The Subatomic Physics (GSC 19) Submission for the 1998 NSERC Reallocations Exercise

GSC 19 Steering Committee:
P.K. Sinervo *(Chair)*, S.A. Page *(co-Chair)*, F.C. Khanna, M.C. Vetterli

January 2, 1998

1 A Vision of Subatomic Physics Research for Canada

Subatomic physics researchers are engaged in a quest to discover the most elementary constituents of matter, to understand their properties and the mechanisms by which they interact. These fundamental intellectual challenges have profound implications for our world, ranging from the origin and ultimate fate of the universe to the structure of matter at the scale of the atomic nucleus. This field is vibrant and exciting, attracting some of Canada's brightest young scientists.

We group research in subatomic physics into two broad, overlapping areas: "nuclear physics" that focusses on atomic nuclei, and "particle physics" that studies the elementary particles that constitute the nucleus. Researchers based at Canadian universities and national laboratories work in international collaborations that address the fundamental questions in subatomic physics, on experiments that often span a decade or more. Given the scope of these projects, Canadian subatomic physicists engage in a process of long range planning to ensure that they make the greatest scientific impact in each project Canada is involved in. The consensus of the most recent community-based planning exercise in 1995[1] was to focus into the next decade on three high priority initiatives. Two of these are based on new facilities under construction in Canada; the third is a partnership in the world's largest particle physics project at the high energy frontier:

- **SNO:** The Sudbury Neutrino Observatory (SNO) will offer Canadian researchers an unparalleled view into the processes taking place in the sun because of its unique sensitivity to all types of neutrinos (ν).[2] SNO will also shed light on fundamental properties of these elusive particles, and may determine whether they have a non-zero mass. Massive neutrinos would have profound cosmological implications – for example, they could determine whether our universe will continue to expand or eventually collapse back on itself.
- **ISAC:** The Isotope Separator and Accelerator (ISAC) at TRIUMF will provide beams of radioactive nuclei in unprecedented quantities. Experimenters at ISAC will measure nuclear reaction rates under conditions comparable to the cores of stars and supernovae. These data are required to fully understand the creation of the heavy elements in our universe, without which the formation of planets and the existence of life as we know it would not be possible.
- **ATLAS:** The Large Hadron Collider (LHC) at CERN will generate the world's highest energy particle collisions. Canadians working on the ATLAS experiment at the LHC will explore a wealth of new physics at this high energy frontier. Their central goal is to discover how the masses of elementary particles arise, which is key to a more fundamental understanding of matter. Furthermore, ATLAS provides our best chance at uncovering what lies beyond our current theory of subatomic phenomena, the Standard Model.

Complemented by a selection of ongoing experiments and a vigorous program of theoretical research, these initiatives will form the core of the Canadian subatomic physics program through the period of the 1998 Reallocations Exercise.

Faced with a financial crisis due to unexpectedly large equipment funding requirements for these three high priority initiatives and reductions in federal support, the NSERC Subatomic Physics Grant Selection Committee (GSC 19) developed a five-year spending plan in 1997 (1997-2001) that was approved by NSERC Council. A necessary feature of this plan, taking into account the Fenton report recommendations, is the sacrifice of operating support to new and ongoing experiments in order to obtain additional funds for the most urgent equipment investments. It is particularly important to restore a more appropriate balance between operating and equipment expenditures as

[1] *Report of the NSERC Advisory Committee for Subatomic Physics*, B. Fenton et al., November 1995, henceforth referred to as the Fenton report.

[2] Neutrinos are almost undetectable particles thought to be massless that are produced prodigiously in the sun.

soon as possible. This will allow Canadian physicists to successfully complete the existing science projects, presently at the field's cutting edge, and prepare for the next generation of experiments.

The TRIUMF laboratory in Vancouver plays an essential role in this scientific program. In 1995, TRIUMF was given an expanded mandate as Canada's national facility for subatomic physics research, with ISAC becoming the flagship of the TRIUMF in-house science program. The laboratory also provides infrastructure support to all areas of subatomic physics research in Canada. It plays a crucial role in the construction of accelerator and detector components for the CERN LHC and ATLAS detector. Furthermore, TRIUMF fosters many interdisciplinary collaborations, with strong programs in condensed matter physics and medical applications of subatomic physics techniques.

The next four years will see previous NSERC investments in subatomic physics come to fruition with several experiments completing their data taking phase. The subatomic physics community has identified three high priority initiatives to take it into the next century. This Reallocations Exercise presents an opportunity to maximize the impact of the Canadian scientists by adequately supporting these projects and by restoring the community's ability to respond to newly emerging areas of research and discovery.

2 Importance to Canada

Canada must continue to support all fields of fundamental science if it is to maintain a strong intellectual capital base. Basic research performed at Canadian laboratories such as TRIUMF, the Saskatchewan Accelerator Laboratory (SAL) and Chalk River Laboratories (CRL/TASCC) has had a major impact on our understanding of nuclear systems and the forces that govern the behaviour of matter at distance scales of order 10^{-12} m and smaller. Canada also has a leading role abroad, where of the five experiments in the particle physics program currently taking data, Canadians have acted as spokespersons or deputy spokespersons[3] for three and as coordinators for the physics analyses of the other two. These achievements were summarized in the report of the international assessors of the subatomic physics program undertaken by the joint CAP/NSERC Review of Physics[4] in 1997: *"Canadians can be justly proud of their scientific results in subatomic physics and of the leadership roles they are playing in several international endeavors. The record of accomplishment by Canadians, the strong established base, and the potential for important new discoveries make the field an attractive one for further investment."*

By providing high quality facilities in Canada where foreign scientists come to collaborate with Canadians and by making significant scientific contributions at foreign facilities, the subatomic physics community has enhanced Canada's reputation for intellectual and technological innovation. Subatomic physics projects regularly push the limits of our knowledge in such areas as high speed electronics, advanced computing, and superconducting magnet design, with developments often made in cooperation with industry. Companies that have developed new products often apply the new technology in other fields. Many recent examples are associated with Canada's contribution to the CERN LHC accelerator, consisting of \$19M in high-tech components provided through the year 2000. At the international level, subatomic physicists are responsible for innovations such as the World Wide Web and ion beam implantation to name but two of many revolutionary technologies.

The existence of major centres for subatomic research in Canada has led to development of new research tools for other disciplines. The award of the 1994 Nobel prize to B. Brockhouse for work in neutron scattering at CRL highlights the importance of this fundamental nuclear physics technique to condensed matter physics. At TRIUMF, researchers in condensed matter physics and chemistry

[3] The spokesperson and deputy are responsible for all aspects of a project, including coordination of the construction of the experiment, data taking, and analysis of the results.

[4] *Summary of Assessors Report on the Canadian Subatomic Physics Program*, J. Deutsch et al., 28 July 1997.

use the muon spin rotation or "μSR" technique to study magnetic properties of materials such as high temperature superconductors. A proposal to build the Canadian Light Source in Saskatoon, which would provide x-ray beams for research in condensed matter physics, chemistry, and biology, is an outgrowth of the development of an electron accelerator for nuclear physics research at SAL.

Among the most important resources provided by a discipline are highly qualified personnel (HQP) who go on to form the intellectual base from which future innovation is born. Subatomic physics provides students with a broad education that includes not only the science but also state-of-the-art electronics, instrumentation, computing, and other information technologies. The mix of problem-solving skills and fluency in technology provided by this training is readily applied to many other fields. A unique aspect of training in subatomic physics results from working in large international collaborations under externally set deadlines and operating budgets. Students and postdoctoral researchers gain experience in project coordination and management that prepares them to compete effectively in a business environment where internationalization has become the norm rather than the exception. Recent studies have shown that people trained in physics are much in demand over a broad range of endeavors.[5] While 25% of recent subatomic physics graduates have found academic positions in Canada or abroad,[6] the majority are employed in industrial positions ranging from the high-tech to financial sectors. These conclusions are reinforced by a recent HQP study[7] that shows the unemployment rate of Canadians trained in physics to be less than 1%.

Canada has benefitted from numerous technical spin-offs from subatomic physics research. A recent study identified annual revenues of $16.5M from Canadian companies spun-off from subatomic physics research, almost equaling the NSERC contribution to this discipline.[8] For example, Canada has become a leader in research on positron emission tomography (PET), a medical imaging technique that relies on short lived radiopharmaceuticals and fast gamma ray detectors. This technique has opened up a new window on *in vivo* studies of the physiology and metabolism of the human brain. TRIUMF has developed cyclotrons for radiopharmaceutical production, in partnership with EBCO Technologies, that are now sold to an international market. TRIUMF is also collaborating with Grumman Corp. to build an accelerator-based system for the detection of explosives and contraband at airports and other risk centres, with high potential for commercialization. The University of Regina subatomic physics group, in collaboration with the U.S. Jefferson Lab and the Saskatchewan Research Council, has developed improved instrumentation for detectors widely used in medical and subatomic physics research. Other examples[6] of similar technological impact include the ISOTRACE dating facility (University of Toronto), proton beam cancer therapy (TRIUMF and UBC), and x-ray detectors for mammography and dentistry (Carleton).

3 The Canadian Subatomic Physics Program

Canadian subatomic physics research is focussed on several important questions regarding how our world works at its most microscopic level. Many of these are phrased in the language of the Standard Model of elementary particle interactions, which considers the known forces of nature as different aspects of a single primordial force. The key to this "unification" is a basic symmetry of space-time known as gauge symmetry. From this simple but profound idea, it follows that the four known forces acquired different strengths and properties due to a symmetry-breaking process that occurred during the expansion of our universe immediately after the big bang. This mechanism is

[5] *Highly Qualified Personnel*, NSERC report, May 1997.

[6] *The Status and Future of Canadian Subatomic Physics: NSERC/CAP Review of Physics*, 14 May 1997, available at http://cepheid.physics.utoronto.ca/Review/.

[7] *Review of Canadian Academic Physics: Highly Qualified Personnel Study*, 16 September 1997.

[8] *Review of Canadian Academic Physics: Economic Impact Study,* Paul S. Vincett, 9 November 1997.

also responsible for the masses of elementary particles, a prediction that will be rigorously tested by the ATLAS experiment.

There is a large body of experimental evidence verifying many predictions of the Standard Model. We know that the elementary constituents of matter consist of particles of two distinct families known as quarks and leptons. The quarks and leptons interact by exchanging field particles – photons, vector bosons and gluons for the electromagnetic, weak, and strong interactions, respectively. A total of six distinct members of each particle family, arranged in three "generations," are needed to describe all known forms of matter. One of the great successes of this theory is the unification of the electromagnetic and weak forces into a single "electroweak" interaction.

Despite the successes of the Standard Model, there remain many questions about the fundamental properties of quarks and leptons, about the mechanism that gives rise to mass, and about how the observed preponderance of matter over anti-matter in the universe was established. Details of the manner in which the quarks arrange themselves into protons and neutrons, and the way protons and neutrons form atomic nuclei remain to be quantitatively understood. Driven by a desire to address these and other fundamental questions, Canadian subatomic physicists have developed a focussed research program, described in the following sections, that takes advantage of the intellectual and technical strengths of Canadian scientists.

3.1 SNO

The Sudbury Neutrino Observatory, under construction in a deep underground site at the Creighton nickel mine, passed a major milestone in November 1997 with the completion of the main detector vessel. This puts the team of 18 Canadian researchers,[9] together with their graduate students, postdoctoral researchers, and international collaborators on track to begin observations in 1998 of the neutrinos produced in nuclear reactions in the core of the sun.

SNO is a unique Canadian project with strong international participation. Canada has provided two thirds of the $76M construction cost (the rest coming from U.S. and U.K. funding agencies) and GSC 19 provides over $3M in annual operating support. Because of the unique sensitivity of its heavy water detection medium (a loan from AECL valued at $300M), SNO will be able to detect neutrinos of different types and measure their energies. Previous measurements imply that the sun is only producing about half of the expected number of neutrinos. However, fundamental neutrino properties which have hitherto escaped detection, such as a finite mass, could be responsible for the discrepancy in the number of solar neutrinos detected on earth. The discovery of a finite neutrino mass would be revolutionary; the abundance of neutrinos in the universe leads to profound cosmological implications.

3.2 Nuclear Physics and ISAC

Canada has a strong nuclear physics program that has been based traditionally at Canadian laboratories – SAL, TASCC and TRIUMF – carried out by approximately 60 NSERC-funded researchers. Physicists using SAL are widely recognized for precise measurements of the electromagnetic structure of nucleons and light nuclei. Scientists using the TASCC facility at CRL achieved world recognition for their discoveries concerning the structure of nuclei spinning at very high angular momentum, for precise measurements of the electroweak force using nuclear beta decays, and for developing techniques to measure nuclear masses to high precision.

Researchers use the TRIUMF 500 MeV cyclotron to perform experiments that test our understanding of the electroweak and strong interactions. These include experiments carried out with

[9] In this submission, we count only full-time-equivalent, NSERC grant-eligible researchers.

proton beams as well as with beams of short lived particles - pions and muons[10] - produced by protons colliding with production targets. The pion physics program focusses on measurements of the elementary pion-pion and pion-nucleus interactions, which are powerful tests of our knowledge of the strong force. TRIUMF scientists have assembled an international team that is preparing to measure the muon decay spectrum with much higher precision than any previous study, searching for small new effects in the electroweak force. TRIUMF physicists have developed a very high intensity polarized ion source that is unique in the world. They use this source for precision symmetry tests of the strong and electroweak interactions. At a precursor to the ISAC facility, Canadian scientists attracted world recognition for their determination of the reaction rate for the conversion of carbon into oxygen in red giant stars, a key step in stellar evolution.

Nuclear physics in Canada is undergoing a dramatic restructuring. In 1995, TRIUMF embarked on a new five-year plan with a mandate to build ISAC, maintain an excellent in-house research program, serve as a national infrastructure base for subatomic physics, coordinate Canada's contribution to the LHC, and foster technology transfer to industry. In 1996, acting on the advice of the Fenton report, GSC 19 terminated its annual \$3M operating support of SAL over three years, and subsequently took steps to redirect the focus of the nuclear research program. Citing financial pressures, AECL withdrew its \$7M annual operating support of TASCC and closed the laboratory in 1997. The majority of the researchers who formerly based their programs at SAL and TASCC are now collaborating on experiments at TRIUMF and at facilities in the U.S. and Europe.

The ISAC project will open up a completely new area of research by delivering beams of hitherto unavailable radioactive nuclei to a variety of target and detection facilities by the year 2000. The centrepiece of ISAC's science will be measurements of nuclear reaction rates under conditions comparable to those found in novae and supernovae. These explosive events are thought to be the origin of heavy elements in the universe, but only a facility like ISAC will provide the data needed to fully understand their creation. Canadian scientists will feed specific radioactive beams into a new world-class laser atom trap, known as TRINAT, which employs cutting edge techniques in laser atom trapping and cooling technologies. These experiments will measure the properties of very short-lived nuclei and improve our knowledge of the electroweak interaction in complementary ways to the particle physics experiments. ISAC also provides condensed matter physicists with a unique tool to probe the structure of materials in ways that are complementary to the μSR techniques developed at TRIUMF.

3.3 Particle Physics and ATLAS

The Canadian particle physics community of approximately 75 NSERC-funded researchers is making important contributions to multinational collaborative projects that address some of the most fundamental questions in the field. The largest element of the current program is the OPAL experiment at the electron-positron LEP collider at CERN. Canada contributed several components of the OPAL detector beginning in the early 1980's, including the innermost tracking detector. Canadians continue to play a leading role in the operation of the experiment and analysis of the data. Notable achievements include precise measurements of the masses and lifetimes of the weak force carriers and other particles. These have established that the three "generations" of known quarks and leptons appear to be a complete set of fundamental constituents of matter. CERN has recently upgraded the energy and intensity of LEP to extend the physics reach of its experimental program and plans to run this facility through the year 1999 and possibly 2000. Support for OPAL is planned through this phase, with a rampdown of the Canadian involvement to follow.

[10] Pions (π^+) are one of the elementary particles known as mesons, which interact primarily via the strong force. Muons are one of the six leptons, which interact only via the electroweak force.

Two Canadian groups are performing experiments at the DESY laboratory in Germany, where they are studying the structure of protons and neutrons. With NSERC funding, these groups provided detection systems for the ZEUS and HERMES experiments and operate them during data taking (8-9 months per year). Canadian scientists have assumed leadership roles, with Canadians having served as deputy spokespersons of both collaborations. The ZEUS experiment, with access to the highest energy electron-proton collisions ever achieved, allows researchers to probe the structure of the proton down to incredibly small distance scales (10^{-18}m). The unique features of the HERMES experiment allow physicists to isolate the contributions by specific classes of quarks to one of the fundamental properties of protons and neutrons, their spin. The DESY accelerator will operate with an intensity upgrade through 2005 with data taking for ZEUS planned through this period. The spin physics program at HERMES is expected to be finished by 2001.

A Canadian group is active in the CDF collaboration at Fermilab in the U.S., currently the world's highest energy particle accelerator. A Canadian played a leading role in the 1995 discovery of the sixth quark ("top"), coordinating the analysis effort to search for this heaviest member of the quark family. A Canadian group also plays a leading role in measurements of rare K-meson decays at Brookhaven National Laboratory (U.S.). This group, with a Canadian as co-spokesperson, made the 1997 discovery of the decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, the rarest particle decay ever seen. This observation forms one part of the puzzle of why matter dominates over antimatter in the universe. Another Canadian group is assembling a large tracking detector at TRIUMF, in preparation for the BaBar experiment at the Stanford Linear Accelerator Center, which will further elucidate the reasons for this matter-antimatter imbalance by studying decays of particles containing "bottom" quarks.[11]

Canada's contribution through TRIUMF to the LHC has made possible a substantial Canadian participation in the LHC physics program. Scientists using the ATLAS detector will identify the products of proton-proton collisions seven times more energetic than any previously studied. They will either discover the Higgs boson, the particle thought to be responsible for the mass of all particles, or a host of complementary phenomena not predicted by the Standard Model. The Canadian ATLAS group is designing, prototyping, and constructing key elements of the detector, called calorimeters, that will measure the energy of particles produced in the collisions at the LHC. This includes the development of advanced electronics modules that will read out the signals from these detector elements.

3.4 Subatomic Theory

There are approximately 75 Canadian physicists who are pursuing a rich and diverse research program in theoretical subatomic physics. Much of this work is based on the idea that underlying mathematical symmetries play a fundamental role, as exemplified in the Standard Model, where these symmetries govern the nature of the electroweak and strong interactions. Canadian scientists are actively involved in developing extensions to the Standard Model, since it is widely believed to be incomplete.

Canadians are making important contributions to the development and application of mathematical methods to the study of the structure of protons, neutrons and other strongly interacting particles. They are approaching this in a number of ways, including the use of phenomenological models, numerical solutions of the basic theory, and "effective theories" that although simpler, incorporate the symmetries of the underlying theory. Extensions of these ideas to statistical models

[11] BaBar was not included in the 1995 long range plan. In 1996, GSC 19 concluded that Canadian participation in this experiment should be supported, based on the experiment's discovery potential and the quality and strength of the team of Canadian proponents. This participation, significantly more limited in scope compared with the proposal considered by the Fenton committee, was made possible by infrastructure support from TRIUMF.

with finite temperatures have received special attention. They are being applied to very energetic nuclear collisions where high temperature systems are created and the explicit effects of the underlying quarks and gluons are expected to be seen.

Canadians are also making important contributions to the study of the theory of atomic nuclei. Examples are the development of symmetry-based algebraic models of nuclear motion, and the study of how interactions between the protons and neutrons are modified inside atomic nuclei.

3.5 Funding of Subatomic Physics

NSERC support of subatomic physics has been administered via a unique "envelope" system since 1991, placing all expenditures for operating, equipment and infrastructure under the purview of GSC 19. This envelope was frozen at \$19.6M from 1991-95; the effects of federal funding cuts to NSERC and the first Reallocations Exercise resulted in a decrease of the envelope to \$17.3M by 1997. The impact of these budget cuts on the subatomic physics program has been severe, as discussed in Section 4. GSC 19 has responded by closing SAL, ramping down specific experiments more rapidly than scientifically justified, and exerting an unprecedented degree of selectivity among NSERC GSCs in the last two years:[12] In the 1997-98 grants competition, the ratio of funds awarded to funds requested was only 55%; only 58 of 92 applications (63%) received support at some level.

Subatomic physics research requires the use of large, custom-built detectors at international facilities. The GSC budget must provide both the equipment funds for the Canadian share of the detectors and the operating support for the participating scientists. This includes a substantial budget for travel to and work at international facilities. Funding for experimental work is usually awarded in three-year Subatomic Physics Project Grants, with a common budget for each experiment. Theoretical work is supported mainly by Individual Research Grants. Excluding equipment expenditures and the direct cost of operating facilities, the average operating award in 1997-98 was \$71K per experimentalist and \$23K per theorist. Although higher than many NSERC disciplines, this level of support remains considerably lower than that of their counterparts in the U.S. and Europe. Even the high degree of selectivity applied by GSC 19 has not made sufficient funds available to operate the highest priority projects on par financially with international collaborators.

The total investment in Canadian subatomic physics research is approximately \$60M in 1997-98. About one-third of this is provided by NSERC through GSC 19 in support of university-based researchers. The rest of this investment is primarily a federal contribution (through NRC) of \$33M to operate TRIUMF and the balance of support comes from other federal and provincial sources, and U.S. and U.K. funding agencies that assist in operating SNO. The Canadian university-based subatomic physics research program could not exist without these additional contributions, which leverage the NSERC investment by more than a factor of three.

4 Proposals for Funding

The large cut to the subatomic physics envelope (-12% for total funding and -20% for operating support since 1991 during a time when total research grant funding has increased by 6%) has required significant reductions in the scope of experimental and theoretical work. GSC 19 has largely followed the Fenton plan in restructuring the experimental program. It cut an entire area of study (the work based at SAL), terminated support of a number of smaller projects, reduced operating support to all of the ongoing experiments and provided only modest increases in funding for the three highest priority projects, SNO, ISAC and ATLAS. The shortfall in operating support has come with a significant scientific price. Canadian groups have been forced to scale back time

[12] NSERC competition data from 1995 to 1997, NSERC memo from C. Charette to Reallocation Steering Committee Chairs, 27 October 1997.

spent at laboratories analyzing data and operating the equipment that they designed, built and installed with NSERC support. They have been unable to contribute to the upgrading of this equipment, leaving their foreign partners to assume this responsibility. They have been forced to significantly reduce their contributions to the training of highly qualified personnel. The support for theorists (about 10% of the total envelope) has fallen by 15%, making it extremely difficult for these scientists to fund graduate students and postdoctoral researchers. The subatomic physics envelope requires a 20% increase to reverse this decline in scientific productivity. The following sections detail five specific proposals for operating and equipment support, all of which have very high priority. We identify the first three as Type 1 requests and the last two as Type 3 requests.

4.1 Support of the GSC's Five Year Plan: $1.2M per Year

The extraordinary financial pressures noted above led the GSC to propose a five-year spending plan[13] that assumes a constant budget envelope of $17.3M, with a spending profile of $19.3M, $17.7M, $17.9M, $17.1M, $14.5M from 1997-2001. The higher spending levels in the first three years are necessary to permit Canadians to provide their equipment contributions to SNO, ISAC and ATLAS on timescales driven by the development of international facilities and research partnerships. NSERC Council, recognizing the strong scientific arguments for this program and the sound financial planning that had been undertaken, approved a loan of just over $3M to allow the implementation of this five-year plan. GSC 19 is committed to a continuous process of financial planning with a five-year horizon as initiated in 1997. **In support of the five-year plan for subatomic physics, we request as our highest priority that there be no cut to the current envelope of $17.3M per year. This corresponds to a return of the $1.2M per year from the Reallocations Exercise.**

Consequences of Loss of Reallocations Funds

The consequences of further cuts to the subatomic physics envelope from the current level of $17.3M would be severe. As noted in the GSC's 1997 Contingency Report,[14] most of the shortfall would have to come out of operating funds, further eroding scientific participation in projects that Canada helped build. Funding for more projects would fall below "critical mass" forcing GSC 19 to prematurely withdraw support altogether. The GSC would also have to postpone equipment purchases for ISAC. This would seriously delay the science program at a premier new facility that represents a substantial investment of federal and provincial construction funds. It would be necessary to reduce operating funds to SNO, which would be particularly harmful just as the detector begins to acquire data and would have damaging implications for Canada's ability to act as a partner in international scientific collaborations. Urgently needed increases in operating support for the ATLAS effort would also have to be postponed, aggravating the severe shortage of funds for ATLAS as noted in the Contingency Report. All development projects and new initiatives would have to be suspended for several years, causing longer term damage to the field.

4.2 R&D and Smaller New Initiatives: $0.6M per Year

Physicists working on the early stages of a subatomic physics experiment must carry out instrumentation development and feasibility studies before a full proposal can be submitted for peer review.

[13] *Report on the 1997 Grant Competition: Awards, Policy Matters, and a Five Year Spending Plan for Subatomic Physics*, NSERC Subatomic Physics GSC, 25 April 1997. A copy of this report can be found at http://cepheid.physics.utoronto.ca/Review/chairs_report_1997.ps.

[14] *Contingency Provisions in the Five Year Spending Plan for Subatomic Physics*, a report to NSERC Council, S.A. Page, chair of GSC 19, 9 May 1997.

This R&D is only possible through grants targeted for this work, since Subatomic Physics Project Grant funds cannot be diverted from one project to another. In recent years, R&D funding for detector development and smaller new experimental initiatives has been severely scaled back due to lack of funds. The GSC's five-year spending plan provides no relief for this situation.

Very strong candidates for this type of support have arisen in every recent NSERC grants competition. Some examples include: R&D into sensitive detectors that could be used in the low-radioactivity site at SNO to detect supernovae and search for dark matter candidates; detector development for a new rare K-meson decay experiment building on the expertise and achievements of leading Canadians in this field; and an experiment to measure the asymmetries in electron-proton scattering (G0 at Jefferson Lab) building on the expertise gained in a related experiment at TRIUMF. Exciting opportunities such as these will be lost to the Canadian community unless a small number of new projects are supported through their R&D phase. In the words of the CAP/NSERC Review of Physics Assessors' Report,[15] '*... As the ongoing programs cannot be further cut without wasting intellectual and material investments, this requires a modest but significant increase of the subatomic physics envelope.*' In 1997, R&D and small project requests amounted to \$1.4M. The GSC was only able to award \$0.1M, leaving over 10 excellent proposals completely unfunded. **We propose that \$0.6M per year be awarded for support of R&D to develop the next generation of experiments. This will bring the success rate of grant requests in this category closer to that of the overall competition.**

4.3 Strengthening of Operating Support: \$1.4M per Year

The subatomic physics community in Canada entered the first year of the previous Reallocations cycle with 229 funded researchers[16] in the 1995-96 competition. Since that time, the number of researchers has remained constant, with new university appointments replacing retirees. However, the funds available for their operating support have decreased by 11% from \$14.0M to \$12.5M. The GSC had to plan a further 10% reduction in operating support through 2001 as part of its five-year budget plan. This shortfall in operating support is particularly harsh for young researchers. Since 1995, 13 young scientists, many who show great promise as outstanding researchers, have entered the discipline (over 30 new faculty have been hired since 1990). There have been no new operating funds available to properly launch their scientific careers by allowing them to initiate new projects or to enhance the scope of existing projects. The experimentalists have been forced to join existing experiments without any increase in the corresponding Project grants, while the new theorists have generally been funded below average levels. The cumulative decrease in operating funds from \$14.0M to \$11.3M urgently needs to be addressed. **We request \$1.4M per year from the Reallocations Exercise, half the projected shortfall in operating funds.**

4.4 Canadian Contribution to ATLAS: \$1.5M of Equipment Funds

ATLAS is the highest priority project for the future of the Canadian particle physics community. By the time ATLAS begins taking data, it is expected that nearly half of this community will be working on this project. The primary goal of these researchers is to use ATLAS to uncover how nature confers mass to all particles, either by detecting the Higgs particle postulated by the Standard Model or discovering the true mechanism. Canadian development of two important detector elements, the liquid argon hadronic endcap (HCAL) and forward hadronic calorimeters (FCAL), and elements of the associated readout electronics are innovative and have made a major impact on the design of the ATLAS experiment. Both the HCAL and FCAL are crucial to detect the Higgs via selected

[15] *Assessors Report on the Canadian Subatomic Physics Program*, J. Deutsch et al., 5 June 1997, p. 2.

[16] A. Isabelle, NSERC, Private Communication. The NSERC staff report, *Research Grants Program: Discipline Dynamics*, October 1997, does not list all grant holders funded by GSC 19.

decay modes, especially if the Higgs particle is relatively massive. It will not be possible to detect these decays unambiguously without these devices.

NSERC signed an Interim Memorandum of Understanding with CERN in 1996, stating Canada's intention to provide Canadian scientists with equipment funds for the ATLAS detector commensurate with the size of the Canadian group and the availability of funds. In 1997, the GSC strongly endorsed the conclusions of an international peer review committee that a Major Installation Grant award of \$15.4M to construct the calorimeters described above would be an appropriate match to the technical leadership, capability, and size of the Canadian ATLAS group. However, the GSC was able to award only \$12.2M for the construction of one half each of the HCAL and FCAL detectors, with a proportionally reduced contribution to the readout electronics. The Reallocations process by itself can allow only a partial solution to the ATLAS funding dilemma. **We propose that an additional \$1.5M contribution be made to the ATLAS detector to build the second half of the forward calorimeter (\$1.25M) and to proportionally increase the Canadian contribution to the readout electronics for this device (\$0.25M).**

4.5 DRAGON – Centre Stage at ISAC: \$0.6M of Equipment Funds

The nuclear astrophysics program at ISAC will focus on measurements of nuclear reaction rates under conditions comparable to those in stars and supernovae. Its success hinges on a dedicated facility, known as DRAGON ("Detector for Recoils And Gammas Of Nuclear reactions"), that will identify interesting reaction products amidst a large background of unreacted beam particles. The facility consists of a gas target surrounded by very efficient, very fast gamma ray detectors, and followed by a high resolution electromagnetic spectrometer. Its total estimated cost is \$3M.

The DRAGON proposal received strong endorsements from three independent peer review panels in 1997. In its five-year financial plan, the GSC was able to identify \$1.9M in equipment funds for DRAGON, allocated from 1998-2000. Together with a \$0.5M contribution from TRIUMF, this will support construction of the electromagnetic spectrometer. However, funds to construct the gamma ray detector would not be available until 2002 at the earliest. This detector is needed to increase the background rejection in DRAGON by a factor of 1000, opening a new window for the study of low reaction rate processes. An important example of such a process is the reaction on one of the oxygen isotopes ($^{15}O(\alpha,\gamma)$) as it is a crucial branching point in stellar evolution. Data on this reaction will not be accessible until the gamma ray detector is operational. **We request equipment funds of \$0.6M to complete the DRAGON facility by the year 2000, commensurate with the availability of radioactive beams at ISAC.**

5 Concluding Remarks

Our proposals for new funds have been carefully selected to maximize the scientific impact of NSERC expenditures in subatomic physics and to ensure the long term excellence of the Canadian research program in this discipline. The pressures on the GSC 19 envelope in recent years have been extraordinary. Difficult decisions have been made to close facilities and wind down Canada's involvement in experiments before the full scientific return could be achieved, while protecting to the extent possible our highest priority initiatives. Even with funding for all of our proposals, the subatomic physics envelope in 2002-03 will be smaller than it was in 1991-92. Considering the demonstrated excellence of the Canadian research program and the size and scope of the overall effort and investment in this field by Canada (of which NSERC contributes roughly 30%), our proposed additional investment will generate a high scientific return and is worthy of support from the Reallocations Exercise.