SECOND DRAFT

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

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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 issues are amongst the most fundamental intellectual challenges facing mankind, with profound implications about the world in which we live, ranging from the origin to the ultimate fate of the universe. The field is vibrant and exciting, attracting some of the brightest young Canadian scientists.

To address the fundamental questions in subatomic physics today and in the future, Canadian researchers actively participate in international collaborative projects that often span a decade or more at facilities in Canada and abroad. Given the size and time-scale of these projects, subatomic physicists regularly engage in a process of long term planning to optimize resources. The consensus that emerged from the most recent community-based planning exercise in 1995[1] was to focus the research programme through the year 2000 and beyond 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. Complemented by a selection of smaller experiments in nuclear and particle physics and a vigorous programme of theoretical research, these initiatives will form the Canadian subatomic physics programme through the period of the 1998 Reallocations Exercise and beyond. The three highest priority initiatives are:

- **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.[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, such as whether the universe will continue to expand or eventually collapse back on itself.
- **ISAC:** The Isotope Separator and Accelerator (ISAC) facility under construction at TRIUMF will provide beams of a wide range of radioactive nuclei in unprecedented quantities. Experimenters at ISAC will measure nuclear reaction rates under conditions comparable to the cores of stars and supernovae. This information is required to fully understand the creation of the heavy elements in the 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 highest energy colliding beams ever produced by mankind. Canadians working on the ATLAS experiment at the LHC will explore a wealth of new physics at this high energy frontier. The central goal of this experiment is to discover the mechanism that gives rise to the masses of elementary particles. In addition, ATLAS will provide our best chance of finding out what lies beyond our current model of subatomic phenomena, the Standard Model.

Faced with a collision course of the capital funding requirements for all three of its highest priority initiatives in 1997, the GSC proposed a five-year spending plan (1997 - 2001) that has been approved by NSERC Council. A necessary feature of the spending plan is the short term sacrifice of operating support to existing programme elements in order to maximize the funds available for the most urgent capital investments. Restoring a more appropriate balance between operating and capital expenditures as soon as possible is necessary to allow Canadian physicists to successfully complete the existing science projects and prepare for the next generation of experiments.

[1] Report of the NSERC Advisory Committee for Subatomic Physics; chair, B. Fenton, Nov.'95, henceforth referred to as the Fenton report.

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

An essential component of support for Canadian subatomic physics research is the existence of a strong national laboratory to provide a home base for scientists and world class technical infrastructure. In 1995, the TRIUMF laboratory in Vancouver was given an expanded mandate as Canada's national facility for subatomic physics research. ISAC is the flagship of the TRIUMF in-house science programme. The laboratory also provides infrastructure support to all areas of subatomic physics in Canada. It plays a crucial role in the construction of accelerator and detector components for the CERN LHC and ATLAS physics programmes, as well as the large central detector for the BaBar project at the Stanford Linear Accelerator (SLAC). Furthermore, TRIUMF fosters many inter-disciplinary collaborations, with strong programmes in condensed matter physics and medical applications of subatomic physics techniques.

The next 3-4 years will see past investments by NSERC come to fruition with several experiments completing the 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 for NSERC to maximize the impact of Canadian subatomic physics by optimizing support for these projects as well as restoring the community's ability to respond to new emerging areas of research. Proposals for timely reallocation of NSERC funding to achieve these goals are described in section 4.

2 Importance to Canada

Canada must continue to support fundamental science if it is to maintain a strong intellectual capital base. Basic research in subatomic physics 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 properties of the forces that govern the behaviour of matter at very short distance scales. Canada also has a leading role abroad, where of the five experiments in the particle physics programme 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 programme 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 and do research and by making significant contributions abroad, the subatomic physics community has enhanced Canada's reputation as a centre for intellectual and technological innovation. Subatomic physics projects regularly push the limits in such areas as high speed electronics, advanced computing, and superconducting magnet design, with advances made in cooperation with industry. Companies that have developed new products go on to sell them directly or apply the new technology in other fields. Many recent examples are associated with Canada's contribution to the CERN LHC accelerator, for which an agreement is in place to provide $19M in high-tech components through the year 2000.[5] 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.

[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.

[5] Review of Canadian Academic Physics: Economic Impact Study; Paul S. Vincett, November, 1997.

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 Chalk River Laboratories highlights the importance of this fundamental nuclear physics technique to condensed matter physics. At TRIUMF, researchers in condensed matter physics and chemistry use the muon spin rotation or 'μSR' technique to study magnetic properties of materials including high temperature superconductors. A proposal to build the Canadian Synchrotron Light Source in Saskatoon, which will provide x-ray beams for condensed matter physics and materials analysis, is an outgrowth of the development of a high energy electron accelerator for nuclear physics research at SAL.

Among the most important resources provided by a discipline are highly trained personnel 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 itself 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 training in subatomic physics can be readily applied to address issues in 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 post-doctoral fellows gain experience in project coordination and management that prepares them to compete effectively in a business environment where internationalization is becoming the norm rather than the exception. Recent studies have shown that people trained in subatomic physics are much in demand over a broad range of endeavors.[6] While 25% of recent graduates have found academic positions in Canada or abroad[7], the majority are employed in industrial positions ranging from the high-tech to financial sectors.

There have been numerous technical spin-offs from subatomic physics that have benefitted Canada. For example, Canada has become a world 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, which cannot be accessed in other ways. In co-operation with EBCO technologies of Vancouver, TRIUMF has developed cyclotrons specifically for radiopharmaceutical production that are now sold to an international market. In collaboration with Grumman, TRIUMF is building an accelerator-based system for the detection of explosives and contraband at airports and other risk centres, with high potential for commercialization. There are numerous other examples of similar technological impact spawned by the Canadian subatomic physics programme (see [5] on p.2).

3 The Canadian Subatomic Physics Programme

The Canadian subatomic physics programme is focussed on several key questions concerning the Standard Model of elementary particle interactions. The Standard Model unifies the known forces of nature by recognizing them 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 have acquired different strengths and properties due to a symmetry breaking process that occurred during the cooling down of the universe immediately after the big bang. This mechanism is also responsible for generating the masses of elementary particles in the Standard Model, a prediction that will be rigorously tested by the ATLAS experiment at the

[6] NSERC Report on Highly Qualified Personnel, May 1997.

[7] Report of the NSERC/CAP Review of Physics: Subatomic Physics, May 1997, available at http://cepheid.physics.utoronto.ca/Review/

CERN Large Hadron Collider.

There is a large body of experimental evidence verifying many predictions of the Standard Model. It is known 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 are needed to describe all known forms of matter. However, there still remain questions about how the fundamental properties of quarks and leptons arise, about the mechanism that gives rise to mass, and about how the observed preponderance of matter over anti-matter in the universe was established. Many details of the way in which the quarks arrange themselves to account for the structure of protons, neutrons and atomic nuclei also remain to be quantitatively understood. Driven by a desire to address these fundamental questions, Canadian subatomic physicists have developed a focussed research programme which is described in the following sections.

3.1 SNO

The Sudbury Neutrino Observatory, under construction since 1990 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. SNO is a unique Canadian project with strong international participation. Canada has provided in excess of two thirds of the $76M construction cost, the rest coming from the US and the UK. A team of 18 Canadian researchers[8] together with their graduate students, postdoctoral research associates, and international collaborators, will use SNO to study the neutrinos produced in nuclear reactions in the core of the sun, beginning in 1998. 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 of such a discovery.

3.2 Nuclear Physics and ISAC

Canada has a strong nuclear and intermediate energy physics programme that has traditionally been based at Canadian laboratories – SAL, TASCC and TRIUMF – carried out by approximately 60 NSERC funded researchers. Researchers at SAL achieved world recognition for precise measurements of the electromagnetic structure of nucleons and light nuclei. Scientists using TASCC at Chalk River Laboratories are widely recognized for discoveries in the field of nuclei spinning at very high angular momentum, for precise tests of the Standard Model using nuclear beta decays, and for developing techniques to measure nuclear masses to high precision.

At the TRIUMF 500 MeV cyclotron, researchers have focussed on experiments that test our understanding of the weak and strong interactions. These include experiments carried out with proton beams as well as with beams of short lived particles - pions and muons - produced by protons colliding with specialized production targets. Researchers have carried out sensitive tests of the weak interaction's properties via high precision measurements of muon decays[9] and of pion

[8] By convention, we count only full-time-equivalent, NSERC grant-eligible researchers when quantifying the size of the research groups in this report.

[9] A major new effort in this field, E614, was initiated this year with support from NSERC, TRIUMF, and international partners. This experiment is designed to measure the muon decay spectrum to an order of magnitude higher

and muon interactions with nuclei. TRIUMF is widely recognized for its development of a very high intensity polarized ion source that is unique in the world and for precision symmetry tests of the strong and weak interactions using these beams. At a precursor to the ISAC facility, Canadian scientists attracted world recognition for their determination of the reaction rate for carbon burning in 'Red Giant' stars, which has improved our understanding of how stars evolve to this stage.

Nuclear physics in Canada is undergoing a dramatic transition. In 1995, TRIUMF embarked on a new five-year plan with a mandate to build the ISAC facility, maintain an excellent research programme with the existing cyclotron, serve as a national infrastructure base for subatomic physics, coordinate Canada's contribution to the CERN LHC, and foster technology transfer to industry. In 1996, acting on the advice of the Fenton report, the GSC terminated its annual \$3M operating support of SAL as of 1998. 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 programmes at SAL and TASCC have now shifted their research emphasis to TRIUMF, the US, and Europe.

The TRIUMF ISAC project will make a major contribution to our understanding of nuclear phenomena of importance to astrophysics and cosmology. This facility will open up a completely new area of subatomic physics research by delivering beams of hitherto unavailable radioactive nuclei to a variety of target and detection facilities for study by the year 2000. The centrepiece of ISAC's science will be measurements of nuclear reaction rates under conditions comparable to those taking place in novae and supernovae. These explosive events are thought to be the origin of heavy elements in the universe, but models of how they are created can only be tested with new data of the type that ISAC can provide. TRINAT, a world-class laser atom trapping facility, will take advantage of ISAC's ability to generate specific radioactive beams tailored for sensitive experimental tests of the Standard Model.

3.3 High Energy Physics and ATLAS

The Canadian high energy physics community of approximately 75 NSERC funded researchers is making important contributions to multinational collaborative projects addressing some of the most fundamental questions in the field. The largest element of the current high energy physics programme is the OPAL experiment at the 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 confirmed 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 programme 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.

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 through being appointed the Deputy Spokesman in both cases. The ZEUS experiment has access to the highest energy electron-proton collisions ever achieved. This gives researchers insight into the structure of the proton down to very small distance scales (10^{-19}m). The unique features of the HERMES

precision, and will provide a sensitive test of possible extensions to the Standard Model.

experiment are allowing physicists to isolate the contributions by specific classes of quarks to one of the fundamental properties of protons and neutrons, their spin. The HERA accelerator will operate through 2005 with data taking for ZEUS planned through this period. The spin physics programme 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.). The 1997 discovery of the decay $K^+ \to \pi^+ \nu\bar{\nu}$, the rarest particle decay ever seen, is 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 SLAC, which will further elucidate the reasons for this matter-antimatter imbalance by studying decays of particles containing "bottom" quarks[10].

Canada's contribution through TRIUMF to the Large Hadron Collider (LHC), currently under construction at CERN, has opened a window of opportunity for a substantial Canadian participation in the LHC physics programme. By identifying the debris from very high energy particle collisions, scientists using the ATLAS detector will either discover the Higgs boson, a new particle thought to be responsible for the generation of mass in the Standard Model, or a host of complementary phenomena indicating new physics beyond the Standard Model. The Canadian ATLAS group is making key contributions to the design, prototyping and construction of elements of the detector, called calorimeters, that will measure the energy deposited by strongly interacting particles produced in high energy collisions at the LHC. This includes the development of electronics modules that will read out the signals from these detector elements.

3.4 Subatomic Theory

Canadian subatomic theorists have developed a programme that is rich and diverse, focussing on applications of the Standard Model and its extensions. A major challenge is the application of the Standard Model to the strong interaction, where calculational techniques must be developed to apply the basic theory formulated at the quark level to describe the complicated bound states that make up ordinary matter such as protons and neutrons. This work has been extended to apply to very hot and dense nuclear matter. The discovery of this new state of matter, the "quark-gluon plasma," is the goal of a new experimental programme.

Canadians have developed mathematical models that are used to predict properties of strongly interacting particles. These have been used to understand the properties of subatomic particles which contain the heaviest quarks. This "Heavy Quark Effective Theory" is the most successful description of the behaviour of these systems.

Canadians are also at the forefront of research into theories that extend the Standard Model. Phenomenological applications of the Standard Model and extensions in the weak and strong interaction sectors have had an important influence on shaping future experiments such as searches for new particles and forces at high energy colliders.

[10]BaBar was not originally included in the 1995 long range plan due to funding constraints and the need to focus on SNO, ISAC and ATLAS. However, the 1996 GSC found the physics case for this project to be so compelling that it recommended participation in BaBar but with significantly reduced scope; effective participation was made possible by infrastructure support from TRIUMF.

3.5 Funding of Subatomic Physics

NSERC support of subatomic physics has been administered via an envelope system since 1991, placing all expenditures on operating, equipment and infrastructure under the purview of one GSC. The subatomic physics envelope was steady at \$19.6M from 1991-95; the effects of federal funding cuts to NSERC and the first Reallocations Exercise resulted in a steady decrease of the envelope to \$17.3M in 1997. The impact of these budget cuts on the subatomic physics programme has been severe, as discussed in section 4. In the 1997 grants competition, the ratio of funds awarded to funds requested was 55%; 58 out of 92 applications received support at some level.

Subatomic physics research requires the use of large, custom-built detectors and international facilities. The GSC budget must provide both the construction capital for the Canadian share of the detectors and the operating support for the participating scientists, including a substantial budget for travel to and subsistence at international facilities. For these reasons, the cost per researcher to support experimental work in subatomic physics is relatively high in comparison to other disciplines. Excluding equipment expenditures and the direct cost of operating facilities via MFA grants to SAL and SNO, the average operating award in subatomic physics was \$71k per experimentalist and \$23k per theorist in the 1997-8 grants competition. The funds in support of experimental work are usually awarded in the form of 3-year Project Grants, with a common budget for each experiment. In contrast, theoretical work is supported mainly by Individual Research Grants.

The total investment in Canadian subatomic physics research is approximately \$60M in 1997-8. Approximately one third of this is provided by NSERC through the subatomic physics envelope; one half consists of federal support to operate TRIUMF, administered through the National Research Council, and the remainder is made up of smaller contributions from other federal and provincial sources, plus U.S. and U.K. contributions to the operation of SNO.

4 Proposals for Funding

The large cut to the subatomic physics envelope (19% since 1995) has made it extremely difficult for the GSC to adequately support the vigorous research program that currently exists. Both experimental and theoretical work have been affected. Theory represents 10% of the envelope and has suffered cuts proportional to the rest of the programme. The GSC has largely followed the Fenton plan, reducing our commitment to current experiments to make room for new projects. This course of action has not come without a price. NSERC support to a major Canadian research facility (SAL) has been terminated. Canadian groups have been forced to scale back on time spent at laboratories 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. This situation has jeopardized the scientific return on major NSERC investments in subatomic physics. Several promising young researchers have recently left Canada for faculty positions elsewhere, citing inadequacy of research support as a major factor in their decisions to leave.[11] The subatomic physics envelope requires a 20% increase to return to a healthy situation. The following sections detail several proposals of the 'Type 1' category for operating and capital support all of which have high priority.

[11]These include D.B. MacFarlane (McGill), recipient of the 1993 Herzberg Award, and G. Savard (CRNL) who was instrumental in the development of the Canadian Penning Trap Mass Spectrometer.

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

The subatomic physics GSC will contribute 6.8% of its current \$17.3M budget envelope to the Reallocations Exercise, corresponding to \$1.2M per year, phased in over a 4 year cycle. The extraordinary financial pressures noted above led the GSC to propose a 5 year spending plan[12] which 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 3 years are necessary to permit Canadians to provide their capital contributions to SNO, ISAC and ATLAS on timescales that are driven by the development of international facilities and research partnerships. NSERC Council, recognizing the strong scientific arguments made by the GSC and the sound financial planning that had been undertaken, approved a loan of just over \$3M to subatomic physics to allow the implementation of this 5 year plan. **In support of the 5 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 contribution of \$1.2M per year from the Reallocations Exercise.**

Consequences of No Reallocations Funding

The consequences of further cuts to the subatomic physics envelope from the current level of \$17.3M, would be very severe. As noted in the GSC's 1997 Contingency Report[13], most of the shortfall would have to come out of operating funds further eroding Canadian participation in projects which they helped build. Some projects would likely fall below "critical mass", forcing the GSC to prematurely withdraw support altogether. The remainder of the funding cuts would be absorbed by delaying 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 likely trigger a proportional reduction in the US contribution to site operations. This would have damaging implications for Canada's ability to act as a partner in international scientific collaborations. All development projects and new initiatives would have to be suspended for several years.

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

Physicists working on the early stages of a subatomic physics experiment require a substantial amount of new instrumentation development and feasibility studies before a full proposal can be submitted and subjected to an expert review. Since funds awarded in the form of Project Research Grants cannot be transferred from one project to another, these developments are only possible with separate, targeted grants. In recent years, such an allocation of R&D funding to detector development and smaller new initiatives has been severely scaled back due to lack of funds. The GSC's 5 year spending plan provides no relief for this situation.

Very strong candidates for this type of support have arisen at every recent grants competition. Some examples include R&D into sensitive new detectors that could be used in the low background site at SNO to detect supernovae and search for dark matter candidates; feasibility studies towards a possible high intensity muon source and other new initiatives that will be part of the next

[12] Report on the 1997 Grant Competition: Awards, Policy Matters, and a Five Year Spending Plan for Subatomic Physics, NSERC Subatomic Physics GSC, April 22, 1997

TRIUMF Five-Year plan; detector development for a new rare kaon decay experiment building on the achievements of the Canadian group with experiment 787; an experiment to measure parity violation in electron scattering (G0) building on the expertise gained in a related experiment at TRIUMF. Without support to prepare these experiments, exciting opportunities will be lost to the Canadian community. At least a small number of new projects should be supported through the R&D phase to develop full proposals, which could then be considered for major investment in the next long range planning exercise. However, without additional targetted funds, development of the future experimental programme will be severely curtailed. In the words of the CAP/NSERC Review of Physics Assessors' Report,[14] '*... 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, with only $100k awarded by the GSC leaving over 10 excellent proposals completely unfunded. **It is proposed 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 to a more appropriate 50%.**

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[15] in the 1995-96 competition. Since that time, the number of researchers has remained stable. However, the funds available to support their operations have decreased by 11% from $14M to $12.5M. The GSC had to plan an additional 10% reduction in operating support to implement its 5 year budget plan. This difficult situation is particularly harsh for young researchers. Since 1995, 13 new individuals have entered the discipline seeking funds to initiate new projects or to enhance the scope of existing projects, which would normally be supported out of operating funds. It has not been possible to properly support the new applicants, many of whom are young people showing great promise for outstanding research careers. The experimentalists have been forced to join existing projects without increasing the corresponding Project Grant grants, while the new theorists are generally funded below average levels. The decrease in operating funds from $14M to $11.25M 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 Capital

ATLAS is the highest priority project for the future of the Canadian high energy physics community. By the time ATLAS begins taking data, it is expected that half of this community will be working on this project. The main goal of ATLAS is to detect the Higgs particle, which is postulated to give rise to the origin of the mass of particles in the Standard Model. Canadian development of two important detector elements, the liquid argon hadronic endcap (HCAL) and forward hadronic calorimeters (FCAL), and of elements of the associated readout electronics, are innovative and have made a major impact on the design of the ATLAS experiment.

NSERC signed an Interim Memorandum of Understanding with CERN in 1996, signifying Canada's intention to make a contribution to the ATLAS detector commensurate with the size of the Canadian group, subject to availability of funds. In 1997, the GSC strongly endorsed the conclusions of an international expert review committee that a Major Installation award of $15.4M

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

[15] A. Isabelle, NSERC, Private Communication. Note that the NSERC Staff Report, *Research Grants Program: Discipline Dynamics*, October 1997, does not list all grant holders funded from the subatomic physics envelope.

to construct the calorimeters described above would be an appropriate match to the technical leadership, capability, and relative size of the Canadian ATLAS group. The GSC was only able to award \$12.2M for the construction of one half of the necessary 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. The discovery of the Higgs particle is a major milestone for particle physics. The forward calorimeter is crucial to detect the Higgs via selected decay modes, especially if the Higgs particle is relatively heavy. It will not be possible to detect these decays unambiguously without the forward calorimeter. **It is proposed that an additional \$1.5M contribution to the ATLAS detector be supplied from Reallocations funds, which is necessary 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 Capital

The nuclear astrophysics programme, which will focus on measurements of nuclear reaction rates under conditions comparable to those in stars and supernovae, will occupy centre stage at ISAC. The success of this programme hinges on a dedicated facility that will identify the interesting reaction products amidst a very large background of unreacted beam particles. The proposed facility for this purpose is DRAGON, a 'Detector for Recoils and Gammas Of Nuclear reactions'. It consists of a gas target surrounded by an array of high-efficiency, very fast gamma ray detectors, and followed by a high resolution electromagnetic spectrometer. The total estimated cost is almost \$3M.

The DRAGON proposal received strong endorsements from three independent expert review panels in 1997. In its five year financial plan, the GSC was able to identify \$1.9M in equipment funds towards DRAGON, allocated from 1998-2000. Together with a \$0.5M contribution from TRIUMF, this will support construction of the electromagnetic spectrometer. However, the GSC was not able to allocate funds to provide the gamma array until 2002 at the earliest. This gamma detector array 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. In particular, a reaction on one of the oxygen isotopes ($^{15}\mathrm{O}(\alpha,\gamma)$) is a branching point in the development of stars. Data on this reaction are eagerly awaited but will not be accessible until the gamma array is operational. **Additional equipment funds of \$0.6M are requested to complete this important new facility on a timescale that is commensurate with the availability of radioactive beams at ISAC beginning in 2000.**

5 Concluding Remarks

The proposals for new funds discussed above have been carefully selected to optimize the scientific impact of NSERC expenditures in subatomic physics and to help ensure the long term excellence of the Canadian research program in this discipline. The pressures on the subatomic physics envelope in recent years have been extraordinary. Many difficult decisions have been made to close facilities and wind down Canada's involvement in experiments before the full scientific return could be achieved. Even with funding for all of the proposals put forth in this document, the subatomic physics envelope in 2002-3 will be smaller than it was in 1994-5. Considering the demonstrated excellence of the Canadian research programme, and the size and scope of the overall effort and investment in this field by Canada (of which NSERC contributes roughly 30%), the additional investment requested here will generate a high scientific return and is worthy of support from the Reallocations Exercise.