The Subatomic Physics (GSC 19) Submission for the 2002 NSERC Reallocations Exercise

GSC 19 Steering Committee:

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1 A Vision for Canada's Subatomic Physics Program

Subatomic physics seeks to understand the nature and structure of matter at the most fundamental and universal level. As we deepen our knowledge of the origin and evolution of the universe we are led to re-examining our ideas about the very structure of space and time. This field of research represents a fascinating intellectual challenge in which Canadians are fully engaged.

Nature's building blocks, particles called quarks and leptons, are characterized by their interactions via the electromagnetic force, the weak force that governs some types of radioactive decay, and the strong force that binds the quarks into nucleons. A beautifully elegant theoretical model has been developed, wherein all these forces share a common underlying nature while also exhibiting individual characteristics. This Standard Model has been experimentally verified with high precision. Yet many questions are left unanswered. We do not, for instance, understand the origin or pattern of masses of the elementary particles. This is likely tied to the unification of two of the forces into the electroweak force at high energies. The concept of an underlying simplicity drives the search for evidence of further unification, which may have been in play during the extreme conditions at the origin of the universe. At the frontiers of theoretical investigation, superstring theories may provide a way to unify gravity, the force that causes masses to attract, with the quantum description of particles and forces.

While particle physics deals with unearthing a fundamental simplicity, nuclear physics confronts head on the complex many-body systems of protons and neutrons comprising the nucleus. A frontier in nuclear physics is a detailed understanding of the nuclear reactions that fuel the stars and forge the chemical elements.

Canadian subatomic physicists have developed a unique program, successfully integrating the study of nuclear and particle physics. Our experimentalists have been leaders in the large international projects Canada has been involved in and our theory community has made important contributions of both formal and phenomenological work. The program has come about by identifying endeavours of fundamental importance through a process of long range planning. In this context, **the Canadian subatomic physics community has three projects as its highest priorities, in fact, as its highlights.**

ISAC: The Isotope Separator and ACcelerator at the TRIUMF laboratory in Vancouver, now one of the world's most advanced radioactive ion beam sources, will make pioneering measurements of the nuclear processes that govern the forging of the heavier elements in the universe.

SNO: The Sudbury Neutrino Observatory will make definitive measurements of the total number of neutrinos coming from the sun. Neutrinos are weakly interacting particles that are produced in nuclear reactions and travel directly from the sun's core to earth. SNO is focussed on solving the “solar neutrino problem,” the discrepancy between the observed and predicted solar neutrino flux. Considered one of the most important physics questions today, SNO has completed the first phase of three in its quest to unravel this difficult challenge. It is already a Canadian science success story, with the 2001 results producing one of the most highly quoted particle physics papers.

ATLAS: Canadians are part of a global collaboration constructing the ATLAS detector for CERN's Large Hadron Collider. The LHC will be the energy frontier for particle physics by 2006 when studies will begin of the highest energy particle collisions ever produced in a laboratory. One of this experiment's central goals is the discovery of the origin of mass, which the current paradigm associates with the mechanism that differentiates the weak and electromagnetic force (electroweak symmetry breaking) and a new particle called the Higgs boson. However, this experiment will advance our understanding of particle physics on several fronts, including the search for new fundamental particles and possibly even evidence for new phenomena such as extra space-time dimensions.

The adventure of subatomic physics goes well beyond these three projects. We do not understand how it is that our universe seems to be full of matter and devoid of anti-matter. Do other forces or elementary particles exist? What is the nature of “Dark Matter,” which appears to dominate the mass of our universe and determine its ultimate fate? Our community has the expertise and intellectual resources to address these questions. So **the Canadian program includes a balance of other experimental initiatives also of great importance, and wherein we take leadership roles.**

Some of the most fascinating and profound questions in science today lie at the interface of astronomy and physics. These include experimental and theoretical issues that go to the heart of the origin, structure and evolution of the universe, such as the Dark Matter problem and the new concept of “Dark Energy,” both needed to explain our most accurate measurements of the expansion and curvature of the universe. These questions, which capture the imagination of both the scientific community and the general public, lie within the realm of the emerging area of particle astrophysics. In Canada, we have an active and growing community working in this exciting area. This includes those applying particle physics techniques to astrophysical problems as well as experiments that use astronomical phenomena to study questions related to particle physics, most notably SNO. However, the interdisciplinary field of particle astrophysics falls between the jurisdictions of NSERC Grant Selection Committees. **Acknowledging its scientific importance, our community advocates that particle astrophysics be recognized and encouraged as an intrinsic part of the subatomic physics research effort in Canada.**

2 The Strategy

Participation in subatomic physics research is part of Canada’s commitment to the community of advanced nations that value fundamental research. Our strategy to meet this commitment requires support of the vigorous renewal of subatomic physics underway in Canadian universities, with 26 academic appointments in the last 5 years, 14 new appointments being planned for July 2002, and a comparable number expected over the subsequent five years. Subatomic physics requires particle accelerators and detectors of a scale that exist only at national and international laboratories, shared by scientists from many countries collaborating over periods of a decade or more to construct the apparatus and jointly publish the results. Canada hosts two subatomic physics facilities that draw researchers from Canada and around the world: the underground SNO facility, and the TRIUMF laboratory, home of the new ISAC radioactive beam accelerator. As a second element of our strategy, we must continue to support SNO and ISAC as part of our contribution to advancing the field of subatomic physics internationally.

Large, technically challenging international collaborations require careful management and coordination. The Canadian subatomic physics community and NSERC have developed several mechanisms to provide this level of strategic planning. Infrequent but large capital requirements are funded not through the NSERC-wide major-equipment competition, but rather by an “envelope” from which the Subatomic Physics Grant Selection Committee (GSC 19) also funds equipment, infrastructure, and operating support. Experiment operating funds are provided primarily through project grants to groups of researchers from several universities. To provide a focused effort, a community based long-range plan (LRP) has been employed. This reallocation exercise is linked to the third such LRP. It is foremost a scientific plan, identifying our goals and priorities. By focusing on a small number of important projects, Canadian subatomic physics researchers have made visible and essential contributions in multinational collaborations. This selection strikes a balance between properly supporting the highest priority projects and maintaining the intellectual breadth of the Canadian program. The LRP has also identified where we want to be positioned for opportunities in the next decade, carrying forward our strategy of selecting projects where Canadians are able and welcome to take on scientific leadership roles.

International peer review is the primary mechanism for funding projects and researchers; GSC 19 has approximately half its members drawn from the very best of the international subatomic physics community. The continued strategy of a strong peer-review process informed by the LRP provides Canada with the subatomic physics program that has the greatest impact at an international scale. We now see this in the recent scientific successes of two of our high priority projects, ISAC and SNO.

Subatomic physics is technology-intensive, providing opportunities for training in instrumentation, integrated electronics, advanced computation, and data analysis. The tools developed for subatomic research have had important applications in research and industry and have had a major impact on the lives of the general public. Much of medical diagnostic instrumentation is derived from nuclear and particle detector technology. The widespread availability of superconducting magnets for magnetic resonance imaging was made possible by the development of superconducting material and magnet technology for particle accelerators and detectors. Synchrotron radiation and neutron scattering facilities for the physical and life sciences are direct applications of subatomic physics technology. The World Wide Web was originally developed at CERN as a means for subatomic researchers to document and communicate their work. Our program must continue the strategy of supporting R&D of advanced instrumentation.

2.1 The New Subatomic Physics Long Range Plan (2002-06)

The LRP is a scientific plan that lays out funding priorities to assist the GSC in making its recommendations. The "status quo scenario" gives our scientific plans for the case of constant funding. The LRP also identifies the consequences of decreased funding resulting from this reallocation exercise and explores the new opportunities arising with an increase in our resources. In any scenario, subatomic physics research requires detailed attention to the balance between operating funds and planning for capital expenditures. The correct funding balance is critical to ensure our community can maintain its reputation of being reliable collaborators who deliver on our international commitments and provide the intellectual leadership to direct each project to deliver on its scientific objective.

Our present LRP concentrates resources on three highest priority projects, ISAC, SNO and ATLAS. These priorities exist in the context of other important investigations in subatomic physics at the international level. Consequently, the scientific program argued for in our LRP recognizes the need for breadth and to plan for complementary projects in a longer term context. We describe the key elements of the status quo scenario in the LRP, as that forms the basis for our reallocation requests.

ISAC and Nuclear Physics: Nuclear astrophysics is the primary focus of the Canadian program at the new ISAC facility at TRIUMF. ISAC's radioactive ion beams allow the study of key reaction chains which otherwise occur only during explosive nucleosynthesis in stars. Our understanding of the production of heavy elements and of the nuclear structure of very unstable isotopes will be significantly advanced with this facility. ISAC has been specifically designed to measure, for example, the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate that would provide a trigger for the evolution from the hot CNO (Carbon, Nitrogen, Oxygen) cycle to the synthesis of heavier elements such as Ne, Na and Al.

The current stage of ISAC, ISAC-I, is restricted to isotopes with nuclear mass A less than 30 atomic mass units (u) and energies of 1.5 MeV per nucleon. The upgrade to ISAC-II, which will accelerate radioactive ions with A<150 u up to energies of 6 MeV per nucleon, has been approved and funded, with delivery of first beams expected in 2005. The ISAC-II nuclear astrophysics program will be expanded beyond that of ISAC-I with the ability to study both nuclear reaction dynamics and structure under extreme conditions. The beams at ISAC will also be exploited for sensitive tests of physics beyond the Standard Model.

A small number of other important nuclear physics projects are also supported. At TRIUMF, the TWIST experiment will make the world's most precise measurements of muon decay, a probe into possible new weak forces. Canadian nuclear physicists are studying the lack of mirror-symmetry in nature and the detailed properties of the proton at the Thomas Jefferson National Laboratory in the U.S. and are making nuclear mass measurements, which are critical input to other experiments, at Argonne National Laboratory and at CERN.

SNO and the Interface with Astrophysics: The Sudbury Neutrino Observatory has dominated the scientific scene with its first results. SNO is a unique facility consisting of a large acrylic vessel filled with 1000 tons of heavy water, immersed in a much larger light water "shield", all located 2 km underground in the INCO Creighton nickel mine. The heavy water allows the detection of all neutrino types, a unique aspect of this experiment. In its first phase, SNO has measured a total solar neutrino flux in excellent agreement with the prediction of the standard solar model, while also finding a deficit in electron neutrino interactions. The interpretation is that neutrinos transform between different species as they travel from the sun to the earth. Increasingly precise measurement of the parameters of neutrino oscillations continues, with the second phase of the experiment underway.

SNO is just one project bringing together particle and nuclear physics techniques to observe astrophysical phenomena, an area of research known as particle astrophysics. Our LRP advocates that we take on this research area of growing global importance as an integral part of our subatomic physics research program. On the theoretical front, there is an explosion of interest in linking our understanding of the origins and structure of the universe to the nature of its fundamental constituents and their interactions, in the form of superstring cosmology. A small experimental particle astrophysics program in Canada includes a Dark Matter search using a novel Canadian technology, and explorations of the phenomena of very high energy gamma rays. Continuing opportunities at the SNO site are being explored. The International CFI competition has invited a full proposal for the expansion of the SNO laboratory into an International Underground Science Facility.

ATLAS and Particle Physics: At the energy frontier, the ATLAS experiment is our best opportunity to further the understanding of interactions among the elementary particles and for the discovery of phenomena that may exist beyond our current understanding. The Canadian group is designing, prototyping, and constructing key components of the ATLAS detector that measure the energy of particles produced in the collisions at the LHC. This includes the development of advanced electronics which must meet unprecedented radiation hardness standards. The status quo scenario of the LRP has the Canadian group meeting its international commitments with delivery of its contributions on schedule and developing competitive analysis capabilities.

An excellent and well rounded program of particle physics projects balances this top priority effort on ATLAS. Canadian roles in the detailed experimental scrutiny of the Standard Model include the very successful OPAL experiment using high-energy e^+e^- collisions at the LEP collider at CERN and the ZEUS and HERMES experiments at the HERA ep collider in Hamburg, Germany. A key test of our understanding of the asymmetry between matter and antimatter in our universe is the study of CP violation. Canadians have driven the search for the rarest particle decay mode ever measured, with the E787 K decay experiment at Brookhaven. We are also part of the BaBar team at the Stanford Linear Accelerator Center, which has confirmed CP violation in the B system. Canadians have leadership roles at the current energy frontier facility, the Fermilab Tevatron where the top quark was first observed.

Ideas and Technology for the Future: The subatomic physics community has identified in the LRP where it needs to be positioned for the future. Work continues on the development of the Dark Matter search technique. Instrumentation for the nuclear physics program of ISAC II must be developed and constructed. R&D for instrumentation for the future international Linear Collider has begun; this facility has been identified worldwide as the next major initiative beyond the LHC. We are also looking to define Canadian participation in an international accelerator-based second generation experiment to study neutrino oscillations.

Financial Plan: The LRP included the development of a funding model for the next five years. The plan for status quo funding is summarized in Table 1. The funding increases for ISAC, SNO and ATLAS are important elements of this plan. However, support for SNO, for example, remains below the historic level prior to the 1995 NSERC cuts. Further, funding of ISAC science and of SNO is essentially "flat" through the period of this reallocations exercise. The plan allows for only minimal support for particle astrophysics. Operating support is constrained by the size of the envelope and by the need to plan for new initiatives and future capital expenditures. Support for theory does increase, but not even enough to fund our researchers at the pre-1995 levels. Capital funding is projected, primarily for a second generation rare K-decay experiment (KOPIO) and the ISAC-II program, with a small amount set aside for unidentified initiatives.[1]

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
SNO Facility	2,325	2,380	2,400	2,450	2,450	2,500
SNO Operating	1,261	1,261	1,500	1,500	1,500	1,500
ISAC Operating	826	979	1,042	1,060	1,060	1,060
ATLAS Operating	1,325	1,590	2,000	2,200	2,450	2,700
Particle Astrophysics	68	201	200	200	250	250
Theory Support	1,920	1,880	2,100	2,190	2,277	2,277
Other Particle Physics	3,944	3,416	3,495	3,230	3,050	2,975
Other Nuclear Physics	1,893	1,830	1,715	1,625	1,370	1,370
R&D	190	359	374	320	320	320
Infrastructure	1,491	1,508	1,610	1,655	1,700	1,745
Capital	4,398	2,183	2,806	4,240	4,564	5,304
Total	19,641	17,587	19,242	20,670	20,991	22,001

Table 1: The financial summary of the Subatomic Physics Long Range Plan.

2.2 Implementation of the Last Reallocations Exercise

The last reallocations exercise was carried out in a context where our three highest priority projects had large capital needs. Extremely difficult decisions, including the closure of facilities, were made in our 1996-2000 LRP. A five-year spending plan was developed with a profile moving the capital costs of ISAC, SNO and ATLAS instrumentation forward, with the overall envelope being constrained to balance over a five year period. In addition, the capital available for ATLAS only funded approximately half of the originally proposed Canadian contribution. The 1998 Reallocations Committee recognized that the subatomic physics submission emphasized fundamental and important questions in the interrelated areas of nuclear and particle physics. They supported the community's five year plan and its specific proposal to fund new projects and R&D aimed at positioning the Canadian subatomic physics community for the future, with a net reallocations gain of $543K. We have now successfully implemented this plan, and the scientific benefits of this commitment are being realized.

The period of implementing the last reallocations decisions coincides with the milestone of first delivery of radioactive beam at ISAC, completion of SNO and the start of ATLAS detector construction. Recognition of the need for strong and timely support of the ISAC program resulted in the award of

[1] The average operating support in the GSC 19 envelope ($14.121M) is subject to the Reallocation Exercise. This does not include expenditures on capital and infrastructure.

reallocations funds for new detector systems (DRAGON - $227K; 4π positron detector - $163K) along with the associated operating funds. The ISAC scientific program is now underway, with the first experiments using accelerated Na beams producing scientific results. Support of the now fully operational SNO project has allowed the SNO team to obtain their first exciting and definitive measurements of the solar neutrino flux. The SNO results have had an extremely high profile both in the scientific literature and the popular media. It has been possible to expand the scope of the ATLAS project using the additional increases to the envelope during this period. Furthermore, as Canada's annual capital spending for ATLAS have now begun to decline, increased operating funds have been allocated to ATLAS to support installation of the Canadian detector components and the development of physics analysis tools.

Total annual spending on ISAC, SNO, and ATLAS peaked at about $10M in 2000, of which $4.3M was capital.

Funding to develop the next generation of experiments has been extremely limited due to the capital needs of the large high priority projects in the program. Reallocations funding of a few projects with the potential for tremendous future impact has begun to address this need. These include work on KOPIO, development of a novel detection system for Dark Matter (PICASSO), and work associated with the proposed search for states with exotic quantum numbers (TJNAF Hall D). Two projects aimed at a future international Linear Collider have been funded through Reallocations awards. This facility will be the highest priority for particle physics beyond the LHC, with the capability to precisely characterize discoveries made at the LHC. Early participation in this important project is critical for Canadian scientists to make an impact in the future. Total spending in the categories of new projects and R&D committed over the implementation period is approximately $1.1M, well in excess of the Reallocation award for R&D funding. New funding has been crucial in meeting commitments to our national and international collaborations and in making progress towards our scientific goals. Reallocations funds targeted for new initiatives put Canadian subatomic physicists in position to continue their leading roles in this field of research.

3 Specific Proposals

3.1 Support for a Balanced Program

Our top priority experimental projects are all forefront investigations with the highest scientific impact. At the ISAC facility, we have begun to use radioactive beams to explore on Earth conditions that otherwise exist only in extreme astrophysical environments. By the end of the implementation period of this reallocation exercise, SNO will have greatly advanced our understanding of the neutrino sector. At that time, we will launch the investigation of electroweak symmetry breaking and explore possible physics beyond the Standard Model using the ATLAS detector at the LHC. These three priorities reflect investments by Canada ranging from 7 to 15 years in scope, and will ensure Canada's leadership role in subatomic physics at an international level.

The LRP also supports a balanced program of smaller excellent projects along with theoretical investigations. This balance encourages scientific creativity while acknowledging our limited resources. Furthermore, it ensures that we maintain a healthy roster of experiments taking data during the lengthy construction periods of the largest projects. As supported in the last reallocations exercise, our LRP also includes R&D funding for future projects. This support allows us to invest in developing instrumentation with the promise of big scientific impact and it assures us a role in the future endeavors that we judge will be the most important global projects in subatomic physics.

The LRP identified specific cuts that would have to be made in the event of a reduction of resources in this reallocations exercise. These cuts, described in Section 4, focus primarily on R&D expenditures for future initiatives and would compromise our opportunities in the longer term. The future of Canadian research in subatomic physics must not be sacrificed. Support of our LRP's status quo scenario will position us to achieve a set of important scientific goals by the end of this reallocation period. It will ensure our continued progress in exploring the most fascinating questions in subatomic physics.

We request the return of $1,412K per annum in support of a strong Canadian program in subatomic physics with identifiable important achievements and goals, and provisions for continued excellence in the long term. **The total request is for $5,648K over four years.**

3.2 Maximize Science Return for Highest Priority Projects

The status quo scenario of the community's LRP supports its highest priorities at a base level. However, under this scenario Canada would fall short of maximizing its scientific opportunities and fully exploiting its considerable investments. We therefore request a level of support that would allow our groups to display greater leadership internationally in the three projects identified by the community as most important for the field. Incremental additional funding for our high priority projects will have a very large impact, with Canadians directly responsible for extracting exciting scientific results in these large collaborations. This is a most cost-effective return on the large investments already made.

ISAC and Radioactive Beam Science: The support of Canadian groups to exploit the ISAC facility in its first five years of operation is highly constrained. The number of experiments that can be done is limited in part by the number of investigators. Canadian universities are now hiring in nuclear astrophysics, recognizing the scientific opportunities that exist at ISAC and that are now attracting international collaborators, such as the study of the $^{15}O(\alpha,\gamma)^{19}Ne$ reaction. With the spectacular success of TRIUMF in developing this state of the art radioactive beam facility, a strong refocusing of the Canadian nuclear physics program has occurred with at least 24 FTE working in the ISAC experimental program. Academic institutions have responded by creating and filling three new positions in 2001, with a further three currently advertised, the loss through retirements being only about 1 FTE. This growth necessitates funding beyond the LRP projections.

We request operating support for these five additional experimenters at the level of $325K per annum for **a total of $1,300K**. This represents an increase of 30% for this rapidly growing high priority area.

SNO Physics Analysis: Funding for the SNO facility has been given the highest priority in the program over the last four years, slowly increasing in a context where overall operating support has fallen by approximately 15%. This has allowed the group to commission the detector and deliver the first dramatic physics results. However, operating support for the SNO university groups had to be severely constrained. Furthermore, because the Canadian groups have large operational responsibilities at the SNO site, their ability to focus on the analysis of the data and extraction of the large scientific potential of SNO has been affected. Now, four new Canadian scientists are joining the team and will provide the Canadian groups with a capacity in data analysis comparable to that available to their foreign partners. The timing is excellent for analysis of the new Phase II data being taken with salt added to the water.

We therefore request additional support for this very positive development, in the amounts of **$120K, $160K, $200K, and $245K** in successive years, to ensure that the augmented Canadian team has the resources needed to play leadership roles in the analysis of the new data being collected by SNO.

Development of an ATLAS Analysis Capability: The LRP allocates sufficient support for the ATLAS Canada collaboration to discharge its obligations with regards to the installation and commissioning of the parts of the detector provided by Canada. The upcoming period will be very intense, demanding a significant presence at CERN. The Canadian ATLAS team must also be involved in the Data Challenge now being implemented at CERN, an important step in developing and testing the data analysis strategy and tools. The core of this effort will consist of 5.0 FTE professional researchers working closely with a team of ATLAS faculty members and students. This team will develop the Grid tools and the software infrastructure necessary to support an analysis effort in Canada.[2] We expect that the capital investment in hardware will be obtained via CFI and NSERC equipment competitions.

We request an increase of $360K per annum, **a total of $1,440K**, for the Canadian ATLAS physics groups to fund the professional staff required for the development of their simulation and data analysis teams during the period 2003-2006.

3.3 Support of Particle Astrophysics

Many exciting scientific opportunities arise at the interface between astronomy, particle, and nuclear physics. The solar neutrino measurement at SNO is currently the highest profile Canadian activity. The SNO collaboration is also part of the ongoing global supernova watch and is considering long range options beyond its current scientific program. The PICASSO project is focused on detection of the puzzling Dark Matter that appears to dominate the mass of the universe; it is planning to leverage Canada's investment in SNO. The group has successfully developed a prototype of a novel Dark Matter detector and proposes to mount an internationally competitive project. The expertise of SNO scientists in building large, low background detectors has already proved to be an asset for the PICASSO program. Furthermore, the SNO site represents an environment with unique low radioactivity and cosmic-ray backgrounds for these future investigations. On another front, Canadians are leading members of a successful gamma ray observation project (STACEE). Gamma rays from extra-galactic sources have been observed with energies that imply high energy processes in nature. Their production is poorly understood but is ultimately related to acceleration of elementary particles to energies far beyond what has been achieved in the laboratory. As such, they may probe high energy physics at a scale not possible on earth. A natural progression for this Canadian group is to join the next generation experiment, VERITAS.

The existing group of Canadian particle astrophysicists is being strengthened through new academic appointments, one made in 2001 and four searches underway. Our LRP gave high priority to the development of new particle astrophysics projects. Partial capital funding was identified in the last years of the LRP for the next phase of the PICASSO experiment, which involves underground installation of a prototype detector at SNO. However, only in the scenario of increased funding to subatomic physics was it possible to properly support either PICASSO or VERITAS.

Given the strong interest worldwide and the growth in the Canadian community of particle astrophysicists, we request additional operating support of $330K per annum, **a total of $1,320K**. This would approximately double the Canadian support for particle astrophysics beyond SNO.

3.4 Strengthening of Subatomic Physics Theory

The development of subatomic physics is critically dependent on the presence of a vibrant and active community of theorists. The Canadian theoretical community has diverse interests and a record of scientific impact of international calibre in areas such as heavy quark physics, theories beyond the Standard Model and string theory. Furthermore, the future looks very exciting. A period of significant renewal among theoretical faculty has begun, with new appointments at nearly all the institutions involved in subatomic physics. Several of these appointments have been in superstring theory, greatly strengthening the Canadian role in this area of intense interest. In the past two years, 10 new theory appointments have been made and an additional 5 searches are currently in progress. These represent a

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[2] Data Grids are geographically separated computing resources, configured for shared use with large data movement between sites.

turn over of 20% of the community. Additionally, the recently established Perimeter Institute will provide new national opportunities for the exchange of ideas and collaboration among theorists.

During the recent planning exercise, theorists identified their highest priority as the enhancement of their research environment by improving their ability to hire top quality research personnel at the postdoctoral level. The Canadian theory community is directly competing with researchers worldwide for a small pool of extremely talented young researchers. A 20% increase in funding above the LRP status quo scenario is required in order to allow Canadians to make competitive postdoctoral appointments.

We request an amount of $430K per annum, **a total of $1,720K**, to support new researchers and to improve the research environment of subatomic physics theory in Canada.

3.5 Advanced Technology Development for Future Projects

It is not uncommon for new experiments to set as their goal an improvement in sensitivity or precision by several orders of magnitude over previous work. This requires the development of new advanced technologies. Canadian subatomic physicists have developed such advanced technologies at an internationally competitive level, resulting in innovations such as extremely sensitive radioactivity assaying techniques, radiation-hard electronics, novel x-ray detectors, and gallium-arsenide charge-coupled readout devices. Many of these have possible applications in other areas, such as medical imaging in the case of the x-ray detectors. This R&D is currently being supported by approximately $360K per annum made possible only through both the last reallocation exercise and the recent increases to the NSERC budget.

The LRP identified as high priority R&D on tracking detectors and accelerator alignment techniques for a future Linear Collider, a scaling-up of the PICASSO experiment to a 1-ton detector, new photon tracking detectors for the KOPIO experiment, and a novel lead-scintillator calorimeter for a next generation neutrino experiment. We estimate these R&D efforts will require $800K per annum over the next four years. The LRP, however, was only able to identify $320K per annum in the status quo scenario.

We therefore propose an additional investment of $480K per annum, **a total of $1,920K**. Without this infusion of R&D support, the long-term competitiveness of the Canadian program will be compromised.

4 Consequences of No Reallocation Funding

The subatomic physics community has identified a prioritized program, focusing over the next five years on maximizing the scientific return of ISAC and SNO, developing the Canadian contribution to the ATLAS effort, maintaining breadth by strategically supporting a modest number of smaller projects, and selecting a small number of longer-term projects for R&D. In the case where the reallocation process reduces the resources to the community, the LRP identified a number of specific areas where we would be forced to make cuts: Instrumentation for ISAC II would have to be delayed, jeopardizing our lead in the radioactive beam research frontier. The PICASSO experiment could not be scaled up to an internationally competitive project. The next generation rare K decay experiment, KOPIO, would have to be significantly curtailed. These cuts would be a severe blow given Canada's leadership in these ground-breaking projects.

With these choices, we would be avoiding explicit cuts in our highest priority projects. However, reduced funding would limit the resources available for the computing facilities required for data processing and scientific analysis of the very large data sets being collected in several of our current experiments. The community's overall ability to perform the essential R&D for the next generation experiments will be curtailed to the point of jeopardizing the future of Canadian subatomic physics.

5 The Importance of Subatomic Physics to Canada

The primary objective of subatomic physics research is the pursuit of fundamental knowledge about our universe, its origin and development. As such, this field represents one of the great challenges to Canadian minds but it also links to other fields of research where similar experimental or theoretical techniques can be applied. Thus it represents an excellent environment for developing problem solving skills. It is also unique in the scale and breadth of collaborations, giving young researchers experience in international cooperation and management of large and long-term projects. The subatomic physics record in the development of highly qualified personnel is particularly strong. Over the last five years, subatomic physics researchers supervised to completion over 100 Ph.D. candidates, and currently have over 75 Ph.D. candidates under supervision. Over the same period, over 120 postdoctoral researchers were supervised. These young people predominantly enter the work force in academic or research positions in not only subatomic physics, but also disciplines ranging from geophysics to financial modeling to large scale computation and networking.

As only one example of the impact of subatomic research on the health of Canadians, one can link the development of positron emission tomography, the imaging technology of choice for cancer management, to the technologies of isotope production separators, multi-element detector arrays, data acquisition, image reconstruction and analysis and simulation techniques. These are all techniques that originated in subatomic experiments over the last several decades. There are many other examples of this synergy in Canada, a very visible one being the MDS Nordion medical isotope manufacturing facility adjacent to TRIUMF.

The demands of subatomic physics experiments on data handling techniques are driving the development of new tools for global computing over the World Wide Web. Canadian groups are involved in the Grid computing development project, which has immense potential in business and commerce. While the economic and societal impacts of this pursuit are open to speculation, Canada would be notable if it were absent in the development of such technologies. In fact, Canada's leadership in developing a fully optical network across the country and the physical extent of the country make Grid technologies particularly attractive.

Working in large international collaborations prepares students for the global economy in an internationally competitive environment. Most groups are multinational in composition and use management techniques akin to the industrial world. All our programs are internationally peer reviewed and expose our students and postdoctoral fellows to reporting, scheduling and decision making in a global context.

A strong fundamental research program has important feedback in other disciplines. The challenge to improve our knowledge of the universe demands the development of new, sophisticated tools that filter into other areas of important research. In the final analysis, however, being involved at the leading edge of subatomic physics is what is important for Canada. The funding of our proposals would support a world-class program in subatomic physics anchored on the recent remarkable achievements of a small but internationally competitive community.

The last two years have seen tremendous successes by the Canadian subatomic physics community. SNO has shown incontrovertible evidence of solar neutrino oscillations. ISAC has produced its first accelerated radioactive beams, making TRIUMF the pre-eminent next generation facility of its type in the world. Both of these developments have given Canadian physics very high visibility internationally, and are the result of the support received from NSERC during the last reallocation exercise. Canada’s subatomic physics program is poised to build on this impact with similar strong support from the 2002 reallocation process.

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