require most of the requested resources because it is complex, requiring a cryogenic system, light and charge readout systems and because it has already reached the second stage of prototyping.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The LXe detectors are developed in collaboration with the l'Université de Montréal. The project was supported by a CFI grant until 2007. New scintillating crystals and photo-sensors will be developed in collaboration with UBC, l'Université de Sherbrooke, and the

University of Regina. The development of CdZnTe will be performed in collaboration with a local company in British Columbia.

INVESTIGATORS (GRANT-ELIGIBLE)
UBC: D. Bryman, V. Sossi, J. Stoessl. *U. de Sherbrooke:* R. Lecomte. *TRIUMF:* L. Kurchaninov, F. Retière, T. Ruth

BROADER IMPACTS
Nearly 100,000 Canadians (and over 1.5 million people in North America) are affected by PD, and while the average age of onset is at age 60, people as young as 30 have been diagnosed with the disease. In addition to a promise of early diagnosis of PD through molecular imaging, PET is also used to investigate animal models of PD and to explore how potential medications work in the brain, thus it may be through this kind of technology that a cure for the disease may be discovered. The use of LXe as a detector is also of interest in the ZEPLIN and LUX dark matter searches potentially located at SNOLab. New photo-sensors may be used in a variety of physics experiment including the International Linear Collider and T2K.

Microfluidics

SCIENTIFIC JUSTIFICATION

As with electronics miniaturization in the last century, a nearly inconceivable jump in the automation and parallelism of chemical processing will occur in the coming few years through the miniaturization of the chemistry lab to the "lab on-a-chip" which implements the synthetic and analytic infrastructure in miniature in the form of microscopic reaction vessels, valves etc. This revolution has the potential to have an enormous effect on radiochemistry in particular where the conventional radiochemical lab is constrained by the safety and cost considerations even the litre scale. The miniaturization of the radiochemistry used to prepare radiotracers has the advantage of higher yields, shorter reaction times and higher purity, all of which provide for more rapid translation from animal studies to human studies. The lab-on-a-chip facility will initially focus on bringing our existing boutique of tracers to a scale that allows simple, rapid production with minimal intervention. Chips will be designed to take advantage of the operations approach to labeling so that we can continue to exploit the advances made in preparing new compounds as they appear in the literature.

RESOURCE REQUIREMENTS

The required equipment will be used to microfabricate the chips for conducting microscale chemical synthesis. After microfabrication, the chips will be tested for various mixing, chemical reaction and separation steps. Subsequently, the chips will be tested with radiotracers. This equipment requested consists of a mask aligner (UV light exposure system, CCD camera alignment system, vacuum mask holder system, vibration isolation system) that will be housed in a soft-wall clean-room enclosure for photomask development. The facility will be housed in designated clean environment lab. One TRIUMF senior scientist, 1 postdoctoral fellow.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The TRIUMF Life Sciences program partners with the BC Cancer Agency and the UBC Pacific Parkinsons Research Centre. This regional team can lead Canada, and in fact, compete globally, by developing microfluidic capabilities. Microfluidics has been widely recognized as a barrier to broad distribution of nuclear medical capabilities because these laboratories traditionally require trained chemists, wet labs, and hot cells. TRIUMF's role in developing microfluidic technology is therefore driven by its broader program in nuclear medicine and the interests of its partners to develop and deploy a set of tools for national impact.

INVESTIGATORS (GRANT-ELIGIBLE)

Dr. Francois Benard (BCCA), Dr. Jon Stoessl (PPRC), Dr. Paul Li (Chem., SFU), Dr. Michael Adam (TRIUMF). Dr. Thomas Ruth (TRIUMF). In addition collaborators at UBC with expertise in microfluidics include Drs. Carl Hansen (Physics) and Boris Stoeber (Mech. Eng.).

BROADER IMPACTS

A TRIUMF-led Canadian win in this area could have profound healthcare-delivery and economic (e.g., technology licensing) benefits for decades to come.

Laboratory Infrastructure

SCIENTIFIC JUSTIFICATION

The TRIUMF laboratories involved in the production of radiotracers for human experimentation require an upgrade to Health Canada's "Good Manufacturing Practices" in order to operate beyond the near-term future. This upgrade affects TRIUMF's partnership with the UBC Pacific Parkinsons Research Centre (PPRC) and the BC Cancer Agency (BCCA). In addition, we are proposing to build new laboratory space that will allow us to drive the development of the next generation of radiotracers for use in functional imaging for both basic and clinical research with a focus on neuroscience and oncology. Recognizing that radiotracer development in many ways mirrors the complexity of pharmaceutical development, we are building a facility that will streamline and speed the development pathway by pursuing a key innovation in process optimization rather than seeking to simply focus on developing a new narrow line of tracers.

RESOURCE REQUIREMENTS

To fully exploit this opportunity, a new clean room facility containing 6 hot cells and a laminar flow hood is proposed. If a lower-impact expansion was selected, one could build a new facility containing only 1 hot cell, 4 fume hoods, and an LC-Mass spectrometer. Operating this facility would require one senior scientist, 1 postdoctoral fellow, and 2 technicians.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

TRIUMF's role in the Canadian nuclear-medicine community is different than its role in the subatomic physics community. In partnership with PPRC and BCCA, TRIUMF's Life Sciences program represents a research output at the forefronts of nuclear-medicine techniques. There is growing national interest in medical isotopes as evidenced by the proposed CFI in cyclotron-produced radiotracers and the public debate surrounding Chalk River. An expansion of the TRIUMF infrastructure in this area would allow the lab to take a leadership role in this wave spreading across Canada.

INVESTIGATORS (GRANT-ELIGIBLE)

Dr. Francois Benard (BCCA), Dr. Jon Stoessl (PPRC), Dr. David Perrin (Chem., UBC), Dr. Michael Adam (TRIUMF). Dr. Thomas Ruth (TRIUMF)

BROADER IMPACTS

BC is uniquely poised to fast-track the establishment of a fully integrated radiotracer program by mobilizing, co-coordinating and expanding on resources that currently exist within the biomedical and basic research communities. BC has outstanding programs of research in nuclear physics, engineering, physics, biophysics, chemistry, biochemistry, radiochemistry, radiopharmacy, mathematics, genome sciences, bio-informatics, epidemiology, radiology, clinical oncology and clinical imaging. By adding key infrastructure for rapid development and testing of novel radiotracers to feed in to the current infrastructure, it would be possible to expedite creation of a focused program of innovative radiotracer research and position BC at the forefront of developments in imaging technology in contrast to many other locations in the world.

PET Targetry

SCIENTIFIC JUSTIFICATION

The need for improved yields and specific activity for radionuclides used in PET imaging is a continual battle. Recent developments point to the benefits of using ultra-high specific activity. The existing TR13 cyclotron at TRIUMF was designed to operate at 19 MeV with >100 microAmps of protons circulating. However, it was situated in a public area with localized shielding that was not capable of providing the necessary radiation safety at the machine's design parameters. At present, operation is restricted to 13 MeV with target beam currents of less than 25 microAmps. While this situation is adequate for a narrowly focused program, the new program will require greater capacity for routine production as well as for development of new target-chemistry systems. This will be especially important for developing highly concentrated high specific activity C-11 where we would like to have multiple curies in very small volumes. We wish to relocate the cyclotron to the basement of a new chemistry laboratory that would include a dedicated vault for the cyclotron.

RESOURCE REQUIREMENTS

The dismantling and move coupled with the upgrade of the beam extraction system is estimated to be $700K by the accelerator staff at TRIUMF. TRIUMF contribution will be in the form of staff riggers, engineers, and physicists for the design and implementation of the relocation and upgrade. The other costs are for the actual materials involved. The subsequent research program would require at least one senior scientist, 1 postdoctoral fellow, and 1 technician.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The Canadian nuclear-medicine community is typically based at the teaching hospitals but there is increasing recognition of the need to couple these efforts with accelerator and radiochemistry experts of physical-science research. Relocating the present TR13 cyclotron would allow TRIUMF to take the lead in this evolution of the Canadian community. There are also indications that if Canada does not redouble its efforts in this area, the United States will simply replicate the Canadian program in a few years and render the Canadian advantage obsolete.

INVESTIGATORS (GRANT-ELIGIBLE)

Dr. Francois Benard (BCCA), Dr. Jon Stoessl (PPRC), Dr. David Perrin (Chem., UBC), Dr. Michael Adam (TRIUMF). Dr. Thomas Ruth (TRIUMF).

BROADER IMPACTS

This proposal would allow TRIUMF to more fully exploit its present infrastructure in its partnership with the UBC Pacific Parkinsons Research centre and the BC Cancer Agency.

Mining Radionuclides

SCIENTIFIC JUSTIFICATION

The spallation/fission targets developed for the actinide-target program at ISAC provide the possibility of producing large quantities of radionuclides that may have therapeutic potential both as beta emitters and alpha emitters. The use of alpha emitting radionuclides is seen as the next major avenue for growth in the use of radionuclides in medicine. Alpha emitting radionuclides are found in the region of the actinides, in particular Ac-225 and At-211 are the most promising and their availability is greatly restricted due to the difficulty of making them with existing facilities worldwide. These radionuclides can have powerful therapeutic value based on their half-lives, decay-spectrum energetics, and the type of decay products. For instance, alpha particles travel only a short distance in human tissue and deliver enough ionizing energy to break both strands of DNA, thereby ensuring cell death. One futuristic vision proposes to deploy PET-labelled target molecules in the human body in combination with identical molecules labelled instead with alpha-particle emitters as “seek and destroy” assassins for cancer. This combination provides the opportunity to visualize the location of the target , e.g. a tumour, and then using the same chemical species to carry the lethal package to that tumour.

RESOURCE REQUIREMENTS

Access to radioisotopes produced from the actinide targets (proton and photofission) which will entail remote handling. Dedicated chemistry lab with 2 fume hoods and two hot cells. One TRIUMF senior scientists, 1 postdoctoral fellows, and 2 technicians.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

This program would fit naturally into the nuclear-medicine focus of the TRIUMF Life Sciences program. It would play to TRIUMF’s strengths in this area and, in partnership with BC Cancer Agency, would develop world-unique capabilities.

INVESTIGATORS (GRANT-ELIGIBLE)

One senior scientist, 1 PDF and 2 graduate students and 1 technician.

BROADER IMPACTS

In terms of healthcare delivery, clinicians have long wished for a magic bullet—even if only for one type of cancer. An exploratory program examining novel radionuclides might uncover significant breakthroughs. Furthermore, the long-range economic impact of contributing to the development of real-time cancer therapy is incalculable.

Proton Therapy

SCIENTIFIC JUSTIFICATION

The Proton Therapy Facility at TRIUMF uses 74-MeV protons extracted from the main cyclotron for the treatment of ocular melanoma. Before proton treatment became available at TRIUMF, the usual course of action for Canadian patients with large tumours or ones at the back of the eye near the optic nerve was to remove the eye entirely. For smaller tumours, the preferred treatment is still to implant a radioactive disk for a few days. Occasionally it is possible to remove small tumours surgically, but this can be difficult. Any of these alternatives could damage other sensitive parts of the eye and result in some loss of vision. Proton therapy offers the possibility of having the tumours stabilized, the eyes preserved, and depending on the location of the tumour, the vision intact.

The proton beam is modified by range modulation and collimation to provide a uniform dose over the volume of the tumour while sparing, if possible, the critical structures such as the lens and optic nerve. The patient positioning chair, which has six motorized degrees of freedom, the patient mask and bite-block, and the X-ray verification system ensure sub-millimetre positioning accuracy.

RESOURCE REQUIREMENTS

Since 1995, TRIUMF has housed Canada's only clinical proton therapy centre for the treatment of choroidal melanoma, a type of eye cancer. The treatment facility is operated as a collaboration between TRIUMF, the BC Cancer Agency (BCCA) and the University of British Columbia Eye Care Centre. Patients, primarily from Western Canada, are referred for proton therapy by oncologists at the BC Cancer Agency and ophthalmologists at the Eye Care Centre. Patient treatments are scheduled about one week per month with the treatment dose of 50 proton-Gy delivered in four daily fractions.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The Proton Therapy Facility is unique in Canada and therefore fills a clinical gap for the treatment of certain eye cancers.

INVESTIGATORS (GRANT-ELIGIBLE)

E. Blackmore, T. Pickles (BCCA), K. Paton (UBC)

BROADER IMPACTS

Proton therapy continues to save vision in patients; since the inception of the program, 130 patients have been successfully treated at TRIUMF. In this way, ??

Generalized Infrastructure

Infrastructure at TRIUMF is critical to its success. Ranging from the ability to provide basic utilities to the experimental halls to maintaining access to the latest information and communications technology, these capabilities are of significant value to the entire research community. In the next five-year plan, TRIUMF faces several decisions about growth paths.

TRIUMF's on-site computing services are primarily geared to providing researchers the tools they need to design, build, operate, and maintain their experiments as well as to acquire, analyze, and publish the data. These services will need some upgrade and expansion if the laboratory's overall programs expand. Core research services for experiments, such as liquid helium, could be upgraded to decrease on-site costs and provide capabilities for the broader "lower mainland" area of British Columbia. Likewise, there are a number of key physical plant issues that could be addressed in the next five years. Finally, compliance with new regulations regarding safety and risk management will need attention. An example would be the need to upgrade and formalize certain aspects of the on-site handling of radioactive materials were the experimental programs to expand.

Helium Liquefaction

JUSTIFICATION

TRIUMF uses about 30,000 litres of liquid helium per year for experiments. Users at the University of British Columbia also require about 10,000 litres. Liquid helium is supplied to TRIUMF and UBC from Praxair under a Product Supply Agreement at a cost of about $10 per litre, which totals about $340,000 per year. This company suffered the loss of two major crude helium sources over the past year. Praxair announced that only 60% of the normal supply will be provided during the term of contingency. Further interruptions in the supply of liquid helium from Praxair can be expected, as well as price increases.

A world-wide shortage of helium gas is putting a strain on physics labs, manufacturers and other businesses that are dependent on helium for their work. A severe shortage of helium supply in the early 21st century has been predicted by the American Physical Society and is currently being examined by the U.S. National Academy of Sciences. Many laboratories and plants are faced with helium supply shortages and price increases. The world-wide demand for helium is growing, fuelled mainly by high-tech manufacturing in developing countries. Moreover, helium in gaseous form released to the Earth’s atmosphere is lost irreversibly.

Therefore, the issue of helium retention and recycling is of a great importance to TRIUMF.

RESOURCE REQUIREMENTS

We propose to address the helium supply problem by erecting a helium liquefaction plant and by recycling used helium gas. To achieve this goal a helium liquefier of about 100 l/hr (similar to the *Linde* L140 or the *Air Liquide* Helial 2000) would be purchased, installed and commissioned to fulfill the experimentalists’ needs. It requires certain capital investment into equipment, buildings and infrastructure. The estimated cost of supplies and equipment is about 1.25M$, where one million is the cost of the liquefier and gas management system alone. Personnel requirements, when commissioned, are a cryogenic engineer (0.2 FT) and cryogenic technician (0.8 FT).

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

There is no helium liquefaction plant of this size in BC to the best of our knowledge. Praxair is delivering liquid helium from the South of the United States. UBC, SFU and local high-tech companies may benefit from the ability to substitute the supplier if required, by having a lower mainland based helium liquefaction plant.

The liquefaction capability will be combined with liquefaction/refrigeration requirements for the SCRF, the superconducting electron linac, superconducting cyclotron, and other liquid helium related developments.

BROADER IMPACTS

All of the above will make TRIUMF a more attractive user facility to local, national and international scientific communities. It is also possible that a helium-liquefaction plant could be operated as a stand-alone company for the lower mainland and would generate revenue through re-sales to the large community.

Generalized Site Infrastructure

JUSTIFICATION

TRIUMF has upgrade needs for its basic infrastructure in 2010-2015. These include the following 5 general areas:

1. Site Services: electrical, mechanical(HVAC, water), minor construction
2. Mechanical Engineering, Design Office, Machine Shop
3. Electronics and Controls
4. Experimental area services/support and magnets/magnet measurements
5. Divisional account for general expenses and travel

It is expected that about $1.5 million/year (in 2007 dollars) is a reasonable annual budget for these upgrades and will allow for minor construction/roof replacement/HVAC upgrades/software support etc as well as a reasonable amount of capital spending for machine shop and computer/electronics equipment. In the period 2010-2015 there will likely be two more CNC machining centres purchased.

However, the specifics of TRIUMF's future program will impact these estimates as consideration is given to maintenance and upgrades of areas important to TRIUMF's operations which are not provided for in the current budget. They include the following:

- Housing of Trailer Occupants. Trailer Gg, Hh and Ff will not survive as viable personnel space until 2015. Trailer Gg needs some work right now as parts of it are sinking and causing problems. There are already health issues with some of the occupants. The space required is 15,000 ft2 with office and laboratory space for about 80 occupants. I don't see this amount of extra space included in the proposed building program. I estimate that we are looking at a $4-5 million building or additions to a building to adequately house these occupants
- Parking lot upgrades. If we manage to keep the remainder of the present parking lot (after the Mouse House space is taken) then we will have to take steps to accommodate all staff parking. The least expensive solution would be to pave the entire lot so that spaces can be clearly marked and used more effectively. This would cost $150-200K. I expect that this will have to happen prior to 2010. However if we have to move all or part of the parking to the south of the TRIUMF site, or build a multilevel parking garage, then there would be substantial extra costs.
- New Regulatory Requirements. The Fire Protection Assessment Report has been received from the consultants. This report identifies the changes that may have to be made to comply with NFPA 801, as required by CNSC. There will be some cost implications in satisfying these requirements, in particular in some upgrades to services, storage of radioactive materials, fire barriers for electrical cables etc. This is just one of the potential costs to satisfy our regulators and adequate

accounting of the total funds necessary will have to be made somewhere. Expansions in site security and remote-monitoring devices are also proposed.

- Power infrastructure. UBC Utilities is in discussion with TRIUMF about upgrades to the substation that might involve one or more 12 kV transformers. The additional power needs for the next Five Year Plan is anticipated to be between 4-6 MW. The substation has spare capacity to satisfy the present 5YP needs, but needs to be reconfigured, since one transformer is loaded more than the other. The reconfiguration requires the upgrade the feeder transformers to the Cyclotron systems (Main magnet and RF) and their lines. In addition, power factor correction and harmonic filters need to be factored in the capital costs equation. Others activities could include:
  - Additional Diesel backed up power for an estimated 300 KW required
  - Additional UPS power for ATLAS Tier-1 300-500 kW. It depends on computing configuration.
  - Additional UPS for new building critical services.
  - Expand fire alarm system, sprinklers, voice and data communication systems.
  - Cooling towers upgrade. The main cyclotron cooling tower consists of 7 units VLT-1200 fed by a raw water system that takes heat for heat exchangers in the service annex. The present system is capable of cooling about 6-7 MW. Operating experience shows that cooling is adequate for 10 months per year except for July and August. This cooling system must be upgraded if a significant additional cooling load is added. The ISAC cooling tower was sized for a load of about 2.5 MW. It has sufficient capacity to add an additional 1 MW.
- Nuclear ventilation upgrade. There is a minor improvement to upgrade the ISAC-I nuclear ventilation system in preparation for handling an actinide target. The existing ISAC Nuclear Ventilation System is operating close to capacity and would have to be expanded when additional targets stations are built.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

One of the mandates specified within the TRIUMF-NRC Contribution Agreement states that TRIUMF is responsible for operating and maintaining the Laboratory as a national accelerator-based research facility in a safe, secure and reliable manner. TRIUMF is also to provide targeted support to the Canadian subatomic physics program as Canada's primary centre for subatomic physics research.

In view of these requirements, it would be of immense benefit to the Canadian research community for TRIUMF to maintain an optimal site infrastructure.

BROADER IMPACTS

Without properly maintained and upgraded infrastructure, scientific outputs would be hampered, which would lead to decreased innovation and idea generation.

Computing Services

SCIENTIFIC JUSTIFICATION

Scientific research is increasingly distributed, both in terms of the planning and execution and the analysis and interpretation stages. TRIUMF maintains an on-site computing group to facilitate the communication among all the participants in each research project as well as to enable specifically their objectives. The TRIUMF Computing Services Group provides resources needed for the whole of the on-site science program and also for the local users of remote facilities. These resources include: local and wide area networking, computing hosts, e-mail, file serving and backup, web services, printing, software license management, video conferencing, scientific computing and data acquisition support.

RESOURCE REQUIREMENTS

The Computer Services Group requires funding for computing infrastructure at roughly the current level. When the new building for the ATLAS Tier 1 is built the Computer Services Group should also be relocated to that building. The costs associated with the relocation have not yet been fully estimated (in part because the future home of the Tier-1 Centre is not yet known). This move would presumably take place in the 2011-2012 timeframe.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The Computer Services Group provides support for all users of the TRIUMF facility independent of where they are physically located. The Computing Services Group has made it an increasingly important objective to present a seamless and integrated interface to users both on-site and off-site. This includes outside users from the Canadian university community. Canadian experimental groups, especially the SNOLab researchers, have requested that TRIUMF provide them with data acquisition support and development. This would only be possible with an increase of at least 2 FTE in personnel. Although discussed separately, the ATLAS Tier 1 computer center is also part of the Computer Services Group and interacts with it for their mutual benefit.

INVESTIGATORS (GRANT-ELIGIBLE)

The following TRIUMF staff members provide support to Canadian grant-eligible investigators:

Group Leader: S. McDonald
Administrative Computing**:** G. Jones, B. Leathem, T. Lowe
Computing and Networking Services: K. Rywood, H. Rafighi, R. Watt, K. Ng, L. Ho
General Scientific Computing: R. Poutissou, R. Amaudruz, K. Olchanski, S. Daviel, P.Gumplinger, J. Chuma, C. Pearson

BROADER IMPACTS

Computers and computer networks are an integral part of our lives. The expertise developed in supporting the computer needs of the experimental program pushes the limits of available technology and has wide applicability. For instance, the Computing Services Group recently hosted an IBM Business Technology conference because of their involvement with the ATLAS Tier-1 Centre. TRIUMF's information technology presence also draws on the local strengths of Vancouver.

Materials Storage & Handling

JUSTIFICATION

The need for materials storage space will depend partially on what new initiatives are undertaken in this five year plan. One of the definite identified needs for additional storage is at ISAC for the spent targets. Having reached a higher reliability with the ISAC production targets and operating high power targets, these targets are now exceeding 30,000 μA-hrs integrated charge. The inventory of activity at these operating conditions is such that the targets require 3 years of decay before they can be shipped away for disposal. One could reduce the integrated charge on target by splitting it between two targets; however, this does not alleviate the requirements for spent target storage. The storage trench for "hot" beam line components from the front end of the meson channels or the high current proton beam lines will reach full capacity with the planned work for the upgrade of M20. Should other projects require the removal of large activated beam line components, consideration would have to be given to additional locations for storage.

RESOURCE REQUIREMENTS

ISAC operation at higher currents means that there is need for an additional spent-target storage facility. The one currently in use was built six years ago and was constructed of steel for the cost of $60K for materials and fabrication. The assembly was done at TRIUMF. Due to significant inflation in the price of steel, a similar storage vault would cost upwards of $100K.

The current area for handling low-level radioactive materials at the east end of the Meson Hall Extension is perhaps not the best use of this space with crane coverage for the hall. The two biggest concerns are the fire load and the lack of space for assaying the materials. Currently the material is assayed in the detector facility where the natural radiation levels are lower and well known. A separate low-level handling facility would free up the east end of the hall and provide a location where the handling, packaging and assaying can be carried out.

Molecular and Materials Science

Accelerators are used for more than just subatomic-physics research. At TRIUMF, teams of scientists have developed several world-leading techniques for using accelerators to probe the phenomena in the domains of chemistry, condensed matter physics and materials science. These advanced techniques are offered to a worldwide community of researchers under the auspices of TRIUMF's Centre for Molecular and Materials Science, and continue to be in very high demand, with requests far outstripping available beam time. Scientists prepare samples of novel materials and then visit TCMMS for a brief period to probe and "image" their material under a variety of conditions. The ability of this program to serve existing (and growing) user demands is limited by the availability of beams from the main cyclotron.

In the next five-year plan, this element of the TRIUMF program faces several growth paths. New beam lines are currently underway for the muon spin resonance (μSR) technique. These beam lines will need continuing TRIUMF support to realize their full scientific potential. Upgrades to the beta nuclear magnetic resonance (βNMR) program are possible in the 2010-2015 period.

Scientific Overview

Although TRIUMF's principal focus has been the study of nuclear and particle physics, one of its major achievements has been in the development of the muon spin rotation (μSR) facility and, more recently, the beta detected NMR (βNMR) facility at ISAC, for materials research. These techniques use beams of light spin-polarized particles as ultrasensitive implanted magnetic probes for fundamental studies of matter at the atomic (rather than subatomic) scale. With its Centre for Molecular and Materials Science (CMMS), TRIUMF is the only laboratory in the world to offer a broad community of chemists and materials scientists with diverse research interests the complementary tools of μSR and βNMR in one integrated facility.

The use of radiotracers is well-known in chemistry. Here the pathway of a radioactively labeled chemical species is followed through a chemical reaction to elucidate the reaction mechanism, e.g. bringing to light important rate-determining steps. The use of the muon as a chemical radiotracer is based on its ability to mimic *hydrogen* by forming a special hydrogen-like atom called muonium with the positive muon (μ^+) playing the role of the atomic nucleus. The information available by μSR is, however, much greater than from traditional radiotracers. This is because the radioactive decay of the muon is used, not just to register the presence of the radiolabelled species, but, through a special property of the β decay called parity violation, to obtain information about the state of the muon's spin at the time of decay, yielding information similar to Nuclear Magnetic Resonance.

Strong correlation problems are notoriously difficult to treat theoretically, so it is extremely important to use all experimental means to guide theorists. Scientists using the CMMS μSR facility continue to make key contributions in this global effort, using the extraordinary sensitivity of the muon as a local magnetic probe to study novel strongly correlated magnetic and superconducting materials. The sensitivity of μSR also makes it ideal for studying certain subtle, but critically important, problems in materials, such as the behaviour of hydrogen in semiconductors, where it is a common and very important impurity, and in potential hydrogen storage materials that can store high concentrations of hydrogen fuel in the relatively safe and convenient form of a solid solution.

While still in its infancy, the βNMR technique, as implemented at TRIUMF, aims to study the properties of nanostructured materials, where interfaces between dissimilar materials play a crucial role. There are very few techniques capable of studying the depth dependent phenomena that occur at heterointerfaces in solids. Recent progress indicates an enormous scientific opportunity: to use the unique capabilities of this new depth-resolved technique to study many phenomena at buried interfaces and near free surfaces that are of both fundamental scientific interest as well as of crucial practical importance in new generations of technological applications.

Facility Overview

Materials and Molecular Science at TRIUMF is not a single experiment, but a large collection of experiments conducted with the support of TRIUMF's Centre for Molecular and Materials Science (CMMS). The CMMS maintains and develops a collection of experimental spectrometers which are used by a wide range of researchers from across Canada and throughout the world. Each experiment is approved by the MMS Experimental Evaluation Committee and then assigned beam time. A total of 105 different experiments have been vetted by this body in the three years 2005-2007. The CMMS is funded via a large ($300k/year) NSERC MFA grant awarded to a collaboration of 10 of the major Canadian users of the facility. This grant currently pays the salaries of most of the technical and scientific staff of the CMMS. In 2008, only two staff of the CMMS are TRIUMF salaried. The CMMS has an excellent track record of scientific output in the form of refereed scientific publications in the fields of chemistry, condensed matter and materials science, accounting for a significant fraction of TRIUMF's overall scientific productivity.

μSR experiments require the 500 MeV proton beam from the main cyclotron to produce muons via nuclear reactions in one of two "production targets" (T1 and T2) on TRIUMF's beam line 1A, the primary beam line in the meson hall. Several secondary muon beams are then directed to experimental areas where CMMS spectrometers are stationed with user supplied samples and specialized equipment. Currently there are three experimental stations, but by 2010, this number will be increased to 5 with improved capabilities.

Similarly, βNMR requires a primary driver beam (currently the 500 MeV proton beam line 2A to ISAC) to create the short-lived radioisotopes it uses, as well as the specialized secondary beam lines of the ISAC low energy hall for the transport and polarization of the beam on its way to one of two experimental spectrometers. As ISAC can currently produce only a single radioactive ion beam at a time, the beam time for βNMR is much more limited than for μSR. The scientific potential of the technique as implemented at TRIUMF has been demonstrated in the period 2004-2008, but expansion of the programme to full user-facility status is not possible with current beam availability.

Because temperature is a key variable in the study of condensed matter systems, CMMS is one of the heaviest users of liquid cryogens (nitrogen and helium) on-site. CMMS also depends upon other TRIUMF infrastructure, such as detector development facilities and expertise, design and engineering expertise, machine and electronics shop and computing and data acquisition capabilities, etc.

Beta NMR

SCIENTIFIC JUSTIFICATION

Metamaterials are formed when two or more materials are brought together into a heterostructure. The presence of the interface modifies the properties of the component materials in a depth dependent manner (sufficiently far from the interface, they recover to those of the bulk). Understanding metamaterials is important both fundamentally and practically. Current solid-state electronic technology depends upon such interfaces, and new generations of devices, incorporating unconventional materials, will require a similarly detailed level of understanding and control. However, very few depth-resolved probes of condensed matter systems exist. Recently, we have demonstrated the ability to implant beta radioactive NMR probes at specific depths into materials. Hence, we have developed a unique and powerful depth-resolved local probe of the electronic and magnetic properties of metamaterials on length scales from a few hundred nanometres to a few nanometres.

RESOURCE REQUIREMENTS

Currently demand for the ISAC radioactive ion beam (RIB) by βNMR far exceeds the time available (about 4 delivered beam-weeks per year). This lack of accessibility is the primary barrier to transforming βNMR from the development phase into a flourishing user facility with continuous demand. Parallel RIB production at ISAC by either a second proton spallation source or a photodisintegration source (based on an e-linac driver) would address this bottleneck. Useful βNMR isotopes are light, short-lived, and generally do not need a high-resolution mass separator. βNMR does, however, require high quality beams with good temporal stability, and new production target designs should take these criteria into account. Apart from beam time, the maintenance and development of the complex spectrometers requires TRIUMF support, specifically one fulltime scientist position and one fulltime technician – with ultrahigh vacuum, cryogenics, high voltage design, beam dynamics, automation, data acquisition, detector development, and materials science skills. With sufficient investment, demand for βNMR beam time will be continuous for the foreseeable future. Some funding for spectrometer development will be sought through NSERC RTI and some personnel costs via the CMMS NSERC MFA.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

TRIUMF has extensive experience in the use of radioactive beams in the study of materials via muon spin rotation and the TRIUMF Centre for Materials and Molecular Science. βNMR builds on this internationally recognized strength.

INVESTIGATORS (GRANT-ELIGIBLE)

W.A. MacFarlane, UBC Chemistry, R.F. Kiefl, UBC Physics, K.H. Chow, University of Alberta Physics, and a *large community of potential users*.

BROADER IMPACTS

βNMR trains many highly qualified people: graduate students, undergraduate students, postdoctoral fellows, as well as technical and scientific staff. It frequently contributes to scientific knowledge at the fundamental level (reflected in research publications) and may be useful for applied research in special cases. Materials research is a keystone of modern economies, and government-funded fundamental materials research at centrally located facilities such as TRIUMF is an important aspect of this since it enables a large national and international scientific community to access state of the art techniques that would otherwise be impossible at their local institution.

New Muon Beam line

SCIENTIFIC JUSTIFICATION

The TRIUMF Centre for Material and Molecular Science (TCMMS) is a user facility that serves a broad community of scientists from Canada and throughout the world with a facility for muon spin rotation (μSR), a technique which uses a beam of short-lived highly spin-polarized muons to probe a host material in a manner analogous to nuclear magnetic resonance, but with extremely high sensitivity (by virtue of the "nuclear" detection scheme that uses the high energy positron from the parity violating weak decay of the muon). This makes it an extremely sensitive magnetic probe of solids. In addition, in many materials, the muon also effectively mimics atomic hydrogen, forming a special hydrogen-like atom called muonium with the positive muon (μ^+) playing the role of the atomic nucleus. Hydrogen is a very simple, common and extremely important atom in organic and inorganic chemistry and as a ubiquitous impurity in solids. Over the past 3 decades, μSR has made important contributions to both chemistry and condensed matter physics. For some time, TCMMS has produced a large fraction of the on-site research at TRIUMF; for example, a recent sample of a 52 month period found that the TCMMS had produced 211 refereed publications, 20 graduate theses and 9 book chapters. This level of scientific productivity is typical of the TCMMS.

RESOURCE REQUIREMENTS

The TCMMS was recently awarded a large CFI grant (total project $6 M) to build new beam lines to address the shortfall of available beam time and extend the capabilities with the first new infrastructure investment at the beam line level in more than 20 years. These beam lines will be commissioned near the beginning of this 5 year plan period. The main resource requirements from TRIUMF during 2010-2015 will then be 1) to provide sufficient proton current to beam line 1A (BL1A) to supply the new muon beam lines to take full advantage of the new infrastructure. To obtain the highest luminosity, under the increasing demands on the cyclotron (from ISAC, proposed ultracold neutron facility, etc.), this will require a redesign of the muon production targets on BL1A with the goal of optimizing them for surface muon luminosity and 2) Increasing the personnel support of the TCMMS from 1 fulltime scientist to 3. The first item will require significant investment by TRIUMF in the form of design, fabrication and testing of a new generation of production targets.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The TCMMS is widely recognized as a flagship of condensed matter research in Canada and around the world. Similarly it is widely known in the Chemistry for its contributions to that field.

INVESTIGATORS (GRANT-ELIGIBLE)

Canadian: P.W. Percival, SFU, G.M. Luke, McMaster, J.E. Sonier, SFU, W.A. MacFarlane, UBC R.F. Kiefl, UBC, K.H. Chow, Alberta, J.H. Brewer, UBC, S.R.

Kreitzman, TRIUMF, D.G. Fleming, UBC, K. Ghandi, Mt. Allison, D.H. Ryan, McGill, J. Clyburne, SFU, D. Leznoff, SFU, A. Mar, Alberta, T. Imai, McMaster.

There are many other major users from the USA, Europe and Japan.

BROADER IMPACTS

The TCMMS trains many HQP in the form of graduate students, summer students and postdoctoral fellows, as well as technical and scientific staff. It contributes to scientific knowledge at the fundamental level (reflected in research publications) and may be useful for applied research in special cases. Scientists currently travel from all over the world to use TCMMS facilities in their research fostering a strong connection between Canada and the global efforts in materials research.

New μSR capabilities

SCIENTIFIC JUSTIFICATION

With the newly commissioned muon beam lines providing high luminosity beams to 5 experimental stations, the focus of the TRIUMF Centre for Materials and Molecular Science (TCMMS) will shift to *enhancing experimental capacity* by 1) making μSR available to a broad community of users who will utilize it as a tool within the context of their particular research; 2) expanding the parameter space for μSR experiments to higher magnetic field, higher applied pressure, higher frequency resolution, the combination of high pressure and ultralow temperature, smaller samples, measurements under applied electric field and optical illumination; and 3) increasing the reliability and ease-of-use of its spectrometers, for instance using a new generation of reconfigurable electronics, software improvements and a higher degree of automation. The first item will widen the user base of μSR, the second will expand its capabilities to currently inaccessible phenomena, while the third will help address the existing approved scientific backlog of 2 years of beam time as well as enable new users to propose experiments and carry them out in a reasonable timeframe.

RESOURCE REQUIREMENTS

The TCMMS requires a guaranteed source of cryogenic liquid helium, ideally from the proposed on-site liquefaction facility. Helium vapour should be collected from all 5 μSR stations as well as from the 2 βNMR spectrometers for reliquefaction. The M20 rebuild will require significant TRIUMF resources: a) Technical & engineering resources; b) Potentially some hard financial contribution to meet its required in-kind contribution of $1,200,000. The redesign of the T1 and T2 targets to optimize muon production will also require the resources of the specialized TRIUMF engineering team that is devoted to target design. Finally, electronics development support for new user-friendly data acquisition systems (based on fast timing FPGA) will also be required.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The TCMMS is widely recognized as a flagship of condensed matter research in Canada and around the world. Similarly, it is widely known in the Chemistry for its contributions to that field. It has further demonstrated practical relevance to basic research on materials design, industrial and environmental processes, an aspect that will become increasingly important.

INVESTIGATORS (GRANT-ELIGIBLE)

Canadian: P.W. Percival, SFU, G.M. Luke, McMaster, J.E. Sonier, SFU, W.A. MacFarlane, UBC R.F. Kiefl, UBC, K.H. Chow, Alberta, J.H. Brewer, UBC, S.R. Kreitzman, TRIUMF, D.G. Fleming, UBC, K. Ghandi, Mt. Allison, D.H. Ryan, McGill, J. Clyburne, SFU, D. Leznoff, SFU, A. Mar, Alberta, T. Imai, McMaster.
There are many other major users from the USA, Europe and Japan.

BROADER IMPACTS

The TCMMS trains many HQP in the form of graduate students, summer students and postdoctoral felloes, as well as technical and scientific staff. It contributes to scientific knowledge at the fundamental level (reflected in research publications) and may be useful for applied research in special cases. Materials research is a keystone of modern economies.

Subatomic Physics On Site

TRIUMF was founded, in large part, in order to provide the centralized facilities and infrastructure that was needed to pursue the most compelling topics in subatomic physics. The on-site experimental program has evolved and grown substantially since those early years.

In the next five-year plan, TRIUMF could pursue several scientific thrusts with its on-site facilities for particle and nuclear physics. TRIUMF is unique in the world in terms of its ability to produce high rates of rare-isotopes using the ISOL technique. These beams of rare ions are used to pursue questions in nuclear physics ranging from fundamental symmetries and nuclear structure to nuclear astrophysics. At present, TRIUMF's ability to provide beams for all of these programs is limited by the availability of the proton beam from the main cyclotron. Certain particle physics experiments, typically those dealing with precision measurements needing large data samples, can also exploit the high intensity beams produced at TRIUMF.

Curiosity-Driven Detector Research

SCIENTIFIC JUSTIFICATION

TRIUMF has a strong reputation for applying established detector technologies in the design and construction of instruments for specific experiments or programs. In addition, there are a few examples of new detector concepts developed at TRIUMF. One is the Time Projection Chamber, applied first at TRIUMF in the 1970's. A liquid xenon PET imaging system is presently under development for medical application. However, these are exceptions because the resources of the group have typically been barely adequate to meet immediate needs, leaving little time for thought and effort directed toward new ideas. The recent infusion of new funding from CFI has brought two new talented scientists and important technical tools. However, the scope of more curiosity-driven detector development is still severely limited by lack of key technical manpower. Most prominently, the group has no dedicated engineer with broad education and experience in the various disciplines that are touched by detector technology, for example in materials and processes. Mechanical engineering services are available from the technology division, and additional electronic engineers are proposed in the LADD-II brief, but other engineering needed for detector construction is now done by physicists. Furthermore the technical manpower of the group is now fully occupied by specific commitments. There is an analogy with the development of civilization---only with the production of a reliable surplus of various basic resources can a culture move beyond a hand-to-mouth existence and develop art and science. It does not require a huge surplus, only a significant one.

RESOURCE REQUIREMENTS

In addition to the new resources identified in the one-pager called LADD-II "Laboratory of Advanced Detector Development," scope for new detector development beyond the ongoing liquid xenon project would require a highly capable engineer as described above, and a high-level technician. Support for a post-doctoral fellow and a few students would also be needed. Together with the infrastructure recently acquired, this would provide a suitable situation to attract an additional scientist with the strong interest and potential to establish an ongoing detector research program beyond the present medical project.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The TRIUMF program and community could be a fertile environment for more basic research into detector technology. The best such research in the past was not abstract—it was inspired by the needs of the next generation of experiments or by specific medical problems. However, the solutions to those problems were then in turn the inspiration for further development and evolution toward new tools and applications. In other words, there is ideally a fruitful symbiosis between solving specific problems and the development of new ideas. This can take place if detector physicists have some time to conceive and discuss these ideas, and sufficient technical resources to design and build prototypes. Furthermore, the availability of these resources can attract the best detector physicists.

The benefits to flow back to our usual clients are clear---those pushing technology boundaries are highly capable of advising the design of all detectors being built by the group. Furthermore, there is a significant portion of the Canadian research community who are pursuing difficult long-term goals, such as dark-matter searches and detector elements for the ILC. These goals would be strongly augmented by collaboration with a strong detector research and development core at TRIUMF.

BROADER IMPACTS

As detector research typically exploits new electronic and materials technologies in ingenious ways, the experience for students in combination with the intellectual rigor of a scientific environment provides an ideal preparation for later pursuing a career in industry. Furthermore, particle detector technologies are finding increased medical and industrial application. Opportunities for technology transfer to industry can be expected to be enhanced by a broader and less constrained detector research program at TRIUMF.

Fundamental Symmetries

SCIENTIFIC JUSTIFICATION

The new fundamental symmetries program combines searches for electric dipole moments in radon, nuclear anapole moments and atomic parity violation in francium, standard model tests using angular and spin correlations in β decay, electron-capture branching ratio measurements for double β decay, and studies of super-allowed β decay to test CKM unitarity.

CP violation in the standard model does not reproduce the observed baryon asymmetry of the universe and therefore additional sources are needed. CPT symmetry implies that if time-reversal invariance is violated, then CP symmetry is also violated. Electric dipole moments (EDMs) violate time-reversal symmetry. They are very small in the standard model, so discovery at foreseeable levels of sensitivity will signal new physics. In certain isotopes of radon, octupole deformation would enhance any observable effect. The Radon EDM collaboration will combine well understood spin-exchange optical pumping techniques to polarize radon nuclei with high-efficiency germanium arrays for γ ray detection in order to detect or put a stringent limit on the size of the electric dipole moment of radon.

Atomic parity violation measures the strength of the weak neutral current at very low momentum transfer. The present result in cesium atoms has better sensitivity to certain standard model extensions than the LEP electroweak measurements and offers sensitivity complementary to Möller scattering experiments at SLAC. The nuclear anapole moment is a parity-violating electromagnetic moment produced by the weak nucleon-nucleon interaction; measuring it will allow determination of both the isoscalar and isovector parts of the weak nucleon-nucleon force. Laser trapping and cooling will enable the exploitation of modern spectroscopic techniques on a small number of rare isotopes.

Both atomic parity violation and β decay correlation studies complement high-energy accelerator experiments by constraining non-standard model 1^{st} generation couplings. Sensitivity to scalar-vector or tensor-axial vector Fierz interference terms in β decay can provide useful, unique constraints on supersymmetric extensions of the standard model. The TRIUMF neutral atom trap (TRINAT) will be used for upgraded β-neutrino correlation and spin-correlation experiments aiming at sensitivity to new four-fermion effective scalar and tensor interactions. Time-reversal violating measurements utilizing time-odd spin-momentum correlations will also reach this level of sensitivity. A similar spectrometer coupled to the atom trap will search directly for massive particles produced in isomer decay.

Double β decay is a nuclear decay mode expected to appear in at least two varieties, the 2 neutrino and the 0 neutrino modes. The 0ν decay is of particular interest as it requires the neutrino to be a Majorana particle. The search for such decay is presently being carried out or planned in a number of experiments, including SNO+. The 0ν–decay rate depends on the neutrino mass but, also on a rather complex nuclear matrix element, making the extraction of the mass heavily dependent on the underlying nuclear theory input. However, theoretical models can readily be tested against the observed 2ν mode. These matrix elements can be determined experimentally for the ground-state transition through electron capture (EC) or single β^- decay of the intermediate odd-odd nucleus. One of the research efforts of the TITAN program is the measurement of EC branching ratios (BR). In most cases, these ratios are poorly known or not known at all, because EC is usually suppressed by several orders of magnitude compared to the competing β^- decay. Traditional methods for measuring these ratios have so far suffered from overwhelming background generated by these high-energy electrons. The unique TITAN measurements will make use of the EBIT (Electron Beam Ion Trap) operating in Penning mode where electrons from the β^- decay will be confined by the magnetic field. K-shell X-rays from EC will be detected by seven X-ray detectors located around the trap, thus providing enormous background suppression. This will improve the quality of the measurements tremendously and enable proper tests for nuclear theory.

Super-allowed Fermi β decay provides the most stringent test of the Conserved-Vector-Current (CVC) hypothesis, the most precise value for the CKM matrix element V_{ud}, and the most stringent limit on the presence of scalar interactions. Using the data from the 13 most precisely measured cases, CVC has been confirmed to a relative precision of 1.3×10^{-4}. With the confirmation of CVC, the up-down CKM matrix element has been found to be $V_{ud} = 0.97416(13)_{Ft}(14)_{\delta C}(18)_{\Delta R}$, where the latter uncertainties arise due to nucleus-dependent isospin-symmetry-breaking and radiative corrections. The size of any possible scalar contribution, relative to the well-known V-A interaction, is currently 1.3×10^{-3}. These limits provide constraints on new physics beyond the standard model that are complementary to direct searches at high energy accelerators. Studies at TRIUMF are designed to test the theoretical calculations of isospin-symmetry breaking and to provide data vital for the refinement of scalar interaction limits. To date, measurements have been performed on ^{18}Ne, ^{26m}Al, ^{38m}K, ^{62}Ga, and ^{74}Rb, all of which have led to significant improvements. Future measurements will include ^{10}C, ^{14}O, ^{34}Ar, ^{46}V, ^{50}Mn, ^{66}As, and ^{70}Br, where high-precision measurements of the lifetimes, branching ratios, and masses will be performed by the fast-tape-transport system at GPS1, the 8π spectrometer, and TITAN.

RESOURCE REQUIREMENTS

The radon EDM, anapole moment, and atomic parity violation experiments require an actinide production target with a second proton beam line at ISAC. The Radon EDM collaboration will use the NSERC-funded TIGRESS Germanium array. The Francium experiments are a collaboration between Manitoba, TRIUMF and Maryland and would seek primarily NSERC funding in Canada, along with US NSF support. Significant development for the anapole moment experiment is being done at Maryland. TRIUMF would provide a dedicated laser clean room in the ISAC I low-energy area and at least one FTE.

TRINAT funding is primarily though an NSERC project grant at $150,000/year. WestGrid is used for Monte Carlo simulations. There is some equipment money from the Israeli Science Foundation through one collaborator. Continued operation of the TRIUMF neutral atom trap at its ISAC I beam line uses 1.3 TRIUMF FTE's, about 200 machine and design shop hours/year, $15,000/year from TRIUMF for infrastructure support, and continued long-term loans from electronics pool. Microchannel plate instrumentation uses TRIUMF clean room facilities. The laser-polarized beam line requires 1.2 FTE's.

TITAN will apply for an NSERC RTI grant for β-detectors, electronics, and vacuum upgrade (~190 k$), an NSERC MRS grant for basic facility operation (90k$/a) and an NSERC project grant for the TITAN EC program (100 k$/a) for maintenance, students, and postdoctoral fellows. The German collaborators under D. Frekkers of Muenster have submitted a DFG proposal (250k$/a for 3 years). TITAN requires continued beam development of new radioactive beams, in particular from the laser ion source group. Resources from TRIUMF would include support from the design office (5 weeks), machine shop (7 weeks), electronics (4 weeks), control systems (4 weeks) and DAQ (5 weeks).

TRIUMF currently provides ongoing technical and DAQ support for the operation of the fast-tape-transport station at GPS1 and the 8π spectrometer at ISAC-I. The manpower and resource requirements for those facilities have been outlined in the nuclear structure document.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The Radon EDM experiment is supported by 7 faculty members at 5 Canadian universities; the use of Canadian nuclear structure expertise is critical to find the best case, carry out the experiment, and quantify the results.

The cold atom community in Canada has about 6 atom trapping groups, ideas are shared at conferences, and undergrads gaining experience here have become grad students in the field elsewhere. Laser expertise and techniques are shared with TRIUMF's laser-polarized beam line and laser ion source, along with advice for laser alignment and for detector testing. Microchannel plate instrumentation expertise is shared at the student level with other projects (DRAGON, TITAN). The experience gained in trapping radioactive nuclei will be useful for the francium trapping program. The francium program has a very strong physics connection to the activities of the QWeak collaboration at Jefferson Lab, which has a strong Canadian (in particular U. Manitoba and TRIUMF) contingent. Theorists such as A. Czarnecki (Alberta) have the unique expertise at the intersection of atomic, nuclear, and particle physics required for this type of research.

INVESTIGATORS (GRANT-ELIGIBLE)

G. Ball, J. Behr, P. Delheij, J. Dilling, G. Hackman, D. Hutcheon, P. Jackson, P. Levy, M. Pearson, S. Yen (TRIUMF), P.E. Garrett, C. Svensson (Guelph), H. Leslie (Queen’s), G. Gwinner (Manitoba), F. Buchinger, J. Crawford, J. Lee (McGill), J.C. Waddington

(McMaster), R.A.E. Austin, R. Kanungo (Saint Mary's), C. Andreoiu, and M. Hayden (Simon Fraser). In addition to the Canadian researchers listed above, international collaborators from Finland, Germany, Israel, Japan, and the US are active members of the fundamental symmetries research collaborations at ISAC.

BROADER IMPACTS

The fundamental symmetries program provides ideal training for undergraduate and graduate students and postdoctoral fellows who will find future employment in industry and academia. It leads to an increase in basic knowledge of nuclear physics, nuclear radiation detection and advanced statistical analysis. Spin-exchange optical pumping is used for nuclear medicine and precision atomic instrumentation has applications in precision instrumentation, such as atomic clocks. Ion traps for mass measurements have been adapted as commercial units for the petrochemical and pharmaceutical industries. Developments at TITAN, where precision, rapid processing, and high sensitivity are key, are in principle transferable to developments in commercial systems.

Nuclear Astrophysics

SCIENTIFIC JUSTIFICATION

One of the fundamental tasks of science is to explain the origin of the matter in the universe. Our current understanding of the origin of the chemical elements starts with the primordial nucleosynthesis that occurred during the cooling phase immediately following the big bang and produced the light elements: H, He, and Li. All other chemical elements in the universe were produced as a result of nuclear reactions in stars, spallation by energetic cosmic rays, or during explosive events such as novae and supernovae. We seek to understand the processes that occur during the life and death of stars such as supernova explosions; the structure and cooling of neutron stars; the origin, propagation, and interactions of the highest-energy cosmic rays; and the nature of galactic and extragalactic gamma-ray sources. Advances in our understanding of these problems are expected from improved nuclear theory and astrophysical models, more and better computational facilities, and increasingly precise observational data. A crucial ingredient for solving these problems is data from experimental nuclear physics.

Many of the key questions are intimately coupled to the behaviour of matter under extreme conditions, such as very high densities and temperatures and/or extreme proton-to-neutron ratios. Under such conditions very short-lived exotic nuclei are produced which we don't have access to under terrestrial conditions, but which play decisive roles in the astrophysical environment. The field has made enormous progress since the advent of radioactive-beam facilities where one can produce these exotic isotopes, and the ISAC facilities are well positioned to play a major role in this field in the coming years. Canadians working at the ISAC facility at TRIUMF play a key role in this active field by carrying out direct measurements of the important nuclear reaction cross sections and by measuring the masses, half-lives, and decay properties of rare nuclei that occur in cataclysmic stellar environments. This research is performed with the unique DRAGON spectrometer, TUDA, TACTIC, and TITAN. New facilities such as EMMA and TIGRESS will be very important for ISAC and ISAC-II in this program, ensuring that TRIUMF stays at the forefront of research in nuclear astrophysics.

To advance our understanding of quiescent and cataclysmic stellar events, and the nucleosynthesis of elements produced therein, astrophysical models are produced containing vast networks of nuclear reactions and a complex set of hydrodynamic relations. These models predict observational signatures such as the abundances of nuclei produced in the events and the energies and intensities of the γ rays they emit. Observations then provide us with a test of the models in which some uncertainties are due to nuclear properties and others to the astrophysics in the model. We seek to directly measure in the laboratory those key reactions that affect the crucial observables, at the relevant energies for explosive stellar events. DRAGON is a recoil spectrometer specifically designed to directly measure the rates of fusion reactions of exotic isotopes with hydrogen and helium that occur in novae, supernovae, and x-ray bursts. DRAGON is the only instrument in the world capable of measuring these radioactive-beam induced reactions in inverse kinematics due to its extremely high suppression of background, high-purity windowless gas target and efficient γ ray and recoil detection. It is considered the world standard for measuring these kinds of reactions directly, and the community has expressed interest in building similar devices at other facilities. However the present combination of ISAC and DRAGON is unique, and the future development of high intensity exotic neutron-deficient beams will ensure that DRAGON continues to provide the experimental data needed to advance our understanding of stellar explosions.

Mass measurements provide basic information of the nuclei involved in the reactions taking place in stars and during explosive events. This allows one to extract the Q value for nuclear reactions and decays and hence is crucial for understanding nuclear production and decay rates and the energy released. TITAN can carry out mass measurements to unprecedented precision due to its unique capability to use highly charged ions, and it is able to measure isotopes with half lives as short as 8.6 ms, almost an order of magnitude shorter than any other highly precise mass measurement device. Measurements would benefit from monoisotopic beams, which are often problematic at ISAC, and hence an isobar separator system is planned for TITAN.

The principal scientific objective of TUDA is the study of the nuclear reactions important in explosive astrophysical scenarios. In particular, TUDA is designed for the direct and indirect study of those reactions with charged particle exit channels. The results of these measurements play a significant role primarily in the understanding of explosive astrophysical phenomena such as novae, supernovae, and x-ray bursts. The TUDA experimental technique, solid and gas cell targets surrounded by upstream and downstream solid-state detectors, is extremely versatile and adaptable to other nuclear physics measurements. TUDA has collaborators involved in nuclear structure programs including proposals involving ^{11}Li beams. The availability of TUDA for these nuclear structure investigations has attracted proposals from the international community.

The principal scientific objective of TACTIC is similar to TUDA, the study of nuclear reactions of astrophysical significance that have charged particles in their exit channels. However since the ion chamber gas serves as the target, the reaction studies can proceed down to very low ion energies as required in the astrophysical region. Furthermore the chamber has an extremely large solid angle (almost 4π) and tracks the exiting ions. Unlike active target ion chambers, it can take high beam fluxes because of an inactive target region. The TACTIC chamber is small; hence surrounding it with γ-ray detectors such as the DRAGON BGO array can extend its capabilities. The three dimensional tracking information produces a large data stream, which demands the development of highly compact fast electronics such as flash ADC's to process. TACTIC is the ultimate low energy ion detector and future developments could see it combined with other facilities such as TIGRESS and EMMA as a target detector. Thus detector development may allow TACTIC technology to be implemented in many areas of nuclear physics.

The ElectroMagnetic Mass Analyser EMMA is a recently funded recoil mass spectrometer designed to separate the recoils of nuclear reactions from the primary beam and to disperse them in a focal plane according to their mass-to-charge ratio (m/q). Measurements of position, energy loss, energy, and time-of flight will suffice to uniquely identify the transmitted recoils. In addition to having a large solid angle of 16 msr, the spectrometer will accept recoils within a large range of m/q (±4%) and energies (±20%) about the central values. These large acceptances result in high detection efficiencies approaching 50% for the recoils of many fusion-evaporation reactions. The trajectories of monoenergetic ions of a single mass within the spectrometer are isochronous within 0.1%, allowing high resolution time-of-flight measurements and large real-to-random ratios in coincidence experiments. These properties make EMMA a recoil mass spectrometer of unprecedented quality that will enable previously impossible experiments. Separation of reaction products from the primary beam at 0° allows the detection of recoils from fusion-evaporation reactions as well as transfer reactions induced by radioactive heavy ions, which emerge from the target in narrow cones centered about the beam direction. The capacity to disperse ions according to m/q combined with multi-wire gas detectors in the focal plane will allow high resolution determinations of the atomic masses and atomic numbers of recoils. These capabilities of large acceptance, beam rejection at 0°, and high mass resolution make EMMA an unparalleled instrument for nuclear physics research. When commissioned in 2010, coupled with the unique radioactive ion beams from ISAC-II and the advanced γ-ray spectrometer TIGRESS, EMMA will position TRIUMF as the world leader in the field.

RESOURCE REQUIREMENTS

DRAGON operates on a ~$200k/a NSERC project grant which allows the maintenance and operation of the facility and the training of a dedicated core of research associates expert in the relevant experimental methods and the larger field of astrophysics. The group relies on an annual $20k contribution from TRIUMF for maintenance, repair and operation, as well as upgrades to keep the technology up-to-date.

The resource requirements for TITAN are given in the fundamental symmetries document.

TUDA will be made portable enabling it to be set up both at ISAC-I and ISAC-II. At ISAC-I it is used to directly measure reactions important in nuclear astrophysics, whereas at ISAC-II the emphasis would be on indirect approaches such as transfer reactions. The cost of making TUDA portable is around $50k and would be borne by TRIUMF. TUDA will continue to apply for NSERC grants mainly for research associate, graduate student, and detector support on the order of $150k per annum. TUDA requires annual support from TRIUMF on the order of $5k for supplies and services, design office (10 hours), machine shop (70 hours), and electronics shop (10 hours) plus the technical groups to maintain the facility. The main attractiveness of TUDA at ISAC is the availability of radioactive ion beams. The TUDA program is extremely dependent on TRIUMF bringing new unstable isotope beams online.

TACTIC is being built as a portable device that will enable it to be set up in ISAC-I and ISAC-II. TACTIC will require annual support from TRIUMF at the same level as TUDA, $5k for supplies and services plus time at the design office, machine shop, and electronics shop along with technical group support into order to maintain the facility. Special assistance of detector development services and the DAQ group is essential especially in the implementation of highly integrated electronics. TACTIC will continue to apply for NSERC grants to continue the development of the technology. This will be support in the range of $190k/a. It will pay not only for hardware development, but also for research associates and graduate students.

Starting in 2009, EMMA will apply for an NSERC grant to support basic facility operation (160k$/a) including students and research associates. EMMA requires vigorous development of new radioactive beams. EMMA and TITAN are ideally suited to exploit the new beams produced by the proposed electron driven photo-fission facility. Starting in 2010, EMMA will require TRIUMF support in the form of a dedicated technician.

INVESTIGATORS (GRANT-ELIGIBLE)

G. Ball, L. Buchmann, B. Davids, P. Delheij, J. Dilling, G. Hackman, D. Hutcheon, A. Olin, C. Ruiz, P. Walden (TRIUMF), R. Austin., R. Kanungo (St. Mary's), F. Buchinger, J. Crawford, J. Lee (McGill), A. Chen (McMaster), J.M. D'Auria (Simon Fraser), P. Garrett, C. Svensson (Guelph), G. Gwinner (Manitoba), A. Hussein (UNBC), J. King, R.E. Azuma (Toronto), and A. C. Shotter (Alberta).

In addition to the Canadian contingent, international collaborators from at least 30 institutions in at least 12 different nations are actively involved in the nuclear astrophysics effort at ISAC.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

"Full exploitation of the high-intensity radioactive beams for nuclear physics and nuclear astrophysics at ISAC and ISAC-II" was identified as one of the five highest priority projects of the Canadian subatomic physics community for the 2006-2016 period in the recently completed NSERC Long-Range Plan. Nuclear astrophysics is an interdisciplinary research field that couples experimental and theoretical nuclear physics to observational astronomy and theoretical astrophysics.

BROADER IMPACTS

The nuclear astrophysics program utilizes a variety of sophisticated detection technologies and ion-optical devices. Our program results in the training of research associates and students in the areas of astrophysics, ion-optics, computer simulation, highly integrated electronics, and sophisticated radiation detector technology, to expert levels; many have entered industry with the skills gained in the group.

Nuclear Structure

SCIENTIFIC JUSTIFICATION

By mass, atomic nuclei account for the overwhelming majority of the matter on Earth and in the solar system. The atomic nucleus therefore represents the dominant form of matter relevant to humanity. Despite prodigious efforts, a detailed and predictive understanding of the strong nuclear force responsible for binding protons and neutrons into nuclei remains elusive. The nature of the strong nuclear force and the limits of nuclear stability are intimately connected to the question of how the chemical elements were formed in stars and the early universe.

Ultimately, we seek a theoretical understanding of the nuclear quantum many-body problem that allows us to reliably predict the properties of experimentally unknown nuclei and make sense of the observed abundances of the elements. To achieve this, it is essential to study nuclei far from stability because our present, inadequate understanding of nuclear structure is based almost entirely on the properties of stable nuclei. Most of the nuclei involved in stellar and explosive nucleosynthesis are unstable; therefore the reactions they undergo have not yet been studied. It is not possible to study every single nucleus, so important cases have been identified, e.g., halo and closed-shell nuclei, that will be used to test nuclear models. With world-leading, high quality radioactive beam intensities and sensitive, highly efficient detectors, ISAC is carrying out the precise experiments needed to further our understanding of the strong nuclear force and the limits of nuclear stability.

RESOURCE REQUIREMENTS

The nuclear structure effort at ISAC includes facilities at both ISAC-I and ISAC-II. While ISAC-I was intended to serve the needs of researchers in nuclear astrophysics and fundamental symmetries in addition to nuclear structure, ISAC-II is an accelerator laboratory intended mainly for nuclear structure research. Thus far, the capital expenditures for ISAC-II have amounted to $16M. With the first measurements completed this year, ISAC-II is poised to make major contributions to nuclear structure research. The principal scientific facilities of ISAC-II will be TIGRESS and EMMA. The former was funded by NSERC, CFI, and TRIUMF at the $8M level and has already been used in first experiments. EMMA is also being funded by NSERC and TRIUMF at a cost of $3M and will be operational in 2010. The neutron detector array DESCANT is now being funded by CFI at the $2M level. In order to take advantage of the unique scientific opportunities presented by ISAC-II beams and these experimental facilities, considerable TRIUMF resources will be required. The dedicated nuclear structure facilities at ISAC-I such as the 8pi spectrometer and TITAN also require continued support. Required resources include dedicated technical and scientific personnel, including particularly support for digital electronics, dedicated laboratory space for setup and testing, and considerable design office time. A minimum of four dedicated TRIUMF board-appointed employees and two dedicated technicians will be required to ensure that nuclear structure research at ISAC is successful.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The nuclear-structure program depends largely on TRIUMF. By focusing the intellectual effort in one institution, this smaller end of experiment nuclear physics is kept vital and above critical mass.

INVESIGATORS (GRANT-ELIGIBLE)

The following Canadian grant-eligible researchers are currently involved in the ISAC nuclear structure program. P. E. Garrett and C. E. Svensson (Guelph); R. Roy (Laval) A. A. Chen & J. C. Waddington (McMaster); J.-P. Martin (Montréal); R. A. E. Austin & R. Kanungo (St. Mary's); C. Andreoiu (Simon Fraser); T. E. Drake (Toronto); G. C. Ball, L. Buchmann, B. Davids, J. Dilling, P. Delheij, G. Hackman, D. A. Hutcheon, B. K. Jennings, M. Pearson, A. Schwenk, A. C. Shotter (Alberta), & P. Walden (TRIUMF)

In addition to the Canadian grant-eligible researchers, large numbers of foreign scientists conduct research in nuclear structure at TRIUMF. Outside of Canada, the EMMA collaboration includes scientists from 9 institutions in 3 countries, while the TIGRESS collaboration includes scientists from 8 institutions in 3 countries.

BROADER IMPACTS

Nuclear structure research at ISAC provides highly-qualified personnel with hands-on experience and training with a wide variety of advanced technologies including state-of-the-art semiconductor, scintillator, and gaseous ionization radiation detectors, ion optical systems with optimized electromagnetic fields, digital electronics and signal processing. The Canadian firm Canberra Canada is a primary supplier for TIGRESS. The advanced detector development required for nuclear structure research is ripe for commercialization in the form of high-resolution radiation detection for biomedical imaging and the detection and monitoring of special nuclear materials for national security purposes. The pioneering development of digital signal processing at the Université de Montréal for nuclear structure research is applicable to the commercial sector as well.

Particle Physics

SCIENTIFIC JUSTIFICATION

The on site particle physics program focuses on searching for physics beyond the Standard Model (SM) through high accuracy tests of its predictions. Precise measurement of the $\pi^+ \to e^+\nu$ branching ratio $R_{e/\mu} = \frac{\Gamma\left(\pi^+ \to e^+\nu + \pi^+ \to e^+\nu\gamma\right)}{\Gamma\left(\pi^+ \to \mu^+\nu + \pi^+ \to \mu^+\nu\gamma\right)}$ provides model-dependent access to hypothetical new physics at high mass scales (up to 1000 TeV) due to the high precision of its SM prediction and the potential for highly accurate measurements. The results may signal discovery of unanticipated new physics effects, provide complementary information on directly produced heavy particles discovered at the LHC, or indicate that new physics effects are limited to extremely high mass scales if the results agree well with the SM prediction. PIENU aims to improve the measurement precision of $R_{e/\mu}$ by an order of magnitude to <0.05%.

RESOURCE REQUIREMENTS

The PIENU experiment which is scheduled to begin in 2008, requires contributions from the design, engineering, detector facility, data acquisition, and beam development groups. Infrastructure including data acquisition (DAQ) systems, counting room, electronics, and the data analysis framework are also provided by TRIUMF. In addition, PIENU takes full advantage of the TRIUMF detector and engineering facilities for precision machining, advanced electronics design, Si strip detector characterization and testing, and plastic scintillation counter construction. Data taking is expected to run through 2012 with intermediate results available in 2010 and final results in 2013. Depending on the results, there may be a follow on experiment.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

PIENU was initiated by UBC and TRIUMF scientists who have a long history of performing leading experiments involving high precision and high sensitivity measurements. It gives Canada a prominent role in light flavour physics at the precision frontier which complements experiments being done in heavy flavours and at the energy frontier.

INVESIGATORS (GRANT-ELIGIBLE)

The Canadians on PIENU are: J. Doornbos, L.Kurchaninov, G.Marshall, T.Numao, A.Olin, R.Poutissou, F.Retiere (TRIUMF); D.Bryman (UBC); A.Hussein (UNBC).

BROADER IMPACTS

PIENU provides excellent opportunities for hands-on training of graduate and undergraduate students in the sophisticated use of state-of-the-art particle detectors, DAQ systems, and analysis techniques.

Subatomic Physics Off Site

By pooling intellectual, financial, and technical resources, TRIUMF has world-leading skills and expertise. With a historical focus on subatomic physics, TRIUMF is a valued contributor to many off-site projects. In the next five-year plan, TRIUMF is faced with many opportunities in this area. TRIUMF's contributions to these projects typically involve detector research, development, design, and construction as well as intellectual capital for leading the science teams.

Within Canada, TRIUMF can contribute to SNOlab's research program. Across the Pacific, TRIUMF could expand its involvement in the T2K neutrino experiment or rare-decay experiments in Japan. Future accelerators planned at Fermilab offer another such opportunity. Also in the United States, TRIUMF could continue and expand its contributions to key Canadian participation in experiments at Jefferson Lab and the Spallation Neutron source. Longer-term projects such as global International Linear Collider or a Super-B Factory have also attracted the interest of some Canadian physicists. Across the other ocean, CERN is preparing for upgrades of the Large Hadron Collider that would require commensurate changes to the ATLAS detector. TRIUMF could be a lead player in some of this work as well as continuing its role as a key contributor to the physics analysis. Finally, the ALPHA anti-hydrogen project at CERN could benefit from TRIUMF involvement.

ALPHA

SCIENTIFIC JUSTIFICATION

Our belief in CPT invariance is partly based on the success of quantum field theories, and also on stringent tests from measurements of equal particle-antiparticle masses and neutral kaon properties. Whether CPT is in fact an exact symmetry is a question that should be fully tested by experiment. Recall that Nature has given us a list of symmetries that are fundamental yet broken: parity, time-reversal, electroweak, chiral, and perhaps supersymmetry. Precision comparisons of antihydrogen with hydrogen atoms could give some of the most stringent tests of CPT, eventually competitive with hydrogen maser and Hg-Cs atomic clock measurements for spatial components of CPT violating terms with a possibility of probing the energy scale beyond the Planck scale. Another important, yet challenging goal is a test of the gravitational interaction between matter and antimatter, for which there exist no direct experimental data. Given that atomic hydrogen is one of the best studied systems in all of physics, comparison with its antimatter counter-part is a compelling experiment for physicists, regardless of theoretical biases.

The ultimate goal of these fundamental tests is ambitious: numerous technical developments are required in order to produce, detect, trap, cool and interrogate anti-atoms. This in turn gives us unique opportunities to drive progress in atomic, plasma, and ion trap physics in regimes previously unexplored, even with matter particles. Our development in antimatter manipulation is receiving much attention in these various communities. One of the unique features is the annihilation signal, a novel and powerful diagnostic for atomic and plasma processes.

RESOURCE REQUIREMENTS

Many of the experimental requirements of ALPHA are well matched to TRIUMF expertise, and there is considerable synergy with other TRIUMF activities such as TITAN (ion trap and control), TRINAT (atom trap, laser), TIGRESS (electronics), TWIST (tracking software), LADD (detector), and Tech Transfer (thin films), as well as the accelerator group.

The TRIUMF infrastructure support in the two year construction phase of ALPHA has been modest. We anticipate support of 0.5–1 FTE/yr for 2010–15. As founding members of ALPHA, Canadians have come to play major roles in the new emerging field of cold antimatter physics.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

TRIUMF involvement in ALPHA is allowing Canadian university faculty and students from diverse fields to participate in a high profile international project at CERN. ALPHA-Canada, now constituting 30% of the collaboration, is taking a leading role in the project. This would not have been possible for a single group or university.

ALPHA brings in new non-traditional users to TRIUMF activities, strengthening its user base. The high visibility of ALPHA, and Canada's leadership role in it, is attracting invitations to conferences and colloquia/seminars in fields such as plasmas and atomic collisions as well as subatomic. Together with the already good publication record, it is helping to raise our profile in the national and international communities.
ALPHA is a truly excellent training ground for students, because of the very wide range of the physics and the technical issues involved. Its small scale, as well as the short turn around (i.e. the high rate of technical output), is allowing the students to play important roles from the construction to the data taking to the analysis to publication.

INVESTIGATORS (GRANT-ELIGIBLE)
With a modest continued support from TRIUMF, Canadians can maintain our leading edge in this exciting field. NSERC Eligible Researchers: M. Fujiwara, D. Gill, L. Kurchaninov, A. Olin (TRIUMF), W. Hardy, D. Jones, (UBC), R. Thompson (Calgary), M. Hayden (SFU), J.-P. Martin (Montreal), S. Menary (York).

BROADER IMPACTS
Public excitement with antimatter is probably disproportionate: Cold antihydrogen production was ranked among Year 2002's top physics news; our ALPHA logo will be used in the upcoming movie based on a Dan Brown novel. Obviously the public interest should not be confused with scientific merit. Nonetheless, having substantial activities in this area could be considered an asset to the laboratory in terms of the benefit to broader society.

ATLAS Physics

SCIENTIFIC JUSTIFICATION

The ATLAS experiment at the CERN Large Hadron Collider (LHC) is designed to probe the physics behind Electro-Weak Symmetry Breaking, EWSB. The Standard Model of Particle Physics is now some 40 years old. Its first great theoretical success was the unification of the electromagnetic and weak nuclear forces, initially by imagining they were part of a larger symmetry, which demanded the existence of a new neutral particle, the Z^0 boson, and precisely predicted the interactions of the photon, charged $W^{\pm}$ bosons and the Z^0. The Standard Model predictions have been tested and experimentally verified to high precision over the past 40 years. Highlights of that history include the discovery of the $W^{\pm}$ and Z^0 at the CERN Super Proton Synchrotron, many detailed studies at the CERN Large Electron Positron Collider and Fermilab Tevatron, and measurements in flavour physics including those from the BABAR at SLAC and BELLE at KEK b-factory detectors. The Standard Model has a remaining unsolved problem: the very symmetries at the core of its concept require that the $W^{\pm}$ and Z^0 bosons be massless. This problem was fixed in the Standard Model by making the vacuum itself interact with matter, giving it an effective energy density. This is called the Higgs mechanism, and requires the existence of a corresponding particle called the Higgs boson. Tests of the Standard Model imply that the Higgs exists, and in the simplest realization has a mass less than 200 GeV (about 200 times larger than the proton), while direct searches exclude masses below 114 GeV. ATLAS at the LHC is sensitive to Higgs and Higgs-like particles with masses beyond about 1000 GeV, referred to as the Terascale (1 TeV). The LHC will collide protons at centre-of-mass energies of 14 TeV. The Higgs itself presents additional problems, and keeping the EWSB theory stable seems to demand new physics, and new particles, at the Terascale and within the ATLAS discovery reach. There are enormous numbers of theories of physics beyond the Standard Model, and it is safe to say that experimentalists need to be sensitive to all possibilities. ATLAS is designed to probe EWSB at, and beyond, the Terascale in the most general way possible, and promises to be the leading project in particle physics for the next decade or more.

It is a high priority of TRIUMF to become a Canadian ATLAS physics analysis centre. This has already started with the hiring of two active ATLAS scientists in 2005, the analysis support personnel at the Tier 1 data centre, and the recent hires of two more ATLAS scientists and an LHC theorist. There are critical remaining issues that must be addressed to complete the formation of an ATLAS physics analysis centre at TRIUMF, which is the subject of this ATLAS physics activity request.

RESOURCE REQUIREMENTS

Canadians have participated extensively in the construction of the ATLAS experiment, with flagship contributions in the critical endcap calorimeters that measure the energy and direction of particles produced in the LHC proton collisions. We also make large contributions to the ATLAS High-Level Trigger systems, and to the ATLAS global computing effort. It is essential that Canada takes on leading roles in all aspects of ATLAS physics studies. TRIUMF, Canada's national laboratory in particle and nuclear physics, coordinates support for Canadians doing ATLAS physics. This support starts with a strong physics analysis effort at TRIUMF, including support for graduate students, postdoctoral fellows and faculty learning to use the complex ATLAS software and analysis tools. TRIUMF sponsors LHC physics workshops and analysis tutorials, organizes ATLAS-Canada collaboration meetings, and hosts visiting faculty and students learning ATLAS analysis techniques. This effort is currently coordinated in Canada by the initial ATLAS-Canada physics coordinator, Isabel Trigger, a TRIUMF scientist. The two new scientist hires will more than double the TRIUMF scientist commitment to ATLAS physics, and enable the lab to play a visible role in this core activity in Canadian particle physics.

A critical issue for the success of TRIUMF's role as the centre of Canadian ATLAS physics is space for faculty, postdoctoral fellows and students. A significant enhancement of visitor office space and local computing for visitors including a so-called ATLAS "Tier 3" analysis centre is essential. An upgrade of the available meeting room and teleconference facilities for ATLAS use at TRIUMF is also essential for successful collaboration, since it is often difficult or impossible to use existing rooms for any given meeting, and very difficult for hosting multi-day workshops.

A resource summary for the TRIUMF ATLAS physics group is:

1) Visitor desk space for a minimum of 10 people, beyond TRIUMF staff. This will allow visiting faculty, postdoctoral fellows, and students to take full advantage of the opportunity of working with TRIUMF scientists and user support people, making TRIUMF a true centre of ATLAS analysis activity in Canada.
2) Meeting room space equipped with video conferencing ability is extremely limited at TRIUMF. In practice, it is difficult to use space for many ATLAS meetings, and impossible to host a few-day long workshop at TRIUMF that requires teleconferencing ability. A dedicated meeting room equipped for teleconferencing, not unlike the new theory conference room, would enormously increase the potential for TRIUMF to both host and engage in ATLAS physics activities.
3) A Tier-3 computing cluster for both TRIUMF personnel and visitors. These resources are not easily funded by either NSERC or CFI, and most universities are funding such facilities from other sources (including startup and other university funds). A minimal facility for active TRIUMF personnel would include 5 "pizza boxes" (8 CPU-cores in each) plus about 30 TB of disk, costing $20k and $30k, respectively, or $50k in total over the five years. Facilities usable by the same number of visitors would double the amount to $100k.
4) The recent TRIUMF scientist hires will make a significant improvement in the local physics effort, more than doubling the TRIUMF scientist commitment to ATLAS physics. Adding one or two TRIUMF-funded postdoctoral fellows,

in a similar fashion to the larger number supported in the theory group, would make a significant increase in the physics output of the TRIUMF laboratory ATLAS group and its ability to lead Canadians in ATLAS. This would also provide a significant opportunity for TRIUMF to engage in the training of excellent physicists between the graduate student and faculty stages.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
ATLAS-Canada includes 10 university groups and TRIUMF, including more than 40 grant-eligible investigators, 20 postdoctoral fellows, and 60 graduate students. The number of graduate students in ATLAS-Canada is growing quickly, with many of the best and brightest students attracted by the highly visible LHC physics programme. With the large Canadian investment in Canada in this program, including about $40M in the LHC accelerator via TRIUMF, $15M in capital for the ATLAS detector by NSERC, $15M in the Tier 1 computing centre by CFI and BCKDF, plus the continued NSERC support for ATLAS-Canada operations, it is essential that Canada reap the full scientific benefits of the LHC physics program. This success is critical for the credibility of Canadian particle physics, and will be vital to success in future funding for our field in Canada. ATLAS-Canada includes five IPP scientists (Corriveau, McPherson, Robertson, Sobie and Teuscher) and four CRC chairs (Dobbs, Vachon, Vincter and Taylor).

INVESTIGATORS (GRANT-ELIGIBLE)
Alberta: Gingrich (also TRIUMF), Moore, Pinfold
British Columbia: Axen, Gay
Carleton: Asner, Oakham (also TRIUMF), Vincter
McGill: Corriveau (also IPP), Dobbs, Robertson (also IPP), Vachon, Warburton
Montreal: Azuelos (TRIUMF), Couture, Leroy, Martin
Regina: Benslama
Simon Fraser: O'Neil, Vetterli (also TRIUMF) plus new hire starting summer 2008.
Toronto: Bailey, Krieger, Orr, Savard (also TRIUMF), Sinervo, Teuscher (also IPP), Trischuk
TRIUMF: Kurchaninov, Losty, Oram, Tafirout, Trigger plus two new hires starting summer 2008.
Victoria: Albert, Astbury, Keeler, Kowalewski, Lefebvre, McPherson (also IPP), Sobie (also IPP)
York: Bhadra, Taylor

BROADER IMPACTS
The training of undergraduate students, graduate students, and postdoctoral fellows on ATLAS is extremely valuable. The LHC will be one of the highest profile scientific projects in the world for at least the next decade, and is already attracting many of the best students in Canada and throughout the world. ATLAS currently includes about 60 Canadian graduate students, a number that will approximately double over the next few years. Most of these students move into other areas, and make valuable contributions to many fields important to Canada. A leading project like ATLAS, by investigating the most basic and fascinating questions about the makeup of our universe, attracts people to

pursue a higher education in science and technology who might not otherwise do so, and offers unique training in high technology and collaborative working environments.

SLHC

SCIENTIFIC JUSTIFICATION

The LHC seems likely to produce physics beyond the Standard Model. It is also likely that the experimental measurements will be consistent with several models of new physics. Understanding the nature of the under-laying new physics will require further measurements.

Once the LHC has begun physics operation, there will be a strong focus on exploiting the facility and extracting physics at the Terascale. The highest priority for the accelerator will be to consolidate and upgrade the reliability of its injection chain, some of which is 50 years old. The CERN European member states allocated 240 million Swiss Francs of new funds in June, 2007, with a top priority of starting these upgrades. Combining those resources with international contributions, CERN plans on replacing the earliest parts of the LHC injection chain including the linear accelerator (LINAC), Booster accelerator, and the Proton Synchrotron (PS). These upgrades have begun and will continue through about 2015 and will allow, together with upgrades to the LHC itself, significant increases in the data-taking rate of the facility, eventually reaching order of magnitude higher rates than the nominal LHC levels. The LHC and upgraded facility, referred to as the "Super LHC" or SLHC, will have the highest direct energy reach of any currently planned project.

RESOURCE REQUIREMENTS

ATLAS is one of the two multi-purpose detectors at the LHC, designed to measure Terascale processes, search for the Higgs boson and for physics beyond the Standard Model. Constructing and running ATLAS is an enormous undertaking, involving nearly 2000 physicists, engineers, and technicians from three dozen countries. The initial ATLAS detector, set to begin collision data-taking in 2008, has largely completed installation and is being commissioned. It is expected to operate until approximately 2015, accumulating significant data sets for measurements of Standard Model processes at high energy scales and searches for physics beyond the Standard Model. By about 2015, some parts of the LHC and the ATLAS detector will have suffered significant radiation damage and will need replacement; even with a fully working detector the gain in experimental statistics from continued running at the same rate would be modest. It is therefore foreseen to increase the LHC interaction rates by an order of magnitude, and corresponding upgrades will be needed to ATLAS to handle these higher radiation doses and detector occupancies. The primary upgrades for the LHC itself will be in the final focus region, achieving smaller beam spots by redesigning the collision optics, including adding magnets inside the experiments themselves. The ATLAS upgrades for the SLHC will likely take place at the same time as the accelerator work to minimize the total period without physics data-taking.

The upgrades needed to continue ATLAS operations in the SLHC era will be extensive. The entire tracking system near the beam intersection point will need to be replaced, including both the detector particle sensors and their readout electronics. This is particularly challenging because the new systems will need approximately an order of magnitude more active elements in order to cope with the extremely high occupancies expected at the SLHC, but the services (cooling, front-end readout electronics, cables) will have to fit into the same space. In addition to the tracking upgrades, the energy-measuring calorimeter systems nearest to the beam axis may see rates beyond their maximum operational values, and new detector systems and readout electronics may be required. The outermost ATLAS muon system will be difficult to operate due to large numbers of interactions from the increased numbers of low energy neutrons created at the SLHC, and technologies for either reducing the number of neutrons or coping with the high rates will be required.

It took about five years of Research and Development (R&D) to develop technologies for the initial ATLAS detector, and another ten years to construct and install the full system. Taking advantage of our expertise from building ATLAS, we plan to compress that time-frame to about three years of R&D and five years of construction and installation for ATLAS upgrades in order to be ready for ATLAS operation in the SLHC era.

To undertake this work at TRIUMF we need to provide infrastructure to the Canadian ATLAS team, which is predominately in the University Community. They will obtain funding through NSERC; however, technical expertise at TRIUMF will be essential for this undertaking. The implications for TRIUMF resources for these detector development projects are estimated below in two tables, one for detector mechanical design and one for the associated electronics design. The personnel needs, in particular, are very uncertain at this time.

	System	**Engineering (FTE/year)**	**Technician (FTE/year)**	**Description**
SLHC	Pixels	1	1	Detector support …
SLHC	Warm Calorimeter	0.5	0.5	Overall engineering, cooling …
	Cold Calorimeter	1	0.5	
	TOTAL	**2.5**	**2.0**	

Table 1: Requirements for detector design and construction during 2010-2015. About 3 FTE/year of design office time will also be required.

	System	**Engineering (FTE/year)**	**Technician (FTE/year)**	**Description**
SLHC	Inner Detector FE	0.5	0.5	Custom ASICs

SLHC	ID back end	0.5	0.25	FPGA, digital boards
SLHC	Calorimeter ASIC	0.5	0.5	Custom ASICs
TOTAL		**1.5**	**1.25**	

Table 2: Requirements for detector electronics design and assembly during 2010-2015. Note that ASIC design capabilities would be new for TRIUMF. Approximately $100,000 of test equipment such as probe stations, a faraday cage for low-noise tests, etc., will also be required.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The ATLAS physics programme has broad support across Canada, having 10 major Canadian Universities involved with more than 40 grant eligible physicists including 4 CRC Chairs.

INVESTIGATORS (GRANT-ELIGIBLE)

Alberta: Gingrich (also TRIUMF), Moore, Pinfold
British Columbia: Axen, Gay
Carleton: Asner, Oakham (also TRIUMF), Vincter
McGill: Corriveau (also IPP), Dobbs, Robertson (also IPP), Vachon, Warburton
Montreal: Azuelos (TRIUMF), Couture, Leroy, Martin
Regina: Benslama
Simon Fraser: O'Neil, Vetterli (also TRIUMF) plus new hire starting summer 2008.
Toronto: Bailey, Krieger, Orr, Savard (also TRIUMF), Sinervo, Teuscher (also IPP), Trischuk
TRIUMF: Kurchaninov, Losty, Oram, Tafirout, Trigger plus two new hire starting summer 2008.
Victoria: Albert, Astbury, Keeler, Kowalewski, Lefebvre, McPherson (also IPP), Sobie (also IPP)
York: Bhadra, Taylor

BROADER IMPACTS

The training of undergraduate students, graduate students and postdoctoral fellows on ATLAS is extremely valuable. The LHC will be one of the highest profile scientific projects in the world for at least the next decade, and is already attracting many of the best students in Canada and throughout the world. ATLAS currently includes about 60 Canadian graduate students, a number that will approximately double over the next few years. Most of these students move into other areas, and make valuable contributions to many fields important to Canada. A leading project like ATLAS, by investigating the most basic and fascinating questions about the makeup of our universe, attracts people to pursue a higher education in science and technology who might not otherwise do so, and offers unique training in high technology and collaborative working environments. Upgrades to the ATLAS experiment involve cutting-edge developments in particle detectors, micro-electronics and fast parallel networking solutions. Canadian involvement will spur training of experts in these areas, and directly involve Canadian companies in the development and manufacturing of these technologies.

Detector simulation and physics modeling

SCIENTIFIC JUSTIFICATION

Particle and nuclear physics experiments pose enormous challenges in the creation of multipurpose software frameworks. Of particular importance to TRIUMF is the demand for large-scale, accurate and comprehensive simulations of particle detectors used in these experiments. The GEANT4 (G4) simulation toolkit provides flexible detector and physics modeling capabilities embedded in an object-oriented structure.

G4 is a C++ program for the simulation of the passage of particles through matter. Its kernel encompasses tracking; geometry description and navigation; material specification; abstract interfaces to physics processes; management of events; run configuration; stacking for track prioritization; tools for handling the detector response; and interfaces to external frameworks, graphics and user interface systems. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. It is a very powerful tool widely used for the conceptual design of detector and understanding of complex instrumentation.

RESOURCE REQUIREMENTS

TRIUMF is a member of the world-wide collaboration of scientists and software engineers whose goal is to develop, maintain and provide support for the G4 toolkit. National Laboratories, such as CERN, FNAL, SLAC, INFN, IN2P3 and TRIUMF, consolidate new involvement in detector design and construction with a strong participation in the advancement of the G4 kernel. The Memorandum of Understanding between TRIUMF and G4 assigns Peter Gumplinger (50%) and Fred Jones (25%) for the elaboration of electromagnetic (EM) and hadronic physics, optical photon modeling, user support, testing and validation. There is also a strong participation of TRIUMF and its member universities in the development of G4 applications for projects associated with TRIUMF. Future development of G4's kernel and advance applications should rely on staff to insure a sustainable expertise at TRIUMF. Possible areas where G4 could grow (complementary to expertise already in place) are EM interactions and hadronic physics. An increase from 0.75 FTE to 1.5 FTE in the near future (2010), and then to 3 FTE in the long term future (2015) would greatly boost TRIUMF's capability for intellectual contribution to the conceptual design and operation of instrumentation for upcoming experiments at ISAC, T2K, muSR, SNOLAB, ATLAS and ILC; as well as support in medical imaging and accelerator physics.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The G4 toolkit is a critical path item on the development of most experiments in particle, nuclear and medical physics. In Canada, GEANT has been (and will be) used for ATLAS calorimeters for precision physics at the LHC; T2K and ILC TPCs; micro-pattern-gas-detectors for T2K, ILC and TACTIC; SiPMs for T2K and ILC, transport in gas (e-) and LAr (ions); SNOLAB design for Picasso, DEAP, SNO+ and EXO; tracking for sLHC;

low energy EM interactions and electronic response (EXO and TACTIC); HPGe detectors for TIGRESS and other ISAC/muSR R&D; TWIST muon decay experiment, ISAC DRAGON; rare decay investigation; and LXe PET imaging.

INVESTIGATORS (GRANT-ELIGIBLE)

All grant-eligible investigators involved in the development of instrumentation and data analysis will benefits from a strong G4 team at TRIUMF. Students and research associates are usually supported by NSERC project grants; core kernel development and support should come from TRIUMF staff, as it is difficult to support software experts with NSERC funds. Simulation codes associated with large-scale and complex experiments have a lifespan that is typically much longer than the employment of research associates or graduate students. Past experience shows that it is crucial and of great benefit to scientific collaboration with TRIUMF to retain expertise and continuity by engaging laboratory staff.

BROADER IMPACTS

The G4 Toolkit is used by a broad scientific community world-wide in diverse experimental domains. G4 is used in production by large-scale high energy physics experiments as well as in smaller scale detector development projects. It is also employed for accurate simulation in mission critical applications in space science and astrophysics, and is the basis for accurate calculations in medical physics, nuclear medicine and radiation protection.

ILC Detectors

SCIENCE JUSTIFICATION

The prime motivation for modern particle physics experiments is the discovery of physics beyond the Standard Model. In the *electroweak-sector*, where the great success of the past decades has been the prediction and verification of electroweak unification, precision measurements at the CERN Large Electron Position Collider (LEP) and the Fermilab proton-antiproton Collider (Tevatron) demand that there be either a light Higgs particle with a mass of less than 200 GeV or a physical mechanism mimicking the Higgs phenomena.

While the case for physics beyond the Standard Model is strong, there is no clear indication what form the new physics takes. There is no substitute for directly probing the energy regime where this physics lies, making the case for Terascale colliders the highest priority in international Particle Physics. There is a world-wide consensus that a Terascale electron-positron collider is required to complement the LHC. The ILC will collide electrons and positrons at centre of mass energies between 500 and 800 GeV, making it the ideal instrument to probe the Terascale and study any physical phenomena beyond the Standard model. Canadians, with the support and leadership of the TRIUMF laboratory, are at the forefront of this international scientific endeavour.

Research and development for the ILC detectors has been underway for more than a decade. Experience from LEP provides considerable guidance for the physics exploitation of a high-energy e^+e^- collider, but the ILC detectors are much more ambitious. To access the new physics ILC detectors require ten times better momentum resolution using a time projection chamber (TPC), jet energy resolution a factor two better, and superb vertex resolution using much less material. The jet energy resolution goal can be achieved, in novel hadronic calorimetry (HCAL) systems, using the “particle flow” technique, making optimal use of information from the tracking and calorimeter systems. The energy resolution is limited by the ability to separate nearby energy clusters, and therefore ILC calorimeters need unprecedented segmentation. For many years, the worldwide ILC detector R&D effort focused on individual subsystems (vertex detector, large volume tracker, electromagnetic calorimeter, hadronic calorimeter and muon detectors). Recently detector concept groups have formed to optimise full experiments.

RESOURCE REQUIREMENTS

In addition to physics, TRIUMF also plays a critical role in Canadian development of detector and electronics R&D, construction of major detectors and experiments. Some of TRIUMF's highly trained staff of scientists, engineers, and technicians are supported at universities across the country, providing an invaluable resource for those universities and experiments in support of this infrastructure role. Canadian involvement in ILC detector projects that will involve TRIUMF personnel and resources over the 2010-2015 period include:

- **TPC detector:** TRIUMF scientists, engineers, and technicians are playing leading roles in ILC TPC prototype design, tests, and construction. This will continue into the overall system design. TRIUMF engineering support will also be sought for the critical TPC end-plate design and manufacture, including the main TPC readout panel. TRIUMF expertise will be invaluable in the design and construction of the TPC gas system, and calibration system (TRIUMF staff: 3.1 FTE engineering, 3.1 FTE technical support).
- **HCAL:** TRIUMF technician support will be used for prototyping of the Scintillator detectors (TRIUMF staff: 0.5 FTE engineering, 0.5 FTE technical support).
- **TPC front-end readout:** custom ASICS will need to be designed and tested (TRIUMF staff: 1.0 FTE engineering, 0.5 FTE technical support).
- **HCAL readout:** the silicon photo-multiplier readout will need the development of custom ASICs and PCBs (TRIUMF staff: 1.0 FTE engineering, 0.5 FTE technical support).

TRIUMF personnel required for these projects will be most efficiently a mixture of Vancouver-based and people based at universities. Much of the infrastructure exists, although in some cases it must grow to meet all the ILC detector development needs. For example the TPC and HCAL readout work proposed to take advantage of the ASIC design capabilities would be a new area for TRIUMF.

RELATIONSHIP TO BROADER CANADIAN COMMUNITY

Canadians have made significant contributions to the ILC detector R&D over the past decade. The initial efforts focused on improving the intrinsic precision of TPC necessary for ILC detectors to achieve their momentum resolution goals. The key element was to replace wire grids with Micro-Pattern Gas Detectors (MPGD) such as gas electron multipliers and Micromegas devices. Prototype TPCs were built in Canada with MPGD readout and were operated at TRIUMF, DESY (Germany), and KEK (Japan). These first tests demonstrated unprecedented precisions, better than 50 microns, were possible with this technology in strong magnetic fields. The MPGD TPC is now a leading candidate for the central tracker for the ILC detectors. TRIUMF has been an active partner with the university groups in this endeavour. Canadian ILC TPC efforts have been growing and today also include calibration systems, chamber gas systems, readout electronics, and overall system integration and engineering. Canadians are recognized international leaders in the ILC TPC design groups, including global coordination roles at the highest levels.

Recently Canadians have become involved in the hadronic calorimetry for the ILC. The requirement for fine segmentation in the calorimeter in order to have good *particle flow* jet energy resolution is challenging. Canadian efforts are currently focusing on the readout of fine-grained scintillators for ILC hadronic calorimetry using silicon photo-multipliers (SiPMs).

INVESTIGATORS

Carleton: Bellerive **McGill**: Corriveau (also IPP); **Montreal:** Martin; **Regina:** Barbi; **TRIUMF/Carleton:** Dixit**; TRIUMF/Victoria:** Karlen

While there is currently a small group of researchers active in the development of ILC detectors it should be understood that early LHC physics is likely to add urgency to the study of ILC electron-positron collisions that may precipitate a significant shift of Canadian investigators from other projects studying Terascale physics (such as ATLAS).

BROADER IMPACTS

The current federal government's Science and Technology strategy emphasises the importance of Canada remaining among the world's leaders in international science – lest it miss out on scientific and technological opportunities. The ILC is a prime example, pushing particle detector technology in the decade ahead, technology, such a SiPMs, that will also find applications in medical imaging and state of the art electronic signal processing. In addition Canadian participation in the design, construction and exploitation of the ILC detectors will allow students and scientists to play a forefront role in the quest to understand nature at its most fundamental for decades to come.

JLAB Physics

SCIENTIFIC JUSTIFICATION

Thomas Jefferson National Accelerator Facility, or Jefferson Lab (JLab), is a U.S. basic research laboratory built to probe the atomic nucleus and enhance our understanding of the quark structure of nuclear matter. The facility consists of a 6 GeV superconducting electron linac, and three experimental halls which can operate concurrently. The unique contribution of JLab to subatomic physics is its very intense but very precise electron beams and well understood detector systems, allowing:

- Precision measurements of the structure of the constituents of nuclear matter (protons, neutrons and other hadrons) to better understand how the strong interaction (Quantum Chromo-Dynamics or QCD) makes its fundamental transition from the high energy scale where only quarks and gluons matter, to the low energy scale where one need only consider composite particles, the nucleons and mesons;
- Precision searches for new physics beyond the Standard Model by performing symmetry tests in nuclear physics.

Both are among the most pressing issues of modern physics, as the first is key to untangling the mystery of quark (color) confinement in QCD, and the second may indicate the way forward for the next major theoretical advances in our field.

RESOURCE REQUIREMENTS

In the coming decade, the JLab program will be centered on a significant enhancement of its capabilities through the “12 GeV Upgrade”. This upgrade is in the final stages of U.S. Government approval, with full operational status planned for 2015. Canadian subatomic physicists are already in leadership roles in this program, including:

- GlueX: a search for hybrid mesons predicted by QCD (PI: Lolos, Groups: Regina, Alberta);
- Experiments in Hall C to study QCD scaling (PI: Huber, Group: Regina);
- Gep-15: the measurement of the proton form factor to Q^2=15 GeV^2 (PI: Sarty, Group: St. Mary's); and the
- 11 GeV Möller experiment (PI: vanOers, Groups: Manitoba, TRIUMF, UNBC, Winnipeg).

The resources required of TRIUMF in support of the Canadian program at JLab over the past decade have been relatively modest, but the contributions have been world leading, and widely recognized in the nuclear physics community on the international scale. The expected total requirements for 2010-2015 are likely to be about 2 FTE/year, similar to the level provided historically by TRIUMF. The services requested of TRIUMF include assistance with detector prototyping and construction, the use of beam for the calibration of detector response to electrons, muons and pions, and electronics design and implementation. Of the projects listed above, 1)-3) are fully approved parts of the JLab 12 GeV program. Project 4) will occur over a longer scale, with a letter of intent now being written. Support for experiments such as these is an important part of TRIUMF's mission as the national support base for the Canadian subatomic physics community.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The availability of TRIUMF's resources on Canadian soil has been of great benefit to the Canadian program at JLab. It is invaluable to easily bring Canadian undergraduate and graduate students to TRIUMF to assist with JLab-destined detector assembly and beam tests prior to sending them across the border. Both the G^0 detectors, as well as the GlueX calorimeter prototypes, have benefited from TRIUMF's local expertise. In some cases, TRIUMF has contributed to the Canadian JLab program by managing a project contracted elsewhere, transferring knowledge to the private sector. The most recent example of this is the Qweak toroidal magnet coil support. It is anticipated that a similar role may be required in support of the 11 GeV Möller experiment. TRIUMF's support has enabled Canadians to play a visible, leading role in key JLab experiments, and the historically high impact to investment ratio provides a powerful argument for the continuation and strengthening of TRIUMF's role in this regard.

INVESTIGATORS (GRANT-ELIGIBLE)

The Canadian grant-eligible investigators currently active at JLab are: J. Birchall, C.A. Davis, W.R. Falk, M.T. Gericke, G.M. Huber, E. Korkmaz, G.J. Lolos, J.W. Martin, S. Page, Z. Papandreou, J. Pinfold, A.J. Sarty, W.T.H. van Oers, as well as their students, PDFs and Research Scientists. In addition, there are several hundred U.S. and other foreign collaborators associated with these JLab experiments.

BROADER IMPACTS

People advantage: The Canadian program at JLab has a significant Highly Qualified Personnel training component. By taking responsibility for various parts of the experimental apparatus or data analysis, students and PDFs learn technical, analytical, computer and other skills which are applicable to a wide variety of high tech career paths.

Knowledge advantage: The JLab 12 GeV Upgrade will offer electron beams with a unique combination of high intensity, duty factor, polarization, and kinematic reach, allowing critically needed data to be obtained for the investigation of a broad range of QCD phenomena that have simply not been experimentally accessible, as well as for seeking subtle signals of new physics beyond the Standard Model. Canadians have made significant impacts to the shaping of the future research program at this facility.

Entrepreneurial advantage: Canadian JLab program has already, and is expected to continue to contribute to the transfer of technology to the private sector through projects such as the G^0, Qweak and GlueX detector development.

SNOLAB

SCIENTIFIC JUSTIFICATION

Sheltered by the Earth's crust from the background commotion of cosmic rays and human activity, exquisitely sensitive particle physics and astrophysics experiments can search for the subtle but unmistakable signatures of a revolutionary new physics. SNOLAB is the newest laboratory in this global quest and is Canada's chief underground science laboratory. SNOLAB provides underground laboratory space for at least three major experiments along with a series of smaller labs for prototyping.

The ultra-low background places SNOLAB centre-stage in two quests—on the cosmic scale for interstellar dark matter and on the microscopic scale for neutrinoless double-beta decay. Astrophysical measurements indicate that 80% of the matter in the universe is "missing" – that is, we can see its gravitational effects but it does not emit any heat or light. This "dark matter" is hypothesized to be the stuff that shapes the destiny of the universe and yet we have no idea what it really is; some believe it might be comprised of new particles uncovered at the next generation of large accelerators. On the microscopic end of the spectrum, neutrinoless double beta decay probes the very nature of antimatter. Advanced theories of particle physics and the Big Bang suggest that the neutrino particle, produced everywhere in stellar fusion, may have a special nature: it might be its own antiparticle. Answering this question about the neutrino could reveal new insights into why the modern universe is predominantly occupied by matter (and dark matter!). The initial program of SNOLAB likely include experiments that focus on direct detection of dark matter (DEAP/CLEAN, PICASSO, Super-CDMS) and neutrinoless-double-beta decay (SNO+, EXO).

RESOURCE REQUIREMENTS

SNOLAB was constructed with $50M from CFI for capital costs; a series of negotiations with NSERC, CFI, and the Ontario provincial government have secured annual operating costs of $6M through 2009 and even to 2012 assuming federal investments continue. DEAP, SNO+ and PICASSO have received NSERC funding for advanced prototyping and all three have current NSERC proposals requesting (at least) first-phase construction capital.

In the near term there are several projects for SNOLAB that would benefit enormously from on-hand TRIUMF expertise. The highest priority items include:

- Engineering and finite element analysis of the rope hold down system for SNO+, and ensuring that the acrylic vessel is able to withstand the external buckling pressure
- Engineering and construction of the glove box and calibration manipulator system for SNO+;
- Liquid argon cryostat and cryogenic engineering for DEAP/CLEAN;

- Design, construction and qualification of the Alberta Low-Radon Laboratory (for DEAP/CLEAN and SNO+);
- Temperature control and hydraulic pressurizing system for PICASSO;
- Readout electronics for PICASSO;
- Shielding, pressure vessel design, for EXO; and
- Electronics/DAQ design for EXO.

At this stage of SNOLAB experiments, the primary need is for engineering and physics design expertise. As the experiments move into a construction, commissioning and operating phase additional support in the form of shop time and technical expertise will be required. Estimates have been made of the amount of effort required on an ongoing basis. For the main Canadian efforts (PICASSO, SNO+, DEAP/CLEAN, EXO, CDMS) this will require the full-time equivalent of 3 scientists, 3 engineers/draftsmen and 6 technical support people.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The Canadian-led projects include 23 FTE of grant-eligible researchers including 17 from TRIUMF member (Alberta, Carleton, and Montreal) and associate member (Queens) institutions. EXO, DEAP, SNO+ and PICASSO have received NSERC funding for advanced prototyping and the latter three have current NSERC proposals requesting (at least) first-phase construction capital. Significant capital requests for the DEAP and SNO+ experiments are expected to among those submitted to the upcoming CFI competition and thus their status will be unknown for at least another 12-18 months (i.e. until well after the five year plan is submitted).

In addition to the TRIUMF staff based at Carleton, scientists based in Vancouver have also expressed an interest in joining the DEAP experiment, proposing that they could provide the readout electronics/data-acquisition hardware. The SNOLAB proponents have suggested that there are important roles that TRIUMF could provide engineering/technical support for: the radon-free air-handling for DEAP, SNO+ and EXO; readout electronics support for DEAP, PICASSO and EXO; finite-element analysis for the SNO+ av-holdown and the EXO cryostat; and general DAQ/detector control systems for PICASSO and EXO.

INVESIGATORS (GRANT-ELIGIBLE)

Alberta: Hallin, Krauss
Carleton: Bellerive, Dixit, Graham, Hargrove, Sinclair
Laurentian: Cleveland, Farine, Hallman, Jillings, Virtue, Wichoski
Montreal: Lessard, Martin, Zacek
Queens: Boulay, Chen, Duncan, Ford, McDonald, Noble, Rau
TRIUMF: Retiere

BROADER IMPACTS

Participation in these SNOLAB experiments would allow for training of graduate students in neutrino and underground science. Technical solutions that develop hardware for long-term performance in confined, underground spaces might also stretch current capabilities and foster innovation. In addition to providing a number of small-scale (20-50 collaborator) experiments that address leading edge questions in dark matter and neutrino physics—which attract and train some of the best an brightest students and postdoctoral fellows in state-of-the-art radio-chemical handling, digital electronics, data-acquisition and cutting edge computer simulation and analysis techniques-- SNO and SNOLAB have been welcome partners at the INCO mine providing significant mine-engineering challenges (large halls at extreme depths) and thus important engineering feedback to INCO in its quest to extract ore efficiently at ever increasing depths.

Cold Neutrons at SNS

SCIENTIFIC JUSTIFICATION

Neutron beta decay is a fundamental process in nuclear physics which can be used to investigate possible extensions of the Standard Model and test QCD at very low energy. The Nab experiment and its second phase, abBA, on the Fundamental Neutron Physics Beam line at the Spallation Neutron Source (SNS) in Oak Ridge, Tennessee will provide precision measurements of the beta decay correlation parameters (*a*, *b*) and (*a*, *b*, *A*, and *B*), respectively. The relevance of these measurements to searches for new physics beyond the Standard Model has been discussed in detail by Herczeg (Prog. Part. Nucl. Phys. 46, 413 (2001)). A measurement of '*a*' can be used to constrain certain left-right symmetric models (L-R models) as well as leptoquark extensions to the SM. The parameter '*b*' is sensitive to the tensor weak interaction (i.e. leptoquarks). A general connection between non Standard-Model (e.g. scalar, tensor) $d \rightarrow ue\overline{\nu}$ interactions on the one hand, and upper limits on the neutrino mass on the other, was recently brought to light [T.M. Ito and G. Prézaeu, Phys. Rev. Lett. 94, 161802 (2005)], providing added motivation for more precise experimental neutron decay parameters.

The aim of the hadronic weak interaction effort is to understand the weak interaction between quarks. The study of the hadronic weak interaction is of great relevance for low energy, non-perturbative QCD. We are long standing members of the hadronic weak interaction experiment NPDGamma, and M. Gericke is the PI on a newly proposed and hadronic weak interaction experiment n^{3}He. The experiments are approved to run at the SNS in the following order: NPDGamma 2009-2010, n^{3}He 2010-2011, Nab 2011-2012, abBA starting in 2012.

RESOURCE REQUIREMENTS

We anticipate a need for 2 FTE over a period of 4 years between 2010 and 2013 mostly in the form of engineering support, with particular emphasis on detector expertise. The group currently holds an NSERC discovery grant and is awaiting the decision on an RTI for detector development.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The search for new physics beyond the Standard Model and the investigation of low energy OCD are represented in research programs at almost all major universities in Canada. The experiments would draw from and benefit greatly from TRIUMF's engineering and detector design expertise. TRIUMF would benefit from involvement in these projects as they potentially relate to the development of future ultracold neutron (UCN) projects at the proposed TRIUMF UCN source.

INVESTIGATORS (GRANT-ELIGIBLE)

Our group consists of Professors S.A. Page, J. Martin and M. Gericke at the Universities of Manitoba and Winnipeg.

BROADER IMPACTS

The importance of indirect searches for new physics beyond the Standard Model (such as those proposed by the above named experiments), is outlined in the subatomic physics portion of the NSERC long range plan. The study of QCD in the non-perturbative regime is identified as an unresolved problem in the long range plan. The proposed activities are especially well suited for training new scientists, and we envision hiring summer undergraduates, graduate students and postdoctoral fellows.

Super B Factory

SCIENTIFIC JUSTIFICATION

The excellent operation of the current B factories has ushered in an era of precision studies in this sector. The main goal of extending this work is to gain access and test indirectly the existence of a new physical scale which will become accessible, directly, at the end of this decade, after LHC turn-on. Once LHC discoveries appear the precise study of these phenomena, through indirect measurements at a Super B factory will help elucidate the structure of this new physics. This is doubly important because the observed CP violation in the standard model is not sufficient to explain the matter/anti-matter asymmetry of the universe. It could be that there need be other sources of CP violation, beyond the standard model, that could be pinned down with measurements at a Super B factory. Achieving these goals would require luminosities of order $10^{36}cm^{-2}s^{-1}$, almost two orders of magnitude higher than in the current B factories. The collider would need to operate at the threshold of producing pair mesons B0-anti B0, as well as lower energy production limit of charmed mesons.

It is clear that the question is of a technical nature, i.e., what would be the best accelerator and the best detector for such a machine. A new proposal that has emerged in the last few years is a machine that would operate with "damping rings" accumulating packets of electrons and positrons colliding them straight sections with a strong final focus for collisions. This solution would profit from several advances made for the future high energy linear collider (the ILC). The damping rings, straight sections, and final focus are all necessary elements of the ILC design. At the same time this machine would result in a prototype of several of the key elements of the ILC on reduced scale.

Many of the components of the proposed machine are foreseen to be recycled from the SLAC B-factory, including large parts of the BaBar experiment. A 450 page TDR describing the physics goals, machine design, and detector has been produced. Feasibility studies related to shipping parts of the BaBar experiment and SLAC machine are already underway. The local government, outside Rome, has already agreed to supply the land necessary and provide initial operating funds. A technically limited schedule foresees operation of this machine early in the next decade – as early as 2012.

RESOURCE REQUIREMENTS

There are several areas for possible TRIUMF involvement in the accelerator complex. The accumulation/damping rings will require fast injection kickers to achieve bunch spacings of a few ns. In addition, the development of the e-linac at TRIUMF would put the lat in a position to participate in the development of the SuperB injector which will be based on 1.3 GHz superconducting RF.

Members of the Canadian particle physics community are already actively studying the impact of refined measurements of the standard model parameters, and how they can be used to pin down new physics that might be seen at the TeV scale.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

Canadians have a long history of working in B physics, starting with the ARGUS experiment at DESY, followed by the CLEO experiment at Cornell and most recently at the SLAC B factory. Significant detector contributions have been made to these experiments in the past. TRIUMF provided the clean room and technical expertise to string the BaBar drift chamber, Canada's main contribution to that experiment. Canadians have been heavily involved in the detector-machine interface at the SLAC B factory. Precision tests of Standard Model predictions for interaction rates, branching ratios and, potentially CP violating, coupling constants are an important complement to the direct searches for new physics at the highest energy colliders.

INVESIGATORS (GRANT-ELIGIBLE)

Carleton: Asner; **McGill:** Patel, Robertson; **UBC:** Hearty (also IPP), McKenna; **Victoria:** Roney, Kowalewski.

BROADER IMPACTS

In addition to the education of highly qualified personnel, the SuperB machine design pushes the envelope of accelerator intensity. This accelerator technology will help push the boundaries for future light sources (that have direct applications to nano-technology and biophysics). In addition intense electron beams have applications in medical treatment and medical physics.

T2K

SCIENTIFIC JUSTIFICATION

Measurements of neutrinos produced in the sun, at reactors, and in the upper atmosphere have provided convincing evidence that neutrinos have mass and oscillate from one flavour to another as they propagate through space. These experiments, carried out in Canada and Japan, have provided measurements of θ_{12}, the coupling between the first and second flavour neutrinos, and θ_{23}, the coupling between second and third flavour neutrinos.

The Tokai-to-Kamioka (T2K) long baseline experiment, located in Japan, will provide precision measurement of the atmospheric mixing angle θ_{23} in ν_μ disappearance and observation of non-zero mixing angle θ_{13} in the search for $\nu_\mu \rightarrow \nu_e$ appearance. If the mixing angle θ_{13}**,** which is not known from solar or atmospheric neutrino experiments, is large enough to be observed by T2K, it could lead to a search for charge-parity (CP) symmetry violation in lepton sector in a second phase. CP violation in the lepton sector is one of the most popular mechanisms to explain the Baryon asymmetry of the universe. Neutrinos will be produced using a 0.75 MW 30 GeV proton beam at the J-PARC facility in Tokai. Pions created when the proton beam hits a target will subsequently decay into muons and muon neutrinos, and neutrino oscillations will be measured by comparing the flux of ν_μ at the near detector (ND280) with that at the far detector, Super-Kamiokande. Phase Two of T2K would upgrade the beam power to 4 MW and potentially involve a 500 ktonne Hyper-Kamiokande detector. An option of having a detector in Korea 1200km away is also under consideration. A proposal to have an intermediate detector at 2km is being developed in order to precisely predict the flux extrapolation between the near and far detectors.

RESOURCE REQUIREMENTS

Canadian responsibility for the T2K experiment includes design of the target station at J-PARC, and production of ND280 components: $600,000 for the time projection chambers (TPC) and $1.1M for the fine-grained calorimeters (FGD). The capital for these detectors has been provided by NSERC but TRIUMF is providing significant infrastructure and manpower to assemble these detector systems (currently peaking at 15 FTE of technical support). By the start of the five year planning period these detector systems will have been delivered to Japan and the on-going resources required from TRIUMF will consist of physicist, DAQ and computing support to operate the experiment and analyse the data. TRIUMF is expected to be the analysis center for the T2K Canada collaboration implying a data storage facility (100 TByte) will be required. Towards the end of the five year planning period the initial T2K results may provide sufficient motivation for upgrades to the near detector. The long baseline-neutrino community is examining liquid-argon TPCs for future upgrades. This work overlaps with efforts already underway in the detector group to support SNOLAB and medical imaging detectors.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The T2K project has been fully funded in Canada and includes researchers from Victoria, UBC, Alberta, Regina, Toronto, and York. The neutrino oscillation studies at T2K augment searches for neutrinoless double-beta decay such as the SNO+ experiment at SNOLAB, which may eventually lead to measurement of neutrino masses and the origin of mass.

INVESTIGATORS (GRANT-ELIGIBLE)

P. Kitching (Alberta); R. Helmer, R. Henderson, A. Konaka, L. Kurchaninov, A. Miller, J.M. Poutissou, R. Poutissou, F. Retiere, S. Yen (TRIUMF);D. Karlen, M. Roney (Victoria); C. Hearty (also IPP), S. Oser, H.Tanaka (also IPP)(UBC); M. Barbi, T. Mathie, R. Tacik (Regina); J. Martin (IPP/Toronto); S. Bhadra (York)

BROADER IMPACTS

Neutrino physics is poised to be one of the most exciting new directions for particle physics and will attract new physicists to study a virtually untouched area of science and inspire new technicians to solve the technical problems innate to measuring these weakly-interacting particles. The T2K project provides opportunities for students and postdoctoral fellows to participate in all aspects of the experiment, from detector construction and operation to data analysis, in this flagship neutrino experiment TRIUMF plays a central role in providing technical expertise and strengthening the role of Canadian participation in T2K. At the same time, it helps TRIUMF to develop leading detector expertise, such as MPPC(SiPM) and TPC, and accelerator/beam line expertise.

Rare Decays

SCIENTIFIC JUSTIFICATION
Precision measurements of rare processes (e.g., $K \rightarrow \pi\nu\nu bar$) and searches for forbidden leptonic and semi-leptonic Lepton Flavor Violation (LFV) processes (e.g., $\mu \rightarrow e$ conversion) which are mediated by flavour-changing neutral currents (FCNCs) are potentially useful for the comprehensive characterization of extremely high mass-scale physics beyond the Standard Model (SM).

The theoretical decay branching ratios of the rare decays $K^+ \rightarrow \pi^+\nu\nu bar$ and $K_L \rightarrow \pi^0 \nu \bar{\nu}$ can be calculated to very high precision. Measurements of $K+ \rightarrow \pi^+ \nu \bar{\nu}$ experiment NA62 at CERN and Project X at Fermilab, are designed to measure the branching ratio of this decay to <10% accuracy. Together with the direct CP-violating decay, $K_L \rightarrow \pi^0 \nu \bar{\nu}$, these measurements could set constraints on new physics expected to be seen at LHC.

The proposed COMET experiment at JPARC will search for neutrinoless $\mu \rightarrow e$ conversion in the field of a nucleus. COMET will probe at a sensitivity of 10^{-16} for this decay, and any detectable signal would be a definite signature of new physics at very high mass scales.

RESOURCE REQUIREMENTS
TRIUMF is expected to contribute $1.5M worth of equipment, such as construction of the tracking detector or construction of the photon veto system around the vacuum vessel. Comparable involvement in the experiment at Project X might be envisioned. Assuming approval of COMET as expressed in the proposal, the required TRIUMF resources are listed in man-years in the table below.

Activity	Years	Engineer	Design-Office	Machine shop	Detector facility
Design & R&D	2009	0.5	0.5	0.5	1
Construction	2010-2011	1	1	1	1.5
Installation	2012	0.5	0.25	0.25	2
Maintenance	2013-	0.2		0.1	0.5

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
M. Hasinoff (UBC) and C. Rangacharyulu (Sask.) are pursuing another K decay process with T-violation at JPARC. Rare decay studies of CP violation at a proposed Super-B factory would complement the offsite K decay studies. Measurements of K decay modes will help discriminate between models if new physics appears at the LHC or at much higher mass scales.

INVESTIGATORS (GRANT-ELIGIBLE)
D. A. Bryman (UBC), L. Kurchaninov, G. Marshall, T. Numao and F. Retiere (TRIUMF).

BROADER IMPACTS

The exacting nature of these studies builds on the strength of the TRIUMF rare decays group. To pursue the PRISM project planned after COMET will demand new ideas and innovations generated in these studies to push sensitivity to $\mu \rightarrow e$ conversion to the 10^{-18} level.

Theory

SCIENTIFIC JUSTIFICATION

The Theory Group plays an important role by contributing to the intellectual leadership of TRIUMF, by providing theoretical guidance and support to the experimental program of TRIUMF, and as a theoretical resource for the broader Canadian subatomic physics program. There is currently an urgent demand for increased theoretical activity in nuclear physics, nuclear astrophysics and in particle phenomenology, in particular for the world-leading ISAC facility and for the upcoming experiments with ATLAS at LHC. A substantial increase in theoretical activities at TRIUMF is pivotal to the science return and to the visibility of the national subatomic physics program. We propose to develop a Theory Program to fill this need and to provide a center for theoretical activity not only for the laboratory, but for the larger Canadian subatomic physics community. Nuclear physics has entered an exciting era, in which substantial progress can be expected on many fundamental problems. This is due to advances on many fronts, including the development of effective field theory and the renormalization group in nuclear physics, the advances in ab-initio methods for nuclear structure, the effort to develop a universal density functional from microscopic interactions, and the application of large-scale computing resources. At the same time, the world-leading ISAC facility will provide critical new data. Therefore, there is a unique opportunity to make progress on existing and brand new problems in nuclear physics during the 2010 to 2015 period. TRIUMF should be at the forefront of this theoretical and experimental synergy. In the next ten years, particle physics will enter a decisive stage, when the LHC will directly probe the nature of electroweak symmetry breaking and the underlying TeV-scale physics. This unprecedented task requires close collaboration between experimental and theoretical particle physicists at TRIUMF. These new physics searches are complemented by low-energy precision experiments on fundamental symmetries, which have been areas of traditional strength at TRIUMF, and by experiments on the nature of neutrinos. To fully harvest these investments, TRIUMF needs strong theoretical leadership connected to these experimental programs.

RESOURCE REQUIREMENTS

Supported by the recommendations of the 2002 NRC External Review of the Theory Group and by ACOT, and to fulfill the national leadership role, *we propose to increase the Theory Group to ten permanent members by the end of the next five-year period. The four new hires in 2010-2015 should support the major new initiatives, with one hire in nuclear astrophysics (e-linac), one hire in fundamental symmetries (second beam line), as well as the existing programs in particle phenomenology and neutrino physics*. The resulting Theory Group will then have a critical mass of five positions that cover nuclear physics and nuclear astrophysics, and five that cover particle phenomenology and related areas in astroparticle and neutrino physics, with significant synergy between nuclear and neutrino physics, as well as nuclear astrophysics and astroparticle physics. The expected size of six permanent members by 2010 is smaller than what is considered to be optimal by major university groups in particle/nuclear theory and by other national labs. In order to strengthen nuclear theory, nuclear astrophysics and particle phenomenology at the TRIUMF member universities, *we propose to create four tenure-track bridge positions*, which would be supported 50% by TRIUMF over five years and then fully by the universities (at present, TRIUMF has no joint positions in theory). During these five years, the faculty member is expected to spend some time at TRIUMF and participate in the TRIUMF program. A similar program at the RIKEN BNL Research Center has been extraordinarily successful.

The research associate program has served TRIUMF very well and was identified in the 2002 NRC External Review as a major success. The TRIUMF-funded research associates are hired as a resource for the whole laboratory. They have served to bring new expertise to TRIUMF, and to support areas of interest not currently covered by the permanent members. A very similar model has been adopted, for instance, by the Perimeter Institute and by the Canadian Institute for Theoretical Astrophysics. The 2002 NRC External Review recommended to establish Five-Year Fellow positions, which would allow TRIUMF to attract some of the best post-doctoral researchers that show outstanding promise and have established excellent research. The holders of Five-Year Fellow positions are expected to develop a program of international recognition, to play a prominent role in the activities of the Theory Group, and to promote TRIUMF in Canada and in the world. With the expansion of the Theory Group, *we propose to increase the number of TRIUMF-funded research associates to six and the Five-Year Fellow positions to two*.

As identified in the 2002 NRC External Review and the 2006 NSERC SAP Long-Range Plan, *an important service to the Canadian subatomic theory community is a vibrant visitor and workshop program. This program supports visits to TRIUMF from a few days up to a year for sabbatical visitors*. These visits not only add to the intellectual atmosphere at TRIUMF, but also increase the profile of TRIUMF in the community. To host visitors, the Theory Group has to be able to provide financial support and, for long-term visits, to cover partial salary and living expenses. The Theory Group we propose, with its larger size and focus, will be a strong attractor for visitors. In addition to an enhanced visitor program, *we propose a workshop program, ranging from topical workshops of one week with 30-40 participants to smaller working group meetings of several weeks with 5-10 participants.* The proposed workshop program will further raise the profile of TRIUMF in Canada and in the world, and bring the expertise of the national and international subatomic theory community to TRIUMF. *The 2002 NRC External Review recommended to increase the funds for the visitor and workshop programs to at least $100k per year.*

The current Theory Group is already cramped for office space. The proposed expansion of the Theory Group must be accompanied by a corresponding increase in the available space.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

The proposed activities are vital to the Canadian subatomic community as well as to an energetic Theory Group, and help address some of the national needs identified by the

2006 NSERC SAP Long-Range Plan. The proposed workshops and meetings can be organized by university colleagues who would not have the infrastructure to host such a group at his or her home institution. The enhanced program will also provide financial support for visits of the research associates and Five-Year Fellows to collaborate with university colleagues.

To facilitate the involvement of the community, the 2006 NSERC SAP Long-Range Plan suggested that a governing council made up of Canadian theorists be formed to consider proposals for workshops and conferences. We propose a Liaison Committee along this line, which would encourage and facilitate the interaction of the TRIUMF Theory Group with their university colleagues. The Liaison Committee could aid in identifying the topics for workshops and act as a more formal channel for communication and feedback to the Theory Group.

INVESTIGATORS (GRANT-ELIGIBLE)
B. Jennings, J. Ng, R. Woloshyn, A. Schwenk (TRIUMF) *and the Canadian subatomic theory community*.

BROADER IMPACTS
The Theory Group and the proposed initiatives offer an excellent training and research experience for undergraduate and graduate students (the theory undergraduate jobs have been the most popular within the TRIUMF summer undergraduate program for the last two years) and a unique research environment for postdoctoral researchers. Many of our research associates have gone on to successful academic and industry careers. The Theory Group therefore provides an integral component for training future leaders in science and technology for Canada.

CFI

As a joint venture of a university consortium, TRIUMF is not able to apply for CFI funds. However, members of the Canadian university community can propose projects to CFI that would provide resources or infrastructure to TRIUMF as well as draw on capabilities already there. In the 2010-2015 Five Year Plan, it is anticipated that TRIUMF resources will be tapped to implement successful CFI proposals.

Electron linear accelerator

SCIENTIFIC JUSTIFICATION

E-linac is a 10 mA, 50 MeV electron linear accelerator (linac) employing superconducting radiofrequency (SRF) technology. Nuclear and particle physics depend on the quality of their instrumentation and infrastructure, as does molecular and materials sciences (MMS). The linac and its photo-fission based actinide target station represent a major infrastructure initiative. It will provide directly an additional source of neutron-rich isotopes for nuclear physics, and of 9Be for β-NMR studies in MMS. E-linac will also benefit users of proton-rich isotopes (e.g. nuclear-astrophysics) by reducing the competition for proton beams at the existing, and planned, ISAC facilities.

Research & development for E-linac may also have direct impacts on the disciplines of accelerator engineering: the quest for higher-accelerating gradients via the use of single/few-crystal cavities, and the quest for higher operational quality factor by improved LLRF and tuning control. MW regime facilities will all benefit from improved input coupler design, and Elinac provides the impetus for such R&D at TRIUMF.
R&D for the target station is covered in a separate "One Pager".

The first SC niobium linac was constructed at Stanford circa 1971; this 50 MeV, 1.3 GHz machine operated at ≈ 2 MV/m. Subsequently, this L-band technology was developed by the TESLA collaboration at DESY, and gradients in excess of 20 MV/m were achieved in the mid 1990s. Today, for pulsed operation, 20 MV/m is considered routine and 40 MV/m the frontier; and L-band SRF is advocated in diverse applications ranging from light sources to high-energy colliders.

For additional discussion of the science at stake, please see the discussions of nuclear structure, nuclear astrophysics, fundamental symmetries, and molecular and materials science. For dependencies relating to the implementation, please also see elements of the on-site accelerators sections.

RESOURCE REQUIREMENTS

During the 5 years of design, construction, installation and commissioning, E-linac will demand significant resources. E-linac will call upon the services of 11, 30, 20 and 40 man years respectively of physics, engineering, design and technical expertise. This will necessitate new hires in cryogenics and RF cavity processing, etc. Excluding civil engineering, M$2.5 will be spent on SRF infrastructure, and a further M$17.5 purchases for materials and components for the linac and its beam line, etc, is foreseen.
E-linac is both a component of the 5-Year Plan and the subject of an imminent CFI capital request for M$20.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

E-linac will draw upon TRIUMF's existing capability to design and operate 100 MHz, 4K and β=v/c <<1 SRF systems, and expand the expertise to 1 GHz, 2 K and β=1. As a result, TRIUMF will become a unique multi-regime centre for SRF science and accelerator physics.

The Canadian university-research program has its sights set firmly on the Large Hadron Collider (LHC) and its upgrade path, the SPL and PS2; and on precision Higgs physics at the International Linear Collider (ILC). Both the CERN Superconducting Proton Linac (SPL) and ILC rely on SRF accelerating structures, at 0.7 and 1.3 GHz respectively; and infrastructure for E-linac could facilitate Canadian contributions to either of these HEP frontier projects. Electron linacs are in operation or proposed around the world[2] as drivers for so-called 4th generation synchrotron light sources; future reconfiguration of E-linac as a Recirculating Linear Accelerator (RLA) or Energy Recovery Linac (ERL) opens the door to such a possibility. A short-cut to high-energy x-rays is proposed via Inverse Compton Scattering (ICS) of optical photons off hundreds MeV electrons. ICS has applications in MMS and medical imaging where the high 6D brilliance and easy tuning of photon energy out-compete synchrotron light sources. E-linac could serve as a test-bed for the enabling technologies for an ICS source at the Canadian Light Source (CLS).

INVESIGATORS (GRANT-ELIGIBLE)

List of potential CFI applicants include: Dean Karlen, Shane Koscielniak, Justin Albert, Mike Roney, Andrew MacFarlane, Rob Kiefl, Tom Mattison, Chris Hearty, Janis McKenna, Corina Andreoiu, Barry Davids, Jeff Sonier, Kim Chow, Mark De Jong, Mauricio Barbi, Paul Garrett, Carl Svensson, Alan Chen, Graeme Luke, Bob Orr, William Trischuk, Alain Bellerive, Jean-Pierre Martin, Rene Roy, Roby Austin, Rituparna Kanungo, etc.

BROADER IMPACTS

E-linac will transform Canada from a purchaser of SRF technology to a nation with the capability to construct, process and sell niobium cavities and their attendant components. Presently, there are only a few vendors world-wide of SRF technology. Through collaboration with a BC-based engineering company, E-linac will enable Canadian industry to join this elite group.

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The ultimate E-linac target station will employ a liquid metal convertor, and this will ally TRIUMF with a key technology for pulsed neutron sources (like the Spallation Neutron Source at ORNL) and sub-critical reactors for power generation.

The E-linac project will provide many opportunities to train highly qualified personnel, and in the following particular fields: cryogenic and radiofrequency engineering; and accelerator science including particle beam and electromagnetic field modeling; and high-power target engineering, etc.

[2]TJNAF IR FEL & UV FEL, Cornell ERL, Daresbury ERLP & 4GLS, ARC-EN-CIEL at Soleil, BINP (Novosibirsk) THz FEL, JAERI ERL-FEL, PKU-ERL-FEL, KAERI EAF, etc.

GRIFFIN

SCIENTIFIC JUSTIFICATION

GRIFFIN (Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei) is a state-of-the-art, new, high-efficiency γ-ray spectrometer that will replace the current 8π Spectrometer as the primary decay spectroscopy facility at ISAC-I. GRIFFIN will provide a 20-fold increase in absolute γ-ray detection efficiency, representing a 400-fold efficiency increase for γ–γ coincidence experiments. This large gain in detection efficiency will enable detailed studies of the most exotic radioactive beams produced by ISAC and its future target and driver upgrades at TRIUMF. Decay and structural properties will be measured for isotopes produced with intensities well below 1 ion/s, extending the reach of ISAC experiments to the extremes of neutron richness. It is the properties of these isotopes, many of which are completely unknown, that are the current focus of the worldwide nuclear structure community as they determine the pathways, time scales, and energy releases in the explosive astrophysical environments responsible for the synthesis of the heavy elements. The GRIFFIN detectors will also be available for use in other ISAC applications in which high-efficiency and/or high-rate γ-ray detection is required. Examples include, but are not limited to, the search for new CP-violating fundamental interactions through precision electric dipole moment (EDM) searches with Rn isotopes at ISAC-I (S929), and high-efficiency decay spectroscopy at the focal plane of the EMMA recoil spectrometer at ISAC-II. GRIFFIN will thus make major contributions to all of the nuclear structure, nuclear astrophysics, and fundamental symmetries programs at TRIUMF's ISAC facility.

RESOURCE REQUIREMENTS

The GRIFFIN proposal is being developed for submission to the Canada Foundation for Innovation and the Ontario Ministry of Research and Innovation as an application led by the University of Guelph. The capital cost will be ~$8M over 4 years, with the 20% matching contribution derived from vendor discounts, as well as in-kind contributions from TRIUMF. The latter will include requests for design office contributions (~6 months), co-ordination of components during the mechanical construction phase (2 years, 1 FTE), dedicated technical support (1 FTE, ongoing), DAQ group support (~0.5 FTE during installation, ~0.25 FTE afterwards), and machining contributions (to be divided among the University and TRIUMF shops, as well as external contractors). TRIUMF currently provides ongoing technical and DAQ support for the operation of the 8π Spectrometer at ISAC-I and the incremental resource requirements associated with the conversion to GRIFFIN are therefore relatively modest. In particular, GRIFFIN will be situated at the current 8π location in the ISAC-I hall, making use of the existing low-energy beam line and its well developed optics and tuning. There are therefore no new requirements of the TRIUMF Accelerator Division associated with GRIFFIN.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

"Full exploitation of the high-intensity radioactive beams for nuclear physics and nuclear astrophysics at ISAC and ISAC-II" was identified as one of the highest priority projects of the Canadian subatomic physics community for the 2006-2016 period in the recently completed NSERC Long-Range Plan. Through its dramatically increased gamma-ray detection efficiency, GRIFFIN will enable the full exploitation of the rare isotope beams produced at ISAC. As a state-of-the-art experimental facility it will complement future accelerator/target developments associated with the ISAC facility, such as the new electron linear accelerator driver, actinide production targets, and the second high-intensity proton beam line to ISAC. Together these advanced accelerator, target, and experimental facility developments will enable the Canadian research community working at TRIUMF's ISAC facility to maintain and enhance its international leadership in the production and use of radioactive ion beams for nuclear structure, nuclear astrophysics, and fundamental symmetries research. The GRIFFIN collaboration represents a broad segment of this community, with current representatives from TRIUMF and 7 Canadian Universities, including 6 Member and Associate Member Universities of the TRIUMF joint venture.

INVESIGATORS (GRANT-ELIGIBLE)

Current Canadian grant-eligible researchers involved in the GRIFFIN project are: P.E. Garrett and C.E. Svensson (Guelph), G.C. Ball, B. Davids, and G. Hackman (TRIUMF), R. Roy (Laval), A. Chen and J.C. Waddington (McMaster), J.-P. Martin (Montréal), R.A.E. Austin and R. Kanungo (Saint Mary's), C. Andreoiu and M. Hayden (Simon Fraser), and T.E. Drake (Toronto), representing TRIUMF and 7 Canadian Universities.

BROADER IMPACTS

GRIFFIN will provide highly-qualified personnel with hands-on experience and training with a wide range of advanced technology from state-of-the-art semiconductor and scintillator radiation detectors to digital electronics and signal processing. Canberra Canada, a primary supplier for TIGRESS, is also a potential supplier of GRIFFIN HPGe detectors. The advanced detector technology developed for such basic science programs finds commercial applications in high-resolution radiation detection for medical imaging and nuclear material monitoring for national security. With GRIFFIN, we will continue the pioneering development of digital signal processing for high-resolution semiconductor detectors carried out by the Université de Montréal group for the TIGRESS project.

IRIS

SCIENTIFIC JUSTIFICATION

Nuclei with extreme neutron to proton ratios offer a unique opportunity to probe the isospin dependences of nuclear interaction and properties that are inaccessible otherwise. These exotic nuclei also contribute to the synthesis of heavy elements. Studies of nuclear reactions provide a view to their internal structure and give the reaction rates governing nucleosynthesis. Due to the weak binding nature, the unbound states in these nuclei have a strong impact on their structure and role in nucleosynthesis. Although gamma detection has been used for observing bound excited states, the low yield of these nuclei often makes it difficult to rely solely on gamma spectroscopy. It is impossible to observe the unbound states by gamma detection. Internal arrangement in a nucleus and the nature of excitation can be studied from the angular distribution of the charged reaction residues. Charged particle reaction spectroscopy is thus necessary for studying exotic nuclei at ISACII. This proposal therefore intends to build a charged particle spectroscopy facility at ISACII.

The facility will be designed for nuclear reactions with E ≥ 3A MeV at ISACII. Two-body reactions like $a+b \rightarrow c+d$ will be measured, where a = incident nucleus, b = light targets (e.g., p, d), c = light particle (e.g., p, d, t, ^{3}He) and d = recoiling nucleus. The ionization chamber counts the beam. We envision fabrication of novel cryogenic solid ^{1}H, ^{2}H targets (collaboration with muonic hydrogen group and Japan). This will increase the luminosity by an order of magnitude, thereby extending the experimental reach to more exotic species. Installation of such targets in the TUDA facility at ISAC1 is not possible with present geometry. The scattering angles and energies of particles c and d will be measured using position sensitive silicon ΔE-E detector telescope. A scintillator detects the unreacted incident nuclei. The facility will be used either as a standalone system or with EMMA. In the latter case, the particle d is separated from beam using EMMA . The ionization chamber can identify the isobaric impurities in the beam. The significant features of this facility are therefore, (a) cryogenic targets that increase the reaction yield by one order of magnitude. (b) identification of the incoming nuclei and (c) the use of a flexible silicon detector telescope system whose configuration can be easily changed to adopt the best geometry for the specific reaction of interest. Commercial electronics will be used for signal processing.

RESOURCE REQUIREMENTS

Rough cost estimate of equipments only $1 M. Funding concept for equipment.

- Combined funds from CFI to be proposed 2008 (St. Mary's University), and TRIUMF
- Requirements of technical personnel from TRIUMF
  - One technician for the facility (full time)

- Cryogenic target fabrication (R&D) and maintenance (full time target facility person at TRIUMF)
- LADD support for ionization chamber fabrication (R&D)
- DAQ group support (for initial setup and maintenance)
- Design office and machine shop support

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
The facility will be used to address key questions outlined in the Canadian subatomic physics long-range plan, by investigating structure of neutron and proton-rich nuclei and their role in nucleosynthesis.

INVESTIGATORS (GRANT-ELIGIBLE)
R. Kanungo , R.A.E. Austin(Saint Mary's University); L. Buchmann, B. Davids, C. Ruiz, P. Walden (TRIUMF); C. Andreoiu (Simon Fraser University); P. Garrett (University of Guelph)

BROADER IMPACTS
The development of new detectors, targets for the facility will provide employment and training to qualified personnel. Involvement of Canadian companies is also foreseen. The facility will provide basic training to university students.

Laboratory of Advanced Detector Development

NOTE THAT THIS PROJECT IS BOTH A TRIUMF CORE CAPABILITY AND A POTENTIAL CFI PROPOSAL.

SCIENTIFIC JUSTIFICATION

TRIUMF expertise in detector development and fabrication for physics experiments is well established and recognized. The aim of the Laboratory of Advanced Detector Development (LADD) in 2010-2015 is to establish TRIUMF as a center of excellence for the development of medical imaging detectors, while being involved in several physics experiments especially SNOLAB experiments, one of the proposed upgrades of the ATLAS experiment, R&D for the International Linear collider (ILC) and a rare decay experiment such as COMET at JPARC.

LADD will focus on detector developments that benefit a subset of experiments pursued by TRIUMF during the coming five year plan, which are described elsewhere: instrumentation for medical imaging, SNOLAB, one ATLAS upgrade project, ILC detectors and rare decay experiments. Five different technologies will be the focus of LADD: electronics, gas, scintillators, Noble liquids, and room temperature semi-conductor. Cutting edge expertise and design capabilities in electronics are essential for any detector projects. Fast digitization and digital data processing will also be at the heart of any new experiments designed or constructed during the 5 year plan, such as DEAP at SNOLAB. The strong expertise in gas detector will enable TRIUMF to be a driving force behind the EXO and ILC Time Projection Chambers, as well as tracking chambers for rare decay experiments and possible upgrade of the successful TACTIC active target TPC at ISAC I. Development of new scintillating crystals and photo-sensors will find applications in medical imaging, particle physics especially ILC and neutrino, and condensed matter (muSR). Noble liquids are very promising in a variety of applications including liquid Xenon for PET detectors, Dark Matter and double beta decay search and liquid Argon for calorimetry, Dark Matter search (DEAP) and precision investigation of neutrino interactions. Room temperature semi-conductors such as CdZnTe offer a wide range of opportunities for medical imaging (SPECT) but also in physics experiments as a possible replacement for germanium detectors.

RESOURCE REQUIREMENTS

TRIUMF resources are necessary to provide equipments and supplies in order to investigate new technology and establish proof of principles. Beyond the early stage of R&D, LADD scientists will seek support from NSERC in collaboration with Canadian institutes. The level of support required is 100k$/year in addition to the amount requested for medical imaging instrumentation. In order to pursue five different technologies, an additional research scientist is required. One additional technician is also required for constructing detectors. Electronics capabilities need to be expanded by hiring two engineers, one specializing in Application Specific IC (ASIC) design, and one specializing in digitization and digital data processing.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

LADD will work in collaboration with TRIUMF scientists and several Canadian Universities by using its expertise and equipment for medical imaging, particle and nuclear physics experiments, and condensed matter experiments. Collaborations with UBC and l'université de Sherbrooke for medical imaging, and the University of Alberta, UBC, Carleton University, l'université de Montreal, Queens University, and the University of Regina for particle physics experiments are foreseen.

INVESTIGATORS (GRANT-ELIGIBLE)

UBC: Tanaka, Bryman. *Carleton:* Bellerive, Dixhit, Graham, Sinclair. *U. de Montreal:* Martin. *Queens:* Boulay. *U. of Regina:* Barbi. *U. de Sherbrooke:* Lecomte. *TRIUMF:* Henderson, Kurchaninov, Miller, Numao, Retière

BROADER IMPACTS

The impact of LADD activities will be three folds: 1) provide training, expertise and access to TRIUMF technical resources to several nuclear and particle physics experiments being pursued in Canada, 2) develop cutting edge technologies with a high potential for application in physics experiments or/and medical imaging 3) exploit the synergies between developments for physics experiments and medical imaging. LADD will be the link allowing cutting edge detector development for basic physics to find a market by training people, especially students, by directly pursuing marketable applications and by working with industry.

National Network for Cyclotron-Produced Radiotracer Research

SCIENTIFIC JUSTIFICATION

A National CFI proposal on the Development of Radiotracers is being proposed by a consortium of 15 Academic centres across Canada representing the 4 regions (as defined by CFI), the East, Quebec, Ontario and the West. All of these centres have received support from the CFI, the federal and provincial governments or other non-governmental agencies to purchase and install cyclotron based facilities. However many of these centres lack the infrastructure to take full advantage of the research capacity thee facilities represent Thus this National effort is aimed at foster exchange of idea and the training of highly qualified personnel to enable Canada nuclear imaging programs to become internationally competitive.

This CFI would focus on the development of radiotracers based on large molecules such as peptides, peptide fragments, oligonucleotides and antibodies in addition to transferring basic radiotracer technology to the new emerging groups. Attaching a radionuclide to an organic entity requires the proper conditions and must be rapid and high yielding. New approaches are being tested that provide for the desired properties. The proposed approaches will be used to fast-track the development of a range of radiotracers that can be evaluated in a clinical setting. These radiotracers will not only address medical needs that have been defined within existing clinical research programs, but also serve to drive the development of a platform process for radiotracer development that will be equally applicable to the generation of novel radiotracers targeted to other diseases.

RESOURCE REQUIREMENTS

TRIUMF matching contributions to the CFI would enable the radiotracer labs to be brought up to modern standards and enable more basic chemistry research to be performed. The specific equipment would include two dedicated chemistry labs with 2 fume hoods and 2 hot cells each.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY

As molecular biology unravels the various pathways for signal transduction and protein interactions the targets for specific tracers has increased dramatically. The challenges the radiochemist faces are enormous. The development of a new probe (radiotracer) is akin to what big pharma deals with in their quest for new and better drugs. The research centres in Canada are few and, in general, small. In order to foster collaboration to help each group to benefit from the efforts of others a national effort is required and the proposed network will form the basis for this program. TRIUMF is a natural leader of this effort because of its strong connections to biomedical programs at UBC via the Pacific Parkinsons Research Centre and the BC Cancer Agency. Moreover, TRIUMF has specific expertise in accelerator science and technology and radiochemistry that make it a crucial partner in any such national effort.

The CFI will partner with three newly funded Centres of Excellence on Commercialization and Research: Advanced Applied Physics Solutions (AAPS at TRIUMF), Centre for Drug Research and Development (CDRD at UBC), and Centre for Probe Development and Commercialization (CPDC at McMaster).

INVESTIGATORS (GRANT-ELIGIBLE)
Dr. Francois Benard (BCCA), Dr. Jon Stoessl (PPRC), Dr. David Perrin (Chem., UBC), Dr. Michael Adam (TRIUMF). Dr. Thomas Ruth (TRIUMF), plus one senior scientist, one postdoctoral fellow, and one technician.

BROADER IMPACTS
The proposed networking on the chemistry can have wide applicability and impact many areas of radiotracer development that cover the full spectrum of imaging and therapy.

Ultracold Neutrons

SCIENTIFIC JUSTIFICATION

We propose to construct the world's highest density ultracold neutron (UCN) source to mount a measurement of the neutron electric dipole moment (nEDM). The TRIUMF UCN source would be unique in the world for its use of superfluid ^{4}He production technology in close proximity to a high intensity spallation production target. The truly high density that could be obtained at TRIUMF would enable a nEDM experiment with a much smaller measurement volume than competing experiments around the world, leading to a reduction in systematic errors and thus a more significant result.

The physics motivation relates to the baryon asymmetry of the universe, which drives the search for new sources of CP-violation beyond the standard model. The neutron EDM is a T-violating observable, and a non-zero EDM would imply CP violation. A next generation search for a nEDM at TRIUMF would aim for a determination at the 10^{-28} e-cm level. This is two orders of magnitude beyond the current best limit, and would tightly constrain new CP-violating phases in a number of theoretical models.

UCN have such remarkably low energies (< 300 neV) that they totally reflect from surfaces and can be confined in material bottles, and thus constitute an ideal source for precision experiments. Besides the nEDM search, the TRIUMF UCN source could be used for a variety of other fundamental physics experiments, such as measurements of neutron beta-decay and of quantized neutron gravity levels. This program could be complemented by a program of surface physics studies using UCN.

RESOURCE REQUIREMENTS

The UCN source requires delivery of a 500 MeV proton beam at 40 μA to a new tungsten spallation target in the meson hall at TRIUMF. A new beam line and a fast kicker system are required to deliver beam to the new spallation target, with a pulsed time structure that would utilize on average 7% of the high intensity beam delivered to the meson hall, leaving the beam otherwise unaffected when not being delivered for UCN production. The MeV-scale spallation neutrons would be cooled via thermal equilibrium with cryogenic moderators at 20 K. Cold neutrons would become ultracold by downscattering in a superfluid ^{4}He volume, producing phonons; the resultant UCN would diffuse out of the ^{4}He for delivery to experiments. Shielding, cooling, and remote handling would be required for the target. The UCN cryostat would require liquid helium.

A window of opportunity exists to capitalize on the UCN source development of the group of Y. Masuda at KEK and at RCNP in Japan, thereby allowing a collaborative TRIUMF project to surpass other proposed UCN sources elsewhere while minimizing the cost of building the facility in Canada. A rough cost estimate to implement the project consists of $4M for magnets, power supplies, and shielding, and $2-3M for the UCN source and cryostat. The CFI NIF program will be approached to fund the project, with an in-kind matching contribution of the UCN source and cryostat from Japan.

Engineering, technical and infrastructure support will be needed from TRIUMF to prepare the proposal and implement the project. Funding for the physics experiments will be pursued through subsequent requests to NSERC.

The UCN project is entering the design and proposal stage. The UCN source would be developed and optimized at RCNP Osaka until 2011. After that time, preparations for installation in the M11/M13 area would commence. Commissioning of the source and achievement of the world record UCN density at TRIUMF are envisioned for 2011. A first flagship physics experiment would be conducted in 2012. Onsite expertise required during operation of the source would be 2-3 scientists FTE, supplemented by graduate students, postdoctoral fellows, and technical support.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY
The project would expand TRIUMF's core capabilities into the active research field of UCN. The project builds upon TRIUMF's core capabilities in fundamental symmetries at ISAC, and on Canadian expertise in fundamental symmetry tests currently underway around the world.

INVESTIGATORS (GRANT-ELIGIBLE) AND OTHER COLLABORATORS
The Canadian grant-eligible UCN collaborators include: J. Martin (U. Winnipeg, Project Spokesman), M. Gericke, S. Page, W. van Oers (Manitoba), E. Korkmaz (UNBC), M. Hayden (SFU), L. Buchmann, and C. Davis (TRIUMF). Martin, Gericke, Hayden and Page have directly relevant experience in cold or ultracold neutron research. This core group is expected to expand and draw substantial international collaboration – particularly from the US and Japan, upon approval of the project, and we would ultimately expect that several world-leading experiments could be conducted at this facility, including also studies of the effects of gravity on UCN (Tokyo group), and a precision neutron lifetime experiment (ORNL / LANL group). Several world experts from the US have already joined the collaboration including: R. Golub (NCSU), a key researcher who invented superfluid ^{4}He UCN source technology, and a leading scientist in past and future nEDM searches; J.D. Bowman (ORNL), B. Filippone (Caltech), and B. Plaster (Kentucky) – all world experts in this field. The Japanese collaboration consists of collaborators from RCNP Osaka, KEK, Osaka U., and U. Tokyo. Y. Masuda from KEK is the leader of the UCN source R&D project, and has successfully developed the only spallation-driven superfluid ^{4}He UCN source in the world.

BROADER IMPACTS
Subatomic physics research has a huge people advantage: it provides the best possible training for a variety of high tech career paths for students. Surface physics applications of UCN would be developed for the study of nano-films, and hence relate to nanotechnology, and represent a potential entrepreneurial advantage. The project has drawn the interest of Acsion, a small company based in Manitoba that is a spin-off of AECL, where part of the activities of the company are in neutron transport in the design of nuclear reactors. Techniques developed for nEDM are strongly related to low-field MRI for medical imaging, and to laser and cryogenics technology.