Memorandum

Date: December 1, 2010

To: Members of the Canadian subatomic physics community

From: Samir Boughaba
Team Leader, Physics and Astronomy

Subject: Update on the Long Range Plan process for Canadian subatomic physics: 2011-2016

This is to provide you with an update on the Long Range Plan process for Canadian subatomic physics:

- The Long Range Plan Committee (LRPC) met on November 28-29, 2010 in Toronto. A substantial part of the meeting was dedicated to the presentation of the briefs prepared by the Canadian Institute of Nuclear Physics (CINP – www.cinp.ca) and the Institute of Particle Physics (IPP – www.ipp.ca/about/lrp_briefs.shtml). The LRPC held discussions on the briefs, as well as on the input received from national and international research organizations (Perimeter Institute, SNOLAB, TRIUMF, CERN, JLAB, and JPARC), with the primary objective of identifying any additional information that should be requested from the community, the CINP, the IPP, and other organizations. The current plans and major research endeavours outside Canada, in particle physics and nuclear physics, were also discussed. Moreover, the LRPC reviewed preliminary data on the evolution of the community's demographics, as well as various mechanisms and programs that provide financial support to the research undertaken by the Canadian subatomic physics community.

- The LRPC was surprised by the lack of responses received from the community regarding the briefs prepared by the CINP and the IPP. On this basis, the LRPC has decided to extend the deadline for submitting such responses to **December 22, 2010**, and it strongly encourages the members of the community to contribute to this important consultation process. It is important to note that responses to the briefs should not be updates on the status of specific research projects, but rather contributions to the discussion on the scientific priorities and the look ahead presented in the briefs (disagreement with assessments or recommendations, perceived misrepresentation, issue of interest to the entire community not discussed, etc.). Members of the community should be aware that, normally, their comments will be circulated to the full LRPC, including the *ex officio* members. However, if a community member wishes, they can request that their identity be revealed only to active LRPC members (i.e., not to the *ex officio* members). In that circumstance, it would be important for the contributor to not identify themselves through their comments. Responses to the briefs are to be submitted to NSERC.

- The national laboratories have formally agreed to the publication of the contributions they submitted in response to an explicit request from the LRPC. You will find the request and the contributions as appendices.

- The dates and locations of the two town hall meetings are:
  - January 12, 2011 – University of British Columbia; St. John’s College (Social Lounge); Vancouver (BC);
  - January 14, 2011 – Delta Montreal Hotel (Opus 2 Salon, Mezzanine Level); Montreal (QC).

- Both town hall meetings will have the same format. Each meeting will cover all subatomic physics sub-disciplines and allow for the presentation and discussion of the two briefs and the responses received. Our objective is that each meeting will provide an open forum for the members of the community to interact with the LRPC and actively contribute to this important process. Each town hall meeting will start at 9:00 am and will extend up to late afternoon.

- Additional information (including the agenda) on the town hall meetings will be provided to the community in early January.

We wish you continuous success in your research endeavours.

<u>APPENDIX 1</u>

Template of LRPC's Request for Information

The Canadian subatomic physics community is engaged in a long-range planning exercise under NSERC's aegis. This planning process will be based on extensive consultations with the Canadian subatomic physics community. It is also essential for the long-range planning committee to consider the role played by major national laboratories and institutes, take into account their planned activities, and understand the constraints and challenges they face.

To that end, we would be grateful if you could provide information to the long-range planning committee on the following issues. Some of the answers may be factually straightforward, but you may wish to make additional comments that add perspective to the factual answer.

- Over the last five years (2006-present), to what extent did the subatomic research activities at [Name of Laboratory] align with the last subatomic physics long-range plan?
- How is [Name of Laboratory] 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 [Name of Laboratory] fit into international subatomic physics priorities?
- What are the priorities of [Name of Laboratory] in support of subatomic physics research for the next five years?
- Do [Name of Laboratory]'s plans anticipate significant new activities or infrastructure for subatomic physics on the horizon on the 5-10 year time frame?
- What strengths/weaknesses do you see with respect to subatomic physics research in Canada (e.g., demographics, funding, governance, etc.)?
- Are there any other comments you wish to make about [Name of Laboratory] and its support of subatomic research in Canada?

APPENDIX 2

Response of the Perimeter Institute for Theoretical Physics

PERIMETER INSTITUTE
FOR THEORETICAL PHYSICS

September 27, 2010

Dear Members of the LRP Committee:

I am writing in response to your request to provide information about the Perimeter Institute's past activity in and future plans for research in subatomic physics.

Perimeter Institute for Theoretical Physics is an independent research centre dedicated to the study of fundamental issues in our understanding of the physical universe. As such, subatomic physics, the study of the most fundamental constituents of matter, lies at the core of our research mandate. Of course, progress in subatomic physics requires experimental advances requiring substantial investments in accelerators and detectors. Hence the last subatomic physics long-range plan focused primarily on recommendations for the support of various experimental efforts. However, theoretical physics plays an essential supporting role in subatomic physics, with exceptional cost-effectiveness. The ideas emerging from theoretical physics help motivate major international experiments in subatomic physics, such as the LHC or SNO, and guide the interpretation of their results.

Perimeter has been actively engaged in theoretical subatomic physics since research operations began here in 2001, and I expect that our activities in this field will only increase in the future. In the past five years, our most active research areas relevant for subatomic physics were string theory, quantum gravity and early universe cosmology. However, more traditional particle phenomenology was also represented by two associate (i.e., part-time) faculty members. In 2006, Perimeter had five full-time faculty and four associate faculty whose research focus was in subatomic physics. Today, these numbers have expanded to ten full-time faculty and four associates. These numbers will continue to increase over the next five years. PI's five-year plan calls for an expansion to a total of 25 Faculty members and 25 Associates (from today's totals of 14 Faculty and 11 Associates). This plan does not envisage a specific breakdown by discipline, as PI's primary focus remains on hiring at the highest international caliber, and the institute must remain flexible to capitalize on outstanding recruitment opportunities as they arise. In this direction, I might add that the institute is now engaging donors to create five new endowed "super-Chairs" at PI. At present, two of these chairs are funded. Our challenge with these and the future chairs will be to recruit eminent senior researchers of the very highest standing in their respective fields. While again no specific fields have been proscribed, it is very likely that several of these chairs will go to researchers in subatomic physics.

Here, I might also add that PI has recently established a program of Distinguished Research Chairs. With this program, we are making PI a "second research home" for

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many of the world's leading theoretical physicists. Currently we have 20 DRCs, including Nima Arkani-Hamed, Gia Dvali, Stephen Hawking and Mark Wise, spending a month or two at Perimeter each year. This program will soon expand to a steady state of 30 such visiting chairs.

Let me outline some of the other research-related programs which have been running at PI over the past five years and which will continue into the future. Perimeter hosts an active program of workshops and conferences every year. These meetings range from small informal meetings to large international conferences. An example of the former is a new series of informal PI-ATLAS workshops which began in the fall of 2009. These one-day meetings held once per semester gather experimental and theoretical particle physicists from Perimeter, Toronto and the local region to discuss new physics opportunities at the LHC. At the other end of the spectrum, PI has hosted major international meetings, such as PASCOS '08 in June of 2008. This was the fourteenth in a series of interdisciplinary symposia on the interface of particle physics, string theory and cosmology and the first that was held in Canada. Perimeter also provides some funding to sponsor significant physics meetings being held at other locations throughout Canada. Examples of such sponsorships include the 2010 edition of the Lake Louise Winter Institute and Strings 05 held at the University of Toronto. As can be seen from the above examples, many of PI's conferences and sponsorships are directly relevant for subatomic physics.

As part of our research activities, Perimeter has established a successful record in the training of highly qualified personnel with both postdoctoral researchers and graduate students.[1] Today, PI is home to 42 postdoctoral fellows and 27 Phd students. These numbers have been growing slowly over the past five years, and I expect this growth will continue. PI's five-year plan calls for growth in the number of postdocs to between 45 and 50, while the number of PhD students is planned to grow to approximately 75. I might add that these two groups already form the two largest constituencies of researchers at Perimeter, and they have always played and will continue to play an essential role in establishing the vital and dynamic research environment at the institute.

Perimeter has also initiated an exciting new graduate program, Perimeter Scholars International (PSI), which aspires to be the world's best Masters level program in theoretical physics. PSI students are brought to the cutting edge of research in a ten-month program taught by the world's leading experts. The program was created in partnership with the University of Waterloo, and so PSI graduates receive both a University of Waterloo Masters Degree and a Perimeter Scholars International Diploma. Our first class of 28 students graduated in June of this year, and the second class has just begun with 31 students. We plan to expand this program to accommodate 50 students per year.

[1] Perimeter is not a degree granting institution and so all of the graduate students are enrolled at a nearby university. In conjunction with this, PI's full-time faculty typically have adjunct appointments at nearby universities to facilitate their supervision of graduate students.

With regards to infrastructure, construction is currently underway of the *Stephen Hawking Centre,* a 55,000 square foot expansion of the existing Perimeter facility. We expect that the new extension will be officially opened in the fall of 2011. As with the existing Perimeter building, we are committed to creating the world's best environment for theoretical physics research.

Let me comment on the observation that the areas of subatomic theory represented at the Perimeter Institute are weighted towards the formal end of this subject. First I believe that while such research may seem to some more like elegant mathematics, progress in these fields frequently leads to important applications. Amongst the areas where I believe Perimeter is now emerging as a world leader is quantum field theory. The powerful techniques developed in this area reach out to all areas of theoretical physics. An exciting illustration of these spin-offs at Perimeter can be found in the work of Freddy Cachazo. Several years ago, he began with the goal of developing a better understanding of "twistor string theory." This research program has now led to powerful new techniques for calculating scattering amplitudes, including those commonly used in calculation of Standard Model backgrounds at the LHC.

Looking to Perimeter's future recruitment, we are making more concerted efforts to recruit individuals with more phenomenological interests in subatomic physics. Of course, talent remains the paramount criterion in PI's recruitment, but it is inevitable that many of the most talented theorists in the world are being drawn to think about the exciting experiments now under way at the LHC. Our two most recent Junior Faculty recruits, Natalia Toro and Philip Schuster, provide an excellent example of this talent, and they already provide PI with their strong ties to CERN and LHC experiments, as well as the experiments they have proposed at JLAB.

I was asked to compare Perimeter with similar institutions in other countries. While I am happy to make such comparisons, I must begin by saying that I believe Perimeter's structure, mandate and ambition make the institute unique on the international stage. In making concrete comparisons, the obvious place to begin is to consider the Institute for Advanced Studies in Princeton. Both institutes are independent institutes focused on resident researchers. However, the activities at the IAS span a much greater range of fields, including subatomic physics, astrophysics, pure mathematics, history and social science. By focusing on theoretical physics, Perimeter can engage in a broader diversity of areas in physics, and I believe the interaction among these areas greatly enhances the possibility of significant advances. Of course, the long history of success and the quality of the researchers at the IAS sets an outstanding example which we aspire to improve on. One strong advantage which the IAS has over Perimeter is its proximity to Princeton University, which again sets a world-class standard that our local partner universities are still striving to attain. However, with the new PSI program, I believe Perimeter is positioned to attract the world's best graduate students in theoretical physics to Canada. I might also make brief comparisons to two new institutes that have been created abroad in the past ten years: the Institute of the Physics and Mathematics of the Universe (IPMU) in Tokyo and the Laboratoire Astroparticule et Cosmologie (APC) in Paris. Again there are numerous similarities between Perimeter and these institutes and a strong overlap in their research mandates. The strongest contrast comes in considering that both the IPMU and APC support programs in both experimental and theoretical physics. While such a partnership of experiment and theory has its natural advantages, supporting experimental programs requires much larger funding, and it was a conscious decision of Perimeter's founders that the greatest cost effectiveness came from focusing investments on theory. As I have emphasized above, however, the institute is committed to engaging with scientists at experimental centres around the world, including the LHC and SNOLab, but also observatories such as the Planck satellite, VISTA, VLT and SKA and gravitational wave detectors such as LIGO and LISA.

At this point, I might also add that Perimeter is developing international partnerships with other theory institutes around the world. For example, we have already established collaboration agreements with the Center for Theoretical Cosmology in Cambridge, the Center for Theoretical Science in Princeton and the Laboratoire Astroparticule et Cosmologie in Paris.

I was asked to comment on strengths/weaknesses with respect to subatomic physics research in Canada. My overall view is that subatomic physics in Canada seems to be in a good state of health and the Canadian community has established a very high profile on the international stage. The recent successes of SNO in solving the solar neutrino puzzle clearly reinforce the view that with judicious investments, Canada can lead the world in an extremely competitive and challenging field. I believe SNOLab will be capable of equally significant successes in advancing our understanding of dark matter. TRIUMF has been and will continue to be an important focal point for Canadian involvement in international experiments, both in the construction of advanced detector components and in computing support with the ATLAS Tier-1 Data Centre. The leadership of the IPP scientists ensures that Canada "gets more bang for our buck" in major particle physics experiments around the world, such as ATLAS and T2K. The generous support of NSERC's Discovery Grants has created a lively and highly regarded theory community across Canada.

As the Director of the Perimeter Institute, I find myself in a unique position worldwide. We are well supported and challenged by our private and public partners to build a truly world-leading centre for theoretical physics. Certainly enormous progress was made towards this goal before my arrival in October 2008, and since then the pace of development has accelerated. We are continually striving for higher levels of research excellence and to create the optimal environment for breakthroughs in theoretical physics.

Let me close by saying that I believe that Perimeter represents a remarkable opportunity for Canada. We are eager to serve as Canada's focal point for foundational physics research and we wish to interact positively with the broader Canadian research community. I might add that in answering your questions, my responses above only cover a part of the activities at Perimeter and our future plans for the institute. Further information can be found in our annual reports and our recent five-year plan, which are

available on Perimeter's website at:
http://www.perimeterinstitute.ca/About/General/About_PI_Overview/.

If I can be of any further assistance in your long-range planning exercise, do not hesitate to contact me. The most efficient manner to do so would be by contacting my office manager, Alexandra Castell, at: acastell@perimeterinstitute.ca.

Sincerely,

Neil Turok
Director

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APPENDIX 3

SNOLAB's Response

SNOLAB submission to

NSERC Sub-atomic Physics Long-Range Planning Committee.

September 2010

Scope

This submission is in response to the request by the Team Leader, Physics and Astronomy, NSERC, in the summer, 2010, to provide information to the committee for the long-range planning exercise in subatomic physics in Canada. The request was in the form of six questions, reproduced below, addressing the science programme and context of SNOLAB as an international facility. As the intended audience for this submission is the long-range planning committee, this document does not include a detailed discussion of the science questions being addressed at SNOLAB, this background knowledge being assumed within this specialised audience. For completeness, and to ensure the committee are appraised of the current status of the facility, a brief overview of the status of SNOLAB is provided.

Overview of status of the SNOLAB facility

SNOLAB has being developed to exploit the opportunities for scientific advance that are only available with a deep underground laboratory. Canada has become an international leader in the rapidly developing fundamental science field of Underground and Astroparticle Physics. Based on the enormous success of the Sudbury Neutrino Observatory, the Canada Foundation for Innovation, FedNor , the Northern Ontario heritage fund and the Ontario Innovation Trust, agreed to provide the construction funds for both an expanded underground laboratory and a supporting surface building.

The SNOLAB facility consists of space underground in which experiments can be mounted, a building on surface to support those experiments, and staff that can operate and maintain the infrastructure and provide support to their operation.

The underground infrastructure is shown in Figure 1. The objective is to provide sufficient space so that a number of experiments can be accommodated, with an expected programme that supports the project lifecycle of prototyping, construction and operation. The major experimental space consists of the existing SNO cavern and support areas, the new large rectangular hall ("Cube Hall") and its support space, the "Cryopit" cavern, engineered to handle experiments with large volumes of cryogens or noxious gasses, and the 'Ladder' labs for medium sized experiments. Basic shared infrastructure underground will include a small chemistry laboratory, background counting facilities and a clean workshop. The background counting facility, currently one large high purity germanium system is being augmented by two new Ge detectors, as well as large-area alpha counting systems and emanation chambers.

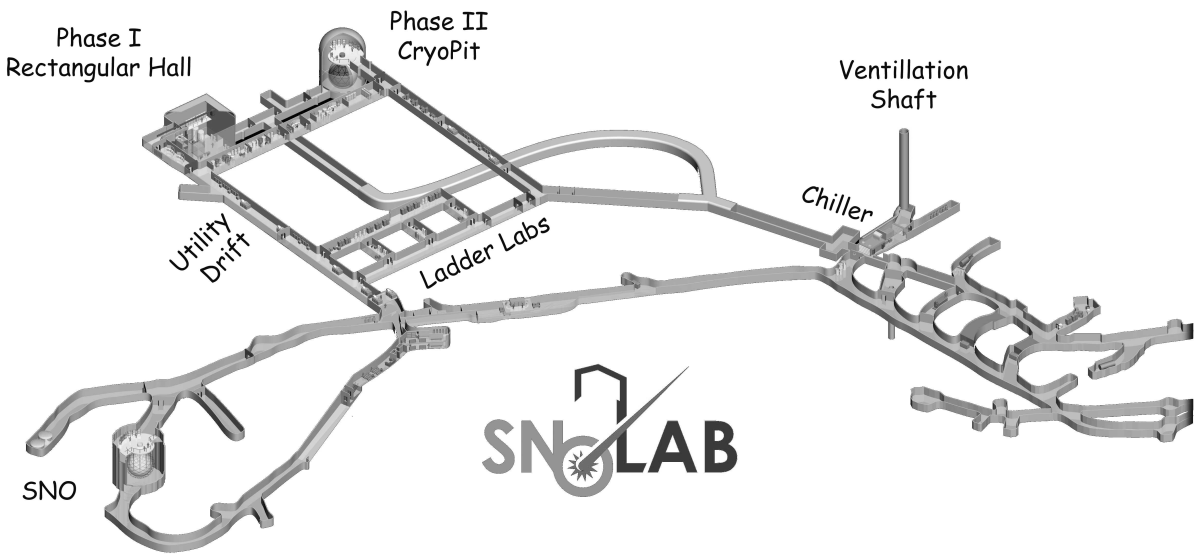

Figure 1. Layout of the SNOLAB Facility.

In contrast to other underground laboratories, the entire space is constructed and operated to be a clean room of about class 2000 through HEPA-filtering of incoming air and careful management and cleaning of materials and personnel. With Class 2000 air quality throughout the laboratory, it will be much easier and more reliable to achieve Class 100 or better in critical spaces required for the next-generation experiments.

The underground infrastructure includes several major systems which need regular operation and maintenance. These include a 330 tonne chiller unit, a 2 MW electrical distribution system, the HVAC system, an ultra-pure water system and a nitrogen cover gas system. It also includes a full sewage treatment plant as well as the more common services such as regular plumbing of lab water, fire protection water, compressed air and instrumentation.

The new surface building includes a 'dry' where personnel, scientists and visitors change into mine gear prior to going underground, a clean assembly area, 4 clean laboratories (Class 2000 or better) of about 1000 square feet each, a low background counting room, office space, control rooms for the underground experiments, an auditorium, several meeting rooms and an IT server room.

Questions raised by the long-range planning committee.

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

The SNOLAB facility has its roots within the Canadian subatomic physics community and the success of the SNO solar neutrino detector, and the research programme at SNOLAB is still dominated by the experimental subatomic physics field. In addition to the facility construction and development, the two main areas of research conducted at SNOLAB are neutrino studies and the direct search for particulate Galactic dark matter. The programme at SNOLAB thus aligns wholly and directly with the recommendations from the previous long-range plan.

Specifically, the previous long-range plan made the following scientific, funding and policy recommendations related to the SNOLAB facility:

Scientific recommendation:

- *completion of the SNOLab facility and development of it into the world's lowest-background laboratory, including participation in a suite of experiments to exploit this unique environment;*

Funding recommendation:

- *Immediate steps must be taken to identify new funds for the operations costs of the new CFI-funded SNOLab facility. With the SNOLab construction nearing completion, the need for these funds is urgent.*

Policy recommendation:

- *A general mechanism should be developed to identify and allocate operations funding as new major capital investments are made.*
- *The NSERC MRS guidelines must be examined closely to ensure that subatomic-physics infrastructure will continue to be eligible for funding, and that infrastructure must be managed in a way that guarantees open access to the broad Canadian subatomic physics community.*

Progress has been made on the policy and funding recommendations from the last long-range plan, with SNOLAB Directorate engaged fully in the dialogue with Industry Canada, CFI and NSERC in moving towards a possible funding model for large scale science infrastructures. The current funding for SNOLAB operations, totalling some $6M/yr, has been derived from both federal (CFI, NERC) and provincial (ORF-RE) sources and is fully secured to end March 2012, contingent on some clarification of governance issues. It is anticipated that by the time the long-range planning committee meets, the longer-term solution for SNOLAB operational funding will be clearer.

The scientific recommendation from the last long-range plan has two components: the completion of the underground facility and the development of a suite of experiments to exploit the unique environment it affords.

On the facility construction, the basic facility infrastructure at SNOLAB has been completed. The surface facility was occupied during September 2005, completion of excavation of the underground facility occurred in May 2008, with a progressive conversion of the underground space to the clean-room status required by the experiment programme. SNOLAB personnel, to provide quality assurance that the facility will achieve the required cleanliness level of Class 2000, or better, undertake this latter phase. This is a major effort, required at the start of occupancy of new areas, but is a required step to minimise future work and contamination of experiments. In parallel with the preparation of the new facility areas, required services, power, ventilation, health and safety, have been deployed, Milestones achieved during the cleaning and outfitting include:

- Commissioning of all major service infrastructures completed during 2008/09, including ventilation, air conditioning, makeup air filtering and cooling, power distribution, waste water and sewage systems. Fire detection installed progressively as new areas opened;
- Conversion to clean status of the refuge and personnel areas in February 2009;
- Conversion to clean status of the Ladder Lab areas in August 2009;
- Conversion to clean status of the Cube Hall areas in February 2010, following construction of the major infrastructure for the DEAP/MiniCLEAN detectors;
- Expected conversion of remaining (Phase II) areas to clean status by April 2011.

Commensurate with the SNOLAB policy of developing these new facility areas whilst providing viable experimental occupancy in parallel, progress has also been significant on the science programme at SNOLAB with substantial implementation support from the SNOLAB facility staff. The main thrust of this programme has been on two fronts: neutrino studies and Galactic dark matter searches, both firmly encapsulated within the scientific objectives of the previous long-range plan, sections 4.8 and 4.2 respectively. A summary of the SNOLAB activities since 2006 is given below, for projects where there is Canadian participation and SNOLAB support:

- **SNO**: (Solar neutrino] The SNO experiment completed data taking in November 2006, with the main liability for SNOLAB, the heavy water in SNO, being returned to AECL by December 2007. The results from the third phase of SNO, using direct detection of neutrons using ^{3}He gas filled counters were published in 2008, with a final low-threshold analysis (LETA) improving statistical errors confirming the previous solar neutrino flux measurements. Many honours have been awarded to the SNO team including the Polyani Prize in 2006, the 2007 Franklin Medal and 2010 Killam Prize;
- **SNO+**: [Neutrinoless Double Beta Decay & Solar/geoneutrinos] This project replaces the heavy water in SNO with Nd-loaded LAB-based liquid scintillator.

This allows a broad range of subatomic physics studies to be performed. Use of Nd-loaded scintillator allows neutrino-less double-beta decay studies to probe the nature of the neutrino and their masses, the study of low energy solar *pep* neutrinos probes new physics in neutrino-matter interactions, the detection of electron antineutrinos from distant nuclear reactors probes oscillation parameters, and potential observation of supernova neutrinos probes both neutrino properties and supernova models. Conversion of the SNO detector to SNO+ is expected to be completed by 2012, with required work on the infrastructure underway at SNOLAB;

- **EXO_Gas**: [Neutrinoless Double Beta Decay] EXO continues to explore the parameters of a possible gaseous xenon double beta decay detector. Studies of Ba++ ion trapping and measurement have been undertaken at the SNOLAB surface facilities, with the construction of a Xenon Electroluminescence Prototype (XEP) at Carleton, expected to be deployed at SNOLAB during 2011.
- **HALO:** [Supernova watch] The HALO detector reuses the SNO NCD neutron counters and 80 tonnes of lead as a supernova neutrino target. Construction of the experiment is well advanced, with the lead matrix complete and NCD testing underway. Expected data taking to start during 2011.
- **MiniCLEAN/DEAP:** [Dark Matter] The DEAP/CLEAN collaboration is developing three detector systems of increasing size for the detection of Dark Matter particles via their interaction with liquid argon. DEAP-1 is a 7kg prototype, MiniCLEAN is a 500 kg detector with a 150 kg fiducial volume and DEAP-3600 a 3.6 tonne liquid argon dark matter search experiment with a 1 tonne fiducial volume. The DEAP-1 prototype has been relocated to SNOLAB from Queen's and has subsequently demonstrated the required level of 10^8 discrimination between nuclear and electronic recoils needed for the larger detector. Construction of the MiniCLEAN and DEAP-3600 detectors is expected to be completed by 2011 and 2012 respectively, with required deck support structure for these detectors already completed in the Cube Hall at SNOLAB.
- **PICASSO:** [Dark Matter] The PICASSO detector focuses on the spin-dependent interaction of dark matter using acoustic pickup of interactions in superheated droplet detectors of C_4F_{10} in a polymerised emulsion. Gamma and alpha rejection is based on the temperature of the detector, the dE/dx required for nucleation and the profile of the acoustic signal. Operational since 2008 with 32 detectors, world-leading limits on the interaction cross-section were set in 2009 using two detectors and 14kg.d exposure on ^{19}F. PICASSO is currently being relocated to the Ladder labs at SNOLAB.
- **SuperCDMS:** [Dark Matter] CDMS is a world-leading spin-independent dark matter experiment, using an array of thirty, 250g, low temperature germanium and silicon cryogenic detectors. Currently operational at the Soudan mine in Minnesota, the final phase of the SuperCDMS project is a 150-200kg target array to be based at SNOLAB. Design of a test facility at SNOLAB, to characterise new detectors before deployment, is underway.

In summary, it can be seen that activities at SNOLAB are firmly embedded within the recommendations and science objectives of the previous long-range plan, both from facility development and experimental programme perspectives.

2. How is SNOLAB 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 SNOLAB fit into the international sub-atomic physics priorities?

SNOLAB is a world-class facility. There are several underground facilities operational around the world, or under development, with a variety of differing characteristics, such as depth, facility area, available space, access mechanisms and backgrounds. At present, SNOLAB is the deepest operational facility with the unique characteristic of operating the entire laboratory as a clean-room. This latter characteristic ensures control of contamination within and between experiments, by minimising the required access points into the facility. The depth of SNOLAB reduces background cosmic ray muons to $0.25/m^2/day$, with commensurate reduction in secondary particle production, a level required for some of the exquisite searches underway such as removal of ^{11}C cosmogenic backgrounds in SNO+. In addition, with the completion of the new experimental areas, SNOLAB is one of the few deep underground sites that has the capacity to host new experiment systems immediately. An example that clearly demonstrates this is the request from the COUPP collaboration to relocate the U.S. COUPP-4 detector from Fermilab to SNOLAB, a relocation completed in summer, 2010.

With huge pressures for space to accommodate new experiments world-wide, there are expansion programs under consideration or construction at shallower sites in Europe and Japan, and several modest new facilities being considered or built around Europe, in India, and in China. In the US, plans for a very large and deep laboratory, DUSEL, are being developed, although the facility will likely only become operational in 2018 or later. Hence for the foreseeable future, SNOLAB will be the premiere facility in the world, and is attracting world-wide interest, as demonstrated by MiniCLEAN, COUPP and SuperCDMS. Both the SuperCDMS and EXO collaborations have held full collaboration meetings at SNOLAB, again illustrating this interest in SNOLAB.

On the international scene, SNOLAB is fully engaged in initiatives to develop and foster collaboration between international facilities and experiments. David Sinclair, SNOLAB Facility Development Director, has chaired Global Science Forum initiatives looking at co-operation between the international facilities, at which the SNOLAB Directorate have participated. SNOLAB hosts a Facility Directors web-page at which information is informally exchanged between Directors for presentations and talks. SNOLAB also recently hosted the third international Low Radiation Techniques Workshop, with ~100 delegates, at which results and techniques for low-background assay were discussed and exchanged.

The scientific strengths of SNOLAB lie in the depth and cleanliness of the facility, allowing demonstrable reduction in potential backgrounds to experiments engaged in rare event searches or low cross-section measurements. The flat over-burden of rock due to the vertical access ensures maximal, and uniformity of, shielding. From logistical considerations, the availability of immediate space for experimental programmes, the reduction in operational costs through use of a working mine, the experience and focus of the on-site operational and science teams and support for world-class ancillary low-background measurements and assays are all significant strengths for the Canadian and international underground and subatomic physics communities.

From a scientific perspective, the SNOLAB facility currently focuses on medium scale subatomic physics experiments, up to the order of kilo-tonne of target, rather than the very large mega-tonne scale detector systems under consideration for long-baseline neutrino studies. Although not a weakness, *per se,* as this is a deliberate focus, it does limit the scale of the potential project that SNOLAB can currently host. From a logistical perspective the vertical access limits the size of objects that can be delivered to SNOLAB, although this is a well-understood issue and the SNOLAB engineering design team have significant expertise in ensuring experiments can be deployed underground to mitigate against this limitation. The location at a working mine may be perceived to be a weakness, with potential access restrictions or competition against production – however, the recent year-long strike at Vale, during which SNOLAB operations were not hampered as both union and company recognised the third-party, and high profile work that we do, illustrates that this is not an issue.

The science programme at SNOLAB also aligns with international prioritisation exercises for the sub-atomic physics community. The core themes of neutrino studies and direct dark matter searches are two of the key questions being raised within experimental programmes world-wide, as both shed knowledge onto sub-atomic physics, but also onto a wider arena such as cosmology and astronomy. Understanding these two issues will such resolve fundamental questions as the evolution, composition and matter dominance of the Universe, as well as probing new theories of subatomic particles and physics beyond the Standard Model. Whenever scientific roadmaps have been generated, such as the ASPERA/ApPEC European roadmap and the U.S. P5 strategic plan, these two fields are always viewed as critical priorities. As a more parochial example, the recent HEPAP requested PASAG review in the U.S. has the "SuperCDMS project at SNOLAB" listed in all funding scenarios as a priority.

3. What are the priorities of SNOLAB in support of subatomic physics research for the next five years?

The priorities at SNOLAB over the next five years are support for the deployment and operation of the initial suite of neutrino and dark-matter experiments and the completion of the Phase-II development of the facility. The main focus of the SNOLAB facility will therefore be on the development of experimental projects in subatomic physics. This five-year time-frame includes the construction and operation of the SNO+,

HALO, EXO-XEP, PICASSO-III, DEAP-3600, MiniCLEAN and SuperCDMS detector systems which include Canadian collaborators, and the, COUPP-60 and COBRA detectors as currently non-Canadian projects.

In addition to the direct support and development of experiments, it is anticipated that SNOLAB will be developing capabilities in low background and material assay. The expertise gained in low background measurement techniques during the development of the SNO detector provides SNOLAB with a strong legacy in this technology. The further development of this capability has a natural partner in Sudbury where the Laurentian geology department operates one of the highest sensitivity ICP-MS assay systems for elemental analysis, and so connections are being developed there.

A more detailed timeline of facility and experiment support priorities over the next five years is presented in the following table:

Short term priority (2010-2011)	Operational support for running detectors (DEAP-1, PICASSO, EXO-Gas, low b/ground tests) Completion of Phase-I facility services SNO+ cavity infrastructure (with SNO+) DEAP3600 Cube Hall infrastructure MiniCLEAN Cube Hall infrastructure HALO detector installation EXO-gas support (surface labs) PICASSO-III infrastructure COUPP-4 experiment infrastructure SuperCDMS Test Facility infrastructure DEAP-1 relocation Phase-II clean-room conversion Emergency generator installation (with DEAP)
Medium term priority (2010-2012)	Operational support for running detectors (DEAP-1, HALO, COUPP, PICASSO, low b/ground tests) DEAP3600 experiment Infrastructure MiniCLEAN experiment infrastructure SNO+ experiment infrastructure COUPP-60 experiment infrastructure EXO-XEP experiment infrastructure Relocation of water pre-treatment plant
Long term priority (2011-2015)	Operational support for running detectors (DEAP, SNO+, HALO, PICASSO, COUPP, EXO-Gas, low b/ground tests, MiniCLEAN, DEAP-3600) SuperCDMS experiment infrastructure Completion of Phase-II services Refurbishment of SNO areas Development of ICP-MS and other low background capabilities

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

The experimental research at any facility is an evolving programme, which reacts to the physics requirements of the fields supported. SNOLAB is no different, and the experimental programme will evolve as determined by the current generation of underground and astro-particle experiments. What is clear is that there will continue to be a need for a deep, clean, underground laboratory in which to conduct these future generation experiments to mitigate against potential background radiations.

On the five to ten year timescale the areas of neutrino studies and direct dark matter searches will continue to be a vibrant area of research with exciting potential for discovery and deeper understanding of our Universe. On this timescale it is anticipated that the direct dark matter experiments will be probing the parameter space currently favoured by theoretical models and current constraints. Larger mass targets, with different target materials, will be required to fully explore the physics of the dark matter particles, especially to constrain the particle physics models that may be used to predict such particles. The neutrinoless double beta decay projects will continue to require greater sensitivity to probe the mass range and nature of the neutrino, especially if the normal hierarchy of neutrino flavours is favoured. Accordingly the expectation is that more massive detector systems will be anticipated, potentially to kilo-tonnes of isotope, in the next generation system. SNOLAB will be ideally placed to support these kilo-tonne scale projects, through deployment in both the Cryopit and the Cube Hall, following completion of the DEAP and MiniCLEAN projects.

The operational planning for SNOLAB on the five to ten year timescale is thus that there will be a continuation of the neutrino and dark-matter experimental programmes, with an expectation that detector systems at the kilo-tonne target scale in both fields will be developed by the Canadian and international underground physics community and be deployed at SNOLAB. This fits with the international perspective, an example being the definition of the US dark matter scenario plans by the DUSEL working group, with an evolution to 'third-generation' detector systems. As an illustration of this planning, the Cryopit has been constructed with the ability to vent a large quantity of cryogenic fluid or high pressure gas, such as xenon or argon, without compromising health and safety, such that it could host a large-scale EXO-type detector.

The nuclear astrophysics community has expressed some informal interest in SNOLAB as a potential site for the development of a low energy accelerator based programme to study cross sections relevant to stellar processes. Surface based measurements on some key processes are dominated by cosmogenic induced backgrounds that limit the energy threshold to above the Gamow peak, requiring extrapolation into the region of interest. This field has been pioneered by the LUNA experiment at Gran Sasso, yet additional capability may be required as these measurements take many months. Although embryonic, this interest will be explored as being of potential benefit to the subatomic community.

The development of the SNOLAB facility infrastructure itself and provision of additional caverns will depend strongly on the scientific development of the field and on the availability of similar deep locations internationally. Whereas it is unlikely that additional caverns would be proposed in the next five years (except perhaps for a radiation isolated underground accelerator facility), such expansion might be considered on a longer time scale for initiation.

On the timescale of five to ten years, the support capabilities of SNOLAB should also be augmented through the provision of additional low background assay techniques. Specifically, the development of high sensitivity ICP-MS and alpha-beta counting systems to allow radio-isotopic assay of materials used in detector construction.

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

The success of SNO, and the subsequent development of SNOLAB as a leading underground facility, demonstrates that the Canadian subatomic physics capability is world-class. Developments such as these, coupled with significant investment in the Canadian Research Chair programme has allowed Canada to attract significant talent into the scientific, including subatomic physics, community. From a SNOLAB perspective this has been extremely beneficial and important, with 11 of 19 recent faculty hires in the subatomic community being in underground physics. The ability of this community to draw together around core experimental projects has been instrumental in ensuring the success of Canadian subatomic physics. A fundamental strength of the field is thus the ability to attract and retain high calibre researchers, and for these researchers to act coherently.

An additional contributing factor to the success of the subatomic physics community has been the ability to obtain capital funding for new initiatives from the CFI. This has allowed the construction of the SNOLAB facility and the capital funding for the SNO+ and DEAP-3600 experiments, with matching funds derived from provincial grants, which has been crucial in the development of the underground capability within Canada.

However, a key challenge at present, but hopefully rectified during the deliberations of the long-range planning committee, is the uncertainty regarding operational support for large-scale science infrastructures within Canada. As discussed previously, the expectation is that a federal solution will be announced regarding support for, at least, some of the research infrastructures developed with CFI funding. The challenges of developing the operational funding for SNOLAB have also illustrated the need for consistent and constant dialogue between the various federal and provincial funding agencies to ensure that benefit from such investments is maximised.

It is essential that the bulk of the ~$6M operational support for SNOLAB is not derived from the NSERC SAP envelope, to ensure that a vibrant experimental programme may be maintained, alongside the operation of the facility. Clearly, ensuring that facility funding is appropriate and aligned with community priorities is required, but this tensioning may be generated through alternative means rather than a financial constraint.

The support that has been provided by TRIUMF for the development of the experimental programme at SNOLAB has been extremely welcome, with significant contributions to several of the detector systems. It is recognised that the recent 'flat funding' provided for TRIUMF places difficult constraints on the laboratory, but continued support for the SNOLAB experiments from TRIUMF is extremely important to their delivery.

6. Are there any other comments you wish to make about SNOLAB and its support of subatomic physics research in Canada?

Related to the challenge of the operational support for large-scale facilities is the eligibility of operational support costs within grants. At present, there are components of the operational costs that are ineligible, with an expectation that they are covered by the host institute, paid through the indirect component of grants. As SNOLAB is ineligible for such indirects and some of the sources of operating funding such as CFI do not provide indirect funding, it would be beneficial to either provide the indirect funding or remove the ineligibity of the expenses for direct funding.

SNOLAB operation costs are based on the 'free at the point of access' model that is ubiquitous within international large-scale research facilities. This model is one that has been reviewed and ratified within the IUPAP (International Union on Pure and Applied Physics) as recommendations for use of major physics facilities, adopted during 1996. The model is also reviewed, and endorsed, within reviews of access models by the OECD and the Global Science Forum in 1998, 2003 and 2008, where obstacles to international co-operation and access were studied, especially within nuclear physics.

In this model the host country supports the costs of operating the facility, allowing free and open peer-reviewed access to the best research wishing to utilise the facility, irrespective of national origin. The host nation therefore covers the fixed costs of the facility, whilst the international science community (including researchers from the host nation, of course) covers the costs of the experiments conducted within the facility. The benefits of this model to the host nation are two fold:

a) quid pro quo access to similar facilities world-wide. As the free, open, access model is adopted throughout the international research community for medium scale international research facilities (as opposed to national or 'mega-science' (e.g. CERN) scale), it provides a mechanism to allow Canadian researchers access to other facilities without the requirement for access charges. This allows Canadian researchers the ability to utilise the best, and most appropriate, research tools world-wide, without multiple and complex charging mechanisms for access. A recent review commissioned by the U.S. APS illustrates the benefits and synergies of this model within the X-ray and neutron scattering communities.

b) leverage and benefit to the host nation and locality, both economical and reputational. Studies by CERN and ESA illustrate that high-tech 'economic utility' is about a factor three, i.e. for each dollar placed in contracts to high-tech engineering and industrial companies, they gained a benefit of factor three in increased turnover or efficiency. In term of overall budget for CERN/ESA this represented a factor of ~1.5 leverage to industry. It is natural that many of these contracts are placed locally at the research facility or within the host nation, and so there is direct leverage from international funding into the Canadian economy. In addition, local services benefit from the influx of researchers into the area.

A more intangible benefit is the promotion of science and engineering within the locality and host nation, for SNOLAB the synergy between our research and the local Science North centre (5000 visitors/week), and the strong international reputation of SNO and SNOLAB, provide inspiration to the next generation of researchers, and a strong flow of highly qualified personnel into research and other areas of the Canadian economy. The accessible and exciting research programme at SNOLAB provides ample opportunity for public outreach, as has been demonstrated by media interest, site visits and external talks.

APPENDIX 4

TRIUMF’s Response

September 30, 2010

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and

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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: • SEBT2 – MAYA detector installed and ran an experiment in Jan. 2007 • SEBT3A – TIGRESS ran an experiment in August 2007 • SEBT1 – TUDA was moved to ISAC-II in Dec 2008. The first experiment was carried out in Spring 2009. SEBT1 in being extended in 2010 to provide a location for HERACLES 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

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

November 26, 2010

Dr. Samir Boughaba
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Dear Samir,

I am writing to make a few general comments concerning the program at TRIUMF that may be of use to the Long Range Planning Committee.

TRIUMF has five areas of research: particle and nuclear physics; materials; nuclear medicine; and accelerator science. The main particle physics program is strong and to a large extent is in an analysis mode, with both ATLAS and T2K. The materials program, which continues to produce important world science class results, is in addition focused on the construction and commissioning of two new beam-lines, M9A and M-20 over the next couple of years and then focusing on data taking and analysis. The nuclear medicine program, albeit small, is having exceptional success in attracting outside funds for high profile projects (for e.g. TRIUMF leads one of the main initiatives in the recent NRCAN competition for Tc-99m production with small medical accelerators). This is an area we are expected to grow modestly.

Given the very strong support of TRIUMF by the Government of Canada through NRC, CFI, and the province of BC, in the present 5-year plan, the main emphasis will be on completion of the ARIEL project phase I, which includes the civil construction and the e-linac. Phase II, not yet funded, will include a target station, frontend mass separator, and an additional proton beam-line from the cyclotron.

I have also emphasized to our research community that performing world class rare isotope beam (RIB) science with ISAC during the ARIEL construction period is essential to maintaining and growing our position in the world as a leading RIB facility.

The laboratory has almost re-aligned itself to tackle the challenges of these new projects and deliver world class science and build ARIEL at the same time. There is great anticipation of good things to come and we are excited about getting on with the job. Although we have raised more funds in this 5-year plan than ever before ($273M), there are challenges around staffing as you are most likely aware. The scientists and staff are being asked for more to meet our goals. Canada and TRIUMF are very fortunate to have such a vital and exciting program with great prospects for the future, but a strong focus is needed to be successful.

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As you look to the future of subatomic physics, I would like to make a few comments. TRIUMF's highest priority is to complete ARIEL, perform world class RIB science with ISAC during the construction period, meet international obligations primarily at CERN and in Japan, and continue to place Canada firmly on the world stage of science.

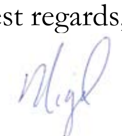
As you may be aware, we are seeking support for the operation of the ATLAS Tier-1 data centre, which was not funded in the 5-year plan but received mention in the Minister's letter where he hoped to find support in the future. Without additional funds, TRIUMF will need to reduce staff. We are committed to supporting the centre under any funding circumstances since ATLAS is such a high profile international project. We are in discussions with CFI and Industry Canada about the path forward since the Tier-1 data centre did not qualify for the new MSI program recently announced by CFI. We fully anticipate your committee will emphasize strong support for ATLAS.

As Director of TRIUMF, my goal is to place Canada and TRIUMF in a world leadership position in subatomic physics. I have begun discussions with Nigel Smith and Neil Turok on how we might work together on these goals. Canada already has a very strong presence in subatomic physics with SNOLAB, Perimeter, and TRIUMF, as well as the university community, and I think our potential is even greater. There are various directions we can pursue. One item on the table now is associate membership at CERN. I think the community should think strategically about this opportunity because the world science arena is changing and we need to be connected. In a recent UK study, they found the number of international papers published versus one nation authored papers has increased significantly in the last ten years. It is not surprising that science continues to ignore borders. Funding such initiatives is a challenge, but we should first decide if it is good for Canada and our science.

Once again, Canada is in a position of strength in subatomic physics. A well thought out plan from your committee will be of great value.

Hope this letter has been helpful.

Best regards,



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