Canadian Spallation Ultracold Neutron Source

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1 Project Overview and Scientific Motivation

We propose the construction of the world's highest density source of ultracold neutrons (UCN), the Canadian Spallation Ultracold Neutron Source (CSUNS).

The appropriate CFI fund is the New Initiatives Fund (NIF). The project is truly a new intiative which has not previously been supported CFI. Matching funds would be provided by a combination of Japanese sources and by TRIUMF (Canada's National Laboratory for Particle and Nuclear Physics), as will be described. The two major thrusts of the research are in fundamental neutron physics, and in surface nanoscience.

The University of Winnipeg has been the lead institution in the project since the very beginning. In the past year, J.W. Martin, the spokesperson for the project, has gone through the process of building an impressive international collaboration. Numerous Canadian and international collaborators are involved in the project. Prof. Martin organized an international workshop "UCN sources and experiments", which was held at TRIUMF on September 13-14, 2007. Fifty experts in neutron physics from around the world attended the workshop. The workshop concluded decisively that Canada would be an ideal location for a next-generation UCN source.

As a part of the planning process, J.W. Martin has presented the project to review committees four times over the past year, and has organized two collaboration meetings. The UCN source project was most recently reviewed by the TRIUMF Special Experimental Evaluation Committee (March 2008). The committee concluded that "a high density UCN source will support a fundamental physics program at TRIUMF well into the future, thus maintaining the strong tradition at the laboratory of a broad program of measurement of nuclear interactions, nuclear structure, nuclear astrophysics, and fundamental symmetry tests. Like the latter it will furthermore bridge the gap between particle and nuclear physics." Such a strong endorsement has resulted partially from the excellent support and interest from the TRIUMF laboratory. The project will be presented again by J.W. Martin to the Advisory Committee on TRIUMF (ACOT) on May 9, 2008. The membership of both committees includes some of the most well-known nuclear and particle physicists in the world. The membership of ACOT additionally includes representatives from the National Research Council Canada (NRC) and from NSERC.

A window of opportunity exists to capitalize on the successes of Japanese collaborators in use of new technology to produce UCN, thereby allowing the Canadian project to surpass other proposed sources elsewhere. The location in Canada at TRIUMF, Vancouver, BC is ideal because of the high-intensity high-energy proton beam available from the TRIUMF cyclotron, which is used to drive the UCN source. The truly high density that could be obtained at TRIUMF would allow a class of precision measurements of the fundamental properties of the neutron to be conducted with significantly higher precision than any other UCN source. The source would therefore make a major impact on studies of fundamental physics with UCN. Funding for physics experiments would be requested in the future from a combination of NSERC, Japanese, and other international sources.

The fundamental neutron physics experiments that are being considered for the UCN source are as follows:

- A search for a non-zero neutron electric dipole moment (nEDM). Such an experiment aims to search for an explanation of the predominance of matter over antimatter in the universe. This experiment would be led by J.W. Martin. Several U.S. collaborators listed on this proposal are involved in a similar experiment at a lower-density UCN source.

- A precision measurement of the neutron lifetime. This experiment has been conceived by J.D. Bowman (Oak Ridge National Lab), and a test experiment is currently being conducted by U.S. collaborators at Los Alamos National Lab.

- Precise spectroscopy of the quantized energy levels of neutrons confined above a mirror in the earth's gravitational field, to test theories of gravity. This experimental proposal is led by S. Komamiya (U. Tokyo) and involves a large number of Japanese collaborators.

The project would represent a new direction in subatomic physics in Canada, with increased involvement in the Canadian scientific program from new users outside Canada.

Previously, most of the successes in neutron research in Canada have been realized at the Chalk River facility. The focus of the research at Chalk River has been on applied research using neutron beams. Here we refer to, for example, the pioneering work conducted by Nobel Laureate in Physics, Bertram Brockhouse, on the development of thermal neutron scattering for materials science research.

Materials science would also be an aspect of research at CSUNS. New avenues of research using the process of UCN inelastic scattering reflectometry (UCN ISR) would be opened up by the construction of the UCN source. UCN ISR can be used for surface nanoscience, for example to study "smart surfaces". Smart surfaces are surfaces that autonomously change their properties in response to external stimuli. An example is found in drug delivery, where the surface of a medicine container could change its permeability based on body temperature, releasing the drug as needed. UCN ISR devices have previously only been operated in test modes at the one previous generation lower-density UCN source, at the Insitut Laue-Langevin (ILL) in Grenoble, France. The advent of new, higher density sources such as CSUNS promises a potential breakthrough in sensitivity to low-energy excitations of even thinner surface films.

2 Required Infrastructure, Budget, and CFI NIF

The UCN source technology is a superthermal source based on downscattering of cold neutrons (CN) in superfluid liquid helium. Neutrons are liberated by proton-induced spallation from a tungsten target. The neutrons are moderated in room temperature heavy water and then 20 K liquid deuterium down to cold neutron energies. The moderator system is surrounded with a graphite reflector. The cold neutrons are down-scattered by phonons in superfluid ^{4}He (He-II) to ultracold neutron (UCN) energies. UCN are transmitted horizontally through a series of valves to experiments.

This source technology has been developed by Y. Masuda's group in Japan. His group's prototype source (at Research Centre for Nuclear Physics, RCNP, Osaka) has produced results already competitive with the current highest-density UCN source in the world. However, the source is limited in intensity because of the limited proton beam current available at RCNP. It is the availability of the high-intensity proton beam at TRIUMF that makes Canada a particularly attractive location for a world-leading effort in this field.

The infrastructure that is required is as follows: a fast "kicker" magnet to divert the proton beam to the UCN source, a fully instrumented beamline to deliver the proton beam, a tungsten spallation target and associated handling and cooling equipment, the cryostat containing the UCN source itself and associated cryogenic equipment, and, finally, radiation shielding in the form of steel and concrete blocks.

An estimate of the costs associated with these components is presented in Table 1. Considerable engineering support from TRIUMF has been necessary to arrive at this cost estimate.

The CFI NIF program would supply 40% of the total project cost, representing approximately \$4 M. It is presently expected that the CFI portion would pay for the shielding, a portion of the neutron moderator materials, and a portion of the beamline and magnets.

The UCN source apparatus and cryogenic assembly would be supplied by Japan, along with the remaining portion of the neutron moderator materials. The Japanese contribution would represent 40% of the overall cost. A portion of these funds have already been requested from Japanese funding sources, and the design and construction of the UCN source itself is expected to begin this year in Japan.

The remaining 20% would be supplied by funds from TRIUMF. TRIUMF is owned and operated by a consortium of universities under an operating grant from NRC. So these funds would be NRC funds and are eligible to use as matching for the CFI funds. This portion of the matching would

Item	Total
UCN source apparatus and cryogenics	\$2.4M
Beamline magnets (including fast “kicker”)	\$1.25 M
Beamline parts and installation	\$1.25 M
Moderator materials (D_2O and D_2)	\$3 M
Steel shielding	\$1.8 M
Concrete shielding	\$540 k
Total	\$10.2 M

Table 1: Summary of some of the major costs for the UCN facility. “Installation” includes such things as outside contractors for water and power.

be requested as a part of TRIUMF’s next operating grant request to NRC. The required funds are modest, and from the successful review process already undergone, these funds would likely be committed in almost any funding scenario considered in the funding request to NRC.

3 Training of HQP

The project would contribute to the training of a large number of undergraduate students, graduate students, and postdoctoral fellows from across Canada. The project has attracted a world-class group of scientists, and will therefore attract HQP from around the world to Canada. In fact, postdoc applications to the U. Winnipeg group have already been received citing interest in the UCN project (from ILL Grenoble and from Indiana U.).

Performing research on neutron physics experiments is excellent training for problem-solving in real-world situations. Students and postdocs in nuclear physics must use a variety of resources in order to achieve highly complex tasks. In the course of an experiment, personnel can be trained on design of future experiments, computer simulation, design and construction of custom hardware, installation and commissioning of hardware, acquisition and analysis of data, and effective communication of progress at meetings and of results through authorship of publications. Unique technologies used in this proposal are cryogenics, vacuum technologies, nuclear instrumentation, RF technology, and superconducting technology. Many of these technologies are common to the medical field as well, and there is typically a large cross-over in personnel.

In addition to traditional research positions in nuclear physics, students trained in experimental nuclear physics have gone on to leadership and technical positions in a variety of industries. Known to me personally are those with positions in: medical physics research, materials research, quantitative analysis of the stock market, management consulting, internet start-up companies, and aerospace engineering. This incredible diversity in possibilities, in such a large variety of highly technical fields, represent the possibilities available to one who possesses the training obtained as an experimental nuclear physicist.

U. Winnipeg students trained in J.W. Martin’s CFI-funded subatomic physics detector lab, and stationed at remote facilities such as LANL and Jefferson Lab, have received offers of employment advancing their positions in physics, and have presented at meetings of physics societies of Canada, Japan, and the U.S. This group of students includes a Rhodes Scholar, two Stevenson awardees, and an NSERC PGS-D awardee.

4 Inter-institutional and Inter-sectoral collaborations

The University of Winnipeg is leading an international group of scientists in this world-class project in basic research. This is truly a unique and important opportunity for the university. The benefits in terms of attraction of HQP to Winnipeg are likely to be immense.

J.W. Martin was involved in the construction of the UCN source at Los Alamos National Lab (LANL) and has been a leader in the physics experiments subsequently conducted there. The LANL UCN source currently holds the world record for highest UCN density ever achieved. This has served as the first and to date most impressive validation of the new technique that will be used to produce UCN's at TRIUMF.

Thus far groups at Canadian universities, at TRIUMF, at KEK, at Japanese universities, and at institutions in the U.S. have joined the project. J.W. Martin (U. Winnipeg) is the collaboration spokesperson and has been responsible for this success in attracting such an excellent list of collaborators. Y. Masuda is the leader of the UCN source development project in Japan.

The proposal would strengthen a pre-existing collaboration between the subatomic physics groups at U. Winnipeg, U. Manitoba, and U. Northern British Columbia. These institutions already collaborate on neutron experiments and on electroweak physics experiments in electron scattering, and are already linked through joint Subatomic Physics Project Grants (a special category of NSERC Discovery Grants). The proposal would forge a new collaboration with M. Hayden's group at Simon Fraser University and with additional new collaborators at TRIUMF, for example L. Buchmann and I. Kato.

The KEK and other Japanese collaborators have generally been involved in the development of Y. Masuda's UCN source at RCNP. New collaborators, mainly from Tokyo (S. Komamiya and collaborators), have joined this effort more recently, with the goal of eventually completing a neutron gravity-levels measurement at TRIUMF.

The U.S. collaborators have been attracted because of their collective strong desire to be involved in the next big UCN project in North America. In particular, we note the involvement of R. Golub (NCSU) who has been one of the chief proponents of the field of UCN physics over the past several decades, coauthor of the seminal book "Ultracold Neutrons". Prof. Golub has been involved in many of the most important experiments performed using UCN over the past 30 years, for example, previous measurements of the neutron EDM at ILL. He has stated strongly that the CSUNS project will result in the world's highest density UCN source, hence his interest and involvement.

5 Canada's and Manitoba's priorities

The CSUNS project addresses the core principles of Canada's Science and Technology (S&T) priorities. The project promotes world-class excellence through the construction of the highest density UCN in the world. The project has already attracted a large number of excellent international collaborators. The project targets an area of strength in basic research in fundamental physics, while at the same time addressing applied research in materials science, particularly surface nanoscience. Partnerships between Japan, Canada, and the U.S. clearly will be enhanced by the project, and significant funding will be committed to the CSUNS project by Japanese sources. The physics experiments that will be performed at CSUNS will likewise be funded by a combination of Canadian (NSERC) and international sources.

Canada's Science and Technology Strategy identifies three distinct Canadian S&T advantages that it aims to foster: a People Advantage, a Knowledge Advantage, and an Entrepreneurial Advantage. The UCN project addresses these priorities in the following ways:

- People Advantage
  - The UCN source project, coupled with the world-class physics experiments that will be conducted there, will attract excellent scientists from around the world to Canada. This is particularly true of Japanese and U.S. scientists.
  - Many undergraduate student research opportunities would be created by the project. The project will train two to three graduate students per year. Typically three postdoctoral scholars would be working on projects at the UCN source.
  - TRIUMF and the University of Winnipeg both are committed aboriginal science education. At TRIUMF, a new initiative has been launched in aboriginal recruiting for coop students, many of whom would be recruited for this project.
- Knowledge Advantage
  - Many of the technologies used to conduct the physics experiments are intimately linked to medical technology. For example, the Hayden research group at SFU additionally conducts research on low-field MRI imaging, because exactly this technology is used in the neutron electric dipole moment experiment.
  - The surface nanoscience experiments that would be conducted at the UCN source relate to the characterization of large hydrogenous molecules for "smart surfaces", where an example in medicine in drug delivery exists. We anticipate that should the UCN ISR technique prove successful, that a large number of users from across the world would be interested in using the technology to study smart surfaces.
- Entrepreneurial Advantage
  - The UCN project has already attracted the interest of a small business in Pinawa, MB, Acsion Industries. Physicists at Acsion design neutron moderators for nuclear reactors, and the same technology and innovation is required for the neutron moderators used in the UCN source. Acsion scientists have already contributed to the project by beginning to study neutron transport in the source. It is possible that Acsion would also supply some small amount of CFI matching to the project. This is just one example, and more industry partners are expected once the project begins.
  - Another technology used extensively in the UCN source is cryogenics. Spin-offs of this technology and of the afore-mentioned technologies used in the physics experiments, that relate to medical applications, could result in new enterprises.

The CFI NIF would be pursued through the University of Winnipeg, but does not request provincial matching from the Government of Manitoba. Nonetheless, we consider the impact on the Strategic Priorities listed in the Manitoba Innovation Framework. The proposal primarily impacts the Advanced Manufacturing aspect of the province's priorities. In fact, Acsion Industries is featured on the Manitoba Science, Technology, Energy, and Mines website (at time of writing), under the heading of advanced manufacturing, based on their application of nuclear physics technologies to manufacturing. The CSUNS proposal also partially addresses life sciences, through the anticipated spin-off technologies and highly-related techniques. Also, as mentioned previously, the development of a skilled workforce through basic research is a primary goal of this proposal. More information can be provided on the project's relationship to the six-point action plan of Manitoba's Innovation Framework.

6 References and Additional Information

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[2] UCN proposal to TRIUMF SEEC. (available from http://admin.triumf.ca/facility/5yp/SEEC-UCN.pdf *or* http://nuclear.uwinnipeg.ca/ucn/triumf/seec-3-26-8/ucn-seec-mar08.pdf).
[3] TRIUMF SEEC report. (expected to be available to the public, soon - unofficial version available upon request)
[4] International Workshop: UCN Sources and Experiments, Sept. 13-14, 2007, TRIUMF, Vancouver, BC. (website: http://www.triumf.info/hosted/UCN).