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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Dear Malcolm and Samir:

**RE: Your letter of July 30, 2010**

Thank you for the opportunity to contribute to the long-range planning process. As you know, TRIUMF is owned and operated by a consortium of 11 Canadian universities and four associate member universities. The mandate of TRIUMF is to address research needs that no single university could tackle on its own by providing ongoing scientific, engineering, and technical knowledge, skills, and abilities at the national level. Over the course of 40 years, TRIUMF's mission has evolved from a facility for intermediate-energy nuclear physics to a multidisciplinary facility addressing particle physics, low-energy nuclear physics, nuclear astrophysics, molecular and materials science, and nuclear medicine in addition to knowledge transfer and commercialization. TRIUMF and its user community lead Canada in the search for answers to important questions in science and technology.

**1) Over the last five years (2006-present), to what extent did the subatomic research activities at TRIUMF align with the last subatomic physics long-range plan?**

TRIUMF's subatomic physics activities were and continue to be aligned with the 2006 community long-range plan. The recommendations in that plan are as follows (quoted from the Committee Report):
*The LRP Committee, after extensive consultation with the subatomic physics community, finds that the highest priority projects for the period of this plan should be:*

- *Full exploitation of the ATLAS experiment at the Large Hadron Collider, exploring proton-proton collisions at the highest energies available;*
- *Full exploitation of the high intensity radioactive beams for nuclear physics and nuclear astrophysics at ISAC and ISAC-II;*

- *Completion and full exploitation of the SNOLab facility, the world's best deep underground laboratory, including capital funding for major participation in experiments to be performed at the new facility;*
- *Participation in a long-baseline neutrino program, and in particular, in the T2K experiment at the Japanese J-PARC facility for the first five years of this plan;*
- *Vigorous R&D towards participation in the International Linear Collider (ILC), with capital funding for major participation in the 2011-2016 time frame.*

*In addition, the LRP Committee recommends that a broad program of smaller efforts be maintained to provide breadth and diversity to the Canadian subatomic physics community, and to allow for novel and emerging initiatives.*

*A strong experimental effort must be complemented by theoretical work. Theory plays a crucial role in subatomic physics by suggesting new directions for experimental studies, interpreting new experimental results, and coalescing these results together with theoretical ideas into a deeper understanding of nature. The Canadian theory community's strength and diversity should be maintained.*

Here we outline, point-by-point, how TRIUMF's activities match the recommendations:

1. **ATLAS:** The ATLAS experiment at CERN's Large Hadron Collider is charting new territory at the energy frontier in particle physics. TRIUMF has supported Canada's involvement in and access to the ATLAS program in three key areas: design and assembly of LHC accelerator components; design, fabrication, and installation of the endcap hadron calorimeter; and hosting the ATLAS Canada Tier-1 Data Analysis Centre as an element of the Worldwide LHC Computing Grid.

   TRIUMF has four on-site experimentalists working on the ATLAS experiment. In addition, TRIUMF contributes salary support toward five ATLAS experimentalists located at Canadian universities. The spokesperson for ATLAS Canada, Rob McPherson (an IPP scientist associated with the University of Victoria), is located at TRIUMF, and two TRIUMF theorists are working on ATLAS-related physics. TRIUMF is also involved with research and development work for the upgrades to the ATLAS detector; for instance, TRIUMF recently provided world-unique beams for irradiation studies of several new detector component prototypes.

   Led by Simon Fraser University, the ATLAS Canada Tier-1 Center is located at and supported by TRIUMF. Currently this centre is funded through a CFI award that combined federal contributions, provincial matching funds, vendor discounts, and TRIUMF contributions for the capital costs. Operations up to roughly the end of calendar year 2011 are covered by CFI IOF funds. The Group Leader for Tier-1 Operations, Reda Tafirout, is supported by TRIUMF. The Canadian particle physics community is committed to delivering the required computing power and computing capacity defined in the Memorandum of Understanding with CERN. It is expected that when the IOF funding completes in late 2011 or early 2012, TRIUMF will combine several funding sources (TRIUMF's NRC Contribution Agreement, new CFI programs, and/or other agency programs) to cover the 2012-2015 operating costs including the salaries for the ten highly qualified technical staff members.

2. **ISAC:** ISAC is Canada's flagship facility in experimental nuclear physics. In the last five years, major progress has been made in the development of this facility. Higher-energy beams are now able to be delivered to the new ISAC-II experimental hall through the completion of a superconducting heavy ion linear accelerator (low and high-beta cavities). The charge state booster is required to accelerate rare isotope beams with A>30 and commissioning is underway. The actinide-target development has begun and two new ion sources have been developed, TRILIS and FEBIAD. Two major detector facilities were also completed, TITAN and TIGRESS. Other experimental facilities are in progress, EMMA, IRIS, RnEDM and FRANCIUM, all aligned with the NSERC LRP priorities. Science benefited from the unique production and beam capabilities at ISAC, such as nuclear structure studies of halo-nuclei (masses, radii, transfer reaction and decay studies), one-of-a-kind direct radioactive capture measurements for nova studies in nuclear astrophysics, and highest precision measurements for symmetry studies toward the CKM-matrix unitarity.

3. **SNOLAB:** TRIUMF contributed to the original SNO experiment and is presently contributing to the EXO, DEAP, HALO, and SNO+ experiments at SNOLAB. TRIUMF has two scientists working on SNOLAB experiments and supports one SNOLAB experimentalist located at Carleton University

4. **T2K:** TRIUMF plays a lead role in the T2K project. The off-axis neutrino beam design, now used for the NOVA experiment at Fermilab, originated at TRIUMF. TRIUMF played a lead role in its implementation in Japan. At the peak of construction there were 22 TRIUMF FTEs working on the project. TRIUMF led the Canadian effort to build and operate the major part of the near-detector tracker system (Fine Grained Detector and Time Projection Chambers) and is currently hosting one of two primary centres for data distribution and analysis. TRIUMF also made a significant contribution to the neutrino beam line, namely the service cell in the target station consisting of the shielding walls, shielding windows and master-slave manipulator system for handling active components and the remote handling system and support structure of the final focus beam monitor.

5. **ILC:** TRIUMF's flagship initiative for 2010-2015 and beyond is the ARIEL project which includes a high-power superconducting-RF electron linear accelerator designed to use ILC technologies. The ARIEL project will build Canadian scientific, technical, and industrial competency in this core technology underpinning the ILC and position Canada for a pivotal role in the global project. One TRIUMF scientist (M. Dixit located at Carleton) has been dedicated to ILC detector development. Another scientist (D. Karlen, joint UVic - TRIUMF) has also been involved in ILC detector development, building on work with the T2K experiment. The TRIUMF Director is a member of the U.S. ILC Steering Committee along with D. Karlen.

6. **Small projects:** As part of its commitment to a broad portfolio of scientific discovery and innovation, TRIUMF continues to support a number of smaller projects including QWeak at JLab and the ALPHA project at CERN. The G0 experiment at JLAB, which received significant TRIUMF support, was completed. The TWIST experiment was

completed, resulting in an order of magnitude reduction in the muon decay parameter uncertainties, and corresponding restrictions on the Lorentz structure of the weak interaction. The PIENU experiment, which tests the universality of the weak couplings, has been commissioned and is now taking data.

7. **Theory:** TRIUMF will maintain a strong theory group to support the efforts in subatomic physics theory across Canada. The group has increased from four to five permanent members. This growth includes the hiring of three new members after two had left. The hires were focused on the two highest priority areas (LHC - 1 hire, ISAC - 2 hires) and align the theory group more strongly with the community priorities.

| NRC Deliverable | TRIUMF Completion |
|---|---|
| Completion of 20 medium beta accelerator cavities by the March 31, 2007 | All 20 cavities were completed early in 2006. |
| Completion of 20 high beta accelerator cavities by March 31, 2010 | All 20 cavities were completed and installed by March 31, 2010. Commissioning was completed in April, 2010 and the first RIB delivered to an experiment in May 2010. |
| Completion of the accelerator cooling system by March 31, 2009 | Cooling system was fully installed, tested and commissioned by early 2008. |
| Commission one experimental location to provide unique exotic isotope beams to approved high profile experiments by March 31, 2007 | The MAYA detector was installed on SEBT2 in fall 2006 and a successful experiment was performed in Jan., 2007. |
| Commission 3 experimental locations to provide unique exotic isotope beams to approved high profile experiments by March 31, 2010. | The 3 experimental locations are:<br>• SEBT2 – MAYA detector installed and ran an experiment in Jan. 2007<br>• SEBT3A – TIGRESS ran an experiment in August 2007<br>• SEBT1 – TUDA was moved to ISAC-II in Dec 2008. The first experiment was carried out in Spring 2009.<br>SEBT1 in being extended in 2010 to provide a location for HERACLES<br>SEBT3B – for EMMA is scheduled for completion in 2011. |

*Table 1: Updated Table from the Five-Year Plan book showing the deliverables from the 2005-2010 TRIUMF five-year plan and what was delivered.*

## 2) How is TRIUMF positioned in the international context, particularly your strengths and weaknesses when compared to similar institutions in other countries? Related to that, how does the science at TRIUMF fit into international subatomic physics priorities?

The international community prioritizes subatomic physics in three areas: accelerator particle physics, non-accelerator (e.g. underground) particle physics, and nuclear physics.

In nuclear physics there is a world-wide consensus on the burning questions and priorities. TRIUMF is well positioned to play a major role in discovery and exploitation in the field of rare-isotope nuclear physics with its on-site ISAC program. In terms of contributions to high-energy nuclear physics experiments outside Canada, the community made several strategic decisions regarding RHIC and the LHC ALICE; TRIUMF and the Canadian subatomic physics community have decided to maintain strong niche contributions in the hadronic structure and symmetry program at J-Lab.

TRIUMF-ISAC is a world class first generation production and post-acceleration facility and is the leading ISOL-based facility in North America. First-generation rare-isotope beam facilities are presently operating in Europe, North America, and Asia and several laboratories are undertaking significant upgrades to prepare second-generation facilities. The first-generation facilities continue to produce important results, and ambitious experiments are planned with them in the next few years. However, the second-generation facilities, such as FAIR (Facility for Anti-proton and Ion Research, anticipated operation 2018) a European facility in Germany, the RIKEN RIB-F (Radioactive Ion

Beam Factory, operational in part since 2007) in Japan, FRIB (Facility for Rare Isotope Beams, expected operation 2018) in the US, and ISAC with the ARIEL facility, are where major breakthroughs in nuclear physics are expected . These discoveries are anticipated to significantly increase our fundamental understanding of atomic nuclei structure as well as clarify the location and details of the formation of the chemical elements heavier than iron in the Universe.

All operating first generation as well as the operational and planned 2nd generation facilities are single user facilities, including ISAC. This presents a major limitation for scientific output, as well as a mismatch in the investment in the highly specialized experimental devices versus their access to beam. ISAC will be the first facility to overcome this problem with the ARIEL project. ARIEL will add a second production line to the RIB operation, which is not only independent of the TRIUMF cyclotron and can run up to12 months per year, but will also provide, due to a different production mechanism, access to a completely different set of rare isotopes than with the existing proton based approach. This represents a major and unique step forward, keeping TRIUMF at the forefront of RIB physics.

In the realm of particle physics, TRIUMF contributes to Canadian global leadership through its support of the ATLAS program. Accelerator expertise is provided on a regular basis to improve the operations of the LHC machine, TRIUMF scientists are working on the ATLAS detector and its upgrades, and the Tier-1 Data Centre at TRIUMF provides "first-hand" access to the data coming from the ATLAS experiment.

TRIUMF's support of dark matter searches at SNOLAB provides world-leading experimental capabilities. TRIUMF's initiatives in superconducting radio-frequency accelerator technology ensure that whatever global accelerator is chosen next to explore the energy frontier will involve Canada at a substantive and leadership level.

Furthermore, TRIUMF's skills and capabilities are a key asset for consideration in negotiations with CERN about Canada's potential future role as a pioneering associate member.

TRIUMF's overall scientific program is becoming well defined and coherent. The 5-year plan was always intended to be a ten-year vision and TRIUMF's broad funding support has allowed the initial components of the plan to realized. TRIUMF has one chief concern beyond the obvious ever-present concern about overall availability of funding. Managing an effective program within tight resource constraints is a challenge and the laboratory management is developing the tools to manage these large efforts effectively. Commitment will be required to stay focused on existing subatomic physics activities while executing the non-subatomic physics components of the 5-year plan and remaining open to emerging new opportunities in nuclear medicine and commercialization. The present outlook for the rest of this 5-year plan suggests that TRIUMF will not be able to be involved in major new subatomic physics projects outside of those already partially or fully funded.

**3) What are the priorities of TRIUMF in support of subatomic physics research for the next 5 years?**

The priorities for the next five years are given in the Schedule C of the NRC Contribution Agreement which is signed by the Presidents of eleven of Canada's premier research institutions. The three points relevant for subatomic physics are:

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

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

3) For the Advanced Rare IsotopE Laboratory supported by multiple agencies and partners, TRIUMF will meet the following milestones:
    a. Fabrication and assembly of the first Injector Cryomodule and a 30 kW beam test will be completed by March 31, 2012.
    b. Civil construction of the ARIEL-I facility will be complete by March 31, 2013.
    c. Installed in the Proton Hall, the e-linac will deliver low-current beams at 25 MeV by March 31, 2014.
    d. Electron beams at 25 MeV, 100 kW will be delivered by March 31, 2015.

**4) Do TRIUMF's plans anticipate significant new activities or infrastructure for subatomic physics on the horizon on the 5-10 year time frame?**

Phase II of the ARIEL project includes: 1) increasing the e-linac energy up to 49 MeV at 500 kW beam power 2) fabrication of a two-stage target system: a photo-converter to produce gammas; followed by a uranium-carbide target producing neutron-rich isotopes via photo-fission 3) building a second 500 MeV proton beam line and target station, and 4) completing the front-end mass separators and beam lines. The process to prepare for funding for these upgrades will begin in 2012/2013. It is expected that by the end of 2020 there will be three independent beams to the experimental halls, thereby tripling the scientific throughput---the present source in ISAC-I and in the ARIEL facility, a new photo-fission source using the e-linac and a new proton beam. This combination will allow the suite of detectors in ISAC to be fully utilized. While TRIUMF already has a comprehensive suite of modern sophisticated detectors for ISAC there will be a need for incremental upgrades. At this time, CINP has not identified any new major experimental facility for ISAC in the 2015-2020 timescale.

TRIUMF is preparing to fully exploit the planned new proton beam line and actinide target system to make possible a world leading program in testing fundamental symmetries. This beam line will make possible measurements of time-reversal violating electric moments, like the Schiff moment of the nucleus with radon-223, and the electric dipole moment (EDM) of the electron with francium. In addition, a new secondary beam line in the meson hall is being reviewed to host a planned EDM experiment of the neutron using an ultra-cold neutron (UCN) source. The UCN project aims to improve the neutron EDM sensitivity by two orders of magnitude. The UCN facility could also play a role in other fundamental physics

experiments, such as neutron life time, beta decay asymmetry, and the quantization of gravitational potential.

IPP has presented its view of particle physics for the 2015-2020 timescale. TRIUMF will work with IPP and the particle physics community to implement the plan that is being developed. The clear priorities at TRIUMF will be ATLAS and T2K data taking and analysis, in firm alignment with the Canadian research community's agenda. The majority of researchers will continue in their present programs for the foreseeable future and are already making commitments to upgrading ATLAS and T2K which will be essential to maximize the physics output as luminosity and intensity increase. These upgrades have long lead times, often several years, and so the work is beginning now.

Additional yet to be funded projects such as the SuperB project in Italy, or on a longer time scale the ILC, will depend on the community interest and the time frame for the development of these projects.

**5) What strengths/weaknesses do you see with respect to subatomic physics research in Canada (e.g., demographics, funding, governance, etc.)?**

The Canadian subatomic physics community is small but one of the strongest and best supported in the world. Nevertheless, investment in this field worldwide is growing, especially in the developing countries. China is building two new major RIB facilities and Korea has also just announced plans to build a new RIB facility. The competition is fierce. The next major high energy particle accelerator may be built in Asia.

Consequently there are critical challenges facing the Canadian subatomic-physics research community in addition to the long-standing issue of identifying ongoing support for the operations of the major science facilities and infrastructure such as TRIUMF and SNOLAB. TRIUMF fares well through its established five-year plan process but operational funding has been flat at a time when capital project expansion is needed to stay ahead of the competition. At present, capital funding is competed for through CFI and NSERC but operating funds are much more difficult to secure; this creates a funding gap when new facilities are ready but no long-term commitments to operate them are being made.

Another challenge is the strength of nuclear physics in the university system. A TRIUMF Board of Management Task force was convened to address this question. The recommendations were accepted by the Board, with the highest priorities being given to increasing the numbers of joint TRIUMF/university faculty positions in nuclear physics, experimental and theory, in existing groups and seeding new groups at key research universities. In the present funding environment, where TRIUMF is reducing staff, this is not possible.

In the new "flat world," Canada will need to continually select the areas where it chooses to compete and where it chooses to collaborate. In the energy frontier of particle physics, Canada is clearly best served by choosing to collaborate as no single country can afford to host the facilities necessary to explore this frontier. In certain areas of the intensity frontier,

Canada can choose to compete with the world: in neutrino physics, Canada is joining forces with Japan to compete with a potential U.S. project, and in particle-astrophysics, SNOLAB could offer a uniquely Canadian advantage in dark-matter searches. We feel that this balance of competition versus collaboration across national borders will become increasingly important in the next 5-10 years.

Another aspect of this growing frontier is the field of advanced accelerator science and technology. The U.S. has identified accelerator science and technology as an area of key strategic national interest (cf. *Accelerators for America's Future* report which features at least two Canadian technologies). How will Canada address this emerging field which has strategic value?

**6) Are there any other comments you wish to make about TRIUMF and its support of subatomic research in Canada?**

Although its operating funds come primarily from NRC, TRIUMF is not a federal-government laboratory but rather is owned and operated by a consortium of universities. Thus it and its scientists are full members of the Canadian academic subatomic physics community. It works with the community in carrying out research, in developing the NSERC sponsored community plan for subatomic physics and in helping to implement the recommendations. TRIUMF's priorities closely mirror the community recommendations and as we have shown above our activities are in accord with them. TRIUMF BAEs are NSERC grant eligible and this helps maintain the close ties between TRIUMF and the rest of the academic research community.

TRIUMF has provided its detector design, construction and testing capabilities to the subatomic research community. It is also providing major analysis infrastructure and support through the ATLAS Tier-1 Data Centre and some of the T2K computing infrastructure. Two other critical elements are the national support for communication network (provided by Canarie ) and large scale computing centres provided by CFI. Continuing operating support for these two national infrastructures will remain essential to the subatomic research effort.

In the past TRIUMF has supplied some technical services to the community without charge. These include the design office and machine shop. The current TRIUMF budget shortfall and an effort to make technical resources unique to TRIUMF more widely available has lead TRIUMF to propose back charging for these resources. These charges would then have to be covered by the NSERC grants of both TRIUMF and non-TRIUMF users.

A large part of the Canadian subatomic physics program (accelerator-based HEP, and NP) relies heavily on the advancement of accelerator science and technology. This critical field is becoming increasingly more sophisticated and requires investment in development, test facilities, and educating the next generation of accelerator physicists. Therefore accelerator R&D must be supported if Canadian subatomic physics is to stay competitive on the world scene. TRIUMF is developing a program of research and education in accelerator science and technology. This initiative involves the offering of graduate-level accelerator-science courses in conjunction with UBC and University of Victoria and the training of graduate

students and post-doctoral fellows. The research program will require support and the scientists involved are applying to NSERC for funding. The accelerator work at TRIUMF is directed primarily toward subatomic physics. Accelerator physics also plays a role in medical accelerator and materials science programs (e.g., βNMR/NQR, μSR and synchrotron radiation).

The Long-Range Plan process is an excellent approach to identifying the emerging scientific thrusts that hold the promise of leadership and impact. We gratefully acknowledge the pivotal role that this process plays in the governance of the field and thank NSERC for its continued patience with and attention to this process.

We hope these comments have been helpful. Please follow up with us if you have additional questions. We appreciate the challenge your committee faces and look forward to the future you will map out for Canada.

Sincerely,

Nigel S. Lockyer
Director
TRIUMF – Accelerating Science for Canada