DRAFT Version 1.0

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

GSC 19 Steering Committee:
P. Kalyniak *(co-Chair)*, P.K. Sinervo *(co-Chair)*, J.-M. Poutissou and K. Sharma

November 14, 2001

1 A Vision for Canada's Subatomic Physics Programme

Physics seeks to understand the nature and structure of matter and to delineate the laws of motion and change. This quest has led to the discovery of the classical forces and laws of motion, the chemical elements and their atomic nature, the structure of atoms and the quantum laws of motion, the nuclear forces, and the structure of the nucleus. Subatomic physics continues this quest for understanding at the most fundamental and universal level. The frontiers of this field include: string theory (attempting the ultimate unification of Einstein's General Relativity with the quantum description of particles and forces); the theoretical description of particle and nuclear phenomena embodied in the Standard Model and beyond; studies of particle interactions at the highest energies where new particles and forces are expected; precision measurements at intermediate energy seeking evidence of new physics through subtle deviations from our present expectations; experiments probing the complex many-body behavior of forces in the nucleus; and gaining an understanding of the nuclear reactions that fuel the stars and forge the chemical elements during their life and death processes. Unique opportunities also exist, at the interface between astronomy and nuclear and particle physics, that contribute to our understanding of the origin and evolution of the universe.

Great strides have been made in identifying the elementary constituents of matter and their interactions. These key discoveries have led to the development of an elegant theory known as the Standard Model (SM), one of the most important scientific achievements of the 20th century. It accounts for a description of all phenomena, observed at the shortest distance scales possible, with a minimal set of particles and a small number of fundamental forces. This model has profound implications for our understanding of the development of the Universe and its behavior at very early times after the "Big Bang." The Standard Model has been verified with high precision. Its accuracy allows us to use it for guiding extrapolation to ever-higher energies (corresponding to shorter periods just after the Big Bang). However, it is only an approximate theory, valid at relatively low energies compared to primordial events. There are many questions that the Standard Model leaves unanswered. We are forced to confront these questions in attempting to understand the extreme environments present in the cosmos such as neutron stars, black holes, supernovae, and gamma ray bursters. We are also forced to confront these questions in understanding the number and nature of quarks and leptons that are the basic SM building blocks.

The source of mass, which in the Standard Model arises from the Higgs mechanism, has not been experimentally established. This is the focus of high-energy physics experiments at the energy frontier, first at the Fermilab TEVATRON and later in this decade at the CERN Large Hadron Collider (LHC). The search for evidence of a new level of unification of the forces will dominate the high-energy program and will also involve many high precision tests at lower energies. Theoretical extrapolations beyond the standard model, constrained by experimental tests, suggest a grand unification of the four fundamental forces identified at our energy (distance) scale. One such theory, Supersymmetry, implies a duplication of the elementary particles discovered so far with a complementary set of supersymmetric partners. Searches for such new particles are underway and the weakly interacting neutral partner may be a candidate for the dark matter in the Universe.

The energy sources in the Universe are derived from nuclear reactions that take place in stars. A frontier in subatomic physics deals with our understanding of the most cataclysmic events (e.g. supernovae) in the cosmos by which the heavy elements are made. While we have a good understanding of the synthesis of the lighter nuclei (up to the mass of iron) in the reactions that take place inside stars (nucleosynthesis), we have been unable to extend this model to the formation of the heavier elements. This is due to the limitation imposed by our experimental facilities, which until recently allowed us to study only reactions in which both the incident and target nuclei were naturally occurring isotopes. A new generation of facilities now provide accelerated beams of short-lived, radioactive nuclei for nuclear physics experiments. This will extend our studies to the nuclear reactions that are critical to this nuclear "forging process." Such studies will critically test nuclear models, which predict the properties of nuclei, under extreme conditions of isospin (ratio of the number of proton and neutrons), shape and temperature and push our modeling of nuclear matter into uncharted territory. There is already some evidence that the shell model of nuclei must be revised as one moves away from the region of stable nuclei. Canada and Canadian subatomic physicists are now playing a leading role in this work through the experiments now underway at the ISAC facility at TRIUMF.

Canada has developed a unique programme that over the last 15 years has successfully integrated the study of nuclear physics (the study of phenomena involving the many-body system of protons and neutrons comprising the nucleus of all atoms) and particle physics (the study of the more elementary particles, the quarks and leptons, that are the building blocks of the nucleons and atoms). By all measures, the Canadian programme has been exceptional in its international impact given its size. Members of the experimental programme have taken leadership roles in each of the large projects Canada has been involved in, and our theory community has made important contributions to the current paradigm, known as the Standard Model.

A very strong scientific relationship has developed between astrophysics and subatomic physics in our attempts to understand understand of the origin and evolution of the Universe in the context of the Standard Model, and this is particularly evident in the Canadian subatomic physics programme. Astrophysics incorporates ideas from particle and nuclear physics while subatomic physics uses astronomical observations to extend its reach. The Canadian community has developed unique facilities as part of this world effort. The next generation of experiments planned at the Sudbury Neutrino Observator (SNO) directly addresses these aspects. Other new initiatives include a detector for dark matter (the PICASSO project), now in its early stages of development, and an observatory for extremely high-energy gamma radiation in cosmic rays (VERITAS).

Many significant advances in subatomic physics have been made by the Canadian programme over the last five years. Recent SNO results have made a significant contribution to the resolution of the longstanding riddle of the dearth in the solar neutrino flux and provided startling new information about the nature of these particles. The TRIUMF ISAC facility, arguably the premier radioactive ion-beam facility in the world today, is now operational, and first results from the facility have already been published and experiments aimed at the detailed study of astrophysical phenomena have begun. Construction of an new facility, ISAC-II, will ensure that the Canada maintains its leadership role at the forefront of radioactive beam physics. Canadian scientists are making major contributions to the ATLAS experiment at the LHC. The experiment is aimed at testing the mechanism of the Standard Model for the generation of mass. The Canadian ATLAS team is on schedule with their contributions to the detector and Canada's contribution to the LHC is nearing completion. Canada is providing the leadership needed to make this future experiment a success.

In this context, the Canadian subatomic physics community has identified three experimental areas of research as its highest priorities:

1. Use the unique SNO detector, which has just started to provide new, exciting results, to completely resolve the Solar Neutrino problem and search for physics beyond the Standard Model in the neutrino sector.

2. Study nuclear astrophysical phenomena using the ISAC facility at TRIUMF and develop the next generation experiments for ISAC-II. The Canadian program has chosen to focus its

research on the nuclear astrophysics phenomena and the nuclear structure issues relevant to them.

3. Participate in the search for an understanding of the origin of mass and for evidence of phenomena beyond the Standard Model at the LHC.

At the same time, initiatives in subatomic physics theory are necessary and must be strongly supported to ensure progress in the field. The three main components, listed above, are balanced by other experimental efforts addressed at the basic properties of the nucleon, the asymmetry between matter and anti-matter and high-precision tests of the Standard Model. These initiatives, together with the three high priority efforts, will ensure that the community will remain as vibrant and successful as it has been in the past. That is our vision

2 The STRATEGY

Our strategy to achieve this vision is based on support of the research at our national facilities, the need to carefully plan the overall programme to maximize its scientific impact, to properly support the highest priority efforts in both experiment and theory, to provide appropriate support for the area that forms the intersection of astrophysics and subatomic physics, namely particle astrophysics, over the next five years, and to develop the next generation of experiments.

Canadian participation in subatomic physics research is part of our nation's commitment to the community of advanced nations that value fundamental research driven by the human quest for understanding. Subatomic physics requires particle accelerators and detectors of a scale that exist only at national and international laboratories, with scientists from institutions in 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 one of the world's most powerful proton cyclotrons and the new ISAC radioactive bea accelerator. At the same time, Canadian physicists play key roles in high priority projects at other international laboratories. We must continue to support SNO and ISAC as part of our contribution to advancing the field of subatomic physics.

Large, long-term, technically challenging international collaborations require careful management and planning. The Canadian subatomic physics community and NSERC have done so through several mechanisms. The infrequent but large capital equipment requirements are funded not through the NSERC-wide major-equipment competition, but rather by an "envelope" from which the Grant Selection Committee (GSC 19) funds capital equipment, infrastructure (MFA), and operating support for subatomic physics. Operating funds are provided primarily through project grants to experimental groups that include researchers from several universities, rather than individual investigator grants. The community has insisted on using international peer review as the primary mechanism for funding projects and researchers – GSC 19 has approximately half of its members drawn from the very best of the international subatomic physics community. To provide a focused effort drawing on unique Canadian capabilities, a community based long range plan (LRP) has been developed. This reallocation exercise is linked to the third such LRP, recently completed under the auspices of NSERC. This 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 recognizable contributions in collaborations where any nation is in the minority. This selection must also strike the appropriate balance between properly supporting the highest priority projects in the Canadian programme and maintaining its intellectual breadth. Furthermore, our LRP has identified where we want to be positioned for opportunities in the next decade.

Subatomic physics is technology-intensive, providing opportunities for training in instrumentation, integrated electronics, advanced computation, and data mining. It is also unique in the scale and breadth of collaborations, providing students and researchers with experience in international cooperation and management of large and long-term projects. The tools developed for subatomic research have had important applications in research, industry, and to 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 ubiquitous World Wide Web was originally developed at CERN as a means for subatomic researchers to document and communicate their work. Our programme must continue to support R&D of advanced instrumentation.

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

The LRP is foremost a scientific plan that also lays out funding priorities to help assist the NSERC Grant Selection Committee in annually allocating resources to specific initiatives. The so-called "status quo scenario" maps out our scientific plans for the case of a constant funding envelope. The LRP also identifies the community's priorities for the case of decreased funding resulting in this reallocation exercise and, of course, 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. With the long time scales involved in our discipline, it is crucial to sustain long term objectives with a stable working environment. The Canadian community has established its reputation by being reliable collaborators who deliver on our international commitments, and providing the intellectual leadership to direct each project to successful completion.

Our present LRP emphasizes a concentration of resources on three highest priority projects, ISAC, SNO and ATLAS. These priorities exist in the context of many important issues in subatomic physics. Consequently, the scientific program argued for in our LRP recognizes the need for breadth and for planning for smaller elements of the programme 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 Astrophysics: 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 isotopes far from the line of stability will be significantly advanced with this facility. The beams at ISAC will also be exploited for sensitive tests of physics beyond the Standard Model.

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 be able to accelerate radiactive ions with $A < 150$ u up to energies of 6 MeV per nucleon, has been approved and funded and delivery of first beams is expected in 2005. The ISAC-II nuclear astrophysics program will be expanded beyond that of ISAC-I with the ability to access further nuclear reaction chains. Both reaction dynamics and nuclear structure under extreme conditions will be studied by Canadian groups from McMaster University, Guelph University and TRIUMF.

Canada has managed to develop a focussed programme through careful selection of a small number of other projects that are expected to have significant impact. At TRIUMF, the TWIST experiment is now poised to make the most precise measurements of muon decay. Nuclear physicists at Universities of Manitoba, Northern British Columbia and Regina are making contributions to studies at the Thomas Jefferson National Laboratory in the U.S. that delve into the lack of mirror-symmetry in nature and the detailed properties of the proton. Researchers at McGill University and Manitoba are making seminal nuclear mass measurements 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 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. The collaboration has now measured a total solar neutrino flux in excellent agreement with the prediction of the standard solar model, while also finding a deficit in the charged current rate. The implication is that neutrinos do oscillate between species and some discrimination between models has already been accomplished. Increasingly precise determination of the parameters of neutrino oscillations will continue. The first phase of the unique neutral current measurement, with salt in the water, is underway.

SNO is just one example of a project which draws together particle and nuclear physics with the observation of astrophysical phenomena. This is a research area of growing global importance. Our LRP advocates that we take on this exciting new area as an intrinsic part of our research program. On the theoretical front, there is an explosion of interest in possibilities linking our understanding of the origins of the universe and its fundamental constituents, in the form of superstring cosmology. A small particle astrophysics program in Canada is currently being supported, and includes a dark matter search using a novel Canadian technology, explorations of the phenomena of ultra-high energy gamma rays, and the continuing opportunities at the SNO site for neutrino astronomy. Indeed, the SNO site represents a unique outstandingly low radioactivity and cosmic-ray background environment for some of these future investigations.

ATLAS and Particle Physics: The primary goal of the ATLAS experiment at the LHC is to understand how the mass of elementary particles is generated. This is part of the program to study the so-called electroweak symmetry breaking and has profound implications for our understanding of both the fundamental interactions and the nature of the early universe. Furthermore, since ATLAS is at the high energy frontier of particle physics, it will provide our best opportunity for the discovery of phenomena which may exist beyond our current understanding, such as supersymmetric particles.

The Canadian ATLAS group is designing, prototyping, and constructing certain key components of the detector, calorimeters, which measure the energy of particles produced in the collisions at the LHC. This includes the development of advanced electronics, some of which must meet unprecedented radiation hardness standards. The status quo scenario of the LRP has the Canadian group meeting its international committments with delivery of its contributions on schedule. Furthermore, the ATLAS Canada community is developing competitive analysis capabilities.

This top priority effort on ATLAS is balanced by an excellent and well rounded program of particle physics projects, chosen to maximize the significance and impact of the Canadian effort on the world stage. Canadians have played seminal roles in the extreme experimental scrutiny of the Standard Model at a number of facilities. The Canadian OPAL group is completing their seminal studies of high-energy e^+e^- collisions at the LEP-II collider, while Canada still plays a significant role in the ZEUS experiment at the HERA e^-p collider in Hamburg, Germany. Our subatomic

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
SNO Operating	3,586	3,641	3,900	3,950	3,950	4,000
ISAC Operating	1,252	1,423	1,442	1,540	1,335	1,365
ATLAS Operations	1,550	1,590	2,000	2,200	2,450	2,700
Particle Astrophysics	68	51	50	50	100	100
Theory Support	1,920	1,880	2,100	2,190	2,277	2,277
Other Particle Physics	3,969	3,456	3,495	3,230	3,050	2,975
Other Nuclear Physics	1,507	1,408	1,435	1,345	1,155	1,155
Infrastructure	1,491	1,508	1,610	1,655	1,700	1,745
R&D	165	469	524	470	470	470
Capital	4,067	2,161	2,686	4,040	4,504	5,214
Total	19,641	17,587	19,242	20,670	20,991	22,001

Table 1: The funding allocations recommended for the "status quo" Long-Range Plan (all figures are in thousands).

physics community continues to confront the nature of CP violation in the B and K systems, a key test of our understanding of the asymmetry between matter and anti-matter in the universe. Our most notable recent contributions have been to the E787 experiment, studying the rare decays of K mesons, which has recently completed the most sensitive study of these decays, and the BaBar experiment studying B meson decays at the Stanford Linear Accelerator Centre. The Canadian effort at the current energy frontier facility, the Fermilab Tevatron, has not only unearthed the top quark but will provide invaluable experience for our ATLAS Canada team as data taking commences towards the end of this reallocations period.

Ideas and Technology for the Future: The subatomic physics community has identified where it would like to be positioned for the future. 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 is rapidly being identified worldwide as the major new initiative beyond the LHC. We are also looking to define Canadian participation in an international accelerator based second generation experiment for precise measurement of the parameters of neutrino oscillations.

Financial Plan: The LRP resulted in the development of model for how funding should be allocated over the next five years. This funding plan is summarized in Table 1, and summarizes the status quo plan.

The explicit increase in funding for SNO and ATLAS are both important consequences of this plan. However, this comes at considerable cost in the support for particle astrophysics, and an essentially "flat" level of support for ISAC science and the theoretical effort. Capital funding is allocated, primarily for the second generation rare K-decay experiment (KOPIO) and the ISAC-II programme, with a small amount set aside for unidentified initiatives in the last two years of the plan.[1]

[1]The average operating support in the GSC 19 envelope ($13.846M) is subject to the Reallocation Exercise.

2.2 Implementation of the Last Reallocations Exercise

The last reallocations exercise was carried out in a context where large capital needs for our three highest priority projects had to be funded. Extremely difficult decisions, including the closure of facilities, were made in our 1996-2000 LRP in order to lay out clear priorities for a well focussed program. A five-year spending plan was developed with a profile moving capital costs of ISAC instrumentation, SNO and ATLAS forward, the overall envelope being constrained to balance over a five year period. That Reallocations Committee recognized that the subatomic physics submission emphasized fundamental and important questions in the overlapping areas of nuclear and particle physics. They supported the community's five year plan and its proposal for research and development funds aimed at positioning the Canadian subatomic physics community for the future. We have now succesfully implemented this plan, and the scientific benefits of this commitment are now being realized. The community enters the 2002-03 funding year having balanced spending with resources over the last five years.

Funding decisions made by the GSC have been consistent with the vision and plan of the subatomic physics community and with the positive recommendations of the 1998 Reallocations Committee.

- The period of implementing the last reallocations decisions coincides with the milestones of first delivery of unaccelerated radioactive beam at ISAC followed by delivery of the high energy beam. The scientific program is now well underway. Recognition of the need for strong and timely support of the ISAC program resulted in the award of reallocations funds for new detector systems, along with the associated operating funds.
- Support of the now fully operational SNO project has generated their first exciting and definitive investigations of the solar neutrino problem. The SNO results have had an extremely high profile, even in the popular media.
- It has been possible to expand the scope of the ATLAS project using additional increases in funding of the GSC 19 envelope. Furthermore, as capital costs for ATLAS have now begun to decline, increased operating funds have been alloated to ATLAS to allow successful delivery of the detector components under construction as well as the development of physics analysis tools.

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 funds in support of a few projects with the potential for tremendous future impact internationally have begun to address this need. These include work on a second generation rare K-decay project (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 such an important project is critical for Canadian scientists to make an impact in the future.

As noted by the 1998 Reallocations Committee, our subatomic physics effort has a high profile internationally. New funding has been critically important in meeting committments 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

The subatomic physics community in Canada has developed a strong program that strikes the correct balance among a small set of carefully selected high priority large initiatives, enough breadth to maintain vital intellectual stimulation, and support for the development of future innovative projects. This program is based on detailed scientific and financial planning and has been subject to extensive international peer review. The scope of the program, commensurate with the expertise of our scientists, provides opportunities for Canadians to continue to take on leadership roles.

Our top priority experimental projects, ISAC, SNO, and ATLAS, are all forefront investigations with the highest possible scientific impact on the international stage. At the ISAC facility, we have just begun to use radioactive beams to explore on earth conditions which 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 that range from 7 to 15 years in scope, and will ensure Canada's leadership role in subatomic physics at an international level.

The LRP takes a considered approach to also support a well-rounded program of smaller excellent projects along with theoretical investigations. This balance encourages scientific creativity while acknowledging our limited resources. Furthermore, it assures 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 Long Range Plan also includes R&D support for future projects. This support is vital for the long term health of subatomic physics in Canada. It allows us take a few chances on developing instrumentation with the promise of big scientific impact and it assures us a role in the future endeavours which we know will be the most important global projects in subatomic physics.

The LRP identified specific cuts which could be made in the event of a reduction of resources in this reallocations exercise. These cuts focussed primarily on R&D expenditures for future initiatives, compromising our opportunities in the long term, and are described in Section 4.1. The future of Canadian research in subatomic physics cannot be sacrificed. Support of our Long Range Plan's status quo scenario will position us to achieve a set of important scientific goals by the end of this reallocation period. Furthermore, it will assure that we continue to make progress in exploring the most fascinating questions in subatomic physics.

We request the return of $1,384K 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.

3.2 Maximize Science Return for Highest Priority Projects

The status quo scenario of the community's LPR supports the communities three highest priorities at the minimum level to achieve the scientific objectives laid out by the investigators. However, under this scenario Canada would fall short of maximizing the scientific opportunities presented by ISAC, SNO and ATLAS and would not get the most out of the considerable investments made over the last 5 years. We therefore request a level of support which would allow our groups to display a leadership role at the international level in the three projects identified by the community as most important for the field.

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. Only a few experiments can be supported at a competitive level by Canadian groups, leaving a significant part of the programme to other international groups who will take advantage of this unique world class facility. With the spectacular success of TRIUMF in developing this state of art radioactive beam facility in the last 5 years a strong refocusing of the Canadian Nuclear Physics programme has occurred with at least 24 FTE involved in the ISAC experimental programme. In the last two years, academic institutions have responded by creating and filling three new positions in 2001 at University of Alberta and TRIUMF, and are currently advertising three positions (McMaster, Alberta and TRIUMF). The net loss to the progamme through retirements is approximately one FTE. NSERC support must be found to allow for this rapid growth of the programme. We request the necessary additional operating support for these five new experimenters at the average level of support providing in this subfield of subatomic physics for programmes at TRIUMF. This amounts to $325K per annum.

Support for Canadian SNO Physics Analysis: Operating support for SNO has been given the highest priority in the programme over the last four years, with overall funding 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 physics results. However, operating support for the SNO university groups had to be severely constrained, leading to significant stress on both the senior and junior researchers. This was partially recognized in the LRP by recommending an increase of approximately $250K over the next few years. However, no provision for inflation nor growth in the Canadian effort was made. 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 compromised and their youngest scientists have been unable to play leading roles in analysis activities given the burden of detector operations at the Sudbury site. At the same time, four new Canadian scientists are joining the team (two at Carleton and two at Queen's) who will provide the Canadian groups with a capacity in data analysis comparable to that available to their foreign partners in the SNO collaboration.

We therefore request additional support initially at $120K per annum growing to a $315K by year four to account for inflation in the salary and travel component of the overall operating grants at a rate of 2.5% per annum.

Build an ATLAS Physics Analysis Effort: 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 Mock Data Challenge effort now being implemented at CERN, an important step in developing and testing the data analysis strategy and tools in time for initial data-taking in 2006. We request additional resources for the Canadian ATLAS physics groups to support the development of their simulation and data analysis teams during the period 2003-2006. 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 core team will develop the GRID tools and the software infrastructure necessary to support a credible analysis effort in Canada. We expect that the capital investment in hardware will be obtained via CFI and NSERC equipment competitions. We therefore request an increase in ATLAS operating support of $360K to fund the professional staff required to support this core effort.

3.3 Support of Particle Astrophysics

Many exciting scientific opportunities arise at the interface between astronomy, particle, and nuclear physics. We recognize the emergence of an active new community in Canada committed to this exciting new area. We propose that GSC 19 be provided the necessary funding resources to take responsibility for support of the particle astrophysics and nuclear astrophysics research in Canada

GSC 19 currently supports several initiatives in the area of particle astrophysics. The solar neutrino measurement at SNO is the highest profile Canadian activity. The SNO collaboration is also part of the ongoing global supernovae watch, will be sensitive to details of the solar neutrino spectrum as their data set grows, and is considering long range options beyond its current scientific mandate, such as measurements of lower energy neutrinos by replacing the heavy water with a scintillator that enhances its response. The PICASSO project is focused on the detection of a puzzling new form of "dark matter," which appears to dominate the mass of the universe. Directly detecting this dark matter and understanding its nature is one of the great challenges in astrophysics. The PICASSO group has successfully developed a prototype of a novel dark matter detector and proposes to mount an internationally competitive search for dark matter candidates. The expertise of SNO scientists in building large, low background detectors has already proved to be an asset for the PICASSO programme. Furthermore, the SNO site represents an environment with unique low radioactivity and cosmic-ray backgrounds for these future investigations.

GSC 19 also supports the STACEE group presently studying high energy gamma rays with particle physics detector techniques. This group, consisting of researchers from McGill University and University of Alberta, has proposed involvement in a next-generation gamma ray experiment known as VERITAS, that has among its objectives a study of supernovae remnants to determine whether they may be the source of ultra-high energy gamma rays. Gamma rays with energies of multi-TeVs have been observed and the mechanism for their production is a fascinating mystery; an understanding may lie in the fundamental interactions of particles. Furthermore, as mentioned above, both the nuclear physics community at ISAC and theorists are working on questions of astrophysical and cosmological interest. of

We now can identify the development of a strong Canadian nuclear and particle astrophysics community. This community is also being strengthened through new hires: Carleton has recently hired a Tier II CRC and recruitments are underway at Queen's (2 FTE), McGill (1 FTE) and Alberta (1 FTE). Given this strong interest, the five-year plan gave high priority to the development of three new particle and nuclear astrophysics projects: i) a next generation SNO experiment aimed at studying lower-energy neutrinos through the use of liquid scintillator, ii) the next phase of the PICASSO experiment that involves underground installation of a prototype detector at SNO, and iii) the development of the VERITAS experiment.

The five-year plan was unable to identify operating funds for any of these initiatives, and only identified a part of the capital funding for PICASSO and VERITAS in the last years of the five-year plan. We therefore request operating support for the new investigators entering this area. This would require additional operating support of $330K.

3.4 The strengthening of Subatomic Physics theory

The development of the science associated with subatomic physics is critically dependent on the presence of a vibrant and active community of theorists in this field. This exists in Canada in the form of a theoretical community with diverse interests and a record of scientific impact of an international calibre. Furthermore, the future looks very exciting because we have begun a period of significant renewal among theoretical faculty, with new appointments at nearly all the institutions involved in subatomic physics in a substantial way. Several of the new appointments have been in superstring theory, greatly strengthening the Canadian role in this area of immense international interest. Superstring theory links well to several of our high priorities, both theoretically and experimentally. These include investigations of the limitations of the Standard Model and its possible extensions, nuclear and particle astrophysics, and cosmology.

In the last two years, 10 new theory appointments have been made and an additional 5 searches are currently in progress. These new appointments represent a turn over of 20% of the population. Taking retirements into account, the number of theorists in subatomic physics will have increased by at least 7 over the 2001 population. Additionally, the recently established Perimeter Institute will greatly enhance the profile of theoretical physics in Canada and provide new national opportunities for the exchange of ideas and collaboration amongst theorists.

During the recent planning exercise, theorists identified their top priority as the enhancement of their research environment with the ability to hire top quality research personnel at the post-doctoral level. The Canadian theory community is directly competing with researchers worldwide, in particular in the U.S., for a small pool of extremely talented people. These people are choosing more lucrative financial offers at academic institutions in other countries or are moving into industry. The development of a stimulating and productive atmosphere within a university group, including interactions between experimentalists and theorists, is vital and of particular importance to the training of highly qualified personnel. Increased resources are necessary to bring Canada into a competitive position.

Research funds for the seven new appointees are needed. This should include an estimated 10% increase in the current contingent of about 20 postdoctoral fellows. In addition, based on the need to compete in hiring excellent personnel, an overall increase in the funds available for theorists, at the 20% level, is required. This increase would, as usual, be distributed through the stringent peer review process to the most deserving researchers. We request amounts of $210K for new researchers and $220K to raise the salaries for research personnel to a more competitive level.

In total we request an amount of $430K to improve the research environment of subatomic physics theory in Canada.

3.5 Advanced Technology Development for Future Projects

New experiments in subatomic physics require development of new advanced technologies in order to maximize the scientific return of each major new initiative. It is not uncommon fo experiments to set as their quantitive goal an improvement in sensitivity or precision by several orders of magnitude over previous work. Canadian subatomic physicists have developed such advanced technologies at an internationally competitive level, resulting in innovations such as the extremely sensitive radioactivity assaying techniques (SNO), radiation-hard electronics for high energy collider experiments (ATLAS collaborators using TRIUMF), novel x-ray detectors now being developed for medical imaging (gas microstrip detectors being developed at Carleton), and gallium-arsenide charge-couple devices developed for the Brookhaven Rare K Decay experiments by TRIUMF. Many of these have possible applications in other areas. Such R&D is currently being supported by approximately $500K per annum to fund design, protoype development and testing, made possible only through the last Reallocation exercies

Over the next five years, the five-year plan identified as high priority the need to perform R&D on i) tracking detectors for an NLC experiment by researchers at Carleton, ii) NLC accelerator alignment techniques by researchers at UBC and TRIUMF, iii) scaling up the PICASSO+ experiment to a 1-ton detector through improvements in the sensitivity of 1 g prototypes by investigators at University de Montreal, iv) new photon tracking detectors for the KOPIO experiment by researchers at TRIUMF, UBC and Alberta, and v) novel lead-scintallator calorimeter for a next generation neutrino source by investigators at TRIUMF. We estimate these R&D efforts will require approximately $800K per year over the next four years. The five-year plan, however, was only able to identify a total of $300K in the "status quo" budget, already a reduction of $200K per annum in R&D funding. We therefore propose an additional investment $500K per annum. Without this infusion of additional R&D support, the long-term competitiveness of the Canadian programme will be compromised.

4 The Effects of Reallocation

4.1 Consequences of No Reallocation Funding

The subatomic physics community has identified a prioritized programme, focusing over the next five years on maximizing the scientific return of SNO and ISAC, 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 ends up reducing the overall resources to the community, the LRP identified a number of specific areas where cuts would have to be made:

- The next generation rare K decay experiment, KOPIO, would have to be significantly curtailed. This would be a severe blow, given Canada's leadership in this ground-breaking experimental programme.
- Instrumentation for ISAC II would have to be delayed, jeopardizing our lead in the radioactive beam research frontier.
- We would be unable to scale up the PICASSO experiment to make it an internationally competitive project.

By making these cuts, we would be avoiding explicit cuts in our highest priority projects.

The resources to provide the data processing and scientific computation to analyze the current large data sets being gathered by Canadian scientists will not be available. This would effect experiments such as E949, TWIST, CDF II, ZEUS and SNO, which depend increasingly on Canadian data-processing capability.

However, we note that even in its "status quo" scenario, the LRP makes no provision for inflation for our highest priority efforts. This means that with the difficult decisions outlined above, the fields's highest priority experiments, SNO, ISAC and ATLAS would suffer significantly as it would impair the ability of Canadian scientists to continue to be leaders in these key areas.

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. The effect of such cuts would be even more profoundly felt in the following five years as Canadian groups would not have been able to stay in tune with the new developments in the field.

There would be a further erosion in the support for Canadian students and postdocs working on Canadian experiments exacerbating even further our ability to compete in the international context and having an adverse effect on training of our students.

4.2 Consequences of a Positive Reallocation Award

The funding of our proposals would support a world-class program in subatomic physics anchored on the recent remarkable achievements of the small but internationally competitive community. Canadian subatomic physics has demonstrated its ability to deliver on commitments made to the international community with SNO, ISAC and ATLAS, at the same time providing scientific leadership and innovation in a few smaller important initiatives selected for their potential scientific impact.

As we are completing a period of major capital investments the pressure on funding for subatomic physics in CANADA has shifted to its operational costs. The most significant benefit provided by additional funding through the reallocation process is the increased ability of Canadian groups to support the development of highly qualified personnel in an international market. The proposed increases in support will allow theoretical physicists to compete for the very best postdoctoral fellows (many of whom are Canadians) who otherwise would be attracted to research positions in other countries. These increases will also augment the scientific impact of the experimental groups by allowing the programme to properly staff the highest priority projects. The Canadian subatomic physics program is attractive in terms of the science it addresses but it needs more resources to remain in the league of the most developed nations that are investing substantially in this field.

4.3 The Importance of Subatomic Physics to CANADA

The primary objective of subatomic physics research is the intellectual pursuit of fundamental questions 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 training ground for problem solving skills. 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 disciplines ranging from oil-well logging to financial modelling 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 (accelerators, targetry, separators), multi-element detector arrays (gamma ray cameras), data acquisition, image reconstruction and analysis and simulation techniques. These are all techniques which originated in subatomic experiments over the last several decades. Of course, the very discovery of the anti-matter partner of the electron in 1932 was the result of fundamental work by Nobel prize winner C.D.Anderson in a cosmic ray experiment. There are many other examples of this synergy in Canada, with a very visible example being the development of the MDS Nordion isotope manufacturing facility adjacent to TRIUMF.

The demands of subatomic experiments on data handling techniques are fostering the development of new tools for global computing over the World Wide Web (itself arising out of particle physics at CERN). Several of our groups are involved in the GRID computing development project. While the economic and societal impacts of this pursuit are open for speculation, Canada would be notable in its absence 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 particlarly 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 can and will have important feedback in other disciplines. It is because challenging our knowledge of the Universe is demanding the development of new sophisticated tools that such consequences are realized.

In the final analysis, however, being involved at the leading edge of our field is what is important for Canada.